U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science Directorate
Geologic Resources Division

Yellowstone National Park

GRI Ancillary Map Information Document

Produced to accompany the Geologic Resources Inventory (GRI) Digital Geologic-GIS Data for Yellowstone National Park

yell_surficial_geology.pdf

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Geologic Resources Inventory Map Document for Yellowstone National Park

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Geologic Resources Inventory Map Document

Yellowstone National Park, Wyoming, Montana and Idaho

Document to Accompany Digital Geologic-GIS Data

yell_surficial_geology.pdf

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This document has been developed to accompany the digital geologic-GIS data developed by the Geologic Resources Inventory (GRI) program for Yellowstone National Park, Wyoming, Montana and Idaho (YELL_surficial).

Attempts have been made to reproduce all aspects of the original source products, including the geologic units and their descriptions, geologic cross sections, the geologic report, references and all other pertinent images and information contained in the original publication.

This document contains the following information:

1) **About the NPS Geologic Resources Inventory Program** – A brief summary of the Geologic Resources Inventory (GRI) Program and its products. Included are web links to the GRI GIS data model, and to the GRI products page where digital geologic-GIS datasets, scoping reports and geology reports are available for download. In addition, web links to the NPS Data Store and GRI program home page, as well as contact information for the GRI coordinator, are also present.

2) **GRI Digital Maps and Source Citations** – A listing of all GRI digital geologic-GIS maps produced for this project along with sources used in their completion. In addition, a brief explanation of how each source map was used is provided.

3) **Map Unit List** – A listing of all geologic map units present on maps for this project, generally listed from youngest to oldest.

4) **Source Map Geologic Units**– A listing of all units with links to source map unit descriptions for each source map the unit is present on.

5) **Ancillary Source Map Information** – Geologic unit descriptions and additional source map information presented by source map. For each source map this may include a stratigraphic column, index map, map legend, report and/or map notes.

6) **GRI Digital Data Credits** – GRI digital geologic-GIS data and ancillary map information document production credits.

For information about using GRI digital geologic-GIS data contact:

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About the NPS Geologic Resources Inventory Program

Background

The Geologic Resources Inventory (GRI) provides geologic map data and pertinent geologic information to support resource management and science-informed decision making in more than 270 natural resource parks throughout the National Park System. Geologic resources for management consideration include both the processes that act upon the Earth and the features formed as a result of these processes. Geologic processes include: erosion and sedimentation; seismic, volcanic, and geothermal activity; glaciation, rockfalls, landslides, and shoreline change. Geologic features include mountains, canyons, natural arches and bridges, minerals, rocks, fossils, cave and karst systems, beaches, dunes, glaciers, volcanoes, and faults.

The GRI is one of 12 inventories funded by the National Park Service (NPS) Inventory and Monitoring Program. The Geologic Resources Division of the NPS Natural Resource Stewardship and Science Directorate administers the GRI. The NPS Geologic Resources Division partners with the Colorado State University Department of Geosciences to produce GRI products. Many additional partners participate in the GRI process by contributing source maps or reviewing products.

The GRI team undertakes three tasks for each park in the Inventory and Monitoring program: (1) conduct a scoping meeting and provide a summary document, (2) provide digital geologic map data in a geographic information system (GIS) format, and (3) provide a GRI report. These products are designed and written for nongeoscientists.

Products

Scoping Meetings: These park-specific meetings bring together local geologic experts and park staff to inventory and review available geologic data and discuss geologic resource management issues. A summary document is prepared for each meeting that identifies a plan to provide digital map data for the park.

Digital Geologic Maps: Digital geologic maps reproduce all aspects of traditional paper maps, including notes, legend, and cross sections. Bedrock, surficial, and special purpose maps such as coastal or geologic hazard maps may be used by the GRI to create digital Geographic Information Systems (GIS) data and meet park needs. These digital GIS data allow geologic information to be easily viewed and analyzed in conjunction with a wide range of other resource management information data.

For detailed information regarding GIS parameters such as data attribute field definitions, attribute field codes, value definitions, and rules that govern relationships found in the data, refer to the NPS Geology-GIS Data Model document available at: https://www.nps.gov/articles/gri-geodatabase-model.htm

Geologic Reports: GRI reports synthesize discussions from the original scoping meeting, follow up conference call(s), and subsequent research. Chapters of each report discuss the geologic setting of the park, distinctive geologic features and processes within the park, highlight geologic issues facing resource managers, and describe the geologic history leading to the present-day landscape. Each report also includes a poster illustrating these GRI digital geologic-GIS data.

For a complete listing of GRI products visit the GRI publications webpage: https://go.nps.gov/gripubs. GRI digital geologic-GIS data is also available online at the NPS Data Store: https://irma.nps.gov/DataStore/Search/Quick. To find GRI data for a specific park or parks select the appropriate park(s), enter "GRI" as a Search Text term, and then select the Search button.

For more information about the Geologic Resources Inventory Program visit the GRI webpage: https://www.nps.gov/subjects/geology/gri.htm. At the bottom of that webpage is a “Contact Us” link if you need additional information. You may also directly contact the program coordinator:

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The Geologic Resources Inventory (GRI) program is funded by the National Park Service (NPS) Inventory and Monitoring (I&M) Division. Learn more about I&M and the 12 baseline inventories at the I&M webpage: https://www.nps.gov/im/inventories.htm.

GRI Digital Maps and Source Map Citations

The GRI digital geologic-GIS maps for Yellowstone National Park, Wyoming, Montana and Idaho (YELL_surficial). Listed with each map is its source map.

Digital Surficial Geologic-GIS Map of Yellowstone National Park and Vicinity, Wyoming, Montana and Idaho (*GRI MapCode YELL_surficial*)

U.S. Geological Survey, 1972, Surficial Geologic Map of Yellowstone National Park: U.S. Geological Survey, Miscellaneous Investigations Series Map I-710, scale 1:125,000 (Yellowstone National Park). (*GRI Source Map ID 1154*).

The GRI extracted the extent that covers the eastern portion of the Buffalo Lake 15' Quadrangle from this source map. All geologic features within that extent were captured. Portions of this source map and the source maps referenced below were used in the compiled GRI Digital Surficial Geologic-GIS Map of Yellowstone National Park and Vicinity.

Digital Surficial Geologic-GIS Map of Abiathar Peak and parts of adjacent 15' Quadrangles, Wyoming and Montana (*GRI MapCode ABPE_surficial*)

Pierce, Kenneth L., 1974, Surficial Geologic Map of the Abiathar Peak and parts of adjacent Quadrangles, Yellowstone National Park, Wyoming and Montana: U.S. Geological Survey, Miscellaneous Investigations Series Map, I-646, scale 1:62,500 (Abiathar Peak and parts of adjacent Quadrangles). (*GRI Source Map ID 1136*).

Digital Surficial Geologic-GIS Map of the Canyon Village 15' Quadrangle, Wyoming (*GRI MapCode CAVI_surficial*)

Richmond, Gerald M., 1977, Surficial Geologic Map of the Canyon Village Quadrangle, Yellowstone National Park, Wyoming: U.S. Geological Survey, Miscellaneous Investigations Series Map I-652, scale 1:62,500 (Canyon Village Quadrangle). (*GRI Source Map ID 1137*).

Digital Surficial Geologic-GIS Map of the Eagle Peak 15' Quadrangle, Wyoming (*GRI MapCode EAPE_surficial*)

Richmond, Gerald M., and Pierce, Kenneth L., 1972, Surficial Geologic Map of the Eagle Peak Quadrangle, Yellowstone National Park and adjoining area, Wyoming: U.S. Geological Survey, Miscellaneous Investigations Series Map I-637, scale 1:62,500 (Eagle Peak Quadrangle). (*GRI Source Map ID 1138*).

Digital Surficial Geologic-GIS Map of the Frank Island 15' Quadrangle, Wyoming (*GRI MapCode FRIS_surficial*)

Richmond, Gerald M., 1974, Surficial Geologic Map of the Frank Island Quadrangle, Yellowstone National Park, Wyoming: U.S. Geological Survey, Miscellaneous Investigations Series Map I-642, scale 1:62,500 (Frank Island Quadrangle). (*GRI Source Map ID 1139*).

Digital Surficial Geologic-GIS Map of the Grassy Lake Reservoir 15' Quadrangle, Wyoming (*GRI MapCode GRLA_surficial*)

Richmond, Gerald M., 1973, Surficial Geologic Map of the Grassy Lake Reservoir Quadrangle, Yellowstone National Park and adjoining area, Wyoming: U.S. Geological Survey, Miscellaneous Investigations Series Map I-644, scale 1:62,500 (Grassy Lake Reservoir Quadrangle). (*GRI Source Map ID 1140*).

Digital Surficial Geologic-GIS Map of the Huckleberry Mountain 15' Quadrangle, Wyoming (*GRI MapCode HUMO_surficial*)

Richmond, Gerald M., 1973, Surficial Geologic Map of the Huckleberry Mountain Quadrangle, Yellowstone National Park and adjoining area, Wyoming: U.S. Geological Survey, Miscellaneous Investigations Series Map I-639, scale 1:62,500 (Huckleberry Mountain Quadrangle). (*GRI Source Map ID 1141*).

Digital Surficial Geologic-GIS Map of the Madison Junction 15' Quadrangle, Wyoming (*GRI MapCode MAJU_surficial*)

Waldrop, H. A., and Pierce, Kenneth L., 1975, Surficial Geologic Map of the Madison Junction Quadrangle, Yellowstone National Park, Wyoming: U.S. Geological Survey, Miscellaneous Investigations Series Map I-651, scale 1:62,500 (Madison Junction Quadrangle). (*GRI Source Map ID 1142*).

Digital Surficial Geologic-GIS Map of the Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle, Wyoming and Montana (*GRI MapCode MAMM_surficial*)

Pierce, Kenneth L., 1973, Surficial Geologic Map of the Mammoth Quadrangle and part of the Gardiner Quadrangle, Yellowstone National Park, Wyoming and Montana: U.S. Geological Survey, Miscellaneous Investigations Series Map I-641, scale 1:62,500 (Mammoth Quadrangle and part of the Gardiner Quadrangle). (*GRI Source Map ID 1143*).

Digital Surficial Geologic-GIS Map of the Mount Hancock 15' Quadrangle, Wyoming (*GRI MapCode MOHA_surficial*)

Richmond, Gerald M., and Pierce, Kenneth L., 1971, Surficial Geologic Map of the Mount Hancock Quadrangle, Yellowstone National Park and adjoining area, Wyoming: U.S. Geological Survey, Miscellaneous Investigations Series Map I-636, scale 1:62,500 (Mount Hancock Quadrangle). (*GRI Source Map ID 1144*).

Digital Surficial Geologic-GIS Map of Mount Holmes and parts of adjacent 15' Quadrangles, Wyoming and Montana (*GRI MapCode MOHO_surficial*)

Pierce, Kenneth L., 1974, Surficial Geologic Map of the Mount Holmes Quadrangle and parts of the Teepee Creek, Crown Butte, and Miner Quadrangles, Yellowstone National Park, Wyoming and Montana: U.S. Geological Survey, Miscellaneous Investigations Series Map I-640, scale 1:62,500 (Mount Holmes and parts of adjacent Quadrangles). (*GRI Source Map ID 1146*).

Digital Surficial Geologic-GIS Map of the Norris Junction 15' Quadrangle, Wyoming (*GRI MapCode NOJU_surficial*)

Richmond, Gerald M., and Waldrop, H. A., 1975, Surficial Geologic Map of the Norris Junction Quadrangle, Yellowstone National Park, Wyoming: U.S. Geological Survey, Miscellaneous Investigations Series Map I-650, scale 1:62,500 (Norris Junction Quadrangle). (*GRI Source Map ID 1147*).

Digital Surficial Geologic-GIS Map of the Old Faithful 15' Quadrangle, Wyoming (*GRI MapCode OLFA_surficial*)

Waldrop, H. A., 1975, Surficial Geologic Map of the Old Faithful Quadrangle, Yellowstone National Park, Wyoming: U.S. Geological Survey, Miscellaneous Investigations Series Map I-649, scale 1:62,500 (Old Faithful Quadrangle). (*GRI Source Map ID 1148*).

Digital Surficial Geologic-GIS Map of the Pelican Cone 15' Quadrangle, Wyoming (*GRI MapCode PECN_surficial*)

Richmond, Gerald M., and Waldrop, H. A., 1972, Surficial Geologic Map of the Pelican Cone Quadrangle, Yellowstone National Park and adjoining area, Wyoming: U.S. Geological Survey, Miscellaneous Investigations Series Map, I-638, scale 1:62,500 (Pelican Cone Quadrangle). (*GRI Source Map ID 1149*).

Digital Surficial Geologic-GIS Map of the Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle, Wyoming and Montana (*GRI MapCode TOJU_surficial*)

Pierce, Kenneth L., 1974, Surficial Geologic Map of the Tower Junction Quadrangle and part of the Mount Wallace Quadrangle, Yellowstone National Park, Wyoming and Montana: U.S. Geological Survey, Miscellaneous Investigations Series Map I-647, scale 1:62,500 (Tower Junction Quadrangle and part of the Mount Wallace Quadrangle). (*GRI Source Map ID 1150*).

Digital Surficial Geologic-GIS Map of the Two Ocean Pass 15' Quadrangle, Wyoming (*GRI MapCode TWOC_surficial*)

Richmond, Gerald M., and Pierce, Kenneth L., 1971, Surficial Geologic Map of the Two Ocean Pass Quadrangle, Yellowstone National Park and adjoining area, Wyoming: U.S. Geological Survey, Miscellaneous Investigations Series Map I-635, scale 1:62,500 (Two Ocean Pass Quadrangle). (*GRI Source Map ID 1145*).

Digital Surficial Geologic-GIS Map of the Warm River Butte 15' Quadrangle, Wyoming and Idaho (*GRI MapCode WARI_surficial*)

Richmond, Gerald M., 1973, Surficial Geologic Map of the Warm River Butte Quadrangle, Yellowstone National Park and adjoining area, Idaho and Wyoming: U.S. Geological Survey, Miscellaneous Investigations Series Map I-645, scale 1:62,500 (Warm River Butte Quadrangle). (*GRI Source Map ID 1151*).

Digital Surficial Geologic-GIS Map of the West Thumb 15' Quadrangle, Wyoming (*GRI MapCode WETH_surficial*)

Richmond, Gerald M., 1973, Surficial Geologic Map of the West Thumb Quadrangle, Yellowstone National Park, Wyoming: U.S. Geological Survey, Miscellaneous Investigations Series Map I-643, scale 1:62,500 (West Thumb Quadrangle). (*GRI Source Map ID 1152*).

Digital Surficial Geologic-GIS Map of the West Yellowstone 15' Quadrangle, Wyoming, Montana and Idaho (*GRI MapCode WEYE_surficial*)

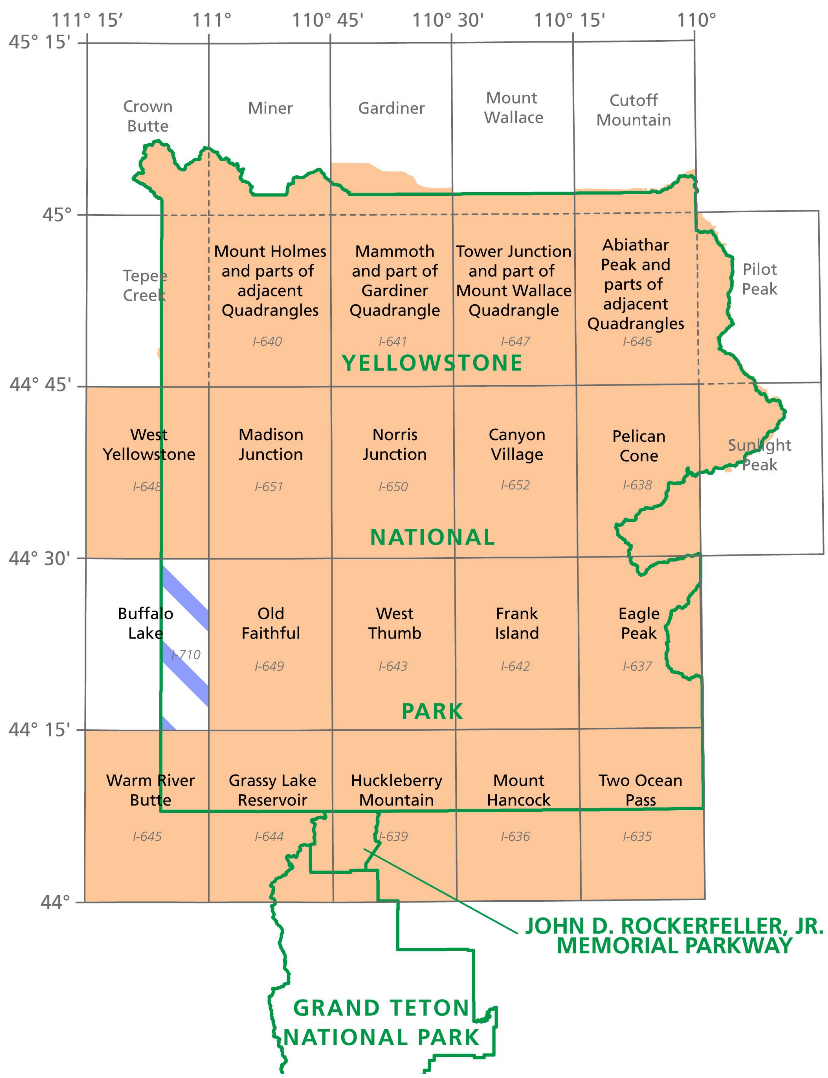
Waldrop, H. A., 1975, Surficial Geologic Map of the West Yellowstone Quadrangle, Yellowstone National Park and adjoining area, Montana, Wyoming, and Idaho: U.S. Geological Survey, Miscellaneous Investigations Series Map I-648, scale 1:62,500 (West Yellowstone Quadrangle). (*GRI Source Map ID 1153*).

Except for the first map listed on this page, the GRI used the full extent of the source maps presented above, and captured all geologic features within their extents.

Additional information pertaining to each source map is also presented in the GIS Source Map Information Table (yellmap_surficial) included with the GRI geologic-GIS data.

Index Map

The following index map displays the extents of the GRI digital geologic-GIS maps produced for Yellowstone National Park (YELL_surficial). The boundary for Yellowstone National Park (as of March, 2020) is outlined in green. 1:62,500 scale source map extents are shown in salmon shading, whereas the extent of the 1:125,000 source map used for Buffalo Lake 15' Quadrangle is shown with a blue stripe. 15' quadrangle boundaries, where not coincident with source map boundaries, are displayed as dotted black lines.



Index Map by Jake Suri (Colorado State University).

Map Unit List

The surficial geologic units present in the digital geologic-GIS data produced for Yellowstone National Park, Wyoming, Montana and Idaho (YELL_surficial) are listed below. Units are listed with their assigned unit symbol and unit name (e.g., Qlst - Younger lake sediments, silt). Units are listed from youngest to oldest. Information about each geologic unit is also presented in the GRI Geologic Unit Information (yellunit_surficial) table included with the GRI geologic-GIS data. Some source unit symbols, names and/or ages may have been changed in this document and in the GRI digital geologic-GIS data. This was done if a unit was considered to be the same unit as one or more units on other source maps used for this project, and these unit symbols, names and/or ages differed. In this case a single unit symbol and name, and the unit's now recognized age, was adopted. Additionally, unit symbols for the Plateau Rhyolite were changed to match symbols of the same units appearing in the GRI geologic GIS dataset for Yellowstone National Park. Unit symbols, names and/or ages in a unit descriptions, or on a correlation of map units or other source map figure were not edited. If a unit symbol, name or age was changed by the GRI, the unit's source map symbol, name and/or age appears with the unit's source map description.

Cenozoic Era

Quaternary Period

Holocene Epoch

Qlst - Younger lake sediments, silt
Qlsg - Younger lake sediments, sandy gravel
Qlgs - Younger lake sediments, gravelly sand
Qml - Modern lake silt
Qgt - Gannett Peak Till
Qgrg - Gannett Peak rock glacier
Qfa - Fine-grained humic alluvium
Qsg - Younger stream deposits, sandy gravel
Qgs - Younger stream deposits, gravelly sand
Qals - Alluvial and lacustrine sand
Qfg - Younger fan gravel
Qfm - Fan deposits, muddy gravel
Qfgs - Fan deposits, gravelly sand
Qfs - Fan deposits, sand
Qfd - Younger flood deposit
Qstr - Younger scree deposit of tuff rubble
Qta - Younger talus deposit
Qtf - Younger talus-flow deposit
Qfr - Younger frost rubble
Qbrb - Younger block rubble
Qad - Avalanche debris
Qtt - Temple Lake Till
Qtrg - Temple Lake rock glacier
Qsd - Younger solifluction deposit
Qls - Younger landslide deposit
Qef - Earth-flow deposit
Qes - Eolian sand
Qtr - Travertine
Qds - Diatomacious silt
Qsi - Silicious sinter

Qhe - Younger hydrothermal explosion deposit
Qtrm - Travertine, pre-modern

Holocene and/or Pleistocene Epoch
Qsh - Sediments of Sevenmile Hole
Qptu - Upper Pinedale Glaciation till
Qprgu - Upper Pinedale Glaciation rock glacier
Qpklu - Upper Pinedale Glaciation ice-dammed lake sediments
Qpru - Upper Pinedale Glaciation rubble veneer
Qpkgu - Upper Pinedale Glaciation kame gravel
Qpgu - Upper Pinedale Glaciation outwash and stream gravel
Qpl - Open-lake sediments, silt
Qpsl - Open-lake sediments, sand
Qplsg - Open-lake sediments, sandy gravel
Qplgs - Younger lake sediments, gravelly sand
Qpg - Stream deposits, gravel
Qpsg - Stream deposits, sandy gravel
Qpgs - Stream deposits, gravelly sand
Qps - Stream deposits, sand
Qpcgr - Stream sand and gravel, cobble gravel
Qpfg - Stream deposits, fan gravel
Qpfs - Gravel, fan sand
Qpfm - Gravel, fan muddy gravel
Qpgc - Stream deposits, cemented gravel
Qpfd - Flood deposit
Qpclm - Colluvium
Qpta - Talus deposit
Qptf - Talus-flow deposit
Qpst - Scree deposit of tuff rubble
Qpfr - Frost rubble
Qprb - Block rubble
Qpsd - Solifluction deposit
Qphl - Lacustrine hydrothermal explosion deposit
Qphe - Hydrothermal explosion deposit
Qplo - Loess
Qpkl - Ice-dammed lake sediments, silt and fine sand
Qpksl - Ice-dammed lake sediments, sand
Qpdgs - Ice-dammed lake sediments, delta gravelly sand
Qpdsg - Ice-dammed lake sediments, delta sand gravel
Qpklb - Ice-dammed lake sediments, beach sandy gravel
Qpls - Landslide deposit
Qpkg - Younger kame deposits, gravel
Qpksg - Younger kame deposits, sandy gravel
Qpkgs - Younger kame deposits, gravelly sand
Qpks - Younger kame deposits, sand
Qpkf - Younger kame deposits, fan gravel
Qpkls - Kame landslide deposit
Qpeg - Younger kame deposits, esker gravel
Qpkc - Younger kame deposits, cemented gravel
Qpt - Pinedale Glaciation till and glacial rubble, till
Qplt - Pinedale Glaciation till and rubble veneer, lacustral till
Qpr - Pinedale Glaciation till and glacial rubble, glacial rubble
Qppl - Proglacial lake sediments

Qppfd - Proglacial flood deposits

Pleistocene Epoch
Qtro - Travertine of pre-Pinedale age
Qpbl - Lake sediments, silt
Qpbsl - Lake sediments, sand
Qpbgl - Lake sediments, gravelly sand
Qwgs - Sediments of West Yellowstone Basin, gravelly sand
Qwsg - Sediments of West Yellowstone Basin, sandy gravel
Qbgs - Stream gravelly sand
Qat - Till of Alden paleovalley
Qak - Kame deposits of Alden paleovalley
Qbkl - Older ice-dammed lake sediments
Qbl - Older lake sediments, silt
Qbsl - Older lake sediments, sand
Qblsg - Older lake sediments, sandy gravel
Qbdgs - Older lake sediments, delta gravelly sand
Qbksg - Older kame deposits, sandy gravel
Qbkc - Cemented kame gravel
Qbkgs - Older kame deposits, gravelly sand
Qbkg - Older kame deposits, gravel
Qbfg - Older fan gravel
Qbks - Kame deposits, sand
Qbt - Bull Lake Glaciation till and glacial rubble, till
Qbr - Bull Lake Glaciation till and glacial rubble, glacial rubble
Qoc - Sediments of Otter Creek
Qbll - Lake silt
Qbfr - Older frost rubble
Qgv - Sediments of Grand View
Qbg - Older gravel
Qpcp - Pitchstone Plateau flow
Qpcg - Grants Pass flow
Qpci - Gibbon River rhyolite flow
Qpcf - Solfatara Plateau rhyolite flow
Qpch - Hayden Valley rhyolite flow
Qpcy - West Yellowstone flow
Qpco - Tuff of Cold Mountain Creek
Qpcr - Belchler River flow
Qpcs - Summit Lake flow
Qpcc - Spring Creek flow
Qpcn - Nez Perce Creek flow
Qbpl - Lacustrine pumiceous sand
Quf - Sediments of Upper Falls
Qpcu - Spruce Creek rhyolite flow
Qrr - Sediments of Red Rock
Qpce - Elephant Back rhyolite flow
Qpcw - West Thumb rhyolite flow
Qpca - Aster Creek rhyolite flow
Qpcb - Buffalo Lake flow
Qpcl - Tuff of Bluff Point
Qch - Chalcedonic sinter
Qpcm - Mary Lake rhyolite flow
Qrst - Shoshone Lake Tuff Member

Qrd - Dry Creek rhyolite flow
Qog - Gravel associated with Osprey Basalt
Qob - Osprey Basalt
Qub - Undine Falls Basalt
Qug - Gravel beneath the Undine Falls Basalt
Qng - Sediments of The Narrows
Qnb - Basalts of The Narrows
Qjb - Junction Butte Basalt
Qjg - Gravel beneath the Junction Butte Basalt
Qpbt - Pre-Bull Lake Glaciation till and rubble veneer, till
Qpbg - Pre-Bull Lake Glaciation gravel
Qpbr - Pre-Bull Lake Glaciation till and rubble veneer, rubble veneer
Qfu - Sediments of Flat Mountain Arm, upper unit
Qfl - Sediments of Flat Mountain Arm, lower unit
Qsbg - Stream boulder gravel
Qst - Sacagawea Ridge Glaciation till and rubble veneer, till
Qsr - Sacagawea Ridge Glaciation till and rubble veneer, rubble veneer
Qip - Sediments of Inspiration Point
Qcc - Sediments of Cascade Creek
Qpud - Dunraven Pass rhyolite flow
Qpuc - Canyon rhyolite flow
Qput - Tuff of Uncle Toms Trail
Qlf - Sediments of Lower Falls
Qprd - Rhyolite dome
Qct - Cedar Ridge (?) Glaciation till

Quaternary or Tertiary Period
QTd - Deposits near Tygee Creek

Quaternary Period and/or older
Qr - Undifferentiated bedrock

Source Map Geologic Units

The source maps each unit is present on are mentioned in the unit listing that follows. For each unit present in the GRI compilation, each source map's unit symbol, unit name and unit age are listed along with a link to view the source map unit description. Unit descriptions for all units are listed with each source map section in the Ancillary Source Map Information section of this document.

Qlst - Younger lake sediments, silt (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

lst - Lake silt (Quaternary, Neoglaciation)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

lst - Lake sediments, silt (Holocene)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

Qlsg - Younger lake sediments, sandy gravel (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

lsg - Lake sediments, sandy gravel (Holocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

lsg - Lake sand and gravel (Quaternary, Neoglaciation)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

lsg - Lake sediments, sandy gravel (Holocene)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

lsg - Lake sand and gravel (Quaternary, Neoglaciation)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

lsg - Lake sediments, sandy gravel (Quaternary, Neoglaciation)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qlgs - Younger lake sediments, gravelly sand (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

lgs - Lake sediments, gravelly sand (Holocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

lgs - Lake sediments, gravelly sand (Holocene)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

lgs - Lake sediments, gravelly sand (Quaternary, Neoglaciation)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qml - Modern lake silt (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

ml - Modern lake silt (Quaternary, Neoglaciation (Holocene))
Geologic unit present on source map: West Yellowstone 15' Quadrangle Geologic Units

Qgt - Gannett Peak Till (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

gt - Gannett Peak Till (Quaternary, Neoglaciation)
Geologic unit present on source map: Abiathar Peak and parts of adjacent 15' Quadrangles Geologic Units

gt - Till and rock glacier, till (Quaternary, Neoglaciation)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

gt - Till (Quaternary, Neoglaciation)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

gt - Till (Quaternary, Neoglaciation)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

gt - Till (Quaternary, Neoglaciation)
Geologic unit present on source map: Two Ocean Pass 15' Quadrangle Geologic Units

Qgrg - Gannett Peak rock glacier (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

grg - Gannett Peak rock glacier (Quaternary, Neoglaciation)
Geologic unit present on source map: Abiathar Peak and parts of adjacent 15' Quadrangles Geologic Units

grg - Till and rock glacier, rock glacier (Quaternary, Neoglaciation)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

grg - Rock glacier (Quaternary, Neoglaciation)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

grg - Rock glacier (Quaternary, Neoglaciation)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qfa - Fine-grained humic alluvium (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

fa - Fined-grained humic alluvium (Quaternary, Neoglaciation)
Geologic unit present on source map: Abiathar Peak and parts of adjacent 15' Quadrangles Geologic Units

fa - Fine-grained humic alluvium (Holocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

fa - Fine-grained humic alluvium (Quaternary, Neoglaciation)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

fa - Fine-grained humic alluvium (Holocene)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

fa - Fine-grained humic alluvium (Holocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

fa - Fine-grained humic alluvium (Quaternary, Neoglaciation)
Geologic unit present on source map: Huckleberry Mountain 15' Quadrangle Geologic Units

fa - Fine-grained humic alluvium (Quaternary, Neoglaciation)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

fa - Fine-grained humic alluvium (Holocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

fa - Fine-grained humic alluvium (Quaternary, Neoglaciation)
Geologic unit present on source map: Mount Hancock 15' Quadrangle Geologic Units

fa - Fine-grained alluvium (Quaternary, Neoglaciation)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

fa - Fine-grained humic alluvium (Holocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

fa - Fine-grained humic alluvium (Quaternary, Neoglaciation)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

fa - Fine-grained humic alluvium (Quaternary, Neoglaciation)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

fa - Fine-grained humic alluvium (Holocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

fa - Fine-grained humic alluvium (Quaternary, Neoglaciation)
Geologic unit present on source map: Two Ocean Pass 15' Quadrangle Geologic Units

fa - Fine-grained humic alluvium (Holocene)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

fa - Fine-grained humic alluvium (Quaternary, Neoglaciation)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

fa - Fine-grained humic alluvium (Quaternary, Neoglaciation)
Geologic unit present on source map: West Yellowstone 15' Quadrangle Geologic Units

fa - Fine-grained humic alluvium (Quaternary, Neoglaciation)
Geologic unit present on source map: Yellowstone National Park Geologic Units

Qsg - Younger stream deposits, sandy gravel (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

sg - Stream gravel (Quaternary, Neoglaciation)
Geologic unit present on source map: Abiathar Peak and parts of adjacent 15' Quadrangles Geologic Units

sg - Stream deposits, sandy gravel (Holocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

sg - Stream gravel (Quaternary, Neoglaciation)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

sg - Stream gravel (Holocene)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

sg - Stream deposits, gravel (Holocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

sg - Stream gravel (Quaternary, Neoglaciation)
Geologic unit present on source map: Huckleberry Mountain 15' Quadrangle Geologic Units

sg - Stream gravel (Quaternary, Neoglaciation)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

sg - Stream gravel (Holocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

sg - Stream gravel (Quaternary, Neoglaciation)

Geologic unit present on source map: Mount Hancock 15' Quadrangle Geologic Units

sg - Stream gravel (Quaternary, Neoglaciation)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

sg - Stream gravel (Holocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

sg - Stream gravel (Quaternary, Neoglaciation)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

sg - Stream gravel (Quaternary, Neoglaciation)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

sg - Stream gravel (Holocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

sg - Stream gravel (Quaternary, Neoglaciation)
Geologic unit present on source map: Two Ocean Pass 15' Quadrangle Geologic Units

sg - Stream gravel (Holocene)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

sg - Stream deposits, sandy gravel (Quaternary, Neoglaciation)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

sg - Steam gravel (Quaternary, Neoglaciation)
Geologic unit present on source map: West Yellowstone 15' Quadrangle Geologic Units

Qgs - Younger stream deposits, gravelly sand (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

gs - Stream deposits, gravelly sand (Holocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

gs - Stream deposits, gravelly sand (Holocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

gs - Stream deposits, gravelly sand (Quaternary, Neoglaciation)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qals - Alluvial and lacustrine sand (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

als - Alluvial and lacustrine sand (Holocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

Qfg - Younger fan gravel (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

fg - Fan gravel (Quaternary, Neoglaciation)
Geologic unit present on source map: Abiathar Peak and parts of adjacent 15' Quadrangles Geologic Units

fg - Fan gravel (Holocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

fg - Fan gravel (Quaternary, Neoglaciation)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

fg - Fan gravel (Holocene)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

fg - Fan deposits, gravel (Holocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

fg - Fan gravel (Quaternary, Neoglaciation)
Geologic unit present on source map: Huckleberry Mountain 15' Quadrangle Geologic Units

fg - Fan gravel (Quaternary, Neoglaciation)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

fg - Fan deposits, gravel (Holocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

fg - Fan gravel (Quaternary, Neoglaciation)
Geologic unit present on source map: Mount Hancock 15' Quadrangle Geologic Units

fg - Fan deposits, gravel (Quaternary, Neoglaciation)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

fg - Fan gravel (Quaternary, Neoglaciation)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

fg - Fan deposits, gravel (Holocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

fg - Fan gravel (Quaternary, Neoglaciation)
Geologic unit present on source map: Two Ocean Pass 15' Quadrangle Geologic Units

fg - Fan deposits, gravel (Quaternary, Neoglaciation)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qfm - Fan deposits, muddy gravel (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

fm - Fan deposits, muddy gravel (Holocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

fm - Fan deposits, muddy gravel (Quaternary, Neoglaciation)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

fm - Fan deposits, muddy gravel (Holocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

Qfgs - Fan deposits, gravelly sand (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

fgs - Fan deposits, gravelly sand (Quaternary, Neoglaciation)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qfs - Fan deposits, sand (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

fs - Fan deposits, sand (Holocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

Qfd - Younger flood deposit (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

fd - Flood deposit (Holocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

Qstr - Younger scree deposit of tuff rubble (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

st - Scree deposit of tuff rubble (Quaternary, Neoglaciation)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

Qta - Younger talus deposit (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

ta - Talus deposit (Quaternary, Neoglaciation)
Geologic unit present on source map: Abiathar Peak and parts of adjacent 15' Quadrangles Geologic Units

ta - Talus deposit (Holocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

ta - Talus deposit (Quaternary, Neoglaciation)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

ta - Talus deposit (Holocene)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

ta - Talus deposit (Holocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

ta - Talus deposit (Quaternary, Neoglaciation)
Geologic unit present on source map: Huckleberry Mountain 15' Quadrangle Geologic Units

ta - Talus deposit (Holocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

ta - Talus deposit (Quaternary, Neoglaciation)
Geologic unit present on source map: Mount Hancock 15' Quadrangle Geologic Units

ta - Talus deposit (Quaternary, Neoglaciation)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

ta - Talus deposit (Quaternary, Neoglaciation)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

ta - Talus deposit (Holocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

ta - Talus deposit (Quaternary, Neoglaciation)
Geologic unit present on source map: Two Ocean Pass 15' Quadrangle Geologic Units

ta - Talus deposit (Holocene)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

ta - Talus deposit (Quaternary, Neoglaciation)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

ta - Talus (Quaternary)
Geologic unit present on source map: Yellowstone National Park Geologic Units

Qtf - Younger talus-flow deposit (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

tf - Talus-flow deposit (Quaternary, Neoglaciation)
Geologic unit present on source map: Abiathar Peak and parts of adjacent 15' Quadrangles Geologic Units

tf - Talus-flow deposit (Quaternary, Neoglaciation)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

tf - Talus-flow deposit (Holocene)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

tf - Talus-flow deposit (Holocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

tf - Talus-flow deposit (Quaternary, Neoglaciation)
Geologic unit present on source map: Huckleberry Mountain 15' Quadrangle Geologic Units

tf - Talus-flow deposit (Quaternary, Neoglaciation)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

tf - Talus flow deposit (Quaternary, Neoglaciation)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

tf - Talus-flow deposit (Holocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

tf - Talus-flow deposits (Quaternary, Neoglaciation)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qfr - Younger frost rubble (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

fr - Frost rubble (Quaternary, Neoglaciation)
Geologic unit present on source map: Abiathar Peak and parts of adjacent 15' Quadrangles Geologic Units

fr - Frost rubble (Quaternary, Neoglaciation)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

fr - Frost rubble (Holocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

fr - Frost rubble (Quaternary, Neoglaciation)
Geologic unit present on source map: Huckleberry Mountain 15' Quadrangle Geologic Units

fr - Frost rubble (Holocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

fr - Frost rubble (Quaternary, Neoglaciation)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

fr - Frost rubble (Quaternary, Neoglaciation)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

fr - Frost rubble (Holocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

fr - Frost rubble (Quaternary, Neoglaciation)
Geologic unit present on source map: Two Ocean Pass 15' Quadrangle Geologic Units

fr - Frost rubble (Quaternary, Neoglaciation)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qbrb - Younger block rubble (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

rb - Block rubble (Quaternary, Neoglaciation)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

rb - Block rubble (Holocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

rb - Block rubble (Quaternary, Neoglaciation)
Geologic unit present on source map: Huckleberry Mountain 15' Quadrangle Geologic Units

rb - Block rubble (Holocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

rb - Block rubble (Quaternary, Neoglaciation)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

Qad - Avalanche debris (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

ad - Avalanche debris (Quaternary, Neoglaciation)
Geologic unit present on source map: Abiathar Peak and parts of adjacent 15' Quadrangles Geologic Units

ad - Avalanche debris (Holocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

ad - Avalanche debris (Quaternary, Neoglaciation)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

ad - Avalanche debris (Holocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

ad - Avalanche debris (Quaternary, Neoglaciation)
Geologic unit present on source map: Mount Hancock 15' Quadrangle Geologic Units

ad - Avalanche debris (Quaternary, Neoglaciation)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

ad - Avalanche debris (Quaternary, Neoglaciation)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

ad - Avalanche debris (Holocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

ad - Avalanche debris (Quaternary, Neoglaciation)
Geologic unit present on source map: Two Ocean Pass 15' Quadrangle Geologic Units

ad - Avalanche debris (Quaternary, Neoglaciation)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qtt - Temple Lake Till (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

tt - Temple Lake Till (Quaternary, Neoglaciation)
Geologic unit present on source map: Abiathar Peak and parts of adjacent 15' Quadrangles Geologic

Units

tt - Till and rock glacier, till (Quaternary, Neoglaciation)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

tt - Till (Quaternary, Neoglaciation)
Geologic unit present on source map: Mount Hancock 15' Quadrangle Geologic Units

tt - Till (Quaternary, Neoglaciation)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

tt - Till and rock glacier, till (Quaternary, Neoglaciation)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

tt - Till (Quaternary, Neoglaciation)
Geologic unit present on source map: Two Ocean Pass 15' Quadrangle Geologic Units

tt - Till (Quaternary, Neoglaciation)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qtrg - Temple Lake rock glacier (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

trg - Temple Lake rock glacier (Quaternary, Neoglaciation)
Geologic unit present on source map: Abiathar Peak and parts of adjacent 15' Quadrangles Geologic Units

trg - Till and rock glacier, rock glacier (Quaternary, Neoglaciation)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

trg - Rock glacier (Quaternary, Neoglaciation)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

trg - Till and rock glacier, rock glacier (Quaternary, Neoglaciation)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

Qsd - Younger solifluction deposit (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

sd - Solifluction deposit (Holocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

sd - Solifluction deposit (Quaternary, Neoglaciation)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

sd - Solifluction deposit (Quaternary, Neoglaciation)
Geologic unit present on source map: Huckleberry Mountain 15' Quadrangle Geologic Units

sd - Solifluction deposit (Holocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

sd - Solifluction deposit (Quaternary, Neoglaciation)
Geologic unit present on source map: Mount Hancock 15' Quadrangle Geologic Units

sd - Solufluction deposit (Quaternary, Neoglaciation)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

sd - Solifluction deposit (Holocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

sd - Solifluction deposit (Quaternary, Neoglaciation)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

sd - Solifluction deposit (Quaternary, Neoglaciation)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

sd - Solifluction deposit (Quaternary, Neoglaciation)
Geologic unit present on source map: Two Ocean Pass 15' Quadrangle Geologic Units

sd - Solifluction deposit (Quaternary, Neoglaciation)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qls - Younger landslide deposit (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

ls - Landslide deposit (Quaternary, Neoglaciation)
Geologic unit present on source map: Abiathar Peak and parts of adjacent 15' Quadrangles Geologic Units

ls - Landslide deposit (Holocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

ls - Landslide deposit (Quaternary, Neoglaciation)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

ls - Landslide deposit (Holocene)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

ls - Landslide deposits (Holocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

ls - Landslide deposit (Quaternary, Neoglaciation)
Geologic unit present on source map: Huckleberry Mountain 15' Quadrangle Geologic Units

ls - Landslide deposit (Quaternary, Neoglaciation)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

ls - Landslide deposit (Holocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

ls - Landslide deposit (Quaternary, Neoglaciation)
Geologic unit present on source map: Mount Hancock 15' Quadrangle Geologic Units

ls - Landslide deposit, landslide deposit undifferentiated (Quaternary, Neoglaciation)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

ls - Landslide deposit (Quaternary, Neoglaciation)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

ls - Landslide deposit (Holocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

ls - Landslide deposit (Quaternary, Neoglaciation)
Geologic unit present on source map: Two Ocean Pass 15' Quadrangle Geologic Units

ls - Landslide deposit (Quaternary, Neoglaciation)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qef - Earth-flow deposit (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

ef - Landslide deposit, earth-flow deposit (Quaternary, Neoglaciation)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

Qes - Eolian sand (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

es - Eolian sand (Holocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

es - Eolian sand (Quaternary, Neoglaciation)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

es - Eolian sand (Holocene)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

es - Eolian sand (Quaternary, Neoglaciation)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

es - Eolian silt and sand (Holocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

es - Eolian sand and silt (Holocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

es - Eolian sand (Quaternary, Neoglaciation)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

es - Eolian sand (Quaternary, Neoglaciation)
Geologic unit present on source map: West Yellowstone 15' Quadrangle Geologic Units

Qtr - Travertine (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

tr - Travertine (Quaternary, Neoglaciation)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

try - Younger travertine (Holocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

tr - Travertine (Quaternary, Neoglaciation)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

tr - Travertine (Quaternary, Neoglaciation)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

tr - Travertine (Holocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

Qds - Diatomacious silt (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

ds - Diatomacious silt (Holocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

ds - Diatomaceous sediment (Holocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

ds - Diatomaceous sediment (Quaternary, Neoglaciation)
Geologic unit present on source map: Huckleberry Mountain 15' Quadrangle Geologic Units

ds - Diatomaceous silt (Quaternary, Neoglaciation)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

ds - Diatomaceous sediment (Holocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

ds - Diatomaceous silt (Holocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

ds - Diatomaceous silt (Quaternary, Neoglaciation)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

ds - Diatomaceous sediment (Holocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

ds - Diatomaceous silt (Quaternary)
Geologic unit present on source map: Yellowstone National Park Geologic Units

Qsi - Silicious sinter (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

si - Silicious sinter (Holocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

si - Siliceous sinter (Quaternary, Neoglaciation)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

si - Siliceous sinter (Holocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

si - Siliceous sinter (Holocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

si - Siliceous sinter (Quaternary, Neoglaciation)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

si - Siliceous sinter (Holocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

si - Siliceous sinter (Quaternary, Neoglaciation)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

si - Siliceous sinter (Quaternary)
Geologic unit present on source map: Yellowstone National Park Geologic Units

Qhe - Younger hydrothermal explosion deposit (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

he - Hydrothermal explosion deposit (Holocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

Qtrm - Travertine, pre-modern (Holocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

trm - Travertine (Holocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

Qsh - Sediments of Sevenmile Hole (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

sh - Sediments of Sevenmile Hole (Holocene and/or Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

sh - Sediments of Sevenmile Hole (Holocene and/or Pleistocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

Qptu - Upper Pinedale Glaciation till (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

ptu - Till (Holocene and/or Pleistocene)
Geologic unit present on source map: Abiathar Peak and parts of adjacent 15' Quadrangles Geologic Units

ptu - Till and rock glacier, till (Holocene and/or Pleistocene)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

ptu - Till (Holocene and/or Pleistocene)
Geologic unit present on source map: Mount Hancock 15' Quadrangle Geologic Units

ptu - Till (Holocene and/or Pleistocene)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

ptu - Till (Holocene and/or Pleistocene)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

ptu - Till (Holocene and/or Pleistocene)
Geologic unit present on source map: Two Ocean Pass 15' Quadrangle Geologic Units

ptu - Upper till and rubble veneer, till (Holocene and/or Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qprgu - Upper Pinedale Glaciation rock glacier (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions presented on each source map).

prgu - Rock glacier (Holocene and/or Pleistocene)
Geologic unit present on source map: Abiathar Peak and parts of adjacent 15' Quadrangles Geologic Units

prgu - Till and rock glacier, rock glacier (Holocene and/or Pleistocene)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

prgu - Rock glacier (Holocene and/or Pleistocene)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

Qpklu - Upper Pinedale Glaciation ice-dammed lake sediments (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pklu - Ice-dammed lake sediments (Holocene and/or Pleistocene)
Geologic unit present on source map: Abiathar Peak and parts of adjacent 15' Quadrangles Geologic Units

Qpru - Upper Pinedale Glaciation rubble veneer (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pru - Rubble veneer (Holocene and/or Pleistocene)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

pru - Upper till and rubble veneer, rubble veneer (Holocene and/or Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qpkgu - Upper Pinedale Glaciation kame gravel (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pkgu - Kame gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

Qpgu - Upper Pinedale Glaciation outwash and stream gravel (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pgu - Outwash and stream gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Abiathar Peak and parts of adjacent 15' Quadrangles Geologic Units

pgu - Outwash gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

pgu - Outwash gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

pgu - Upper outwash gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Two Ocean Pass 15' Quadrangle Geologic Units

Qpl - Open-lake sediments, silt (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pl - Open-lake sediments, silt (Holocene and/or Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

pl - Open lake sediments, silt (Holocene and/or Pleistocene)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

pl - Lake sediments, silt (Holocene and/or Pleistocene)

Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

pl - Lake sediments, silt (Holocene and/or Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

pl - Lake sediments (Holocene and/or Pleistocene)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

pl - Lake sediments, silt (Holocene and/or Pleistocene)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

pl - Open lake sediments, silt (Holocene and/or Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

pl - Lake silt (Holocene and/or Pleistocene)
Geologic unit present on source map: West Yellowstone 15' Quadrangle Geologic Units

Qpsl - Open-lake sediments, sand (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

psl - Open-lake sediments, sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

psl - Open lake sediments, sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

psl - Lake sediments, sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

psl - Lake sediments, sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

psl - Lake sediments, sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

psl - Open lake sediments, sand (Holocene and/or Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qplsg - Open-lake sediments, sandy gravel (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

plsg - Open-lake sediments, sandy gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

plsg - Lake sand and gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

plsg - Open lake sediments, sandy gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

Qplgs - Younger lake sediments, gravelly sand (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

plgs - Lake sediments, gravelly sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

plgs - Lake sediments, beach gravelly sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

plgs - Open lake sediments, gravelly sand (Holocene and/or Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qpg - Stream deposits, gravel (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pg - Outwash and stream gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Abiathar Peak and parts of adjacent 15' Quadrangles Geologic Units

pg - Stream deposits, gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

pg - Gravel, outwash and stream gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

pg - Stream gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

pg - Stream deposits, gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

pg - Stream, sand, and gravel, gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Huckleberry Mountain 15' Quadrangle Geologic Units

pg - Stream deposits, gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

pg - Gravel, stream and outwash gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

pg - Gravel, stream terrace gravel (Holocene and/or Pleistocene)

Geologic unit present on source map: Mount Hancock 15' Quadrangle Geologic Units

pg - Outwash and stream gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

pg - Outwash and stream deposits, gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

pg - Stream deposits, gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

pg - Stream sand and gravel, gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

pg - Gravel, stream and outwash gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

pg - Gravel, outwash and stream gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Two Ocean Pass 15' Quadrangle Geologic Units

pg - Stream sand and gravel, gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

Qpsg - Stream deposits, sandy gravel (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

psg - Stream deposits, sandy gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

psg - Stream deposits, sandy gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

psg - Stream, sand, and gravel, sandy gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Huckleberry Mountain 15' Quadrangle Geologic Units

psg - Stream deposits, sandy gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

psg - Gravel, sandy gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Mount Hancock 15' Quadrangle Geologic Units

psg - Outwash and stream deposits, sandy gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

psg - Stream deposits, sandy gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

psg - Stream sand and gravel, sandy gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

psg - Stream deposits, sandy gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

psg - Sandy gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: West Yellowstone 15' Quadrangle Geologic Units

pg - Sand and gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Yellowstone National Park Geologic Units

Qpgs - Stream deposits, gravelly sand (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pgs - Stream deposits, gravelly sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

pgs - Stream deposits, gravelly sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

pgs - Outwash and stream deposits, gravelly sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

pgs - Stream deposits, gravelly sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

pgs - Stream sand and gravel, gravelly sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

pgs - Stream deposits, gravelly sand (Holocene and/or Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qps - Stream deposits, sand (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

ps - Stream deposits, sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

ps - Stream deposits, sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

ps - Stream, sand, and gravel, sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Huckleberry Mountain 15' Quadrangle Geologic Units

ps - Stream deposits, sand (Holocene and/or Pleistocene)

Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

ps - Gravel, stream sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

ps - Outwash and stream deposits, sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

ps - Stream sand and gravel, sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

ps - Stream sand and gravel, sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

ps - Stream deposits, sand (Holocene and/or Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qpcgr - Stream sand and gravel, cobble gravel (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pcg - Stream sand and gravel, cobble gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

Qpfg - Stream deposits, fan gravel (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pfg - Fan gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Abiathar Peak and parts of adjacent 15' Quadrangles Geologic Units

pfg - Stream deposits, fan gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

pfg - Gravel, fan gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

pfg - Fan gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

pfg - Fan gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

pfg - Fan gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Huckleberry Mountain 15' Quadrangle Geologic Units

pfg - Stream deposits, fan gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

pfg - Gravel, fan gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

pfg - Gravel, fan gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Mount Hancock 15' Quadrangle Geologic Units

pfg - Alluvial and outwash fan gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

pfg - Outwash and stream deposits, fan gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

pfg - Stream deposits, fan gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

pfg - Stream sand and gravel, fan gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

pfg - Gravel, fan gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

pfg - Gravel, fan gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Two Ocean Pass 15' Quadrangle Geologic Units

pfg - Stream sand and gravel, fan gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

pfg - Fan gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

pfg - Fan gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: West Yellowstone 15' Quadrangle Geologic Units

Qpfs - Gravel, fan sand (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pfs - Gravel, fan sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

Qpfm - Gravel, fan muddy gravel (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pfm - Gravel, fan muddy gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

Qpgc - Stream deposits, cemented gravel (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pgc - Stream deposits, cemented gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

Qpfd - Flood deposit (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pfd - Flood deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

pfd - Flood deposits (Holocene and/or Pleistocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

pfd - Flood deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

pfd - Flood deposits (Holocene and/or Pleistocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

Qpclm - Colluvium (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pco - Colluvium (Holocene and/or Pleistocene)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

pco - Colluvium (Holocene and/or Pleistocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

pco - Colluvium (Holocene and/or Pleistocene)

Geologic unit present on source map: Huckleberry Mountain 15' Quadrangle Geologic Units

pco - Colluvium (Holocene and/or Pleistocene)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

pco - Colluvium (Holocene and/or Pleistocene)
Geologic unit present on source map: Mount Hancock 15' Quadrangle Geologic Units

pco - Colluvium (Holocene and/or Pleistocene)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

pco - Colluvium (Holocene and/or Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

pco - Colluvium (Holocene and/or Pleistocene)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

pco - Colluvium (Holocene and/or Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qpta - Talus deposit (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pta - Talus deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Abiathar Peak and parts of adjacent 15' Quadrangles Geologic Units

pta - Talus deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

pta - Talus deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

pta - Talus deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

pta - Talus deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

pta - Talus deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Huckleberry Mountain 15' Quadrangle Geologic Units

pta - Talus deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

pta - Talus deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

pta - Talus deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Mount Hancock 15' Quadrangle Geologic Units

pta - Talus deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

pta - Talus deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

pta - Talus (Holocene and/or Pleistocene)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

pta - Talus deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

pta - Talus deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

pta - Talus deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Two Ocean Pass 15' Quadrangle Geologic Units

pta - Talus deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

pta - Talus deposits (Holocene and/or Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

pta - Talus deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: West Yellowstone 15' Quadrangle Geologic Units

Qptf - Talus-flow deposit (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

ptf - Talus-flow deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

ptf - Talus-flow deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Huckleberry Mountain 15' Quadrangle Geologic Units

ptf - Talus-flow deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

ptf - Talus-flow deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

ptf - Talus flow deposit (Holocene and/or Pleistocene)

Geologic unit present on source map: Mount Hancock 15' Quadrangle Geologic Units

ptf - Talus-flow deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

ptf - Talus-flow deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

ptf - Talus-flow deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

ptf - Talus flow deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

ptf - Talus-flow deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

ptf - Talus-flow deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

ptf - Talus-flow deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: West Yellowstone 15' Quadrangle Geologic Units

Qpst - Scree deposit of tuff rubble (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pst - Scree of tuff rubble (Holocene and/or Pleistocene)
Geologic unit present on source map: Abiathar Peak and parts of adjacent 15' Quadrangles Geologic Units

pst - Scree deposit of tuff rubble (Holocene and/or Pleistocene)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

pst - Scree deposit of tuff rubble (Holocene and/or Pleistocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

pst - Scree deposit of tuff rubble (Holocene and/or Pleistocene)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

pst - Scree deposit of tuff rubble (Holocene and/or Pleistocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

Qpfr - Frost rubble (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pfr - Frost rubble (Holocene and/or Pleistocene)
Geologic unit present on source map: Abiathar Peak and parts of adjacent 15' Quadrangles Geologic Units

pfr - Frost rubble (Holocene and/or Pleistocene)
Geologic unit present on source map: Mount Hancock 15' Quadrangle Geologic Units

pfr - Frost rubble (Holocene and/or Pleistocene)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

pfr - Frost rubble (Holocene and/or Pleistocene)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

Qprb - Block rubble (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

prb - Block rubble (Holocene and/or Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

prb - Block rubble (Holocene and/or Pleistocene)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

prb - Block rubble (Holocene and/or Pleistocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

prb - Block rubble (Holocene and/or Pleistocene)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

prb - Block rubble (Holocene and/or Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

prb - Block rubble (Holocene and/or Pleistocene)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

prb - Block rubble (Holocene and/or Pleistocene)
Geologic unit present on source map: Two Ocean Pass 15' Quadrangle Geologic Units

Qpsd - Solifluction deposit (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

psd - Solifluction deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

Qphl - Lacustrine hydrothermal explosion deposit (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

phl - Lacustrine hydrothermal explosion deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

Qphe - Hydrothermal explosion deposit (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

phe - Hydrothermal explosion deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

phe - Hydrothermal-explosion deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

phe - Hydrothermal explosion deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

phe - Hydrothermal-explosion deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

phe - Hydrothermal-explosion deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

phe - Hydrothermal explosion deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

phe - Hydrothermal explosion deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qplo - Loess (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

plo - Loess (Holocene and/or Pleistocene)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

plo - Loess (Holocene and/or Pleistocene)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

Qpkl - Ice-dammed lake sediments, silt and fine sand (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pkl - Ice-dammed lake sediments (Holocene and/or Pleistocene)
Geologic unit present on source map: Abiathar Peak and parts of adjacent 15' Quadrangles Geologic Units

pkl - Ice-dammed lake sediments, silt and fine sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

pkl - Ice-dammed lake deposits, lake silt (Holocene and/or Pleistocene)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

pkl - Ice-dammed lake sediments, silt (Holocene and/or Pleistocene)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

pkl - Ice-dammed lake silt (Holocene and/or Pleistocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

pkl - Ice-dammed lake silt (Holocene and/or Pleistocene)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

pkl - Ice-dammed lake deposits, silt (Holocene and/or Pleistocene)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

pkl - Ice-dammed lake silt (Holocene and/or Pleistocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

pkl - Ice-dammed lake sediments (Holocene and/or Pleistocene)
Geologic unit present on source map: Two Ocean Pass 15' Quadrangle Geologic Units

pkl - Ice-dammed lake sediments, silt (Holocene and/or Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qpksl - Ice-dammed lake sediments, sand (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pksl - Ice-dammed lake sediments, sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

pksl - Ice-dammed lake sediments, sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

pksl - Ice-dammed lake sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

pksl - Ice-dammed lake deposits, sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

pkls - Kame deposits, kame landslide deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Two Ocean Pass 15' Quadrangle Geologic Units

pksl - Ice-dammed lake sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

pksl - Ice-dammed lake sediments, sand (Holocene and/or Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qpdgs - Ice-dammed lake sediments, delta gravelly sand (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pdgs - Ice-dammed lake sediments, delta gravelly sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

pkdg - Ice-dammed lake sediments, delta gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qpdsg - Ice-dammed lake sediments, delta sand gravel (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pdsg - Ice-dammed lake sediments, delta sand gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

Qpklb - Ice-dammed lake sediments, beach sandy gravel (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pklb - Ice-dammed lake sediments, beach sandy gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

pklb - Ice-dammed lake deposits, lake beach deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

pklb - Ice-dammed lake sediments, beach deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

pklb - Ice-dammed lake sediments, beach deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qpls - Landslide deposit (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pkls - Kame landslide deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

pls - Landslide deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

Qpkg - Younger kame deposits, gravel (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pkg - Kame deposits, gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Abiathar Peak and parts of adjacent 15' Quadrangles Geologic Units

pkg - Kame deposit, gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

pkg - Kame deposits, gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

pkg - Kame deposits, gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

pkg - Kame deposits, kame gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Huckleberry Mountain 15' Quadrangle Geologic Units

pkg - Kame deposits, gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

pkg - Kame deposits, gravel (Holocene and/or Pleistocene)

Geologic unit present on source map: Mount Hancock 15' Quadrangle Geologic Units

pkg - Kame gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

pkg - Kame deposits, gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

pks - Kame deposits, gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

pkg - Kame deposits, gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

pkg - Kame deposits, gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

pkg - Kame deposits, gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Two Ocean Pass 15' Quadrangle Geologic Units

pkg - Kame deposits, gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

pkg - ***on map but not in legend -- interpreted to be pkgs (Holocene and/or Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qpksg - Younger kame deposits, sandy gravel (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pksg - Kame deposits, sandy gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

pksg - Kame deposit, sandy gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

pksg - Kame deposits, sandy gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

pksg - Kame deposits, sandy gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

pksg - Kame deposits, kame sandy gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Huckleberry Mountain 15' Quadrangle Geologic Units

pksg - Kame deposits, sandy gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

pksg - Kame deposits, sandy gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Mount Hancock 15' Quadrangle Geologic Units

pksg - Kame deposits, sandy gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

pksg - Kame deposits, sandy gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

pksg - Kame deposits, sandy gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

pksg - Kame deposits, sandy gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Two Ocean Pass 15' Quadrangle Geologic Units

pksg - Kame deposits, sandy gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

pksg - Kame deposits, sandy gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qpkgs - Younger kame deposits, gravelly sand (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pkgs - Kame deposits, gravelly sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

pkgs - Kame deposit, gravelly sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

pkgs - Kame deposits, gravelly sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

pkgs - Kame deposits, gravelly sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

pkgs - Kame deposits, gravelly sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

pkgs - Kame deposits, gravelly sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Mount Hancock 15' Quadrangle Geologic Units

pkgs - Kame deposits, gravelly sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

pkgs - Kame deposits, gravelly sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

pkgs - Kame deposits, gravelly sand (Holocene and/or Pleistocene)

Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

pkgs - Kame deposits, gravelly sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Two Ocean Pass 15' Quadrangle Geologic Units

pkgs - Kame deposits, gravelly sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

pkgs - Kame deposits, gravelly sand (Holocene and/or Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qpks - Younger kame deposits, sand (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pks - Kame deposits, sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Abiathar Peak and parts of adjacent 15' Quadrangles Geologic Units

pks - Kame deposits, sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

pks - Kame deposits, sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

pks - Kame deposits, sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

pks - Kame deposits, sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

pks - Kame deposits, sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

pks - Kame deposits, sand (Holocene and/or Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qpkf - Younger kame deposits, fan gravel (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pkf - Kame deposits, fan gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

pkf - Kame deposits, inwash fan gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle

Geologic Units

pkf - Kame inwash fan gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

pkf - Kame deposits, fan gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

pkf - Kame deposits, fan gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

pkf - Kame deposits, inwash fan deposits (Holocene and/or Pleistocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

Qpkls - Kame landslide deposit (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pkls - Kame landslide deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

pkls - Kame landslide deposit (Holocene and/or Pleistocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

Qpeg - Younger kame deposits, esker gravel (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

peg - Kame deposits, esker gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

peg - Kame deposits, esker gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

peg - Kame deposits, esker gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

peg - Esker gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

peg - Kame deposits, esker gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

peg - Kame deposits, esker gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

Qpkc - Younger kame deposits, cemented gravel (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pkc - Kame deposits, cemented sand (Holocene and/or Pleistocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

pkc - Kame deposits, cemented gravel (Holocene and/or Pleistocene)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

Qpt - Pinedale Glaciation till and glacial rubble, till (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pt - Till (Holocene and/or Pleistocene)
Geologic unit present on source map: Abiathar Peak and parts of adjacent 15' Quadrangles Geologic Units

pt - Till and glacial rubble, till (Holocene and/or Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

pt - Till and rubble veneer, till (Holocene and/or Pleistocene)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

pt - Till and glacial rubble, till (Holocene and/or Pleistocene)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

pt - Till and rubble veneer, till (Holocene and/or Pleistocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

pt - Till (Holocene and/or Pleistocene)
Geologic unit present on source map: Huckleberry Mountain 15' Quadrangle Geologic Units

pt - Till and rubble veneer, till (Holocene and/or Pleistocene)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

pt - Till (Holocene and/or Pleistocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

pt - Till and glacial rubble, till (Holocene and/or Pleistocene)
Geologic unit present on source map: Mount Hancock 15' Quadrangle Geologic Units

pt - Till (Holocene and/or Pleistocene)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

pt - Till and glacial rubble, till (Holocene and/or Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

pt - Till and rubble veneer, till (Holocene and/or Pleistocene)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

pt - Till and rubble veneer, till (Holocene and/or Pleistocene)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

pt - Till (Holocene and/or Pleistocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

pt - Till and glacial rubble, till (Holocene and/or Pleistocene)
Geologic unit present on source map: Two Ocean Pass 15' Quadrangle Geologic Units

pt - Till and rubble veneer, till (Holocene and/or Pleistocene)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

pt - Tills and rubble veneer, till (Holocene and/or Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

pt - Till (Holocene and/or Pleistocene)
Geologic unit present on source map: West Yellowstone 15' Quadrangle Geologic Units

pt - Till (Holocene and/or Pleistocene)
Geologic unit present on source map: Yellowstone National Park Geologic Units

Qplt - Pinedale Glaciation till and rubble veneer, lacustral till (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

plt - Tills and rubble veneer, lacustral till (Holocene and/or Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qpr - Pinedale Glaciation till and glacial rubble, glacial rubble (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pr - Rubble veneer (Holocene and/or Pleistocene)
Geologic unit present on source map: Abiathar Peak and parts of adjacent 15' Quadrangles Geologic

Units

pr - Till and glacial rubble, glacial rubble (Holocene and/or Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

pr - Till and rubble veneer, rubble veneer (Holocene and/or Pleistocene)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

pr - Till and glacial rubble, glacial rubble (Holocene and/or Pleistocene)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

pr - Till and rubble veneer, rubble veneer (Holocene and/or Pleistocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

pr - Glacial rubble (Holocene and/or Pleistocene)
Geologic unit present on source map: Huckleberry Mountain 15' Quadrangle Geologic Units

pr - Till and rubble veneer, rubble veneer (Holocene and/or Pleistocene)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

pr - Rubble veneer (Holocene and/or Pleistocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

pr - Till and glacial rubble, rubble (Holocene and/or Pleistocene)
Geologic unit present on source map: Mount Hancock 15' Quadrangle Geologic Units

pr - Rubble veneer (Holocene and/or Pleistocene)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

pr - Till and glacial rubble, glacial rubble (Holocene and/or Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

pr - Till and rubble veneer, rubble veneer (Holocene and/or Pleistocene)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

pr - Till and rubble veneer, rubble veneer (Holocene and/or Pleistocene)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

pr - Rubble veneer (Holocene and/or Pleistocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

pr - Till and glacial rubble, glacial rubble (Holocene and/or Pleistocene)
Geologic unit present on source map: Two Ocean Pass 15' Quadrangle Geologic Units

pr - Till and rubble veneer, rubble veneer (Holocene and/or Pleistocene)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

pr - Tills and rubble veneer, rubble veneer (Holocene and/or Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qppl - Proglacial lake sediments (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

ppl - Proglacial lake silt (Holocene and/or Pleistocene)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

ppl - Proglacial lake sediments (Holocene and/or Pleistocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

Qppfd - Proglacial flood deposits (Holocene and/or Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

ppfd - Proglacial flood deposits (Holocene and/or Pleistocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

Qtro - Travertine of pre-Pinedale age (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

tro - Travertine of pre-Pinedale age (Pleistocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

Qpbl - Lake sediments, silt (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pbl - Lake sediments, silt (Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

Qpbsl - Lake sediments, sand (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pbsl - Lake sediments, sand (Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

Qpbgl - Lake sediments, gravelly sand (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pbgl - Lake sediments, gravelly sand (Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

Qwgs - Sediments of West Yellowstone Basin, gravelly sand (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

wgs - Sediments of West Yellowstone Basin (Pleistocene)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

wgs - Sediments of West Yellowstone Basin, gravelly sand (Pleistocene)
Geologic unit present on source map: West Yellowstone 15' Quadrangle Geologic Units

Qwsg - Sediments of West Yellowstone Basin, sandy gravel (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

wsg - Sediments of West Yellowstone Basin, sandy gravel (Pleistocene)
Geologic unit present on source map: West Yellowstone 15' Quadrangle Geologic Units

Qbgs - Stream gravelly sand (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

bgs - Stream gravelly sand (Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

Qat - Till of Alden paleovalley (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

at - Till of Alden paleovalley (Pleistocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

Qak - Kame deposits of Alden paleovalley (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

ak - Kame deposits of Alden paleovalley (Pleistocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

Qbkl - Older ice-dammed lake sediments (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

bkl - Ice-dammed lake sediments (Pleistocene)
Geologic unit present on source map: Abiathar Peak and parts of adjacent 15' Quadrangles Geologic Units

bkl - Ice-dammed lake silt (Pleistocene)
Geologic unit present on source map: Huckleberry Mountain 15' Quadrangle Geologic Units

bkl - Ice-dammed lake silt (Pleistocene)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

bkl - Ice-dammed lake sediments (Pleistocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

Qbl - Older lake sediments, silt (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

bl - Lake sediments, silt (Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

bl - Lake sediments (Pleistocene)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

bl - Ice-dammed lake silt (Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

bl - Lake sediments, silt (Pleistocene)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

bl - Lake sediments (Pleistocene)
Geologic unit present on source map: Two Ocean Pass 15' Quadrangle Geologic Units

bl - Lake sediments, silt (Pleistocene)

Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qbsl - Older lake sediments, sand (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

bsl - Lake sediments, sand (Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

bsl - Ice-dammed lake sand (Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

bsl - Lake sediments, sand (Pleistocene)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

bsl - Lake sediments, sand (Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qblsg - Older lake sediments, sandy gravel (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

blsg - Lake sediments, sandy gravel (Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qbdgs - Older lake sediments, delta gravelly sand (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

bdgs - Lake sediments, delta gravelly sand (Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

Qbksg - Older kame deposits, sandy gravel (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

bksg - Kame deposits, sandy gravel (Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

bksg - Sandy kame gravel (Pleistocene)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

bksg - Kame sandy gravel (Pleistocene)

Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

bkgs - Kame sandy gravel (Pleistocene)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

bksg - Kame sandy gravel (Pleistocene)
Geologic unit present on source map: West Yellowstone 15' Quadrangle Geologic Units

bk - Kame sand and gravel (Pleistocene)
Geologic unit present on source map: Yellowstone National Park Geologic Units

Qbkc - Cemented kame gravel (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

bkc - Cemented kame gravel (Pleistocene)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

bkc - Cemented kame gravel (Pleistocene)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

Qbkgs - Older kame deposits, gravelly sand (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

bkgs - Kame deposits, gravelly sand (Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

bkgs - Kame deposits, gravelly sand (Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

Qbkg - Older kame deposits, gravel (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

bkg - Kame deposits, gravel (Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

bkg - Kame gravel (Pleistocene)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

bkg - Kame gravel (Pleistocene)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

bkg - Kame deposits, sandy gravel (Pleistocene)

Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

bkg - Kame gravel (Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qbfg - Older fan gravel (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

bfg - Fan gravel (Pleistocene)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

Qbks - Kame deposits, sand (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

bks - Kame deposits, sand (Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

Qbt - Bull Lake Glaciation till and glacial rubble, till (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

bt - Till and glacial rubble, till (Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

bt - Till and rubble veneer, till (Pleistocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

bt - Till (Pleistocene)
Geologic unit present on source map: Huckleberry Mountain 15' Quadrangle Geologic Units

bt - Till and rubble veneer, till (Pleistocene)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

bt - Till and glacial rubble, till (Pleistocene)
Geologic unit present on source map: Mount Hancock 15' Quadrangle Geologic Units

bt - Till (Pleistocene)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

bt - Till and rubble veneer, till (Pleistocene)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

bt - Till and rubble veneer, till (Pleistocene)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

bt - Till and rubble veneer, till (Pleistocene)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

bt - Till and rubble veneer, till (Pleistocene)
Geologic unit present on source map: West Yellowstone 15' Quadrangle Geologic Units

bt - Till (Pleistocene)
Geologic unit present on source map: Yellowstone National Park Geologic Units

Qbr - Bull Lake Glaciation till and glacial rubble, glacial rubble (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

br - Till and glacial rubble, glacial rubble (Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

br - Till and rubble veneer, rubble veneer (Pleistocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

br - Glacial rubble (Pleistocene)
Geologic unit present on source map: Huckleberry Mountain 15' Quadrangle Geologic Units

br - Till and rubble veneer, rubble veneer (Pleistocene)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

br - Till and glacial rubble, rubble (Pleistocene)
Geologic unit present on source map: Mount Hancock 15' Quadrangle Geologic Units

br - Rubble veneer (Pleistocene)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

br - Glacial rubble (Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

br - Till and rubble veneer, rubble veneer (Pleistocene)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

br - Till and rubble veneer, rubble (Pleistocene)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

br - Glacial rubble (Pleistocene)
Geologic unit present on source map: Two Ocean Pass 15' Quadrangle Geologic Units

br - Till and rubble veneer, rubble veneer (Pleistocene)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

br - Rubble veneer (Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

br - Till and rubble veneer, rubble veneer (Pleistocene)
Geologic unit present on source map: West Yellowstone 15' Quadrangle Geologic Units

Qoc - Sediments of Otter Creek (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

oc - Sediments of Otter Creek (Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

Qbll - Lake silt (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

bll - Lake silt (Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

Qbfr - Older frost rubble (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

bfr - Frost rubble (Pleistocene)
Geologic unit present on source map: Mount Hancock 15' Quadrangle Geologic Units

bfr - Frost rubble (Pleistocene)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

bfr - Frost rubble (Pleistocene)
Geologic unit present on source map: Two Ocean Pass 15' Quadrangle Geologic Units

Qgv - Sediments of Grand View (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

gv - Sediments of Grand View (Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

Qbg - Older gravel (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

bg - Gravel (Pleistocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

bg - Gravel (Pleistocene)
Geologic unit present on source map: Huckleberry Mountain 15' Quadrangle Geologic Units

bg - Gravel (Pleistocene)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

bg - Stream gravel (Pleistocene)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

bg - Gravel (Pleistocene)
Geologic unit present on source map: West Yellowstone 15' Quadrangle Geologic Units

Qpcp - Pitchstone Plateau flow (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

Rp - Pitchstone Plateau rhyolite flow (Pleistocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

Rp - Pitchstone Plateau rhyolite flow (Pleistocene)
Geologic unit present on source map: Huckleberry Mountain 15' Quadrangle Geologic Units

Rp - Pitchstone Plateau flow (Pleistocene)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

Rp - Pitchstone Plateau rhyolite flow (Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qpcg - Grants Pass flow (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

Rgp - Grants Pass flow (Pleistocene)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

Qpci - Gibbon River rhyolite flow (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

Rgr - Gibbon River rhyolite flow (Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

Qpcf - Solfatara Plateau rhyolite flow (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

Rs - Solfatara Plateau rhyolite flow (Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

Rs - Solfatara Plateau rhyolite flow (Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

Qpch - Hayden Valley rhyolite flow (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

Rh - Hayden Valley rhyolite flow (Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

Rh - Hayden Valley rhyolite flow (Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

Qpcy - West Yellowstone flow (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

Ry - West Yellowstone flow (Pleistocene)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

Ry - West Yellowstone flow (Pleistocene)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

Ry - West Yellowstone rhyolite flow (Pleistocene)
Geologic unit present on source map: West Yellowstone 15' Quadrangle Geologic Units

yr - West Yellowstone flow (Pleistocene)
Geologic unit present on source map: Yellowstone National Park Geologic Units

Qpco - Tuff of Cold Mountain Creek (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

Rtc - Tuff of Cold Mountain Creek (Pleistocene)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

Qpcr - Bechler River flow (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

Rbr - Bechler River rhyolite flow (Pleistocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

Rbr - Bechler River flow (Pleistocene)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

Rbr - Bechler River rhyolite flow (Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qpcs - Summit Lake flow (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

Rsl - Summit Lake rhyolite flow (Pleistocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

Rsl - Summit Lake flow (Pleistocene)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

Rsl - Summit Lake rhyolite flow (Pleistocene)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

R - Rhyolite flows, basalt flows, ash-flow tuffs, and pre-Quaternary rocks (Quaternary and pre-Quaternary)
Geologic unit present on source map: Yellowstone National Park Geologic Units

Qpcn - Nez Perce Creek flow (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

Rn - Nez Perce Creek flow (Pleistocene)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

Rn - Nez Perce Creek rhyolite flow (Pleistocene)

Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

Qbpl - Lacustrine pumiceous sand (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

bpl - Lacustrine pumiceous sand (Pleistocene)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

Quf - Sediments of Upper Falls (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

uf - Sediments of Upper Falls (Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

uf - Sediments of Upper Falls (Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

Qpcu - Spruce Creek rhyolite flow (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

Rsp - Spruce Creek rhyolite flow (Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

Qrr - Sediments of Red Rock (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

rr - Sediments of Red Rock (Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

Qpce - Elephant Back rhyolite flow (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

Re - Elephant Back rhyolite flow (Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

Re - Elephant Back rhyolite flow (Pleistocene)

Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

Re - Elephant Back rhyolite flow (Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

Re - Elephant Back rhyolite flow (Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qpcw - West Thumb rhyolite flow (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

Rw - West Thumb rhyolite flow (Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

Rw - West Thumb rhyolite flow (Pleistocene)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

Rw - West Thumb rhyolite flow (Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

Rw - West Thumb rhyolite flow (Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qpca - Aster Creek rhyolite flow (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

Ra - Aster Creek rhyolite flow (Pleistocene)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

Ra - Aster Creek rhyolite flow (Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qpcb - Buffalo Lake flow (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

Rbl - Buffalo Lake rhyolite flow (Pleistocene)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

Rb - Buffalo Lake flow (Pleistocene)
Geologic unit present on source map: West Yellowstone 15' Quadrangle Geologic Units

br - Buffalo Lake flow (Pleistocene)
Geologic unit present on source map: Yellowstone National Park Geologic Units

Qpcc - Spring Creek flow (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

Rsc - Spring Creek flow (Pleistocene)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

Rsc - Spring Creek rhyolite flow (Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qpcl - Tuff of Bluff Point (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

Rbp - Tuff of Bluff Point (Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

Qch - Chalcedonic sinter (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

ch - Chalcedonic sinter (Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

Qpcm - Mary Lake rhyolite flow (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

Rm - Mary Lake rhyolite flow (Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

Qrst - Shoshone Lake Tuff Member (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

Rst - Shoshone Lake Tuff Member (Pleistocene)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

Rst - Shoshone Lake Tuff Member (Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qrd - Dry Creek rhyolite flow (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

Rd - Dry Creek rhyolite flow (Pleistocene)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

Qog - Gravel associated with Osprey Basalt (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

og - Gravel associated with Osprey Basalt (Pleistocene)
Geologic unit present on source map: Abiathar Peak and parts of adjacent 15' Quadrangles Geologic Units

og - Osprey Basalt and associated gravel, gravel (Pleistocene)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

Qob - Osprey Basalt (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

ob - Osprey Basalt (Pleistocene)
Geologic unit present on source map: Abiathar Peak and parts of adjacent 15' Quadrangles Geologic Units

ob - Osprey Basalt and associated gravel, Osprey Basalt (Pleistocene)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

ob - Osprey Basalt (Pleistocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

Qub - Undine Falls Basalt (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

ub - Undine Falls Basalt (Pleistocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

Qug - Gravel beneath the Undine Falls Basalt (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

ug - Gravel beneath the Undine Falls Basalt (Pleistocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

Qng - Sediments of The Narrows (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

ng - Sediments of The Narrows (Pleistocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

Qnb - Basalts of The Narrows (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

nb - Basalts of The Narrows (Pleistocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

Qjb - Junction Butte Basalt (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

jb - Junction Butte Basalt (Pleistocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

Qjg - Gravel beneath the Junction Butte Basalt (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

jg - Gravel beneath the Junction Butte Basalt (Pleistocene)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

Qpbt - Pre-Bull Lake Glaciation till and rubble veneer, till (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pbt - Till (Pleistocene)
Geologic unit present on source map: Mount Hancock 15' Quadrangle Geologic Units

pbt - Till (Pleistocene)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

pbt - Till and rubble veneer, till (Pleistocene)
Geologic unit present on source map: West Yellowstone 15' Quadrangle Geologic Units

Qpbg - Pre-Bull Lake Glaciation gravel (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pbg - Gravel of pre-Bull Lake age (Pleistocene)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

pbg - Gravel (Pleistocene)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

Qpbr - Pre-Bull Lake Glaciation till and rubble veneer, rubble veneer (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

pbr - Till and rubble veneer, rubble veneer (Pleistocene)
Geologic unit present on source map: West Yellowstone 15' Quadrangle Geologic Units

Qfu - Sediments of Flat Mountain Arm, upper unit (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

fu - Sediments of Flat Mountain Arm, Upper unit (Pleistocene)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

Qfl - Sediments of Flat Mountain Arm, lower unit (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

fl - Sediments of Flat Mountain Arm, Lower unit (Pleistocene)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

Qsbg - Stream boulder gravel (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

sbg - Stream boulder gravel (Pleistocene)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

Qst - Sacagawea Ridge Glaciation till and rubble veneer, till (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

st - Till and rubble veneer, till (Pleistocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

st - Till and rubble veneer, till (Pleistocene)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

Qsr - Sacagawea Ridge Glaciation till and rubble veneer, rubble veneer (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

sr - Till and rubble veneer, rubble veneer (Pleistocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

sr - Till and rubble veneer, rubble veneer (Pleistocene)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

Qip - Sediments of Inspiration Point (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

ip - Sediments of Inspiration Point (Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

Qcc - Sediments of Cascade Creek (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

cc - Sediments of Cascade Creek (Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

Qpud - Dunraven Pass rhyolite flow (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

Rdp - Dunraven Pass rhyolite flow (Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

Qpuc - Canyon rhyolite flow (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

Rc - Canyon rhyolite flow and tuff of Sulphur Creek (Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

Rc - Canyon rhyolite flow (Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

Qput - Tuff of Uncle Toms Trail (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

Rut - Tuff of Uncle Toms Trail (Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

Qlf - Sediments of Lower Falls (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

lf - Sediments of Lower Falls (Pleistocene)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

Qprd - Rhyolite dome (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

Rrd - Rhyolite dome (Pleistocene)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

Qct - Cedar Ridge (?) Glaciation till (Pleistocene)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

ct - Till (Pleistocene)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

ct - Till (Pleistocene)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

QTd - Deposits near Tygee Creek (Quaternary or Tertiary)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

QTd - Deposits near Tygee Creek (Quaternary or Tertiary)
Geologic unit present on source map: West Yellowstone 15' Quadrangle Geologic Units

Qr - Undifferentiated bedrock (Quaternary and/or older)

This unit appears on the following source maps (click link to view geologic unit descriptions for that specific source map).

R - Bedrock (Pleistocene to Precambrian)
Geologic unit present on source map: Abiathar Peak and parts of adjacent 15' Quadrangles Geologic Units

R - Undifferentiated bedrock (Quaternary and Tertiary)
Geologic unit present on source map: Canyon Village 15' Quadrangle Geologic Units

R - Bedrock (Pleistocene to Paleozoic)
Geologic unit present on source map: Eagle Peak 15' Quadrangle Geologic Units

R - Undivided bedrock (Quaternary, Tertiary, and Mesozoic)
Geologic unit present on source map: Frank Island 15' Quadrangle Geologic Units

R - Undivided bedrock (Pleistocene to Precambrian)
Geologic unit present on source map: Grassy Lake Reservoir 15' Quadrangle Geologic Units

R - Undifferentiated rock (Quaternary to Paleozoic)

Geologic unit present on source map: Huckleberry Mountain 15' Quadrangle Geologic Units

R - Undivided older volcanic rocks of Quaternary age (Quaternary)
Geologic unit present on source map: Madison Junction 15' Quadrangle Geologic Units

R - Bedrock (Pleistocene to Precambrian)
Geologic unit present on source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle Geologic Units

R - Bedrock (Pleistocene to Paleozoic)
Geologic unit present on source map: Mount Hancock 15' Quadrangle Geologic Units

R - Bedrock (Pleistocene to Precambrian)
Geologic unit present on source map: Mount Holmes and parts of adjacent 15' Quadrangles Geologic Units

R - Tuff of Yellowstone Group (Quaternary, K-Ar age about 600,000 years)
Geologic unit present on source map: Norris Junction 15' Quadrangle Geologic Units

R - Bedrock undivided (Quaternary)
Geologic unit present on source map: Old Faithful 15' Quadrangle Geologic Units

R - Bedrock (Pleistocene and Eocene)
Geologic unit present on source map: Pelican Cone 15' Quadrangle Geologic Units

R - Undivided bedrock (Pleistocene to Precambrian)
Geologic unit present on source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle Geologic Units

R - Bedrock (Pleistocene to Paleozoic)
Geologic unit present on source map: Two Ocean Pass 15' Quadrangle Geologic Units

R - Undivided bedrock (Quaternary)
Geologic unit present on source map: Warm River Butte 15' Quadrangle Geologic Units

R - Undivided bedrock (Quaternary and Tertiary)
Geologic unit present on source map: West Thumb 15' Quadrangle Geologic Units

R - Bedrock undivided (Quaternary, Paleozoic, and Precambrian age)
Geologic unit present on source map: West Yellowstone 15' Quadrangle Geologic Units

Ancillary Source Map Information

The following sections present ancillary source map information, including unit descriptions, associated with the source maps used for this project. Unit symbols mentioned in source map text are as per the source map, and not necessarily the unit symbol present in the GRI digital geologic-GIS data. Some source maps contained grouped geologic unit descriptions. These grouped units will be shown as a series of geologic units followed by the description for all units grouped.

Abiathar Peak and parts of adjacent 15' Quadrangles

The formal citation for this source.

Pierce, Kenneth L., 1974, Surficial Geologic Map of the Abiathar Peak and parts of adjacent Quadrangles, Yellowstone National Park, Wyoming and Montana: U.S. Geological Survey, Miscellaneous Investigations Series Map, I-646, scale 1:62,500 (*GRI Source Map ID 1136*).

Description of geologic units, prominent graphics and text associated with this source.

Description of Map Units

gt - Gannett Peak Till (Quaternary, Neoglaciation)
tt - Temple Lake Till (Quaternary, Neoglaciation)

Gray to brown, nonstratified and unsorted rock debris. Forms end moraines 10-50 feet high near well-developed cirques. Gannett Peak Till (gt) forms a single morainal ridge incompletely covered with lichens, but little other vegetation. Temple Lake Till (tt) forms several slightly weathered morainal ridges covered with lichen, local trees and grasses. Temple Lake Till may be present in fresh, well-developed cirques along ridges of Barronette Peak and The Thunderer but was not seen from top of cirque headwalls. Thickness 10-50 feet.

grg - Gannett Peak rock glacier (Quaternary, Neoglaciation)
trg - Temple Lake rock glacier (Quaternary, Neoglaciation)

Glacier-shaped tongue of angular rock debris that heads in talus from cirque headwalls. Surface-flow ridges and furrows convex downslope. Occurs in northern part of area where cirque headwalls readily frost riven. Deposits of Gannett Peak Stade (grg) have very steep unstable fronts and are active, fresh, and non-vegetated. Only Temple Lake rock glacier (trg) in mapped area is at head of Pebble Creek; it is inactive; its surface is slightly weathered, locally forested, lichen covered and partly mantled with humic debris. Thickness 20-100 feet.

fa - Fined-grained humic alluvium (Quaternary, Neoglaciation)

Silt and subordinate sand, clay, and plant material that underlies wet ground along drainages and in upland depressions; supports lush stands of tall grasses and sedges. On Mirror Plateau, locally deposited against upthrown sides of late Quaternary faults. Along Slough Creek, the deposits are thick, horizontally bedded, and may include lake sediments. Thickness 2-30 feet.

sg - Stream gravel (Quaternary, Neoglaciation)

Tan to gray, moderately sorted and stratified sandy gravel with minor interbeds of sand and silt; underlies flood plains and low terraces. Gravel is subrounded, mostly 2-6 inches in diameter. Generally 10-30 feet thick, but Holocene and older alluvial deposits may be more than 100 feet thick in valleys of Lamar River, and Soda Butte and Slough Creeks.

fg - Fan gravel (Quaternary, Neoglaciation)

Tan, poorly sorted, crudely stratified, pebble to boulder gravel; forms alluvial fans below cliffs and steep slopes. Includes beds of sand and finer grained sediment, especially towards distal edges of fans. Deposited by local floods, mudflows, and sheetwash. Mostly 10-50 feet thick.

ta - Talus deposit (Quaternary, Neoglaciation)

Rock rubble forming cones or aprons on steep slopes near timberline. Clasts commonly more than 6 inches across; shapes angular except for roundstones derived from bedrock conglomerates. Interstices void near surface but containing silty matrix at depth. Nonvegetated except for lichens. Active piecemeal accumulation from cliffs or positions upslope. Mostly 5-30 feet thick.

tf - Talus-flow deposit (Quaternary, Neoglaciation)

Similar to talus, but occurs on gentler slopes and has been emplaced by flowage. Mass movement shown by lobate form, flow ridges, and unstable or recently turned rock fragments. Thickness 3-10 feet.

fr - Frost rubble (Quaternary, Neoglaciation)

Abundant cobble-sized rock fragments in a fine-grained matrix. Seasonal movement indicated by sparse or disrupted tundra and thin azonal soil. Occurs on uplands above timberline where formed by frost mixing, sliding, and solifluction. Thickness 3-6 feet.

ad - Avalanche debris (Quaternary, Neoglaciation)

Boulder- to pebble-sized rock fragments in a fine-grained matrix; crudely bedded; nonsorted to poorly sorted. Forms fan-shaped or lobate deposits at base of avalanche chutes. In places gradational headward into talus and downslope into fan gravel. Locally characterized by torrent and alpine mudflow levees. Consists of debris transported by snow avalanche, slush flow, debris avalanche, and mudflow. Gradational with fan gravel (fg). Mostly 5-20 feet thick.

ls - Landslide deposit (Quaternary, Neoglaciation)

Nonsorted debris in a clayey matrix; forms lobate masses. Generally results from failure in a fine-grained bedrock unit, but includes blocks from harder bedrock that overlies fine-grained unit. Local activity, especially near toes of many landslides, indicated by fresh ridges, depressions, and slump scarps. Swelling clay, is exposed at the earthflow-type toe of the landslide just southwest of Soda Butte, thus indicating the nature of the probable unit of failure for this landslide, the bulk of which consists of volcanic rocks of the Absaroka Volcanic Supergroup.

Most of the landslide movement probably occurred during de-glaciation, as the valley walls slumped against stagnating ice. Along Slough and Soda Butte Creeks landslides are commonly in contact with, and locally grade into, kame deposits suggesting an ice-contact origin. Also the surface topography of many of these landslides has a more moraine-like appearance than normal landslides, with some kettle-like depressions and steep ice-contact scarps. Thickness 20-200 feet.

ptu - Till (Holocene and/or Pleistocene)

Similar to Pinedale Till (pt), and mapped separately only in southeastern corner of mapped area where it forms morainal loops 0.5-2 miles from cirques, a common position for late Pinedale moraines in Yellowstone National Park. Morainal deposits mapped along Little Lamar River not traversed on foot, but observed in riverbank exposures from air; if these moraines are younger than late Pinedale and of Temple Lake age, then they are unusually far from their cirque source areas. Thickness 10-50 feet.

prgu - Rock glacier (Holocene and/or Pleistocene)

Similar in texture to younger Neoglacial rock glaciers (grg, trg), but flow features largely obliterated; locally forested; coarse rubble forms ridges, furrows, and kettles and defines glacier-like form. Mapped only at head of Pebble Creek where collapsed rock glacier is thought to be of latest late Pinedale age because of position well upvalley from late(?) Pinedale moraines near Junction Butte (Pierce, 1974) and downvalley from Temple Lake rock glacier (trg). Thickness 20-50 feet.

pklu - Ice-dammed lake sediments (Holocene and/or Pleistocene)

Gray, massive to varved silt and sand. Commonly display distinct horizontal bedding. Mostly in drainage of upper Lamar River (stratigraphic sections 11, 12, 16, 17, 18) where include extensive lake sand between Soda Butte and Cache Creeks, and gravel-mantled lake silt, sand, and gravel from Cache Creek to south of map area. Lamar River dammed by glacier flowing down Soda Butte Creek in late(?) Pinedale time. Similar lake sediments exposed along Pebble Creek (stratigraphic section 1), Soda Butte Creek (stratigraphic section 5), Amphitheater Creek (stratigraphic section 3), and South Cache Creek (stratigraphic sections 7, 8). Thickness 20-400 feet.

Abiathar Stratigraphic Sections

pgu - Outwash and stream gravel (Holocene and/or Pleistocene)

Tan to gray, moderately sorted, stratified gravel with sandy matrix; stones rounded to subrounded, mostly 1-4 inches in diameter. Forms terraces 5-40 feet above streams; occurs mainly near confluence of Lamar River and Soda Butte Creek. Largely of latest Pinedale age. Mostly 10-30 feet thick. Alluvium near Soda Butte-Lamar confluence may be 100 feet thick.

pg - Outwash and stream gravel (Holocene and/or Pleistocene)

Similar to upper Pinedale gravel (pgu) but occurs along Wrong Creek in area deglaciated in middle Pinedale time. Thickness 5-10 feet.

pfg - Fan gravel (Holocene and/or Pleistocene)

Buff, poorly to moderately sorted, well-stratified, alluvial fan gravel containing interbeds of sand, silt-clay, and mudflow deposits. Fan fronts commonly trenched 10-40 feet by main stream and locally about 10 feet by fan stream. Ice-contact scarps and crevasse fills are present on some fans, as the one just north of Icebox Canyon and the ones along Calfee Creek. Most fans are laterally bordered by kame deposits (pks, pkg) and at least the higher parts of some fans were deposited against stagnant ice on the valley floor. Fan gravel (pfg) generally occurs at the base of steep, readily eroded slopes. Includes thin patches of younger fan gravel (fg) mantling part of the fan surface. Thickness 10-40 feet.

pta - Talus deposit (Holocene and/or Pleistocene)

Rock rubble containing clasts 0.3-2 feet across; forms aprons and cones on steep slopes generally below cliffs. Fine-grained matrix commonly extends to surface where soil is weak, humic, and 1-2 feet thick. Stones mostly angular, but rounded where formed of clasts from Eocene conglomerates. Inactive and generally forested. May locally be thinly mantled by younger talus of Holocene age. Mostly 5-20 feet thick.

pst - Scree of tuff rubble (Holocene and/or Pleistocene)

Small-pebble-sized angular fragments of stony rhyolite forming thin sheets over tuff bedrock and forming aprons and cones farther downslope. Generally covered by open forest; includes active surface material that slides and tumbles downhill against trees and other obstacles. Mapped only in southwest corner of area. Thickness of sheets 0-5 feet; of aprons and cones 5-30 feet.

pfr - Frost rubble (Holocene and/or Pleistocene)

Abundant cobble-sized rock fragments in a fine-grained matrix on uplands near timberline.

Covered by turf except for large blocks of lichen-covered rubble. Locally includes small areas of active Neoglacial frost rubble (fr). Mostly 2-5 feet thick.

pkl - Ice-dammed lake sediments (Holocene and/or Pleistocene)

Gray silt, massive to varved, horizontally bedded. Occurs in southwestern corner of mapped area in and near stratigraphic section 14 where deposited during deglaciation in middle Pinedale time. Thickness 5-20 feet.

Abiathar Stratigraphic Sections

pkg - Kame deposits, gravel (Holocene and/or Pleistocene)
pks - Kame deposits, sand (Holocene and/or Pleistocene)

Buff to gray, moderately well sorted gravel (pkg) and gravelly sand (pks); unevenly bedded with abrupt vertical and lateral changes in grain size; some fine-grained interbeds. Upper surface forms irregular terraces, ridges, and kettles. Gravel (pkg) mostly 2-4 inches in diameter, subrounded. Locally contains or is mantled by poorly sorted beds of mudflow debris. Exposed in stratigraphic sections 2, 5, 9, 10, 12, 16, 18, and 20. In southwest corner of map area, thick sands (pks) form a topographically perched outwash plain (stratigraphic section 13) of middle Pinedale age. In remainder of area, kame deposits lie upvalley from the late(?) Pinedale moraines near Junction Butte, and therefore are probably mostly of late Pinedale age. Along the Lamar River upstream from Cache Creek, field relations suggest that some kame deposits are overlapped by and are at least slightly older than the ice-dammed lake sediments there. Also in this same area, parts of the mapped kame deposits probably include sand and gravel deposited by streams draining into an ice-dammed lake. Mostly 20-100 feet thick.

Abiathar Stratigraphic Sections

pt - Till (Holocene and/or Pleistocene)

Grayish-brown, nonsorted, nonstratified, compact mixture of roundstones, sand, silt, and clay; deposited by glaciers. Includes deposits of both middle Pinedale and late Pinedale age. Stones mostly subrounded; glacially striated clasts uncommon. Consists mostly of reworked andesitic volcanic debris. Locally, as in the valleys of Slough, Soda Butte, and Pebble Creeks, clasts from Paleozoic limestones and Precambrian crystalline rocks are also present.

Till mostly forms rather featureless ground moraine, but locally forms drumloid ridges and moraines. Surface of till not very bouldery. Till well exposed in stratigraphic sections 1, 2, 4, 8, and 11.

Upper part of till modified by soil development, frost heaving, solifluction, and creep. Below cliffs and steep slopes, as in the headwaters of Cache Creek, till may be partly mantled with talus, avalanche debris, and slope wash. Soil profiles are generally 1-3 feet thick with weak color, texture, and structure development in B horizon.

The till includes deposits of late(?) Pinedale age from which it cannot be differentiated. For example the surface till in the valleys of Slough, Pebble, Soda Butte, and Amphitheater Creeks was deposited during and after deposition of the late(?) Pinedale moraines near Junction Butte, but the upper limit of this Junction Butte ice-margin could not be distinguished on the valley walls. The end moraines near Junction Butte are 6 miles down the Lamar River valley from the western map boundary and are probably of late Pinedale age.

Till thickness generally increases from 0-5 feet on uplands and upper slopes to 20 feet or more near base of slopes.

Abiathar Stratigraphic Sections

pr - Rubble veneer (Holocene and/or Pleistocene)

Thin mantle over bedrock of rubble in a loose fine-grained matrix on glaciated uplands. Mostly frost riven from local volcanic bedrock, but locally contains glacial erratics and other glacially moved debris. Areas underlain by rubble veneer (pr) gradational with and similar in appearance to that underlain by till (pt), but glacial deposits are sparse in rubble veneer areas (pr). Includes areas glaciated in both middle Pinedale and late Pinedale time. Also includes discontinuous bands of solifluction debris and frost rubble, especially near timberline, as well as many small glaciated rock outcrops, and on moderate slopes, deposits of colluvium locally more than 5 feet thick. Mostly 0-5 feet thick.

bkl - Ice-dammed lake sediments (Pleistocene)

Clay, sand, silt; well bedded; compact. In southwest corner of mapped area (stratigraphic sections 13, 14, 15), massive to laminated silt, locally varved, gray where fresh but oxidized to light purplish brown near joint surfaces. Along South Cache Creek (stratigraphic sections 7, 8), tan to brown varved clay and silt, massive silt, and laminated sand. Deposits relatively impermeable as revealed by spring line and landsliding. Age uncertain, but thought to date from Bull Lake deglaciation. Overlain by less compact Pinedale sediments. Thickness 20-150 feet.
Abiathar Stratigraphic Sections

og - Gravel associated with Osprey Basalt (Pleistocene)

Coarse, crudely bedded, cobble conglomerate. Brownish-red staining and thick exfoliation shells of altered rock on roundstones produced by hydrothermal alteration; matrix also commonly altered and indurated. Roundstones mostly Eocene volcanic rocks but some are of Quaternary Lava Creek Tuff. Generally overlain by Osprey Basalt (ob). Deposits locally extend below present stream level. Generally 10-50 feet thick.

ob - Osprey Basalt (Pleistocene)

Dark-gray, dense tholeiitic basalt flow(s), lower parts columnar jointed, upper parts vesicular. Generally overlies gravel (og). Occurs along Lamar River valley; exposed from stream bottom to 100 feet above stream grade. Thickness 10-50 feet.

R - Bedrock (Pleistocene to Precambrian)

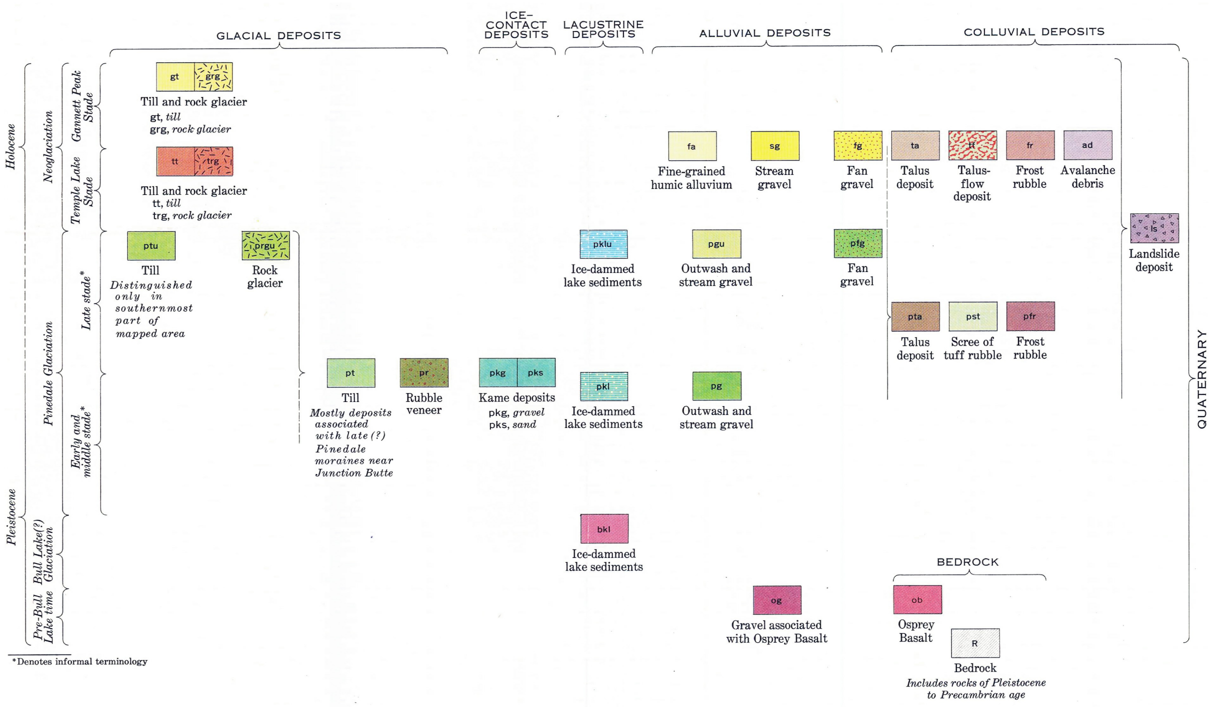
(After U.S. Geological Survey Map I-711, 1972). Includes rocks of Pleistocene to Precambrian age. Most of the mapped area is underlain by nearly flat-lying, andesitic rocks of the Eocene Absaroka Volcanic Supergroup. Of these, chaotically bedded debris flow, lava flow, and breccia deposits, and ash beds underlie about 25 percent of the mapped area. They occur mainly southeast of Cache Creek where they form hoodoos, and in the Amphitheater Mountain-Republic Pass area. About 45 percent of the mapped area is underlain by well-bedded volcanic sediments: thick-bedded conglomerates, breccia, and sandstone. Eocene basalt sheets underlie about 10 percent of the mapped area, capping peaks in the central, eastern, and southeastern parts of the area; they also form the upper ledges on the northeast side of the Mirror Plateau. Mostly fine-grained, Eocene volcanic sediments overlie the basalt sheets on the Mirror Plateau.

Rocks older than the Eocene volcanics are exposed in about 5 percent of the mapped area. Precambrian gneisses crop out along Slough Creek and underlie extensive areas north and northeast of the mapped area. Paleozoic rocks, mostly carbonates, crop out in the lower valley walls of Slough Creek, Pebble Creek, and Soda Butte Creek, especially in the area of the Northeast Entrance.

About 10 percent of the mapped area is underlain by the 0.6-m.y. old Lava Creek Tuff; it occurs on the southwest flank of the Mirror Plateau and on benches at about 8,000 feet between The Thunderer and Castor Peak.

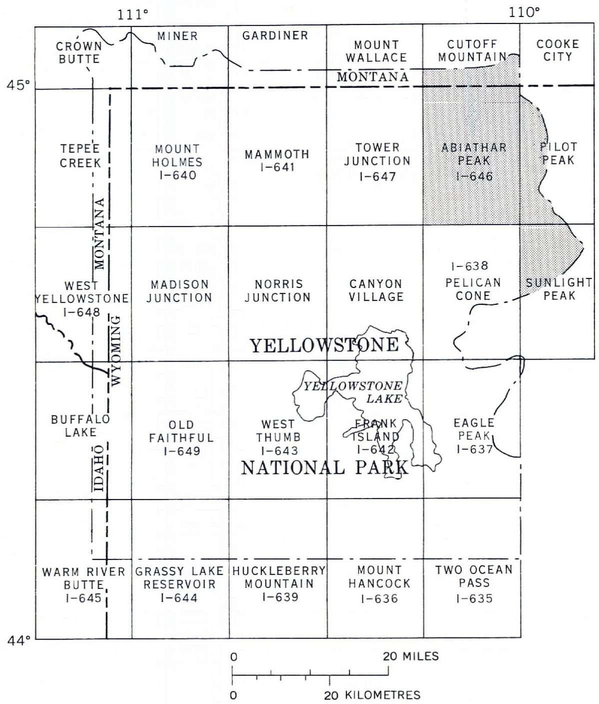
Text from source map: [Abiathar Peak and parts of adjacent 15' Quadrangles]

Correlation of Map Units



Graphic from source map: [Abiathar Peak and parts of adjacent 15' Quadrangles]

Index Map



INDEX MAP OF YELLOWSTONE NATIONAL PARK SHOWING LOCATION OF ABIATHAR PEAK, CUTOFF MOUNTAIN, PILOT PEAK, AND SUNLIGHT PEAK QUADRANGLES AND PUBLISHED MISCELLANEOUS GEOLOGIC INVESTIGATIONS MAPS

Graphic from source map: Abiathar Peak and parts of adjacent 15' Quadrangles

Map Legend

Contact, dashed where inferred

Fault having Quaternary movement

Solid where map unit is offset; dashed where map unit is probably offset but mantled by unmapped local colluvium; short dashed where topographically expressed but mantled by unfaulted map units. Bar and ball on downthrown side

PD

Limit of late middle Pinedale Deckard Flats ice

Dashed where inferred

PM

Various middle Pinedale ice margins

Dashed where inferred. Mostly based upon inferred ice-contact colluvial embankments or upon slight increase downslope in freshness of glaciated surface of readily eroded bedrock. Probably includes Deckard Flats equivalent in eastern and northern part of area

PL

Limit of early Pinedale ice

Dashed where inferred

Direction of Pinedale ice movement

Shown by glacial molding, streaming, or scouring feature

Pinedale glacial striation

Pinedale melt-water channel

Showing direction of flow

Crest of morainal ridge

Underlain by till or kame deposits

20 10

Stream terrace scarp

Number indicates height, in feet, of terrace above stream, including terraces separated by contact rather than scarp symbol

Kame terrace scarp

14

Location and number of stratigraphic section

≤5

Estimated thickness of surficial deposits, in feet

≤5, *indicates less than 5 feet thick*

*C,L

Location and kind of erratic

A, *volcanic rocks from the Absaroka Volcanic Supergroup*
C, *Precambrian crystalline rocks, mostly coarse-grained gneiss*
L, *limestone*
Y, *tuff of the Yellowstone Group, includes basal vitrophyre erratics resting on other tuff units*

HYDROTHERMAL FEATURES

Travertine-depositing hot spring

Gas vent

HA

Area of hydrothermal alteration and deposition

Graphic from source map: [Abiathar Peak and parts of adjacent 15' Quadrangles]

Stratigraphic Sections

Units, separated by slashes, are shown in descending order; numbers show thickness in feet. Letter symbols represent map units; where unit is not a map unit, lithology is described.

Stratigraphic section locations are presented in the GRI Geologic Observation Localities (yellgol) feature class. In that feature class, the section identifier is stored in the Location ID (LOC_ID) field. The section information presented here is also contained in the Geologic Observation Localities (yellgol) feature class Notes (NOTES) field.

See Description of Units for information about map units listed here.

1. 15 fg/5 pklu/2 diamicton/5 pklu/>5 pt
2. 15 pkg, sandy/30 pt, brown/>10 pt, gray
3. 20 pfg/15 pklu
4. >20 pkg 60 pt
5. 2 pgu/30 ls/2 pkg/30 pklu/10 pkg
6. 10 ls, rubbly/20 ls, swelling clay/8 sg
7. 30 pgu/20 pklu/50 bkl(?)
8. 20 pfg/15 pklu/30 pt, abundant tuff/32 lake sediments, proglacial(?)/12 gravel, proglacial(?)/10 bkl, compact/15 gravel, com pact/>50 bkl, very compact
9. 50 pkg/(units below are hydrothermally altered): 100 pkg/10 pkg, bouldery/100 pks
10. 60 pkg/10 lake sediments
11. 10 pgu/40 pklu, sandy/20 pklu/10 pt/40 lake sediment, compact
12. 40 pkg, sandy/20 pklu
13. 100 pks/120 bkl, compact
14. >5 pkl/1 pt/>10 bkl, compact
15. 5 pg/>5 bkl, compact
16. 30 pklu/>10 pkg, with limestone erratic
17. 10 pgu/10 pklu, sandy/40 pklu/25 covered/5 pt(?)
18. 5 fa/20 pkg/4 pklu
19. 15 Lava Creek(?) Tuff/10 ash/20 diamicton/Eocene bedrock
20. 15 pt, colluviated/40 pkg
21. >5 rubble of Lava Creek(?) Tuff/10 ash/Eocene bedrock

Text from source map: Abiathar Peak and parts of adjacent 15' Quadrangles

Surficial Geologic History

INTRODUCTION

The mapped area covers the northeastern corner of Yellowstone National Park and is almost entirely in the drainage of the Lamar River. The area is in the Absaroka Range, where high cliffs of volcanic rock commonly rise to peaks above 10,000 feet. Mountains in glacial source areas north and northeast of the map area rise to above 10,500 feet. The Lamar River drainage upstream from Soda Butte Creek is here referred to as the upper Lamar.

FEATURES ASSOCIATED WITH QUATERNARY VOLCANIC ROCKS

A Quaternary tuff occurs on the uplands in the headwaters of the Lamar River. This tuff previously was assigned to the 2.0-m.y.-old Huckleberry Ridge Tuff (U.S. Geological Survey, 1972), but fission-track ages on zircons from the tuff, and the chemical and petrographic characteristics of bedded ash at the base of the tuff indicate it is probably not the Huckleberry Ridge Tuff. Fission-track ages of 0.56, 0.24, 0.97, 0.37, 0.82, 0.36, 0.92, 0.27, 0.61, 0.30, 0.57, 0.3, and 1.1±0.38 m.y. were obtained (C. W. Naeser, written commun., 1972, 1973) on samples of the upland tuff. The chemical and petrographic characteristics of the ash at the base of this tuff on Notch Mountain are similar to those associated with the Lava Creek Tuff and not that of the Huckleberry Ridge Tuff (G. A. Izett, written commun., 1973). It seems possible, therefore, that this upland tuff should be assigned to the Lava Creek Tuff. Southwest of Hoodoo Peak and at stratigraphic sections 19 and 21, the tuff occurs at altitudes near and above 10,000 feet and rests on an old, high-level erosion surface that truncates bedding in the Eocene volcanic bedrock. At stratigraphic section 19, the tuff overlies a nonsorted, locally derived boulder deposit that may be a till; although the stones are rounded and appear faceted and some have concave surfaces suggestive of glacial action, no striated stones were noted.

In the upper Lamar drainage, the 0.6-m.y.-old Lava Creek Tuff occurs on a bench at about 8,000 feet, intermediate between remnants of the high-level erosion surface and the present valley bottoms. This tuff was deposited on the floors of broad valleys which are now incised 400-800 feet by the larger streams. Fission-track ages on zircons of 0.6±0.28 and 0.76,0.3 m.y. were obtained (C. W. Naeser, written commun., 1973) on samples from Lava Creek Tuff along Buffalo Fork southeast of the Mirror Plateau and at the south end of Mt. Norris, respectively. Thus, the Lava Creek in this area either has been warped since its emplacement, or was initially draped over a broad-valley topography with at least 2,000 feet of relief.

The Osprey Basalt and associated gravels lie on the floor of the Lamar River valley. The basalt has a K-Ar age of about 0.2 m.y. (J. D. Obradovich, written commun., 1972). Basaltic lava flowed down the Lamar valley and buried gravel on the valley floor. The gravel may be of glacial or interglacial origin. It occurs in valleys cut 400-800 feet below the 0.6-m.y.-old Lava Creek Tuff. No net downcutting by the Lamar River has occurred since this gravel was deposited.

PLEISTOCENE GLACIATIONS

Great icecaps overwhelmed most of Yellowstone National Park repeatedly during the Pleistocene. These glaciations are (from oldest to youngest): pre-Bull Lake (probably several full-scale glaciations), Bull Lake, and Pinedale. Pinedale glaciers buried all but some of the highest peaks in the map area; older deposits are identified only where they lie beneath Pinedale deposits. During Bull Lake and at least the youngest of the pre-Bull Lake glaciations, glaciers built up, climaxed and receded in a manner probably similar to that described below for the Pinedale Glaciation.

Compact to very compact, partly oxidized lake sediments occur beneath Pinedale deposits along Wrong Creek (stratigraphic sections 13, 14, and 15), along South Cache Creek (stratigraphic sections 7, 8), and along the upper Lamar River; these lake sediments date from times when the drainage was blocked by glaciers down valley, causing deposition of lake sediments in a manner similar to that when Pinedale glaciers blocked the same streams.

Northwest of Soda Butte, a large mass with a general landslide form occurs valleyward from an amphitheater of cliffs that defines the headwall of a large landslide. Although the parts of this slide mapped as "ls" have been active since the Pinedale Glaciation, about one-half of its surface area shows signs of glacial molding (shown by flow arrows on map) and is covered by a thin mantle of Pinedale Till (pt). Emplacement of the glaciated part of this slide may have occurred during deglaciation in Bull Lake time.

PINEDALE GLACIATION

EARLY PINEDALE ADVANCE

Except for peaks along or near the eastern map boundary, the entire map area was covered by early and middle Pinedale ice. Because the map area is in the glacial source area, there appears to be no discernible difference between the height of ice, areas covered by ice, or flow directions at the glacial maxima in early or middle Pinedale time. Therefore most of the till and scour features in the map area date either from middle Pinedale time, or from and following deposition of the moraines near Junction

Butte (west of the map area) in late(?) Pinedale time.

At the inception of Pinedale Glaciation, valley glaciers formed in cirques throughout the map area; they also formed in the mountains north and northeast of the map area and also in cirques at the head of the Lamar just west of the southernmost part of the map area in the Pelican Cone quadrangle (Richmond and Waldrop, 1972). These valley glaciers grew until they coalesced forming a trunk glacier which flowed into and then down the Lamar valley to the Yellowstone River valley (west of the map area). As the glaciation continued to build, valley glaciers in the mountains north and northeast of the map area coalesced to form a large mountain icecap. Outflow from this icecap flowed down the valleys of Slough Creek, Pebble Creek, and Soda Butte Creek where it eventually reached a thickness of more than 3,000 feet, or an elevation above 10,000 feet, overtopping divides below 10,000 feet to form a large ice sheet flowing southwest towards the Lamar valley.

The early Pinedale glacier flowing down Soda Butte Creek probably reached the confluence of Soda Butte Creek and the upper Lamar River well before the arrival of that from the upper Lamar drainage. Some of the unoxidized but compact lake sediments in the upper Lamar drainage (such as in stratigraphic sections 8, 10, and 11) probably were deposited in a lake dammed by a Soda Butte glacier in early Pinedale time. Eventually glaciers in the upper Lamar drainage built to the level of the glaciers feeding from the northeast into the valley of the lower Lamar River.

Ice in the Lamar drainage above Soda Butte Creek was dammed by the large outflow from the northeast. Although ice levels in the upper Lamar drainage reached levels above 10,000 feet, outflow was minor compared to that down Soda Butte, Pebble, and Slough Creeks. This is indicated by the remarkably poor development of glacial scour features, the V-shape of the valleys, the extensive areas of rubble veneer (pr), and the minor volume of till which is commonly less than 5 feet thick. Scour features are well developed only where ice flowed eastward across the divide marking the eastern boundary of Yellowstone National Park. Scour features are visible on aerial photographs and in the field in most places along this divide below 10,000 feet; they are especially well developed on the broad divides just south of Hoodoo Peak, and around Canoe Lake at the head of Miller Creek. Striations on boulders of nearly black andesite in the Eocene bedrock were noted at about six localities along this divide.

At a few places along the eastern map boundary, the upper limit of Pinedale Glaciation (PL) is mapped at altitudes that diminish northward from 10,400 feet just east of Notch Mountain to 10,000 feet along the middle part of the eastern boundary. This is based upon observing fresh evidence of glacial scour in bedrock (R) or rubble veneer areas (pr) above which no evidence of glaciation was observed, but where such evidence seems likely to have been preserved since Pinedale time had it existed. Where the upper Pinedale limit (PL) is not shown along the eastern map boundary, it was not possible to infer whether some high area had been glaciated, because most evidence would have been removed by subsequent erosion of the soft rock outcrops or frost churning of the thin surficial mantle.

Thus it appears that glaciation in early and middle Pinedale time of the upper Lamar consisted mainly of filling to an altitude of about 10,000 feet with a thick but generally static, nearly level fill of local ice, restricted from flowing downvalley by a high, more active mass of ice from the northeast.

Ice flowing southwest down the valleys of Soda Butte, Pebble, and Slough Creeks coalesced to form a glacier that flowed northwest down the lower valley of the Lamar, completely overfilling it with ice more than 3,000 feet thick. On uplands southwest of the Lamar River, large scour features and striations northwest of Chalcedony Creek show that glacial flow was to the northwest down the Lamar valley rather than southwest across it. The absence or extreme rarity above 9,000 feet of erratics derived from the northeast also indicates that during the last glaciation ice from the north did not flow into this area. Numerous fresh glacial striations on the top of Amethyst Mountain (altitude 9,614 at the head of Chalcedony Creek and just west of the map area) indicate flow to the northwest, demonstrating that the surface altitudes of ice masses were concordant between the Lamar River valley and the Mirror Plateau (southwest corner of the map area).

The terminal moraines of the Pinedale glaciers lie well outside the map area-60 miles down the Yellowstone River valley from the west map boundary.

MIDDLE PINEDALE RECESSION

A recession from the early Pinedale maximum followed by a re-advance to a middle Pinedale maximum occurred in the Yellowstone area and elsewhere in the Rocky Mountains. Evidence for this re-advance is scant or absent in the map area; it is possible that the highest of the several middle Pinedale limits (PM) along the eastern map boundary may represent the middle Pinedale maximum. Most, if not all, of these boundaries represent middle Pinedale ice positions younger than the middle Pinedale maximum. Excepting the Mirror Plateau area the lines showing various middle Pinedale ice margins (PM and PD) represent places where low but generally long embankments of colluvium appear to have been deposited against a stationary ice margin or where there is slight but noticeable uphill increase in the amount of postglacial erosion or modification. On the Mirror Plateau, the margin of the Deckard Flats ice (PD) and also the position a younger middle Pinedale ice margin (PM) are defined by till embankments or an increase in till thickness. For the map area several levels and times are indicated by the various "PM" lines but only one time is indicated by the PD line.

After the middle Pinedale maximum, glaciers receded intermittently, locally leaving moraines and kame gravels along the retreating ice margin. Most deposits associated with this recession are downvalley west of the map area, with the exception of the kame sand (pks) and ice-contact lake sediments (pkl) along Wrong Creek.

The Deckard Flats readjustment occurred near the end of middle Pinedale time and terminated about 30 miles down the Lamar-Yellowstone drainage from the west map boundary. This readjustment is named for a set of closely spaced lateral moraines that rim Deckard Flats in the southern part of the Gardiner quadrangle (Pierce, 1973). Lateral moraines, ice-marginal deposits and channels, and the southern limit of abundant erratics of Precambrian rocks have been used to trace the Deckard Flats ice-margin from the terminal moraine area up the Yellowstone-Lamar drainage to the Specimen Ridge-Mirror Plateau area where these criteria indicate the Deckard Flats ice margin at an altitude of about 9,000 feet. Erratics or Precambrian rocks and limestone occur below 9,000 feet along Specimen Ridge just west of the map area in the Tower Junction quadrangle (Pierce, 1974). The surface of Deckard Flats ice increased in altitude northward from the Mirror Plateau toward the source of ice in the northern part of and north of the map area. Temporary ice margins suggested by changes in the amount of gullying on Mt. Norris at an altitude of 9,000 feet and slight differences in the freshness of glacial scour at an altitude of 9,800 feet on Mt. Hornaday appear to reasonably represent the Deckard Flats ice margin northward from the Mirror Plateau. North from Mt. Hornaday, it was not possible to delimit the Deckard Flats ice margin from other Pinedale ice positions, and all inferred ice margin positions are shown as "PM." Likewise it was not possible to delimit the Deckard Flats ice margin in the upper Lamar drainage.

As one approaches the source area from the end moraines, the amount of separation between ice limits at early Pinedale time and at Deckard Flats time tend to decrease. At the west edge of the Mirror Plateau on Amethyst Mountain (just west of the map area), the early Pinedale limit is at least 800 feet higher than the Deckard Flats limit; in the northern part of the map area these limits are probably not more than several hundred feet apart. Along the east boundary of the map area, the Deckard Flats ice margin is probably represented by one of the levels marked "PM" 100-400 feet below the maximum level of Pinedale ice.

Following the Deckard Flats readjustment, ice continued to recede to the Junction Butte position.

LATE(?) PINEDALE TIME

A late(?) Pinedale ice margin is defined by bouldery moraines near Junction Butte in the Tower Junction quadrangle (Pierce, 1974) 6 miles down the Lamar River from the west map boundary.

From the northwest corner of the map area, Slough Creek flows southwest to the Lamar, which it joins about 5 miles west of the map area. The moraines near Junction Butte were deposited by a glacier that flowed from the valley of Slough Creek and which probably was augmented by a glacier in the lower valley of the Lamar River. The latter glacier was fed by glaciers in the valleys of Soda Butte, Pebble, and Amphitheater Creeks, but apparently not by glaciers from the upper Lamar drainage.

Along the Lamar River valley for several miles upstream from Soda Butte Creek, erratics of Precambrian crystalline rocks and Paleozoic limestone in Pinedale Till indicate that a glacier from the valley of Soda Butte Creek blocked and advanced up the Lamar. Local ice in the upper Lamar, if present at all, must have been restricted to positions farther upvalley. Diminished but continued glacial flow down Soda Butte Creek formed a dam which retreated down the Lamar and held a large lake in the valley of the upper Lamar; lake sediments up to 300 feet thick accumulated in this lake. Ice-rafted erratics of limestone and Precambrian rocks were carried as much as 7 miles upvalley from the mouth of the upper Lamar and deposited in ice-dammed lake sediments (pklu).

Elsewhere in Yellowstone National Park outside this map area, end moraines of late Pinedale age are found 1-5 miles downvalley from cirques similar to those at the head of most drainages in the map area. With the exception of the southern corner of the map area late Pinedale moraines were not noted in the interval from 0-10 miles downvalley from the cirques in the map area. The moraines near Junction Butte appear to represent a late Pinedale ice margin. Although these moraines are much farther downvalley from cirques than late Pinedale moraines elsewhere in Yellowstone, they are the only known candidate for the late Pinedale of the very significant glacial source area in the northern part of, and north of, the map area. Thus it is inferred that the extensive high country to the northeast supported an icecap in late Pinedale time.

Because the moraines near Junction Butte do not appear to represent a major advance (Pierce, 1974) and because the cirques in most of the valleys are similar to those elsewhere in Yellowstone that produced a late Pinedale readvance of a few miles, ice probably remained in most of the valleys between Deckard Flats time and Junction Butte time.

As the ice receded from the Junction Butte ice-margin, melt water deposited kame gravels, sands, and silts at the margin of stagnant ice and in ice-dammed lakes. Local alluvium was washed down from valley walls against stagnating glaciers to form kame inwash fan deposits; in some places the fan fronts show a stairstep pattern indicating successively lower ice positions. Above Icebox Canyon, the margins of kame fans locally show the form of crevasse fills.

Late Pinedale glaciers from an icecap north and northeast of the map area continued to flow into the map area even after local late Pinedale glaciers from cirques capable of producing sizable late Pinedale glaciers had receded. This is shown by ice-dammed lake sediments (pklu) deposited in a lake in the valley of Amphitheater Creek dammed by a glacier flowing down Soda Creek. Continued inflow of late Pinedale ice from an icecap northeast of the map area into areas probably just deglaciated by late Pinedale ice from local cirques is also indicated by a Precambrian erratic just beyond the Temple Lake moraines of the cirque north of Abiathar Peak and by bearing Precambrian rocks backfilling high into the valleys of Republic Creek (W. G. Pierce, written commun., 1972) north of Republic Pass and just east of the map area.

PINEDALE ALLUVIATION AND COLLUVIATION

As glaciers melted in the valleys, saturated bedrock and surficial debris from the valley walls slumped down against stagnant ice initiating many of the landslides (ls) in the map area, especially those in the valleys of Soda Butte and Slough Creeks.

During deglaciation, frost wedging on steep bedrock slopes produced talus (pta). Frost mixing and solifluction on uplands produced frost rubble (pfr).

Gravel forming the large terraces (pgu) near the confluence of the Lamar River and Soda Butte Creek shows a braided pattern and is probably outwash deposited during deglaciation following the late(?) Pinedale standstill near Junction Butte. Gravel eroded from local drainages was deposited on fans (pfg).

NEOGLACIATION

Pinedale glaciers appear to have completely melted during the altithermal interval about 7,000-4,000 years age. After this, small cirque glaciers and rock glaciers grew in high, well-protected cirques, mainly in the northeast and southeast parts of the area. One to two moraines of Temple Lake age were built in some cirques, and in a few cirques a single moraine of Gannett Peak age was built.

Well after the Yellowstone mapping was completed, Birkeland and Miller (1973) determined that the type Temple Lake moraines in the Wind River Mountains may be of latest Pinedale age and not of early Neoglacial age. It appears likely that the moraines in the northern part of the mapped area, especially those north of Abiathar Peak and Amphitheater Mountain may correlate with the type Temple Lake moraines and be of latest Pinedale rather than early Neoglacial age.

NEOGLACIAL COLLUVIATION, EROSION, AND ALLUVIATION

After late Pinedale deglaciation, frost activity and solifluction continued, probably with diminished intensity in altithermal time and slightly increased activity in Neoglacial time. Almost the entire map area has been affected by colluvial and alluvial processes in Neoglacial time. In the areas mapped as rubble veneer (pr) and as till (pt) frost churning, solifluction, and sheet wash are common. Avalanche debris is accumulating at the base of avalanche chutes by processes ranging from snow avalanches to torrential floods. Slumps and earthflows have produced sizable landslides (ls); small movements have occurred in areas of till and kame deposits.

The streams have eroded trenches in the glacial deposits heaped on the valley floors, as along Amphitheater Creek, Pebble Creek, and the upper Lamar drainages. On gentle slopes, at the heads of valleys and where tributary streams debouche into open valleys, alluvial fans have been built from late Pinedale time to the present. In modern times, fan deposits accumulate mainly during snowmelt and spring floods. The depth of surficial fill in the Lamar valley is not known; it may be hundreds of feet.

Spires of rocks called hoodoos are formed by the erosion of Eocene bedrock; they are common on certain rock types in the upper Lamar drainage.

QUATERNARY FAULTING AND HYDROTHERMAL ACTIVITY

Many faults on the Mirror Plateau and in the Lamar River valley appear to have been active since the last glaciation. In many places swampy deposits (fa) have accumulated against the upthrown fault block. For a fault scarp 10-50 feet high it is difficult to tell whether the till along a fault scarp has been offset a few feet since the Pinedale Glaciation or simply deposited on both sides of the fault scarp. In a few places offset of the till was observed. In one place in the center of the Mirror Plateau, pull-apart cracks with half a foot of vertical offset expose living tree roots indicating recent movements.

Hydrothermal alteration and gas vents smelling of hydrogen sulfide occur at Wahb Springs and near the Lamar River-Soda Butte Creek confluence. At the latter, they appear associated with faults having postglacial movement. Hot waters were not noted in the map area except at Soda Butte.

Text from source map: Abiathar Peak and parts of adjacent 15' Quadrangles

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References from source map: Abiathar Peak and parts of adjacent 15' Quadrangles

Canyon Village 15' Quadrangle

The formal citation for this source.

Richmond, Gerald M., 1977, Surficial Geologic Map of the Canyon Village Quadrangle, Yellowstone National Park, Wyoming: U.S. Geological Survey, Miscellaneous Investigations Series Map I-652, scale 1:62,500 (*GRI Source Map ID 1137*).

Description of geologic units, prominent graphics and text associated with this source.

Description of Units

lsg - Lake sediments, sandy gravel (Holocene)
lgs - Lake sediments, gravelly sand (Holocene)

Gray to brownish-gray sandy gravel (lsg) and gravelly sand (Lsg) deposits of modern beaches and lake terraces 10, 15, 25, and 30-35 feet (3, 4.5, 7.6, and 9-10.6 m) above Yellowstone Lake. Gravel on west and north sides of lake composed chiefly of rhyolite and obsidian; on northeast side it is chiefly of silica-cemented sediment, andesite, and basalt. Most deposits are 2-4 feet (0.6-1.2 m) thick, but some form thick spits and bars at the level of successive terraces and also in the lake, for example, at Gull Point, on Stevenson Island, and between Fishing Bridge and Storm Point. The lake terraces are cut in older deposits of Pinedale and pre-Pinedale age and in rock.

fa - Fine-grained humic alluvium (Holocene)

Dark- to light-gray or grayish-brown silt, sand, and clay mixture underlying flood plains of streams and depressions in Pinedale Till (pt). Marshy to seasonally marshy. Commonly overlies Holocene stream gravel (sg) and Pinedale stream deposits (psg, pgs) on valley floors. Thickness 2-15 feet (0.6-4.5 m).

sg - Stream deposits, sandy gravel (Holocene)
gs - Stream deposits, gravelly sand (Holocene)

Buff to gray gravel and cobbles in coarse sandy matrix (sg) and sand containing scattered small pebbles (gs). Clasts chiefly of rhyolite. Gravelly sand (gs) mapped only north-northeast of Fishing Bridge. Thickness 5-10 feet (1.5-3 m).

fg - Fan gravel (Holocene)

Gray to buff poorly sorted silty sandy angular gravel; chiefly of rhyolite. Occurs in alluvial fans along streams at foot of hills. Thickness 5-30 feet (1.5-9 m).

fd - Flood deposit (Holocene)

Gray unsorted bouldery cobble gravel with little matrix; dents chiefly of rhyolite. Found at sharp bend in Grand Canyon of the Yellowstone approximately 1 mile (1.6 km) south of north boundary of quadrangle. Thickness 20-40 feet (6-12 m).

ta - Talus deposit (Holocene)

Angular to subangular rock fragments forming sheet or cone of debris at base of cliff. Clasts mostly of rhyolite, in places hydrothermally altered. Sandy matrix. Deposits all in Grand Canyon of the Yellowstone, chiefly on northwest side. Thickness 5-50 feet (1.5-15 m).

ad - Avalanche debris (Holocene)

Gray-brown unsorted to poorly sorted mixture of subround to angular boulders, cobbles, and pebbles in silty to sandy matrix. Much of material derived from hydrothermally altered sources.

Deposits contain some mudflow debris. Forms fans at mouths of gullies in walls of Grand Canyon of the Yellowstone. Thickness 5-30 feet (1.5-9 m).

sd - Solifluction deposit (Holocene)

Gray-brown coarse to fine unsorted stony silty sand. Forms lobate terraces 5-10 feet (1.5-3 m) high that extend from valley wall out over flood plain along central sector of Broad Creek. Associated with seepage zones. Seasonally active. Thickness 5-15 feet (1.5-4.5 m).

ls - Landslide deposit (Holocene)

Mixture of mostly angular large and small blocks in sandy to clayey matrix. Forms lobate mass at base of a steep slope. Deposits mostly in Grand Canyon of the Yellowstone, which they locally dammed to form lakes in which sediments (included in sediments of Sevenmile Hole, sh) as much as 30 feet (9 m) thick accumulated. Ridge-like toes of deposits commonly on opposite side of river from headward parts. One slide occurred across the river from stratigraphic section 2 in 1971. Some may have formed during melting of the Pinedale glacier in canyon. Deposit along Sour Creek is a fault-controlled block slide: that at Turbid Lake is a slump from the rim of a hydrothermal explosion crater.

Canyon Village Stratigraphic Sections

es - Eolian sand (Holocene)

Buff medium to fine sand forming small dunes or an irregular mantle. Locally crossbedded. Occurs on bluffs along north side of Yellowstone Lake, on Stevenson Island, and on east rim of the Grand Canyon of the Yellowstone. Deposits mostly stable, grass-covered, and bear a thick humic soil, but some are active. Thickness 3-10 feet (0.9-3 m).

ds - Diatomacious silt (Holocene)

White to light-brownish-gray; composed mostly of siliceous diatom tests. Locally contains lenses of silty sand. Deposits chiefly near thermal areas. Mapped only near Forest Springs south of Grand Canyon of the Yellowstone, but thin deposits occur in many places in bluffs around Yellowstone Lake.

si - Silicious sinter (Holocene)

White to light-gray deposit of amorphous silica forming hot-spring terrace in Grand Canyon of the Yellowstone about 1 mile (1.6 km) south of north boundary of quadrangle. Also forms local cones (not all mapped) around small warm springs along Pelican Creek, in the area of the Ponuntpa Springs group. and north of Clear Lake.

he - Hydrothermal explosion deposit (Holocene)

Gray weathering buff unsorted massive clayey silty sand containing scattered large and small angular slabs of yellowish silica-cemented silt, sand, gravelly sand, till, and round to subround pebbles and cobbles of andesite, basalt, rhyolite, and pumice. Tough and hard when dry, plastic and soft when wet. Forms ridge around Turbid Lake and around Squaw Lake. Deposited by subaqueous hydrothermal explosion (Muffler and others, 1971). Deposit at Turbid Lake rests on humic zone (stratigraphic section 58) C-14 dated as 8,000±500 (W2486) and 8,310±300 (W1944) years old; the latter sample collected by J. D. Love. The deposit at Squaw Lake is overlain by humic clay C-14 dated as 3,500±250 years old (W2734), and overlies lake silt (pl) containing in its lower part, charcoal dated as 10,720±350 years old (W2738) (stratigraphic section 75). Thickness 6 feet (1.8 m) to more than 100 feet (30 m).

Canyon Village Stratigraphic Sections

sh - Sediments of Sevenmile Hole (Holocene and/or Pleistocene)

Sequence of sediments in Grand Canyon of Yellowstone, chiefly lacustrine, locally hydrothermally altered to white and shades of yellow, pink, or red. Though mapped as a single

unit, deposits represent three different age groups and consist, from top to bottom, of eight units:
Unit 1.-Bouldery cobble-gravel on local terrace cut on older deposits of sequence about 15 feet (4.5 m) above Yellowstone River. Holocene age. Thickness 10-40 feet (3-12 m).
Unit 2.-Complex of buff- to pink-weathering sediments consisting of talus deposits (ta in stratigraphic sections 2, 4) 5-30 feet (1.5-9 m) thick; dark-gray unsorted blocky landslide deposits (ls in stratigraphic sections 1, 2, 3) 3-50 feet (0.3-15 m) thick; bluish-gray massive to laminated lake silt (lst in stratigraphic sections 2, 3, 4) 5-20 feet (1.5-6 ml thick; pale-gray, poorly sorted, evenly bedded, medium lake sand (lad in stratigraphic section 3) 15-20 feet (4.5-6 m) thick; and local boulder gravel (fd in stratigraphic section 3) 8-15 feet (2.4-4.5 m) thick. Deposits interlens. The lake silt (lst in stratigraphic sections 2, 3, 4) contains logs altered to charcoal and coated with sulphur by hydrothermal activity that have been C-14 dated as 2,430 ±250 years old (W2735). Holocene age. Total thickness of unit 15-80 feet (4.5-24 m).
Unit 3.-Complex of sediments, commonly hydrothermally altered, consisting of varved silt (pl in stratigraphic section 1) 10-15 feet (3-4.5m) thick; landslide deposits composed mostly of hydrothermally altered rhyolite (pls in stratigraphic section 3) 10-50 feet (3-15 m) thick; and mudflow deposit (pmf in stratigraphic section 2). Mudflow deposit is a bluish-gray, buff-weathering unsorted mixture of sand and silt 5-15 feet (1.5-4.5 m) thick that contains angular clasts of altered rhyolite, andesite, and basalt, and wood C-14 dated as 10,900±350 years old (W27361 Late Pinedale age. Total thickness of unit 5-80 feet (1.5-24 m).
Unit 4-Gray to buff pebble to boulder gravel in sparse sandy matrix (psg in stratigraphic sections 2 and 3); poorly sorted, irregularly bedded. Clasts mostly of rhyolite, but a few of andesite, basalt, gneiss, and chalcedonic sinter. Pinedale age. Thickness 1-15 feet (0.3-4.5m).
Unit 5.-Gray, bluish-gray, or buff, locally rusty, unsorted silty sandy stony Pinedale Till (pt in stratigraphic sections 1, 2, 3, and 4). Stones round to subangular, mostly of altered rhyolite, but include erratics of andesite, basalt, granite, gneiss, tuff of Yellowstone Group, quartzite, and an agglutinate phase of the tuff of Sulphur Creek, all derived from the north. It also includes fragments of silicified sediments derived locally or from the south. The deposits contain and locally overlie lenses of gravel. Thickness of unit 1-15 feet (0.3-4.5 m) Disconformity locally cuts through underlying unit 7.
Unit 6.-Buff to gray fine sandy lake silt (ppl in stratigraphic section 1) showing long foreset beds dipping downriver. Probably deposited in Pinedale proglacial lake dammed by ice advancing from north. Thickness 25 feet (7.6 m).
Unit 7.-Buff to gray well-sorted medium lake sand (pbsl in stratigraphic sections 1, 2, 4) locally containing a few twigs and small thin pieces of wood commonly completely replaced by iron oxide. Deposits locally folded and crumpled by overriding Pinedale ice. Bull Lake-Pinedale interglacial age. Thickness 5-30 feet (1.5-9 m).
Unit 8.-Gray to bluish-gray, massive to laminated silt (pbl in stratigraphic sections 2, 4) containing dark, slightly organic films on bedding planes. Probably deposited in landslide-dammed lake during Bull Lake-Pinedale interglaciation. Locally crumpled and folded by overriding Pinedale ice. Thickness 15-25 feet (45-7.6 m).
Canyon Village Stratigraphic Sections

pl - Open-lake sediments, silt (Holocene and/or Pleistocene)
psl - Open-lake sediments, sand (Holocene and/or Pleistocene)
plsg - Open-lake sediments, sandy gravel (Holocene and/or Pleistocene)

Gray to bluish-gray, massive to laminated, locally varved silt (pl) between Pelican Creek and Yellowstone River, in the valley of Pelican Creek (stratigraphic sections 40, 41, 42, 44, 45, 49, 50, 51, 52, 53), along the bluffs of Mary Bay (stratigraphic sections 72, 73, 74, 76), along Sedge Creek (stratigraphic sections 62, 63), on Stevenson Island, and along the west side of Yellowstone Lake (stratigraphic sections 81, 83, 84, 87, 88, 90, 92). Gray to buff, massive to laminated, well- sorted, medium sand (psl) northeast of Yellowstone Lake outlet, in bluff of Yellowstone Lake southeast of Squaw Lake (stratigraphic sections 73, 74, 75, 76), and at and

east of the narrows of Pelican Creek (stratigraphic sections 45, 46, 47, 48). Thickness 10-20 feet (3-6 m). The 12,000- or 12,600-year-old Glacier Peak or possibly St. Helens J ash occurs locally in their lower part (stratigraphic sections 74, 92). Gray to tan, channel-and-fill crossbedded, sandy gravel (pl sg forming beaches and near-shore deposits of former open-water levels of Yellowstone Lake 60-65, 55, and 40-45 feet (18-20, 17, and 12- 14 m) above the present lake. Terrace at the 60-65-foot (18-20 m) level is broadest and most continuous. Most deposits are only a few feet thick and cap terraces cut in older Pinedale or pre-Pinedale deposits or rock. However, they form thick deltas, for example, on both sides of the valley of Pelican Creek below its narrows, along the lower 1.5 miles (2.4 km) of Sedge Creek, and along the lower mile (1.6 km) of Weasel Creek. They also locally form spits and bars, as at Gull Point (stratigraphic sections 88, 89).
Canyon Village Stratigraphic Sections

pg - Stream deposits, gravel (Holocene and/or Pleistocene)
psg - Stream deposits, sandy gravel (Holocene and/or Pleistocene)
pgs - Stream deposits, gravelly sand (Holocene and/or Pleistocene)
ps - Stream deposits, sand (Holocene and/or Pleistocene)
pfg - Stream deposits, fan gravel (Holocene and/or Pleistocene)

Gray to grayish-brown, gravel (pg), sandy gravel (psg), gravelly sand (pgs), and sand (ps) deposited in part by streams flowing from ice but mostly by drainage unrelated to ice in middle and late Pinedale time. Deposits poorly sorted, crudely bedded; mostly of locally derived rocks but include some erratics. Commonly form fill on valley floors; covered in places by younger fine-grained alluvium (fa) Also cap terraces 15-25 feet (4.5-7.6 m) above secondary streams and 15-50 feet (4.5-15 m) above Yellowstone River. Commonly 5-20 feet (1.5-6 m) thick, but widespread deposits of gravelly sand (pgs) mapped in Hayden Valley and north of Sour Creek are only a few inches thick; these rest on Pinedale lake silt (pkl) and are associated with fall of Pinedale lake in that area. Small deposits of alluvial fan gravel (pfg) are most abundant in the upper sector of Sour Creek; clasts angular to rounded, composed chiefly of hydrothermally altered rhyolite debris.

pfd - Flood deposit (Holocene and/or Pleistocene)

Gray to grayish-brown, unsorted sandy bouldery cobble gravel above Grand Loop Road north of Trout Creek In part hydrothermally altered. Clasts round to subangular, chiefly of rhyolite. Largest boulders mostly subangular blocks of tuff of Yellowstone Group, also includes clasts of silica-cemented sandstone, altered rhyolite, obsidian, andesite, basalt and balls of soft clayey silt. Material deposited against steep slope eroded in compact, varved silt (bl) of late Bull Lake age and massive, hard hydrothermally altered lake silt (bill of intra-Bull Lake interstadial age (stratigraphic section 34). Thickness as much as 40 feet (12.2 m).
Canyon Village Stratigraphic Sections

pta - Talus deposit (Holocene and/or Pleistocene)

Angular blocks of rhyolite in sandy matrix. Forms cone or sloping sheet of debris at base of cliff. Not abundant except along Grand Canyon of the Yellowstone where it is chiefly of hydrothermally altered rhyolite. Stable, commonly forested, and bears a thin soil like that on Pinedale Till. Thickness 5-50 feet (1.5-15 m).

prb - Block rubble (Holocene and/or Pleistocene)

Block rubble-Angular blocks of rhyolite or rhyolite tuff forming open-textured mass of debris on slope unrelated to cliff. Little interstitial material, stable, not forested. Small deposits northeast of Fern Lake and southwest of Sulphur Hills. Thickness 3-10 feet (0.9-3 m).

phl - Lacustrine hydrothermal explosion deposit (Holocene and/or Pleistocene)

Brown massive to weakly bedded silty clay containing scattered angular fragments of white to

yellow silica-cemented silt and sand, and scattered round to subangular pebbles and cobbles chiefly of andesite and basalt. Deposit occurs on flanks of ridge northeast of Mary Bay and grades into the hydrothermal explosion deposit (phe) underlying the ridge. Along Pelican Creek it rests disconformably on Pinedale lake silt (pl) (stratigraphic sections 49, 50, 51, 52, 53). It appears to be a lacustrine phase of the hydrothermal explosion deposit (phe). Thickness 5-15 feet (1.5-4.5 m).
Canyon Village Stratigraphic Sections

phe - Hydrothermal explosion deposit (Holocene and/or Pleistocene)

Yellowish-gray to brown unsorted massive clayey silty sand containing scattered large and small angular fragments and slabs of yellowish silica-cemented silt, sand, gravelly sand, round to subround pebbles and cobbles of andesite, basalt, rhyolite, pumice, and, at Mary Bay, porphyritic rhyodacite. Tough and hard when dry, soft and plastic when wet. Forms a ridge around north and east side of Mary Bay, around Fern Lake, and partly around depression in area of Josephs Coat Springs. Deposited by a subaqueous hydrothermal explosion, probably during a rapid fall of lake level (Muffler and others, 1971). Deposit around Mary Bay rests on varved silt (pl) (stratigraphic section 72, 75) or ice-dammed lake sand (pksl) (stratigraphic sections 69, 70, 71) and is overlain by sandy silt (psl) containing the 12,000- to 12,600-year-old Glacier Peak or possibly St Helens J ash bed (stratigraphic section 74). At stratigraphic section 7, explosion deposit intrudes organic lake mud C-14 dated as 13.650±650 years old (W2894).
Canyon Village Stratigraphic Sections

pkl - Ice-dammed lake sediments, silt and fine sand (Holocene and/or Pleistocene)
pksl - Ice-dammed lake sediments, sand (Holocene and/or Pleistocene)
pdgs - Ice-dammed lake sediments, delta gravelly sand (Holocene and/or Pleistocene)
pdsg - Ice-dammed lake sediments, delta sand gravel (Holocene and/or Pleistocene)
pklb - Ice-dammed lake sediments, beach sandy gravel (Holocene and/or Pleistocene)

Bluish-gray, buff-weathering, varved silt and fine sand (pkl). Deposits in area of Hot Springs Basin Group mostly hydrothermally altered. In Hayden Valley, they consist locally of five units of varved silt resting on a lower well-sorted medium sand (stratigraphic section 33). Each unit is characterized by thick lower valves becoming thinner upward. Varved silt also present in basin northeast of Hayden Valley across Yellowstone River (stratigraphic sections 20, 22, 24). Small deposit of silt on canyon wall immediately downstream from Lower Falls is probably an ice-dammed deposit. Thickness of unit throughout quadrangle 10-70 feet (3-21 ml. Gray, buff-weathering, well-sorted medium to fine sand (pksl) found on bench east of confluence of Sour Creek and Yellowstone River, on the north slope of Pelican Valley, on the slopes of the ridge east of Mary Bay where it is overlapped by a hydrothermal explosion deposit (phe) (stratigraphic sections 68, 69, 70, 71), and on Stevenson Island (stratigraphic sections 93, 95, 96, 97). Thickness, 20-80 feet (6-24 m). Gray, gravelly delta sand (pdgs) characterized by long foreset bedding in valley of Sour Creek north of Yellowstone River (stratigraphic section 20); similarly bedded sandy gravel (pdsg) forms deltas on north slope of Pelican Valley. Thickness 10-50 feet (3-15 m). Gray to grayish-brown, crossbedded, sandy gravel (pklb) forming beach and local delta deposits on terraces cut in older Pinedale ice-contact deposits (pkgs) 110-150 feet (33-46 ml above Yellowstone Lake. Thickness 2-40 feet (0.6-12 m).
Canyon Village Stratigraphic Sections

pksg - Kame deposits, sandy gravel (Holocene and/or Pleistocene)
pkgs - Kame deposits, gravelly sand (Holocene and/or Pleistocene)
pks - Kame deposits, sand (Holocene and/or Pleistocene)
peg - Kame deposits, esker gravel (Holocene and/or Pleistocene)

Buff to gray sandy gravel (pksg) and gravelly sand (pkgs) that form kame terraces with ice-contact frontal scarps, or valley fills with down-valley ice-contact scarps. Both have irregular hummocky surfaces. Deposits are widespread around Yellowstone Lake between altitudes of

7840 feet (2390 m) and 7200 feet 12195 m), or between 470 and 110 feet (143 and 33 m) above the lake. Thickness 20 feet (6 nil to more than 50 feet (15 m). Extensive deposits also occur in area of White and Tern Lakes, where they are characterized by many large kettles, and in valleys in the central part of the quadrangle. Buff to gray well-sorted sand (pks) forms ice-contact deposits southeast of White Lake and in the vicinity of Hot Springs Basin Group where the deposits are hydrothermally altered. Some may be of lacustrine origin. Gray to grayish-brown esker deposits (peg) chiefly of cobbles and a very little sand matrix form an irregular ridge 40 to 60 feet (12 to 18 m) high that separates the two parts of Tern Lake, and two ridge segments, locally more than 80 feet (24 m) high, that nearly cross White Lake and extend along its northeast shore.

pt - Till and glacial rubble, till (Holocene and/or Pleistocene)
pr - Till and glacial rubble, glacial rubble (Holocene and/or Pleistocene)

Grayish-brown to gray stony silty unsorted loose to compact sand (pt). Most silty in eastern third of quadrangle. Silica cemented at Steamboat Point. Surface of deposits smooth to hummocky. Undrained depressions common in valley areas. Ice-molded topography rare. Clasts mostly of rhyolite but rounded erratics of Eocene basalt and andesite are fairly common. Erratics of Precambrian granite and gneiss, quartzite, and chalcedonic sinter are present in till in northwestern part of quadrangle. Thickness commonly less than 5-10 feet (1.5-3 m), locally as much as 40 feet (12 m). Soil on deposits less than a foot thick and weakly developed. Uplands in area of Elephant Back Mountain mantled with thin sandy glacial nibble (pr) in general less than a foot thick. Scattered erratics and local patches of till, shown by pattern on map, mantle areas of pre-Pinedale lake silt (bl) in Pelican Valley, in Hayden Valley, and northeast and north of Hayden Valley.

pbl - Lake sediments, silt (Pleistocene)
pbsl - Lake sediments, sand (Pleistocene)
pbgl - Lake sediments, gravelly sand (Pleistocene)

Bluish-gray silt (pbl), weathering brownish gray to brown; laminated to nonbedded (stratigraphic sections 64, 80). Deposits at Fishing Bridge (stratigraphic sections 78, 79) contain a pumice bed about 1.5 feet (0.45 m) thick and have dark slightly organic films on bedding planes. These deposits are included in the Bull Lake-Pinedale interglacial because they immediately underlie Pinedale sediments, but might be of intra-Bull Lake interstadial age. The pumice bed has not been dated. Similar silt without pumice forms unit 8 in lower part of sediments of Sevenmile Hole (stratigraphic sections 2, 4). Gray to buff weakly to well-bedded medium sand (pbsl) (stratigraphic section 80); forms deposits similar to unit 7 in lower part of sediments of Sevenmile Hole in Grand Canyon of the Yellowstone (stratigraphic sections 1, 2, 4). Deposits in Pelican Valley contain reworked pumice (stratigraphic section 48). Deposits mapped northeast of Fishing Bridge are cemented by silica and show a northwesterly streaking of postcementation and possible glacial origin on aerial photographs. Deposits mapped in bluff of Yellowstone Lake in southeast corner of quadrangle are pumiceous as are those exposed above Bull Lake Till and below Pinedale deposits at Steamboat Point (stratigraphic section 65). Buff to gray clean well-sorted weakly- to well-bedded, medium to coarse gravelly lake sand (pbgl) contains local layers of round to subangular pebble gravel and irregular inclusions of bedded silt. Lower part poorly sorted; local gravel layers contain pumice pebbles and fragments of hard clay. Clasts mostly tuff of Yellowstone Group and a few pebbles of Eocene andesite and basalt. Sediment cemented by silica around now extinct hot-spring pipes. Deposit observed only in area of stratigraphic sections 58 and 59 in bluffs of Bear Creek southeast of Turbid Lake where it rests on lake silt (bl) of late Bull Lake age and is overlain by Pinedale Till (pt) and younger hydrothermal explosion deposit (he). Thickness 150 feet (45 m).
Canyon Village Stratigraphic Sections

bgs - Stream gravelly sand (Pleistocene)

Gray, white, and pink, hydrothermally altered and silica cemented, poorly sorted; exposed along Yellowstone River east of Mud Volcano. Contains abundant pumice, and small globules and very delicate irregularly shaped particles of obsidian from rhyolite flows nearby to the south. Lies in a channel cut in hydrothermally altered lake silt (bl) of late Bull Lake age and is overlain by uncemented Pinedale Till (pt) and stream gravel (psg). Probably of Bull Lake-Pinedale interglacial age. Thickness about 40 feet (12 m), but only 5-10 feet (1.5-3 m) exposed in most places.

bl - Lake sediments, silt (Pleistocene)
bsl - Lake sediments, sand (Pleistocene)
bdgs - Lake sediments, delta gravelly sand (Pleistocene)

Bluish-gray, weathering buff to brown silt (bl); altered to red, yellow, and whitish hues in areas of thermal activity. Extensive deposits in Hayden Valley are as much as 200 feet (60 m) thick; commonly varved, locally massive or laminated (stratigraphic sections 31, 33, 34, 36, 37); extend to 8,120 feet (2,566 m) altitude east of Yellowstone River, and to 7,840 feet (2,390 m) altitude beneath Pinedale ice-contact deposits (pkgs) along Sour Creek (stratigraphic sections 23, 25, 26, 27, 28). Varved deposit at Natural Bridge, west of Bridge Bay, is at an altitude of about 8,040 feet (2,450 m). Deposit in bluff of Yellowstone Lake at Lake Hotel is varved and contorted. It contains lenses of till, and basalt and andesite erratics of late Bull Lake age. Deposits at Turbid Lake contain a few pebbles of andesite and basalt (stratigraphic section 58, 59). A deposit on the east rim of the Grand Canyon of the Yellowstone exposed temporarily in an excavation back of the restrooms at Uncle Toms Trail parking area on the southeast rim of the canyon between Upper and Lower Falls (stratigraphic section 11) contains a pumice bed and abundant scattered pumice grains. All these deposits probably formed in ice-dammed lakes. Exposures of lake silt overlying the Hayden Valley rhyolite flow (Rh) east of Yellowstone River (bl in stratigraphic section 17) locally contain a pumice bed 4.5 feet (1.4 m) thick. They are included with deposits of late Bull Lake age because they overlie the Hayden Valley flow, but might be of intra-Bull Lake interstadial age. The pumice bed has not been dated. Gray medium sand (bsl), probably deposited in ice-dammed lakes, occurs between glacial gravel (bgu) of late Bull Lake age and kame sand (pks) of Pinedale age in the headwaters of Astringent Creek (stratigraphic section 55) and interfingers with glacial rubble of late Bull Lake age on the east rim of the canyon near Lower Falls (br in stratigraphic sections 10, 12). Buff to gray, silica-cemented gravelly sand (bdgs) shows long foreset bedding. Occurs only along Sour Creek north of Yellowstone River. Overlapped disconformably by uncemented delta gravelly sand (pdgs) of Pinedale age. Thickness 15-20 feet (4.5-6 m).
Canyon Village Stratigraphic Sections

bksg - Kame deposits, sandy gravel (Pleistocene)
bkgs - Kame deposits, gravelly sand (Pleistocene)
bkg - Kame deposits, gravel (Pleistocene)

White, pinkish-brown, red, and gray, hydrothermally altered, well-sorted to poorly sorted, crossbedded to flat-bedded gravel (bkg), sandy gravel (bksg), or gravelly sand (bkgs) showing sharp changes in texture. Deposits form hills. Clasts are chiefly of rhyolite, but some pebbles and cobbles are of Eocene basalt and andesite, and tuff of the Yellowstone Group. No casts of Precambrian crystalline rocks or chalcedonic sinter were observed. All of the deposits are partly overlapped by unaltered or little-altered Pinedale Till which, south of Point Sublime, contain erratics of chalcedonic sinter and Precambrian granite and gneiss. Modern hot springs and fumaroles surrounded by areas of extensive acid alteration of the deposit to clay occur in each deposit. Commonly, a basin has been eroded in such areas. It is probable that the deposits owe their location to the release of gravel from ice melting over hot-spring areas. The deposit in the area of Josephs Coat Springs may include some undifferentiated material of Pinedale age. The others appear wholly of Bull Lake age. Deposits exposed in cemented and glaciated outcrops northeast of Tern Lake contain pebbles and cobbles of rhyolite, tuff of the Yellowstone Group, and Eocene andesite and basalt. They show weak channel-and-fill crossbedding and are overlain by uncemented Pinedale kame gravelly sand (pkgs).

bt - Till and glacial rubble, till (Pleistocene)
br - Till and glacial rubble, glacial rubble (Pleistocene)

Grayish-brown unsorted mixture of silt, sand, and stones of all sizes (bt); contains sparse erratics of Eocene basalt and andesite. A few basalt pebbles are striated. Soil yellowish brown, locally as much as 3 feet (0.9 m) thick. Deposit occurs on upland in northeast part of quadrangle. Small deposit along Moss Creek is silica cemented, hydrothermally altered, and disconformably overlain by little-altered uncemented Pinedale Till (pt) bearing a soil less than 1 foot (0.3 m) thick. On the western slope of the upland the contact between the Bull Lake Till (bt) and Pinedale Till (pt) downslope is marked by a zone of irregular hummocky lateral moraines of thick Pinedale Till-bearing soil less than 1 foot (0.3 ml thick. Glacial rubble (br) is a thin mantle composed of sand and subround to angular stones that mantles upland east of area of till (bt). Clasts mostly of subjacent Canyon rhyolite flow (Rc) but some are erratics of Eocene andesite and basalt. Undersides of some basalt pebbles striated. Weathering rind on basalt pebbles as much as 0.25 inch (0.6 cm) thick. A similar rubble also containing erratics of basalt and andesite rests on sediments of Upper Falls (uf) at stratigraphic sections 10 and 12. Unit commonly thin, but thickness locally as much as 10 feet (3 m).
Canyon Village Stratigraphic Sections

gv - Sediments of Grand View (Pleistocene)

Sequence of chiefly lacustrine sediments exposed beneath a hydrothermally altered landslide deposit at stratigraphic section 5 in northwest wall of Grand Canyon of the Yellowstone 0.6 mile (0.9 km) east of Grand View and northeastward toward Inspiration Point. The sediments comprise 9 units, from top to bottom as follows:

1. Sand, gray, medium to coarse, locally pebbly, mostly evenly bedded but some layers crossbedded. Contains abundant rhyolite and obsidian, partly hydrothermally altered, and some pumice locally. Mostly unconsolidated, locally weakly to moderately silica cemented. Thickness about 39 feet (11.9 m).
2. Silt, gray-blue, weathering gray, massive. Mostly soft, but local thin silicified layers. Thickness 17 feet (5.2 m).
3. Sand, gray-blue, medium to fine, massive. Thickness 3 feet (0.9 m).
4. Silt, gray-blue, weathering gray, thinly varved, compact Thickness 11 feet (3.4 m).
5. Sand, gray, medium to coarse, local pebbly layers. Composed chiefly of fresh and altered rhyolite and obsidian. Pebbles subround to subangular. Mostly unconsolidated, but some layers silica cemented. Thickness about 30 feet (9 m).
6. Silt, gray-blue, weathering gray, thinly laminated, compact, a few laminae silicified. Thickness 6 feet (1.8 m).
7. Sand, gray, medium to coarse, mostly massive or evenly bedded, but some layers crossbedded. Includes a few thin silt layers. Pebbly to gravelly layers in lower and upper parts. Deposit composed chiefly of rhyolite and obsidian, including much altered material. Abundant medium to fine pumice. A few layers silica cemented. Thickness about 32 feet (9.7 m).
8. Silt, greenish-gray, massive to thinly laminated, compact Thickness 1.8 feet (0.5 m).
9. Colluvium, gray to brown, hydrothermally altered, angular to subangular clasts of rhyolite in unsorted clayey silty sand matrix. Thickness 1-4 feet (0.3-1.2 m).

Overall, the sediments of Grand View are little altered at stratigraphic section 5, though they become more altered to the northeast, toward Inspiration Point They are broadly similar in character to units 1-5 of the sediments of Upper Falls (uf), and may be roughly equivalent in age to the uppermost sand (bslu) of those sediments. The top of the sediments of Grand View is 150 feet (46 ml lower, and the base 300 feet (91 m) lower than the base of the sediments of Upper

Falls at Lower Falls. The total thickness of the sediments of Grand View is about 142 feet (43 m).
Canyon Village Stratigraphic Sections

Rs - Solfatara Plateau rhyolite flow (Pleistocene)
Rh - Hayden Valley rhyolite flow (Pleistocene)
Re - Elephant Back rhyolite flow (Pleistocene)
Rw - West Thumb rhyolite flow (Pleistocene)
Rdp - Dunraven Pass rhyolite flow (Pleistocene)
Rc - Canyon rhyolite flow and tuff of Sulphur Creek (Pleistocene)
Rut - Tuff of Uncle Toms Trail (Pleistocene)

The quadrangle is almost wholly underlain by Quaternary volcanic rocks. These have been mapped and stratigraphically subdivided by R. L. Christiansen and H. R. Blank, Jr. (U.S. Geol. Survey, 1972), from whose work the index map of rhyolite flows is derived. Eocene volcanic and sedimentary rocks in the northern and eastern part of the quadrangle have been mapped and stratigraphically subdivided by H. W. Smedes and H. J. Prostka U.S. Geol. Survey, 1972). I mapped outcrops of the Quaternary rhyolite flows because their stratigraphic or physiographic relations to the Quaternary sediments contribute to an understanding of the glacial and lacustrine history. Potassium-argon dates are by J. D. Obradovich.

The northeast side of a large caldera, which collapsed following eruption of a tuff, K-Ar dated about 600,000 years old, trends northwest across the northern quarter of the quadrangle, partly along the drainage of Broad Creek. All the rhyolite flows on this map are younger than this caldera. The east edge of the Solfatara Plateau rhyolite flow (Rs) extends into the quadrangle north of Hayden Valley and west of the Yellowstone River. It yielded a K-Ar age of about 107,000 years, but overlies the Hayden Valley rhyolite flow (Rh), more reliably K-Ar dated as about 100,000 years old, The Solfatara Plateau flow appears to overlie lake silt of the sediments of Upper Falls at the northeast edge of the flow at and below the level of the road along the Yellowstone River. The silt contains abundant particles of pumice. The Hayden Valley rhyolite flow (Rh) underlies the northern part of Hayden Valley, north of Crater Hills. It also underlies the hills across the Yellowstone River northeast of Hayden Valley. The flow is overlain by lake silt (bl) of the late stade of Bull Lake Glaciation, In the western part of Hayden Valley, in the Norris Junction quadrangle (Richmond and Waldrop, 1975), till of the late stade of Bull Lake Glaciation lies between the lake silt and the flow. Lake silt (bil, bll) of the intra-Bull Lake interval and early stade of Bull Lake Glaciation, included in the sediments of Upper Falls (uf), underlies the flow at stratigraphic sections 18 and 19 along the Yellowstone River in Hayden Valley and elsewhere. The Elephant Back rhyolite flow (Re) forms Elephant Back Mountain and the hills to the south. This flow yielded a K-Ar age of about 150,000 years, but overlies the West Thumb rhyolite flow, more reliably dated at about 144,000 years. The West Thumb rhyolite flow (Rw) is exposed in bluffs along the west side of Yellowstone Lake and northward, west of the Yellowstone River. The Dunraven Pass rhyolite flow (Rdp) is exposed on the hills northeast of Canyon Village. It rests on the Canyon rhyolite flow (Rc), K-Ar age about 590,000 years, which extends northwest across the canyon in the northeast part of the quadrangle. The Canyon flow rests on a thick tuff, known as the tuff of Sulphur Creek (Christiansen and Blank, 1972), here mapped with the flow. Along Broad Creek the tuff contains inclusions of bedded silt from a caldera lake existing at the time of its eruption. The tuff of Uncle Toms Trail (Rut) is white, locally limonite-stained, partly welded tuff exposed in the Grand Canyon of the Yellowstone just above Lower Falls, and discontinuously upstream nearly to Upper Falls. Its lower part contains local masses of well-rounded pebbles and cobbles of rhyolite, altered rhyolite, obsidian, quartzite, basalt, andesite, quartz, and gneiss. The masses are swirled upward into the tuff. Near its upper contact the tuff contains subangular inclusions of biotite diorite like those in the diamicton of the sediments of Lower Falls (lf) that overlies the tuff at Lower Falls (stratigraphic section 12). Elsewhere the tuff is disconformably overlain by the Canyon rhyolite flow (Rc). Thickness of the tuff is about 150 feet (45 m) at Lower Falls, but no more than 30 feet (9 m) are exposed upstream.

Canyon Village Stratigraphic Sections

uf - Sediments of Upper Falls (Pleistocene)

Sequence of chiefly lacustrine sediments and underlying pumice beds that include 13 lithologic units of four different geologic age groups. From top to bottom these are: intra-Bull Lake interval (bslu, bil, bisl), early stade of Bull Lake Glaciation (bll, bsll, bgl), Sacagawea Ridge-Bull Lake interglaciation (s-bl, s-bsl), Sacagawea Ridge glaciation (ssg, pumice bed uf-III, and diamicton (ufd), and older Pleistocene time (pumice beds uf-II and uf-I). Though the deposits are not distinguishable at the scale of the map, the 13 lithologic units can be identified in stratigraphic sections. The most complete exposure is at stratigraphic section 13. Correlative units of the sediments of Upper Falls as distinguished and described in the Norris Junction quadrangle (Richmond and Waldrop, 1975), are shown in parentheses.

bslu (unit 1) - Sand: Gray, medium to coarse, moderately silica-cemented, shallow channel-and-fill crossbedding; contains local lenses of pebble gravel. Mostly quartz, sanidine, rhyolite, altered rhyolite, obsidian, and pumice. No erratics. Exposed along canyon rim as far as Artist Point parking area. Highly altered at stratigraphic section 9. Above trail to Upper Falls overlook on southeast side of canyon a lens of pumice in the sand yielded a K-Ar age of about 99,000 years. Probably of latest intra-Bull Lake interstadial age. Deposit best exposed at stratigraphic section 13. At stratigraphic sections 10, 11, 12, and 14, it is disconformably overlain by cemented glacial sediment of late Bull Lake age containing erratics of Eocene andesite and basalt. Beyond the limits of the canyon, the cemented sand underlies areas around hills to north and south where it is mapped as sediments of Upper Falls (uf). Thickness 20-45 feet (6-14 m).

bil (unit 2) - Silt Gray to bluish-gray, weathering chocolate brown, clayey, compact, massive to laminated; locally contains small pumice grains and leaves of water plants. Probably of intra-Bull Lake interstadial age. Well exposed below rim of canyon at stratigraphic section 13 and near footbridge east of Upper Falls. Also exposed in east bluff of Yellowstone River beneath Hayden Valley rhyolite flow (Rh) (stratigraphic sections 18, 19) where dikes of the silt have been forced 30-50 feet (9-15 m) up into the flow by the pressure of the overriding extrusion. Exposed in Hayden Valley (stratigraphic sections 29, 30, 33) and in east bluff of Yellowstone Lake at Steamboat Point (stratigraphic section 65). Thickness 4-30 feet (1-9 m).

bisl - Sand: Gray to buff, poorly sorted, flat-bedded to crossbedded, fine to coarse; some pebbly layers; composed of quartz, sanidine, rhyolite, altered rhyolite, obsidian, and pumice; some thin pink to brown silt layers. Probably of intra-Bull Lake interstadial age. Exposed only in areas of stratigraphic sections 13, 14, and 65. Thickness about 4-23 feet (1.2-7 m).

bll (unit 3) - Silt Bluish-gray, weathering pink to buff, commonly varved, locally laminated or banded. Includes a few thin beds of coarse pumiceous sand. Locally hydrothermally altered. Exposed at stratigraphic sections 9, 13, 16. Probably of latest early Bull Lake age. Thickness about 6-13 feet (1.8-4 m).

bsll (units 4, 5, 6) - Sand: Buff to gray, pebbly, channel-and-fill crossbedded, moderately silica-cemented. Exposed in area of Grand Canyon of the Yellowstone (stratigraphic sections 9, 14, 15, 16), in Hayden Valley (stratigraphic sections 29, 30), and in headwaters of Astringent Creek (stratigraphic section 55). Composed chiefly of quartz, sanidine, rhyolite, altered rhyolite, and pumice. In northeast part of Yellowstone Lake basin (stratigraphic sections 55, 65), composed chiefly of rhyolite, basalt, and andesite. At stratigraphic section 30, the sand lies both over and under sandy gravel (bgl); at stratigraphic section 29 it underlies but is lacking above the sandy gravel (bgl). Probably of early Bull Lake age. Thickness 6-52 feet (1.8-16 m).

bgl (unit 7) - Sandy gravel Similar to the sand (bsll) but contains subround to angular cobbles of rhyolite and erratics of Eocene andesite and basalt. Exposed at stratigraphic sections 13, 29, 30, 55. Probably a glacial sediment or outwash of early Bull Lake age. Thickness generally 0.2 to 2.0 feet (0.06-0.6 m); 30 feet (9 m) at stratigraphic section 55.

s-bl - Silt: Bluish-gray, weathering brown, laminated, locally thickly banded. Exposed only in area of Grand Canyon of the Yellowstone (stratigraphic sections 13, 16) and in the southern part of Canyon Village. Probably of late Sacagawea Ridge-Bull Lake age. Thickness 1.5-8 feet (0.5-2.4 m).

s-bsl (unit 8) - Sand: Gray, weathering buff, thin-bedded, silty, fine grading upward through medium to coarse; interlayered silt laminae. Pumice and obsidian grains in increasing abundance upward. Exposed at stratigraphic sections 14, 29, and 30, and in the northern part of Canyon Village. Probably of Sacagawea Ridge-Bull Lake interglacial age. Thickness 4-25 feet (1-7.6 m). Sandy gravel: Cobbles and boulders mostly of rhyolite but also of quartzite, biotite diorite, obsidian, and altered rhyolite, in poorly to well-sorted coarse pumiceous sand matrix. Local well-sorted pumiceous sand layers. No erratics found, Exposed only at stratigraphic section 13. Probably of late Sacagawea Ridge glacial age. Thickness 0.5-2 feet (0.15-0.6 m).

uf-III - Pumice bed -Gray to grayish-green, coarse to fine, massive, hard; contains numerous angular fragments of obsidian as large as 1 inch (2.5 cm) in diameter. K-Ar age about 266,000 years. Thickness about 12 feet (3.6 m).

ufd - Diamicton-Dark-gray to gray-brown pumiceous silty medium sand; compact, poorly sorted, massive, tough, nonbedded to lacustrine crossbedded, locally streaked by thin irregular lenses of fine to medium sand. Contains numerous scattered subangular to subround stones as much as 8 inches (20 cm) in diameter, chiefly of gray fine-grained biotite diorite, but also a few of rhyolite and quartzite; also many angular pumice pebbles. Sand increasingly pumiceous in lower part. Probably of glaciolacustrine origin and of early Sacagawea Ridge age. Thickness 5-6 feet (1.5-1.8 m).

uf-II - Pumice bed -Gray to grayish-green. coarse to fine, massive, hard; contains numerous small angular fragments of obsidian. K-Ar date of about 741,000 years indicates presence of age contaminants, Thickness about 8 feet (2.4 m).

uf-I - Pumice bed -Yellowish-gray, coarse to fine, massive, hard, jointed; contains small angular fragments of obsidian. Upper 12 feet (3.6 m) stained bright orange, probably by ground water. Basal two feet similarly stained. At stratigraphic section 13, rests disconformably on diamicton of sediments of Lower Falls (lf). Thickness about 22 feet (6.7m).
Canyon Village Stratigraphic Sections

rr - Sediments of Red Rock (Pleistocene)

Chiefly lacustrine sediments exposed at stratigraphic sections 7 and 8 along lower part of trail to, and below both sides of, Red Rock, a promontory jutting from the middle part of the northwest wall of the Grand Canyon of the Yellowstone between Inspiration Point and Lower Falls. Three sedimentary sequences, moderately silica cemented and separated by disconformities, are exposed. From top to bottom, these are:

1. Gray to bluish-gray, weathering buff, slabby fine to medium sand and silt grading down first into laminated clayey silt and then further down into fine to coarse flat-bedded rhyolitic pebbly sand; crossbedded down-canyon within beds. Thickness about 100 feet (30 m).
2. Buff medium sand and rhyolitic pebbly gravel; down-canyon delta crossbedding. Grades down into bluish-gray buff-weathering silt having down-canyon delta crossbedding, and grades at base into sandy beds and coarse rhyolitic pebbly sand. Thickness about 45 feet (13.7 m).
3. Bluish-gray, weathering buff, massive silty clay grading down into basal coarse pebbly sand

and talus mixed with rounded gravel. Includes a few round pebbles of biotite diorite and andesite. Thickness about 80 feet (24 m).
All of the sediments are hard, compact, and silica-cemented. Although largely composed of hydrothermally altered rocks, they are themselves only locally altered. Though broadly similar to units 1-7 of the sediments of Upper Falls (uf), these sediments are probably older. They lie in a paleocanyon of the ancestral Yellowstone River between 220 and 400 feet (67 and 122 m) above the present river. They contain no megascopic obsidian. Total thickness of sediments 117-224 feet (35-68 m).
Canyon Village Stratigraphic Sections

ip - Sediments of Inspiration Point (Pleistocene)

Intensively altered and silicified white, buff, and pink, fine to coarse, poorly to well-sorted alluvial rhyolitic sand, pebbly sand, and silt. Locally interbedded with chalcedonic sinter. Deposits occur on both rims of Grand Canyon of the Yellowstone. Near Glacial Boulder, they are about 30 feet (9 ml thick, cemented, but not intensely altered. West of Glacial Boulder, highly opalized deposits, difficult to distinguish as sediments, are exposed discontinuously along rim as far as trail to Red Rock These opalized deposits appear to be chiefly sand containing local silt layers, are 5-15 feet (1.5-4.5 m) thick, and overlie irregular surface of Canyon rhyolite flow (Rc). At edge of highway along canyon rim at stratigraphic section 6, chalcedonic sinter rests on opalized alluvial silt and sand. The distribution of fragments of opalized sand and silt in valley northeast of Canyon Village suggests that this area is also underlain by sediments of Inspiration Point. These appear to form an alluvial fan extending downslope south from the water tanks. Southeast of the canyon, chalcedonic sinter is interbedded with alluvial pebbly sand and silt along highway west of Artist Point, and deposits of chalcedonic sinter as much as 16 feet (4.9 m) thick overlie the surface of the Canyon rhyolite flow at altitudes as high as 7,800 feet (2,377 m) on the hills to the southeast The chalcedonic sinter is white, light gray, or pink, hard, layered chalcedony; layers 1/8 to 3/4 inch (0.2-1.9 cm) thick are locally separated by thin irregular cavities, some filled with quartz and small crystals of pyrite. According to White, Brannock, and Murata (1956), chalcedonic sinter was originally hot-spring-deposited opaline sinter that became buried and remained for a long time in a subsurface hydrothermal environment in which the opaline sinter was converted to chalcedonic sinter.
Canyon Village Stratigraphic Sections

cc - Sediments of Cascade Creek (Pleistocene)

Gray tuffaceous locally sandy moderately silica-cemented lake silt contains small angular fragments of pumice, obsidian, and rhyolite and local interbedded pebbly sand layers; exposed only along lower part of Cascade Creek near confluence with Yellowstone River (stratigraphic section 15). Deposits grade westward abruptly into a coarse alluvial-fan facies composed of rhyolitic and tuffaceous sand containing boulders of obsidian derived from Canyon rhyolite flow (Re). Deposit rests on surface of Canyon flow and is overlain disconformably by sediments by Upper Falls (bs II, stratigraphic section 16) Thickness 15-93 feet (4.5-28m).
Canyon Village Stratigraphic Sections

lf - Sediments of Lower Falls (Pleistocene)

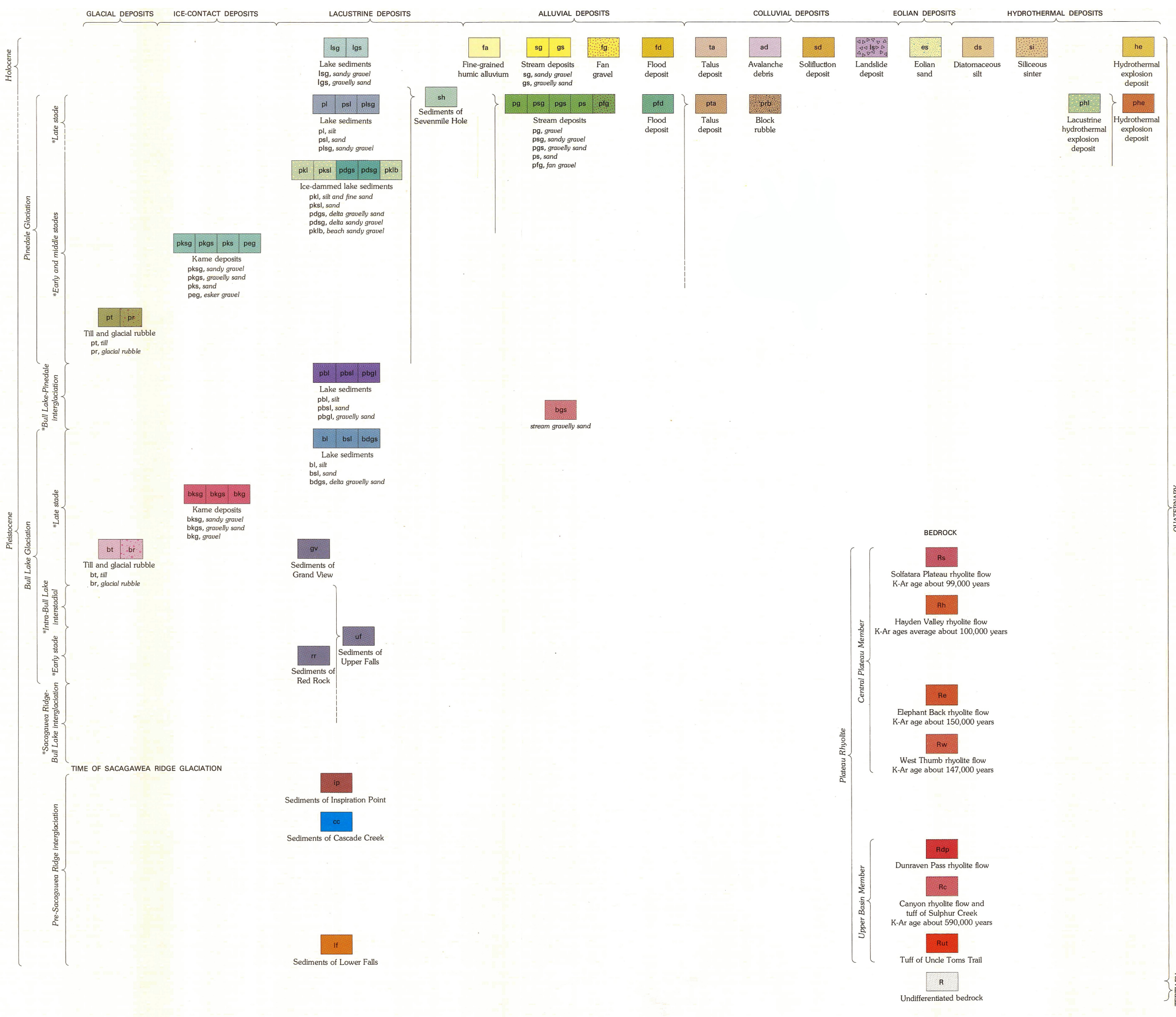
Consist of two units: upper unit is a grayish- to yellowish-brown diamicton, probably a subaqueous mudflow or subaqueous tuff, doubtfully a till. Deposit is massive hard nonbedded unsorted tuffaceous silty sand containing abundant subangular fragments of gray fine-grained biotite diorite as much as 2 feet (0.6 m) in diameter. A few rhyolite pebbles in uppermost part and a few pebbles and cobbles of quartzite and rhyolite in lower part Thickness 75-200 feet (23-61 m). Exposed along southeast wall of Grand Canyon of the Yellowstone above Lower Falls, Locally rests disconformably on lower unit or on tuff of Uncle Toms Trail (Rut); extends from river level nearly to rim of canyon. Steep disconformity separates it from overlying Canyon rhyolite flow (Rc). Lower unit is gray, weathering brown, compact massive to laminated, or thin-bedded,

tuffaceous lake silt, locally sandy. Exposed just above Lower Falls beneath diamicton (stratigraphic section 11). Rests disconformably on tuff of Uncle Toms Trail (Rut). Thickness 30-48 feet (9-15 m).
[Canyon Village Stratigraphic Sections]

R - Undifferentiated bedrock (Quaternary and Tertiary)
Undifferentiated bedrock-Includes two tuffs of the Yellowstone Group, K-Ar dated at 600,000 and 2 million years old. These crop out in the faulted domelike area in the central part of the quadrangle and also northeast of Broad Creek in the northeast part. Quaternary rhyolite and basalt older than the Canyon rhyolite flow (Rc) and Eocene andesite and associated pyroclastic sediments are also exposed in that area.
[Canyon Village Stratigraphic Sections]

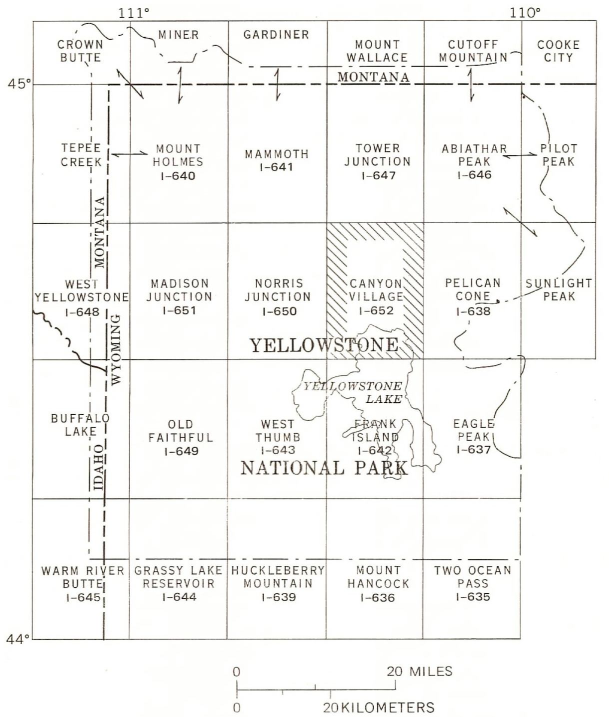
Text from source map: [Canyon Village 15' Quadrangle]

Correlation of Units



Graphic from source map: [Canyon Village 15' Quadrangle]

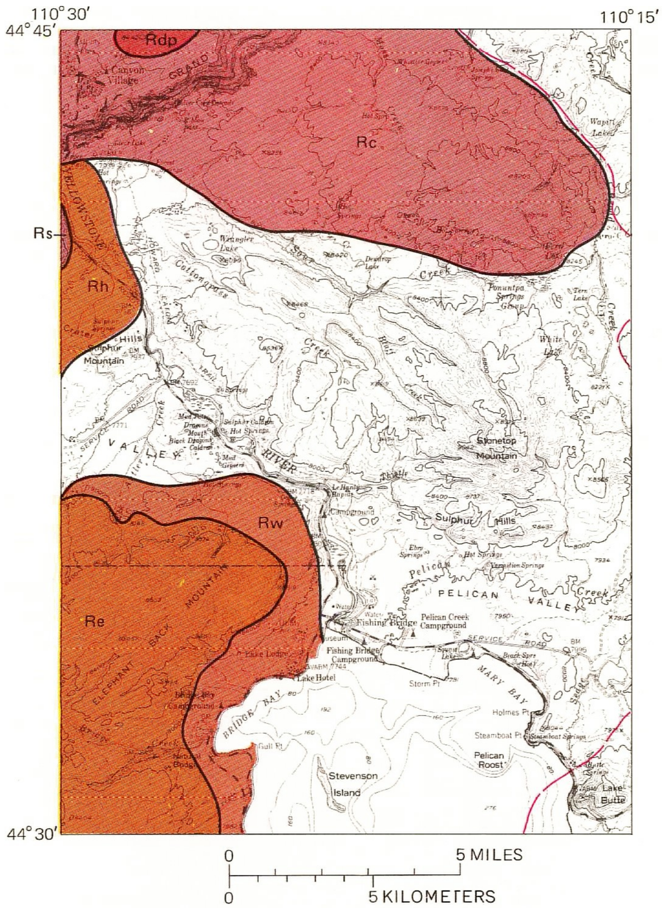
Index Map



INDEX MAP OF YELLOWSTONE NATIONAL PARK SHOWING LOCATION OF CANYON VILLAGE QUADRANGLE AND PUBLISHED U.S. GEOLOGICAL SURVEY MISCELLANEOUS GEOLOGIC INVESTIGATIONS MAPS

Graphic from source map: [Canyon Village 15' Quadrangle]()

Rhyolite Flow Map



SMALL MAP OF CANYON VILLAGE QUADRANGLE SHOWING DISTRIBUTION OF QUATERNARY RHYOLITE FLOWS

Modified from "Geologic Map of Yellowstone National Park", (U.S. Geological Survey, 1972) and "Geologic Map of the Canyon Village Quadrangle, Wyoming", U.S. Geol. Survey Geol. Map GQ–1192, 1975

EXPLANATION

Letter symbols as in map explanation

Margin of flow

Inferred position of northeast rim of 600,000-year old caldera

See Description of Units page for this map to view information about geologic units shown on this graphic.

Graphic from source map: Canyon Village 15' Quadrangle

Map Legend

Graphic from source map: Canyon Village 15' Quadrangle

Stratigraphic Sections

Units separated by slashes are in descending order; numbers represent thickness in feet (meters). D indicates disconformity. Sections show distribution and stratigraphic relations of significant units vertically exposed and thus too small to be shown on the map.

Stratigraphic section locations are presented in the GRI Geologic Observation Localities (yellgol) feature class. In that feature class, the section identifier is stored in the Location ID (LOC_ID) field. The section information presented here is also contained in the Geologic Observation Localities (yellgol) feature class Notes (NOTES) field.

See Description of Units for information about map units listed here.

1. sh: 25 (7.6) ls/10 (3) pl, varved/15 (4.5) pt, containing gravel lenses/D/25 (7.6) ppl, deltaic/D/15 (4.6) pbsl, containing wood chips

2. sh: 3 (0.9) ls/10 (3) ta/20 (6) 1st, containing charcoal logs/8 (2.4) pmf, containing wood/8 (2.4) psg/1O (3) pt/D/5 (1.5) pbsl, containing soft wood chips/6 (1.8) pbl
3. sh: 5 (1.5) lst/15 (4.5) ls/10 (3) fd/15 (4.5) lsd/20 (6) pls/15 (4.5) psg/5 (1.5) pt
4. sh: 5 (1.5) ta/10 (3) lst/15 (4.5) pt, containing gravel lenses/D/30 (9) pbsl, containing soft wood chips/15 (4.5) pbl (section hydrothermally altered)
5. 10 (3) ls, hydrothermally altered/39 (11.9) gv-1, sand/16 (4.9) gv-2, silt/6 (1.8) gv-3, sand/5 (4.5) gv-4, silt, varved/30 (9) gv-5, sand/6 (1.8) gv-6, silt/32 (9.7) gv-7, sand/1.8 (0.5r gv-8, silt/3 (0.9) gv-9, colluvium/Rc, hydrothermally altered
6. 2 (0.6) ip, chalcedonic sinter/10 (3) ip, alluvial sand and silt, porcelainized/Rc, altered
7. 18 (5.5) rr-1, gravelly sand, channel crossbedding/10 (3) rr-2, gravelly sand, deltaic crossbedding/31 (9.4) rr-2, silt, deltaic crossbedding/5 (1.5) rr-2, pebbly sand/22 (6.7) rr-3, silt/3 (0.9) rr-3, sand/25 (7.6) rr-3, silt/5 (1.5) rr-3, talus containing gravel/Re, altered. Section silica cemented
8. 75 (23) rr-1, fine sand, pebbly coarse sand interbeds/10 (3) rr-1, silt, laminated/16.1 (4.9) rr-1, pebbly sand, thin silt interbeds/12 (3.6) rr-2, coarse to medium sand/14.3 (4.3) rr-2, coarse pebbly and fine sand/12.5 (3.8) rr-2, silt/2.3 (0.7) rr-2, coarse pebbly sand/5 (1.5) rr-3, fine sand/20 (6) rr-3, silt/4.5 (1.4) rr-3, fine sand and pebbly sand/5 (1.5) rr-3, silt/3 (0.9) rr-3, pebbly sand/4 (1.2) rr-3, boulder bed/5 (1.5) rr-3, pebbly sand/15 (4.6) rr-3, ta, gravelly/Re, altered.Section weakly silica cemented
9. 13 (4) bl; varved/D/uf: 13 (4) bslu, sand, fine, altered/13 (4) bll, varved silt, altered/6 (1.8) bsll sand, altered
10. 4 (1.2) bl, varved/2 (0.6) bsl/1 (0.3) br, containing erratics/D/uf: 5 (1.5) bslu
11. 3 (1) fill/1 (0.3) bl/0.5 (0.15) bsl, medium/1.5 (0.45) bsl, fine, pumiceous/1 (0.3) bl, pumiceous/0.7(0.2) pumice/0.8(0.24) bl, pumiceous/0.2-0.5 (0.06-0.15) zone of erratics/D/uf: 3.6 (1) bslu
12. 4 (1.2) bsl/3 (0.9) br, containing erratics/D/15 (4.5) bslu/D/75 (23) lf, diamicton/48 (14.6) lf, silt, laminated/D/rv--200 (rv--60) Rut
13. uf: 31.8 (9.7) bslu/7.3 (2.2) bil/4.4 (1.3) bisl/9.4 (2.8) bll/7 (2.1) bsll/0.6 (0.2) bgl/D/7.3 (2.2) s-bl/1.5 (0.5) s-bsg/D/10 (3) uf-111/0/6 (1.8)ufd/D/8 (2.4) uf-11/22 (6.7) uf-l/D/20 (6) lf, diamicton of sediments of Lower Falls
14. 15 (4.6) bgs, containing erratics/uf: 3 (0.9) bslu/15 (4.6) covered/5.5 (1.2) bslu/23 (7.0) bisl/9.6 (2.9) bsll/D/4 (1.2) s-bsl
15. uf: 6 (1.8) bsll/14 (4.3), covered/93 (28) cc, tuffaceous silt having thin sand and pebbly layers/ D/35 (10.6) Rc/D/20 (6) Rut
16. uf: 6 (1.8) bll/14 (4.2) bsll/D/8 (2.4) s-bl/D/15 (4.5) cc, obsidjan-boulder fan deposit/Re
17. 20 (6) pt/3 (0.9) bl/4.5 (1.4) pumice/20 (6) bl/30 (9) Rh
18. 15 (4.5) pt/5 (1.5) bl/75 (23) Rh/uf: 10 (3) bil
19. 5 (1.5) pt/20 (6) bl/40 (12) Rh/uf: 10 (3) bil
20. 0.5 (0.15) pgs/15 (4.5) pkl
21. 5 (1.5) lgs/15 (4.5) pdgs
22. 2 (0.6) fa/3 (1) pkl
23. 10 (3) pkgs/4 (1.2) bl
24. 6 (1.8) pgs/4 (1.2) pkl
25. 3 (1) fa/4 (1.2) bl
26. 2 (0.6) fa/6 (1.8) bl
27. 2 (0.6) fa/4 (1.2) bl
28. 4 (1.2) sg/3 (1) bl
29. 4 (1.2) bl/1 (0.3) bgu, erratics/10 (3) Rh/uf: 4 (1.2) bil/0.5 (0.1) bgl, erratics/18 (5.5) bsll, gravelly, faulted/22 (6.7) bsll, slumped and faulted/14 (4.3) s-bsl
30. 5 (1.5) pt/3 (1) bl/4 (1.2) bgu, erratics/20 (6) Rh/2 (0.6) pumice/uf: 4 (1) bi1/20 (6) bsll/2 (0.6) ogl, unsorted, silty, sandy, erratics/D/52 (15.8) bsll/25 (7.6) s-bsl
31. 6 (1.8) pkgs/7 (2.1) pt/D/12 (3.6) bl
32. 1.5 (0.45) pgs/5 (1.5) pkl
33. 20 (6) bl, varved/2 (0.6) bgu/D/uf: 30 (9) bil, altered
34. 20 (6) pfd, banked against/D/3 (0.9) pt/D/20 (6) bl, varved/0.5-2 (0.1-0.6) bgu, erratics, sandy/D/ uf: 30 (9) bil, altered

35. 4 (1.2) co/1.5 (0.45) pgs/27.3 (8.3) psl/5.5 (1.67) pl, varved/7 (2.1) pl, varved/6.6 (2) pl, varved/7.6 (2.6) pl, va rved/19 (5.8) psi
36. 2 (0.6) co/20 (6) pl, varved/15 (4.5) pt/6 (1.8) pgs/6 (1.8) bl
37. 5 (1.5) pt/D/12 (3.6) bgs/4 (1.2) bl
38. 40 (12) pl/30 (9) psl/50 (15) pt
39. 40 (12) covered/40 (12) psl/40 (12) pt
40. 10 (3) pl/20 (6) pgs/10 (3) pl, massive/D/20 (6) pl, varved
41. 40 (12) pl/15 (4.5) pt/10 (3) Ryt
42. 12 (3.6) pl/8 (2.4) pt/D/6 (1.8) bgs, cemented/5 (1.5) Ryt
43. 15 (4.6) psl/10 (3) pt
44. 10 (3) pl/8 (2.4) pt/D/4 (1.2) bt?, compact, cemented
45. 2 (0.6) co/40 (12) psl/3·0 (9) pl, deltaic, contains two thin volcanic-ash laminae separated by 0.5 in. (1.3 cm) silt/10 (3) pl, laminated/D/20 (6) pl, compact, varved/15 (4.6) pl, contorted
46. 40 (12) psl/10 (3) pt, striated stones/18 (5.5) Ryt, pumice breccia
47. 45 (13.7) psl/10 (3) pt/5 (1.5) pt, rusty, cemented/65 (19.8) Ryt, pumice breccia
48. 25 (7.6) psl/5 (1.5) pt/10 (3) pbsl, pumiceous/2 (0.6) bt/3 (1) Ryt
49. 30 (9) phl/D/50 (15) pl, compact, laminated
50. 12 (3.6) phl/D/12 (3.6) pl, compact, laminated
51. 3 (1) lsg, cemented/20 (6) phl/D/10 (3) pl
52. 18 (5.5) phl/D/5 (1.5) pl, laminated
53. 20 (6) phl/D/30 (9) pl
54. 3 (1) co/4 (1.2) gs/D/8 (2.4) sg, containing twigs
55. 20 (6) pks/D/30 (9) bsl/8 (2.4) bgu/D/uf: 35 (10.6) bsll, altered/30 (9) bgl, altered
56. 50 (15) phe/D/30 (9) psl/20 (6) pl/4 (1.2) pgs/D/3 (1) pbsl, pumiceous deltaic
57. 30 (9) pkg/D/20 (6) pbl
58. 20 (6) he (Turbid Lake)/0.2 (0.06) wood and charcoal/1 (0.3) pg/0.5-2.0 (0.15-6) pt/D/72 (22) pbgl/50 (15) b-pgl, covered/30 (9) bl
59. 15 (4.5) he/20 (6) pt/10 (3) pbgl/D/25 (7.6) bl
60. 10 (3) he/D/5 .(1.5) lst/3 (1) sg/1·5 (4.6) lgs, deltaic (section altered).
61. 15 (4.5) he/D/6 (1.8) pl
62. 2.5 (0.7) ds/33 (10) p.d s g, deltaic/30 (9) pl
63. 27 (8) pdsg, deltaic/3 0 (9) pl
64. 5 (1.5) pt/20 (6) pbl/5 (1.5) bkgs, pumiceous
65. 30 (9) pksg/0/20, (6) pbsl, gravelly/6 (1.8) pbsl, containing bluish crossbedded pumiceous layers/18 (5.5) bsl, silty, flat-bedded, local gravel lenses/6 (1.8) btu, containing interlayered gravel/D/5 (1.5) bisl/4 (1.2) bisl, pumiceous/4 (1.2) bil; laminated. (Entire section moderately cemented.)
66. 60 (18) pksg, cemented, interbedded with lake sand and silt lenses/40 (12) pt, cemented, erratics
67. 60.(18) pkgs, cemented/40 (12) pt, cemented
68. 12 (3.6) phe/30 (9), covered/15 (4.5) pkgs
69. 3 (1) co/40 (12) psl/18 (5.5) ph e/3 (1) pksl, a few cobbles of andesite and basalt/15 (4.5) pksl
70. 140 (42.7) phe/60 (43) pksl
71. 60 (43) phe/40 (12) pksl/10 (3) pt
72. 5 (1.5) co/15 (4.5) lgs/18 (5.5) covered/7.3 (2.2) pl, varved, contorted
73. 8 (2.4) es/0.25 (0.07) charcoal and humus/1 (0.3) co/0.7 (0.2) ds/3 (1) he (Squaw Lake)/10 (3) psl/0.5 (0.15) pl, varved, contorted/3 (1) phe (Mary Bay)/9 (2.7) pl, varved
74. 3 (1) es/0.25 (0.07) soil containing charcoal/2 (0.6) co/0.5 (0.15) humic clay/0.5 (0.15) oxidized sandy silt/8 (2.4) he (Squaw Lake)/15 (4.5) psi, containing charcoal 8.6 feet (2.6 m) below top/0.25 inches (0.7 cm) volcanic ash/2 (0.6) psl/3 (1) phe (Mary Bay)
75. 7 (2.1) es/0.5 (0.15) wood in humus/2 (0.6) co/4 (1.2) lgs/3.5 (1.06) he (Squaw Lake)/12.5 (3.8) psl (twigs at 8.5 (2.6) and 9.3 (2.8); mat of aquatic moss, Fontinalis sp., at 10.6 (3.2) below top)/5.5 (1.7) psl/3 (1) phe (Mary Bay)/9.3 (2.8) pl, varved
76. 3 (1) co/2 (0.6) lgs/3.5 (1.06) he (Squaw Lake)/18 (5.5) ps·I/0. 2 (0.06) organic lake mud intruded

by phe ·(M ary Bay)/1 (0.3) psl/5 (1.5) pl, varved, contorted
77. 4 (1.2) alluvial sand/11 (3.3) sg/5 (1.5) psl/10 (3) pl, varved/2 (0.6) psl/5 (1.5) pt
78. 2 (0.6) co/1 (0.3) gs/13.5 (4.1) pl, containing thin sands/0.5 (0.15) psi, pumiceous/1.5 (0.45) psl/ D/16 (4.9) pbl, compact, laminated/1.4 (0.4) pumice containing obsidian grains/11 (3.3) pbl, compact, laminated, carbon films
79. 2 (0.6) co/0.9 (0.27) ds/8 (2.4) pl/2 (0.6) plsg/9.3 (2.8) pl/4 (1.2) psl/1.5 (0.45) psi, pumiceous/3.5 (1) psl/0.6 (0.2) psi, pebbly/1 (0.3) psl/D/8.5 (2.6) pbl, compact, laminated/1.5 (0.45) pumice containing obsidian grains/7.5 (2.3) pbl, compact, laminated, carbon films
80. 3 (1) co/2 (0.6) lsg/8 (2.4) pt/10 (3) pbl/12 (3.6) pbsl/8 (2.4) bl, varved, contorted, contains erratics and lenses of till (btu)
81. 3 (1) pg/8 (2.4) psil/6 (1.8) pl, varved/3 (1) pt/0.5 (0.15) pbl, in interstices of flow breccia (Re)
82. 3 (1) co/4 (1.2) lsg/4 (1.2) lsg, cemented/14 (4.3) plsg, deltaic.
83. 2 (0.6) co/1 (0.3) ds/10 (3) pl1 va·rv ed/3 (1) pt, lacustral
84. "2 (0.6) ds, silty, peaty/1 (0.3) lgs/15 (4.5) pl, varved/2.5 (0.7) pt. ·"
85. 4 (1.2) pgs/40 (12) plsg, deltaic
86. 2 (0.6) lgs/25 (7.6) psi, deltaic
87. 2 ('0.6) lgs/25 (7.6) plsg/1 5 (4.5) pl, varved
88. 3 (1) lgs/30 (9) plsg, deltaic/10 (3) pl, varved
89. 3 (1) lgs/20 (6) plsg, deltaic/1O (3) pt
90. 3 (1) lgs/8 (2.4) pl/25 (7.6) plsg
91. 5 (1.5) lgs/35 (10.6) pl
92. 4 (1.2) lgs/5.5 (1.2) psi, laminated/0.015 (0.004) volcanic ash/0.5 (0.15) psl/3 (1) pl, varved
93. 4 (1.2) es/30 (9), pksJ/6 (1.8) pt
94. 3 (1) pl/1 (0.3) pt
95. 3 (1) plsg/12 (3.6) pksl/5 pt
96. 6 (1.8) es/3 (1) co/35 (10.6) pksl/4 (1.2) pt
97. 5 (1.5) co/0.5 (0.15) humus containing charcoal/2 (0.6) co/3 (1) pksl
98. 1 (0.3) co/5 (1.5) Jsg/6 (1.8) plsg

Text from source map: Canyon Village 15' Quadrangle

References

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References from source map: Canyon Village 15' Quadrangle

Eagle Peak 15' Quadrangle

The formal citation for this source.

Richmond, Gerald M., and Pierce, Kenneth L., 1972, Surficial Geologic Map of the Eagle Peak Quadrangle, Yellowstone National Park and adjoining area, Wyoming: U.S. Geological Survey, Miscellaneous Investigations Series Map I-637, scale 1:62,500 (*GRI Source Map ID 1138*).

Description of geologic units, prominent graphics and text associated with this source.

Description of Units

lst - Lake silt (Quaternary, Neoglaciation)

Humic silt at edge of modern Yellowstone delta, and at site of small Holocene lake dammed by avalanche debris near East Entrance (stratigraphic section 23). Similar to fine-grained humic alluvium (fa) but of lacustrine origin.
Eagle Peak Stratigraphic Sections

lsg - Lake sand and gravel (Quaternary, Neoglaciation)

Gray to tan sand and gravel forming present and past beaches of Yellowstone Lake, up to and including the 25-foot shoreline. Deposits well sorted, commonly crossbedded. Gravel mostly well rounded. Some deposits lie on wave-cut benches cut in older ice-dammed lake deposits (pkl) or on rock; others form constructional features such as spits and bars that locally retain lagoons.

gt - Till and rock glacier, till (Quaternary, Neoglaciation)
tt - Till and rock glacier, till (Quaternary, Neoglaciation)

Forms moraines in north- and east-facing cirques in Absaroka Range. Consists of angular to subangular fragments in fine-grained silty matrix; unsorted, nonstratified, buff to gray. Moraines of Gannett Peak Stade (gt) are fresh and bear little or no vegetation, except lichens. Moraines of Temple Lake Stade (tt) are very slightly weathered, grass covered, and locally forested, and commonly are partly covered by talus and avalanche debris from the cirque headwall.

grg - Till and rock glacier, rock glacier (Quaternary, Neoglaciation)
trg - Till and rock glacier, rock glacier (Quaternary, Neoglaciation)

Glacier-shaped tongue of angular to subangular rock debris that heads against steep cirque headwall; composed mainly of dense intrusive rocks. Material at surface open textured; silty matrix at depth. Surface displays flow ridges and furrows arcuate downslope. Frontal slopes steep; commonly more than 50 feet high. Deposits of the Gannett Peak Stade (grg) are fresh and barren, and have active fronts. Deposits of the Temple Lake Stade (trg) are inactive and locally forested. Fragments at surface are slightly weathered, and interstitial voids are locally filled with humic debris.

fa - Fine-grained humic alluvium (Quaternary, Neoglaciation)

Silt, sand, and clay in a seasonally marshy environment. Underlies flood plain and delta of Yellowstone River, poorly drained meadows along streams, kettles, and old lagoons on kame or lake terraces, and small glacial depressions on uplands. In most areas deposition seasonally active. Charcoal in the lower part of a 5-foot section (stratigraphic section 20) of tan sandy silt, 1.3 miles southwest of Grizzly Peak, has a C-14 age of 3,100±250 years (sample W -2003; Meyer Rubin, written commun., 1968).
Eagle Peak Stratigraphic Sections

sg - Stream gravel (Quaternary, Neoglaciation)

Gravel with coarse sand matrix in stream beds and terraces less than 30 feet above Yellowstone River and larger creeks. Deposits include lenses of sand and finer grained material; they are gray to tan, well sorted, and well bedded. Gravel is well rounded, mostly less than 3 inches in diameter. In valley of Middle Creek, near East Entrance, sand and gravel fill over bedrock is more than 100 feet thick.

fg - Fan gravel (Quaternary, Neoglaciation)

Alluvial fan gravel, tan to gray, subrounded to subangular, moderately sorted, and crudely bedded. Contains lenses of sand and silt. Boulders abundant at head of deposit which commonly grades upstream into avalanche debris in upper valleys and cirques. Distal sector of deposits commonly silty.

ta - Talus deposit (Quaternary, Neoglaciation)

Angular to subangular rock fragments underlying steep slopes at base of cliffs. Interstices void at surface but filled with silty matrix at depth. Thickness 5-50 feet; deposits commonly accumulating above 9,000 feet altitude at present; unstable. Vegetation commonly absent except for lichens.

tf - Talus-flow deposit (Quaternary, Neoglaciation)

Material same as talus, but forms a lobate, arcuate ridge, 5-20 feet high, at toe of a talus; formed by downslope flow.

fr - Frost rubble (Quaternary, Neoglaciation)

Thin mantle of angular to rounded clasts of andesite and, locally, basalt in silty matrix. Weathered from bedrock, moved slightly downslope and vertically mixed by frost action. Thin humic azonal soil. Commonly occurs on upland above timberline. Where formed from massive rock, material is angular, contains little matrix, and is sparsely vegetated; where formed from poorly consolidated conglomeratic bedrock, it is rounded to angular, contains abundant matrix, and is commonly covered with alpine turf. Though locally seasonally active, most deposits are stable, some since Pinedale time.

rb - Block rubble (Quaternary, Neoglaciation)

Large angular blocks forming barren open rubble. Single deposit mapped on toe of landslide on west side of ridge separating south fork of Middle Creek from Cabin Creek.

ad - Avalanche debris (Quaternary, Neoglaciation)

Rounded to angular debris in a muddy matrix forming fan-shaped or lobate deposits. Occurs below cliffs at base of avalanche chutes. Deposits unsorted to poorly sorted, crudely bedded, tan to gray, locally very bouldery. In places gradational headward into talus and downslope into fan gravel. Locally characterized by torrent and alpine mudflow levees. Includes debris transported by torrential runoff, mudflow, slushflow, and snow avalanche.

sd - Solifluction deposit (Quaternary, Neoglaciation)

Buff coarse to fine stony sandy silt; unsorted and unsized. Forms lobes 15-20 feet high on lower valley walls of Beaverdam and Howell Creeks where saturation of lake silt under gravel in steep terrace fronts has caused flowage out over outwash gravel (pgu) of late stade of Pinedale Glaciation. On east side of Signal Hills, deposit is derived from glacial deposits and frost rubble.

ls - Landslide deposit (Quaternary, Neoglaciation)

Lobate masses of rubble or gravel in a muddy matrix. Includes slumped colluvium and alluvium on high bench west of East Entrance, slumped bedrock at head of the south fork of Middle Creek, and slumped kame deposits east of the delta of the Yellowstone River.

es - Eolian sand (Quaternary, Neoglaciation)

Brown fine sand forming dunes 10-15 feet high along modern shoreline at west edge of Yellowstone River delta. Massive to crossbedded; mostly stable; supports grass and a few trees; locally active in fresh blowout areas.

ptu - Till and rock glacier, till (Holocene and/or Pleistocene)

Subangular to subrounded rock fragments in gray-brown to gray, fine-grained silty matrix; unsorted, unsized, and nonstratified. Boulders as much as 1 foot in diameter common on surface. End moraines mark outer limit of late stade of Pinedale Glaciation, are commonly 10-40 feet high. On upper Beaverdam Creek (stratigraphic section 12) the till matrix is a dark, locally bedded stony silt, suggesting deposition in water. Along Columbine, Beaverdam, and Trappers Creeks, the till rests on kame deposits of middle Pinedale age. Moraines are commonly forested and covered with forest litter. Brown podzolic soil is weakly developed, and about 1.5 feet thick.

Eagle Peak Stratigraphic Sections

prgu - Till and rock glacier, rock glacier (Holocene and/or Pleistocene)

A rock glacier of the late stade of Pinedale Glaciation about 0.75 mile long lies in the south-facing cirque between Avalanche and Hoyt Peaks in the northern part of the quadrangle. It displays large collapse features probably associated with melting of a former ice core. Its frontal slope is several hundred feet high. Deposit similar to Neoglacial rock glaciers, but surface is locally well forested and mantled by silty humic soil.

pgu - Outwash gravel (Holocene and/or Pleistocene)

Coarse crudely sorted and weakly bedded outwash gravel underlying terraces that locally extend to moraines of late stade of Pinedale Glaciation. Thickness 20-40 feet. Deposits overlap or are entrenched into kame deposits of the middle stade along Howell, Trappers, Beaverdam, Rocky, and Columbine Creeks. At mouth of Beaverdam Creek, deposits are graded to beach deposits of 60-to 65-foot level of Yellowstone Lake.

plsg - Lake sand and gravel (Holocene and/or Pleistocene)

Gray to tan sand and gravel forming beaches of former open-water levels of Yellowstone Lake 60-65 and 45 feet above present lake level. Crossbedded; well sorted; but with textural variation both vertically and horizontally. Some deposits lie on benches wave-cut in older ice-dammed lake deposits (pkl) or on rock. Others form con-structural features such as spits and bars that locally retain lagoons, especially at the 60- to 65-foot former shoreline.

pg - Gravel, outwash and stream gravel (Holocene and/or Pleistocene)

Underlies meander-scarred terraces more than 25 feet above Yellowstone River near Trail Lake, and small terrace remnants along Beaverdam and Columbine Creeks. Lithology and texture similar to Neoglacial gravel. Probably mostly of late Pinedale age, but not physically connected with moraines of late stade.

pfg - Gravel, fan gravel (Holocene and/or Pleistocene)

Similar to Neoglacial fan gravel, but incised 25-50 feet by streams. At head of Beaverdam Creek, associated with outwash and moraines of late Pinedale age. At mouth of Columbine Creek, similar to other alluvial fans but built into ice-dammed lake.

pco - Colluvium (Holocene and/or Pleistocene)

Colluvial mantle on moderate slopes above upper limit of Pinedale ice in northeast part of quadrangle. Consists of slabs and subrounded boulders in a tan silty matrix. Thickness 2-20 feet; commonly 10 feet. Mostly stable and supporting open forest vegetation.

pta - Talus deposit (Holocene and/or Pleistocene)

Similar to Neoglacial talus (ta), but inactive and mostly forested or grass covered; includes some frost rubble and colluvium on steep slopes. Occurs at lower elevations than Neoglacial talus and laterally beyond the limits of that talus in cirque basins. Especially abundant on steep rocky slopes of canyons east of crest of Absaroka Range.

pkl - Ice-dammed lake deposits, lake silt (Holocene and/or Pleistocene)

Ice-dammed lake silt and sand—Light-tan to gray, massive to thinly laminated lake silt (01) deposited in embayments and lagoons of ice-dammed lake. Unit mapped 1.5 miles west of Trail Creek Patrol Cabin. Also occurs in stratigraphic sections 3, 6, 7, 8, 12, and 14 along Trappers Creek, Beaverdam Creek, and Rocky Creek. On Rocky Creek (stratigraphic section 14) humic silty clay in this unit yielded a radiocarbon age of 13,140±700 years (sample W -2037; Meyer Rubin, written commun., 1969). Gray to tan, massive to evenly bedded, well-sorted, medium-grained, ice-dammed lake sand (pksl), observed in stratigraphic sections 6, 7, 8, and 13 only.
Eagle Peak Stratigraphic Sections

pklb - Ice-dammed lake deposits, lake beach deposit (Holocene and/or Pleistocene)

Gravelly to sandy beach deposits and gray to buff lacustrine sand and gravel of ice-dammed lakes and ponds 240, 220, 180, 135, 110, 90, and 75 feet above Yellowstone Lake. Beach deposits, commonly 5-15 feet thick, lie on wave-cut platforms cut in ice-dammed lake sand and silt or on rock; locally forms only a veneer on rock.

pkg - Kame deposit, gravel (Holocene and/or Pleistocene)
pksg - Kame deposit, sandy gravel (Holocene and/or Pleistocene)
pkgs - Kame deposit, gravelly sand (Holocene and/or Pleistocene)

Buff to gray sand and gravel forming kame terraces with ice-contact frontal scarps and irregularly benched upper surfaces. Commonly between elevations of 8,480 and 7,840 feet (110-750 feet above Yellowstone Lake). Deposits are 20-100 feet thick, and are most extensive in valleys tributary to Yellowstone Lake. They are moderately well sorted, but abrupt vertical changes in grain size are common. Bedding is uneven and locally dips steeply in several directions over a small area. The sand is commonly coarse grained and subangular; the gravel commonly rounded and less than 6 inches in diameter. Some deposits include lenses of lake silt and sand. Locally they contain or are mantled by poorly sorted units such as mudflow debris, solifluction debris, and till. In the upper section of Rocky Creek lake silts, locally containing mollusk shells, occur at the upstream end of the kame terrace deposits.

pt - Till and rubble veneer, till (Holocene and/or Pleistocene)

Subangular to subrounded andesite rock fragments in gray compact silty matrix; unsorted, unsized, and nonstratified; 0-10 feet thick on uplands and upper slopes, 10-15 feet thick on lower slopes. Local morainal form. Some stones striated and glacially shaped; most have same shape as stones in local bedrock. Deposits in part moved downslope by colluvial processes; contain nonglacial accretions of weathered bedrock. Brown podzolic soil on till is weakly developed and 1-1.5 feet thick. South of Middle Creek, in northeast corner of the quadrangle, well-defined moraines occur on bench 500-1,000 feet above local drainage. Well-defined moraines also border kame gravel deposits (pkg) near Sylvan Lake. Along upper Beaverdam Creek (stratigraphic section 13), Columbine Creek (stratigraphic section 18), and Clear Creek (stratigraphic section 21), the till consists of scattered stones, some striated, in a massive, blocky, locally bedded dark-gray silt that appears to have been deposited under water.
Eagle Peak Stratigraphic Sections

pr - Till and rubble veneer, rubble veneer (Holocene and/or Pleistocene)

Thin mantle (0-5 feet) of rubble in a silty matrix; mantles hills east of Yellowstone Lake. No striated stones found and no striations found on small outcrops included with deposits as mapped. However, the hills were covered by Pinedale ice to depths of at least several hundred feet, and much of the surficial debris was probably deposited by ice filling against slopes with no scouring action. Deposits probably moved downslope by solifluction and frost action during and after deglaciation.

ppl - Proglacial lake silt (Holocene and/or Pleistocene)

Moderately compact greenish-gray to brown silt mapped along Clear Creek. Also noted in stratigraphic sections 2, 5, 9, and 21, beneath Pinedale Till. Commonly poorly exposed, but indicated by seepage zone at top of lake silt and by landsliding of overlying units. Along Clear Creek, deposit is more than 25 feet thick and consists of a lower well-bedded sandy unit and an upper massive silt unit. Ice-rafted pebbles, including obsidian, common in upper part; material grades upward into clayey Pinedale Till.

Eagle Peak Stratigraphic Sections

bl - Lake sediments (Pleistocene)

Bluish-gray, weathering pinkish brown, compact dense thinly laminated silt, varved silt, or megavarved silt interspersed with beds of silt and fine sand. A few ice-rafted striated stones. Local beds of massive silt or fine sand, 6 inches to 2 feet thick. In stratigraphic section 8, the upper part of the lake sediment includes thin laminae of fine sand containing scouring rush (*Equisetum*) and small corn-pressed branches or twig fragments; a log from this zone dated >42,000 years B. P. (sample W-2197; Meyer Rubin, written commun.,1968). Laminated beds along Beaverdam Creek dip 5° W. Top marked by erosion bench beneath overlying less-consolidated Pinedale deposits.

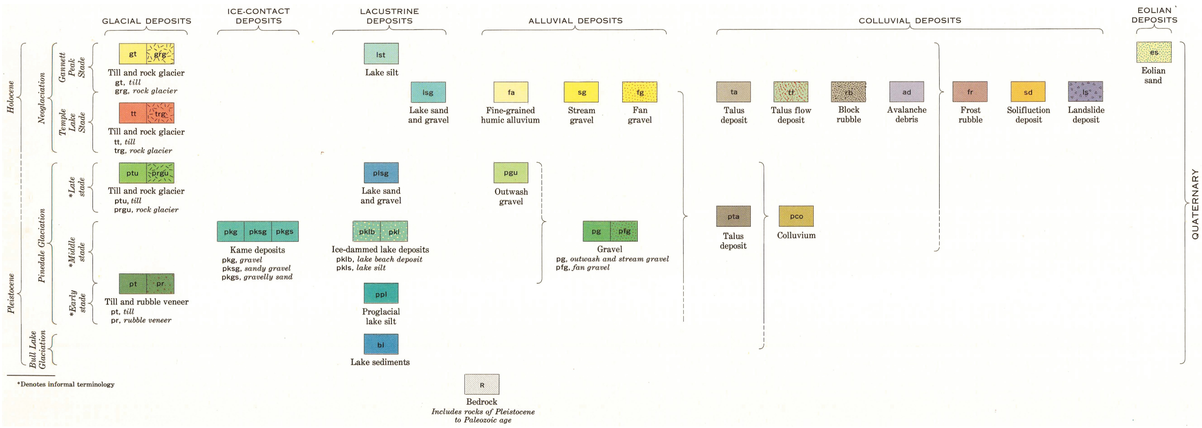
Eagle Peak Stratigraphic Sections

R - Bedrock (Pleistocene to Paleozoic)

(The following is based on unpublished data supplied by H. W. Smedes and H. J. Prostka, oral commun., 1969.) Yellowstone Tuff of Pleistocene age underlies most of the lowlands in the Clear Creek-Cub Creek drainage and a minor area in the Columbine Creek drainage. The rest of the quadrangle is underlain by lower Tertiary rocks of the Absaroka volcanic field. The oldest unit crops out below an altitude of 8,500 feet in the northeast corner of the quadrangle, and consists of several basalt flows interbedded with conglomerates containing roundstones of andesite and basalt. Resting on this unit, and underlying most of the area of the quadrangle, are crudely bedded andesitic rocks of the vent facies of the Absaroka volcanic field and a lesser amount of well-bedded andesitic rocks of the alluvial facies of the Absaroka volcanic field. Plugs of rhyodacite, some half a mile or larger in diameter, surrounded by contact zones of hornfels, form many of the peaks along and near the divide that forms the eastern boundary of the Park. Abundant andesite dikes occur in the northern and northeastern third of the quadrangle. A body of granodiorite in the upper part of Clear Creek is largely covered by Yellowstone Tuff and Pinedale Till.

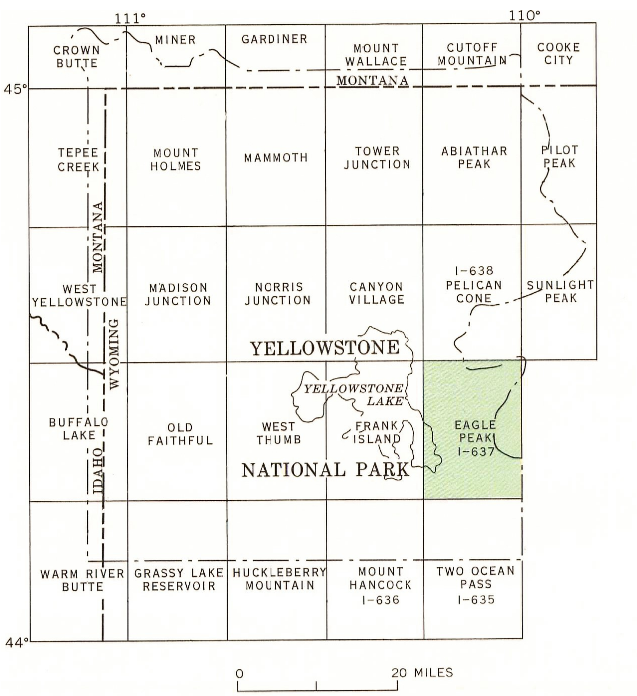
Text from source map: Eagle Peak 15' Quadrangle

Correlation of Units



Graphic from source map: Eagle Peak 15' Quadrangle

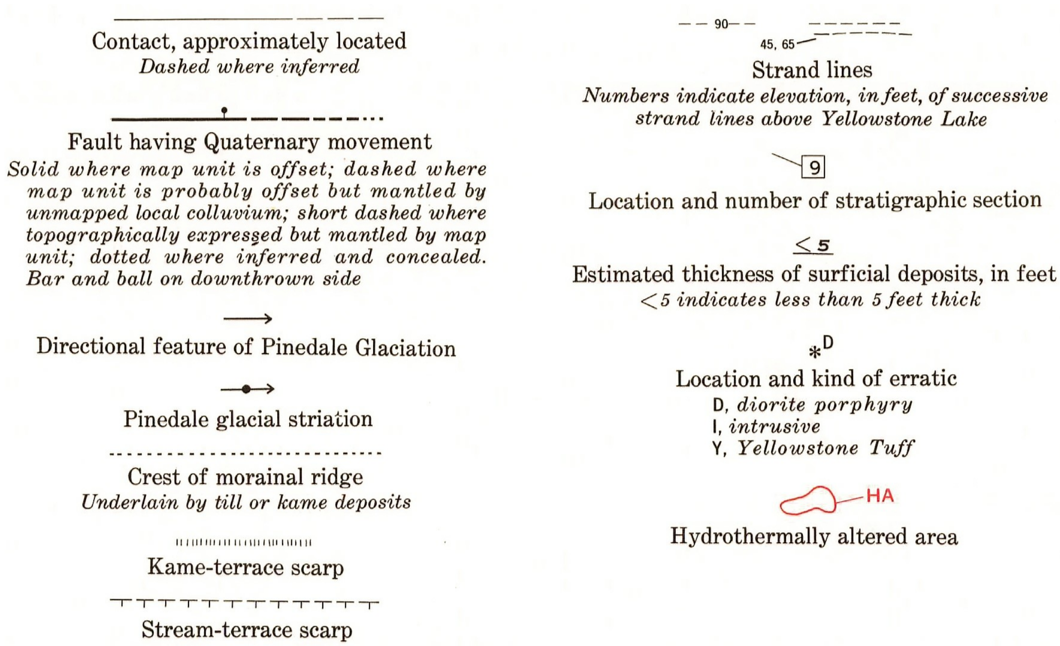
Index Map



INDEX MAP OF YELLOWSTONE NATIONAL PARK SHOWING LOCATION OF EAGLE PEAK QUADRANGLE AND PUBLISHED MISCELLANEOUS GEOLOGIC INVESTIGATIONS MAPS

Graphic from source map: Eagle Peak 15' Quadrangle

Map Legend



Graphic from source map: Eagle Peak 15' Quadrangle

Stratigraphic Sections

Units shown in descending order; numbers denote thickness, in feet.

Stratigraphic section locations are presented in the GRI Geologic Observation Localities (yellgol) feature class. In that feature class, the section identifier is stored in the Location ID (LOC_ID) field. The section information presented here is also contained in the Geologic Observation Localities (yellgol) feature class Notes (NOTES) field.

See Description of Units for information about map units listed here.

1. Yellowstone River 8sd /40bl /0.25va[1] /75bl
2. Trappers Creek 10st[2] /20pgu /20pl with 0.3va[1] /40pkgs /25pt /15ppl /30bg
3. Trappers Creek 10pkg /20pkl /25pt /25bg(?) /20bt(?)
4. Beaverdam Creek 6 sd /5pgu /35pksg
5. Beaverdam Creek 15pt /15pp1 /30ppls /40ppg /40 bl
6. Beaverdam Creek 25pksg /30pkl /20pksl /30pksg /24 pksl /20bl
7. Beaverdam Creek 40pksg /15pksl /45pkl /30bl /50bg
8. Beaverdam Creek 15pkgs /20pksg /15pksl /30pkl /20bl /40bg
9. Beaverdam Creek 12pt /11ppl /25ppg /18ppl /30ppg /14ppl /30bl
10. Beaverdam Creek 12ptu /40pksg
11. Beaverdam Creek 30ptu /50pksg
12. Beaverdam Creek 4pkl /45ptu /4pkl /20pt
13. Beaverdam Creek 4pkl /7pksg /20pt /3pksl /30pt
14. Rocky Creek 10st[2] /25pgu/10pkl/20pkgs/10pt
15. Middle Creek 30pkg /40pt

16. Alluvium Creek	10fa /10sg /5p[3]
17. Brimstone Basin	15pt /20bg
18. Columbine Creek	10ptu /10pt /10bl(?)
19. Columbine Creek	20pt /10bg
20. Signal Hills	4fa /0.15c[4] /1fa/>2sg
21. Clear Creek	25pt /25pp1
22. Cub Creek	15pt /10bg /15bt(?)
23. Middle Creek	5lst /0.5w[5] /3sg

[1] Volcanic ash.
[2] Gray silt of late Pinedale or younger age.
[3] Peat.
[4] Charcoal.
[5] Wood.

Text from source map: Eagle Peak 15' Quadrangle

Surficial Geologic History

INTRODUCTION

The Eagle Peak 15' Quadrangle is southeast of Yellowstone Lake in Yellowstone National Park and adjacent parts of Shoshone National Forest. The terrain comprises the southeastern shore of Yellowstone Lake (elev. 7,733 feet), including the delta of the Yellowstone River, and the Absaroka Range to the east. The Absaroka Range consists of a western zone of foothills dissected by broad valleys, a central high rugged glaciated crest cut by numerous cirques, and an eastern zone of deep U-shaped glaciated valleys separated by high cliffed ridges. The crest of the Absaroka Range attains altitudes between 10,000 and 11,350 feet. Individual peaks rise 2,500-3,000 feet above adjacent canyon floors.

PLEISTOCENE GLACIATION

During at least three Pleistocene glaciations (from oldest to youngest: pre-Bull Lake, Bull Lake, and Pinedale), great icecaps covered most of Yellowstone Park. In this quadrangle, no deposits or erosional features of the pre-Bull Lake glaciation have been found. Evidence of Bull Lake Glaciation is scanty but, together with that from other areas of the Park, indicates that Bull Lake Glaciation was somewhat more extensive than Pinedale Glaciation for which abundant evidence as to character and extent is preserved.

BULL LAKE GLACIATION

Bull Lake glacial deposits are limited to a few exposures (stratigraphic sections 3 and 22) where compact gray till is overlain by poorly sorted, irregularly bedded gravel of probable ice-contact origin, which in turn is overlain disconformably by till (pt) of Pinedale age and associated deposits. The extent of Bull Lake ice could not, therefore, be determined from observations in this quadrangle. At other exposures (stratigraphic sections 7, 8, and 19) gravel (bg) of Bull Lake age grades upward into compact blue-green lake silt, overlain disconformably, by Pinedale deposits. At these and still other exposures (stratigraphic sections 5, 6, and 9) the lower part of the Bull Lake lake deposits is thickly varved to thinly laminated and contains striated stones, probably ice-rafted. Thus, the lake probably formed during recession of Bull Lake ice. However, the upper part of the lake deposits at some exposures (stratigraphic sections 1, 8, and 9) is not varved and contains wood fragments (stratigraphic section 8), inter-layered thin mats of scouring rush (Equisetum), and carbon films of probable algal origin. These organic materials suggest that the lake existed during the interval between the Bull Lake and Pinedale Glaciations. Wood from stratigraphic section 8 has a radiocarbon age of > 42,000 years (sample W - 2197; Meyer Rubin, written commun., 1968).

East of the Continental Divide, the upper or more eastward part of some of the deposits mapped as Pinedale Till may be of Bull Lake age.

PINEDALE GLACIATION

Early in Pinedale time, valley glaciers descended from the high parts of the Absaroka Range southeast of the quadrangle and coalesced in the valley of the Yellowstone River into a single large glacier which flowed northwest into the basin of Yellowstone Lake. Here the ice formed a center for snow accumulation and enlarged gradually, encroaching into the valleys and over the foothills east of the lake until it ultimately overflowed the crest of the Absaroka Range at altitudes of 10,000-10,500 feet. Evidence for this is preserved in valleys east of the lake where thick deposits of proglacial gravel and lake silt, formed in ponds dammed by ice downstream, are overlain by clayey Pinedale Till derived from the lake basin and containing local erratics of light-gray coarse-grained diorite porphyry. This porphyry is not known in the drainage to the east and was probably derived from the headwaters of the Yellowstone River. In the upper sectors of the valleys, the till is of local origin, showing that descending valley glaciers met ice building up in the basin in the middle sectors of the valleys. Further evidence of buildup of the basin ice is found on the uplands east of the lake which are covered with a thin mantle of locally derived glacial rubble (pr) but lack grooves or striae indicative of downslope glacial scour. At the glacial maximum, the ice over the east side of the lake basin and in the valley of the Yellowstone River was at least 3,000 feet thick. Saddles, cirque headwalls, and some summits along the crest of the range have been scoured by ice flowing east across the divide, and thin deposits of till containing erratic fragments from the west occur on the divide and to the east where ice flowing across the divide merged with local glaciers. In Sylvan Pass, ice more than 1,000 feet thick flowed eastward into the drainage of Middle Creek. Though no terminal moraines were recognized in this valley, lateral moraine crests about 3.5 miles upstream from East Entrance, near altitude point 8570, slope upstream into the south fork of Middle Creek and show that the ice from Sylvan Pass flowed at a higher level than the ice in the valley of the south fork.

A recession from the outermost moraines of the early Pinedale maximum and a subsequent readvance in middle Pinedale time is suggested by a sequence of end moraines near the confluence of Middle Creek with its south fork, and in the valley north of Arthur Peak.

Stagnation of the Pinedale icecap.

- At the end of middle Pinedale time, shrinking of the icecap gradually exposed first the crests and then the foothills of the Absaroka Range. Melt water temporarily drained across the rock floor of Sylvan Pass (now covered by about 70 feet of talus), about 740 feet above present Yellowstone Lake, and cut about 40 feet into bedrock along the drainage immediately to the east. Subsequently, the cap appears to have separated from local glaciers in the upper valleys. Kame terrace deposits of fluvioglacial gravel and interbedded local silt, built against an ice front receding downstream, occur as high as 8,480 feet altitude (750 feet above Yellowstone Lake) on Clear Creek, as high as 8,400 feet altitude (670 feet above Yellowstone Lake) on Columbine Creek, Beaverdam Creek, Cabin Creek, and Trappers Creek (locally 8,640 feet), and as high as 8,300 feet altitude (570 feet above Yellowstone Lake) on Howell Creek. The kame terraces extend downslope as low as 7,840 feet altitude (110 feet above Yellowstone Lake), indicating that the ice margin was lowered 460-660 feet during deposition. As many as six different terraces have been observed in places; most are discontinuous.

Along Rocky Creek, 350 feet above Yellowstone Lake, peaty ice-contact lake sediments (stratigraphic section 14) overlying kame sand and gravel deposited during middle Pinedale deglaciation has a radiocarbon age of 13,140± 700 years B.P. (sample W-2037; Meyer Rubin, written commun., 1969).

Ice-dammed lake deposits of interbedded sand, gravel, and silt occur below the kame terraces at the canyon mouths and extend along the slopes of the foothills between canyons. The upper limit of these lake deposits ranges from 7,970 feet altitude (240 feet above Yellowstone Lake) to 7,840 feet (110 feet above the lake). These deposits indicate that ponded waters opened along the ice margin earlier in some places than in others. Lake beaches formed as the ice front lowered and ponded waters became more continuous along the ice margin. The beaches occur discontinuously at the following heights in feet above present lake level: 240, 220, 180, 135, 110, 90, and 75 to 80 (heights measured by hand level). The 110-foot level is the most continuously developed.

A lower terrace, 60-65 feet above the lake, is also extensively developed. The deposits of this terrace are characterized by large spits, bars, and enclosed lagoons (for example, north of Columbine Creek), that are indicative of strong longshore currents found only in a large and long-lived body of open water. This terrace is believed to represent the level at which the lake became free of ice.

Late Pinedale readvance.

- A readvance of the glaciers from north-and northeast-facing cirques in the Absaroka Range occurred in late Pinedale time. Headwalls of cirques thus reoccupied were sharpened and steepened by the ice. End moraines (ptu) in the valleys show that the glaciers were 1-4 miles long. The average altitude of the end moraines is 8,560 feet. A single rock glacier, more than half a mile long, and having a steep front at least 200 feet high, lies in the cirque southeast of Avalanche Peak. The end moraines and their outwash gravel deposits (pgu) overlie or are entrenched into kame terrace deposits (pkg) of middle Pinedale age, for example, on Beaverdam Creek, Trappers Creek, Columbine Creek, and Howell Creek. Out-wash from the moraines is graded to the beach deposit of the 60-foot lake level at the mouth of Beaverdam Creek, and indicates correlation of the advance with the younger deposits of this lake level.

Pinedale frost riving and solifluction.

- As the Pinedale icecap wasted, frost-riving of freshly exposed cliffs formed extensive talus deposits (pta), now preserved beyond the limits of Neoglacial talus in cirques and along canyon walls. In many places the material is mixed with glacial debris washed or slumped from steep slopes. The deposits are more widespread on the slopes of the deep canyons east of the crest of the Absaroka Range than in the more open valleys to the west. Talus formation appears to have continued until after the recession of the late Pinedale glacial readvance. The deposits are now stable and forested. It is probable that some upland frost rubble deposits (fr), mapped as Neoglacial in age, include deposits of Pinedale age.

NEOGLACIATION

After recession of the late Pinedale valley glaciers, cirques were empty and slopes throughout the quadrangle were relatively stable during what is known as the Altithermal interval. Subsequently, during what is known as the Neoglaciation, small ice masses less than half a mile long formed below the north and northeast facing parts of many cirque headwalls, and deposited moraines or rock glaciers in the upper parts of the cirque basins. However, many cirques occupied by late Pinedale glaciers were not reoccupied or were only in part reoccupied in Neoglacial time.

The moraines of Neoglacial age commonly mark two advances. Till (tt) of the older advance, known as the Temple Lake Stade, underlies stable moraines or rock glaciers (trg) partly covered by vegetation. Their average altitude is 9,430 feet. Till (gt) of the younger advance, known as the Gannett Peak Stade, lies upslope from the older, and is characterized by fresh blocky moraines and rock glaciers whose average altitude is 9,760 feet. More Neoglacial moraines occur east of the range crest than west of it. Some cirques occupied by Temple Lake ice were not reoccupied in Gannett Peak time. During neither stade did the ice extend beyond the cirque lips, and in some instances it was restricted to the cirque headwalls. Very little cirque headwall modification was effected.
Two small glaciers occur east of the range crest—one on the north face of Eagle Peak, the other north of Avalanche Peak.

LOWERING OF YELLOWSTONE LAKE

Below the 60-foot lake terrace ,whose deposits represent the oldest open-water stage of Yellowstone Lake, are at least seven successive lower lake terraces, represented by beach deposits, deltas, spits, bars, lagoons, and terraces cut on rock. They occur discontinuously around the lake at the following levels in feet above the lake: 45, 35, 25, 20, 15, 10, and 5. Those at 45, 25, and 10 feet are the most prominent. Although some deposits, such as the spits, bars and deltas in the vicinity of Columbine Creek, are entirely of depositional origin, and others are cut on bedrock, some are cut on Pinedale ice-dammed lake deposits (pkl) which extend beneath the terrace deposits to points below present lake level in several places. The stratigraphic relation of these terrace deposits to glacial deposits is unknown, except that they are younger than the maximum late Pinedale advance. Deposits (plsg) of the 45- and 35-foot terraces are thought to be of late Pinedale age; those of lower terraces (lsg) of altithermal or Neoglacial age. Lowering of the lake appears to have been controlled by erosion of the outlet.

NEOGLACIAL FROST ACTION, SOLIFLUCTION, AND AVALANCHE ACTIVITY

Frost-riving in Neoglacial time produced extensive deposits of talus below cirque headwalls and cliffed slopes, especially east of the Absaroka Range crest. These deposits are much less extensive than those of Pinedale age. They are gradational downslope into avalanche debris (ad), which also forms at the foot of cliffs where talus is lacking. Avalanche debris tends to be the product of transport by avalanche processes, debris avalanche, mudflow, nivation wash, and torrential floods rather than simply transport by gravity as is talus. Talus flow deposits (tf), which are ridges of debris resulting from the downslope flowage of the toe of a talus, occur in a few places, for example, west of Mount Doane and northeast of Hoyt Peak.

Frost rubble (fr) is widespread on the summit uplands. Some is locally active; some is of Pinedale age. A few deposits have formed in situ; many have moved downslope. Most are barren and of blocky to rubbly material.

Neoglacial solifluction deposits occur primarily in two settings. Some are in the form of lobes of debris with fronts as much as 20 feet high that have flowed from the valley walls out over outwash terrace deposits of late Pinedale age on the valley floor, for example, along Howell Creek and along the upper sector of Beaverdam Creek. These deposits are seasonally active during the spring and early summer. Other deposits, also seasonally active, form low terraces and lobes on gently sloping uplands, for example on Table Mountain, where small frost-sorted features such as sorted streams, sorted nets, and sorted circles are developed in frost rubble. A single block field (rb) is developed on the edge of a small landslide below cliffs along the divide between the southeast fork of Middle Creek and Cabin Creek. Landslide activity is not significant in the Eagle Peak 15' Quadrangle, though a few small deposits (ls) were observed.

HOLOCENE ALLUVIATION AND EROSION

Holocene alluviation is most extensive in the valley of the Yellowstone River, whose broad flat floor is overlain in many places by 10-15 feet of humic silty to sandy alluvium (fa), and is underlain to an unknown depth by sand and gravel (sg). The river is subject to strong floods during spring runoff and its flood channel is characterized by bars of bouldery gravel as much as 15 feet high. Bordering the flood plain are gravel terraces (sg) that merge downstream at and north of Trail Lake, with lake beaches of the 45- , 25- , and 10-foot levels of Yellowstone Lake. A measure of the rate of growth of the delta of the river is indicated by the distance of the present shoreline from older beach deposits: 45-foot beach, 3 miles, 25-foot beach, 2.5 miles, and 10-foot beach, 2 miles. The delta area north of the 10-foot shoreline is characterized by low sandy gravel levees bordered by broad areas of thick deposits of fine-grained humic muck (fa) deposited in former estuarine areas of the lake. Similar organic sediments extend only a few inches below the lake surface for more than a quarter of a mile offshore on the modern delta, through which the Yellowstone River flows in a channel at least 50 feet deep. Irregular dune ridges of fine sand (es) lie at the exposed edge of the delta. Most are stabilized by brush and a few trees, but some small areas are active.

Along streams other than the Yellowstone River, Holocene alluviation is characterized by narrow modern flood plains bordered locally, as on Beaverdam Creek, by local gravel terraces (sg) 5, 10, and 25 feet above the streams, and by alluvial fans (fg) both at drainage confluences and in the valley heads.

Just southwest of the East Entrance, modern debris avalanching onto the valley floor is indicated by piles of boulders overwhelming trees and by a C-14 date of 550 ±250 years (sample W-2008; Meyer Rubin, written commun., 1968) from wood at the base of sediments (stratigraphic section 23) deposited in a local lake just upstream from a large debris avalanche fan.

The extent of Holocene erosion is indicated by the depth to which the stream deposits (sg) of this age are entrenched below outwash deposits (pgu) of late Pinedale age. Along Columbine, Beaverdam, and Howell Creeks, this erosion amounts to from 30 to 80 feet. Cirque headwall areas unoccupied by ice since late Pinedale time are locally gullied as much as 10 feet, and those unoccupied since middle Pine-dale time as much as 30 feet, especially on south-facing slopes. Channels at the heads of debris avalanche cones along valley walls are commonly 25-40 feet deep.

QUATERNARY FAULTS AND ACID ALTERATION

White unvegetated areas resulting from acid alteration of both bedrock and surficial deposits occur along a zone of late Quaternary faulting just east of Yellowstone Lake. This zone of faults is a northern extension of that along the eastern side of the valley of the Yellowstone River. Along it, between the delta of the river and Brimstone Basin, deposits of Pinedale Till and kame sediments are altered, the more porous units being altered the most. The modern alteration appears to be entirely an acid alteration resulting from upward percolation, primarily along fault zones, of hydrogen sulfide gas. Hot springs are lacking, and no warm areas have been detected on infrared imagery of the region. In Brimstone Basin, altered debris forms a white chip wash. Brimstone Basin is a graben bounded by and including normal faults. Pinedale Till and kame deposits are locally offset 5-20 feet by these faults.

North of Brimstone Basin, well-defined fault lineaments cut across Pinedale kame deposits and continue northward to Cub Creek, where altered areas and pools of cool acidic water occur.

In Sylvan Pass area, no evidence of alteration was noted along the faults shown. Although no offset of surficial deposits was observed, the freshness of the lineaments suggests Quaternary movements. Sylvan Pass is a fault zone, deeply notched by the overflow of ice and water from icecaps in the Yellowstone Lake Basin; displacement, probably mostly pre-Quaternary, is 200-240 feet, downthrown to the north (H. W. Smedes, written commun., 1969).

Text from source map: Eagle Peak 15' Quadrangle

Frank Island 15' Quadrangle

The formal citation for this source.

Richmond, Gerald M., 1974, Surficial Geologic Map of the Frank Island Quadrangle, Yellowstone National Park, Wyoming: U.S. Geological Survey, Miscellaneous Investigations Series Map I-642, scale 1:62,500 (*GRI Source Map ID 1139*).

Description of geologic units, prominent graphics and text associated with this source.

Description of Units

lst - Lake sediments, silt (Holocene)
lsg - Lake sediments, sandy gravel (Holocene)
lgs - Lake sediments, gravelly sand (Holocene)

Gray to blue-gray, weathering buff, clayey silt (lst) underlying lake terraces that are 10, and 20-25 feet above Yellowstone Lake. Chiefly around the southern part of the lake. Deposits are mostly 3-6 feet thick, but are thicker at mouths of Chipmunk Creek and Grouse Creek. Modern deltas of Chipmunk and Grouse Creeks are of similar material. Sandy gravel (lsg) consists of pebbles and locally cobbles, mostly of rhyolite, in a sandy matrix. Gravelly sand (lgs) is coarse to medium grained. Both are gray to buff, well sorted, and locally crossbedded. They form beach deposits around Yellowstone Lake and cap lake terraces, 10, 15, and 20-25 feet above the lake. The terraces are cut in older deposits of Pinedale or pre-Pinedale age, or bedrock. The sandy gravel (lsg) and gravelly sand (lgs) are mostly 2-10 feet thick, but in places, such as Wolf Point, Eagle Bay, Plover Point, and Elk Point, the sandy gravel forms thick bars and spits both at the level of successive terraces and in the modern lake. Sandy gravel also forms local beaches around Heart Lake.

fa - Fine-grained humic alluvium (Holocene)

Dark- to light-gray or gray-brown silt, sand, and clay underlying swamps and depressions in Pinedale Till (pt) and kame deposits (pkg, pkgs, pksg). Also overlies Holocene stream gravel (sg) and Pinedale stream gravel (pg) on valley floors, and covers lake sediments (pl, plsg, lsg) in lagoonal depressions on lake terraces around Yellowstone Lake. Deposits are marshy, at least seasonally, and 2-30 feet thick.

sg - Stream gravel (Holocene)

Buff to gray gravel, cobbles, and boulders in coarse sandy matrix; poorly sorted; 5-10 feet thick. Mapped only along flood plains, but occurs in channels of most streams and beneath fine-grained alluvium (fa) along many valley floors.

fg - Fan gravel (Holocene)

Gray to buff, poorly sorted sand and angular gravel in alluvial fans. Mostly at mouths of small streams east of Heart Lake and along upper parts of valleys of Outlet and Surprise Creeks. Material is mostly of rhyolite tuff.

ta - Talus deposit (Holocene)

Coarse angular blocks of rhyolite in sparse sandy matrix at base of rhyolite cliffs around Flat Mountain and locally along canyons of Surprise and Outlet Creeks. Very few deposits elsewhere. Deposits unstable, actively accumulating, sparsely vegetated and display very little soil development.

tf - Talus-flow deposit (Holocene)

Coarse angular blocks of rhyolite forming lobate mass extending downslope from toe of a talus. Characterized by steep front and, locally by surface furrows arcuate downslope. Deposits occur only below north-facing rhyolite cliffs of Flat Mountain and ridge to southwest. They are unstable, and unvegetated, bear no soil, and may be partly active at present.

ls - Landslide deposit (Holocene)

Large mass of debris, mostly derived from bedrock and till (pt) mantle that has slumped and flowed downslope from a steep arcuate headwall scarp. Material is clayey to sandy; contains numerous large and small clasts, mostly of tuff and rhyolite but locally of Mesozoic sandstone and limestone. Deposits characterized by steep hummocky topography, flow ridges, and depressions. Locally, they are dissected as much as 40 feet by present drainage.

es - Eolian sand (Holocene)

Buff, medium to fine sand, forming small dunes or an irregular mantle. Deposits crossbedded. Mapped only at Rock Point and Dot Island, but occurs as small deposits on many wind-exposed bluffs around Yellowstone Lake. Deposits are mostly stable, and grass covered, and bear a very thin humic soil. However, some are active.

pl - Open lake sediments, silt (Holocene and/or Pleistocene)
psl - Open lake sediments, sand (Holocene and/or Pleistocene)
plsg - Open lake sediments, sandy gravel (Holocene and/or Pleistocene)

Gray to blue-gray, varved, laminated, or massive silt (pl), gray to buff, deltaic crossbedded to massive, well-sorted, medium sand (psl) and gray to tan crossbedded beach sand and gravel (plsg) of former open-water levels of Yellowstone Lake, 60-65, 50-55, 40-45, and 30-35 feet above present lake level. The 60-65-foot terrace is the most continuous and commonly the broadest. At the south end of the lake, the deposits are mostly silt. Elsewhere, however, the silt commonly overlies or underlies lake sand above Pinedale Till or kame deposits (pkgs) in bluffs along the lakeshore (stratigraphic sections 10, 34, and 67). The beach deposits mantle the slopes up to the upper limit of the 60-foot terrace, and are thicker on terrace surfaces than on intervening slopes. The terrace floors beneath the beach deposits are cut in underlying sand and silt (pl, psl) or, where these deposits are lacking, in older Pinedale or pre-Pinedale deposits or bedrock.

Along Grouse Creek (stratigraphic section 65) the sandy foreset beds of a delta, 60-70 feet above the lake, grade down into lake silt (p1) containing the 12,000-year-old Glacier Peak ash in its lower part and plant debris yielding a radiocarbon date of 9,060±300 years (W2041) in its upper part. At promontories around the lake or at the site of former embayments, such as Alder Lake, sand and gravel (plsg) form large longshore spits and bars, some 60 feet high, whose upper surfaces are at the level of corresponding terrace deposits. Similar deposits tie former islands to the mainland at the level of particular terraces, for example, southwest of Plover Point.
Frank Island Stratigraphic Sections

pg - Stream gravel (Holocene and/or Pleistocene)

Gray to gray-brown, sandy; poorly sorted, poorly exposed; chiefly pebbles and cobbles; contains only a few boulders. Material predominantly of rhyolite in southwestern part of quadrangle; predominantly of andesite and basalt in eastern part. Deposits apparently formed mostly during recession of ice in late middle Pinedale time.

pfg - Fan gravel (Holocene and/or Pleistocene)

Gray to gray-brown, poorly sorted, sandy; locally bouldery. Lithologically like stream gravel (pg). Occurs along lower sectors of streams in southern and northeastern part of quadrangle.

pta - Talus deposit (Holocene and/or Pleistocene)

Angular blocks of rhyolite in sandy matrix. Forms coalescing cones of debris at base of cliffs along Surprise and Outlet Creeks. Deposits are inactive, stable, forested, and bear a thin soil like that on Pinedale Till.

pkl - Ice-dammed lake sediments, silt (Holocene and/or Pleistocene)
pksl - Ice-dammed lake sediments, sand (Holocene and/or Pleistocene)
pklb - Ice-dammed lake sediments, beach deposit (Holocene and/or Pleistocene)

Gray to blue-gray, weathering buff, varved, laminated, or massive silt (pkl) and massive to bedded, medium to fine sand (pksl). Thickness at least 20 feet, probably more. Deposits mantle slopes between 110 and 60 feet above south end of Yellowstone Lake. They form a broad, nearly continuous, undulating, ice-contact terrace 110 feet above the lake and a narrow discontinuous bench 80 feet above it. Elsewhere around the lake, slopes between 110 feet and 60 feet above the lake are mantled by poorly exposed gravel and sand beach deposits (pklb) 5-30 feet thick. East of the lake these deposits locally extend as high as 240 feet above it. Terraces formed of these deposits or cut in older kame terrace deposits (pksg, pkgs) or in bedrock occur 240, 200, 135, 120, 110, 90, and 80 feet above the east side of the lake. Only the 110-, 90-, and 80-foot terraces occur on the south and west sides. The 110-foot terrace is nearly continuous around the lake.

pkls - Kame landslide deposit (Holocene and/or Pleistocene)

Mass of debris, derived from bedrock and overlying till (pt) mantle, that has slumped and flowed downslope. Deposits characterized by steep hummocky topography, including collapsed kettlelike depressions and melt-water drainageways that extend around arcuate heads of individual slump masses. They occur on both sides of the valley of Grouse Creek in south-central part of quadrangle. Consist mostly of clasts and large masses of tuff in a silty to clayey matrix. They grade northward into kame terrace deposits (pkgs). These relations and their morphology suggest that the slides took place over stagnant ice and were subsequently modified by collapse of ice and melt-water activity.

pkg - Kame deposits, gravel (Holocene and/or Pleistocene)
pksg - Kame deposits, sandy gravel (Holocene and/or Pleistocene)
pkgs - Kame deposits, gravelly sand (Holocene and/or Pleistocene)
peg - Kame deposits, esker gravel (Holocene and/or Pleistocene)

Buff to gray gravel containing a little sand (pkg), gravel with sandy matrix (pksg) and gravelly sand (pkgs) forming kame terraces having ice-contact frontal scarps and irregular hummocky upper surfaces. Deposits are 20 feet to more than 50 feet thick, are poorly sorted, and display numerous slump structures and minor faults. Locally they are covered with large boulders and till-like material derived from nearby till-covered slopes or former adjacent ice. Deposits mantle most slopes surrounding Yellowstone Lake between altitudes of 7,840 and about 8,000 feet—or between 110 and 270 feet above the lake. They also extend beneath younger lake deposits down to and below present lake level, and are exposed in lake bluffs in many places (for example: stratigraphic sections 37, 39, 40, 42, 43, 48, 72, and 74). Extensive deposits of unknown thickness occur in the area around Delusion Lake where they enclose numerous large and small kettles. The unnamed flat-topped upland west of Flat Mountain Arm is underlain mainly by these deposits, thick sections of which are exposed on its western slope. South of Flat Mountain, a sequence of kame terraces extends to an altitude of 8,450 feet, or 720 feet above Yellowstone Lake. To the south, ice-contact gravels extend continuously down the valley of Beaver Creek and form the promontory in Heart Lake. Small eskers (peg) composed of sandy cobble gravel are present in the valley of Chipmunk Creek.
Frank Island Stratigraphic Sections

pt - Till and glacial rubble, till (Holocene and/or Pleistocene)
pr - Till and glacial rubble, glacial rubble (Holocene and/or Pleistocene)

Gray-brown to gray stony silty sand (pt); loose to compact; stones angular to subround. Deposits commonly thin, but range in thickness from less than 5 to more than 30 feet. Surface smooth to hummocky. Undrained depressions common in valley areas; many contain water. Ice-molded topography common on uplands. In eastern part of quadrangle, deposits are silty and contain abundant clasts of Eocene andesite and basalt. In western part, deposits are sandy. Clasts are mostly of rhyolite, but some are erratics of andesite and basalt and, west of Flat Mountain Arm, of sandstone and limestone. The soil on the till is commonly less than 12 inches thick and consists of a weakly oxidized horizon containing little or no clay. The uplands south of Flat Mountain are littered with thin glacial rubble (pr) consisting mostly of sand and locally derived fragments of rhyolite. Some stones are soled and faceted; a few are striated.

Re - Elephant Back rhyolite flow (Pleistocene)
Rw - West Thumb rhyolite flow (Pleistocene)
Ra - Aster Creek rhyolite flow (Pleistocene)
Rst - Shoshone Lake Tuff Member (Pleistocene)

Three Quaternary rhyolite flows and a tuff crop out in the northwestern and western parts of the quadrangle (see index map). Outcrops of the individual flows and of the tuff have been mapped because of their significant stratigraphic relations to Quaternary sedimentary deposits in this and adjacent quadrangles. The Elephant Back rhyolite flow (Re) (K-Ar age about 150,000 years) overlies the West Thumb rhyolite flow (Rw) (K-Ar age also about 150,000 years). The West Thumb rhyolite flow is locally overlain by lake sediments (s-bl) containing a pumice (K-Ar age about 150,000 years) (stratigraphic section 19) that was probably deposited during eruption of the Elephant Back rhyolite flow. Younger Bull Lake Till overlies these lake sediments in places (stratigraphic section 33). The Aster Creek rhyolite flow (Ra) (K-Ar age about 150,000 years) overlies the upper sediments of Flat Mountain Arm. The Shoshone Lake Tuff Member (Rst) (K-Ar age about 155,000 years) occurs between the upper and lower units of the sediments of Flat Mountain Arm. (K-Ar dates were determined by J. D. Obradovich).
Frank Island Stratigraphic Sections

fu - Sediments of Flat Mountain Arm, Upper unit (Pleistocene)
fl - Sediments of Flat Mountain Arm, Lower unit (Pleistocene)

Lacustrine silt, sand, and gravel deposits disconformably underlying the Aster Creek rhyolite flow (Ra) (K-Ar age, about 150,000 years) along the north shore of Flat Mountain Arm. The deposits are divided into an upper unit (fu) and a lower unit (fl), separated by the Shoshone Lake Tuff Member (Christiansen and Blank, 1972) (Rst) (K-Ar age about 155,000 years), here about 40 feet thick. Sediments of the upper unit (fu), are compact but not hard. They consist of blue-gray, chocolate-weathering, laminated, pumiceous lake silt, 4-8 feet thick, overlying medium to fine, massive to weakly bedded, pumiceous sandy silt, 6-25 feet thick (stratigraphic sections 54, 55, 56, 58 and 60). The sandy silt overlies dark-gray-brown, hard, massive to finely laminated silty clay, 8-12 feet thick, which in turn overlies well-rounded manganese-stained sandy gravel, composed mostly of rhyolite and 1-3 feet thick. The basal gravel rests disconformably on the Shoshone Lake Tuff Member. The tuff rests with slight disconformity on the sediments of the lower unit (fl). These consist of compact, hard, blue-gray, chocolate-weathering, massive to laminated, pumiceous silt, 3-8 feet thick, overlying green, blue-gray, or rust-brown, hard, compact, medium to fine, pumiceous silty sand, 6-25 feet thick (stratigraphic sections 53, 57, and 59). The silty sand rests on a basal gray to rust-brown, hard, compact, crossbedded, well-rounded, sandy gravel and poorly sorted sand, 2-5 feet thick. The basalt gravel and sand grades laterally westward into dark-gray to pinkish-brown, compact, sandy to silty, unsorted and unstratified till-like diamicton containing angular to well-rounded pebbles and cobbles of rhyolite and andesite, fragments of Cretaceous quartzite and limestone, chunks of bedded lake silt and reworked silicified concretions of lake silt. This diamicton is probably till, but might be a landslide deposit derived from Flat Mountain to the south. All of the sediments of the lower unit contain small pyrite crystals and are locally hydrothermally altered.

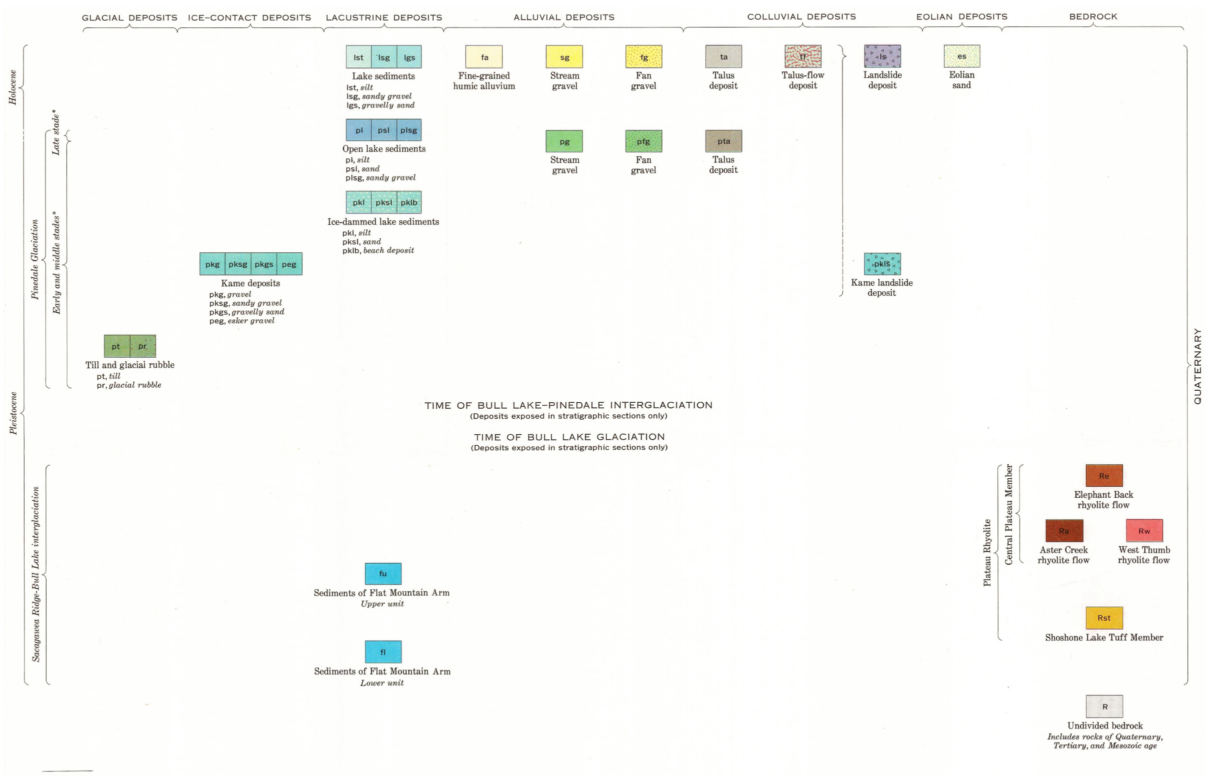
Frank Island Stratigraphic Sections

R - Undivided bedrock (Quaternary, Tertiary, and Mesozoic)

Two tuffs of the Yellowstone Group—one 600,000 years old, the other 2 million years old—underlie most of the lower slopes east of Yellowstone Lake and the southwest quarter of the quadrangle (R. L. Christiansen, written commun., 1970). Eocene mudflow rock, basalt, and andesitic rocks underlie the higher hills east of Yellowstone Lake, The Promontory, and the southeastern part of the quadrangle east of Grouse Creek (H. J. Prostka and H. W. Smedes, written commun., 1970). Mesozoic rocks, mostly shale, sandstone, and limestone, underlie most of Chicken Ridge in the southern part of the quadrangle and crop out, locally north, west, and southeast of Flat Mountain (W. R. Keefer, written commun., 1970).

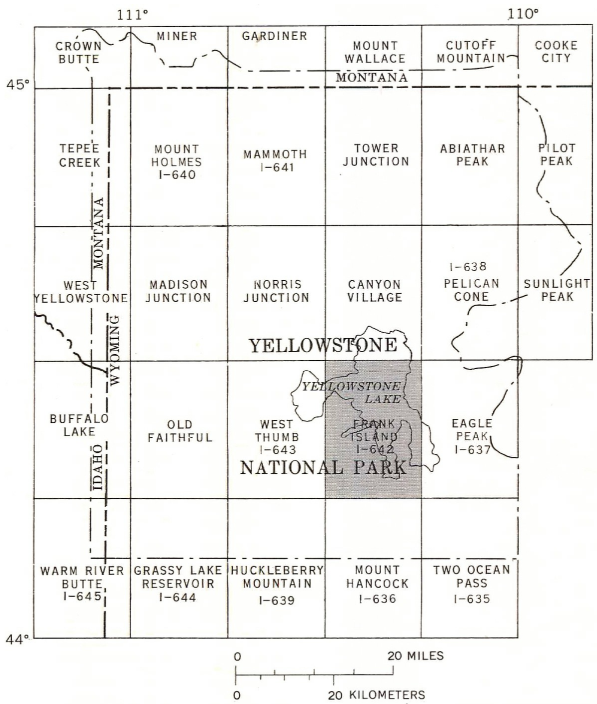
Text from source map: Frank Island 15' Quadrangle

Correlation of Units



Graphic from source map: Frank Island 15' Quadrangle

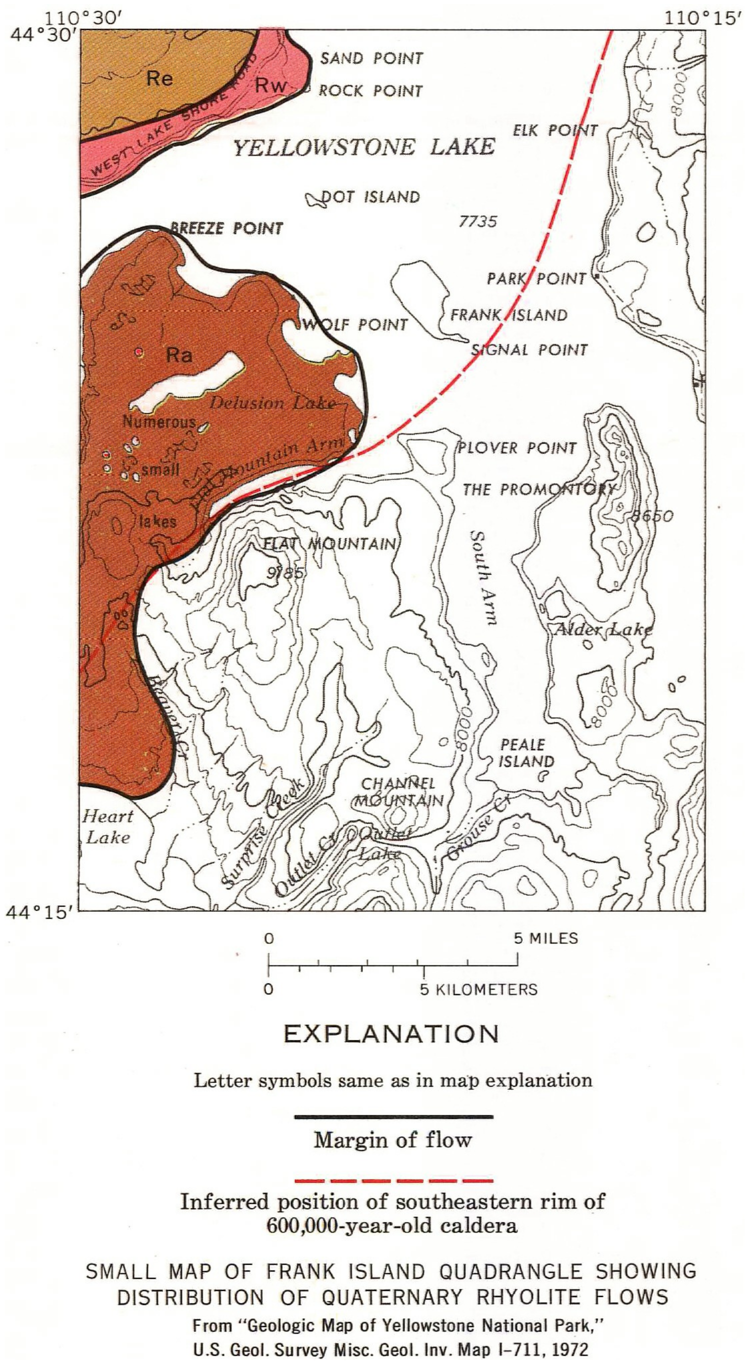
Index Map



INDEX MAP OF YELLOWSTONE NATIONAL PARK SHOWING LOCATION OF FRANK ISLAND QUADRANGLE AND PUBLISHED MISCELLANEOUS GEOLOGIC INVESTIGATIONS MAPS

Graphic from source map: Frank Island 15' Quadrangle

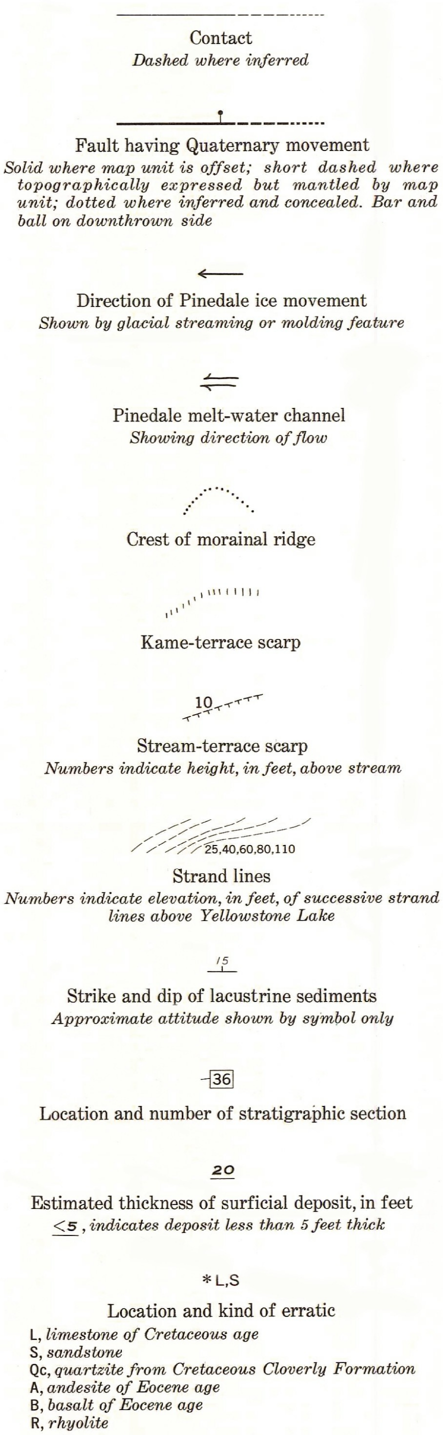
Rhyolite Flow Map



See Description of Units page for this map to view information about geologic units shown on this graphic.

Graphic from source map: Frank Island 15' Quadrangle

Map Legend



Graphic from source map: [Frank Island 15' Quadrangle]

Stratigraphic Sections

Units separated by slashes, are shown in descending order; numbers (where shown) represent thickness, in feet. Sections demonstrate stratigraphic relations of units vertically exposed and thus too small to be shown on the map.

Stratigraphic section locations are presented in the GRI Geologic Observation Localities (yellgol) feature class. In that feature class, the section identifier is stored in the Location ID (LOC_ID) field. The section information presented here is also contained in the Geologic Observation Localities (yellgol) feature class Notes (NOTES) field.

See Description of Units for information about map units listed here.

1. 20 pkgs/5pt/6b-pl
2. "30 psl, deltaic/10 pl"
3. 2 co/2 plsg/31 b-pl. pumiceous/2.1 bt
4. "4 lsg/15 pl, varved/10 pksl/15 pt, lacustral"
5. "30 psi/5 pl, varved/6 pt"
6. "25 psl/10 pl/6 pt/5 b-psl, massive"
7. 10 pl/5 pt/8 b-pl/10 Rw
8. 4 lsg/8 pksl/4 pt/10 Rw
9. 10 psl/10 pt/8 b-pl/2 Rw
10. 3 co/2 lsg/12 pl/18 psl/10 pt
11. 4 co/0.5 lsg/4.5 psl/3 pl/15 pt
12. 3 co/2 lsg/13 pl/8 pt
13. 3 co/2 lsg/20 pksl/4 pt
14. 3 co/4 lgs/20 psl
15. "4 lsg/20 psl, deltaic"
16. 13 psl/8 pt/2 Rw
17. "3 lsg/10 pl, altered/3 pl/2 pt/5 pt, lacustrine"
18. "3 lsg, cemented/10 pl, altered/3 pt, cemented"
19. 5 bt/5 s-bsl/2 Rw
20. "2 co/3.5 lsg/18 b-psl, deltaic/10.2 s-bsl, pumiceous/1.2 pumice, K-Ar age 150,000 years/1.8 s-bsl/4 s-bl"
21. "3 lgs/Pinedale boulder line/20 b-psl, deltaic/13 s-bl, containing 1.5 pumice, K-Ar age 150,000 years"
22. "3 lgs/15 b-psl/17 s-bl, containing 1.3 pumice, K-Ar age 150,000 years/6 s-bsl"
23. "3 lgs. cemented/10 b-psl/20 s-bl, containing 2.5 pumice, K-Ar age 150,000 years"
24. "8 pl, varved/20 psl/Pinedale stone line, rusty/10 b-pl, massive/7 b-psl, pumiceous/8 s-bl/1 pumice, K-Ar age 150,000 years"
25. "3 co/2 pl. varved/8 pt/2 bl, contorted, striated erratic stones"
26. "1 co/2 lsg/8 p1/14 pt/6 bl, containing erratic stones/6 bt"
27. "3 lgs/16 pl, varved/8 pt/2 bl, contorted. striated stones"
28. "3 co/18 pl, varved/3 pt/2 b-psl/3 bl, contorted, striated stones"
29. "3 lgs/4 pl/3 pt/4 b-psl/5 b-pl/4 b-psl/2 bl, contorted. striated stones"
30. "1 co/2 lgs/3 pl/4 pt/8 b-pl/3 b-psl/5 bt, clayey, erratics"
31. "8 lgs/12 pt/3 b-psl, pebbly/3 Rw, with fracture fillings of b-psl"
32. 2 lgs/20 pl/10 pt/2 bl/3 bt
33. 3 es/2 lgs/12 bt/5 s-bl/3 Rw
34. 10 lgs/2 p1/4 psl/3 Rw
35. 10 psl/80 pkgs/10 b-pl
36. "2 co/3 lsg/4 pt and crumpled psi/8 psl, deltaic/4 psi/4 pl"
37. lsg/pl/pksg

38. pksg/b-pl
39. pl/pksg
40. pksg/pt
41. lgs/pl/pt
42. 8 lgs/6 psi/6 pl. varved/pksg
43. "3 lgs/6 psi/40 pl, varved/pkgs"
44. 6 lgs/11 psl/4 pl
45. 6 lgs/8 psl/7.6 p1
46. 3 co/15 pkgs/20 pt
47. 3 co/15 pkgs/15 pt/15 b-psl
48. 3 co/10 lgs/3 pkgs
49. 15 es/8 co/10 plsg/6 p1/10 pt
50. 6 lsg/4 pl
51. 3 lsg/7 pt
52. "10 lgs, diatomaceous/2.3 pl/0.02 Glacier Peak ash/1.5 pi, varved/0.5 plsg"
53. pkgs/Rst/P
54. 20 Ra/9.8 fu/2 Rst
55. 25 Ra/20 covered/8.2 fu/2 Rst
56. 2 pt/20 fu/9.5 Rst
57. 20 Rst/25 fl
58. 20 Ra/36 fu/2 Rst
59. 30 Rst/8.2 fl
60. 30 Ra/4.6 fu/40 Rst
61. 8 pksg/15 pkl
62. 2 lsg/3 psl/6 pt
63. "pksl, deltaic/b-pl"
64. pksl. deltaic/b-pl
65. "1.3 co/4.6 fa/9.2 psl, deltaic/7.7 psl/8 pl/0.013 Glacier Peak ash/9.5 pl, varved/1 pt"
66. 2 co/15 b-psl/0.9 pumice/20 b-pl
67. 2 co/4 pl/1.5 psl/4 pksg/4.5 pt/18 b-pl/1 pumice/14 b-pl
68. 5 psl/6 pksg/1.5 pt/26 b-pl/0.3 pumice/3 b-pl
69. 10 pg/3 pt/1 0 b-pl
70. 15 pg/20 b-pl
71. 5 pg/15 b-pl
72. 5 co/5 pg/5 psi/10 pkg/10 b-pl
73. plsg/pt
74. pkl/pksg
75. "60 pksg, deltaic"
76. lsg/pl
77. 1 lsg/2 pt/2 b-psl/2 pumice
78. "10 lsg/4 pt/18 bks, containing two reworked pumice layers"
79. "10 lsg/8 b-pl/10 bkgs, containing two reworked pumice layers"
80. "10 pl/0.6 diatomite/6 pl/pt - boulder zone/9 b-psl, containing reworked pumice layer/12 bkgs/2 bt"
81. 4 pt/20 b-psl containing reworked pumice layer/15 bkgs
82. 3 pt/15 b-pl/25 b-psl/3 bkgs/3 bt
83. 10 lsg/3 pt
84. 6 lsg/2 pt
85. 2 pl/3 pt
86. 6 plsg/34 pksg

Text from source map: Frank Island 15' Quadrangle

Surficial Geologic History

INTRODUCTION

The Frank Island 15' Quadrangle is in south-central Yellowstone National Park and includes most of Yellowstone Lake. The hills to the northeast are foothills of the Absaroka Range, and The Promontory at the south end of the lake is geologically also a part of that range. Chicken Ridge, in the southern part of the quadrangle, is the north end of a range of folded and faulted pre-Quaternary sedimentary rocks that extends far to the south. The east-facing escarpment that trends northwest from Chicken Ridge to Flat Mountain is a Quaternary fault scarp. The South and Southeast Arms of Yellowstone Lake appear to have been excavated along fault blocks. Heart Lake lies in a structural trough downfaulted to the west. Flat Mountain Arm lies along the southern inner margin of a large caldera (see small map) which collapsed after eruption of a tuff of the Yellowstone Group about 600,000 years ago. The areas north of Flat Mountain Arm and north of West Thumb represent the east edge of the Central Plateau of Yellowstone National Park. The highest points in the quadrangle are Overlook Mountain (9,32I feet), Channel Mountain (8,745 feet), and Flat Mountain (9,204 feet).

PLEISTOCENE GLACIATIONS

Although great icecaps covered most of Yellowstone National Park and adjacent areas during several glaciations in Pleistocene time (Richmond, 1970), deposits of only the last two, the Bull Lake (older) and the Pinedale (younger), have been identified in this quadrangle. During each glaciation, cap ice developed on the high plateaus of the Absaroka Range to the southeast and flowed north along the upper valley of the Yellowstone River into the basin of Yellowstone Lake. Here the ice accumulated to a thickness of about 3,000 feet and flowed across the Continental Divide to the southwest into the drainage of the Snake River and Jackson Hole. During the Sacagawea Ridge-Bull Lake interglaciation, which preceded the Bull Lake Glaciation, the basin of Yellowstone Lake was occupied by an open lake whose extent and level were affected by a violent eruption of tuff coincident with the collapse of a caldera immediately west of the quadrangle in West Thumb and by subsequent outpouring of rhyolite flows. Following these events, the lake was 370 feet above present Yellowstone Lake. During the interglaciation separating the Bull Lake and Pinedale Glaciations another open lake formed in the basin at a level about 250 feet above present Yellowstone Lake.

SACAGAWEA RIDGE-BULL LAKE INTERGLACIATION

Deposits of the Sacagawea Ridge-Bull Lake interglaciation crop out in several places in the bluffs surrounding Yellowstone Lake. They are best exposed along the north side of Flat Mountain Arm (fu, fl), where they are informally designated as sediments of Flat Mountain Arm. Here, the lower unit (fl), comprises a basal till-like diamicton, which may represent the Sacagawea Ridge Glaciation, and associated crossbedded gravelly sand. These deposits are overlain by lake sand and silt (stratigraphic sections 53, 57, and 59). In this quadrangle, the ancient lake occupied the area of present Yellowstone Lake, the area between Flat Mountain Arm and West Thumb and probably the area north of West Thumb. The highest deposits of the ancient lake are now about 20 feet above present Yellowstone Lake whose elevation is 7,733 feet. The ancient lake may have drained northwest through an area now covered by younger rhyolite flows (Norris Junction quadrangle) and across the old caldera rim at the site of present Madison Canyon.

The lower unit (f1) is overlain by a pumiceous tuff, the Shoshone Lake Tuff Member, which is about 40 feet thick and consists of weakly welded to loose material. The tuff has a K-Ar age of about 155,000 years. The caldera associated with eruption of the tuff occupies the circular part of West Thumb in the West Thumb quadrangle adjacent to the west and developed either at the edge of the lake or beneath its waters.

The upper unit of the sediments of Flat Mountain Arm (fu) consists of a thin basal gravel overlain by lake sand and silt, and has a maximum thickness of about 35 feet (stratigraphic sections 54, 55, 56, and 58).

The deposits show that the lake rose over the tuff and attained a somewhat higher level than in pre-tuff time. Though affected by faulting, the lake beds are now at a maximum height of about 50 feet above present lake level. The extent of the lake was probably less than that of the pre-tuff lake, as it was modified by changes in the terrain resulting from deposition of the tuff, and by collapse of the caldera of West Thumb. During this time, the lake may have drained southwest to Heart Lake across the divide now covered by the Aster Creek rhyolite flow (see small map).

The lake was next changed by the eruption of the Aster Creek (Ra) and West Thumb (Rw) rhyolite flows (see small map), both K-Ar dated at about 150,000 years. The Aster Creek flow poured from the present Continental Divide near the west edge of the quadrangle southward across the area west of Beaver Creek to Heart Lake, and northeastward across the peninsular area between Flat Mountain Arm and West Thumb. It covered the entire area of present Flat Mountain Arm, as shown by an exposure on the south side of the arm. The West Thumb rhyolite flow (Rw) poured into the northwestern part of the quadrangle and forms the present northwest margin of Yellowstone Lake in that area. Its base is below present water level. To the north, in the Canyon Village 15' Quadrangle, a lobe of the West Thumb rhyolite flow extended across the ancient lake in the area of present LeHardys Rapids and impinged against the upland to the east. The dam thus formed raised the waters of the lake to an altitude of about 8,100 feet, or about 370 feet above present lake level. This lake drained across the dam and northward into a shallow paleocanyon of the Yellowstone River (Canyon Village 15' Quadrangle) which lead across the north rim of the old caldera. Deposits of this lake (s-bl, s-bsl) occur locally in bluffs along the northwest shore of Yellowstone Lake and are well exposed. At stratigraphic sections 19, 20, 21, 22, 23, 24, and 33 they consist of silts and pumiceous sands and contain a pumice bed K-Ar dated at about 150,000 years. Locally, they overlie the West Thumb rhyolite flow (stratigraphic sections 19 and 53). The pumice was probably deposited during the eruption of the Elephant Back rhyolite flow (Re) into the northwest corner of the quadrangle across the surface of the West Thumb rhyolite flow. The Elephant Back flow also has a K-Ar age of about 150,000 years but, like the pumice, is clearly somewhat younger than the West Thumb flow. The deposits of the Sacagawea Ridge-Bull Lake interglaciation s-bsl) are separated from lake deposits or till of the Bull Lake Glaciation by a disconformity (stratigraphic sections 22, 23, 24, and 33).

BULL LAKE GLACIATION

Bull Lake Till (bt) crops out in bluffs around Yellowstone Lake (stratigraphic sections 3, 19, 26, 30, 32, 33, and 81), but is not exposed extensively enough to be mapped. The presence of abundant erratics of andesite and basalt in Bull Lake Till on the west side of the lake indicates that the ice was derived from the Absaroka Range east and southeast of the lake. However, the abundance of reworked lake silt in the till at some localities (stratigraphic sections 3, 81, and 82) and its high content of reworked pumice and obsidian at others (stratigraphic sections 32 and 33) show that the ice derived most of its load from older Quaternary lacustrine and tuffaceous deposits, such as those of the Sacagawea Ridge-Bull Lake interglaciation, that underlie the lake basin. Flat Mountain Arm and the basin of Delusion Lake were probably excavated in these deposits by the Bull Lake ice. The local blue-gray unoxidized character of the till further suggests that the till may have been deposited under water.

The distribution of outcrops of Bull Lake Till shows that an icecap filled the basin of Yellowstone Lake in Bull Lake time. End moraines formed by the icecap lie outside Yellowstone National Park beyond those of the subsequent Pinedale Glaciation. Bull Lake ice was therefore more extensive than Pinedale ice and was also thicker. The history of recession of the ice is not well documented in this quadrangle. Slumped and faulted ice-contact gravel (bkgs) and crossbedded lake sand (bks), locally containing beds of reworked pumice (stratigraphic section 79) and overlain in places by younger lake deposits and (or) Pinedale Till (stratigraphic sections 78, 80, 81, and 82), represent a recessional phase of the glaciation on the east side of the lake. On the west side, varved lacustrine silts on Bull Lake Till and under Pinedale Till (stratigraphic section 32) were also deposited as Bull Lake ice receded from the area. Associated deposits of contorted irregularly bedded silt, containing striated stones and erratics of basalt and andesite, that underlie massive or laminated lake deposits (b-pl, b-psl) beneath Pinedale Till (stratigraphic sections 25, 26, 27, 28, and 29) were probably formed during recession of the Bull Lake ice. The Bull Lake Glaciation ended at sometime prior to about 70,000 years ago, the age of the Pitchstone Plateau Rhyolite flow (Map I-639) which, though in the path of Bull Lake ice, has no Bull Lake deposits on it.

INTRA-BULL LAKE INTERVAL

The Bull Lake Glaciation is subdivided into two stades, separated by a nonglacial interval (Richmond, 1965). In this quadrangle a sequence of lake silts (b-bl) exposed at stratigraphic sections 66, 67, 68, and 69 are believed to represent deposits of an open lake during this interval because they contain a pumice bed K-Ar dated at about 103,000 years. No till of the late stade of Bull Lake Glaciation was found on them, but they are truncated by a disconformity overlain by Pinedale Till. In the Canyon Village 15' Quadrangle, the Hayden Valley and Solfatara Plateau rhyolite flows, both K-Ar dated at about 105,000 years, are locally overlain by deposits of late Bull Lake age.

BULL LAKE-PINEDALE INTERGLACIATION

Deposits of the Bull Lake-Pinedale interglaciation are insufficiently exposed to be mapped, but crop out beneath Pinedale Till or ice-contact deposits around the lake and in drainages from the south. Most are massive to laminated silts and fine sands (b-psl, b-pl) recording deep-water conditions (stratigraphic sections 3, 6, 7, 20, 21, 22, 23, 24, 28, 29, 30, 77, 79, 80, 81, and 82). Though the level of the lake cannot be determined in this quadrangle, huge deltas of similar material, stratigraphically between Bull Lake Till and Pinedale Till, attain altitudes up to about 7,980 feet, or 250 feet above present Yellowstone Lake, in the Eagle Peak (Map 1-637) and Two Ocean Pass (Map 1-635) quadrangles, adjacent to the east and southeast, respectively. This lake was impounded, as before Bull Lake Glaciation, by the lava dam in the area of LeHardys Rapids to the north in the Canyon Village 15' Quadrangle. The dam, however, was about 120 feet lower than during the Sacagawea-Bull Lake interglaciation. Plant material from deposits of the lake, along Solution Creek (stratigraphic section 35), has a radiocarbon age >38,000 years (W2012). Similar material from deposits near the mouth of Solution Creek (stratigraphic section 36) that has a radiocarbon age of 29,000± 1,000 years (W2583) were crumpled by overriding ice of the Pinedale Glaciation. Wood from delta deposits of the lake in the Eagle Peak 15' Quadrangle (Map 1-637) yielded a radiocarbon age of > 42,000 years (W2197) and >45,000 years (W2411). The lake is therefore considered to have existed from the end of Bull Lake Glaciation at sometime prior to 70,000 years ago to a time somewhat less than 29,000 years ago as spits, bars, or elongate lagoonal depressions common to large bodies of open water. They are considered to have formed at a time when the stagnant ice in the basin was surrounded by an irregular band of water draining north to an outlet at this level onto ice in the Grand Canyon of the Yellowstone River (Canyon Village 15' Quadrangle). Similar deposits are associated with discontinuous and less well developed terraces 90 and 75-80 feet above the present lake.

PINEDALE GLACIATION

Early in Pinedale time, glaciers formed in the higher parts of the Absaroka Range southeast of the quadrangle and coalesced westward into a large mass, which flowed north down the upper valley of the Yellowstone River into the basin of Yellowstone Lake. Here the ice became a center of local accumulation and developed into a cap which, in this quadrangle, spread southwest across the uplands enclosing Delusion Lake and overrode and crumpled preexisting lake beds 29,000 years old and older along Solution Creek (stratigraphic sections 35 and 36). The cap gradually thickened and eventually overrode the divides surrounding the basin. In the eastern part of the quadrangle it must have attained a maximum thickness of over 3,000 feet, for it overrode the crest of the Absaroka Range to the east. In the southwestern part of the quadrangle it flowed across the Continental Divide, across the basin of Heart Lake, and, at its maximum, merged with glaciers from the Teton Range in the basin of Jackson Hole.

STAGNATION OF THE PINEDALE ICECAP

During deglaciation, one and locally more readvances of the ice took place, but their end moraines lie outside the limits of this quadrangle. As the surface of the icecap lowered, uplands such as Flat

Mountain and Overlook Mountain began to emerge and melt waters flowed between the ice and adjacent slopes. A high melt-water channel (altitude 8,700 feet) extends across the Continental Divide just north of Overlook Mountain, and four others occur along the divide to the north at altitudes between 8,250 and 8,100 feet. Locally, ice-contact outwash sandy gravels (pksg) were also deposited. The highest are in valleys of the Absaroka Range east of the lake (Map 1-637). In the Frank Island 15' Quadrangle, high deposits form an immense kame west of Flat Mountain Arm at an altitude of about 8,380 feet. The kame is over 400 feet high and 650 feet above Yellowstone Lake. It may have been deposited over a high point on the Aster Creek rhyolite flow and may represent deposition in a depression melted in the ice by underlying hot springs or fumaroles. Subsequently, a drainageway developed southeast of the high kame at an altitude of 8,I00 feet, 370 feet above Yellowstone Lake. It led ice-margin gravel-laden melt waters southward across the divide onto and against stagnant ice downwasting in the basin of Heart Lake, as shown by the succession of irregular ice-contact terrace deposits (pksg) extending down the valley of Beaver Creek and separating the present lobes of Heart Lake. At about the same time somewhat different events took place in the topographic saddle at an altitude of 7;960 feet south of Channel Mountain. Here, as the divide was exposed by downwasting of ice to the east and west, two small end moraines arcuate to the east were deposited on it. Melt waters undoubtedly flowed west from these moraines across stagnant ice in the valley of Outlet Creek. However, the degree of preservation of the moraines and the absence of ice-contact deposits at the head of the valley of Outlet Creek suggest that such flow was short lived. Some investigators have held that the channel was the outlet of an open late glacial lake. However, as indicated by Howard (1937), the channel was utilized only by ice-margin waters.

As the ice downwasted farther into the basin of Yellowstone Lake, melt waters deposited ice-margin sand and gravel (pkgs. pksg) almost continuously around it from about 270 feet above the present lake down to about 110 feet above it in this quadrangle. In the Eagle Peak 15' Quadrangle (Map 1-637), adjacent to the east, similar deposits extend as high as 750 feet above the lake, and, at a height of 350 feet above it, have yielded a radiocarbon age of 13,140+700 years (W2037). Lacustrine deposits (pkl) higher than 110 feet above the east shore of the lake represent initial development of ponded water against southwest-facing slopes. Ice-contact gravel terraces occur in the shelter of northeast-facing slopes as low as 90 feet above the lake at the south end of Southeast Arm, where they enclose large ice-block depressions, and as low as 70 feet above the lake at the west end of Flat Mountain Arm. They demonstrate that the ice lasted longest against these slopes.

A prominent terrace underlain by lacustrine silt (pkl) and poorly sorted sand and gravel (pklb) extends almost continuously around the lake at the 110-foot level. In places the terrace is cut on older kame terrace gravels. The lacustrine deposits locally have ice-contact fronts and in places are mantled with bouldery slumped till. They commonly enclose large ice-block depressions, but lack features such

LATE PINEDALE AND POST-PINEDALE HISTORY OF YELLOWSTONE LAKE

A prominent terrace and associated well-sorted lacustrine deposits extend almost continuously around the lake at a level 60-65 feet above it. The deposits differ from those at higher levels in that they are characterized by numerous large spits, bars, and lagoonal depressions indicative of strong longshore currents found only in a large body of open water. This terrace is believed to mark the level at which the lake became entirely free of ice. Its width and continuity suggest that the lake probably maintained this level for a fairly long time. On Grouse Creek (stratigraphic section 65), crossbedded sands of a delta 60-70 feet above the present lake grade down into lake silts, the upper part of which contains plant material dated at 9,600+300 years (W2041). The lower part contains an ash, identified by R. E. Wilcox (written commun., 1970) as probably the Glacier Peak ash, 12,000 years old. The ash also occurs in massive lake silt immediately overlying Pinedale varved silt at the northeast end of Flat Mountain Arm (stratigraphic section 52). Outwash gravels of late Pinedale age, probably deposited from about 10,500 to about 9,000 years ago, are graded to the 60-70 foot terrace along Beaverdam Creek in the Eagle Peak 15' Quadrangle (Map 1-637) adjacent to the east. No glacial deposits of late Pinedale age occur in the Frank Island 15' Quadrangle.

Lower terraces and associated lake deposits 40-45 and 30-35 feet above the lake are considered to be of altithermal age. At the time of publication of the Eagle Peak 15' Quadrangle map (I-637) they were believed to be of prealtithermal age. The 40-foot terrace is older than a minimal date of 5,590+250 years (W2286) derived from plant material from the lower 25 cm of peat in a lagoon associated with the terrace. A still-lower sequence of terraces, 25, 15 and 10 feet above the lake, is of altithermal and younger age. Charcoal under colluvium overlying beach gravel of the 10-foot terrace has a radiocarbon age of 620+250 years (W1999). The 5-foot terrace is the modern storm beach.

At the south end of South Arm, the open lake occupied a series of former ice-block depressions from the time of its 60- 70-foot level to its 15-foot level. Pollen and macrofossils from organic matter in these depressions were analysed by Baker (1969, 1970), who demonstrated the following late-glacial and postglacial pollen assemblage zone sequence: (1) a lower zone of Engelmann spruce, prostrate juniper, and whitebark pine is subdivided into a lower subzone of birch and an upper subzone of balsam and poplar; (2) an upper zone of lodgepole pine beginning somewhat more than 11,550+350 years B.P. (W2285) is subdivided into a lower subzone of lodgepole pine and whitebark pine, a middle subzone of lodgepole pine, from which radiocarbon dates of 9,240+300 B.P. (W2284) and 5,390+250 B.P. (W2281) were derived, and an upper subzone of spruce, fir and lodge-pole pine, from which a date of 2,470+250 B.P. (sample W2280) was derived. Baker (1970) suggested that the presence of dwarf mistletoe in the lower subzone of the lodgepole pine zone implies a mean annual temperature of about 30°F, which is 3° F cooler than at present.

PINEDALE AND HOLOCENE PERIGLACIAL ACTIVITY

Very little periglacial activity took place in the quadrangle during and after wastage of the Pinedale icecap. Talus and protalus deposits have formed beneath cliffs along the canyons of Outlet and Surprise Creeks and on Flat Mountain. Below other cliffs only sparse frost rubble (not mapped) has developed. The landslides probably began to form as, or soon after, the Pinedale ice wasted. Along Grouse Creek, melt-water channels around slump units of landslide debris, well above the floor of the valley, attest that ice was still present when the material collapsed and melt water passed over it. The landslide in the southwest corner of the quadrangle closed a former outlet of Heart Lake, which now drains from its southeast end. Most of the slides are still locally active.

PINEDALE AND HOLOCENE ALLUVIATION AND EROSION

Very little alluviation or stream erosion has taken place since wastage of the ice. Pinedale stream gravels form relatively thin fills and have been subsequently dissected only 10-30 feet. Younger alluvial gravels are mostly thin and are commonly covered by fine alluvium. Extensive alluviation has taken place only at the foot of gullies cut in the southwest-facing slope of the ridge northeast of Heart Lake.

QUATERNARY FAULTING

The normal faults which trend in a northerly direction across the southern part of the quadrangle are for the most part regional lineaments that extend far to the south. They intersect the southeast wall of the caldera that collapsed after the eruption of the 600,000-year old tuff of the Yellowstone Group. The caldera rim (see small map) extends along the south side of Flat Mountain Arm and northeastward across Yellowstone Lake. The South and Southeast Arms of the lake are inferred to have been eroded in downdropped blocks, probably in precaldera time. Faults cutting the north side of Flat Mountain Arm offset the Aster Creek rhyolite flow (K-Ar age, about 150,000 years), and, at the east end of the arm, a fault zone offsets lacustrine terrace deposits formed since recession of Pinedale ice. Extension of this fault zone to the north is based on a lineament of cold-water springs detected in the lake on infrared imagery (Smedes, 1968). Mapping of faults was done in cooperation with R. L. Christiansen, W. R. Keefer, and H. J. Prostka.

Text from source map: Frank Island 15' Quadrangle

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References from source map: Frank Island 15' Quadrangle

Grassy Lake Reservoir 15' Quadrangle

The formal citation for this source.

Richmond, Gerald M., 1973, Surficial Geologic Map of the Grassy Lake Reservoir Quadrangle, Yellowstone National Park and adjoining area, Wyoming: U.S. Geological Survey, Miscellaneous Investigations Series Map I-644, scale 1:62,500 (*GRI Source Map ID 1140*).

Description of geologic units, prominent graphics and text associated with this source.

Description of Units

fa - Fine-grained humic alluvium (Holocene)

Dark-gray to gray-brown silt, sand, and clay underlying swamps and flood plains of sluggish streams. Also overlies Pinedale gravel (pg, psg, pgs) in abandoned glacial drainageways, and Pinedale Till (pt) in glacial depressions. Deposits marshy, at least seasonally, and 3-10 feet thick.

sg - Stream deposits, gravel (Holocene)
gs - Stream deposits, gravelly sand (Holocene)

Buff to gray gravel, cobbles, and boulders in coarse sandy matrix (sg); poorly sorted; 5-20 feet thick. Underlies flood plains of major streams, such as South Boone and Owl Creeks, and ephemeral melt-water channels on the Pitchstone Plateau. Stones mainly 1-8 inches across, but boulders as much as 18 inches across locally. Obsidian sand (gs) with minor gravel occurs on flood plain of Bechler River below Bechler Canyon.

fg - Fan deposits, gravel (Holocene)
fs - Fan deposits, sand (Holocene)

Alluvial fans consisting predominantly of subrounded to sub-angular pebbles, cobbles, and boulders in coarse sandy matrix (fg); along upper sector of Bechler River, composed mainly of sand (fs). Buff to gray, moderately to poorly sorted, channel and fill crossbedding.

ta - Talus deposit (Holocene)

Angular to subangular rock fragments forming actively accumulating cone or sheet of rubble at base of cliff. Interstices void near surface but filled with silty sand at depth. Surface sparsely vegetated and unstable. Deposits restricted to Bechler Canyon, Birch Hills, and north end of Teton Range in Grand Teton National Park in southeastern part of quadrangle.

tf - Talus-flow deposit (Holocene)

Lobate mass of rock fragments extending out from the toe of a talus deposit (ta). Restricted to Bechler Canyon and Teton Range in southeastern part of quadrangle, mainly where spring zones at base of cliffs of rhyolite or tuff have induced solifluction of talus.

fr - Frost rubble (Holocene)

Thin mantle of slabby angular frost-shattered rubble on summit areas in southeastern part of quadrangle. Deposits 2-5 feet thick, and developed mainly on tuff of Yellowstone Group and Paleozoic limestone.

rb - Block rubble (Holocene)

Angular blocks, as much as 2 feet across, forming sloping mass of rubble 5-10 feet thick, and unrelated to cliffs. Interstices void. Deposits occur only on tuff of Yellowstone Group in southeast part of quadrangle.

ls - Landslide deposits (Holocene)

Large mass of debris, mainly derived from till-covered bedrock, that has slumped and flowed downslope from an arcuate headwall scarp. Many are developed in Mesozoic shale. Material clayey to silty containing numerous clasts and some large masses of rock, particularly in the headward part. Deposits characterized by hummocky topography, flow ridges and undrained depressions. Most are in part active at present. Hidden Lake, in southwestern part of quadrangle, is retained by an adjacent inactive landslide deposit and may represent the former position of ice or snow against which the landslide moved.

ds - Diatomaceous sediment (Holocene)

Light-gray to white, fine-grained sediment deposited in cool marshy areas around thermal springs. Composed mostly of tests of diatoms which live in the cool but highly siliceous thermal waters. Deposits mainly restricted to small areas in Bechler Meadows, but also occur in small low mounds along Mountain Ash Creek northeast of its confluence with Proposition Creek, and around thermal springs in its headwaters.

pl - Lake sediments, silt (Holocene and/or Pleistocene)
psl - Lake sediments, sand (Holocene and/or Pleistocene)
plgs - Lake sediments, gravelly sand (Holocene and/or Pleistocene)

Widespread poorly exposed silt (pl) in Bechler Meadows, Gibson Meadows, and Squirrel Meadows; sand (psl) along the lower sector of Proposition Creek and between Beula and Hering Lakes; and local small beach deposits of gravelly sand (plgs) along the north side of Bechler Meadows. Silt deposits massive to thinly laminated, locally varved. Exposed mostly in streambanks; covered by thin veneer of colluvial silt (not mapped). Probably 10 to about 20 feet thick in Bechler Meadows; only a few feet thick in Gibson and Squirrel Meadows. Between Beula and Hering Lakes, deposits form a delta which divides the once continuous lakes. Lake deposits (not mapped) also underlie fine-grained alluvium (fa) in the basins along Falls River at its confluence with Mountain Ash Creek and north of its confluence with Calf Creek (stratigraphic section 5), and in the basin of Tillery Lake along Cascade Creek (stratigraphic sections 6 and 7).

Grassy Lake Reservoir Stratigraphic Sections

pg - Stream deposits, gravel (Holocene and/or Pleistocene)
psg - Stream deposits, sandy gravel (Holocene and/or Pleistocene)
pgs - Stream deposits, gravelly sand (Holocene and/or Pleistocene)
ps - Stream deposits, sand (Holocene and/or Pleistocene)

Gray to buff sand (ps), gravel with sandy matrix (pg), sand with small amounts of gravel (pgs), and gravel with considerable sand (psg). Irregularly bedded, poorly to well sorted. The gravel (pg, psg) commonly contains cobbles and boulders as much as 1 foot in diameter. Material mostly of rhyolite, but includes some basalt in western part of quadrangle and some quartzite, limestone, dolomite, sandstone, and Precambrian crystalline rocks in drainage of South Boone Creek. Deposits underlie valley bottoms or form low terraces bordering modern flood plains. Most are glacial outwash of middle Pinedale age; some in southwestern part of quadrangle are of early Pinedale age.

pfg - Fan gravel (Holocene and/or Pleistocene)

Gray to buff sandy gravel, commonly bouldery, underlying alluvial fans graded to Pinedale stream gravel or entrenched by modern streams. Deposits form compound fan between North Boone Creek and Jackass Meadows in southwestern part of quadrangle and extend between segments of early Pinedale end moraine to merge with middle Pinedale outwash gravel (pg). In headwaters of Conant Creek, they grade up into fine alluvial silty sand (not mapped separately) as much as 10 feet thick. Along Berry Creek they extend between segments of Pinedale kame terrace deposits (pkg, pksg) and terminate in scarps above present flood plain.

pco - Colluvium (Holocene and/or Pleistocene)

Thin locally derived subangular to subrounded rubble on uplands above or beyond limits of Bull Lake ice. On Pitchstone Plateau material all of rhyolite; on uplands to southeast, mostly of tuff; around Hominy Peak, mainly of quartzite and andesite; around Survey Peak and Carrot Knoll, mainly of limestone and tuff. Deposits mostly of creep and solifluction origin; are now stable and bear a soil about 1 foot thick like that on Pinedale Till.

pta - Talus deposit (Holocene and/or Pleistocene)

Angular blocky rock fragments forming cone or sheet at base of cliff. Interstices locally void, but commonly filled with sandy material on which a thin soil like that on Pinedale Till is developed. Forest- or grass-covered; not accumulating at present.

ptf - Talus-flow deposit (Holocene and/or Pleistocene)

Lobate mass of rock fragments extending out from toe of a talus deposit (pta). Interstices at depth filled with sandy material on which a thin soil like that on Pinedale Till is developed. Deposits mainly in southeastern part of quadrangle along east-facing escarpment where spring zones at base of cliff of tuff induce flowage in underlying Mesozoic shale.

pkg - Kame deposits, gravel (Holocene and/or Pleistocene)
pksg - Kame deposits, sandy gravel (Holocene and/or Pleistocene)
pkgs - Kame deposits, gravelly sand (Holocene and/or Pleistocene)

Buff to gray gravel (pkg), sandy gravel (pksg.) containing numerous cobbles and boulders, and gravelly sand (pkgs) containing only small amounts of gravel. The coarse deposits are mostly along Berry Creek where they underlie irregular terrace segments at different levels along the valley walls. The sandy deposits are mostly along Mountain Ash Creek where they also underlie irregular terraces with ice-contact scarps. Some are in areas of thermal springs whose heat induced melting of the ice and localized the deposits.

pt - Till and rubble veneer, till (Holocene and/or Pleistocene)

Gray-brown to gray stony sandy silt; loose to compact; stones angular to subround. Deposits 5-30 feet thick; grade into thin rubble veneer (pr) on some uplands. Soil on till weakly oxidized and less than a foot thick. Till surface is smooth to hummocky; undrained depressions common in lowland areas; ice-molded topography common on uplands in Falls River Basin and in basin of Mountain Ash Creek. In northern and central parts of quadrangle, stones in till are composed almost exclusively of rhyolite except for local erratics of quartzite in central part. In west-central part till is of rhyolite and basalt. In major drainages of Teton Range, till clasts are of tuff of Yellowstone Group, Paleozoic limestone and Paleozoic and Mesozoic sandstone and shale. Precambrian crystalline rocks are present in the till only in the canyons of Grizzly Creek, Owl Creek, and, locally, of Berry Creek. An end moraine at the west end of the meadows along Berry Creek contains abundant Precambrian crystalline rocks from nearby outcrops to the east.

pr - Till and rubble veneer, rubble veneer (Holocene and/or Pleistocene)

Thin (0-5 feet) veneer of sand, and subangular to angular gravel, cobbles, and boulders on uplands, contains a few striated stones. On Pitchstone Plateau material all of local rhyolite, obsidian, and pumice. Material thickest in swales between pressure ridges of Pitchstone Plateau rhyolite flow (Rp). Locally, the obsidian crust of the flow is well striated. In west-central part of quadrangle, rubble is mainly of rhyolite, and a few erratics of quartzite; in southeastern part mainly of limestone.

bt - Till and rubble veneer, till (Pleistocene)

Gray to brown stony sandy silty till (bt) containing numerous cobbles and boulders; stones subangular to well rounded. Some boulders 4 feet in diameter. North of South Boone Creek stones are mostly of rhyolite, obsidian, tuff, and basalt; south of South Boone Creek, mostly of tuff, andesite and quartzite, with some sandstone and limestone; north of Owl Creek, mostly of limestone, tuff, and Precambrian crystalline rocks. Deposits mostly 5-10 feet thick, but thicker deposits form large lateral moraines at mouth of canyon of South Boone Creek. Oxidized soil 1.5-2 feet thick. Most of these deposits are probably of late Bull Lake age, though the highest lateral moraines along the slopes south of South Boone Creek may be of early Bull Lake age.

br - Till and rubble veneer, rubble veneer (Pleistocene)

Thin (0-5 feet) mantle of angular to subround fragments of rock debris; mostly locally derived; contains a few striated stones. Material mostly of tuff with local erratics of quartzite and obsidian north of Berry Creek and of quartzite, limestone, and Precambrian crystalline rocks southwest of Survey Peak.

bg - Gravel (Pleistocene)

Gray to brown sandy bouldery gravel forming terraces 20-30 feet above level of Pinedale gravel along inside margin of Bull Lake Till along South Boone Creek and in Jackass Meadows in southwestern part of quadrangle; locally overlain by Pinedale fan gravel (stratigraphic section 4) and separated from it by a weathered zone.
Grassy Lake Reservoir Stratigraphic Sections

Rp - Pitchstone Plateau rhyolite flow (Pleistocene)
Rbr - Bechler River rhyolite flow (Pleistocene)
Rsl - Summit Lake rhyolite flow (Pleistocene)

The northern part of the quadrangle is underlain by three flows of the Plateau Rhyolite (Christiansen and Blank, 1972) (see index map): the Pitchstone Plateau flow (Rp), K-Ar dated as about 70,000 years old, the Summit Lake flow, (Rsl), K-Ar dated at 129,000 years old, and the Bechler River rhyolite flow (Rbr), known only to be younger than 156,000 years. These rocks have been discussed and informally named by R. L. Christiansen and H. R. Blank (1972).

st - Till and rubble veneer, till (Pleistocene)

Gray to yellowish-brown stony silty sand containing locally derived boulders. Erratic stones mostly small, but large erratic boulders of granite present in deposit on northern upper slope of Conant Basin. Morainal topography rarely preserved. Deposits lie above upper limit of Bull Lake Till within canyons, and are dissected as much as 100 feet by present streams. Most are 5-10 feet thick and contain decayed stones. Weathering profile rarely well exposed. North of Bechler Meadows, at the mouth of an unnamed canyon three-fourths mile west of Lake Wyodaho, sandy till (st) of Sacagawea Ridge age crops out beneath the Summit Lake rhyolite flow (Rsl) (stratigraphic section 1), which has a K-Ar age of about 129,000 years. Here, conformably beneath the flow, the till has been stained dark orange red to a depth of 8 feet. Stones in the till are mostly of tuff and basalt. The deposit overlies older mudflow debris and tuffaceous lake sand which fill a channel cut in the 0.6-million-year-old tuff of the Yellowstone Group.
Grassy Lake Reservoir Stratigraphic Sections

sr - Till and rubble veneer, rubble veneer (Pleistocene)

Thin (0-5 feet) rubble of angular to well-rounded clasts in sandy to silty matrix; deposits in southwestern part of quadrangle between South Boone Creek and Conant Creek contain erratics of quartzite, basalt, granite, gneiss, quartz, obsidian, and sandstone.

ct - Till (Pleistocene)

Single deposit of blocky sandy silt capping ridge 1.5 miles northwest of Survey Peak. Material 100-120 feet thick; reddish; composed mainly of limestone and minor amounts of welded tuff, sandstone, and quartzite. Quartzite cobbles mostly broken, welded tuff boulders exfoliated. Limestone blocks angular to subangular; solution fretted to depth of 1/2-3/4 inch. Deposit modified by subsequent landsliding and gullying; no morainal topography preserved. Cut by present canyon of South Boone Creek. Rests on 2 million-year-old tuff of Yellowstone Group.

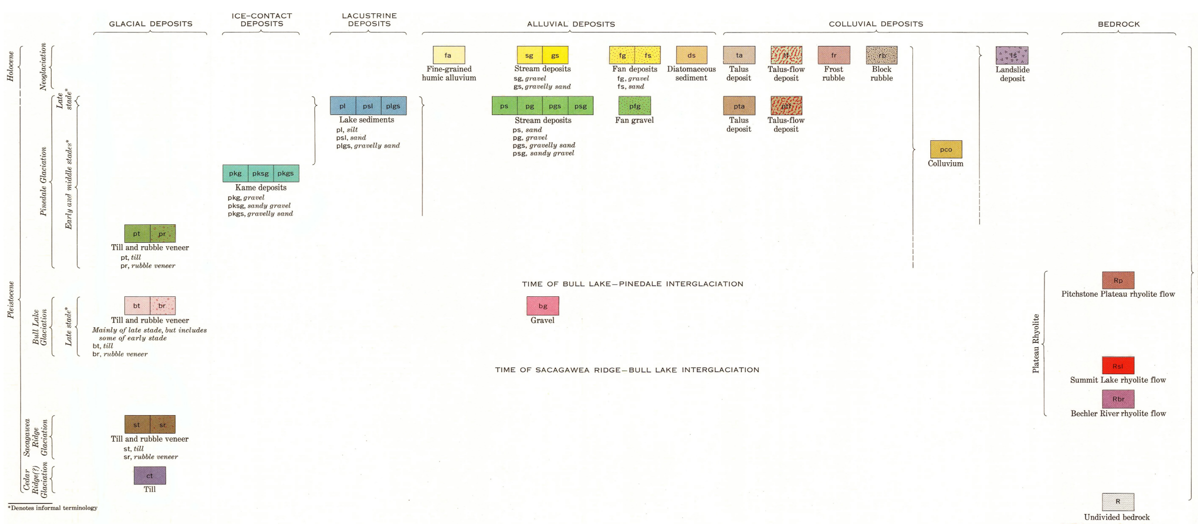
R - Undivided bedrock (Pleistocene to Precambrian)

Undivided bedrock—The north-central part of the quadrangle is underlain by a tuff of the Yellowstone Group, K-Ar dated as about 0.6 million years old, and by younger Falls River Basalt (Christiansen and Blank, 1972). Eocene intrusive rock and Paleozoic sandstone and limestone underlie the Birch Hills and the area to the southwest as far as Calf Creek. In the southern part of the quadrangle a tuff of the Yellowstone Group, K-Ar dated as about 2 million years old, overlaps older rocks of the northern end of the Teton Range. Eocene andesitic volcanic rocks, a Paleocene conglomerate of quartzite cobbles and Mesozoic sandstone and shale appear from beneath the tuff along the northeast and northwest flanks of the range. Paleozoic limestone and sandstone form most higher parts of the range, but Precambrian crystalline rocks underlie the area between Owl and Berry Creeks, northeast of Forellen Peak.

The above information on Paleozoic, Mesozoic, and Tertiary rocks is from Love and Reed (1968) and W. R. Keefer (written commun., 1970); for Quaternary volcanic rocks, it is from the Geologic Map of Yellowstone National Park (U.S. Geol. Survey, 1972). Potassium-argon (K-Ar) dates are by J . D. Obradovich.

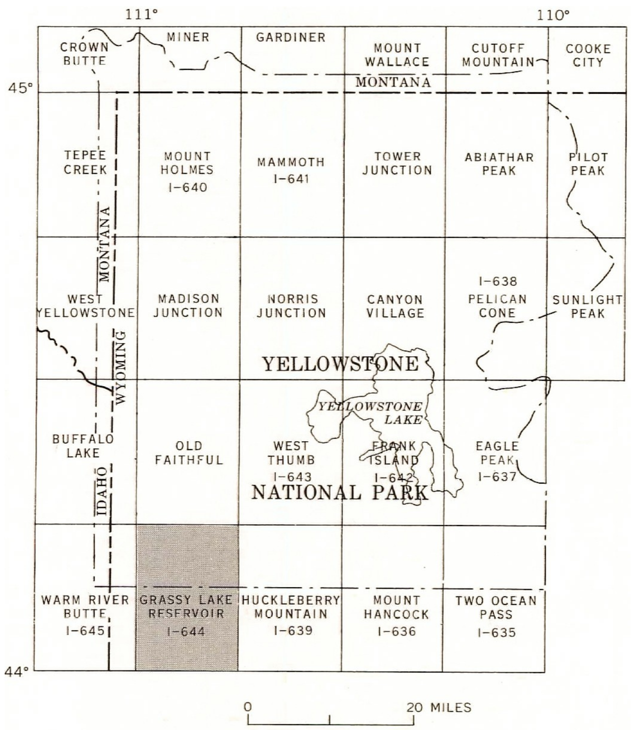
Text from source map: Grassy Lake Reservoir 15' Quadrangle

Correlation of Units



Graphic from source map: Grassy Lake Reservoir 15' Quadrangle

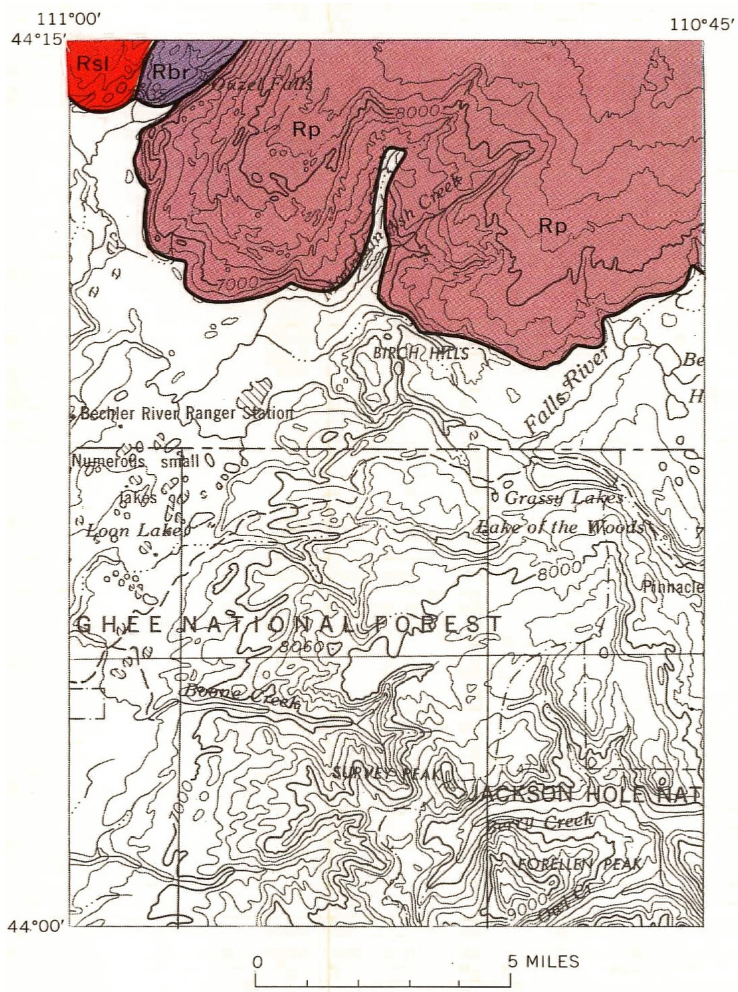
Index Map



INDEX MAP OF YELLOWSTONE NATIONAL PARK SHOWING LOCATION OF GRASSY LAKE RESERVOIR QUADRANGLE AND PUBLISHED MISCELLANEOUS GEOLOGIC INVESTIGATIONS MAPS

Graphic from source map: [Grassy Lake Reservoir 15' Quadrangle]

Rhyolite Flow Map



EXPLANATION

Letter symbols same as in map explanation

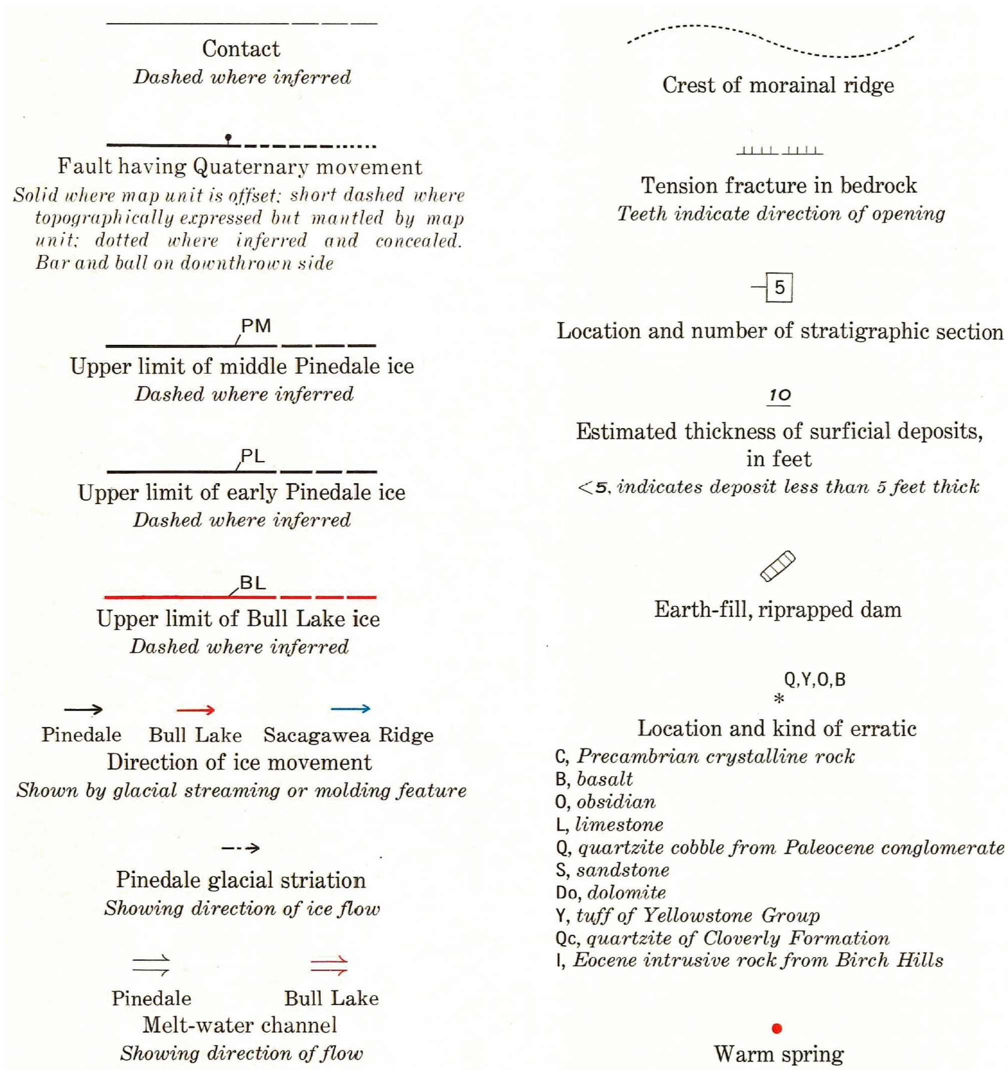
Margin of flow

MAP OF GRASSY LAKE RESERVOIR QUADRANGLE SHOWING DISTRIBUTION OF QUATERNARY RHYOLITE FLOWS
From "Geologic map of Yellowstone National Park," U.S. Geol. Survey Misc. Geol. Inv. Map I-711, 1972

See Description of Units page for this map to view information about geologic units shown on this graphic.

Graphic from source map: Grassy Lake Reservoir 15' Quadrangle

Map Legend



Graphic from source map: Grassy Lake Reservoir 15' Quadrangle

Stratigraphic Sections

Units, separated by slashes, are shown in descending order; numbers represent thickness in feet. Sections demonstrate stratigraphic relations of significant, vertically exposed units having insufficient surface area to be mapped.

Stratigraphic section locations are presented in the GRI Geologic Observation Localities (yellgol) feature class. In that feature class, the section identifier is stored in the Location ID (LOC_ID) field. The section information presented here is also contained in the Geologic Observation Localities (yellgol) feature class Notes (NOTES) field.

See Description of Units for information about map units listed here.

1. 20 Rsl /0.17 dark-gray zone/2 st, brown/8 st orange red/15 mf, orange-brown/3 sl orange/8 LT

2. 5 pt/4 organic clay containing wood/10 bl
3. 6 bl/3 bt
4. 3 pfg/2 soil/5 bg
5. 5 pfg/3 pl
6. 2 fa/2 pl
7. 3 sg/2 pl

Units shown only in these sections:

bl, lake silt and sand of late Bull Lake glacial recession and Bull Lake-Pinedale interglaciation.

mf, orange-red, massive, sandy silty mudflow debris containing angular to subrounded small pebbles of rotted Falls River Basalt, and tuff of the Yellowstone Group, many fragments of red scoria, and small chunks of pumice 1/4 inch in diameter. Deposit is irregularly intruded by seams of gray bedded lake sand squeezed up from underlying lake-sand unit.

sl, gray bedded tuffaceous lake sand.

LT, tuff of Yellowstone Group, 0.6 m.y. old.

Text from source map: Grassy Lake Reservoir 15' Quadrangle

Surficial Geologic History

INTRODUCTION
The Grassy Lake Reservoir 15' Quadrangle is half in the southwestern part of Yellowstone National Park and half in Teton National Forest, Targhee National Forest, and Grand Teton National Park. Most of the quadrangle is drained to the southwest by Bechler River, Falls River, North and South Boone Creeks, and Conant Creek. The southeastern part is drained to the southeast by Glade Creek, Berry Creek, and Owl Creek. The Pitchstone Plateau, in the north-central and northeastern parts of the quadrangle, and the Madison Plateau, in the northwestern part northwest of Bechler Canyon, are rolling glaciated uplands rising from 7,000 feet to over 8,800 feet. The southern part of the quadrangle, in Grand Teton National Park, contains peaks that rise above glaciated canyons to a maximum altitude of 9,776 feet (Forellen Peak). Local relief averages about 1,800 feet.

PLEISTOCENE GLACIATIONS
Great icecaps covered most of Yellowstone National Park (Richmond, 1970) during several different glaciations in Pleistocene time. Deposits of three and possibly four of these glaciations—from oldest to youngest: Cedar Ridge, Sacagawea Ridge, Bull Lake, and Pinedale—occur in the quadrangle. During the three younger glaciations, an icecap spread southeast from its source area in Yellowstone National Park across the northern part of the quadrangle and joined with cap ice and valley glaciers in the Teton Range. Deposits possibly related to the older glaciation, the Cedar Ridge, occur in the Teton Range.

CEDAR RIDGE(?) GLACIATION
An ancient till (ct), first recognized by Love (1956) and Love and Reed (1968, map) occurs at the head of South Boone Creek on a ridge about 11/2 miles northwest of Survey Peak at the north end of the Teton Range. The deposits, described above, are deeply weathered, lack morainal topography, and overlie the 2-m.y.-old tuff of the Yellowstone Group. They are dissected by the modern canyon of South Boone Creek, on the slopes of which is till of Sacagawea Ridge age. For these reasons, they are considered to be of pre-Sacagawea Ridge age and probably of Cedar Ridge age. The till is wholly derived from the Teton Range. Its relation to glaciers in Yellowstone Park and to the 0.6-m.y.-old tuff of the Yellowstone Group is unknown.

SACAGAWEA RIDGE GLACIATION

Till (st) and glacial rubble (sr) of the Sacagawea Ridge Glaciation occur in the southwestern part of the quadrangle. The till and rubble were deposited by an icecap which spread southwest from Yellowstone National Park into the drainage of Falls River before eruption of any of the mapped rhyolite flows, and thus on a land surface several hundred feet lower than the present surface of the Pitchstone and Madison Plateaus to the north and northwest. The ice from Yellowstone Park abutted the northwest flank of the Teton Range to altitudes as high as 7,400 feet and joined with valley glaciers from the Teton Range in the canyons of South Boone and Conant Creeks. To the west, it spread across and beyond the adjacent Warm River Butte quadrangle. South of Yellowstone National Park, the ice flowed into Jackson Hole where it merged with a large piedmont glacier formed by the coalescence of valley glaciers flowing east from the Teton Range.

SACAGAWEA RIDGE-BULL LAKE INTERGLACIATION

During the interglaciation separating the Sacagawea Ridge and Bull Lake Glaciations, interglacial weathering lead to the decay of basalt and sandstone clasts, to solution of limestone clasts, and to fracturing of quartzite clasts in till and glacial rubble of Sacagawea Ridge age. It also produced a dark red zone of oxidation and clay enrichment on the till which, though stripped from the till in most places, is locally as much as 8 feet thick (stratigraphic section 1). The Summit Lake rhyolite flow erupted over the till in the northwest corner of the quadrangle about 129,000 years ago.

BULL LAKE GLACIATION

The Bull Lake Glaciation in the Rocky Mountains includes two times of major ice development separated by a nonglacial interval (Richmond, 1965). During both glacial times, widespread icecaps formed in Yellowstone National Park. However, the deposits of these caps could not be separated stratigraphically in the Grassy Lake Reservoir 15' Quadrangle. During at least one and probably both times of Bull Lake Glaciation, ice flowed south from Yellowstone into Jackson Hole, where it merged with valley glaciers flowing east from the Teton Range. The upper limit of the ice on the northeast flank of the Teton Range, north of the elbow of Berry Creek, was at about 8,600 feet, and the thickness of the ice in the canyon of Owl Creek, at the southeast corner of the quadrangle, was about 1,500 feet. The Bull Lake Till and glacial rubble on the uplands north of Berry Creek are composed chiefly of locally derived 0.6 m.y. old tuff and include some erratics of obsidian from the base of the tuff. Westward, the deposits contain some cobbles of quartzite from conglomerate beds beneath the tuff.

The shapes of the uplands above 8,600 feet suggest that they were covered by ice, and a few erratics of obsidian occur near the summit of Mount Berry (elevation 8,957 feet). However, no erratics or other distinct evidence of glaciation were found in the areas above 8,600 feet altitude to the north and west where the surface deposits have been mapped as Pinedale colluvium (pco). It is possible that local cap ice may have covered these uplands above the upper limit of Bull Lake ice from Yellowstone Park to the north and east.

On the northwest flank of the Teton Range, Bull Lake ice from Yellowstone National Park flowed across the north rim of the canyon of South Boone Creek. Here, it was joined by ice from the Teton Range that overflowed across the divide at the head of South Boone Creek from its source in the headwaters of Berry Creek. Ice from the canyon of Berry Creek also overflowed westward across the divides north and south of Carrot Knoll into the canyons of Conant Creek and Grizzly Creek. In the canyon of Conant Creek, the ice terminated just downstream from Conant Basin. The cirquelike amphitheaters in the headwaters of South Boone and Conant Creeks are formed by the headward collapse of a cliff of the 2-m.y.-old tuff of the Yellowstone Group as a result of sapping by springs issuing at the contact of the tuff with the underlying Mesozoic shale. Tension fractures indicating the gradual continuation of this activity are well developed in the tuff along the west base of Survey Peak.

At the mouth of the canyon of South Boone Creek the upper limit of Bull Lake ice was at an altitude of about 7,000 feet. West of the canyon, the ice extended beyond the boundary of Yellowstone National Park into the adjacent Warm River Butte quadrangle. To the south, it flowed along the west base of the Teton Range at an altitude of about 6,800 feet to a southern limit along the canyon of Conant Creek.

No glacial deposits of Bull Lake age occur on the slopes of the Pitchstone Plateau rhyolite flow (Rp) (see index map). In two areas, enclosed but not covered by ice of the subsequent Pinedale Glaciation, the pressure ridges and intervening swales of the flow are unglaciated and mantled only by sparse local colluvium of Pinedale age (pco). The more westerly area is transected by numerous Pinedale melt-water channels. These areas lie in an altitude range between 7,250 and 8,400 feet, well below the 8,600 foot upper limit of Bull Lake ice from Yellowstone Park on the north slopes of the Teton Range to the south. In the Old Faithful quadrangle to the northwest, Bull Lake glacial deposits occur at altitudes as high as 8,500 feet on the surface of the Summit Lake rhyolite flow (Rsl). In the Huckleberry Mountain quadrangle (Map 1-639; Richmond, 1973) to the east, they occur as high as 9,400 feet. The low unglaciated areas on the Pitchstone Plateau flow therefore demonstrate that eruption of the flow about 70,000 years ago occurred after late Bull Lake ice had disappeared. The presence of Bull Lake glacial deposits at higher altitudes northwest and east of the limits of the flow further suggest that late Bull Lake ice from Yellowstone National Park flowed across the area now covered by the flow. At that time, the highest areas of the plateau along the northern margin of the quadrangle are estimated to have been about 300 feet lower than at present.

BULL LAKE-PINEDALE INTERGLACIATION

Eruption of the Pitchstone Plateau rhyolite flow (Rp), weathering, and deposition of certain lacustrine deposits constitute the record of the Bull Lake-Pinedale interglaciation in this quadrangle. The soil on deposits of Bull Lake age is characterized by an oxidized zone that ranges in thickness from 11/2 to 3 feet, except where stripped by subsequent erosion. Bull Lake Till, exposed beneath Pinedale Till at the southwest end of the Grassy Lake Reservoir dam bears an oxidized weathered zone 3 feet thick. Lacustrine deposits of the Bull Lake-Pinedale interglaciation are exposed on the southwest shore of Grassy Lake Reservoir (stratigraphic section 2). Here, beneath Pinedale Till, is a succession of dark-brown massive silts containing plant remains and wood dated at > 42,000 years (W2264; Meyer Rubin, written commun., 1969) in their upper part. Farther west along the reservoir shore these silts rest on the oxidized weathered zone developed on Bull Lake Till (stratigraphic section 3). These relations indicate that soil development on the till preceded formation of a shallow lake, and that the lake gradually filled to form a swamp in post-Bull Lake time before the onset of Pinedale Glaciation.

PINEDALE GLACIATION

During the last Pleistocene glaciation, the Pinedale, an icecap spread southwest from its center in Yellowstone National Park down the valley of the Snake River just east of this quadrangle to the foot of Jackson Lake (Richmond, 1969). At its maximum, the ice abutted the southeast flank of the Pitchstone Plateau at an altitude of about 8,400 feet in the Huckleberry Mountain quadrangle (Map 1-639, Richmond, 1973) adjacent to the east. Farther south, in this quadrangle, it abutted the northeast margin of the Teton Range at an altitude of about 8,250 feet. Still farther south, it merged with glaciers in the canyons of Berry and Owl Creeks in the Teton Range and at its maximum extent maintained the upper limit of ice at the mouths of these canyons at an altitude of about 8,200 feet.

The ice also flowed west across the Grassy Lake Reservoir divide, where it attained a maximum thickness of about 1,100 feet and was joined from the north by ice flowing south from a local icecap on the Pitchstone Plateau. That icecap spread radially from a center to the north on the plateau in the Old Faithful quadrangle. Its direction of flow in the Grassy Lake Reservoir 15' Quadrangle is indicated by numerous striations oriented across the structure of the Pitchstone Plateau rhyolite flow. Those at the crest of cliffs overlooking the basin of Mountain Ash Creek show that the ice flowed across the cliffs into the basin. Ice molded topography on the surface of the Pitchstone Plateau flow in the basin, previously inferred on the basis of air-photograph interpretations to represent the work of Bull Lake ice (Love, 1961; Richmond, 1964), is in fact of Pinedale age. West of the basin, a network of melt-water channels extends irregularly across the unglaciated rhyolite upland southwest of the mapped upper limit of Pinedale ice.

West of Grassy Lake Reservoir, the ice flowed across the cliffs on the east side of Falls River Basin and into that basin where it merged with another tongue of ice that flowed from the center in Yellowstone Park around the north side Pitchstone Plateau and across the south end of the Madison Plateau down Bechler Canyon into the Bechler Meadows area. Here it merged with the ice flowing west across the Grassy Lake Reservoir divide. Farther west, the combined ice mass spread into the adjacent Warm River Butte quadrangle to a terminus extending along and just beyond the southwest boundary of the park. To the south it formed a low terminal moraine along Squirrel Creek south of Squirrel Meadows.

The headwaters of South Boone and Conant Creeks contain no cirques, but a Pinedale glacier in the canyon of Grizzly Creek overflowed onto the low divide at the southeast margin of Conant Basin. Similarly a glacier in the canyon of Berry Creek overlapped into the canyon of Grizzly Creek south of Carrot Knoll and across the escarpments to the north at the heads of Conant and South Boone Creeks, below which it formed small end moraines. A small glacier, probably heading on the steep northeast face of Survey Peak, merged with the glacier in Berry Creek to the southeast and extended northwest nearly to the edge of the escarpment overlooking the canyon of South Boone Creek.

Following its maximum advance in early Pinedale time, the ice retreated an unknown distance and then readvanced one or more times during middle Pinedale time. The low moraine north of Squirrel Meadows may represent such an advance, but is mainly underlain by bedrock. The moraines east and west of Moose Lake and their extension irregularly northward mark a more definite boundary that can be traced north through the Warm River Butte quadrangle to well-developed end moraines southeast of Bechler Meadows. Analogous end moraines, formed by the ice lobe stemming from Bechler Canyon, lie west of Bechler Meadows in the Warm River Butte quadrangle. As this ice receded, the moraine southeast of Bechler Meadows impounded a lake in the meadows area where extensive silt (pl) and sand (psl) were deposited.

A lateral moraine high on the east wall of the upper valley of Berry Creek, west of Forellen Peak, probably represents an older stand of the ice in middle Pinedale time. Other lateral moraines near the floor of the canyon to the northwest mark a readvance which terminated near the center of sec. 24, T. 47 N., R. 117 W. The till in the moraines is mostly of locally derived limestone.

Along the trail between Berry Creek and Owl Creek the dipslope of Paleozoic limestone has been eroded and dissolved by subglacial melt waters to form an intricate network of closely spaced irregular channels, as much as 18 inches deep and 2-6 inches wide. Both the channels and the narrow ridges separating them are solution-cusped and pitted. Such solution phenomena are rare in the Rocky Mountains.

An end moraine at the upper end of the swampy floor of Berry Creek (SE ¼ sec. 13, T. 47 N., R. 117 W.), is also of middle Pinedale age. This moraine, moreover, is arcuate upstream as is also its ice-contact slope. The till is composed predominantly of gneiss, schist, and granite from sources immediately downstream though it includes some limestone, dolomite, and sandstone from sources upstream. The moraine extends, as a lateral, upslope to the east along the north side of the valley and is inferred to have been deposited by a readvance of ice extending up the valley of Berry Creek from the large glacier flowing south from Yellowstone Park into the Jackson Lake area. A sequence of kame terrace deposits (pkg, pksg) bordering the valley of Berry Creek below the moraine indicate subsequent stagnation of the ice in the valley.

Kame terrace deposits (pkgs) in the basin of Mountain Ash Creek were deposited following separation of the cap on the Pitchstone Plateau from Yellowstone ice on the Grassy Lake Reservoir divide.

PINEDALE PERIGLACIAL EVENTS

No glacial deposits of late Pinedale age occur in the quadrangle. However, throughout Pinedale time frost action and solifluction were active on uplands above the upper limit of Pinedale ice and produced extensive though commonly thin colluvial deposits (pco). In places these probably include reworked older glacial rubble of Sacagawea Ridge or Bull Lake age, but erratic stones were not observed in them. Talus deposits (pta) formed at the base of cliffs beyond the limits of Pinedale ice and, as the ice withdrew, formed below cliffs throughout the quadrangle. In a few places, as along Falls River east of Rainbow Falls, talus flow deposits formed as solifluction took place along the lower margins of talus deposits. None of the above deposits are now actively accumulating. Landslides occurred on some slopes, notably those underlain by soft Mesozoic shales, for example the south slopes of Conant Basin and the slopes between Glade and Berry Creeks. Some of these slides have continued intermittent activity to the present.

POST-PINEDALE EVENTS

Surficial processes active in the quadrangle since the end of the Pinedale Glaciation have produced few changes in the landscape. Most weathering and oxidation of Pinedale deposits is less than 1 foot thick and commonly only a few inches thick on rhyolitic materials. Rarely it is as much as 18 inches thick on material derived from Paleozoic and Mesozoic rocks.

There has been relatively little erosion. Bechler River has entrenched itself a few feet into Pinedale lake deposits (pi) in Bechler Meadows. South Boone, Conant, and Owl Creeks have also locally dissected their valley floors a few feet. Gravelly stream deposits (gs, sg) have been deposited at the mouth of Bechler Canyon, along South Boone and Owl Creeks, and as alluvial fans (fg) at the foot of secondary canyons throughout the quadrangle. Most streams, however, have deposited only a few feet of humic sandy silt (fa) over older Pinedale gravel (pg) on their flood plains. Similar silty deposits have formed in depressions in Pinedale Till.

Talus deposits (ta), still actively accumulating, have formed at the base of cliffs, but are not as widespread as the inactive deposits of Pinedale age. Talus flows (tf) have developed locally. At higher elevations in the Teton Range frost rubble (fr), composed of small fragments, and coarse block rubble (rb) have formed on summit uplands and are still active.

The activity of some deposits mapped as post-Pinedale in age may represent a continuation of Pinedale activity. Others appear to represent a regeneration of activity in late Holocene time following an episode of inactivity. This inactivity probably took place during the Altithermal interval prior to the climatic change which induced regeneration of small glaciers during the Neoglaciation both in the mountains of Yellowstone National Park and in the Teton Range. However, no glacial deposits of Neoglacial age occur in this quadrangle.

QUATERNARY NORMAL FAULTS

The normal faults shown were mapped in cooperation with R. L. Christiansen who is studying the Quaternary volcanic rocks of the area. They are probably incompletely mapped in the southern part of the quadrangle. Quaternary movement along faults which trend northward in the southeastern part of the quadrangle was probably associated with uplift of the Teton Range. The displacements appear to be only a few tens of feet. Those near Beula and Hering Lakes have been discussed by Love (1961). They do not offset, and are probably older than, the Pitchstone Plateau rhyolite flow (Rp). The faults that trend southwestward in the central part of the quadrangle are probably related to collapse of the caldera associated with the eruption of the Lava Creek Tuff 600,000 years ago.

Text from source map: Grassy Lake Reservoir 15' Quadrangle

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References from source map: Grassy Lake Reservoir 15' Quadrangle

Huckleberry Mountain 15' Quadrangle

The formal citation for this source.

Richmond, Gerald M., 1973, Surficial Geologic Map of the Huckleberry Mountain Quadrangle, Yellowstone National Park and adjoining area, Wyoming: U.S. Geological Survey, Miscellaneous Investigations Series Map I-639, scale 1:62,500 (*GRI Source Map ID 1141*).

Description of geologic units, prominent graphics and text associated with this source.

Description of Units

fa - Fine-grained humic alluvium (Quaternary, Neoglaciation)

Dark-gray to gray-brown silt, sand, and clay; underlies older parts of flood plains and glacial depressions; commonly marshy; mostly 5-10 feet thick; overlies stream gravel (sg) along flood plains and till (pt) in glacial depressions.

sg - Stream gravel (Quaternary, Neoglaciation)

Gravel, cobbles, and boulders in coarse sand matrix. Underlies bed of Snake River, its adjacent low terraces, and flood plains of other streams. Clasts are mainly 1-6 inches across but locally exceed 1 foot. Deposits are buff to gray, well sorted, poorly bedded, and include some beds of sand and silty sand.

fg - Fan gravel (Quaternary, Neoglaciation)

Alluvial fans which consist predominantly of subrounded to subangular gravel but which contain sandy and silty beds, especially toward their lower margin. Gravel is buff to gray, moderately to poorly sorted; channel-and-fill crossbedding.

ta - Talus deposit (Quaternary, Neoglaciation)

Angular to subangular rock fragments that form cone or sheet of rubble at base of cliff. Interstices void near surface, filled with silty sand at depth. Sparsely vegetated and unstable. Deposits on Wildcat Ridge are silty and contain small angular clasts.

tf - Talus-flow deposit (Quaternary, Neoglaciation)

Lobate mass of rock fragments that extends out from toe of a talus as a result of flowage. Single deposit in cirque in northeast part of quadrangle.

fr - Frost rubble (Quaternary, Neoglaciation)

Thin mantle of angular slabby rubble of rhyolite on upland in northeast part of quadrangle.

rb - Block rubble (Quaternary, Neoglaciation)

Angular to slabby blocks that form a sloping sheet of rubble on tuff of the Yellowstone Group along south side of Snake River above confluence with Lewis River. Deposits 3-10 feet thick; interstices void in upper part.

sd - Solifluction deposit (Quaternary, Neoglaciation)

Buff coarse to fine stony sandy silt, unsorted and unsized; forms lobes and lobate depositional terraces that encroach over terraced stream gravel (sg) deposits at foot of north-facing slopes along Snake River. Some deposits seasonally active, others may be as old as middle Pinedale. Most deposits derived from Pinedale Till (pt), and many deposits mapped as Pinedale Till have moved downslope by subsequent solifluction.

ls - Landslide deposit (Quaternary, Neoglaciation)

Large mass of debris including both till (pt) and bedrock that has slumped and flowed downslope from an arcuate headwall scarp. Material is clayey to silty with numerous large and small clasts. Matrix derived mainly from Cretaceous shale. Deposits characterized by steep hummocky topography, flow ridges, and undrained depression.

ds - Diatomaceous sediment (Quaternary, Neoglaciation)

Light-gray to white, fine-grained sediment deposited in cool marshy areas downslope from thermal springs. Composed predominantly of tests of diatoms which live in the cool but highly siliceous thermal waters. Particularly widespread in drainages of Polecat, Crawfish, and Spirea Creeks.

pg - Stream, sand, and gravel, gravel (Holocene and/or Pleistocene)
psg - Stream, sand, and gravel, sandy gravel (Holocene and/or Pleistocene)
ps - Stream, sand, and gravel, sand (Holocene and/or Pleistocene)

Gray gravel (pg) underlying stream terraces 10-60 feet above present drainage. Irregularly bedded, well sorted, well rounded. Contains cobbles and boulders as much as 1 foot in diameter, and moderate amounts of sand, mostly medium to coarse grained. Deposits along Snake River near Flagg Ranch are notably sandy (psg). In places they form two outwash terraces, locally containing kettles. All deposits probably of middle Pinedale age. Gravel deposits (pg) in headwaters of Polecat Creek are bouldery, composed mostly of obsidian, rhyolite, and pumice, and occur in bedrock channels cut marginally to ice. Sand deposits (ps) on Pitchstone Plateau near Phantom Campsite are composed of medium-grained pumice and obsidian sand. B-horizon of soil on all deposits is about 1 foot thick.

pfg - Fan gravel (Holocene and/or Pleistocene)

Gray to tan sandy gravel underlying steeply sloping alluvial fans graded to Pinedale stream gravel deposits (pg). Material poorly sorted, irregularly bedded, poorly to well rounded. Incised by modern drainage. All probably of middle Pinedale age. B-horizon of soil on deposits is about 1 foot thick.

pco - Colluvium (Holocene and/or Pleistocene)

Rock rubble that locally mantles slopes beyond limit of the Pinedale icecap. In southeast part of area, consists mostly of sandstone fragments, or of quartzite cobbles in a silty matrix. In high mountain basins, commonly includes small unmapped and locally active solifluction and nivation deposits. In northwest part of quadrangle, material consists of subangular to subrounded fragments of rhyolite, obsidian, and pumice in a sandy pumiceous matrix. These materials are derived by weathering, solifluction, and creep from underlying pumice and rock of Pitchstone Plateau rhyolite flow. Deposits bear weakly oxidized soil as much as 3 feet thick that locally grades down into underlying pumice.

pta - Talus deposit (Holocene and/or Pleistocene)

Angular blocky deposits of rock fragments that form a cone or sheet at base of cliff. Interstices locally void in upper part, but commonly filled with sandy material. Forest or grass covered. Not now accumulating.

ptf - Talus-flow deposit (Holocene and/or Pleistocene)

Single large deposit of coarse blocky tuff fragments of Yellowstone Group that forms lobate mass extending downslope from foot of talus along north and east sides of Huckleberry Mountain. Deposit is stable and bears a soil about 1 foot thick. Overlies shaly Cretaceous bedrock.

pkg - Kame deposits, kame gravel (Holocene and/or Pleistocene)

pksg - Kame deposits, kame sandy gravel (Holocene and/or Pleistocene)

Buff to gray gravel (pkg) and sandy gravel (pksg) underlying terraces that have local ice-contact scarps. Deposits irregularly bedded and poorly to well sorted; display abrupt changes in texture. Material is well rounded; contains cobbles and boulders 6-18 inches across. Along east side of Jackson Lake the deposits merge northward into a lateral moraine.

pt - Till (Holocene and/or Pleistocene)

Gray-brown to gray, stony clayey sandy silt; loose to compact; stones angular to subround. Deposits 5-30 feet thick; grade into thin glacial rubble (pr) on some uplands. Surface smooth to hummocky; undrained depressions common in lowland areas; ice-molded topography common on uplands. In eastern part of quadrangle deposits are clayey and contain abundant shale and sandstone clasts; in southeastern part, they contain abundant quartzite cobbles. In western and northern parts, deposits are sandy and clasts are mostly of rhyolite. A recessional lateral moraine lies along the east side of Jackson Lake. Erratics of crystalline rocks, derived from the Teton Range, occur in this moraine as far north as 11/2 miles south of the National Forest boundary.

pr - Glacial rubble (Holocene and/or Pleistocene)

Thin (0-5 ft) veneer of sand, gravel, cobbles, and boulders that locally contains striated stones and erratics on uplands of Huckleberry Ridge and Red Mountains. Includes small exposures of bedrock. On Pitchstone Plateau, consists of patches of till including local small end moraines and sparse veneer of gravel, cobbles, and boulders of locally derived obsidian and rhyolite in pumiceous matrix. Some stones are glacially shaped or striated. Deposits rest on glacially striated upland characterized by closely spaced pressure ridges and elongate interridge depressions of underlying rhyolite flow. Ridges are forested; interridge depressions are grass covered. Soil on till has weakly oxidized B-horizon about 1 foot thick.

bkl - Ice-dammed lake silt (Pleistocene)

Gray to blue-gray laminated silt and sand that contains white pumiceous sand layers and, in its lower part, scattered pebbles and cobbles of tuff of the Yellowstone Group, quartzite cobbles from a Paleocene conglomerate, and Eocene andesite. Deposits are along Coulter Creek near east boundary of quadrangle, are about 20 feet thick, and occur 20-40 feet above the stream. They are overlain by Pinedale Till (pt) that contains fragments from the pumice beds.

bt - Till (Pleistocene)

Gray to brown stony sandy silt; nonbedded, unsorted, compact. Stones are subangular to well rounded; locally striated; most are of locally derived sandstone and quartzite cobbles but some are erratics of tuff of Yellowstone Group. Deposits are in southern part of quadrangle where they form a continuous ground moraine east of Bailey Creek and small patches along steeply dissected slopes of tributaries of Pilgrim Creek in southeast part. They lie beyond outer limit of Pinedale Till (pt) and locally above Pinedale gravel deposits (pg) on valley floor. In places they bear partly stripped well-oxidized soil 1-2 feet thick.

br - Glacial rubble (Pleistocene)

Thin mantle of rock debris in sandy to silty clay matrix. In drainage of Pilgrim Creek material composed mostly of fractured and whole quartzite cobbles and pebbles, and sparse erratic stones of Eocene andesite. East of Bailey Creek, material composed mostly of angular to subangular sandstone fragments and local erratics of Eocene andesite, quartzite and rhyolite tuff of Yellowstone Group. Deposits on Huckleberry Mountain, mostly of local rhyolite tuff of Yellowstone Group but contain a few erratics of Eocene andesite. Deposits lie above or beyond outer limit of the Pinedale icecap and are mostly less than 5 feet thick.

bg - Gravel (Pleistocene)

Gray to tan outwash gravel composed mostly of quartzite cobbles and boulders derived from a Paleocene conglomerate. Underlies terrace about 40 feet above Pilgrim Creek along south boundary of quadrangle. Material is well rounded, obscurely bedded, at least 40 feet thick.

Rp - Pitchstone Plateau rhyolite flow (Pleistocene)

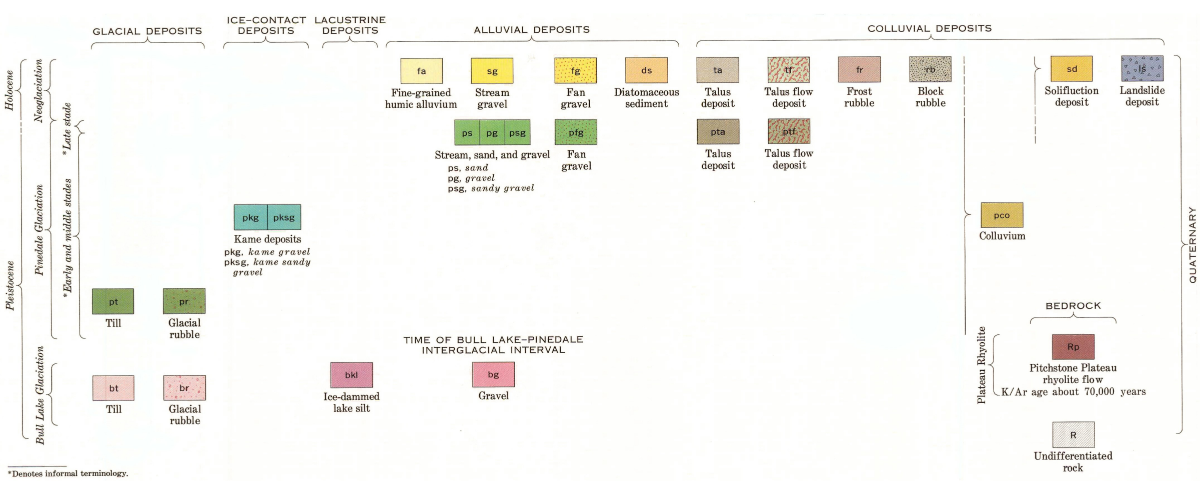
Obsidian rhyolite dated by K-Ar method at about 70,000 years old; forms the Pitchstone Plateau. (see index map).

R - Undifferentiated rock (Quaternary to Paleozoic)

The quadrangle is underlain by a variety of bedrock types. Paleozoic limestone, sandstone, and shale occur south of Snake River and east of the park entrance, south of Red Mountains, and west of Jackson Lake. Soft Mesozoic and Paleocene shale, sandstone, and conglomerate underlie the entire southeast part of the quadrangle, the area south of Glade Creek, and the southeast slope of the Red Mountains. Andesitic mudflows of the Absaroka Volcanic Supergroup of Eocene age occur between Snake River and Harebell Trail. Tuff of the Yellowstone Group underlies most of the Red Mountains and the region east and west of Lewis River. In these areas, it consists of two units, one 2.0 million years old, the other 0.6 million years old. The bedrock has been mapped by R. L. Christiansen, J. D. Love and W. R. Keefer. (U.S. Geological Survey, 1972). Potassium-argon (K/Ar) dates are by J. D. Obradovich (written commun., 1972).

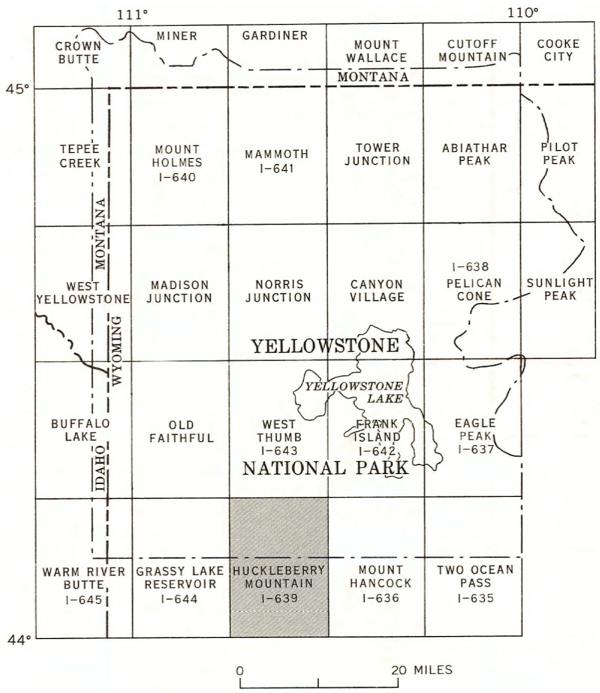
Text from source map: Huckleberry Mountain 15' Quadrangle

Correlation of Units



Graphic from source map: Huckleberry Mountain 15' Quadrangle

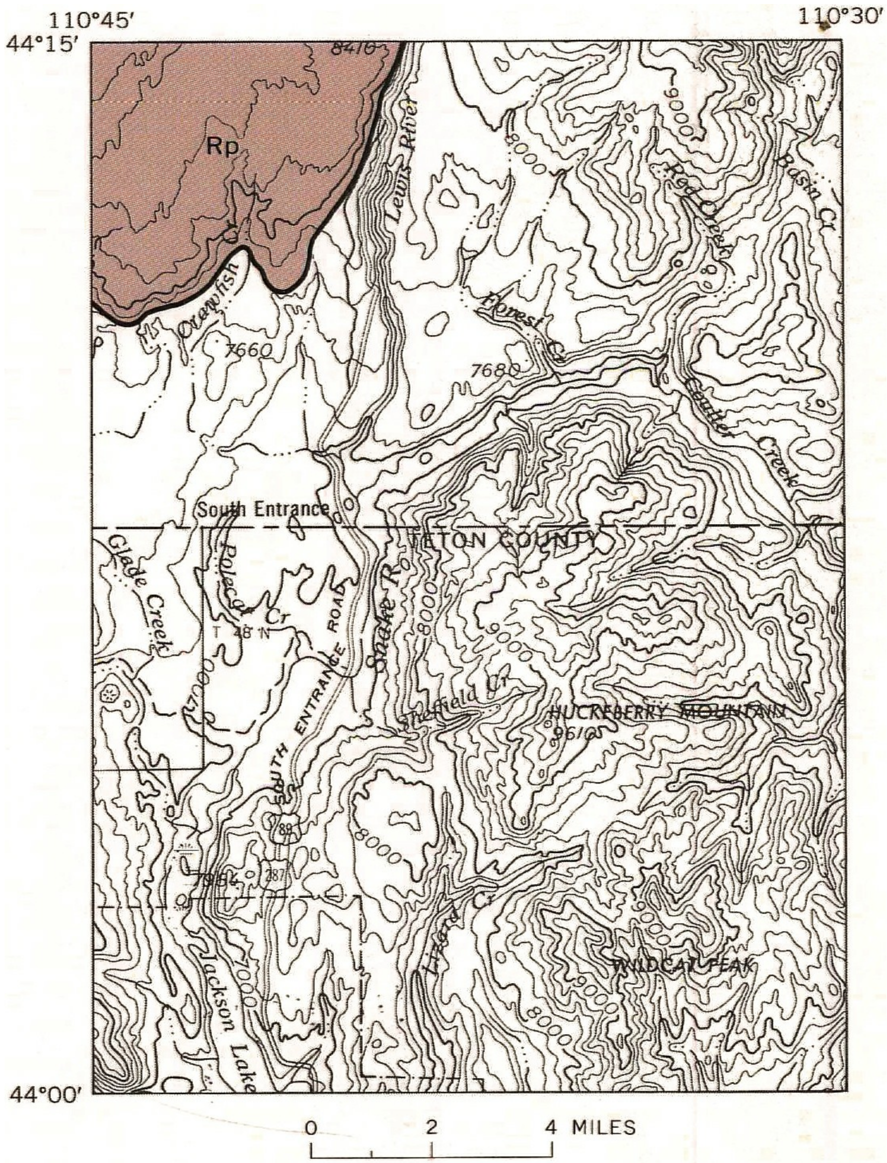
Index Map



INDEX MAP OF YELLOWSTONE NATIONAL PARK SHOWING LOCATION OF HUCKLEBERRY MOUNTAIN QUADRANGLE AND PUBLISHED MISCELLANEOUS GEOLOGIC INVESTIGATIONS MAPS

Graphic from source map: Huckleberry Mountain 15' Quadrangle

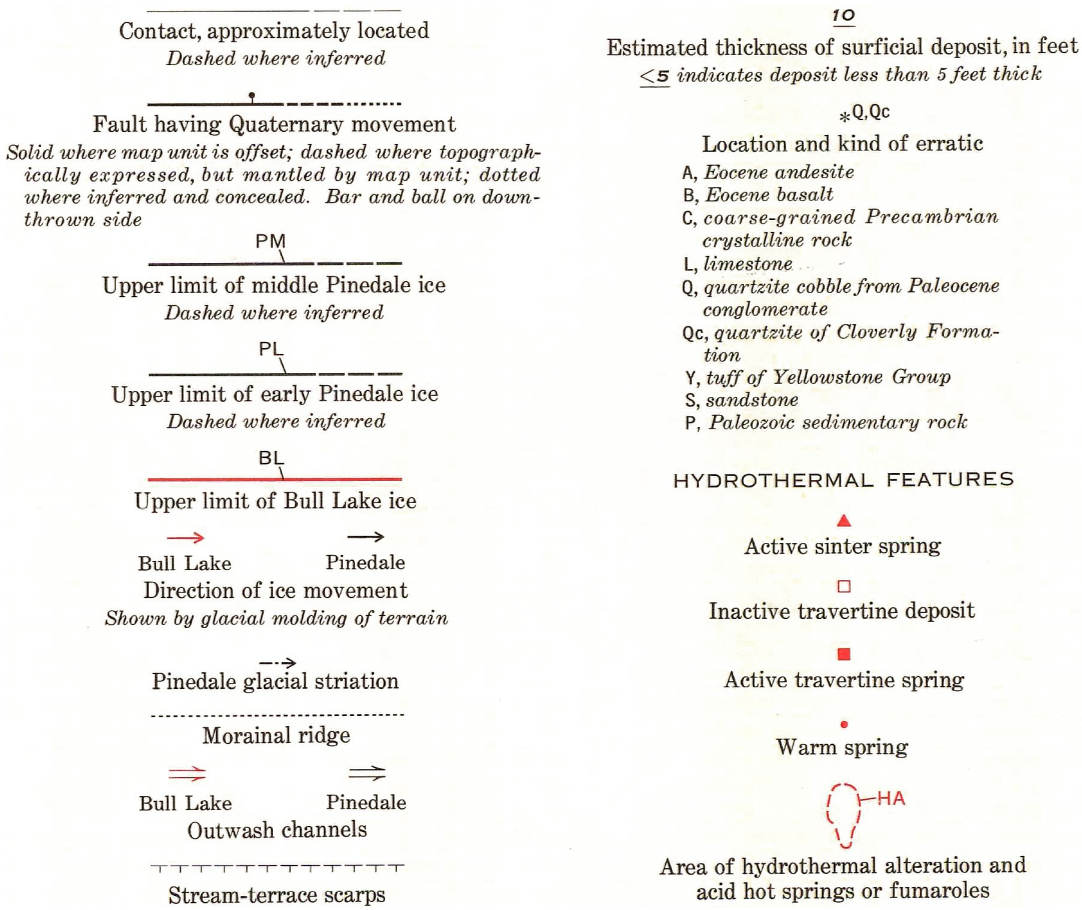
Rhyolite Flow Map



See [Description of Units]() page for this map to view information about geologic units shown on this graphic.

Graphic from source map: [Huckleberry Mountain 15' Quadrangle]()

Map Legend



Graphic from source map: Huckleberry Mountain 15' Quadrangle

Surficial Geologic History

INTRODUCTION

The north half of the Huckleberry Mountain 15' Quadrangle lies in the southern part of Yellowstone National Park, the south half in Teton National Forest and northern Teton National Park. Most of the area is drained southwest by the deep valley of the Snake River and its tributaries to Jackson Lake. The southeast part is drained to the south by Arizona Creek, Bailey Creek, and the headwaters of Pilgrim Creek. The drainage divides the quadrangle into five upland units. Huckleberry Ridge (culminating in Huckleberry Mountain, elev. 9,615 ft.) occupies the central part; the Red Mountains lie to the northeast, the Pitchstone Plateau to the northwest, the flank of the Teton Range to the southwest, and the dissected masses of Wildcat Ridge and Wildcat Peak (elev. 9,693 ft.) to the southeast. Local relief is as much as 2,000 feet between major valley floors and upland summits.

PLEISTOCENE GLACIATIONS

Although great icecaps covered most of Yellowstone Park and adjacent areas during several different glaciations in Pleistocene time, deposits of only two of these glaciations (from oldest to youngest, the Bull Lake and Pinedale) occur in the quadrangle. During each, an icecap flowed southwest across the quadrangle into Jackson Hole from sources in the mountainous headwaters of the Yellowstone River and the basin of Yellowstone Lake.

BULL LAKE GLACIATION
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Small glaciers may have existed in cirques in the Red Mountains and on Wildcat Peak in late Pinedale time, but no deposits of such glaciers were found. No glaciers existed in the quadrangle in Neoglacial time.

Post-glacial frost riving and solifluction. —During wasting of the Pinedale icecap and in late Pinedale time, frost-riving of freshly exposed cliffs of hard rock formed deposits of talus (pta) at their base. Such deposits are widespread in cirques in the Red Mountains and below cliffs that border the valley of the Snake River, the canyon of Lewis River, and the north and east sides of Huckleberry Mountain and its extension to the south. These deposits are now stable and mostly forested. Actively accumulating talus occurs only locally in cirques in the Red Mountains, in the canyon of Lewis River, and as minor deposits (not mapped) beneath cliffs at the heads of some landslides.

Solifluction, also, was widespread during recession of the Pinedale ice and in late Pinedale time. Many deposits mapped as till (pt) have, in fact, flowed downslope after original deposition by the ice. Mapped solifluction deposits are mainly those that have flowed out over terrace gravels (pg) of Pinedale age as lobate sheets with steep fronts 5-15 feet high. Others, such as those in the high southwest-facing basins on Wildcat Ridge, are hummocky nivation deposits. On the north and east sides of Huckleberry Mountain and its extension to the south, solifluction of the shaly bedrock under saturated conditions in late glacial time has carried talus accumulations downslope from the cliff base to form an extensive but relatively thin blocky lobate sheet mapped as talus flow deposit (ptf). All these solifluction deposits are now stable and forested, but minor movements continue along the steep fronts of some deposits at the base of north-facing steep valley walls.

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Many large landslide deposits (ls) occur in the quadrangle, a result of oversteepening of slopes by glacial scour in Pinedale time and of widespread saturation of bentonitic shale bedrock and shale-derived till mantle during and after Pinedale deglaciation. The lower parts of the large landslides along the Snake River south of Flagg Ranch contain bedded gravel, suggesting that these and other landslides in the quadrangle may have slumped against or over stagnant ice. Others appear to be of postglacial origin, some in relatively recent time. Most of the landslides appear to have originated as coherent masses along single arcuate planes of failure. However, the masses broke up to form earth flows as movement progressed. Large blocks and multiple arcuate scarps locally indicate some headward progression or lateral extension by successive failures. Internal slump scarps, enclosed depressions, and lobate surface forms are evidence of secondary movements, and parts of nearly all of the landslides still move slowly, at least seasonally.

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The north half of the Huckleberry Mountain 15' Quadrangle lies in the southern part of Yellowstone National Park, the south half in Teton National Forest and northern Teton National Park. Most of the area is drained southwest by the deep valley of the Snake River and its tributaries to Jackson Lake. The southeast part is drained to the south by Arizona Creek, Bailey Creek, and the headwaters of Pilgrim Creek. The drainage divides the quadrangle into five upland units. Huckleberry Ridge (culminating in Huckleberry Mountain, elev. 9,615 ft.) occupies the central part; the Red Mountains lie to the northeast, the Pitchstone Plateau to the northwest, the flank of the Teton Range to the southwest, and the dissected masses of Wildcat Ridge and Wildcat Peak (elev. 9,693 ft.) to the southeast. Local relief is as much as 2,000 feet between major valley floors and upland summits.

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Text from source map: (Huckleberry Mountain 15' Quadrangle).

References

Love, J. D., 1961, Reconnaissance study of Quaternary faults in and south of Yellowstone National Park, Wyoming: Geol. Soc. America Bull., v. 72, no. 12, p. 1749-1764.

U.S. Geological Survey, 1972, Geologic map of Yellowstone National Park: U.S. Geol. Survey Misc. Geol. Inv. Map I-711.

References from source map: Huckleberry Mountain 15' Quadrangle

Madison Junction 15' Quadrangle

The formal citation for this source.

Waldrop, H. A., and Pierce, Kenneth L., 1975, Surficial Geologic Map of the Madison Junction Quadrangle, Yellowstone National Park, Wyoming: U.S. Geological Survey, Miscellaneous Investigations Series Map I-651, scale 1:62,500 (*GRI Source Map ID 1142*).

Description of geologic units, prominent graphics and text associated with this source.

Description of Units

fa - Fine-grained humic alluvium (Quaternary, Neoglaciation)

Dark-gray to light-brown silt, sand, and humus deposited in seasonal marshes on stream flood plains, poorly drained meadows, and in a few closed depressions on till and flow top. 1 to about 10 feet (0.3-3 m) thick.

sg - Stream gravel (Quaternary, Neoglaciation)

Gray to brown sand, pebbles, and cobbles of lithoidal and obsidian rhyolite and Lava Creek Tuff of the Yellowstone Group. Underlies small discontinuous flood plains along Madison and Firehole Rivers and smaller streams. 2 to more than 20 feet (0.6-6.1 m) thick.

fg - Fan gravel (Quaternary, Neoglaciation)

Grayish-brown cobbly to sandy gravel forming alluvial fans at base of slopes. Deposits poorly sorted, crudely bedded. 10 to more than 50 feet (3-15 m) thick.

st - Scree deposit of tuff rubble (Quaternary, Neoglaciation)

Light-brown sand-and small pebble-sized fragments of stony rhyolite forming sheets of scree over bedrock slopes and aprons below outcrops. Actively accumulating; nonforested; bears sparse lichens; much of deposit exhibits downslope creep. 2-20 feet (0.6-6.1 m) thick.

ls - Landslide deposit (Quaternary, Neoglaciation)

Earthflow in Secret Valley that displaces alluvial fan deposits composed chiefly of Lava Creek Tuff of the Yellowstone Group. Material is silica-impregnated from hydrothermal action; contains stems, twigs, and branches. Of historic age.

es - Eolian sand (Quaternary, Neoglaciation)

Buff sand along north rim of Madison Canyon. Consists of rhyolite grains blown from cliffs of rhyolite up onto forested flats. 5-15 feet (1.5-4.5 m) thick.

tr - Travertine (Quaternary, Neoglaciation)

Light-gray porous deposit of calcium carbonate. Forms mounds around Terrace Spring and near Firehole Lake. Includes areas of active deposition. As much as 50 feet (15 m) thick.

ds - Diatomaceous silt (Quaternary, Neoglaciation)

White to light-brownish-gray silt composed largely of diatom tests; includes minor clay and fine sand; deposited in marshy areas associated with hot springs in Lower and Midway Geyser Basins. About 1-15 feet (0.3-4.5 m) thick.

si - Siliceous sinter (Quaternary, Neoglaciation)

Chiefly in Lower and Midway Geyser Basins. White to light-gray deposits of amorphous silica forming rims and cones of hot springs and geysers; unit includes low-gradient alluvial fans composed predominantly of sinter fragments; locally includes small patches of sandy gravel (psg) cemented by siliceous sinter. 2-20 feet (0.6-6.1 m) thick.

pg - Stream deposits, gravel (Holocene and/or Pleistocene)
psg - Stream deposits, sandy gravel (Holocene and/or Pleistocene)
ps - Stream deposits, sand (Holocene and/or Pleistocene)
pfg - Stream deposits, fan gravel (Holocene and/or Pleistocene)

Gray to light-brown, moderately to well sorted and stratified, unconsolidated sand (ps), gravel (pg), sandy gravel (psg), and fan gravel (pfg). Gravel is predominantly stony rhyolite; sand is mostly obsidian. Sand and gravel form alluvial terraces and fills along streams. Fan gravel (pfg) between the mouth of Madison Canyon and Maple Creek forms broad, low-gradient outwash fans that lap up onto the older Pinedale terminal moraines and ground moraine. Elsewhere, the fan gravel forms poorly sorted crudely bedded steep fans at the foot of slopes. Locally, such fans include small amounts of Neoglacial fan deposits at the fan head; many are incised by modern streams. 2-30 feet (0.6-9.1 m) thick.

pco - Colluvium (Holocene and/or Pleistocene)

Light-brown silt and small-pebble-sized fragments of stony rhyolite derived from underlying tuff bedrock. Occurs on sloping uplands north of Madison Canyon. Near northeast margin of deposit includes some basalt fragments derived from patches of basalt bedrock. Evidence for glaciation in this area, such as erratics or scour features, was not noted. Mostly stable, but probably affected by frost processes in Pinedale time, when nearly surrounded by ice. Generally 2-5 feet (0.6-1.5 m) thick and gradational into underlying tuff.

pta - Talus deposit (Holocene and/or Pleistocene)

Angular to subangular rubble, chiefly rhyolite, in blocks 0.5-4 feet (15-122 cm) in diameter, and fine-grained matrix at depth but contains voids near surface; forms steep fans or aprons along valley sides below cliffs. Inactive and supports lichen cover on blocks but little or no tree cover. Locally includes small amounts of Neoglacial and historic rock-fall rubble. As much as 50 feet (15.2 m) thick.

ptf - Talus-flow deposit (Holocene and/or Pleistocene)

Similar to talus deposit but has concentric flow ridges parallel to front that indicate downslope movement. Inactive at present.

pst - Scree deposit of tuff rubble (Holocene and/or Pleistocene)

Hackly small-pebble-sized fragments of stony rhyolite forming sheets of scree over bedrock slopes and aprons below outcrops. Commonly stable and forested; locally surface fragments exhibit downslope creep. 2-20 feet (0.6-6.1 m) thick.

prb - Block rubble (Holocene and/or Pleistocene)

Large angular blocks forming barren open rubble north of Madison Canyon; fine-grained matrix may occur near base of deposit. Inactive;lichen covered. 5-10 feet (1.5-3 m) thick.

phe - Hydrothermal-explosion deposit (Holocene and/or Pleistocene)

(Data from Muffler and others, 1971, p. 725-731.) Rubble formed by a steam explosion in surficial deposits triggered by abrupt decrease in confining pressure. In Lower Geyser Basin, where Fountain freight road crosses the Firehole River, the rubble forms a well-defined crater with steep inner and gentle outer slopes; the rubble is composed of angular fragments of tough, quartz-cemented, yellow-stained sandstone, siltstone, and conglomerate and a few cobbles of rhyolite. Most fragments are less than 1 foot (0.3 m), but a few blocks are 6-8 feet (1.8-2.4 m) in diameter. The deposit east of Twin Buttes has a less regular form, although the small lakes there occupy the central part of the crater. The rubble there is composed of opal-cemented sandstone and conglomerate derived from cemented kame gravels of Bull Lake age. Much of the Twin Buttes deposit was emplaced by landsliding as well as by direct airfall.

plo - Loess (Holocene and/or Pleistocene)

Buff silt and some sand and clay. Mantles deposits of Bull Lake age north of Madison River. Three to 10 feet (0.93 m) thick. Thinner loess mantle is present but not mapped on other pre-Pinedale deposits. Post-Bull Lake soil developed on or in lower part of loess; soil commonly mantled with 1-2 feet (30-61 cm) of loose silt presumably of early Pinedale age.

pksg - Kame deposits, sandy gravel (Holocene and/or Pleistocene)
pkgs - Kame deposits, gravelly sand (Holocene and/or Pleistocene)
pkf - Kame deposits, fan gravel (Holocene and/or Pleistocene)
peg - Kame deposits, esker gravel (Holocene and/or Pleistocene)

Light-gray to brownish-gray poorly sorted, crudely to moderately well bedded sandy gravel (pksg), gravelly sand (pkgs), fan gravel (pkf), and esker gravel (peg). Five to more than 100 feet (1.5-30.5 m) thick. Deposited by ice-marginal and melt-water streams. Commonly unconsolidated; characterized by great variation in texture, sorting, and stratification, by postdepositional slumping, by crevasse-fill ridges, and by kettles. Composed almost entirely of rhyolite. Form numerous large mound kames in and around Midway and Lower Geyser Basins and covers smaller areas near Buffalo Meadows, White Creek, and along the Madison and Gibbon Rivers.

pt - Till and rubble veneer, till (Holocene and/or Pleistocene)

Angular to subround boulders and cobbles in silty to sandy matrix; unsorted and nonstratified. In most of the quadrangle the till is composed almost entirely of rhyolite but locally bears sparse erratics of basalt, granite gneiss, and andesite. Near Cougar Creek and northward the till has a clayey to sandy matrix, contains numerous basalt boulders, and bears sparse erratics of Tertiary andesitic intrusive rock, Precambrian crystalline rock, and Paleozoic limestone and quartzite. In most places the till forms ground moraine less than 10 feet (3 m) thick. At the mouth of Madison Canyon it forms a well-developed multiple terminal moraine with ridges 20-40 feet (6.1-12.2 m) high. The moraine surface there is not bouldery, but the interior contains small- to medium-sized rhyolite boulders in a silty matrix. At the mouth of Cougar Creek the till forms a multiple terminal moraine with sharp bouldery ridges, 10-50 feet (3-15 m) high; the boulders are dominantly basalt. The Madison Canyon terminal moraine has been incised and the trenches filled with Pinedale outwash gravel (pg). North of Cougar Creek the till is overlapped by fan gravel (pfg) within the inferred outer limit of Pinedale Glaciation (PL). Pinedale Till has little or no loess mantle. Where composed of rhyolitic sand and silt, the till has weakly developed soil less than 1 foot (30 cm) thick. Clayey till in the northwestern part of the quadrangle has somewhat thicker, better developed soil.

pr - Till and rubble veneer, rubble veneer (Holocene and/or Pleistocene)

Thin (<5 ft or 1.5 m) and largely discontinuous mantle of locally derived rubble, predominantly rhyolite, but locally bearing several basalt erratics, on areas of glaciated bedrock. In part glacially deposited; in part the product of rock weathering and mass wasting.

bksg - Sandy kame gravel (Pleistocene)

Brownish-gray unconsolidated gravel composed mainly of rhyolite and obsidian; lies on the West Yellowstone rhyolite flow (Ry) and at the west side of Lower Geyser Basin. Contains occasional cobbles of sandstone and pebble conglomerate that probably were derived from cemented gravel deposits (bkc) of early(?) Bull Lake age. Ranges from less than 10 to more than 200 feet (3-61 m) thick. Lower part of gravel near Twin Buttes contains well-sorted fine sand that may have been deposited in a proglacial lake. Locally appears to grade laterally into hydrothermally cemented kame gravel (bkc). Most of the gravel is of late(?) Bull Lake age, but the upper part has been reworked during Pinedale incision and colluviation, giving the gravel a surface veneer of Pinedale age (indicated by an overprint on the map).

bkc - Cemented kame gravel (Pleistocene)

Gray to brownish-gray sandstone and conglomerate composed almost entirely of rhyolite clasts. Firmly cemented with opal and zeolites by hydrothermal action. At Porcupine Hills and other mound kames in Lower Geyser Basin the conglomerate is characterized by great variation in texture, sorting, stratification, and local postdepositional slumping typical of ice-contact deposition. In those areas the gravel could be of early(?) or late(?) Bull Lake age. At Twin Buttes and on the West Yellowstone rhyolite flow, the conglomerate is of late(?) Bull Lake age. It is characterized by regular cross-stratification, lateral continuity of sets of cross-strata, and lack of slump structures that all suggest normal alluvial deposition. It contains pebbles to boulders of cemented sand and gravel derived from a pre-existing conglomerate. Total thickness of cemented gravel at Twin Buttes is more than 250 feet (76 m).

bkg - Kame gravel (Pleistocene)

Brownish-gray gravel composed mainly of rhyolite but including occasional fragments of basalt, andesite, granite gneiss, limestone, and quartzite. Unconsolidated; crudely to moderately well bedded and sorted. Lies beyond Pinedale end moraines between Madison River and Cougar Creek, where it is partially mantled by loess (plo) and trenched by Pinedale outwash gravel (pg). 10-50 feet (3-15 m) thick. Of early(?) Bull Lake age.

bt - Till and rubble veneer, till (Pleistocene)

Blocks, boulders, and smaller fragments in sandy to silty matrix; unsorted and nonstratified; massive and compact. Stones are mainly Lava Creek Tuff of the Yellowstone Group, which is the predominant local bedrock (included within the "R" map unit), and abundant basalt erratics. Less than 5 to about 10 feet (1.5-3 m) thick. Forms gently undulating ground moraine mantled in most places by post-Bull Lake loess.

br - Till and rubble veneer, rubble veneer (Pleistocene)

Thin (<5 ft or 1.5 m) and largely discontinuous mantle of blocks, boulders, and smaller fragments in a sandy to silty matrix. Composed almost entirely of rhyolite; contains several basalt erratics. Occurs on steep slopes and elsewhere above areas of Bull Lake Till (bt). In part glacially deposited; in part the product of rock weathering and mass wasting.

Ry - West Yellowstone flow (Pleistocene)

Rhyolite flow with K-Ar age of 114,500 ±7,300 years.

Rn - Nez Perce Creek flow (Pleistocene)

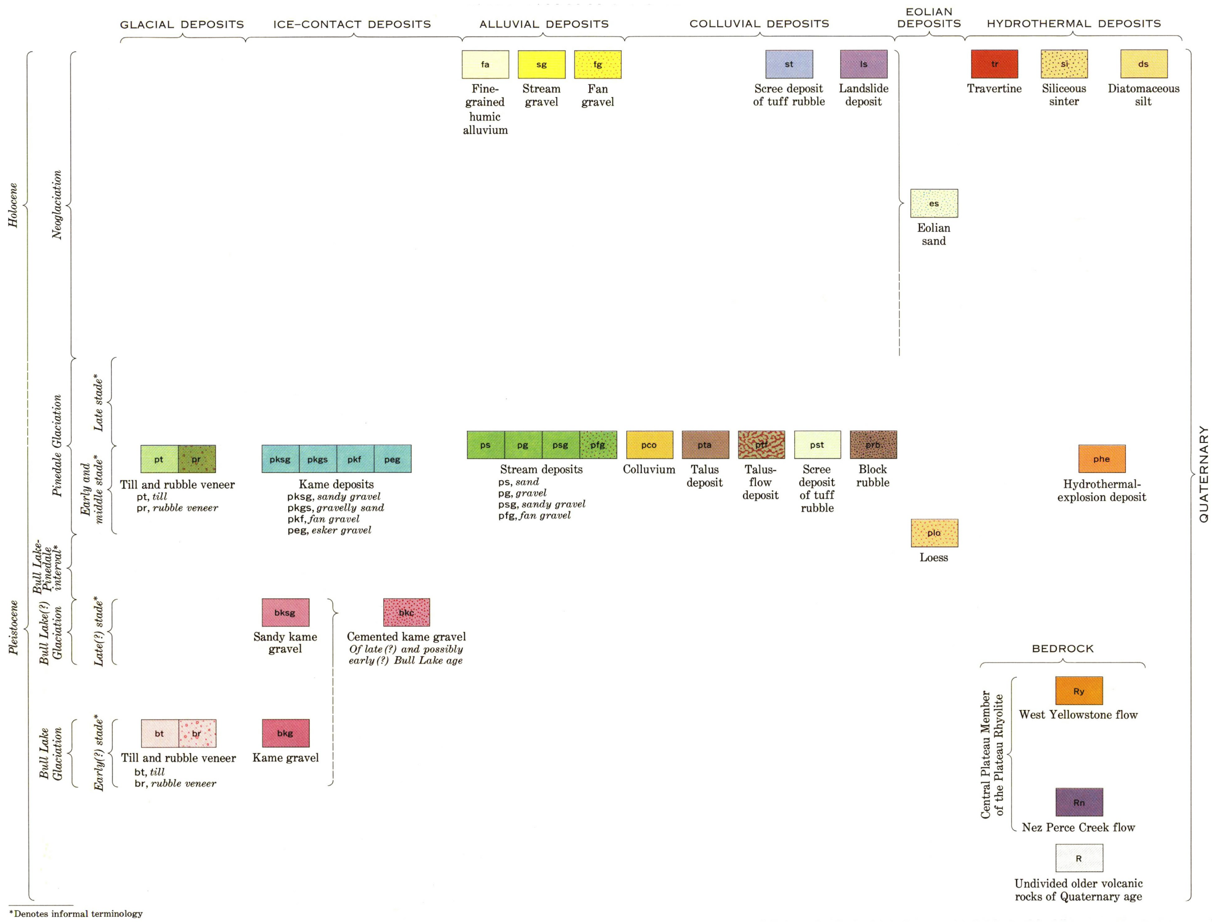
Rhyolite flow with K-Ar age of about 160,000 years.

R - Undivided older volcanic rocks of Quaternary age (Quaternary)

Undivided older volcanic rocks of Quaternary age 'Volcanic stratigraphy from Christiansen and Blank (1972). K-Ar dates from J. D. Obradovich (written commun., 1975).

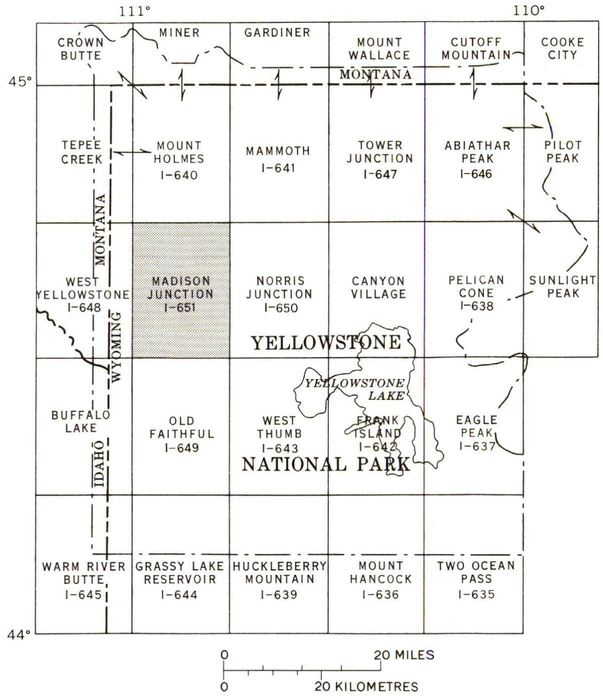
Text from source map: Madison Junction 15' Quadrangle

Correlation of Units



Graphic from source map: Madison Junction 15' Quadrangle

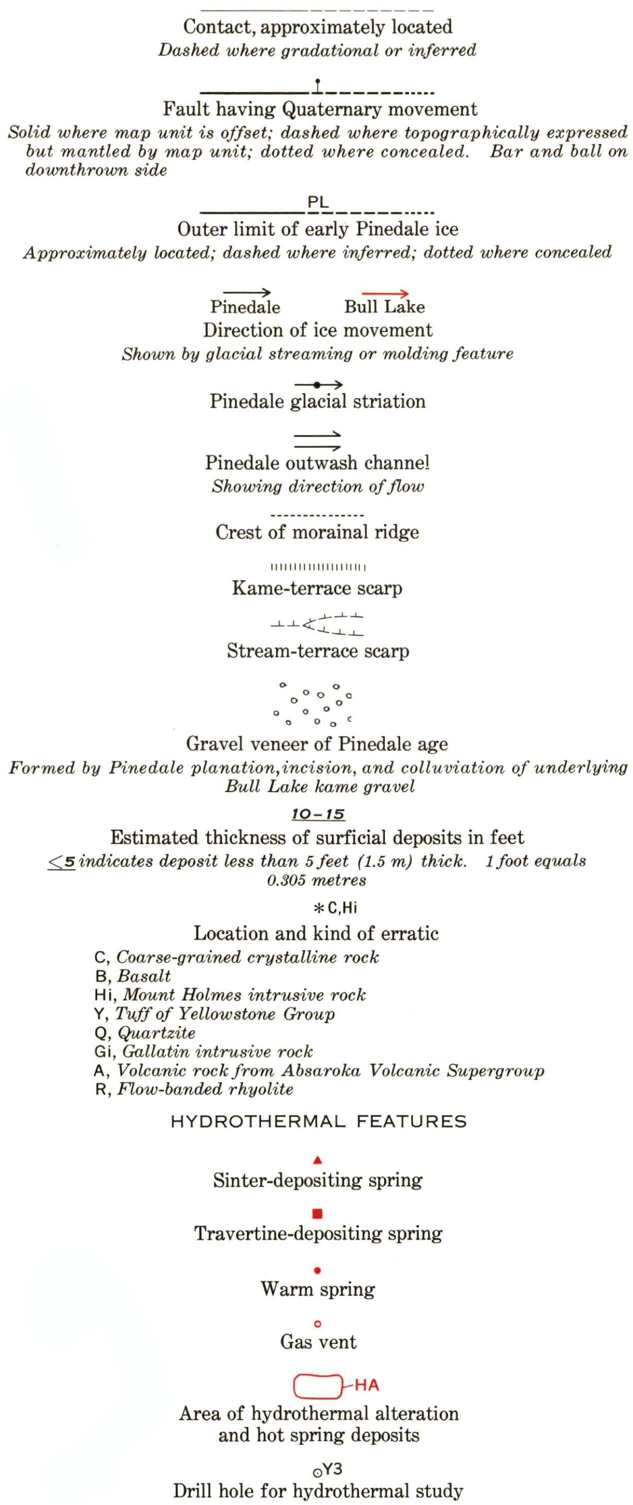
Index Map



INDEX MAP OF YELLOWSTONE NATIONAL PARK, SHOWING LOCATION OF MADISON JUNCTION QUADRANGLE AND PUBLISHED MISCELLANEOUS GEOLOGIC INVESTIGATIONS MAPS

Graphic from source map: Madison Junction 15' Quadrangle

Map Legend



Graphic from source map: Madison Junction 15' Quadrangle

Surficial Geologic History

INTRODUCTION

The Madison Junction 15' Quadrangle lies in the west-central part of Yellowstone National Park, Wyoming. Bedrock of the area, generalized on the accompanying index map, is composed of rhyolite lava flows, tuffs, and basalt of Pleistocene age. Its topography consists of broad volcanic plateaus, steep-sided canyons that follow flow boundaries, and large basins between flow fronts. The Madison River-Gibbon River canyon divides the quadrangle roughly into north and south halves. In the north half, the plateau slopes gently westward toward the alluviated West Yellowstone Basin (Madison Valley of this map). In the south half, the West Yellowstone rhyolite flow forms the Madison Plateau on the west, and older rhyolite flows form a highland on the east. Lower and Midway Geyser Basins occupy a broad hollow enclosed by flow fronts and mantled by surficial and hydrothermal deposits.

Runoff from the quadrangle drains westward, chiefly through the Madison River and its tributaries, the Firehole and Gibbon Rivers. The Firehole drains most of the south half of the quadrangle, the Gibbon the northeastern part, and Cougar Creek the plateau top in the northwestern part. Local relief is seldom more than 500 feet (150 m), but in Madison Canyon it reaches 1,400 feet (425 m).
The surficial geologic history of Madison Junction 15' Quadrangle is chiefly a record of late Pleistocene glaciations and their relation to the West Yellowstone rhyolite flow and to hydrothermal activity.

PLEISTOCENE EVENTS SUMMARY

Evidence for at least three Pleistocene glaciations (named, from oldest to youngest, pre-Bull Lake, Bull Lake, and Pinedale) has been found in the Yellowstone National Park area (Richmond, 1970, p. 112). No glacial deposits of pre-Bull Lake age have been found in the Madison Junction 15' Quadrangle, but pre-Bull Lake glaciation is inferred in the area because it lies between the former center of the pre-Bull Lake ice cap to the east and deposits of that glaciation to the west. Whatever pre-Bull Lake deposits were present have either been removed by erosion or been covered by younger rhyolite flows or by deposits of younger glaciations.

An early and a late stade of the Bull Lake Glaciation have been recognized in Yellowstone Park (Richmond, 1970, p. 112). Bull Lake ice moved northwestward across the Madison Junction 15' Quadrangle from large icecaps that developed over the central part of the park. The most extensive Bull Lake advance covered nearly the entire quadrangle and occupied most of West Yellowstone Basin to the west. That main advance is assigned to this report to the Bull Lake Glaciation and provisionally to its early stade. A much smaller advance younger than the West Yellowstone flow and older than the Pinedale culmination is assigned provisionally to the Bull Lake Glaciation, and provisionally to its late stade.

The West Yellowstone rhyolite flow appears to have overrun deposits of the early(?) Bull Lake advance, and its eastern part is overlain by deposits of Pinedale and late(?) Bull Lake age. Morphology of the flow suggests that its east and north sides were confined by glacial ice but that its west side was not. That and the position of the flow relative to the Yellowstone icecap and terminal moraines imply that the flow was emplaced when a Bull Lake ice front stood well short of the maximum Bull Lake advance.

Ice of the Pinedale Glaciation covered about three-fourths of the quadrangle; it overlapped the east side of the West Yellowstone flow but was confined east of the crest of the Madison Plateau, except where it spilled westward in outlet glaciers down the narrow Madison Canyon and down the broad ramp between Cougar and Maple Creeks, depositing large terminal moraines at the plateau edge.

PRE-WEST YELLOWSTONE FLOW TOPOGRAPHY

The West Yellowstone flow did not exist during the advance of early(?) Bull Lake ice. Before the flow was erupted a broad depression probably extended west and northwest from present Lower and Midway Geyser Basins to the southeast-facing escarpment of the Yellowstone Caldera near Mount Haynes. The

Nez Perce Creek flow and older rhyolite flows formed a highland rimming the east side of the depression. Emplacement of the West Yellowstone flow filled much of the depression, enclosing the geyser basin and forming a high plateau in the southwestern part of the quadrangle that would present a new topographic barrier to succeeding expansions of the Yellowstone icecap.

BULL LAKE GLACIATION: EARLY(?) STADE

Ice of the early(?) stade of the Bull Lake Glaciation covered nearly the whole quadrangle and occupied most of West Yellowstone Basin to the west. A massive Bull Lake terminal moraine lies at The Narrows of Hebgen Lake, 12 miles (19.3 km) northwest of the Pinedale terminal moraine at the mouth of Madison Canyon. Till, rubble, and erratics of Bull Lake age mantle slopes of the West Yellowstone quadrangle and this quadrangle beyond the Pinedale limit.

Early(?) Bull Lake ice moved generally northwest across the quadrangle, from the central Yellowstone icecap toward the terminal moraine at Hebgen Lake. But west-trending glacial scour features on the north part of the Nez Perce Creek flow indicate that in that area ice movement was channeled westward, parallel to the north wall of present Madison Canyon. Two relationships suggest that these scour features were formed by Bull Lake ice. First, the Nez Perce Creek flow is about 160,000 years old (J. D. Obradovich, written commun., 1975), which makes it much younger than pre-Bull Lake glaciations. Second, the fact that scour features terminate at the west edge of the Nez Perce Creek flow and do not extend across the adjacent West Yellowstone flow, which was glaciated by Pinedale ice, suggests that they were formed before emplacement of the West Yellowstone flow, which limits their formation to one of the Bull Lake advances.

Till and rubble of early(?) Bull Lake age in this area are characterized by basalt erratics derived from the Madison River Basalt, which crops out in Madison Canyon and northward along the west side of the plateau. The abundance of basalt erratics southwest of Mount Haynes suggests they may have been derived from outcrops now covered by the West Yellowstone flow.

WEST YELLOWSTONE FLOW

The West Yellowstone flow is a part of the Central Plateau Member of the Plateau Rhyolite (Christiansen and Blank, 1972, p. B12), which comprises flows emplaced after formation of the Yellowstone Caldera. The flow has a K-Ar age of about 114,500 years (J. D. Obradovich, written commun., 1975). Only the northeast end of the flow lies in the Madison Junction 15' Quadrangle.

The high, western part of the West Yellowstone flow in the quadrangle is apparently unglaciated. With one exception, discussed below, no basalt erratics have been found on that part of the flow, although they characterize till and rubble of early(?) Bull Lake age on older flows and tuff to the northwest. The western part of the flow also lacks evidence of scour and plucking, erosion of pressure ridges, or till and kame deposits typical on glaciated flows. Lack of glaciation there, and its position across the path of the Bull Lake advances, indicate that the flow is younger than at least the early(?) Bull Lake glacial maximum and presumably overran deposits of early(?) Bull Lake age.

The lower, eastern part of the West Yellowstone flow in this quadrangle is mantled by thick glacial deposits of Pinedale age and of late(?) Bull Lake age, which indicates that the flow had been emplaced prior to the Pinedale and the late(?) Bull Lake advances.

Studies of the morphology of the West Yellowstone flow by R. L. Christiansen (written commun., 1973) suggest that the eastern and perhaps northern margins of the flow must have been confined in places by glacial ice. Rather than exhibiting the convex, lobate front typical of most rhyolite flows, the eastern margin of the West Yellowstone flow is embayed by several concave reentrants, the largest of which form Lower-Midway Geyser Basin area and Buffalo Meadows. Secondary tongues of lava from the flow advanced into the reentrants, and the relative age of these secondary tongues decreases in the down-flow direction. The anomalous reentrants suggest that advance of the main flow was initially blocked by some large mass that soon after disappeared, permitting secondary tongues of the flow to advance into the reentrants. Emplacement of the West Yellowstone flow against glacial ice seems the most likely mechanism for producing the observed flow shape and relationships.

The effectiveness of water-chilling to check and divert a lava flow has been demonstrated in a recent attempt in Iceland to divert an advancing flow from the fishing port of Vestmannaeyjar by pumping seawater onto the flow margin (Williams and Moore, 1973). The lower temperature and greater volume of ice encountered by the West Yellowstone flow would have been much more effective than seawater in checking a flow advance.

Two reentrants at the northern margin of the West Yellowstone flow may indicate advance against glacial ice there. One is in Madison Canyon, 1.5 miles (2.4 km) southwest of Harlequin Lake, the other is 0.5 mile (0.8 km) southeast of the summit of Mount Haynes. Both reentrants form anomalous gaps between the steep front of the West Yellowstone flow and the terrain barrier that in other places blocked its advance. Ice would have been thick over the low ground along the line of present Madison Canyon, which helps explain its persistence to form reentrants in the front of the advancing rhyolite flow.

From Mount Haynes westward the flow may have been contained by the southeast-facing scarp of the Yellowstone Caldera, but an anomalous basin that contains Big Bear Lake, 1 mile (1.6 km) west of the quadrangle, suggests ice-contact emplacement there. West of Big Bear Lake the flow has a normal, lobate, topographically controlled form and apparently did not encounter glacial ice.

The ice-contact margin of the West Yellowstone flow in this quadrangle indicates that it was emplaced when ice occupied the area of the quadrangle but not the area to the west of it. Ice lay far west of the present site of the flow during the early(?) Bull Lake maximum, so the flow must have been emplaced when an ice front stood short of that limit. There were three times when an ice front could have occupied such a position with respect to the flow: during recession of the early(?) Bull Lake glacier, and during advance or recession of the late(?) Bull Lake glacier. At this time no definitive evidence has been found that eliminates any of these possibilities. Exposures in key areas are rare and are obscured by colluvium. The stratigraphic relations are subject to several interpretations, each of which can account for origin and relation of the deposits to each other and to the West Yellowstone flow.

In this report the following interpretation is favored, that the West Yellowstone flow was emplaced against receding early(?) Bull Lake ice. This explanation seems the most likely because it agrees with the relation of deposits of early and late Bull Lake age to other rhyolite flows of similar age in Yellowstone National Park, and the pattern of glaciation in Bull Lake time observed elsewhere in the Rocky Mountains. However, further investigation may reveal evidence that substantiates one of the alternate interpretations, and for that reason their significance to origin and age of the surficial deposits is summarized in a later section.

By the favored interpretation, when the West Yellowstone flow was emplaced the early(?) Bull Lake ice front had receded eastward from its maximum advance and lay somewhere close to the west side of the Madison Junction 15' Quadrangle. Advance of the flow against the early(?) Bull Lake glacier must have rapidly melted a sizeable volume of ice, and water quenching probably granulated much obsidian at the flow margin. The basal part of the thick sequence of obsidian sand and gravel filling West Yellowstone Basin may have been deposited by floods or high water flows caused by ice-contact emplacement of the West Yellowstone flow. No deposits or erosion features from such floods are apparent up Madison Canyon from the Pinedale terminal moraine, presumably because they were eroded during Pinedale Glaciation or covered by Pinedale deposits.

Ice-contact emplacement of the West Yellowstone flow may account for a puzzling occurrence of basalt erratics on the apparently unglaciated western part of the flow. Several basalt erratics lie on the western scarp of the flow near the Old Fountain Trail, 2 miles (3.2 km) southwest of Mount Haynes. The erratics occur above and beyond the Pinedale terminal moraine in Madison Canyon, so they must have been deposited by a more extensive Bull Lake advance. Yet relations described above suggest that the West Yellowstone flow overran deposits of the early(?) Bull Lake advance and indicate that the western part of the flow was not glaciated by late(?) Bull Lake ice.

The erratics could have been deposited in this manner. Near a glacial terminus bedload rocks are commonly dragged up along shear planes in the glacier to englacial or supraglacial positions. This process, and ice ablation, concentrate rock debris on the glacier surface. As the West Yellowstone flow advanced against the ice margin, some supraglacial rocks could have tumbled or washed onto the slowing and congealing rhyolite flow front, resulting in the exceptional case of deposition of erratics from passive ice onto the edge of an advancing rock mass. Such a mechanism would account for deposition of erratics on the flow scarp while the flow top remained unglaciated.

The erratics might also have been emplaced from a late(?) Bull Lake ice lobe that flowed around but not over the high, western part of the West Yellowstone flow. But no convincing evidence indicates the terminus of such an ice lobe in the area west of the anomalous erratics. And the channel the ice would have had to traverse, the gorge south of Mount Haynes, was probably too small to pass enough ice to maintain such an ice front at the location of the erratics, especially because most of the gorge was probably cut during Pinedale deglaciation, after advance of the postulated lobe.

BULL LAKE(?) GLACIATION: LATE(?) STADE

Judging from the fragmentary evidence available, the ice advance assigned to the late(?) stade of the Bull Lake in this report was much less extensive than the early advance. Clearly the late(?) advance stopped short of, or bypassed, the unglaciated part of the West Yellowstone flow. Its terminal position is indeterminate, probably because it was overrun in this area by the Pinedale advance.

High heat flow from Lower-Midway Geyser Basin seems to have affected the character of deposits of late (?) Bull Lake age more than it affected position of the late(?) Bull Lake ice front. Fournier, White, and Truesdell (1970, p. 47) calculated the present average heat flow of the entire Firehole River drainage area, which includes Upper, Midway, and Lower Geyser Basins, to be 45 times the global average, enough to melt 15 feet (4.5 m) of ice at the freezing point from the area of the geyser basins each year. Clearly, advance of the ice front across Lower-Midway Geyser Basin would have produced an enormous amount of melt water. And outwash and kame deposits, rather than till, seem to characterize late(?) stade of the Bull Lake Glaciation in the area.

In this quadrangle a thick and widespread deposit of perched outwash gravel, locally cemented by hydrothermal action, covers the West Yellowstone flow west and northwest of Lower-Midway Geyser Basin and is overlain in places by glacial erratics of probable Pinedale age. The gravel (bksg) and cemented gravel (bkc) are here assigned to the late(?) stade of the Bull Lake and constitute the only certain deposits of that advance in the area.

Cemented kame deposits in the quadrangle that do not overlie the West Yellowstone flow could have formed during either Bull Lake advance. At Porcupine Hills in Lower Geyser Basin, L. J. P. Muffler (oral commun., 1969) found that hydrothermally cemented mound kame gravels are unconformably overlain by uncemented Pinedale kame gravels, which suggests that the cemented gravels had been deposited during a preceding glaciation, either the early or the late stade of the Bull Lake Glaciation. Similar relationships suggest that other hydrothermally cemented kame deposits in the geyser basin are also of Bull Lake age.

The hydrothermally cemented kames at Porcupine Hills and other spots on the floor of Lower Geyser Basin have the chaotic cross-stratification, lateral discontinuity, and slump structures typical of mound kames deposited against glacial ice. Their close association with hot springs suggests that they probably originated where rising hot water melted holes through stagnant, downwasting Bull Lake ice, inducing deposition of debris from superglacial streams and later cementing the ice-contact gravel.

In contrast to the mound kames in the geyser basin, the hydrothermally cemented gravel that forms Twin Buttes has regular cross-stratification, lateral continuity, and lack of slump structures more typical of glacial outwash than of mound kame gravel. Definitive exposures have not been found, but the cemented gravel at Twin Buttes (bkc) appears to grade laterally into uncemented gravel (bksg) that presumably has the same age and origin. This relationship suggests that the cemented gravel forming Twin Buttes is the erosional remnant of a widespread and formerly more continuous perched outwashlike deposit. It is mapped as kame gravel because it owes its elevated topographic position, as do kame terraces, to emplacement from a former high stand of glacial ice. Similar stratigraphic relationships at outcrops of cemented gravel that rest on the West Yellowstone flow south and west of Twin Buttes suggest that those outcrops are locally cemented parts of the same deposit.

Both the cemented and uncemented gravel on the plateau top contain cobbles and boulders of cemented sand and gravel. Their presence in the uncemented gravel might be accounted for by erosion of the cemented gravel. But their presence in the cemented gravel suggests that they were derived from cemented gravel of a previous glaciation, presumably the early(?) Bull Lake advance.

Given the relations described above, it seems most reasonable to interpret the cemented gravel at Twin Buttes and the thick sequence of uncemented gravel that it apparently grades into on the plateau top as parts of a widespread perched outwash deposit of late(?) Bull Lake age that was later incised during Pinedale deglaciation. Despite the heat flow, late(?) Bull Lake ice must have maintained its continuity nearly to the west edge of the geyser basin, otherwise much of the basin would be filled with lake and outwash deposits. The 400-foot (122 m)-thick sequence of gravel underlying Twin Buttes at the west edge of the basin probably represents an area where the ice had melted out and deposits were built up proglacially. Beds of well-sorted fine sand near the base of the Twin Buttes section suggest that the gap in the ice may have been occupied at times by a lake. As the late(?) Bull Lake advance waxed and buildup of proglacial deposits diffused the concentration of thermal water, the ice would have been able to advance across the plateau top, depositing several huge granite gneiss erratics, and raising the base level of outwash streams to the point where outwash from the ice front could overspread the plateau top. By this interpretation the gravel deposit covering West Yellowstone flow west and north of Twin Buttes was deposited as outwash during the late(?) Bull Lake advance, and had a continuous surface at an altitude of about 7,900 feet (2,408 m) from its southern margin near the Fairy Creek Trail to its northwestern margin near the Old Fountain Trail. Locally, the deposit was cemented by rising hydrothermal waters, probably during the stade maximum, when the water table was high (D. E. White, oral commun., 1970). The deposit has since been incised about 300 feet (91 m) down a sequence of erosional terraces.

The negligible soil development on even the highest of these erosional terraces is typical of soil on gravel of Pinedale age and suggests that the incision occurred during Pinedale recession, covering the kame gravel of late(?) Bull Lake age with a veneer (indicated by an overprint on the map) of alluvial and colluvial gravel of Pinedale and younger age.

A different explanation, that the cemented gravel at Twin Buttes and on the plateau top has the same origin as the mound kames at Porcupine Hills, and that all the uncemented gravel on the plateau top was deposited as successively lower kame terraces during Pinedale deglaciation, does not account for these features—the regular outwashlike bedding rather than ice-contact bedding of the cemented gravel; its apparent lateral gradation into uncemented gravel of the same age and origin; accordance of elevation of the top of cemented and uncemented gravel; lack of ice-contact features such as kettles, slump structures, or crevasse-fillings along the terrace edges; and nested paired terraces west of Twin Buttes and across the Old Fountain Trail.

During the late(?) Bull Lake advance, melt water crossing the top of the West Yellowstone flow probably began cutting the large bedrock channels south of Madison Canyon. Cutting of the huge ice-marginal channel between Mount Haynes and the north end of the flow and the small channel south of Midway Geyser Basin was probably initiated during late(?) Bull Lake deglaciation.

A thin layer of windblown silt was deposited on pre-Pinedale terrain at the east edge of West Yellowstone Basin, mostly in the time interval following the early(?) Bull Lake advance and before the Pinedale maximum. Between the Madison Canyon and Cougar Creek it underlies grasslands on Bull Lake deposits and, where mapped, is more than 2 feet (60 cm) thick. The younger loess there appears in the upper part of the soil and may date from Pinedale time before the Pinedale maximum.

GLACIER-OUTBURST FLOODS

It seems possible that Lower-Midway Geyser Basin contained a succession of glacier-dammed lakes that may have drained intermittently by failure of their ice dams and that much if not the major part of the obsidian sand and gravel of West Yellowstone Basin just west of this quadrangle could have been deposited by such intermittent floods. Emplacement of West Yellowstone flow enclosed the west and north sides of Lower-Midway Geyser Basin and created conditions favorable for development of a glacially dammed lake. Heat flow from the geyser basin would have melted much of the ice that advanced into it, and the northeast end of the flow forms a buttress that ice would have advanced against, damming melt water in the geyser basin. Fine sand and silt deposits in the geyser basin suggest lacustrine deposition. And open-work texture and flat sets of planar cross strata in the obsidian sand and gravel fill of West Yellowstone Basin suggest flood deposition. Conditions necessary for flooding would have existed during the late(?) Bull Lake advance and the early and perhaps middle Pinedale advance. The scale of such flooding would have been much smaller than that accompanying drainage of Lake Bonneville or Glacial Lake Missoula or the major jokulhlaups described in Iceland. Small deposits of flood bar gravels in Madison Canyon and downstream may record glacier-outburst floods during Pinedale recession.

PINEDALE GLACIATION

Three stades of Pinedale Glaciation have been described in central Yellowstone National Park (Richmond, 1970, p. 113). In the western part of the park, ice of the early and possibly the middle Pinedale advances flowed westward into the Madison Junction 15' Quadrangle. At its maximum advance early Pinedale ice formed a narrow tongue in Madison Canyon, depositing a prominent multiple terminal moraine at the canyon mouth. Early Pinedale ice also formed a broad lobe that flowed down the west slope of the plateau between Cougar and Maple Creeks, depositing a hummocky, bouldery terminal moraine on the south side of Cougar Creek and north side of Maple Creek, which is largely overlapped and concealed by young fan gravel (pfg) in the intervening area. West of this moraine the Pinedale outwash fan (pfg) extended westward over the sediments of the West Yellowstone Basin. Outwash channels can be traced westward from the Pinedale end moraines for several miles. South of Madison Canyon the early Pinedale ice front lay only 1-2 miles (1.6-3.2 km) west of Lower-Midway Geyser Basin but extended farther westward into the basin containing Buffalo Meadows near the south edge of the quadrangle. Maximum extent of the middle (?) Pinedale advance is poorly expressed in the area, possibly because heat flow over the geyser basins disrupted the ice front.

During the Pinedale Glaciation enormous amounts of melt water must have been released on the plateau top by heat flow from Lower-Midway Geyser Basin. The deep gorge between Mount Haynes and the north end of the West Yellowstone flow apparently diverted the melt water away from the Pinedale ice lobe at the mouth of Madison Canyon. Much of the gorge must have been cut and its sides oversteepened during this diversion; its bottom is choked by talus deposits that accumulated after the channel was abandoned. Outwash gravel (psg) in the lower part of the channel overlaps the outer ridge of the Pinedale terminal moraine.

During the Pinedale maximum and deglaciation melt water deepened several ice-front and ice-marginal channels on the north end of the West Yellowstone flow. The largest of the channels, 2 miles (3.2 km) southwest of Three Brothers Mountains, probably follows the margin between two lobes of the flow (R. L. Christiansen, oral commun., 1970). Numerous small channels southwest of Madison Junction record successively lower margins of down-wasting Pinedale ice.

During the Pinedale maximum the base-level of melt-water streams was high enough for them to rework the thick kame gravel of late(?) Bull Lake age on the West Yellowstone flow, veneering it with gravel of Pinedale age. Downwasting of Pinedale ice successively lowered the base-level, incising the kame gravel of late(?) Bull Lake age in a series of nested alluvial terraces, and, as the ice margin lowered below the basin rim, gravel eroded from the kames of late(?) Bull Lake age was redeposited in kames of Pinedale age on the basin slopes and floor. Stagnation and down-wasting of Pinedale ice resulted in deposition of a descending series of mound kames and kame terraces on the West Yellowstone flow, around Buffalo and Gibbon Meadows, in Secret Valley, east of Lower-Midway Geyser Basin, and finally along the Madison and Gibbon Rivers.

During a late phase of Pinedale deglaciation an ice-marginal channel was cut into the east edge of the West Yellowstone flow just southwest of Midway Geyser Basin. Though on a smaller scale than the channel south of Mount Haynes, this channel has the same over-steepened sides, encroaching talus, and lack of integration with present drainage, and contains a well-developed plunge pool below the upstream edge of the flow.

Hydrothermal-explosion craters and deposits record the most spectacular feature of Pinedale deglaciation in Lower-Midway Geyser Basin. These features are described in detail in a report by Muffler, White, and Truesdell (1971, p. 723-740), which forms the basis of the following description. The ponds southeast of Twin Buttes and a basin by the Firehole River just west of Rush Lake (Pocket Basin in the report) are hydrothermal-explosion craters, formed by the violent expansion of ground water at temperatures as high as 250°C into steam, probably triggered by a sudden decrease of confining pressure. The craters are surrounded by rims and blankets of explosion breccia (phe) composed chiefly of hydrothermally cemented kame and outwash deposits of late(?) Bull Lake age, the same deposits that lie beneath and surround the craters. The fact that fragments of explosion breccia lie on surrounding uncemented Pinedale kame gravels indicates that the explosions took place during Pinedale deglaciation, after the kames had formed. Muffler, White, and Truesdell (1971, p. 723) observe that "This association with ablating ice suggests that an ice-dammed lake existed over a hydrothermal system at the Pocket Basin site and that the hydrothermal explosion was triggered by the abrupt decrease in containing pressure consequent to sudden draining of the lake." The craters at Twin Buttes probably originated by the same mechanism, although the explosion deposits there were emplaced largely by mudflows and landslides (Muffler, White, and Truesdell, 1971, p. 730).

The floor of Lower-Midway Geyser Basin is largely covered by outwash gravel (psg) deposited in front of retreating Pinedale ice. Much of this gravel is cemented and overlain by hot spring deposits and by Holocene alluvium. Small steep fans of Pinedale alluvium (pfg) built up at the base of steep slopes and into side canyons, and broad, low-gradient outwash fans lap up onto the Pinedale terminal moraines at Madison Canyon and to the north. Extensive talus deposits (pta) at the foot of glacially oversteepened cliffs probably formed mainly during the late stade of Pinedale Glaciation, when ice no longer occupied the area.

ALTERNATE INTERPRETATIONS

Emplacement of the West Yellowstone flow during recession of early(?) Bull Lake ice, and deposition of kame gravel of late(?) Bull Lake age on the flow, have been presented as the most likely interpretation of the flow age and stratigraphic relations of deposits. However, present knowledge does not preclude two alternate interpretations, which are summarized here.

Emplacement during late(?) Bull Lake advance. —This interpretation requires that late(?) Bull Lake ice, although checked temporarily where the rhyolite flow was emplaced against it, subsequently advanced over the east side of the flow. Considering the relatively short time involved for emplacement of a rhyolite flow and the much longer time involved in buildup to a glacial maximum this seems a reasonable possibility.

This interpretation implies little change from the first in relation or age of deposits other than that the ice-contact embayments in the flow, the anomalous basalt erratics on the flow scarp, and ice-contact floods and flood deposits would date from the late(?) stade of the Bull Lake rather than the early(?) stade of the Bull Lake.

Emplacement during late(?) Bull Lake recession.—This interpretation requires that the perched outwash gravel on the surface of the West Yellowstone flow was deposited and locally cemented during the early stade of Pinedale Glaciation rather than the late(?) stade of Bull Lake Glaciation. The sequence of glacial events and associated deposits implied by the interpretation would have been as follows.

During the early(?) stade of the Bull Lake Glaciation basalt-rich till was deposited beyond the Pinedale terminal moraine, the massive Bull Lake terminal moraines were deposited at The Narrows of Hebgen Lake, and possibly mound kames and outwash were deposited and cemented during recession in Lower Midway Geyser Basin.

During the Bull Lake intraglacial lake sediments were deposited on till of early(?) Bull Lake age behind the terminal moraines.

During the late(?) stade of the Bull Lake Glaciation, ice advanced at least as far as the West Yellowstone flow. If it advanced farther west its terminal features are not well preserved or they are buried beneath the younger sand and gravel fill of West Yellowstone Basin.

During emplacement of the West Yellowstone flow, the Madison Canyon, Lower Geyser Basin, Buffalo Meadows, and Big Bear Lake ice-contact embayments were produced in the flow front and the anomalous basalt erratics were deposited on the flow scarp. The flow enclosed Lower-Midway Geyser Basin on its west and north sides. Floods from ice-contact emplacement may have deposited the basal obsidian sand in West Yellowstone Basin.

During the early part of the Pinedale advance ice moved against the northeast end of the West Yellowstone flow, impounding melt water produced by advance of ice into Lower-Midway Geyser Basin. Intermittent glacier-outburst flooding probably occurred. Lake sediments and proglacial gravels gradually filled the southwest corner of the geyser basin where Twin Buttes now stand, incorporating cobbles eroded from cemented Bull Lake kame deposits.

During the maximum Pinedale advance, the ice front advanced over the proglacial outwash, depositing granite gneiss erratics on the flow surface; then perched outwash overspread the West Yellowstone flow, forming a continuous surface at about 7,900 feet (2,408 m); Twin Buttes and other parts of the outwash were cemented by hydrothermal waters; and the diversion channel south of Mount Haynes was initiated.

During Pinedale recession downwasting induced incision of the perched outwash, the Mount Haynes and other bedrock channels were cut deeper, mound kames and eskers were deposited at the flow edge and on the basin floor, and glacial-outburst floods triggered hydrothermal explosions and their deposits.

HOLOCENE EVENTS

The altithermal warm period and the Neoglaciation left only slight imprint in the Madison Junction 15' Quadrangle. Small cirque glaciers formed in high mountains surrounding and in Yellowstone National Park, but no ice formed in or entered the quadrangle, which was little modified beyond the effects of slightly increased runoff and frost action. Pinedale outwash was incised by Holocene stream gravel (sg) or was covered by fine-grained humic alluvium (fa). Pinedale outwash in Lower-Midway Geyser Basin was locally cemented and covered by travertine (tr) and siliceous sinter (si) or covered by deposits of diatomaceous silt (ds).

HYDROTHERMAL ACTIVITY
Lower-Midway Geyser Basin is the most extensive area of hydrothermal activity in Yellowstone National Park. In addition to the number and variety of hot springs, geysers, and mudpots displayed there, it contains the most accessible and spectacular examples in the park of hydrothermal-explosion craters and deposits and of kame gravel concentrated and cemented by hydrothermal action.

Nontechnical descriptions of the thermal features are available from the National Park Service, and the activity of many geysers and hot springs has been recorded, chiefly by Marler (1964, 1969). Detailed investigations of the thermal features by D. E. White and others are currently being made. Hydrothermal activity has modified surficial deposits chiefly of Pinedale and Neoglacial age in the quadrangle, but the existence of hydrothermally cemented kame gravels unconformably overlain by Pinedale deposits suggests that hydrothermal activity has persisted at least since Bull Lake time.
Porcupine Hills at the northeast corner of Lower Geyser Basin are the most varied examples of the association of cemented Bull Lake kame (bkc) with uncemented Pinedale kame (pksg). Nearby hot springs and fumaroles on the sides of the kames show continued activity of the agent that induced their deposition.

The hydrothermal explosion crater in the River Group by Fountain freight road is a type example of the crater form and deposits (phe) produced by such an event.

Lower-Midway Geyser Basin is partly filled by kame sand and gravel (pksg) and by outwash (sg) deposited during stagnation and recession of Pinedale ice. Much of the outwash and kame terrace sand is impregnated and overspread by siliceous sinter (si) deposited around geysers and hot springs and by diatomaceous silt (ds) that accumulated in swales on the sinter and outwash.

In the northeastern part of the quadrangle, Gibbon Geyser Basin contains deposits of cemented Bull Lake kame and uncemented Pinedale kame, and diatomaceous silt overlies much of Gibbon Meadows east of the geyser basin. Activity at Monument Geyser Basin, which is perched on a hillside south of Gibbon Meadows, is limited now chiefly to fumaroles and acid alteration of the rhyolite bedrock, but siliceous sinter indicates former geyser and hot spring deposition.

The travertine fan (tr) deposited by Terrace Spring near Madison Junction is an unusual occurrence of carbonate sinter in a region of dominantly siliceous hydrothermal deposits. Composition of hot spring deposits is controlled by bedrock the hydrothermal water has traversed, and in most of the park reflects the silicic composition of underlying rhyolite flows. The extensive travertine deposits at Mammoth Hot Springs near the north entrance were derived from solution of limestones in the subsurface (Allen and Day, 1935, p. 363). The travertine at Terrace Spring, and its proximity to the rim fault of the Yellowstone caldera, suggest that limestone may locally be accessible to hydrothermal water along the fault surface.

Text from source map: Madison Junction 15' Quadrangle

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References from source map: Madison Junction 15' Quadrangle

Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle

The formal citation for this source.

Pierce, Kenneth L., 1973, Surficial Geologic Map of the Mammoth Quadrangle and part of the Gardiner Quadrangle, Yellowstone National Park, Wyoming and Montana: U.S. Geological Survey, Miscellaneous Investigations Series Map I-641, scale 1:62,500 (*GRI Source Map ID 1143*).

Description of geologic units, prominent graphics and text associated with this source.

Description of Units

fa - Fine-grained humic alluvium (Holocene)
Silt and subordinate sand, clay, and plant material that underlie wet ground along drainages, in upland depressions or in original depressions on top of rhyolite flows; supports lush stands of tall grasses and sedges. Thickness 3-20 feet.

sg - Stream gravel (Holocene)
Tan to gray, moderately sorted, well-bedded gravel with a sand matrix; forms alluvial flats 0-15 feet above the Yellowstone River or within a few feet of the level of the smaller streams. Includes lenses of sand and fine-grained material, especially along smaller streams and in areas of rhyolite tuff. Mostly 5-15 feet thick.

fg - Fan deposits, gravel (Holocene)
fm - Fan deposits, muddy gravel (Holocene) Fan gravel (fg) is poorly sorted, crudely bedded, locally bouldery; in areas of rhyolite tuff, deposit is mostly angular sand and small pebbles. Muddy fan gravel (fm) is very poorly sorted, with abundant fines derived from clayey bedrock. Deposited by local floods, mudflows, and sheet wash. Thickness 5-50 feet.

ta - Talus deposit (Holocene)
Angular rock rubble forming cones or aprons on steep slopes at base of cliffs. Barren except for lichens. Mapped only along Black Canyon and Sheepeater Canyon where modern accumulation noted. Generally 5-20 feet thick.

fr - Frost rubble (Holocene)
Abundant cobble-sized rock fragments in a fine-grained matrix on crest of Washburn Range. Seasonal activity is indicated by partly disrupted tundra. Formed by frost mixing, sliding, and solifluction. Thickness 2-5 feet.

rb - Block rubble (Holocene)
Angular blocks 0.5-5 feet across. Interstices open, but fine-grained matrix present at depth. Barren except for lichens; found near timberline on Bunsen Peak and Palmer Mountain. Derived from frost-heaved andesitic intrusive rocks. Thickness 3-6 feet.

ad - Avalanche debris (Holocene)
Boulder- to pebble-sized rock fragments in a fine-grained matrix at base of avalanche chutes. Deposits unsorted, crudely bedded. Thickness 5-10 feet.

sd - Solifluction deposit (Holocene)
Scattered stones in muddy matrix. Unsorted, nonbedded. Formed by flowage of surface layer during thaw. Thickness 5-10 feet.

ls - Landslide deposit (Holocene)

Nonsorted debris in a clayey matrix. Generally results from failure in shaly bedrock. Fresh ridges, depressions, and slump scarps indicate recent movement of most deposits. The slide at The Hoodoos consists of large blocks of older travertine from Terrace Mountain (tro) and the underlying rhyolite tuff that have rotated backward. The extensive areas of landslides north of Mammoth displays a progression from block glide movement (shown by double-hachured scarp symbol) through blocky landslides to earthflows. A large fresh rockslide occurs in the Black Canyon of the Yellowstone. Thickness 10-100 feet.

es - Eolian silt and sand (Holocene)

Poorly sorted sand and silt on MacMinn Bench (stratigraphic section 3). Wind-carried from downslope exposures of till and lake sediments. Thickness 3-10 feet.
Mammoth Stratigraphic Sections

try - Younger travertine (Holocene)

Light-gray, yellowish- to grayish-weathering calcium carbonate, commonly subhorizontally layered. Younger travertine (try) now being deposited or recently was deposited. Thickness 5 feet to at least 50 feet.

ds - Diatomaceous sediment (Holocene)

White siliceous sediment composed of microscopic diatom shells. Mushy when wet; powdery when dry. Thickness 5-10 feet.

si - Siliceous sinter (Holocene)

Nearly white, porous, amorphous silica. Mapped only in southwest corner of area. Mostly 2-10 feet thick.

trm - Travertine (Holocene)

Similar to younger travertine (try) but no evidence of modern deposition. Deposits not glaciated. Contains caverns tens of feet deep north of Capitol Hill.

pg - Gravel, stream and outwash gravel (Holocene and/or Pleistocene)
ps - Gravel, stream sand (Holocene and/or Pleistocene)
pfg - Gravel, fan gravel (Holocene and/or Pleistocene)
pfs - Gravel, fan sand (Holocene and/or Pleistocene)
pfm - Gravel, fan muddy gravel (Holocene and/or Pleistocene)

Most deposits (pg, ps, pfg, pfs,) are tan to gray, moderately sorted and stratified, and subangular to subrounded. They are mostly locally derived alluvium found along intermittent streams. Near Lava Creek Campground the gravel (pg) is outwash. At the mouth of Sheepeater Canyon the gravel (pg) is cemented by travertine. Stream sand (ps) and fan sand (pfs) in southern part of mapped area are derived from rhyolite tuff and flows and underlie normally dry bottomlands which apparently were modified only by minor surface wash in Holocene time. Muddy fan gravel (pfm) is poorly sorted and derived from clayey bedrock. In most places Pinedale alluvium (pg, ps, pfg, pfs, pfm) is not clearly incised by modern streams, but its coarseness and volume suggest it dates from glacial time. Thickness 5-30 feet.

pfd - Flood deposits (Holocene and/or Pleistocene)

Buff, coarse boulder gravel, poorly to moderately sorted, poorly bedded; boulders mostly gneiss and basalt and commonly display percussion spalls. Deposits form large longitudinal and midchannel bars as much as 50 feet high and flood-modified alluvial terraces. Flood deposits (pfd) beneath Gardiner contain, just beneath surface, many boulders more than 3 feet across; pockets of sand are also present. In the railroad cut one-fourth mile northwest of Gardiner High School, about 10 feet of large-boulder gravel rests on 20 feet of more sandy gravel. Meandering dry channels cross the surface of alluvial flats south of the confluence of the Gardner and Yellowstone Rivers; there and immediately to the west, the flood deposits may veneer older alluvial deposits. Steep-sided depressions at Crevice Lake and about 3 miles downstream may be the product of flood currents or melting of buried ice blocks. Mostly 10-50 feet thick.

pta - Talus deposit (Holocene and/or Pleistocene)

Angular blocks 0.5-4 feet in diameter. Forms aprons and cones on steep slopes, generally below cliffs. Fine-grained matrix fills voids between blocks and commonly extends to surface where a weak humic soil is developed. Mostly inactive and covered with trees or grass. Thickness 5-50 feet.

ptf - Talus-flow deposit (Holocene and/or Pleistocene)

Angular blocks on moderate slopes. Similar to talus, but displays ridges and furrows formed by flowage downhill. In Lava Creek area mostly slabby rubble surrounded by scree deposit of tuff rubble (pst). In Black Canyon formed from Quaternary basalt. Mostly inactive. Mostly 3-10 feet thick.

pst - Scree deposit of tuff rubble (Holocene and/or Pleistocene)

Hackly small-pebble-sized fragments and local large slabs of stony rhyolite forming sheets over tuff bedrock and aprons or cones farther downslope. Generally covered by open forest. Includes active surface material that locally slides and tumbles downhill against trees and other obstacles. Thickness of sheets 0-5 feet; of aprons and cones 5-30 feet.

prb - Block rubble (Holocene and/or Pleistocene)

Similar to Neoglacial block rubble, but inactive and partly forested. Surface blocky, but space between blocks generally nearly filled with fine material. Mapped on Bunsen Peak and Palmer Mountain. Thickness 3-20 feet.

phe - Hydrothermal explosion deposit (Holocene and/or Pleistocene)

Angular tuff fragments 1-6 inches in diameter in a fine-grained matrix; forms circular deposit 1-2 miles across that thickens towards center where there are explosion craters 50-150 feet deep. Both matrix and fragments hydrothermally altered before emplacement. Occurs on uplands of Roaring Mountain. Thickness increases from 2 feet to about 15 feet towards center of deposit.

pkl - Ice-dammed lake silt (Holocene and/or Pleistocene)

Gray to tan, well-bedded lake silt, sand, and clay deposited in valleys of Lava, Bear, and Obsidian Creeks when blocked by glaciers. Generally concealed by gravel. Near Clearwater Springs, consists of tan silt with thin laminae of brown hydrothermal clay. Mostly 20-100 feet thick.

pkg - Kame deposits, gravel (Holocene and/or Pleistocene)
pks - Kame deposits, sand (Holocene and/or Pleistocene)
pkc - Kame deposits, cemented sand (Holocene and/or Pleistocene)
pkf - Kame deposits, inwash fan gravel (Holocene and/or Pleistocene)

Kame gravel (pkg) and sand (pks), moderately well sorted, mostly gray, unevenly bedded with abrupt vertical changes in grain size. Roundstones mostly 2-4 inches in diameter. Deposited by ice-margin streams with ice-contact frontal scarps commonly preserved. Along Obsidian Creek contains obsidian and is unsuitable for concrete aggregate. As indicated by lush vegetation near Amphitheater and Crystal Springs and along Eagle Creek, the mapped kame gravel (pkg) includes either till or lake sediments. Hydrothermally cemented kame sand (pkc) occurs at Roaring Mountain.

Along Bear Creek and in Gardners Hole, kame inwash fan gravel (pkf) is cobbly, well sorted, and bedded; it was deposited against an ice mass by outwash from a glacier upvalley. West of Grebe Lake along south margin of area, deposit (pkf) consists of sand and pebble gravel of hackly rhyolite tuff and is marked by kettles. East of Grebe Lake, deposit (pkf) is poorly sorted mudflow debris derived from Eocene volcanic rocks. Mostly 10-50 feet thick.

pkls - Kame landslide deposit (Holocene and/or Pleistocene)

Rubble in a muddy matrix slumped from valley walls out and down against stagnant glaciers. Mapped along Lava Creek where forms morainelike ice-contact ridges. Thickness 10-100 feet.

pt - Till (Holocene and/or Pleistocene)

Unsorted, nonstratified, compact mixture of roundstones, sand, silt, and clay deposited by glaciers. Stones mostly subrounded but more faceted than stream gravel. Glacially striated and faceted stones locally common in deposit, but difficult to recognize on surface.

In a belt extending from Mount Everts and Mammoth through Swan Lake Flat to Twin Lakes, the till is gray, calcareous, and clayey with a diversity of cobble-sized erratics (B, C, Gi, Hi, L, Q). In the Washburn Range the till is brown and clayey with stones almost entirely of andesite from conglomerates and breccias of the Absaroka Volcanic Supergroup. On the basalt and tuff bench south of Sheepeater Cliffs the till is tan and consists mostly of basalt cobbles, and tuffaceous sand and silt. In a belt about 4 miles wide bordering the Yellowstone River, the till is mostly brown and clayey, especially in the northern part of the mapped area, and contains abundant boulders of Precambrian crystalline rocks.

Soils developed on Pinedale Till are variable, reflecting differences in parent material and local climate. Soil profiles I, J, and M are on silty noncalcareous till and are shallow and poorly developed. Soil profile K is in clayey parent material and is about 3 feet thick; soil profiles A, B, and L are more than 3 feet thick and show moderate structure development apparently related to the swelling(?) clays present. At lower and more arid sites, soils on calcareous till display a caliche horizon about 2 feet thick; such caliche zones occur beneath A and B horizons totaling 1 foot thick (soil profiles F and H) to more than 2 feet thick (soil profiles D, E, and G).

In much of the northern half of the mapped area the till forms drumloidal topography. End moraines are common just inside the Deckard Flats limit of glaciation (PD). The till has been modified by frost heaving and, on slopes, by solifluction and creep. Generally 5-20 feet thick.
Mammoth Soil Profiles

pr - Rubble veneer (Holocene and/or Pleistocene)

Thin mantle of rubble in a loose fine-grained matrix on glaciated uplands. Mostly derived, especially by frost processes, from local bedrock, but contains some glacial erratics and other probably glacially moved debris. Terrain underlain by rubble veneer (pr) gradational with and similar in appearance to much of terrain underlain by till (pt), but undisturbed glacial deposits are present only locally in rubble veneer areas. Mapped areas include many small glaciated outcrops of bedrock.

ppl - Proglacial lake sediments (Holocene and/or Pleistocene)

Gray to pink silt and sand in MacMinn Bench area. Coarsely bedded, locally laminated. Some sand displays wavy subhorizontal laminations. Age thought to be early Pinedale because unit grades upward into tan till (stratigraphic section 3) of probably early Pinedale age. Overlain also by Pinedale kame gravel (pkg) (stratigraphic section 4). Thickness 40-80 feet.
Mammoth Stratigraphic Sections

ppfd - Proglacial flood deposits (Holocene and/or Pleistocene)

Gray, locally bouldery gravel. Occurs beneath proglaical lake sediments (ppl) in scarp of

MacMinn Bench and protrudes from alluvial fans to south. Two or more beds (stratigraphic sections 3, 4) contain boulders 3-10 feet in diameter. Thick-bedded with many layers of angular cobble and pebble openwork gravel. Larger boulders mostly Quaternary basalt; remainder mostly andesitic volcanic rocks. Glacial-flood origin of parts of unit uncertain; andesitic detritus in lower part of unit may be related to landsliding of Sepulcher Mountain area. Early Pinedale age assignment based on conformable and sequently logical relation to overlying lake sediments (ppl) and till of probable Pinedale age. Thickness 20-25 feet.
Mammoth Stratigraphic Sections

tro - Travertine of pre-Pinedale age (Pleistocene)

Similar to younger travertine (try) but older travertine (tro) is mantled by glacial till or erratics and predates the Pinedale Glaciation; it forms extensive deposits on Terrace Mountain and on the bench north of Gardiner. Stones from glaciers or reworked from glacial deposits occur in the travertine (tro) in Snow Pass and on the bench north of Gardiner.

pbg - Gravel of pre-Bull Lake age (Pleistocene)

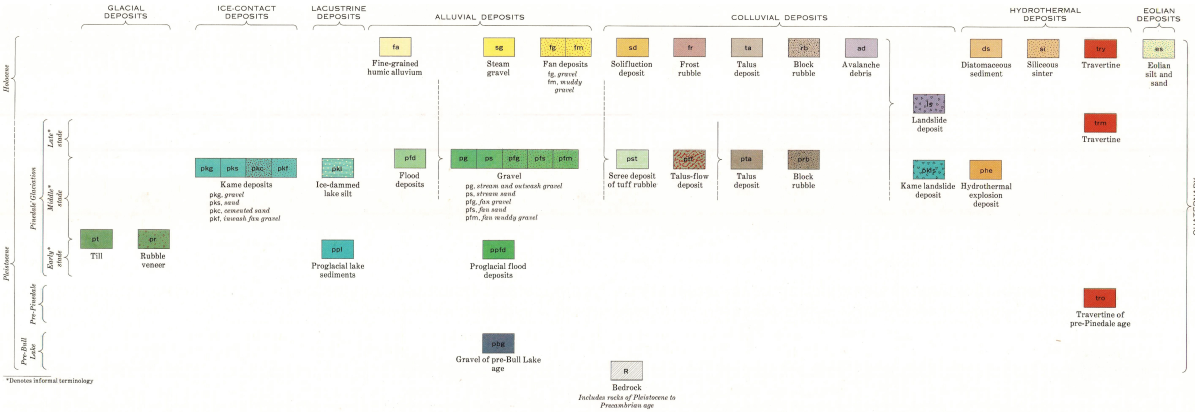
Well-sorted, coarsely stratified, cobble gravel exposed (stratigraphic sections 1, 2) beneath the basalt flows on Deckard Flats. Round-stones mostly of Precambrian rocks; a few are of tuff. At stratigraphic section 1 and farther up Bear Creek, the lowermost part of the deposit consists of boulders, many as large as 5 feet and some as large as 10 feet in diameter. At stratigraphic section 2 the deposit rests on stream-polished and fluted bedrock. At the east end of Deckard Flats, the deposit (pbg) is a poorly sorted bouldery fanglomerate. A knob of oxidized gravel (pbg) protrudes into gray Pinedale deposits in a roadcut 1 mile northeast of Gardiner.
Mammoth Stratigraphic Sections

R - Bedrock (Pleistocene to Precambrian)

(After U.S. Geological Survey map I-711, 1972) Precambrian schists, gneisses, and mineralized and altered rocks occur northeast of the bedrock Gardiner fault (not shown) in the Black Canyon of the Yellowstone region. Mesozoic shales and minor amounts of sandstone occur on and east of Mount Everts. Quaternary basalts form the bench north of Gardiner, Deckard Flats, and the bench from Sheepeater and Lava Creek Canyons to Horseshoe Hill; they crop out discontinuously from the Lava Creek Campground northeast to the Yellowstone River. Quaternary rhyolite tuff underlies the southern part of Mount Everts, the Blacktail Deer Plateau, the Roaring Mountain-Arrow Canyon area, and the Tower Creek area. At and southeast of Obsidian Cliff is the Obsidian Cliff flow (about 176,000 years old) of Roaring Mountain Member of Plateau Rhyolite; one-half mile northeast of Obsidian Lake is the Crystal Spring flow (about 79,000 years old) (K-Ar age dates, J. D. Obradovich, written commun., 1972). Andesitic volcanic and sedimentary rocks of the Eocene Absaroka Volcanic Supergroup form the Washburn Range. Paleozoic and Mesozoic rocks locally crop out in a belt extending from Whiterock Springs northward through Horseshoe Hill to elevation point "8109".

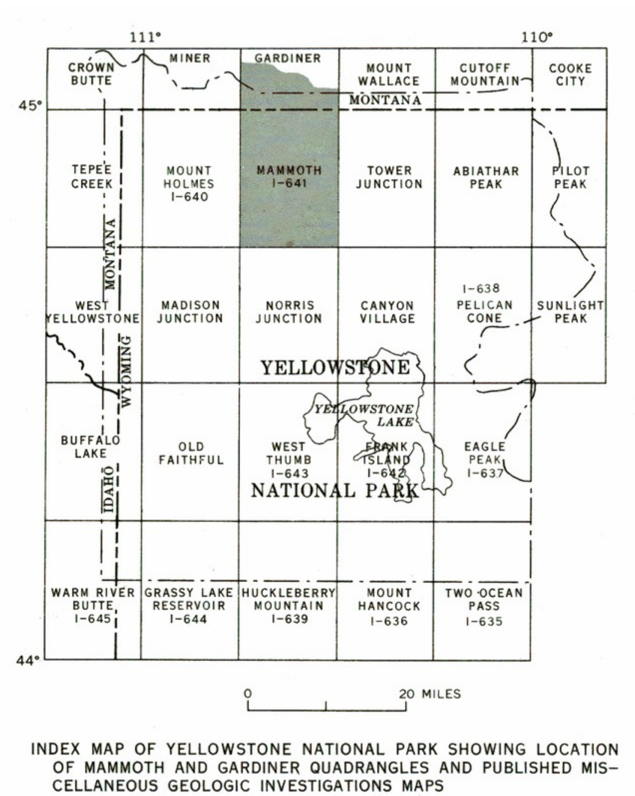
Text from source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle

Correlation of Units



Graphic from source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle

Index Map



Graphic from source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle

Map Legend

Graphic from source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle

Stratigraphic Sections

Units, separated by slashes, are shown in descending order; numbers show thickness in feet, except in section 7. Letter symbols represent units listed in Description of Units; where no unit is appropriate, lithology is stated.

Stratigraphic section locations are presented in the GRI Geologic Observation Localities (yellgol) feature class. In that feature class, the section identifier is stored in the Location ID (LOC_ID) field. The section information presented here is also contained in the Geologic Observation Localities (yellgol) feature class Notes (NOTES) field.

See Description of Units for information about map units listed here.

1. >50 basalt flows/20 pbg/10 pbg, sandy/bedrock
2. >50 basalt/0.5 soil, red/3 soil caliche/100 pbg/15 pbg, coarse boulders/bedrock
3. 3 es/15 pt, gray/25 pt, dark tan/25 pt, tan/80 ppl/30 ppfd, sand, silt, and gravel/30 ppfd. cobbly/30 ppfd. basalt boulders/30 ppfd, angular/15 ppfd, angular, boulders at top
4. 5 es/75 pkg, sandy/40 ppl/40 ppfd, bouldery/45 ppfd, angular/25 ppfd, basalt boulders
5. >50 tuff/6 ash/2 hg, sand, red, clayey/5 hg
6. 180 six basalt flows and local interbeds of gravel (og)/20 og/bedrock
7. 100 cm peat/128 cm marl with humic layers/0.5 cm volcanic ash/ 172 cm marl with humic layers/50 cm humic mud/50 cm silt, gray, laminated

Text from source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle

Soil Profiles

Soil horizons, separated by slashes, are shown in descending order; numbers give depth in inches below surface. Symbols A, B, and C. refer to soil horizons; B1 B2 and B3 refer to subdivisions of B horizon; and Cca refers to carbonate zone in C horizon. Modifiers "moderate" and "strong" show how well structure of B horizon is developed, or how well caliche is developed in Cca horizon. Where no modifier is given, property is weakly developed: that is, the B horizon would generally be regarded as a "color B," or the Cca horizon is developed in calcareous parent material and carbonate has simply been rearranged with only minor translocation.

Soil profile locations are presented in the GRI Geologic Observation Localities (yellgol) feature class. In that feature class, the section identifier is stored in the Location ID (LOC_ID) field. The profile information presented here is also contained in the Geologic Observation Localities (yellgol) feature class Notes (NOTES) field.

A. 0-4 A/4-11 B1,'strong/11-23 B2, strong/23-40 B3, moderate/C
B. 0-9 A/9-13 B1/13-25 B2, moderate/25-56 B3/>56 C
C. 0-18 A/18-28 B/28->36 Cca, moderate
D. 0-8 A/8-11 B1/11-20 B2, moderate to weak/20-31 B3/31-> 36 Cca
E. 0-10 A/10-17 B2/17-28 B3/28->36 Cca
F. 0-2 A/2-11 B/11-35 Cca/C
G. 0-6 A/6-26 B/26-39 Cca/C
H. 0-1 A/1-13 B/13-22 Cca/22-43 Cca. moderate/C
0-11 A/11-15 B/15-38 C, compact/C, loose
J. 0-1 A/1-14 B/C
K. 0-3 A/3-34 B/C
L. 0-12 A/12-23 B1, moderate/23-38 B2strong/C
M. 0-4 A/4-17 B/C

Text from source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle

Surficial Geologic History

INTRODUCTION

This mapped area lies in the north-central part of Yellowstone National Park. The terrain comprises: (1) in the southeast part of the map, the western part of the Washburn Range (elev. 9,300-9,700 feet), (2) in the northern part, the valley of the Yellowstone River (elev. of river, 5,200-5,600 feet) including the Black

Canyon of the Yellowstone, (3) in the west-central part, the Gardner River valley, and (4) in most of the remainder, plateaus (elev. 7,000-8,500 feet) dissected by the deep canyons of Lava Creek, Arrow Canyon Creek, and Tower Creek. West of the mapped area lies the Gallatin Range; north and northeast, the northern end of the Absaroka Range (the Snowy Range of previous workers); and south, the Yellowstone plateaus.

PRE-BULL LAKE ALLUVIAL DEPOSITS

All pre-Bull Lake alluvial deposits noted, except for that outcrop 1 mile northeast of Gardiner, are overlain by volcanic rocks whose age is at least approximately known. On Mount Everts (stratigraphic section 5) about 6 feet of sand and gravel (noted by Boyd, 1961, p. 395) is overlain by 2-m.y.-old Huckleberry Ridge Tuff (Christiansen and Blank, 1972). The Eocene volcanic rocks in the gravel indicate that it was probably deposited by a stream draining the present area of Lupine and Blacktail Deer Creeks. No pre-Eocene rocks were noted, such as are common in the Pinedale Till of the area. Thus it is suspected that the gravel is nonglacial and may be preglacial in origin. At the top of the gravel is a reddish clayey silty sand which may be a buried soil.

Preserved beneath the basalts of Deckard Flats (strati-graphic sections 1, 2) is thick gravel almost entirely of Precambrian rocks. This gravel was observed by R. L. Christiansen and me to contain clasts probably derived from the Huckleberry Ridge Tuff. The basalts and gravels are probably between 0.6 and 0.7 m.y. old, for their magnetic polarity is normal and they are correlated with basalts older than the 0.6-m.y.-old Lava Creek Tuff (R. L. Christiansen, oral commun., 1971). Just west of stratigraphic section 2, successively younger basalt flows have buried and preserved a prebasalt terrace scarp about 100 feet high. The size and concentration of boulders in the basal gravels, from stratigraphic section 1 toward Bear Creek, seem unusual in nonglacial Quaternary deposits; they may represent a lag or flood deposit of glacial boulders.

The Osprey Basalt and associated gravels (stratigraphic section 6) postdate canyons cut in 0.6-m.y.-old tuff (Christiansen and Blank, 1972). The quartzite and intrusive rocks in the gravel indicate drainage from part of the Gallatin Range through this area at this time (Boyd, 1961, p. 402).

PRE-PINEDALE TRAVERTINE

Older travertine (tro) is mantled by Pinedale glacial deposits on Terrace Mountain, on the bench north of Gardiner, and at two places south of Sheepeater Canyon. No evidence was found to indicate the travertine to be of pre-Bull Lake age; tentative assignment to the Bull Lake-Pinedale interval seems most reasonable. These travertine deposits indicate the location of pre-Pinedale springs, probably of hot water.

PLEISTOCENE GLACIATIONS

Great icecaps covered most of Yellowstone Park repeatedly during Pleistocene time. These glaciations are (from oldest to youngest): pre-Bull Lake (which probably includes several full-scale glaciations), Bull Lake, and Pinedale.

No distinctly glacial deposits of pre-Bull Lake or Bull Lake age are recognized within the mapped area, but 0.1 mile west of it along the Gardner River, probably Bull Lake Till is exposed beneath Pinedale Till. Compared to the Bull Lake Till the erratics in the Pinedale Till are from a more southerly source, thus indicating that the influence of the Bull Lake icecap on glaciers flowing eastward from the Gallatin Range was less than that of the Pinedale. West and southwest from Yellowstone National Park, the Bull Lake Glaciation was more extensive than the Pinedale, but northward from Yellowstone, the Pinedale appears equally or more extensive.

PINEDALE GLACIATION

The Pinedale glacial history consists of the formation and building of icecaps on the northern Absaroka Range (to the northeast of mapped area), Gallatin (to the west), and Washburn Ranges, and eventually on the Yellowstone Park plateaus (to the south); it culminated in a full-glacial flow regimen with nearly every feature in the mapped area covered by ice. This was followed by a waning of glacial conditions accompanied by variations in the residual influence of ice from different sources.

Early Pinedale advance—Early in Pinedale time, valley glaciers formed west of the mapped area in the Gallatin Range, northeast of the area in the northern Absaroka Range, and probably also in the Washburn Range. Eventually a local icecap became established in the Washburn Range, as recorded by the fresh striations numbered "1" on Observation Peak indicating flow away from the center of the range. At that time a large icecap became established on the northern Absaroka Range north of the park and another one was forming on the plateaus south of the mapped area.

Exposures beneath MacMinn Bench (stratigraphic sections 3, 4) provide evidence for advancing Pinedale glaciers. Glaciers from the Absaroka Range north of the park advanced down the Yellowstone River valley and blocked the Gardner River before glaciers from other sources reached this area. Flood deposits (ppfd) of probable early Pinedale age filled a buried valley beneath MacMinn Bench; they probably represent periodic release of glacially dammed lakes in the Mammoth area, most likely by flotation of the glacial dam. Eventually a lake formed in which were deposited lake sediments (ppl) and then lake sediments containing masses and lenses of tan till. This lake was displaced by a glacier that advanced up the Gardner River valley from the Yellowstone River valley and deposited the tan till (stratigraphic section 3), containing Precambrian erratics from the Yellowstone drainage but no erratics characteristic of the Gallatin Range. Then a glacier pushed down the Gardner River valley, displacing the Yellowstone River valley ice and deposited the overlying zone of dark-tan till (stratigraphic section 3).

While icecaps continued to build on the plateau both south and west of the mapped area, flow of ice across Observation Peak changed from southwestward to northwestward, as indicated by intermediate striations, and then strongly to the north, as indicated by well-developed striations numbered "2." At this time, which I considered approximately the time of glacial maximum or full-glacial conditions, the entire mapped area, except for Palmer Mountain (along the north boundary), was covered by ice.

Under full-glacial conditions a large icecap lay in the southern part of the mapped area. The axis of this icecap trended westward from south of Observation Peak, over Lake of the Woods and beyond the mapped area to Dome Mountain in the Gallatin Range. North of this axis, ice flowed north toward the Yellowstone River valley; south of it, ice flowed southwest toward the Madison Canyon. Glacial scour features were not noted in a band several miles wide beneath the icecap axis, where basal shearing would be minimal. Scour features are increasingly apparent away from the axial belt, as illustrated by the Obsidian Cliff flow. Southeast of The Landmark flow-top ridges and depressions are remarkedly well preserved, as expressed by the areas of "fa" on the map, but northward from the Landmark flow top ridges and depressions become progressively more modified; just north of the Obsidian Cliff flow they are even less apparent on the younger Crystal Spring flow (northeast of Obsidian Lake). The Obsidian Cliff and Crystal Spring flows belong to the Roaring Mountain Member of the Plateau Rhyolite. The distribution of erratics also indicates an icecap axis or divide over this belt with flow away from, and not into, this area; erratics from the Gallatin Range, Washburn Range, northern Absaroka Range, or plateau of rhyolite flows are absent or at least 100 times less common than they are in areas occupied by ice masses from these sources.

Except for the southwestern corner of the mapped area, where flow was to the southwest, flow under full-glacial conditions was toward the Yellowstone River valley. This flow can be divided into four segments: (1) the western segment, (2) the Obsidian Creek-Lava Creek segment, (3) the Washburn Range segment, and (4) the Black Canyon of the Yellowstone segment. These four segments are discussed below.

1. West of the mapped area and along the western boundary as far east as Terrace Mountain, scour features on the higher elements of the topography and drumloidal features in lower areas indicate a north-northeast flow. Erratics (C, Hi) from the south end of the Gallatin Range (5 miles west of Obsidian

Cliff) are common in a belt that extends from Sheepeater Canyon to Terrace Mountain—another indication of north-northeastward flow.

2. In the Obsidian Creek-Lava Creek area the glacial scouring and molding of the topography and the scarcity or absence of erratics from the Gallatin, northern Absaroka, and Washburn Ranges (erratics of Q, K. L are locally derived) indicate northerly flow, except for a late-glacial flow pattern around Bunsen Peak. The striations on Bunsen Peak and the complete dominance of Quaternary basalt erratics from the area to the south show that at full-glacial conditions above and south of Bunsen Peak glacial flow was from south to north.

3. East of Lava Creek abundant striations on the Washburn Range indicate northwesterly flow. On Mount Everts exceptionally strong glacial scour features also indicate northwesterly flow.

4. Along the valley of the Yellowstone River in the eastern part of the mapped area scour features indicate a westerly flow. Between Crevice and Cottonwood Creeks striations are well preserved on schist and extend from below to considerably above the Deckard Flats ice limit (PD). From the upper limit of Pinedale Glaciation on Palmer Mountain to the northwest corner of the area, flow was west-northwest down the Yellowstone River valley. Glaciers moving southwest down the valleys of Bear Creek, Crevice Creek, and Cottonwood Creek flowed around to the northwest as they joined the glacier in the Yellowstone River valley.

On Palmer Mountain, ice reached an altitude of about 9,100 feet. Just west of the mapped area on Sepulcher Mountain it reached an altitude of 8,800 feet. At Gardiner, Mont., the ice was at an altitude of about 8,700 feet and was 3,500 feet thick. A deep ice-margin channel now partly filled with talus (pta) occurs at an altitude of 8,500 feet 2.7 miles north of Gardiner. The glacier in the Yellowstone River valley terminated 35miles downvalley from Gardiner after having been joined on the way by 10 tributary glaciers.

In most of the mapped area, the ice surface was above 9,000 feet. The ice overrode Cook Peak (alt. 9,742 feet) and merged with an equally high glacier from the Obsidian Creek-Lava Creek segment. If ice at least 250 feet thick was needed to produce the striations on Cook Peak, the ice surface there and to the south was higher than 10,000 feet. A similar conclusion is reached by projecting gradients from Gardiner to the source area. The gradient from Gardiner to the glacial terminus is 100 feet per mile; if the same gradient is projected to the icecap axis above Lake of the Woods, the altitude of the ice surface there exceeded 10,000 feet and the icecap was more than 2,000 feet thick there. This projection may be approximately correct, for the normal decrease in gradient towards the icecap axis was probably offset by the marked local increase in gradient where the ice plunged several thousand feet down from the plateaus (alt. 7,000-8,000 feet) northward into the valley of the Yellowstone River (alt. 5,200 feet).

Middle Pinedale recession—A recession from the early Pinedale maximum followed by a readvance to a middle Pinedale maximum occurred in the Yellowstone area and elsewhere in the Rocky Mountains. Evidence for this readvance was not noted in the mapped area, probably because ice levels at that time diminished very little in this, the source area. After the postulated middle Pinedale maximum, glaciers receded, probably in pulses, and ice-margin streams cut into bedrock and glacial deposits.

As the ice level lowered, flow changed, reflecting both topographic effects and the differing capacities of the source areas to continue supplying ice under a waning glacial climate. The following changes in flow, especially the Deckard Flats advance or standstill, illustrate these effects.

As the ice level fell below the crest of the Washburn Range, the ice, instead of flowing across the range, had to flow down the natural slope along Tower Creek, leaving well-developed northeasterly striations that transect northwesterly ones on the ridge along the east boundary of the mapped area.

After ice ceased flowing over the crest of the Washburn Range, an incursion of northern Absaroka Range ice across the northwest flank of the range left Precambrian erratics and striations indicating southwesterly flow below an altitude of 8,800 feet. (Seven of these Precambrian erratic localities are from G. M. Richmond (written commun., 1972).) Farther southwest, nearly stagnant ice lay in the Obsidian Creek-Lava Creek area as indicated by the general absence of Precambrian rocks. This near reversal in flow from full-glacial conditions occurred in part because the icecap on the northern Absaroka Range could better sustain glaciers than the icecap on the 2,000-foot-lower terrain in the Lake of the Woods area. A lower level of this northern Absaroka Range incursion is represented by ice-dammed lake sediments (pkl) and kame gravels (pkg) along Lava Creek and Precambrian erratics just west of Lava Creek.

As the ice level fell below the top of Bunsen Peak, glaciers flowed around it and left flow features and erratics different from those of full-glacial conditions.

Deckard Flats advance—Late in middle Pinedale time, there was a readvance or standstill, here called the Deckard Flats advance for the lateral moraines just upslope from Deckard Flats (east of Gardiner). Deckard Flats end moraines have been removed by subsequent floods on the floor of the Yellowstone River valley, but descending lateral moraines on the south side of the valley indicate that the terminus was near the mouth of Reese Creek, 2 miles northwest of the map boundary. This ice position requires an upvalley recession of about 30 miles from the Pinedale maximum. The Deckard Flats moraines on Deckard Flats and on the travertine bench above Gardiner are more bouldery and have stronger morainal topography than the Pinedale Till upslope. Along Bear Creek, thick inwash fan gravel (pkf) and ice-dammed lake sediments (pkl) were deposited against ice of the Deckard Flats advance.

In Deckard Flats time, Yellowstone River valley ice moved into the Gardner River valley to a point downstream from the deeply kettled kame gravel at the south end of MacMinn Bench. This ice deposited boulders of Precambrian rocks from the Black Canyon of the Yellowstone in the landslide area southwest of Gardiner. At the north end of MacMinn Bench, abundant large Precambrian erratics from the Black Canyon define a band which extends from the north side of Mount Everts into the Gardner River valley where they appear to be associated with the gray, uppermost till at stratigraphic section 3.

On the Blacktail Deer Plateau the Deckard Flats boundary passes around the lower flank of the Washburn Range and descends Lava Creek into Mammoth "hole." It encircles Mount Everts, which was then a nunatak. Extensive kame sand and gravels (pks, pkg) are associated with ice-margin drainage on the Blacktail Deer Plateau. The icecap in the Obsidian Creek-Lava Creek area had apparently vanished, allowing for minor incursion of Deckard Flats ice from both the Gallatin and northern Absaroka Ranges.

Near the western map boundary, ice carrying erratics from the Gallatin Range (Hi, Gi. L, C. Q) moved eastward down the drainages into the western part of the mapped area. Ice-dammed lake deposits (pkl) accumulated in the Roaring Mountain area. Along Obsidian Creek, extensive kame deposits erratics (C, Hi, Q), striations, and small-scale glacial streaming features indicate that Deckard Flats flow was at 60°-90° to the drumloidal topography and transport direction of erratics under full-glacial conditions.

Ice with erratics from the Gallatin Range poured down Sheepeater Canyon and through Golden Gate into the Mammoth "hole" area. leaving high lateral moraines east of Sheepeater Canyon, and smaller moraines northeast of Golden Gate Canyon and west of Golden Gate. This boundary may be represented by kame gravels draped around the drumloidal hill north of Mammoth. Capitol Hill and other conical hills of kame gravel (pkg) near Mammoth probably represent places where sediment from melt waters filled holes in the stagnant ice perhaps formed by the melting effect of hot springs.
In the Obsidian Creek-Mammoth area the Deckard Flats flow regimen, as compared to the previous full-glacial flow regimen, apparently reflects lowering of ice levels, together with topographic effects and the stagnation of the icecap to the south. With melting of the icecap to the south, glaciers from valleys in the Gallatin Range were free to flow eastward down the drainages, and had to flow around the

topographic obstacles of Bunsen Peak, Terrace Mountain, and the bedrock ridge west of Swan Lake.

Deposits of a younger phase of Deckard Flats time, the Sheepeater Canyon Bridge phase, form fresh bouldery moraines southeast of Mammoth. The main glacier that deposited these moraines flowed down Sheepeater Canyon of the Gardner River, where it picked up abundant basalt erratics; the inner set of these moraines arcs up Lava Creek—an indication that Gallatin ice was the last in that area. Moraines and outwash correlative with those near Sheepeater Canyon Bridge occur a mile west of Blacktail Pond.

South of the Washburn Range, inwash fan deposits (pkf) indicate an ice-front position roughly correlated, by mapping, with the Deckard Flats position of both northern Absaroka Range and Gallatin Range glaciers; the nature of the inwash (pkf) is controlled by the bedrock upslope.

Evidence for Pinedale age of glaciation—A Pinedale age for the last glaciation of the entire mapped area (excluding Palmer Mountain) is favored over assigning some higher elements to the Bull Lake Glaciation or to the pre-Bull Lake glaciations, for the following reasons:

1. All the striations on andesites and basalts from the crest of the Washburn Range to levels covered by Deckard Flats advance are equally fresh, with weathering rinds less than one-fourth mm thick.

2. Most striations on the Washburn Range are on 1- to 3-foot boulders which have been loosened but not removed from their soft volcanic matrix.

3. In places, striations from the highest glacial phase are crossed on the same boulder by those of a lower glacial phase. Since the last glaciations these boulders have weathered completely or partly out of the bedrock. If the glacial scourings forming these striations had been separated by a nonglacial time (perhaps 40,000-100,000 years long), interim weathering and frost action would have so loosened the boulders that the later glaciation would have removed them.

4. The variability of soils does not correlate well with the different levels of glaciation. Soil profiles T and M are weakly developed, yet related to the highest levels. Soil profiles D and E are similar, yet separated by the Deckard Flats boundary. Soil profile L is deep and shows clay films but is within the Deckard Flats limit. Soil profile A is well developed; this apparently reflects the parent material, which includes clay that, when locally concentrated in lenses at the top of profile A and also in post-Deckard Flats alluvial fans, displays extraordinarily well developed color, texture, and structure.

5. Aside from perhaps the Deckard Flats limit, no boundary of age significance is apparent, from the valley floors to the highest glacial features, and no break could be traced laterally for any distance.

6. Above the Deckard Flats limit, in places such as Bunsen Peak, the Obsidian Creek-Lava Creek area, and Mount Everts, all glacial features are related to the full-glacial flow pattern.

7. Pinedale glaciers extended 30 miles downvalley from the Deckard Flats limit; upvalley from the end moraines the highest topographic evidence of fresh glacial erosion and deposition traces to and terminates at the Pinedale end moraines. For glaciations of different age and extent, ice-surface profiles always tend to converge upvalley towards the glacial source area; assignment of the higher level glacial features in the mapped area to a pre-Pinedale glaciation would require just the opposite—that the profiles cross and then diverge upvalley towards the source.

Pinedale hydrothermal explosion—During deglaciation of the Roaring Mountain area, hydrothermal explosions ejected altered rock debris for a radius of 0.5-1 mile. They left two nearby areas of multiple craters that are now more than 80 feet deep (not to be confused with shallower pits due to acid leaching). These explosions probably occurred during the final stages in the melting of the icecap whose axis was in the same area. This places the explosion in the later part of middle Pinedale time and not, as I had tentatively concluded, in late Bull Lake time (in Muffler and others, 1971, p. 732). According to the mechanism postulated, as the icecap was thinning during deglaciation geothermal heat melted through the ice in the Roaring Mountain area and formed an ice-surrounded lake. Hydrothermal ground water beneath the lake would reach a boiling-point temperature equilibrated to the hydrostatic pressure, including the depth of the lake. Then, by the mechanism postulated for the Yellowstone Park area by Muffler, White, and Truesdell (1971, p. 734-736), failure of some part of the ice dam would suddenly drain the lake, thereby lowering the hydrostatic pressure and causing the thermal waters below the surface of. Roaring Mountain to flash to steam and eject the enveloping rocks.

Pinedale floods—Upon the sudden release of glacially dammed lakes, floodwaters about 150 feet deep rushed down the Yellowstone River valley. At least one flood came into the Yellowstone River from Lamar River (east of the mapped area) probably in late Pinedale time, and a later flood came down the Yellowstone River through The Narrows area (east of the mapped area) perhaps in latest Pinedale time. Along the Black Canyon of the Yellowstone, floodwaters picked up talus blocks and, probably during waning stages, left longitudinal and midchannel bars in the wider areas. Near the confluence of Bear Creek and the Yellowstone, floodwaters eroded the bedrock to form so-called scablands. About 0.5 mile east of Gardiner, floodwaters rushed around a bedrock knob and reached about 150 feet above the present Yellowstone River.

Boulder-studded longitudinal bars as much as 1 mile long are found below Gardiner, and a midchannel bar with a bouldery crest and 40 feet of relief occurs just downstream from the Gardiner High School.

Pinedale alluviation and colluviation—Pinedale outwash was noted in only a few places, probably because most Pinedale end moraines lie outside the mapped area. More widespread, especially in the southwestern half of the mapped area, is locally derived alluvium (ps, pg, pfs, pfg) along intermittent stream courses; this alluvium is thought to have been emplaced mainly during deglaciation and in late Pinedale time.

During deglaciation and in late Pinedale time frost action and solifluction were favored by freshly undercut slopes and probably by more moist as well as more severe climates. Glaciated slopes of rhyolite tuff in the Lava Creek area, of basalt in Sheepeater Canyon, and gneiss, schist, and basalt in the Black Canyon were frost riven to produce Pinedale talus or scree (pta, pst). Frost attacked the well-jointed intrusive rocks of Bunsen Peak and Palmer Mountain to produce slopes of block rubble (prb).

Solifluction activity occurs in fine-matrixed deposits when the ground thaws from the surface down, forming a soupy slurry of rocks and mud that flows on even gentle slopes. Such activity was probably common throughout the mapped area during deglaciation and in late Pinedale time.

HOLOCENE COLLUVIATION AND ALLUVIATION

Frost activity and solifluction continued with diminished intensity into Holocene time. In places such as the block rubble (rb) on Bunsen Peak and on Palmer Mountain and the talus (ta) in Black and Sheepeater Canyons, modern activity is clearly evident. In most areas of Pinedale activity (pta, pst, prb) as well as in till and glacial rubble areas, Holocene movement has locally occurred.

Stream gravels were transported and deposited along the larger streams, and fans of gravel and mudflow deposits accumulated on flats below eroding slopes, especially in the northern part of the mapped area.

Peaty deposits are accumulating in marshy areas. On Swan Lake Flat (stratigraphic section 7) about 4.5 meters of peaty marl has accumulated since glaciation. The base of these sediments has a C-14 date of 13,530±130 years B. P. (M. Bender, Univ. Wisconsin, sample WIS-432). A volcanic ash similar in properties to the 6,700-year-old Mazama ash (R. E. Wilcox, written commun, 1970) from Crater Lake, Oregon, occurs at a depth of 2.3 meters.

LANDSLIDING

Most of the area between Bunsen Peak and the Yellowstone River is susceptible to landsliding because of shaly bedrock that commonly contains swelling clays. As described by Waldrop and Hyden (1963), failure in underlying shaly rocks causes overlying rocks to break away along fissures and move by block gliding. With increasing movement the material becomes more homogenized and eventually forms mudflows.

In this area of probable general landsliding throughout late Quaternary time, post-Pinedale movement ranges from earthflows several miles long to only partly disrupted till. The entire area of mapped landslides (ls) north of Gardiner either is now actually moving or is susceptible to movement if disturbed.

The bench southwest of Gardiner displays many small scarps cutting the basalt bedrock (Fraser and others, 1969, p. 69-73); more scarps are present than can be shown at map scale. Like Fraser, Waldrop, and Hyden (1969, p. 74) I consider most if not all of these scarps to represent gravity slumping, forming small-scale graben-and-horst patterns because of failure of the underlying shaly rocks. The fault blocks moved downward and outward toward the Yellowstone River valley 500-1,000 feet below.

Most of the landslides in the area probably started in late middle Pinedale time; during deglaciation, conditions were most favorable for landsliding because of oversteepened slopes and abundant ground moisture.

HYDROTHERMAL ACTIVITY

Travertine is accumulating at Mammoth Hot Springs and locally along the Yellowstone River near Bear Creek. The character of springs varies, with some springs having a life cycle of less than 50 years. Above Mammoth Hot Springs, Pinyon Terrace is inactive and forested, yet is of postglacial age.

In the southwest corner of the mapped area acidic hydrothermal solutions continue to alter bedrock and surficial deposits. Sinter deposits accumulate around hot springs and diatomaceous sediment accumulates in siliceous waters in cooler marshy areas.

QUATERNARY FAULTING

North-trending normal faults, mostly downdropped to the east, are common in the southern part of the mapped area. Most were not observed to offset any surficial deposits; they do offset tuff of the Quaternary Yellowstone Group and are topographically expressed. In a few places in the southeastern corner of the mapped area, offset of surficial units was noted. Two miles west of Grebe Lake, Pinedale gravel is offset 10 feet. North and northeast of Grebe Lake, sag ponds and small abrupt escarpments apparently indicate postglacial movement.

Text from source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle

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References from source map: Mammoth 15' Quadrangle and part of the Gardiner 15' Quadrangle

Mount Hancock 15' Quadrangle

The formal citation for this source.

Richmond, Gerald M., and Pierce, Kenneth L., 1971, Surficial Geologic Map of the Mount Hancock Quadrangle, Yellowstone National Park and adjoining area, Wyoming: U.S. Geological Survey, Miscellaneous Investigations Series Map I-636, scale 1:62,500 (*GRI Source Map ID 1144*).

Description of geologic units, prominent graphics and text associated with this source.

Description of Units

fa - Fine-grained humic alluvium (Quaternary, Neoglaciation)

Silt, sand, and clay underlying marshy or seasonally wet upland depressions and stream-flood plains. Humic content is result of seasonal accumulation and burial of local vegetable debris.

sg - Stream gravel (Quaternary, Neoglaciation)

Pebbles and cobbles in a medium- to coarse-sand matrix; underlies beds of larger streams and forms adjacent terraces up to 30 feet above streams. Deposits include minor sand and silt lenses and are well sorted and well bedded; stones are well rounded. Along Snake River 4- to 10-inch cobbles are common.

fg - Fan gravel (Quaternary, Neoglaciation)

Small alluvial fans of sand, gravel, and silt; mostly in southwestern part of quadrangle.

ta - Talus deposit (Quaternary, Neoglaciation)

Rubble of angular rock fragments or quartzite cobbles with a silty matrix at depth; 5 to 50 feet thick. Lies below cliffs of quartzite conglomerate, sandstone, and rhyolite. Deposits form smooth steep slopes; most are unstable and barren; many are forming at present.

ad - Avalanche debris (Quaternary, Neoglaciation)

Mixture of boulder- to pebble-sized angular rock fragments or quartzite cobbles in sandy to silty matrix at foot of avalanche chutes in and below cirques on Pinyon Peak and Mount Hancock. Poorly sorted to nonsorted.

tt - Till (Quaternary, Neoglaciation)

A single moraine in a cirque on Big Game Ridge at Park boundary. Deposit forms a small rubbly ridge 20 feet high; locally supports sparse grass and trees; consists of blocks and slabs of sandstone in a sandy silt matrix.

sd - Solifluction deposit (Quaternary, Neoglaciation)

Light-brown stony sandy silt; unsorted; derived from Pinedale Till and landslide debris. Forms lobate fans and sheets on lower valley sides and valley floors. Fronts of lobes 2 to 15 feet high. Most deposits seasonally active.

ls - Landslide deposit (Quaternary, Neoglaciation)

Rock-fragment rubble in a silt-clay matrix forming thick lobate masses with flow ridges and undrained depressions. Commonly derived from bentonitic shale of Cretaceous to Paleocene age. Only well-defined deposits mapped, but slumping is widespread in areas underlain by shale. The rock debris, other than shale, in and on the deposits is derived from rock units overlying the shale or from till which mantled the slope before failure. Most slides seem inactive, but parts of many continue to move at least seasonally.

ptu - Till (Holocene and/or Pleistocene)

Subround fragments, mainly andesite and quartzite cobbles, in a sandy clay-silt matrix; forms small morainal mound more than 50 feet high north of Pinyon Peak. Soil on deposit is 1.5 feet thick and has a well-developed B horizon.

pg - Gravel, stream terrace gravel (Holocene and/or Pleistocene)
psg - Gravel, sandy gravel (Holocene and/or Pleistocene)
pfg - Gravel, fan gravel (Holocene and/or Pleistocene)

Gray sandy gravel forming terraces (pg, psg) more than 30 feet, and alluvial fans (pfg) more than 15 feet, above present drainage. Along Snake River, Mink Creek, and Coulter Creek, forms well-rounded cobble gravel (pg, psg) deposited as outwash during late middle Pinedale time. Fan gravel (pfg) forms small fans of local origin.

pco - Colluvium (Holocene and/or Pleistocene)

Stable sandstone rubble and quartzite cobbles in a silty to sandy matrix beyond the limit of glaciation in Pinedale time along south edge of quadrangle. Three to five feet thick. Poorly developed zonal soil. Vegetation-covered.

pta - Talus deposit (Holocene and/or Pleistocene)

Similar to Neoglacial talus (ta), but inactive and forested or grass-covered. Occurs beneath cliffs along canyons of Snake and Heart Rivers. Forms stable mantle of quartzite cobbles and subangular andesite volcanic debris on steep slopes and in cirques on Pinyon Peak.

ptf - Talus flow deposit (Holocene and/or Pleistocene)

Coarse rubble below cliffs; similar to talus, but occurs on moderate slopes (15° to 20°) and has transverse flow ridges and troughs that are mostly arcuate downslope. Locally forested, but commonly barren except for lichen; interstitial areas are open to depth of 1-2 feet. South of Wolverine Creek, deposits overlie landslide debris along base of landslide scarp, and consist of blocks of Yellowstone Tuff from cliff above. In northern part of Two Ocean Plateau deposits consist of slabs and blocks of basalt.

pfr - Frost rubble (Holocene and/or Pleistocene)

Angular, blocky to slabby rubble; 3-5 feet thick; Pleistocene Yellowstone Tuff fragments on summit of Mount Hancock. Interstices void. Local erratics of fresh pale-gray basalt, derived from region of Passage Creek to northeast, show that rubble was formed after summit was exposed during wasting of Pinedale ice cap.

pkg - Kame deposits, gravel (Holocene and/or Pleistocene)
pksg - Kame deposits, sandy gravel (Holocene and/or Pleistocene)
pkgs - Kame deposits, gravelly sand (Holocene and/or Pleistocene)

Gray moderately well sorted gravel and sand with minor silty interbeds; irregularly bedded; abrupt vertical changes in grain size. Deposits underlie irregular terraces, many with ice-contact frontal slopes, along Snake River and Passage Creek. Forms mounds mantled with limestone blocks in Fox Park: outwash fans and related terraces in southwestern corner of quadrangle. Deposits 30 to 200 feet thick.

pt - Till and glacial rubble, till (Holocene and/or Pleistocene)

Gray-brown to gray stony sandy clayey silt: unsorted, moderately compact; stones subangular to rounded. In eastern part of quadrangle, till is bouldery and derived primarily from conglomerate and sandstone of the Absaroka volcanic field and from young basalt flows; in southern part, till is sandy and stones are mainly quartzite cobbles derived from Cretaceous and Tertiary conglomerate; in north half, till is clayey and contains slabs and blocks of sandstone and fragments of shale. Till mantles valley slopes and uplands; thickest (10 to 20 feet) on lower slopes. Drumlinoid forms are common near Fox Park and also at the confluence of Heart and Snake Rivers. In south-central part of quadrangle thick till forms lateral moraines which descend toward Pacific Creek south of the quadrangle.

pr - Till and glacial rubble, rubble (Holocene and/or Pleistocene)

Thin (less than 5 feet) rubbly veneer on glaciated uplands, mainly along Big Game Ridge and Chicken Ridge. Mostly locally derived, but contains a few erratics of volcanic rocks. Veneer is partly of glacial origin and partly the product of postglacial weathering of underlying bedrock. Solifluction and frost action are still affecting the deposits.

bt - Till and glacial rubble, till (Pleistocene)

Gray to brown, locally pink (stratigraphic sections 5 and 6), stony sandy silt; unsorted, moderately compact. Occurs on upland areas beyond upper limit of glaciation in Pinedale time in southern part of quadrangle, and in stratigraphic sections 2, 3, 5, 6, and 8. Stones primarily quartzite cobbles and quartzite chips broken from Pinyon Conglomerate and related conglomerates, but include erratics of Precambrian rock on ridge northeast of Bobcat Ridge and in Pinyon Peak area. Till forms well-defined broad moraines on ridge northeast of Bobcat Ridge and in Pinyon Peak area that bear a moderately developed soil 2 to 3 feet thick. Till underlies pink lake silt of Bull Lake age at stratigraphic section 3.
Mount Hancock Stratigraphic Sections

br - Till and glacial rubble, rubble (Pleistocene)

Thin (0 to 5 feet) mantle of rubble and fine-grained colluvium in areas covered by Bull Lake glaciers. Contains scattered erratics of basalt and andesite. Occurs on upland areas above Pinedale glacial limit. Bedrock locally shows signs Of glacial scour and melt-water channeling. Deposits and underlying rock commonly gullied. Veneer is partly glacial in origin and partly weathered from underlying rock.

bfr - Frost rubble (Pleistocene)

Blocky to slabby rubble above upper limit of glaciation in Bull Lake time on Big Game Ridge. Composed of large sandstone blocks in a sandy matrix. Though formed in Bull Lake time, it was probably reactivated in Pinedale time; now stable.

pbt - Till (Pleistocene)

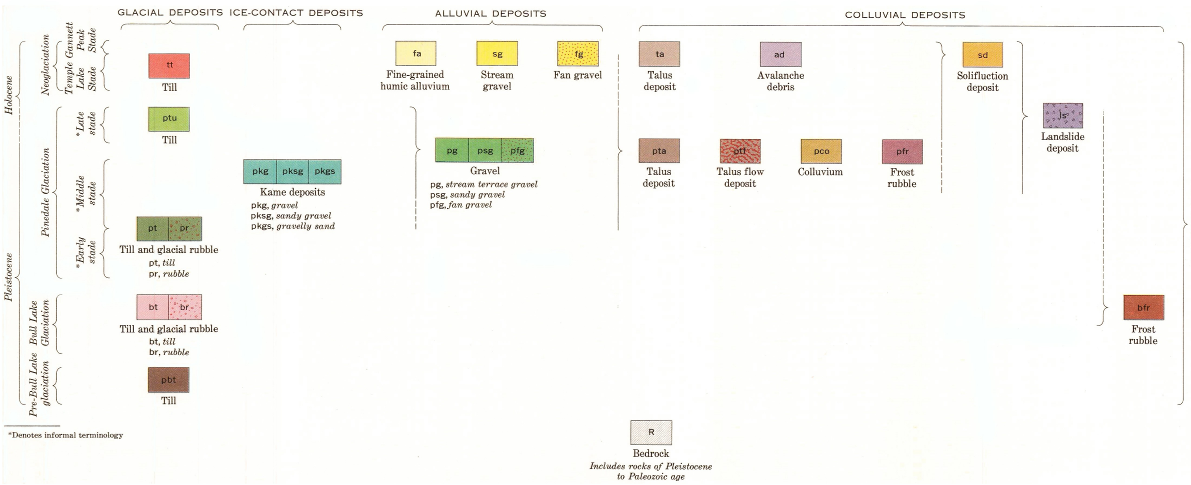
Stony clayey sandy silt; unsorted; compact. Oxidized reddish brown to depth of 15 feet. Occurs as patches of formless till on Pinyon Peak and on ridge northeast of Bobcat Ridge. Contains unweathered striated quartzite cobbles and fresh to partly weathered granite, gneiss, schist, and amphibolite. Most limestone fragments completely leached but some are only deeply etched; broken quartzite cobbles commonly litter the surface. Thickness 10 to 30 feet. Overlies conglomerate of quartzite cobbles.

R - Bedrock (Pleistocene to Paleozoic)

Paleozoic and Mesozoic carbonate rocks, shale, and sandstone are locally exposed along streams and lower slopes in Fox Park-Mink Creek area. Cretaceous shale and sandstone underlie much of south half of quadrangle from Chicken Ridge and Big Game Ridge to lower slopes of Bobcat Ridge-Pinyon Peak-Gravel Peak divide. Cretaceous and Tertiary quartzite-cobble conglomerate and interbedded sandstone and shale underlie the area south of this divide. Tertiary volcanic conglomerate, sandstone, and ashy mudstone of the Absaroka volcanic field underlie the Two Ocean Plateau along east boundary of quadrangle. Pleistocene Yellowstone Tuff underlies areas east and west of Heart River, south of Wolverine Creek, the basin of Chipmunk Creek, and the top of Mount Hancock. A dense gray basalt of Pleistocene age underlies the upland north of Fox Park.

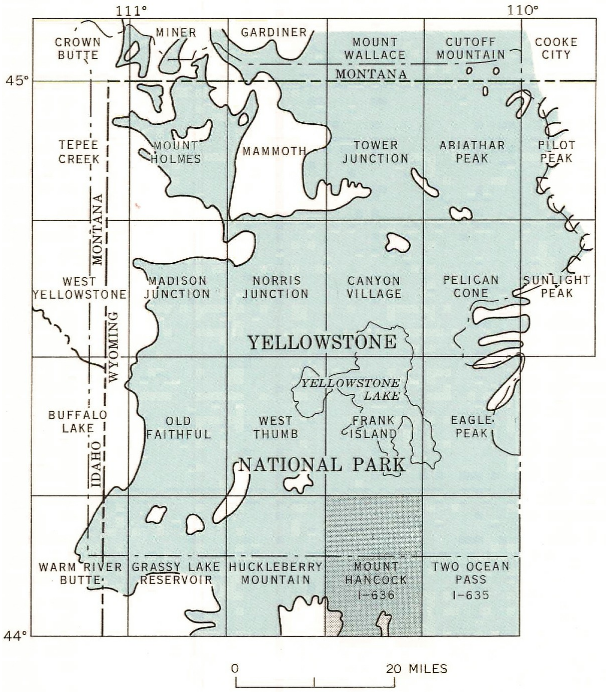
Text from source map: [Mount Hancock 15' Quadrangle]

Correlation of Units



Graphic from source map: [Mount Hancock 15' Quadrangle]

Index Map

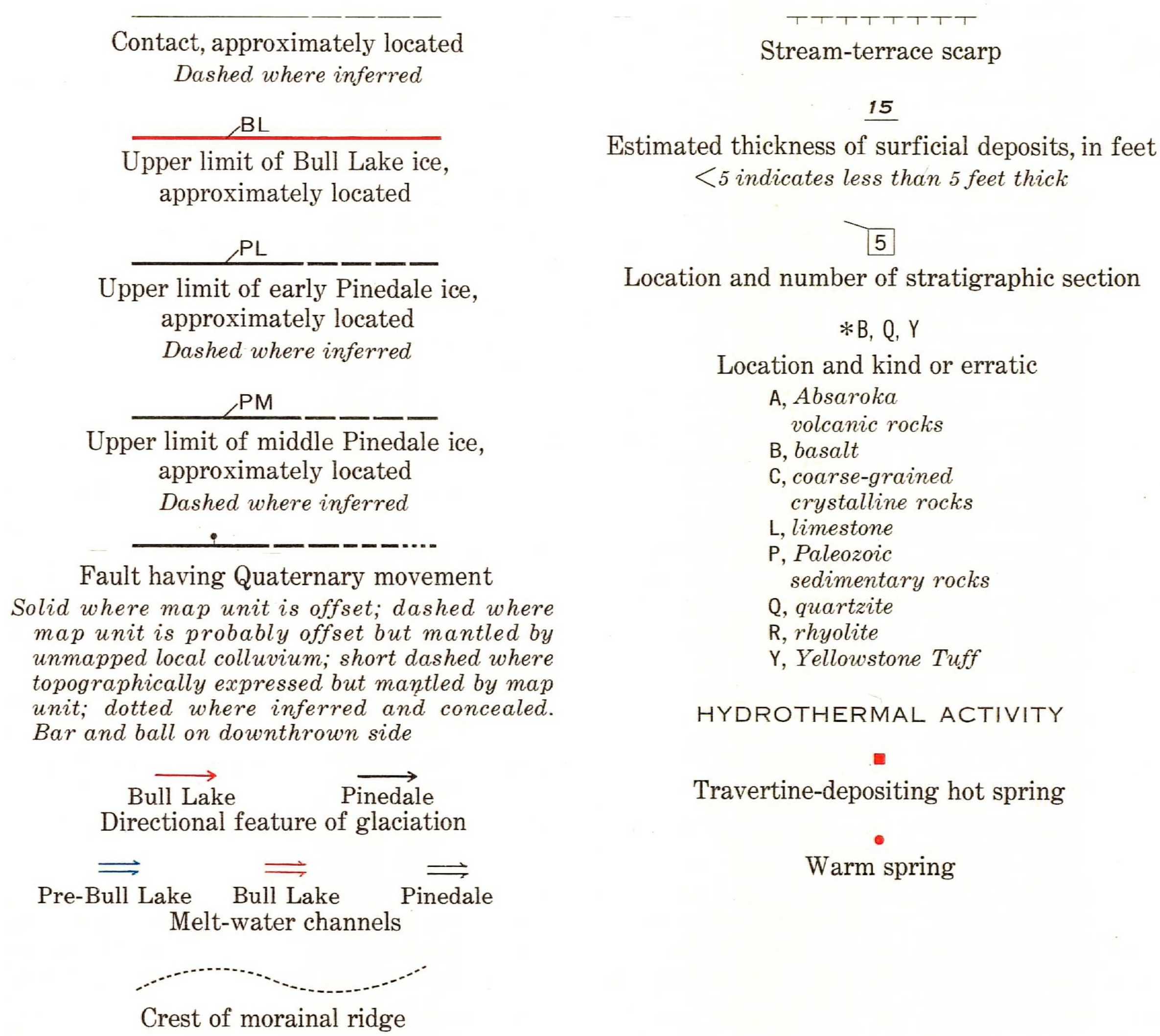


INDEX MAP OF YELLOWSTONE NATIONAL PARK SHOWING LOCATION OF MOUNT HANCOCK QUADRANGLE AND PUBLISHED MISCELLANEOUS GEOLOGIC INVESTIGATIONS MAPS

Color indicates maximum extent of Pinedale icecap

Graphic from source map: Mount Hancock 15' Quadrangle

Map Legend



Graphic from source map: Mount Hancock 15' Quadrangle

Stratigraphic Sections

Units shown in descending order; numbers represent thickness, in feet. *, Soil of the Bull Lake/Pinedale interval.

Stratigraphic section locations are presented in the GRI Geologic Observation Localities (yellgol) feature class. In that feature class, the section identifier is stored in the Location ID (LOC_ID) field. The section information presented here is also contained in the Geologic Observation Localities (yellgol) feature class Notes (NOTES) field.

See Description of Units for information about map units listed here.

1. 12 pt/ 30 bgs
2. 15 pt/18 ppl/4 ppg/20 bt

3. 2 sg/4 bl/3 bt(?)
4. 20 pt/5 bl
5. 10 pr/30 pt/3 bt
6. 10 pr/20 pt/4 sb*/15 bt
7. 6 pt/4 bl
8. 5 pt/8 bt
9. 6 pt/3 bl

Text from source map: Mount Hancock 15' Quadrangle

Surficial Geologic History

INTRODUCTION

The Mount Hancock 15' Quadrangle covers an area in south-central Yellowstone National Park and the adjacent Teton National Forest to the south. In the northeast part of the quadrangle the Continental Divide separates drainage which flows into the South Arm of Yellowstone Lake only 2 miles to the north, from that of westward-flowing tributaries of the Snake River. Another important divide, extending west across the southern part of the quadrangle, separates the Snake River and Pacific Creek drainages.

The area is characterized by broad high uplands separated by deep valleys. To the east lies the Two Ocean Plateau, ranging in altitude from 8,500 to 9,400 feet; to the north and northwest Chicken Ridge and Big Game River rise to altitudes above 9,000 feet and are more than 2,000 feet above the Snake River. In the center, at an altitude of 10,214 feet, is Mount Hancock, the highest point in the quadrangle.

PLEISTOCENE GLACIATIONS

Great icecaps covered most of Yellowstone Park during at least three Pleistocene glaciations: pre-Bull Lake (oldest), Bull Lake, and Pinedale (youngest). The pre-Bull Lake icecap probably covered most, if not all, of the quadrangle, for its deposits are found on nearly all of the highest summits. The Bull Lake icecap was somewhat less extensive; the Pinedale icecap was like the Bull Lake, but 200 to 300 feet thinner in this quadrangle.

PRE-BULL LAKE GLACIATION

Deposits of till (pbt) of a pre-Bull Lake glaciation occur in the southern part of the quadrangle on Pinyon Peak, between 9,550 and 9,700 feet altitude, and on the ridge northeast of Bobcat Ridge, between 9,000 and 9,500 feet. These deposits lie about 100 feet above the upper limit of Bull Lake Till or moraines, but lack any semblance of glacial form. The till contains erratics of Precambrian gneiss, granite, amphibolite, and schist, and Paleozoic limestone and sandstone. Several glacially striated quartzite cobbles were found on Pinyon Peak. The source of the Precambrian rocks is not known. They may be derived either from a nearby Tertiary conglomerate or from the basal unit of the Absaroka volcanic field; or they may have been transported by glaciers from outcrops of these rocks in the headwaters of Buffalo Fork to the southeast.

The till is deeply weathered. Northeast of Bobcat Ridge it is oxidized reddish brown to a depth of 15 feet, and limestone and sandstone cobbles in the weathered zone are decayed and soft. On Pinyon Peak the weathered zone seems to have been stripped by erosion, for solution-etched cobbles of siliceous limestone normally found at the base of the soil occur at its surface. Extensive stream erosion, which cut valleys as much as 200 feet deep, took place between deposition of the pre-Bull Lake till and the subsequent Bull Lake Glaciation.

BULL LAKE GLACIATION

Deposits of the Bull Lake Glaciation, like those of pre-Bull Lake age, are known only from the southern part of the quadrangle. They occur on Big Game Ridge, and on the ridges north and south of Gravel

Peak. They also occur on the flanks of Pinyon Peak, Gravel Peak, the ridge northeast, of Bobcat Ridge, and on the east dank of Bobcat Ridge itself. In most places the deposits are only a veneer of glacial rubble (br), but on the flanks of Pinyon Peak, in the area of Gravel Peak, and on the ridge northeast of Bobcat Ridge there are deposits of Bull Lake Till (bt) that form distinct broad mature morainal ridges. An outwash channel cut by Bull Lake melt waters in the till is preserved south of Gravel Peak. The till contains erratics of Precambrian granite and gneiss, of Tertiary andesite and basalt from the Absaroka volcanic area to the north, of Paleozoic limestone from the north, and of quartzite cobbles from nearby outcrops of Tertiary conglomerate. The Precambrian rocks may be derived either from pre-Bull Lake till, from the local Tertiary conglomerate, or from rocks near the base of the Absaroka volcanic field. Bull Lake Till commonly extends to higher elevations than moraines of the Pinedale Glaciation.

In Fox Park, Bull Lake Till and overlying lake beds form the cores of drumlins mantled with Pinedale Till. The Bull Lake deposits are exposed in cutbanks of the Snake River (stratigraphic sections 4 and 5). At stratigraphic section 6, Pinedale Till overlies a reddish soil, 4 feet thick, developed on Bull Lake Till. In stratigraphic sections 3-8, the till and lake beds are reddish and are considered to be of Bull Lake age because of their position locally beneath Pinedale Till.

Areas not glaciated since Bull Lake time are more extensively modified by colluvial processes, especially solifluction, and are locally more deeply gullied than those glaciated in Pinedale time. This difference in weathering and erosion is especially noticeable on the flanks of Bobcat Ridge, Gravel Peak, and the ridge north of Gravel Peak.

PINEDALE GLACIATION

During the Pinedale Glaciation ice covered all the quadrangle except the upland in the southwest corner and the summit areas of Pinyon Peak, Gravel Peak, and the unnamed upland north of Gravel Peak. Undoubtedly snow accumulated and glaciers developed in the local cirques, such as those on the northeast side of Big Game Ridge and on many of the uplands, but deposits of local glaciation are lacking. The direction of glacial molding of the topography shows that ice invaded the quadrangle from an icecap in the Yellowstone Lake Basin to the east and northeast. A pass along the Continental Divide (altitude 7,950 feet), at the head of Outlet Creek in the Frank Island 15' Quadrangle to the north, was probably the course of the earliest overflow of ice into the westerly drainage of the Heart and Snake Rivers. At about the same time Two Ocean Pass (altitude 8,050 feet), in the Two Ocean Pass quadrangle to the east, was the path of the earliest overflow of ice into the southerly drainage of Pacific Creek. The intervening area of the Continental Divide was ultimately overwhelmed by ice, but the direction of flow continued to be diverted west and south by the high mass of Big Game Ridge. The valley of Wolverine Creek contains little evidence of ice-scour or molding of the topography, although it was probably backfilled by ice flowing down the Snake River and across a pass (altitude 8,920 feet) from the valley of Mink Creek.

The valley of Coulter Creek was similarly backfilled by ice from the valley of Wolverine Creek. The valley of Whetstone Creek was first penetrated by ice flowing from the head of the valley of Wolverine Creek across a pass at 8,400 feet altitude.

At the maximum of Pinedale Glaciation, in early Pinedale time, the ice was more than 2,600 feet thick in the valley of the Snake River, north of Mount Hancock, and 2,000 feet thick along Mink Creek east of Gravel Peak and along Wolverine Creek north of Pinyon Peak. Erratics of fresh pale-gray basalt derived from bedrock along Passage Creek occur on the top of Mount Hancock, and deep glacial grooves cross the crests of Chicken Ridge and Big Game Ridge. The surface of the ice sloped to the southwest and south at a gradient of about 110 feet per mile. Arrows on the map show the direction of ice flow as represented by glacially shaped bedrock, drumlins, and grooves.

A recession followed the early Pinedale glacial maximum, lowering the ice surface at least 200 feet. The ice then readvanced during middle Pinedale time to a terminal position short of its former maximum extent. End moraines of this middle Pinedale advance were found on the ridge south of Pinyon Peak and on the ridge northeast of Bobcat Ridge, where they are large, well defined, and 100 to 200 feet lower in elevation than the moraines of early Pinedale age. At the latter locality spectacular outwash channels lead from the moraines of the middle advance across till of the early advance in notches cut through the ridge. During downwasting of the ice, following the middle Pinedale advance, as many as five lateral moraines were deposited on the slopes of the valleys of Whetstone and Gravel Creeks in a vertical interval of 1,000 feet. Melt waters cut channels into bedrock along the ice margin in several places, as, for example, in the areas southwest of Pinyon Peak and on the slope of the valley of Mink Creek near the south edge of the quadrangle. Along the east edge of the quadrangle many tributaries of Mink Creek are incised 50 to 100 feet into bedrock, probably as a result of melt waters flowing west from ice tongues in the upper valley of the Yellowstone River, across passes through the Two Ocean Plateau.

In the northern and central parts of the quadrangle most upland areas are covered by only a thin glacial rubble (pr), mostly locally derived, which suggests that the upper part of the icecap was relatively free of debris. In contrast, many valley slopes and floors are mantled with thick till, some of which may have slumped down from higher slopes by solifluction or landsliding during and after wasting of the ice. Typical are the broad valleys of Chipmunk Creek, Fox Park, Whetstone Creek, and Gravel Creek.

Near the end of middle Pinedale time local deposits of fluvial sand and gravel (pkg, pksg, pkgs) accumulated as kame terraces adjacent to ice masses in the valley of Chipmunk Creek, in Fox Park, and along the lower valley of the Snake River, especially near its confluence with Heart River. Elsewhere along the Snake River, and along some other streams such as Coulter Creek, locally derived alluvial gravel (pg) and alluvial fan gravel (pfg) is preserved in low terraces 10 to 20 feet above the present flood plains. Curiously, the valleys of Mink Creek and Pacific Creek contain almost no deposits of sand and gravel. Apparently the gradients of these streams are sufficiently steep and the rate of erosion into bedrock is sufficiently rapid that materials reaching the creeks were transported to the broad gravel-covered lowlands of Pacific Creek south of the quadrangle.

During late Pinedale time, perhaps only about 9,000 years ago, after the quadrangle area was free or nearly free of ice, small glaciers formed again in the north-facing cirque of Pinyon Peak and possibly also in some of the cirques on Big Game Ridge. Small glaciers also formed at this time in valleys on the east side of Two Ocean Plateau, in the Absaroka Range, and in the Gallatin Range.

Pinedale frost action and solifluction. During wasting of the Pinedale icecap and also in late Pinedale time frost action and solifluction were more widespread than now. Talus (pta) and talus flows (ptf) of Pinedale age that are now stable and vegetated lie below cliffs of resistant rock along the Snake River and elsewhere at altitudes well below those of modern deposits. Other talus flows (ptf) occur on the northern part of the Two Ocean Plateau and inactive frost rubble mantles the summit of Mount Hancock. Solifluction deposits are far more numerous than indicated on the map. In the central and southern parts of the quadrangle, probably more than half the till (pt) of Pinedale age shown on the map has moved downslope by slumping and solifluction during and since wasting of the ice.

NEOGLACIATION

Following the presumably cool climate of late Pinedale time, the climate became warmer and drier during what is known as the "altithermal interval." Cirques were ice-free and slopes throughout the quadrangle probably were relatively stable. Subsequently, during the early part of Neoglacial time a very small glacier formed in a cirque on Big Game Ridge on the Park boundary and deposited a small rubbly moraine. Frost action was renewed and has continued to the present, forming fresh talus deposits (ta) at high altitudes on Big Game Ridge, Mount Hancock, Gravel Peak, and the ridge northeast of Bobcat Ridge. Solifluction deposits (sd), which began to form in Pinedale time and whose frontal scarps are still seasonally active, spread over Holocene stream gravel (sg) along Crooked Creek, Snake River, and Wolverine Creek.

NEOGLACIAL EROSION AND ALLUVIATION

Holocene stream terraces 15 to 30 feet above the flood plains of the Snake River and Wolverine Creek indicate considerable erosion and deposition of gravelly alluvium in Neoglacial time. Gullies as much as 20 feet deep, cut mainly during spring runoff, -occur on slopes underlain by shale on Bobcat and Big Game Ridges. Extensive fine-grained humic alluvium (fa) overlies Pinedale gravel fills in basins such as Fox Park, in certain valleys such as Wolverine Creek and Gravel Creek, and in many glacially eroded shallow depressions on the Two Ocean Plateau.

LANDSLIDES

Landslides (ls) are widespread throughout the quadrangle west of the Two Ocean Plateau. Most are earth flows derived from steep slopes underlain by soft bentonitic shale of Cretaceous and Paleocene age. Locally, a thick sheet of massive Pleistocene Yellowstone Tuff overlies the shale and forms a cliff at the head of the slide. Some slides seem to have resulted from oversteepening of valley slopes by Pinedale glaciers, and from saturation by melt water during wasting of the ice. The surface morphology of certain large slides, such as those along Wolverine Creek and along the Snake River near the edge of the quadrangle, suggests that they originally slumped or flowed over stagnant ice on the valley floors in Pinedale time. Other slides formed soon after disappearance of the ice, and still others are of very recent age, indeed even locally active.

In the southwest corner of the quadrangle the landslides consist of shallow sheets of debris that have intermittently slumped or flowed piecemeal downslope. Most are stable at present. Mass wasting in this area, which was beyond the outer limits of the Pinedale icecap, may have been brought about through saturation by melting snow and thawing permafrost.

BEDROCK, QUATERNARY FAULTS, AND HOT SPRINGS

The major rock types underlying the quadrangle are discussed under "Description of Units."

Evidence of normal faulting occurs along the valley of the Snake River between Fox Park and Crooked Creek where till (pt) of Pinedale age is offset along fresh topographic scarps. A possible northward extension of these faults along Crooked Creek is suggested by the dip of compact Bull Lake(?) lake beds, 25°-30° W., at stratigraphic section 3. At stratigraphic section 4 along the Snake River, Bull Lake (?) lake beds beneath Pinedale Till dip 10° N. Two normal faults are suggested by north-trending lineaments at the head of Crooked Creek, but no offset of the Pinedale Till was observed. Another east-trending normal fault offsets Pinedale Till along the south boundary of the quadrangle between Whetstone Creek and Gravel Creek.

Large vertical movements of early or middle Quaternary age are suggested by the presence of the same unit of the Pleistocene Yellowstone Tuff at an altitude of about 10,200 feet on Mount Hancock and 2,000 feet lower on the ridge south of Wolverine Creek, 4 miles to the southwest.

A group of hot springs occurs in the gravel plain of the Snake River in the northwest part of the quadrangle. About a mile to the north are several travertine-depositing hot springs. The thermal waters feeding these hot springs may flow upward along faults in the area.

Text from source map: Mount Hancock 15' Quadrangle

Mount Holmes and parts of adjacent 15' Quadrangles

The formal citation for this source.

Pierce, Kenneth L., 1974, Surficial Geologic Map of the Mount Holmes Quadrangle and parts of the Teepee Creek, Crown Butte, and Miner Quadrangles, Yellowstone National Park, Wyoming and Montana: U.S. Geological Survey, Miscellaneous Investigations Series Map I-640, scale 1:62,500 (*GRI Source Map ID 1146*).

Description of geologic units, prominent graphics and text associated with this source.

Description of Units

gt - Till (Quaternary, Neoglaciation)
tt - Till (Quaternary, Neoglaciation)

Gray, nonstratified, and unsorted angular rock debris in sparse matrix. Forms small end moraines 10-40 feet high in north-facing cirques. Gradational with and includes protalus ramparts. Gannett Peak Till (gt) forms a single morainal ridge incompletely covered with lichen, but little other vegetation. Temple Lake Till (tt) forms several slightly weathered morainal ridges covered with lichen, and local trees and grass. Thickness 10-40 feet.

grg - Rock glacier (Quaternary, Neoglaciation)
trg - Rock glacier (Quaternary, Neoglaciation)

Glacier-shaped tongue of angular rock debris that heads in talus from cirque headwalls. Surface-flow ridges and furrows are convex down-slope. Rubble is mainly resistant andesitic intrusive rocks. Deposits of Gannett Peak Stade (grg) have very steep, unstable fronts and are active, fresh, and barren. Deposits of Temple Lake Stade (trg) are inactive or less active with local unstable fronts, locally support trees, are more completely covered with lichens, and are locally overridden by Gannett Peak rock glaciers. Thickness 20-200 feet.

fa - Fine-grained alluvium (Quaternary, Neoglaciation)

Silt and subordinate sand, clay, and plant material that underlies wet ground along drainages and in upland depressions; supports lush stands of tall grasses and sedges. Peaty at surface; locally includes marl at depth (stratigraphic section 5). Thickness 2-20 feet.
Mount Holmes Stratigraphic Sections

sg - Stream gravel (Quaternary, Neoglaciation)

Sandy gravel with minor interbeds of sand and silt; forms alluvial flats 0-10 feet above the present streams; moderately sorted. Gravel is subrounded, 1-4 inches in diameter, and calcareous. Generally 10-30 feet thick, but in Gallatin River valley possibly 100 feet thick.

fg - Fan deposits, gravel (Quaternary, Neoglaciation)
fm - Fan deposits, muddy gravel (Quaternary, Neoglaciation)

Alluvial fans of boulders, cobbles, and pebbles in a sandy matrix below steep slopes. Fan gravel (fg) poorly sorted, crudely bedded; contains finer grained interbeds. Muddy fan gravel (fm) is very poorly sorted flood and mudflow deposits containing abundant fines. Mostly 10-50 feet thick.

ta - Talus deposit (Quaternary, Neoglaciation)

Angular rock rubble forming cones or aprons on steep slopes near timberline. Clasts commonly more than 6 inches across. Deposit bears little vegetation except lichens. Interstices void near surface, but silty matrix at depth. Active piecemeal accumulation from cliffs or positions upslope. Mostly 5-30 feet thick.

tf - Talus-flow deposit (Quaternary, Neoglaciation)

Open rubble of angular rocks on moderate slopes. Mass movement shown by lobate form, deformation of turf at toe, and by unstable or recently turned rock fragments. Thickness 5-30 feet.

fr - Frost rubble (Quaternary, Neoglaciation)

Rubble, mostly cobble-sized, with a fine-grained matrix on gentle slopes above timberline. Seasonal movement indicated by sparse or disrupted tundra and by thin azonal soil. Formed by frost mixing, sliding, and solifluction. Intermediate between solifluction deposit (sd) and block rubble (rb) in ratio of matrix to blocks. Thickness 3-6 feet.

rb - Block rubble (Quaternary, Neoglaciation)

Large angular blocks; interstices void, although fine-grained matrix occurs near base of deposit. Barren; occurs near or above timberline on moderate to gentle slopes. Frost riven from underlying bedrock or from bedrock immediately up slope. Lichen cover incomplete. Thickness 3-10 feet.

ad - Avalanche debris (Quaternary, Neoglaciation)

Boulder- to pebble-sized rock fragments in a fine-grained matrix; forms fan-shaped or lobate deposits at base of avalanche chutes. Deposits crudely bedded, unsorted to poorly sorted, locally very bouldery. Consists of debris transported by snow avalanche, slush flow, debris avalanche, and mudflow. Generally mapped only below active chutes where normal forest is replaced by small trees. Mostly 5-20 feet thick.

sd - Solufluction deposit (Quaternary, Neoglaciation)

Stony mud on gentle and moderate slopes above timberline. Unsorted, nonbedded. Generally overlies shaly bedrock. Seasonally active, forming small terraces where emplaced by shallow flow during thaw. Contains more fine and fewer coarse particles than frost rubble (fr). Deposit 2-5 feet thick.

ls - Landslide deposit, landslide deposit undifferentiated (Quaternary, Neoglaciation)
ef - Landslide deposit, earth-flow deposit (Quaternary, Neoglaciation)

Nonsorted debris in a clayey matrix; forms lobate masses. Generally results from failure in shaly bedrock, but includes blocks of harder bedrock that overlies the shale. Most deposits have moved recently as indicated by fresh ridges, depressions, and slump scarps. Earth-flow deposits (ef) are especially clayey and characterized by smooth flow ridges and troughs parallel to periphery of deposit. North of Sportsman Lake, landslide appears glaciated by late Pinedale ice. Mostly 20-100 feet thick.

tr - Travertine (Quaternary, Neoglaciation)

Light-gray, porous calcium carbonate that cements gravel 1.5 miles west of Fawn Pass. No modern deposition; vertical sections 10 feet thick exposed by erosion.

ptu - Till (Holocene and/or Pleistocene)

Similar to adjacent older Pinedale Till (pt) but slightly more bouldery and restricted to mountain valleys. Commonly forms three sets of well-defined end moraines 10-50 feet high and 0.5-5 miles down-valley from high, north-facing cirques. The B horizon, and the C. horizon if present, of soil profiles F, G, and Q look like those on nearby older Pinedale deposits, but are about 0.5 foot thinner. Along Panther and Fawn Creeks outer end moraines (ptu) are poorly expressed, significantly eroded, and may be older. Till of late Pinedale age probably occurs in headwaters of Gardner River, but no end moraines observed. Thickness 5-100 feet.

Mount Holmes Soil Profiles

prgu - Rock glacier (Holocene and/or Pleistocene)

Materials similar to younger Neoglacial rock glaciers (grg, trg), but form of deposit quite different; characterized by collapse depressions, largely obliterated flow features and rounded frontal-slope crest. Locally forested and mantled by humic soil. Thickness 10-50 feet.

pru - Rubble veneer (Holocene and/or Pleistocene)

Similar to older Pinedale rubble veneer (pr), but scour features of enclosed bedrock areas fresher. Occurs upvalley from late Pinedale moraines.

pkgu - Kame gravel (Holocene and/or Pleistocene)

Similar to Pinedale kame gravel (pkg) but deposited within area occupied by late Pinedale ice.

pgu - Outwash gravel (Holocene and/or Pleistocene)

Similar to older Pinedale outwash gravel (pg) but associated with end moraines of late Pinedale age. Soil profile G has weak B horizon over C. horizon marked by caliche coatings ¼ inch thick on pebbles. Mostly 10-30 feet thick.

Mount Holmes Soil Profiles

pg - Outwash and stream gravel (Holocene and/or Pleistocene)

Gray to buff, moderately sorted gravel with sandy matrix; underlies terraces 5-15 feet above streams and abandoned melt-water channels; stones subrounded to rounded, mostly 1-6 inches in diameter. Except in southwest corner of mapped area, roundstones are, in order of decreasing abundance: carbonate rocks, intrusive andesite rocks, friable quartzite, sandstone, and gneiss. Silty alluvial mantle has infiltrated gravels to aid in forming a weak soil with a "color" B horizon 1-2 feet thick underlain by a moderately developed caliche 1-2 feet thick. Thickness 5-30 feet.

pfg - Alluvial and outwash fan gravel (Holocene and/or Pleistocene)

Mostly similar to Neoglacial fan gravel (fg) but bulk of deposit accumulated in Pinedale time; locally incised by modern streams. In southwest part of area forms outwash fan of moderately sorted pebble gravel which extends west from Pinedale end moraines and laps over sediments of West Yellowstone Basin (wgs). Mostly 10-50 feet thick.

pfd - Flood deposit (Holocene and/or Pleistocene)

Buff, coarse bouldery gravel; poorly to moderately sorted; poorly bedded; boulders mostly of basalt and gneiss and have percussion spalls. Deposits form large longitudinal bars, giant ripple marks, and sharp bars and swales. In the Yellowstone River valley, deposits extend from river level 200 feet upslope to flood-ripped and resedimented fronts of alluvial fans. Probably of late Pinedale age. Much smaller deposits along Grayling Creek form boulder-studded terraces and a barand-swale topography. Probably of late Pinedale age. Thickness 20-100 feet.

pco - Colluvium (Holocene and/or Pleistocene)

Locally derived rock rubble in an abundant fine-grained matrix. In western part of area mapped beyond limits of Bull Lake and Pinedale Glaciations, but contiguous with areas of pre-Bull Lake till (pbt). Mostly stable with a weakly developed soil 1-3 feet thick. Deposits locally include a younger active surface layer. Mostly 3-8 feet thick.

pta - Talus deposit (Holocene and/or Pleistocene)

Rubble of angular rocks as large as 4 feet in diameter. Forms aprons and cones on steep slopes, generally below cliffs. Fine-grained matrix commonly extends to surface where soil is weak, humic, and 1-3 feet thick. Deposit inactive and generally covered with trees or grass. Thickness 5-50 feet.

ptf - Talus-flow deposit (Holocene and/or Pleistocene)

Similar to younger, Neoglacial talus flow (tf) but inactive and partly vegetation-covered.

pst - Scree deposit of tuff rubble (Holocene and/or Pleistocene)

Small-pebble-sized fragments of stony rhyolite forming sheets over tuff bedrock and aprons or cones farther downslope. Generally covered by open forest; includes surface material that slides and tumbles downhill against trees and other obstacles. Thickness of sheets 0-5 feet; of aprons and cones 5-30 feet.

pfr - Frost rubble (Holocene and/or Pleistocene)

Similar to younger, Neoglacial frost rubble (fr) but covered by turf except for protruding large blocks of lichen-covered rubble; virtually stable. Occurs in dry open areas near timberline. Mostly 2-5 feet thick.

prb - Block rubble (Holocene and/or Pleistocene)

Similar to younger, Neoglacial block rubble (rb), but inactive and below timberline. Interstices open at surface; deposits well drained, and vegetation sparse except for heavy lichen cover. Mostly 3-8 feet thick.

pkl - Ice-dammed lake silt (Holocene and/or Pleistocene)

Gray, bedded, calcareous silt. Occurs where glacier from Gallatin River valley dammed lower Fan Creek, and upstream where glacier from East Fork valley dammed the drainage to the south. Mostly 10-30 feet thick.

pkg - Kame gravel (Holocene and/or Pleistocene)

Buff to gray, moderately well sorted gravel and gravelly sand commonly having ice-contact frontal scarps. Upper surface displays irregular terraces, ridges, and kettles. Irregularly bedded with abrupt vertical and lateral changes in grain size, including local sand and silt beds. Gravel mostly less than 6 inches in diameter; composed of limestone, sandstone, intrusive andesite, and, locally, Precambrian crystalline rocks. Locally overlies unweathered Pinedale Till (stratigraphic section 1). Thickness 20-100 feet.

pkf - Kame inwash fan gravel (Holocene and/or Pleistocene)

Similar to kame gravel (pkg) but more uniformly bedded and sized. Deposited behind ice dam near stratigraphic section 2 and soil profile P. Mostly 10-30 feet thick.

Mount Holmes Soil Profiles
Mount Holmes Stratigraphic Sections

peg - Esker gravel (Holocene and/or Pleistocene)

Sinuous ridge of well-sorted gravel deposited by subglacial stream. More gravelly and better sorted than kame gravel. Mostly 10-30 feet thick.

pt - Till (Holocene and/or Pleistocene)

Unsorted, nonstratified, compact mixture of roundstones, sand, silt, and clay deposited by glaciers. Stones mostly subrounded. Glacially striated and faceted clasts are common in deposit but are difficult to recognize on surface. South of Mount Holmes, the till is brown, sandy, noncalcareous, and rich in rhyolite tuff with lesser amounts of basalt, gneiss, and intrusive andesite. In northwestern corner of mapped area, brown, silty, noncalcareous; clasts mainly andesite boulders 0.3-1 foot in diameter. In central two-thirds of area, pinkish-gray to gray, clayey, and calcareous; most clasts <1 foot across and of intrusive andesite, limestone, and friable quartzite. Till mostly occurs as undulating ground moraine. In western part of area forms end moraines with hummocky topography and undrained depressions; ridges are 10-40 feet high, 20-200 feet wide, and slope as much as 20°. Crests of end moraines partly covered (10-30 percent) by protruding stones 0.5-1 foot across. End moraines along Grayling Creek studded with large boulders of gneiss from The Crags. End moraines elsewhere are not particularly bouldery, owing to a lack of boulder-forming bedrock and the abundance of fine-grained materials. Drumloidal topography conspicuous in and near Gardners Hole.

In central two-thirds of area, Western Brown Forest pedocal soils are formed on the calcareous, clayey till. The degree of apparent development is variable; in better developed profiles (soil profiles A, B, D, H, I, J, L, M, P, and U) the B horizon extends about 2-3 feet below the surface. Soil color, texture, and structure are weakly to perhaps moderately developed. Carbonate lenses and rinds in the C. horizon are as much as ¼ inch thick. On noncalcareous till brown podzolic soils mostly less than 2 feet thick are formed. Weathering rinds average less than 0.5 mm thick for each of about 20 suites of 10 or more glacially abraded intrusive andesites collected from the crests of the outermost to the innermost end moraines.

The till has been modified by frost heaving and, on slopes, by solifluction and creep. Till is commonly more than 20 feet thick along valley bottoms and at end moraines, but ground moraine mostly less than 5 feet thick on uplands and steep slopes.
Mount Holmes Soil Profiles

pr - Rubble veneer (Holocene and/or Pleistocene)

Thin mantle over bedrock of rubble in loose fine-grained matrix on glaciated uplands. Mostly weathered, especially by frost processes, from local bedrock, but contains some glacial erratics. Terrain underlain by rubble veneer (pr) gradational with and similar in appearance to much of that underlain by till (pt), but undisturbed glacial deposits are present only locally in glacial rubble areas. Includes discontinuous bands of solifluction debris, especially near tree line. Mapped areas include many small outcrops of glaciated bedrock. Uplands of Quadrant Mountain appear glaciated, but no erratics were found. Thickness 0-5 feet.

wgs - Sediments of West Yellowstone Basin (Pleistocene)

Gray sand and fine gravel forming coalescing alluvial fans of low gradient. Deposit coarsens eastward towards source. Incised 10-20 feet by modern streams and original slope of surface of deposit modified by tectonic tilting. Deposit well bedded with beds 1-2 feet thick: cross-stratification in beds at low angles; gravel commonly openwork. Eastern contact with outwash fan of Pinedale gravel (pfg) mapped at edge of recognizable Pinedale channel morphology.Clasts are dominantly stony rhyolite but to southwest, in West Yellowstone quadrangle, obsidian clasts become dominant. Highly permeable; upper surface generally dry supporting sparse stand of lodgepole pine. Weakly developed soil has admixed windblown silt in upper 12-18 inches. Occurs inside loop of early Bull Lake moraines and is overlain by early Pinedale outwash. Mostly 40-100 feet thick.

bkl - Ice-dammed lake silt (Pleistocene)

Pinkish-tan, massive-bedded silts grading into till where glacier from Bacon Rind Creek dammed Gallatin River. Thickness 5-10 feet.

bkg - Kame gravel (Pleistocene)

Similar to Pinedale kame gravel (pkg), but more deeply weathered and eroded. Mapped in southwest part of area where both deposits include inwash increment. Thickness 5-20 feet.

bfg - Fan gravel (Pleistocene)

Similar to Neoglacial fan gravel (fg). Mapped only in northwest part of area: more deeply incised (about 50 ft) than Pinedale fan gravel (pfg). Soils locally deep and have strong caliche. Unit largely mantled by thick colluvium from adjacent hillsides. Thickness 20-50 feet.

bt - Till (Pleistocene)

Unsorted, nonstratified compact mixture of roundstones, sand, silt, and clay beyond limit of Pinedale Till. Forms bulky moraines with subdued slopes and scarce boulders at surface. Closed depressions generally absent. East of Gallatin Range, subsurface till in stratigraphic sections 3 and 4 is pinker than the overlying Pinedale Till and is probably of Bull Lake age. On north side of West Yellowstone Basin, forms smooth, bulky moraines, mantled by 1-4 feet of windblown silt, and containing much basalt, rhyolite tuff, and Precambrian rocks. On the end moraines shown in the southwest corner of the map soil profiles S and T are 3-4 feet thick with moderate to strong texture, color, and structure development. Along Fan Creek, soil profile C has a moderately well developed B horizon about 3 feet thick. Till mostly 20-100 feet thick.
Mount Holmes Soil Profiles
Mount Holmes Stratigraphic Sections

br - Rubble veneer (Pleistocene)

Similar to Pinedale rubble veneer (pr) but generally thicker, more weathered and stable.

bg - Gravel (Pleistocene)

Mapped only in southwest part of area. Includes both outwash and inwash. Mantled by colluvium; interior of deposit not exposed.

pbt - Till (Pleistocene)

Unsorted, nonstratified, compact mixture of roundstones, sand, silt, and clay on benches in western part of area beyond Bull Lake and Pinedale Till. Generally recognized by erratics. Morainal form generally absent as in the area near stratigraphic section 6 but subdued ridges locally preserved. Original upper surface eroded and disrupted by frost action. Locally mantled by as much as 2 feet of silt. Where partly preserved, relict soil (soil profiles K, R) distinguished by B horizon about 2 feet thick with strongly developed structure, color, and clayey texture. Striated stones of rhyolite tuff from the Yellowstone Group occur in till beneath pre-Bull Lake ice-contact sand and gravel (stratigraphic section 7, 8). In Daly Creek drainage basin in northwest corner of mapped area, erosion of segments of moraines and subdued expression of cirques suggest that the till (pbt) is of pre-Bull Lake age. Along neighboring Black Butte Creek, a formless deposit containing abundant boulders of Precambrian rock, not known to crop out upvalley, is mapped as pre-Bull Lake till (pbt) but might be a Tertiary conglomerate. Thickness 5-50 feet.
Mount Holmes Soil Profiles
Mount Holmes Stratigraphic Sections

pbg - Gravel (Pleistocene)

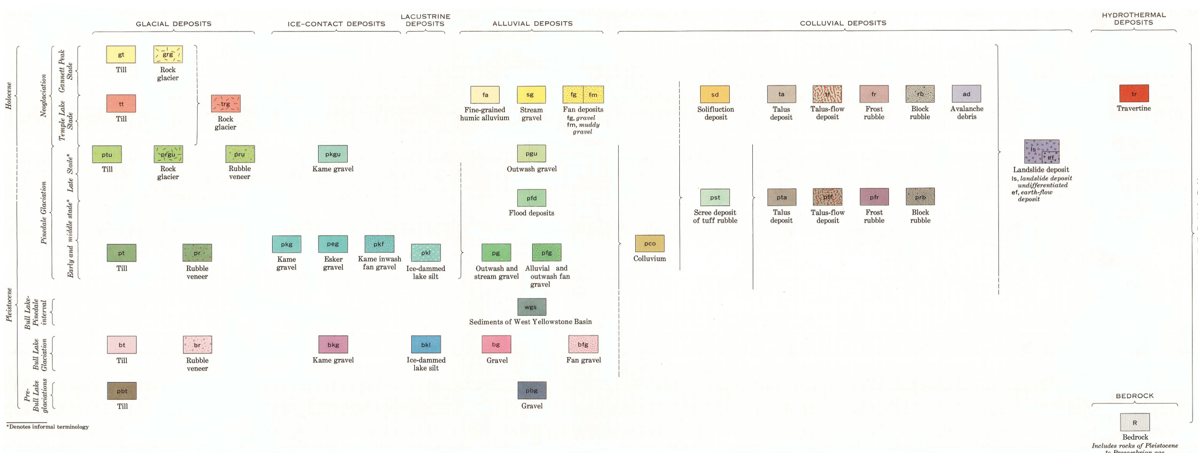
Moderately sorted gravel and deposits of kame sand and lake sediments. Eroded, and mantled by colluvium and alluvial fans. Pre-Bull Lake age suggested by association with pre-Bull Lake till (pbt), height above present drainage, and post-depositional weathering or burial of original deposit. Kame sand leached at soil profile O to depth of 90 inches. Kame sand at stratigraphic section 7 has a moderately developed soil 2-4 feet thick under 2 feet of windblown silt. Relict soil on outwash at soil profile K has B horizon more than 2 feet thick with strong reddish colors, clayey texture, and strong structure. In northwest corner of mapped area, coarse outwash(?) containing Precambrian clasts occurs as much as 60 feet above Gallatin River; mantled by colluvium and alluvial fan deposits and locally deeply weathered. Thickness 20-100 feet.
Mount Holmes Soil Profiles
Mount Holmes Stratigraphic Sections

R - Bedrock (Pleistocene to Precambrian)

(After U.S. Geological Survey map 1-711, 1972) Pinkish gneisses of Precambrian age are exposed low at the south end of the Gallatin Range and also in and south of The Crags. Paleozoic limestones and shales crop out from the south end of the range to the Gallatin River-Panther Creek area. Upper Paleozoic quartzite forms the uplands near Quadrant Mountain. From Fawn Pass north to Electric Peak and in the northeast part of the mapped area, Mesozoic shales and sandstones predominate. However, near Sepulcher Mountain and from Fan Creek to the north map boundary, andesitic volcanic and sedimentary rocks of the Absaroka Volcanic Supergroup crop out. Andesitic laccoliths, stocks, and sills cut the Mesozoic sedimentary rocks in the Electric Peak-Joseph Peak-Indian Creek area, and a biotitic stock crops out near Mount Holmes. Precambrian and Paleozoic rocks crop out along the west boundary of the area, and volcanic rocks of the Absaroka Supergroup occur south of The Crags. Quaternary rhyolite tuff of the Yellowstone Group underlies much of the partially dissected terrain east, south, and west of the Gallatin Range. Quaternary basalt flows locally mantle the tuff.

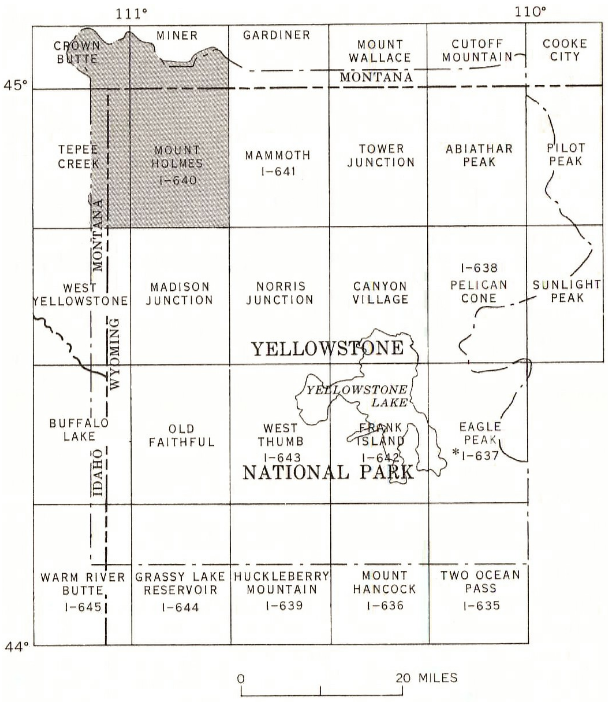
Text from source map: Mount Holmes and parts of adjacent 15' Quadrangles

Correlation of Units



Graphic from source map: Mount Holmes and parts of adjacent 15' Quadrangles

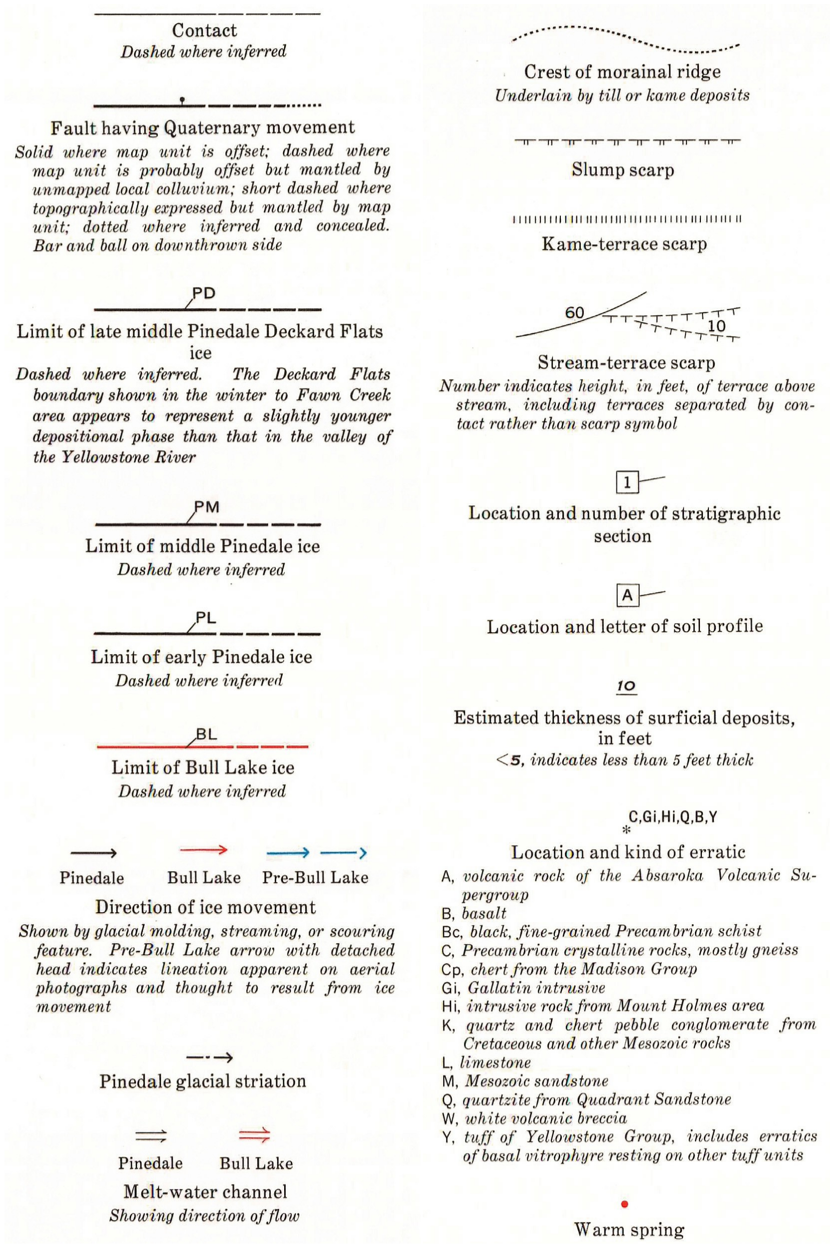
Index Map



INDEX MAP OF YELLOWSTONE NATIONAL PARK SHOWING LOCATION OF MOUNT HOLMES, TEPEE CREEK, CROWN BUTTE, AND MINER QUADRANGLES AND PUBLISHED MISCELLANEOUS GEOLOGIC INVESTIGATIONS MAPS

Graphic from source map: [Mount Holmes and parts of adjacent 15' Quadrangles]

Map Legend



Graphic from source map: Mount Holmes and parts of adjacent 15' Quadrangles

Stratigraphic Sections

Units, separated by slashes, are shown in descending order; numbers show thickness in feet. Letter symbols represent map units; where unit is not a map unit, lithology is described.

Stratigraphic section locations are presented in the GRI Geologic Observation Localities (yellgol) feature class. In that feature class, the section identifier is stored in the Location ID (LOC_ID) field. The section information presented here is also contained in the Geologic Observation Localities (yellgol) feature class Notes (NOTES) field.

See Description of Units for information about map units listed here.

1. 2 soil/20 pkg/30 pt/R
2. 3 soil/15 pkf/10 pkf, sandy
3. 2 soil/38 pt, grayish/15 bt?, reddish
4. 21 pt, tan/2 soil?/18 bt, brown and pink
5. 16 fa, marly (with volcanic ash at 14.8 feet)/pkg?
6. 1 silt, windblown/3 soil/> 5 pbt
7. 2 silt, windblown/4 soil/5 pbg, sandy/> 3 pbt
8. 5 pfg or bfg/2 oxidized gravel/5 sand, gray/15 pbt/R

Text from source map: Mount Holmes and parts of adjacent 15' Quadrangles

Soil Profiles

Soil horizons, separated by slashes, are shown in descending order; numbers give depth in inches below surface. Symbols A, B, and C refer to soil horizons; B1, B2, and B3 refer to subdivisions of B horizon; and Cca refers to carbonate zone in C horizon. Modifiers "moderate" and "strong" show how well structure of B horizon is developed, or how well caliche is developed in Cca horizon. Where no modifier is given, property is weakly developed: the B horizon would generally be regarded as a "color B," or the Cca horizon is developed in calcareous parent material and carbonate has simply been rearranged with only minor translocation.

Soil profile locations are presented in the GRI Geologic Observation Localities (yellgol) feature class. In that feature class, the section identifier is stored in the Location ID (LOC_ID) field. The profile information presented here is also contained in the Geologic Observation Localities (yellgol) feature class Notes (NOTES) field.

A. 0-3A/3-27B/27-43 Cca
B. 0-3A/3-31B/31->46C
C. 0-6A/6->42B, moderate
D. 0-5A/5-22B/22-35 Cca , very weak
E. 0-6A/6-25B, moderate/25->44Cca
F. 0-6A/6-15B, moderate/15->30C
G. 0-10A/10-306/30-40 Cca, moderate
H. 0-5A/5-34B/34-> 48 Cca
I. 0-7A/7-22B/22-33 C, leached/Cca
J. 0-8A/8-30B/30-> 45 Cca
K. 0-6A/6-12B, modern/12->32B, relict, strong
L. 0-8A/8-22B/22->40 Cca
M. 0-9A/9-33B/33->44 Cca
N. 0-8A/8-15B1 /15-37B2, weak to moderate/C.
0. 0-20A, colluvial/20-50B/50-90C, leached/Cca
P. 0-3A/3-30B/30->65 Cca
Q. 0-5A/5-20B/20-23 Cca/C
R. 0-20A, colluvial/20—>50B, strong, relict
S. 0-6A/6-54B, moderate/C
T. 0-22A/22-32B, strong/C
U. 0-3A/3-28B/28-41 Cca/C

Text from source map: Mount Holmes and parts of adjacent 15' Quadrangles

Surficial Geologic History

INTRODUCTION

The mapped area covers the northwestern corner of Yellowstone National Park. The glacially sculptured Gallatin Range extends from the south-central part northward, where it encompasses the entire northern map boundary. Its peaks rise several hundred feet above timberline to altitudes mostly between 10,000 and 10,550 feet. Electric Peak is 10,992 feet in altitude. Dissected benches flank the range at altitudes between 7,600 and 8,000 feet. The lowest places are at elevations of 5,200 feet along the Yellowstone River to the northeast, 6,800 feet along the Gallatin River to the northwest, and 6,600 feet in the West Yellowstone Basin to the southwest.

PLEISTOCENE GLACIATIONS

Great icecaps repeatedly covered most of Yellowstone Park during Pleistocene time. These glaciations are (from oldest to youngest): pre-Bull Lake (which probably included several full-scale glaciations), Bull Lake, and Pinedale. During the Pinedale, and probably the Bull Lake and pre-Bull Lake glaciations, ice accumulated in cirques along the Gallatin Range and, more significantly, in a large icecap on plateaus to the east and southeast. A smaller icecap formed in the uplands at the head of Specimen Creek. In addition, glaciers advanced eastward into this map area from the Madison Range and down the valley of the Yellowstone River from sources east of the map area.

PRE-BULL LAKE GLACIATIONS

The featureless, deeply weathered till (pbt) on the uplands around stratigraphic section 6 is probably the oldest in the area. It overlies and contains fragments of the Huckleberry Ridge Tuff, which is 2 million years old (Christiansen and Blank, 1972). Its relation to the 0.6-m.y.-old Lava Creek Tuff is not known. Other deposits of pre-Bull Lake till, outwash gravel, and kame gravel (see stratigraphic sections 6, 7, and 8, and soil profiles O and R) overlie and contain fragments of the 0.6-m.y.-old tuff which they therefore postdate. Most of the till surface, especially along Daly Creek, preserves visible but subdued, glacial morphology.

A south-southeast lineation of the terrain apparent on aerial photographs suggests that a large pre-Bull Lake ice mass flowed southward from Grayling Creek into the West Yellowstone Basin. This glaciation probably represents the youngest pre-Bull Lake—the Sacagawea Ridge Glaciation—for kame morphology is locally preserved and scour features are observed on aerial photographs paralleling the present topography. In the northwest corner of the mapped area, terrace gravels (pbg) 60 feet above the Gallatin River contain cobbles and boulders of diverse rock types (including abundant Precambrian rocks); they may represent outwash of a pre-Bull Lake glaciation whose end moraines have since been obliterated.

At stratigraphic sections 7 and 8 and soil profile O, glaciofluvial and lacustrine deposits represent the stagnation of probable Sacagawea Ridge glaciers. During such stagnation Grayling Creek may have flowed northward across the low divide.

BULL LAKE GLACIATION

Bull Lake deposits in the map area occur primarily on the north side of the West Yellowstone Basin where bulky but subdued morainal ridges overlie tuff of the Yellowstone Group. Till and locally sandy gravel form these moraines. The till contains abundant basalt and tuff and some metamorphic, sedimentary, and intrusive rocks; these constituents demonstrate a source at the south end of the Gallatin Range. The moraines slope west very gently; the orientation of ice-molded topography just south of the mapped area and obsidian erratics in the till (near soil profile T) indicate that a very large glacial lobe flowed from near the present Madison Canyon (south of mapped area) northwestward into the mapped area, where it joined smaller glaciers descending Gneiss and Maple Creeks. The deposits thicken west of the mapped area toward the terminal moraines at The Narrows of Hebgen Lake about 6 miles west of the area.

In the northwestern part of the area, subdued Bull Lake moraines occur just downvalley from fresher Pinedale moraines. A Bull Lake age for these moraines is suggested by the development expressed in soil profiles C and E. The Bull Lake age of the till along Bacon Rind, Fan, and Specimen Creeks is not certain, because neither the weathering nor the morphology could be reliably compared.

Bull Lake glaciers did not extend as far as Pinedale glaciers along the Gallatin River, Grayling Creek, or in the area just east of the Gallatin Range. (A possible exception is the morainal loop where soil profile N is slightly better developed than other profiles on Pinedale deposits.)

East of the Gallatin Range, a pinkish till of probable Bull Lake age occurs beneath grayish Pinedale Till in the cores of drumlins (stratigraphic sections 3, 4). The pink till lacks erratics of Precambrian gneiss found in the Pinedale Till (stratigraphic section 3). This lack shows that the pink till comes from nearby parts of the Gallatin Range, whereas the Pinedale comes from places as distant as the south end of the Gallatin Range. Therefore the influence of the Bull Lake icecap on glaciers flowing eastward from the Gallatin Range was less than that of the Pinedale icecap.

BULL LAKE-PINEDALE INTERVAL

The sediments of West Yellowstone Basin (wgs) were deposited after the Bull Lake end moraines and before the early Pinedale end moraines. The sediments may be glacially derived; they form large alluvial fans rich in obsidian built by the Madison River and smaller fans rich in stony rhyolite built by Cougar, Gneiss, and Maple Creeks. (The Madison River is south of the mapped area.) Rapid deposition and an abundant supply of material are indicated by planar bedding, the openwork texture of the sediments, and the estimated thickness of about 100 feet.

PINEDALE GLACIATION

Early Pinedale advance—The Pinedale Glaciation left the most prominent record on the present landscape. While early Pinedale glaciers formed in cirques and advanced down valleys in the Gallatin and Madison Ranges, an icecap tens of miles across grew on the plateaus to the east and southeast of the Gallatin Range, eventually becoming several thousand feet thick. Glacial striations and streaming show that this icecap poured around the south end of the Gallatin Range and drained down Maple, Gneiss, and Grayling Creeks. East of the Gallatin Range, drumloidal topography and bedrock scour and striations show the ice to have been so thick that it flowed north-northeast oblique to the Gallatin Range front. Glacial molding and scour show that this flow was essentially undeflected by both topographic obstacles 500 feet high and the valley glaciers from the Gallatin Range (as shown by drumloidal topography across the valley mouths). Fresh glacial striations and scour features occur at altitudes of 8,800 feet on Sepulcher Mountain. For the 12 miles parallel to glacial flow features from Grizzly Lake to Sepulcher Mountain, a presumed gradient of 100 feet per mile is reasonable. Therefore, above Grizzly Lake (alt. 7,508 feet) the icecap probably reached an altitude of 10,000 feet and was about 2,500 feet thick. In Gardners Hole, thick Pinedale and older deposits were molded beneath thick Pinedale ice into pronounced drumloidal topography. This ice was probably well in excess of 1,000 feet thick. This northward-flowing ice converged with ice at equal height on the east (Mammoth quadrangle) to form the Yellowstone Valley glacier whose terminus was 30 miles downvalley from the northeastern corner of this map.

The icecap east of the Gallatin Range dammed valley glaciers in the range, causing them to thicken and flow westward across divides such as Fawn Pass and Bighorn Pass (note flow arrows), where they greatly augmented flow from local glaciers formed within the Gallatin and Grayling drainages. Part of the glacier in the valley of the Gallatin River flowed across the low divide into Fan Creek, where it extended both upvalley (to soil profile D) and downvalley. Lake sediments and gravel (stratigraphic section 2) were deposited along Fan Creek upstream from this ice dam. The Pinedale glacier advancing down Bacon Rind Creek forced the Gallatin River to the eastern side of its valley, where it is now locally incised into bedrock.

A small icecap on the uplands in the north-central part of the area flowed both south into the forks of Specimen Creek and north out of the mapped area.

Outwash from Pinedale glaciers (pg) accumulated along the major valleys near present stream levels and in addition it probably forms the flood plains (sg, fa) of many streams. A large Pinedale outwash fan (pfg) was built across the eastern part of the sediments of West Yellowstone Basin (wgs).

Middle Pinedale advances and stagnation—After the early Pinedale advance, the ice receded and readvanced to the middle Pinedale limit (PM). Middle Pinedale glaciers at their maximum were about nine-tenths the size of those of the early Pinedale.

Abundant recessional moraines in the Gallatin River valley show that the glaciers receded intermittently after the middle Pinedale maximum. Near Divide Lake, glaciofluvial gravels washed around ice blocks which melted, forming kettles in which fine-grained humic marly sediments accumulated. In a kettle near Divide Lake (stratigraphic section 5) an air-fall layer of volcanic ash one-fourth inch thick was deposited after 1.6 feet of a total of 16.4 feet of sediment accumulated. Preliminary petrographic examination by R. E. Wilcox (written commun., 1970) indicates this ash to have the petrographic characteristics of two informally named ash beds—the Glacier Peak ash bed (about 12,000 years old) and the recently discovered set J from Mount St. Helens (between 8,000 and 12,000 years old; Mullineaux and others, 1972). When the ash at stratigraphic section 5 was deposited about 8,000-12,000 years ago, the Gallatin glacier had receded from the middle Pinedale glacial maximum, ice-blocks in kettles had melted, and one-tenth of the sediment now in the kettle had accumulated

The widespread, thick kame gravels along Grayling Creek are related to the icecap near the south end of the Gallatin Range and not simply to the glaciers from the small cirques of Grayling Creek. When the icecap so diminished that inflow into the deep valley of Grayling Creek ceased, the thick ice mass in that valley stagnated, and much fluvioglacial material was deposited.

The last widespread and well-defined advance or standstill of middle Pinedale ice is here referred to as the Deckard Flats advance or standstill (PD). Ice from east of the Gallatin Range flowed down the Gardner River, combined with ice coming down the Yellowstone Valley, and terminated near the mouth of Reese Creek in the northeast corner of the area.

Pinedale frost activity and colluviation—The cold and moist Pinedale climate gave rise to much frost activity and mass wasting. In areas not glaciated in Pinedale time, downslope movement of Pinedale colluvium (pco) and frost rubble (pfr) occurred on moderate to gentle slopes, as did the accumulation of some talus (pta) and block rubble (prb). During glacial recession when areas scoured and steepened by Pinedale ice became exposed, frost wedging of outcrops produced talus or scree (pta, pst) and block rubble (prb). Over much of the area mapped as till or rubble veneer, frost action, solifluction, and creep have caused mixing and downslope movement of unconsolidated materials.

Pinedale floods—Glacially dammed lakes east of the mapped area released at least two floods with waters up to 200 feet deep down the Yellowstone River. Longitudinal bars as much as 1 mile long and 50 feet high occur in the northeast corner and just east of the area. Just north of elevation point 5179 "giant ripple marks" form ridges 50 feet apart, studded with boulders 3-5 feet across. The flood-ripped fronts and transverse scour bars on the lower parts of successively deposited alluvial fans of Reese Creek attest scour by two separate floods. A smaller flood along Grayling Creek deposited boulders as much as 10 feet in diameter which form a bar-and-swale topography with about 8 feet of relief above the sharp bend in the creek.

Late Pinedale glacial advance—In late Pinedale time following middle Pinedale recession, glaciers readvanced from high, well-protected cirques to termini 1 to about 5 miles downvalley. Icecaps and icefields were apparently absent in the mapped area. Three distinct sets of late Pinedale end moraines, representing three phases of glacial advance and recession, are found in the valleys of the Gallatin River, Indian Creek, Panther Creek, and Fawn Creek.

PINEDALE AND HOLOCENE LANDSLIDES
Landslides are common in the northern two-thirds of the mapped area. Most are caused by failure in Mesozoic shales and show fresh morphologic form and other evidence of modern movement. Earthflows display streaming and lobate flow patterns which indicate movement as slow viscous flow rather than as quasi-rigid blocks. Scarps formed by the incipient movement of large masses of bedrock are conspicuous on Sepulcher Mountain and Quadrant Mountain.

In the northwestern part of the mapped area, slides beyond the limits of glaciation probably started moving considerably before Pinedale time. Slides near the Gallatin Range crest probably started moving during middle and late Pinedale deglaciation.

NEOGLACIATION
No glaciers were probably present in the map area during the Altithermal interval about 7,000 to 4,000 years ago. Subsequently, small cirque glaciers and rock glaciers formed in high well-protected cirques. The glaciers deposited one to three rubbly morainal ridges. Temple Lake moraines average 9,000 feet in altitude; rock glaciers average 8,720 feet. Till or rock glaciers of Gannett Peak age occur in about half the cirques with Temple Lake deposits; end moraines average 9,220 feet in altitude, and the rock glaciers, 9,030 feet. Trees are yet to be established on Gannett Peak moraines, indicating the moraines as being less than several hundred years old. Gannett Peak rock glaciers are actively advancing, locally over less active or inactive Temple Lake ones, as in the cirques of Electric Peak. Temple Lake rock glaciers have generally stagnated; locally they are still moving, but were formed in Temple Lake time.

NEOGLACIAL COLLUVIATION
Frost riving continues to produce extensive talus deposits below glacially steepened cirques and other cliffs in the Gallatin Range, especially in hard, well-jointed intrusive rocks. Avalanche debris is accumulating at the base of avalanche chutes by processes ranging from snow avalanches to torrential floods. Solifluction occurs in muddy deposits when the ground thaws from the surface down, thus forming a soupy slurry of rocks and mud (sd) that flows on very gentle slopes. Solifluction and frost heaving together produce rubble (fr). Frost heaving is forming block rubble (rb).

HOLOCENE ALLUVIATION AND EROSION
Most streams in the area now flow within a few feet of their Pinedale level. Although little downward erosion is evident, the streams have reworked and transported Pinedale alluvium in addition to new material supplied from the slopes. Along Specimen Creek and Reese Creek, alluvial fans of poorly sorted debris have coalesced below cliffy slopes.

In Gardners Hole, the larger streams have cut trenches across low points in the drumloidal topography.

QUATERNARY FAULTING
Most Quaternary faults on the map cut rhyolite tuff of the Yellowstone Group and are drawn according to mapping by R. L. Christiansen (U.S. Geol. Survey, 1972). In the West Yellowstone Basin, a fault scarp 10 feet high cuts the outwash fan of Pinedale gravel (pfg).

Text from source map: Mount Holmes and parts of adjacent 15' Quadrangles

References

Christiansen, R. L., and Blank, H. R., Jr., 1972, Volcanic stratigraphy of the Quaternary rhyolite plateau in Yellowstone National Park: U.S. Geol. Survey Prof. Paper 729-B, 18 p.

Mullineaux, D. R., Hyde, J. H., and Rubin, Meyer, 1972, Preliminary assessment of upper Pleistocene and Holocene pumiceous tephra from Mount St. Helens, southern Washington: Geol. Soc. America Abs. with Programs, v. 4, no. 3, p. 204-205.

U.S. Geological Survey, 1972, Geologic map of Yellowstone National Park: U.S. Geol. Survey Misc. Geol. Inv. Map 1-711.

References from source map: Mount Holmes and parts of adjacent 15' Quadrangles

Norris Junction 15' Quadrangle

The formal citation for this source.

Richmond, Gerald M., and Waldrop, H. A., 1975, Surficial Geologic Map of the Norris Junction Quadrangle, Yellowstone National Park, Wyoming: U.S. Geological Survey, Miscellaneous Investigations Series Map I-650, scale 1:62,500 (*GRI Source Map ID 1147*).

Description of geologic units, prominent graphics and text associated with this source.

Description of Units

fa - Fine-grained humic alluvium (Holocene)

Gray to gray-brown humic silt, sand, and clay underlying floodplains, marshes, and depressions in Pinedale Till (pt). Locally overlies Pinedale outwash or stream deposits (ps, pg, pgs, psg). In basin of Nez Perce Creek and around Norris Geyser Basin, deposits are light-brown or gray clay derived from nearby areas of hydrothermal alteration. Contain thin lenses of sand composed mostly of sinter. About 1-10 feet (0.3-3 m) thick.

sg - Stream gravel (Holocene)

Light-gray to gray-brown poorly sorted well rounded weakly bedded sand, gravel, and cobbles. Clasts predominantly of rhyolite or tuff; a few are of andesite or basalt. Deposits underlie floodplain of Yellowstone River and form local terraces 10-20 feet (3-6 m) above it. They also occur locally on Central Plateau.

als - Alluvial and lacustrine sand (Holocene)

Light-gray moderately sorted angular to subrounded well-bedded sand and some silt in Norris Geyser Basin. Composed chiefly of hydrothermally altered tuff of Yellowstone Group and siliceous sinter. Includes deposits of siliceous sinter around hot springs.

sd - Solifluction deposit (Holocene)

Buff fine- to coarse-grained stony silty sand; contains numerous subrounded to subangular pebbles, cobbles, and boulders. Deposits have irregular lobate form, and steep convex fronts 10-15 feet (3-4.6 m) high. Are developed along spring zone at outer margin of Pinedale kame terrace deposits along Arnica Creek. Are seasonally active. Similar deposits, too small to show on map, are widespread along contact between Pinedale kame gravelly sand (pkgs) and underlying lake sediments of late Bull Lake age (bl) along valleys of streams flowing into Hayden Valley from the south.

ds - Diatomaceous silt (Holocene)

White to light-brownish-gray silt composed mostly of siliceous diatom tests. May contain lenses of sand along streams. Deposits are chiefly downstream from nearby thermal spring areas along Gibbon River, especially in Elk Park and Gibbon Meadows. About 2-12 feet (0.6-3.7 m) thick.

si - Siliceous sinter (Holocene)

White to light-gray deposit of amorphous opaline silica forming smooth-surfaced irregular terraces and cones on rims of active and inactive hot springs and geysers in and around Elk Park and Gibbon Meadows. Local internal structure perpendicular to layers. Deposits include some alluvial pebbly sand composed chiefly of small flat angular sinter fragments. As much as 20 feet (6 m) thick.

pl - Lake sediments, silt (Holocene and/or Pleistocene)
psl - Lake sediments, sand (Holocene and/or Pleistocene)

Gray to blue-gray weathering buff massive to laminated locally varved silt (pl) containing minor thin laminae of fine sand along Alum Creek at east edge of quadrangle. Light-gray to white thin-bedded silt and hydrothermal clay (pl) with associated beds of gray sand and rhyolitic gravel along east side of highway in Gibbon Canyon. Plant debris in clays has radiocarbon age of 9,440±300 years (W 1364) (Levin and others, 1965), suggesting deposit formed in late Pinedale time. Gray to buff crossbedded medium sand (psi) forms beach deposit 20 feet (6 m) above east shore of Beach Lake.

pg - Outwash and stream deposits, gravel (Holocene and/or Pleistocene)
psg - Outwash and stream deposits, sandy gravel (Holocene and/or Pleistocene)
pgs - Outwash and stream deposits, gravelly sand (Holocene and/or Pleistocene)
ps - Outwash and stream deposits, sand (Holocene and/or Pleistocene)
pfg - Outwash and stream deposits, fan gravel (Holocene and/or Pleistocene)

Gray to light-brown moderately sorted and stratified unconsolidated sand (ps), gravel (pg), sandy gravel (psg), and gravelly sand (pgs). Gravel is chiefly of rhyolite. Deposits form terraces 20-40 feet (6-12 m) above streams in valleys and fill upland basins and outwash channel floors. Most are 10-20 feet (3-6 m) thick. Similar deposits (pfg) form gently sloping alluvial fans where streams open into basins or valleys.

pco - Colluvium (Holocene and/or Pleistocene)

Gray to gray-brown sandy debris and angular to subangular blocks derived from nearby bedrock. Mapped only above upper limit of Pinedale glacial erratics on Gibbon Hill, where deposit is all of gray rhyolite, and on uplands to east, where deposit is all of pumice or obsidian. A few boulders of local gray rhyolite, having a possible glaciated shape, were found at the top of Gibbon Hill, a rhyolite dome (Rrd). No glacially shaped stones were found on the upland to the east, underlain by pumice rock and obsidian of the Gibbon River rhyolite flow (Rgr).

pta - Talus deposit (Holocene and/or Pleistocene)

Angular to subangular blocky rubble, mostly of rhyolite, forming cones and sloping sheets of debris at base of cliffs. Deposits as much as 50 feet (15.2 m) thick, sparsely vegetated, and inactive.

ptf - Talus-flow deposit (Holocene and/or Pleistocene)

Lobate mass of taluslike material extending downslope from toe of a talus. Indicates forward movement of the mass by flowage. Deposits inactive at present.

prb - Block rubble (Holocene and/or Pleistocene)

Irregular sheet of angular blocks 1-4 feet in diameter lacking matrix and derived from underlying rhyolite flow. Slopes gentle to steep. 2-10 feet (0.6-3 m) thick.

phe - Hydrothermal-explosion deposit (Holocene and/or Pleistocene)

Yellowish-gray loose to compact mixture of angular rock fragments as much as 18 inches (46 cm) in diameter and subround stone mostly pebble size sparsely scattered in a nonbedded unsorted silty sand matrix. Angular fragments and most stones are of tuff of Yellowstone Group; a few stones of obsidian. Material mostly hydrothermally altered before and since deposition; encloses a shallow crater. Believed to be of hydrothermal-explosion origin, possibly under water (Muffler, White, and Truesdell, 1971). Single deposit found by D. E. White and L. J. P. Muffler in western part of Norris Geyser Basin.

pksl - Ice-dammed lake sand (Holocene and/or Pleistocene)

Light-gray medium to fine well-sorted; local silt layers. Crossbedded pebbly beach sand at base.

Thin veneer of gravel and cobbles containing clasts of rhyolite, basalt, and andesite at top. Deposits overlap Pinedale Till (pt), merge laterally with ice-contact gravelly sand (pkgs), and overlie lake sediments (bl) of late Bull Lake age. They occur only in southwestern part of Hayden Valley. About 50 feet (15.2 m) thick.

pls - Landslide deposit (Holocene and/or Pleistocene)

Lobate mass of large and small angular blocks of rhyolite in sandy matrix. Extends downslope from cliff source. Gradational laterally and abruptly into kame sandy gravel (pksg) or gravelly sand (pkgs) terrace deposits. Surface of large deposit along Spruce Creek characterized by numerous hummocks and kettles; local relief as much as 80 feet (24.4 m); some individual rhyolite blocks more than 100 feet (30.5 m) long.

pkg - Kame deposits, gravel (Holocene and/or Pleistocene)
pksg - Kame deposits, sandy gravel (Holocene and/or Pleistocene)
pkgs - Kame deposits, gravelly sand (Holocene and/or Pleistocene)
pks - Kame deposits, sand (Holocene and/or Pleistocene)

Light-gray to brownish-gray poorly sorted crudely to moderately well-bedded sand (pks), gravel (pkg), sandy gravel (pksg), and gravelly sand (pkgs). Thickness a few feet to as much as 80 feet (24.4 m). Cemented by hydrothermal silica locally in thermal areas. Deposits characterized by great variation in texture, sorting, and stratification, by post-depositional slumping and, locally, by crevasse-fill ridges and kettles. They form kame terraces around stagnant ice basins in valleys and valley reentrants. South of Hayden Valley, they underlie an extensive hummocky area characterized by numerous large collapse depressions and, by ice-contact scarps along its northern margin. Along the east side of Gibbon Canyon, deposits form a long ice-contact delta in which the foreset beds dip upriver.

pt - Till and glacial rubble, till (Holocene and/or Pleistocene)
pr - Till and glacial rubble, glacial rubble (Holocene and/or Pleistocene)

Gray-brown to gray stony sandy silty till (pt), loose to compact unsorted unsized. Stones rounded to angular, chiefly of rhyolite. In the southern half of the quadrangle, till contains sparse erratics of basalt and andesite from Absaroka Range to the east. In Hayden Valley and on Solfatara Plateau, the erratics are of basalt and andesite from the Washburn Range to the northeast and of granite and gneiss from the northeastern part of Yellowstone National Park. West of Solfatara Plateau to Norris Geyser Basin the erratics are chiefly of basalt and andesite from the Washburn Range. In the northwest part of the quadrangle, the erratics are of granite, gneiss, and intrusive and sedimentary rocks from the Gallatin Range to the north, and of obsidian from the area of Obsidian Cliff, also to the north. In the area of Norris Geyser Basin, and to the south and west, there are also erratics of chalcedonic sinter, derived from outcrops in the northwest part of Norris Geyser Basin and west of Elk Park. The till is mostly ground moraine, 5-20 feet (1.5-6 m) thick, but locally forms morainal ridges as much as 40 feet (12.2 m) high. Soil on the till is weakly oxidized and commonly less than 1 foot (0.3 m) thick. Glacial rubble (pr) is a thin mantle of stony sandy debris, mostly locally derived but containing a few erratics. It is mainly on glaciated uplands in western and northwestern parts of the quadrangle.

bl - Ice-dammed lake silt (Pleistocene)

Bluish-gray weathering brownish gray compact massive to laminated locally varved silt with local inter-beds of gray fine to medium sand. Underlies most of Hayden Valley, where it locally overlies Bull Lake Till (stratigraphic sections 9 and 10). Mantled by a thin veneer of Pinedale erratics and patches of Pinedale Till (pt). South of Hayden Valley, the lake silt underlies the headwaters of Trout and Alum Creeks where it is mantled by thick Pinedale ice-contact deposits. Extends north from Hayden Valley east and west of Yellowstone River. Deposits attain an altitude of 8,080 feet (2,463 m) along their western margin; range in thickness from 20 to about 200 feet (6-61 m). They overlie the Solfatara Plateau (Rs) and Hayden Valley (Rh) rhyolite

flows in Hayden Valley and extend along: the valley of the Yellowstone River to the north.
Norris Junction Stratigraphic Sections

bsl - Ice-dammed lake sand (Pleistocene)

Light brownish gray to brown unsorted, nonbedded to crudely stratified rhyolitic sand containing scattered angular to subangular pebbles. Underlies hills around hydrothermal basin southwest of Paintpot Hill. Composed of rhyolite, obsidian, perlite, and fine granular glass of local derivation. Contains no erratics but is overlain by Pinedale Till containing chalcedonic sinter and other erratics from the north. Some rhyolite pebbles, hydrothermally altered prior to deposition, are derived from Paintpot Hill, an altered rhyolite dome. Others may be derived from altered parts of the Nez Perce Creek(?) rhyolite flow (Rn?), which the deposits locally overlap. However, the abundant fresh grains and fragile irregular blebs of obsidian and perlite, and the large quantity of fine granular glass are derived from the Gibbon River rhyolite flow (Rgr), which underlies most of the deposits. The sediments are moderately to strongly cemented with silica except in areas of acid alteration. Around hot springs and fumaroles, all of the material is altered, and the obsidian and perlite have been leached, leaving numerous small cavities. Acid alteration is also responsible for erosion of the present basin in the deposits. At and below an altitude of 7,720 feet (2,352 m), the deposits are clean medium- to well-sorted flat-bedded to crossbedded fine to coarse sand; hard and well cemented with silica. These deposits occur east, southeast, and west of Paintpot Hill and north of the trail to Artists Paintpots. Like those at higher altitudes, they contain abundant obsidian, perlite and glass, though those east of Paintpot Hill are mostly altered by hydrothermal activity. At stratigraphic section 12, west of Paintpot Hill, the uppermost part of the sediments, at an altitude of about 7,500 feet (2,287 m) contains layers of black, sandy, silicified, mixed and broken plant debris. Total thickness of deposits ranges from about 30 feet (9 m) to about 170 feet (52 m).
Norris Junction Stratigraphic Sections

bkgs - Kame deposits, gravelly sand (Pleistocene)
bkg - Kame deposits, sandy gravel (Pleistocene)
bks - Kame deposits, sand (Pleistocene)

Light-brownish-gray to brown poorly sorted crudely to well stratified rhyolitic sandy gravel (bkg), forming ridge in eastern part of Hayden Valley. Cemented by silica; locally altered by hydrothermal activity; contains erratics of basalt and andesite. Light-pinkish-gray to gray poorly sorted irregularly bedded rhyolitic gravelly sand (bkgs) in Norris Geyser Basin. In northern part of basin, deposits contain layers of till in lower part. Gray medium-grained rhyolitic sand (bks) forms knob west of Elk Park. Deposit characterized by long foreset beds, but has channel-and-fill, somewhat gravelly topset beds that contain subangular to subround fragments of chalcedonic sinter. All of these deposits are locally mantled by Pinedale Till or erratics. Thickness as much as about 100 feet (30.5 m).

br - Glacial rubble (Pleistocene)

Thin discontinuous mantle 0-5 feet (0-1.5 m) thick of subangular to subround gravel, cobbles, and boulders in a sandy matrix on uplands in southern part of quadrangle. Material mostly of rhyolite, but includes erratics of basalt and andesite locally. May include rock weathering products. Soil, where preserved, consists of an oxidized horizon 2-3 feet (0.6 - 1 m) thick.

oc - Sediments of Otter Creek (Pleistocene)

Gray diatomaceous silt grading westward into gray to rusty silica-cemented gravelly sand; exposed along bed of Otter Creek between 1.3-1.7 miles (2.1-2.6 km) west of highway crossing. Silt is brecciated and contorted; it contains angular grains of obsidian and pumice, pods and fracture fillings of angular pumice and obsidian sand, and scattered pebbles of rhyolite. Gravelly sand is poorly sorted with sharp changes in texture and bedding; composed of angular to subangular grains of obsidian, quartz, sanidine, pumice, and rhyolite; a few spherulites and glass shards. Gravel chiefly of ¼ cobbles as much as 6 inches (15 cm) in diameter and having alteration rinds 1/4 inch (0.6 cm) thick. Westward, the gravelly sand merges abruptly with a silica-cemented glassy breccia consisting of angular coarse sand-sized fragments and masses of angular pebble-to-cobble-sized shattered obsidian in a dense pale-gray fine-grained glass sand and shard matrix. This rock, in turn, grades westward abruptly into the flow-front breccia of the Solfatara Plateau rhyolite flow (Rs). The sediments lie topographically above, but are not in contact with, the Hayden Valley rhyolite flow (Rh), which is exposed downstream and underlies the Solfatara Plateau rhyolite flow elsewhere.

bll - Lake silt (Pleistocene)

Bluish-gray weathering buff massive to thinly laminated silt, containing abundant small pumice and perlite fragments, glass shards, and diatoms. Exposed beneath, and is intricately infolded and injected into, base of Hayden Valley rhyolite flow (Rh) along Grand Loop Road-at and just south of Chittenden Bridge (stratigraphic section 7), along the east side of Yellowstone River south of Chittenden Bridge, and along Otter Creek 1 mile (1.6 km) west of the highway crossing. This unit (bll) is included in the upper part of the unit called sediments of Upper Falls (uf) along Yellowstone River north of Chittenden Bridge and along Cascade Creek (stratigraphic sections 2, 3, 4, 5). Maximum exposed thickness of the silt in this quadrangle is about 25 feet (7.6 m).
Norris Junction Stratigraphic Sections

uf - Sediments of Upper Falls (Pleistocene)

Sequence of sediments, chiefly lacustrine, exposed along the valley of Cascade Creek and Yellowstone River. In this quadrangle, the sediments comprise ten units, from top to bottom as follows:

1. Sandstone-Gray medium- to coarse-grained moderately silica cemented; mostly of rhyolite and obsidian, but contains numerous pumice particles; shallow channel-and-fill cross-bedding characteristic of a near-shore lake deposit. Along north-trending sector of Cascade Creek, at an altitude of about 7,880 feet (2,4G2 m), the sand is cemented to quartzite along its contact with the overlying Hayden Valley rhyolite flow (Rh). It extends as irregular quartzite veins up into the flow, where it was injected when the lava entered the lake and overrode the then soft sand. Unit is as much as 15 feet (4.6 m)

2. Silt -- Gray greenish-gray pink or buff massive to laminated. This unit, here as much as 15 feet (4.6 m) thick, is the same as the lake silt (bll) of the intra-Bull Lake interval south of Chittenden Bridge. In vicinity of the sharp bend in the canyon of Cascade Creek, the nearshore facies upper sand unit is lacking and the Hayden Valley flow, intensively perlitized, rests directly on contorted greenish-gray silt containing abundant small pumice chunks. In several places, pale-buff hard brittle baked silt extends as thick irregular seams as much as 100 feet (30.5 m) up into the flow, where it was injected when the lava flowed across the soft silt. The units below the silt are not exposed in this sector of the canyon.

3. Varved silt-Gray; varved pairs each about 1/2 inch (1.3 cm) thick; total thickness about 21/2 feet (0.8 m). Exposed only on south side of canyon of Cascade Creek at old dam about 1/2 mile (0.8 km) west of highway.

4,5,6. (Undivided) Sand-Gray coarse massive to irregularly bedded; uncemented to moderately cemented by silica. Grains chiefly of rhyolite, some hydrothermally altered, and obsidian. Local silt seams in upper part. Contains a few pebbles of rhyolite, andesite, and basalt in lower part. Thickness 6-10 feet (1.8-3 m). Sediment of Upper Falls (uf) mapped along Yellowstone River are chiefly cemented ledges of this sand. The sand is exposed beneath the overlying silt at Chittenden Bridge (stratigraphic section 7) but not farther south along Yellowstone River.

7. Gravel-Angular to subround pebbles and cobbles, coated with dark iron oxide, in silty sand matrix. Chiefly of rhyolite, but some of andesite and basalt; some striated, indicating glacial transport. Deposit commonly only a few inches thick (stratigraphic sections 2 and 5). It rests with angular unconformity on older sedimentary units.

8. Pumiceous lake sand-Gray medium sized silty poorly sorted massive to evenly bedded. Exposed only at stratigraphic section 5, where it is 5 feet (1.5 m) thick. Composed chiefly of lake-transported pumice aggregates in silt and hydrothermal clay matrix.

9. Stream gravel-Composed wholly of rhyolite. Exposed only in stratigraphic section 2.

10. Pumiceous tuff (tuff of Bluff Point(?)-Compact, massive; consists of pumice and obsidian chunks as much as 1/2 inch (1.3 cm) in size, in a finer pumice matrix. Exposed only at stratigraphic section 5, where it is 4 feet (1.2 m) thick; rests disconformably on Canyon rhyolite flow (Rc).

Sediments of Upper Falls, between Canyon flow and Hayden Valley flow in this quadrangle, are 22-75 feet (6.7-23 m) thick.
Norris Junction Stratigraphic Sections

ch - Chalcedonic sinter (Pleistocene)

White, light-gray or pink, hard layered chalcedony. Layers, 1/16-1/2 inch (0.2-1.3 cm) thick, are locally separated by thin irregular cavities, some filled with quartz; in places layers are very compacted. Layering is irregular and indistinct near contact with underlying rock; locally becomes a nodular structure of chalcedony and massive quartz containing irregular casts of sand or fragment fillings, some still extant, especially along partings. Base of deposit is a mixture of altered sand and rock fragments in a chalcedony-quartz matrix. According to White and others (1956) chalcedonic sinter was originally ordinary opaline sinter which became buried for a long time in an area of thermal activity under which conditions the opaline sinter was converted to chalcedonic sinter.

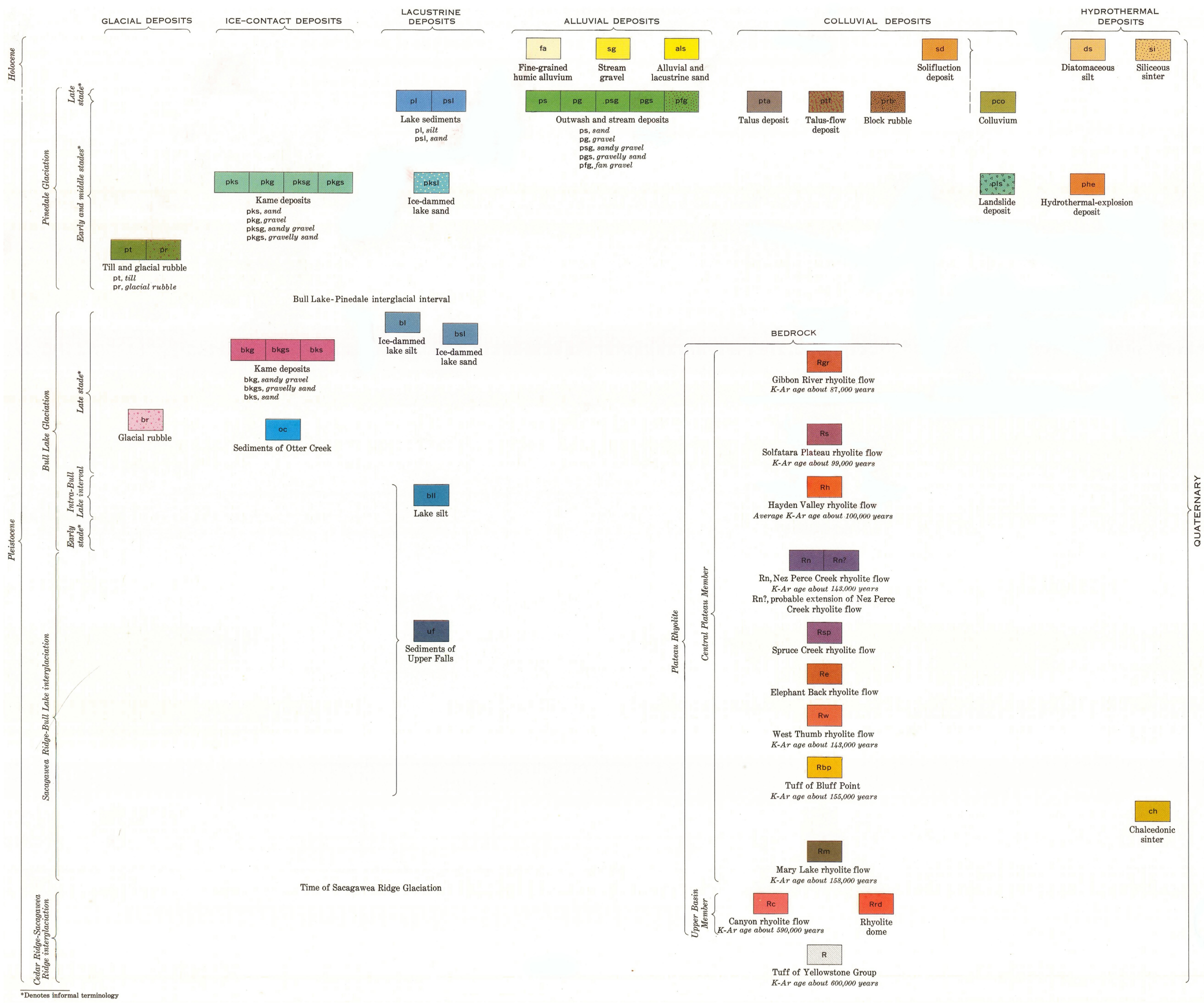
Rgr - Gibbon River rhyolite flow (Pleistocene)
Rs - Solfatara Plateau rhyolite flow (Pleistocene)
Rh - Hayden Valley rhyolite flow (Pleistocene)
Rn - Nez Perce Creek rhyolite flow (Pleistocene)
Rsp - Spruce Creek rhyolite flow (Pleistocene)
Re - Elephant Back rhyolite flow (Pleistocene)
Rw - West Thumb rhyolite flow (Pleistocene)
Rbp - Tuff of Bluff Point (Pleistocene)
Rm - Mary Lake rhyolite flow (Pleistocene)
Rc - Canyon rhyolite flow (Pleistocene)
Rrd - Rhyolite dome (Pleistocene)
R - Tuff of Yellowstone Group (Quaternary, K-Ar age about 600,000 years)

The quadrangle is underlain entirely by Quaternary volcanic rocks. These have been mapped and stratigraphically subdivided by R. L. Christiansen and H. R. Blank, Jr. (1972; U.S. Geol. Survey, 1972; Christiansen, 1975,) from whose work the inset map of rhyolite flows is derived. We have mapped the outcrops of these rocks because their stratigraphic and (or) physiographic relation to the Quaternary sediments contributes to our interpretation of the Quaternary glacial and lacustrine history. Potassium-argon dates are by J. D. Obradovich The northwest rim of a large caldera, about 600,000 years old, trends northeast across the northern part of the quadrangle, north of Canyon Creek and along the crest of Solfatara Plateau (see index map). All the rhyolite flows and domes are younger than this caldera. The Gibbon River rhyolite flow (Rgr) (K-Ar age about 87,000 years) lies on the caldera rim in the northwest part of the quadrangle. Its

western margin forms much of east rim of Gibbon Canyon. Southwest of Paintpot Hill it is overlapped by cemented lake deposits of late Bull Lake age. The Solfatara Plateau rhyolite flow (Rs) underlies the Solfatara Plateau and extends south to Hayden Valley and west across the Central Plateau. It yielded a K-Ar age of about 99,000 years, and overlies the Hayden Valley rhyolite flow (Rh), from which two K-Ar dates of about 97,000 and 103,000 years were derived. The frontal breccia of the Solfatara Plateau flow merges with the sediments of Otter Creek (oc), and probably was extruded against a glacier of late Bull Lake age. The flow is overlain by till (bt) and varved lake silt (bl) of late Bull Lake age. The Hayden Valley rhyolite flow (Rh) extends eastward from the Central Plateau across Hayden Valley beyond the east edge of the quadrangle. Near Chittenden Bridge and along Cascade Creek the flow is perlitized, and involuted with lake silt (bll) of the intra-Bull Lake interval, which in turn overlies varved silt and glacial gravel of early Bull Lake age. The Nez Perce Creek rhyolite flow (Rn) (K-Ar age about 143,000 years) rests on the Spruce Creek rhyolite flow (Rsp) in the central part of the quadrangle. A flow that may be a part of the Nez Perce Creek and is mapped as Nez Perce Creek(?) rhyolite flow (Rn?) (Christiansen, 1975) yielded a K-Ar age of 157,000 years. The flow erupted against the caldera rim at Gibbon Canyon along whose eastern wall it is exposed beneath the younger Gibbon River rhyolite flow (Rgr). At the north end of the canyon it protrudes from beneath the Gibbon River flow to form the ridge between the canyon and Paintpot Hill. Its stratigraphic relation to other flows and to the tuff of Bluff Point is unknown. The Spruce Creek flow rests on the Elephant Back rhyolite flow (Re), which underlies most of the southern part of the quadrangle. The Elephant Back flow yielded a K-Ar age of about 150,000 years, but rests on the West Thumb rhyolite flow, K-Ar dated at about 143,000 years. The West Thumb rhyolite flow (Rw) crops out in the southeast corner of the quadrangle. The Nez Perce Creek, Spruce Creek, Elephant Back, and West Thumb rhyolite flows represent a succession of eruptions closely related in time. The tuff of Bluff Point (Rbp) crops out as a welded tuff dipping steeply to the west against the Mary Lake rhyolite flow on the escarpment west of Mary Lake. It also crops out in the canyon of Nez Perce Creek to the southwest. The tuff at the base of stratigraphic section 5 in the canyon of Cascade Creek may represent a nonwelded facies of the tuff of Bluff Point. The Mary Lake rhyolite flow (Rm) (K-Ar age about 158,000 years) is exposed at and west of Mary Mountain. The oldest rhyolite extrusives in the quadrangle are three small domes (Rrd) on the wall of the caldera in area of Gibbon Hill, and the Canyon rhyolite flow (Rc) (K-Ar age about 590,000 years) which lies just inside the caldera rim, and crops out along Cascade Creek. The oldest rock (R) in the quadrangle is a tuff of the Yellowstone Group, K-Ar dated at 600,000 years. It was erupted at the time of development of the caldera. The tuff forms the west wall of Gibbon Canyon and underlies much of the northwest part of the quadrangle.
Norris Junction Stratigraphic Sections

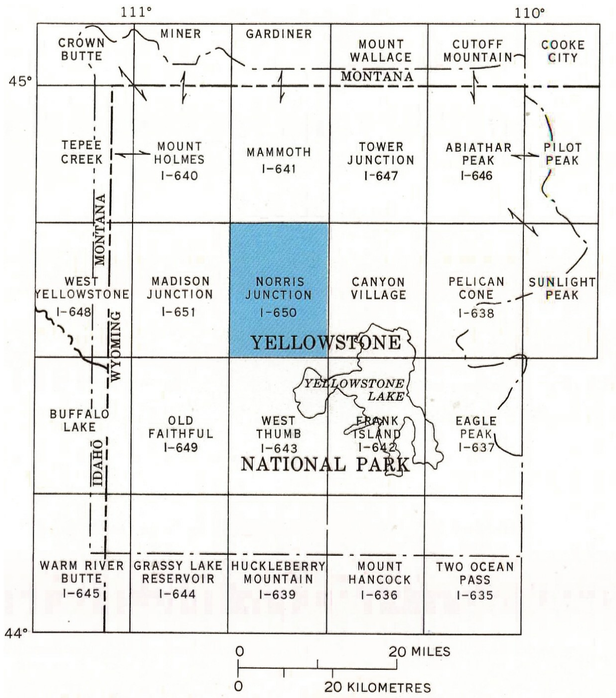
Text from source map: Norris Junction 15' Quadrangle

Correlation of Units



Graphic from source map: [Norris Junction 15' Quadrangle]

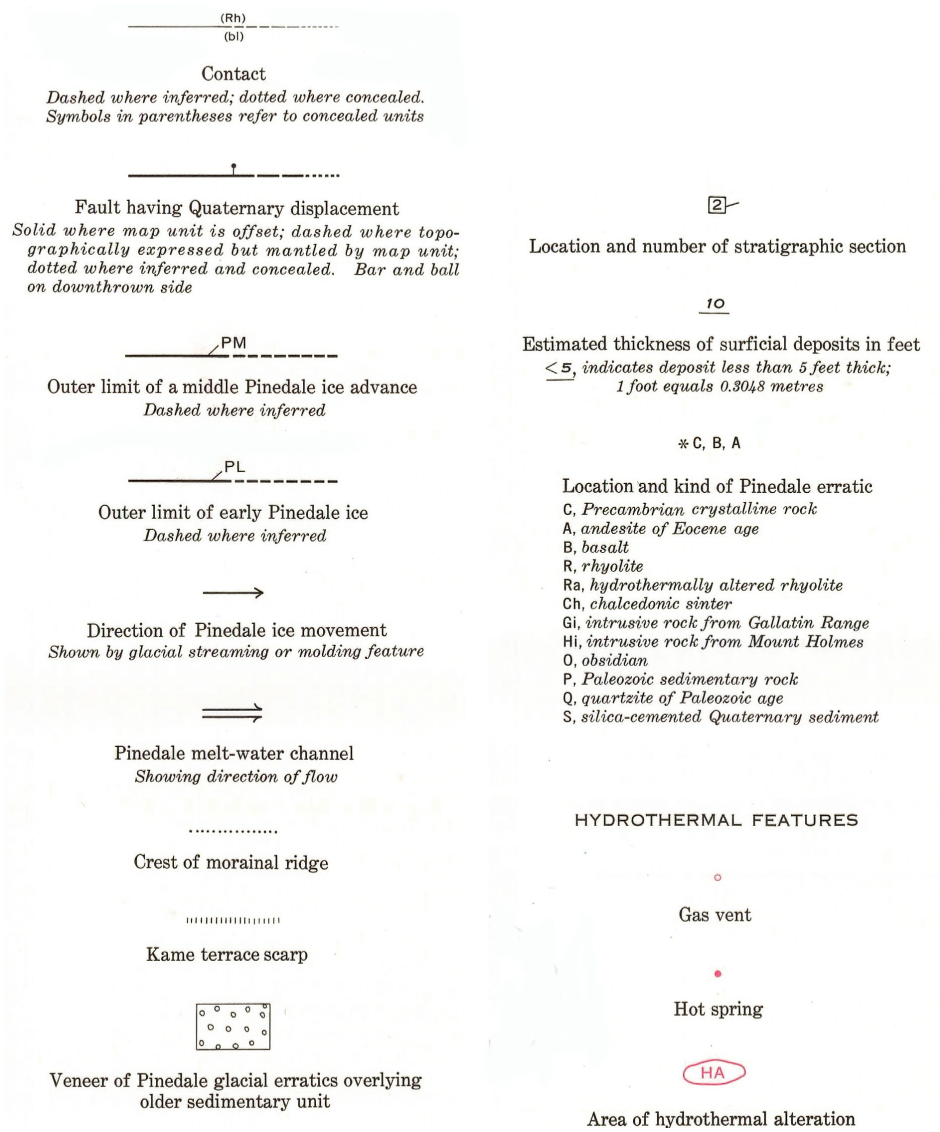
Index Map



INDEX MAP OF YELLOWSTONE NATIONAL PARK SHOWING LOCATION OF NORRIS JUNCTION QUADRANGLE AND PUBLISHED MISCELLANEOUS GEOLOGIC INVESTIGATIONS MAPS

Graphic from source map: Norris Junction 15' Quadrangle

Map Legend



Graphic from source map: Norris Junction 15' Quadrangle

Stratigraphic Sections

Units, separated by slashes, are shown in descending order; numbers represent thickness in feet (metres in parentheses). Sections demonstrate stratigraphic relations of units having too small a surface area to be shown on the map. Numbered units of uf (sediments of Upper Falls) are those described in text.

Stratigraphic section locations are presented in the GRI Geologic Observation Localities (yellgol) feature class. In that feature class, the section identifier is stored in the Location ID (LOC_ID) field. The section information presented here is also contained in the Geologic Observation Localities (yellgol) feature class Notes (NOTES) field.

See Description of Units for information about map units listed here.

1. 3 (0.9) pt/2 (0.6) bll/2 (0.6) br (early Bull Lake age)/8 (2.4) Rc
2. 30 (9.1) pt/12 (3.7) uf (unit 1)/37 (11.3) uf (units 2 and 3, mostly covered)/11 (3.3) uf (units 4-6, undivided)/0.4 (0.12) uf (unit 7)/9 (2.7) uf (unit 8, silt)/8 (2.4) uf (unit 8, sand)/3 (0.9) uf (unit 9, stream gravel)
3. 25 (7.6) Rh/15 (4.6) uf (unit 1)/6 (1.8) uf (unit 2)
4. 100 (30.5) Rh/10 (3) uf (unit 2)
5. 40 (1.2) Rh/3 (0.9) uf (unit 2)/2.8 (0.85) uf (unit 3)/5 (1.5) uf (units 4-6, undivided)/0.5 (0.15) uf (unit 7)/5 (1.5) uf (unit 8)/4 (1.2) uf (unit 10, Rbp?)/4 (1.2) Rc
6. 40 (12.2) Rh/28 (6.3) uf, undivided, mostly lake sand/15 (4.6) Rc
7. 8 (2.4) Rh/26 (7.9) bll/4 (1.2) uf (units 4-6, undivided)
8. 2 (0.6) pco, colluvium/3 (0.9) pt/6 (1.8) involuted and crumpled lake silt mixed with pt/21 (6.4) bl, thickly varved
9. Pinedale erratics/25 (7.6) bl/4 (1.2) bt/15 (4.6) Rh
10. 6 (1.8) pt/10 (3) bl/2 (0.6) bt/10 (3) Rh
11. 6 (1.8) psl/36 (11) p1/17 (5.2) psl/zone of erratics/3 (0.9) bl
12. 35 (10.7) bsl/8 (2.4) Rgr

Text from source map: Norris Junction 15' Quadrangle

Surficial Geologic History

INTRODUCTION

The Norris Junction 15' Quadrangle lies in the central part of Yellowstone National Park. It is chiefly occupied by the Central Plateau and its extension to the northeast, the Solfatara Plateau. These plateaus are drained eastward by tributaries of the Yellowstone River, which enters its Grand Canyon at Chittenden Bridge, and westward by Gibbon River and Nez Perce Creek. The plateaus are underlain by a series of Quaternary rhyolite flows erupted within and along the rim of a large caldera, mentioned under "Bedrock." Four basins are partly or wholly enclosed by the steep margins of the flows. The Norris Geyser Basin and Gibbon Geyser Basin lie on the rim of the caldera; the basins of Nez Perce Creek and Hayden Valley lie within the caldera. Each basin is the locus of significant hydrothermal activity, the most spectacular being that in Norris Geyser Basin. The uplands along the northern border of the quadrangle form the southern margin of the Washburn Range, which lies just north of the caldera rim.

PLEISTOCENE GLACIATIONS

During at least three Pleistocene glaciations-from oldest to youngest: Sacagawea Ridge, Bull Lake, and Pinedale-great icecaps covered most of Yellowstone National Park (Richmond, 1970; Pierce, 1970; Waldrop, 1970), and, locally, evidence is found for still older Pleistocene glaciations. However, only deposits of the Bull Lake and the Pinedale Glaciations are recognized in this quadrangle. During each glaciation, an icecap flowed in a generally westward direction across the quadrangle from sources in the drainage basin of Yellowstone Lake to the southeast. In Pinedale time, the lake-basin icecap merged in the northeastern part of the quadrangle with ice overflowing to the south from a very large west-flowing glacier in the drainage of the Lamar and Yellowstone Rivers to the North. In the northwestern part of the quadrangle, it also merged with ice flowing southward from the Gallatin Range and adjacent uplands to the east.

PRE-BULL LAKE TIME

According to Christiansen and Blank (1972), a widespread tuff of the Yellowstone Group was erupted about 600,000 years ago, during development of the large caldera whose northern rim trends northeast across the northern part of the quadrangle. (See small map.) A large lake existed in the caldera following its development. Deposits of this lake occur in the Canyon Village 15' Quadrangle, adjacent to the east. The Canyon rhyolite flow (Rc) (K-Ar age about 590,000 years) was extruded into the lake along the caldera rim in the northeastern part of the quadrangle. Three rhyolite domes (Rrd) were also extruded on the caldera rim in the northwestern part.

After development of the caldera, but during pre-Bull Lake time, hot springs deposited opaline sinter in the northwestern part of Norris Geyser Basin and West Elk Park. This probably took place during an interglacial age. Subsequently, the opaline sinter was buried for a long time by younger sediments, possibly of glacial origin. While buried, the opaline sinter was reconstituted by hydrothermal activity (White, Brannock, and Murata, 1956) to form the present deposits of chalcedonic sinter (ch).

There is evidence of glaciation in Yellowstone National Park just prior to about 160,000 years ago. However, we found no pre-Bull Lake glacial deposits in this quadrangle.

About 158,000 years ago, the Mary Lake rhyolite flow (Rm) was erupted within the caldera in the central part of the quadrangle. Somewhat later, about 155,000 years ago, the tuff of Bluff Point (Rbp) (former Shoshone Lake Tuff Member) was erupted in association with the development of a caldera at the site of the present West Thumb of Yellowstone Lake (Christiansen and Blank, 1972). The pumiceous tuff (unit 10) at the base of the sediments of Upper Falls (uf) at stratigraphic section 5 may be the tuff of Bluff Point. The welded facies of the tuff is inclined against the steep front of the Mary Lake flow southwest of Mary Lake. Eruption of the tuff was followed about 10-15 thousand years later by the eruption of a series of thick rhyolite flows, including the West Thumb flow (Rw), Elephant Back flow (Re), Spruce Creek flow (Rsp) and Nez Perce Creek flow (Rn). (See index map.) These flows, all about the same age, built up the Central Plateau to its present height and separated the original caldera lake into two drainages. One, to the east, was occupied by lakes in and north of present Hayden Valley and in the basin of Yellowstone Lake. The other, to the west, was in the drainage of the present Firehole and Gibbon Rivers. The pumiceous lake sand (unit 8) of the sediments of Upper Falls (uf) at stratigraphic section 5 was deposited in the lake that lay in and north of present Hayden Valley.

The Nez Perce Creek(?) rhyolite flow (Rn?), considered by Christiansen (1972) to be a part of the Nez Perce Creek flow (Rn), extended into the area of Gibbon Canyon. It flowed against cliffs of the 600,000-year-old tuff that formed the wall of the caldera (along present Gibbon Canyon) and probably dammed a lake upstream. If so, the altitude of the flow front at the head of Gibbon Canyon suggests that the surface altitude of the lake may have been at about 7,600 feet (2,317 m). At this altitude, the lake would have extended north into the area of Gibbon Meadows, Elk Park, and Norris Geyser Basin. No deposits of the lake have been identified. Outflow from the lake would have been along the contact between Nez Perce Creek(?) flow and the tuff of the caldera rim. A paleocanyon, ancestral to present Gibbon Canyon, may have been eroded, but no remnant of such a paleocanyon was found.

BULL LAKE GLACIATION

The Bull Lake Glaciation in Yellowstone National Park comprised two distinct widespread glacial advances separated in time by a nonglacial interval when glaciers were absent from the basin of Yellowstone Lake. During both advances, icecaps nearly covered the entire park. At both times, the ice that covered this quadrangle originated as valley glaciers in the Absaroka Range east and south of Yellowstone Lake. The glaciers flowed into the basin of Yellowstone Lake where they merged and grew into an icecap locally over 3,000 feet (914 m) thick. The caps of both advances flowed northwest across the northern part of the quadrangle, and west across the central part. Their outer limits lay west of this quadrangle.

EARLY STADE

Before the eruption of the Hayden Valley (Rh) and Solfatara Plateau (Rs) rhyolite flows, a lake basin occupied the area east of the Central Plateau from the south side of Hayden Valley north to Cascade Creek. The early Bull Lake icecap invaded this basin from the southeast and gradually thickened against the slopes to the west and north. The ice deposited a thin layer of gravel containing erratics of basalt and andesite, some striated, on preexisting lake sediments. The gravel is exposed at stratigraphic section 5 and was found by digging at stratigraphic section 2. It is also exposed at stratigraphic section 1 where it rests on the Canyon rhyolite flow and contained, when examined by us, a striated boulder of basalt about 8 inches (20 cm) in diameter. Pebbles and small cobbles of rhyolite, andesite, and basalt occur in the lower part of the lake sand overlying the gravel (stratigraphic section 5). We infer that they were ice-rafted during the recession of early Bull Lake ice. Varved silt above the lake sand (stratigraphic section 5) was also deposited in the lake during recession of the ice.

As discussed below, the glacial gravel of early Bull Lake age is overlain by lake deposits that are overlain in turn by the Hayden Valley rhyolite flow (Rh), whose average K-Ar age is about 100,000 years. The early stade of Bull Lake Glaciation therefore ended before about 100,000 years ago.

INTRA-BULL LAKE INTERVAL

Following recession of the early Bull Lake icecap, an open lake again occupied the lake basin east of the Central Plateau. Its deposits were chiefly massive to laminated silt (bll and unit 2 of uf) which underlies and interfingers with crossbedded lake sand, a near-shore facies of the lake, along the canyon of Cascade Creek (unit 1 of uf, stratigraphic sections 2 and 3). The shore of the lake probably lay against the slopes of the Canyon rhyolite flow (Rc) at an altitude of about 7,800 feet (2,377 m).

About 100,000 years ago, the Hayden Valley rhyolite flow (Rh) (K-Ar dated at about 97,000 and 103,000 years) erupted from the Central Plateau into the lake. Exposures along the north-trending sector of Cascade Creek show where it flowed across the near-shore lake sand, which was locally squeezed up into fractures in its base, and down a steep underwater slope into the silt. Exposures on the floor of the canyon of Cascade Creek near its bend show where the flow invaded the soft silt, infolding and injecting it up into the flow as much as 80 feet (24.4 m) and baking it to a pale-buff color. Along the east side of Yellowstone River, about 1 mile (1.6 km) south of Chittenden Bridge, similar injections of the silt show as white zones extending up into the dark flow rock. The flow itself, upon entering the lake, was intensely hydrated to granular perlite, which is extensively exposed along the canyon of Cascade Creek and at the bend in the highway just south of Chittenden Bridge. At the latter locality, a large involution of silt in the perlitized flow is well exposed. Everywhere beneath the flow the silt contains abundant chunks and grains of pumice, erupted just prior to eruption of the flow itself.

LATE STADE

The late Bull Lake icecap invaded the quadrangle from the southeast and spread northwest and west across it. In the northwest corner of the quadrangle it may have abutted another icecap flowing south and southwest from the Gallatin Range to the north. In the southwestern part of the quadrangle, Bull Lake glacial rubble (br) is preserved on uplands above the upper limit of younger Pinedale Till. In Hayden Valley, till (bt) of late Bull Lake age, or a layer of stones containing erratics of basalt and andesite, overlies the Hayden Valley rhyolite flow (Rh) (stratigraphic sections 9, 10, and 11). The glacial deposits are therefore younger than about 100,000 years. They are overlain by a widespread younger varved silt (bl) of late Bull Lake age.

The Solfatara Plateau rhyolite flow (Rs) (K-Ar age about 99,000 years) erupted in part over the Hayden Valley flow. Its abnormally convex shape along the western and northern margins of Hayden Valley suggests that it erupted against the late Bull Lake glacier. This hypothesis is supported by the unusual character of the sediments of Otter Creek (oc), exposed in the narrow valley of Otter Creek between two lobes of the flow; in particular by the abrupt transition of the flow-front breccia into the sediments and by the pattern of fractures, filled by a granular glassy matrix, that shatter large and small obsidian fragments in both the breccia and the sediments. Also of significance is the predominance of pumice and obsidian in the sediments, the admixture in the sediments of rock foreign to the flow-front breccia, such as hydrothermally altered and fresh stony rhyolite, and the sharp changes in texture and bedding characteristic of the sediments. These features suggest explosive cooling in contact with late Bull Lake ice or ice-marginal water. If so, the late Bull Lake glacier lay in this area about 99,000 years ago. The sediments were found only at the margin of the Solfatara Plateau flow.

Numerous ice-contact deposits were formed during recession of the late Bull Lake icecap. In the northwestern part of the quadrangle, a large kame, composed mostly of cemented, well-sorted lake sand (bks), that displays long foreset beds dipping to the west, was deposited on the flank of the upland west of Elk Park. At the top of the kame are beds of channel-and-fill crossbedded coarse sand containing a little gravel. Pebbles of chalcedonic sinter in the gravel are derived from outcrops of the sinter immediately to the north and are distinct from a variety of Pinedale erratics on the deposit. They suggest local drainage from the north over the stagnating ice. In the thermal area of Norris Geyser Basin, the ice probably stagnated and melted rapidly, for the area contains extensive deposits of hydrothermally altered and cemented ice-contact gravelly sand (bkgs). These deposits are overlain by unaltered or little altered uncemented Pinedale Till and ice-contact deposits. In the northwestern part of Norris Geyser Basin, along the bluffs south of Gibbon River, the altered cemented gravelly sand overlies and interfingers with altered, cemented till of late Bull Lake age. Both the till and the gravelly sand are chiefly of tuff and rhyolite but contain a few erratics of andesite and basalt derived from the east. Pinedale erratics, scattered over the surface of the cemented deposits are from sources to the north. Ice-contact gravelly sand (bkgs), in part lacustral, is also well exposed in the hills, known as the Ragged Hills, in the central part of Norris Geyser Basin. It contains no fragments of chalcedonic sinter (ch), whereas overlapping Pinedale Till contains fragments of the sinter derived from outcrops in the northern part of the basin, as well as other erratics from north of the quadrangle. These differences indicate that the gravelly sand (bkgs) of the Ragged Hills was probably derived from the east. The well to poorly sorted, flat-bedded to crossbedded character of the deposits, and the sharp changes in texture and structure within them are characteristic of ice-contact deposits. We conclude that the gravelly sand was deposited in this thermal area during stagnation of the late Bull Lake icecap.

The Gibbon River rhyolite flow (Rgr) (K-Ar age about 87,000 years) erupted from a vent along the caldera rim in the northwest part of the quadrangle. The vent area forms the hill southeast of Gibbon Hill, where it was mapped by Boyd (1961). On this hill, the upper part of the flow is thickly mantled with gray porous pumicite, through which low ridges of obsidian locally project. In a swale in the north-central part is an area of steepsided volcanic pits, 15-25 feet (4.6-7.6 m) deep and 40-60 feet (12.2-18.3 m) across, that are floored and rimmed by fresh obsidian and pumicite. The area of pits is surrounded by a volcanic fossa, 20-30 feet (6-9 m) deep, that opens to the east. Though forested, this fresh-appearing volcanic terrain displays no evidence of having been glaciated, and no glaciated stones, erratics, or other indications of glaciation were found elsewhere on the flow above altitudes of 8,360-8,400 feet (2,648-2,660 m), the upper limit of Pinedale ice. Inasmuch as the Bull Lake icecap attained altitudes well above the highest point on the flow, and as the flow exhibits no ice-contact features, the ice must have receded from this area before eruption of the flow about 87,000 years ago.

The flow extended principally to the west of the vent area. Its north edge wrapped around hills on the caldera rim. Its northwest end extended northward over the Nez Perce Creek(?) rhyolite flow in the area of present Gibbon Canyon to a point about 1/2 mile (0.8 km) north of Beryl Spring. Here it formed a dam blocking drainage from the north. The resulting lake rose over the Gibbon River flow to an altitude of 7,840 feet (2,390 m) as shown by the deposits of lake sand (bsl) on the flow southwest, south, and southeast of Paintpot Hill. The abundance of fresh obsidian, perlite, and gray granular glass in the lake sediments indicates their derivation from the Gibbon River flow. The unsorted and non-bedded to crudely stratified character of the higher sediments suggests rapid reworking of the surface materials of the flow in a short-lived body of water. The clean medium- to well-sorted flat-bedded to crossbedded character of the sediments at and below an altitude of 7,720 feet (2,353 m) suggests a longer stand of the lake at this level. The presence of a matte of plant debris at an altitude of about 7,500 feet (2,286 m) (stratigraphic section 12) indicates conditions permitting the growth of swamp vegetation at the lake margin. Any open lake above an altitude of 7,550 feet (2,300 m) would have drained across the divide north of Norris Geyser Basin into the present northward drainage of Obsidian Creek. Inasmuch as this lake stood for a time at least 170 feet (53 m) higher, and for a short time as much as 290 feet (88 m), we conclude that it must have been retained to the north by receding or stagnating late Bull Lake ice. Possibly, at first the ice may have been as near as Gibbon Meadows or Gibbon Rapids; possibly some of the ice-contact deposits in Norris Geyser Basin were formed in the lake; clearly ice covered the drainage divide north of Norris Geyser Basin until the lake fell below an altitude of 7,550 feet (2,201 m). Though the lake may have drained in part under ice to the north, its major outflow was to the south. At first it drained along the contact between the Gibbon River rhyolite flow (Rgr) and the tuff underlying the wall of the caldera. Subsequently Gibbon River has cut through the Gibbon River flow and deeply into the underlying Nez Perce Creek(?) flow to form Gibbon Canyon.

As the late Bull Lake icecap wasted east of the Central Plateau, a lake opened in Hayden Valley. Its silty sediments (bl), in large part varved, extend throughout the valley beneath younger Pinedale Till (pt) or erratics, and ice-contact deposits (pkgs). The silt overlaps the Solfatara Plateau flow (Rs) to altitudes as high as 8,080 feet (2,463 m) in the western part of Hayden Valley. This altitude, as pointed out by Howard (1937), is higher than the highest point on the rim of the canyon of the Yellowstone River to the north. The lake in which these deposits formed must therefore have been retained by ice. Its outlet may have been to the west. Probably the highest silts were deposited when the ice first melted from the slopes, ponding water against them. Later, as the ice disappeared from the valley, silt was deposited throughout it and on the slopes bordering the Yellowstone River to the north. At the bend in the highway south of the turnoff to Upper Falls, compact, thickly varved silt was exposed at the time of our study (stratigraphic section 8). Above the silt was a zone a few feet (a few metres) thick in which lenses and fragments of silt are involuted, crumpled, slickensided, and mixed with sandy, stony till containing erratics of basalt, andesite, and granite. This zone grades upward into Pinedale Till containing the same kinds of erratics, which indicates that the silt was overrun and its upper layers disturbed and reworked by Pinedale ice. The silt itself contains no stones. Howard (1937) correctly inferred that the lake in which the silt (bl) was deposited must have been dammed to the north in the area of the canyon of the Yellowstone River by ice flowing south from the Lamar River drainage northeast of this quadrangle. However, he associated the lake with the last (Pinedale) glaciation. We conclude that the lake was retained by receding ice of late Bull Lake age from the time of its highest level at about 8,080 feet (2,463 m) down to a level of about 7,760 feet (2,365 m), the approximate altitude of a dam formed by the overlap of the Solfatara Plateau flow (rs) against the Hayden Valley flow (rh) in the Canyon Village 15' Quadrangle.

BULL LAKE-PINEDALE INTERGLACIAL INTERVAL

In Hayden Valley, the lake existing at the end of Bull Lake Glaciation probably remained at a surface altitude of about 7,760 feet (2,304 m) for a time but was drained when the Yellowstone River entrenched itself along the contact between the Solfatara Plateau (Rs) and Hayden Valley (Rh) rhyolite flows in the Canyon Village 15' Quadrangle, adjacent to the east. Whether the drainage and entrenchment resulted in part from catastrophic floods is not known. From the trench of the Yellowstone River, the valleys of Alum Creek and Trout Creek, and their intricate tributaries, were dissected headward into the lake deposits of late Bull Lake age (bl) and locally into the underlying Hayden Valley flow (R h) in Hayden Valley. Pinedale Till on the walls of the trench and locally on the dissected lake-silt slopes in Hayden Valley shows that the silts could not have been deposited in a proglacial Pinedale lake, as suggested by Howard (1937).

Pollen analyses by R. G. Baker (written commun., 1973) of lake sediments of this interglacial interval at Grassy Lake Reservoir, just south of Yellowstone National Park, suggest that the climate of the early part of the interval was somewhat like today, but that most of the interval was cold. Wood from the upper part of those lake sediments is greater than 42,000 years old (Sample W-2264, Meyer Rubin, written commun., 1970). In the basin of Yellowstone Lake plant debris found in sediments of this interval beneath ice-contact gravels of Pinedale age yielded a radiocarbon age of >40,000 years (Sample W-2955, Meyer Rubin, written commun., 1973).

PINEDALE GLACIATION

During the Pinedale Glaciation, an icecap flowed northwest into this quadrangle from the basin of Yellowstone Lake. It spread westward across the Central Plateau to a terminus near the west boundary of the Park. Over most of this quadrangle the ice deposited a thin mantle of till but, in Hayden Valley, where it moved across preexisting lake silts (bl) of late Bull Lake age, it deposited only small patches of till and a discontinuous veneer of stones. At some time, the icecap was joined by a glacier flowing south into Norris Geyser Basin from the Gallatin Range and adjacent uplands to the east. The distribution of erratics, derived from the Gallatin Range, from Obsidian Cliff north of the quadrangle, and from outcrop areas of chalcedonic sinter in the northern part of Norris Geyser Basin, shows that this ice completely covered the basin despite the considerable heat given off by the local hydrothermal activity. Along the north edge of the quadrangle, this ice spread as far as the main fork of Solfatara Creek.

South of the Norris Geyser Basin, Pinedale erratics of obsidian, altered rhyolite, tuff of the Yellowstone Group, and chalcedonic sinter, all derived from the north, occur to altitudes as high as 8,300 feet (2,530 m) on Gibbon Hill and on the west and northwest slopes of the upland to the east. Above this altitude on Gibbon Hill, only possibly glaciated boulders of the unaltered rhyolite bedrock of the hill itself were found. Erratics of basalt, obsidian from Obsidian Cliff, chalcedonic sinter, and intrusive rock from the Gallatin Range on the upland west and south of Paintpot Hill show that ice from the north extended southward at least as far as the southern part of Gibbon Canyon.

On the southeast slope of the upland east of Gibbon Hill, Pinedale erratics of basalt and andesite from the Washburn Range to the northeast were found to altitudes of 8,400 feet (2,560 m). At the west edge of the upland, erratics from the north were found as high as 8,360 feet (2,548 m). The upper limit of erratic-bearing Pinedale ice therefore sloped westward from 8,400 feet to 8,360 feet (2,560 m to 2,548 m) around the upland.

The icecap from Yellowstone Lake was also joined by ice which overflowed from the north around the east end of the Washburn Range northeast of the quadrangle, and then southwest into the quadrangle. The distribution of Precambrian crystalline erratics deposited by this ice shows that it spread southwest across the crest of the Solfatara Plateau and the northern part of Hayden Valley. That it crossed the highest part of the Central Plateau is indicated by an erratic of granite at an altitude of 8,500 feet (2,591 m) on Mary Mountain (Howard, 1937).

Recession from the early Pinedale maximum was marked by secondary readvances and halts of the ice in middle Pinedale time. In Gibbon Canyon, one such readvance from the east is marked by the ice-contact gravelly sand (pkgs) of a delta in which the foreset beds dip upcanyon. As this ice receded south of the present abrupt westerly bend in the canyon of the Gibbon River, a former southerly course of the river to Canyon Creek was filled as much as 80 feet (24.4 m) with ice-contact gravelly sand (pkgs). This plug of sediment impounded a short-lived pond in Gibbon Canyon which overflowed westward along the back slope of a tilted fault block, where the river has cut a canyon about 100 feet (30.5 m) deep. North of Gibbon Canyon, a readvance of ice from the north is marked by a well-developed end moraine in the northern part of Gibbon Meadows (PM). Lateral moraines extending upslope west of Gibbon Rapids contain abundant erratics of rock from the Gallatin Range End from Obsidian Cliff to the north as well as fragments of chalcedonic sinter (ch) from outcrops southwest of Elk Meadows. The ice of this advance covered Norris Geyser Basin, but no end moraine marking its eastern limit was found. The broad west end of the terrace sand (ps) along the Gibbon River northeast of Norris Geyser Basin may represent the delta of a lake in the basin during recession of the ice. In the central part of the quadrangle, a middle Pinedale readvance of ice from the east is marked by discontinuous end moraines (PM) that trend irregularly along the crest of the Solfatara and Central Plateaus. Small melt-water channels are related to these moraines in many places, and a scabland topography on the rhyolite slope west of the canyon of Spruce Creek records local flood conditions. Extensive ice-contact deposits (pkg, pksg, pkgs, pks) in the basin of Nez Perce Creek and in small basins on the plateau uplands indicate that stagnant ice masses became isolated during the general wasting of the ice. Some deposits were probably localized by melting of the ice over thermal centers. In the headwaters of Spruce Creek, and locally in the canyon of Gibbon River, masses of rock debris fell or slid from cliffs, oversteepened by glacial scour, onto the stagnant ice. The largest of these deposits (pls) is characterized by depressions caused by melting or underlying ice.

As the ice wasted eastward below the plateau divide, melt-water drainage was controlled by ice-marginal slopes. Extensive ice-contact gravelly sand (pkgs) was deposited over lake deposits of late Bull Lake age in the area south of Hayden Valley by water flowing northwest from an ice margin near Dryad Lake into the present headwaters of Alum and Trout Creeks and against ice in the area of Hayden Valley. A deposit of lake sand (pksl) at an altitude of 8,040 feet (2,450 m) in the headwaters of Alum Creek suggests only local ice-marginal ponding. For a time, the water drained west through the pass at an altitude of 8,020 feet (2,445 m) northeast of Mary Mountain. Later, as downwasting, continued, it drained along a large channel leading west at an altitude of 7,840 feet (2,390 m) through Cascade, Grebe and Wolf Lakes to the Gibbon River. At this time, a lake existed at the same altitude in the southern part of Hayden Valley in the Canyon Village 15' Quadrangle adjacent to the east (Map 1-652, Richmond, in press). In the Norris Junction 15' Quadrangle, the large deposit of fan gravel at the lower end of the north-trending sector of Trout Creek probably abutted this lake.

Subsequent wasting of the ice in Hayden Valley in this quadrangle must have been rapid, for no large ice-dammed lake, such as existed in late Bull Lake time, developed. A small lake in which varved silt (p1) was deposited was retained at an altitude of 7,700 feet (2,347 m) in the entrenched valley of Alum Creek and in the basin of Sour Creek adjacent to the east in the Canyon Village 15' Quadrangle (Map 1-652, Richmond, in press) by ice to the north. Its drainage is the last record of Pinedale Glaciation in this quadrangle.

HOLOCENE EVENTS
No late Pinedale or Neoglacial glacial deposits occur in the quadrangle. However, during recession of the Pinedale ice and in Holocene time, frost action produced local talus (pta) and talus-flow deposits (ptf). Holocene alluvium, mostly fine grained (fa), was deposited over Pinedale outwash and stream gravel along valley floors, and in glacially scoured basins and depressions in Pinedale Till on the uplands. Deposits of siliceous sinter (si) formed around hot springs in thermal areas and the debris from them was redistributed as low-gradient fan deposits. Deposits (a ls) in Norris Geyser Basin suggest the existence of shallow lakes. Diatomaceous silt (ds), locally several feet thick, formed in wet meadow areas near, but downstream from, hot springs. In general, little erosion seems to have taken place, though the soft silts underlying Hayden Valley were dissected as much as 10-15 feet (3-4.6 m). The Yellowstone River also lowered its channel 10-15 feet (3-4.6 m).

QUATERNARY FAULTING
The north- and northwest-trending normal faults in the northern part of the quadrangle displace tuff of the Yellowstone Group that has a K-Ar age of about 600,000 years. Recurrent movement continuing into post-Pinedale time is indicated by the fault at Wolf Lake, which offsets Pinedale sandy gravel (psg) a maximum of 8 feet (2.4 m). The west- and northeast-trending normal faults in the southern part of the quadrangle are younger than the Elephant Back rhyolite flow. The faults were mapped in cooperation with R. L. Christiansen.

Text from source map: Norris Junction 15' Quadrangle

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References from source map: Norris Junction 15' Quadrangle

Old Faithful 15' Quadrangle

The formal citation for this source.

Waldrop, H. A., 1975, Surficial Geologic Map of the Old Faithful Quadrangle, Yellowstone National Park, Wyoming: U.S. Geological Survey, Miscellaneous Investigations Series Map I-649, scale 1:62,500 (*GRI Source Map ID 1148*).

Description of geologic units, prominent graphics and text associated with this source.

Description of Units

lsg - Lake sand and gravel (Quaternary, Neoglaciation)

Dark-gray to brown pebbles and sand of obsidian and lithoidal rhyolite forming the beach at the west end of Shoshone Lake. 1-10 feet (0.3-3 m) thick.

fa - Fine-grained humic alluvium (Quaternary, Neoglaciation)

Gray to light-brown silt, sand, and humus deposited in seasonal marshes on stream flood plains, poorly drained meadows, and closed depressions on till and flow tops. 1 to about 10 feet (0.3-3 m) thick.

sg - Stream gravel (Quaternary, Neoglaciation)

Gray to brown sand, pebbles, and cobbles of lithoidal and obsidian rhyolite. Lies along small flood plains of modern stream courses, where in many places it is covered by fine-grained humic alluvium (fa). 2-10 feet (0.6-3 m) thick.

sd - Solifluction deposit (Quaternary, Neoglaciation)

Gray to brown humic silt, sand, and rock fragments underlying a swampy lobate terrace east of Douglas Knob and in Moose Creek drainage. Seasonally active. As much as 20 feet (6.1 m) thick.

tr - Travertine (Quaternary, Neoglaciation)

Small mounds of light-gray calcium carbonate deposited at Hillside Springs west of Sinter Plain and north of Morning Glory Pool in Upper Geyser Basin. 2-5 feet (0.6-1.5 m) thick.

ds - Diatomaceous silt (Quaternary, Neoglaciation)

White to light-brownish-gray silt composed largely of siliceous diatom tests; includes minor clay and fine sand; deposited in marshy areas associated with hot springs. About 1-15 feet (0.34.5 m) thick.

si - Siliceous sinter (Quaternary, Neoglaciation)

White to light-gray deposit of amorphous silica forming rims and cones of hot springs and geysers; also low-gradient alluvial fans composed predominantly of siliceous sinter fragments. 2-20 feet (0.6-6.1 m) thick.

pg - Stream deposits, gravel (Holocene and/or Pleistocene)
psg - Stream deposits, sandy gravel (Holocene and/or Pleistocene)
pgs - Stream deposits, gravelly sand (Holocene and/or Pleistocene)
pfg - Stream deposits, fan gravel (Holocene and/or Pleistocene)
pgc - Stream deposits, cemented gravel (Holocene and/or Pleistocene)

Gray to light-brown moderately sorted to well-sorted and stratified gravel (pg), sandy gravel (psg), gravelly sand (pgs), fan gravel (pfg), and cemented gravel (pgc). Commonly unconsolidated, but east of Douglas Knob partially cemented (pgc) by hydrothermal action. Composed of lithoidal rhyolite and obsidian. The sandy gravel (psg) forms alluvial fill and terraces along modern streams and marks the courses of a network of Pinedale outwash channels on the broad top of the Madison Plateau. The fan gravel (pfg) generally forms poorly sorted crudely bedded fans at the foot of slopes. 2-20 feet (0.6-6 m) thick.

pta - Talus (Holocene and/or Pleistocene)

Angular to subangular rhyolite rubble in blocks 1/2-4 feet (15-122 cm) in diameter, with fine-grained matrix at depth but inter-block voids near surface, forming steep fans or aprons along valley sides below cliffs. Inactive; supports lichen cover on blocks but little or no tree cover. As much as 50 feet (15 m) thick.

ptf - Talus-flow deposit(Holocene and/or Pleistocene)

Similar to talus deposit but has concentric flow ridges parallel to front that indicate downslope movement. Inactive at present.

phe - Hydrothermal-explosion deposit (Holocene and/or Pleistocene)

(Data from Muffler and others, 1971, p. 733.) Rubble formed by a steam explosion in surficial deposits that was triggered by abrupt decrease in confining pressure. A small deposit in this quadrangle just east of Sapphire Pool in Biscuit Basin consists of scattered breccia blocks as much as 3 feet (1 m) in diameter of sinter and opal-cemented sandstone and conglomerate.

pks - Kame deposits, gravel (Holocene and/or Pleistocene)
pksg - Kame deposits, sandy gravel (Holocene and/or Pleistocene)
pkgs - Kame deposits, gravelly sand (Holocene and/or Pleistocene)
pkf - Kame deposits, fan gravel (Holocene and/or Pleistocene)
peg - Kame deposits, esker gravel (Holocene and/or Pleistocene)
pkc - Kame deposits, cemented gravel (Holocene and/or Pleistocene)
pt - Till and rubble veneer, till (Holocene and/or Pleistocene)
pr - Till and rubble veneer, rubble veneer (Holocene and/or Pleistocene)
bkc - Cemented kame gravel (Pleistocene)

Dark- and brownish-gray to buff pebble conglomerate, sandstone, and sandy siltstone characterized by great variation in texture, sorting, stratification, and local postdepositional slumping. Composed almost entirely of rhyolite. Firmly cemented by hydrothermal opal and zeolites; ranges from unaltered to highly altered. Forms hills near Lone Star Geyser and Douglas Knob and a broad, somewhat dissected terrace southwest of Little Firehole Meadows. Rests on West Yellowstone flow (Ry) at north end of Little Firehole Meadows. As much as 150 feet (45.7 m) thick. Locally is unconformably overlapped by unconsolidated Pinedale kame sandy gravel (pksg). Where Pinedale rubble and till that mantle the cemented Bull Lake kame gravel are composed predominantly of fragments of the cemented kame, the rubble and till are shown by a black overprint pattern on the map.

bt - Till and rubble veneer, till (Pleistocene)

Blocks, boulders, and small fragments in sandy to silty matrix; unsorted and unstratified; generally less than 5 feet (1.5 m) thick. Composed of rhyolite, which forms the local bedrock; no definite erratics observed. Locally bears a thin loess mantle (not mapped). Forms thin smooth-surfaced ground moraine on the west slope of the Madison Plateau.

br - Till and rubble veneer, rubble veneer (Pleistocene)

Thin (<5 ft or 1.5 m) and largely discontinuous mantle of rhyolite blocks, boulders, and smaller fragments in a sandy to silty matrix. In part glacially deposited, in part the product of rock weathering and mass wasting.

Rp - Pitchstone Plateau flow (Pleistocene)

Rhyolite flow with K-Ar age of about 70,000 years; stratigraphically younger than Grants Pass flow.

Rgp - Grants Pass flow (Pleistocene)

Rhyolite flow with K-Ar age of about 70,000 years.

Ry - West Yellowstone flow (Pleistocene)

Rhyolite flow with K-Ar age of about 105,000 years; age relative to next four flows uncertain.

Rtc - Tuff of Cold Mountain Creek (Pleistocene)

Ash-flow tuff older than Grants Pass flow, younger than Bechler River flow.

Rtk - Trischman Knob Dome (Pleistocene)
Rdk - Douglas Knob Dome (Pleistocene)

Rhyolite flows older than Pinedale Glaciation, younger than Bechler River flow. Appear only on map of rhyolite flows..

Old Faithful Rhyolite Flow Map

Rbr - Bechler River flow (Pleistocene)

Rhyolite flow with K-Ar age of about 105,000 years.

Rsl - Summit Lake flow (Pleistocene)

Rhyolite flow with K-Ar age of about 115,000 years.

Rsc - Spring Creek flow (Pleistocene)

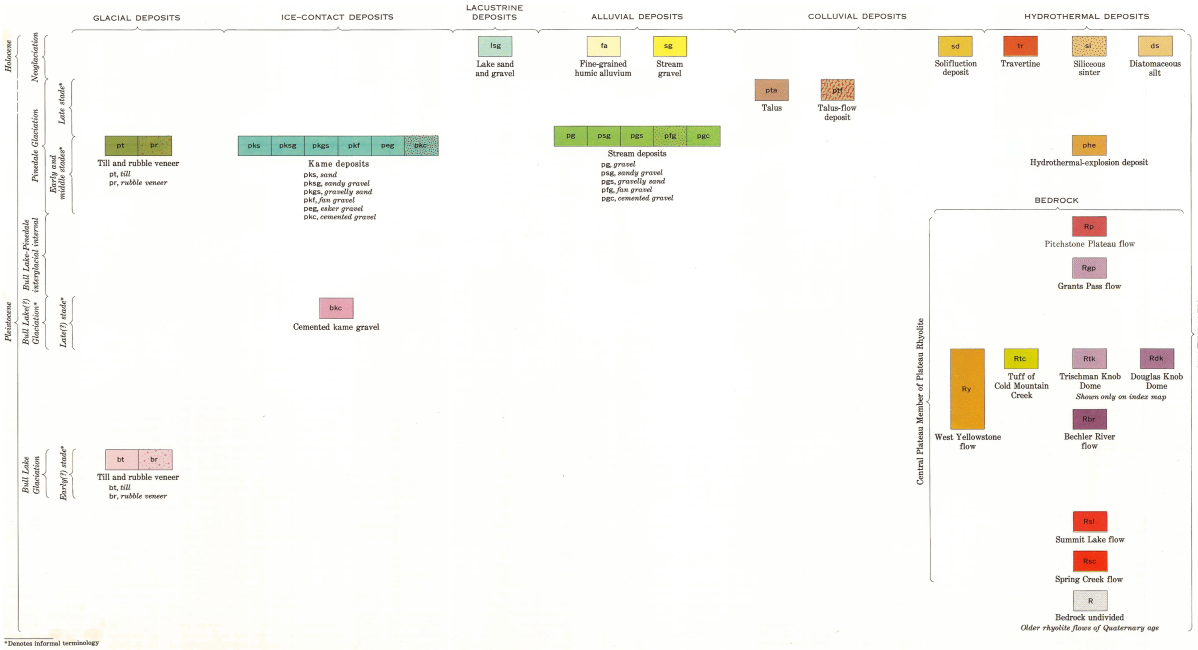
Rhyolite flow with K-Ar age of about 150,000 years.

R - Bedrock undivided (Quaternary)

Older rhyolite flows of Quaternary age 'Volcanic stratigraphy from R. L. Christiansen and H. R. Blank, Jr. (written commun., 1973). K-Ar dates from J. D. Obradovich (written commun., 1973).

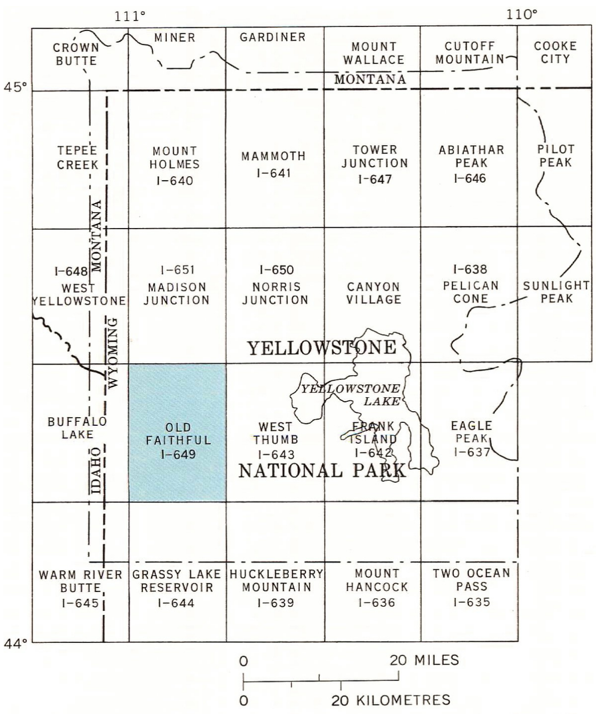
Text from source map: Old Faithful 15' Quadrangle

Correlation of Units



Graphic from source map: Old Faithful 15' Quadrangle

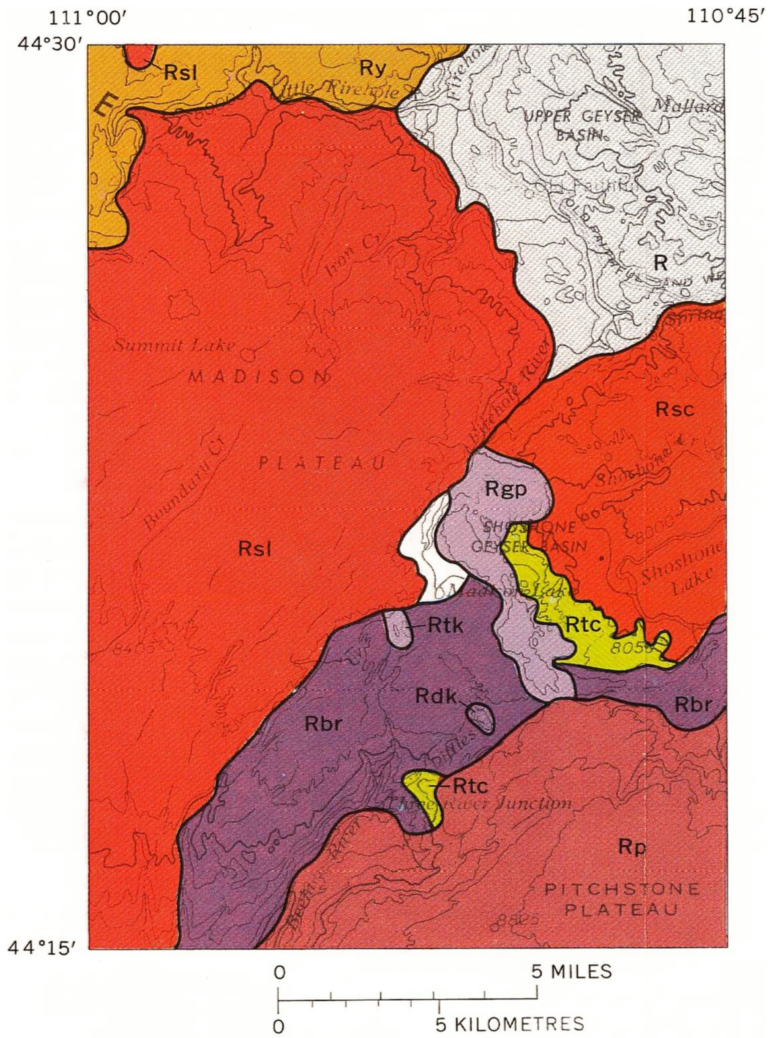
Index Map



INDEX MAP OF YELLOWSTONE NATIONAL PARK SHOWING LOCATION OF OLD FAITHFUL QUADRANGLE AND PUBLISHED MISCELLANEOUS GEOLOGIC INVESTIGATIONS MAPS

Graphic from source map: Old Faithful 15' Quadrangle

Rhyolite Flow Map



MAP OF OLD FAITHFUL QUADRANGLE SHOWING
DISTRIBUTION OF QUATERNARY RHYOLITE FLOWS

(From "Geologic map of Yellowstone National Park,"
U.S. Geol. Survey Misc. Geol. Inv. Map I–711, 1972)

EXPLANATION

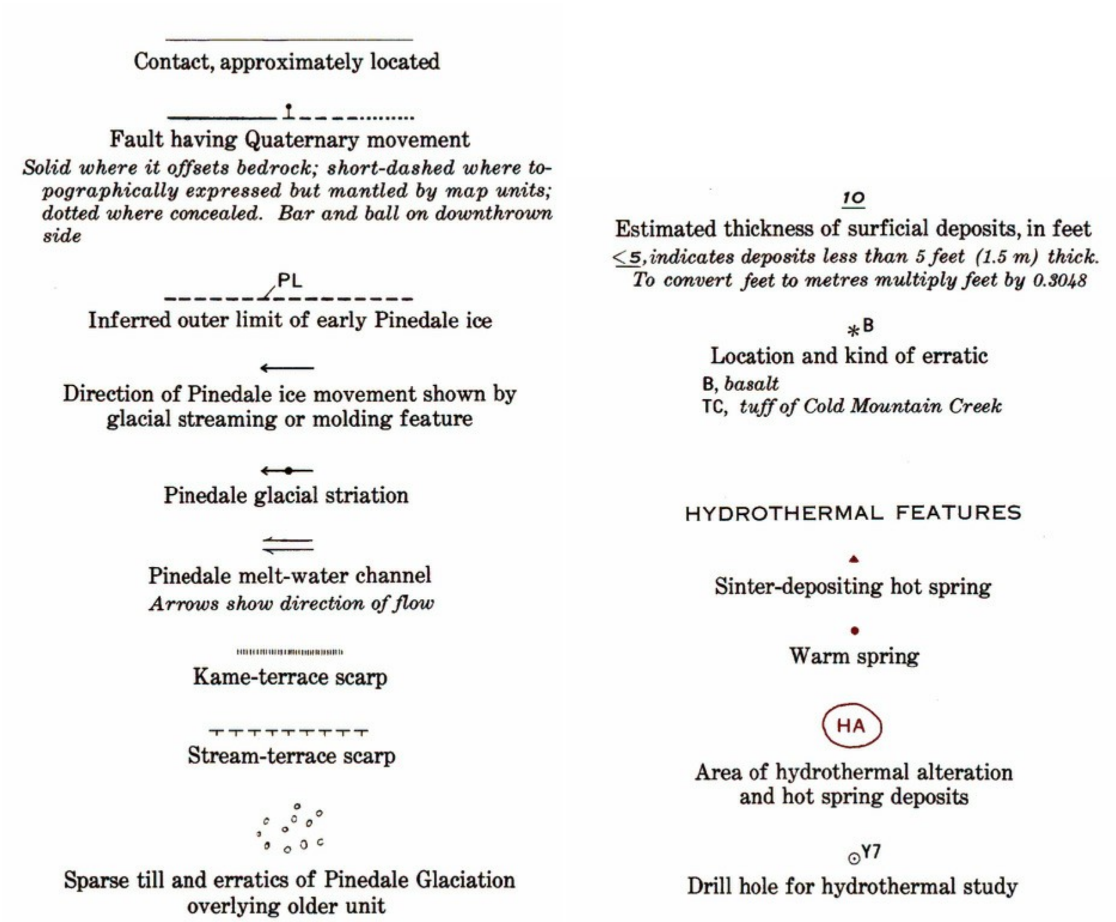
Letter symbols same as in map explanation

——— Margin of flow

See Description of Units page for this map to view information about geologic units shown on this graphic.

Graphic from source map: Old Faithful 15' Quadrangle

Map Legend



Graphic from source map: Old Faithful 15' Quadrangle

Surficial Geologic History

INTRODUCTION

The Old Faithful 15' Quadrangle lies in the southwestern part of Yellowstone National Park, Wyo. Its bedrock, generalized on the accompanying index map, consists entirely of rhyolite flows and ash-flow tuffs of Pleistocene age. Its topography is characterized by high volcanic plateaus, steep-walled canyons incised along lava-flow boundaries, and basins enclosed by steep flow fronts. The flow tops range in relief from the relatively smooth surface of the young Madison and Pitchstone Plateaus to the faulted and eroded surface of older flows east of Old Faithful. Total relief in the quadrangle is about 2,100 feet (640 m); locally, the relief ranges from 400 to 1,400 feet (122 to 427 m).

The Continental Divide crosses the quadrangle, trending southeast along the broad Madison Plateau summit to Trischman Knob, where it swings northeast along the high ground between Old Faithful and Shoshone Lake. In the Atlantic watershed north of the divide the Firehole River basin drains northward toward the Madison River. In the Pacific watershed south of the divide, Bechler River and Ouzel Creek drain the south and west sides of the Madison and Pitchstone Plateaus southwestward toward Henrys Fork of the Snake River; Shoshone Lake basin drains east and then south to the Snake River.

The surficial geologic history of Old Faithful 15' Quadrangle is a striking record of the alternation of late Pleistocene glaciations with late Pleistocene volcanic and hydrothermal activity.

PLEISTOCENE EVENTS SUMMARY

Evidence for at least three Pleistocene glaciations (named, from oldest to youngest, pre-Bull Lake, Bull Lake, and Pinedale) has been found in central Yellowstone National Park (Richmond, 1970, p. 112). No glacial deposits of pre-Bull Lake age have been found in the Old Faithful 15' Quadrangle, but, because the quadrangle lies between the former center of the pre-Bull Lake icecaps to the northeast and terminal deposits of those icecaps to the south, pre-Bull Lake glaciation is inferred in the area.

An early and a late stade of the Bull Lake Glaciation have been recognized in Yellowstone Park (Richmond, 1970, p. 112). Bull Lake ice moved southwestward across the Old Faithful 15' Quadrangle from large icecaps that developed over the central part of the park. The most extensive advance evidently covered the entire quadrangle; that main advance is assigned in this report to the Bull Lake Glaciation and provisionally to its early stade. A much smaller advance younger than the West Yellowstone flow and older than the Pinedale culmination is assigned provisionally to the Bull Lake Glaciation and provisionally to its late stade.

Ice of the Pinedale Glaciation covered all but the west edge of the quadrangle, advancing southwestward from a large Pinedale icecap over the central part of Yellowstone National Park. It flowed through a broad saddle between Madison and Pitchstone Plateaus, forming a large valley glacier in Bechler Canyon that terminated in a piedmont lobe in the southwest corner of Yellowstone Park (Richmond, 1973a, b).

Pleistocene volcanism has been as active as glaciation in the quadrangle; several rhyolite flows were erupted during the interval of the late Pleistocene glaciations. The Summit Lake flow seems to have been emplaced during the pre-Bull Lake-Bull Lake interval. The West Yellowstone flow probably advanced against retreating early(?) Bull Lake ice, and the Pitchstone Plateau and Grants Pass flows were emplaced during the Bull Lake-Pinedale interglacial interval.

VOLCANIC MODIFICATION OF TOPOGRAPHY

Only the northeast quarter of the quadrangle still has the bedrock surface (R on index map) that existed at the end of pre-Bull Lake glaciation. The rest of the area has been covered by a series of rhyolite flows emplaced between the pre-Bull Lake glaciation and the Pinedale Glaciation. During that interval the western and southeastern parts of the quadrangle were built up into the broad uplands of the Madison and Pitchstone Plateaus. The rhyolite flows forming these plateaus (index map) are units of the Plateau Rhyolite (Christiansen and Blank, 1972, p. B13), a sequence of flows emplaced after formation of the Yellowstone caldera. The flows cover the southwest sector of the caldera rim, which is located immediately west and south of the Old Faithful 15' Quadrangle (Christiansen and Blank, 1975). Pre-Bull Lake topography under the flows probably consisted of a caldera basin northeast of the rim, partly filled by now-buried rhyolite flows. The exact thickness of the Plateau Rhyolite flows is not known, but they have raised the plateau surface 400-800 feet (122-244 m) during the Pre-Bull Lake-Pinedale interval, presenting successively higher terrain barriers to ice flowing southwestward from the central Yellowstone icecaps.

PRE-BULL LAKE GLACIATIONS AND VOLCANISM

Central Yellowstone National Park was the locus of several pre-Bull Lake icecaps. In areas southwest of the park, deposits of two pre-Bull Lake glaciations have been found (Richmond, 1973a and b). Ice of pre-Bull Lake glaciations probably covered the entire Old Faithful 15' Quadrangle. Whatever pre-Bull Lake deposits were present have either been eroded, masked by Bull Lake and Pinedale deposits, or covered by younger rhyolite flows that have overrun much of the quadrangle since pre-Bull Lake time.

Till apparently of the latest pre-Bull Lake glaciation is overlain by the Summit Lake rhyolite flow at an exposure 1.5 miles (2.4 km) south of the southwest corner of this quadrangle (Richmond, 1973b).

Relationship of that till to older flows in this quadrangle is uncertain. The till contains obsidian grains that could have been derived from the Spring Creek rhyolite flow or the tuff of Cold Mountain Creek, thereby being younger than one or both of them. But the obsidian could also have come from older flows now covered.

SUMMIT LAKE FLOW OF THE PLATEAU RHYOLITE

The Summit Lake flow has a K-Ar age of about 115,000 years (J. D. Obradovich, written commun., 1973). Its northeastern scarp borders Upper Geyser Basin and the Lone Star Geyser area. The flow is overlain by the younger Bechler River flow to the southeast and has been overrun by the younger West Yellowstone flow to the northwest (Christiansen and Blank, 1975). It rests on apparent latest pre-Bull Lake till just south of this quadrangle (Richmond, 1973b) and probably was covered by early(?) Bull Lake ice, which indicates that it was erupted during the interval between the pre-Bull Lake glaciation and the Bull Lake Glaciation. The Summit Lake flow occupies nearly half the area of the quadrangle; its emplacement formed a broad dome across the old caldera rim, raising a new barrier to southwest flow of central Yellowstone ice.

BULL LAKE GLACIATION: EARLY(?) STADE

Ice of the early(?) stade of the Bull Lake Glaciation probably covered the entire quadrangle, inasmuch as the quadrangle lies between the former icecap center and the early Bull Lake terminus mapped southwest of the park (Richmond, 1973a). The Madison Plateau west of the outer limit of Pinedale ice bears only thin ground moraine with a local loess cover and lacks exotic erratics. Glaciation of this part of the Summit Lake flow is indicated chiefly by glacial streaming over the western flow scarp in the adjoining Buffalo Lake quadrangle and by erosion of rhyolite pressure ridges, which are unmodified on unglaciated flows. The absence of exotic erratics on the rhyolite flow is not surprising, for ice reaching it had traversed an unbroken rhyolite terrane from the center of the icecap.

WEST YELLOWSTONE FLOW OF THE PLATEAU RHYOLITE

The West Yellowstone flow has a K-Ar age of about 105,000 years (J. D. Obradovich, written commun., 1973). Field relations in the Madison Junction 15' Quadrangle to the north suggest that the flow was emplaced against receding early Bull Lake ice (Waldrop and Pierce, 1975). In the northwest corner of this quadrangle, the steep scarp of the West Yellowstone flow east of Plateau Lake and the embayment of the flow front north of Little Firehole Meadows suggest that the southeast margin of the flow may have been Confined against glacial ice lying on the plateau. Emplacement against an ice barrier would explain why the West Yellowstone flow did not advance farther east over the lower lying Summit Lake flow and Little Firehole Meadows. Once the flow margin had been chilled and solidified by the ice it would act as a dam, diverting flow of the lava northward.

In this quadrangle, as in the Madison Junction 15' Quadrangle to the north, the high western part of the West Yellowstone flow seems to be unglaciated. It lacks the erratics, till, and kame deposits and the scour and plucking features typical of glaciated rhyolite flows elsewhere in the area. The eastern part of the flow is covered by till and kame deposits of Pinedale and of possible late(?) Bull Lake age.

The West Yellowstone flow raised the surface of the Madison Plateau northwest of the Summit Lake flow, presenting a new barrier to the advance of late(?) Bull Lake and Pinedale ice.

BULL LAKE(?) GLACIATION: LATE(?) STADE

The extent of the late(?) Bull Lake advance has not been determined in the quadrangle, but it seems to have been much smaller than that of the early advance. The West Yellowstone flow apparently overran Bull Lake Till of the early(?) stade in the Madison Junction 15' Quadrangle to the north (Waldrop and Pierce, 1975), but the high, west side of the flow is unglaciated in that quadrangle and in this one, which indicates that late(?) Bull Lake ice did not advance that far west. Till and kame deposits of Pinedale age mantle the lower, east side of the West Yellowstone flow, which suggests that in the Madison Junction area Pinedale ice may have been more extensive than late(?) Bull Lake ice.

No deposits that are unquestionably of late Bull Lake age have been identified in the quadrangle, but several are correlated with deposits assigned to the late(?) stade of the Bull Lake in the Madison Junction 15' Quadrangle on the basis of similar origin, occurrence, and stratigraphic relationships. A subdued hill just south of Douglas Knob is composed of cemented and highly altered gravel that may be the remnant of a mound kame that has been localized, cemented, and altered by hydrothermal action. The cemented and altered gravel rests on the Bechler River flow, which probably was emplaced shortly after the early(?) Bull Lake advance because, like the West Yellowstone flow, it has a K-Ar age of about 105,000 years (J. D. Obradovich, written commun., 1973) but has no ice-contact features. That fact and the fact that this gravel is overlain unconformably by Pinedale Till and kame suggest that it was deposited during the late(?) Bull Lake advance. Other cemented mound kames occur on the floor of Little Firehole Meadows, some of them apparently overlapped unconformably by uncemented Pinedale kame gravels; and a broad, somewhat dissected cemented kame terrace, mantled with Pinedale Till, lies just west of the meadows. Because of their common origin, their cementation, the unconformable relationship of overlying Pinedale deposits, and their resemblance to deposits assigned to the late(?) stade of the Bull Lake in the Madison Junction 15' Quadrangle, these cemented kames are also believed to be of late(?) Bull Lake age. Similar cemented mound kames in the Lone Star Geyser area, in places unconformably overlain by uncemented Pinedale kame gravel, are also provisionally correlated with the late(?) Bull Lake advance.

It has been suggested that the character of deposits of late(?) Bull Lake age observed in neighboring Madison Junction 15' Quadrangle was the result of enormous heat flow from Lower and Midway Geyser Basins, which disrupted the ice front and induced deposition of widespread kame gravel deposits rather than till (Waldrop and Pierce, 1975). Heat flow may have similarly disrupted the late(?) Bull Lake advance in this quadrangle, and produced the large cemented kame gravel deposits (bkc) west of Little Firehole Meadows. There are only a few hot springs and fumaroles in Little Firehole Meadows now, but sinter deposits and the widespread hydrothermally cemented kame gravel there indicate that it was once an active hydrothermal area. Overlap of these cemented kame deposits of late(?) Bull Lake age by till and kame gravels of Pinedale age may reflect a reduction of heat flow that resulted in Pinedale ice advancing beyond the late(?) Bull Lake limit west of Little Firehole Meadows.

The limit of the late(?) Bull Lake advance in other parts of the quadrangle has not been established. The advance may have been more extensive away from the major hydrothermal areas. Soil development has not been useful in differentiating deposits of early(?) and late(?) Bull Lake age in other places in the area, and no stratigraphic relationships indicate whether till west of the Pinedale limit is early(?) or late(?) Bull Lake in age.

GRANTS PASS FLOW AND PITCHSTONE PLATEAU FLOW OF THE PLATEAU RHYOLITE
Both the Pitchstone Plateau flow and Grants Pass flow have K-Ar ages of about 70,000 years (J. D. Obradovich, written commun., 1973), but stratigraphic relations indicate the Pitchstone Plateau flow is the younger (R. L. Christiansen, written commun., 1973). They are the youngest rhyolite flows in Yellowstone National Park. They were emplaced during the interval between Bull Lake and Pinedale Glaciations and bear till, erratics, scour features, and striations of the Pinedale advance.

The Pitchstone Plateau forms a broad dome almost 9,000 feet (2,743 m) in altitude, the highest terrain in the southwestern part of the park. This flow represents the latest accretion in the development of a broad high rhyolite plateau along the southwest rim of the Yellowstone caldera.

PINEDALE GLACIATION
Three stades of Pinedale Glaciation have been described in central Yellowstone National Park (Richmond, 1970, p. 113). Deposits of the separate stades of the Pinedale were not differentiated in this quadrangle, but terminal moraines of the early and middle stades mapped in Bechler Meadows southwest of the quadrangle (Richmond, 1973a) indicate that ice moved southwest through the area

during early and middle Pinedale time. Pinedale ice moved west and southwestward from the central Yellowstone icecap and covered all but the west edge of the quadrangle. Near Little Firehole Meadows the ice front was confined east of the crest of the Madison Plateau. South of that area the Pinedale ice front probably fluctuated somewhat just west of the plateau crest, depositing no terminal moraines but feeding a network of outwash channels that score the western slope of the plateau. The outer limit of early Pinedale ice mapped across the Madison Plateau is inferred and is based on greater thickness and morphology of till, presence of basalt erratics, and decrease in density and incision of outwash channels inside the limit, rather than on sharply defined terminal features. Southeast of Ouzel Creek, Pinedale ice flowed southwest through the broad saddle between Madison and Pitchstone Plateaus and down Bechler Canyon, forming a large piedmont lobe that deposited hummocky multiple end moraines in the southwest corner of the park (Richmond, 1973a). The terrain of Bechler Canyon bears abundant striations, ice streaming and scour features, and thick till typical of a valley subjected to the vigorous flow of thick outlet glaciers.

Two small rhyolite domes that rest on the Bechler River flow near the head of Bechler Canyon, Trischman Knob flow and Douglas Knob flow, exhibit such fresh volcanic morphology on aerial photographs that they appear to be unglaciated, and would therefore postdate the Pinedale advance. Although the domes have not been dated radiometrically, presence of till and basalt erratics on them indicates that they are older at least than the Pinedale Glaciation. And a small deposit of cemented kame gravel on the southeast ridge of Douglas Knob suggests that it may predate the late(?) Bull Lake advance.

Orientation of striations on the Pitchstone Plateau, mapped by G. M. Richmond, suggests radial flow of ice from the plateau summit, implying the existence there of a local Pinedale icecap. However, presence of an erratic of tuff of Cold Mountain Creek near the plateau summit indicates that ice moved southwestward over the summit area during the Pinedale Glaciation. The erratic, identified by R. L. Christiansen (oral commun., 1971), could have come only from outcrops northeast and north of the Pitchstone summit.

Recession of the Pinedale ice front allowed headward development of outwash channels on the west slope of the Madison Plateau. Hydrothermal action localized and cemented Pinedale kame gravel (pkc) and terrace gravel (pgc) around the basin southeast of Douglas Knob. Final downwasting of stagnant Pinedale ice northeast of the Madison Plateau led to deposition of the extensive Pinedale kame terraces (pksg) and eskers (peg) in Little Firehole Meadows and kame terraces (pkgs) in Upper Geyser Basin. Hydrothermal activity probably induced deposition of Pinedale mound kames (pksg) that unconformably overlap the cemented Bull Lake kames (bkc) around Lone Star Geyser. And at Shoshone Geyser Basin hydrothermal solutions have locally cemented some of the Pinedale mound kames (pkc and pksg).

Outwash gravel (psg, pgs) was deposited in narrow channels and small basins on the Madison and Pitchstone Plateaus during the early Pinedale maximum and recession. It floors many of the basins between flow fronts, such as Little Firehole Meadows, the meadows around Madison Lake, around Moose Creek, and around Lone Star Geyser, but is largely overlain by fine-grained Holocene alluvium (fa). Talus deposits (pta) and talus flow deposits (ptf) at the foot of flow fronts and along the fault scarps near Mallard Lake probably formed during the late stade of Pinedale Glaciation, when ice no longer occupied the area.

CONFLICTING DATA

After fieldwork in the quadrangle was completed, a newly developed technique for dating glacial deposits (K. L. Pierce, written commun., 1974) yielded Pinedale dates for glacial deposits near Big Grassy meadow, 10 miles west of the Pinedale ice limit mapped on the Madison Plateau. Irving Friedman and K. L. Pierce (oral commun., 1974) found that thicknesses of hydration rims on glacially abraided obsidian pebbles from the deposits indicate Pinedale rather than Bull Lake age.

This occurrence of an apparent Pinedale glacial deposit beyond the mapped Pinedale boundary has several implications to interpretation of the glacial history. A local Pinedale icecap might have formed on the Madison Plateau, with a western margin that extended near Big Grassy meadow. Or the margin of the central Yellowstone icecap might have extended much farther west than other evidence suggests. If the second possibility is true, then the glacial limit mapped on the plateau could belong to the middle Pinedale. In either case, the Summit Lake flow might have been emplaced after, rather than before, the early(?) Bull Lake advance.

No direct evidence has been found for age of glaciation of the west side of the flow. The inference presented here has been that the west side was glaciated only by early(?) Bull Lake ice because it lies beyond the mapped Pinedale limit. However, if Pinedale ice advanced to Big Grassy meadow, then the west side of the flow could have been covered by both advances, or only by the Pinedale advance. No datable deposits or stratigraphic relationships have been found on that side of the flow that point unequivocally to the early(?) stade of the Bull Lake Glaciation. Moreover, the K-Ar age of the Summit Lake flow (about 115,000 years) is rather close to that of the West Yellowstone flow (about 105,000 years). While it is possible that enough time elapsed between emplacement of the two flows for the Summit Lake flow to have been glaciated by early(?) Bull Lake ice (which the West Yellowstone flow overran) it is also possible that the flows were nearly contemporaneous, and that the Summit Lake flow postdates the early(?) Bull Lake advance. If this is so, the till overlain by the Summit Lake flow 1.5 miles (2.4 km) south of the southwest corner of this quadrangle (Richmond, 1973b) could be equivalent to the till of early(?) Bull Lake age overrun by the West Yellowstone flow in the Madison Junction 15' Quadrangle (Waldrop and Pierce, 1975), and the west side of the Summit Lake flow would have been glaciated by Pinedale ice alone.

Such speculations cannot be substantiated until additional sampling and perhaps independent dating methods establish the age of glacial deposits beyond the mapped Pinedale ice limit and until detailed field work confirms the mapped Pinedale ice limit or identifies an alternate one.

HOLOCENE EVENTS

The Altithermal warm period and the Neoglaciation added only small details to the surficial geology of the Old Faithful 15' Quadrangle. Small cirque glaciers formed in high mountains around and in Yellowstone National Park during the Neoglaciation, but none formed in the quadrangle, which was little modified beyond the effects of increased runoff and frost action. Pinedale outwash (psg) was locally incised and extensively covered by fine-grained humic alluvium (fa). The kame terrace gravels (pkgs) flooring much of Upper Geyser Basin were locally cemented and covered by siliceous sinter (si), and siliceous sinter and diatomaceous silt (ds) coated other surficial deposits around Lone Star Geyser and Shoshone Geyser Basin.

QUATERNARY FAULTING

Normal faults offset rhyolite flows of Quaternary age in two areas of the quadrangle. The meadow between Trischman Knob and Douglas Knob is a shallow graben partly filled by Pinedale and younger gravel. Pinedale Till plasters the fault scarps rather than being offset across them. Rhyolite bedrock is displaced about 25 feet (7.6 m) on the northeast side of the graben.

The area surrounding Mallard Lake is part of a resurgent structural dome within the Yellowstone caldera; the rhyolite flow covering that area was broken by a network of northwest-trending normal faults that form a complex graben along the axis of the dome (Christiansen and Blank, 1972, p. B12). Topographic expression of the graben system has been little modified by glacial erosion, but rubble of Bull Lake age and till and talus deposits of Pinedale age mantle the fault scarps.

HYDROTHERMAL ACTIVITY

Old Faithful 15' Quadrangle contains several areas of hydrothermal activity, of which the Upper Geyser Basin, containing Old Faithful Geyser, is justly the best known. Nontechnical descriptions of the thermal features are available from the National Park Service, and the activity of many geysers and hot springs has been recorded, chiefly by Marler (1964, 1969). The thermal features are being studied in detail by D. E. White and others. Hydrothermal activity has modified surficial deposits chiefly of Pinedale and Neoglacial age in the quadrangle, but the existence of hydrothermally cemented kame gravels unconformably overlain by Pinedale deposits suggests that hydrothermal activity has persisted at least since late(?) Bull Lake time.

Upper Geyser Basin is underlain and bordered on the east by old postcaldera rhyolite flows. It is enclosed on the west by the younger Summit Lake flow. The basin is partly filled by kame terrace sand (pkgs) deposited during stagnation of receding Pinedale ice. Much of the kame sand is impregnated and overspread by siliceous sinter (si) deposited around geysers and hot springs. Small travertine deposits (tr) have formed at Hillside Springs and upslope from Morning Glory Pool. Diatomaceous silt (ds) has accumulated in swales on the sinter and kame sand.

Near Lone Star Geyser deposition of mound kames has apparently been localized by hydrothermal activity. Just north of the geyser a hill of cemented kame gravel of probable late Bull Lake age (bkc) is unconformably overlapped by uncemented Pinedale kame gravel. Cemented kame deposits overlain by till and kame gravel of Pinedale age in Little Firehole Meadows and south of Douglas Knob suggest similar localization of kame deposition in areas where hydrothermal activity has apparently diminished during Pinedale and Neoglacial time.

The active geyser and hot spring basin at the west end of Shoshone Lake has also been a site of kame deposition, some of it clearly related to hydrothermal activity. But absence of unconformably overlapping kame gravel or till of Pinedale age on the cemented kame suggests that here the cemented kame dates from Pinedale deglaciation.

Siliceous sinter and diatomaceous silt are widespread in Shoshone Geyser Basin and have developed at the hot springs near Three River Junction in Bechler Canyon. At the Smoke Jumper Hot Springs group on the Summit Lake flow hydrothermal activity has resulted chiefly in acid alteration of the rhyolite bedrock.

Text from source map: Old Faithful 15' Quadrangle

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References from source map: Old Faithful 15' Quadrangle

Pelican Cone 15' Quadrangle

The formal citation for this source.

Richmond, Gerald M., and Waldrop, H. A., 1972, Surficial Geologic Map of the Pelican Cone Quadrangle, Yellowstone National Park and adjoining area, Wyoming: U.S. Geological Survey, Miscellaneous Investigations Series Map, I-638, scale 1:62,500 (*GRI Source Map ID 1149*).

Description of geologic units, prominent graphics and text associated with this source.

Description of Units

gt - Till (Quaternary, Neoglaciation)
tt - Till and rock glacier, till (Quaternary, Neoglaciation)

Gray to buff, unsorted, unsized, angular fragments of local volcanic rocks in silty matrix. Forms small end moraines 5-20 feet high below headwalls of a few sheltered cirques; mostly near Cathedral Peak and Pyramid Peak. Moraines of the Gannett Peak Stade (gt) lie close to cirque headwalls, are unweathered, bear little or no vegetation. Moraines of the Temple Lake Stade (tt) lie a few hundred feet downslope from Gannett Peak moraines, are very slightly weathered, grass covered and locally forested, and locally overlap Pinedale Till.

fa - Fine-grained humic alluvium (Quaternary, Neoglaciation)

Light-brown to gray silt, fine sand, coarse sand, and pebbles; includes some decayed plant material. Overlies flood-plain deposits of stream gravel (sg), Pinedale lake silt (pl), or Pinedale Till (pt). As much as several feet thick.

sg - Stream gravel (Quaternary, Neoglaciation)

Light-gray to grayish-brown pebble to boulder gravel of volcanic rocks in sandy matrix; underlies flood plains and low terraces of modern streams; commonly less than 10 feet thick.

fg - Fan gravel (Quaternary, Neoglaciation)

Alluvial fan deposits at valley mouths; grades from bouldery gravel near fan heads to silty sand at distal edges; a few feet to about 50 feet thick.

ta - Talus deposit (Quaternary, Neoglaciation)

Angular to rounded rock fragments with sandy to silty matrix at depth; underlies slopes below cliffs, mostly east of crest of Absaroka Mountains. Much less extensive than Pinedale talus deposits (pta). Accumulating at present; lacks soil or vegetative cover, except for lichens. A few feet to 40 feet thick.

tf - Talus flow deposit (Quaternary, Neoglaciation)

Lobate downslope extension of talus, 5-20 feet high, local crude imbricate fabric; lacks soil or vegetation cover.

fr - Frost rubble (Quaternary, Neoglaciation)

Thin mantle of coarse, angular, or irregularly rounded rock fragments lacking matrix. Occurs along high ridges north and south of Jones Creek. Bears a thin humic azonal soil but appears seasonally active in places.

ad - Avalanche debris (Quaternary, Neoglaciation)

Unsorted angular fragments and irregularly rounded boulders and cobbles in sandy matrix. Forms cones and fans below steep gullies along valley walls, mostly along Jones Creek and

Crow Creek. Characterized by irregular bedding and by channels bordered by mudflow levees. Deposits a few feet to 50 feet thick. Commonly accumulate during snow-melt and torrential runoff.

trg - Till and rock glacier, rock glacier (Quaternary, Neoglaciation)

Tongue of coarse rubble, with finer interstitial material below surface, in small cirque northeast of Frost Lake. Overlaps Pinedale Till and is overlapped by modern talus.

sd - Solifluction deposit (Quaternary, Neoglaciation)

Buff unsorted angular to subrounded stones in coarse to fine sandy silt matrix. Forms lobes and terraces 10-20 feet high on valley floors of Mist Creek and Willow Creek. Deposit derived from Pinedale Till on valley walls by solifluction.

ls - Landslide deposit (Quaternary, Neoglaciation)

Lobate mass consisting of slump blocks and stony silty to sandy debris on valley slopes and floors down-slope from headwall along ridge crest. Most occur where Eocene volcanic conglomerates overlie weak tuffaceous units; some are controlled in part by normal faults. Deposits 1/8-11/2 square miles in area and as much as 200 feet thick. Individual slump blocks several hundred feet long. Deposit southeast of Frost Lake is relatively recent.

ptu - Till (Holocene and/or Pleistocene)

Angular to subangular stones of local volcanic rocks in grayish-brown to gray sandy to silty matrix; unsorted, unsized, and unconsolidated. Forms hummocky end moraines, 10-40 feet high, 1-3 miles downvalley from north- to northeast-facing cirques near Cathedral, Pyramid, and Silvertip Peaks. Moderately weathered; forested.

pl - Lake sediments (Holocene and/or Pleistocene)

Buff to tan silt and sand; unconsolidated to moderately consolidated; massive to thin bedded, 5-40 feet thick. Deposited in arm of ancestral Yellowstone Lake in Pelican Valley 110 feet above present Yellowstone Lake.

pg - Stream sand and gravel, gravel (Holocene and/or Pleistocene)
pgs - Stream sand and gravel, gravelly sand (Holocene and/or Pleistocene)
ps - Stream sand and gravel, sand (Holocene and/or Pleistocene)

Sand (ps), gravel (pg), and gravelly sand (pgs). Form thin sheets mostly less than a foot thick over lake deposits in Pelican Valley. In the basin of Raven Creek the sand is 15 feet thick, and along Wrong Creek and Lamar River the gravel forms fill terraces 20-40 feet above the stream.

pfg - Stream sand and gravel, fan gravel(Holocene and/or Pleistocene)

Light-brown to brown; sand to boulders, mainly of volcanic rocks; forms steep alluvial fans at gully mouths along Lamar River. Deposits are 50 feet thick or more and have been incised 20-40 feet by modern streams.

pta - Talus deposit (Holocene and/or Pleistocene)

Angular to subrounded blocky rubble, mostly andesite, on steep slopes below cliffs. Occurs mainly along crest of Absaroka Range, along valleys to east, and in valleys draining Little Saddle Mountain. Deposits are as much as 60 feet thick, inactive; many support vegetation. They are much more extensive than Neoglacial talus deposits.

ptf - Talus flow deposit (Holocene and/or Pleistocene)

Similar to Neoglacial talus flow deposit, but inactive and forested. A single deposit borders Neoglacial talus flow near junction of Mist Creek and Cold Creek.

pfr - Frost rubble (Holocene and/or Pleistocene)

Similar to Neoglacial frost rubble, but is inactive; contains considerable matrix, supports azonal soil, and is commonly grass covered.

prb - Block rubble (Holocene and/or Pleistocene)

Irregular mantle of blocks, 6 inches to 3 feet long, lacking matrix, derived by frost-sorting from landslide debris and talus; occurs on slopes north and east of Pyramid Peak and north of Giant Castle Mountains. Rubble is 3-10 feet thick.

psd - Solifluction deposit (Holocene and/or Pleistocene)

Buff to brown stony sandy silt, unsorted, nonbedded; forms irregular lobes 5-15 feet high. Deposits locally cut by channels and overlapped by levees of modern alpine mudflows; overlie kame gravel (pkg) on west sides of Cold Creek and Lamar River valleys.

phe - Hydrothermal explosion deposit (Holocene and/or Pleistocene)

In southwest part of quadrangle, consists of massive compact yellowish to brownish clay-silt containing angular pebble- to boulder-sized fragments of silica-cemented gravel, sand, and laminated silt from underlying deposits. Formed by subaqueous hydrothermal explosion at Turbid Lake (Canyon Village 15' Quadrangle), 50-200 feet thick. In northwest part of quadrangle, consists of hydrothermally altered blocks and fragments of Eocene andesite conglomerate in a similarly altered gray to buff sand, silt, and clay matrix. Deposit forms ridge around west side of a vent in undisturbed Eocene conglomerate, much altered by still active hydrothermal springs. Probably formed by a subaqueous hydrothermal explosion when a lake lay in area during recession of Pinedale ice.

pkl - Ice-dammed lake deposits, silt (Holocene and/or Pleistocene)
pksl - Ice-dammed lake deposits, sand (Holocene and/or Pleistocene)

Silt (pkl) and sand (pksl) deposited in ice-dammed lakes along Raven Creek, upper Pelican Creek, and Pelican Valley. Silt is gray to bluish gray, moderately compact, massive to thinly laminated, locally varved; weathers buff to tan, or rusty brown where poorly drained; contains a few striated stones, and, in upper basin of Raven Creek, films of organic material on laminae. Sand is buff to tan, well sorted, medium grained; lies mainly in southeast part of Pelican Valley. Deposits are commonly 20-100 feet thick, are characterized by steep ice-contact slopes and landforms, and occur in topographic situations in which lakes could only have been dammed by ice.

pkg - Kame deposits, gravel (Holocene and/or Pleistocene)
pksg - Kame deposits, sandy gravel (Holocene and/or Pleistocene)
pkgs - Kame deposits, gravelly sand (Holocene and/or Pleistocene)
pks - Kame deposits, sand (Holocene and/or Pleistocene)
pkf - Kame deposits, fan gravel (Holocene and/or Pleistocene)

Light-gray to brownish-gray, poorly sorted, pkg crudely bedded sand (pks), gravel (pkg), sandy gravel (pksg), pksg gravelly sand (pkgs), and fan gravel (pkf); range in thickness pkgs from a few feet to 70 feet; deposited by streams in contact with glacial ice; mostly unconsolidated, but locally well cemented by silica; characterized by great variation in texture, sorting, and stratification, by postdepositional slumping, by crevasse-filling ridges, and by local enclosed depressions; form irregular terraces along valleys of Pelican Creek, Raven Creek, Cold Creek, and Lamar River.

pt - Till and rubble veneer, till (Holocene and/or Pleistocene)

Grayish-brown to gray, stony sandy silt; unsorted, loose to compact; stones round to angular, a few faceted and striated, mostly local volcanic rocks. A single erratic of gneissic granite was found about a mile southeast of Mirror Lake. Deposits commonly 5-30 feet thick; form smooth to locally hummocky slopes. Upper limit of middle stade marked by local lateral moraines and by zones of thick hummocky till on steep slopes or in valley reentrants. Small recessional moraines in saddle separating Lamar River and Pelican Valley drainages.

pr - Till and rubble veneer, rubble veneer (Holocene and/or Pleistocene)

Thin mantle (0-5 ft) of locally derived rubble on glaciated uplands and valley walls; product of both glacial and weathering processes.

bl - Lake sediments, silt (Pleistocene)

bsl - Lake sediments, sand (Pleistocene)

Bluish-gray, compact, massive to laminated clayey silt (bl) with local thin layers of fine sand. Crops out below Pinedale lacustrine deposits (pkl), till (pt), and interglacial gravel (ig) in Pelican Valley (stratigraphic sections 20, 21, 28, 29, 30, and 31). Along upper Pelican Creek deposits are silty sand (bsl) mostly much altered by hydrothermal activity, locally varicolored, and cemented by silica. At stratigraphic sections 11 and 12 an interstadial conglomerate (big) separates them from underlying pumiceous lake beds (bpl) of probable early Bull Lake age. In upper basin of Raven Creek deposits (bsl) consist of compact, grayish-green, massive to evenly bedded, well-sorted, medium- to fine-grained sand and lie beneath Pinedale sand (ps) and kame gravel (pkg) (stratigraphic sections 6 and 7). Deposits are 20-30 feet thick.
Pelican Cone Stratigraphic Sections

bksg - Kame sandy gravel (Pleistocene)

Gray to buff, poorly sorted, irregularly bedded, silica-cemented sandy gravel in upper basin of Raven Creek. Abrupt changes in texture, channel-and-fill crossbedding, and slump structure. Cobbles and pebbles mostly andesite and rhyolite. Disconformably underlies well-sorted Pinedale sand (ps) or kame gravel (pkg) in stratigraphic sections 5 and 8.

bt - Till and rubble veneer, till (Pleistocene)

Brownish-gray to gray stony sandy silt, loose to compact, unsorted and unsized; stones subangular to subrounded, composed dominantly of locally derived andesite and basalt; deposits weathered to depth of 3 feet in places. Slopes covered by the till are commonly smooth, locally dissected; depressions mostly filled with colluvium. Deposits mainly on shoulders of ridges north of Crow Creek and Jones Creek, on uplands east of Frost Lake, and on Mirror Plateau. Till is 5-30 feet thick.

br - Till and rubble veneer, rubble (Pleistocene)

Thin mantle (0-5 ft) of locally derived rubble on glaciated uplands north of Frost Lake and east of Little Saddle Mountain above upper limit of Pinedale ice. In part glacial, in part the product of rock weathering.

bfr - Frost rubble (Pleistocene)

bpl - Lacustrine pumiceous sand (Pleistocene)

Light-bluish-gray to light-brown, well-sorted, evenly bedded, fine- to medium-grained pumiceous sand. Lower part of unit contains rounded to subangular pumice chunks and shards and a few pebbles of rhyolite and andesite. It is also deltaic with dips 15°-25° N. Overlies a silica-cemented pumiceous sandy rhyolite pebble gravel. Crops out in three places along upper sector of Pelican Creek (stratigraphic sections 11 and 12) and in Pelican Valley (stratigraphic section 32). Locally altered by hydrothermal activity; total unit as much as 70 feet thick; lower, deltaic part about 20 feet thick. Probably of early Bull Lake age.
Pelican Cone Stratigraphic Sections

og - Osprey Basalt and associated gravel, gravel (Pleistocene)

Yellowish - brown, poorly sorted,crudely to well bedded boulder and cobble conglomerate with local pebble and sand lenses; moderately cemented. Clasts mainly of andesite, basalt, and some Yellowstone Tuff. Crops out along Lamar River at mouth of Willow Creek and along Timothy Creek near confluence of Buffalo Fork. More than 100 feet thick.

ob - Osprey Basalt and associated gravel, Osprey Basalt (Pleistocene)

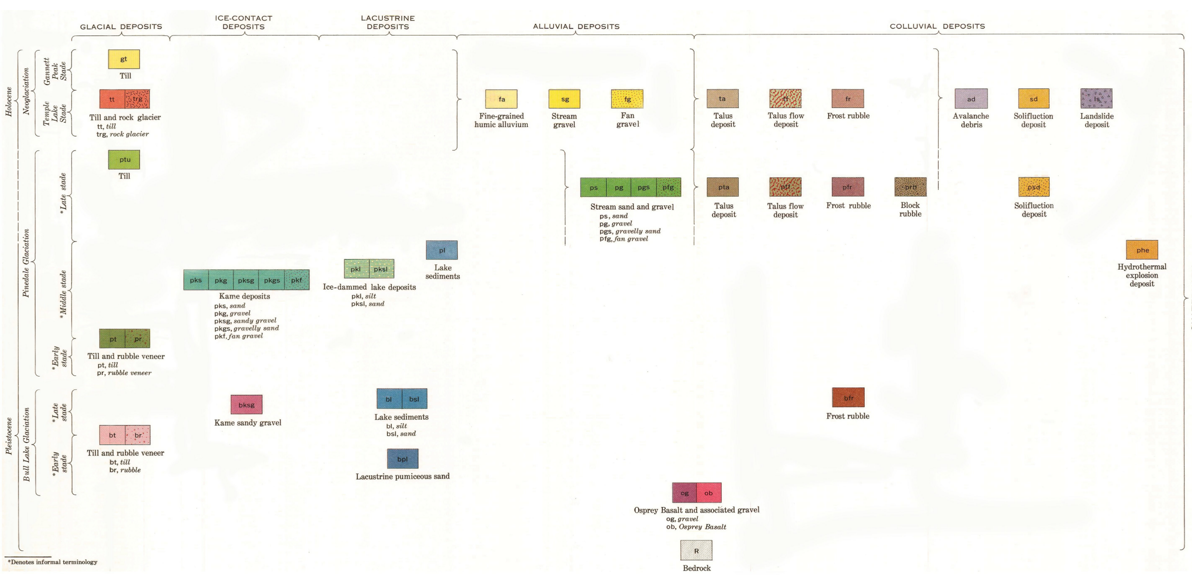
Medium-gray, dense to fine-grained basalt; crops out along Lamar River at north edge of quadrangle, along Timothy Creek about 2 miles above its mouth, and extensively along the upper reaches of Buffalo Fork. About 20 feet thick.

R - Bedrock (Pleistocene and Eocene)

(The following is based on unpublished data supplied by H. W. Smedes and H. J. Prostka, written commun., 1969.) Mainly Eocene volcanic rocks of Absaroka volcanic field and lesser areas of Yellowstone Tuff of Pleistocene age. The Eocene rocks dip gently south to southwest; in northern part of the quadrangle (Little Saddle Mountain and eastern part of Mirror Plateau) and on uplands in east-central part of quadrangle they are mainly andesite breccias and flows overlain by basaltic flows. On western part of Mirror Plateau, Pelican Cone, and the high ridges of Absaroka Range in the south part of the quadrangle the Eocene rocks include light-colored volcanic conglomerates, chiefly andesitic, and underlying lava flows. Giant Castle Mountain, Silvertip Peak, and Cody Peak in southeast corner of quadrangle are capped by Eocene andesite flows. Yellowstone Tuff unconformably overlies rocks of the Absaroka volcanic field on the west side of Mirror Plateau, on uplands southwest and northeast of Lamar River, southwest of Jones Pass, and on the bench north of Jones Creek.

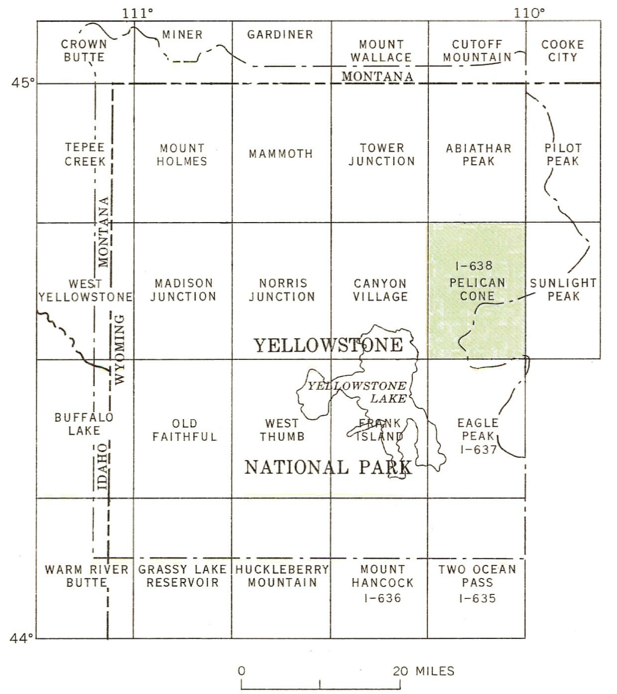
Text from source map: Pelican Cone 15' Quadrangle

Correlation of Units



Graphic from source map: Pelican Cone 15' Quadrangle

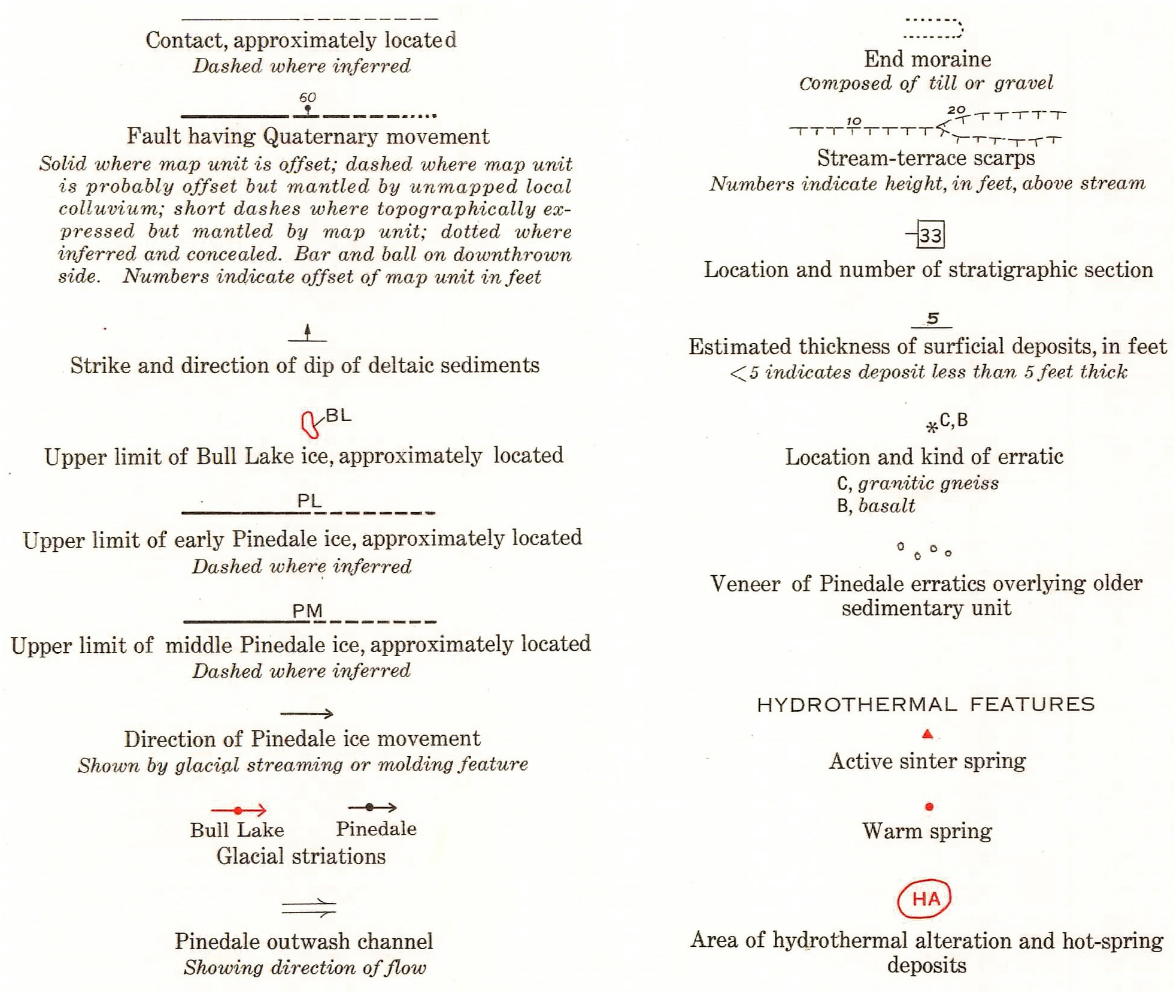
Index Map



INDEX MAP OF YELLOWSTONE NATIONAL PARK SHOWING LOCATION OF PELICAN CONE QUADRANGLE AND PUBLISHED MISCELLANEOUS GEOLOGIC INVESTIGATIONS MAPS

Graphic from source map: [Pelican Cone 15' Quadrangle]

Map Legend



Graphic from source map: Pelican Cone 15' Quadrangle

Stratigraphic Sections

Units shown in descending order; numbers (where shown) represent thickness, in feet. Sections demonstrate distribution and stratigraphic relations of significant units vertically exposed and thus too small to be shown on the map.

Stratigraphic section locations are presented in the GRI Geologic Observation Localities (yellgol) feature class. In that feature class, the section identifier is stored in the Location ID (LOC_ID) field. The section information presented here is also contained in the Geologic Observation Localities (yellgol) feature class Notes (NOTES) field.

See Description of Units for information about map units listed here.

1. fa/sg/bsl
2. pks/pt

3. 10 pt/45 bt
4. pg/pkl
5. ps/bksg/bt
6. 25 ps/30 bsl
7. 5 pkg/48pksl/3lbsl
8. pkg/bksg
9. pkl/pt
10. pkl/bl
11. pt/bl/big/bpi
12. 2 pt/7 bsl/18 big/70 bpl/3 eg
13. pkl/pkg
14. 6 pg/15 pkl/10 bsl
15. 40-50 pkl/40-50bsl(?)/10_-15 bpi(?) (section hydrothermally altered)
16. 15-25 pkl/20-30 bsl
17. 0.5 pg/10 pksl/12 ig
18. 2 fa/5 sg/12 bsl
19. pkl/bsl
20. 3 co/8-15 pkl/3-4 ig/30 bl
21. 35 pkl/10 pt/22 bl
22. pkl/pksl
23. pg/pksl
24. pkl/pt
25. pksl/pt
26. pksg/pt
27. 4 ps/10 pkl
28. 12 pkl/32 bl
29. 10 pkl/10 ig/20 bl
30. 4 pkl/3 ig/5 bl
31. 12 pkl/30 bl/22 bsl/20 bl
32. 2 co/22 pksl/8 ig/15 bsl/2 big/10 bpi
33. 10 pt/3 ig/20 bl
34. 10 pt/20 bl
35. 20 bl/2 bt

Text from source map: Pelican Cone 15' Quadrangle

Surficial Geologic History

INTRODUCTION
The Pelican Cone 15' Quadrangle is located northeast of Yellowstone Lake in Yellowstone National Park and in adjacent parts of Shoshone National Forest. The quadrangle is drained by Pelican Creek, which flows southwest across a broad grassy basin into Yellowstone Lake; by Lamar River, which flows northwest through a deep trough-like valley to the Yellowstone River; and by Crow Creek and Jones Creek, which flow east through deep U-shaped canyons into the North Fork of the Shoshone River.

The serrate crest of the Absaroka Range forms a divide across the southeast part of the quadrangle. From it, just east of Mount Chittenden, a more subdued divide extends northward to the Mirror Plateau. Local relief in the eastern part of the quadrangle is from 1,000 to 3,000 feet, and in the western part from 500 to 1,000 feet:

PLEISTOCENE GLACIATION
Great icecaps covered most of Yellowstone Park during at least three glaciations in Pleistocene time.

From oldest to youngest these are called the pre-Bull Lake, Bull Lake, and Pinedale.

PRE-BULL LAKE GLACIATION OR BULL LAKE GLACIATION

No glacial deposits of the pre-Bull Lake glaciation have been recognized in the Pelican Cone 15' Quadrangle but outcrops of deeply weathered, poorly cemented cobble gravel (gravel associated with Osprey Basalt, og) along the Lamar River at the mouth of Willow Creek, and along Timothy Creek near the confluence of Buffalo Fork, are of pre-Bull Lake age. The gravel is of the same age as the Osprey Basalt (ob) with which it is intimately interlayered in the Tower Falls quadrangle.

BULL LAKE GLACIATION

Glacial deposits of the Bull Lake Glaciation consist of till (bt) and glacial rubble (br) that lie above the upper limit of Pinedale Glaciation on Mirror Plateau, Little Saddle Mountain, Pelican Cone, the ridge northeast of Lovely Pass, uplands north and east of Frost Lake, and broad benches on the north slopes of the valleys of Jones Creek and Crow Creek. The distribution and altitudes of these deposits show that an icecap covered almost all of the quadrangle in Bull Lake time and that it was more extensive than the subsequent Pinedale icecap. On the benches north of Jones and Crow Creeks the till has a mature but distinctly morainal topography, and is more deeply weathered than Pinedale Till. Bull Lake Till crops out beneath Pinedale Till and associated kame deposits at stratigraphic sections 3 and 5.

From evidence in other areas it is known that the Bull Lake Glaciation consisted of an early stade and a late stade. Though no till of the early stade was positively identified in this quadrangle, the presence of a lake in the Yellowstone Lake Basin during glacial recession in the latter part of the early stade and during the subsequent interstade, before the glacial advance of the late stade, is suggested by deposits of lacustral pumiceous silty sand and gravel (bpl) in Pelican Valley and along the northern sector of Pelican Creek. At stratigraphic sections 11, 12, 15, and 32 the pumiceous sand is characterized by deltaic foreset beds dipping 15°-25° N. The pumice is mixed with other materials and was probably reworked from older deposits by a lake that at one time extended up Pelican Creek to an altitude of at least 8,160 feet. The lowest outcrop of the pumiceous sand in this quadrangle is at 7,840 feet in Pelican Valley (stratigraphic section 32). The deposits are separated from lake silts of the late stade by an interstadial gravel (big) in stratigraphic sections 11, 12, and 32.

Little is known about the recession of the icecap in late Bull Lake time. The distribution and character of silica-cemented kame gravel (bksg) beneath Pinedale deposits in the upper basin of Raven Creek (stratigraphic sections 5 and 8) suggest that the Bull Lake ice stagnated at altitudes as high as 8,300 feet. At lower altitudes, deposits of lacustral silt and sand of late Bull Lake age underlie hills capped by Pinedale Till or by a veneer of Pinedale erratics in the area south of Pelican Creek near the west margin of the quadrangle and at stratigraphic sections 11, 12, and 34. The silts also disconformably underlie a post-Bull Lake and pre-Pinedale alluvial gravel at stratigraphic sections 20, 19, 30, 32, and 33 in Pelican Valley. The distribution and altitude range of the lacustrine deposits suggest that an ice-marginal lake opened gradually in Pelican Valley and its tributaries as the late Bull Lake ice receded to successively lower altitudes.

PINEDALE GLACIATION

Two ice masses covered most of the quadrangle during the Pinedale Glaciation. The larger and older was an icecap that developed in the Yellowstone Lake Basin to a maximum thickness of about 2,200 feet in this quadrangle. It overrode all but the highest peaks of the Absaroka Range to the east , reshaping many of them into huge roches moutonnées. The upper limit of the ice near Mount Chittenden was at about 10,000 feet altitude. This ice flowed eastward down the canyons of Jones Creek and Crow Creek and down the North Fork of Shoshone River to about 1 ½ miles north of Pahaska Tepee in the Sunlight Peak quadrangle. North of Mount Chittenden, the ice overtopped the divide between Pelican Valley and the Lamar River, rising to 9,500 feet altitude on Pelican Cone, and lay in contact with a smaller ice mass in the Lamar River drainage along a line trending northwest from Pyramid Peak to Mirror Lake.

The Lamar ice mass rose to 9,400 feet altitude on the uplands north of Frost Lake, and part of it flowed southeast through a pass east of Frost Lake to join ice flowing down Bear Creek from a local center of accumulation south of Pyramid Peak. To the north, the Lamar ice mass rose to 9,600 feet altitude on Little Saddle Mountain, and overtopped the Mirror Plateau at about 9,120 feet. In the valley of the Lamar River it was as much as 2,200 feet thick.

After the maximum advance of Pinedale Glaciation, which is called the early stade, the ice receded an unknown distance, and then built up again to a second stand, about 300 feet below the first maximum. This stand, which was in places a series of closely related stands, is correlated with the middle stade of Pinedale Glaciation. It is marked by lateral moraines, by areas of thick hummocky till along steep slopes and, in valley reentrants, by ice-marginal inwash deposits, and by drainage outlets leading away from stagnant ice depressions in the till. The limits of the middle stade are most clearly delineated in the northwest quarter of the quadrangle.

Following readvance of the middle stade, downwasting of ice first exposed the crest of the Absaroka Range and then the divide that separated the icecap in Yellowstone Lake Basin from ice in the Lamar River drainage . For a short time, melt waters flowed through some of the saddles in this divide. Saddles at the head of Cold Creek and at Mist Creek Pass were the first to be exposed, but there is little evidence of fluvial erosion or deposition in them.

Kame gravels were deposited along Cold Creek against ice that receded downvalley from 8,200 feet altitude near the headwaters to 7,600 feet near the Lamar River.

The saddle at the head of Willow Creek contains a recessional end moraine convex to the south, suggesting drainage to the south, at least temporarily. Recessional end moraines in the headwaters of Raven Creek, however, are convex to the north. Kame gravels enclosing a stagnant ice depression in the headwaters of Buffalo Fork were deposited against ice that receded down Buffalo Fork from an altitude of 7,750 feet nearly to its confluence with the Lamar River.

The southwest side of the Lamar River valley is bordered almost continuously by terraces of laminated silt deposited in a lake dammed by ice that receded northward downstream. These lacustrine silts extend from an altitude of 7,600 feet near the mouth of Cold Creek to 7,520 feet at the narrows above the mouth of Buffalo Fork, and from about 7,240 feet at the mouth of Buffalo Fork to 7,200 feet at the north edge of the quadrangle. The receding ice that dammed the lake was about 400 feet high when at the mouth of Cold Creek but was only about 160 feet high when at the north edge of the quadrangle. No lake deposits were found along the Lamar River valley upstream from the mouth of Cold Creek.

Stagnation and downwasting of the Yellowstone Lake basin icecap in the drainage of Pelican Creek are recorded by kame terrace deposits and by ice-dammed lake sediments deposited in the earliest waters ancestral to Yellowstone Lake itself. The upper basin of Raven Creek is enclosed by fluvial ice-contact gravels (pkg) to altitudes as high as 8,400 feet. As the ice receded into the narrows below the basin an ice-dammed lake opened up, and lake silts (pkl) were deposited at 8,240 feet altitude, or approximately 600 feet above present Yellowstone Lake. Subsequently as the ice downwasted into Pelican Valley , the lake receded from the basin of Raven Creek and alluvial gravel covered the lake beds to a depth of about 25 feet.

The lake next opened in the northeastern part of Pelican Valley where ice-dammed lake silt (pkl) occurs as high as 8,240 feet altitude. In the southeastern part of Pelican Valley, streams deposited kame gravel between ice and the valley slopes from 8,320 to 8,080 feet. Opening of an ice-marginal lake at 8,080 feet is recorded by deposits of ice-dammed lake sand (pksl) from 8,080 feet to 8„000 feet and by ice-dammed lake silt (pkl) at lower altitudes. In the basin of Pelican Creek, north of Pelican Valley, streams deposited gravelly sand (pkgs) around stagnant ice from 8,320 feet to 8,080 feet but, as the ice receded southward, an ice-marginal lake opened gradually from north to south. This event is recorded by lake silt (pkl) as high as 8,160 feet altitude at the north end of the basin, but only to 8,080 feet at the south end. A similar history is also recorded in the valley of Astringent Creek, where fluvial ice-contact sandy gravel (pkgs) occurs from 8,400 to 8,080 feet, and lake sediments (pkl) at lower altitudes.

After the lake had opened in the eastern end of Pelican Valley and its tributaries, it gradually enlarged westward at successively lower levels as the damming ice receded to the southwest. Thick silts (pkl) deposited in the lake at this time fill the valley floor, and overlap Pinedale kame deposits (pkgs) and Pinedale glacial rubble (pr) mantling older Bull Lake lake sediments (bl). The lake level at the west edge of the quadrangle at this time was at 8,000 feet altitude, or 270 feet above present Yellowstone Lake. The subsequent history of lowering of the lake can be inferred from the distribution of its deposits in the Canyon Village 15' Quadrangle, adjacent to the west.

Thin deposits of alluvial gravel (pg) or sand (ps) overlap the lake deposits at the mouths of tributaries to Pelican Creek. Some are graded to lake and marsh deposits (pp 10-15 feet above the creek, and represent a final phase of the lake in Pelican Valley. Others are graded to terraces 20-30 feet above Pelican Creek that extend through Pelican Valley to the west.

In the northwest corner of the quadrangle an ice-dammed lake formed in the headwaters of Wrong Creek. Laminated lake silt (pkl), locally much altered by hydrothermal activity, is widespread in Hot Springs Basin up to about 8,400 feet altitude. It also occurs in the valley of Wrong Creek, in the upper sector of which it merges with Pinedale delta and alluvial fan gravel (pfg). The lake opened gradually as the ice front receded northwest down Wrong Creek. The lake silt (pkl) overlies older compact dense laminated lake silt (bl) of probable Bull Lake age and is locally overlain by Neoglacial stream gravel (sg).

Late Pinedale readvance. -Following stagnation and disappearance of ice at the end of middle Pinedale time, valley glaciers readvanced from cirques in the Absaroka Range during a cool interval called the late stade of Pinedale Glaciation. Sixteen such glaciers formed in this quadrangle, all in east- or north-facing cirques. The glaciers were ½-2 ½ miles long, mostly ½-1 mile wide. The longest formed in the valley northeast of Cathedral Peak and overrode older Pinedale kame gravel (pkg) deposits along Cold Creek. The average lower limit of these glaciers throughout the Absaroka Range was 8,560 feet altitude. Some of them built prominent end moraines, 30-60 feet high. The till (ptu) is commonly more stony and the stones are more angular than in older Pinedale Till (pt). The headwalls of cirques occupied by these glaciers are fresh and sharp, in marked contrast to the rounded crests and smoothed headwalls of older Pinedale cirques, many of which were overridden by the Pinedale icecap. Talus in the cirques is also fresher than that in the older Pinedale cirques.

Pinedale frost riving and solifluction -During wasting of the Pinedale icecap and in late Pinedale time frost riving of the freshly exposed cliffs of cirques and steep valley slopes in the Absaroka Range, in particular the south slopes of Little Saddle Mountain, produced talus deposits (pta). Most are thin sheets of frost-fractured detritus, but some include glacial rubble washed or slumped from steep slopes. South-facing slopes tend to have greater accumulations than north-facing slopes. Locally, the lower parts of talus have flowed forward to produce lobate talus flow deposits (ptf) with arcuate frontal ridges.

On high gently sloping uplands above the limit of Pinedale ice, such as those east of Cathedral Peak and south of Pyramid Peak, widespread coarse- to fine-grained angular to subangular frost rubble (pfr) formed essentially in situ. These deposits, now stable, bear a brown podzolic soil 12-15 inches thick that supports a thick grassy tundra vegetation. Block rubble deposits (prb), composed of angular blocks 6 inches to 3 feet in diameter, formed locally on steep slopes, such as east of Cold Creek, where blocks riven from bedrock have moved irregularly downslope across underlying surficial deposits.

Solifluction deposits (psd) produced by slow downslope flowage of saturated mantle form broadly lobate constructional terraces around the margins of upland basins, such as the upper section of Willow Creek.

Most are derived from till. Small unmapped solifluction deposits are widespread throughout the quadrangle.

Pinedale alluviation and erosion. - Little alluviation, other than ice-contact fluvial deposition, took place in Pinedale time. Thin alluvial fan and terrace deposits (pg), mostly of late Pinedale age, lie 15-25 feet above the streams in Pelican Valley and its tributaries. Along the Lamar River the alluvial gravel is 30 feet to more than 70 feet thick, and successive episodes of late Pinedale deposition and erosion have formed terraces 25-60 feet above the river. Alluvial fans (pfg) along valley sides at mouths of tributaries have been incised 25 feet or more by modern streams.

Maximum stream erosion occurred in late Pinedale time. It is greatest in the valley of the Lamar River, along tributaries to Pelican Creek such as Raven Creek, and in the valleys of Crow Creek and Jones Creek where it is from 30-60 feet.

Pinedale hydrothermal explosion activity. - A hydrothermal explosion deposit (phe) lies between Sedge Creek and Bear Creek along the west edge of the quadrangle. It is part of a larger mass that surrounds Turbid Lake just to the west, in the Canyon Village 15' Quadrangle. The explosion is inferred to have taken place under water. The explosion debris overlies an organic layer dated at 8,310±300 years B. P. (sample W-1944; Meyer Rubin, written commun., 1967). Another and probably older Pinedale hydrothermal explosion deposit occurs in Hot Springs Basin.

NEOGLACIATION

During the altithermal interval following recession of the late Pinedale valley glaciers, cirques were empty, and slopes were relatively stable. Subsequently, during the Neoglaciation, small glaciers less than half a mile long formed in three cirques in the Absaroka Range. Two small moraines were built in the cirque on the north face of Pyramid Peak and in the high east-facing shelflike cirque southwest of Cathedral Peak. A single moraine formed in the east-facing cirque 1 mile southwest of Cathedral Peak. The outer moraines (tt), including the single moraine, are 20-30 feet high and are mostly grass covered and support a few trees; they represent the Temple Lake Stade of Neoglaciation. The inner moraines (gt) are similar, but fresher, and support only a local sparse grassy vegetation; they represent the Gannett Peak Stade of Neoglaciation.

NEOGLACIAL FROST RIVING AND SOLIFLUCTION

Frost riving and solifluction in Neoglacial time were far less widespread than in Pinedale time. Talus (ta) is mainly restricted to areas beneath cirque headwalls and south-facing cliffs along ridge crests above Jones Creek and Crow Creek. The deposits locally grade into cirque avalanche debris (ad). Frost rubble (fr) formed and is locally forming today along the crests of the Absaroka Range, but is not so widespread as it is south of the quadrangle. A few block rills and sorted circles were noted east of Cathedral Peak. Small active solifluction lobes and terraces (sd) are present in areas such as the upper basin of Raven Creek and the Lamar Valley where ground water, perched on lake silt, saturates the overlying mantle. Peat deposits as much as 6 feet thick occur in some solifluction lobes and terraces in the upper basin of Raven Creek.

NEOGLACIAL ALLUVIATION AND EROSION

Since late Pinedale time, 5-15 feet of gravel (sg) has been deposited along Pelican Valley and its tributaries. Most of this gravel is mantled by 1-4 feet of fine-grained humic alluvium (fa). In the Lamar River valley, alternating erosion and deposition have formed a sequence of gravel terraces less than 25 feet above the river. East of the Absaroka crest, avalanche processes have gullied the steep slopes and deposited extensive avalanche debris (ad) on the valley floors. Throughout the quadrangle, fine-grained humic alluvium (fa) has formed in depressions in Pinedale Till, in upland basins, along Pinedale meltwater channels, and on many flood plains.

LANDSLIDES

A number of large landslides (ls) have occurred where lava flows or mudflow breccias of the Absaroka volcanic field overlie tuffaceous units that become saturated and fail on steep slopes. Some of the landslide deposits contain huge masses of rock that have collapsed as a unit from the headwall. Such deposits occur on both sides of the ridge crossed by Lovely Pass, where they are in part controlled by normal faults, and on the north slope of the valley of Bear Creek, east of Pyramid Peak. Others occur west of Pelican Creek, and north of Pelican Cone. Many small slides have occurred in the lake beds (pkl) underlying the southwest side of Lamar River valley. Most of the landslides are in part seasonally active. Some, for example, that on Bear Creek-appear to have originated in Neoglacial time, others in Pinedale time. Part of the large slide at the head of Willow Creek may have flowed onto stagnant ice.

QUATERNARY NORMAL FAULTING

A southeast-trending belt of normal faults that offset Quaternary deposits extends from the northwestern part of the quadrangle south across the south-central part, individual faults are from 3/10 to 6 miles long and near-vertical, and have throws that range from 10 to at least 100 feet. The arcuate pattern of the faults in the northwestern part suggests a relation to a caldera that lies just west of the quadrangle. These faults delineate at least two complex grabens. The faults to the south, however, appear to be related to a zone of en echelon faulting that extends south of Yellowstone Lake, up the valley of the Yellowstone River.

Movement on the faults occurred at different times during the late Quaternary. Some faults are overlapped by Pinedale Till, some offset Pinedale Till, and some offset Holocene alluvium. The scarps of some of the latter are so fresh, and their relation to ponds and drainage changes are so delicate that their most recent movement may possibly be related to the Hebgen Lake earthquake of August 17, 1959. However, along some faults stratigraphic throw exceeds topographic throw, which suggests that movement was recurrent and that it may have begun before late Quaternary time.

HYDROTHERMAL ALTERATION

Major areas of hydrothermal alteration occur along Pelican Creek and in the Hot Springs Basin Group along Wrong Creek; minor areas lie along East Entrance Road, along faults northeast of Pelican Cone, and west and north of Little Saddle Mountain. With the exception of minor travertine deposits in Pelican Creek, the alteration is acidic, produced by sulfur-laden gas and water. Both bedrock and surficial deposits are commonly altered to light-colored clay or to a crumbly aggregate that supports little or no vegetation. Surficial deposits, particularly those of Bull Lake age, are locally cemented by silica.

Text from source map: Pelican Cone 15' Quadrangle

Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle

The formal citation for this source.

Pierce, Kenneth L., 1974, Surficial Geologic Map of the Tower Junction Quadrangle and part of the Mount Wallace Quadrangle, Yellowstone National Park, Wyoming and Montana: U.S. Geological Survey, Miscellaneous Investigations Series Map I-647, scale 1:62,500 (*GRI Source Map ID 1150*).

Description of geologic units, prominent graphics and text associated with this source.

Description of Units

fa - Fine-grained humic alluvium (Holocene)

Silt and subordinate sand, clay, and plant material deposited in marshy environment. Occurs in glacial scour depressions and kettles, and on flood plains of low-gradient streams. Mostly 2-15 feet thick.

sg - Stream gravel (Holocene)

Tan to gray, moderately sorted and stratified sandy gravel; gravel is subrounded, mostly 1-6 inches in diameter. Forms alluvial flats 0-15 feet above the Yellowstone River or 0-5 feet above other streams. Narrow deposits of alluvium along smaller drainages were not mapped. Mostly 5-15 feet thick.

fg - Fan deposits, gravel (Holocene)
fm - Fan deposits, muddy gravel (Holocene)

Fan gravel (fg) is poorly sorted, crudely stratified, and locally bouldery. Fan gravel derived from rhyolite tuff is mostly angular sand and small pebbles. Muddy fan gravel (fm) is very poorly sorted mudflow, sheetwash, and torrential flood deposits containing abundant fines derived from clayey bedrock. Mostly 5-25 feet thick.

ta - Talus deposit (Holocene)

Angular rock rubble forming cones or aprons on steep slopes. Clasts commonly more than 6 inches across. Active piecemeal accumulation from cliffs or positions upslope. No vegetation except lichens. Mostly 5-20 feet thick.

tf - Talus-flow deposit (Holocene)

Similar to talus, but occurs on gentler slopes and has been emplaced by flowage. Mass movement shown by upslope source, unstable or recently turned rock fragments, flow ridges and furrows, and deformation of turf at toe of deposit. Occurs in northern part of mapped area. Mostly 3-10 feet thick.

fr - Frost rubble (Holocene)

Abundant rock fragments, mostly cobble-sized, in fine-grained matrix. Occurs on Mount Washburn where formed by frost mixing, sliding, and solifluction; seasonal activity is indicated by locally disrupted vegetation and thin azonal soil. Active since middle Pinedale deglaciation. Mostly 2-5 feet thick.

ad - Avalanche debris (Holocene)

Boulder- to pebble-sized rock fragments in fine-grained matrix at base of avalanche chutes. Deposit unsorted, crudely stratified. Occurs in cirque basins of Washburn Range. Mostly 5-20 feet thick.

ls - Landslide deposit (Holocene)

Nonsorted debris in a muddy matrix; forms lobate masses. Fresh ridges, depressions, and slump scarps show that most deposits have moved recently. Formed mostly of local bedrock that has failed on shale or other fine-grained bedrock. Includes earth-flows derived from lake sediments in Grand Canyon of the Yellowstone above Tower Fall. Thickness 10-100 feet.

es - Eolian sand and silt (Holocene)

Poorly sorted sand and silt on rim of Grand Canyon of Yellowstone. Blown from exposures of hydrothermally disintegrated bedrock in canyon. Probably occurs elsewhere along canyon rim. Thickness 3-15 feet.

tr - Travertine (Holocene)

Light-gray, porous calcium carbonate. Unit includes modern deposits near Tower Junction and Calcite Springs, and deposit beneath Pinedale Till north of Rainey Lake that may be same as that in stratigraphic sections 4 and 6. Mostly 2-10 feet thick.

Tower Junction and Part of Mount Wallace Stratigraphic Sections

ds - Diatomaceous sediment (Holocene)

White siliceous silt composed of microscopic diatom shells. Mushy when wet, powdery when dry. Identified only at site west of Washburn Hot Springs, but probably occurs nearby in other poorly drained flats. Thickness 5-20 feet.

si - Siliceous sinter (Holocene)

Nearly white, porous, amorphous silica. Mapped in south-central part of area. Mostly 2-10 feet thick.

sh - Sediments of Sevenmile Hole (Holocene and/or Pleistocene)

Gravel, sand, silt, and colluvium in Sevenmile Hole. At stratigraphic section 18, very compact lake sediments are varved and contain plant material. At stratigraphic section 17, relatively uncompact beds of silt and gravel apparently deposited in ice-marginal lakes and streams. Probably includes landslide deposits and sediments deposited in landslide-dammed lakes. May include deposits of pre-Bull Lake, Bull Lake, Pinedale, and Holocene age. Mostly 100-200 feet thick. A 200-foot-thick sequence of hydrothermally altered lake sediments, gravel, and landslide debris was viewed eastward across the river near the south map boundary.

pg - Gravel, stream and outwash gravel (Holocene and/or Pleistocene)
pfg - Gravel, fan gravel (Holocene and/or Pleistocene)

Stream and outwash gravel (pg) and fan gravel (pfg) are tan to gray, moderately sorted and stratified, and subrounded. Gravel mostly 10-30 feet thick.

pfd - Flood deposits (Holocene and/or Pleistocene)

Buff, bouldery gravel; poorly to moderately sorted, poorly stratified. Boulders mostly of gneiss and basalt and commonly display percussion spalls. Mainly form longitudinal bars against valley sides; relief on depositional surface of bars commonly exceeds 10 feet. Boulders 3-5 feet in diameter common, with some larger than 10 feet. Along Yellowstone River below The Narrows, deposits extend as much as 50 feet above river and contain one boulder 20 feet across. Along Lamar-Yellowstone drainage flood deposits extend more than 100 feet above drainage. Along Lamar River above Slough Creek, flood deposits are less bouldery and bars less developed; local kettles. Deposits thickest upstream from bedrock constrictions of valleys. Thickness 10-50 feet.

pta - Talus deposit (Holocene and/or Pleistocene)

Angular rock debris; the larger blocks 0.5-2 feet across. Forms aprons and cones on steep slopes, generally below cliffs. Fine-grained matrix fills voids between blocks and commonly extends to surface where soil is weak, humic, and 1-2 feet thick. Mostly inactive and tree-covered. Thickness 5-50 feet.

ptf - Talus-flow deposit (Holocene and/or Pleistocene)

Angular blocks on moderate to gentle slopes. Voids are open at surface, but may be filled at depth. Derived from outcrops upslope. Mostly inactive; blocks weathered and covered with lichen. Mostly 5-20 feet thick.

pst - Scree deposit of tuff rubble (Holocene and/or Pleistocene)

Small-pebble-sized fragments and local large slabs of stony rhyolite forming thin sheets over tuff bedrock and aprons and cones farther downslope. Generally covered by open forest; includes active surface material that locally slides and tumbles downhill against trees and other obstacles. Thickness of sheets 0-5 feet; of aprons and cones 5-30 feet.

pkl - Ice-dammed lake silt (Holocene and/or Pleistocene)

Gray, massive to laminated silt. Main deposit occurs in Grand Canyon of the Yellowstone above Tower Fall and extends as much as about 600 feet above Yellowstone River; ice dam was near stratigraphic section 10. Locally exposed and probably more widespread than where mapped beneath kame deposits (pkg, pks) above confluence of Lamar River and Slough Creek (map, stratigraphic section 2). Thickness 10-400 feet.

Tower Junction and Part of Mount Wallace Stratigraphic Sections

pkg - Kame deposits, gravel (Holocene and/or Pleistocene)
pks - Kame deposits, sand (Holocene and/or Pleistocene)
pkf - Kame deposits, inwash fan deposits (Holocene and/or Pleistocene)

Kame gravel (pkg) and gravelly sand (pks) are mostly gray, unevenly stratified, moderately well sorted, and have abrupt vertical changes in grain size. Roundstones mostly 2-4 inches in diameter. Deposited by ice-marginal streams; ice-contact frontal scarps commonly preserved. Near Tower Fall, along Shallow Creek, and east of Lamar River-Slough Creek confluence, deposits (pks, pkg) locally are laterally gradational with or overlie ice-dammed lake silt (pkl). East of Lamar-Slough confluence, well-preserved kame terraces with kettle-ponds are of probably late Pinedale age. Kame inwash fan deposits (pkf) mostly nonsorted nonstratified andesitic debris. On south side of Washburn Range, deposits commonly form several escarpments at decreasing altitudes and facing south; deposited by mudflows and debris flows against glacier margins at or near the Deckard Flats (PD) limit. Thickness of kame deposits mostly 20-100 feet.

pkls - Kame landslide deposit (Holocene and/or Pleistocene)

Rubble in a fine-grained matrix; slumped from valley walls against stagnant ice. Locally, as along Slough Creek, in contact with kame gravel. Deposit looks more morainal than do normal landslides (ls), has some kettlelike depressions and steep ice-contact scarps. Some mass movement still occurs. Large slide north of Specimen Ridge mostly angular debris derived from ridge. Along Carnelian Creek forms steep-fronted, largely inactive landslides containing large blocks of rhyolite tuff slumped from cliffed headwall. Thickness 20-200 feet.

pt - Till (Holocene and/or Pleistocene)

Gray to grayish-brown, nonsorted, nonstratified, compact mixture of roundstones, sand, silt, and clay; deposited by glaciers. Stones mostly subrounded, but more faceted than stream gravel. Glacially striated and faceted stones locally common in deposit, but difficult to recognize on surface.

In the northern third of the mapped area, the till is gray and sandy and contains about equal amounts of material derived from Precambrian crystalline rocks and Eocene andesite; a minor amount of quartzite, carbonate, and clay has been derived from Paleozoic sedimentary rocks.

In the southern two-thirds of the area the till is brownish and is derived mostly from Eocene andesites. The till is generally clayey except on the tuff benches above Tower Creek and south of Deep Creek where it is sandy. Erratics of Precambrian rocks are common as far south as a curved line extending from the confluence of Tower and Carnelian Creeks across the flats of Antelope Creek to just south of Agate Creek.

Till forms undulating ground moraine in most places. The surface till upstream from the ice position near Junction Butte (JB) probably is of late Pinedale age. End moraines or an increase in till thickness commonly occurs just inside the limit of the Deckard Flats advance (PD).

Upper part of till modified by soil development and frost heaving, and, on slopes, by solifluction and creep. Soils on till are variable, mostly 1-3 feet thick, and generally display weak color, texture, and structure development of the B-horizon. Weathering of roundstones since deposition is minor. Till thickness generally increases from 5 feet on uplands and upper slopes to 20 feet or more near base of slopes and on bottomlands.

pr - Rubble veneer (Holocene and/or Pleistocene)

Thin mantle of rubble in a loose fine-grained matrix on glaciated uplands. Mostly derived, especially by frost processes, from local bedrock, but contains some glacial erratics and other glacially moved debris. Terrain underlain by rubble veneer (pr) gradational with and similar in appearance to that underlain by till (pt), but undisturbed glacial deposits are present only locally in rubble veneer areas. Mapped areas include many small glaciated rock outcrops. Thickness 0-5 feet.

at - Till of Alden paleovalley (Pleistocene)

Similar to Pinedale Till (pt). Contains abundant Precambrian boulders. Mapped only in Alden paleovalley (stratigraphic section 10). Age uncertain. As much as 40 feet thick.
Tower Junction and Part of Mount Wallace Stratigraphic Sections

ak - Kame deposits of Alden paleovalley (Pleistocene)

Sand, lake silt, and gravel. Well stratified, moderately well sorted; local strong hydrothermal alteration. Clasts mostly of rhyolite, but some of Precambrian crystalline rocks. Exposed in and near stratigraphic section 10. Deposited behind ice dam in Yellowstone canyon. Includes, for mapping convenience, small exposure of gravel rich in partially decomposed boulders of Precambrian crystalline rocks just downstream from stratigraphic section 12 Age uncertain. Thickness 100 feet.
Tower Junction and Part of Mount Wallace Stratigraphic Sections

bkl - Ice-dammed lake sediments (Pleistocene)

Compact, well-stratified silt and sand deposited along Shallow and Wrong Creeks when ponded by glacier. At stratigraphic section 14, mostly sandy and oxidized to tan. Elsewhere, as at stratigraphic section 15, dark-gray silt and minor sand beds, mostly rhythmically bedded; oxidized tan near joint surfaces. From stratigraphic section 15 on up Wrong Creek, unit (bkl) same as "blue-gray claystone and mudstone***from which oil seeps emerge" at Rainbow Springs (Love and Good, 1970, p. B11). Deposit relatively impermeable as revealed by spring line and landsliding. Overlain by less compact Pinedale sediments. Thickness 20-50 feet.

ob - Osprey Basalt (Pleistocene)

Dark-gray basalt in bank of Lamar River just above Lamar Canyon. Basalt has K-Ar age of about 210,000 years (J. D. Obradovich, written commun., 1972). Interbedded with gravels in Abiathar quadrangle east of mapped area. About 30 feet thick.

ub - Undine Falls Basalt (Pleistocene)

Dark-gray basalt flow in Grand Canyon of the Yellowstone (stratigraphic section 13). Underlies 0.6-m.y.-old Lava Creek Tuff; normally polarized and considered 0.6-0.7-m.y.-old (Christiansen and Blank, 1972, p. B12). Thickness 60 feet.

ug - Gravel beneath the Undine Falls Basalt (Pleistocene)

Moderately sorted, rounded, and polished, cobble gravel (stratigraphic section 13). Composed mostly of Eocene andesite, lava-flow rhyolite, and Quaternary basalt. About 40 feet exposed.

ng - Sediments of The Narrows (Pleistocene)

Oxidized, partly indurated gravel interbedded with basalt flows (nb). Gravel mostly cobbles 3-6 inches in diameter: sand matrix and rims of cobbles colored yellow by hydrothermal alteration. Contains cobbles of Eocene andesite, basalt, quartzite, crystalline rocks, and tuff from the 2-m. y.-old Huckleberry Ridge Tuff. Locally overlain (stratigraphic section 4) by the 0.6-m.y.old Lava Creek Tuff. Stratigraphic sections 4, 6, and 9 include glacial till with clasts of Precambrian crystalline rock, Eocene andesite, basalt, and rhyolite tuff in a gray, fine-grained matrix. The underlying Junction Butte Basalt (jb) is locally polished and striated, and glacially striated clasts occur in the till. Stratigraphic sections 4, 6, 7, and 8 include lake sediments, which at section 7 contain megascopic plant remains and pollen indicating a tundra vegetation (R. G. Baker, written commun., 1970). At section 7, the upper basalt has a K-Ar age of about 1.5 m.y. and the ash of about 1.5 m.y.; a clean, coarse ash in lake sediments conformably just beneath the till at section 6 also has a K-Ar age of about 1.5 m.y. (J. D. Obradovich, written commun., 1972). At section 6, till is overlain by ancient talus and lake sediments, which in turn are overlain by the upper basalt of The Narrows. Thickness about 200 feet.

nb - Basalts of The Narrows (Pleistocene)

Dark-gray basalt flows; lower parts columnar jointed. Locally as many as four flows; interbedded with sediments of the Narrows (ng). Upper flow coarse grained. Magnetic polarity of all flows reversed (Christiansen and Blank, 1972, p. B11). Individual flows mostly 20-40 feet thick.

jb - Junction Butte Basalt (Pleistocene)

Dark-gray, fine-grained basalt. Columnar jointed in lower part. Forms Overhanging Cliff just northwest of Tower Fall. Mapped only in area of Yellowstone Canyon where it overlies gravel beneath Junction Butte Basalt (jg). Magnetic polarity reversed (Christiansen and Blank, 1972, p. B9-B10). Sample collected from Overhanging Cliff has K-Ar age of about 2.0 m.y. (J. D. Obradovich, written commun., 1972). Mostly 50-200 feet thick.

jg - Gravel beneath the Junction Butte Basalt (Pleistocene)

Cobbles mostly 3-8 inches in diameter; clasts of Eocene andesite, quartzite, dense Precambrian crystalline rocks, and basalt. Does not contain rhyolite tuff from the Quaternary Yellowstone Group. At stratigraphic section 12, contains clasts of flow rhyolite. Thickness 10-30 feet.

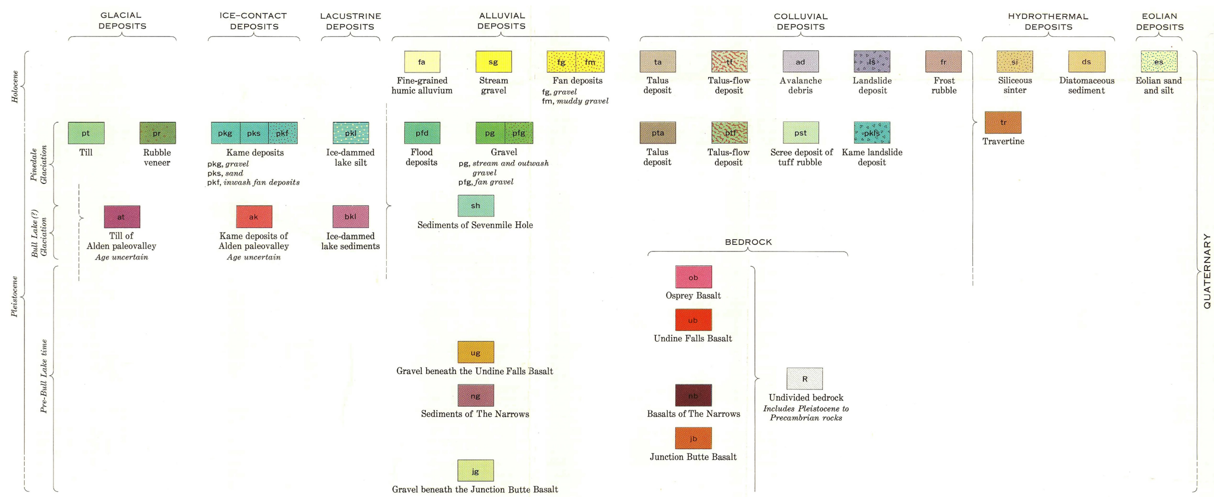
R - Undivided bedrock (Pleistocene to Precambrian)

(after U.S. Geological Survey, 1972) Rhyolite tuff of the Quaternary Yellowstone Group forms the benches above Tower, Carnelian, Deep, and Shallow Creeks. The 0.6-m.y.-old Lava Creek Tuff is the bedrock in most of the tuff areas, but locally the 2.0-m.y.-old Huckleberry Ridge Tuff is exposed. Quaternary basalt flows occur in the Yellowstone and Lamar River valleys. Quaternary rhyolite flows occur in the southwest corner and south of the mapped area. Andesitic breccias, conglomerates, sandstones and lavas of the Eocene Absaroka Volcanic Supergroup underlie the Washburn Range, Specimen Ridge, and many high points in the north part of the area. An

Eocene conglomerate containing quartzite and Precambrian crystalline rocks occurs on the south flank of the Washburn Range, and probably in the headwaters of Carnelian Creek. Precambrian gneisses and other crystalline rocks crop out along and north of the Lamar-Yellowstone drainage. Between the Eocene and Precambrian rocks, small patches of Paleozoic quartzite, limestone, and shale crop out north of the Lamar-Yellowstone alinement.

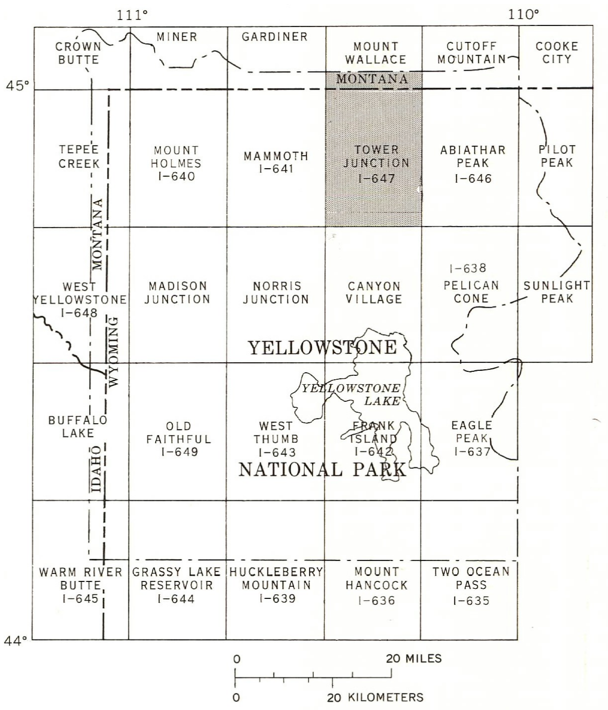
Text from source map: [Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle]

Correlation of Units



Graphic from source map: [Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle]

Index Map



INDEX MAP OF YELLOWSTONE NATIONAL PARK SHOWING LOCATION OF TOWER JUNCTION AND MOUNT WALLACE QUADRANGLES AND PUBLISHED MISCELLANEOUS GEOLOGIC INVESTIGATIONS MAPS

Graphic from source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle

Map Legend

Graphic from source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle

Stratigraphic Sections

Units, separated by slashes, are shown in descending order; numbers show thickness in feet. Letter symbols represent map units; where unit is not a map unit, lithology is described.

Stratigraphic section locations are presented in the GRI Geologic Observation Localities (yellgol) feature class. In that feature class, the section identifier is stored in the Location ID (LOC_ID) field. The section information presented here is also contained in the Geologic Observation Localities (yellgol) feature class Notes (NOTES) field.

See Description of Units for information about map units listed here.

1. 20 pkg, sandy/10 till, tan, calcareous/20 gravel, partly oxidized/ 10 till, gray, calcareous, some oxidation.
2. 5 pg/40 pkl.
3. 10 pkg/20 jb/10 jg/R, Eocene breccia.
4. Lava Creek Tuff/15 covered/10 tuff rubble/125 ng (in detail: 15 ice contact sediments/10 gravel/20 till, abundant Precambrian/25 till/5 lake sediments, travertine cemented/50 gravel).
5. 5 silt/20 diamicton, till(?)/30 flood deposits(?)/20 diamicton, very bouldery/basalt and lake sediments of stratigraphic section 6.
6. 30 ng, gravel, altered/8 nb, upper basalt/113 ng (in detail: 5 lake sediments, pebbly/15 basalt rubble/65 till, cemented/3 ash/20 lake sediments, pebbly/5 travertine, pebbly).
7. 5 pt/20 nb, upper basalt/78 ng (in detail: 60 gravel/5 lake silt/ 13 sandy gravel)/15 nb, channel fill/35 ng (in detail: 10 gravel/5 ash/20 gravel)/20 nb, lower basalt/5 ng, gravel/R, Eocene breccia.
8. 30 pks/15 pkl/20 nb, upper basalt/135 ng (in detail: 40 gravel, coarse/30 gravel, medium/5 diamicton/50 lake sediments/ 10 gravel, bouldery)/20 nb, lower basalt/5 ng, diamicton, bouldery/R, Eocene breccia.
9. 20 nb, lower basalt/14 ng (in detail: 2 lake silt/4 gravel/8 till)/R, Eocene breccia.
10. 85 pks/110 pkl/20 covered/75 at and ak/30 covered, relation to units below uncertain/100 ak, gravel and lake sediments.
11. 10 pkg/5 diamicton/15 pkl.
12. Lava Creek Tuff/50 jb/50 jb, large phenocrysts/5 sand/> 50 jg.
13. Lava Creek Tuff/50 ub/40 ug/R, Eocene breccia.
14. 20 pkg, sandy/ (section moved 100 feet upstream) /30 bkl, tan, slumped/20 bkl, gray, sandy/5 bkl, clayey.
15. 15 pkl, tan/10 bkl, gray, sandy/10 bkl, gray.
16. 8 pkg, tan/55 pkl(?), tan.
17. 128 sh (in detail: 10 colluvium/7 gravel/15 silt, tuffaceous/15 gravel/38 lake sediments, deformed/10 gravel/23 lake sediments/10 gravel.
18. 113 sh (in detail: 60 colluvium/20 lake sand/33 lake silt, varved, plant remains).

Text from source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle

Surficial Geologic History

INTRODUCTION

The Yellowstone River, mostly entrenched in its Grand Canyon and Black Canyon, flows through the middle of this map area. Prominent mountains are the Washburn Range (southwest part), Specimen Ridge (east-central part), and northern Absaroka Range (northern part), called the Snowy Range by most previous workers.

PRE-BULL LAKE SEDIMENTS AND ASSOCIATED VOLCANIC ROCKS

The oldest surficial deposits in this area are gravels beneath the Junction Butte Basalt (jb) (exposed at Overhanging Cliff near Tower Fall (Howard, 1937, fig. 10) and in stratigraphic sections 3 and 12). An ancestral Yellowstone River deposited these gravels on the floor of a broad valley between the high areas of Specimen Ridge and the northern end of the Washburn Range at a level about 100-250 feet above the present river. Clasts include Eocene andesite from the Washburn Range, and resistant quartzites and felsic Precambrian crystalline rocks reworked either from Eocene conglomerates in the Washburn Range or perhaps from older conglomerates in the area of the present Yellowstone caldera or in the headwaters of the upper Yellowstone drainage. These gravels (jg) do not contain tuff from the Yellowstone Group, and together with the overlying Junction Butte Basalt (jb) are thought to date from about 2 m.y. ago. At stratigraphic section 12, gravel beneath Junction Butte Basalt contains clasts from a rhyolite flow probably only slightly older than the Huckleberry Ridge Tuff.

The sediments of The Narrows (ng) and basalts of The Narrows (nb) are younger than the 2-m.y.-old Huckleberry Ridge Tuff and older than the 0.6-m.y.-old Lava Creek Tuff. They (ng, nb) form the main exposures along the east side of The Narrows but along the west side they alternate with patches of Junction Butte Basalt and underlying gravel (jb, jg); these relations were first understood by Howard (1937, p. 36-66). After emplacement of the Junction Butte Basalt, the ancestral Yellowstone River eroded a small canyon through the basalt and underlying Eocene bedrock before filling of this 200-foot-deep canyon by the sediments and basalts of The Narrows (ng, nb).

Glacial till in stratigraphic sections 4 and 6 demonstrates a glaciation about 1.5-m.y. old, as dated by ash in immediately underlying glacially dammed lake sediments. On the north side of Bumpus Butte the till overlies glacially polished Junction Butte Basalt (jb) with striations trending northwest, parallel to the alinement of the Lamar-Yellowstone drainage. Abundant Precambrian erratics show that ice from the Absaroka Range (north and northeast of the map area) reached at least this far. At stratigraphic sections 9 beneath the lower basalt of The Narrows (nb), a Precambrian erratic 10 feet across in a till-like matrix indicates glaciation at a time probably older than the till at Bumpus Butte whose topographic and stratigraphic position is inferred to be above the lower basalt. The glaciers that reached The Narrows from the northern Absaroka Range about 1.5 million years ago were at least 30 miles long and, for comparison, were at least slightly larger than glaciers of the much younger late Pinedale stand near Junction Butte (JB).

Glaciers from the north apparently blocked the ancestral Yellowstone River and thereby caused deposition of most of the lake sediments and some of the gravels in the sediments of The Narrows (ng). A tundra-type pollen assemblage found in the lake sediments of stratigraphic section 7 and correlated with lake sediments of sections 4, 6, and 8 suggests glacial conditions (R. G. Baker, written commun., 1970). On the other hand the interbedding and inter-fingering of some of the gravels with the basalt flows, and the apparent increase in the basalt: gravel ratio downstream suggest that damming by basalt flows probably also caused deposition of some gravel.

Undine Falls Basalt and underlying gravel crop out in the Grand Canyon near Deep Creek (stratigraphic section 13). The gravel was deposited on the floor of a rather broad valley cut into Eocene bedrock on the northeast flank of Mount Washburn. Eocene volcanic rocks from the Mount Washburn area predominate in this gravel: roundstones of rhyolite tuff, quartzite, and Precambrian rocks were not observed. The basalt and gravel underlie and are older than the 0.6-m.y.-old Lava Creek Tuff, but they are considered to be less than 0.7-m.y.-old because the basalt is normally polarized (Christiansen and Blank, 1972, p. B12) and because the gravel contains roundstones of flow rhyolite probably from the nearby Wapiti Lake flow (Christiansen, oral commun., 1970), which is only slightly older than the Lava Creek Tuff (Christiansen and Blank, 1972, p. B11). In the Deep Creek area after emplacement of the Lava Creek Tuff on the Undine Falls Basalt, the Yellowstone River has cut a canyon about 1,200 feet deep, to a position 400 feet below the drainage when the gravel beneath the Undine Falls Basalt was deposited.

Outcrops at river level of Osprey Basalt (ob) just upstream from the Lamar Canyon and of Osprey Basalt and associated gravels east of the map area demonstrate that the Lamar River upstream from the Lamar Canyon has downcut little since gravel and basalt emplacement probably 0.1 to 0.3 m.y. ago.

PLEISTOCENE GLACIATIONS

Great icecaps overwhelmed most of Yellowstone Park repeatedly during the Pleistocene. These glaciations are (from oldest to youngest): pre-Bull Lake (probably several full-scale glaciations), Bull Lake, and Pinedale. The pre-Bull Lake 1.5-m.y.-old glaciation has been described above. Other younger pre-Bull Lake glaciations almost certainly occurred, but little evidence for them was noted in the map area. At stratigraphic section 1, till and gravel beneath Pinedale kame deposits is tentatively assigned to the youngest pre Bull Lake glaciation, the Sacagawea Ridge Glaciation, because of their degree and depth of oxidation. But if this oxidation results from hydrothermal activity, as perhaps indicated by the turbidity of a nearby kettle-lake, then the till could well be of Pinedale age.

BULL LAKE GLACIATION

Compact sediments of lakes most likely dammed by Bull Lake glaciers crop out beneath Pinedale kame deposits along Shallow and Wrong Creeks. These "claystones and mudstones" were first noted by Love and Good (1970, p. B10-B12), who collected samples for diatom and pollen analysis that indicated a climate similar to the present. Ice -rafted pebbles are common in some of the sediments. Although these sediments contain bands of aphanitic black material, not enough carbon could be obtained for a C14 age determination. The sediments at stratigraphic section 14 are more sandy, oxidized, and turbiditelike than the rest of the lake sediments; their bedding is locally vertical, indicating slumping during deposition. No till of Bull Lake age is recognized in the map area except possibly the till of Alden paleovalley (at).

Three large erratics of granitic Precambrian rocks (C) were noted in the map area south of the Washburn Range; other large erratics of Precambrian rocks have been noted for at least 15 miles southwest of the map area to elevations as high as 8,500 feet (see Howard, 1937, fig. 15, table 10). These erratics indicate that glaciers moved at some time from the northern part of the map area to south of the Washburn Range. Between these erratics and their source area to the north, erratics of Precambrian rocks are absent or extremely scarce in a belt that extends from the Washburn Range to Amethyst Mountain; this lack of a continuous erratic train is not consistent with emplacement of the erratics south of the Washburn Range by flow southward across the map area during the last glaciation (Pinedale) of the area. Also, above an altitude of about 8,600 feet in the Washburn Range, glacial scour features (rat-tail ridges, low-angle friction cracks, polished sides of protuberances) indicate flow to the north. Therefore any high-level flow to the south must be older than the last, or Pinedale, flow northward across the range.

Within a few miles south of the Washburn Range, quartzite and felsic granitic erratics less than 6 inches in diameter (X) are probably mostly reworked from a conglomerate in the Eocene bedrock, which is exposed 1.2 miles south of Dunraven Peak.

In the Grand Canyon of the Yellowstone 2.5 miles upstream from The Narrows, a gravel (included with "ak" map unit) at river level contains cobbles and boulders mostly of Precambrian rocks. A pre-Pinedale age for this deposit is suggested by its partial induration and weathering of the boulders to grus. The deposit indicates a pre-Pinedale glacial advance up the Grand Canyon. Perhaps this deposit dates from the glacial advance before Pine-dale full-glacial time that carried boulders of Precambrian rock south of the Washburn Range.

FILL OF ALDEN PALEOVALLEY

A pre-Pinedale valley of the Yellowstone River first recognized by Alden (1928, p. 66, fig. 2) and named "Alden Valley" by Howard (1937, p. 132) is located about one-half mile east of The Narrows and trends northward. The paleovalley is filled by glacial deposits of Pinedale and perhaps older age (stratigraphic section 10) as much as 400 feet thick. After the glaciation that left the till (at) in the middle of stratigraphic section 10, the Yellowstone cut The Narrows. Howard (1937, p. 132) considered that rotted boulders in the till indicated it to be older than the last glaciation of the area (Pinedale). Most boulders I observed were fresh and rotting of the boulders seems to be limited to areas where hydrothermal effects were also noted. Thus, I consider it equally reasonable to interpret the entire Alden paleovalley fill as a conformable Pinedale sequence. The lower half of the fill of Alden paleovalley is of Pinedale or older age and is mapped in the units "at" and "ak" which are placed in the Bull Lake age position, mainly because this is intermediate in the possible range of age assignments from Pinedale to pre-Bull Lake time.

SEDIMENTS OF SEVENMILE HOLE

The sediments of Sevenmile Hole (sh) are probably of several ages and origins. Most deposits probably are of late Pleistocene glacial lake (stratigraphic sections 17, 18), ice-contact (gravels in stratigraphic section 17), and landslide origin. Deposits as old as the original caldera fill following eruption of the Lava

Creek Tuff may also be present.

PINEDALE GLACIATION
Pinedale glaciers and icecaps first grew in the mountains in and near Yellowstone National Park; eventually an icecap became established on the Yellowstone plateau south of the map area. Pinedale Glaciation culminated in a full-glacial flow regimen with the entire map area's being covered by ice; in fact the terminal moraines for the north side of this ice mass lie 45 miles down the Yellowstone River valley from the map area. A waning of glacial conditions followed, accompanied by departures from full-glacial flow directions caused both by differences in the residual influence of ice from different sources and by topographic effects.

Soils on Pinedale deposits are quite variable, ranging from moderately developed profiles several feet thick on deposits derived from clayey bedrock, to weakly expressed profiles on deposits derived from sandy rhyolitic bedrock. Below 8,000 feet soil caliche several feet thick occurs locally.

EARLY PINEDALE ADVANCE
At the inception of Pinedale Glaciation, valley glaciers formed in cirques in the Absaroka Range north of the map area and in nearby mountains to the west, east, and southwest of the map area. In the map area, valley glaciers probably developed in the cirques in the Washburn Range and on the north side of Specimen Ridge.

As glaciers continued to grow, a large icecap formed on the northern Absaroka Range, and another on the plateau south of the map area. Valley glaciers grew in the upper Lamar River drainage east of the map area, but their outflow was partially confined by the larger glaciers from the Absaroka Range icecap flowing southward down the valleys of Hellroaring, Buffalo, and Slough Creeks and, east of the map area, Soda Butte Creek. An icecap also formed on the Washburn Range in the southwestern part of the map area and left striations indicating flow to the southwest across Observation Peak, which is just west of the map area (Pierce, 1973, see striations labeled 1).

Eventually the Pinedale icecap on the plateau south of the map area must have grown high enough to flow north across the Washburn Range (max. elev. 10,243 feet), leaving many well-preserved striations which clearly indicate flow to the north. By this time, approximately the glacial maximum or full-glacial conditions, the entire map area was covered by ice. Arguments for the Pinedale age of the last high-level glaciation of northern Yellowstone National Park are summarized by Pierce (1973). On Amethyst Mountain (elev. 9,614 feet), fresh striations indicate flow to the northwest, demonstrating that ice levels northeast and southwest of Specimen Ridge were concordant and that the ice surface there sloped northwest. Along the west-central map boundary, striations at 9,540 feet and glacial scour features also indicate flow to the northwest parallel to the Yellowstone River valley. Cap ice from the south flowed northwesterly down the Yellowstone River valley, where it joined an irregular sheet of ice as much as 3,500 feet thick from the northern Absaroka Range. As shown by glacial scouring and molding features, southerly flow of northern Absaroka Range ice swung around to the west as it approached the Lamar-Yellowstone alinement, where it then merged with ice flowing northwest down the major drainage.

Until Deckard Flats time Pinedale ice from the northern part of the Absaroka Range did not advance south of the Lamar-Yellowstone alinement either at or following the Pinedale maximum. This is shown both by the absence or rarity of northern Absaroka Range erratics in a belt 6 miles wide which extends from Amethyst Mountain to the Washburn Range, and by the northerly flow direction indicated by striations above the Deckard Flats limit. In the southern part of the map area, glacial flow carried obsidian erratics (0) from Quaternary rhyolite flows and hydrothermally silicified sediments (Hs)) probably from the Canyon Village area northward onto Eocene volcanic bedrock. South of Dunraven Pass from a source in the Eocene bedrock near BM 8549, well-rounded quartzite cobbles have been carried uphill and northward towards the pass.

MIDDLE PINEDALE RECESSION

Although a middle Pinedale readvance occurred in the Yellowstone area and elsewhere in the Rocky Mountains, it is not evident in the map area, because ice levels during the preceding recession fell very little in this, the source, area. After this readvance glaciers receded, eventually exposing peaks in the southern part of the area. Alongside the receding glaciers, moraines were locally deposited and ice-margin streams cut channels into bedrock and surficial deposits.

As the ice level fell, flow direction locally changed as a result of topographic effects combined with the relative ability of the source areas to produce ice under a waning glacial climate. The following changes in flow, especially those of the Deckard Flats readjustment, illustrate these effects.

High-level striations along the west-central boundary of the map area and to the west (Pierce, 1973) show that ice flowed northwest from the Tower Creek drainage during full-glacial conditions. But when the ice level later fell below the range crest, the ice had to flow down the topographic slope parallel to Tower Creek, leaving the northeasterly striations.

DECKARD FLATS READJUSTMENT AND STAGNATION

The Deckard Flats limit (PD) of late middle Pinedale age (Pierce, 1973) represents a glacial advance or standstill that terminated about 15 miles down the Yellowstone River from the map area. Most of the mountain tops in the central and southern part of map area were above the ice at this time.

In the eastern part of the map area the Deckard Flats advance is shown by erratics of limestone and Precambrian rocks from the north occurring at elevations up to 9,000 feet on Specimen Ridge and as far south as the north rim of Deep Creek canyon. Striations on Specimen Ridge below 9,000 feet confirm this same southerly flow pattern and, as shown by striation arrows, transect the northwest striations formed during full-glacial conditions. These highly different flow directions date from different phases of the same glaciation rather than from different glaciations separated by an interglacial weathering interval, for the following reasons. First, the crossed striations are equally fresh. Second, striations indicating highly divergent directions of flow occur on either the same boulder or nearby boulders, all of which have weathered entirely or mostly out of the poorly consolidated Eocene bedrock since the last glaciation. The striations are not likely to date from two separate glaciations, for weathering during the intervening interglaciation would have loosened the boulders from the bedrock, and scour during the later glaciation would have removed them.

The Deckard Flats ice level on the north side of the Washburn Range reached 8,600-8,700 feet; locally higher ice probably flowed north from Washburn Range cirques to join the incursion of ice from the Absaroka Range. The Deckard Flats advance carried many large Precambrian rocks south from the northern Absaroka Range into the midsection but not upper reaches of Antelope, Carnelian, and Tower Creeks. Erratics of Precambrian rocks were found to an altitude of 8,500 feet and one limestone erratic was found at an altitude of 8,700 feet on the spur north of Mount Washburn. On the same spur, weakly developed striations suggest flow to the southwest at a time later than formation of the well-developed, higher-level striations. Below 7,600 feet in the Antelope Creek drainage, Precambrian crystalline boulders more than 3 feet in diameter are locally so common that several can be seen at a site. Along the ridges above these creeks, erratics of Precambrian rocks are rather common up to altitudes as high as about 8,400 feet. (Three of the Precambrian erratic localities northeast of Mount Washburn were located by G. M. Richmond (written commun., 1972).) These erratics are about 200 feet below the upper limit of the Deckard Flats incursion from the north.

Several miles east of the Mount Washburn summit, Howard (1937, table 10) noted "granite" erratics to an altitude of 8,300 feet and rhyolite boulders to 8,500 feet. Richmond (written commun., 1972) noted two erratics at an elevation of about 8,600 feet. My observations indicate that erratics of Precambrian rocks are common to an altitude of about 8,000 feet, and are rare above that altitude to an upper limit of about 8,600 feet. From an altitude of 8,600 feet to the summit of Mount Washburn 1,600 feet higher, glacial scour features on bedrock indicate that the last flow of ice was to the north. It appears clear that the erratics below an altitude of about 8,000 feet were brought in from the north by the Deckard Flats advance. For the erratics near 8,600 feet, I suggest three possible explanations. First, they may have been emplaced at the southern limit of the Deckard Flats incursion, whose approximate boundary is at the level of the highest erratics. Second, they may have been deposited by an incursion similar to the Deckard Flats, but prior to the Pinedale maximum. Third, they may have been reworked from pre-Pinedale, Precambrian-boulder-bearing deposits located south of the Washburn Range and emplaced, along with the erratic of hydrothermally silicified sediment (Hs) found several hundred feet higher, during full-glacial time by north-flowing Pinedale ice.

Precambrian erratics are absent or extremely scarce in a belt that extends west between the east boundary of the map south of Amethyst Mountain and the Washburn Range: no advance from the northern Absaroka Range appears to have extended into or beyond this belt during or after the Pinedale maximum, including the Deckard Flats readjustment.

On the south side of the Washburn Range, the Deckard Flats ice margin is represented by local till embankments and inwash kame fan gravels (pkf) with ice-contact frontal scarps at altitudes of 8,600 to 8,300 feet.

After the Deckard Flats readjustment, the Pinedale glaciers again receded. On the upland between Tower and Antelope Creeks, numerous small north-sloping morainal ridges hear Precambrian erratics; they were deposited by glaciers draining north, back out of valleys of Carnelian and Tower Creeks, following the Deckard Flats movement south into these valleys. Valley glaciers also flowing north out of the cirques of the Washburn Range and Specimen Ridge left discontinuous morainal ridges. These moraines generally form only partial loops and they contain Precambrian rocks pushed up these valleys by Deckard Flats ice and then moved back downvalley by local flow.

Along the Yellowstone River valley between the west boundary of the map and Tower Junction, kame gravels (pkg) and deep ice-margin channels cut in bedrock attest to the successive eastward positions of the ice margin and the Yellowstone River outflow. The best known of these channels is The Cut traversed by the old Mammoth-Tower Junction road. Extensive kame sands (pks) were deposited along Shallow Creek by waters retained against the slope by stagnant ice.

Glacial lake silts that extend 4 miles up the Yellowstone River canyon from the upper part of the Alden paleovalley fill (strati-graphic section 10) demonstrate that a lake, Retreat Lake of Howard (1937, p. 134), was dammed by a glacier blocking The Narrows area. It probably took hundreds of years to fill this lake with silt (pkl) which is locally as much as 400 feet thick and reaches an elevation of almost 6,800 feet. The Yellowstone River, after flowing through Retreat Lake, drained northwest along an ice margin near the 6,800-foot contour and into a deep ice-margin channel now occupied by Lost Lake. After the ice wasted from the hill north of Lost Lake, the melt water occupied a channel just southeast of Roosevelt Lodge, where thick ice-contact deposits occur. Following further recession, the Yellowstone River flowed in an ice-margin channel just east of Bumpus Butte. As the river occupied these successively lower channels, it progressively trenched the sediments of Retreat Lake and left a veneer of gravel (pg) on the lake sediments (pkl). The flood deposits below The Narrows are too low and too far northeast to have resulted from draining of Retreat Lake.

LATE PINED ALE(?) MORAINES NEAR JUNCTION BUTTE

Hummocky end moraines in the Lamar River valley just upstream from Junction Butte appear to represent a significant pause in the general recession of the ice, here called the Junction Butte ice margin (JB). The moraines are studded with large boulders of Precambrian rocks, many more than 10 feet across. They were deposited by a glacier flowing in large part from the Slough Creek drainage. The moraines at Junction Butte appear to represent a standstill rather than an advance, for bouldery moraines that extend for a mile or so downvalley without a well-defined outer limit are similar to those marking the standstill. The boundary of the Junction Butte ice margin could not be mapped outside the end moraine area, apparently because of steep valley walls and the probable subdued character of the standstill.

The moraines marking Junction Butte ice margin (JB) and perhaps also those for a mile farther downvalley are thought to be of late Pinedale age, inasmuch as no large end moraines were noted upvalley towards the cirques of the Lamar River or Slough Creek, whereas elsewhere in Yellowstone late Pinedale end moraines are commonly found 1-5 miles downvalley from cirques. Because the moraines at Junction Butte do not appear to represent a major advance, I conclude that the northern Absaroka Range was able to maintain an icecap between middle and late Pinedale time.
Abundant erratic boulders of Precambrian rocks probably from the Slough Creek drainage occur in moraines southeast from the Lamar Canyon to as far as Amethyst Creek. They indicate that glaciers spilled over the divide from Slough Creek and backfilled the Lamar River valley after flow down the Lamar either diminished or ceased.

During recession following deposition of the moraines near Junction Butte, a lake was dammed in the valley of the Lamar by the Slough Creek glacier. Lake sediments deposited in this lake were described by Howard (1937, p. 145) beneath "terrace gravels"; some exposures of these lake sediments are large enough to be shown on the map (pkl, see also stratigraphic section 2).

Small glaciers may have existed in the north-facing cirques of the Washburn Range and Specimen Ridge during late Pinedale time. Several morainal heaps were found in many of these valleys, but none noted formed a good horseshoe shape. Late Pinedale glaciers, if present, were probably no longer than 2 miles and may have come out on stagnant ice in the main valleys, thus accounting for their extremely poor delineation by moraine crests.

PINEDALE FLOODS
Floodwaters more than 100 feet deep rushed down the Lamar-Yellowstone drainage, apparently upon release of the late Pinedale(?) lake (described above) as dammed by the Slough Creek glacier. Large longitudinal bars occur up to 100 feet above the present drainage. They consist mostly of boulder gravel (pfd) with some boulders larger than 10 feet across. At bedrock constrictions of the valley, floodwaters were hydraulically dammed, resulting in deposition of flood deposits (pfd) in areas upstream from these constrictions and, in the constrictions, erosion of talus blocks and till.
A smaller and younger flood about 50 feet deep rushed down the Yellowstone below The Narrows, as indicated by bouldery gravel (pfd) forming large longitudinal bars that extend from river level up for 50 feet. Near the confluence of the Yellowstone and Lamar, flood deposits along the Lamar are transected by younger flood deposits along the Yellowstone which are rich in boulders of percussion-spalled basalt from The Narrows area.

PINEDALE ALLUVIATION AND COLLUVIATION
As glaciers melted in the valleys, saturated bedrock and surficial debris from the valley walls slumped against stagnant ice, forming kame landslide deposits (pkls).

During middle Pinedale deglaciation and in late Pinedale time, frost action and solifluction were favored by freshly undercut slopes and probably by a moister and colder climate. Glaciated slopes of rhyolite tuff along the Yellowstone River, and along Deep, Broad, and Tower Creeks were frost riven to produce Pinedale talus (pta, ptat). Solifluction occurs in fine-matrixed deposits when the ground thaws from the surface down, forming a soupy slurry of rocks and mud that flows on even gentle slopes. Solifluction was probably common throughout the map area during middle Pinedale deglaciation and during late Pinedale time in areas mapped as Pinedale Till (pt) and rubble veneer (pr).

Pinedale gravels (pg, pfg) are not common in the area, probably because it was covered by ice during most of Pinedale time. Outwash gravel (pg) occurs along Hellroaring Creek, and fan gravel (pfg,) occurs locally below cliffy slopes.

HOLOCENE COLLUVIATION AND ALLUVIATION
Frost activity and solifluction continued with diminished intensity into Holocene time, forming talus (ta), talus flows (tf), and frost rubble (rb). In most areas of Pinedale frost deposits (pta, pst), as well as in areas of till and glacial rubble, Holocene movement has occurred locally. Landslides (ls) have continued to move downslope, especially during wet times. Stream gravels were transported and deposited along the larger streams, and gravels and mudflows accumulated on fans below eroding slopes.

HYDROTHERMAL ACTIVITY AND QUATERNARY FAULTS
Travertine is accumulating near Roosevelt Lodge and Calcite Springs. The travertine or travertine-cemented deposits beneath the till at sections 4 and 6 occur in a stratigraphic section about 1.6-m.y.-old. Hydrothermal alteration, including acid leaching, occurs near Sevenmile Hole and Tower Fall and has probably been going on for hundreds of thousands of years.

None of the Quaternary faults in the area were observed to clearly offset surficial deposits, but they do offset Quaternary rhyolite and basalt (U.S. Geological Survey, 1972) and most are usually well expressed by the topography.

Text from source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle

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References from source map: Tower Junction 15' Quadrangle and part of the Mount Wallace 15' Quadrangle

Two Ocean Pass 15' Quadrangle

The formal citation for this source.

Richmond, Gerald M., and Pierce, Kenneth L., 1971, Surficial Geologic Map of the Two Ocean Pass Quadrangle, Yellowstone National Park and adjoining area, Wyoming: U.S. Geological Survey, Miscellaneous Investigations Series Map I-635, scale 1:62,500 (*GRI Source Map ID 1145*).

Description of geologic units, prominent graphics and text associated with this source.

Description of Units

gt - Till (Quaternary, Neoglaciation)
tt - Till (Quaternary, Neoglaciation)

Gray to buff stony silty sand: unsorted; fragments more angular than in older tills. Forms small fresh arcuate moraines, commonly two sets, in cirques in southeast corner of quadrangle and in two cirques tributary to Mountain Creek from the south. Two deposits mapped in cirque west of Trident VABM represent veneers of debris outlining former extent of ice. Moraines of Temple Lake Stade are very slightly weathered, grass covered, and locally forested. Moraines of Gannett Peak Stade are fresh and bear little or no vegetation.

fa - Fine-grained humic alluvium (Quaternary, Neoglaciation)

Silt, sand, and clay deposited in poorly drained upland depressions and marshes along streams. Flood plain along Yellowstone River includes extensive over-bank flood deposits of sandy mud, characterized by seasonal wetness and lush grass. Humic content results from burial of vegetation at times of deposition which occurs annually in many places.

sg - Stream gravel (Quaternary, Neoglaciation)

Pebbles, cobbles, and boulders in coarse sand matrix: forms present streambed and terraces along Yellowstone River and other large streams. Includes minor sand and finer grained beds. Well-sorted, well-bedded; well-rounded clasts, generally smaller than 3 inches.

fg - Fan gravel (Quaternary, Neoglaciation)

Alluvial fans consisting predominantly of bouldery gravel beds, but containing sand and mud beds, especially toward the distal edges. Near heads of fans, bouldery with clasts larger than 1 foot.

ta - Talus deposit (Quaternary, Neoglaciation)

Rounded to angular rubble with silty interstitial matrix at depth; accumulates on steep slopes below cliffs; best developed below resistant bedrock units (basalt in Two Ocean Pass area and resistant conglomerate in Trident area). Mostly restricted to higher elevations below cirque headwalls or north-facing cliffs. Thickness 5 to 50 feet. Much of material consists of rounded boulders released by weathering of mudflow and conglomerate bedrock units. Most deposits not vegetated except for lichen cover; many actively accumulating at present.

fr - Frost rubble (Quaternary, Neoglaciation)
ad - Avalanche debris (Quaternary, Neoglaciation)

Rubble in a muddy matrix on slopes at foot of avalanche chutes below cirque headwalls and cliffs of mudflow bedrock. Material poorly sorted to nonsorted: little evidence of increased rounding, though containing rounded clasts from mudflow source rock. Deposits fan shaped. Includes debris transported by floods, mudflow, slushflow, and snow avalanches. Locally gradational downslope into fan gravel (fg).

sd - Solifluction deposit (Quaternary, Neoglaciation)
ls - Landslide deposit (Quaternary, Neoglaciation)

Lobate masses of rubble in a muddy matrix that have flowed downslope. Only three relatively small slides mapped, including one north of Pacific Creek that appears to have been an earth flow or mudflow.

ptu - Till (Holocene and/or Pleistocene)

Gray-brown to gray stony sandy silt, unsorted; loose, locally bouldery. Deposits lie downslope from cliffed cirque headwalls mostly oriented north or northeast. Outer limits commonly marked by one or more end moraines 10 to 20 feet high and 0.5 to 3.5 miles from the cirque headwalls.

pgu - Upper outwash gravel (Holocene and/or Pleistocene)

Gray sandy gravel, cobbles, and boulders forming local narrow outwash plains associated with end moraines of upper till (ptu). Mapped only along Howell Creek, where it caps a terrace about 60 feet above the stream and overlies lake deposits (not mapped) of Pinedale and Bull Lake age.

pg - Gravel, outwash and stream gravel (Holocene and/or Pleistocene)
pfg - Gravel, fan gravel (Holocene and/or Pleistocene)

Gray sandy pebbles, cobbles, and boulders. Deposits form terraces (pg) 10 to 40 feet above Yellowstone River and Atlantic Creek. In Bridger Lake area deposits form a large pitted outwash plain that encloses low hills of kame sandy gravel (pksg) , but whose distal end is buried by Neoglacial alluvial deposits of the Yellowstone River. Alluvial fans (pfg) lie along the valley floors of Mountain, Atlantic, and Jay Creeks at the mouths of tributary streams, which have dissected them from 10 to 40 feet.

pta - Talus deposit (Holocene and/or Pleistocene)

Similar to Neoglacial talus, but inactive and commonly grass-covered or forested. Occurs laterally from Neoglacial talus below cirque cliffs and extends to lower altitudes at foot of cliffs bordering Two Ocean Plateau, Trident, and the plateau in southeast part of quadrangle.

prb - Block rubble (Holocene and/or Pleistocene)

Angular blocks of frost-fractured basalt forming small block fields on ridge south of Pacific Creek in southwest part of quadrangle. Blocks are 6 inches to 2 feet in diameter. Interstices void to depths of 2 to 3 feet.

pkl - Ice-dammed lake sediments (Holocene and/or Pleistocene)

Gray laminated silt deposit banked against divide at head of Falcon Creek, and ice-contact gray laminated lacustrine silt and silty sand in stratigraphic sections 4, 5, and 6.
Two Ocean Pass Stratigraphic Sections

pkls - Kame deposits, kame landslide deposit (Holocene and/or Pleistocene)
pkg - Kame deposits, gravel (Holocene and/or Pleistocene)
pksg - Kame deposits, sandy gravel (Holocene and/or Pleistocene)
pkgs - Kame deposits, gravelly sand (Holocene and/or Pleistocene)

(kame sand in stratigraphic section 6 only) Gray poorly sorted crudely coarse sand and gravel (pebbles to boulders) underlying irregular kame terraces having ice-contact frontal scarps. Mapped deposits mantled in many places by till-like material mass-wasted from higher slopes or from ice (flow-till). The deposits form a succession of terraces along the valley of the Yellowstone River, where the highest lie at about 8,400 feet altitude, and extend up tributaries to both west and east. In Two Ocean Pass they occur at 7,900 to 8,100 feet, but extend up to 8,400 feet along Jay Creek. Near Bridger Lake, the deposits form kames 40 to 60 feet high in a Pinedale recessional outwash gravel plain (pg).

Two Ocean Pass Stratigraphic Sections

pt - Till and glacial rubble, till (Holocene and/or Pleistocene)

Gray-brown to gray stony sandy silt; unsorted, loose to compact; stones round to angular. Deposit (plt) at stratigraphic section 2, mainly dark silt with scattered striated stones, appears to have been deposited in a lake. Stones in the till (pt) derived mainly from mudflow breccia, but some are porphyry erratics from areas to east and south. The till mantles valley slopes and uplands; is thickest (15-20 ft) on lower slopes. Its slopes are smooth to hummocky, ice molded, or drumloidal. Discontinuous moraines occur locally; those in the vicinity of the mouths of Thorofare Creek and Escarpment Creek may mark a recessional stand of the ice near Bridger Lake.

Two Ocean Pass Stratigraphic Sections

pr - Till and glacial rubble, glacial rubble (Holocene and/or Pleistocene)

Thin (0-5 ft) veneer of sand, gravel, cobbles, and boulders in silty matrix on glaciated uplands. Mostly derived from local mudflow or conglomerate bedrock, but in places contains a few erratics of light-gray basalt. Some material glacial in origin: some weathered from bedrock. Some locally reworked into solifluction terraces, garlands, nets, and sorted features; in places seasonally active. Underlying bedrock locally grooved or striated; a few elongate tarns, some roches moutonnées.

bl - Lake sediments (Pleistocene)

Blue-gray, weathering pinkish brown, lacustrine clay-silt; massive, thinly laminated, varved, or megavarved. Sandy in places (bsl in stratigraphic sections 2 and 3); local 3-inch-thick volcanic-ash layer in section 2 about 40 feet below top. Maximum exposed thickness 120 feet. Underlies proglacial gravel, till, and kame gravel of Pinedale age along valley of Yellowstone River; well exposed along west side of river near confluence of Mountain Creek. Includes beds of sand and gravel in stratigraphic section 4 on Mountain Creek near confluence of Howell Creek.

Two Ocean Pass Stratigraphic Sections

br - Glacial rubble (Pleistocene)
bfr - Frost rubble (Pleistocene)

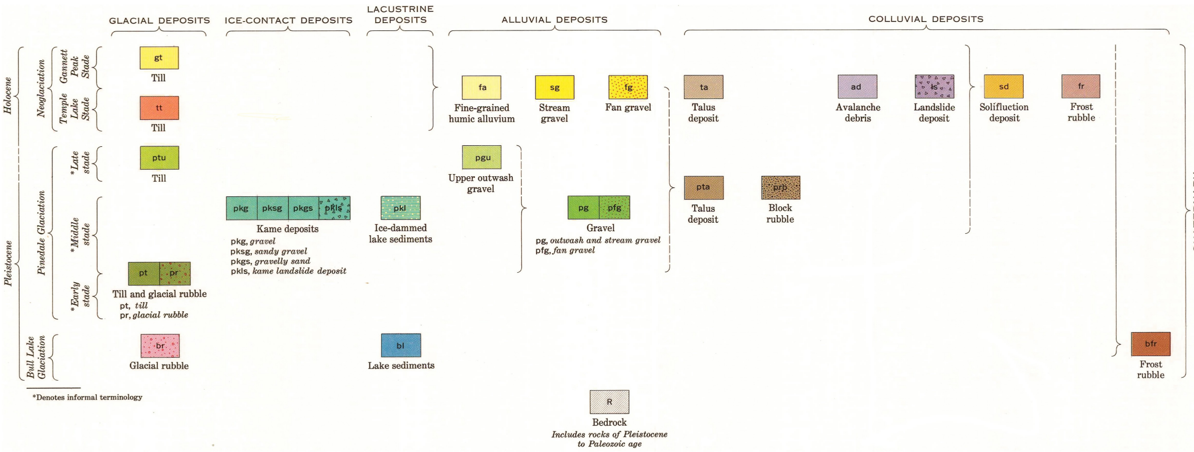
Coarse angular frost-riven rubble 2 to 15 feet thick. Developed on basalt above upper limit of glaciation in Bull Lake time. Probably active in both Bull Lake and Pinedale times.

R - Bedrock (Pleistocene to Paleozoic)

According to mapping by H. W. Smedes and H. J. Prostka (written commun., 1968), the nearly flat-lying bedrock can be separated into five gross units: Paleozoic carbonate and other rocks in the extreme southwest corner of the quadrangle; basal basalt flows overlying the Paleozoic rocks; lower Tertiary vent breccia and agglomerate exposed on the lowest slopes of the Trident; lower Tertiary dark conglomerate that forms the lowest cliffs on the Trident; and lower Tertiary laharic mudflow breccias which underlie about 90 percent of the area of the quadrangle. The laharic breccias consist of basaltic to andesitic roundstones suspended in a silty matrix. Upon weathering (mainly mechanical), the matrix disaggregates, forming a sandy silty mud and releasing the larger clasts. Near the top of the Trident, several basalt flows and flow breccias are interbedded with the upper part of the laharic breccia unit. A dense medium-gray olivine-bearing basalt locally caps the section on the Two Ocean Plateau.

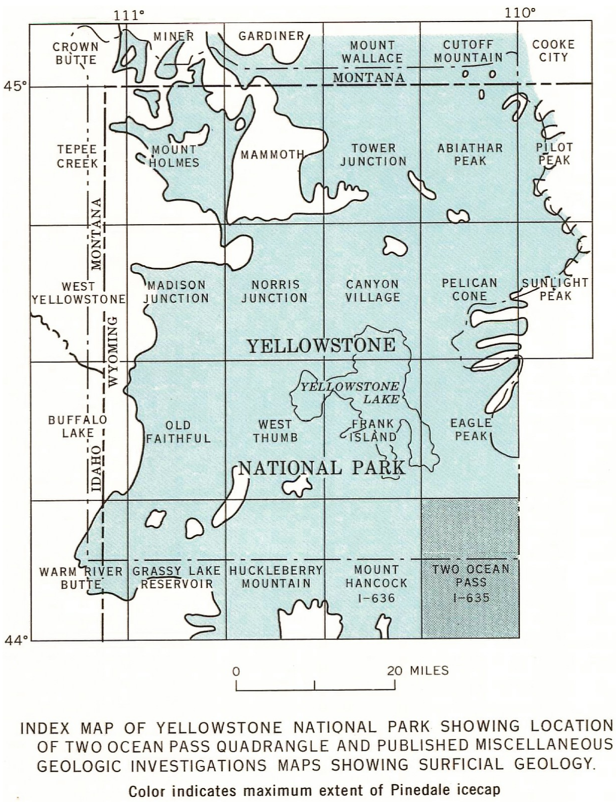
Text from source map: Two Ocean Pass 15' Quadrangle

Correlation of Units



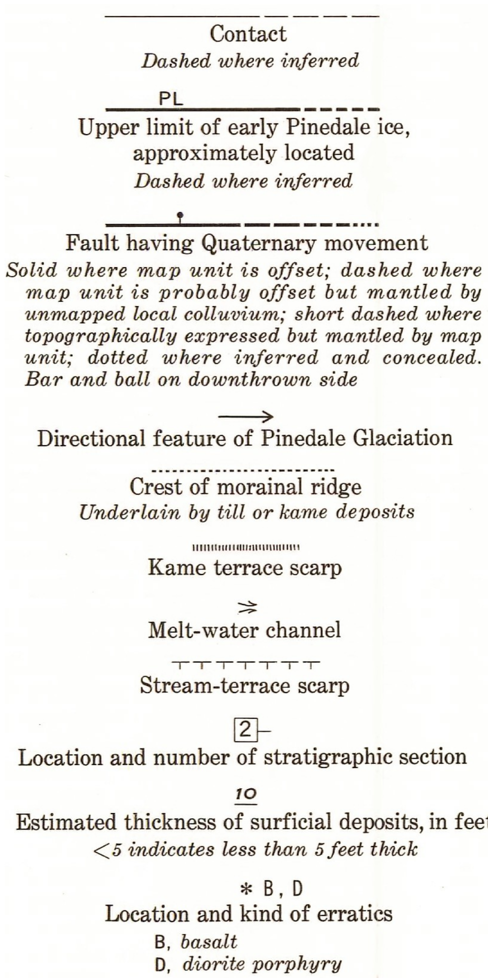
Graphic from source map: Two Ocean Pass 15' Quadrangle

Index Map



Graphic from source map: Two Ocean Pass 15' Quadrangle

Map Legend



Graphic from source map: Two Ocean Pass 15' Quadrangle

Stratigraphic Sections

Units shown in descending order; numbers represent thickness, in feet.

Stratigraphic section locations are presented in the GRI Geologic Observation Localities (yellgol) feature class. In that feature class, the section identifier is stored in the Location ID (LOC_ID) field. The section information presented here is also contained in the Geologic Observation Localities (yellgol) feature class Notes (NOTES) field.

See Description of Units for information about map units listed here.

1. 20 pkgs/20 pt/20 ppg/60 bl
2. 10 plt/10 ppg/20 bsl/30 bl/0.3 va[1] /60 bl
3. 20 pkg/50 bl/20 bsl/15 bt
4. 10 st[2]/30 pgu/10 pkl/30 pkgs/30 bl
5. 50 pkgs/10 pkl/10 pt

6. 20 pkl/6 pks/0.5 pt(?)/8 ppg(?)/13 pkl/30 pt

[1] Volcanic ash of Bull Lake age
[2] Brown silt of late Pinedale or younger age

Text from source map: Two Ocean Pass 15' Quadrangle

Surficial Geologic History

INTRODUCTION

The Two Ocean Pass 15' Quadrangle occupies the southeast corner of Yellowstone National Park and an area to the south in the Teton National Forest. The terrain is a high rolling upland—including the Two Ocean Plateau, the Trident, and the plateau in the southeast part of the quadrangle—that is dissected by the broad deep valleys of the Yellowstone River and its tributaries. The general altitude of the plateau rises from 9,500 feet in the west to as much as 10,800 feet in the east. The valley of the Yellowstone River is a steep-sided trench about 2,000 feet deep and 1 to 3 miles wide. In the southwest part of the quadrangle is Two Ocean Pass, a flat marshy saddle on the Continental Divide, from which Atlantic Creek drains east to the Yellowstone and Missouri Rivers, and Pacific Creek west to the Snake and Columbia Rivers.

PLEISTOCENE GLACIATIONS

Great icecaps covered most of Yellowstone Park during at least three Pleistocene glaciations (from oldest to youngest: pre-Bull Lake, Bull Lake, and Pinedale). During each, the invasion of ice into the basin of Yellowstone Lake (north of this quadrangle) was apparently down the valleys of Yellowstone River, Thorofare Creek, and Mountain Creek, from sources high in the Absaroka Mountains to the southeast. Upon entering Yellowstone Lake, the ice formed a center for snow accumulation which developed gradually into a self-perpetuating mass that ultimately built up over the surrounding uplands to altitudes higher than 10,500 feet. No deposits or erosional features of the pre-Bull Lake icecap have been found in the quadrangle.

BULL LAKE GLACIATION

A thick sequence of lake beds of Bull Lake and subsequent interglacial age is exposed in stratigraphic sections 1, 2, and 3. A thin bed of volcanic ash is exposed in the upper part of section 2. In section 3, compact stony clayey till (not mapped) of inferred Bull Lake age underlies the mapped lake sediments (bl). Southeast and west of Two Ocean Pass, a veneer of glacial rubble (br) thinly mantles locally striated bedrock above the upper limit of Pinedale Glaciation. Two nunataks on which frost rubble of Bull Lake age (bfr) is developed occur in the southeast corner of the quadrangle at 10,600 feet altitude.

PINEDALE GLACIATION

The Pinedale icecap covered nearly all the quadrangle, leaving a thin veneer of rubble (pr) on the uplands and stony silty till (pt) of variable thickness on the valley slopes. Upland areas now covered by frost rubble (fr and bfr) northeast of Jay Creek projected as nunataks above the ice. It is possible that the summit area of the Trident is a nunatak and that the till (pt) mapped on the Trident above 10,500 feet may be residual debris weathered from a bedrock mudflow. Ice-scour lineaments indicate that the Pinedale icecap flowed southwestward across the Two Ocean Plateau.

Evidence of an episode of recession of the icecaps from an early Pinedale maximum and of readvance in middle Pinedale time has been observed in other parts of the Park, but no positive evidence for these events was noted in this quadrangle.

Stagnation of the middle Pinedale icecap.—At the end of middle Pinedale time, waning of the cap gradually exposed the uplands of the high plateaus. For a short time, the glacial melt waters probably flowed from the ice in Yellowstone Valley through the high passes leading west across the Two Ocean Plateau. That these waters flowed over stagnant ice in the passes is suggested by the presence in them of large undissected kettles, dead-ice depressions, and small moraines arcuate to the west. Although no erosion was accomplished in the passes, melt waters appear to be responsible for the deep channels cut into bedrock on the western slope along Chipmunk Creek, Plateau Creek, Snake River, Burnt Creek, and Pacific Creek.

The passes probably were abandoned by the melt waters in the order of their altitude: head of Phlox Creek (9,540 ft), head of Lynx Creek (9,280 ft), Phelps Pass (8,840 ft), head of Badger Creek (8,780 ft), and Two Ocean Pass (8,270 ft). Recession of the ice east of Phelps Pass is marked by deposits of ice-dammed lake silt just below the summit at the head of Falcon Creek. Two Ocean Pass is the lowest pass across the divide enclosing Yellowstone Lake south of Outlet Creek (Frank Island 15' Quadrangle). Melt waters appear to have flowed west on ice through Two Ocean Pass throughout its history as a drainage outlet, for small kames and kame terrace deposits (pkg) bordering the floor of the pass indicate stagnant ice in the pass just prior to its abandonment by the melt waters.

As the passes across Two Ocean Plateau were abandoned, the melt water flowed north along the margins of stagnant ice in the valley of the Yellowstone River and constructed extensive ice marginal kame terrace deposits (pkgs, pksg) . The highest deposits are in the heads of valleys in the east side of Two Ocean Plateau at altitudes between 8,400 and 8,500 feet. Along the Yellowstone River, the highest kame terraces are at an altitude of about 8,400 feet. Extensions of these terraces also occur along Thorofare Creek and Mountain Creek. A series of successively lower kame terraces, in places as many as eight, descend in steps from the highest terrace to the valley floors. The kame terrace deposits rest on Pinedale Till and proglacial Pinedale outwash gravel, which in turn locally overlie more than 80 feet of varved silts (bl) deposited in a glacial lake during recession of the Bull Lake icecap.

Associated with the Pinedale kame terrace deposits are several large ice-contact landslides (pkls). These appear to be the result of oversteepening of the valley walls by glaciation and possible normal faulting, followed by collapse as the ice wasted downward. They slumped and flowed out against and over stagnant ice in the valley of the Yellowstone River. The largest of the landslides borders the narrows of the Yellowstone River 5 to 6 miles south of Hawks Rest Patrol Cabin in the Teton National Forest. The material in its lower part is in places intimately associated with kame gravel, and many depressions in the lower parts of the slide appear to represent collapse features following melting of buried stagnant ice.

An extensive pitted outwash plain (pg) and associated kame mounds (pksg) near Bridger Lake and in the valley of Thorofare Creek suggest a recessional stand of the ice in this area; lateral moraines rise upstream from these deposits along both sides of the valley of Thorofare Creek where they merge with kame terrace deposits (pkgs). However, this stand may be merely a matter of topographic control of the wasting ice rather than renewed growth, for the ice would have been sheltered from the sun by a high interfluve known as Hawks Rest, and the deposits have no known counterparts along the Yellowstone River or Mountain Creek.

Pinedale frost riving and solifluction.—During wasting of the Pinedale icecap, frost riving of freshly exposed cliffs induced formation of extensive talus (pta) below cliffs. In many places the deposits are mixed with glacial debris washed or slumped from the steep slopes. In a few places block fields formed on basalt bedrock. The frost riving appears to have continued until after recession of the late Pinedale glacial advance. Today these deposits are stable and forested or grass covered.

Late Pinedale advance.—An advance of valley glaciers in late Pinedale time cut fresh cirque headwalls in the north- and east-facing escarpments of the Two Ocean and other plateaus, previously smoothed and rounded by the Pinedale icecap. End moraines of till (ptu) of late Pinedale age in the valleys below show that the glaciers were I to 4 miles long. The moraines locally overlie kame terraces (pkgs, pksg) of middle Pinedale age, especially along Mountain Creek.

NEOGLACIATION
After recession of the late Pinedale valley glaciers, cirques were empty and slopes throughout the quadrangle were relatively stable during the altithermal interval. Subsequently, during the Neoglaciation, small ice masses, less than half a mile long, formed again in the cirques on the north side of the Trident, and high on the east-facing cliffs overlooking the valley of the Yellowstone River in the southeast corner of the quadrangle. The moraines of these small glaciers commonly occur in two sets, indicating at least two advances of the ice. Temple Lake Till (tt) forms stable moraines at least partly covered by vegetation. Gannett Peak Till (gt) is less extensive and characterized by fresh blocky moraines bearing little or no vegetation. The ice did not extend beyond the cirque lips during either stade and in some instances it was restricted to the headwalls. Although no glaciers now exist in the quadrangle, two occur east of the Absaroka Mountain crest in the Eagle Peak 15' Quadrangle to the north. Neoglacial time thus extends to the present.

NEOGLACIAL FROST RIVING AND SOLIFLUCTION
Frost-riving and solifluction activity have been much more restricted than in Pinedale time. Talus deposits (ta), commonly actively accumulating, are restricted to areas below headwalls of cirques formerly occupied by late Pinedale glaciers and to other steep and commonly east- or north-facing cliffed exposures. The deposits are gradational with cirque avalanche debris (ad), which commonly occurs below cliffs of mudflow breccia and is primarily the product of freeing of clasts from that rock. Avalanche debris is transported by avalanche processes, mudflow, and torrential floods rather than simply by gravity as in the case of talus. A number of spectacular cones of avalanche debris (ad) occur in the upper reach of the canyon of Jay Creek.

Solifluction deposits (sd) occur primarily in two settings. Some deposits are in the form of steep-fronted lobes and irregular blocky terraces encroaching over valley bottoms at altitudes between 8,000 and 9,000 feet. The solifluction has resulted from saturation of Pinedale Till along the valley slopes. Some deposits are seasonally active. A typical example occurs along Mink Creek west of Phelps Pass. Other solifluction deposits occur on the summit uplands of the plateaus as lobes and terraces formed in thin glacial rubble (pr) or in frost rubble (fr). These have moved primarily as a result of saturation of the mantle by snow melt water and their location is closely related to the distribution of snowbanks. Parts of such deposits were active until well into August of 1966 on the Trident, on summits at the head of Jay Creek, and locally on the higher parts of the Two Ocean Plateau.

NEOGLACIAL ALLUVIATION
The most obvious Neoglacial alluvial activity in the quadrangle has been the partial filling of the valleys of Yellowstone River, Thorofare Creek, and Mountain Creek. Each year, during snow melt, these streams, in flood, carry and redeposit enormous quantities of bouldery gravel (sg). Some flood bars are as much as 15 feet high. The Yellowstone River has been forced to the west side of its valley by the great influx of gravel carried by Mountain and Thorofare Creeks. The present channels of these streams are entrenched within the broad alluvial valley floors, underlain to unknown depths by gravel but covered by 5 to 15 feet of fine-grained humic silt (fa). Few postglacial terraces are present along the lower part of Thorofare Creek or in the Yellowstone Valley, indicating that filling is continuing into the present. The fan of Pinedale outwash (pg) near Bridger Lake is being buried by continued alluviation (fa, sg) in the Yellowstone Valley. Young gravelly alluvial fans (fg) lie along the sides of the valleys at the mouths of tributary streams, and terraced gravel deposits (sg), marking former Neoglacial levels of the valley floor, occur along Mountain Creek. Near the periphery of the fan at the mouth of Escarpment Creek, considerable modern deposition is indicated by 10 feet of sand, gravel, and mud burying a mat of vegetable material 440 ±250 years old (sample W2010, Meyer Rubin, written commun. 1969). Most gravel deposits along smaller streams heading in the plateaus are too small to be shown on the map. Fine-grained humic alluvium (fa) covers the floors of many upland valleys, such as Two Ocean Pass, but is commonly underlain by gravel at shallow depths. Humic or peaty alluvium (fa) and peat deposits also fill bedrock

depressions, kettles, and dead-ice depressions in the till on the uplands.

QUATERNARY NORMAL FAULTS

Normal faults parallel to the valley of Yellowstone River cut Quaternary sediments along both sides of the valley. On the west side, a series of echelon faults, downthrown to the east, extend north and south from Lynx Creek. They cut Pinedale kame deposits (pksg, pkgs, pkg) and Neoglacial alluvium (sg and fa). Maximum observed displacements are about 15 feet on individual faults. On the east side of the valley, echelon normal faults, mostly downthrown to the west, extend along the west base of the Trident, across Thorofare Creek, and traverse the ridge east of the summit of Hawks Rest. They cut till (pt) of late Pinedale age, Pinedale kame deposits (pkgs, pksg), Pinedale outwash gravel (pg), and Neoglacial alluvium (sg, fg, and fa). None display more than 15 feet of displacement. A fault, on the floor of the valley north of Cliff Creek, shows minor downdropping to the east. It is likely that faults on both sides of the valley are more numerous than shown. The valley probably represents a graben, downdropped between the plateaus to east and west. The relative downward displacement of the valley floor since Pinedale time appears to have been on the order of a few tens of feet, but during Pleistocene time it may have been more than 1,000 feet.

Text from source map: Two Ocean Pass 15' Quadrangle

Warm River Butte 15' Quadrangle

The formal citation for this source.

Richmond, Gerald M., 1973, Surficial Geologic Map of the Warm River Butte Quadrangle, Yellowstone National Park and adjoining area, Idaho and Wyoming: U.S. Geological Survey, Miscellaneous Investigations Series Map I-645, scale 1:62,500 (*GRI Source Map ID 1151*).

Description of geologic units, prominent graphics and text associated with this source.

Description of Units

fa - Fine-grained humic alluvium (Holocene)

Dark-gray to gray-brown silt, sand, and clay, 3-10 feet thick; underlies swamps and flood plains. Also overlies Pinedale stream deposits (pg, psg) in abandoned glacial drainageways, and Pinedale Till (pt) in glacial depressions. Deposits marshy, especially in and south of Yellowstone National Park.

sg - Stream gravel (Holocene)

Buff to gray gravel and sandy gravel in coarse sand matrix; poorly sorted; 5-20 feet thick. Deposits mainly along Boundary Creek in Bechler Meadows area, where they contain much obsidian sand, and along flood plains of Robinson Creek and Falls River, where they contain many cobbles and boulders. Along Robinson Creek, gravel is mostly of rhyolite; along Falls River, of tuff, rhyolite and basalt with minor amounts of quartzite.

ta - Talus deposit (Holocene)

Angular to subangular rock fragments forming cone of blocky rubble at base of cliff. Most are along Robinson Creek and Falls River. Interstices void near surface, but filled with sandy debris at depth. Surface sparsely vegetated and unstable. Deposits accumulating very slowly at present.

pl - Lake sediments, silt (Holocene and/or Pleistocene)
psl - Lake sediments, sand (Holocene and/or Pleistocene)
plgs - Lake sediments, beach gravelly sand (Holocene and/or Pleistocene)

Widespread poorly exposed silt (pl) in Bechler Meadows and Squirrel Meadows, sand (psl) in northern part of Bechler Meadows, and beach deposits of gravelly sand (pigs) at northern edge of Bechler Meadows. Silt is blue gray, massive to thinly laminated, locally varved. Mostly covered by thin veneer of colluvial silt (not mapped). Sand is gray brown, medium to fine grained, weakly bedded; gradational southward into silt. Beach deposits are poorly sorted, subrounded gravel; form low terraces 10-20 feet above general level of sand and silt lake plain. Silt (pl) and sand (psl) deposits are mostly swampy; upper 2-3 feet contains organic silt and vegetal matter.

pg - Stream sand and gravel, gravel (Holocene and/or Pleistocene)
psg - Stream sand and gravel, sandy gravel (Holocene and/or Pleistocene)
ps - Stream sand and gravel, sand (Holocene and/or Pleistocene)
pcg - Stream sand and gravel, cobble gravel (Holocene and/or Pleistocene)
pfg - Stream sand and gravel, fan gravel (Holocene and/or Pleistocene)

Gray to buff, coarse-grained sand (ps), gravel with sandy matrix (pg), gravel with considerable sand (psg), and coarse cobble gravel (pcg). Irregularly bedded; poorly to well sorted. The cobble gravel (pcg) contains numerous boulders as much as 12 inches across. Within Yellowstone National Park, material is mostly of rhyolite; to south and southwest it contains abundant basalt. Deposits are 5-20 feet thick; most are glacial outwash. Those along Conant Creek are probably derived from older gravel of Bull Lake age. Within outer limit of Pinedale Till (pt), deposits floor basins left by receding or stagnant ice. They also form terraces 10-25 feet above major streams, and a few small alluvial fans at confluences of tributaries with major streams. Soil less than a foot thick.

pco - Colluvium (Holocene and/or Pleistocene)

Thin mantle of locally derived subangular to subrounded rock debris, locally mixed with loess, on uplands in northwest part of quadrangle beyond outer limit of glaciation. Deposits, locally as much as 30 feet thick, occur on slopes of canyons such as those of Snow Creek and Conant Creek. Clasts mostly of tuff or basalt depending on local bedrock source. Deposits, mostly of creep and solifluction origin, are now stable and bear a soil less than a foot thick. However, movement is locally being regenerated by timbering activity.

pta - Talus deposit (Holocene and/or Pleistocene)

Angular blocky rock fragments forming cone or sheet at base of cliff. Interstices locally void but commonly filled with sandy material or loess, on which a weak post-Pinedale soil about a foot thick is developed. Deposits occur along front of rhyolite flows in northeast part of quadrangle, along canyons of Snow Creek, Falls River, and Conant Creek, and below a few glaciated cliffs in upland areas. All are stable and vegetated at present.

plo - Loess (Holocene and/or Pleistocene)

Gray, buff-weathering, massive eolian silt which forms a widespread mantle over Bull Lake and older deposits and bedrock in west part of quadrangle. In southwest part, the deposits locally are 20-30 feet thick and form low rolling hills, but they are also locally so thin that the underlying till or bedrock projects through them. To the north, they locally overlie loess of Bull Lake age, not mapped, but exposed in stratigraphic section 7. Eastward, where they support a forest cover, the deposits thin to a mantle only a few feet to a few inches thick, overlying till of Sacagawea Ridge (st) or Bull Lake (bt) age (stratigraphic sections 1, 2, 3, and 4). The loess fills depressions in Bull Lake Till, beneath a thin layer of younger fine-grained alluvium (fa). However, the easternmost areas of Bull Lake Till bear no loess cover and none occurs on Pinedale Till (pt). The soil profile on the loess is less than a foot thick. In the west part of the quadrangle it is calcareous as is the fresh loess. Eastward, above an altitude of about 6,000 feet, the soil is leached of carbonate as is also the fresh loess.

Warm River Butte Stratigraphic Sections

pksl - Ice-dammed lake sand (Holocene and/or Pleistocene)

Buff to gray, medium- to coarse-grained sand; composed mostly of obsidian, rhyolite, and quartz; weak flat bedding. Underlies broad terrace about 30 feet above lake deposits (psi) north of Bechler Meadows and about 20 feet below gravelly sand (pkgs) kame terrace adjacent to west. Topographic setting and kettles on surface indicate nearby ice dam during deposition.

pkg - Kame deposits, gravel (Holocene and/or Pleistocene)
pksg - Kame deposits, sandy gravel (Holocene and/or Pleistocene)
pkgs - Kame deposits, gravelly sand (Holocene and/or Pleistocene)
peg - Kame deposits, esker gravel (Holocene and/or Pleistocene)

Buff to gray gravel (pkg), sandy gravel (pksg) containing many cobbles and boulders, and gravelly sand (pkgs). Deposits form irregular mounds and terraces with ice-contact slopes. The gravel (pkg) underlies two hills about 40-50 feet high along the west side of Bechler Meadows. The sandy gravel (pksg) underlies an extensive area, northwest of Lilypad Lake, that is characterized by irregular, steep-sloped mounds, ridges, and kettles having local relief of 40-70 feet. The gravelly sand (pkgs) underlies an extensive broad irregular terrace, 20-30 feet high, along the north and west margins of Bechler Meadows. Similar sandy deposits occur southeast of Robinson Lake. There are three eskers, each composed of sandy gravel (peg). One, about 20 feet high and one-fourth mile long, is north of the gravel hills (pkg) west of Bechler Meadows. A second, about 50 feet high and more than one-half mile long, lies in the area of kame sandy gravel south of Bechler Meadows. It terminates at the head of a broad gently sloping outwash plain of sandy gravel (psg). The third esker, along the southwest side of the out-wash plain, is 50-70 feet high, about 11/2 miles long, and as much as 1,000 feet wide. It represents a slightly older melt-water course than the esker at the head of the outwash plain. Soil on all deposits less than a foot thick.

pt - Till and rubble veneer, till (Holocene and/or Pleistocene)
pr - Till and rubble veneer, rubble veneer (Holocene and/or Pleistocene)

Gray-brown to gray, stony silty sandy till (pt); loose to compact; stones angular to subround. Deposits about 5 feet to more than 30 feet thick. Surface smooth to hummocky; kettles and undrained depressions common, particularly in Yellowstone National Park. Till-mantled lake basins south and west of park are mostly ice-scoured in basalt bedrock. Northwest of Bechler Meadows, clasts in till chiefly of rhyolite; mainly of rhyolite and basalt in southwest part of park and south of park. Soil consists of thin humic horizon overlying weakly to moderately oxidized horizon less than a foot thick. Rubble veneer (pr) is thin (0-5 ft) deposit of sand, gravel, cobbles, and boulders on rock uplands; material mostly of tuff and rhyolite. Deposits west of Robinson Creek are strewn over network of flood-scour channels and bedrock scabland knobs.

bkgs - Kame sandy gravel (Pleistocene)

Pebble to cobble gravel in yellowish-brown medium to coarse sand matrix; locally a few boulders. Deposits in north part of quadrangle, along Robinson Creek, are mostly of rhyolite and tuff; form fills 40-60 feet thick in mouths of tributaries and along east side of canyon; were constructed against stagnant ice in canyon. Similar, but smaller deposits lie to west along Fish Creek. Deposits along Sawmill Creek in west-central part of quadrangle are of tuff and basalt. Those along Coyote Creek, at and near its confluence with Conant Creek, are mostly of Paleocene quartzite pebbles with minor amounts of basalt, tuff, and Precambrian crystalline rocks. They are nearly 300 feet thick at the confluence of Coyote and Conant Creeks.

bt - Till and rubble veneer, till (Pleistocene)
br - Till and rubble veneer, rubble veneer (Pleistocene)

Till (bt) is a gray-brown to brown stony sandy silt containing numerous cobbles and boulders; stones subangular to well rounded. Some boulders 3-4 feet in diameter. Material mainly of tuff rhyolite, obsidian, and basalt. Between Robinson and Squirrel Creeks it contains a few erratics of quartzite, chert, limestone, and andesite and, south of Squirrel Creek, a few erratics of Precambrian crystalline rock. Deposits are mostly 5-15 feet thick and overlie an irregular bedrock surface. End moraines, 10-20 feet high, occur locally along western limits, for example along Reclamation Road. However, till commonly thins to terminus unmarked by an end moraine. Outwash channels, cut in bedrock and veneered with gravel, extend westward from the outer limit of the till in many places. The soil on the till consists of a yellowish-orange zone of oxidation and clay accumulation as much as 4 feet thick, with moderate coarse angular blocky structure (stratigraphic sections 1 and 4). However, the soil is partly or completely stripped in many places. On uplands in the northeast part of quadrangle, and on the north wall of Conant Creek in the southeast part, the local bedrock is covered by glacial rubble veneer (br), consisting of stones, including sparse striated stones and erratics, and finer debris.
Warm River Butte Stratigraphic Sections

bg - Stream gravel (Pleistocene)

Cobble and pebble gravel in sandy matrix, locally bouldery. Deposits underlie valley floor of Snow Creek in north-central part of quadrangle, and of Bear Creek in west-central part. Form terrace about 30 feet above Rock Creek, and local valley fills on nearby uplands. Along the western reaches of Falls River the gravel forms a bouldery outwash terrace, about 30 feet above the river, that extends downstream from the outer limit of Bull Lake Till; north of Conant Creek, it forms valley fills and low terraces at and just back of the outer limit of the till. The deposits are mostly 10-30 feet thick and, in many places, occur in drainages not reoccupied by subsequent Pinedale melt waters. Soil represented by oxidized horizon commonly 4-6 feet thick.

Rsl - Summit Lake rhyolite flow (Pleistocene)
Rbl - Buffalo Lake rhyolite flow (Pleistocene)

The northeastern part of the quadrangle is underlain by two rhyolite flows of the Plateau Rhyolite (Christiansen and Blank, 1972). The Summit Lake rhyolite flow (Rsl), K-Ar dated as about 127,000 years old, and the Buffalo Lake rhyolite flow (Rbl), K-Ar dated as about 156,000 years old. These rocks have been discussed and informally named by R. L. Christiansen and H. R. Blank (1972). Three fourths of a mile east of the site of the Boundary Creek Patrol Cabin in the northern part of Bechler Meadows, the Summit Lake flow (Rsl) overlies till of Sacagawea Ridge age at the mouth of an unnamed canyon just east of the quadrangle boundary in the adjacent Grassy Lake Reservoir 15' Quadrangle (Map 1-644). The Buffalo Lake flow (Rbl) forms the steep hills along the north boundary of the quadrangle in the headwaters of Robinson Creek.

sbg - Stream boulder gravel (Pleistocene)

Boulders, cobbles, and pebbles in yellowish-brown coarse sandy matrix; compact, poorly sorted, weakly stratified. Clasts are of basalt and tuff. Deposits cap the bench traversed by road along Snow Creek (sec. 31, T. 10 N., R. 45 E.), about 100 feet above the stream. Similar deposits also occur one-fourth mile upstream from road crossing of Fish Creek and south of road crossing of Robinson Creek, both just west of quadrangle. At the latter locality, the gravel rests on Sacagawea Ridge Till. Remnants of a reddish-brown clayey sandy soil, as much as 5 feet thick, are present locally on the gravel beneath a younger loess cover.

st - Till and rubble veneer, till (Pleistocene)
sr - Till and rubble veneer, rubble veneer (Pleistocene)

Yellowish-brown to gray-brown compact till (st) consisting of clayey silty sand with subangular to subrounded pebbles, cobbles, and boulders. Platy structure. Clasts mostly of tuff basalt, obsidian, and rhyolite, but in south part of quadrangle some are of Precambrian crystalline rock, Paleozoic sandstone and limestone, well-rounded Paleocene quartzite cobbles, and Eocene andesite and basalt. Deposits 5-30 feet thick; overlie an irregularly dissected terrain, including canyons such as Sawmill Creek and Conant Creek which were as much as 200 feet deep when till was deposited. Till and underlying bedrock are dissected as much as 50 feet by secondary streams and as much as 200 feet by major streams such as Snow Creek. Surface of till locally preserves a mature morainal topography. Locally it is covered by Pinedale colluvium (pco) (stratigraphic section 9). More commonly, it is covered by yellowish-gray Pinedale loess (plo) (stratigraphic sections 2, 3, and 8), thickest to west, absent locally to east, and commonly mixed with upper part of till on slopes. At stratigraphic section 10, weathered Sacagawea Ridge Till is overlain by brown Bull Lake loess and, at stratigraphic sections 1 and 11, by Bull Lake Till. Soil on till under Bull Lake loess is more than 5 feet thick, and red brown. It has a strong coarse subangular blocky structure and well-developed clay skins. Stones in the soil are mostly rotted; both rotted and fresh stones occur in the till beneath the soil. Stones of basalt and tuff are the most weathered. The rubble veneer (sr) consists of silty sand and rock fragments including a few erratics; overlies uplands adjacent to the till in north and south parts of the quadrangle. The material is less than 5 feet thick and commonly only a veneer over weathered bedrock. Some stones are rotted, others fresh. In southwest part of quadrangle, rubble veneer (sr), overlying basalt bedrock and containing striated stones and erratics, locally projects through the widespread Pinedale loess cover.
Warm River Butte Stratigraphic Sections

ct - Till (Pleistocene)

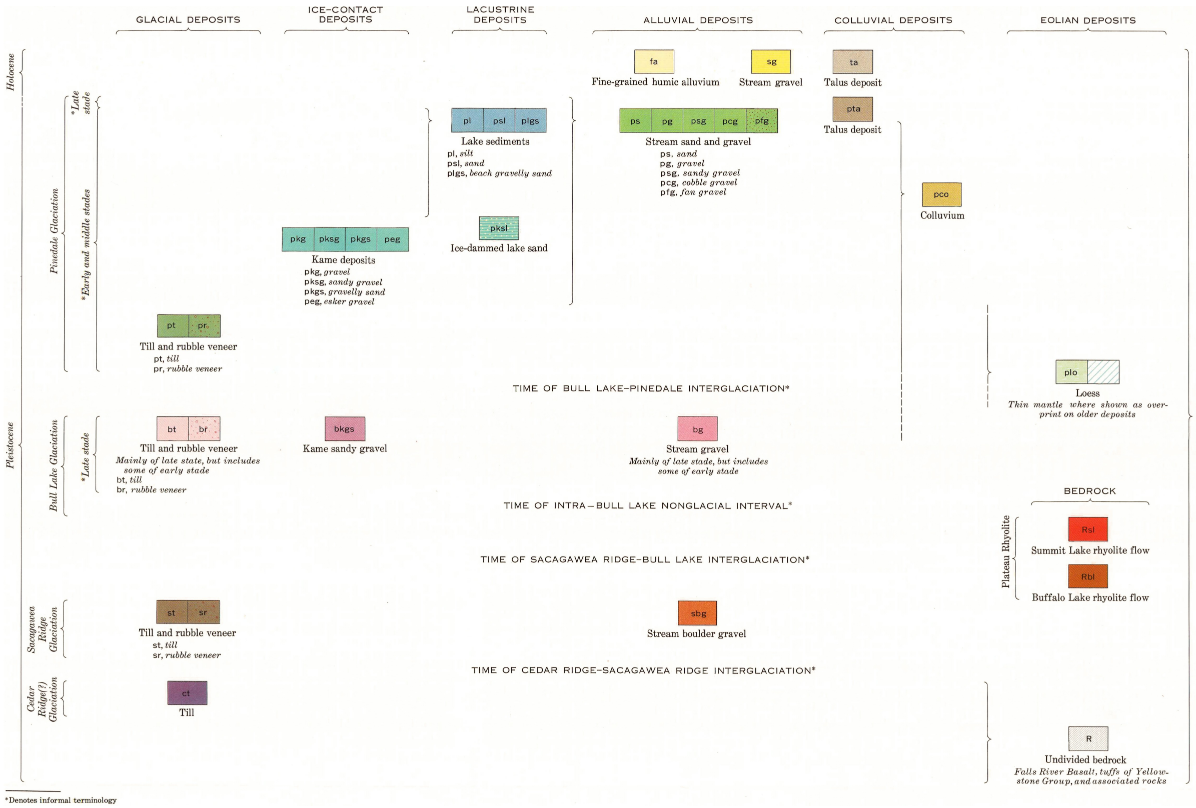
Dark-orange-brown tuffaceous clayey silty sand containing subangular pebbles and cobbles of basalt, tuff, rhyolite, and obsidian; a few cobbles striated. Matrix is weathered throughout; stones are both rotted and fresh. Exposed along road up southeast side of Warm River Butte, between 6,400 and 6,440 feet altitude, beneath a thin cover of Pinedale loess (plo) (stratigraphic section 5). Overlies a deeply weathered rhyolite flow. Till is 400 feet above outer limit of known deposits of Sacagawea Ridge Till (st) in valley to northeast. It is separated from them by a slope on which Pinedale loess (plo) mantles older brown Bull Lake loess (blo) (stratigraphic section 7) and reddish-brown Sacagawea Ridge loess (slo) (stratigraphic section 6). The loesses overlie deeply weathered bedrock on the slope of the butte. The absence of till on this slope suggests that the till along the road above is of Cedar Ridge(?) age.
Warm River Butte Stratigraphic Sections

R - Undivided bedrock (Quaternary)

That part of the quadrangle northwest of Robinson Creek is underlain chiefly by a tuff of the Yellowstone Group, K-Ar dated as about 600,000 years old. Older rhyolite flows underlie Warm River Butte and form the steep slopes west and northwest of Moose Creek Butte. The central part of the quadrangle, between Robinson Creek and Squirrel Creek, is underlain chiefly by Falls River Basalt, which locally overlies the 600,000-year-old tuff. The hills west of Sawmill Creek are underlain by an older tuff of the Yellowstone Group, K-Ar dated as about 1.2 m.y. old. The southern part of the quadrangle, south of Squirrel Creek, is underlain chiefly by still older tuff of the Yellowstone Group, K-Ar dated as about 2.0 m.y. old, which is locally overlain by Falls River Basalt in the southeastern part. This distribution of bedrock units was provided by R. L. Christiansen (written communication, 1972); the K-Ar age determinations are by J. D. Obradovich (written commun., 1972).

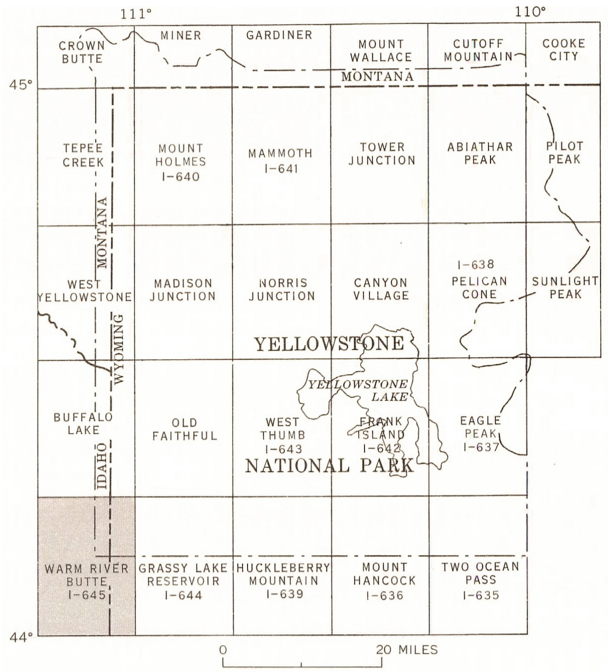
Text from source map: Warm River Butte 15' Quadrangle

Correlation of Units



Graphic from source map: [Warm River Butte 15' Quadrangle]

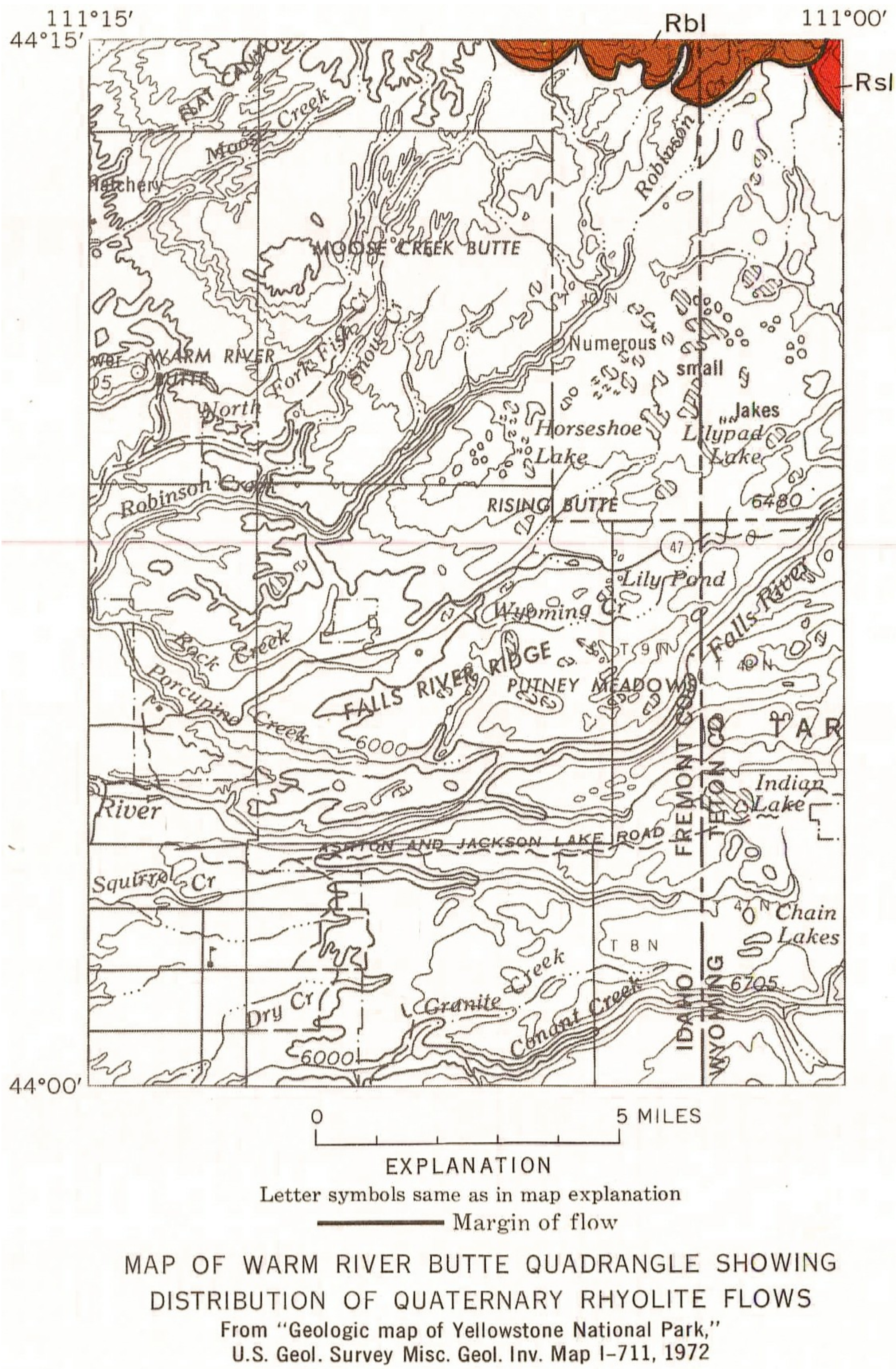
Index Map



INDEX MAP OF YELLOWSTONE NATIONAL PARK SHOWING LOCATION OF WARM RIVER BUTTE QUADRANGLE AND PUBLISHED MISCELLANEOUS GEOLOGIC INVESTIGATIONS MAPS

Graphic from source map: [Warm River Butte 15' Quadrangle]

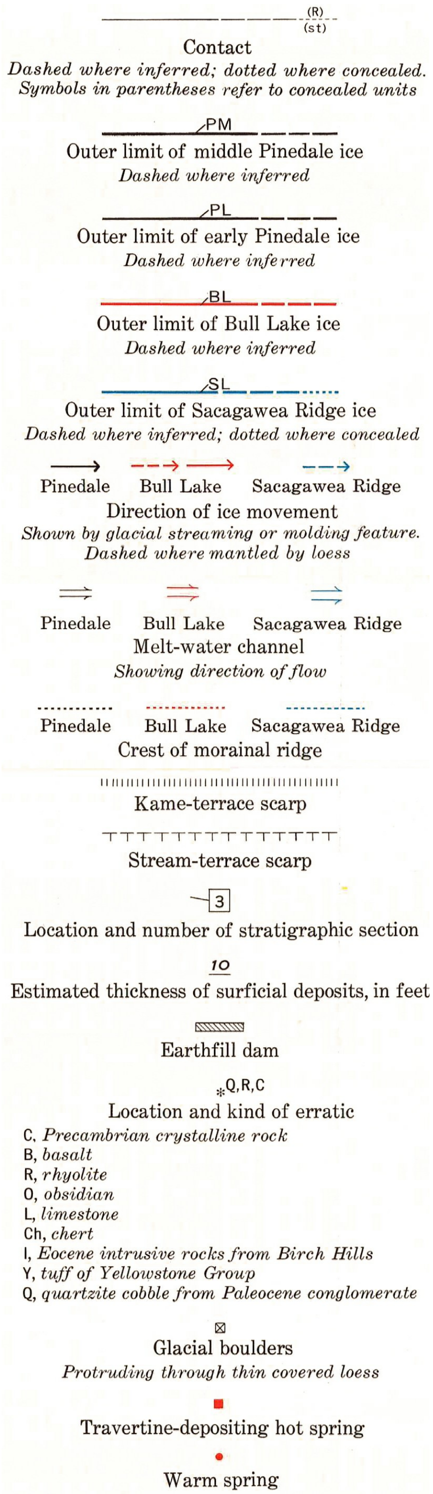
Rhyolite Flow Map



See Description of Units page for this map to view information about geologic units shown on this graphic.

Graphic from source map: Warm River Butte 15' Quadrangle

Map Legend



Graphic from source map: Warm River Butte 15' Quadrangle

Stratigraphic Sections

Units, separated by slashes, are shown in descending order; numbers (where shown) represent thickness in feet. Sections demonstrate stratigraphic relations of units vertically exposed and thus having too small a surface area to be shown on the map.

Stratigraphic section locations are presented in the GRI Geologic Observation Localities (yellgol) feature class. In that feature class, the section identifier is stored in the Location ID (LOC_ID) field. The section information presented here is also contained in the Geologic Observation Localities (yellgol) feature class Notes (NOTES) field.

See Description of Units for information about map units listed here.

1. 1 plo/3.5 B-horizon/6 bt/1.5 eroded Cca-horizon/3 st/4 slo
2. 3 plo/3 st
3. 2 plo/4 st/basalt
4. 2 plo/3-4 B-horizon/6 bt
5. 2 pco/6 ct/weathered rock
6. 2 plo/0.5 mixed zone/5 weathered slo/weathered rock
7. 2 plo/3.5 brown B-horizon/3 blo
8. 3 plo/disconformity/gray-brown st
9. 2 pco/2.5 red-brown B-horizon in st
10. 3 B-horizon/2 brown blo/5 red-brown B-horizon in st
11. 2.5 bt/6 weathered st

Text from source map: Warm River Butte 15' Quadrangle

Surficial Geologic History

INTRODUCTION

The Warm River Butte 15' Quadrangle includes the southwest corner of Yellowstone National Park. More than half the quadrangle lies in Targhee National Forest west and south of the park. An area of thick loess in the southwest part of the quadrangle is under agriculture, chiefly potatoes but, at higher altitudes, wheat. Principal streams are Falls River, Robinson Creek, Snow Creek, and Conant Creek. All but Conant Creek head in areas of large springs, including some thermal springs, which are at the southwestern fronts of rhyolite flows north east of the quadrangle and along its north boundary. The highlands in the northwest part of the quadrangle are remnants of a dissected rhyolite plateau having a present relief of 1,000 feet. The central part of the quadrangle is a dissected and glaciated basalt lowland in which the valleys are 100-200 feet deep. The upland in the southeast part of the quadrangle rises eastward to the northwest flank of the Teton Range in the adjacent Grassy Lake Reservoir 15' Quadrangle. Conant Creek has cut a canyon as much as 450 feet deep into this upland.

PLEISTOCENE GLACIATIONS

During at least three glaciations in Pleistocene time great icecaps covered most of Yellowstone National Park (Richmond, 1970). Deposits of all three glaciations—from oldest to youngest: Sacagawea Ridge, Bull Lake, and Pinedale—occur in the quadrangle. During each glaciation, ice flowed southwest across the quadrangle from the central part of the park and, in Pinedale time, also from a local cap on the Pitchstone Plateau northeast of the quadrangle. The ice was joined by glaciers flowing west from the Teton Range. Deposits of a fourth older glaciation, the Cedar Ridge(?), occur on the east slope of Warm River Butte.

CEDAR RIDGE(?) GLACIATION

An ancient till (ct), exposed at altitudes from 6,400 to 6,440 feet along the road up Warm River Butte, may represent the oldest glaciation in the quadrangle. The deposit, described above, is deeply weathered and rests on a deeply weathered rhyolite flow younger than 1.2 million years and older than 600,000 years (R. L. Christiansen, oral commun., 1972). It lies 400 feet above the known outer limit of Sacagawea Ridge Till (st), which rests on tuff of the Yellowstone Group, 600,000 years old, in the valley at the foot of the butte to the east. Thus, though the till cannot be stratigraphically distinguished from Sacagawea Ridge Till, its topographic position suggests that it is older. The lithology of the till implies that the ice came from the region of Yellowstone National Park to the northeast rather than from the Teton Range to the southeast.

The thick rhyolite flows, which today form the Madison and Pitchstone Plateaus to the northeast, are all less than 160,000 years old, and were not in existence in Cedar Ridge time. The region where these plateaus are now, as well as the central part of Yellowstone National Park, is inferred to have been a hilly or mountainous upland on which an icecap could have accumulated in Cedar Ridge time prior to the development, 600,000 years ago, of the present caldera basin and associated tuff of the Yellowstone Group, as well as the younger eruptions of basalt and rhyolite.

CEDAR RIDGE-SACAGAWEA RIDGE INTERGLACIATION

Little is known of the Cedar Ridge-Sacagawea Ridge inter-glaciation. If the till discussed above is of Cedar Ridge age, dissection and valley development to depths of at least 400 feet, together with deep and intensive weathering, must have taken place. The canyon of Sawmill Creek, which is about 200 feet deep and has a deposit of Sacagawea Ridge Till on its floor, was also cut at this time as a former southerly course of Robinson Creek.

SACAGAWEA RIDGE GLACIATION

The Sacagawea Ridge Glaciation includes several times of ice development. Deposits of one, near Upper Falls in the Canyon Village 15' Quadrangle, underlie a pumice bed that is more than 265,000 years old. The deposits in the Warm River Butte 15' Quadrangle are more than 127,000 years old, the age of the Summit Lake rhyolite flow which overlies Sacagawea Ridge Till in the Grassy Lake Reservoir 15' Quadrangle (Map 1-644) adjacent to the east. The deposits in the Warm River Butte 15' Quadrangle may also be older than the eruption of the

Buffalo Lake rhyolite flow (Rbl) about 156,000 years ago. Deeply weathered loess and loessial alluvium, similar to loess associated with Sacagawea Ridge Till (st) in this quadrangle (stratigraphic section 1), underlie the flow in the Buffalo Lake quadrangle. However, no basis for precise dating is available. The Sacagawea Ridge Till in the Warm River Butte 15' Quadrangle rests on the dissected depositional surface of the 600,000-year-old tuff of the Yellowstone Group arid younger Falls River Basalt. Along Squirrel Creek (stratigraphic section 1) and in the canyon of Sawmill Creek (stratigraphic section 11) deeply weathered Sacagawea Ridge Till is overlain by Bull Lake Till. Differences in the lithology of the Sacagawea Ridge Till in the north and south parts of the quadrangle show that much of the ice flowed southwest across the quadrangle from sources in Yellowstone National Park, but that some flowed west from sources at the north end of the Teton Range southeast of the quadrangle. The outer limit of Sacagawea Ridge Glaciation, based on the extent of its till, extends across the northwest part of the quadrangle northeast, east, and south of Moose Creek Butte. Locally a thick deeply weathered soil on the till is overlain by less weathered loess of Bull Lake age (stratigraphic section 10). However, both the Bull Lake loess and the soil are commonly partly or wholly stripped from the till, and a mantle of Pinedale loess (plo) or loessial solifluction debris covers much of the till surface (stratigraphic sections 2, 3, and 8). East and south of Warm River Butte, the Pinedale loess mantle thickens, and the outer limit of the till is inferred from only a few exposures. On the slopes of the butte, Pinedale loess mantles intensely weathered loess of Sacagawea Ridge age (stratigraphic section 6). South of Falls River, small areas of glacially derived boulders projecting through younger loess show that Sacagawea Ridge ice extended beyond the west boundary of the quadrangle. Deposits of Sacagawea Ridge Till in the southern part of the quadrangle are derived mainly from the Teton Range. This till extends for many miles south of the quadrangle boundary on the uplands flanking the west slope of the Teton Range, where it was originally called "Buffalo Till" (Blackwelder, 1915).

SACAGAWEA RIDGE-BULL LAKE INTERGLACIATION

During the Sacagawea Ridge-Bull Lake interglaciation, deposits of Sacagawea Ridge age were weathered to depths as much as 5 feet. Intense oxidation and clay enrichment characterize soils on Sacagawea Ridge deposits above about 6,200 feet altitude; at lower altitudes some carbonate enrichment is additionally present. The Buffalo Lake rhyolite flow (Rbl) invaded the northeast corner of the quadrangle about 156,000 years age, but its relation to Sacagawea Ridge Till in this quadrangle could not be established. In the adjacent Grassy Lake Reservoir 15' Quadrangle (Map 1-644), the Summit Lake rhyolite flow was extruded across the till about 127,000 years ago. Extensive dissection took place along secondary streams throughout the quadrangle and canyons were incised as much as 200 feet along major streams and in the Buffalo Lake rhyolite flow.

BULL LAKE GLACIATION

The Bull Lake Glaciation includes two major times of ice development, separated by a nonglacial interval (Richmond, 1965). The deposits of the two glacial times could not be separated in the Warm River Butte 15' Quadrangle, but those at the outer limit of Bull Lake Glaciation (BL) are probably of early Bull Lake age. In the Canyon Village 15' Quadrangle, till of late Bull Lake age rests on lake sand containing pumice, K-Ar dated as about 99,000 years old; in the Huckleberry Mountain 15' Quadrangle (Map 1-639), it is shown to be older than a rhyolite flow, K-Ar dated as about 70,000 years old.

Probably during both times of Bull Lake Glaciation, a lobe of ice from a large icecap in central Yellowstone National Park flowed southwestward into the quadrangle. To the south, the lobe merged with glaciers flowing west from the north end of the Teton Range, just east of the quadrangle. Northwest of Robinson Creek, the Bull Lake ice lobe covered terrain as high as 6,900 feet altitude near its outer limit. This suggests that, at its maximum, the ice was probably at least 800-900 feet thick over Bechler Meadows and perhaps 700 feet thick over Bechler River at Sheep Falls. The front of the ice was probably about 200 feet high, as shown by the steeply rising outer limits of the till along canyon walls between Robinson Creek and Conant Creek. To the south, the ice was more than 500 feet thick along its terminus in the canyon of Conant Creek.

BULL LAKE-PINEDALE INTERGLACIATION

During the Bull Lake-Pinedale interglaciation, deposits of Bull Lake age were weathered to depths of 3-4 feet. The soil is oxidized and contains moderate but not abundant clay. Some secondary carbonate was noted in soils on Bull Lake loess below about 6,000 feet altitude. Erosion during the interglaciation appears to have been slight. Bull Lake outwash gravel has been entrenched at least 30 feet by major streams such as Falls River, but only a few feet by streams such as Bear Creek and Snow Creek. Pinedale loess (plo) forms thick widespread deposits in the western part of the quadrangle and thins eastward over deposits of Sacagawea Ridge and Bull Lake age, locally resting on the Bull Lake-Pinedale soil. The loess is not present on Pinedale Till, indicating that eolian activity was not effective as a depositional agent in this area during the maximum stand and recession or stagnation of the Pinedale ice. Probably, the loess began to be deposited during the Bull Lake-Pinedale interglaciation, and attained a maximum rate of accumulation during the advance of Pinedale ice. Deposition ceased before significant recession of that ice began.

PINEDALE GLACIATION

During the Pinedale Glaciation two lobes of an icecap, which developed in central Yellowstone National Park, flowed southwest into the quadrangle. One entered Bechler Meadows after flowing around the north side of the Pitchstone Plateau northeast of the quadrangle (Map 1-644, Grassy Lake Reservoir 15' Quadrangle); the other entered the basin of Falls River near the park boundary after flowing around the south side of the plateau. These two lobes were joined by ice flowing from a local cap on the plateau and merged in the area between Bechler Meadows and Falls River, where the ice spread southwest across the lowland. In the northeast part of the quadrangle, the ice extended across Robinson Creek, impounding a lake in its headwaters at an altitude of about 6,600 feet. The lake drained irregularly across the uplands to the west and, as the ice stagnated, broke across it as a flood which scoured the uplands west of Robinson and Little Robinson Creeks to form a scabland terrain. The flood passed down Robinson Creek, stripping its canyon of slope deposits for more than 3 miles. In the central part of the quadrangle, Pinedale ice extended beyond the boundary of Yellowstone National Park and terminated in narrow tongues along successive drainages to the southwest. Lateral moraines on valley walls suggest that these tongues were 50-100 feet thick at their distal ends. The altitude of the outer limit of Pinedale Till northwest of Boundary Creek suggests that the ice was 700-800 feet thick over Bechler Meadows; its altitude northwest of Robinson Creek suggests a thickness of 500-600 feet over Falls River at the east edge of the quadrangle.

Several end moraines mark secondary readvances during recession of the Pinedale ice. The small moraines on the slopes in the headwaters of Boundary Creek probably represent very minor oscillations. The moraine north of Squirrel Meadows marks a temporary stand while a shallow lake existed in the area of the meadows. The large end moraines southwest of Bechler Meadows are deposits of the glacial lobe flowing around the north side of the Pitchstone Plateau. They may mark significant regional readvances of middle Pinedale age. Extensive thick ice-contact gravel deposits in the form of kame terraces (pksg) and large eskers (peg), immediately east of these end moraines, suggest rapid stagnation of the ice and abundant gravel-laden melt waters. Kame terrace deposits northwest of Bechler Meadows indicate that the area of the meadows was occupied by stagnant ice for a time. Subsequently the meadows were occupied by a large but probably shallow lake dammed by end moraines deposited by the glacial lobe flowing around the south side of the Pitchstone Plateau in the adjacent Grassy Lake Reservoir 15' Quadrangle.

PINEDALE PERIGLACIAL EVENTS

No glacial deposits of late Pinedale age occur in the quadrangle. However, throughout Pinedale time frost action and solifluction were active in areas beyond the limits of Pinedale ice. The unglaciated uplands in the northwest part of the quadrangle are covered by colluvial debris (pco) mixed with Pinedale loess. Slopes underlain by Sacagawea Ridge Till or Bull Lake Till also display evidence of movement in Pinedale time, and the floors of secondary valleys are commonly covered with coarse debris derived from these tills and mixed with Pinedale loess. Broader valleys have local small but distinct solifluction lobes and terraces along their sides. Exposures in valleys and swales in the loess area in the southwest part of the quadrangle display stratification and folded structures indicating downslope flowage of the loess, and in places, abundant stones and sand in the loess indicate mixing of debris from the underlying bedrock by frost action or solifluction. Talus, now inactive and commonly supporting vegetation, lies at the base of many cliffs beyond the limit of Pinedale ice. Some may be in part of Bull Lake age, but the surface deposits accumulated in Pinedale time and bear a thin post-Pinedale soil. Talus deposits, within the area covered by Pinedale ice, formed during and after wasting of the ice, some probably in late Pinedale time. The lower part of alluvial deposits (fa) overlying Pinedale stream gravel, or in depressions in Pinedale Till, is probably also of Pinedale age.

POST-PINEDALE EVENTS

Surficial processes have produced a few changes in the quadrangle since Pinedale time. A thin and weakly developed soil, less than a foot thick, has formed on Pinedale deposits, including pro-Pinedale loess. Talus is actively forming at the base of a few cliffs, especially in the canyon of Robinson Creek, along Falls River, and in the northeast part of the quadrangle. Erosion has dissected Pinedale gravel (pg, pcg) about 15-20 feet along major streams such as Falls River and Conant Creek. Slow alluviation has continued to form fine-grained humic deposits (fa) in depressions and swampy basins in Pinedale Till in the eastern part of the quadrangle and on flood plains throughout the quadrangle.

Text from source map: Warm River Butte 15' Quadrangle

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References from source map: Warm River Butte 15' Quadrangle

West Thumb 15' Quadrangle

The formal citation for this source.

Richmond, Gerald M., 1973, Surficial Geologic Map of the West Thumb Quadrangle, Yellowstone National Park, Wyoming: U.S. Geological Survey, Miscellaneous Investigations Series Map I-643, scale 1:62,500 (*GRI Source Map ID 1152*).

Description of geologic units, prominent graphics and text associated with this source.

Description of Units

lsg - Lake sediments, sandy gravel (Quaternary, Neoglaciation)
lgs - Lake sediments, gravelly sand (Quaternary, Neoglaciation)

Sandy gravel (lsg) and gravelly sand (lgs) forming beach deposits of modern lakes, including storm beaches about 5 feet above mean low water level. Also form beach and nearshore deposits of older lake levels 10, 15, and 25 feet above Yellowstone Lake and 10 feet above Lewis Lake. Material subrounded to well rounded, well sorted, crossbedded; locally cemented by silica. Commonly 3-10 feet thick.

grg - Rock glacier (Quaternary, Neoglaciation)

Lobate tongue of fresh angular to subangular blocky rock debris at foot of headwall of southeast-facing cirque on Mount Sheridan. Clasts mainly of rhyolite. Deposit has open texture at surface, sandy matrix at depth; barren of vegetation except lichen. Overlaps moraine of Temple Lake Stade.

fa - Fine-grained humic alluvium (Quaternary, Neoglaciation)

Dark-gray to gray-brown silt, sand, and clay; occurs on flood plains, on gravel along former Pinedale drainageways and in depressions in Pinedale Till. Mostly 1-5 feet thick.

sg - Stream deposits, sandy gravel (Quaternary, Neoglaciation)
gs - Stream deposits, gravelly sand (Quaternary, Neoglaciation)

Light-gray to buff, poorly sorted, coarse sandy gravel (sg) and gravelly sand (gs) in streambeds and flood plains. Underlies fine-grained alluvium (fa) locally. In places, contains cobbles and boulders. Clasts mostly subangular to subround; chiefly of rhyolite and obsidian. Five to 20 feet thick.

fg - Fan deposits, gravel (Quaternary, Neoglaciation)
fgs - Fan deposits, gravelly sand (Quaternary, Neoglaciation)

Gray to buff, poorly sorted, crudely bedded sandy gravel (fg) and gravelly sand (fgs) in alluvial fans. Gravel deposits contain some cobbles and boulders. Material chiefly of rhyolite.

ta - Talus deposit (Quaternary, Neoglaciation)

Angular to subangular rock fragments forming sloping sheet or cone at base of cliff. Interstices void at surface, filled with sandy matrix at depth. Clasts mostly of tuff. Deposits are chiefly in Red Mountains at and above 8,000 feet altitude. They are unstable, are actively accumulating, bear no soil, and lack vegetation. Thickness 5-50 feet.

tf - Talus-flow deposits (Quaternary, Neoglaciation)

Angular to subangular rock fragments forming a lobate mass extending downslope from toe of a talus. Characterized by steep front and, locally, surface furrows arcuate downslope. Deposits restricted to north-and northeast-facing cirques in Red Mountains. They are mostly of tuff, unstable, lack vegetation, bear no soil, and are locally active at present. Thickness 5-20 feet.

fr - Frost rubble (Quaternary, Neoglaciation)

Thin mantle of angular, slabby to blocky clasts of tuff, locally in a sandy matrix. Weathered from bedrock and moved slightly downslope by frost action. Thin humic azonal soil. Restricted to uplands of Red Mountains above 9,000 feet altitude. Supports lichen, irregular areas of alpine turf, and scattered trees. Some deposits appear seasonally active but most are stable. One to 3 feet thick.

ad - Avalanche debris (Quaternary, Neoglaciation)

Gray to tan angular debris in a sandy matrix. Occurs in Red Mountains in avalanche chutes and as fan-shaped or lobate deposits below them. Deposits unsorted to poorly sorted, crudely bedded, locally very bouldery. In places characterized by mudflow levees. Includes debris transported by torrential runoff, mudflow, slushflow, and snow avalanche. Thickness 5-30 -feet.

tt - Till (Quaternary, Neoglaciation)

Forms small blocky end moraines in north- and east-facing cirques of Red Mountains. Consists of angular to subangular fragments in buff to gray sandy matrix; unsorted, nonstratified. Deposits are very slightly weathered, support grass or forest vegetation, and are partly mantled by talus and avalanche debris from cirque headwall.

sd - Solifluction deposit (Quaternary, Neoglaciation)

Buff to gray-brown, coarse to fine stony silty sand; contains numerous rounded to angular pebbles, cobbles, and boulders. Deposits form irregular lobes, terracelike masses, and hummocky sheets on spring-fed slopes. They are seasonally active. Five to 10 feet thick.

ls - Landslide deposit (Quaternary, Neoglaciation)

Large mass of blocky to slabby debris in silty sand matrix; mostly derived from bedrock and till (pt). Clasts mostly of tuff. Largest deposits are on east side of Mount Sheridan, where they have slumped and flowed downslope from fault-controlled headwall scarps. Deposits characterized by hummocky topography and local enclosed depressions. They are dissected as much as 40 feet by present drainage.

es - Eolian sand (Quaternary, Neoglaciation)

Buff, medium to fine sand and silt displaying eolian crossbedding and low dune topography. Occurs as small deposits, 3-6 feet thick, on bluff along northeast side of West Thumb arm of Yellowstone Lake. Mapped only at one locality.

si - Siliceous sinter (Quaternary, Neoglaciation)

White to light-gray deposit of amorphous silica forming cones and rims of hot springs and irregular terraces at West Thumb, Potts Hot Spring, and Heart Lake Geyser Basins. Local internal structure perpendicular to layers. Includes deposits of small flat angular sinter fragments mixed with locally derived sand and fine gravel. Thickness ranges from a few inches to 10 feet.

ptu - Upper till and rubble veneer, till (Holocene and/or Pleistocene)
pru - Upper till and rubble veneer, rubble veneer (Holocene and/or Pleistocene)

Gray-brown stony silty sand (ptu); unsorted; locally blocky. Clasts angular to sub-angular; mostly of tuff. Deposits form ground moraine and small end moraines below east- and north-facing cirques in Red Mountains at altitudes between 7,800 and 8,250 feet. Soil on deposits has weakly developed B horizon about a foot thick. Scattered stones and sandy debris form thin patchy rubble (pru) on bedrock floors of two cirques in Red Mountains. Some stones glacially shaped and striated. Deposits are less than 5 to more than 20 feet thick. Mapped areas include numerous small areas of unmapped bedrock.

pl - Open lake sediments, silt (Holocene and/or Pleistocene)
psl - Open lake sediments, sand (Holocene and/or Pleistocene)
plgs - Open lake sediments, gravelly sand (Holocene and/or Pleistocene)

Gray to blue-gray, varved, laminated or massive silt (pl); gray to buff, massive to well-bedded, well-sorted, medium-gray sand (psl) locally with delta foreset bedding; and gray to tan crossbedded beach sand and gravel (plgs). Deposits form terraces 65-60, 40, and locally 35 feet above Yellowstone Lake; the 65-60 foot terrace is most continuous. The silt and sand deposits are variably 20-40 feet thick; the gravelly beach deposits are 2-6 feet thick. Lake silt (pl) and sand (psl) also form irregular fill terraces 40 and 10-15 feet high along the lower part of the valley of De Lacy Creek north of Shoshone Lake.

psg - Stream deposits, sandy gravel (Holocene and/or Pleistocene)
pgs - Stream deposits, gravelly sand (Holocene and/or Pleistocene)
ps - Stream deposits, sand (Holocene and/or Pleistocene)

Gray to gray-brown sandy gravel (psg), gravelly sand (pgs), and sand (ps); poorly sorted, crudely bedded; 5-30 feet thick. Gravel is chiefly pebbles and cobbles with a few boulders; predominantly of rhyolite. Deposits fill former Pinedale drainageways and are covered by younger fine-grained alluvium (fa) in many places. They also form discontinuous terraces 15-30 feet above present streams. On Pitchstone Plateau, outwash sand (ps) fills drainageways along the outer limit of the Pinedale glacial rubble (pr). The soil on these deposits is weakly oxidized and less than a foot thick.

pfg - Fan gravel (Holocene and/or Pleistocene)

Gray to gray-brown pebble to cobble gravel, forming fan-shaped deposit at mouth of secondary stream; 5-30 feet thick; commonly entrenched by younger alluvial deposit. Soil weakly oxidized and less than a foot thick.

pco - Colluvium (Holocene and/or Pleistocene)

Angular to subangular fragments of rhyolite, obsidian, and pumice in a sandy pumiceous matrix. Derived by weathering, solifluction, and creep from underlying Pitchstone Plateau rhyolite flow (Rp). Deposits are mostly less than 5 feet thick and bear weakly oxidized soil 1-3 feet thick that locally grades down into underlying pumice on crust of the flow.

pta - Talus deposits (Holocene and/or Pleistocene)

Angular blocks in sandy matrix forming cones and sheets at base of cliffs. Mostly in northwestern part of quadrangle and in Red Mountains. Deposits 5-50 feet thick, inactive, stable, and forested. Soil like that on Pinedale Till (pt).

ptf - Talus-flow deposit (Holocene and/or Pleistocene)

Angular blocks forming lobate mass extending downslope from toe of a Pinedale talus deposit. Deposits are 5-20 feet thick, inactive, stable, and forested. Bear a soil like that on Pinedale talus. Occur only in northwestern part of quadrangle.

phe - Hydrothermal explosion deposit (Holocene and/or Pleistocene)

Buff to yellowish-brown, locally reddish, massive, medium to coarse, pumiceous sand with silty matrix forming ridge around Duck Lake. Contains abundant small chunks of pumice and local fragments, slabs, and blocks of tuff and cemented bedded lacustrine sand. Hydrothermally altered to clay in places. Deposit is 15-100 feet thick. It rests on Pinedale Till and older deposits, including the Shoshone Lake Tuff Member of the Plateau Rhyolite, from which it is largely derived. Deposit is believed to be the product of a subaqueous hydrothermal explosion.

pkl - Ice-dammed lake sediments, silt (Holocene and/or Pleistocene)

pksl - Ice-dammed lake sediments, sand (Holocene and/or Pleistocene)
pkdg - Ice-dammed lake sediments, delta gravel (Holocene and/or Pleistocene)
pklb - Ice-dammed lake sediments, beach deposit (Holocene and/or Pleistocene)

Blue-gray, buff-weathering, massive to laminated, locally varved silt (pkl); buff to gray, massive to bedded, medium to fine sand (pksl), and buff to gray beach gravel (pklb), underlying terraces 160, 110, 90, and 80 feet above Yellowstone Lake. The 110-foot terrace is nearly continuous; others are discontinuous. The silt deposits (pkl) are chiefly along the south and west slopes of the lake basin between altitudes of 8,000 and 7,840 feet, and are as much as 30 feet thick. The sand deposits (pksl), also as much as 30 feet thick, lie along southeast and north slopes of basin; the gravelly beach deposits (pklb) form the 110- and 80-foot terraces along northeast slope, and are as much as 10 feet thick. Kettles in sand and silt deposits and irregularities of terrace scarps indicate ice-contact origin in a lake retained by stagnant ice. North of Shoshone Lake, in the drainage basin of De Lacy Creek, are extensive deposits of delta gravel (pkdg) and lake sand (pksl) as much as 50 feet thick. The delta gravel displays long foreset bedding. Its constructional surface is 330 feet above present Shoshone Lake. A constructional surface on the lake sand is 130 feet above the lake. The deposit of sand (pksl) along lower Moose Creek displays delta foreset bedding.

pksg - Kame deposits, sandy gravel (Holocene and/or Pleistocene)
pkgs - Kame deposits, gravelly sand (Holocene and/or Pleistocene)
pks - Kame deposits, sand (Holocene and/or Pleistocene)

Buff to gray gravel with sandy matrix (pksg), gravelly sand (pkgs), and sand with very small amounts of gravel (pks) forming kame terraces with ice-contact frontal scarps and irregular hummocky surfaces. Deposits are 20 to more than 50 feet thick, and, where exposed in section, display numerous slump structures and minor faults. Locally, they are mantled with large boulders and thin till-like material slumped from nearby higher till-covered slopes or from former adjacent ice. Deposits occur north of Yellowstone Lake between 7,880 and 8,000 feet altitude and are especially thick in the area of Nuthatch and Chickadee Lakes. Thick deposits also border the basin of De Lacy Creek between 8,400 and 7,880 feet altitude, and extend discontinuously around Shoshone Lake and locally around Lewis Lake.

pt - Tills and rubble veneer, till (Holocene and/or Pleistocene)
plt - Tills and rubble veneer, lacustral till (Holocene and/or Pleistocene)
pr - Tills and rubble veneer, rubble veneer (Holocene and/or Pleistocene)

Till (pt) is gray-brown to gray massive stony sandy silt; loose to compact; stones angular to subround; mostly of rhyolite except in Red Mountains where mostly of tuff. Deposits smooth to hummocky; contain local undrained depressions. Thickness commonly less than 5 feet, locally as much as 40 feet. Soil on deposits has weakly oxidized profile less than 1 foot thick. North of Continental Divide, between Solution Creek and Thumb Creek, are deposits of lacustral till (plt), a massive clayey silt containing numerous scattered, angular to subround, locally striated pebbles and cobbles. It is inferred that this material was deposited from ice in subglacial water during recession of middle Pinedale ice. Uplands north of Shoshone Lake and in the Red Mountains are covered with a thin glacial rubble veneer (pr) which consists of angular to subangular sandy gravel, containing cobbles and boulders, some of which are striated. Mapped areas of this rubble include small exposures of bedrock and some frost-riven debris. Similar deposits on Pitchstone Plateau consist of locally derived obsidian and rhyolite in a pumiceous matrix, and are covered in places by a thin colluvium composed chiefly of pumice. The deposits lie in swales between locally striated, elongate pressure ridges of the Pitchstone Plateau rhyolite flow.

bl - Lake sediments, silt (Pleistocene)
bsl - Lake sediments, sand (Pleistocene)
blsg - Lake sediments, sandy gravel (Pleistocene)

Gray, massive to weakly bedded silt (bl) containing scattered grains of obsidian. Ten feet thick. Overlies Bull Lake Till and is overlain by Pinedale Till (stratigraphic section 7) along highway west of West Thumb, south of Duck Lake. Gray, massive to thin-bedded, medium pumiceous pebbly sand (bsl); cemented by hydrothermal silica. Forms discontinuous ledges along and on east slope of De Lacy Creek 1 1/4 miles north of highway crossing, where it is about 20 feet thick and overlain by Pinedale Till (pt) and, in places, by Pinedale kame deposits (pkgs). Also exposed as wave-cut cave fillings in West Thumb rhyolite flow (Rw) in bluff of point on northeast shore of West Thumb (stratigraphic section 2). There, the sand contains numerous gravel size pumice chunks and is not cemented. Blue-gray sandy gravel (blsg) containing numerous thin lenses of well-sorted crossbedded lacustral fine to medium silty pumiceous sand. Exposed at gravel pit northwest of Potts Hot Spring Basin. Gravel composed chiefly of obsidian and rhyolite, but contains scattered pebbles and cobbles of andesite; includes numerous blocks of rhyolite, obsidian, and tuff derived from cliff of Elephant Back rhyolite flow (Re) and underlying Shoshone Lake Tuff Member (Rst), against which deposit is banked. Gravel locally rests on Bull Lake Till (stratigraphic section 6) and is overlain by Pinedale Till (pt) and talus (pta). Thickness 30-50 feet.

West Thumb Stratigraphic Sections

bkg - Kame gravel (Pleistocene)

Blue-gray, weathering rusty brown, pebbles, cobbles, and boulders in coarse sandy matrix; locally silica cemented and hydrothermally altered. Characterized by great variation in texture, sorting, and bedding. Clasts rounded to subrounded; some rotted; most are of rhyolite; a few are of andesite. Deposits on west side of drainage basin of De Lacy Creek are more than 50 feet thick. Those north of west arm of Shoshone Lake form cemented knobs.

br - Rubble veneer (Pleistocene)

In west-facing bluff along north shore of West Thumb (stratigraphic sections 3 and 4) till (bt) is gray-brown, compact, massive unsorted silty sand; composed chiefly of obsidian and pumice, but contains scattered rounded erratic pebbles and cobbles of basalt and andesite, some striated, and angular blocks of obsidian. At gravel pit northwest of Potts Hot Spring Basin (stratigraphic section 6), till is unsorted, sandy, moderately compact, and composed chiefly of rhyolite, obsidian, tuff of the Shoshone Lake Tuff Member, and a few erratics of andesite. Along highway west of West Thumb, south of Duck Lake (stratigraphic section 7), till is a gray compact massive silt containing obsidian grains and scattered rounded to subangular, iron-stained pebbles and cobbles of rhyolite, obsidian, tuff, and andesite, some striated. At each locality thickness is 10-15 feet. Beyond limit of Pinedale Glaciation (PL) in northwest part of quadrangle, uplands are mantled by a thin glacial rubble veneer (br) composed of subangular to subround pebbles, cobbles, and boulders in a sandy matrix. Material mostly of rhyolite, but contains a few erratics of basalt and andesite. Soil, where preserved, is oxidized to depth of 3-4 feet.

West Thumb Stratigraphic Sections

Rp - Pitchstone Plateau rhyolite flow (Pleistocene)
Rbr - Bechler River rhyolite flow (Pleistocene)
Rsc - Spring Creek rhyolite flow (Pleistocene)
Re - Elephant Back rhyolite flow (Pleistocene)
Rw - West Thumb rhyolite flow (Pleistocene)
Ra - Aster Creek rhyolite flow (Pleistocene)
Rst - Shoshone Lake Tuff Member (Pleistocene)
Rd - Dry Creek rhyolite flow (Pleistocene)

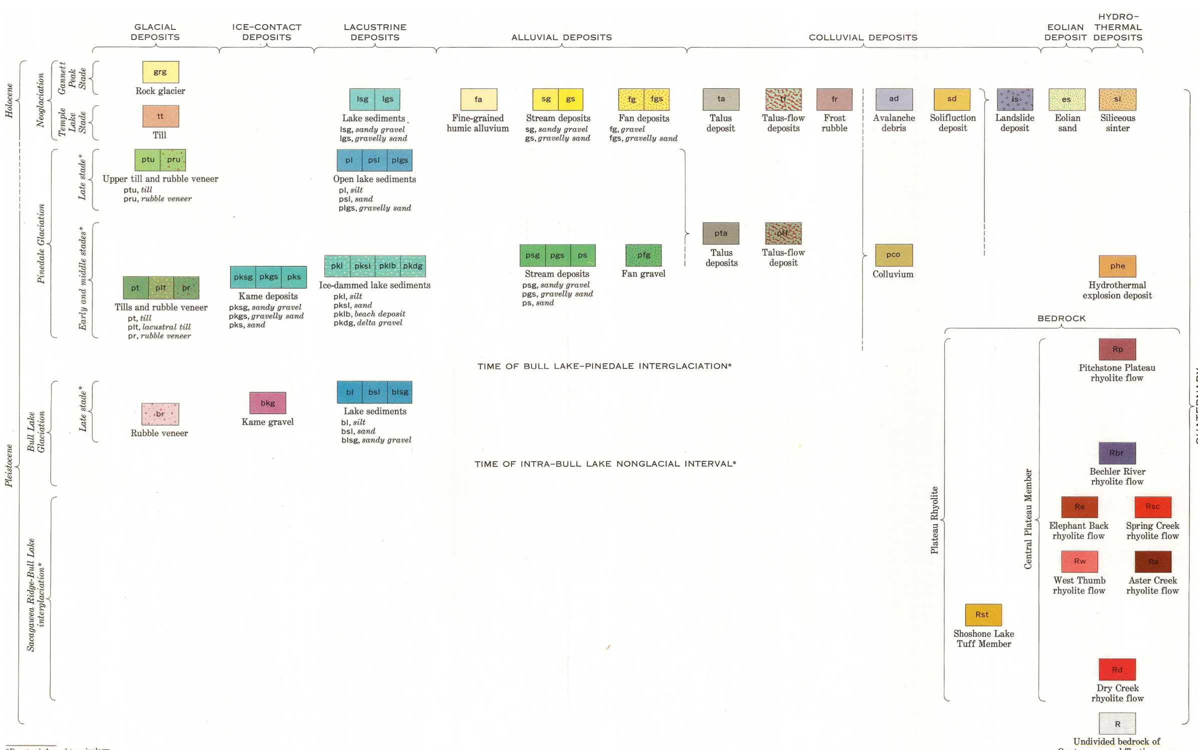
Most of the quadrangle is underlain by Quaternary rhyolite flows and tuff. These rocks have been mapped (U.S. Geological Survey, 1972) and described `by R. L. Christiansen and H. R. Blank, Jr. (1972). I have mapped the outcrops of those whose emplacement or stratigraphic relations bear on the Quaternary glacial and lacustrine history. All erupted within the past 160,000 years, either on the rim of or in an ancient caldera about 600,000 years old (see small map). The Pitchstone Plateau rhyolite flow (Rp) is K-Ar dated as about 70,000 years old. The Bechler River rhyolite flow (Rbr) is known only to be younger than the Shoshone Lake Tuff Member (Rst) on which it rests along the southwest shore of Shoshone Lake. The Elephant Back rhyolite flow (Re), the Spring Creek rhyolite flow (Rsc), the West Thumb rhyolite flow (Rw), and the Aster Creek rhyolite flow (Ra) are all K-Ar dated as about 150,000 years old. However, the Elephant Back flow rests on the West Thumb flow and must therefore be slightly younger. Both the West Thumb and Aster Creek flows overlap the wall of a caldera at the site of the present West Thumb arm of Yellowstone Lake. The Shoshone Lake Tuff Member (Rst) was erupted during development of this caldera. The tuff underlies the Bechler River flow, the Aster Creek flow, and the Spring Creek rhyolite flow. It overlies the Dry Creek rhyolite flow (Rd), K-Ar dated as about 160,000 years old. The tuff and the caldera at West Thumb are therefore probably about 155,000 years old. All K-Ar dates are by J. D. Obradovich.

R - Undivided bedrock (Quaternary and Tertiary)

Two tuffs of the Yellowstone Group, one about 600,000 years old and the other about 2 million years old underlie most of the Red Mountains. Eruption of the younger tuff was associated with development of a large caldera, whose southern rim extends across the southern part of the quadrangle (see small map). Small areas of Tertiary conglomerate occur south of Mount Sheridan in the southeast corner of the quadrangle.

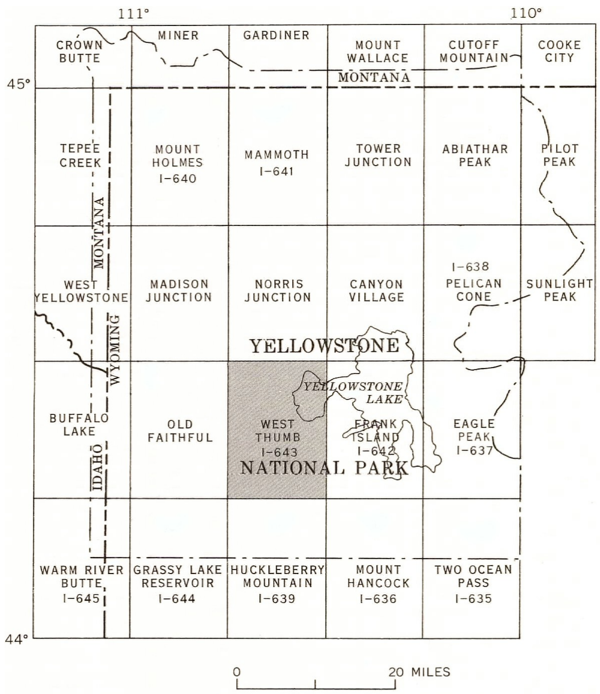
Text from source map: West Thumb 15' Quadrangle

Correlation of Units



Graphic from source map: West Thumb 15' Quadrangle

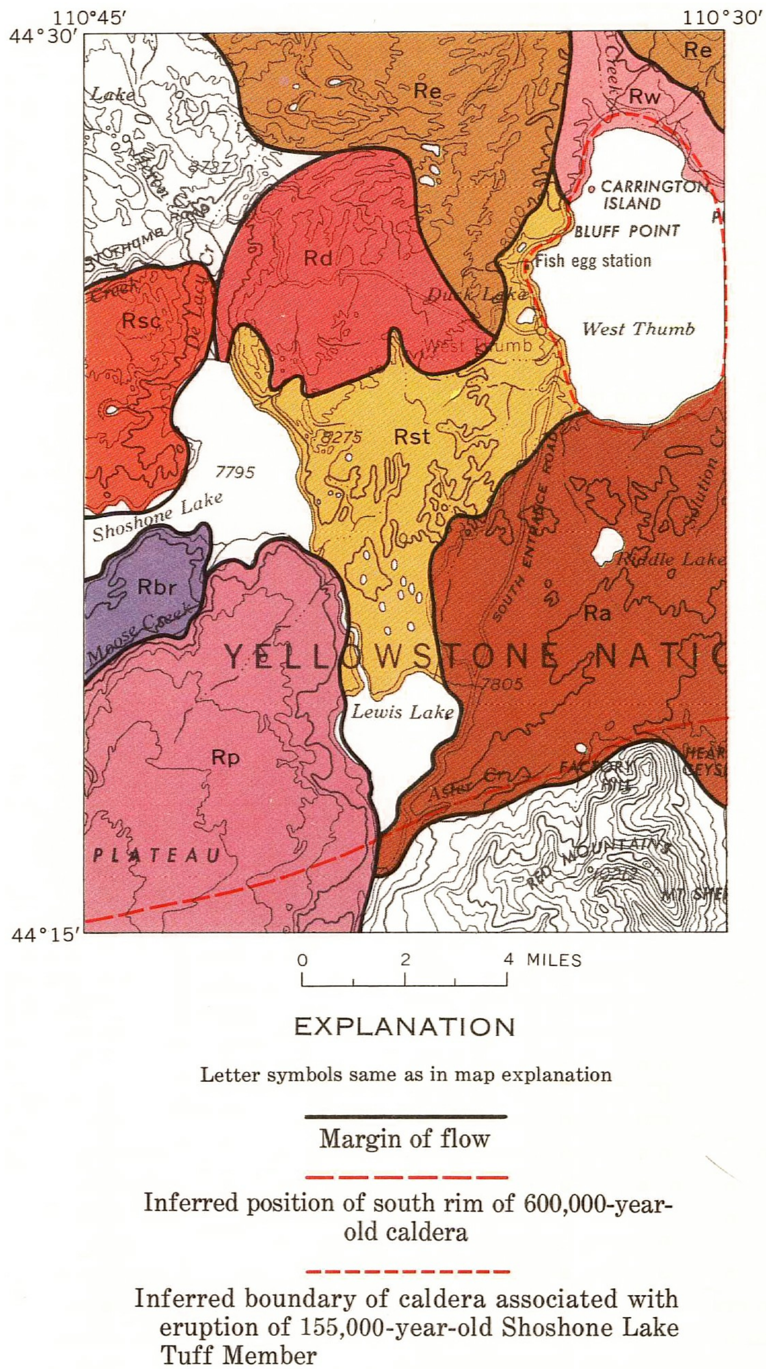
Index Map



INDEX MAP OF YELLOWSTONE NATIONAL PARK SHOWING LOCATION OF WEST THUMB QUADRANGLE AND PUBLISHED MISCELLANEOUS GEOLOGIC INVESTIGATION MAPS

Graphic from source map: [West Thumb 15' Quadrangle]

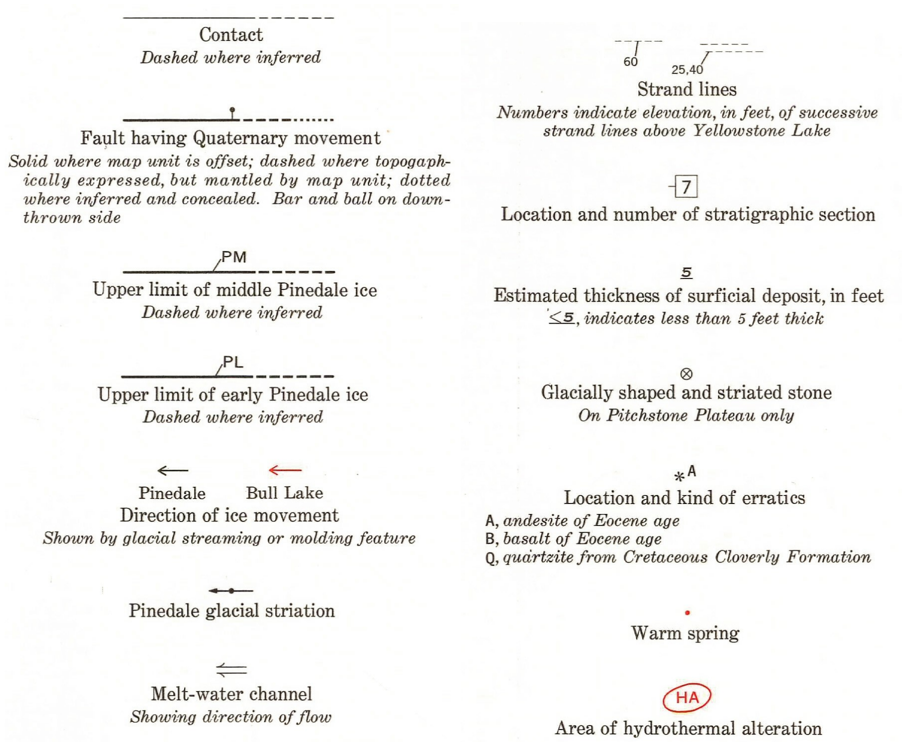
Rhyolite Flow Map



See Description of Units page for this map to view information about geologic units shown on this graphic.

Graphic from source map: West Thumb 15' Quadrangle

Map Legend



Graphic from source map: West Thumb 15' Quadrangle

Stratigraphic Sections

Units, separated by slashes, are shown in descending order; numbers (where shown), represent thickness, in feet. Sections demonstrate stratigraphic relations of units vertically exposed and too small to be shown on the map.

Stratigraphic section locations are presented in the GRI Geologic Observation Localities (yellgol) feature class. In that feature class, the section identifier is stored in the Location ID (LOC_ID) field. The section information presented here is also contained in the Geologic Observation Localities (yellgol) feature class Notes (NOTES) field.

See Description of Units for information about map units listed here.

1. 8 psl/6 pt/12 Rw
2. bsl in caves in Rw
3. 2 co/4 lgs/1.5-5 plt/15 bt/2 Rw
4. 2 co/Pinedale stone line, some stones striated/20 bt/layer of round-stones, many of basalt/6 lake sand, pumiceous/6 Rw
5. 20 pkgs/6 bl, varved
6. 5 pta/30 blsg/5 bt/10 Rst
7. 2 pt/10 bl/4 bkg/3 bt

Text from source map: West Thumb 15' Quadrangle

Surficial Geologic History

INTRODUCTION

The West Thumb 15' Quadrangle is in south-central Yellowstone National Park. The Red Mountains, in its southeast corner, rise to altitudes of about 10,000 feet and are cut by numerous cirques. Mount Sheridan, the highest peak, is 10,308 feet high. In the southwest part of the quadrangle, the Pitchstone Plateau rises to altitudes above 8,800 feet. The central and northern parts of the quadrangle are occupied by broad volcanic uplands, as much as 8,600 feet high, which separate the basins of Shoshone Lake, Lewis Lake, and the West Thumb arm of Yellowstone Lake.

PLEISTOCENE GLACIATIONS AND RELATED VOLCANISM

The West Thumb 15' Quadrangle is mostly within a large caldera, whose southern rim lies along the north flank of the Red Mountains (see small map). Tuff, erupted during formation of the caldera and deposited on the mountains, has a K-Ar age of about 600,000 years (J. D. Obradovich, written commun., 1968) and has been petrographically and chemically correlated with the type 0 Pearlette volcanic ash of latest Kansan or early Yarmouth age on the High Plains (Izett and others, 1971). Subsequently great icecaps covered most Yellowstone Park and adjoining areas during several different glaciations. However, in this quadrangle, deposits of only the last two glaciations, the Bull Lake (older) and Pinedale (youngest), are recognized.

After its development 600,000 years ago, the caldera was occupied by a large lake and probably at times by ice of glaciations for which no record has been found in this quadrangle. Within the quadrangle, the lake was separated subsequently into three subsidiary lake basins by successive outpourings of rhyolite flows and by deposition of the Shoshone Lake Tuff Member. The oldest eruption was the Dry Creek (Rd) rhyolite flow (see small map), which has a K-Ar age of about 160,000 years. Shortly thereafter, the Shoshone Lake Tuff Member (Rst) was erupted during development of a small caldera now occupied by the West Thumb arm of Yellowstone Lake (see small map). Its deposition probably caused the initial separation of the basin of Yellowstone Lake from a former larger extension to the southwest that included the present areas of Shoshone and Lewis Lakes. The tuff has yielded K-Ar dates ranging from about 159,000 to about 219,000 years. It therefore probably contains an age contaminant. However as the tuff overlies the 160,000-year-old Dry Creek flow and is overlain by the Spring Creek rhyolite flow (Rsc), the West Thumb rhyolite flow (Rw), and the Aster Creek rhyolite flow (Ra), all K-Ar dated at about 150,000 years, it is estimated to be about 155,000 years old.

The Aster Creek (Ra) and West Thumb (Rw) rhyolite flows were extruded from the south and north, respectively, across the Shoshone Lake Tuff Member and across the rim of the West Thumb caldera. To the northeast, in the Canyon Village 15' Quadrangle, the West Thumb rhyolite flow crossed a narrows in the lake and formed a dam (Richmond, 1971) which raised the water of the lake about 370 feet to an altitude of about 8,100 feet. Subsequently, the Elephant Back rhyolite flow (Re) was extruded across the West Thumb rhyolite flow into the northwest part of this quadrangle to about the position of the shore of that ancient lake. The Elephant Back flow also has a K-Ar age of about 150,000 years, but must be somewhat younger than the West Thumb rhyolite flow on which it rests. Deposits of the lake overlie the West Thumb rhyolite flow and are overlain by Bull Lake Till on the north side of West Thumb (stratigraphic section 3).

BULL LAKE GLACIATION

The Bull Lake Glaciation is estimated to have begun about 120,000 years ago. In the Wind River Mountains of Wyoming and other ranges it comprised two major advances of the ice separated by an interval of soil development whose character suggests complete or nearly complete deglaciation (Richmond, 1962, 1965). In Yellowstone Park, but not in the West Thumb 15' Quadrangle, the stratigraphic relations of deposits of these two advances and of the intervening nonglacial interval to K-Ar dated rhyolite flows indicate that they represent separate glaciations. The earlier advance crossed the surface of a flow 127,000 years old in the Old Faithful 15' Quadrangle to the west. The later advance is younger than nonglacial lake deposits containing a pumice bed about 99,000 years old, and older than the Pitchstone Plateau rhyolite flow about 70,000 years old. In the West Thumb 15' Quadrangle, no evidence for subdivision of the Bull Lake Glaciation was observed, but most of the Bull Lake deposits described are probably of late Bull Lake age.

Bull Lake Till is exposed above the West Thumb rhyolite flow along the north shore of West Thumb (stratigraphic sections 3 and 4), at the gravel pit northwest of Potts Hot Spring Basin (stratigraphic section 6) and south of Duck Lake along the highway west of West Thumb (stratigraphic section 7). Glacial rubble of Bull Lake age lies on uplands in the northwest part of the quadrangle above the upper limit of Pinedale ice (PL), and Bull Lake terminal moraines lie beyond those of Pinedale age outside the boundaries of Yellowstone National Park. It is therefore inferred that, at its maximum, Bull Lake ice covered the entire quadrangle.

The ice probably originated on the high plateaus of the Absaroka Range southeast of the park and flowed down the upper valley of the Yellowstone River into the basin of Yellowstone Lake. This basin served as a center for its development into a cap covering most of the park. Deglaciation was mainly by stagnation. Bull Lake ice-contact gravels occur in the northern part of the basin of Yellowstone Lake and part of the lacustrine sandy gravel (blsg) exposed in the gravel pit northwest of Potts Hot Spring Basin (stratigraphic section 6) may also be of ice-contact origin, as it contains erratic pebbles of andesite. Ice-contact deposits (bkg) and ice-dammed pumiceous lake sand (bsl), exposed in the northern part of the basin of Shoshone Lake, indicate that stagnant ice also lay in that basin during deglaciation. Varved lake silt (bl), exposed beneath Pinedale deposits at stratigraphic section 5 and 8, was probably formed in an open lake near the end of Bull Lake time.

BULL LAKE-PINEDALE INTERGLACIATION

Numerous deposits of lake silt, beneath Pinedale Till and locally underlain by Bull Lake Till, at altitudes up to about 7,980 feet around the basin of Yellowstone Lake indicate that during the Bull Lake-Pinedale interval the lake was about 250 feet higher than at present. Some of the deposits contain wood greater than 42,000 years old (W-2197; Meyer Rubin, written commun., 1969). In this quadrangle, the lacustrine sandy gravel (blsg) exposed in the pit northwest of Potts Hot Spring Basin (stratigraphic section 6) was mostly formed during this interval. The top of the deposit is at an altitude of about 7,920 feet. Pumiceous lake sand exposed as cave fillings in the West Thumb rhyolite flow (Rw) along the north shore of West Thumb (stratigraphic section 2) may also have been deposited during this interval.

The Pitchstone Plateau rhyolite flow (Rp), K-Ar dated at about 70,000 years old, was extruded in the southwest part of the quadrangle along the rim of the old caldera (see small map) and into the basin to the northeast. It spread to the present position of Lewis River above Lewis Lake and probably caused the separation of the basin of Lewis Lake from that of Shoshone Lake.

PINEDALE GLACIATION

Early in Pinedale time, glaciers formed in the higher parts of the Absaroka Range, southeast of the basin of Yellowstone Lake, and flowed west and north into the basin, where the ice overrode lake beds 29,000 years old in the Frank Island 15' Quadrangle (Map 1-642) adjacent to the east. In the basin, the ice developed into a large cap which flowed west and southwest across the West Thumb 15' Quadrangle, where it was joined by valley glaciers formed in cirques in the Red Mountains. A local icecap, centered over the highest part of the Pitchstone Plateau, west of this quadrangle, flowed radially across the plateau surface and into this quadrangle. Though it merged with the main icecap to the north, it failed to do so on the east flank of the plateau where sandy outwash deposits (ps) mark its outer limit. To the east, the upper limit of the main Pinedale icecap is marked by ice-margin outwash deposits, overlain by younger alluvium (fa) and by ice-margin outwash channels along the flank of the plateau between altitudes of 8,600 and 8,550 feet. Across the valley of the Lewis River, the upper limit on the flank of the Red Mountains is at about 9,000 feet. In the northwest part of the quadrangle, the upper limit ranges from 8,900 to 8,600 feet in altitude, and is marked by a zone of thick hummocky till and discontinuous lateral moraines banked against uplands covered by a weathered veneer of Bull Lake glacial rubble (br). Outwash channels lead from the Pinedale ice margin across saddles in the rubble-covered uplands in many places.

Stagnation of the Pinedale icecap-As deglaciation of the Pinedale icecap began, the surface of the ice was lowered and uplands above 8,400 feet altitude north and west of Chickadee Lake and northeast of Shoshone Lake became exposed. The full extent of this recession is unknown but probably was not great. The ice then readvanced and established a maximum position (PM) at about 8,400 feet altitude between the basin of Yellowstone Lake and that of Shoshone Lake. The maximum is marked by local discontinuous lateral moraines, till embankments, and drainage outlets. No evidence of this readvance was noted on the heavily forested slopes northeast of the Pitchstone Plateau or west of the Red Mountains, though the ice probably lay slightly below 8,400 feet altitude.

After the readvance, the ice sheet stagnated and wasted rapidly. Around the north end of the basin of Shoshone Lake, gravelly sand (pkgs) was extensively deposited at altitudes up to 8,320 feet against dead ice by melt waters flowing down Dry Creek and from the headwaters of De Lacy Creek and Herron Creek. As downwasting of the ice in the basin of Shoshone Lake continued, a lake, retained by the ice, developed in the valley of De Lacy Creek. A large delta (pkdg) at the mouth of the canyon of Dry Creek was deposited in this lake at an altitude of about 8,120 feet, or 330 feet above present Shoshone Lake. Elsewhere, around Shoshone Lake, ice-contact deposits (pksg, pkgs, pks) at altitudes below 8,080 feet record subsequent down-wasting of the ice. A lower level of the ice-dammed lake is recorded by a terrace underlain by lake sand (pksl) in the basin of De Lacy Creek and by the top of an ice-contact delta (pksl) near the mouth of Moose Creek. Both are at an altitude of 7,920 feet, or 130 feet above present Shoshone Lake. Lake sand (psl) and varved silt (pl) at and below an altitude of 7,840 feet along lower De Lacy Creek are inferred to have been deposited when at least the eastern part of Shoshone Lake was free of ice, but was retained at this level by stagnant ice along Lewis River above Lewis Lake.

Details of deglaciation in the basin of Lewis Lake are not well recorded. The ice became separated from that in the basin of Yellowstone Lake as the intervening Continental Divide became exposed at an altitude of about 8,000 feet. Within the basin of Lewis Lake, several large ice-contact deposits (pksg, pkgs, pks) at altitudes between 8,000 feet and present lake level record downwasting of the ice without notable ponding. Large melt-water channels, mostly veneered with younger alluvium (fa), that extend south from the Continental Divide toward Lewis Lake, indicate that water overflowed across the divide from the basin of Yellowstone Lake during most of the interval of downwasting. Deglaciation in the basin of Lewis Lake was thus probably rapid.

The history of stagnation of the ice in the West Thumb arm of Yellowstone Lake is documented by extensive deposits. As the ice down-wasted from the maximum position (PM) of its secondary advance west of Chickadee and Nuthatch Lakes, thick ice-contact deposits of sand (pks) were formed in the area of these lakes, which are, in fact, large kettles. Melt waters flowed west through several outwash channels at altitudes between 8,380 and 8,430 feet into drainageways tributary to Dry Creek and the basin of Shoshone Lake. At this time, the Yellowstone Lake basin divide to the south was still covered by ice. As the ice wasted and the divide became exposed, melt waters drained through outlet channels across the divide at successively lower altitudes. The highest channels are a group northwest of West Thumb at altitudes between 8,310 feet (580 feet above Yellowstone Lake) and 8,190 feet (460 feet above Yellowstone Lake). These channels all lead into the headwaters of Dry Creek. Further downwasting of the ice exposed the Continental Divide to the south and southeast. Extensive deposits of lacustral till (plt) along its northeast slope suggest that the ice in this area either was floating or had quiet water locally beneath it. East and west of South Entrance Road, silt (pkl) was deposited in water ponded between the ice and the Continental Divide. These waters drained southwest and south across the divide onto stagnant ice in the basin of Lewis Lake through a series of channels ranging in altitude from 8,150 feet (420 feet above Yellowstone Lake) to 7,950 feet (220 feet above Yellowstone Lake). The lowest are two channels on the divide about one-half and three-quarters of a mile east of South Entrance Road. As other investigators have noted (Howard, 1937, p. 100), none of the channels is deeply scoured and none appears to have been occupied more than a very short time.

After the general level of the ice in the basin of West Thumb fell below 7,950 feet altitude, melt waters were diverted northward along its margin, and drainage to the south ceased. Gravelly sand (pkgs) was deposited by streams marginal to the ice between altitudes of 7,950 and 7,840 feet on both the north and south sides of the basin. The ice-margin lake in the area of South Entrance Road extended itself to the north and east at successively lower levels. A discontinuous terrace was developed at a level about 160 feet above present Yellowstone Lake. A more prominent and nearly continuous terrace, about 110 feet above the lake, shows that, at this level, ponded ice-margin water, extended nearly all around the basin. Minor lake terrace segments, about 90 and 80 feet above the present lake, suggest that the ice-margin water fell rapidly from the 110-foot level to another prominent terrace 60-70 feet above the present lake. This terrace, around the basin of West Thumb, is mainly underlain by sand (psl) or silt (pl), capped by a veneer of beach gravel. On the northeast side of the basin, and extensively elsewhere around Yellowstone Lake, the terrace is characterized by large gravel spits and bars, and by enclosed lagoons, indicative of strong longshore currents found only in a large long-lived open body of water. This terrace is therefore believed to represent the level at which the basin of Yellowstone Lake became free of ice.

Late Pinedale readvance-One or more readvances of the valley glaciers in the Red Mountains occurred in late Pinedale time, probably between about 10,500 and 9,000 years ago. Reoccupied cirque headwalls are sharp and steep, and talus (ta) along them is mostly of Holocene age. The lowest altitude attained by the glaciers ranges from 7,840 to 8,200 feet, depending on local orographic conditions, and averages 8,040 feet. In this quadrangle, no stratigraphic relation can be established between till of late Pinedale age (ptu) and the lake deposits around the basin of West Thumb. However, in the Eagle Peak 15' Quadrangle (Map 1-637), outwash from moraines of late Pinedale age is graded to the shoreline of the terrace 60 feet above Yellowstone Lake.

NEOGLACIATION

After the late Pinedale valley glaciers receded, cirques were empty and slopes were relatively stable during the so-called altithermal interval. Subsequently, during the Temple Lake Stade of Neoglaciation, very small glaciers developed in orographically favored parts of five cirques in the Red Mountains. Their end moraines in four cirques are between 9,400 and 9,240 feet altitude and average 9,310 feet. In the fifth, the deposit, an accumulation at the base of a high cliff on which ice developed, is at 8,360 feet altitude. A small rock glacier, developed at the head of this material during the Gannett Peak Stade, is the only deposit of glacial affinity formed in the Red Mountains in late Neoglacial time.

PINEDALE AND NEOGLACIAL PERIGLACIAL ACTIVITY

Evidence of periglacial frost activity is sparse throughout most of the quadrangle. Talus (pta) of Pinedale age formed at the base of cliffs in the northwest part, and talus flows (ptf) developed locally in the lower part of the talus, especially where this overlay a fault. In the Red Mountains, however, the accumulation of Pinedale and Neoglacial periglacial deposits was widespread. Stable and commonly forested Pinedale talus (pta) and talus flows (ptf) formed along the inner steep headwalls of cirques. Avalanche debris (ad) partly filled avalanche chutes, and formed cones at their base. Debris avalanches and mudflows still occur seasonally. Neoglacial frost rubble (fr) formed a mantle on most upland areas and is commonly characterized by evidence of active creep or solifluction on slopes. A large landslide (ls), developed on the southeast flank of the mountains, is partly stable but locally active. Apparently it first moved during a late phase of the stagnation of Pinedale ice in the basin of Heart Lake and closed a former outlet of the lake to the south at the southeast corner of the quadrangle (see also Frank Island 15' Quadrangle, Map 1-642).

LATE PINEDALE AND POST-PINEDALE LOWERING OF YELLOWSTONE LAKE

After the late Pinedale glacial maximum, Yellowstone Lake began to be lowered from its level 60-65 feet above its present surface. In the area of the West Thumb arm, terraces and associated lake deposits 40 feet and 35 feet above the present level are considered to be of altithermal age. At the time of publication of the Eagle Peak 15' Quadrangle (Map 1-637) (Richmond and Pierce, 1972) they were considered to be of prealtithermal age. Around the south side of the arm, these terraces are underlain chiefly by silt (pl); on the west and north sides chiefly by sand (psl) (stratigraphic section 1). In the area of Pumice Point, they are underlain by gravelly sand (plgs). In the Frank Island 15' Quadrangle (Map 1-642) to the east, plant material from the lower 25 centimeters of peat in a lagoonal depression on the 40-foot terrace has a radiocarbon age of 5,590±250 years (sample W2286; Meyer Rubin, written commun., 1969). The underlying terrace deposits are therefore older than this minimal date. A lower sequence of terraces, 25, 15, and 10 feet above the lake, are of altithermal and younger age. These terraces are underlain mainly by gravelly sand (lgs). Peaty material beneath colluvium overlying the 25-foot terrace in the Canyon Village 15' Quadrangle has a radiocarbon age of 3,500±250 years (sample W2734; Meyer Rubin, written commun., 1972). Charcoal under colluvium overlying the 10-foot terrace in the Canyon Village 15' Quadrangle has a radiocarbon age of 620+250years (sample W1999; Meyer Rubin, written commun., 1968). A terrace 5 feet above present lake level represents the modern storm beach. A post-altithermal stand of Lewis Lake about 8 feet above its present level is marked by beach deposits (lgs) back of a broad marsh at its northeast end.

HYDROTHERMAL ACTIVITY

The products of hydrothermal activity observed in the quadrangle appear to be mostly of post-Pinedale age though some are related to deposits formed during stagnation of the Pinedale ice. Older hydrothermal activity presumably occurred but no positive evidence of it was found. A hydrothermal explosion deposit (phe) around an explosion pit now occupied by Duck Lake is at the level of an ice-dammed lake terrace 110 feet above the present lake. The explosion is believed to have taken place under water as ice-margin waters in that area were lowered suddenly from that level. A mechanism for the origin of similar deposits in the Old Faithful 15' Quadrangle has been proposed (Muffler and others, 1971). The West Thumb Basin is characterized by active mudpots and steaming pools developed on a largely inactive sinter terrace extending from 10 feet to about 40 feet above present lake level. The lake bluff is of banded sinter. Active hot springs occur locally on the terrace and a few active sinter cones lie several inches beneath mean low lake level (Peale, 1883, p. 118) and suggest a slightly lower level of the lake during the recent past. The Potts Hot Spring Basin is characterized by steaming pools and hot springs on a sinter terrace about 10 feet above the lake. Similar sinter terraces occur locally along the lake bluff opposite Carrington Island. To the north, and locally near Pumice Point, deposits of the 10-, 15-, 25-, 40- and 60-foot terraces are partly cemented by hydrothermal silica. Excavation for the marina at Grant Village revealed that gravelly sands of the present lake bottom are well cemented with silica to depths of at least several feet. Tin cans locally embedded in the lake deposits show that the cementation is of very recent age (J. M. Good, Natl. Park Service, written commun., 1968). Drilling tests for water in the area of Grant Village revealed temperatures near the boiling point at depths of about 100 feet (E. R. Cox, oral commun., 1968). Along the south side of West Thumb arm, beach deposits of the 10- and 15-foot terraces are locally cemented by silica, and layers of diatomaceous silt are common near the top of the deposits.

Around the northern part of Shoshone Lake modern beach gravels are locally cemented with silica, and along the western shore of Lewis Lake beach deposits cemented by silica have been locally broken in slabs and upended by lake ice expansion. Hot springs and local sinter mounds are scattered on the alluvial fan (fgs) and marshy deposits (fa) west of Lewis Lake, and a few hot springs occur along Lewis River above the lake and just below its outlet. Areas of hydrothermally altered rhyolite (HA) and local hot springs on the slopes of the Pitchstone Plateau rhyolite flow (Rp) west of Lewis Lake may have localized the deposition of ice-contact deposits (pkgs) in depressions melted in stagnating Pinedale ice. The Heart Lake Geyser Basin is characterized by geysers, hot springs, and fumaroles associated with broad sloping sinter terraces. Hot springs along the upper sector of Witch Creek are very acid. Hydrothermal alteration zones occur along fault zones in the Aster Creek rhyolite flow (Ra).

QUATERNARY FAULTING

In the Red Mountains, several northwest-trending normal faults are, for the most part, regional lineaments that extend far to the south. They intersect the south wall of the caldera that collapsed in association with an eruption of tuff about 600,000 years ago. The south rim of the caldera (see small map) extends along the north flank of the Red Mountains. The faults cut the tuff, and some cut the Aster Creek rhyolite flow, which is about 150,000 years old. A complex of normal faults in the northeast part of the quadrangle is associated with uplift of a resurgent dome in the caldera after its collapse. The dominant faults trend northwest and bound two prominent grabens. Two north-trending normal faults east of Shoshone Lake bound a graben that cuts across the Shoshone Lake Tuff Member, about 155,000 years old. Northeast-trending normal faults in the northern part of the quadrangle cut the West Thumb rhyolite flow and the Elephant Back rhyolite flow, both about 150,000 years old. Mapping of faults was primarily by R. L. Christiansen (U.S. Geological Survey, 1972).

Text from source map: West Thumb 15' Quadrangle

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U.S. Geological Survey, 1972, Geologic map of Yellowstone National Park: U.S. Geol. Survey Misc. Inv. Map 1-711.

References from source map: West Thumb 15' Quadrangle

West Yellowstone 15' Quadrangle

The formal citation for this source.

Waldrop, H. A., 1975, Surficial Geologic Map of the West Yellowstone Quadrangle, Yellowstone National Park and adjoining area, Montana, Wyoming, and Idaho: U.S. Geological Survey, Miscellaneous Investigations Series Map I-648, scale 1:62,500 (*GRI Source Map ID 1153*).

Description of geologic units, prominent graphics and text associated with this source.

Description of Units

ml - Modern lake silt (Quaternary, Neoglaciation (Holocene))

Brownish-gray sandy silt that was deposited on stream gravel (sg) flooded after construction of Hebgen Dam. Exposed by northward tilting of the basin by the Hebgen Lake earthquake of 1959. Less than 1 foot (30 cm) thick.

fa - Fine-grained humic alluvium (Quaternary, Neoglaciation)

Gray to light-brown silt, sand, and humus deposited in seasonal marshes on stream flood plains, in poorly drained meadows, in a few closed depressions on Bull Lake Till (bt), and on unglaciated West Yellowstone rhyolite flow (Ry). Not mapped where thin and discontinuous over stream gravel (sg). Several inches to several feet (0.2-5 m) thick.

sg - Steam gravel (Quaternary, Neoglaciation)

Gray to brown sand, pebbles, and cobbles, predominantly of rhyolite but locally includes moderate amounts of basalt and Lava Creek Tuff of the Yellowstone Group and sparse limestone, quartzite, granite gneiss, and andesite. Underlies flood plain and forms small terraces less than 4 feet (1.2 m) above the Madison River and its South Fork. About 2-20 feet (0.6-6 m) thick.

es - Eolian sand (Quaternary, Neoglaciation)

Gray, fine to very fine grained obsidian sand in irregular dunes 2-8 feet (0.6-2.5 m) high along top edge of bluff on northeast shore of Madison Arm. Locally active; partly stabilized by grass and small trees.

pl - Lake silt (Holocene and/or Pleistocene)

Massive light-yellowish-tan silt and clay in the center of Big Bear Lake basin; mixed with obsidian and lithoidal rhyolite sand at the basin edge; moderately consolidated and plastic when wet; well consolidated when dry. Lower part may be of late Bull Lake age. As much as 70 feet (21 m) thick.

psg - Sandy gravel (Holocene and/or Pleistocene)

Outwash from Pinedale glaciers and local nonglacial stream gravel. Gray to brown small cobbles, pebbles, and sand composed of volcanic rocks, chiefly rhyolite, but on South Fork of Madison River contains some andesite and basalt and sparse amounts of limestone and quartzite. Moderately to well sorted and stratified, unconsolidated. Forms layer 1-3 feet (30-90 cm) thick on well-developed terraces 4-65 feet (1-20 m) above Madison River and its South Fork. Derived mainly from sediments of West Yellowstone Basin (wgs, wsg) in which terraces are cut. Forms alluvial fills as much as 30 feet (9 m) thick along small tributary streams. Locally cemented and forms a conglomerate on east bank of Madison River near Bakers Hole Campground.

pfg - Fan gravel (Holocene and/or Pleistocene)

Same color, composition, and texture as sandy gravel (psg). Forms broad low-gradient outwash fans that overlap sediments of West Yellowstone Basin (wgs, wsg) and Pinedale Till (pt) and head in the valleys of Maple Creek, Cougar Creek, and Madison River east of the quadrangle. Also forms steeper alluvial fans along Denny Creek, the South Fork Madison River, in Jack Straw Basin, and other streams and a coarse boulder fan 1.5 miles (2.4 km) southwest of Big Bear Lake. A few inches (cm) to 30 feet (9 m) thick.

pta - Talus deposit (Holocene and/or Pleistocene)

Angular to subangular blocky rubble, mostly rhyolite, forming steep fans or aprons along valley sides below cliffs, as much as 30 feet (9 m) thick. Deposits inactive and support lichen cover but have little or no tree cover and scant interstitial soil. Small discontinuous talus and boulder aprons on the front of the West Yellowstone rhyolite flow are not mapped.

ptf - Talus-flow deposit (Holocene and/or Pleistocene)

Similar to talus but has concentric flow ridges parallel to front of deposit that indicate downslope movement. Inactive.

pt - Till (Holocene and/or Pleistocene)

Dark-brown to gray subangular to subrounded boulders and cobbles in a pebbly to silty matrix; unsorted and nonstratified. Composed chiefly of basalt and rhyolite but contains moderate amounts of andesite and Precambrian crystalline rocks and sparse amounts of limestone and quartzite. Forms bouldery terminal moraine 20-30 feet (6-10 m) high near Maple Creek in northeast corner of quadrangle; the moraine is segmented by overlapping Pinedale fan gravel (pfg). Till has weakly developed soil less than 1 foot (30 cm) thick; it lacks a loess mantle.

wgs - Sediments of West Yellowstone Basin, gravelly sand (Pleistocene)
wsg - Sediments of West Yellowstone Basin, sandy gravel (Pleistocene)

Gray to dark-gray gravelly sand (wgs); dominantly obsidian, mainly as sand and small pebbles; larger pebbles and small cobbles are mainly lithoidal rhyolite and welded tuff. Deposit forms a large low-gradient compound alluvial fan that heads in mouths of Madison Canyon, Cougar Creek, and Maple Creek east of the quadrangle. Material is coarsest near top of deposit and at eastern head of fan; is finer grained northwestward and is almost all sand around Hebgen Lake. Deposit is unconsolidated, well sorted, and. mostly cross-stratified in straight, medium-angle, medium-scale sets one-half foot (15 cm) to at least 2 feet (60 cm) thick. Some of the gravel has openwork texture. Northwest of the quadrangle the deposit overlies sediments of a lake dammed by terminal moraines of Bull Lake age (Richmond, 1964, p. 227-228). It overlaps Bull Lake Till (bt) at the south, west, and north sides of the basin, and is overlapped by Pinedale fan gravel (pfg) on the east side of the quadrangle. The deposit is 40-100 feet (12-30 m) thick. Loessial silt is mixed with the top 12-18 inches (30-45 cm) of the deposit, but there is no discrete loess cover. Soil on the deposit is weakly developed and less than 1 foot (30 cm) thick. A low-gradient alluvial fan at the junction of the South Fork Madison River and Cream Creek is composed of gray sandy gravel (wsg) consisting mostly of cobbles and pebbles of quartzite, lithoidal rhyolite, basalt, and Precambrian crystalline rocks. Obsidian makes up less than half the deposit, chiefly as sand and pebbles. The deposit is accordant with the fan of gravelly obsidian sand (wgs) but reflects a different provenance. The deposit has stratigraphic relations, structure, and soil similar to those of the gravelly sand (wgs) but has been separated from it by incision of the South Fork Madison River.

bksg - Kame sandy gravel (Pleistocene)

Grayish-brown gravel and sand composed of basalt and rhyolite; fairly well sorted and stratified; unconsolidated; 10-20 feet (3-6 m) thick. Forms a flat-topped bench just west of South Fork Arm. Mantled by grayish-brown loess 5 feet (1.5 m) thick. Soil on gravel beneath loess has light-brownish-yellow B horizon 8-10 inches (20-25 m) thick.

bt - Till and rubble veneer, till (Pleistocene)

Angular to rounded blocks, boulders, and smaller rock fragments in tan to brown sandy to silty matrix; unsorted and nonstratified; massive and compact. Composition varies locally, but is dominantly Lava Creek Tuff of the Yellowstone Group, the predominant local bedrock. It contains abundant erratic boulders of Madison River Basalt (Christiansen and Blank, 1972, p. B16) as much as 10 feet (3 m) in diameter derived from outcrops near the mouth of Madison Canyon east of the quadrangle. Southwest of Mosquito Gulch, the till is almost entirely of Lava Creek Tuff of the Yellowstone Group. In the northwest corner of the quadrangle till contains many Precambrian crystalline rocks derived from outcrops west of Denny Creek and South Fork Arm. Northwest of the West Fork Cream Creek, the till also contains Precambrian crystalline rocks derived from deposits near Tygee Creek (QTd) by downslope creep and earthflow. Mesozoic sedimentary rocks underlying the till in that area are subject to continued landsliding; the mantling Bull Lake Till has been considerably modified by postglacial earthflow action. The till ranges in thickness from about 5 to about 30 feet (1.5 to 9 m). It forms gently rolling topography, chiefly ground moraine, with a few closed depressions and some surface boulders. It is locally covered by Pinedale or post-Bull Lake-pre-Pinedale loess, 2-5 feet (0.6-1.5 m) thick. The loess is in part reworked by solifluction and contains stones derived from the till. Remnants of well-developed soil, as much as 2 feet (60 cm) thick, are preserved on the till beneath the loess in a few places. A weakly developed soil 1-2 feet (30-60 cm) thick is formed on the loess and in many places on the till.

br - Till and rubble veneer, rubble veneer (Pleistocene)

Thin (<5 feet or 1.5 m) and largely discontinuous mantle of blocks, boulders, and smaller fragments in a sandy to silty matrix. Southeast of West Yellowstone chiefly composed of Lava Creek Tuff of the Yellowstone Group and older rhyolite; in the western part of the quadrangle chiefly composed of basalt, trachyandesite, and Lava Creek Tuff of the Yellowstone Group. Rubble also contains erratics of obsidian, Madison River Basalt, rocks of the Absaroka Volcanic Supergroup, and Precambrian crystalline rocks derived from deposits near Tygee Creek (QTd). Occurs on steep slopes and elsewhere above areas of Bull Lake Till (bt). In part glacially deposited; in part the product of rock weathering and mass wasting.

bg - Gravel (Pleistocene)

Coarse gravel and boulders, chiefly of basalt; poorly sorted and stratified; unconsolidated; about 10 feet (3 m) thick. Forms small alluvial fill in terrain of Bull Lake Till (bt) east of the South Fork Madison River in central part of quadrangle.

Ry - West Yellowstone rhyolite flow (Pleistocene)

A rhyolite flow with a K-Ar age of about 105,000 years.

Rb - Buffalo Lake flow (Pleistocene)

An obsidian-rhyolite flow with a K-Ar age of about 156,000 years. Shown only on index map.

pbt - Till and rubble veneer, till (Pleistocene)

Subangular to rounded boulders and smaller rock fragments in plastic silty brown matrix; unsorted and nonstratified; massive and very compact. Stones are mostly Tertiary volcanic rocks, chiefly basalt and trachyandesite, that form most of the underlying bedrock; also contains Lava Creek Tuff of the Yellowstone Group, and colluvium of Precambrian crystalline rocks derived from the deposits near Tygee Creek (QTd). The till ranges in thickness from less than 5 to about 20 feet (1.5 to 6 m). In Tygee Creek Basin it forms ground moraine, with subdued topography, few surface boulders, and no closed depressions. Grades into rubble (pbr) on surrounding slopes. Soil on the till is red, deeply oxidized, and in many places mostly truncated by solifluction. The till bears a mantle of Pinedale and older loess (not mapped) about 4 feet (1.2 m) thick. The loess contains stones probably derived from the till and mixed with the loess by solifluction.

pbr - Till and rubble veneer, rubble veneer (Pleistocene)

Thin (<5 feet or 1.5 m) and largely discontinuous mantle of rock fragments and sandy silt; composed chiefly of basalt and andesite of rocks of Absaroka Volcanic Supergroup; includes erratics of quartzite and of waterworn Absaroka andesite cobbles on some topographic saddles. Occurs on slopes above areas of pre-Bull Lake till (pbt). In part glacially deposited; in part the product of rock weathering and mass wasting.

QTd - Deposits near Tygee Creek (Quaternary or Tertiary)

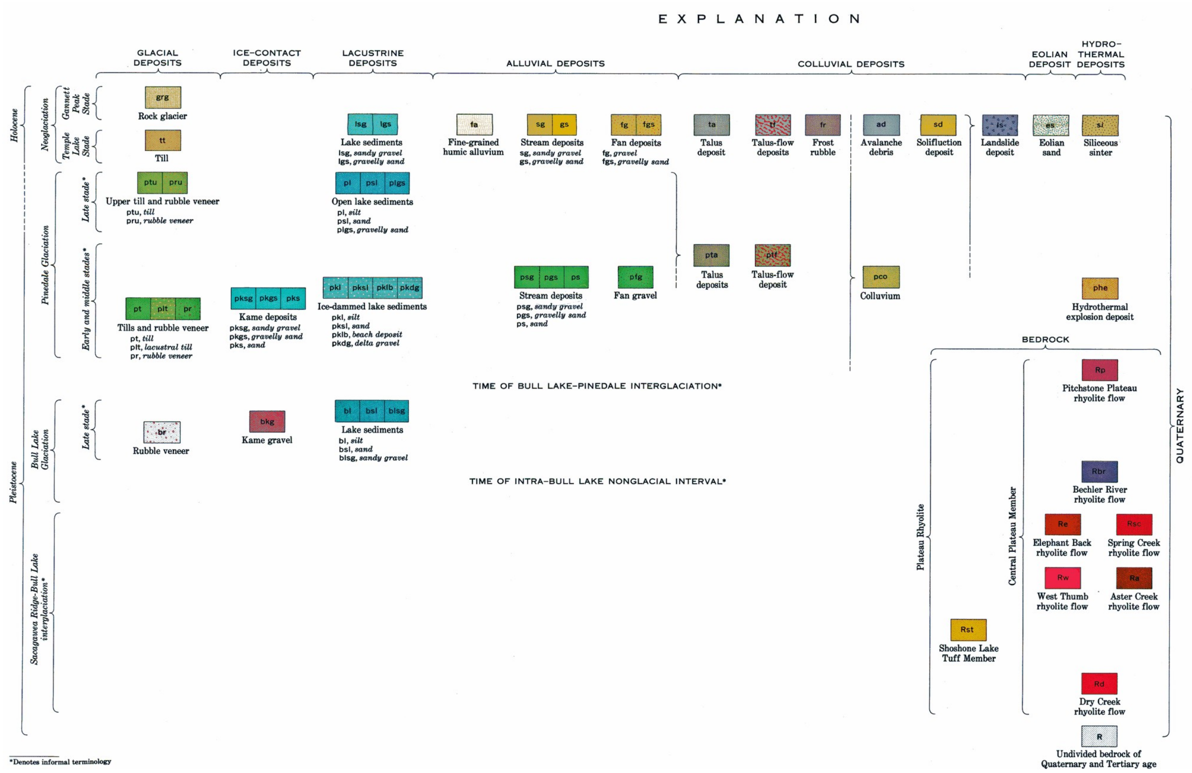
Cap ridge north of Tygee Creek Basin. Consist of three units where exposed in landslide scarp 0.2 mile (0.3 km) west of quadrangle: a lower unit more than 80 feet (24 m) thick containing many large gneiss boulders, a middle unit about 10 feet (3 m) thick of sandy mudstone, and an upper unit 15-20 feet (4.5-6 m) thick also containing many large gneiss boulders. Lower unit rests on Mesozoic shale and sandstone. The bouldery units are virtually identical. Boulders range in diameter from less than 1 foot (0.3 m) to 15 feet (4.5 m), and many are more than 8 feet (2.4 m) in diameter. Most are of granite gneiss; a few cobbles and pebbles are of amphibolite, mica schist, basalt, rhyolite, and vein quartz. The boulders are enclosed in a fine granitic grus matrix that is poorly washed, poorly sorted, and poorly bedded. Many boulders have weathered rinds several inches thick. The middle sandy mudstone unit is massive and moderately lithified and contains abundant euhedral biotite flakes and fairly abundant muscovite; its upper half is oxidized and weathered to a clayey consistency.

R - Bedrock undivided (Quaternary, Paleozoic, and Precambrian age)

Lava Creek Tuff and Mount Jackson Rhyolite of Quaternary age, Paleozoic sedimentary rocks, and Precambrian crystalline rocks undivided 'Volcanic stratigraphy from Christiansen and Blank (1972). K-Ar dates from J. D. Obradovich (written common., 1973).

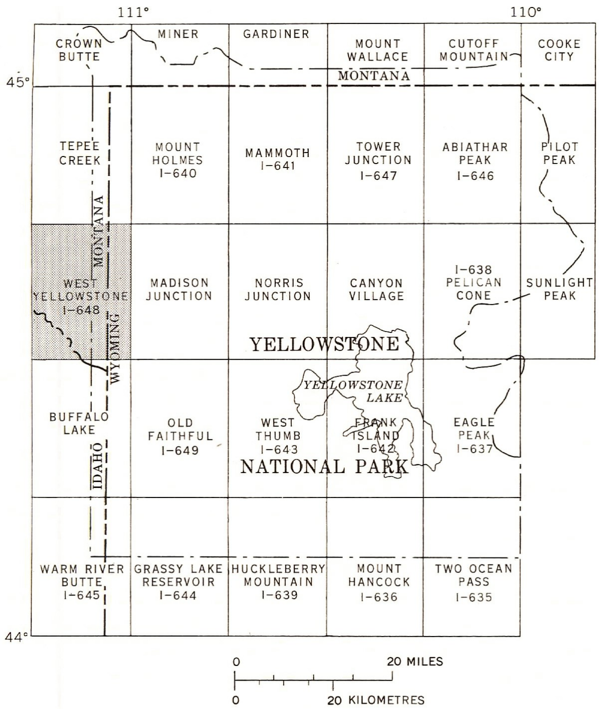
Text from source map: West Yellowstone 15' Quadrangle

Correlation of Units



Graphic from source map: West Yellowstone 15' Quadrangle

Index Map



INDEX MAP OF YELLOWSTONE NATIONAL PARK SHOWING LOCATION OF WEST YELLOWSTONE QUADRANGLE AND PUBLISHED MISCELLANEOUS GEOLOGIC INVESTIGATIONS MAPS

Graphic from source map: West Yellowstone 15' Quadrangle

Rhyolite Flow Map

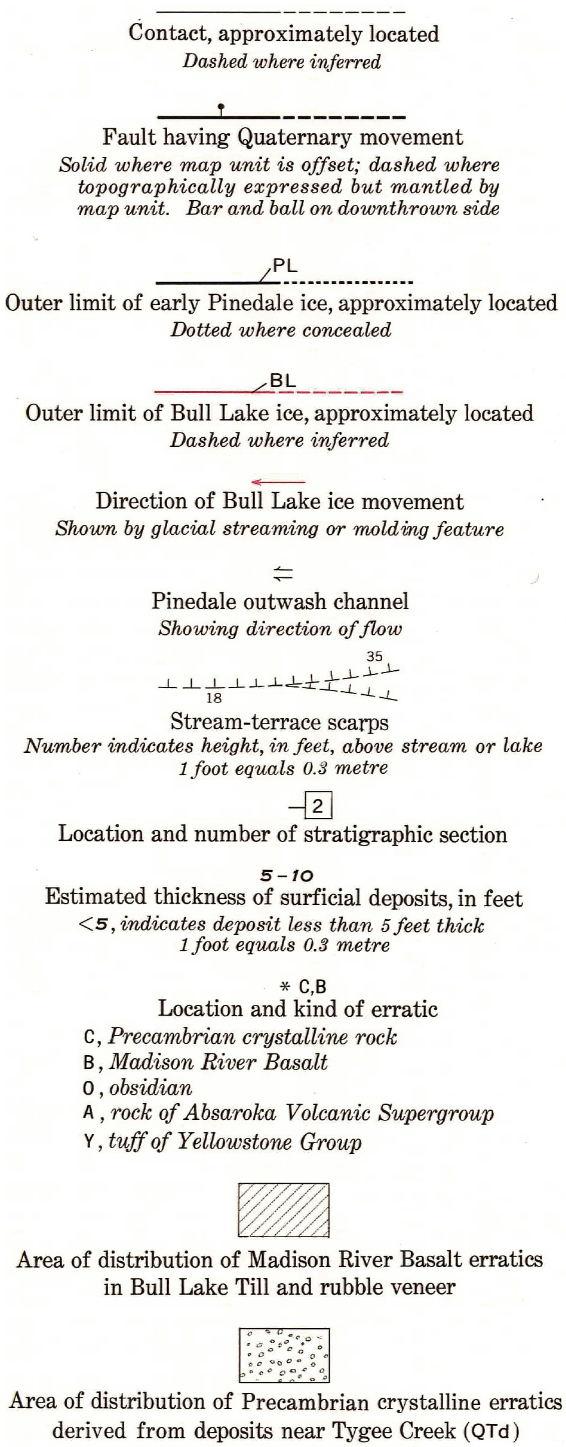
MAP OF WEST YELLOWSTONE QUADRANGLE SHOWING DISTRIBUTION OF QUATERNARY RHYOLITE FLOWS

Modified from "Geologic map of Yellowstone National Park," U.S. Geol. Survey Misc. Geol. Inv. Map I-711, 1972

See Description of Units page for this map to view information about geologic units shown on this graphic.

Graphic from source map: West Yellowstone 15' Quadrangle

Map Legend



Graphic from source map: West Yellowstone 15' Quadrangle

Surficial Geologic History

INTRODUCTION

The eastern part of the quadrangle lies in Yellowstone National Park; the western part is in Gallatin National Forest in Montana and Targhee National Forest in Idaho. West Yellowstone Basin, a broad alluviated basin of low relief, occupies most of the northern part of the quadrangle. The Madison Plateau, an upland formed by rhyolitic flows and tuffs of Quaternary age, occupies the southern part. The Henrys Lake Mountains, composed largely of trachyandesite, andesite, and basalt of Tertiary age, occupy the west edge.

Most of the quadrangle is drained by the Madison River and its South Fork, which flow northwestward into Hebgen Lake, a reservoir impounded behind Hebgen Dam at the northwest corner of West Yellowstone Basin. The southwest corner of the quadrangle is drained by Tygee Creek, Reas Pass Creek, and lesser tributaries to Henrys Fork of the Snake River. The Continental Divide, which separates the Snake and Madison drainages, trends northwest across the Madison Plateau to Reas Pass and northward along the crest of the Henrys Lake Mountains.

The surficial geologic history of West Yellowstone 15' Quadrangle is chiefly a record of successive Pleistocene glaciations, interspersed with episodes of Quaternary faulting and volcanism.

DEPOSITS NEAR TYGEE CREEK

The oldest surficial deposits (QTd) in the quadrangle are a sequence of two boulder beds and an interlayered sandy mudstone that cap the ridge just north of Tygee Creek Basin. Although origin and age of the deposits have not been definitely established, available evidence suggests that the boulder beds were deposited by mudflows, and that the inter-layered mudstone is a secondary volcanic deposit, probably reworked from a volcanic ash. The deposits may be Tertiary in age and are certainly no younger than early Quaternary.

The huge boulders and the poor sorting and stratification of the boulder beds imply deposition by a highly competent nonselective agent; additional characteristics suggest deposition by mudflows rather than by glacial ice or high-velocity floods. The wholly exotic composition of the boulder beds, which rest on Mesozoic sandstone and shale, is not typical of till; the lack of channeling at the base of the upper boulder bed is not typical of flood deposits. Mudflows, however, are capable of carrying material derived from one terrane across another, overrunning different rocks without channeling them appreciably or incorporating them in their deposits. Precambrian crystalline rocks like those in the boulder beds crop out 3 miles (5 km) north of the deposits. Mudflows originating in this terrane could have overrun the Mesozoic sedimentary rocks, depositing the thick exotic boulder beds that now cap the ridge north of Tygee Creek.

The sandy mudstone interlayered with the boulder beds has both volcanic and metamorphic constituents. Although it contains abundant euhedral biotite, which is characteristic of Tertiary volcanic ashes, it also contains muscovite (G. A. Izett, written commun., 1971), which has not been found in the local primary ash deposits but is abundant in the granite gneiss of the underlying boulder bed. This mixture of volcanic and metamorphic components suggests that the mudstone may be a reworked volcanic ash, deposited between episodes of mudflow deposition.

Depth of weathering of the mudstone and boulder beds implies considerable age. Also, presence of Precambrian crystalline erratics derived from the boulder beds in surrounding Bull Lake Till and pre-Bull Lake till indicates that the boulder deposits antedate those tills and are therefore older at least than late Quaternary. But tills of early Quaternary age typically occur on remnants of upland surfaces above subsequently deepened valleys and bear a normal rather than reversed relationship to topography. The thickness of the deposits near Tygee Creek suggests that they were laid down in a topographic basin and that the topography has since been reversed by erosion, leaving them capping a ridgetop. This, together with the fact that biotite flakes in the sandy mudstone are typical of Tertiary rather than Quaternary volcanic ashes, suggests that the deposits accumulated during Tertiary rather than Quaternary time.

In his geologic map of the neighboring Henrys Lake quadrangle to the west, I. J. Witkind (1972) mapped the boulder beds as till of pre-Bull Lake age.

PLEISTOCENE EVENTS

Evidence for at least three Pleistocene glaciations has been found in the Yellowstone National Park area (Richmond, 1970). No deposits in the West Yellowstone 15' Quadrangle can definitely be assigned to early Pleistocene glaciation. During succeeding glaciations—pre-Bull Lake (older), Bull Lake (younger), and Pinedale (youngest)—ice advanced westward into the quadrangle from large icecaps centered over Yellowstone National Park. The pre-Bull Lake glaciation was most extensive; its ice evidently covered the whole quadrangle. Bull Lake ice covered all the quadrangle except the higher part of the Henrys Lake Mountains. Pinedale ice was least extensive and covered only a small area in the northeast corner of the quadrangle.

PRE-BULL LAKE GLACIATION

The extent, centers of ice accumulation, and directions of ice movement of pre-Bull Lake glaciations are imperfectly known in the Yellowstone area, largely because evidence for them is in most places obscured by deposits of later glaciations. Pre-Bull Lake till, outwash, and lake deposits are covered by Bull Lake Till and outwash north of the West Yellowstone 15' Quadrangle (Richmond, 1964, p. 224-225). Deposits of a pre-Bull Lake glaciation lie on the upper slopes of the Henrys Lake Mountains beyond the limit of Bull Lake ice. The deposits bear sparse erratics of weathered andesite and basalt of Tertiary age, welded tuff and quartzite, and, from Tygee Creek Basin northward, abundant erratics of Precambrian crystalline rocks derived from the deposits near Tygee Creek (QTd). The distribution of quartzite and metamorphic erratics in the till south of their source suggests that pre-Bull Lake ice moved southward over the Henrys Lake Mountains, possibly from an icecap on the Madison Range to the northwest, to merge in this area with ice moving westward from Yellowstone National Park. At that time ice must have been more than 2,000 feet (610 m) thick over West Yellowstone Basin.

BULL LAKE GLACIATION

During the Bull Lake Glaciation ice from large icecaps centered over Yellowstone National Park advanced westward across the West Yellowstone 15' Quadrangle and up the eastern flank of the Henrys Lake Mountains. The terminal moraines of that glaciation loop around Horse Butte, just north of the northwest corner of the quadrangle (Alden, 1953, p. 178; Richmond, 1964, p. 225). In this quadrangle, the greatest extent of the Bull Lake advance is not marked by end moraines but is mapped on the basis of distribution of erratics. On the hillside west of South Fork Arm of Hebgen Lake, the boundary is mapped on the upslope limit of erratics of Madison River Basalt, which were derived from outcrops of flows near the east edge of the quadrangle. The upslope limit of these erratics defines a contact that rises regularly southward about 100 feet per mile (19 m per km) into the valley of Denny Creek west of the quadrangle.

South of the Denny Creek valley the Bull Lake boundary cannot be mapped on the basis of the upslope limit of Madison River Basalt erratics, partly because all erratics diminish in the discontinuous glacial rubble (br) below the contact and partly because that area lies southwest of the fan of distribution of erratics heading at the Madison River Basalt outcrops. The boundary between pre-Bull Lake rubble (pbr) and Bull Lake rubble (br) is inferred from distribution of Precambrian crystalline and obsidian erratics and from weathering of tills above and below the contact. In the valleys of Buttermilk and Cream Creeks, within the limit of Bull Lake ice, Precambrian crystalline erratics derived colluvially from the deposits near Tygee Creek (QTd) lie on small ridgetops that rise above the general slope. The erratics could therefore have been emplaced by glacial transport but not by mass wasting. They do not appear on similar ridgetops above the boundary. On the south and southeast slopes of the Henrys Lake Mountains, numerous erratics of a distinctive massive obsidian are found to an altitude of nearly 8,000 feet (2,440 m), but not above. These obsidian erratics could not have come from the West Yellowstone rhyolite flow (ry), which is younger than the early Bull Lake Glaciation, but they could have come from the underlying Buffalo Lake rhyolite flow which has a K-Ar age of about 156,000 years (J. D. Obradovich, written commun., 1972) and, thus, is probably younger than the pre-Bull Lake glaciation. If so, the upper limit of these obsidian erratics on the Henrys Lake Mountains defines the limit of the Bull Lake advance. Pre-Bull Lake till in Tygee Creek Basin (stratigraphic section 3), beyond the Bull Lake limit, is much more deeply weathered than Bull Lake Till in stratigraphic sections 1 and 2. As inferred from distribution of Precambrian crystalline and obsidian erratics, the Bull Lake drift boundary continues to rise about 100 feet per mile (19 m per km) southward to nearly 8,000 feet (2,440 m) at the Continental Divide on the south end of the Henrys Lake Mountains.

Bull Lake Till (bt) in the quadrangle forms gently rolling ground moraine, locally as much as 30 feet (9 m) thick, with some surface boulders and a local loess mantle 2-5 feet (0.6-1.5 m) thick. Thick till lies generally on low gentle slopes flanking the south and west sides of West Yellowstone Basin. It grades into discontinuous glacial rubble (br) on steeper, higher slopes. Although the till forms massive end moraines around Horse Butte, north of the Madison Arm of Hebgen Lake, in most of the quadrangle it has little morainal form. Road-cuts on prominent northwest-trending ridges 3 miles (5 km) southwest of West Yellowstone reveal that they are bedrock ridges mantled by thick till, rather than lateral moraines. The ridges parallel the trend of several faults having Quaternary displacement (U.S. Geological Survey, 1972; Myers and Hamilton, 1964, pl. 5); they may have been produced by faulting.

South and west of West Yellowstone large erratics of Madison River Basalt form a conspicuous part of the Bull Lake Till (bt), which consists chiefly of Lava Creek Tuff of the Yellowstone Group. The basalt erratics can be traced to an altitude of almost 8,000 feet (2,440 m) 2 miles (3.2 km) north of Big Bear Lake and as high as 6,800 feet (2,090 m) at the northwest edge of the quadrangle. Southwest of Mosquito Gulch the basalt erratics disappear, and the till consists almost entirely of fragments of Lava Creek Tuff of the Yellowstone Group.

Evidence of the Bull Lake ice advance is preserved beneath the sediments of West Yellowstone Basin (wgs, wsg). On drillers' logs of water wells, Richmond (1964, p. 227) identified bouldery Bull Lake Till beneath yellow Bull Lake lake silt and sand that is overlain by about 80 feet (24 m) of obsidian sand (wgs).

A flat-topped bench composed of kame gravel (bksg) just west of South Fork Arm records a period of stagnation during recession of the Bull Lake ice. Similar low benches nearby may contain kame gravel rather than till beneath their thick loess mantle.

WEST YELLOWSTONE RHYOLITE FLOW OF THE PLATEAU RHYOLITE

The West Yellowstone rhyolite flow has a K-Ar age of about 105,000 years (J. D. Obradovich, written commun., 1973). In the southern part of the quadrangle, terrain mantled by Bull Lake glacial deposits was overrun by the West Yellowstone flow (Richmond, 1964, p. 228-229). The flow was not glaciated by late Bull Lake ice in this quadrangle, but, in the Madison Junction 15' Quadrangle to the east, cemented kame deposits provisionally correlated with the late Bull Lake advance lie on the flow top. Studies of the morphology of the flow by R. L. Christiansen (oral commun., 1972) have indicated that its east edge and part of its north edge must have advanced against glacial ice. These relations suggest that the flow may have been emplaced during recession of the early stade of Bull Lake Glaciation. If so, Bull Lake glacial deposits in the West Yellowstone 15' Quadrangle represent only the early stade of that glaciation; ice from the late stade probably did not advance into the West Yellowstone Basin.

BULL LAKE-PINEDALE INTERGLACIAL INTERVAL

In this quadrangle the interval between the Bull Lake and Pinedale Glaciations is recorded chiefly by deposition of lake sediments and the obsidian sand and gravel (wgs, wsg) that form the sediments of

West Yellowstone Basin. The obsidian sand and gravel rest on silty clay 10-30 feet (3-9 m) thick deposited in a lake dammed by the Bull Lake terminal moraines (Richmond, 1964, p. 227). The lake probably formed during recession of the early Bull Lake ice; thickness of the lake sediments suggests that they may have accumulated through most of late Bull Lake time before the moraine was breached and the lake drained. Obsidian sand and gravel overlying the lake sediments probably were derived from obsidian-rhyolite flows in Yellowstone National Park (Hamilton, in Richmond, 1964, p. 228). Emplacement of the West Yellowstone flow against Bull Lake ice would have granulated much of the obsidian breccia of the flow front, and stream transport of the brittle obsidian would fragment it still more. Although the lowest part of the obsidian sand and gravel may have been deposited during late Bull Lake time, the major, upper part was probably deposited during the Bull Lake-Pinedale interglacial interval. Obsidian hydration-rim dating and studies of bedding structures (K. L. Pierce, oral commun., 1973) suggest that at least the upper third of the deposit may have originated as proglacial outwash deposited by glacier-burst floods during the early Pinedale advance. The floods could have resulted from catastrophic drainage of an ice-dammed lake that may have occupied the geyser basins of Madison Junction 15' Quadrangle to the east.

A moderately well developed soil formed on the Bull Lake Till (bt) in West Yellowstone Basin before accumulation of 2-5 feet (0.6-1.5 m) of overlying loess (stratigraphic sections 1, 2). Solifluction and frost heaving have truncated the soil profile and have mixed stones from the till into the loess. Most of the loess mantle probably accumulated during the Bull Lake-Pinedale interglacial interval, concurrently with deposition of sediments of West Yellowstone Basin (wgs, wsg). A thinner less mature soil similar to the soil on Pinedale Till has developed on the loess and on the sediments of West Yellowstone Basin.

PINEDALE GLACIATION AND PERIGLACIAL ACTIVITY

The Pinedale Glaciation was much less extensive than the Bull Lake Glaciation in the West Yellowstone area. During the early stade of the Pinedale, a small tongue from the Yellowstone icecap advanced westward into the area near the junction of Maple and Cougar Creeks. Part of the bouldery Pinedale terminal moraine there is segmented by overlapping younger Pinedale fan gravel (pfg) that also conceals the southeastward extension of the early Pinedale boundary to its reappearance in the moraine at the mouth of the canyon of Cougar Creek 1 mile (1.6 km) east of the quadrangle. The limit of early Pinedale ice in the Madison River drainage is marked by a large multiple terminal moraine at the mouth of Madison Canyon, one-half mile (0.8 km) east of the West Yellowstone 15' Quadrangle. The middle and late stades of Pinedale Glaciation were successively much less extensive than the early stade, and had slight effect on surficial deposits in the quadrangle other than intensification of alluvial and periglacial processes.

During retreat of the early Pinedale ice, outwash from the Madison River and Maple Creek-Cougar Creek tongues built low gradient coalescing fans of sand and gravel (pfg) across the east edge of West Yellowstone Basin. The fans are scoured by shallow distributary channels; they overlap and feather out westward into the sediments of West Yellowstone Basin (wgs). Small deposits of fan gravel (pfg) and sandy stream gravel (psg) also formed in the quadrangle, probably during early and middle Pinedale time. The deposit in Jack Straw Basin probably resulted from partial blockage of that valley by the West Yellowstone flow.

After Pinedale fan gravel (pfg) was deposited, the Madison River incised its course across West Yellowstone Basin, depositing the reworked sand and gravel (psg) on a series of unpaired terraces cut into the sediments of West Yellowstone Basin (wgs). The wide swath of gravel covered terraces south of Madison Arm of Hebgen Lake contrasts with the narrow, discontinuous terraces north of Madison Arm, indicating that the Madison River shifted laterally northward during incision, a shift that may have been produced by northward tilting of West Yellowstone Basin. Small terraces in gravel deposits east of South Riverside Cabin and along South Fork Arm probably were cut about the same time as those along the Madison River.

Big Bear Lake occupies a closed basin between the West Yellowstone flow and an older rhyolite flow. The basin probably originated in this manner: ice of the early stade of the Bull Lake Glaciation occupying a valley on the southeast side of the older flow locally blocked advance of the West Yellowstone flow, causing it to seal off the lower end of the valley rather than fill it. The basin has never had a through-flowing stream and has, therefore, acted as a trap for lacustrine and eolian sediments. Closed drainage and sheltered position have favored deposition of windblown silt in the basin that has not accumulated to significant thickness on the surrounding, more exposed plateau top. After enough silt accumulated to seal the permeable rhyolite floor, the basin probably contained a lake that persisted in some form through much of post-West Yellowstone flow time; the bulk of the silt that was blown or washed into the basin was ultimately deposited in the lake and is therefore mapped as lake silt (pl). The deposit ranges in age from possible late Bull Lake through Pinedale.

Big Bear Lake does not seem to be a remnant of the lake in which the silt was deposited, but a new lake occupying troughs formed in deposits of an older lake. Rather than being a shallow subcircular pond rimmed with aquatic plants and marsh vegetation, as most closed-basin lakes on the plateau top are, it has a conspicuous gridlike shape, is more than 20 feet (6 m) deep even in its narrowest arms, and contains few aquatic plants typical of stagnant plateau-top ponds. The lake occupies rather straight narrow intersecting arms that trend northeast and northwest, parallel to several Quaternary faults and joints; it is floored and banked by massive lake silt (p1) that underlies a forested flat 15 to 20 feet (4.5-6 m) above existing lake level and was clearly deposited before the present lake formed. The record of seismic activity in the West Yellowstone area and the lake's peculiar gridlike shape and unusual depth suggest that the new lake occupies troughs which may have been formed by sapping of older lake silt through recent joints or faults in underlying bedrock.

The frost climate accompanying Pinedale Glaciation produced several talus (pta) and talus-flow (ptf) deposits along valley walls on the West Yellowstone flow and on older volcanic rocks. The deposits have been only sporadically active since Pinedale time.

HOLOCENE EVENTS

Neoglacial activity during Holocene time was restricted to a few high cirques in Yellowstone National Park and neighboring mountain ranges; surficial processes have produced few changes in the landscape of the West Yellowstone 15' Quadrangle since the end of Pinedale Glaciation. The Madison River and its South Fork have cut down 2-5 feet (0.6-1.5 m) below the level of Pinedale fan and terrace deposits (pfg, psg), depositing the reworked gravel (sg) on their flood plains. Fine-grained humic alluvium (fa) has accumulated in marshy areas of flood plains and meadows. Eolian obsidian sand (es) blown from the bare lake bluff north of Madison Arm has accumulated in a discontinuous strip along the top edge of the bluff. Modern lake silt (ml) that accumulated on stream gravel (sg) flooded after the construction of Hebgen Dam was exposed above lake level by northward tilting of West Yellowstone Basin during the Hebgen Lake earthquake of 1959.

Continuing seismic activity in the quadrangle is recorded by faults that offset Pleistocene and Holocene deposits. In a study of deformation accompanying the Hebgen Lake earthquake, Myers and Hamilton (1964, p. 62-63, pl. 5) found that many of the faults, fissures, and monoclines formed by that earthquake in the surficial deposits follow preexisting faults and that there is evidence for repeated offset on those faults during late Quaternary time. The northwest-trending till-draped ridges southwest of West Yellowstone and the gridlike pattern of the arms of Big Bear Lake may be other expressions of the same seismic activity.

Text from source map: West Yellowstone 15' Quadrangle

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References from source map: West Yellowstone 15' Quadrangle

Yellowstone National Park

The formal citation for this source.

U.S. Geological Survey, 1972, Surficial Geologic Map of Yellowstone National Park: U.S. Geological Survey, Miscellaneous Investigations Series Map I-710, scale 1:125,000 (*GRI Source Map ID 1154*).

Description of geologic units, prominent graphics and text associated with this source.

Description of Units

fa - Fine-grained humic alluvium (Quaternary, Neoglaciation)
Overlies sand and gravel (sg) in valleys.

ta - Talus (Quaternary)
Mostly blocky deposits, but includes some pebblescrees and block streams. Mostly of Neoglacial and late Pinedale age.

ds - Diatomaceous silt (Quaternary)
White; commonly present downstream from hotspring areas. Mostly of Neoglacial age.

si - Siliceous sinter (Quaternary)
Hydrated silica deposits forming cones, terraces, and aprons around active and inactive hotspring areas. Mostly of Neoglacial age.

pg - Sand and gravel (Holocene and/or Pleistocene)
Outwash, alluvial fan, or terrace deposit; sand to boulder size. Locally in part of late Pinedale age.

pt - Till (Holocene and/or Pleistocene)
Stony ground moraine and local end moraine; brownish gray and silty in eastern part of Park, gray and sandy in western part, gray and clayey in Gallatin Range and Mammoth area; includes thin glacial rubble,mostly locally derived, on some uplands. Typically bears weak zonal soil oxidized less than 1 foot in depth. Pinedale till beyond maximum limit of Pinedale ice (PL) is equivalent to ut of late Bull Lake or Pinedale age.

bk - Kame sand and gravel (Pleistocene)
Ice-contact fluvioglacial deposits and local inwash deposits forming terraces, mounds, ridges, fans, and a few eskers. Around Yellowstone Lake, deposits lie from 70 to 770 feet above lake.

bt - Till (Pleistocene)
Stony ground moraine; gray where sandy, brownish gray where silty; commonly compact. Soil oxidized 11/2-4 feet in depth. Locally covered by loessal or solifluction mantle. Deposits include thin glacial rubble, mostly locally derived, on some uplands. May include some deposits of early stade in northwest part of Park.

R - Rhyolite flows, basalt flows, ash-flow tuffs, and pre-Quaternary rocks (Quaternary and pre-Quaternary)
Potassium-argon (K-Ar) dated rhyolite flows and tuffs. Central Plateau Member:

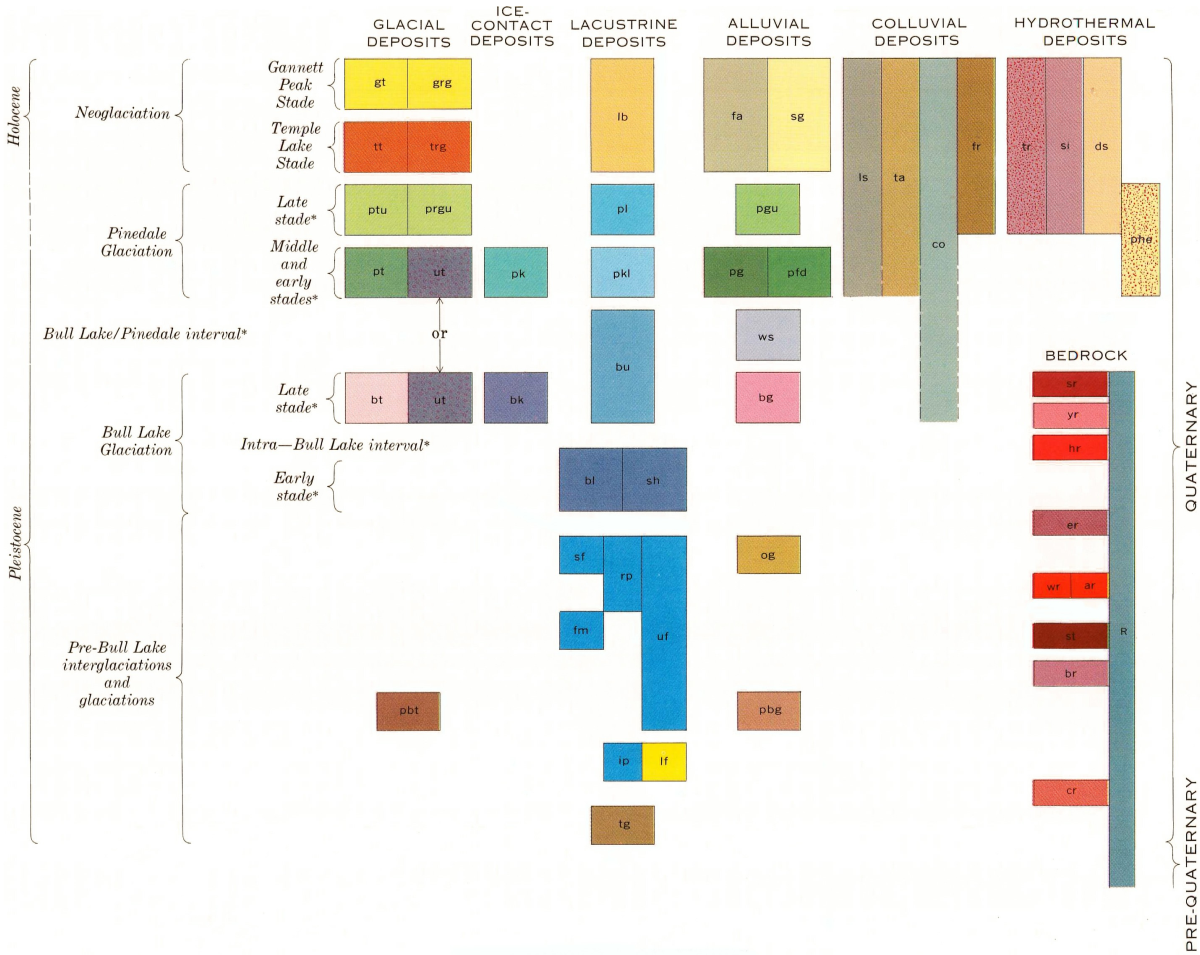
yr - West Yellowstone flow (Pleistocene)
K-Ar age about 120,000 years.

br - Buffalo Lake flow (Pleistocene)

K-Ar age > 180,000 years.

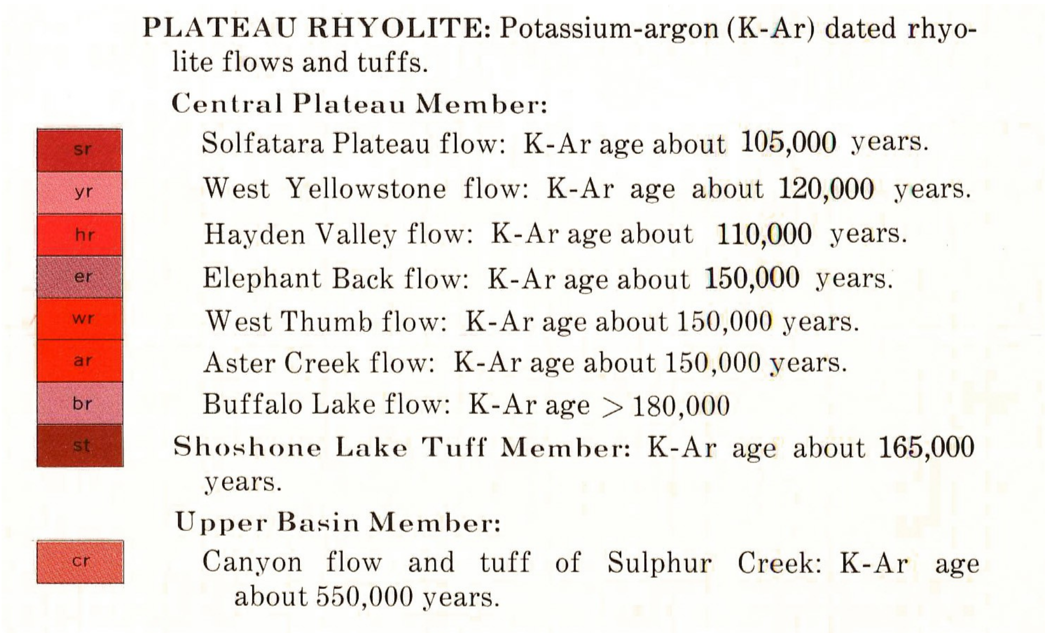
Text from source map: Yellowstone National Park

Correlation of Units



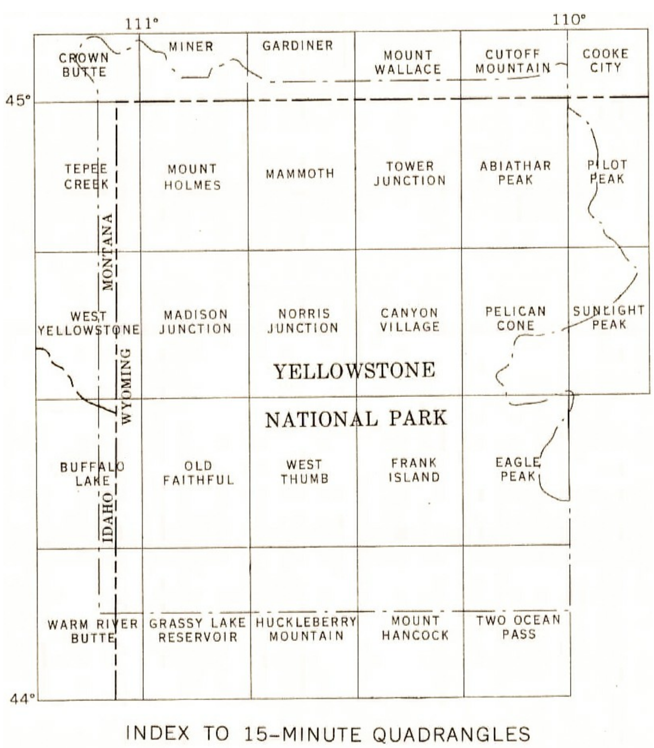
Graphic from source map: Yellowstone National Park

Plateau Rhyolite



Graphic from source map: [Yellowstone National Park]

Index Map

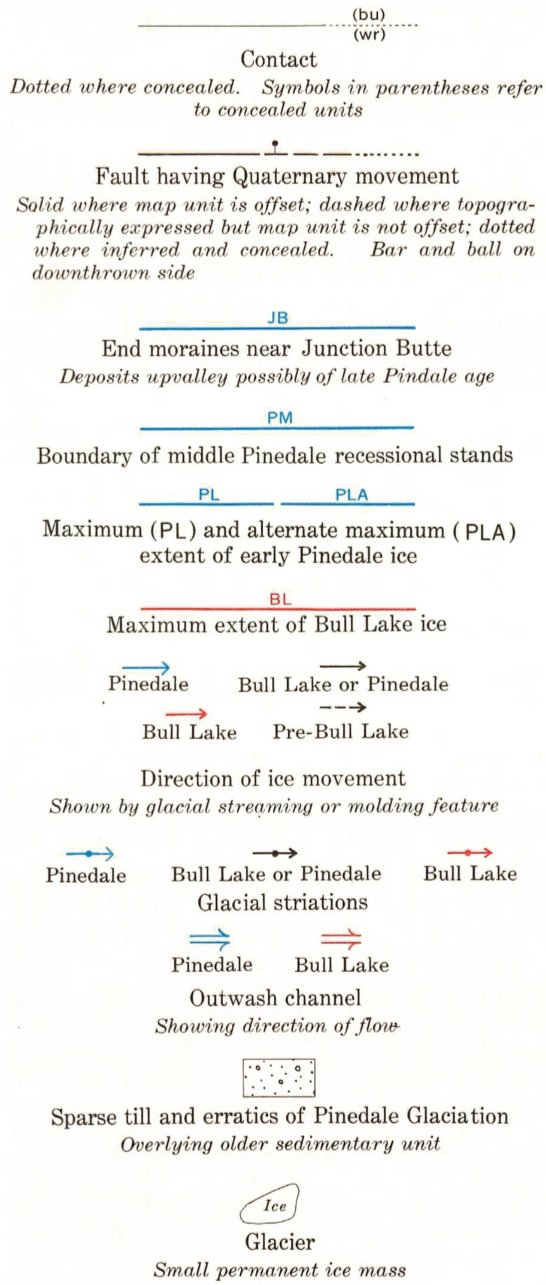


Graphic from source map: [Yellowstone National Park]

Location Map

Graphic from source map: Yellowstone National Park

Map Legend



Graphic from source map: Yellowstone National Park

References

Geology mapped by G. M. Richmond, K. L. Pierce and H. A. Waldrop, 1966-70, and compiled with modifications from quadrangle maps at 1:62,500.

Faults having Quaternary movement mapped in cooperation with R. L. Christiansen, W. R. Keefer, H. J. Prostka, E. T. Ruppel, and H. W. Smedes.

Identification of rhyolite flows by R. L. Christiansen, (U.S. Geological Survey, 1972, Geologic map of Yellowstone National Park; U.S. Geol. Survey Misc. Inv. Map |-711).

Preliminary potassium-argon (K-Ar) dates by J. D. Obradovich. Carbon-14 (C-14) dates by Meyer Rubin

References from source map: Yellowstone National Park

GRI Digital Data Credits

This document was developed and completed by Jake Suri and James Chappell (Colorado State University) for the NPS Geologic Resources Division (GRD) Geologic Resources Inventory (GRI) Program. Quality control of this document by James Chappell and Stephanie O'Meara (Colorado State University).

The information in this document was compiled from GRI source maps, and intended to accompany the digital geologic-GIS map(s) and other digital data for Yellowstone National Park, Wyoming, Montana and Idaho (YELL_surficial) developed by James Chappell, Stephanie O'Meara, James Winter, Ronald Karpilo, Jake Suri, Sarah Lowe, Philip Reiker, Jason Isherwood, Heather Stanton, Tim Cleland, Georgia Hybels (Colorado State University) and Andrea Croskrey (NPS GRD) (see the GRI Digital Maps and Source Map Citations section of this document for all sources used by the GRI in the completion of this document and related GRI digital geologic-GIS maps).

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