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

Devils Postpile National Monument

GRI Ancillary Map Information Document

Produced to accompany the Geologic Resources Inventory (GRI) Digital Geologic Data for Devils Postpile National Monument

depo_geology.pdf

Version: 9/29/2022

Geologic Resources Inventory Map Document for Devils Postpile National Monument

Table of Contents

Geologic Resources Inventory Map Document 1
About the NPS Geologic Resources Inventory Program 3
GRI Digital Maps and Source Map Citations 5
Index Map 6
Map Unit List 7
Map Unit Descriptions 10
Qpe - Phreatic ejecta (late Holocene) 10
Qp - Pumice deposits (late Holocene) 11
Qal - Alluvium, undivided (Holocene and late Pleistocene) 11
Qric - Rhyolite and rhyodacite of Inyo chain (Holocene) 11
Qrcd - Rhyolite of Cratered Dome (Holocene) 12
Qrcw - Rhyolite of caldera wall (Holocene) 13
Qrnd - Rhyolite of North Deadman Creek Dome (Holocene) 13
Qbrc - Basalt of Red Cones (Holocene) 13
Qav - Rockfall avalanche deposits (Holocene and late Pleistocene) 15
Qs - Surficial deposits, undivided (Holocene and late Pleistocene) 15
Qgud - Undivided glacial deposits (late and middle Pleistocene) 16
Qgcc - Till of Cold Water Canyon (late Pleistocene) 17
Qgdc - Till of Dry Creek (late Pleistocene) 18
Qglb - Till derived from Lakes Basin (late Pleistocene) 18
Qgmm - Till derived from Mammoth Mountain (late Pleistocene) 18
Qmdn - Basaltic trachyandesite northeast of Deadman Pass (late Pleistocene) 19
Qdnw - Trachydacites of northwest moat (late Pleistocene) 20
Qbhl - Basalt of Horseshoe Lake (late Pleistocene) 22
Qmcv - Basaltic trachyandesite south of Crestview (late Pleistocene) 22
Qrss - Alkalic rhyodacite of Solitude ski run (late Pleistocene) 23
Qdlp - Trachydacite of Lincoln Peak (late Pleistocene) 23
Qddu - Trachydacite of upper Dragons Back (late Pleistocene) 23
Qdgr - Trachydacite of Gold Rush Express (late Pleistocene) 24
Qddl - Trachydacite of lower Dragons Back (late Pleistocene) 24
Qdbp - Trachydacite of Bottomless Pit (late Pleistocene) 25
Qeb - Explosion breccia deposit of Bailey (late Pleistocene) 25
Qrsq - Alkalic rhyodacite of Quicksilver ski run (late Pleistocene) 25
Qrmf - Alkalic rhyodacite of Mammoth Mountain fumarole (late Pleistocene) 26
Qdsu - Trachydacite of Mammoth Mountain summit (late Pleistocene) 26
Qdfl - Trachydacite of Face Lift (late Pleistocene) 26
Qdrc - Trachydacite of upper Reds Creek (late Pleistocene) 27
Qdnk - Trachydacite of North Knob (late Pleistocene) 27
Qdnh - Trachydacite north of Horseshoe Lake (late Pleistocene) 27
Qmsd - Basaltic trachyandesite scoria southeast of Dry Creek (late Pleistocene) 28
Qdms - Trachydacite of McCoy Station (late Pleistocene) 28
Qmnd - Basaltic trachyandesite northwest of Dry Creek (late Pleistocene) 28
Qdml - Trachydacite of Main Lodge Coulee (late Pleistocene) 29
Qdsk - Trachydacite of Skyline Dome (late Pleistocene) 29
Qdwr - Trachydacite of White Bark Ridge (late Pleistocene) 29

Qdtl - Trachydacite of Twin Lakes outlet (late Pleistocene) 30
Qrce - Alkalic rhyodacite of Canyon Express (late Pleistocene) 30
Qdsd - Trachydacite of South Summit Dome (late Pleistocene) 31
Qd61 - Trachydacite of Dome 2861 (late Pleistocene) 31
Qmdp - Basaltic trachyandesite of Devils Postpile (late Pleistocene) 32
Qrrc - Alkalic rhyodacite of Reds Creek (late Pleistocene) 32
Qamp - Trachyandesite of Mammoth Pass (late Pleistocene) 33
Qbar - Trachybasalt of Arcularius Ranch (late Pleistocene) 34
Qbar1 - Trachybasalt of Arcularius Ranch, single flow (late Pleistocene) 34
Qbmn - Trachybasalt northeast of Minaret Summit (late Pleistocene) 34
Qbmn1 - Trachybasalt northeast of Minaret Summit, southwesternmost proximal lava (late Pleistocene) 35
Qaml - Trachyandesite of McLeod Lake (late Pleistocene) 35
Qdrf - Trachydacite of Rainbow Falls (late Pleistocene) 35
Qbmc - Basalt of Mammoth Crest (late Pleistocene) 36
Qddc - Trachydacite of Dry Creek (late Pleistocene) 37
Qrdm - Rhyolite of Deer Mountain (late Pleistocene) 37
Qd81 - Trachydacite of Dome 2781 (late Pleistocene) 37
Qa62 - Trachyandesite of Cone 2962 (late Pleistocene) 38
Qmss - Basaltic trachyandesite of upper Soda Springs (late Pleistocene) 38
Qbed - Basalt east of Dry Creek (late Pleistocene) 38
Qmdm - Basaltic trachyandesite of Deer Mountain (late or middle Pleistocene) 39
Qaic - Trachyandesite of Inyo Craters (late middle Pleistocene) 39
Qapb - Trachyandesite of Pumice Butte (middle Pleistocene) 40
Qbdc - Trachybasalt west of Deer Creek (middle Pleistocene) 40
Qbcf - Trachybasalt south of Crater Flat (middle Pleistocene) 40
Qmcl - Basaltic trachyandesite of Canyon Lodge (middle Pleistocene) 41
Qrbt - Bishop Tuff (middle Pleistocene) 42
Tbld - Trachybasalt south of Lost Dog Lake (Pliocene) 42
Tdww - Trachydacite of White Wing Mountain (Pliocene) 42
Td65 - Trachydacite of Dome 2965 (Pliocene) 43
Tmcv - Basaltic trachyandesite of Crestview (Pliocene) 43
Tbpl - Trachybasalt east of Pond Lily Lake (Pliocene) 43
Tmcr - Basaltic trachyandesite of Mammoth Crest (Pliocene) 44
Tdud - Trachydacite complex of upper Deadman Creek (Pliocene) 44
Tmsd - Basaltic trachyandesite south of Deer Creek (Pliocene?) 44
Tmcm - Basaltic trachyandesite south of Upper Crater Meadow (Pliocene) 44
Tdsd - Trachydacite of Dome 3321 (Pliocene) 45
Tdsj - Trachydacite block-and-ash-flow deposits of San Joaquin Ridge (Pliocene) 45
Tdpd - Trachydacite pyroclastic-density-current deposit of Deadman Pass (Pliocene) 45
Taww - Trachyandesite north of White Wing Camp (Pliocene) 46
Tmcw - Basaltic trachyandesite west and east of Obsidian flow (Pliocene) 46
Tbtb - Basalt of The Buttresses (Pliocene) 47
Tmww - Basaltic trachyandesite of White Wing Mountain (Pliocene?) 47
Tbdp - Trachybasalt of Deadman Pass (Pliocene) 47
Tacc - Trachyandesite of Crater Creek (Pliocene) 48
Tasj - Trachyandesite of San Joaquin River (Miocene) 48
Kmo - Mono Creek Granite (Late Cretaceous) 49
Kjl - Granite of June Lake (Late Cretaceous) 49
MZgd - Granodiorite northeast of Minaret Summit (Mesozoic) 49
MZmv - Metavolcanic rocks of Ritter Range pendant (Mesozoic) 50
PZms - Metasedimentary rocks of Mount Morrison pendant (Paleozoic) 50

Ancillary Source Map Information 51

Eruptive History of Mammoth Mountain and its Mafic Periphery 51

Correlation of Map Units 51
Legend 51
Pamphlet 52
Geochronology and Geochemistry Data 52
Source Map Plate Photographs 53
Basaltic Scoria Cone Photograph 53
Mammoth Mountain and Lakes Basin Photograph 54
Rainbow Falls Photo 54
GRI Digital Data Credits 55

Geologic Resources Inventory Map Document

Devils Postpile National Monument, California

Document to Accompany Digital Geologic-GIS Data

depo_geology.pdf

Version: 9/29/2022

This document has been developed to accompany the digital geologic-GIS data developed by the Geologic Resources Inventory (GRI) program for Devils Postpile National Monument, California (DEPO).

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 Map Citations** – A listing of the GRI digital geologic-GIS maps produced for this project along with source map used in their completion. In addition, a brief explanation of how the 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) **Map Unit Descriptions** – Descriptions for all geologic map units. If a unit is present on multiple source maps the unit is listed with its source geologic unit symbol, unit name and unit age followed by the unit's description for each source map.

5) **Ancillary Source Map Information** – Additional source map information presented. The includes the complete source map correlation of map units, as well as a pamphlet important to the map.

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 Devils Postpile National Monument, California (DEPO) are listed below. Users are encouraged to use the monument and vicinity (DEPO) map has the map is larger-scale and more recent, however, for areas near the monument that are not covered by the monument and vicinity map users should use the Devils Postpile Quadrangle (DVPO) map.

Digital Geologic-GIS Map of Devils Postpile National Monument Area, California (*GRI MapCode DEPO*)

The map was produced from the following source map.

> Hildreth, Wes, and Fierstein, Judy, 2016, Eruptive History of Mammoth Mountain and its Mafic Periphery, California: U.S. Geological Survey, Professional Paper 1812, scale 1:24,000 (Eruptive History of Mammoth Mountain and its Mafic Periphery). (*GRI Source Map ID 76090*).

Only a portion of the source map, the extent of the source map within the Crystal Crag and Mammoth Mountain 7'5' quadrangles, however, all geologic features within the extent, including geologic sample localities, were captured.

In addition the the above GRI digital geologic-GIS map another GRI digital geologic-GIS map is also relevant to the monument.

Digital Geologic-GIS Map of Devils Postpile 15' Quadrangle, California (*GRI MapCode DVPO*)

The map was produced from the following source map.

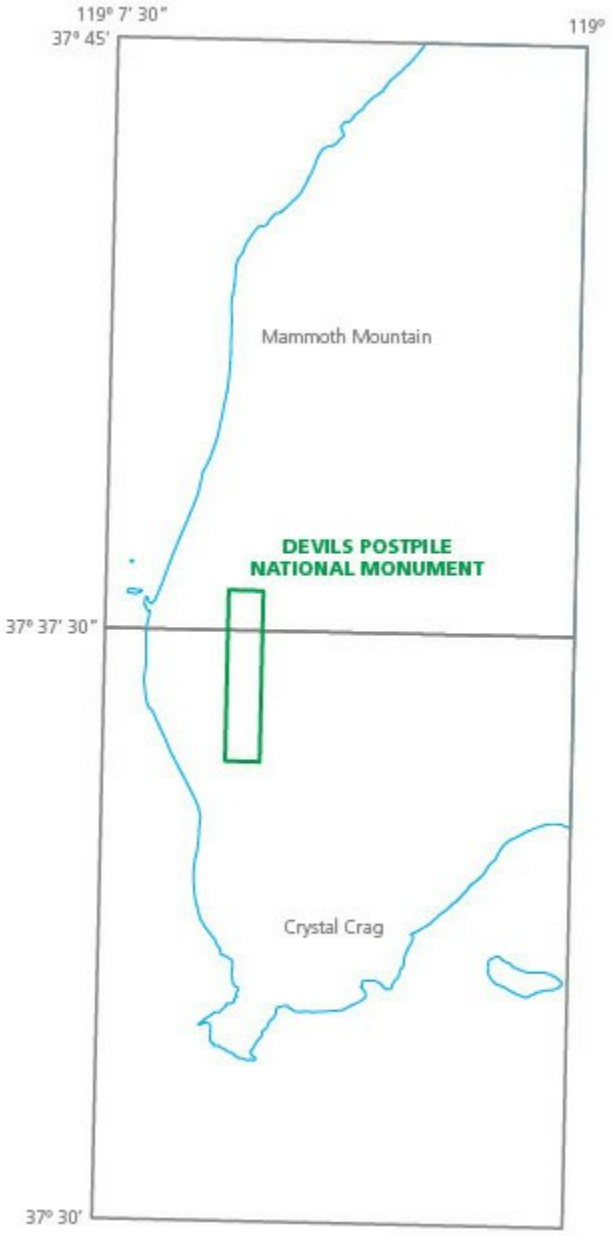
> Huber, N.K., and Rinehart, C.D., 1965, Geologic Map of the Devils Postpile Quadrangle, Sierra Nevada, California: U.S. Geological Survey, Geologic Quadrangle Map GQ-437, scale 1:62,500

The full extent of the source map was used and all geologic features within this extent were captured. For the Devils Postpile Quadrangle (DVPO) map, this map uses the Yosemite National Park (YOSE) GRI ancillary map information document (.pdf) file (yose_geology.pdf), and not this document for unit descriptions, cross section and other ancillary map information.

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

Index Map

The following index map displays the extent of the GRI digital geologic-GIS map produced for Devils Postpile National Monument (DEPO), as well as the extent of the monument (as of August, 2022). The latter is outlined in green. The extent of the GRI digital geologic-GIS map is an extent defined by the Crystal Crag and Mammoth Mountain 7.5' quadrangles and the blue line shown, and is the area that includes the monument.



Index map by Stephanie O'Meara (Colorado State University).

Map Unit List

The geologic units present in the digital geologic-GIS data produced for Devils Postpile National Monument, California (DEPO) are listed below. Units are listed with their assigned unit symbol and unit name (e.g., Qpe - Phreatic ejecta). Units are listed from youngest to oldest. No description for water is provided. Information about each geologic unit is also presented in the GRI Geologic Unit Information (DEPOUNIT) table included with the GRI digital geologic-GIS data. Of note, Quaternary source map unit symbols were changed in this document and in the GRI digital geologic-GIS data to denote their age by adding "Q" before the source map unit symbol.

Cenozoic Era

Quaternary Period

Qpe - Phreatic ejecta
Qp - Pumice deposits
Qal - Alluvium, undivided
Qric - Rhyolite and rhyodacite of Inyo chain
Qrcd - Rhyolite of Cratered Dome
Qrcw - Rhyolite of caldera wall
Qrnd - Rhyolite of North Deadman Creek Dome
Qbrc - Basalt of Red Cones
Qav - Rockfall avalanche deposits
Qs - Surficial deposits, undivided
Qgud - Undivided glacial deposits
Qgcc - Till of Cold Water Canyon
Qgdc - Till of Dry Creek
Qglb - Till derived from Lakes Basin
Qgmm - Till derived from Mammoth Mountain
Qmdn - Basaltic trachyandesite northeast of Deadman Pass
Qdnw - Trachydacites of northwest moat
Qbhl - Basalt of Horseshoe Lake
Qmcv - Basaltic trachyandesite south of Crestview
Qrss - Alkalic rhyodacite of Solitude ski run
Qdlp - Trachydacite of Lincoln Peak
Qddu - Trachydacite of upper Dragons Back
Qdgr - Trachydacite of Gold Rush Express
Qddl - Trachydacite of lower Dragons Back
Qdbp - Trachydacite of Bottomless Pit
Qeb - Explosion breccia deposit of Bailey
Qrsq - Alkalic rhyodacite of Quicksilver ski run
Qrmf - Alkalic rhyodacite of Mammoth Mountain fumarole
Qdsu - Trachydacite of Mammoth Mountain summit
Qdfl - Trachydacite of Face Lift
Qdrc - Trachydacite of upper Reds Creek
Qdnk - Trachydacite of North Knob
Qdnh - Trachydacite north of Horseshoe Lake
Qmsd - Basaltic trachyandesite scoria southeast of Dry Creek
Qdms - Trachydacite of McCoy Station
Qmnd - Basaltic trachyandesite northwest of Dry Creek
Qdml - Trachydacite of Main Lodge Coulee
Qdsk - Trachydacite of Skyline Dome
Qdwr - Trachydacite of White Bark Ridge
Qdtl - Trachydacite of Twin Lakes outlet
Qrce - Alkalic rhyodacite of Canyon Express
Qdsd - Trachydacite of South Summit Dome
Qd61 - Trachydacite of Dome 2861

Qmdp - Basaltic trachyandesite of Devils Postpile
Qrrc - Alkalic rhyodacite of Reds Creek
Qamp - Trachyandesite of Mammoth Pass
Qbar - Trachybasalt of Arcularius Ranch
Qbar1 - Trachybasalt of Arcularius Ranch, single flow
Qbmn - Trachybasalt northeast of Minaret Summit
Qbmn1 - Trachybasalt northeast of Minaret Summit, southwesternmost proximal lava
Qaml - Trachyandesite of McLeod Lake
Qdrf - Trachydacite of Rainbow Falls
Qbmc - Basalt of Mammoth Crest
Qddc - Trachydacite of Dry Creek
Qrdm - Rhyolite of Deer Mountain
Qd81 - Trachydacite of Dome 2781
Qa62 - Trachyandesite of Cone 2962
Qmss - Basaltic trachyandesite of upper Soda Springs
Qbed - Basalt east of Dry Creek
Qmdm - Basaltic trachyandesite of Deer Mountain
Qaic - Trachyandesite of Inyo Craters
Qapb - Trachyandesite of Pumice Butte
Qbdc - Trachybasalt west of Deer Creek
Qbcf - Trachybasalt south of Crater Flat
Qmcl - Basaltic trachyandesite of Canyon Lodge
Qrbt - Bishop Tuff

Tertiary Period
Tbld - Trachybasalt south of Lost Dog Lake
Tdww - Trachydacite of White Wing Mountain
Td65 - Trachydacite of Dome 2965
Tmcv - Basaltic trachyandesite of Crestview
Tbpl - Trachybasalt east of Pond Lily Lake
Tmcr - Basaltic trachyandesite of Mammoth Crest
Tdud - Trachydacite complex of upper Deadman Creek
Tmsd - Basaltic trachyandesite south of Deer Creek
Tmcm - Basaltic trachyandesite south of Upper Crater Meadow
Tdsd - Trachydacite of Dome 3321
Tdsj - Trachydacite block-and-ash-flow deposits of San Joaquin Ridge
Tdpd - Trachydacite pyroclastic-density-current deposit of Deadman Pass
Taww - Trachyandesite north of White Wing Camp
Tmcw - Basaltic trachyandesite west and east of Obsidian flow
Tbtb - Basalt of The Buttresses
Tmww - Basaltic trachyandesite of White Wing Mountain
Tbdp - Trachybasalt of Deadman Pass
Tacc - Trachyandesite of Crater Creek
Tasj - Trachyandesite of San Joaquin River

Mesozoic Era

Cretaceous Period
Kmo - Mono Creek Granite
Kjl - Granite of June Lake

Mesozoic Era
MZgd - Granodiorite northeast of Minaret Summit
MZmv - Metavolcanic rocks of Ritter Range pendant

Paleozoic Era
PZms - Metasedimentary rocks of Mount Morrison pendant

Map Unit Descriptions

Descriptions of all geologic map units, generally listed from youngest to oldest, are presented below. All unit descriptions were taken from the source map, Eruptive History of Mammoth Mountain and its Mafic Periphery. For Holocene and Pleistocene units the source map unit symbol, denoted without a "Q" for Quaternary, along with the source map unit name and age are also presented.

References to units within a unit description are the unit's source map unit symbol, and therefore for units of Quaternary age, Holocene and/or Pleistocene units, do no have the "Q" at the beginning of their unit symbol. As an example, unit "Qpe" is referenced as "pe", the unit's source map unit symbol in unit descriptions. In some cases unit descriptions may references areas not within the extent of the GRI digital geologic-GIS data, or source map units that are not presented here as the unit is also not within the extent of the GRI digital geologic-GIS data.

Qpe - Phreatic ejecta (late Holocene)

pe - Phreatic ejecta (late Holocene)
Poorly sorted fines-rich debris ejected in steam explosions from Inyo Craters in 1350 C.E. and, at uncertain times, from crater clusters west of Inyo Craters (Mastin, 1991) and from small craters beneath Chair 11 at northwest toe of Mammoth Mountain. Ejecta blankets extend 50–300 m radially from lesser craters but as far as 1 km northeastward from three principal Inyo Craters, which erupted in continuous sequence from north to south—Summit Crater (on Deer Mountain), North Inyo Crater, then South Inyo Crater (Mastin, 1991). Deposits are typically a few meters thick proximally but as thick as 13 m on east rim of South Inyo Crater and >20 m on walls of North Inyo Crater. Around Inyo Craters, ballistic ejecta are as big as 70 cm and up to 1 m around Summit Crater. Most block-sized fragments are crystal-poor mafic lavas (largely from unit aic) around South and North Inyo Craters. On floor of North Inyo Crater, sparse crystal-rich basaltic boulders are as big as 50 cm and granitoids are as big as 2.5 m, both presumed to have been entrained from unexposed underlying till. Around Summit Crater, white biotite rhyolite (from unit rdm) provided both ejected blocks and much of the cream to buff deposit matrix. Smaller and less abundant fragments from Inyo Craters include Early rhyolite tuff and lava (from unit rer) as well as granitoids and metavolcanics (both probably from subsurface gravels or till); Mastin (1991) tabulated lithologic proportions of finer ejecta. Ejecta around Summit Crater (3–10 m thick) likewise include granitoids and mafic lavas (crystal-poor and crystal-rich) but no fragments of oxidized crystal-poor mafic agglutinate from nearby unit mdm. Where exposed on crater walls, deposits are crudely stratified in meter-scale plane-parallel beds that show no evidence of erosion between successive eruptive pulses. Phreatic deposits around the three principal craters rest directly upon the pumice-fall deposits of the magmatic Inyo eruptions; because alignment of the phreatic craters extends that of the magmatic vents (unit ric), all are inferred to have resulted from southward propagation of a rhyolite dike (Miller, 1985; Eichelberger and others, 1984, 1985, 1988).

The West Crater and Middle Crater clusters of Mastin (1991) lie 0.5–1 km west of the three principal craters and, although undated, likewise erupted soon after the 1350 C.E. Inyo pumice falls, upon which their phreatic ejecta blankets rest. Ejected blocks include granitoids, metavolcanics, and Pliocene mafic lavas (all probably from till) as well as crystal-poor and crystal-rich Quaternary mafic lavas. Predominance of crystal-poor mafic lavas in the ejecta blanket, many meters thick, around the Middle Crater cluster suggests presence of buried lava flows like those exposed in South Inyo Crater (unit aic).

Phreatic ejecta beneath Chair 11, ~200–400 m southwest of Main Lodge in Mammoth Mountain Ski Area, issued from a contiguous pair of small craters (Bailey, 1989) now bulldozed for ski runs and a reservoir. Where undisturbed, deposit is >10 m thick, thinning to ~1 m within 100 m laterally. It directly underlies 1350 C.E. Inyo pumice falls (fig. 13) and rests on a layer of white crystal-poor rhyolitic ash (2–4 cm thick), which is thought to have erupted at Mono Craters. The poorly sorted, unconsolidated phreatic deposit consists of medium-gray mud that encloses subangular-to-subrounded matrix-supported clasts—exclusively of Mammoth Mountain lavas. Where deposit is ~1 m thick, clasts are 1–

35 cm across; where deposit is proximally thickest, clasts are as big as 1 m and many are in mutual contact. Internally, deposit has modest porosity (especially around big clasts) that facilitated interstitial steam flux, which produced irregular lenses and patches of red, orange, and yellow alteration of matrix mud. Swelling clays impart puffy texture to pale gray dried external surfaces. Matrix and clasts are thought to represent underlying till and colluvium remobilized by phreatic blasts.

Additional phreatic craters were depicted 500–700 m north of Lincoln Peak on northeast slope of Mammoth Mountain (three craters by Bailey [1989], four by Huber and Rinehart [1965a]), but our repeated scrutiny has identified neither explosive fragmental deposits nor thermal or fluid alteration effects. The sites have been groomed for several ski runs, but undisturbed areas between such runs consist only of rhyolitic unit rce, derivative regolith and colluvium, and limited patches of till.

Qp - Pumice deposits (late Holocene)

p - Pumice deposits (late Holocene)
Pumice falls, local proximal pyroclastic-flow deposits, and derivative reworked deposits, all resulting from Inyo Chain eruptions of unit ric. Shown only where thick enough (=2 m) to obscure underlying rocks sufficiently to prevent inference of their extent. Deposited by series of subplinian eruptions in 1350 C.E. (Millar and others, 2006). Within western half of map area, pumice mantle was originally ubiquitous, combined product of two successive outbursts from Deadman Creek vent and a third from Glass Creek vent (Miller, 1985; Nawotniak and Bursik, 2010; see unit ric). Deposits are unconsolidated and consist of pale-gray to cream, biotite-plagioclase rhyolite pumice lapilli, along with crystal-vitric ash and minor accidental lithic fragments. Combined primary thickness as great as 10 m near vents, 8 m on White Wing Mountain, and ~1 m near Mammoth Mountain and Devils Postpile. Widely sloughed from slopes and redeposited in areas of low local relief.

Qal - Alluvium, undivided (Holocene and late Pleistocene)

al - Alluvium, undivided (Holocene and late Pleistocene)
Unconsolidated, water-transported mud, sand, gravel, and bouldery debris deposited in or adjacent to active, ephemeral, or recently abandoned streams; includes local marsh and pond deposits.

Qric - Rhyolite and rhyodacite of Inyo chain (Holocene)

ric - Rhyolite and rhyodacite of Inyo chain (1350 C.E.)
Compositionally complex lava flows and pumiceous ejecta (70–74% SiO_2) that erupted from a dike-fed, 5-km-long, north south chain of three separate vents (Miller, 1985) in late summer of 1350 C.E. (Millar and others, 2006). (1) Southern vent released ~0.05 km3 of magma as pyroclastic flows (>10 m thick proximally), which extend as far as 6 km from vent, as well as a similar volume as pumiceous fall deposits distributed in two narrow sequential lobes that extend >20 km northeast and >25 km south-southwest. These were followed by extrusion of ~0.13 km3 of lava as Deadman Creek flow, pancake-shaped, weakly lobate flow on south bank of Deadman Creek, ~1 km inside northwest topographic wall of Long Valley Caldera. Barren, rugged, sprawling flow is nearly circular in plan, 1.3 km in diameter, and has flow fronts as high as 40 m and total relief of 170 m. Pyroclastic-flow deposits near Deadman Creek flow have poorly sorted, tan matrix of fine-to-coarse ash that carries scattered clasts, mostly lapilli but commonly 10–20 cm across, of wide textural variety, ranging from pumiceous to finely microvesicular to dense black vitrophyre.

(2) Northern vent was second to erupt, releasing ~0.02 km3 of magma as a nar row lobe of pumiceous fallout that extends >25 km northeast, followed by thin proximal pyroclastic flows. These were followed by extrusion of ~0.17 km3 of lava as Obsidian flow, just north of Glass Creek at foot of Sierran rangefront fault scarp. Rugged barren lava flow is 1.5 by 1.8 km across, and its steep margins

are 30–50 m high, thickening to more than 100 m centrally. Because emplaced on a slope, its total exposed relief reaches ~190 m. Its conduit lava remains as wide as 33 m where intersected by drilling at a depth of ~500 m (Eichelberger and others, 1984, 1985).

(3) Last of three magmatic vents to open was high on topographic rim of Long Valley Caldera, ~1.5 km south of vent for Obsidian flow and 3.5 km north of that for Deadman Creek flow. It released ~0.1 km3 of pumiceous fallout, as thick as 10 m proxi mally, that extends more than 190 km southward, by far most widespread and volumi nous explosive product of 1350 C.E. sequence (“Tephra 1” of Wood, 1977; Miller, 1985). Along crest of White Wing Mountain (fig. 26), where fallout is 8 m thick, 2–4 km south west of Glass Creek vent, tree-ring study of numerous trees killed by the eruption yielded an eruption age of 1350 C.E. (Millar and others, 2006). This outburst was followed by remobilized flows of pumiceous proximal ejecta (Miller, 1985), which are poorly exposed for several kilometers eastward along Glass Creek, and finally by extrusion of ~0.1 km3 of lava as rugged, blocky Glass Creek flow (fig. 26). From its vent on caldera rim, this 700-to-900-m-wide flow spread ~500 m northward (to a steep northerly flow-front as high as 75 m) as well as ~1 km southward, descending 220 m in elevation to foot of caldera wall.

None of the four pumice-fall deposits (Nawotniak and Bursik, 2010) overlie any of the three still-barren lavas, although they blanket Devils Postpile region, Mammoth Mountain, west moat of caldera, and plateaus north of caldera, widely obscuring con tacts among older units. Although one vent lies within topographic basin of Long Valley Caldera, all three vents are well outside structural ring-fault margin of caldera (Hildreth, 2004). Although sometimes referred to as “Inyo Domes” or popularly called “Inyo Craters” (presumably in deference to phreatic craters that formed soon after magmatic sequence; see unit pe), all three 1350 C.E. effusive units are pancake-style flow-foliated lava flows with extensive low-angle surfaces of shattered craggy glass. Phenocrysts: products of crystal-poor magma (2–3% phenocrysts) dominate fall deposits and Obsidian flow. Crystal-rich lava (25–40% phenocrysts) makes up 30–40% of Glass Creek flow and more than 50% of Deadman Creek flow, its proportion thus increasing southward along chain. Central areas of latter two flows consist of relatively homogeneous, white, mod erately vesicular crystal-rich phase (71.5±0.5% SiO_2), which grades radially into periph eral zones where it is either interlayered with crystal-poor lava or broken up into lenses, blobs, and streaks that were disaggregating into it when frozen (Sampson, 1987). Crystal poor phase is texturally more heterogeneous, ranging from coarsely to finely vesicular to dense obsidian or microcrystalline felsite; moreover, it is chemically zoned (70–74% SiO_2) as described by Sampson and Cameron (1987) and Vogel and others (1989) and reviewed by Hildreth (2004). Crystal-rich lava contains 15–20% plagioclase, 10–15% sanidine, 2% biotite, ~2% hornblende, ~1% quartz, ~1% titanomagnetite, and trace amounts of ilmenite, cpx, opx, apatite, zircon, and allanite. Feldspars are as big as 10 mm and biotite and hornblende are commonly >3 mm. Crystal-poor lava contains most of these phases but lacks quartz and allanite, and higher-silica samples along its zoned array also lack hornblende; few of its mafic phenocrysts are larger than 0.5 mm, and most of its feldspars are smaller than 2 mm (though rarely as big as 5 mm). Sparse fine-grained enclaves, dense to vesicular, <1 to 10 cm across, are distributed within crystal-rich rhyolite in high central parts of Deadman Creek and Glass Creek flows, where lavas can be inferred to represent latest material extruded from directly subjacent vents (Varga and others, 1990). Bulk enclave compositions are intermediate (59.5–60.7% SiO_2), but their cargo of abundant disequilibrated phenocrysts from host rhyolite indicates that they are magmatic mixtures of mafic and silicic magma. Mafic contribution may represent seldom-seen source of long-lived thermal flux beneath west moat of Long Valley Caldera.

Qrcd - Rhyolite of Cratered Dome (Holocene)

rcd - Rhyolite of Cratered Dome (Holocene)
Disrupted rhyolite minidome (73.2% SiO_2) on north bank of Glass Creek, 150 m north of Glass Creek flow (unit ric); extruded through Mesozoic granitoid at foot of Sierran escarpment on trace of Hartley Springs Fault. Dome is <150 m in diameter, and its craggy rim stands only 10–15 m above its external base. Most of dome center, however, is now a closed funnel-shaped crater 25–30 m deep and ~100 m wide at its rim. An annular terrace 5–10 m wide rings much of inner pit, ~10 m below its rim and ~18

m above its floor. Coarsely block-jointed flow-foliated rhyolite forms ragged narrow rim and steep inner walls of crater; foliation was mapped by Mayo and others (1936). Rock is glassy, micropumiceous, pale gray, and weathers tan to pale orange-brown; its groundmass is rich in microlites. Phenocrysts: 1–2% feldspar (mph to 1.5 mm), some in clusters; trace amounts of biotite, opx, cpx, and Fe-Ti oxides (all mph). Unit is chemically similar to evolved end of zoned array of phenocryst-poor member of unit ric erupted in 1350 C.E. (Sampson and Cameron, 1987). Cratered Dome is older, however, as its floor and parts of its rim are covered by 1350 C.E. pumice-fall deposit. Apparent absence of tephra from nearby South Mono and Wilson Butte eruptions, each ~1.3 ka (Bursik and Sieh, 1989), suggests that cratering (if not necessarily eruption) of Cratered Dome postdates those events. Coarse ejecta around crater, dominated by a sheet that extends ~150 m south and southeast of rim, include granitoids, Mesozoic metavolcanic rocks, and mafic lavas as well as juvenile rhyolite. Some blocks are as big as 50 cm; abundance of rounded ones suggests (at least partial) derivation from underly ing till. Rhyolite debris appears inadequate to account for crater volume, suggesting that magma withdrawal could have contributed to crater formation. Undated but apparently bracketed between 700 C.E. and 1350 C.E.

Qrcw - Rhyolite of caldera wall (Holocene)

rcw - Rhyolite of caldera wall (Holocene)
Sparsely porphyritic rhyolite minidome (72.2% SiO2) on northwest wall of Long Valley Caldera, <100 m west of southwestern snout of Glass Creek flow (unit ric). Tiny forested protrusion, only ~50 m wide and 20 m high, perched partway up wall at 2,440–2,460 m elevation, erupted through scree-mantled Mesozoic granite (unit Kjl) just west of trace of Hartley Springs Fault. Rock is pale gray, glassy, micropumiceous, and carries abundant microlites. Phenocrysts: 1–2% feldspar (mph to 1 mm), some in clusters; < 1% biotite (mph to 1 mm); trace hornblende (mph to 1.5 mm long); trace cpx (mph to 0.7 mm long); trace tiny Fe-Ti-oxide mph; also contains rare mafic blebs as big as 5 mm that carry pyroxene and oxide mph. Unit is chemically similar to evolved end of zoned array of phenocryst-poor member of unit ric that erupted in 1350 C.E. (Sampson and Cameron, 1987). Age unknown, but mantle of Inyo tephra and absence of South Mono and Wilson Butte tephras appear to bracket its extrusion (like that of unit rcd) to between 700 and 1350 C.E. (Sampson, 1987; Sampson and Cameron, 1987).

Qrnd - Rhyolite of North Deadman Creek Dome (Holocene)

rnd - Rhyolite of North Deadman Creek Dome (Holocene)
Compact middle Holocene lava dome (74.7% SiO2) at foot of northwest topographic wall of Long Valley Caldera, on north bank of Deadman Creek, just north of barren and rugged Deadman Creek flow (southernmost of 1350 C.E. chain of Inyo lavas; unit ric). Forested dome is steep-sided, craggy, nearly circular in plan, 600 m in diameter, and has 130 m relief. Pale gray aphyric lava is glassy, block-jointed, flow-foliated, and micropumiceous to massive; sheds coarse talus of angular blocks. Volume of virtually uneroded dome is ~0.03 km3 , and coerupted ejecta (if any) are not exposed. Phenocrysts: none; but glassy groundmass is rich in feldspar and biotite microlites (<0.1 mm) with sparse feldspar-lath mph (0.1–0.3 mm). Apparently erupted through Mesozoic granite (unit Kjl), exposed in adjacent caldera wall. Overlain by Inyo pumice-fall deposits of 1350 C.E. Undated, but estimated to be roughly 6,000 years old by Miller (1985).

Qbrc - Basalt of Red Cones (Holocene)

brc - Basalt of Red Cones (Holocene)
Glacially eroded remnants of phenocryst-rich scoria and agglutinate (52.4–53.7% SiO2) surrounding each of three vents, aligned northwest-southeast partway up west wall of Long Valley Caldera, south of upper Deadman Creek and 1.5–2 km northeast of Deadman Pass. Northwest vent is shallow

crater, 100 m across, surrounded by 300-m-wide ejecta ring of loose brick-red scoria. Ejecta are mostly lapilli but include finely to coarsely vesicular bombs, abundantly 20–50 cm, sparsely 1–2 m, and as big as 3.5 m; many large bombs have dense interiors. Two ledges of tack-welded to dense agglutinate crop out on eastern outer slope, 15–25 m below rim. Circular crater, heavily mantled by Inyo pumice-fall deposits, has 13 m relief on its southeast inner wall and at least twice that much on its north wall.

Middle exposure is a northeast-facing agglutinate cliff, 8–15 m high and ~200 m long. Lowest 1 m of exposure is brick-red agglutinate, dense but streaky, that grades up into ~10 m of massive gray fountain-fed lava, almost homogenized but locally displaying subtle flow foliation and carrying cream-white metavolcanic xenoliths (1–7 cm) that tend to be elongate and oriented along flow-foliation planes. Lava sheet and its foliation dip ~20º NE. Top 3 m of cliff is brick-red massive agglutinate with faint streaky or blobby structure patchily discernible. Sparse scoria bombs as big as 50 cm near cliff rim suggest that vent lies nearby, probably concealed by adjacent moraine that extends from Deadman Pass cirque on southwest and, in turn, by Inyo pumice-fall deposit.

Southeast exposure includes a 600-m-long ridge of lightly welded brick-red agglu tinate and an adjacent steep-walled gorge, both walls of which expose denser agglutinate 50–80 m thick. Ridgecrest becomes narrow arête to northeast and consists mostly of tack welded scoria lapilli sprinkled with sparse scoria blocks (20–70 cm) and spindle bombs up to 1 m. On gorge walls, deposit is dense red-brown agglutinate with a few thin lava ledges intercalated, some of which are block-jointed and dark gray. Wall sections grade down into dense fountain-fed lava near gorge floor. Narrow gorge through vent complex was probably cut glacially and later deepened by glacial outlet stream; its walls remain glacially striated, but stream now draining it is feeble and intermittent.

Products of all three vents are chemically and petrographically alike and presumed to have been erupted contemporaneously from a common dike; vents align along local rangefront scarp . A lone distal exposure crops out 2.8 km northeast of those vents as a water-smoothed lava ledge ~30 m long at 2,445 m elevation on floor of Deadman Creek (UTM 2115/7618); outflow lavas are elsewhere wholly concealed by surficial deposits. Products are not related to Cone 2652 (large scoria cone of phenocryst-poor unit mcv), toward which the mdn vent alignment roughly strikes.

Phenocrysts: 10–15% plagioclase (1–3 mm, rarely 4–5 mm); 1–3% olivine (0.5–1 mm); 1–2% cpx (0.5–2 mm); and common 5–10 mm intergrowths of 10–15 grains each of cpx and plagioclase (both 0.5–2 mm). Northwestern vent ejected metavol canic xenoliths (1–4 cm, rarely to 8 cm), some partially melted; middle vent ejected partially melted xenoliths of both granitoids and silicic metavolcanics. Base not exposed but presumed to overlie Mesozoic granitic rocks and still older metamorphic rocks, both exposed nearby but covered locally by till, colluvium, and Inyo pumice-fall deposit. All three proximal exposures were overtopped and eroded by glacial ice and strewn with basement erratics. Scoria lapilli (1–6 cm), chemically and petrographically indistin guishable from unit mdn, are scattered atop Dome 2861, 6 km southeast of mdn vents. 40Ar/39Ar age: 16±2 ka.

The undated basaltic trachyandesite of June Lake (unit mjl), which lies on the range front fault system 10 km north of unit mdn, is similar to it in composition, mineralogy, and unusually steep paleomagnetic direction (Hildreth and others, 2014). As both are overlain by MIS 2 glacial deposits, they may have erupted contemporaneously.

Blocky rubble, designated subunit mdn', banked against southwest base of Lookout Mountain (at UTM 03277/41769), consists exclusively of coarsely vesicular blocks of unit mdn, indistinguishable from near-vent outcrops chemically, petrographically, and in age (40Ar/39Ar age: 16.9±1.3 ka). Angular clasts (10–300 cm) protrude from thick mantle of Inyo pumice-fall deposit over an area 65 m along slope (north-south) and 35 m upslope (east-west), forming a flat-topped bench ~10 m high. Of 140 clasts counted, all are of unit mdn lithology. In drill hole OIP-1 (fig. 6), ~1 km northeast of Deer Mountain, a 10-m-thick lava flow chemically and petrographically similar to unit mdn is topmost of seven mafic lava flows penetrated and is covered there by ~18 m of Inyo ejecta (unit pe) and glacial deposits. Material was apparently transported from caldera-wall vents, first as periglacial or englacial lava flows, subsequently as fragmental flows. Straight-line path north of Deer Mountain would be 7–8

km from vents to moraine limit and additional 2 km to rubble deposit banked against Lookout Mountain.

Qav - Rockfall avalanche deposits (Holocene and late Pleistocene)

av - Rockfall avalanche deposits (Holocene and late Pleistocene)
Sheets or tongues of monolithologic rubble fallen from steep scarps. Principal example here is apron of debris that wraps around east base of Dome 2861 (unit d61) and extends into 1-km-long tongues at northeastern and southeastern toes of dome. Unstratified monolithologic deposits consist of pale gray dacite blocks, some tinted pinkish and mostly angular, typically 10–50 cm across but rarely as big as 2 m, in a gritty pale gray matrix, which is nonindurated and seriate from gravel to fine sand. Blocks weather tan, and most are dense or finely vesicular, and glassy, partly glassy, or devitrified. Where southeast tongue overlaps till of unit gmm, it lacks the black and brick-red vitrophyre blocks (from Mammoth Mountain sources) predominant in the till. Northeast apron banks against Dry Creek Dome (unit rdc), exhibits subdued hummocks with 10–20 m relief, and appears to be modified and truncated by lateral moraine of late Pleistocene Dry Creek glacier. Roadcut in northeast apron is exceptionally matrix-rich and conceivably exposes a pyroclastic facies of unit d61, but no prismatic blocks or thermal effects of blocks on matrix were observed. Deposits were probably emplaced piecemeal from steep-sided dome over extended time interval.

Lesser rockfall deposits mapped on southwest wall of caldera near Mammoth Rock consist of angular blocks of granitoids and metavolcanics. Such deposits grade into piecemeal talus slopes, which we largely ignore on this map. A small rockfall avalanche from steep flow front of one of the unit dnw coulees emplaced a narrow blocky deposit that armors right-bank terrace of Deadman Creek for 200 m eastward (UTM 237/7775); many blocks exceed 1 m, but there is no equivalent deposit on left-bank terrace. Another avalanche mass, ~100 m wide, fell from east scarp of unit bmc and lodged just southwest of Crystal Lake.

Qs - Surficial deposits, undivided (Holocene and late Pleistocene)

s - Surficial deposits, undivided (Holocene and late Pleistocene)
Generally combinations of glacial, fluvial, pond, aeolian, and reworked fallout deposits or locally mixed accumulations of till, talus, protalus, or other colluvium. Widely omitted; mapped principally where such deposits form discrete landforms or are extensive enough to prevent inference of underlying rocks. Bulldozed ski runs on Mammoth Mountain combine debris that had naturally been colluvium, till (unit gmm), aeolian sand, and Inyo pumice falls (unit p).

Numerous pits, typically 2–4 m deep and 10–30 m across, excavated by Mammoth Mountain Ski Area to control storm and snowmelt runoff, currently entrap slurries that consist principally of sand and silt flushed from loose surficial debris and carry sparse dispersed clasts of Inyo pumice or Mammoth Mountain lavas and pumice. In low-relief areas around toe of Mammoth Mountain and on benches and swales higher on the edifice, such excavations commonly expose older slurry deposits beneath layers of 1350 C.E. Inyo fallout. Such diamicts could be misinterpreted as small pyroclastic-flow deposits. Sparse clasts in such diamicts are principally subangular to subrounded dense fragments (mostly 1–10 cm across) of texturally varied lavas, along with subordinate pumice, all exclusively trachydacites and alkalic rhyodacites of Mammoth Mountain. In most pits, pumiceous and hydrothermally altered clasts are sparse or absent, and sand-silt matrix is fresh and nonindurated.

In a few pits beneath 1350 C.E. fallout, there is also a massive sandy layer (30–112 cm thick), probably aeolian, that carries sparse pumice granules and sparser lapilli (as big as 4 cm) of Mammoth Mountain biotite-bearing rhyodacite pumice (like those of unit rfp). Such tan to orange-brown layers of massive sand overlie coarser diamicts thought to be ground moraine. Sieve analyses at four sites yield median diameters (Md) that range 0.2–0.4 mm (medium sand) with 4–11 wt% silt and only 4–10

wt% coarser than 2 mm. A charcoal lens within a 45-cm-thick sand layer excavated at UTM 200/687 (near Chair 11) gave an age of 1,970±20 14C yr B.P. Charcoal layer that separates 112-cm-thick layer of massive sand from an underlying paleosol developed on diamict (probably till) at UTM 192/683 (along Reds Lake Road) gave 4,130±25 14C yr B.P. (fig. 13).

Along resurgent graben system that cuts Early rhyolite (unit rer), several shallow depressions crossed by Highway 395 contain multicomponent surficial deposits (unit s) eroded into small ridges with 10–20 m of local relief. Exposure is poor, owing to aeolian veneer, Inyo pumice falls, and near-absence of Holocene streamflow. At north end where graben is crossed by course of ephemeral Dry Creek, such ridges reveal small exposures of Pleistocene gravel (UTM 275/749 and 282/745) that includes cobbles of crystal-poor mafic lavas, hornblende-biotite rhyolite, and trachydacite of Mammoth Mountain, indicating late Pleistocene transport from west moat. Near junction of Sawmill Cutoff with Highway 395 (UTM 280/740), another 15-m-high ridge has scattered clasts of nearby units mcl and rer as well as sparser clasts of metasedimentary and granitic rocks that probably originated at west wall of caldera. As indicated by their clast contents and volcanic units they bank against, these depression-filling deposits are younger than 66±2 ka and their relief owes to late Pleistocene streamflow. A few kilometers farther south, Smokey Bear Flat (UTM 290/730) is a large flat-floored depression surrounded by Early rhyolite; lacking relief and streamflow, its depth of fill is unknown and its floor is covered by aeolian deposits, Inyo pumice, and rhyolitic pea gravel. At south end of graben, another depression (UTM 303/683; west of geothermal plant) includes a 10-m-high east-west ridge of surficial fill incised by Highway 395; in addition to pebbles of local units rer and bcd (125±2 ka), fill has sparse clasts of granitic unit Kmo and common clasts of hornblende-biotite rhyolite (100–150 ka).

Qgud - Undivided glacial deposits (late and middle Pleistocene)

gud - Undivided glacial deposits (late and middle Pleistocene)
Moraines at Sherwin, Laurel, and Convict Creeks, moraines buried by Holocene pumice-fall deposits in caldera's west moat, and discontinuous till remnants near Middle Fork San Joaquin River canyon, are largely or entirely of Tioga age—broadly of last major glacial episode during MIS 2. Several distal lobes of Sherwin, Laurel, and Convict Creek moraine complexes may be pre-Tioga (fig. 21), as suggested by Rinehart and Ross (1964), Sharp (1969), and Bailey (1989), but this is unproven. Scattered patches of till along ice-scoured Middle Fork canyon and ground moraine west of Mammoth Pass consist largely of locally derived material. Speculation by Fullerton (1986) about middle Pleistocene glaciation near Reds Meadow was based on a K-Ar age far too old for intracanyon lava of Devils Postpile (unit mdp), now dated at 82±1 ka. Main occurrences of unit gud are the following.

Till of west moat. Glacial deposits in caldera's west moat, poorly exposed beneath late Holocene pumice-fall deposits (unit p), form several buried moraines between Crater Flat and Deadman Creek. Scattered erratic blocks and sparse gully exposures through pumice cover indicate that clasts from Mammoth Mountain are uncommon, granitoid clasts are abundant, and clasts of metamorphic rocks, Pliocene lavas, and units ddc, bar, and bmn are all ubiquitous but subordinate. Dacite erratics from Mammoth Mountain on divide northeast of Minaret Summit (UTM 188/695) provide evidence that some late Pleistocene ice flowed north-northwestward from edifice along ridgecrest, as well as northward toward Dry Creek.

Till of Convict Creek. Main components are (1) north-trending lobate complex, 2 km wide and 3 km long, constructed of many nested loop and lateral moraines, and (2) older northeast-trending double-crested lateral moraine, 3 km long and >300 m high; both were characterized in detail by Sharp (1969) and not restudied by us. Sharp (1969) reviewed several previous interpretations of moraine-emplacement sequence and concluded that entire lobate complex (plus set of seven lateral moraines just east of Convict Lake and north-trending lateral moraine along east side of Convict Creek) are all of Tioga age (MIS 2). Sharp (1969) showed the enormous northeast-trending lateral moraine to be older and, by regional comparison, inferred it to be of Tahoe (early Wisconsin) age, but he suggested that it might conceal still older buried till. Surface exposure dating (Phillips and others, 2009) has shown many eastern Sierra Nevada moraines long called Tahoe to have been deposited 165–130 ka

(MIS 6). Stones are predominantly metasedimentary and granodioritic, along with subordinate metavolcanics.

Till of Laurel Creek. Moraine complex, ~3 km long and as wide as 1.5 km, that extends north from canyon of Laurel Creek to caldera floor near Sherwin Creek Road; characterized by Rinehart and Ross (1964) and not restudied in detail by us. Treeless Laurel Creek moraines contain subordinate granodioritic debris but consist predominantly of metasedimentary material, in contrast to adjacent Sherwin Creek moraines, which are densely forested (see fig. 36 of Rinehart and Ross, 1964) and consist almost exclusively of granodiorite till, suggesting lithologic or edaphic control of vegetation. A sharp-crested lateral-terminal moraine loop that closes at ~2,560 m elevation is generally thought to be of Tioga age (MIS 2). Older lateral moraines that extend ~1 km farther north and 300 m lower (fig. 21) are morphologically more subdued though lithologically similar; their termini at 2,260–2,300 m are similar in elevation to Casa Diablo Till (unit gcd) of Mammoth Creek, only 2–4 km north, suggesting that they too could have been deposited during MIS 6 (or alternatively during early MIS 2). Prominent alluvial fans issuing from these distal moraines may in part be comparably old.

Till of Sherwin Creek. Massive apron, 3 km wide, of unusually coarse till that emerges from two rangefront canyons and extends ~3 km farther northward on both sides of Sherwin Creek to caldera floor near Sherwin Creek Campground. At least 200 m thick, complex deposit includes a few modest longitudinal ridges distally but lacks high lateral moraines typical of most canyon-mouth glacial deposits in eastern Sierra Nevada. Till consists almost entirely of granodiorite (from unit Krv) derived from steep canyon walls; abundant boulders armoring deposit are commonly as big as 2–5 m. Jointed bedrock of narrow cirque-canyons so overloaded glaciers with coarse debris that glacier rheology (and morphology of resulting deposit) approached those typical of rock glaciers, as noted by Kesseli (1941b) and Rinehart and Ross (1964). At northeast extremity of deposit, two morainal ridges, each ~40 m high, diverge ~700 m beyond main lobe; although emplaced before massive main lobe, neither appears definitively older on basis of boulder weathering or soil development. Nonetheless, they could be either early MIS 2 lateral moraines that predated overloading of ice that led to construction of the massive rock-glacier-like lobe atop them or, alternatively, they could represent MIS 4 or 6. Eastern distal ridge of Sherwin Creek moraine complex (UTM 301/650) is relatively unforested (unlike other Sherwin Creek glacial deposits); although armored by granodiorite boulders like rest of complex, its matrix contains abundant pebbles and cobbles of metasedimentary rocks, which apparently inhibited forest development as on adjacent Laurel Creek moraines (see fig. 36 of Rinehart and Ross, 1964). Like distal Laurel Creek moraines, it probably predates main advance of LGM (fig. 21). Excepting this anomalous northeasternmost moraine, distal till of Sherwin Creek laps against units bsr (99±1 ka) and amp (97±1 ka), showing that voluminous Sherwin moraines were deposited in late Pleistocene (not during MIS 6).

Qgcc - Till of Cold Water Canyon (late Pleistocene)

gcc - Till of Cold Water Canyon (late Pleistocene)
Glacial deposit dominated by clasts of metavolcanic rocks (unit Mzmv) transported northwestward down Cold Water Canyon to Lake Mary and Panorama Dome. During major ice advances, such material merged with and medially mixed with granite-dominant debris (units glb and gcd) quarried by ice from Mammoth Crest. Clast counts at Panorama Dome (n=450) give 80–90% metavolcanics, 10–20% unit bhl (31±1 ka), and <3% small granitoids; around Lake Mary, metavolcanic clasts exceed 95%, and in Cold Water Canyon, they approach 100%. By contrast, adjacent till of unit glb near Twin Lakes outlet is granitoid-dominant and has common clasts of Mammoth Mountain dacites as well as subordinate clasts of units }mv and bhl. Deposit contains many 2–3 m boulders and represents final glacial advance along Cold Water and upper Mammoth Creeks; ice followed a deep narrow canyon from cirque headwalls at elevations as high as 3,350 m (11,000 ft). Overlies units bhl, ddl, ddu, dom, and dtl; younger than all contiguous units except al and sd. Banks against, overlies, and locally grades into unit glb, deposited contemporaneously during MIS 2.

Qgdc - Till of Dry Creek (late Pleistocene)

gdc - Till of Dry Creek (late Pleistocene)
Lobe of glacial till as wide as 3 km that extends along both sides of Dry Creek from base of Mammoth Mountain to sharp terminus 8 km northeast. Marked by few prominent moraines, hummocky sheet appears to reflect ablation of dead ice of a debris-laden piedmont lobe. West margin obscured by Inyo pumice-fall deposit (unit p) related to unit ric (1350 C.E.). Clasts in till near Dry Creek are predominantly basaltic but include abundant trachydacite from Mammoth Mountain (100–50 ka). Clast count (n=374) in Scenic Loop roadcut (UTM 259/743) gave 51% crystal-poor mafic lavas, 20% Mammoth Mountain lavas, ~8% each of units ddc, bar, and bmn, and 4% hornblende-biotite rhyolite. Along fault scarp 1.5 km farther west (UTM 245/738), clast count (n=175) gave 53% crystal-poor mafic lavas, 12% Mammoth Mountain lavas, 18% ddc, 13% bar, 4% bmn, and no rhyolite. Few stones are larger than 1 m. Lack of basement clasts shows that ice came from Mammoth Mountain, not from caldera's southwest wall. Deposit overlies units d61 (87±2 ka) and mor (66±2 ka); till is younger than all contiguous units except Inyo pumice fall and phreatic ejecta of 1350 C.E. Deposited during MIS 2.

Qglb - Till derived from Lakes Basin (late Pleistocene)

glb - Till derived from Lakes Basin (late Pleistocene)
Set of 40-odd nested morainal ridges and associated ground moraine that extends 6 km eastward from outlet of Mammoth Lakes Basin to area of Sherwin Creek campground, where its most distal end moraine is breached by Mammoth Creek. Till was deposited during MIS 2 by a broad piedmont glacier that terminated ~1.5 km short of the Casa Diablo moraines of MIS 6 (unit gcd). Some morainal ridges are as high as 40–50 m, and numerous drill holes adjacent to such ridges penetrated 10–90 m of till (fig. 6). Moraine surfaces are boulder-rich, sharp-crested, and little weathered. Boulders are dominantly granitoids but include metavolcanics, mafic lavas, Mammoth Mountain dacites, and rare metasedimentary rocks. Source of ice-transported debris was principally Lakes Basin with lesser but important contributions from south slope of Mammoth Mountain and granodiorite and metavolcanic debris from rangefront scarp south and east of Mammoth Rock. North of Mammoth Creek, stones in till are 80–90% porphyritic granite (unit Kmo) as big as 5 m, ~5% crystal-rich basalt of unit bhl (31±1 ka) as big as 3 m, and 3–5% metavolcanics, also as big as 3 m; sparser constituents are stones from big-feldspar basaltic unit bmc, crystal-poor scoria and lava clasts of units mcl and amp, fine-grained granitoids, and rare hornblende-biotite rhyolites. Northernmost moraines are poor in metavolcanics and carry only sparse Mammoth Mountain dacites, but both of these clast groups are present in inner moraines close to Mammoth Creek. South of Mammoth Creek, granodiorite stones (unit Krv) derived from south wall commonly outnumber porphyritic granites (unit Kmo) derived from Lakes Basin; in southernmost moraines granodiorite typically dominates, but metavolcanics are also abundant and are locally dominant; sparser constituents are boulders of units bhl, amp, and various Mammoth Mountain dacites. Few clasts of unit bmc are present south of Mammoth Creek. Innermost moraines south of Mammoth Creek are poor in Mammoth Mountain dacite but relatively enriched in porphyritic granite; during recession, shrinking axial ice from Lakes Basin flowed principally through a Twin Lakes outlet trough already deeply incised through several Mammoth Mountain dacite units. Whether entire nested moraine set represents Last Glacial Maximum and its recessional stillstands awaits testing by surface-exposure dating; presence of clasts of unit bhl (31±1 ka) in all moraines on both sides of Mammoth Creek as far east as confluence of Sherwin Creek nonetheless proves that all were deposited during MIS 2, not in early or middle Wisconsin time. Deposits overlie units amp (97±1 ka), bhl (31±1 ka), ddl (58±2 ka), dtl (76±1 ka), asr, bsr, and mcl.

Qgmm - Till derived from Mammoth Mountain (late Pleistocene)

gmm - Till derived from Mammoth Mountain (late Pleistocene)
Two tongues of glacial till that extend eastward from sources exclusively on Mammoth Mountain. One extends 3 km from northeast base of Mammoth Mountain into downtown Mammoth Lakes; second

extends 3 km along valley between Dragons Back and Lincoln Peak as far as Juniper Ridge. Linking the tongues, till west of Camp High Sierra grades up steep east-facing scarp of Timber Ridge into colluvium rich in rhyodacite of unit rce. Sandy-gravelly fines-poor matrix dominates and encloses boulders and smaller stones that are nearly all (>99%) Mammoth Mountain dacites and rhyodacites (100–50 ka), accompanied by sparse mafic lavas and rare metavolcanic and granitoid clasts. Stones range from subrounded to subangular, and many are 10–50 cm across but rarely 1–2 m. In contrast to granitoid boulders, ice transport of Mammoth Mountain dacites tended to re-fracture rather than round them. Major outcrop area in residential neighborhood that extends from Canyon Lodge to downtown is an irregular terrain of hills and short ridges with 15–30 m local relief; abundance of small moraines and weak development of lateral moraines may reflect short runout of glaciers and overloading of ice by debris from numerous brecciated silicic lava domes. A few elongate moraines, all east-trending, include Juniper Ridge, ridges just east of The Village, a ridge just north of Forest Trail, and another along valley 1 km south of Lincoln Peak (Gold Hill ski run); the last is actually a medial moraine (without laterals) squeezed between convergent ice sheets that draped slopes of Dragons Back and Lincoln Peak. Although they were deposited in large part contemporaneously, distal till of unit gmm overlies till of unit glb along an abrupt contact, from which we infer that ice advancing down Mammoth Mountain outlasted retreat of the Lakes Basin glacier from distal lowlands. Their contrasting compositions are readily compared on adjacent moraines of Juniper Ridge (gmm) and Lone Tree Hill (glb). Northern tongue was previously interpreted as deposit of a debris-avalanche from Lincoln Peak (Bailey, 1989), but it lacks hummocks, megablocks, and composite blocks; its varied Mammoth Mountain clasts (64.0–70.5% SiO2; n=12), moreover, are not derived principally from Lincoln Peak, which in any case lacks evidence for an amphitheater or other avalanche scar. Volume of 3-km2 northern tongue of unit gmm (~0.1 km3) alone exceeds that of Lincoln Peak (unit dlp). Very sparse boulders of mafic lava in unit gmm are correlated chemically with units bhl (31±1 ka), aml, amp, and mcl. Deposits overlie units d81, dtl, rce, rss, glb, scoria cone mcl, and bank against units mkv, bsm, mcl, and rmk. Overlain by rockfall avalanche deposits from Dome 2861 (unit av) and by Inyo pumice-fall deposits (unit p; 1350 C.E.). Deposited during MIS 2.

Qmdn - Basaltic trachyandesite northeast of Deadman Pass (late Pleistocene)

mdn - Basaltic trachyandesite northeast of Deadman Pass (late Pleistocene)
Glacially eroded remnants of phenocryst-rich scoria and agglutinate (52.4–53.7% SiO2) surrounding each of three vents, aligned northwest-southeast partway up west wall of Long Valley Caldera, south of upper Deadman Creek and 1.5–2 km northeast of Deadman Pass. Northwest vent is shallow crater, 100 m across, surrounded by 300-m-wide ejecta ring of loose brick-red scoria. Ejecta are mostly lapilli but include finely to coarsely vesicular bombs, abundantly 20–50 cm, sparsely 1–2 m, and as big as 3.5 m; many large bombs have dense interiors. Two ledges of tack-welded to dense agglutinate crop out on eastern outer slope, 15–25 m below rim. Circular crater, heavily mantled by Inyo pumice-fall deposits, has 13 m relief on its southeast inner wall and at least twice that much on its north wall.

Middle exposure is a northeast-facing agglutinate cliff, 8–15 m high and ~200 m long. Lowest 1 m of exposure is brick-red agglutinate, dense but streaky, that grades up into ~10 m of massive gray fountain-fed lava, almost homogenized but locally displaying subtle flow foliation and carrying cream-white metavolcanic xenoliths (1–7 cm) that tend to be elongate and oriented along flow-foliation planes. Lava sheet and its foliation dip ~20º NE. Top 3 m of cliff is brick-red massive agglutinate with faint streaky or blobby structure patchily discernible. Sparse scoria bombs as big as 50 cm near cliff rim suggest that vent lies nearby, probably concealed by adjacent moraine that extends from Deadman Pass cirque on southwest and, in turn, by Inyo pumice-fall deposit.

Southeast exposure includes a 600-m-long ridge of lightly welded brick-red agglu tinate and an adjacent steep-walled gorge, both walls of which expose denser agglutinate 50–80 m thick. Ridgecrest becomes narrow arête to northeast and consists mostly of tack welded scoria lapilli sprinkled with sparse scoria blocks (20–70 cm) and spindle bombs up to 1 m. On gorge walls, deposit is dense red-brown agglutinate with a few thin lava ledges intercalated, some of which are block-

jointed and dark gray. Wall sections grade down into dense fountain-fed lava near gorge floor. Narrow gorge through vent complex was probably cut glacially and later deepened by glacial outlet stream; its walls remain glacially striated, but stream now draining it is feeble and intermittent.

Products of all three vents are chemically and petrographically alike and presumed to have been erupted contemporaneously from a common dike; vents align along local rangefront scarp . A lone distal exposure crops out 2.8 km northeast of those vents as a water-smoothed lava ledge ~30 m long at 2,445 m elevation on floor of Deadman Creek (UTM 2115/7618); outflow lavas are elsewhere wholly concealed by surficial deposits. Products are not related to Cone 2652 (large scoria cone of phenocryst-poor unit mcv), toward which the mdn vent alignment roughly strikes.

Phenocrysts: 10–15% plagioclase (1–3 mm, rarely 4–5 mm); 1–3% olivine (0.5–1 mm); 1–2% cpx (0.5–2 mm); and common 5–10 mm intergrowths of 10–15 grains each of cpx and plagioclase (both 0.5–2 mm). Northwestern vent ejected metavol canic xenoliths (1–4 cm, rarely to 8 cm), some partially melted; middle vent ejected partially melted xenoliths of both granitoids and silicic metavolcanics. Base not exposed but presumed to overlie Mesozoic granitic rocks and still older metamorphic rocks, both exposed nearby but covered locally by till, colluvium, and Inyo pumice-fall deposit. All three proximal exposures were overtopped and eroded by glacial ice and strewn with basement erratics. Scoria lapilli (1–6 cm), chemically and petrographically indistin guishable from unit mdn, are scattered atop Dome 2861, 6 km southeast of mdn vents. 40Ar/39Ar age: 16±2 ka.

The undated basaltic trachyandesite of June Lake (unit mjl), which lies on the range front fault system 10 km north of unit mdn, is similar to it in composition, mineralogy, and unusually steep paleomagnetic direction (Hildreth and others, 2014). As both are overlain by MIS 2 glacial deposits, they may have erupted contemporaneously.

Blocky rubble, designated subunit mdn', banked against southwest base of Lookout Mountain (at UTM 03277/41769), consists exclusively of coarsely vesicular blocks of unit mdn, indistinguishable from near-vent outcrops chemically, petrographically, and in age (40Ar/39Ar age: 16.9±1.3 ka). Angular clasts (10–300 cm) protrude from thick mantle of Inyo pumice-fall deposit over an area 65 m along slope (north-south) and 35 m upslope (east-west), forming a flat-topped bench ~10 m high. Of 140 clasts counted, all are of unit mdn lithology. In drill hole OIP-1 (fig. 6), ~1 km northeast of Deer Mountain, a 10-m-thick lava flow chemically and petrographically similar to unit mdn is topmost of seven mafic lava flows penetrated and is covered there by ~18 m of Inyo ejecta (unit pe) and glacial deposits. Material was apparently transported from caldera-wall vents, first as periglacial or englacial lava flows, subsequently as fragmental flows. Straight-line path north of Deer Mountain would be 7–8 km from vents to moraine limit and additional 2 km to rubble deposit banked against Lookout Mountain.

Qdnw - Trachydacites of northwest moat (late Pleistocene)

dnw - Trachydacites of northwest moat (late Pleistocene)
Five discrete nonglaciated extrusions of related but variably contaminated magma (60.4–67.3% SiO_2) in northwest moat of Long Valley Caldera, 9 km north of Mammoth Mountain; their vents are aligned roughly northwest-southeast along a 2.5-km-long trend. From northwest to southeast, the five are generally more voluminous and more contaminated. All are glassy but choked with microlites and carry 15–20% crystals larger than 0.5 mm—phenocrysts, antecrysts, and xenocrysts. All have abundant biotite and sparser amphibole (both mph to 1.5 mm), both euhedral but ranging from fresh to opacitized. All contain rounded quartz (1–3 mm), many of them embayed. Intergrown clots (1–4 mm) of cpx, Fe-Ti oxides, and plagioclase (all generally mph) are common in all five. Free cpx (and rare opx) euhedra (mph to 1 mm) are probably disaggregated from such clots. Feldspars (1–25 mm) domi nate all assemblages, include both sanidine and plagioclase, and are mostly sieved and partly resorbed; some have clear overgrown rims, and some were in advanced stages of dissolution when eruptively quenched. Subordinate plagioclase populations (0.5–3 mm) are euhedral. Sparse mafic

blebs and enclaves are crystal-poor but olivine-bearing, and some enclose sieved feldspars from host dacite. From north to south, the five subunits mapped are:

1. Small coulee (65.7% SiO2), 20–30 m thick, that crops out 500 m long and 400 m wide below snout of 1350 C.E. Glass Creek flow (unit ric), which conceals its vent at caldera wall. Coulee is glassy and rugged, its knolls and ridges consisting of joint blocks with rough scoriaceous surfaces; rich in hornblende, biotite, and plagioclase, but few phenocrysts >5 mm. Contains mafic blebs as big as 1 mm; larger enclaves were sought but none found.

2. Small steep-sided dome (66.0% SiO2), nearly circular in plan, intrudes east margin of subunit 1 near base of caldera wall. Dome is 250 m in diameter, 50 m high, largely glassy, coarsely blocky, and little eroded. Rocks are mostly massive, with scat tered irrregular vugs and a few internal shear planes of oxidized breccia; some blocks have scoriaceous surfaces. Contains abundant feldspar (both plagioclase and sanidine; mostly 1–3 mm, fewer 6–10 mm); Carries sparse cpx+olivine+plagioclase-bearing mafic enclaves (1–10 cm), but fewer than in subunits to southeast.

3. Adjacent to subunits 1 and 2, knob 2430 caps a coulee that spread radially from a vent marked by a steep dome 30 m high. Knobby lobate coulee is 750 by 1000 m wide and has relief of 20–80 m, greatest at its eastward-descending lobe. This subunit, too, is glassy and block jointed but, in addition, is strongly flow foliated, its foliation ramping radially upward toward coulee margins. Crystal cargo is like that of subunit 2, including abundant biotite, but its mafic enclaves are more abundant, mostly 1–5 cm across, and irregularly distributed; a sampled enclave has 56.4% SiO2 . Vent dome and adjacent south east surface of coulee differ from rest of subunit in containing abundant and conspicuous large feldspar crystals (10–25 mm). At 67.3% SiO2 , vent dome is most silicic part of unit dnw sampled; subjacent coulee has 65.2–65.7% SiO2 (n=5).

4. Fourth in line is a bilobate lava flow (62.5–64.3% SiO2 —strongly hybridized) that spread radially from its apparent vent at knob 2400+. Sections of its chilled cara pace were dragged and spread by its then still-mobile interior to produce a labyrinth of rifted troughs on its surface; such fissures are typically 10–15 m wide, as deep as 10 m, and extend for several hundred meters. Flow surface is glassy and coarsely blocky, and northeast flow front is 25–30 m high. Surfaces of blocks are commonly scoriaceous and oxidized, though smooth on walls of fissures. Contains abundant plagioclase and sanidine crystals (mostly 5–15 mm but overall 1–25 mm), many equant but some elon gate or broken; also a varied cargo of biotite, hornblende, opx, cpx, rounded or wormy quartz, cpx-olivine-oxide-plagioclase clots, and rare olivine xenocrysts. Also contains abundant mafic enclaves (1–10 cm), typically fine-grained, phenocryst-poor, olivine bearing, and oxidized.

5. Most voluminous, most contaminated (60.4–61.7% SiO2), and southeasternmost of the five subunits is a major coulee, 1–1.5 km wide, that flowed 2 km northeastward from its vent. Its surface is a rough craggy plateau that descends gently northeastward to a steep lobate flow front as high as 20 m, which overlies lava field of unit mcv (~33 ka). Rugged block-jointed ridges and swells on its surface have 3–8 m of local relief. Like subunit 4, flow surface has rifted troughs, fewer and smaller than on its neighbor, vari ously oriented, 100–200 m long, their floors 5–12 m wide and their walls 3–7 m high. Nearly all outcrops are black crystal-rich vitrophyre carrying scattered irregular vesicles; block surfaces are commonly scoriaceous and oxidized brown. Contains same crystal cargo as accompanying subunits, including abundant plagioclase and sanidine as big as 25 mm; coexisting quartz and magnesian olivine; opacitized biotite and hornblende; numerous rounded, embayed, or strongly sieved crystals; microdioritic inclusions; and abundant mafic enclaves (1–10 cm). Xenoliths of granitic and metamorphic rocks are also present (Rinehart and Ross, 1964; Bailey, 2004). Vent for coulee, near its southwest limit, is marked by tack-welded to dense agglutinate and lineated rolls of extrusive lava. Unit dnw overlies units bar, mnd, and mcv; probably also rests on Mesozoic granite and Pliocene mafic lavas, both of which crop out within a few hundred meters of north margins of dnw. Overlain by Inyo pumice-fall deposit and rhyolitic Glass Creek flow (both 1350 C.E.). 40Ar/39Ar ages (sanidine from each subunit): (1) 40±1 ka; (2) 42±1 ka; (3) 40±1 ka; (4) 30±1 ka; (5) 27±1 ka (1–2 from table 2; 3–5 from Mahood and others, 2010).

Qbhl - Basalt of Horseshoe Lake (late Pleistocene)

bhl - Basalt of Horseshoe Lake (late Pleistocene)
Phenocryst-rich lava flows (48.9–49.3% SiO2) that floor 1-km-wide shelf between Lake Mary and Horseshoe Lake in Mammoth Lakes Basin. Thickest exposure of severely eroded unit is ~60 m on glacially excavated cliffs overlooking Twin Lakes. Ice-scoured ledges and swells are block-jointed to slabby, locally flow-foliated, and typically massive but slightly to moderately vesicular in places; some lava outcrops adjacent to lake are heterogeneously streaky, as if fountain fed. Glacially ravaged source vent was at site of Horseshoe Lake and is partly preserved on its east peninsula where a remnant of block-jointed lava caps and thus preserved a proximal scoria-fall deposit. Primary basaltic ejecta are mostly 5–25 cm, but a few are as big as 50–80 cm, and some have oxidized rinds. A smaller exposure on northeast rim of lake (UTM 032189/416440) likewise consists of scoria fall armored by a lava remnant. Elsewhere, southeast and east shores of lake are strewn with scoria and angular vesicular blocks of bhl lava, all ice mobilized and mixed with granitic erratics (many as big as 1–3 m) and sparser erratics of unit amp. Stratified surficial deposit that dips into lake at its southwest corner is largely a scree cone of scoria lapilli that washed down the cirque wall from unit bmc scoria cone atop Mammoth Crest. Phenocrysts in unit bhl: 10–15% plagioclase (0.5–5 mm); 5–7% cpx (1–3.5 mm); and 1–2% olivine (1–2.5 mm). Lava flows are notably rich in Mg and Ca but relatively poor in Al. Overlies units dbp and amp (97±1 ka). Overlain only by late Pleistocene till. Clasts of unit bhl are present in all late Pleistocene moraines of unit glb on both sides of Mammoth Creek. 40Ar/39Ar age: 31±1 ka.

Qmcv - Basaltic trachyandesite south of Crestview (late Pleistocene)

mcv - Basaltic trachyandesite south of Crestview (late Pleistocene)
Scoria cone west of Crater Flat and lava flow field (53.3–54.2% SiO2) that extends northward across Deadman Creek to terminus near Crestview highway maintenance station, 9 km from vent. Cone is 130 m high, 1 km wide, and heavily covered by Inyo pumice-fall deposit. Its unusually deep and steep-walled crater is breached and open to north. Outcrops on cone are limited to east and south rims, consisting of brick-red ejecta, both loose scoria and tack-welded stratified agglutinate. Coarse scoriae armoring crater rim are abundantly 30–50 cm and as big as 1 m. Lithic clasts among rim ejecta include a 5-m block of unit bar; Mesozoic metavolcanics; various mafic and felsic lavas (many probably from subjacent till); and abundant fragments (1–8 cm) of uncorrelated black, glassy, moderately porphyritic, hornblende-biotite-plagioclase rhyolite (72.1% SiO2) that is somewhat more evolved than rhyolite of nearby Deer Mountain (unit rdm). One mcv lava flow crops out poorly along draw at south base of cone, but lava apron north of cone is wholly concealed by Inyo pumice. Lavas flowed northeast around Deer Mountain, beneath later sites of rhyolitic Deadman Creek flow (unit ric) and coulee of unit dnw, emerging from beneath latter ~7 km from vent cone. North of flow front of dnw coulee, unit mcv forms a low-relief sagebrush-covered lava flow field that extends 2–2.5 km northward to end against north wall of Long Valley Caldera. Its rough, little-eroded surface is marked by low swells and hillocks, a few crags, and scattered small tumuli. Lavas are generally block-jointed, vesicular, commonly scoriaceous and oxidized reddish brown, and seldom expose more massive internal zones. Phenocrysts: 1–2% plagioclase (0.5–2 mm); traces of olivine and cpx (each mostly mph but as big as 1 mm); much of cpx occurs in clots with plagioclase. Overlies units bar and mor. Overlain by unit dnw (27±1 ka), by Inyo pumice deposits (primary and reworked), and by alluvium of Deadman Creek. Drill hole DC-1 (fig. 6; Sorey and others, 1978), located at UTM 259/781, ~800 m northwest of Crestview roadside rest, penetrated to base of unit mcv at ~25 m depth, then successively downward through a 30-m-thick flow of unit mor (66±2 ka), a 20-m flow compositionally identical to unit bsr (99±1 ka), a 15-m flow of unit aic, and a 10-m uncorrelated phenocryst-poor flow, before passing into ~75 m of gravels and ashy sediments, and finally, at a depth of 191 m, into tuff and lava of Early rhyolite (unit rer; ~700 ka). 40Ar/39Ar ages of unit mcv: 31±2 ka (Mahood and others, 2010); 33.8±1 ka (table 2).

Qrss - Alkalic rhyodacite of Solitude ski run (late Pleistocene)

rss - Alkalic rhyodacite of Solitude ski run (late Pleistocene)
Moderately porphyritic Solitude Dome, knob 3160+, between Lincoln Peak and Mammoth Mountain summit. Dome (70.0– 70.6% SiO_2) lies 500 m northeast of summit (figs. 1, 7), just across ice-excavated trough (The Chasm) that separates it from summit's northeast face (which consists of units dfl and dsu). Flow foliation dips radially on slopes of dome and defines a broad open fold on dome's south face; top central part of dome is more disrupted and may include a final breccia-enveloped protrusion, ~20 m wide and ~80 m long. Exposures are black to pale-gray vitrophyre, only locally oxidized, strongly flow-foliated but also com monly block-jointed; some domains are cream-white and microvesicular; spherulitic, lithophysal, and tan-to-pink flow layers are subordinate. Phenocrysts: 7–12% feldspar (0.5-5 mm); ~2% biotite (mph to 1.5 mm); =1% opx (0.5–1.5 mm, rarely as long as 3 mm); sparse Fe-Ti-oxide mph. Also contains sparse feldspar clusters and biotite oxide-pyroxene-feldspar clots. Overlies units rce (81±1 ka) and dsd (87±6 ka). Dome is distinguished from rhyodacite units rce and rmf by its higher Sr, Ca, Mg, Fe, Ti, and P abundances and lower K, Na, Nb, and Zr. Dome is distinguished from lava-flow unit rsq by greater Mg, Ti, Rb, and Sr abundances, lower Ba and Zr, and by different paleomag netic directions. Despite chemical and magnetic differences, alkalic rhyodacite units rce (80±1 ka), rsq (63.7±4 ka), and rss evidently issued sequentially at a common vent site. 40Ar/39Ar age: 50±3 ka.

Qdlp - Trachydacite of Lincoln Peak (late Pleistocene)

dlp - Trachydacite of Lincoln Peak (late Pleistocene)
Phenocryst-rich Dome 3079 (67.7–68.5% SiO_2) centered 1.5 km northeast of Mammoth Mountain summit (fig. 1). In plan view, glaciated lava dome is 500 by 700 m, elongate to east-northeast. Steep north face has 160 m of relief and east face as much as 220 m; south and west slopes are gentler. Many exposures are black to medium-gray vitrophyre that splits blocky to slabby. Flow folia tion conspicuous and nearly ubiquitous; common for pale gray or reddish brown layers to interleave with dark glassier ones. Eastern cliffs dominated by buttresses of shiny black vitrophyre; northern cliff includes such vitrophyre but also has medium-gray partly devitrified domains that weather dull gray and, locally, flow-laminated domains that split into thin plates with tan and pink films. Phenocrysts: 15–20% feldspar (0.5–8 mm, few >5 mm); 2–4% biotite (mph to 1.5 mm); 1–3% hornblende (mph to 2.5 mm); trace cpx (0.4–0.8 mm); common Fe-Ti oxide mph. Flow-foliated rocks of summit and nearby southeast spur (UTM 222/672) are physically disturbed, as inferred from anomalous paleomagnetic vectors; after partial cooling, upper crags were probably heaved and rotated by renewed inflation of dome. Overlies units rce (80±1 ka) and probably banks against unit dgr. Unit rsq (63.7±4 ka) banks against south toe of Lincoln Peak dome. 40Ar/39Ar age: 64±7 ka.

Qddu - Trachydacite of upper Dragons Back (late Pleistocene)

ddu - Trachydacite of upper Dragons Back (late Pleistocene)
Phenocryst-rich coulee (66.0–66.9% SiO_2) as thick as 160 m that caps uppermost 1-km-long segment of cleaver called Dragons Back, southeast of Mammoth Mountain summit; flow extends along ridgecrest from ~3,270 m down to eroded flow front at ~2,960 m. Much of crest is pale gray or iron-stained, crumbly vitrophyre or partly devitrified lava, but blocky remnants of massive dark gray vitrophyre, some of it vesicular, survive locally; flow foliation is locally conspicuous and many blocks retain thin brown scoriaceous crusts. Ice-scoured buttresses on north slope of flow are slabby to platy near base of unit. An erosional outlier <100 m wide that forms nubbin 3120+ (UTM 210/669), ~700 m north of upper end of Dragons Back and ~400 m northeast of Mammoth Mountain summit, is a precise match compositionally. Distal remnants also crop out through till on northeast side of Panorama Dome and in vicinity of 2,610-m switchback on Old Mammoth Road (UTM 240/652). Phenocrysts: 12–15% feldspar (0.5–7 mm); ~5% hornblende (1–5 mm, rarely 10 mm long); 1–2% biotite (mph to 1.5 mm); sparse Fe-Ti oxides; also contains common clots of all combinations of these

phases. Overlies units dsd (87±6 ka), dbp, and ddl (58±2 ka). Chemically almost identical to subjacent flow unit ddl but consistently slightly richer in Al (n=17 analyses; ddl and ddu together). Undated.

Qdgr - Trachydacite of Gold Rush Express (late Pleistocene)

dgr - Trachydacite of Gold Rush Express (late Pleistocene)
Ice-scoured remnant of phenocryst rich lava dome (68.7–68.8% SiO2) that forms north-trending ridge 350 m long and only 150 m wide, just west of Lincoln Peak. Flat summit of ridge is current terminus of Gold Rush Express (Chair 10); lava nose that descends to north has ~100 m relief. Ridgecrest consists of pale-to-dark gray vitrophyre, block-jointed and flow-foliated; nose below to north is partly devitrified, widely oxidized, and strongly flow-laminated. Phenocrysts: 15–20% feldspar (0.5–4 mm, many atypically small for Mammoth Mountain); 5–6% biotite (mph to 2 mm); sparse hornblende (=1 mm); =1% pyroxene (0.2–0.7 mm); com mon Fe-Ti oxide mph. Although slightly more evolved, this unit is chemically similar to Lincoln Peak (unit dlp); however, it contains far less hornblende and has a paleomagnetic direction distinct from that of adjacent Lincoln Peak. Contact relations with units dlp (64±7 ka) and rce (80±1 ka) are obscured by colluvium, but dgr is probably younger than rce and older than dlp. Undated.

Preserved atop dgr dome (UTM 217/670) is a 50-m-long remnant of poorly sorted, unstratified diamict 6–7 m thick. Enclosed in sandy matrix are angular clasts of phenocryst-rich dacite (typical of Mammoth Mountain) seriate in size from granules to blocks as big as 50–80 cm. Absence of thermal effects and prismatic jointing, along with contrasting textures among blocks (fresh vs altered; vesicular vs dense; glassy vs devitri fied), suggests deposit is glacial or colluvial, not pyroclastic. One large block analyzed is petrographically and chemically indistinguishable from unit dsd (87±6 ka), which crops out ~1 km uphill.

Qddl - Trachydacite of lower Dragons Back (late Pleistocene)

ddl - Trachydacite of lower Dragons Back (late Pleistocene)
Phenocryst-rich coulee (66.0– 66.8% SiO2) as thick as 180 m that caps distal 600 m of Dragons Back, southeast ridge of Mammoth Mountain (fig. 22). Flow forms steep east-facing bluff above Twin Lakes as well as north- and south-facing scarps of ridge itself. Narrow ridgetop plateau is capped by blocky to craggy unglaciated vitrophyre that survived as cleaver above adjacent late Pleistocene glaciers. Eroded scarps are block-jointed ledges and buttresses of dense vitrophyre with locally pronounced flow foliation; blocks typically have thin brown scoriaceous rinds while freshly broken surfaces are sheer, black, and shiny. Where ddl flow overlaps oxidized unit dbp, it locally exposes a 10-m-thick massive red-brown lower zone that grades down into oxidized basal breccia, both of which pinch out toward eastern cliff. At north foot of steep Dragons Back ridge, chemically identical lava forms a glaciated shelf 30 m wide and 80 m long (UTM 225/659), which is block jointed on top but platy to slabby on its 15-m-high north-facing scarp, with oxidized flow brec cia at base of flow. Glacial excavation of Twin Lakes Basin separated Dragons Back segment from its eastward extension, which survives as till-mantled Panorama Dome (2,723 m on top); this segment crops out only in roadcuts on Lake Mary Road (2,640 to 2,660 m), where exposures are block jointed to slabby, moderately flow-foliated vitrophyre and felsite, widely iron-stained along partings. Phenocrysts: 10–15% feldspar (0.5–10 mm), 3–5% hornblende (1–5 mm); 1–2% biotite (mph to 1.5 mm); trace pyrox ene mph; common Fe-Ti oxide mph; also contains oxide-amphibole-feldspar clots and cpx-oxide-feldspar clots. Overlies units dbp, dom (73±1 ka), and dtl (76±1 ka). Overlain by unit ddu. Paleomagnetic direction differs from those of unit dbp below and unit ddl above.40Ar/39Ar age: 58±2 ka (Mahood and others, 2010).

Qdbp - Trachydacite of Bottomless Pit (late Pleistocene)

dbp - Trachydacite of Bottomless Pit (late Pleistocene)
Phenocryst-rich coulee (66.8–67.1% SiO2) as thick as 160 m that forms east-facing bluff that rises above middle of the three Twin Lakes at southeast toe of Mammoth Mountain (fig. 22). Name derives from erosion al tunnel, a rocky sloping passageway that descends through flow from high rim to talus at foot of bluff. Tunnel is flanked by several open chutes nearby, all eroded into bluff rim parallel to near-vertical northwest-striking flow foliation and jointing. Elsewhere, unit is block-jointed and glacially scoured into rounded knobs and buttresses. Flow is pervasive ly oxidized, atypically strongly so for Mammoth Mountain; crops out pale pinkish brown to reddish brown or locally tan with streaks and layers of black vitrophyre. Phenocrysts: 10–15% feldspar (0.5–6.5 mm); 3–4% hornblende (1–2 mm, rarely as long as 10 mm); 1–3% biotite (mph to 2 mm); common Fe-Ti-oxide mph, mostly in clots with feldspar. Overlies units dnh (64.5±0.8 ka), dsd (87±6 ka) and amp (97±1 ka). Overlain by units ddl (58 ±2 ka), ddu, and bhl (31±1 ka). Undated.

Qeb - Explosion breccia deposit of Bailey (late Pleistocene)

eb - Explosion breccia deposit of Bailey (late Pleistocene)
Unconsolidated heterogeneous assemblage of erratic blocks atop low-relief crest of granitic ridge 3044 (Hemlock Ridge; fig. 7), which buttresses west flank of Mammoth Mountain. Along most of 600-m-long crest of ridge, rocks exposed through Inyo pumice cover are exclusively loose clasts of porphyritic granite (unit Kmo), rounded to subangular, pebbles seriate to 2-m boulders, plucked and redistributed from local bedrock by ice. Limited to a 50-m-long strip (~20 m wide) on southwest slope of saddle along crest, however, abundant granite boulders are joined by blocks of crystal-poor mafic lavas, biotite rhyodacite, and various felsite and vitrophyre clasts containing hornblende, biotite, and feldspars—each clast type as big as 30–75 cm. Seven chemically analyzed clasts are identified as Mammoth Mountain rhyodacites and trachydacites and andesite of Mammoth Pass (unit amp). Interpreted tentatively as accidental ballistic ejecta from a (phreatic?) outburst on Mammoth Mountain; unit was probably more widely distributed but survived glacial scour only in saddle.

South of our map area, Bailey (1989) also assigned to this unit comparable lithic assemblages sparsely scattered on upland surfaces; those atop the Pliocene erosion surfaces of Mammoth Crest and Red Mountain, however, are not ejecta from Mammoth Mountain but are, instead, clasts of rhyolite, dacite, and basalt derived from a precaldera volcanic highland on the later site of Long Valley Caldera.

Qrsq - Alkalic rhyodacite of Quicksilver ski run (late Pleistocene)

rsq - Alkalic rhyodacite of Quicksilver ski run (late Pleistocene)
Moderately porphyritic lava flow (70.0–70.3% SiO2) that issues from beneath Solitude Dome (unit rss) and extends 1.5 km eastward (south of Lincoln Peak) to flow front at ~2,750 m. Crops out patchily through colluvium and bulldozed ski-slope rubble as flow-foliated block-jointed vitro phyre, black to pale gray, but irregularly streaked tan or pink and locally lithophysal. Flow was glacially scoured and plucked distally into a few block-jointed ledges 5–20 m high. Phenocrysts: ~10% feldspar (mph to 3.5 mm); ~2% biotite (0.5–1.5 mm); sparse pyroxenes (0.2–0.7 mm); sparse Fe-Ti oxide mph; and rare hornblende mph. Flow is distinguished from Solitude Dome (unit rss) by paleomagnetic directions; flow also has consistently greater Ba and Zr abundances than unit rss and lower Ti, Mg, Rb, and Sr. Flow overlies unit rce (80±1 ka); also apparently overlies toe of adjacent Lincoln Peak dome (unit dlp; 64±7 ka), but thick colluvial wedge obscures contact. Flow is overlain by dome unit rss (50±3 ka). 40Ar/39Ar age of lava flow: 63.7±4 ka.

Qrmf - Alkalic rhyodacite of Mammoth Mountain fumarole (late Pleistocene)

rmf - Alkalic rhyodacite of Mammoth Mountain fumarole (late Pleistocene)
Moderately porphyritic lava flow (69.9–70.7% SiO2) that forms 800-m-long dipslope that is referred to as Face Lift planèze (figs. 7, 12). It descends northward from 3,208-m knob to eroded flow front facing McCoy Station reservoir at 2,940 m. Erosionally isolated knob, 400 m north of Mammoth Mountain summit, is upper terminus of Face Lift Express (Chair 3). Dipslope forms glacially eroded planèze 200–350 m wide. Midway up dipslope surface, wispy fumarole issues from joints in lava (and from small artificial pipes) at ~3,030 elevation. Below fumarole, strip of modest acid alteration extends ~200 m downslope, largely confined to surficial debris along a gulch and to films on fractures in the rhyo dacitic lava. Flow is mostly dark- or medium-gray vitrophyre, strongly flow foliated, with subordinate layers devitrified, spherulitic, or locally lithophysal; layers are commonly 2–10 cm thick, locally folded convolutely, and ramped into steep inward dips around flow margins. South-facing 25-m-high scarp of knob 3208 is acid-altered, which facili tated glacial excavation of 150-m-wide notch (The Chasm; fig. 12) that separates knob from north scarp of summit dome (units dfl and dsu). Phenocrysts: 10–12% feldspar (0.5–3 mm, rarely 5 mm); ~2% biotite (mph to 2 mm); =1% opx (0.3–1.2 mm); sparse Fe-Ti-oxide mph. Also carries mafic blebs and sparse clots of all these minerals in varied proportions. Overlies units dms (68±1 ka) and dfl (61±3 ka). Overlain by remnant outlier of unit dsu (61.4±2 ka). 40Ar/39Ar age: 61±1.5 ka.

Qdsu - Trachydacite of Mammoth Mountain summit (late Pleistocene)

dsu - Trachydacite of Mammoth Mountain summit (late Pleistocene)
Phenocryst-rich summit dome (68.0–69.6% SiO2) of Mammoth Mountain (elevation 3,369 m; figs. 1, 7). Ice-scoured dome-flow complex extends ~700 m along crest and has ~150 m of relief. A large but uncertain fraction has been glacially stripped. Summit is site of café, interpre tive center, and terminus of góndola that ascends from north toe of edifice. Most expo sures are ledges and cliffs of flow-foliated vitrophyre, black to pale gray, widely exhibit ing reddish brown films on joint surfaces. Cliffs also expose shear zones of flow breccia as thick as 10 m. Much of upper surface and south slope are acid altered, whereas freshest rocks are cliffs at southeast end of unit and a strongly flow-foliated lava flow along its northwest rim. An outlying remnant, only ~300 m long and 50 m wide, banks against unit rmf along upper east side of glaciated Face Lift planèze, where it is youngest unit preserved. Phenocrysts: 10–15% feldspar (0.5–7 mm); 3–5% biotite (mph to 2.5 mm); 1–2% hornblende (mph to 2.5 mm); sparse pyroxene (0.3–1 mm); sparse Fe-Ti oxide mph; also carries mafic blebs, biotite-oxide-feldspar clots, hornblende-feldspar clots, and angular biotite-felsite xenoliths (1–15 cm). Intrudes and overlies unit dsd (87±6 ka. Overlies units drc, dfl (61±3 ka) and rmf (61±1.5 ka); apparently banks against unit dsk (71±1.5 ka). 40Ar/39Ar age: 61.4±2 ka.

Qdfl - Trachydacite of Face Lift (late Pleistocene)

dfl - Trachydacite of Face Lift (late Pleistocene)
Phenocryst-rich lava flows (63.0–65.9% SiO2) that extend from north face of Mammoth Mountain summit for ~1.5 km northward beneath unit rmf on Face Lift planèze (fig. 12) and bank against unit dms of McCoy Station plateau. Base not exposed but has as much as 80 m of relief along east margin, 50 m along west margin, and ~60 m at foot of summit scarp along The Chasm. Generally hackly or block jointed; flow foliation locally pronounced. Everywhere glacially eroded, but exposures are mostly glassy; oxidation and iron-staining along joint planes only mod est and local. Phenocrysts: 15–20% feldspar (0.5–5 mm); 5–7% biotite plus amphibole in varied but subequal amounts (each as big as 2.5 mm); 1–2% pyroxene (0.3–2 mm); com mon Fe-Ti oxide mph. Also carries mafic blebs, oxide-pyroxene clots, feldspar clusters, and sparse angular xenoliths of pale-gray or tan, moderately porphyritic felsite (1–4 mm). Apparently extruded beneath summit or where The Chasm was eroded (fig. 12). Several dfl flows underlie unit rmf (61±1.5 ka) along both flanks of Face Lift planèze. Proxi mally, unit underlies summit-capping unit dsu (61.4±2 ka); distally, it banks against both sides of

unit dms (68±1 ka) as well as apparently against unit dnk (60.4±1.2 ka). Several adjacent units here yield eruptive ages that are similar, but unit dfl is distinctive among them in being chemically less evolved and richer in pyroxene. Unit is similar in composi tion and paleomagnetic direction to unit drc, which crops out to south, on opposite side of Mammoth Mountain. 40Ar/39Ar age: 61±3 ka.

Qdrc - Trachydacite of upper Reds Creek (late Pleistocene)

drc - Trachydacite of upper Reds Creek (late Pleistocene)
Phenocryst-rich lava flow (63.8– 65.7% SiO_2) on upper southwest slope of Mammoth Mountain; exposed as 250-m-wide swath ~600 m long that descends steeply from beneath summit dome (unit dsu) at ~3,260 m to an eroded flow front at 3,040 m on west wall of Reds Creek. Rock is flow-foliated and block-jointed vitrophyre, black to medium gray; only locally vesicular or oxidized. Uppermost outcrops are ribs and ledges widely concealed by scree; distal outcrops are steep rugged cliffs that weather dark brown. Phenocrysts: 15% feldspar (0.5–7 mm); 3–5% hornblende (mph to 2 mm, rarely to 3.5 mm); ~1% biotite (mph to 1.5 mm); ~1% pyroxene (mph to 2.5 mm); common Fe-Ti oxide mph. Also carries mafic blebs, oxide+cpx±plagioclase clots, and brick-red dacitic autoliths. Base not well exposed but fresh drc overlies adjacent unit dsd (87±6 ka), which is acid-altered at and near contact. Also overlies units dwr (73±2 ka) and dsk (71±1.5 ka), but is overlain by unit dsu (61.4±2 ka). Unit is similar in composition and paleomagnetic direction to unit dfl (61±3 ka), which crops out to north, on opposite flank of Mammoth Mountain. Undated.

Qdnk - Trachydacite of North Knob (late Pleistocene)

dnk - Trachydacite of North Knob (late Pleistocene)
Phenocryst-rich lava dome (66.4–66.5% SiO_2) centered 450 m west of McCoy Station at midslope on north flank of Mammoth Mountain (fig. 7). Terminus of Broadway Express (Chair 1) is on summit of dome (3,016 m). Dome exposure is altogether 700 m in diameter and includes 400-m-long ice-scoured rib separated by scree chute just west of main knob; relief is ~200 m on steep north slope of dome. Outcrops are mostly medium-gray vitrophyre, massive or flow foliated, and widely oxidized reddish brown (especially upper parts); extensive domains are partly devitrified (owing to glacial removal of original glassy carapace), and southeast slope is hydrothermally altered. Phenocrysts: 12–15% feldspar (0.5–8 mm); 3–5% biotite (mph to 2 mm, rarely to 5 mm); 2–3% hornblende (mph to 2 mm); common Fe-Ti oxide mph. Also carries plagioclase clusters and biotite-oxide-feldspar clots. Almost surrounded by surficial deposits but probably older than unit dfl along its east margin. Northerly paleomagnetic declination and moderate (40°) inclination differ from steep northwesterly directions of flow sequence that built adjacent Face Lift planèze (units dml, dms, dfl, rmf, and dsu). 40Ar/39Ar age: 60.4±1.2 ka.

Qdnh - Trachydacite north of Horseshoe Lake (late Pleistocene)

dnh - Trachydacite north of Horseshoe Lake (late Pleistocene)
Two phenocryst-rich lava flows (67.9–68.4% SiO_2) in poorly exposed window between units amp and dbp, ~700 m north of Horseshoe Lake. Widely covered by colluvium, unit crops out as minor southeast trending rib ~500 m long and ~150 m wide, expressed mainly as two 10-m-high glaciated ledges (at elevations 2,760 and 2,860 m) that probably represent two southeast-sloping lava flows. Both ledges are block-jointed vitrophyre, black to pale gray or locally oxi dized. Phenocrysts: 12–15% feldspar (0.5–5 mm); 2–3% biotite (mph to 3 mm); 0.5–2% hornblende (mph to 1.2 mm); ~1% opx (mph to 2.5 mm); common Fe-Ti oxide mph. Also carries sparse mafic blebs. Paleomagnetic directions of both flows are apparently excur sional, contrasting with those for units dsd, dbp, and others nearby (Hildreth and others, 2014). Lower ledge contains abundant gray fine-grained enclaves (56.7% SiO_2), 1–20 cm across and variously rounded, angular, or crenulate; they carry fewer crystals than host lava but their crystal cargo consists of same species plus common cpx. Base of unit not

exposed but inferred to bank against unit amp (97±1 ka). Overlain by unit dbp. 40Ar/39Ar age: 64.5 ±0.8 ka.

Qmsd - Basaltic trachyandesite scoria southeast of Dry Creek (late Pleistocene)

msd - Basaltic trachyandesite scoria southeast of Dry Creek (late Pleistocene)
Phenocryst poor scoria (51.8–53.0% SiO_2) exposed poorly in 100-m-wide window at northwest end of saddle between Domes 2861 and 2781. Largely obscured by colluvium from adjacent domes; no stratified cinders or lava flows are exposed; instead, site is a scattering of scoria blocks and bombs as big as 50 cm, finely to coarsely vesicular, mostly dark gray but some oxidized brick- red. Phenocrysts: <1% plagioclase (0.5–5 mm; many probably xenocrysts) and trace of olivine (<1 mm). Base not exposed. Overlain by glacial erratics and by colluvial debris from both domes (units d61 and d81), which appear to be older. Chemically and petrographically similar to presumptively comagmatic units mnd and mor (66±2 ka), for which unit is inferred to mark source vent. Undated.

Qdms - Trachydacite of McCoy Station (late Pleistocene)

dms - Trachydacite of McCoy Station (late Pleistocene)
Phenocryst-rich coulee (68.5–69.6% SiO_2) that emerges from beneath sloping apron of unit rmf and extends ~1 km northward, forming plateau site of McCoy Station (fig. 7) and distal lobe farther downslope atop unit dml. Although thinned substantially by glacial erosion, flow is still as thick as 60 m on northeast-facing scarp of plateau. Farther north, unit pinches out as a few deeply scoured remnants exposed patchily through till, colluvium, and Inyo pumice covering surface of underlying dml coulee. Moderately to strongly flow-foliated vitrophyre; dense black glassy layers alternate with pale gray partly devitrified layers and lenses, some lithophy sal or spherulitic; glassy parts often disintegrate crumbly where weathered. Phenocrysts: 10–12% feldspar (0.5–5 mm); 2–5% biotite (mph to 3 mm); ~1% opx (mph to 2 mm); sparse hornblende (0.3–1 mm; rarely as long as 3 mm); common Fe-Ti oxide mph; also carries sparse mafic blebs and common pyroxene-oxide-feldspar clots. Composition significantly more silicic than adjacent units dfl and dml. Overlies unit dml (67±1 ka); overlain by units dfl (61±3 ka) and rmf (61±1.5 ka). 40Ar/39Ar age: 68±1 ka (Mahood and others, 2010).

Qmnd - Basaltic trachyandesite northwest of Dry Creek (late Pleistocene)

mnd - Basaltic trachyandesite northwest of Dry Creek (late Pleistocene)
Phenocryst-poor lava flows and agglutinate (53.3–54.0% SiO_2) exposed in six different places along 6-km-long belt northwest of Dry Creek; correlated chemically, petrographically, and stratigraphi cally. Largest patch is 1.3-km-wide unglaciated lobe that extends 1 km beyond limit of late Pleistocene till (unit gdc) to terminus 4 km northeast of Deer Mountain; margins and flow front are little modified and have 10–20 m relief. Surface is marked by sev eral tumuli and rootless vents that fed ragged piles and ridges (3–5 m high) of oxidized tack-welded agglutinate, rich in scoria bombs. Second large exposure is 1-km-wide unglaciated steep-sided lobate bench, just north of Dry Creek and west of Highway 395, that rises steeply 40 m higher than both; probably fault-bounded as well as eroded by Pleistocene Dry Creek. In both unglaciated areas, most surfaces are rubbly and sco riaceous, whereas sparse outcrops of flow interiors are block-jointed and massive to weakly vesicular. Several lesser exposures to southwest are glaciated windows through blanket of till. Narrow sliver of oxidized tack-welded agglutinate at north end of west facing fault scarp, 2 km northeast of Deer Mountain, is probably part of a rootless vent. Three southernmost outcrops are a cluster of discrete ice-scoured swells that rise above till blanket within 1 km west of rhyolitic Dry Creek Dome and only 100–400 m west of Dry Creek; each is ~100 m wide, has only a few meters of ledgy relief, and consists of streaky

to flow-foliated, aphanitic lava. Sites drilled at several of the outcrops yield similar paleomagnetic directions (Hildreth and others, 2014). Phenocrysts: <1% % plagioclase (0.5–1 mm); trace olivine mph (rarely as big as 0.5–1 mm). Also contains rare but widespread xenocrysts or antecrysts of rounded or corroded plagioclase (1–6 mm). Overlies units mcl (~175 ka) and bar (~95 ka). Overlain by units mor (66±2 ka), dnw, and gdc. Geothermal corehole PLV-2 (Benoit, 1984), collared in northernmost area of the unit, penetrated 169 m of mafic lavas (perhaps as many as 8 flows), which overlie at least 467 m of rhyolitic tuffs and lavas that extend to bottom of hole (fig. 6). Many distal samples of extensive flow field of unit mor are chemically and petrographically indistin guishable from those of unit mnd, whereas steep-sided, well-defined, proximal-to-medial part of mor, which directly overlies mnd, carries significantly more phenocrysts and has 1–2 percent less SiO2 than unit mnd. Medial and distal sites drilled in unit mor and sites in unit mnd (both east and west of mor) all yield similar paleomagnetic directions (Hildreth and others, 2014). It is thus inferred that unit mnd represents early phase of more extensive (and chemically more varied) subsequent effusion of unit mor (66±2 ka), probably from same source vent (southwest of Dome 2861; see unit msd) and of virtually same age. Not independently dated.

Qdml - Trachydacite of Main Lodge Coulee (late Pleistocene)

dml - Trachydacite of Main Lodge Coulee (late Pleistocene)
Phenocryst-rich coulee (65.6–68.6% SiO2) that emerges from beneath unit dms at 2,900 m elevation and extends 1 km northward to an eroded flow front at 2,710 m, just east of MMSA Main Lodge. Outcrops of glaciated flow are patchy because of heavy mantle of till and colluvium, but relief of at least 50 m is exposed along east margin. Exposures are weakly to moder ately flow-foliated vitrophyre, medium gray to black with subordinate layers vesicular, sheared, or weathered reddish brown; splits slabby but more commonly coarsely blocky; weathered outcrops crumbly. Where bulldozed for ski runs, pale gray or pinkish gray devitrified interior facies is locally exposed. Phenocrysts: 12–20% feldspar (mph to 5 mm); 2–4% biotite (mph to 2.5 mm); 1–4% hornblende (mph to 2 mm; ~1% pyroxene (0.5–2.5 mm); common Fe-Ti oxide mph. Also contains rare 1–3 mm inclusions of inter grown feldspar and black pyroxene. Base not exposed. Overlain by unit dms (68±1 ka). 40Ar/39Ar age: 67±1 ka (Mahood and others, 2010).

Qdsk - Trachydacite of Skyline Dome (late Pleistocene)

dsk - Trachydacite of Skyline Dome (late Pleistocene)
Phenocryst-rich lava dome (67.2–69.8% SiO2), ~700 m wide, on crest of Mammoth Mountain (fig. 7) just southeast of Scottys Dome (unit dwr). On precipitous north rim is conspicuous terminal of Chair 23; north face has more than 200 m exposure, its toe concealed by talus. Unit is block-jointed or slabby, and flow foliation is subdued (relative to lavas of adjacent domes). Upper part of unit is widely acid-altered, its surfaces cream-white, yellow, or rusty reddish brown, but interiors of some thick slabs are pale to medium gray and fairly fresh. Lower part of north face is fresher, eroding into coarsely block-jointed ledges. Erosional outlier, similar in composition and paleomagnetic declination, forms ice-scoured rib at 3,100 m elevation (UTM 204/672), 600 m north of summit and 270 m lower; northwest-trending rib, ~80 m wide and 250 m long with <20 m local relief, consists of flow-foliated black and reddish brown vitrophyre with a slabby devitrified domain exposed at its lower end. Phenocrysts: 12–15% feldspar (0.5–5 mm); 3–5% biotite (mph to 1.5 mm); sparse Fe-Ti oxide mph; trace pyroxene (0.3–0.8 mm); also contains biotite-oxide-feldspar clots and rare clusters of pyroxene. Overlies unit dwr (73±2 ka). Overlain by units drc and dsu (61.4±2 ka). 40Ar/39Ar age: 71±1.5 ka.

Qdwr - Trachydacite of White Bark Ridge (late Pleistocene)

dwr - Trachydacite of White Bark Ridge (late Pleistocene)
Phenocryst-rich lava dome-flow complex (67.9–69.5% SiO2) that makes up entire west flank of

Mammoth Mountain (fig. 7). Outcrop belt is ~1 km wide and extends ~2.5 km north-south, including White Bark Ridge (UTM 192/677), Scottys Dome (UTM 197/671), and southwest flank west of Reds Creek. Exposed up to 3,175 m atop steep-walled dome, down to 2,850 m on White Bark Ridge, and as low as 2,780 m at southwest extremity. From 2,800 m to 2,960 m, pumice-mantled southwest lobe consists of four ledges of block-jointed vitrophyre, which appear to be discrete (but compositionally similar) lava flows. Most outcrops are black to medium-gray vitrophyre, strongly to weakly flow-foliated, block-jointed or slabby, and only locally either vesicular or partly devitrified. Craggy rim of dome retains reddish brown scoriaceous crusts and may have stood above ice; unit is everywhere else glacially eroded. Although unit consists of several physiographic components, no simple subdivi sion of sprawling complex can be made on basis of broadly similar compositional data; for example, TiO2 (0.50–0.58%) and K2 O (4.25–4.46%) exhibit no systematic spatial pattern (n=15). Nonetheless, two extrusive episodes are indicated by paleomagnetic data: northern coulee and western flow lobe share modest inclination and northeasterly decli nation, whereas younger components (Scottys Dome and topmost coulee to southwest) share steep inclination and northerly declination (Hildreth and others, 2014).

Phenocrysts: 10–15% feldspar (0.5–6 mm); 3–5% biotite (mph to 2.3 mm); <1% hornblende (mph to 1.5 mm); sparse pyroxene (0.2–1 mm); sparse Fe-Ti oxide mph; also carries varied clots of these phases in all combinations. Overlies units rrc, amp (97±1 ka), and dsd (87±6 ka), and banks against Mesozoic granite (unit Kmo) at topo graphic wall of Long Valley Caldera, thereby enclosing 1-km-long hollow that now contains Reds Lake. Overlain by units drc and dsk (71±1.5 ka). 40Ar/39Ar ages: 79 ±12 ka for western flow lobe; 73±2 ka for top of Scottys Dome.

Qdtl - Trachydacite of Twin Lakes outlet (late Pleistocene)

dtl - Trachydacite of Twin Lakes outlet (late Pleistocene)
Phenocryst-rich lava flow of low-silica trachydacite (63.0–64.0% SiO2) that extends ~1 km eastward from Twin Lakes outlet bridge. Crops out as a 50-m-high ledge above Lake Mary Road just north of outlet and extends downstream along both banks of Mammoth Creek, supporting a scenic waterfall at 2,550 m. Elsewhere extensively covered by glacial deposits, unit is also exposed in 2,530-m roadcut on Old Mammoth Road (240/6575) and as three small windows at 2,760–2,810 m on floor of till-mantled valley north of Dragons Back. Every where glaciated, outcrops are partly glassy or widely devitrified, block-jointed or slabby, patchily oxidized, variously massive, vuggy, or weakly vesicular, with flow foliation typically poorly developed. Phenocrysts: 15–25% feldspar (0.5–7 mm); 3–5% hornblende (0.5–7 mm); 3–5% biotite (mph to 1.5 mm); 1–2% pyroxene (mph to 2 mm); common Fe-Ti-oxide mph. Also contains mafic blebs, fine-grained cpx-oxide-plagioclase clots, intergrowths of plagioclase and hornblende (1–2 cm), and finely porous, fine-grained inclusions (1–25 mm, rounded to angular) that carry mph of plagioclase, hornblende, biotite, and pyroxene—all typically =0.5 mm. Base not exposed but probably overlies unit amp (97±1 ka). Inferred to be overlain by nearby units dbp and ddl (58±2 ka), but all contacts are covered by surficial deposits. 40Ar/39Ar age: 76±1 ka.

Qrce - Alkalic rhyodacite of Canyon Express (late Pleistocene)

Arce - Ikalic rhyodacite of Canyon Express (late Pleistocene)
Moderately porphyritic lava-flow apron (70.3–70.8% SiO2) that emerges from beneath unit rss west of Lincoln Peak and spreads northward for 2 km to foot of Dome 2781(unit d81) and eastward for 2.5 km to east-facing bluffs (Timber Ridge) southeast of Canyon Lodge. Upper terminus of Canyon Express (Chair 16) is built on this rhyodacite at 2,910 m elevation near northwest base of Lincoln Peak. Exposures include black to gray flow-foliated vitrophyre and extensive tracts of cream-white massive felsite; locally oxidized pink or weathered brown, espe cially along vuggy foliation planes. Some outcrops form bold ledges and nubbins; others are crumbly vitrophyre surfaces bulldozed smooth for ski runs. Unit everywhere glacially eroded, strewn with till and colluvium, and widely concealed by such deposits distally. Phenocrysts: 4–7% feldspar (0.5–3 mm); 1–2% biotite (mph to 2

mm); trace Fe-Ti-oxide mph. Also carries rare mafic blebs, feldspar clusters, and biotite-oxide-feldspar clots. Vent inferred to underlie unit rss at Solitude Dome. Consistently distinguished from nearby units rmf and rss by lower Fe and Sr contents and higher Nb, Zr, K, and Na. Overlies or banks against unit d81 (99±7 ka) and Canyon Lodge scoria cone (unit mcl; 175±3 ka). Overlain by units rsq (63.7±4 ka), rss (50±3 ka), dfl (61±3 ka), and dlp (64±7 ka). 40Ar/39Ar ages: 81±1 ka (Mahood and others, 2010); 80±1 ka (table 2).

Qdsd - Trachydacite of South Summit Dome (late Pleistocene)

dsd - Trachydacite of South Summit Dome (late Pleistocene)
Phenocryst-rich lava dome (67.3–68.4% SiO2) that forms 500-m-wide plateau just south of summit dome (unit dsu) and most of south slope of Mammoth Mountain (figs. 1, 22)—from 3,320 m down to 2,900 m. One of most extensive on edifice, unit also crops out as altered arete 3180+ (500 m east of summit) and in windows through till as low as 2,860 m in valley north of Dragons Back. Long south slope is mantled by thick colluvium, and steep northeast face is widely draped by till. Upper slopes, northeast arete 3180+, and Reds Creek area are ex tensively acid altered (cream-white to yellow) and locally also oxidized brick red. Altera tion facilitated glacial excavation of northwest-trending trough (The Chasm, which is not a fault zone) along base of steep northeast face of Mammoth Mountain. Deep erosion has exposed varied lithologies, ranging from devitrified through pale-gray or black vitrophyre and from massive to weakly or strongly flow foliated. Best outcrops are block-jointed ledges. Phenocrysts: 10–15% feldspar (0.5–7 mm); 3–5% biotite (mph to 2.5 mm); 2–5% hornblende (mph to needles as long as 10 mm); sparse pyroxene (mph to 2.5 mm); common Fe-Ti oxide mph; also has mafic blebs, pyroxene-oxide-plagioclase clots, and clots as big as 20 mm of oxides, amphibole, biotite, and feldspars in varied proportions. Overlies units rrc (83±1 ka) and amp (97±1 ka). Overlain by units dbp, ddu, drc, and dsu (61.4±2 ka). 40Ar/39Ar age (at south toe of unit): 87±6 ka.

In drill hole HSL-1 near Horseshoe Lake (fig. 6), a trachydacite flow ~15 m thick (nowhere exposed) is similar to unit dsd chemically and petrographically, but it underlies stack of thin flows of unit amp, which predates dsd. It may be the oldest trachydacite known on Mammoth Mountain.

Qd61 - Trachydacite of Dome 2861 (late Pleistocene)

d61 - Trachydacite of Dome 2861 (late Pleistocene)
Large dome of phenocryst-rich lava (66.1–67.6% SiO2) of Mammoth Mountain type centered 2 km northeast of toe of Mammoth Mountain edifice and 3 km northwest of Mammoth Lakes business district (fig. 23). Steep- sided dome is 1.5–2 km wide and >300 m high. Most exposures are flow-foliated and variously block-jointed, hackly, or slabby. Rolling unglaciated up per surface of dome remains glassy and micropumiceous, but steep faces have at least been frost riven, as much of their glassy carapace has been removed. Ten steep (55º) chutes are cut into upper 120 m of south face; because there is little catchment area above, their excavation along parallel vertical joints may have been accomplished by late Pleistocene frost action beneath a thin mantle of ice or nevé. Dome was called “Mammoth Shoulder dome” by Suemnicht and Varga (1988). Inappropriately called “Earthquake Dome” (for example, by Bailey, 1989) because that name associates dome with “Earthquake Fault” (a tourist attraction and open fissure), which cuts adjacent Dome 2781 (see unit d81) but not this one. Low-relief aprons adjacent to southeast and northeast toes of dome consist of monolithologic fragmental deposits derived from it, including angular to subrounded clasts (1–50 cm) enclosed in a dominant matrix of pale-gray fine-to-coarse ash; blocks are pale purplish-gray, tan-weathering, glassy, and finely to non- vesicular. Deposits are unstratified, tan-weathering, and at least 2–7 m thick. Hummocky surfaces suggest deposition as rockfall avalanches (unit av) from steep faces of dome, but a few increments may have originated as pyroclastic flows. Phenocrysts: 10–15% feldspar (0.5– 4 mm); 1–2% biotite (mostly mph but as big as 1.5 mm); 2–3% hornblende (mph to 3.5 mm); trace pyroxene (0.2–0.7 mm); common Fe-Ti-oxide mph. Roof of piston-like dome lifted a 500-

m-long slab containing mafic lavas of units mcl (175±3 ka) and bar (88±5 ka). Dome appears to overlap adjacent dome (unit d81; 99±7 ka). 40Ar/39Ar age: 87±2 ka (Mahood and others, 2010).

Qmdp - Basaltic trachyandesite of Devils Postpile (late Pleistocene)

mdp - Basaltic trachyandesite of Devils Postpile (late Pleistocene)
Glacially eroded sheet of phenocryst-rich lava (53.9–54.4% SiO2) preserved discontinuously along floor of Middle Fork San Joaquin River canyon in two major remnants and several small ones, distrib uted for 7 km downstream from near (upper) Soda Springs Campground. Vent location unknown, but unit is inferred to have erupted near or upstream from that campground, where scoria cone and dikes of subjacent unit mss are exposed. No dikes or near-vent features of unit mdp are recognized. Largest remnant measures 2 km north-south, ~1 km wide, and includes near its south end the spectacular columnar jointing that constitutes the Devils Postpile, which was designated a National Monument in 1911. At base of columnar cliff is a remarkable postglacial talus of fallen columns (fig. 11). Far more than half of original unit has been lost to erosion, as shown by 3.5-km-long gap between cliffy outcrops near Reds Meadow and small remnants southeast of Rainbow Falls. As with unit Tbtb, just downstream, river re-incised through intracanyon lava only to granitic floor of pre-lava channel, and no deeper. Ice-polished polygonal mosaic on bench at top of iconic columnar cliff is 50 m higher than basal colonnade at 2,295-m river level. Just east of that bench, however, glacially scoured top of flow extends up to elevation 2,405 m, 60 m higher than top of main colonnade and 110 m above flow base at riverside. At three addi tional locations, one 300 m north of Sotcher Lake and two on west side of river (opposite Pumice Flat and Devils Postpile Campgrounds), scoured top of flow is also at 2,400– 2,410 m elevation. Vesicular lava and scoriaceous joint blocks on these glaciated surfaces suggest proximity to primary flow top. By coincidence, ~110-m original flow thickness is same as that of 1959 Kilauea Iki lava lake (Hawaii), which took 20–25 years to solidify fully and produced audible cracking as polygonal contraction joints advanced incremen tally into thickening crust (Peck and Minakami, 1968; Ryan and Sammis, 1978).

Lava is widely striated and plucked, eroded into knolls, ridges, and sidewall benches; surviving exposures are nearly all massive and have only sparse scattered vesicles. Slender columns of Devils Postpile colonnade are 15–20 m high, polygonal, typically 0.5–1 m thick, and variously vertical, curved, inclined, or subhorizontal (Huber and Rinehart, 1965b); elsewhere in unit, sets of stouter or less regular columns are widespread, but hackly and block jointing is common, too. Partly glassy chunk jointing is present at riverside, and locally fanned or chevron sets of columns reflect localized control of cooling geometry by major fractures. Evidence for ice-contact emplacement has not been observed and would not be expected here at time of eruption. Some column faces exhibit wavy undulations and, although widely obscured by weathering and glacial scour, bands (“chisel marks”) are present locally, representing incremental advance and stoppage as contraction fractures penetrated stepwise into solidifying interior (DeGraff and Aydin, 1987).

Phenocrysts: 7–10% plagioclase (0.5–4 mm); 2–3% olivine (0.5–1.5 mm), common ly clustered; and ~1% cpx (1–3 mm), both free and intergrown with plagioclase. Overlies units amp, mss, and drf. Widely rests on and wedges out laterally against Mesozoic granite on both walls of canyon. At its northwesternmost outcrop, unit mdp lava rests on ~9 m of fluvial sand and gravel. 40Ar/39Ar ages: 82 ±1 ka (near Minaret Falls Campground; Mahood and others, 2010); 82±2 ka (distal downstream outlier at UTM 03121/41161; table 2). K-Ar age of 940±160 ka reported by Dalrymple (1964b) suggests either an abun dance of excess Ar in the plagioclase fused or an error in decimal-place transcription.

Qrrc - Alkalic rhyodacite of Reds Creek (late Pleistocene)

rrc - Alkalic rhyodacite of Reds Creek (late Pleistocene)
Moderately porphyritic lava flow (70.9–71.2% SiO2) that crops out only in 200-by-300-m area along

gorge of Reds Creek at southwest toe of Mammoth Mountain. Most of exposure is highly flow-foliated, even laminated, cream-white felsite that breaks slabby to platy and forms 20-m-high cliffs on both walls of creek; rusty films are widespread on foliation planes and cross joints, but only upstream-most end of unit is hydrothermally altered like overlying trachydacite (unit dsd) along Reds Creek. Lowermost parts of exposures on both banks are black vitrophyre, 3–8 m thick, hydrated and crumbly, but generally massive with sparse devitrified layers. Phenocrysts: 4–5% feldspar (0.5–2 mm); 1–2% biotite (mph to 1 mm); trace pyroxene mph; sparse Fe-Ti- oxide mph; also contains sparse clusters of feldspar and biotite-feldspar clots. Base not exposed, but probably overlies nearby unit amp (97±1 ka), contact with which is obscured by scree rich in 1350 C.E. Inyo pumice. Overlain by units dsd (87 ±6 ka) and dwr (73±2 ka). Unit is richest in K2 O and SiO2 and poorest in MgO and FeO of all units of Mammoth system. 40Ar/39Ar age: 83±1 ka.

Qamp - Trachyandesite of Mammoth Pass (late Pleistocene)

amp - Trachyandesite of Mammoth Pass (late Pleistocene)
Aprons of phenocryst-poor lava flows (57.2–61.6% SiO2) that erupted on high divide north of Mammoth Pass at vent later covered by construction of Mammoth Mountain. Flows emerge from beneath south toe of Mammoth Mountain edifice and turn both east and west, extending 9 km east to terminus near Sherwin Creek Campground and at least 7 km southwest where remnants survive on both sides of lower Crater Creek. Entire western apron is glacially scoured from Mammoth Pass down to Sotcher Lake, Reds Meadow, and Boundary and Crater Creeks. Lavas of eastern tongue have been more severely eroded and widely concealed by late Pleistocene till, although windows are exposed along Mammoth Creek, and a 1-km-wide blocky terminal lobe just beyond distal moraines of unit glb is virtually uneroded. Lavas form glaciated ribs, nubbins, and ledges, block-jointed or slabby, rarely platy, and typically massive and aphanitic with pale-gray mottling; locally oxidized, especially in healed flow-breccia zones. Vesicular zones are widely stripped. Thickest exposures are typically massive with vertical joints, irregularly prismatic. On west slope, belt between 2,750 and 2,850 m elevation was glacially eroded into west-trending noses, each sculpted from a single lava flow, each having 10–25 m local relief, and scoured free of till and all but sparse erratics. Thickest exposures are 30 m near upper Twin Lakes, 100 m near Horseshoe Lake, and >140 m along Boundary Creek where at least 5 cliffy flows are exposed, each 10–30 m thick. Drill hole HSL-1 (fig. 6), near Horseshoe Lake, penetrated 7–10 flows in a total thickness of 73 m of unit amp, which rests at depth on an unexposed trachydacite lava flow of typical Mammoth Mountain lithology. On north facing scarp of Hill 2938 (high point of unit), a glacially excavated trough at south toe of Mammoth Mountain exposes a pair of 8-m-thick platy lava flows of unit amp; minor scoriaceous lava-flow rubble is present but no ejected scoria exposed. Vent is inferred to have been farther north, subsequently covered by Mammoth Mountain trachydacite pile. Vents shown by Bailey (1989) at hill 2938 and Sherwin Creek Campground do not exist. Phenocrysts: typically ~1% plagioclase (0.5–1.5, rarely as big as 3 mm), uncommonly in clots; traces of olivine and cpx (both =1 mm); sparse Fe-Ti-oxide mph (0.1–0.3 mm); rare plagioclase antecrysts (3–5 mm). Among many flows, plagioclase content ranges from almost none to as much as 3%. Groundmass is grainier, slightly coarser than in subjacent unit drf, with which unit can easily be confused, especially where unit is locally platy and mottled. Olivine crystals, where oxidized light to dark brown, can resemble opx prisms of unit drf, but olivine is generally equant, not elongate.

Unit overlies Mesozoic granite, Bishop Tuff (unit rbt; 767±2 ka), unit drf (98±1 ka) near western limit, and unit bsr (99±1 ka) at eastern limit. Overlies unit aml in drilholes at Horseshoe Lake and southeast of downtown Mammoth Lakes (fig. 6). Overlain by unit mdp (82±1 ka) near Sotcher Lake, by units dbp, dnh, and bhl near Twin Lakes, and widely overlain by late Pleistocene till (unit glb). Flows of unit amp emerge from beneath base of South Summit Dome (unit dsd; 87±6 ka) at drainage divide, but they overlie an unexposed trachydacite lava flow in drill hole HSL-1 (fig. 6). Southwest distal remnants overlie unit drf and fill paleochannels cut in granite. Steep slope extending 2 km north of Boundary Creek at 2,500–2,600 m elevation reflects draping and conceal ment of previously glaciated granitic canyon sidewall by flows of unit amp. Low-relief belt along western slope at 2,700–2,750 m is poorly exposed, as is southwest corner of apron where lavas bank against Bishop Tuff; both areas are mantled by Inyo pumice and ground moraine. Sites sampled near Reds Meadow and in Valentine

Reserve Ecologi cal Study Area on Mammoth Creek yield similar paleomagnetic directions (Mankinen and others, 1986; Hildreth and others, 2014). 40Ar/39Ar ages: 97±1 ka (table 2); 81±1 ka (Mahood and others, 2010); K-Ar age: 86±10 ka (Mankinen and others, 1986).

Qbar - Trachybasalt of Arcularius Ranch (late Pleistocene)

bar - Trachybasalt of Arcularius Ranch (late Pleistocene)
Scoria cone (fig. 7) and extensive phenocryst-rich lava flows (50.6–52.4% SiO2) that erupted on southwest wall of Long Valley Caldera, 2 km northeast of Minaret Summit and 4 km north of summit of Mam moth Mountain. Lava flows covered much of caldera's southwest moat, next poured 13 km northeastward between Deer Mountain and West Moat Coulee (unit rwm), wrapped west side of Lookout Mountain, then turned eastward at north wall of caldera near Big Springs, and extended additional 10 km along north moat to terminus along Owens River (fig. 9). Scoria cone, 160 m high and 700 m wide, consists of lapilli and bombs as big as 70 cm, mostly oxidized, generally loose but locally agglutinated. Strati fied cinders at least 12 m thick exposed along gulch just south of cone are palagonitized and capped by a unit bar lava-flow remnant ~10 m thick; bombs in fall deposit include common representatives of phenocryst-poorer unit bmn as well as predominant pheno cryst-rich bombs of unit bar. Cone banks high against wall of precaldera basement and, though degraded, was not devastated by late Pleistocene glaciation. Proximal lava-flow apron and windows through till south of Crater Flat are glacially scoured, but exposures west, north, and east of Lookout Mountain lie outside the glacial limit and thus remain ruggedly scoriaceous, even craggy. Wherever exposed, individual flows are 3–10 m thick, both proximally and along north moat, where two (virtually identical) flows extend to gether almost to ultimate terminus. Block joints are common, and crudely prismatic joints locally mark vesicular surfaces. Phenocrysts: 15–25% plagioclase (1–7 mm, rarely to 10 mm); 2–5% olivine (0.5–2 mm, rarely to 3 mm), commonly in clusters; cpx (0.5–2.5 mm) is sparse proximally and rare distally. Scoria bombs on cone contain scattered silicic xenoliths (1–5 cm), some partially melted, probably of metavolcanic basement. Over lies units bcf, bmn (87±7 ka), and ddc (103 ±9 ka). Overlain by units mcv, mnd, mor (66±2 ka), and gdc. Locally uplifted on roof of large dacite dome, unit d61 (87±2 ka). Subunit bar' includes this uplifted fragment as well as a medial exposure west of Lookout Mountain; compositionally, lavas at the two sites are identical (n=3), but they differ slightly from rest of unit bar (n=17) in being somewhat richer in Al and slightly poorer in Mg, K, and P. Subunit bar' is inferred to be a single flow, slightly poorer in olivine (1–2%) and a bit richer in plagioclase (20–25%), much of which is more sieve textured than in associated flows of bar. Six sites drilled, proximally, medially, and distally, all yield similar paleomagnetic directions for bar and bar' (Mankinen and others, 1986; Hildreth and others, 2014). K-Ar ages: 108±12 ka (distal at Big Springs) and 95±13 ka (proximal) (Mankinen and others, 1986). 40Ar/39Ar ages: 88±5 ka (quarry north of MMSA Main Lodge) and 94±9 ka (toe of scoria cone) (Mahood and others, 2010).

Qbar1 - Trachybasalt of Arcularius Ranch, single flow (late Pleistocene)

Qbar1 - Trachybasalt of Arcularius Ranch (late Pleistocene)

Single flow. See unit Qbar (bar on source map) for the unit's description.

Qbmn - Trachybasalt northeast of Minaret Summit (late Pleistocene)

bmn - Trachybasalt northeast of Minaret Summit (late Pleistocene)
Apron of modestly por phyritic lava flows (51.3–53.1% SiO2) that extends for 2.8 km northeast from basin east of Minaret Summit; exposed discontinuously (through thick mantle of late Holocene Inyo pumice). Source vent is scoria cone 2 km northeast of Minaret Summit, same cone that later produced lavas of phenocryst-rich unit bar. Proximal scoria-fall deposit at south base of cone, 12 m thick where dissected by stream, includes ballistic bombs, 10–70 cm across and dense to

scoriaceous, that are predominantly of bar type but commonly also of bmn petrography and composition. Lava apron, ~1 km wide, is everywhere glacially scoured and crops out as jointed ledges and platy floors of shallow draws; only distally is it eroded into cliffs and noses with 15–20 m relief. Southwesternmost proximal lava exposure (UTM 1993/6998) is compositionally most evolved part of unit (52.4–53.1% SiO2 , designated subunit bmn') and carries about half as many phenocrysts as the rest. Phenocrysts in most of unit: 3–5% plagioclase (1–3 mm, rarely 4–8 mm); 0.5–3% olivine (0.5–2 mm), and rare Fe-Ti-oxide mph (0.1–0.2 mm); cpx is absent or rare, found only in clots with plagioclase. Overlies unit ddc (103±9 ka). Overlain by unit bar (88±5 ka), late Pleistocene till, and 1350 C.E. Inyo pumice-fall deposit. Proximal, medial, and distal drill sites yield similar paleomagnetic directions (Mankinen and others, 1986; Hildreth and others, 2014). 40Ar/39Ar age: 87±7 ka (Mahood and others, 2010).

Qbmn1 - Trachybasalt northeast of Minaret Summit, southwesternmost proximal lava (late Pleistocene)

bmn - Trachybasalt northeast of Minaret Summit (late Pleistocene)

Southwesternmost proximal lava. See unit Qbmn (bmn on source map) for the unit's description.

Qaml - Trachyandesite of McLeod Lake (late Pleistocene)

aml - Trachyandesite of McLeod Lake (late Pleistocene)
Phenocryst-poor lava flow (61.5– 62.3% SiO2) exposed as narrow sliver along north-striking fault 40 m east of McLeod Lake (also variously rendered McCloud or McClowd, but named for U.S. Forest Service Ranger Malcolm McLeod), ~1 km south of southern toe of Mammoth Mountain. Crops out as 1-m-high ledge of black massive aphanitic lava, locally weakly vesicular and partly glassy; block-jointed or locally slabby; weathers tan and carries pink films along joint planes. Unit banked against Mesozoic granite (unit Kmo), and both are severely glacially eroded; more remnants of lava may be buried by glacial deposits or beneath lake. Phenocrysts: 1–2% plagioclase (0.5–2 mm); 1–2% amphibole (0.1–1.3 mm long; rare opx microphenocrysts (in clots with oxides and plagioclase); and sparse Fe-Ti-oxide microphenocrysts (0.1–0.4 mm). At bottom of 98-m-deep drill hole (HSL-1; fig. 6) near Horseshoe Lake carpark, scoria lapilli (oxidized, not rounded) of a 10-m-thick stratified fall deposit (rich also in granitoid and metavolcanic lithic lapilli) are compositionally similar to lava of unit aml; scoria fall directly underlies a 15-m-thick trachydacite lava flow similar to unit dsd, which is in turn overlain by 73-m-thick stack of 7–10 pheno cryst-poor vesicular lava flows of unit amp (97±1 ka). It can be inferred that unit aml predates all or much of Mammoth Mountain and that its vent lay within a few kilometers of Horseshoe Lake. In water well 30M (fig. 6), 2 km southeast of downtown Mammoth Lakes, a 15-m-thick lava flow of unit aml was penetrated at a depth of 45–60 m, where overlain by a thin flow of unit amp and ~35 m of late Pleistocene till (unit glb, which extends to surface). Lava of unit aml thus flowed as far east as Sherwin Creek, but none is exposed farther east nor recognized in other south moat drill holes. Undated.

Qdrf - Trachydacite of Rainbow Falls (late Pleistocene)

drf - Trachydacite of Rainbow Falls (late Pleistocene)
Phenocryst-poor coulee (65.7–67.1% SiO2) that extends from near Reds Meadow for 6 km southward along or near course of Middle Fork San Joaquin River. Severely glaciated flow is 30–40 m thick in north and as thick as 80 m in south; its surviving width is ~600 m but was originally more expansive and may have extended much farther downstream. Unit fills paleochannels cut in Meso zoic granite, and it supports two prominent waterfalls along Middle Fork (the eponymous fall being 30 m high). Striking meander of Middle Fork, 250 m in amplitude and ~800 m upstream from

Rainbow Falls, produced channel entrenched in dacite and abandon ment of shallower channel along west edge of unit that had temporarily accommodated overflow when intracanyon dacite lava flow displaced river. Where exposed atop granite, basal zone includes vertical prismatic joints that locally form slender polygonal columns 3–8 m high, overlain by abrupt transition to platy interior of flow (fig. 24). Surface is rolling terrain of ice-scoured hillocks, ridges, ribs, and ledges. Some outcrops are mas sive, block-jointed, hackly, chunky, or slabby, but most are strongly flow-foliated and thinly platy. A few glassy domains survive, notably basal vitrophyre zones locally, but most exposures are devitrified, aphanitic, pale gray, and commonly mottled. Phenocrysts: 1–3% plagioclase (mostly 0.5–1 mm; some slender laths as long as 3 mm); rare biotite (mph to 1 mm); sparse opx (0.3–1 mm; either equant or prismatic); trace Fe-Ti oxides (0.1–0.3 mm); with or without sparse hornblende needles (mph to 2 mm long, some with rounded resorbed ends), unevenly distributed. Also contains pale gray, tan-weathering sugary enclaves (1–30 mm), some vesicular and either angular or rounded; in thin section, enclaves are meshwork of slender plagioclase and hornblende prisms, stud ded with tiny equant pyroxenes and oxides. Unit overlies Mesozoic granite (unit Kmo) and banks against unit Tbtb (3,754±7 ka). Overlain by units mdp (82±1 ka) and amp (97±1 ka). Contact of massive unit amp atop platy unit drf is well exposed on south wall of gorge just below Rainbow Falls. 40Ar/39Ar ages: 98±1 ka (Mahood and others, 2010); 98.8±0.6 ka (table 2).

Qbmc - Basalt of Mammoth Crest (late Pleistocene)

bmc - Basalt of Mammoth Crest (late Pleistocene)
Eroded scoria cone (49.5–51.1% SiO2) preserved as 1-km-long remnant, 500 m wide, atop north end of Mammoth Crest, an arête on main regional drainage divide, 1 km west of Crystal Crag. Upper half of cone remnant consists of stratified scoria, mostly brick-red but locally black, that dips radially and includes a few tack-welded layers; lapilli dominate but bombs as big as 1.5 m are common along crest. Gutted crater is enlarged and modified by erosion. Lower half of 120-m-thick unit consists of stratified agglutinate and fountain-fed lavas in layers 1–5 m thick that drape granite rim of arête; centrally these thicken downslope eastward to fill a paleoswale, where they are now eroded into a 40–50 m-high ledgy cliff. Massive cliff section is hackly or block-jointed but grades up into stratified agglutinate at its 3,100-m rim. Directly downslope from toe of cliff, at ~3,000 m, a bench-forming outlier of partly glassy massive lava is 70 m long, 25 m wide, and >8 m thick on its steep downslope face, which lies only ~55 m above Crystal Lake; outlier is in place, as shown by its intact jointing, consistently north-trending glacial striae, and paleomagnetic direction identical to cliff above. A second outlier, 150 m southwest of Crystal Lake, is a chaotic slide mass (unit av on map). Lava evidently flowed down floor of Lakes Basin, from which it was subsequently stripped by glacial erosion, and extended 18 km to terminus near Hot Creek Fish Hatchery, where unit bfh is chemically, petrographically, paleomagnetically, and geochronologically identical. It is inferred that Lakes Basin contained little or no ice at time of eruption. Nonetheless, it seems required that stripping of unit bmc/bfh from most of Lakes Basin took place before emplacement of unit bhl (31±1 ka), which survives on the basin floor. This inference suggests that bmc/bfh lavas were removed during the interval 90–30 ka, presumably during MIS 4, by cirque glaciation within Lakes Basin. Scoriae reworked from the cone postglacially form a 5-m-thick stratified deposit of well rounded lapilli (1–10 cm) at southwest shore of Horseshoe Lake. Lowest 1.5 m of this reworked section dips 25º NE into lake, and its clasts are less rounded than those higher in deposit, where wave reworking continues during seasonal highstands. Section repre sents a scree fan of sloughed cinders, in which many lapilli layers are separated by thin partings of buff ash. Phenocrysts: Unit ranges from moderately to highly porphyritic; 8–15% plagioclase (1–22 mm, mostly 3–10 mm); 1–2% olivine (0.5–3 mm, plus sparse crystals as long as 8 mm); and sparse cpx (1 mm). Also contains olivine clusters of as many as 20 grains, rare olivine-plagioclase intergrowths, sparse xenocrysts of feldspar and quartz, and scattered granitoid xenoliths (1–15 cm), both rounded and angular. Scoria cone rests on Mesozoic granite and contacts no other volcanic unit. 40Ar/39Ar age: 105±7 ka (Mahood and others, 2010); 92.7±2.4 ka (cf. 92.4±2.4 ka for distal lava flow of unit bfh).

Qddc - Trachydacite of Dry Creek (late Pleistocene)

ddc - Trachydacite of Dry Creek (late Pleistocene)
Moderately porphyritic lava flow (66.9–67.4% SiO2) that crops out in a north-northwest-trending belt 2.5 km long in up per Dry Creek basin, west of Dome 2861. As thick as 40–50 m, flow was everywhere glacially eroded into ridges, knobs, bluffs, and ledges; its width of exposure is only ~1 km because it was overrun by younger lavas. Exposures range from glassy to finely devitrified with pale-gray mottling, and from massive and block-jointed to (more widely) flow-foliated and thinly platy; platy jointing is commonly ramped or even near-vertical. Phenocrysts: 3–5% plagioclase (=1 mm, rarely to 2 mm), a minority coarsely sieved internally; =1% opx (0.5–1 mm); and abundant Fe-Ti oxide mph (0.1–0.3 mm). Not coarsely porphyritic like hornblende-biotite trachydacites of units d61, d81, and Mam moth Mountain. Source vent buried by younger units to south or southwest, probably beneath Mammoth Mountain. Base not exposed, but may bank around base of unit d81 (99±7 ka). Overlain by units bar (88±5 ka) and bmn (87±7 ka). K-Ar age: 103±9 ka (Mankinen and others, 1986).

Qrdm - Rhyolite of Deer Mountain (late Pleistocene)

rdm - Rhyolite of Deer Mountain (late Pleistocene)
Phenocryst-rich lava dome (71.9–72.1% SiO2) centered 7.5 km north of Mammoth Mountain summit and 2.5 km inside north west topographic wall of Long Valley Caldera. Steep-sided dome is nearly circular in plan, 900 m in diameter, and ~180 m high. Exposures are largely of glassy, white, finely pumiceous carapace, but outcrops are limited to areas near summit and upper west slope of dome, owing to extensive cover by late Holocene phreatic ejecta from Inyo Craters; denser vitrophyre layers and lenses are present locally. North and South Inyo Craters lie at south toe of Deer Mountain, and two additional phreatic craters (roughly con temporaneous with them) were excavated through its summit and its lower north flank (Mastin, 1991). Total phenocrysts 25–35%. Contains 10–15% feldspar (both plagioclase and sanidine); 10–12% quartz (rounded and embayed, commonly broken, 0.2–4 mm); ~3% biotite (mph to 1.5 mm); ~1% hornblende (mph to 1.5 mm); trace tiny Fe-Ti-oxide mph. Also contains trace amounts of cpx, opx, zircon, allanite, apatite, and pyrrhotite (Mayo and others, 1936; Reid and others, 1997). Appears to overlap and partly cover adjacent, severely eroded, scoria cone of unit mdm. 40Ar/39Ar age: 101±8 ka (Heumann and others, 2002). K-Ar age: 115±3 ka (Mankinen and others, 1986).

Qd81 - Trachydacite of Dome 2781 (late Pleistocene)

d81 - Trachydacite of Dome 2781 (late Pleistocene)
The “real” Earthquake Dome, a sprawl ing phenocryst-rich flow-dome complex (68.6–69.1% SiO2) that lies between adjacent younger edifices of Dome 2861 (unit d61) and Mammoth Mountain. Gently sloping edifice is 2 by 2.5 km wide, has total relief of 180 m to north and 300 m to south, and is centered 3.5 km northeast of Mammoth Mountain summit (fig. 23). Poorly exposed slopes are deeply mantled by colluvium and by 1350 C.E. Inyo pumice-fall deposit. Good exposures are present at summit, along west and southeast margins, and along open fissure nicknamed “Earthquake Fault” (Benioff and Gutenberg, 1939). Exposures are generally crumbly, thinly flow-foliated vitrophyre, black or locally oxidized, but include pale-gray, brown-weathering pumiceous carapace preserved near summit. Surface around summit consists of knolls of block-jointed and flow-foliated vitrophyre, commonly frost riven but not glaciated. Moderately sloping morphology of edifice contrasts with cliffy form of adjacent Dome 2861, which is of similar (Mammoth Mountain type) lithology and slightly less silicic. Phenocrysts: 10–12% feldspar (0.5–4 mm); 2–3% biotite (mostly mph but as big as 1.5 mm); =1% hornblende (mph to 2 mm); sparse pyroxene (mph to 1 mm); common Fe-Ti-oxide mph. Overlies unit mcl scoria cone (175±3 ka). Overlain by units msd and d61 (87±2 ka). Margin of edifice is lapped or abutted by units ddc and rce, and by late Pleistocene till on its northwest (unit gdc) and southeast (unit gmm) sides. 40Ar/39Ar age: 99±7 ka. Oldest unit exposed having Mammoth Mountain lithology.

Qa62 - Trachyandesite of Cone 2962 (late Pleistocene)

a62 - Trachyandesite of Cone 2962 (late Pleistocene)
Scoria cone and adjacent lava-flow apron (57.1–59.2% SiO2) on divide between Deer and Crater Creeks, 7 km south of Mammoth Mountain. Cone is 160 m high, ~1 km wide, elongate northeast, and is centered 2 km northeast of Pumice Butte (fig. 10). From its southwest toe emerges a 1-km-wide apron of blocky lava flows that extends 3 km southwest to rim of San Joaquin River canyon. Vent-proximal half of apron is plateau where lavas were lightly ice-scoured and striated but remain block-jointed and vesicular. Southwest-sloping distal half of apron, however, was ice-free and remains ruggedly blocky, glassy, and scoriaceous (although weath ered and frost-damaged). Longitudinal troughs between flow ridges and knolls provide 10–20 m local relief, and several stairstep flow fronts are 10–15 m high. At San Joaquin River canyon rim, apron drapes granitic wall, exposing at least ten flows in a steeply dipping stack as thick as 200 m. Scoria cone is poorly exposed except on its nonglaci ated summit flat, around margins of which arcuate ridges of coarse red scoria (loose or tack-welded) appear to be rim remnants of a filled crater; scoria bombs there are as big as 70 cm. True summit is a 10-m-high pile, ~25 m in diameter, of frost-shattered lava blocks, massive to vesicular, that was a knob-like extrusion; its southeast margin adjoins a stack of red scoria bombs, some >1 m in diameter. Lower slopes of cone locally expose glaciated ledges of massive platy lava. Phenocrysts: bombs and lapilli on cone and lava flows alike are crystal-poor, containing =1% plagioclase (0.5–1.5 mm), still sparser olivine mph, and trace cpx (mph to 1 mm). Scoria cone overlies Mesozoic granite and basaltic lava flows of unit bdc (155±2 ka); lava-flow apron overies units Tasj and rbt and banks around Pumice Butte (unit apb; 142±5 ka). 40Ar/39Ar age: 118±10 ka (Mahood and others, 2010).

Qmss - Basaltic trachyandesite of upper Soda Springs (late Pleistocene)

mss - Basaltic trachyandesite of upper Soda Springs (late Pleistocene)
Phenocryst-poor lava flows (52.7–53.2% SiO2) that erupted at severely eroded scoria cone exposed on west bank of Middle Fork San Joaquin River, opposite upper Soda Springs Camp ground. Riverbank exposure of stratified scoria is 8–25 m high, black to yellow-orange, thin-to-thick bedded, and includes three layers of dense agglutinate (each 2–3 m thick); scoria are predominantly lapilli but include blocks as big as 35 cm. Because at least half of cone has been eroded away by river, all layering dips 15–20º W; base of scoria is not exposed. Two vertical dikes, respectively <1 m and ~5 m thick, strike east-northeast and cut scoria section on riverbank; at rim, thicker southern dike grades into dense agglutinate, which in turn grades into a thin lava flow. From cone, eroded remnants of lavas extend 300 m upstream and ~1 km downstream, preserved as a narrow ice-scoured strip (100–250 m wide) between Pacific Crest Trail and river. Lava flow surface is rolling glaciated plateau marked by knobs and ledges cut on a single downstream flow. Unit is as thick as 40 m near vent but thins (largely owing to erosion) to <10 m both up stream and downstream. Lavas and dikes are massive, hackly, chunky, or block-jointed. Phenocrysts: 1–3% plagioclase (1–3 mm) and <1% olivine (0.5–1 mm, rarely 2 mm). Some exposures ~400 m downstream from dikes carry as much as 5% plagioclase but are chemically indistinguishable from rest of unit. Cpx is absent (or extremely rare) in contrast to overlying unit mdp. Overlies Mesozoic granite (unit Kmo). Overlain by phenocryst-richer unit mdp (82±1 ka), which has certain compositional affinities (fig. 20) with lower-SiO2 unit mss. Nonetheless, in addition to differences in age, chem istry, mineral content, and paleomagnetic direction, units mdp and mss differ in Pb, Nd, and Sr isotope ratios (Cousens, 1996); for example, 87Sr/86Sr = 0.70613 and 0.70596, respectively. 40Ar/39Ar age: 121±2 ka.

Qbed - Basalt east of Dry Creek (late Pleistocene)

bed - Basalt east of Dry Creek (late Pleistocene)
Poorly exposed, glacially eroded, phenocryst rich spatter cone (52.0–52.1% SiO2) between Dry Creek and Dome 2861. Cone 2580+ is ~500 m wide, ~50 m high, and moderately degraded, with a

subdued crater open to north. Ejecta are almost entirely hidden by late Holocene Inyo pumice-fall deposit, and cone is also strewn with glacial erratics of unit ddc and trachydacites of Mammoth Mountain. Lone significant outcrop is on east rim of summit where ledges of oxidized agglutinate are 1–2 m thick and enclose thin dark-gray massive lenses. Most is tack-welded with oxidized lapilli and bombs still discernible, but this facies grades abruptly into massive domains, somewhat homogenized though still streaky. No lava flows associated with cone are exposed proximally, but flows of unit bcd (125±2 ka), ~8 km east-southeast, are chemically and petrographically identical; although paleomagnetic directions differ, this may reflect mobility of cone agglutinate. Phenocrysts: 7–10% plagioclase (1–5 mm); % olivine (1–2 mm); 1–2% cpx (1–3 mm); Fe-Ti oxides limited to crystalline ground mass. Base not exposed; unit is in exposed contact with no other except till. 40Ar/39Ar age: 121±3 ka (Mahood and others, 2010).

Qmdm - Basaltic trachyandesite of Deer Mountain (late or middle Pleistocene)

mdm - Basaltic trachyandesite of Deer Mountain (late or middle Pleistocene)
Poorly exposed scoria cone (55.7–56.0% SiO_2) partly overlapped by northeast base of rhyolitic Deer Mountain dome in west moat of Long Valley Caldera. Exposures limited to loose scoria and tack-welded agglutinate, all brick-red, that form a ledge, 1–3 m high, around east to southeast rim of cone and to a 15-m-high stack of agglutinate ledges lower on east slope. Subdued crater, open to north, is filled and obscured by 1350 C.E. Inyo pumice fall deposits (see units ric and p) and ensuing lithic ejecta (unit pe) from phreatic erup tions of nearby Inyo Craters. Abundant lithics here include granitoids, rhyolite of Deer Mountain, and varied mafic and silicic lavas (many from underlying gravels and till), but they were ejected in 1350 C.E., not with mdm scoria. These late Holocene fall deposits blanket >90% of the mafic cone and obscure its contacts with contiguous rhyolite of Deer Mountain (unit rdm; 101±8 ka), which is probably younger. Cone is at least ~90 m high and ~400 m wide. Scoriae are oxidized, predominantly lapilli but as big as 30 cm, and almost aphyric, containing rare plagioclase (0.5–2 mm) and still rarer oxidized mafic mph. Crude layers are 20–100 cm thick; within coarser layers, dominant lapilli (1–6 cm) are accompanied by subordinate 10–15 cm scoriae and by rare spindle bombs. Composi tions of scoria are unlike those of units mic and aic (131±1 ka) exposed in nearby South Inyo Crater; their relative ages are not established, but all three units appear to be older than unit rdm. Undated.

Qaic - Trachyandesite of Inyo Craters (late middle Pleistocene)

aic - Trachyandesite of Inyo Craters (late middle Pleistocene)
Stack of at least five pheno cryst-poor lava flows (57.5–59.4% SiO_2) exposed on walls of South Inyo Crater (at south toe of Deer Mountain) and along south-striking fault scarp for ~1 km south from crater. Flows are thin and rubbly, but their (modestly vesicular) more massive interior zones support ledges 3–6 m thick. All have sparse plagioclase and still sparser olivine and cpx (both =1 mm), and some carry rare feldspar and quartz xenocrysts as large as 10 mm. Relations on crater walls suggest flow direction was toward northeast. Base not exposed, but a set of at least five (compositionally correlative) flows, each 5–13 m thick, was cored by Inyo-4 slant drill hole at slant depths of ~21–62 m (fig. 6), where they overlie a contrasting set of basaltic trachyandesite lavas (see unit mcl) and cinders (Eichelberger and others, 1988; Vogel and others, 1994). In drill hole DC-1 (Sorey and others, 1978), located at UTM 259/781 (fig. 8), ~6 km northeast of South Inyo Crater, a 15-m lava flow of unit aic was penetrated at depth of ~90–105 m (fig. 6), beneath flows of units mcv, mor, and another flow compositionally indistinguishable from unit bsr (99±1 ka). Flows compositionally correlative with unit aic have not been identified elsewhere.

Flows exposed on crater wall are directly covered by 8–12 m of red mafic pyro clastic strata (unit mic), suggesting presence of an unexposed vent nearby; these in turn are overlain by ~1 m of Inyo pumice fall (1350 C.E.), atop which lies as much as 13 m of phreatic ejecta (unit pe) that extends to

crater rim and was explosively emplaced at end of 1350 C.E. eruptive sequence (Mastin, 1991). Three flows drilled at top, middle, and bottom of stack exposed on crater wall gave nearly identical paleomagnetic direc tions (Mankinen and others, 1986). Absence of rhyolitic ejecta or float from nearby Deer Mountain intercalated between lava flows (or within or beneath subjacent pile of mafic lavas cored by Inyo-4 strongly suggests that unit aic is older than Deer Mountain (unit rdm; 101±8 ka). Vogel and others (1994) gave 40Ar/39Ar ages of 151±17 ka and 161±14 ka for two flows in the uppermost set of lava flows in Inyo-4 core, flows chemi cally similar to those exposed on crater walls, for which we obtained a 40Ar/39Ar age of 131±1 ka.

Qapb - Trachyandesite of Pumice Butte (middle Pleistocene)

apb - Trachyandesite of Pumice Butte (middle Pleistocene)
Scoria cone and moderately por phyritic lava flows (58.4–59.0% SiO_2) atop plateau between canyons of Fish Creek and San Joaquin River, 6 km east of their confluence and 8 km south-southwest of Mam moth Mountain (fig. 10). Pumice Butte scoria cone, ~750 m wide and 150 m high, stood above Pleistocene ice and is only moderately eroded, its slopes strewn with red and black sloughing scoria. Lava flows form a stubby lobe at north toe of cone and a narrow tongue that extends southwestward from midway up west slope. Lavas are glacially scoured, coarsely blocky, partly glassy, and massive or vesicular. Summit preserves a low-relief dish-like crater, largely filled; below its northwest and east rims are steep faces, 20–30 m high, of coarse red scoria—some loose but mostly tack-welded. Scoria bombs are as big as 1 m. Phenocrysts: 2–3% plagioclase (0.5–3.5 mm; mostly =1 mm); ~1% olivine (most ly mph but rarely as big as 1.5 mm); ~1% cpx (mph, some clustered with plagioclase and (or) oxides); trace Fe-Ti-oxide mph. In thin section, glassy groundmass is choked with microlites and plagioclase-lath mph. Overlies Mesozoic granite (unit Kmo) and Bishop Tuff (unit rbt; 767±2 ka). Overlain by lava flows of unit a62 (118±10 ka) from nearby scoria cone 2962. 40Ar/39Ar age: 142±5 ka (Mahood and others, 2010).

Qbdc - Trachybasalt west of Deer Creek (middle Pleistocene)

bdc - Trachybasalt west of Deer Creek (middle Pleistocene)
Moderately porphyritic lava flows (51.6% SiO_2) that crop out as a pair of 10-m-high benches that extend for ~1 km along southeast toe of Cone 2962, just west of Deer Creek. Fresh angular joint blocks are mas sive, nonvesicular, and moderately ice-scoured. Contains 3–5% olivine (0.5–1 mm) and 8–10% plagioclase (mostly 0.5–1 mm but as big as 4 mm). Not related to Pliocene mafic center 3206, 2–4 km east (Bailey, 1989), which consists of weathered lava flows of cpx olivine basaltic trachyandesite (unit Tmsd) that lacks plagioclase phenocrysts. Veneer of till obscures contact with closely underlying granite of unit Kmo. Unit is directly overlain by scoria Cone 2962 (unit a62; 118±10 ka). 40Ar/39Ar age: 155±2 ka.

Qbcf - Trachybasalt south of Crater Flat (middle Pleistocene)

bcf - Trachybasalt south of Crater Flat (middle Pleistocene)
Spatter cone 2545, consisting of phenocryst-poor agglutinate (51.7–51.8% SiO_2), 500 m south of Crater Flat and 5 km north of summit of Mammoth Mountain. Low cone is glacially scoured, 500 m wide, and only 40 m high. Mantled by late Holocene Inyo pumice-fall deposit, cone is poorly exposed, cropping out only as brick-red ledges of dense agglutinate on south slope, a few reaches along shallow draw at southeast toe of cone, and one massive lava ledge just southeast of that draw. Phenocrysts: ~1% plagioclase (0.5–4 mm); traces of olivine and cpx mph (both 0.1–0.2 mm); Fe-Ti oxides limited to finely crystalline groundmass; also contains sparse quartz and feldspar xenocrysts with reaction rims. Base not exposed. Overlain by units bmn (87±7 ka) and bar (88±5 ka). 40Ar/39Ar age: 164±2 ka.

Qmcl - Basaltic trachyandesite of Canyon Lodge (middle Pleistocene)

mcl - Basaltic trachyandesite of Canyon Lodge (middle Pleistocene)
Phenocryst-poor scoria cone and lava flows (53.8–55.9% SiO2 ; n=22) that crop out at several isolated locations (fig. 9), correlated on basis of composition, petrography, stratigraphy, and paleomagne tism. Scoria cone, ~600 m wide, was bulldozed for chairlifts in front of Canyon Lodge; it consists predominantly of brick-red scoria lapilli in layers 10–100 cm thick, ranging from loose to tack-welded to moderately agglutinated. Sparse bombs are as big as 1.5 m, a few of which have dense unoxidized interiors. Most extensive lava outcrops are several block-jointed knolls and ledges, east and west of Highway 395 near its crossing of Dry Creek, 7–9 km from vent, where Inyo pumice-fall deposit obscures continuity among numerous local exposures. From Canyon Lodge cone, lavas flowed northeast along west moat prior to emplacement of rhyolite lavas there (units rwm, rdc, rmk). An intricately shattered slab of unit mcl lava, as thick as 25 m and 250 by 450 m in plan view, was up lifted on roof of Dome 2861 (unit d61) during its plug-like extrusion (86±2 ka) and now dips 25º–30º NNE. Lavas from the cone also flowed at least 8.5 km eastward along south moat, where unit is identified at depths of 110–190 m (beneath till in and near the town of Mammoth Lakes) in at least three water wells (fig. 6), as a ledge near southern base of Knolls Vista (UTM 265/6875), and as a faulted remnant that forms 10-m-high bench (UTM 319/678) ~300 m southeast of Casa Diablo geothermal plant. Near the geothermal plant, outcrop of unit mcl is surrounded and lapped by rhyolite-derived sandstone and pebble conglomerate (unit ss) of Pleistocene Long Valley Lake.

Lava exposures are generally massive or locally vesicular, block-jointed or hackly, rarely slabby, and commonly erode as ledges 3–7 m high. Scoria cone and Knolls Vista exposure were glaciated, and exposures beyond glacial limits are fairly degraded; many joint blocks have been rounded and stripped of primary scoriaceous carapace. Pheno crysts: Plagioclase (0.5–2 mm) content is 0.5–2% at most exposures and up to 5% in a few intercalated flows, which additionally carry sparse plagioclase crystals as long as 4 mm (many larger ones sieved or rounded) and feldspar xenocrysts as large as 10 mm with reaction rims. Olivine is sparse and tiny (0.1–0.7 mm), seldom in clusters. Cpx is typically absent but present rarely as microphenocrysts. Granitic xenoliths occur sparsely. Within compositional range of unit mcl (7.5-6.8% FeO*; 1.8-2.2% K2 O), phenocryst poorer flows (or domains within them) tend to be slightly more evolved chemically. Overlain by units bsm (165±2 ka), rwm (~150 ka), mkv (153±1 ka), mor, mnd, and bar (in slab uplifted atop Dome 2861).

In south moat water wells (fig. 6), unit is also overlain by units amp, bcd, bsc, and gcd. Along south moat, unit is inferred older than units mmc and bfh. Drill hole SF66–31 on Sawmill Road [UTM 302/6765], ~1 km west of geothermal plant, is col lared in unit bcd, which caps a 67-m-thick section of mafic lava flows; lowest flow is chemically and petrographically identified as unit mcl, which rests on ~9 m of crystal rich ash that overlies Early rhyolite tuff (unit rer) hundreds of meters thick. In water well 30M, 2 km southeast of downtown Mammoth Lakes, a 27-m-thick section of two or three mcl lava flows penetrated at 110–137 m depth directly underlies unit bsc (172±2 ka) and overlies unit asr. In Inyo-4 slant drill hole beneath South Inyo Crater (Eichelberger and others, 1988), unit mcl closely underlies unit aic (131±1 ka) at slant depths of ~70–245 m; several flows comprising upper ~75 m of Group II of Vogel and others (1994) are compositionally indistinguishable from unit mcl, and several more comprising the lower ~55 m of Group II are similar but not identical. In drill hole OIP-1 (UTM 237/749), ~1 km northeast of Deer Mountain, phenocryst-poor lava flows corre lated chemically with unit mcl were penetrated at depths between 90 and 190 m, where they underlie one flow of unit mdn and another of unit bmn. At exposures southwest of Lookout Mountain, hilly local relief of 20–40 m, multiledge knolls, steep bluffs, and rhyolite remnant (unit rwm) atop 40-m-high knoll of unit mcl indicate that unit mcl is significantly eroded. Relief probably owes to combination of displacements on resurgent graben fault system and Pleistocene incision by Dry Creek drainage system, which issued from glacial limit only 2 km to west. 40Ar/39Ar ages: 175±3 ka (UTM 278/742); 172±2 ka (UTM 282/755); 179.5±2.4 ka (UTM 319/678). Inyo-4 core sample at slant depth of 461.5 ft (140.6 m), upper Group II, gave 186±2 ka. One 40Ar/39Ar age of 190±9 ka (UTM 281/757) was determined by Mahood and others (2010).

Qrbt - Bishop Tuff (middle Pleistocene)

rbt - Bishop Tuff (middle Pleistocene)
Rhyolitic ignimbrite, voluminous compositionally zoned pyroclastic unit (71–78% SiO2), eruption of which permitted collapse of Long Valley caldera (Gilbert, 1938; Hildreth, 1979; Bailey, 1989; Wilson and Hildreth, 1997; Hildreth and Wilson, 2007). Variably welded outflow sheets crop out radially around caldera; concurrently erupted fall deposit is preserved patchily from Pacific Ocean to Nebraska. Intracaldera thickness beneath postcaldera volcanics and sediments exceeds 1 km, as recorded in many drill holes (McConnell and others, 1995). Total eruptive volume of equivalent magma estimated to have been 600–650 km3 (Hildreth, 2004). Within map area, main outcrops are (1) nonwelded to densely welded outflow sheet along north wall of caldera; and (2) glaciated remnants along walls of Middle Fork San Joaquin River canyon—including nonwelded to sintered exposures east of Sotcher Lake, sintered to densely welded ledges southwest of Pumice Butte, and densely welded (vitric and devitri fied) zones near Reds Meadow, Boundary Creek, Crater Creek, King Creek, and Fish Creek. Remnants are generally steep, and some welded zones are columnar jointed. More than 95 percent of the ignimbrite originally deposited along San Joaquin canyon has been removed by glacial and fluvial erosion. Thicknesses preserved generally increase downcanyon from ~160 m near Reds Meadow to ~195 m near King Creek and 230 m southwest of Pumice Butte. Unit is also exposed along north edge of map area where many outcrops range from sintered to densely welded; nonwelded base is exposed in Highway 395 roadcut at UTM 242/813. Accidental clasts of welded Bishop Tuff as big as 50 cm are locally abundant in intracaldera pyroclastic deposits (subunits rtav, rtcd) of early postcaldera rhyolite (unit rer), which had excavated them explosively from the cal dera fill hundreds of meters deeper. Phenocrysts: total content zoned from ~1% to ~25%, including sanidine, quartz, plagioclase, biotite, allanite, Fe-Ti oxides, zircon, and (in late subunits) antecrysts of cpx and opx (Hildreth, 1979; Hildreth and Wilson, 2007). Rests on Mesozoic granitoids, Paleozoic metasedimentary rocks, glacial till (unit gst), alluvium (unit pal), and various Tertiary mafic and intermediate lavas. Overlain in map area by units a62, amp, apb, drf, and gud (and by many more outside map area and beneath caldera floor). 40Ar/39Ar age: 767±2 ka (Rivera and others, 2011).

Tbld - Trachybasalt south of Lost Dog Lake (Pliocene)

Two glaciated remnants of olivine-rich basalt (51.9–52.1% SiO2) 0.6–1.3 km south of Lost Dog Lake and ~7 km west of Mam moth Mountain summit. North remnant is east-trending lava ridge, 100 m wide, 350 m long, and as thick as 20 m at its eastern scarp. South remnant is 200 x 400 m across and likewise thickest at its eastern scarp, which exposes 10 m of massive lava atop 10 m of agglutinated red scoria fall and a lower 10 m slope concealed by its own blocky talus. Vent complex, centered on south remnant, consists predominantly of agglutinated red scoria lapilli but includes scoria bombs as big as 30 cm and angular lava fragments up to 40 cm. Lava flows are dense, massive, and dark gray, weathering orange-brown or pale gray-brown; rock splits on irregular fractures into angular blocks on scarps and on sets of parallel hairline fractures into plates and flakes on ice-scoured ridgetop surfaces. Weath ering rinds are commonly 1–1.5 cm thick. Phenocrysts: 5–7% olivine (0.1–1.2 mm); no plagioclase or pyroxene phenocrysts; Fe-Ti oxides limited to finely crystalline ground mass. Also contains sparse quartz xenocrysts as big as 5 mm and scattered anhedral feld spar xenocrysts (1–4 mm). Compositionally unrelated to nearby basalt of The Buttresses (unit btb). Rests on Mesozoic granite. 40Ar/39Ar age: 3,353±31 ka.

Tdww - Trachydacite of White Wing Mountain (Pliocene)

Phenocryst-rich lava dome (66.8% SiO2) and associated fragmental deposits that cap western quarter of White Wing Moun tain, which consists predominantly of Mesozoic granite and forms steep northwestern segment of Long Valley Caldera wall. Glaciated dome is 1 by 1.5 km in area and has 100–200 m of relief, much of it blanketed by 1350 C.E. Inyo pumice-fall deposits. Summit of White

Wing Mountain (peak 3051), which stands 50 m higher than any exposure of dacite lava, consists almost entirely of fragments of same dacite, angular to subrounded, many as big as 1–2 m, that form a deflated lag deposit that armors summit and its west ridge. Rare blocks of granite suggest deposit could have been glacially trans ported from adjacent dome. However, remnant deposits of similar angular dacite blocks down at 2,660–2,775 m elevation on south ridge of White Wing Mountain lack base ment clasts and include fragments of hydrothermally altered dacite, suggesting emplace ment as explosively driven fragmental flows. Blocks and dome lava are glassy or finely crystalline, dense to finely vesicular, and flow foliated. Phenocrysts: 25–30% plagioclase (1–6 mm); 6–8% biotite (mph to 1.5 mm); ~1% hornblende (0.3–1 mm); traces of quartz (0.5–1.5 mm) and Fe-Ti oxide mph. Overlies granitic unit Kjl. K-Ar age: 2.6±0.4 Ma (Jenny Metz, analyst; reported by Chaudet, 1986).

Td65 - Trachydacite of Dome 2965 (Pliocene)

Phenocryst-rich lava dome (64.4% SiO2) just southwest of White Wing Mountain on divide between headwaters of Glass and Deadman Creeks. Subcircular in plan view, dome is ~1.3 km in diameter and has as much as 350 m of relief. Outcrops are limited, as lower slopes of dome are brush-covered, but crest and south ridge are largely bare, covered by coarsely blocky to platy scree. Although dome was locally glaciated and is lapped on west by till deposits, material exposed consists mostly of glassy to finely crystalline, pale-gray blocks and slabs that weather tan to orange-brown. Phenocrysts: ~30% plagioclase (1–5 mm); 6–8% biotite (mph to 1.5 mm); 1–2% hornblende (0.5–3 mm); traces of opx (mph to 1 mm) and Fe-Ti oxide mph. Base not exposed, but unit is inferred to intrude and overlie granitic and metasedimentary basement rocks. Undated but may be similar in age to lithologically similar lava dome, adjacent unit Tdww.

Tmcv - Basaltic trachyandesite of Crestview (Pliocene)

Olivine-rich lava flows notably enriched in K and P (53.1–54.9% SiO2 ; ~4.5% K2 O; ~0.85% P2 O5) that crop out discontinuously on scarps east, north, and west of confluence of Glass and Deadman Creeks. South-facing scarp 600 m southeast of Crestview is stack of flows ~40 m thick that rests on Mesozoic granodiorite. On steep nose 500 m northwest of Crestview, unit is ~60 m thick. Along rim of southeast-facing scarp 1–2 km southwest of Crestview, unit may be single flow; its exposure there is at least 10–30 m thick, but its upland slope continuing northwest above rim is wholly concealed by 1350 C.E. Inyo ejecta. Exposures are block-jointed and mas sive to sparsely vesicular. Phenocrysts: 7–10% olivine (mostly 0.2–3 mm; locally hopper shaped crystals as big as 4–7 mm); sparse cpx (0.3–1 mm); sparse plagioclase-lath mph; and cpx-plagioclase microdioritic inclusions. Also carries quartz and feldspar xenocrysts. Overlies Mesozoic granodiorite and units Taww (2,950±90 ka), Tmwo (3,153 ±26 ka), Taec, and Tb84. Overlain by Sherwin Till (unit gst). Relative elevations of three main outcrop strips suggest a westerly source vent, now concealed. Undated.

Tbpl - Trachybasalt east of Pond Lily Lake (Pliocene)

Glaciated stack of phenocryst-rich lava flows (48.8–51.7% SiO2) that extends 2 km along east wall of Middle Fork San Joaquin River canyon as far as nose above its convergence with Fish Creek, ~10 km south-southwest of Mammoth Mountain. Above exposed base at rim of 2,100-m shelf traversed by Pacific Crest Trail, ledgy stack is as thick as 300 m. About ten ledges crop out in particular sections, and total number of flows is ~20. Massive zones are 5–15 m thick, slabby or hackly, locally vesicular, and commonly polygonally jointed to colum nar; one flow at north limit of outcrop is ~30 m thick. Flows are dark gray, weather ing pale gray to tan and typically having 1-cm-thick weathering rinds. Within stack of flows, two unstratified intervals of coarsely blocky, oxidized autobreccia are each ~20 m thick; most blocks are nonvesicular, suggesting fragmentation during downslope flow rather than proximity to vent. Vent location unknown, but attitudes of flows and breccia sheets and interflow unconformities indicate flow directions toward west and southwest, not southward along Middle Fork

canyon. Phenocrysts: all flows examined have 5–10% olivine (0.3–1.5 mm); most contain 1–5% cpx (0.1–2 mm, commonly in clusters); plagioclase is limited to groundmass and rare xenocrysts (as big as 3 mm); rimmed quartz xenocrysts (also up to 3 mm) are not uncommon. Samples analyzed are unusually rich in Sr (fig. 20D). Unit rests directly on Mesozoic granite (unit Kmo). Overlain by unit rbt (767±1 ka). Undated.

Tmcr - Basaltic trachyandesite of Mammoth Crest (Pliocene)

Olivine-rich mafic lava flow remnant (53.3% SiO_2 , 7.5% MgO) preserved as hill 3228 atop Mammoth Crest, ~1 km southwest of Crystal Crag. Remnant of single flow, resting on Cretaceous granite, is 250 by 400 m in plan view and only ~25 m thick. Ice-scoured, finely crystalline, massive lava is frost-riven into whaleback pile of slabs. Phenocrysts: ~7% olivine (mph to 2 mm); common Fe-Ti oxide mph. Source vent unknown. Lower MgO content than olivine-rich 3.15-Ma basalt (unit Tbmm) at Mammoth Mine, base of which lies 300 m lower in eleva tion and 3.5 km northeast across Lakes Basin, but the two are lithologically and petro graphically similar. Undated.

Tdud - Trachydacite complex of upper Deadman Creek (Pliocene)

Phenocryst-rich pyroclastic vent complex with two lava domes centered on knoll 3025 between headwaters forks of Deadman Creek. Tuff (stippled) crops out over rugged area of 0.3 km2 with >300 m of relief. Domes, which erupted through and overlap tuff complex, have maximum dimen sions of 350 m and 600 m and relief of 150 m and 300 m, respectively. Lavas are glassy or finely crystalline, massive to finely vesicular, flow foliated, block jointed, and gener ally pale to medium gray, weathering tan to orange-brown. Tuff is massive to chaotic, locally crudely stratified, is nonwelded but widely indurated by silicification, and carries abundant dacitic and basement lithics and abundant punky dacitic pumice; generally white, it weathers tan or yellow, hackly, pitted, or cavernous, and erodes into spires and hoodoos. Tuff lithology is unlike that of pyroclastic units Tdpd or Tdsj ~1 km south. Tuff is cut by dikes and irregular intrusive masses of crystal-rich hornblende-biotite-plagioclase trachy dacite (67.4–70.7% SiO_2), which are presumed comagmatic. Both domes have 20-25% plagioclase (1–4 mm), 5–7% biotite (mph to 1.5 mm), trace hornblende (mph to 12 mm), and trace Fe-Ti oxide mph. Larger dome (68.5% SiO_2) contains common ovoid inclusions (5–20 mm) of similar micropumiceous feldspar-rich dacite in which mafic phenocrysts are smaller and generally oxidized. Smaller southwest dome has 67.9% SiO_2 . Domes and tuff all erupted through and rest upon (or steeply against) unit Pzms. Undated but presumed Pliocene in common with several other trachydacite domes nearby.

Tmsd - Basaltic trachyandesite south of Deer Creek (Pliocene?)

Moderately porphyritic lava flows (53.2% SiO_2) that cap high divide between upper Deer Creek and Fish Creek canyon. Stack of flows is ~150 m thick where exposed on cirque headwall at head of Deer Creek. Glaciated unit extends 2 km west from vent remnant at hill 3206, which lies 5 km east of Pumice Butte and 9 km south of Mammoth Mountain. Upland surface of unit is blocky colluvial rubble with a few ledgy exposures. Phenocrysts: 5–7% olivine (0.2–3 mm); trace cpx but no feldspar. Overlies Mesozoic granite (unit Kmo). Undated.

Tmcm - Basaltic trachyandesite south of Upper Crater Meadow (Pliocene)

Remnants of single glaciated olivine-rich lava flow (53.2% SiO_2 ; 7.5% MgO; 5.25% K_2O) on both rims of a gorge tributary to Crater Creek (UTM 190/608), ~600 m south of Upper Crater Meadow. Rim ledges are 1–4 m thick and overlain by thin till deposits and Inyo pumice. Pheno crysts: ~7% olivine

(0.5–2 mm), many with tiny spinel inclusions; also contains sparse quartz xenocrysts with reaction rims. Holocrystalline groundmass, rich in flow-aligned plagioclase-lath mph, also carries abundant olivine mph and rare Fe-Ti oxides (both ~0.1 mm). Rests on and armors 20-m-thick remnant of massive white grus exposed on gorge walls where grus grades down into fresh Mesozoic granite. Unit is unusually rich in Sr (2,050 ppm) and Ba (3,600 ppm) (fig. 20). 40Ar/39Ar age: 3,363±15 ka.

Tdsd - Trachydacite of Dome 3321 (Pliocene)

Phenocryst-rich lava dome (67.3% SiO2) on crest of San Joaquin Ridge 2 km northwest of Deadman Pass. Equivalent to “South Dome” of Bailey and others (1990), 500-by-700-m dome is partly covered by dacitic pyroclastic deposits but has ~120 m relief on its steeply exposed east face. Exposures are coarsely block-jointed, finely crystalline or vitrophyric, medium to dark gray, weathering brown with oxidized dark-brown rinds on joint faces; lower parts of east face are strongly flow foliated. Phenocrysts: 25–30% plagioclase (mph to 2.5 mm), 5–7% biotite (mph to 2 mm), ~1% hornblende (0.5–2 mm), and traces of opx and Fe-Ti oxide mph. Dome lava overlies trachydacitic pyroclastic complex (unit Tdpd), which is probably its own vent opening eruptive phase that, in turn, rests on unit |ms. Dome is partly surrounded and overlapped by trachydacitic block-and-ash-flow deposits (unit Tdsj), which were in part derived from Two Teats dome (1 km northwest) but in part produced during fitful extru sion of Dome 3321 itself. K-Ar age: ~2.8±0.1 Ma (Curry, 1966).

Tdsj - Trachydacite block-and-ash-flow deposits of San Joaquin Ridge (Pliocene)

Phenocryst-rich block-and-ash-flow deposits (66.8–67.0% SiO2) that cap San Joaquin Ridge (Sierran drainage divide) as 700-m-wide ridgecrest swath extending 3 km south east from Dome 3321 (unit Tdsd). As thick here as 120 m, unit is equivalent to “upper pyroclastic member” of Bailey and others (1990). Clasts are almost exclusively juvenile dacite shed during extrusive dome growth, in contrast to underlying “lower pyroclastic member” of those authors (our unit Tdpd), which is rich in basement clasts excavated during explosive reaming of vent later filled by dome lava. Clasts are angular to sub rounded, mostly glassy, and dense or weakly vesicular; many are prismatically jointed. Clast sizes are seriate from ashy matrix to meter-scale blocks, a few as large as 5 m. On wind-scoured ridgecrest, deposit is widely deflated, concentrating coarse blocks on surface, which, with thick colluvium, obscures any internal stratification in the deposit. Bailey and others (1990) reported similar deposits surrounding lithologically similar trachydacite domes (San Joaquin Mountain and Two Teats) farther northwest, beyond our map area; what fractions of such deposits had issued from each of those and from Dome 3321 has not been determined. Phenocrysts: ~25% plagioclase (mph to 4 mm), 5–7% biotite (mph to 1.5 mm), ~1% hornblende (0.5–1 mm), and traces of opx and Fe-Ti oxide mph. Overlies units Tbdp (~3.28 Ma), Tdpd, and |ms. Not directly dated but probably equivalent in age to inferred source lava dome, 2.8-Ma unit Tdsd.

Tdpd - Trachydacite pyroclastic-density-current deposit of Deadman Pass (Pliocene)

Stratified assemblage of phenocryst-rich pumiceous pyroclastic-flow and surge deposits rich in accidental lithic fragments; best exposed along northeast face of San Joaquin Ridge between Dome 3321 and Deadman Pass. Equivalent in part to “lower pyroclastic mem ber” of Bailey and others (1990). Interpreted here as vent-opening explosive phase of eruption that ended with extrusion of Dome 3321 (unit Tdsd), just east of which pyro clastic assemblage exposes its maximum thickness of ~150 m and is eroded into spires and fluted cliffs. Thins to ~30 m at Deadman Pass, 2 km southeast. Dominant lithology of thick cliff sections is white nonwelded ignimbrite, indurated by weak silicification and crudely stratified by varied abundances of lithics. Massive lithic-poor intervals are as thick as 10

m, separated by numerous lithic-richer layers 0.5–3 m thick and an interval of thin-bedded fall and surge deposits, together ~7 m thick (see fig. 5 of Bailey and others, 1990). Most layers are ash-dominant, carrying abundant pumice (1–5 cm) and highly varied contents (5–30%) of lithics (1 m. Unit is observed to rest only on metasedi mentary rocks (unit |ms), but plutonic, hypabyssal, and basaltic rocks are inferred to be concealed nearby, possibly beneath dome 3321. Not directly dated but probably same age as inferred vent-filling lava dome, 2.8-Ma unit Tdsd.

Diamicton at Deadman Pass (Bailey and others, 1990) is deflated colluvial lag residual from this pyroclastic unit; much of ash and pumice has been stripped from top few meters, concentrating coarse lithics in wind-scoured ridgecrest saddle. Clast suite is same as within intact pyroclastic assemblage north of pass: Felsic and mafic granitoids > metapelite, hornfels, and quartzite > porphyritic Mesozoic dike rocks; only ~5% each of clasts are Pliocene basalt (as big as 70 cm) and (juvenile) Pliocene trachydacite (as big as 25 cm). No metavolcanic clasts from Ritter Range or upper Middle Fork are present. Most blocks larger than 1 m are granitoids or quartzite. Most clasts are angular or suban gular except some subrounded grussy granitoids.

Taww - Trachyandesite north of White Wing Camp (Pliocene)

Phenocryst-poor lava flows (59.0–59.7% SiO2) that form southeast-facing caldera-wall scarp east of Glass Creek flow and ~700 m north of White Wing Camp. Unit crops out in a few ledges and buttresses for ~1 km along 80-m-high scarp. Ledges suggest presence of several flows, but mantle of pumiceous scree from 1350 C.E. Inyo ejecta obscures most of unit. Unit may be thicker than 80 m, but upland slope above scarp rim is covered by Inyo ejecta. Outcrops are flow-foliated, nonvesicular, slabby or irregularly block-jointed, and pale gray, weathering orange-brown or gray-brown. Phenocrysts: 1–3% olivine (0.5–2.5 mm); sparser cpx (0.5–1 mm); and 1–2% microphenocrystic plagioclase laths, rarely longer than 0.5 mm. Overlies unit Tmwo (3,153±26 ka) near Glass Creek. Overlain on caldera rim by unit Tmcv. K-Ar age: 2,950±90 ka for outcrop at UTM 241/790 (Mankinen and others, 1986).

Tmcw - Basaltic trachyandesite west and east of Obsidian flow (Pliocene)

Phenocryst-rich lava flows and agglutinate (53.1-54.5% SiO2) that crop out as glaciated near-vent remnants just west of Obsidian flow (unit ric) and along walls of Glass Creek from beneath Obsid ian flow for ~1.3 km eastward. Three proximal remnants form north-south alignment only 200 m long, each only 30–70 m in maximum dimension. Northern remnant is largest, a 15-m-high steep pile of brick-red agglutinated spatter and scoria with ejecta as large as 30 cm; this is invaded by thin dikes and on its north and west walls by irregular masses of dark-gray block-jointed lava. Middle remnant is 6-m-high ledge of coarsely block-jointed massive lava ~30 m long. Southern remnant is another ledge of similar lava ~70 m long, somewhat more vesicular and strewn with glacial erratics and Inyo ejecta. Lavas are locally streaky but generally dense and massive or weakly flow-foliated, their surfaces weathering dark brown to orange brown. Outcrops on walls of Glass Creek are irregu larly block-jointed ledges as thick as 10 m, but exposure is limited by Inyo ejecta and derivative scree; ledges suggest possibility of more than one flow. Drill holes beneath and adjacent to Obsidian flow (Eichelberger and others, 1985) penetrated 250–350 m of unex posed mafic lavas sandwiched between till and granitic basement; unit Tmwo represents at least upper part of mafic section. Phenocrysts: 3–7% olivine (0.2–1 mm), iddingsite rims common; 1–4% plagioclase (0.3–1 mm long, mostly laths); 1–3% cpx (0.5–1.5 mm), many in clusters; also carries sparse quartz xenocrysts. Finely crystalline groundmass is rich in tiny plagioclase laths and clusters of pyroxene mph. Distal exposure on south wall of Glass Creek is least evolved chemically and poorest in phenocrysts, with plagioclase limited to microphenocrysts. Base not exposed, but inferred to rest on Mesozoic granite (exposed nearby). Overlain by units Taww (2,950±90 ka), Tmcv, and gst, which is in turn overlain by unit rbt. Fresh condition of lava led Putnam (1949) to infer Pleistocene age, but unit was called Pliocene by Bailey (1989). 40Ar/39Ar age: 3,153±26 ka.

Tbtb - Basalt of The Buttresses (Pliocene)

Stack of severely glaciated phenocryst-rich lava flows (46.5–50.6% SiO2) that form stairstep benches just west of Middle Fork San Joaquin River, southwest of Devils Postpile. Main remnant is ~1 km wide and extends 2 km north-south; consists of several flows, individually 15–40 m thick, altogether at least 100 m thick, but draping granitic basement to produce local relief of ~170 m. A 300-m-long columnar outlier lies south of King Creek at southwest surviving limit of unit. Three more outlying remnants, ~1 km west of main one, extend to elevation of 2,750 m, ~470 m higher than base of unit along Middle Fork. Several ledge-forming flows have tiers of bold vertical columns, typically 30–80 cm wide and locally as tall as 10 m; else where flows are block-jointed, or intricately hackly jointed with spacings of 10–30 cm, or locally exhibit crude variously oriented columns. Except for rubbly breccia zones locally exposed, flows are massive, nonvesicular, and (though phenocryst-rich) have aphanitic crystalline groundmass. Rocks are dark gray, weathering gray-brown; weathered surfaces are speckled by crystals (1–3 mm) of olivine and cpx (or clusters thereof) that stand out in relief. Along 300-m-long reach of Middle Fork that begins 400 m south of Devils Postpile, unit Tbtb drapes steep west-bank granite wall all the way to riverside, indicat ing that river has here simply re-incised its pre-basalt channel and cut no deeper during entire Pleistocene. Above river and elsewhere, zones of interflow autobreccia as thick as 8 m are conspicuous; angular dense clasts and subrounded vesicular clasts coexist within clast-supported pale-gray matrix of unstratified coarse ash; yellow-orange altera tion is superficial, confined to fracture films and patchy domains in ash-rich breccia, not penetrative into lava blocks. There is no explosively ejected facies nor evidence for a vent here or elsewhere; vent is inferred to have been far upstream, north or northwest of map area. Phenocrysts: some flows contain 2–3% plagioclase (0.5–1.5 mm, rarely to 3 mm); 7–10% olivine (1–3 mm); and 10–12% cpx (1–2.5 mm), commonly in clusters. Other flows contain no plagioclase phenocrysts but have 5–10% each of olivine and cpx (both as big as 3 mm), including abundant cpx clusters, in olivine-rich groundmass. Contains sparse quartz xenocrysts as big as 6 mm. Sites in north-central and King Creek sectors of unit yield same (reversed) paleomagnetic direction (Hildreth and others, 2014). Rests exclusively on Mesozoic granite. 40Ar/39Ar age: 3,754±7 ka.

Tmww - Basaltic trachyandesite of White Wing Mountain (Pliocene?)

Moderately porphyritic scoria cone, agglutinate, and subordinate lava (52.3–52.4% SiO2) preserved as two remnants on southwest ridge of White Wing Mountain. Major remnant is 300 by 500 m across, extending downslope just south of summit from elevation 2,990 m to 2,830 m. Massive lava exposed at base is pale gray, weathers orange-brown, splits slabby, and contains vesicle sheets. Principal outcrops are cliffs, 30–50 m high, of crudely stratified ejecta, tack-welded to moderately agglutinated. Ejecta are dominantly lapilli but seriate from coarse ash to 30 cm, enclosing scattered scoria bombs as big as 50–200 cm. Most clasts are vesicular scoria, but many are dense juvenile fragments. Cliffy pyroclastic section is black below but grades upward to brick-red, then orange-brown with yellow palagonitic matrix locally. Major ridge-capping remnant erodes craggy; huge agglutinate blocks were ice-transported into a hollow 250 m east. Smaller remnant, down ridge at elevation 2,700 m, is only 100 m across and consists of ledges of scoria lapilli and tack welded agglutinate. Phenocrysts: 5–8% olivine (mostly mph but a few as big as 1.5 mm), and rare cpx (<1 mm). Overlies granitic unit Kjl. Undated.

Tbdp - Trachybasalt of Deadman Pass (Pliocene)

Stack of numerous mafic lava flows on San Joaquin Ridge between Minaret Summit and Deadman Pass (figs. 3, 4, 7). Samples analyzed range in SiO2 from 50.4 to 53.2%. Flows are subset of sequence that continues along ridge beyond map area, altogether for 12 km northwest as far as Clark Lakes and Agnew Pass (Huber and Rinehart, 1965a; Chaudet, 1986; Bailey, 1989, 2004). Within map

area, at least 30 flows range in thickness from ~3 m to >70 m, supporting benches and cliffs widely frost-riven into slabby ledges. Cliffs, 200 m high, ~1 km east of Deadman Pass, expose stack of ~20 thin rubbly flows, capped by a few flows 15–40 m thick. Entire sequence is as thick as 300 m on east-facing caldera wall and as thick as 450 m where it filled a paleotributary of Middle Fork on southwest-facing side of San Joaquin Ridge, ~1 km south of Deadman Pass (fig. 9). Dark gray in fresh interiors, most exposures are weathered and resinous; whether massive or vesicular, slabs and hackly blocks typically carry orange-brown weathering rinds 1–2 cm thick. Unit includes degraded scoria cone ~250 m wide, on west rim of main ridge (UTM 182/715); cone consists of brick-red lapilli and sparse bombs in palagonitized coarse ash matrix, arranged in decimeter-to-meter-scale fall layers that dip 15º–20ºW or NW; east half of cone is covered by surficial debris. Flows contain 5–15% olivine (0.5–2 mm, commonly altered); some (generally thicker) flows also have 1–5% cpx (1–5 mm) and abundant Fe–Ti oxide mph; but none carry plagioclase phenocrysts. Zeolites and veinlets of silica and carbonate are common. Overlies pre-Cenozoic basement rocks. Overlain by Pliocene trachydacite pyroclastic deposits of units Tdpd and Tdsj (Bailey, 1989, 2004; Bailey and others, 1990). K-Ar age: 3.15±0.1 Ma (Dalrymple, 1964a; recalculated by 40K decay constants of Steiger and Jäger, 1977) for flow at east rim of stack. 40Ar/39Ar ages: 3,700±12 ka for lowest flow in channel-filling stack (UTM 170/719) just east of Agnew Meadows; 3,277±7 ka for top flow of stack, on caldera rim (UTM 191/720) ~2 km east and 400 m higher.

Tacc - Trachyandesite of Crater Creek (Pliocene)

Pair of glacially eroded knobs of phenocryst-poor andesite (58.3–62.6% SiO2) on east rim of Crater Creek canyon, 2 km north of Pumice Butte (fig. 10). Centered ~1 km apart, both knobs are elongate northeast-southwest. Larger northeast knob is 600 m long with 90 m relief, whereas southwest knob is 300 m long with 50 m relief. Both consist of pale-to-medium-gray massive lava, locally mottled, that weathers tan or pale pink and disintegrates into chaotic talus of blocks, plates, and slabs that reflect crude flow foliation. Rocks are nearly aphyric but contain hornblende needles (0.2–2 mm long), some with swallowtail morphology; trace amounts of olivine (0.5–1 mm), opx (0.5–1 mm), and cpx (2–4 mm long, some in clusters) are present. Both knobs also contain common xenocrysts of 1-mm quartz, singly or in clusters, with reaction rims; less common are composite xenocrysts of quartz and cloudy feldspar; free feldspar crystals (1–4 mm) are rare and probably also xenocrystic. Lack of exposure in saddle between knobs leaves unresolved whether they are separate domes or eroded parts of a once-continuous coulee. Two analyses of northeast knob yield 61.3–62.6% SiO2 whereas two of southwest knob yield 58.3–58.7% SiO2, suggesting separate domes; the four analyses, however, define linear compositional arrays for most elements. Steep north face of southwest knob exhibits near-vertical jointing, but lack of oxidation, ejecta, or breccia provides no suggestion of vent features. Unit rests on Mesozoic granite and lavas of unit Tasj (9.164±0.017 Ma). 40Ar/39Ar age: 4.29±0.20 Ma (G.A. Mahood, unpublished data, 2010).

Tasj - Trachyandesite of San Joaquin River (Miocene)

Glaciated phenocryst-rich lava flows (58.0–58.1% SiO2) and subjacent intrusive mass that extend for ~1.1 km along east wall and rim of Middle Fork canyon, north and west of Pumice Butte and ~7 km southwest of Mammoth Mountain. On plateau near rim, as high as 2,820 m, massive lavas are ice-scoured into smooth swells, nubbins, and ledges, their surfaces typically polygonally jointed, locally columnar, and widely glassy or partly so. Cliffy outcrop is as thick as 250 m at its north end where it fills a reentrant in the granitic canyon wall, there displaying glassy chunky structure with local tiers of short irregular columns; lower half is probably intrusive. Phenocrysts: 15–20% plagioclase (0.5–2.5 mm); ~1% cpx (0.5–2 mm); <1% olivine (0.2–1mm); and scattered Fe-Ti oxide mph. Unit intrudes and rests on Mesozoic granite (unit Kmo). Overlain by units Tacc (4.29±0.20 Ma) and a62. 40Ar/39Ar age: 9,164±17 ka. A trachyandesite lava flow as thick as 75–85 m at Kennedy Table near Millerton Lake Reservoir (Huber, 1981; Bateman and Busacca, 1982) on San Joaquin River (fig. 2), 66–85 km downstream and 2,400 m lower in elevation, is mineralogically and chemically similar and yields a

40Ar/39Ar age of 9,192±15 ka.

Kmo - Mono Creek Granite (Late Cretaceous)

One of several extensive plutons of megacrystic granite emplaced during terminal stages of 140-million-year-long accumulation of Sierra Nevada composite batholith (Bateman, 1992a, b). Elongate pluton extends >50 km northwest from Pine Creek to Minaret Summit and, within map area, forms Mammoth Crest and underlies parts of Mammoth Mountain and valley of Middle Fork San Joaquin River. Light-colored granite carries several percent alkali-feldspar megacrysts (1–3 cm) in medium-grained (1–5 mm) groundmass. Ranges of mineral contents: 20–35% total alkali feldspar; 20–40% quartz; 30–50% plagioclase; ~5% biotite; and trace amphibole (Rinehart and Ross, 1964; Huber and Rinehart, 1965a; Bateman, 1992a); mafic enclaves uncommon. Foliation is generally inconspicuous except along Rosy Finch Shear Zone (Tikoff and Saint Blanquat, 1997), a steeply foliated belt that encompasses both pluton margin and its metavolcanic wall rocks; zone strikes beneath Mammoth Mountain and is well exposed south of Lake George. Pluton intrudes unit Mzmv and, south of map area, units Pzms and Krv.

Kjl - Granite of June Lake (Late Cretaceous)

Elongate granitic pluton that forms White Wing Mountain at northwest rim of Long Valley Caldera and extends at least 13 km northwest through June Lake to Grant Lake. Medium-grained hornblende-biotite granite is not strongly porphyritic but contains scattered alkali-feldspar megacrysts—seldom bigger than 1 cm. Ranges of mineral contents (Kistler, 1966): 11–25% quartz; 22–42% alkali feldspar; 27–55% plagioclase; 5–12% biotite; and 1–6% hornblende. Formerly correlated with Late Triassic megacrystic pluton of Wheeler Crest by Huber and Rinehart (1965a) and Kistler (1966), but reassigned to Cretaceous by Bateman (1992a). Two isolated exposures that intrude Paleozoic metasedimentary rocks along caldera wall east and northeast of Deadman Pass are apparently correlative; quite felsic and medium-to-fine-grained, they have ~74% SiO2, carry only ~10% mafic minerals, and contain aplitic masses and dikes and locally thick quartz veins. Third and southernmost plutonic outcrop along west wall of caldera, ~2.5 km southeast of Deadman Pass, is different (see unit Mzgd).

MZgd - Granodiorite northeast of Minaret Summit (Mesozoic)

Cliffy exposure of mafic granodiorite, ~1 km long, on west wall of Long Valley Caldera 2 km northeast of Minaret Summit and just northwest of unit bar scoria cone. Medium-grained equigranular rock carries 25–30% mafic and accessory minerals, including anhedral biotite and hornblende-biotite aggregates. Intrudes unit |ms, includes abundant wall-rock fragments, and injects aplite dikes (1–2 m thick) into metasedimentary host rocks. Pluton is cut, in turn, by two porphyritic granitic dikes (74% SiO2), each 5–10 m thick, which trend east-northeast and carry quartz and feldspar phenocrysts (1–10 mm) in dark-gray, finely crystalline matrix laced locally by epidote veinlets. A similar porphyritic granitoid dike, 2 km north-northwest of Deadman Pass (UTM 165/754), is 5–15 m thick, strikes ~25° NW, and intrudes vertically foliated unit Pzms for ~150 m; arbitrarily assigned to unit Mzgd, it may or may not be correlative. Unit was correlated improbably by Huber and Rinehart (1965a) and Bailey (1989) with Late Triassic Granite of Lee Vining Canyon (Kistler, 1966; Bateman, 1992a), which has only 2–7% mafic minerals. Main southern outcrop overlain by Pliocene basaltic unit Tbdp. Age unknown but certainly Mesozoic.

MZmv - Metavolcanic rocks of Ritter Range pendant (Mesozoic)

Heterogeneous assemblage of subaerial (and sparser subaqueous) arc-volcanic rocks of Triassic through Cretaceous age, moderately metamorphosed during intrusion by plutons of Sierra Nevada batholith in Cretaceous. Thicker than 10 km, assemblage was deposited as felsic ignimbrites, varied pyroclastic and volcaniclastic deposits, andesite-dacite lava flows, and subordinate shallow-water sedimentary intercalations (mostly tuffaceous), as described by Rinehart and Ross (1964) and Huber and Rinehart (1965a); see summary by Bateman (1992a, p. 10–13). Deformed during Cretaceous plutonism, sequence now forms steeply west-dipping homoclinal section that extends west to Ritter Range and strikes northwest from south of Mammoth Rock through Minaret Summit, west of caldera rim. Within map area, intruded by major Late Cretaceous plutons Kmo and Krv.

PZms - Metasedimentary rocks of Mount Morrison pendant (Paleozoic)

Deep-water continental-slope and submarine-fan sedimentary deposits of Cambrian through Permian age, moderately metamorphosed during intrusion by plutons of Sierra Nevada batholith in Mesozoic. Assemblage thicker than 7 km consists of calc-silicate and siliceous hornfels, argillite, chert, limestone and marble, siltstone, sandstone, and quartzite, as mapped and described by Rinehart and Ross (1964), Stevens and Greene (1999), and Greene and Stevens (2002). Sequence was coeval with shallow-water continental-shelf and platform deposits now exposed in White-Inyo Mountains to southeast. Assemblage makes up much of south wall of Long Valley caldera; components of it also crop out on west and north walls (Bailey, 1989) and have been penetrated in drill holes deep beneath caldera floor.

Ancillary Source Map Information

The following section presents ancillary source map information associated with source map used for this project.

Eruptive History of Mammoth Mountain and its Mafic Periphery

The formal citation for this source.

> Hildreth, Wes, and Fierstein, Judy, 2016, Eruptive History of Mammoth Mountain and its Mafic Periphery, California: U.S. Geological Survey, Professional Paper 1812, scale 1:24,000 (*GRI Source Map ID 76090*).

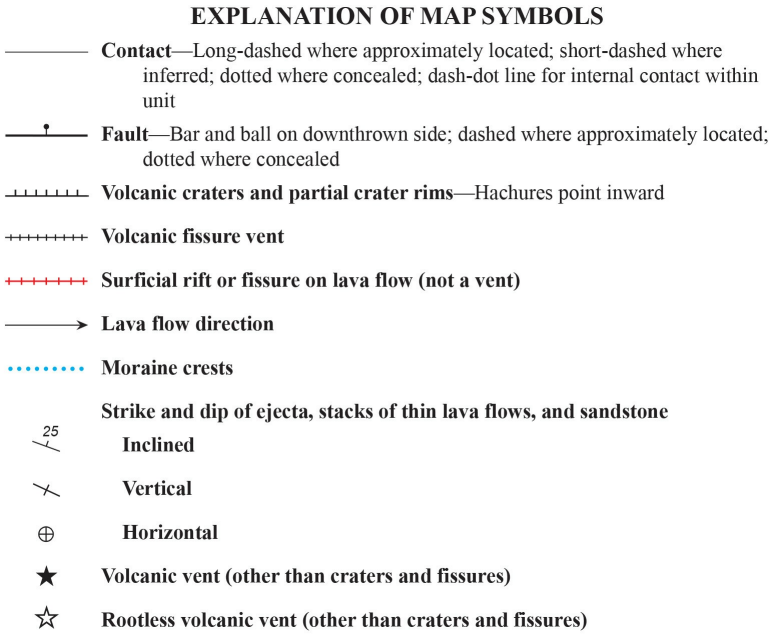
Prominent graphics and pamphlet associated with this source:

Correlation of Map Units

The correlation of map units is available as an embedded document, and is accessible by double-clicking the following link: correlation_of_map_units.pdf

Of note, as the GRI digital geologic-GIS map is of only a portion of the full source map only a subset of units shown on the correlation of map units figure are actually within the extent of the GRI digital geologic-GIS map. Also, units of Quaternary age, Holocene and/or Pleistocene units, are depicted in the correlation of map units figure with their source map unit symbol, and therefore do no have "Q" (add by the GRI to denote Quaternary in age) at the beginning of their unit symbol.

Legend



Graphic from source map: Eruptive History of Mammoth Mountain and its Mafic Periphery

Pamphlet

The pamphlet associated with the source map is available as an embedded document, and is accessible by double-clicking the following link: pp1812_pamphlet.pdf

The pamphlet has information concerning the geologic setting, features, units and processes concerning the mapped area, as well as several figures and tables related to the geologic map including geochronology and geochemistry measurement and locality data tables. As with unit descriptions, as well as the source map's correlation of map units figure, unit symbols within the pamphlet are also reference their source map unit symbol and therefore don't have "Q", added to denote Quaternary units, as is present in the GRI digital geologic-GIS data.

Geochronology and Geochemistry Data

The GRI digital geologic-GIS data contains both geochronology measurement and locality data, as well as geochemistry measurement and locality data. For additional information concerning both types of data users are encouraged to reference the source map's pamphlet.

Source Map Plate Photographs

The following photographs, along with the captions, were present on the two source map plates. These are presented below.

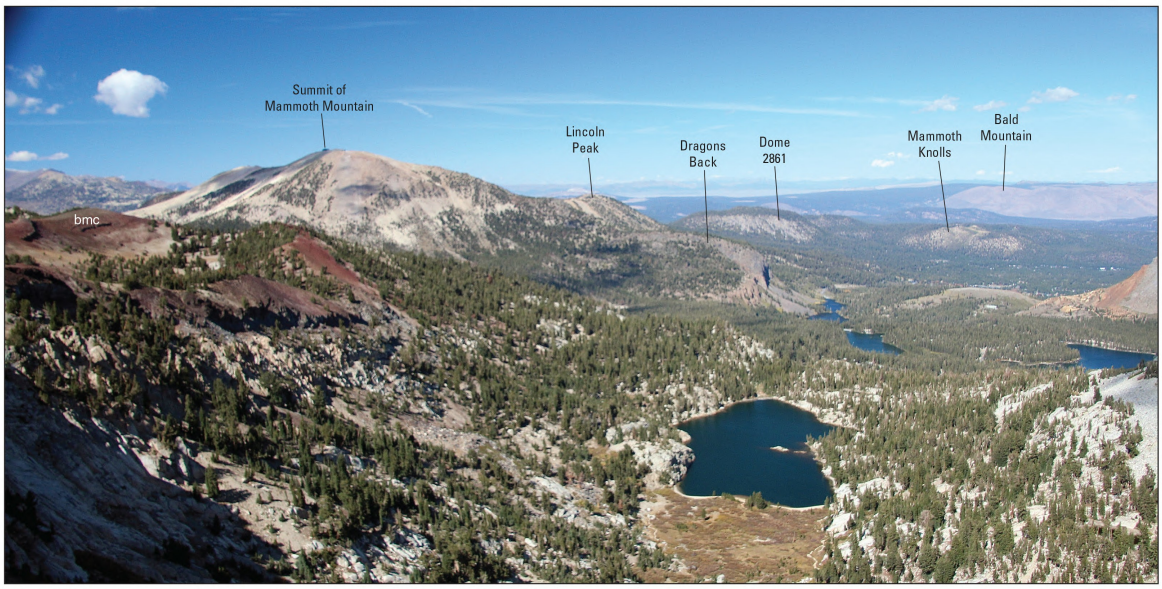
Basaltic Scoria Cone Photograph



Basaltic scoria cone 5 km south-southwest of Mammoth Mountain summit. The cone is 120 m high and 500 m wide and has a twin cone just south of it (see fig. 10). Named Red Cones, the pair erupted concurrently about 8,000 years ago, representing the most recent magmatic eruption of the entire Mammoth system. Both cones are breached to the west, where they jointly formed an agglutinate fan, which fed a lava field that extends 2.5 km southwest. See unit brc in Description of Map Units.

Graphic from source map: Eruptive History of Mammoth Mountain and its Mafic Periphery

Mammoth Mountain and Lakes Basin Photograph



Mammoth Mountain and Lakes Basin, viewed northward from Mammoth Crest. Draping the cirque wall of Cretaceous granite on Mammoth Crest at the left, an eroded red scoria cone (unit bmc) is the source of 92-ka lava flows of phenocryst-rich basalt (unit bfh) that extend 18 km, all the way to Hot Creek. Crystal Lake in foreground. Twin Lakes, at the foot of the Dragons Back coulees of Mammoth Mountain trachydacite, are 750 m lower than the summit of the trachydacite dome complex.

Graphic from source map: Eruptive History of Mammoth Mountain and its Mafic Periphery

Rainbow Falls Photo



Rainbow Falls, 2.5 km downstream from Devils Postpile on the Middle Fork San Joaquin River, drops 30 m over a receding ledge of 99-ka phenocryst-poor trachydacite (unit drf). At the right, on the left-bank rim only, the platy dacite is overlain by a massive flow of 97-ka phenocryst-poor trachyandesite (unit amp). Both units erupted high on the east rim of the canyon at the later site of Mammoth Mountain, descended to the canyon bottom, and flowed along the granitic canyon floor for several kilometers. Both were severely eroded by the Middle Fork glacier during MIS 2 (Tioga glaciation in the Sierra Nevada).

Graphic from source map: Eruptive History of Mammoth Mountain and its Mafic Periphery

GRI Digital Data Credits

This document was developed and completed by Stephanie O'Meara and Shea Slonkosky (Colorado State University) for the NPS Geologic Resources Division (GRD) Geologic Resources Inventory (GRI) Program. Quality control of this document by Ron Karpilo (Colorado State University).

The information in this document was compiled from GRI source maps, and is intended to accompany a digital geologic-GIS map and other digital data for Devils Postpile National Monument, California (DEPO) developed by Stephanie O'Meara and Ronald Karpilo (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 map).

GRI finalization by Stephanie O'Meara.

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