

**National Park Service
U.S. Department of the Interior**



Natural Resource Program Center

Lake Clark National Park and Preserve

Ancillary Map Information Document

Produced to accompany the Geologic Resources Inventory Digital Surficial
Geologic Data for Lake Clark National Park and Preserve

lacl_surficial_geology.pdf

Version: 9/15/2022

Geologic Resources Inventory Map Document for Lake Clark National Park and Preserve

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Geologic Resources Inventory Map Document



Lake Clark National Park and Preserve, Alaska

Document to Accompany Digital Geologic-GIS Data

[lACL_surficial_geology.pdf](#)

Version: 9/15/2022

This document has been developed to accompany the digital surficial geologic-GIS data developed by the Geologic Resources Inventory (GRI) program for Lake Clark National Park and Preserve, Alaska (LACL).

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 Map and Source Map Citations** – A listing of the GRI surficial digital geologic-GIS map produced for this park and preserve along with sources used in its completion. In addition, a brief explanation of how each source map was used is provided.
- 3) **Map Unit List** – A listing of all surficial map units present on the map, listed from youngest to oldest.
- 4) **Map Unit Descriptions** – Descriptions for all surficial map units present on the map.
- 5) **Ancillary Source Map Information** – Additional source map information presented for the source maps. This includes a report, index maps, figures and references.
- 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

Recognizing the interrelationships between the physical (geology, air, and water) and biological (plants and animals) components of the earth is vital to understanding, managing, and protecting natural resources. The Geologic Resources Inventory (GRI) helps make this connection by providing information on the role of geology and geologic resource management in parks.

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 Geologic Resources Inventory aims to raise awareness of geology and the role it plays in the environment, and to provide natural resource managers and staff, park planners, interpreters, researchers, and other NPS personnel with information that can help them make informed management decisions.

The GRI team, working closely with the Colorado State University (CSU) Department of Geosciences and a variety of other partners, provides more than 270 parks with a geologic scoping meeting, digital geologic-GIS map data, and a park-specific geologic report.

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: Park-specific geologic reports identify geologic resource management issues as well as features and processes that are important to park ecosystems. In addition, these reports present a brief geologic history of the park and address specific properties of geologic units present in the park.

For a complete listing of Geologic Resource Inventory products and direct links to the download site visit the GRI publications webpage: http://go.nps.gov/gri_products

GRI geologic-GIS data is also available online at the NPS Data Store Search Application: <http://irma.nps.gov/App/Reference/Search>. 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>, or contact:

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The Geologic Resources Inventory (GRI) program is funded by the National Park Service (NPS) Inventory and Monitoring (I&M) Division.

GRI Digital Map and Source Map Citations

The GRI digital surficial geologic-GIS map for Lake Clark National Park and Preserve, Alaska (LACL) and its source maps:

GRI Digital Surficial Geologic-GIS Map of Lake Clark National Park and Preserve and Vicinity, Alaska (GRI MapCode LACL_surficial)

Wilson, F.H., Bundtzen, T.K., Harvey, J., and Spencer, P., 2009, Quaternary Geologic Map of Lake Clark National Park and Preserve; Western Alaska Range, Alaska, digital data, U.S. Geological Survey, Open File Report 2009-XXXX, scale 1:250,000 ([Quaternary Geologic Map of Lake Clark National Park and Preserve](#))

The source data above was compiled from the following sources listed below. In addition, where available more detailed information and data was derived from the below digital datasets and added to the GRI digital geologic-GIS data.

Wilson, F.H., Bundtzen, T.K., Harvey, J., and Spencer, P., 2009, Quaternary Geologic Map of Lake Clark National Park and Preserve; Western Alaska Range, Alaska: Tyonek 1 x 3 Quadrangle, digital data, U.S. Geological Survey, Open File Report 2009-XXXX, scale 1:250,000. (*GRI Source Map ID 75288*)

Wilson, F.H., Bundtzen, T.K., Harvey, J., and Spencer, P., 2009, Quaternary Geologic Map of Lake Clark National Park and Preserve; Western Alaska Range, Alaska: Lime Hills 1 x 3 Quadrangle, digital data, U.S. Geological Survey, Open File Report 2009-XXXX, scale 1:250,000. (*GRI Source Map ID 75289*)

Wilson, F.H., Bundtzen, T.K., Harvey, J., and Spencer, P., 2009, Quaternary Geologic Map of Lake Clark National Park and Preserve; Western Alaska Range, Alaska: Kenai 1 x 3 Quadrangle, digital data, U.S. Geological Survey, Open File Report 2009-XXXX, scale 1:250,000. (*GRI Source Map ID 75290*)

Wilson, F.H., Bundtzen, T.K., Harvey, J., and Spencer, P., 2009, Quaternary Geologic Map of Lake Clark National Park and Preserve; Western Alaska Range, Alaska: Lake Clark 1 x 3 Quadrangle, digital data, U.S. Geological Survey, Open File Report 2009-XXXX, scale 1:250,000. (*GRI Source Map ID 75291*)

Wilson, F.H., Bundtzen, T.K., Harvey, J., and Spencer, P., 2009, Quaternary Geologic Map of Lake Clark National Park and Preserve; Western Alaska Range, Alaska: Taylor Mountains 1 x 3 Quadrangle, digital data, U.S. Geological Survey, Open File Report 2009-XXXX, scale 1:250,000. (*GRI Source Map ID 75292*)

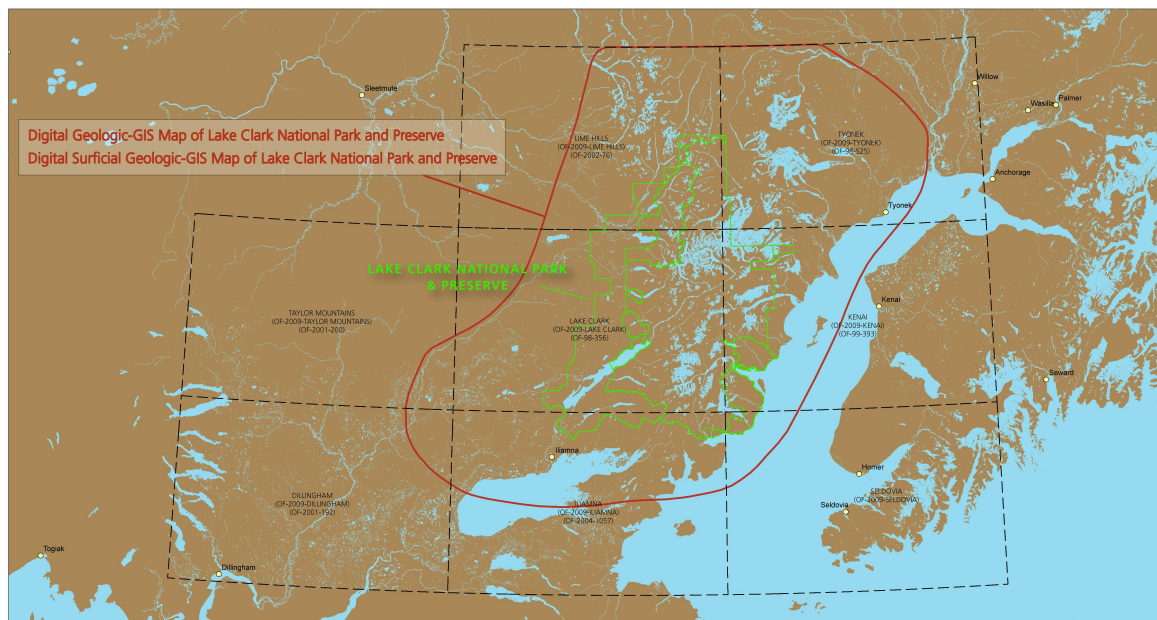
Wilson, F.H., Bundtzen, T.K., Harvey, J., and Spencer, P., 2009, Quaternary Geologic Map of Lake Clark National Park and Preserve; Western Alaska Range, Alaska: Seldovia 1 x 3 Quadrangle, digital data, U.S. Geological Survey, Open File Report 2009-XXXX, scale 1:250,000. (*GRI Source Map ID 75293*)

Wilson, F.H., Bundtzen, T.K., Harvey, J., and Spencer, P., 2009, Quaternary Geologic Map of Lake Clark National Park and Preserve; Western Alaska Range, Alaska: Iliamna 1 x 3 Quadrangle, digital data, U.S. Geological Survey, Open File Report 2009-XXXX, scale 1:250,000. (*GRI Source Map ID 75294*)

Wilson, F.H., Bundtzen, T.K., Harvey, J., and Spencer, P., 2009, Quaternary Geologic Map of Lake Clark National Park and Preserve; Western Alaska Range, Alaska: Dillingham 1 x 3 Quadrangle, digital data, U.S. Geological Survey, Open File Report 2009-XXXX, scale 1:250,000. (*GRI Source Map ID 75295*)

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

The following index map displays the extent of GRI digital geologic-GIS maps for Lake Clark National Park and Preserve. These maps include the Digital Surficial Geologic-GIS Map of Lake Clark National Park and Preserve and Vicinity, as well as the Digital Geologic-GIS Map of Lake Clark National Park and Preserve and Vicinity. Both maps share the same extent. The boundary of Lake Clark National Park and Preserve (as of September, 2022) is displayed in light green. The GRI digital surficial and geologic-GIS maps are defined by the red boundary. The extents and names of relevant 1' x 3' quadrangles are also shown. Surficial 1' x 3' source maps from an unpublished 2009 source are also indicated (see the source citations in this document), as are the relevant 1' x 3' Alaska Resource Data Files (ARDF) sources.



Graphic by Jake Suri, Stephanie O'Meara and Ron Karpilo (Colorado State University).

Map Unit List

The units present in the digital surficial geologic-GIS data produced for Lake Clark National Park and Preserve, Alaska (LACL) are listed below. Units are listed with their assigned unit symbol, unit name and unit age (e.g., g - Glaciers and permanent icefields (Holocene)). Units are generally listed from youngest to oldest. No description for water is provided. Information about each geologic unit is also presented in the Surficial Geologic Unit Information (LACLUNIT) table included with the GRI surficial digital geologic-GIS data.

Cenozoic Era

Quaternary Period

[g](#) - Glaciers and permanent icefields (Holocene)
[Qfa](#) - Artificial fill (Quaternary)
[Qus](#) - Surficial deposits, undivided (Quaternary)
[Qsg](#) - Superglacial drift (Holocene)
[Qal](#) - Alluvium (Holocene)
[Qdr](#) - Drift River mudflows (late Holocene)
[Qhv](#) - Volcanic rocks (Holocene)
[Qvr](#) - Undivided volcanic rocks and deposits (Holocene and late Pleistocene)
[Qrg](#) - Active and recently active rock glacier deposits (late Holocene)
[Qtf](#) - Modern tidal flat and estuarine deposits (Holocene)
[Qnd](#) - Moraines of Neoglacial and modern glaciers (Holocene)
[Qno](#) - Outwash deposits (Holocene)
[Qdf1](#) - Debris flow deposits of North Fork, Crescent River (late Holocene)
[Qdf2](#) - Older debris flow deposits of North Fork, Crescent River (Holocene)
[Qd](#) - Dune deposits (Quaternary)
[Qav](#) - Volcanic avalanche deposits (Holocene)
[Qpd](#) - Pyroclastic deposits (late Holocene)
[Qca](#) - Ash-rich colluvium (Quaternary)
[Qdf](#) - Debris flow and mudflow deposits (Quaternary)
[Qad](#) - Andesite and dacite domes (Quaternary)
[Qld](#) - Lacustrine deposits (Holocene?)
[Qmt](#) - Marine terraces and deposits (Holocene?)
[Qat](#) - Terrace deposits (Quaternary)
[Qlv](#) - Natural levee deposits (Quaternary)
[Qaf](#) - Alluvial fan deposits (Quaternary)
[Qcf](#) - Colluvial-alluvial fan deposits (late Pleistocene to Holocene)
[Qcd](#) - Colluvial deposits, undivided (Quaternary)
[Qtc](#) - Talus cone deposits (Quaternary)
[Qsf](#) - Solifluction deposits (Quaternary)
[Qls](#) - Landslide deposits (Quaternary)
[Qsu](#) - Frozen silt, undifferentiated (Quaternary)
[Qbd](#) - Beach deposits (Quaternary)
[Qsw](#) - Swamp deposits (Quaternary)
[Qao](#) - Older alluvium (Holocene)
[Qes](#) - Estuarine deposits (Quaternary)

Quaternary Period and late Tertiary Period

[QTgu](#) - Glacial deposits, undivided (Quaternary and late Tertiary?)

Quaternary Period

[Qwg](#) - Undifferentiated glacial deposits of late Wisconsin age (late Pleistocene or earliest Holocene?)
[Qwg1](#) - Latest Wisconsin moraine, Iliuk or late Farewell II (latest Pleistocene or earliest Holocene?)
[Qglf](#) - Glaciolacustrine fan deposits (Pleistocene)
[Qgl](#) - Glaciolacustrine deposits (Pleistocene)
[Qwgo](#) - Outwash and ice-contact deposits of late Wisconsin age (late Pleistocene or earliest

Holocene?)

[Qek](#) - Esker and related ice-contact deposits (Pleistocene and Holocene?)

[Qwg2](#) - Late Wisconsin moraine, Newhalen or Farewell II (late Pleistocene or earliest Holocene?)

[Qwg3](#) - Earlier late Wisconsin moraine, Iliamna and older Farewell II (late Pleistocene or earliest Holocene?)

[Qwg4](#) - Oldest Late Wisconsin moraine, Kvichak or earliest Farewell II (late Pleistocene or earliest Holocene?)

[Qac](#) - Abandoned channel deposits and landforms (Pleistocene)

[Qat2](#) - Older terrace deposits (Pleistocene)

[Qgme](#) - Modified glacial deposits (upper Pleistocene)

[Qge](#) - Glacioestuarine deposits (upper Pleistocene)

[Qbc](#) - Bootlegger Cove Formation (upper Pleistocene)

[Qdl](#) - Deltaic deposits (Quaternary)

[Qew](#) - Glacial deposits of probable Early Wisconsin age (upper Pleistocene)

[Qmg](#) - Ground moraine of Mak Hill or Knik age (upper Pleistocene)

[Qewo](#) - Outwash deposits of probable early Wisconsin age (upper Pleistocene)

[Qiu](#) - Older glacial deposits (middle or lower Pleistocene)

[Qio](#) - Older outwash deposits (middle or lower Pleistocene)

Quaternary Period or Tertiary Period

[QTV](#) - Old volcanic rocks, undivided (Pleistocene or Pliocene)

Cenozoic Era to Paleozoic Era

[Qsb](#) - Glacially scoured bedrock (Paleozoic to Cenozoic)

[bu](#) - Undifferentiated bedrock (Paleozoic to Cenozoic)

Map Unit Descriptions

Descriptions of all surficial geologic map units, generally listed from youngest to oldest, are presented below. The 1 x 3 Quadrangle(s) a unit is present on is also listed (see the [GRI Digital Map and Source Map Citations](#) section or the [GRI Ancillary Source Map Information](#) section for additional information on these Quadrangle source maps).

g - Glaciers and permanent icefields (Holocene)

Glacial ice or perennial snowfields as identified from: 1) 1949-56 1:40,000 scale black and white aerial photography for more than 80 percent of the project area; 2) 1979-82 U-2, infrared red, 1:63,360 scale aerial photography for about 15 percent of the study area; and 3) authors notes, photographs, and observations of glacial ice conditions from ground stations occupied during 1988, 1989, 1992- 1994, and 2004. Ice and snow generally occupies cirques ranging in elevation from 1,500 to 1,900 m (4,800 to 6,100 ft) in the southern part of LCNP glaciers reach altitudes approaching 100 m or a feet 100 feet above sea level. Most glaciers in Lime Hills and western-most Tyonek quadrangles have a strong northerly or easterly aspect; in the southern part of LCNP, glacial ice is more abundant and aspect is more variable. On the basis of comparison of 1949-56 air photo data and Bundtzen's field observations since 1988, most glaciers in the northern part of the study area appear to be in retreat. Comparison of similar mid-1950's air photos with 2006 satellite imagery indicated that glaciers in the Lake Clark and western Kenai quadrangles to the south have lost about 13 percent in surface area during that 50 year period (F.H. Wilson and K.A. Labay, unpublished data, 2007). The data from this comparison did not indicate a preferential loss of ice in any quadrant. Unit present on source maps: Tyonek 1 x 3 Quadrangle, Lime Hills 1 x 3 Quadrangle, Kenai 1 x 3 Quadrangle, Lake Clark 1 x 3 Quadrangle, Seldovia 1 x 3 Quadrangle and Iliamna 1 x 3 Quadrangle.

Qfa - Artificial fill (Quaternary)

Artificial fill largely consisting of gravel and boulders at Drift River and West Foreland oil production facilities. Unit present on source map: Kenai 1 x 3 Quadrangle.

Qus - Surficial deposits, undivided (Quaternary)

Mainly unsorted gravel, sand, and silt deposited and reworked by action of wind, water, glaciers, and frost, including solifluction. In many areas of the map, this unit is a mixture of surrounding surficial deposit units that could not be readily sub-divided. In the vicinity of the Drift River delta, this unit contains a significant proportion of volcanic debris derived from mudflows and lahars from Redoubt Volcano. Unit present on source maps: Tyonek 1 x 3 Quadrangle, Kenai 1 x 3 Quadrangle, Lake Clark 1 x 3 Quadrangle, Taylor Mountains 1 x 3 Quadrangle, Seldovia 1 x 3 Quadrangle, Iliamna 1 x 3 Quadrangle and Dillingham 1 x 3 Quadrangle.

Qsg - Superglacial drift (Holocene)

Consists of unsorted boulder to fine-grained debris on the surface of modern glaciers. In the vicinity of Redoubt Volcano and Iliamna Volcano, may include a significant component of ash and other air-fall debris from eruptions. Unit present on source maps: Kenai 1 x 3 Quadrangle, Lake Clark 1 x 3 Quadrangle, Seldovia 1 x 3 Quadrangle and Iliamna 1 x 3 Quadrangle.

Qal - Alluvium (Holocene)

Mainly moderately to well sorted, gravel and sand deposited by modern streams. Consists in part of colluvial, glacial, and glaciofluvial material reworked by postglacial streams. Forms floodplains along major streams and rivers; in smaller first- and second-order streams and gulches consists of coarser grained gravels and sands, with minor admixtures of colluvium. Edges of unit commonly covered by

sphagnum moss, and thickets of willow (*Salix* sp.), alder (*Alnus* sp.), cottonwood (*Populus balsamifera*), and other pioneer species. Unit generally ranges from 3-34 feet (1-10 m) thick. Unit present on source maps: Tyonek 1 x 3 Quadrangle, Lime Hills 1 x 3 Quadrangle, Kenai 1 x 3 Quadrangle, Lake Clark 1 x 3 Quadrangle, Taylor Mountains 1 x 3 Quadrangle, Seldovia 1 x 3 Quadrangle, Iliamna 1 x 3 Quadrangle and Dillingham 1 x 3 Quadrangle.

Qdr - Drift River mudflows (late Holocene)

Deposits composed largely of poorly sorted deposits of silt, sand, and gravel material. Till and others (1993) postulate that these are “derived from the ejection of hot pyroclastic material onto to snow or ice” and then mobilized by melting of the snow and ice and resulting in highly fluid mudflows from the volcano. Till and others (1993) suggested that the Drift River valley mudflows are younger than the Crescent River debris flows, possibly representing 4 to 6 debris flows deposited in the last 2,000 and possibly as recently as the last 200 to 400 years. Till and others (1993) subdivided these into two subunits, and older set of mudflows and mudflows resulting from the Redoubt Volcano eruption of 1966. These are distinguished by internal unit contacts and a pattern on the younger mudflows. Unit present on source map: Kenai 1 x 3 Quadrangle.

Qhv - Volcanic rocks (Holocene)

Volcanic rocks, associated with Iliamna and Redoubt Volcanoes (Till and others, 1993; Waythomas and Miller, 1999) consisting largely of andesitic lava flows and pyroclastic rocks. At Iliamna Volcano Detterman and Hartsock (1966) described light-gray hypersthene-augite andesitic lava flows, breccia, and associated pyroclastic debris and (Nelson and others, 1983) also noted yellowish-gray opaline tuff. Unit present on source maps: Tyonek 1 x 3 Quadrangle, Kenai 1 x 3 Quadrangle, Lake Clark 1 x 3 Quadrangle, Seldovia 1 x 3 Quadrangle and Iliamna 1 x 3 Quadrangle.

Qvr - Undivided volcanic rocks and deposits (Holocene and late Pleistocene)

Consists of volcanic rocks and deposits associated with Iliamna, Redoubt, and Double Glacier Volcanoes. Typically restricted to immediate vicinity of these volcanic centers; however, locally, debris flows and air-fall material may be somewhat distal. Locally subdivided into: Qav, Qpd, Qca, Qhv, Qdf, Qdr, Qdf1, Qdf2 and Qad. Unit present on source maps: Kenai 1 x 3 Quadrangle and Iliamna 1 x 3 Quadrangle.

Qrg - Active and recently active rock glacier deposits (late Holocene)

Chiefly unsorted, angular, frost-shattered rubble and coarse rock debris, that may contain interstitial ice; largely interpreted from air photos. Morainal deposits of Holocene age (see below) may also be transitional into rock glacier deposits, depending on the rock and ice proportion. Rock glacier deposits occur throughout the Alaska Range and Revelation Mountains and uncommonly in the Lyman Hills (usually inactive), but are best developed in areas of the Alaska Range and Revelation Mountains underlain by Upper Jurassic to Lower Cretaceous, turbidite-dominated, sedimentary rocks. In the Lake Clark quadrangle part of LCNP, rock glaciers are common and most common on the west side of the Alaska Range, formed on a variety of bedrock types. In the southernmost part of LCNP, according to Detterman and Reed (1973), “rock glaciers are rare in the Iliamna quadrangle, as the area is near the southern limit at which they form and are preserved. The 5 small rock glaciers mapped in the quadrangle are inactive or nearly so, and probably have been since the Tunnel Stade of the Alaskan Glaciation.” No identifiable Tunnel Stade moraines are associated with these features, suggesting there may not have been enough ice during the Tunnel Stade to form a true glacier (Detterman and Reed, 1973). Unit present on source maps: Tyonek 1 x 3 Quadrangle, Lime Hills 1 x 3 Quadrangle, Kenai 1 x 3 Quadrangle and Lake Clark 1 x 3 Quadrangle.

Qtf - Modern tidal flat and estuarine deposits (Holocene)

Well-sorted, stratified silt and some sand and local gravel deposited in shallow embayments. Unit present on source maps: Tyonek 1 x 3 Quadrangle, Kenai 1 x 3 Quadrangle, Seldovia 1 x 3 Quadrangle and Iliamna 1 x 3 Quadrangle.

Qnd - Moraines of Neoglacial and modern glaciers (Holocene)

Moraine and outwash deposits associated with modern glaciers and glacial remnants. Deposits tend not to be vegetated and to preserve morainal ridge and outwash fan morphology. Detterman and Hartsock (1966) subdivided this unit into two events or stades of the Alaskan Glaciation (Tunnel and Tustumena Stades); that subdivision was not universally possible on this map although in a number of valleys clear evidence of multiple events was visible on the air photos and from observation in the field. Consist of: Youngest till- Fresh, largely unmodified diamicton composed of angular rock debris eroded from cirques and valley walls and deposited immediately in front of active or recently melted glacial ice. Consists of unsorted boulder to clay-size particles. Generally restricted to or just outside of cirques. Terminal positions of these late Holocene advances are well preserved, except where, in some cases, recent alluvial meltwater channels originating from upstream glacial ice have cut through the deposits. Includes deposits of the "Little Ice Age"; organic silt with in-situ root materials at Shamrock Glacier in the southwestern Tyonek quadrangle yielded a radiocarbon age of 109.3 yr BP (Sample 04BT170; Beta Analytic, Inc.). In northern part of map area, the deposits always occupy cirques having a northerly aspect and occur at elevations ranging from 1,460-1,980 m (4,800-to-6,500 feet). Although these deposits are generally confined to cirque basins, they can occur as spatula-shaped debris trains up to 1,820 m (6,000 feet) beyond the terminus of active glaciers. Somewhat older, but probably still Holocene age, deposits were distinguished during mapping in the northern part of LCNP (Bundtzen, unpublished data, 2005). These older deposits may occur as much as 3.5 km down valley from cirque headwalls. In more southerly parts of LCNP the distinction between the two ages of Holocene morainal deposits was generally not mapped, except where Detterman and Hartsock (1966) distinguished the deposits of the Tunnel and Tustumena stades of the Alaskan Glaciation of Karlstrom (1957). Additional mapping may allow correlation of the more northern deposits of this unit with the Tunnel and Tustumena stades. Unit present on source maps: Tyonek 1 x 3 Quadrangle, Lime Hills 1 x 3 Quadrangle, Kenai 1 x 3 Quadrangle, Lake Clark 1 x 3 Quadrangle, Seldovia 1 x 3 Quadrangle and Iliamna 1 x 3 Quadrangle.

Qno - Outwash deposits (Holocene)

Small areas of outwash deposits associated with cirque moraines and larger modern glaciers. Probably consist of poorly to well-sorted silt, sand, and gravel. Unit present on source maps: Tyonek 1 x 3 Quadrangle, Kenai 1 x 3 Quadrangle, Lake Clark 1 x 3 Quadrangle, Seldovia 1 x 3 Quadrangle and Iliamna 1 x 3 Quadrangle.

Qdf1 - Debris flow deposits of North Fork, Crescent River (late Holocene)

Deposits of the youngest, most extensive, and probably most fluid debris flow derived from southwest flank of Redoubt Volcano. Flow was apparently derived from a presently glacier free valley draining south from Redoubt Volcano. The date of 3,500 yrs. BP reported by Riehle and others (1981) may correspond to this deposit, young enough to possibly explain the lack of glaciers in the source valley, as all surrounding valleys have extensive glaciers and glacial deposits. Extends to coast of Cook Inlet and also back flowed up the main fork of the Crescent River, creating Crescent Lake. Unit present on source map: Kenai 1 x 3 Quadrangle.

Qdf2 - Older debris flow deposits of North Fork, Crescent River (Holocene)

Deposits of multiple debris flows off the west and southwest flanks Redoubt Volcano. Oldest(?) deposit is derived from west flank of Redoubt Volcano. Next oldest deposit appears derived from a presently

glaciated valley draining to the southwest of Redoubt Volcano. These deposits are of relatively limited extent. They may have dammed the North Fork of the Crescent River, creating a temporary lake in the valley. Unit present on source map: Kenai 1 x 3 Quadrangle.

Qd - Dune deposits (Quaternary)

Well-sorted, irregularly cross-bedded sand and silt transported and deposited by wind. Form active and stabilized dunes on outwash plains and raised beaches. Areas of dune formation and preservation include forms ranging from sandur to local barchan dunes. Bundtzen and Jorgenson (2005) reported cliff exposures along Swift River, in upland areas west of Lime Village, and on an unnamed tributary of Stony River south of VABM Toklat. Dunes are only about 20 feet (6 m) in maximum height, well-drained. Radiocarbon ages indicate regional loess deposition at 1,800-2,450 B.P. in the western part of the Park; however, in most instances the loess is relatively thin (<80 cm) and not shown on the map (Bundtzen and Jorgenson, 2005) product of this study (Bundtzen and Jorgenson (2005). Unit present on source maps: Lime Hills 1 x 3 Quadrangle, Iliamna 1 x 3 Quadrangle and Dillingham 1 x 3 Quadrangle.

Qav - Volcanic avalanche deposits (Holocene)

Recent volcanic avalanche deposits consisting of poorly sorted mixture of angular sand, cobbles, and boulders derived from Iliamna Volcano (Waythomas and Miller, 1999). All deposits contain clasts of gray andesitic lava and yellow-orange hydrothermally altered rocks. Estimated age is less than 1,000 years and some may be historic, < 200 years. Unit present on source maps: Kenai 1 x 3 Quadrangle and Iliamna 1 x 3 Quadrangle.

Qpd - Pyroclastic deposits (late Holocene)

Equivalent to Johnson Glacier dome tephra deposits of Waythomas and Miller (1999). Consists of pumiceous lapilli tephra exposed at the head of Lateral Glacier on the northeast side of Iliamna Volcano. Waythomas and Miller (1999) correlate these deposits with dated volcanic ash deposits on the Kenai Peninsula and suggested an age of about 4,000 yr B.P. Unit present on source map: Lake Clark 1 x 3 Quadrangle.

Qca - Ash-rich colluvium (Quaternary)

Consists of tephra-rich colluvium in the vicinity of and west of Redoubt Volcano. These deposits probably consist of ash- to block-sized pyroclasts; on the flanks of Redoubt Volcano, these deposits mantle and are incorporated in deposits that reflect Holocene glaciation. West of the volcano, they mantle bedrock and older glacial deposits. East of the volcano, they apparently cover one long low ridge- this is apparently an erosional remnant as other ridges to the east do not seem to have these deposits. Interpreted from air-photos. *Unit present on source maps:* Tyonek 1 x 3 Quadrangle and Kenai 1 x 3 Quadrangle.

Qdf - Debris flow and mudflow deposits (Quaternary)

Consist of unsorted silt, sand, and cobble to boulder-sized deposits primarily of volcanic origin interpreted as lahar deposits by Riehle and others (1981) and as debris flow deposits by Till and others (1993). An important location for these is in the Crescent River valley, south of Redoubt Volcano. Radiocarbon dating by Riehle and others (1981) indicate that the stratigraphically lowest of the deposits in the Crescent River valley that they could sample is approximately 3,500 years old (uncorrected radiocarbon date). According to Riehle and others (1981), additional lahars flowed down the north flank of Redoubt Volcano at the same time as the Crescent River lahars. Begét and Nye (1994) described an extensive deposit they termed the Harriet Point debris avalanche in the valley of Redoubt Creek on the east side of Redoubt Volcano. They described it as consisting of angular

volcanic rock cobbles and boulders dispersed in an unconsolidated matrix of coarse sand and granule-sized debris and containing zones of finer-grained material. Isolated voids and open zones are found between many clasts and are characteristic of zones of coarser material. The deposit has been eroded away in the upper part of the valley but is well exposed along the coast around Harriet Point. Available age control suggests the Harriet Point deposit is between 10,500 and post-glacial (Begét and Nye (1994) estimated 13,000 yr B.P.) or latest Pleistocene to earliest Holocene. Lahars of the 1966 Redoubt Volcano eruption flowed down the same northern valleys as the older lahars (Riehle and others, 1981). Includes lahar deposits of late Holocene age mapped by Waythomas and Miller (1999) related to Iliamna Volcano and part of unit Qls. Deposits of mass wasting – landslide deposits of Riehle and Emmel (1980) where this unit consists of debris flows from Redoubt Volcano. Unit also includes an apparent debris flow deposit of upper Crescent River valley. These unusual deposits emanate from valley on east side of Crescent River valley. Source valley is along extension of a normal fault trending to the northeast and having apparent Holocene motion. These deposits have not been examined on the ground and probably are non-volcanogenic. Locally subdivided into: Qdr, Qdf1, and Qdf2. Unit present on source maps: Tyonek 1 x 3 Quadrangle, Kenai 1 x 3 Quadrangle and Lake Clark 1 x 3 Quadrangle.

Qad - Andesite and dacite domes (Quaternary)

Dome complexes of Double Glacier Volcano and Johnson Glacier dome complex of Iliamna Volcano. Composite dome complex of Double Glacier Volcano consists of medium- to coarsely porphyritic hornblende andesite and dacite. Three K-Ar andesite whole-rock ages were determined on these domes, two are considered minimum ages at 627 ± 24 and 763 ± 17 ka (sample 78AR 290) and one (sample 90AR 99), yielded 887 ± 15 ka (Reed and others, 1992, table 1 here). Also includes the Johnson Glacier dome complex of Iliamna Volcano, which was described as an assemblage of nested lava domes, most likely andesitic (Waythomas and Miller, 1999). Waythomas and Miller (1999) suggested that these domes represent the site of eruptive activity 4,000 to 5,000 years ago. Unit present on source maps: Kenai 1 x 3 Quadrangle and Lake Clark 1 x 3 Quadrangle.

Qld - Lacustrine deposits (Holocene?)

Well-sorted, well-stratified, commonly varved clay, silt, and fine-sand deposited in ephemeral glacial and postglacial lakes. Thought to be typically covered by several feet of muck and peat. Unit present on source maps: Tyonek 1 x 3 Quadrangle, Lime Hills 1 x 3 Quadrangle, Kenai 1 x 3 Quadrangle, Iliamna 1 x 3 Quadrangle and Dillingham 1 x 3 Quadrangle.

Qmt - Marine terraces and deposits (Holocene?)

Uplift along Cook Inlet has produced terraces containing beach deposits and wave-cut bedrock platforms. Wave-cut platforms are well developed 90 and 50 feet above modern sea level; beach deposits overlie these platforms. Lower and younger beach ridges are found below the 50-foot level. Unit present on source maps: Kenai 1 x 3 Quadrangle and Iliamna 1 x 3 Quadrangle.

Qat - Terrace deposits (Quaternary)

Moderately to well sorted, gravel, sand, and silt forming terraces adjacent to and above modern floodplains. Unit ranges from 3-12 m (10-40 feet) thick above active river floodplains. Locally mapped subdivision: Qat2. Unit present on source maps: Tyonek 1 x 3 Quadrangle, Lime Hills 1 x 3 Quadrangle, Kenai 1 x 3 Quadrangle, Lake Clark 1 x 3 Quadrangle, Taylor Mountains 1 x 3 Quadrangle, Iliamna 1 x 3 Quadrangle and Dillingham 1 x 3 Quadrangle.

Qlv - Natural levee deposits (Quaternary)

Natural levee or overbank deposits on deltaic or fan delta deposits. Found along Cook Inlet coast, especially in the vicinity of Bachatna Flats. Unit present on source map: Kenai 1 x 3 Quadrangle.

Qaf - Alluvial fan deposits (Quaternary)

Generally poorly sorted, partially stratified, gravel, sand, and silt, in fan-shaped deposits. Commonly deposited at mouth of small tributary canyons to main drainages. Includes some colluvial deposits; in the northern part of LCNP, in fan deposits where the colluvial component becomes more significant, unit is subdivided into: Qcf. Unit present on source maps: Tyonek 1 x 3 Quadrangle, Lime Hills 1 x 3 Quadrangle, Kenai 1 x 3 Quadrangle, Lake Clark 1 x 3 Quadrangle, Taylor Mountains 1 x 3 Quadrangle, Seldovia 1 x 3 Quadrangle, Iliamna 1 x 3 Quadrangle and Dillingham 1 x 3 Quadrangle.

Qcf - Colluvial-alluvial fan deposits (late Pleistocene to Holocene)

Poorly to moderately sorted, silt, sand, and gravel in alternating stratified and unstratified zones and lenses in gullies and fan-shaped slopes along edges of mountain fronts. Qca unit on steep slopes of mountainous terrane is a series of many small fans carrying alluvial and colluvial debris down slope to third order valley floors. Qcf unit is transitional variant of Qaf deposits and contains, on the average, 10-40 percent colluvium, and 60-90 percent alluvium. Unit thickness is highly variable and is estimated to range from 10 to 100 m (34 to 330 ft) thick. Undated but probably ranges from Late-Pleistocene to Holocene in age. Unit not mapped separately in southern part of LCNP. Unit present on source maps: Lime Hills 1 x 3 Quadrangle and Iliamna 1 x 3 Quadrangle.

Qcd - Colluvial deposits, undivided (Quaternary)

Unsorted to poorly sorted, fine to coarse grained, rubble, gravel, sand, silt, and clay. Composed of gravity-transported angular bedrock-derived debris derived from frost-riven disintegration of bedrock below steep slopes and fine-to-coarse-grained colluvium covered by vegetation and thin, fine-grained eolian sheets. Consists of talus, solifluction, and other slope debris deposits; also locally includes alluvium of minor streams, and glacial, rock glacier, and other mass-wasting deposits. On steep slopes of U-shaped valleys in Alaska Range includes reworked glacial drift and locally grades into glacial deposits. Commonly frozen in Lime Hills and western Tyonek quadrangles. Locally subdivided into: Qtc. Unit present on source maps: Tyonek 1 x 3 Quadrangle, Lime Hills 1 x 3 Quadrangle, Kenai 1 x 3 Quadrangle, Lake Clark 1 x 3 Quadrangle, Taylor Mountains 1 x 3 Quadrangle, Seldovia 1 x 3 Quadrangle, Iliamna 1 x 3 Quadrangle and Dillingham 1 x 3 Quadrangle.

Qtc - Talus cone deposits (Quaternary)

Angular debris derived from frost riving of bedrock followed by rapid gravity transport on steep slopes, cirque headwalls, steep gullies, and avalanche chutes. The characteristic landform is a cone or apron- or a series of cones and aprons "stitched" to each other, and situated near or at angle of repose along a steep slope. Distal ends may transition into ice-rich rock glacier deposits. Unit present on source maps: Lime Hills 1 x 3 Quadrangle, Lake Clark 1 x 3 Quadrangle and Iliamna 1 x 3 Quadrangle.

Qsf - Solifluction deposits (Quaternary)

Solifluction mantle, consisting of poorly sorted rock rubble, gravel, sand, silt, clay, and organic deposits derived from local upslope sources. Unit present on source maps: Kenai 1 x 3 Quadrangle, Lake Clark 1 x 3 Quadrangle and Iliamna 1 x 3 Quadrangle.

Qls - Landslide deposits (Quaternary)

Chiefly rubble, gravel, sand, silt, and clay. Consisting of chaotically deformed colluvium and near-surface bedrock derived from catastrophic mass movement of bedrock or surficial deposits along planes of failure. Deposits are characteristically hummocky and lack integrated drainage. Recent landslide deposits show surface disturbances such as randomly tilted trees, and disrupted vegetation mats. Most extensive north of Turquoise Lake where 3 large slumps as much as 2 km wide have been mapped. Unit present on source maps: Tyonek 1 x 3 Quadrangle, Lime Hills 1 x 3 Quadrangle, Kenai 1 x 3 Quadrangle, Lake Clark 1 x 3 Quadrangle, Seldovia 1 x 3 Quadrangle and Iliamna 1 x 3 Quadrangle.

Qsu - Frozen silt, undifferentiated (Quaternary)

Frozen silt, undifferentiated. Unit present on source maps: Tyonek 1 x 3 Quadrangle and Lime Hills 1 x 3 Quadrangle.

Qbd - Beach deposits (Quaternary)

Well-sorted sand and gravel on shores of major lakes, especially along Lake Clark and along shore of Cook Inlet where silt is more common. Elevated beach ridges of well-sorted, well-stratified, and well-drained sand and gravel occur locally along Cook Inlet coast (Detterman and Hartsock, 1966; Riehle and Emmel, 1980). Unit present on source maps: Kenai 1 x 3 Quadrangle, Lake Clark 1 x 3 Quadrangle, Taylor Mountains 1 x 3 Quadrangle, Seldovia 1 x 3 Quadrangle and Iliamna 1 x 3 Quadrangle.

Qsw - Swamp deposits (Quaternary)

Silt, sandy silt, and peaty bog deposits. May in part represent old lake beds. Unit present on source maps: Kenai 1 x 3 Quadrangle, Lake Clark 1 x 3 Quadrangle, Iliamna 1 x 3 Quadrangle and Dillingham 1 x 3 Quadrangle.

Qao - Older alluvium (Holocene)

Older alluvial deposits found in larger stream valleys at levels higher than modern alluvium. Also includes overbank deposits composed of interbedded, dark brown to gray, organic-rich, micaceous sand and silt ranging from 3-34 feet (1-10 m) thick. Over-bank deposits are flood cycles consisting of rhythmically bedded silt layers up to 6 feet (2 m) thick. Unit mainly forms in broad, inter-channel areas. Unit is most likely of Holocene age. Grades into terrace deposits of unit Qat. Unit present on source map: Lime Hills 1 x 3 Quadrangle.

Qes - Estuarine deposits (Quaternary)

Well-sorted, stratified silt and some sand deposited in shallow embayments, supra-tidal, hence probably uplifted. Also includes glacioestuarine deposits related to the Pleistocene history of the Cook Inlet basin. Unit present on source maps: Tyonek 1 x 3 Quadrangle, Kenai 1 x 3 Quadrangle, Seldovia 1 x 3 Quadrangle and Iliamna 1 x 3 Quadrangle.

QTgu - Glacial deposits, undivided (Quaternary and late Tertiary?)

Undifferentiated glacial and related deposits consisting of silt sand, gravel, and boulders. Includes end and recessional moraine deposits as well as ground moraine. Also, locally includes colluvium and talus, landslide debris, alluvium, and wind-blown silt. Locally subdivided into: Qsg, Qrg, Qnd, Qno, Qwg, Qwg1, Qwg2, Qwg3, Qwg4, Qwgo, Qek. Unit present on source maps: Lime Hills 1 x 3

Quadrangle, Kenai 1 x 3 Quadrangle, Lake Clark 1 x 3 Quadrangle and Dillingham 1 x 3 Quadrangle.

Qwg - Undifferentiated glacial deposits of Late Wisconsin age (late Pleistocene or earliest Holocene?)

Includes morainal deposits of all types. Can generally be correlated with the Brooks Lake glaciation of Late Wisconsin age (Detterman and Reed, 1973; Detterman, 1986) or the Farewell II Glaciation (Fernald, 1960; Kline and Bundtzen, 1986). Deposits are progressively more modified by weathering and erosion to the southeastward and locally divided into the deposits of four events. Because age control is largely lacking, some glacial deposits assigned to this event may be of earliest Holocene age. Local subdivisions used herein are: Qwg1, Qwg2, Qwg3, and Qwg4. Unit present on source maps: Tyonek 1 x 3 Quadrangle, Lime Hills 1 x 3 Quadrangle, Kenai 1 x 3 Quadrangle, Lake Clark 1 x 3 Quadrangle, Seldovia 1 x 3 Quadrangle and Iliamna 1 x 3 Quadrangle.

Qwg1 - Latest Wisconsin moraine, Iliuk or late Farewell II (latest Pleistocene or earliest Holocene?)

End and ground moraine deposits best correlated with the Iliuk advance (Detterman and Reed, 1973) of the Brooks Lake glaciation. Consist of poorly sorted, clay, silt, sand, and diamicton. Clast compositions are variable and largely reflect local source areas. Tend to be restricted to glacially carved valleys within the mountains, reaching the mountain front or slightly beyond. However, along a 32-km-wide (20 mi) front on the western slopes of the Revelation Mountains, some of the broad, piedmont-shaped surface is covered by relatively fresh glacial till having terminal ice positions nearly 18 km (12 mi) downstream from cirque headwall source areas to the east, these deposits have been suggested by Bundtzen to be of earliest Holocene age. In the Lake Clark quadrangle, moraine of this event partially constrains Twin Lakes; in the vicinity of Lake Clark and southward, deposits of this event tend to reflect smaller alpine glaciers rather than outflows from large ice sheets. Little eroded; therefore these deposits control drainage patterns. Small kettle lakes are common; mapping in the northern part of LCNP by Bundtzen indicates 12-30 kettles per square km. Bundtzen estimates the deposits of this event range from 3 to 53 m (10 to 175 ft) thick, with the thickest portions exposed in terminal ice positions. Locally, there is a prominent transition outward to outwash deposits. In the eastern part of LCNP, there generally are no prominent moraine deposits associated with this event. Unit present on source maps: Tyonek 1 x 3 Quadrangle, Lime Hills 1 x 3 Quadrangle, Kenai 1 x 3 Quadrangle, Lake Clark 1 x 3 Quadrangle and Iliamna 1 x 3 Quadrangle.

Qglf - Glaciolacustrine fan deposits (Pleistocene)

Consist of unconsolidated material in well-developed fan-shaped deposits in glaciolacustrine lakes. Particularly well-developed on the Koksetna River south of Mesa Mountain and north of Lake Clark (Wilson, 2006); however, recent fieldwork suggests these deposits may represent till from a glacier that terminated in the lake. Unit present on source maps: Lake Clark 1 x 3 Quadrangle and Iliamna 1 x 3 Quadrangle.

Qgl - Glaciolacustrine deposits (Pleistocene)

Low-lying, swampy deposits in basins generally surrounded by morainal ridges. Likely well-sorted, well-stratified clay, silt, sand, and gravel including varved silt and sand layers. Locally, incised shorelines are present. Deposited in ephemeral glacial and postglacial lakes. Typically covered by several feet of muck and peat. Most of the lakes these deposits represent were probably short-lived and drained once the moraine ridges were breached or other drainage pathways developed (Wilson, 2006). Recognized from aerial photography by Wilson and Bundtzen and from limited fieldwork in 1992-1993 by Bundtzen on the basis of shoreline deposits, delta front deposits, and planar distribution of landforms, generally behind terminal ice positions. One radiocarbon age of 6,210 BP (Sample 04BT172B, Beta 67665) from organic-rich varved silt indicates early Holocene lake impoundment behind a Late Wisconsin moraine

in Swift River basin. Unit present on source maps: Tyonek 1 x 3 Quadrangle, Lime Hills 1 x 3 Quadrangle, Kenai 1 x 3 Quadrangle, Lake Clark 1 x 3 Quadrangle, Taylor Mountains 1 x 3 Quadrangle and Iliamna 1 x 3 Quadrangle.

Qwgo - Outwash and ice-contact deposits of Late Wisconsin age (late Pleistocene or earliest Holocene?)

Stratified gravel and sand of outwash aprons and plains generally showing graded surfaces and multiple well-developed distributary channels. The most extensive surfaces tend to be associated with unit wg4. Typically forms well-drained, moderately hummocky surfaces of low relief and varies from 3 to 50 m (10 to 160 ft) thick. Locally, may include undifferentiated drift. In northern part of LCNP, unit may include areas of permafrost, unit may also be blanketed by a thin veneer of eolian loess in lowland areas. Data collected by T.K. Bundtzen and Torre Jorgenson in the northern part of LCNP suggests glacial-fluvial sediments comprise 65-80 percent of unit whereas the "ice-contact" deposits comprise 20-35 percent of the total. Also includes outwash fans and their dissected remnants of exposed on terraces and benches from 8 to 76 m (25 to 250 feet) above modern floodplains. Drumlin deposits- Drumlin and roche moutonnée deposits and land forms in ground moraine fields of Brooks Lake glacial deposits, only shown on southern part of map. Unit present on source maps: Tyonek 1 x 3 Quadrangle, Lime Hills 1 x 3 Quadrangle, Kenai 1 x 3 Quadrangle, Lake Clark 1 x 3 Quadrangle, Taylor Mountains 1 x 3 Quadrangle, Iliamna 1 x 3 Quadrangle and Dillingham 1 x 3 Quadrangle.

Qek - Esker and related ice-contact deposits (Pleistocene and Holocene?)

Stratified sand and gravel deposited on, against, or under stagnant masses of glacial ice by meltwater streams. Esker, kame, and kettle terraces are most common geomorphic features recognized from aerial photography; in the southern part of LCNP, only esker deposits are included in this unit, which are typically associated with older glacial deposits. Individual layers within the deposits may be extremely variable in lateral extent, degree of sorting, and thickness. Unit ranges in age from late Pleistocene to Holocene, most deposits observed in map area are judged to be late Pleistocene in age. Where observed in field, deposits range from 1.5 to 30 m (5 to 100 feet) thick and are well drained. Unit present on source maps: Lime Hills 1 x 3 Quadrangle and Lake Clark 1 x 3 Quadrangle.

Qwg2 - Late Wisconsin moraine, Newhalen or Farewell II (late Pleistocene or earliest Holocene?)

Unsorted to poorly sorted, clay, silt, sand, gravel and diamicton. Consists of prominent moraines that are not dissected by small second and third order streams, but cut by major rivers such as the Swift, Stony, Big, and Newhalen Rivers. Along the Big River, the terminal ice position is marked by a prominent granitic boulder field in a restricted 6 to 7-km-long (4mi) canyon, about 12 km (8 mi) below the confluence of Lyman Fork and Big River. Distinctive lateral moraines ranging from 490 to 670 m (1,600 to 2,400 ft) in elevation reflect this event in the valleys of Stony, Swift, and Big Rivers as they exit the mountain front. A large pro-glacial lake deposit is found up-valley of moraine in the valley of Stony River; the 19 to 22-km-long (12 to 14 mi), ancestral lake is centered on the mouth of the Telequana River where it enters Stony River. End or recessional moraine deposits from this event form the dams that retain the waters of Turquoise Lake and partially of Lake Telequana, as well as the westernmost of the Twin Lakes. Correlates with the Newhalen advance of the Brooks Lake glaciation (Detterman and Reed, 1973) and as mapped by Bundtzen, the undivided deposits of the Farewell II glaciation. Small kettle lakes are common and there is a prominent transition outward to outwash deposits. Unit present on source maps: Lime Hills 1 x 3 Quadrangle, Kenai 1 x 3 Quadrangle, Lake Clark 1 x 3 Quadrangle and Iliamna 1 x 3 Quadrangle.

Qwg3 - Earlier late Wisconsin moraine, Iliamna and older Farewell II (late Pleistocene or earliest Holocene?)

Unsorted to poorly sorted, clay, silt, sand, gravel and diamicton found in moderately modified morainal deposits that reflect a major glacial advance Late Wisconsin time. Moraine ridges are dissected by small second and third order streams; and extensively eroded by the Swift, Stony, and Big Rivers. Moraines, which in the northern part of LCNP contain 2-7 kettles per km², still retain prominent arcuate fronts with significant outwash gravel deposits positioned below the often reworked moraine edges. Within LCNP limits, deposits of this event are only subtly different than deposits of the next oldest event (wg4) and in the northern part of LCNP, the deposits of this and the maximum LGM event, wg4, are not separately mapped. South and west of LCNP limits, these two deposits become more distinctive, where the younger of the deposits forms the present-day limit of Lake Iliamna and the older deposits form the boundary of a larger ancestral Lake Iliamna. In the southern part of LCNP and southward these deposits are correlated with the Iliamna advance of the Brooks Lake Glaciation (Detterman and Reed, 1973). Small remnant kettle lakes are common and there is a prominent transition outward to outwash deposits. In the northern part of LCNP, deposits of this and the slightly older event, equivalent to the Kvichak advance of the Brooks Lake glaciation have not been mapped separately; they are lumped together as the oldest Farewell II deposits. Unit present on source maps: Lime Hills 1 x 3 Quadrangle, Kenai 1 x 3 Quadrangle, Lake Clark 1 x 3 Quadrangle, Taylor Mountains 1 x 3 Quadrangle and Iliamna 1 x 3 Quadrangle.

Qwg4 - Oldest Late Wisconsin moraine, Kvichak or earliest Farewell II (late Pleistocene or earliest Holocene?)

Deposits of this advance are found largely outside of LCNP boundary; nonetheless they reflect maximum extent of the Last Glacial Maximum in this area. As with the other glacial deposits, these consist of unsorted to poorly sorted diamicton found as ground moraine and in prominent terminal and recessional moraines. Whitefish Lake, west of LCNP is bounded by deposits of this event and it forms a prominent set of morainal ridges along the northern Mulchatna River south of Whitefish Lake. In the northern part of LCNP and map area, the bulk of the deposits of this unit have been overridden by younger outwash behind the leading edges of the terminal positions. Lateral moraines associated with this unit form about 150 to 200 m (500 to 800 ft) higher in elevation than lateral moraines of wg3 age. Small kettle lakes are common and there is a prominent transition outward to outwash deposits. Typically there are one or more prominent ridges associated with this advance. These deposits tend to be associated with extensive outwash fans which may reflect this and the next younger advance. This unit is best correlated with the Kvichak advance of the Brooks Lake Glaciation (Detterman and Reed, 1973), the earliest record and maximum extent of the LGM. This unit is also equivalent to the oldest Farewell II Glaciation deposits in the McGrath quadrangle to the north (Kline and Bundtzen, 1986; Bundtzen and others, 1997). Unit present on source maps: Lime Hills 1 x 3 Quadrangle, Lake Clark 1 x 3 Quadrangle, Taylor Mountains 1 x 3 Quadrangle, Iliamna 1 x 3 Quadrangle and Dillingham 1 x 3 Quadrangle.

Qac - Abandoned channel deposits and landforms (Pleistocene)

Gravel, sand, and silt originally deposited as alluvial deposits. Also abandoned channel landforms, primarily meltwater channels that indicate drainage routes resulting from the melting of massive Pleistocene glaciers. Cut older surficial deposits and commonly the landforms contain small lakes or underfit streams. Arrow symbol indicates inferred direction of water flow. Unit present on source maps: Tyonek 1 x 3 Quadrangle, Lime Hills 1 x 3 Quadrangle, Kenai 1 x 3 Quadrangle, Lake Clark 1 x 3 Quadrangle, Taylor Mountains 1 x 3 Quadrangle, Iliamna 1 x 3 Quadrangle and Dillingham 1 x 3 Quadrangle.

Qat2 - Older terrace deposits (Pleistocene)

Gravel, sand, silt forming higher-level terraces above younger terraces on modern floodplains; generally confined to major third and fourth order stream valleys. Locally transitions to outwash deposits and locally could be equivalent to outwash gravel terrace deposits. Unit present on source maps: Lake Clark 1 x 3 Quadrangle, Taylor Mountains 1 x 3 Quadrangle and Dillingham 1 x 3 Quadrangle.

Qgme - Modified glacial deposits (upper Pleistocene)

Consist of glacial deposits modified by estuarine or lacustrine processes. Deposits originally most likely associated with Last Glacial Maximum (Naptowne?) and (or) Knik glacial advances; however, includes terraced deposits mapped by Karlstrom (1964) as Eklutna in age. Well-defined moraine morphology either not developed due to deposition in water or has been modified by later submergence. Deposits consist of a variety of interbedded materials including diamicton, gravel, stony silt, silt, fine-grained sand, and some clay and that generally have much fine-grained material. Winnowing of diamicton clasts and a cover of better sorted materials locally observed. Locally includes moraine reworked into drumlin-like forms. Unit present on source maps: Tyonek 1 x 3 Quadrangle and Lake Clark 1 x 3 Quadrangle.

Qge - Glacioestuarine deposits (upper Pleistocene)

Chiefly well-bedded and sorted, medium to coarse sand, includes some interbeds of fine gravel. Probably deposited as a cover sand during waning phases of glacioestuarine environment in which underlying Bootlegger Cove Formation was deposited. Includes Hood Lake deposits of Schmoll and others (1999). Commonly overlain by peat that may be more than 1 m thick over large areas. Thickness of deposits is as much as 10 m, but locally much thinner or even absent where surface peat directly overlies Bootlegger Cove Formation. Includes some abandoned beach ridges that rise a few meters above surrounding plain. Unit present on source map: Tyonek 1 x 3 Quadrangle.

Qbc - Bootlegger Cove Formation (upper Pleistocene)

Silty clay and clayey silt containing minor interbedded silt, fine to medium sand, and thin beds of diamicton, and containing scattered pebbles and cobbles in widely varying concentrations (Updike and others, 1988). Miller and Dobrovolsky (1959) defined the unit as the Bootlegger Cove Clay and considered the deposit of glaciolacustrine origin, as did Karlstrom (1964) except for one shell-bearing marine horizon. Established as glacioestuarine in origin throughout the exposed formation by Schmidt (1963). Radiocarbon ages of 14,000 to 16,500 years B.P. reported from shells at Anchorage by Schmoll and others (1972) and by Reger and others (1995) from shells near Kenai. Thickness as much as 35 m at type area in Anchorage (Updike and others, 1988), but poorly known in the Susitna River and Yentna River region (Tyonek quadrangle) where only small outcrops along those rivers have been observed. However, thought to be widely extensive beneath cover sand deposits. Unit present on source map: Tyonek 1 x 3 Quadrangle.

Qdl - Deltaic deposits (Quaternary)

Deltaic deposits, including outwash and alluvial deposits (F.H. Wilson, unpublished data, 2007); include deposits in hanging deltas marginal to glacial lakes and the ancestral Cook Inlet glacial-estuary. Unit present on source maps: Tyonek 1 x 3 Quadrangle and Kenai 1 x 3 Quadrangle.

Qew - Glacial deposits of probable Early Wisconsin age (upper Pleistocene)

Glacial moraine deposits correlated with Mak Hill advance of the Alaska Peninsula or Farewell Bend advance of southwestern Alaska. Age control is lacking; however, Detterman (1986) reports a

radiocarbon date suggesting a minimum age of 40 ka for similar deposits of the Mak Hill glaciation on the Alaska Peninsula. Consists of a number of prominent end moraine deposits and limited ground moraine. Largely consists of end moraine deposits, composed chiefly of gravelly till. Unit present on source maps: Tyonek 1 x 3 Quadrangle, Lime Hills 1 x 3 Quadrangle, Lake Clark 1 x 3 Quadrangle, Taylor Mountains 1 x 3 Quadrangle, Iliamna 1 x 3 Quadrangle and Dillingham 1 x 3 Quadrangle.

Qmg - Ground moraine of Mak Hill or Knik age (upper Pleistocene)

Consists of ground moraine, includes some organic and lacustrine material. Unit present on source maps: Lime Hills 1 x 3 Quadrangle, Lake Clark 1 x 3 Quadrangle, Taylor Mountains 1 x 3 Quadrangle, Iliamna 1 x 3 Quadrangle and Dillingham 1 x 3 Quadrangle.

Qewo - Outwash deposits of probable Early Wisconsin age (upper Pleistocene)

Stratified gravel and sand of outwash aprons and plains. May include ground moraine of older glacial advances. Unit present on source maps: Lime Hills 1 x 3 Quadrangle, Lake Clark 1 x 3 Quadrangle, Taylor Mountains 1 x 3 Quadrangle, Iliamna 1 x 3 Quadrangle and Dillingham 1 x 3 Quadrangle.

Qiu - Older glacial deposits (middle or lower Pleistocene)

Prominent, but modified morainal deposits of Eklutna glaciation of Karlstrom (1964) and Johnson Hill drift and older deposits of Detterman (1986). Occur on relatively flat lying to sloping surfaces on some lower mountains where diamicton may be somewhat weathered and subjected to minor gravitational reworking. Probably no more than a few meters to 10 m thick. Flat surfaces containing bedrock rubble and scattered glacial erratic cobbles and small boulders, occur at highest elevations, notably on Mount Susitna. Includes pebble- and boulder-bearing diamicton observed at one upland location at West Foreland and in sea cliffs along West Foreland and from Katchin Creek south to near Redoubt Point (Riehle and Emmel, 1980). Unit present on source maps: Lime Hills 1 x 3 Quadrangle, Lake Clark 1 x 3 Quadrangle and Taylor Mountains 1 x 3 Quadrangle.

Qio - Older outwash deposits (middle or lower Pleistocene)

Stratified gravel and sand of outwash aprons of Eklutna glaciation of Karlstrom (1964) and Johnson Hill drift and older deposits of Detterman (1986). Unit present on source maps: Lake Clark 1 x 3 Quadrangle and Taylor Mountains 1 x 3 Quadrangle.

QTV - Old volcanic rocks, undivided (Pleistocene or Pliocene)

Detterman and Reed (1980) mapped two eruptive centers within the Jurassic part of the Alaska-Aleutian Range batholith in the Iliamna quadrangle. Only the southern site was examined briefly by Detterman and Reed (1980). Scoriaceous olivine basalt at Seven Sisters (about 40 km west of Augustine Island) is thought to represent a volcanic neck and feeder-dike system. Second site, to the north, about 17 km northwest of Chinitna Bay, was thought to consist largely of andesitic tuff and breccia having a smooth to gently rounded topographic expression. No age control exists for either center; however, Detterman and Reed (1980) suggested olivine basalt of the Seven Sisters is most closely related to the Intricate Basalt of possible Pliocene age, whereas the andesite(?) at West Glacier Creek seemed more similar to Augustine Volcano and Iliamna Volcano products. Also included in this map unit, but too small to show, are basaltic andesite porphyry dikes and sills intruding Jurassic sedimentary rocks between Chinitna and Iniskin Bays and andesite (Detterman and Hartsock, 1966). Unit present on source map: Iliamna 1 x 3 Quadrangle.

Qsb - Glacially scoured bedrock (Cenozoic to Paleozoic)

Areas that interpretation of air photos suggest may be glacially scoured bedrock. May have patchy, thin drift, including both ice-contact deposits and glacial-fluvial sediments. Indicates former ice positions, valley trim lines, side glacial melt water features, and scoured valley bottoms where glaciers or glacial channels have resided, but do not obscure underlying bedrock features such as bedding, jointing, or structural features. However, map unit is primarily indicative of areas where significant glacial scour has taken place, in contrast to deposition of glacially derived materials. Most likely associated with Late Wisconsin glacial advances. Consist of a wide variety of lithologies including sedimentary, igneous, and metamorphic rocks of Cenozoic to Paleozoic age. See Nelson and others (1983) and Wilson and others (1998; 2006) for descriptions of most bedrock units. Many of the areas shown within this unit in the Lake Clark quadrangle were shown as surficial deposits by Nelson and others (1983). Unit present on source maps: Tyonek 1 x 3 Quadrangle, Lime Hills 1 x 3 Quadrangle, Kenai 1 x 3 Quadrangle, Lake Clark 1 x 3 Quadrangle and Taylor Mountains 1 x 3 Quadrangle.

bu - Undifferentiated bedrock (Cenozoic to Paleozoic)

Consist of a wide variety of lithologies including sedimentary, igneous, and metamorphic rocks of Cenozoic to Paleozoic age in outcrop, rubble-crop, and felsenmeer (Price, 1972). See Nelson and others (1983) and Wilson and others (1998; 2006) for descriptions of most bedrock units. Unit present on source maps: Tyonek 1 x 3 Quadrangle, Lime Hills 1 x 3 Quadrangle, Kenai 1 x 3 Quadrangle, Lake Clark 1 x 3 Quadrangle, Taylor Mountains 1 x 3 Quadrangle, Seldovia 1 x 3 Quadrangle, Iliamna 1 x 3 Quadrangle and Dillingham 1 x 3 Quadrangle.

Ancillary Source Map Information

The following sections present ancillary source map information associated with sources used to produce the GRI digital surficial geologic-GIS map for Lake Clark National Park and Preserve, Alaska (LACL).

USGS Map References

USGS geologic spatial data for the Alaska region maintains geologic source information as an attribute attached to each geologic feature. Although the GRI considers the USGS to be the mapping source for this project, sources used and referenced by the USGS have been preserved in the GRI digital surficial geologic-GIS product. Geologic features in the GRI digital surficial geologic-GIS data and the unit descriptions listed in this document have references to the sources listed here.

DI001 U.S. Geological Survey, Dillingham, Alaska: U.S. Geological Survey Alaska Topographic Series, scale 1:250,000.

DI005 Wilson, F.H., Blodgett, R.B., Blome, C.D., Mohadjer, Solmaz, Preller, C.C., Klimasauskas, E. P., Gamble, B.M., and Coonrad, W.L., in prep., Reconnaissance bedrock geologic map for the northern Alaska Peninsula area, southwest Alaska; including the Dillingham, Iliamna, Lake Clark, Taylor Mountains and the western part of the Kenai and Seldovia 1:250,000-scale quadrangles: U.S. Geological Survey Scientific Investigations Map SIM-????, pamphlet, 111 ms. p., 2 sheets, scale 1:350,000.

DI009 Wilson, F.H., Hudson, T.L., Grybeck, Donald, Stoesser, D.B., Preller, C.C., Bickerstaff, Damon, Labay, Keith, and Miller, M.L., 2003, Preliminary geologic map of the northeast Dillingham quadrangle (D-1, D-2, C-1, and C-2), Alaska: U.S. Geological Survey Open-file Report 03-105, 13 p., scale 1:100,000.

DI013 Wilson, F.H., 2008, Surficial units to be included in new surficial map.

IL001 U.S. Geological Survey, Iliamna, Alaska: U.S. Geological Survey Alaska Topographic Series, scale 1:250,000.

IL002 Detterman, R.L., and Reed, B.L., 1980, Stratigraphy, structure, and economic geology of the Iliamna quadrangle, Alaska: U.S. Geological Survey Bulletin 1368-B, 86 p., 1 sheet, scale 1:250,000.

IL003 Detterman, R.L., and Reed, B.L., 1973, Surficial deposits of the Iliamna quadrangle, Alaska: U.S. Geological Survey Bulletin 1368-A, 64 p., 1 plate, scale 1:250,000.

IL006 Wilson, F.H., Blodgett, R.B., Blome, C.D., Mohadjer, Solmaz, Preller, C.C., Klimasauskas, E. P., Gamble, B.M., and Coonrad, W.L., in prep., Reconnaissance bedrock geologic map for the northern Alaska Peninsula area, southwest Alaska; including the Dillingham, Iliamna, Lake Clark, Taylor Mountains and the western part of the Kenai and Seldovia 1:250,000-scale quadrangles: U.S. Geological Survey Scientific Investigations Map SIM-????, pamphlet, 111 ms. p., 2 sheets, scale 1:350,000.

IL007 Detterman, R.L., and Hartsock, J.K., 1966, Geology of the Iniskin-Tuxedni region, Alaska: U.S. Geological Survey Professional Paper 512, 78 p., 6 plates, map, scale 1:63,360.

IL008 Waythomas, C.F., and Miller, T.P., 1999, Preliminary volcano-hazard assessment for Iliamna Volcano: U.S. Geological Survey Open-File Report 99-373, 31 p. 1 plate.

- IL009 Bouley, B.A., St. George, Phil, and Wetherbee, P.K., 1995, Geology and discovery at Pebble Copper, a copper-gold porphyry system in southwest Alaska, in *Porphyry deposits of the northwest Cordillera of North America: Canadian Institute of Mining, Metallurgy, and Petroleum Special Volume 46*, p. 422-435.
- IL013 Wilson, F.H., 2008, Surficial geology for Lake Clark National Park region.
- KN001 U.S. Geological Survey, Kenai, Alaska: U.S. Geological Survey Alaska Topographic Series, scale 1:250,000.
- KN002 Magoon, L.B., Adkison, W.L., and Egbert, R.M, 1976, Map showing geology, wildcat wells, Tertiary plant localities, K-Ar age dates, and petroleum operations, Cook Inlet area, Alaska: U. S. Geological Survey Miscellaneous Investigations Series Map I-1019, scale 1:250,000, 3 sheets.
- KN005 Detterman, R.L., and Hartsock, J.K., 1966, Geology of the Iniskin-Tuxedni region, Alaska: U.S. Geological Survey Professional Paper 512, 78 p., 6 plates, map, scale 1:63,360.
- KN006 Riehle, J.R., and Emmel, K.S., 1980, Photointerpretation map of the surficial geology, Polly Creek to MacArthur River, Cook Inlet, Alaska: Alaska Division of Geological and Geophysical Surveys Geologic Report 64, 2 sheets, scale 1:63,360.
- KN008 Wilson, F.H., Blodgett, R.B., Blome, C.D., Mohadjer, Solmaz, Preller, C.C., Klimasauskas, E. P., Gamble, B.M., and Conrad, W.L., in prep., Reconnaissance bedrock geologic map for the northern Alaska Peninsula area, southwest Alaska; including the Dillingham, Iliamna, Lake Clark, Taylor Mountains and the western part of the Kenai and Seldovia 1:250,000-scale quadrangles: U.S. Geological Survey Scientific Investigations Map SIM-????, pamphlet, 111 ms. p., 2 sheets, scale 1:350,000.
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- LC005 Wilson, F.H., Blodgett, R.B., Blome, C.D., Mohadjer, Solmaz, Preller, C.C., Klimasauskas, E. P., Gamble, B.M., and Coonrad, W.L., in prep., Reconnaissance bedrock geologic map for the northern Alaska Peninsula area, southwest Alaska; including the Dillingham, Iliamna, Lake Clark, Taylor Mountains and the western part of the Kenai and Seldovia 1:250,000-scale quadrangles: U.S. Geological Survey Scientific Investigations Map SIM-????, pamphlet, 111 ms. p., 2 sheets, scale 1:350,000.
- LC006 Wallace, W.K., 2002, Unpublished geologic mapping dated 1985, done while at ARCO, made available July 2002.
- LC007 Detterman, R.L., and Hartsock, J.K., 1966, Geology of the Iniskin-Tuxedni region, Alaska: U.S. Geological Survey Professional Paper 512, 78 p., 6 plates, map, scale 1:63,360.
- LC010 Waythomas, C.F., and Miller, T.P., 1999, Preliminary volcano-hazard assessment for Iliamna Volcano: U.S. Geological Survey Open-File Report 99-373, 31 p. 1 plate.
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- LC012 Eakins, G.R., Gilbert, W.G., and Bundtzen, T.K., 1978, Preliminary bedrock geology and mineral resource potential of west-central Lake Clark quadrangle of Alaska: Alaska Division of Geological and Geophysical Surveys Alaska Open-File Report 118, 15 p., 2 plates, scale 1:125,000.
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- LH006 Bundtzen, T.K., and Jorgenson, Torre, 2005, Lime Hills and western Tyonek quadrangles surficial geologic mapping and ecosystem development analysis of glacial deposits: U.S. National Park Service Contract #D9855040060 to: ABR, Inc P.O. Box 80410 Fairbanks, Alaska 99708 , 85 p., 35 plates, scale 1:63,360.
- LH007 Wilson, F.H., and Gamble, B.M., 2007, Unit assignment edits.
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- SV002 Bradley, D.C., Kusky, T.M., Haeussler, P.J., Karl, S.M., and Donley, D.T., 1999, Geology of the Seldovia quadrangle: U.S. Geological Survey Open-File Report 99-18, scale 1:250,000.
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- TA001 U.S. Geological Survey, Taylor Mountains, Alaska: U.S. Geological Survey Alaska Topographic Series, scale 1:250,000.
- TA015 Wilson, F.H., Blodgett, R.B., Blome, C.D., Mohadjer, Solmaz, Preller, C.C., Klimasauskas, E. P., Gamble, B.M., and Coonrad, W.L., in prep., Reconnaissance bedrock geologic map for the northern Alaska Peninsula area, southwest Alaska; including the Dillingham, Iliamna, Lake Clark, Taylor Mountains and the western part of the Kenai and Seldovia 1:250,000-scale quadrangles: U.S. Geological Survey Scientific Investigations Map SIM-????, pamphlet, 111 ms. p., 2 sheets, scale 1:350,000.

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- TY004 Solie, D.N., Gilbert, W.G., Harris, E.E., Kline, J.T., Liss, S.A., and Robinson, M.S., 1991, Preliminary geologic map of Tyonek D-6 and eastern Tyonek D-7 quadrangles, Alaska: Alaska Division of Geological and Geophysical Surveys Public-data File 91-10, scale 1:63,360, 15 p., not paginated.
- TY005 Haeussler, P.J. 1997, Unpublished compilation, Tyonek quadrangle, includes contributions from Madeline Milholland.
- TY007 Wilson/Hults edits.
- TY008 Schmoll 2007 compilation.
- TY009 Haeussler, 2007.
- TY016 Weber, F.R., 1961, Reconnaissance engineering geology for the selection of highway route from Talkeetna to McGrath, Alaska: U.S. Geological Survey Open-File Report 61-169, 2 sheets, scale 1:250,000.

References from source map: [Quaternary Geologic Map of Lake Clark National Park and Preserve](#)

Wilson, F.H., Bundtzen, T.K., Harvey, J., and Spencer, P., 2009, (OFR 2009-XXXX)

The formal citation for this source.

Wilson, F.H., Bundtzen, T.K., Harvey, J., and Spencer, P., 2009, Quaternary Geologic Map of Lake Clark National Park and Preserve; Western Alaska Range, Alaska, digital data, U.S. Geological Survey, Open File Report 2009-XXXX, scale 1:250,000.

As previously stated, the above source map was produced from the following 1 x 3 Quadrangle digital datasets:

Tyonek 1 x 3 Quadrangle (*GRI Source Map ID 75288*)
Lime Hills 1 x 3 Quadrangle (*GRI Source Map ID 75289*)
Kenai 1 x 3 Quadrangle (*GRI Source Map ID 75290*)
Lake Clark 1 x 3 Quadrangle (*GRI Source Map ID 75291*)
Taylor Mountains 1 x 3 Quadrangle (*GRI Source Map ID 75292*)
Seldovia 1 x 3 Quadrangle (*GRI Source Map ID 75293*)
Iliamna 1 x 3 Quadrangle (*GRI Source Map ID 75294*)
Dillingham 1 x 3 Quadrangle (*GRI Source Map ID 75295*)

Prominent graphics and text associated with this source.

Report

Quaternary Geologic Map of Lake Clark National Park and Preserve; Western Alaska Range, Alaska

By Frederic H. Wilson, Thomas K. Bundtzen, Jon Harvey, and Page Spencer

Introduction and Previous work

This geologic map of Lake Clark National Park and Preserve (LCNP) and surrounding area shows the distribution of Quaternary age rocks and unconsolidated deposits. It presents a compilation of the best available geologic map data in an integrated fashion. A wide range of sources were used to construct the map, including published mapping of Robert Detterman and others in the Iliamna and Kenai quadrangles (Detterman and Hartsock, 1966; Detterman and Reed, 1973; 1980; Magoon and others, 1976; Riehle and Emmel, 1980; Fritschen, 1995), unpublished mapping of Wilson in the Lake Clark and western Kenai quadrangles, and of Bundtzen and Jorgensen (2005) in the Lime Hills and southwestern Tyonek quadrangle. Studies in the vicinity of Redoubt and Iliamna Volcanoes (Till and others, 1993; Waythomas and Miller, 1999) were also used. It however, does not reflect changes due to the recent (2009) eruption of Redoubt Volcano.

This map has been produced as part of a larger compilation effort mapping the west side of Cook Inlet and including the Dillingham, Taylor Mountains, Lake Clark, Iliamna, and the western parts of the Kenai and Seldovia 1:250,000-scale quadrangles. The map was created in response to a request by the National Park Service for a map that shows surficial deposits as an aid in ecosystem mapping within Lake Clark National Park and Preserve as well as an aid for park interpretive staff. Previous work in the area is limited; surficial deposits were mapped around Iniskin and Tuxedni Bays by Detterman and Hartsock (1966); along the Cook Inlet coast by Riehle and Emmel (1980), in the vicinity of Iliamna Volcano by Waythomas and Miller (1999), and in the vicinity of Redoubt Volcano by Till and others (1993). Local detailed studies and reconnaissance mapping were done by Fritschen (1995) along the western side of the Chigmit Mountains and Bundtzen and Kline (1979) in the vicinity of Portage Creek on the northeast shore of Lake Clark. In adjacent areas, surficial deposits have been mapped in the Iliamna quadrangle, which also includes the southern margin of LCNP (Detterman and Reed, 1973). Unpublished mapping by D.H. Richter in the Lime Hills quadrangle was available for reference.

Geologic and Physiographic Framework

Although Redoubt and Iliamna Volcanoes are the highest mountains in LCNP, the Alaska-Aleutian Range batholith (Reed and Lanphere, 1973; Nelson and others, 1983; Wilson and others, 1999; 2006) is the dominant geologic feature of the eastern part of LCNP and it forms the backbone of the southern Alaska Range and northern Aleutian Range in LCNP. The mountains on the west side of Cook Inlet are part of the southern Alaska Range and northern Aleutian Range; the transition in name between these two mountain ranges is approximately at Chakachamna Lake, and in common usage, the mountains along the west side of Cook Inlet are called the Alaska-Aleutian Range. Roof pendants to the batholith consist of rocks of the Talkeetna Formation and metamorphosed equivalents of the Triassic Cottonwood Bay Greenstone or equivalent Chilikadrotna Greenstone and the Kamishak Formation. The two prominent volcanoes are emplaced on top of this backbone and young volcanic rocks represent only a small fraction of the bedrock even in the vicinity of these volcanoes. Bedrock east of the batholith along the Cook Inlet coast consists of the Talkeetna Formation, overlying Jurassic sedimentary rocks of the Tuxedni Group, and other sedimentary rock units as young as early Tertiary (Detterman and Hartsock, 1966; Wilson and others, 2006). The bedrock of the southern Alaska Range and northern Aleutian Range is characteristic of the Alaska Peninsula terrane (Wilson and others, 1985; 1999) where the batholith and roof pendants form the Iliamna sub-terrane and the sedimentary rocks are typical of the Chignik sub-terrane. West of the batholith is a poorly defined assemblage of Mesozoic sedimentary and igneous rocks intruded by latest Cretaceous and early Tertiary granitic plutons and locally overlain by early Tertiary volcanic rocks (Nelson and others, 1983; Wallace and others, 1989; Wilson and others, 2006).

LCNP occupies part of two of the physiographic Provinces of Alaska, as defined by Wahrhaftig (1965). The Alaska-Aleutian Province is represented by the Alaska Range (southern part) Section, which constitutes the eastern part of LCNP. This part of LCNP is characterized by rugged, glaciated ridges that trend north, north of Lake Chakachamna and trend northeast, south of the lake Wahrhaftig (1965). Elevation is higher north of the lake, which is largely outside of LCNP. Within LCNP, the ridges tend to be 4,000-6,000 feet (1,220-1,830 m) high, capped by higher peaks (Wahrhaftig, 1965). Redoubt Volcano (3,108 m) and Iliamna Volcano (3,053 m) are the most prominent of the peaks. The highest peak in the northern part of LCNP is Goldpan Peak (2,270 m) near Merrill Pass. This section is drained by large braided streams that flow to the Kuskokwim, Mulchatna (thence Nushagak), Newhalen (thence Kvichak) Rivers, or to Cook Inlet. Some of the glacially carved valleys contain moraine-dammed lakes, such as Two Lakes, Lake Telequana, Twin Lakes, or Turquoise Lake. Additionally, Lake Clark occupies a major tectonic trough cutting through LCNP.

The Western Alaska Province is represented by the Nushagak-Big River Hills Section, which covers the western part of LCNP. The Nushagak-Big River Hills Section is characterized by generally rounded hills and mountains that have elevations rarely exceeding 2,500 feet (760 m) and decreasing westward (Wahrhaftig, 1965). In the northern part of LCNP, ridgelines in this Section have a pronounced northerly trend. Drainage in the northern part of LCNP goes to the Kuskokwim River whereas the Mulchatna (thence Nushagak) and Newhalen (thence Kvichak) Rivers are the primary drainages for the southern part of LCNP. No glaciers are found in this section (Wahrhaftig, 1965) although many glacial deposits and deposits reflecting drained glacially-dammed lakes are common. Permafrost is common and the deposits of periglacial erosion processes are a prominent feature (Wahrhaftig, 1965).

During extensive glacial events, including the Late Wisconsin last glacial maximum (LGM), glaciers from the southern Alaska Range and northern Aleutian Range apparently covered the range and flowed eastward into Cook Inlet and westward toward Bristol Bay. In the vicinity of Iliamna Lake (south of LCNP) the divide between Cook Inlet and Bristol Bay is low; a major tongue of ice flowed into the Kvichak River drainage suggesting ice drainage derived from the Cook Inlet Basin. A smaller ice tongue flowed through the Tlikakila River drainage into Lake Clark, joining with ice derived from the highlands of the southern Alaska Range and northern Aleutian Range. Moisture to nourish the glacial masses was derived from the north Pacific and to a lesser extent the Bristol Bay (Bering Sea) basin if present day conditions can be used to suggest the past. Existing weather records indicate that at present, although Bristol Bay is a significant source of moisture, precipitation is significantly less on the west side of the mountains (table 1, fig. 2). In addition, in contrast to stations east of the mountains, precipitation is lower during the winter compared to summer. This may be due to Bristol Bay freezing over during winter months (LaBelle and others, 1983). Lowered sea level at maximum glacial extent would suggest that Bristol Bay was at best a distant source. The large ice mass in the southern Alaska Range and northern Aleutian Range and on the islands of the Kodiak archipelago meant that the west side of the LCNP was in the precipitation shadow of the dominant moisture source. At the present time, many remnant glaciers remain in the mountains along Cook Inlet although they are receding rapidly.

Port Alsworth is apparently in a precipitation shadow, whereas at Intricate Bay and Iliamna, precipitation is higher than at King Salmon, which may indicate either an orographic effect of the mountains or spill over from the Pacific Ocean contribution or both. Data for the city of Anchorage is included in the table for comparison because it is relatively sheltered from both Bristol Bay and the north Pacific; its precipitation and temperature patterns are more similar to stations west of the Alaska Range than stations such as Seward directly affected by the north Pacific weather patterns. Winter temperature is significantly lower west of the mountains and the ratio of winter to summer precipitation is less in the west suggesting that Bristol Bay may be an important source of moisture only in summer west of the mountains. Anchorage matches the pattern of the western stations, though at generally lower precipitation levels. Stations such as Seward and Kodiak, which have a strong contribution from the north Pacific have increased precipitation in the winter in contrast with the western stations.

Table 1. Climate data from weather recording stations in the vicinity of Lake Clark National Park and Preserve.

(abstracted from Annual station records, National Climate Data Center, National Oceanic and Atmospheric Administration) [Precipitation and temperatures shown are averages reflecting years of record as shown in column 2. precip. = precipitation in inches, temp. = temperature in degrees F. Winter is considered October through March, summer is April through September. Precipitation values may not sum due to missing data for some months. Dillingham is missing many years of record over the interval shown.]

Station	Years of record	Annual precip.	Winter precip.	Summer precip.	Annual temp.	Winter temp.	Summer temp.
Port Alsworth	1962-2002	14.36	6.02	8.35	34.6	20.7	47.5
Iliamna	1943-1969, 1978-2002	26.05	10.58	15.27	34.7	22.2	47.0
Intricate Bay	1960-2002	34.62	17.08	17.44	34.7	22.5	47.3
Dillingham	1920-2002, intermittent years	27.36	11.12	15.15	33.7	21.0	46.5
King Salmon	1951-2002	19.37	7.53	11.88	33.8	20.6	47.1
Cold Bay	1948-2002	37.68	20.60	17.65	38.3	31.8	44.8
Seward	1908-2002, some missing data	66.10	37.51	28.59	39.6	30.1	49.2
Kodiak	1882-1890, 1899-2002	61.10	33.11	28.10	41.0	33.6	48.3
Anchorage	1915-2002	15.12	5.96	9.12	35.5	21.4	49.7

Regionally, from east to west, the landforms change from mainly erosional features in the southern Alaska Range and northern Aleutian Range to mainly constructive, depositional features related to glaciation in the lowlands. The Mulchatna River valley cuts diagonally, trending southwest, west of LCNP; this major physiographic feature has long been postulated as the locus of a major terrane-bounding bedrock fault system, see for example Jones and others (1981) or Nokleberg and others (1994). However, that supposition has proved difficult to demonstrate or prove (see for example, Wallace and others, 1989, Nelson and others, 1983; Mohadjer and others, 2006). The Mulchatna River valley has the classic cross-section of a glacially carved valley. South and east of the valley, glaciers have been clearly the dominant agent of landform development. North and west of the valley, direct impact by glaciers is not as readily apparent and in general was not a major direct control during the Late Wisconsin.

The Lake Clark region lies at the southern margin of the boreal forest; a lobe of the forest extends into the central part of the map area. To the east, the mountains are today actively shedding their remnant glaciers, to the west the lowlands have yet to be reforested. The lakes of the region are important spawning areas for sockeye salmon. Recent studies by Patricia Heiser (University of Alaska, oral communication., 2003; Finney, 2003) suggest that the abundance of spawning salmon is negatively correlated with climatic temperature. ¹⁵N isotope studies of sediment cores from the vicinity

of Lake Clark suggest decreased productivity during the Medieval warm period, increased salmon productivity during the Little Ice Age and decreasing productivity into the 20th century as regional temperatures increased. A potentially interesting and useful study would be to help elucidate the history of salmon and climate in the region by coring deposits associated with the ephemeral meltwater lakes and using dating and isotope studies of the cores.

Discussion

Our map was largely produced through air-photo interpretation and limited field checks. The most complete photographic coverage of the map area dates from 1952-1957; access to newer photography is limited to just a few areas, such as around Redoubt Volcano. Limited field checks during previous geologic studies were made by Bundtzen in the upper Mulchatna and Chilikadrotna River drainages, the Portage Creek area and in the northern part of LCNP (Bundtzen and Jorgenson (2005). In order to be consistent and provide a snapshot of the area at a point in time, it was decided to use the 1950's photos to produce this map. Clearly, post-1957 eruptions of Redoubt Volcano have resulted in changes in its vicinity. Much more widespread changes result from the significant melting of glaciers and ice fields in the last 50 years. Using satellite imagery from 2003 and the glacier extents as shown on the 1950's photographs, we find that there has been approximately 13 percent loss in the surface area of glaciers in the map area (K.A. Labay and F.H. Wilson, unpublished data, 2004).

Little absolute age control exists for surficial geologic units in LCNP. Bundtzen and Jorgenson (2005) reported two Holocene radiocarbon dates which document the age of eolian deposits that overlie till and outwash of presumed Wisconsin age. Unpublished dates by Patricia Heiser (University of Alaska, oral communication., 2003) document latest Wisconsin and Holocene sedimentation in lakes in the vicinity of Lake Clark.

Detterman (1986) established a framework for the glacial history of the Alaska Peninsula and, though legitimately questioned with respect to some details, this framework continues to serve well today (table 2). Much of its original definition was based on geology mapped by Detterman and Reed (1973) in the Iliamna quadrangle, which includes the southernmost part of LCNP. South of LCNP, the Brooks Lake Glaciation, the Late Wisconsin last glacial maximum event (LGM), has been divided into 4 advances, named from oldest to youngest, the Kvichak, Iliamna, Newhalen, and Iliuk advances (Detterman, 1986). This established framework was used as an outline for the history of the Lake Clark region. Along the border with the Iliamna quadrangle, the chronology and correlation of glacial events can be well established based on the Iliamna example and with minor changes was used as a starting point for this map. It became apparent that the number of advances and/or recessional still-stands in the Lake Clark region exceeded the 4-fold structure of the Brooks Lake Glaciation as generally used on the Alaska Peninsula. Yet, clear ties to the Kvichak advance and to two of the younger of the Brooks Lake advances, the Newhalen and the Iliuk, suggested that at a minimum, the time range for Late Wisconsin glaciation in the Lake Clark region matched that of the areas to the south. Fernald (1960) and Kline and Bundtzen (1986) developed a glacial stratigraphic terminology on the basis of their work in generally north of LCNP. Table 3 shows a tentative correlation of the two glacial terminologies and is the basis for the map units used here. In the northern part and north of LCNP, glacial deposits of significantly older age are recognized than in the southern part of LCNP. West of the southern part of LCNP, older deposits can be seen and these are thought to correlate with some of the older deposits described by Kline and Bundtzen (1986). However, the discontinuous distribution and varying weathering, erosion, faulting, and burial make correlation between older glacial deposits on the basis of relative age difficult (Kline and Bundtzen (1986).

Table 2. Alaska Peninsula glacial stratigraphy and comparison to the Lake Clark map area.
[Based on Detterman, 1986]

Time	Event	Character on the northern Alaska Peninsula	Location in the map area of these features
Holocene	Neoglacial (Alaskan Glaciation)	Morainal deposits as much as 2 km in front or along side of modern day glaciers and rock glaciers.	Throughout the northern Aleutian Range. Particularly well-developed in northern part of map area and along eastern portion of Lake Clark quadrangle.
Late Wisconsin	Undivided	Trim lines and enigmatic surficial deposits, widespread glacial landforms, particularly U-shaped valleys and over-steepened slopes	Widely distributed along Cook Inlet coast region, especially apparent in vicinity of Summit Lake and Lake Clark Pass.
Latest Wisconsin	Brooks Lake, Iliuk advance	Last advance of the Late Wisconsin, tends to be restricted to mountains, essentially an alpine episode	Morainal deposits(?) along Cook Inlet and moraines around Telequana, Turquoise, and Twin Lakes
Late Wisconsin	Brooks Lake, Newhalen advance	Filled the Lake Clark drainage and extended into the Iliamna quadrangle on the Newhalen River.	Along the Newhalen River and moraines in the Koksetna and Chulitna River drainages, as well as along the upper Chilikadrotna River in the vicinity of Snipe Lake
Late Wisconsin	Brooks Lake, Iliamna advance	Moraines forming the present-day outer margin of Iliamna Lake	Secondary moraines along the Chulitna River and surrounding Tutna Lake and east Whitefish Lake
Late Wisconsin (maximum)	Brooks Lake, Kvichak advance	Prominent moraine along the Kvichak River	Major moraine along Chulitna River at west edge of map, surrounding Whitefish Lake and along the Chilikadrotna River as it enters the Mulchatna River valley.
Early (?) Wisconsin	Mak Hill	Subdued morainal deposits west of the Kvichak River in the Dillingham quadrangle	Subdued moraine and outwash deposits Hoholtna River and along Mulchatna River
Illinoian	Johnson Hill (?)	Sea-cliff exposures along Bristol Bay	Extremely subdued moraine(?) and outwash(?) deposits in the northwest part of the map area

Table 3. Comparison of glacial chronologic sequences in the northern and southern parts of Lake Clark National Park and Preserve.

[Division between northern and southern terminology is at about 61° N latitude. Northern stratigraphic terminology from Fernald (1960) and Kline and Bundtzen (1986); southern stratigraphic sequence based on Detterman (1986)]

Time	Event	Northern region of LCNP	Southern region of LCNP
Holocene	Neoglacial, including "Little Ice Age"	Unnamed, at least 3 rock glacier forming phases and 2 or 3 minor glacial advances.	Alaskan Glaciation, subdivided into Tunnel (younger) and Tustumena stades
Late Wisconsin	Last Glacial Maximum (LGM), well formed to moderately dissected moraines. Deranged drainage	Farewell II (4 phases)	Brooks Lake, 4 advances, from youngest to oldest: Iliuk, Newhalen, Iliamna, and Kvichak.
Early (?) Wisconsin	Dissected moraines, subdued and modified morainal forms	Farewell I (2 phases)	Mak Hill, possibly 2 phases, may include Johnston Hill also.
Illinoian?	Subdued moraine forms, kettles completely filled, weathered glacial erratic boulders.	Selatna (2 or 3 phases)	Not present, outside area mapped as "oldest glaciation"
Early Pleistocene?	Moraine forms largely destroyed; highly weathered glacial erratic boulders.	Lone Mountain, (possibly multiple phases)	Not present
Tertiary?	Isolated patches and cut banks of dipping diamicton and outwash deposits.	Big Salmon Fork	Not present

In addition to mapping of the morainal features, an effort was made to display moraine complexes in a manner consistent with the expected four-fold chronology and consistent with the local record. Along much of the Alaska Peninsula, glacial ice in the Late Wisconsin advanced from an accumulation zone along the Pacific Ocean toward the Bering Sea. In the Iliamna and to a greater extent, the Lake Clark regions, there was a much more "continental" aspect to the glaciation. This continental aspect played an important role in the overall character of the surficial deposits in the region. A prime effect was that of Late Wisconsin glaciers predominantly developed in the southeast part of the area, most likely due to inadequate moisture sources for areas farther north and west. The Mulchatna River valley trends southwest to the west of LCNP and is a rough approximation of a divide in regional precipitation and circulation patterns during the LGM. From studies on the Alaska Peninsula (Detterman and others, 1981; 1987; Riehle and Detterman, 1993; Wilson and others, 1997; 2001) a clear pattern emerges showing the north Pacific Ocean was the dominant moisture source. However, glaciation patterns showing extensive glacier development in the Ahklun Mountains of southwest Alaska (Manley and others, 2001; Briner and Kaufman, 2000) indicate that regardless of lower sea-level, the Bering Sea must have been an important moisture source. It is our supposition that glaciers

in the Iliamna and southwest part of the Lake Clark quadrangle benefited from this moisture source, whereas, further north, they suffered from the cumulative effects of being in the precipitation shadow of the Ahklun Mountains and of their greater distance inland.

In the Lake Clark quadrangle, unlike on the Alaska Peninsula to the south, Late Wisconsin glacial deposits, though important, do not so overwhelmingly dominate the landscape. In particular, though the dominant feature in the southwest part of the quadrangle, Late Wisconsin deposits are generally lacking northwest part LCNP. The Mulchatna River valley clearly serves as a divide between areas intensely affected by Late Wisconsin glaciation and those seeing limited impact.

As mentioned above, the geologic record shows evidence for a series of glacial advances or still-stands during Late Wisconsin time. A large number of short-lived meltwater lakes were present in the area, generally dammed behind morainal ridges; some have well-developed shorelines and show remnants of well-developed alluvial deltas from meltwater streams. Deposits along the Koksetna River were originally interpreted as a tiered series of delta deposits (Wilson, 2006) built in a temporary lake that drained once the glacier damming the east side of the lake had melted sufficiently to allow for an outlet (fig. 3). However, recent fieldwork suggest that these deposits may instead represent till deposits from a glacier that terminated in the lake. The smooth arcuate front and unsorted nature of the deposits and lack of any distributary channels are evidence arguing against these deposits representing alluvial deltas. The process that yielded successive levels of the deposits is not clear. It is likely that this lake drained in stages during a relatively short period based on the successive levels of fan-like deposits built into the lake basin. In following through this area, the Koksetna River has cut deeply down into bedrock along a series of entrenched meanders.

Late Wisconsin refugia existed in the locally named "Telequana Highlands," south of Telequana Lake, probably in the Bonanza Hills, and possibly in local areas to the south. In the southeastern part of LCNP, only glacial deposits of Neoglacial or Holocene events or the most recent part of the Late Wisconsin are apparent on air-photos. Possibly during the LGM, ice fields covered much of the entire southeast area of the map. It appears that another large refugium was present at the higher elevations of Chisik Island; more detailed work may show large nunataks or refugia in this area.

Although available data does not allow a definitive answer, the presence of shallowly buried bedrock on Kustatan Ridge and at West Foreland is suggested by a number of factors. Previously mapped as glacial deposits (Riehle and Emmel (1980), on this map, the bulk of the ridge is shown as glacially scoured bedrock. Riehle and Emmel (1980) did mention this possibility; on this map, that character is emphasized because it does not apply to most other high ground previously mapped as glacial deposits along the coast. On Kustatan Ridge, distinctive and regular linear ridge lines suggest glacially eroded bedded rocks underlie the ridge. Additionally, its significantly higher relief (as much as 450 feet, 137 m) is also suggestive of bedrock. At West Foreland, the topographic map shows extensive reefs, including Knutruin Rock, along its east coast, which is unusual for the coast within the map area. Taken together, these observations suggest the presence of shallowly buried or locally exposed bedrock. This area is worth examining in the field to resolve this question.

Volcanic features

Along Cook Inlet, the dominant Quaternary features are Iliamna and Redoubt Volcanoes. Both have had Holocene eruptions, of which Redoubt Volcano has had the most significant impact on human activity in the recent past. Documented eruptions occurred in 1902, 1966, 1968, and 1989-1990 (Till and others, 1993), 1996, and 2009. Mudflows resulting from the 1996 eruption came close to the Drift River oil terminal facility and during the 1989-1990 eruption, overran parts of the facility (oral communication, A.B. Till, 2003). Departing to some extent from exclusive use of 1950's air photos, the debris flows and mudflows along the Drift River shown on the map are primarily derived from the 1966 eruption (Till and others, 1993). (Note, in this report, debris flow and mudflow deposits form a continuum, mudflow deposits represent a more fluid variant of a debris flow deposit.) Additional debris flow deposits were recognized by Till and others (1993), but were not mapped separately by them within the undivided surficial deposits of the Drift River delta. Extensive debris flow deposits fill the Crescent River valley south of the volcano; these deposits were emplaced about 3,500 years ago on

the basis of mapping and radiocarbon dating by Riehle and others (1981).

On the present map, the volcanic products of Redoubt Volcano shown are significantly more extensive than on previous maps; in large part this is because previous studies were focused on specific aspects of the volcanic center, such as the debris flows along the Crescent River (Riehle and others, 1981) or volcanic hazards (Till and others, 1993). The overview nature of this report does result in suggested revisions to the interpretation of Riehle and others (1981) regarding the Crescent River debris flows. Riehle and others (1981) suggest that the largest of the debris flows originated principally from an unnamed tributary valley of the North Fork of the Crescent River that enters the main valley in section 24 (fig. 4). However, as shown in figure 4, the part of the debris flow derived from this valley, presently occupied by a glacier, has a distinctively different morphology relative to other parts of the debris flow. It forms a thicker and more fan-shaped deposit and truncates older debris flow deposits up-valley and is truncated by a newer fan that grades smoothly into the main debris flow deposit down-valley. The section 24 fan also appears to have a subtly different vegetation character than the main debris flow deposits; this character is more like the older deposits along the valley. A larger tributary, entering the main valley in section 30 does not contain a glacier; the herein preferred alternative interpretation is that the deposits present in this section 30 valley are the proximal deposits of the eruption that created the main debris flow. Plastered to the sides of the valley and high on the side of the volcano are abundant unconsolidated deposits that grade smoothly into the main debris flow deposits. The sheer volume of the Crescent River debris flow deposits should have left a significant mark on the volcano. The large area of unconsolidated volcanic debris and the fact that this "section 30" valley is the only valley draining Redoubt Volcano that doesn't have a glacier is suggestive that the head area of this valley was the origin of the main debris flow. All but this of the south-facing valleys draining Redoubt Volcano contain glaciers. Presumably, the present extent of these glaciers is in part a reflection of the Little Ice Age maximum and, in part a, reflection of Neoglacial advances. The timing suggested by Riehle and others (1981) for the main Crescent River debris flows may possibly have destroyed any Neoglacial ice in the lone (section 30) unglaciated valley and Little Ice Age conditions were insufficient to regenerate ice in this valley. By inference, the older Crescent River debris flows were either small enough to have had less impact on the glaciers, or occurred earlier during the Holocene, prior to establishment of Neoglacial ice.

Reed and others (1992) described evidence for another Quaternary volcanic center, Double Glacier Volcano, north of Redoubt Volcano. However, other than the single nunatak, which constitutes the volcanic center, no other volcanic deposits associated with the center were recognized. Coats (1950) reported the existence of another volcanic center called Black, which has not been confirmed or located by modern mapping. Reed and others (1992) reported that the feature named Black Peak probably consists of amphibolite intruded by Jurassic plutonic rocks. However, similar to Coats' (1950) report of "Double" as a volcanic center, a center may exist near Black Peak rather actually being at Black Peak. Detailed mapping is severely lacking in this region.

Holocene faulting

Quaternary (late Holocene) faulting is present north of the Tuxedni River and west of Crescent Lake and along an unnamed upper tributary of the Drift River. In both of these areas, well-developed fault traces cross the countryside, trending northeast. In both cases, the clear cutting of Neoglacial moraines by the faults is evidence of late Holocene activity. The southern fault trace shows clear development of sag ponds and a step in the moraine of a small glacier that indicates it is largely a normal fault and down-dropped to the southeast. The northern of the faults is clearly visible in the areas of glacial scour resulting from Neoglacial glaciers. It also shows clear offset of bedrock, having a down-dropped to the northwest character. Stream and glacial flow patterns suggest possible right-lateral motion also. If the glacial deposits and areas of scour are the result of Little Ice Age advances, then the at least some of the offset along these faults is potentially historic.

Crescent Lake is dammed by a debris flow derived from Redoubt Volcano (Riehle and others, 1981; Till and others, 1993). Other older debris flows were also shown in the valley of the North Fork of the Crescent River that may have temporally dammed a lake in this valley. Deposits that may be debris flow deposits also occur in the upper reaches of the main channel of the Crescent River, above Crescent Lake. These deposits appear to emanate from a valley on trend with the southern of the two

Holocene faults mentioned above. As such, they may represent mass movements related to recent movement on the fault. Alternatively, they may be the product of volcanic activity from Redoubt or a satellite center located between the two forks of the Crescent River. At present, bedrock geologic mapping is not adequate to determine if a small, satellite center might exist, though this is considered unlikely. Surficial deposits in this area have an unusual morphology, suggesting the presence of large amounts of loose material. These deposits are distinctive relative to colluvial deposits at distance from Redoubt Volcano, and are similar to deposits on the volcano that are known or inferred to be ash-rich. Whether the deposits between the forks of the Crescent River reflect a satellite center or a localized accumulation of ash from Redoubt is uncertain. Ultimately, fieldwork will be necessary to resolve the nature of the deposits in this area.

Cook Inlet coastal uplift

Along the west coast of Cook Inlet, surficial deposits show clear evidence of long-term uplift. Along much of the coast, extensive tidal flats are present; inland of these tidal flats, there are frequently well-developed coastal plains or marine terraces that are interpreted to be uplifted estuarine or tidal flat deposits. Between the Drift and Crescent Rivers, the landward limits of these plains or terraces show well-developed sea-cliff morphology, representing older coastlines. Near the mouth of Cannery Creek (south of the Drift River) and south of the mouth of the McArthur River, and on Kalgin Island, paleo-beach ridges are developed. Uplift could result from multiple sources, including isostatic rebound, tectonic, and volcano-tectonic. The Holocene faulting in the region, discussed above, suggests that tectonism must be a component of the uplift. At the same time, post-glacial isostatic rebound effects must be considered an important factor.

The evidence for uplift increases northward along the coast of Cook Inlet. In the vicinity of Tuxedni Bay, present day tidal flats extend far up the Tuxedni River and the fan delta derived from the glaciers off Iliamna Volcano show a terrace suggesting an old shoreline. Northward along the coast from here, paleo-estuarine deposits are intermixed with debris and mudflow deposits from Redoubt Volcano as well as glacial outwash. Continuing northward, to the Big River, apparent estuarine and beach deposits occur far inland, particularly around the lakes at the head of the South Fork of the Big River. Farther north yet, to the north edge of the map area, outwash derived fan deltas or alluvial plains overwhelm the estuarine deposits nearly all the way to the coast. These fan deltas have well developed distributary channels. Active drainage channels show well-developed natural levees and associated overbank deposits. Abandoned channels are common, reflecting higher flows in the past and constantly shifting channels. The dynamism of this area is reflected in significant changes in active channel positions between 1950's era and more recent aerial photography (not shown here).

The geologic evidence reported above results in conflicting interpretations. How does one uplift the coast while at the same time building a fan delta complete with natural levees along streams and abundant abandoned channels? The fan deltas suggest basin filling. There is little evidence of down cutting along rivers and abandoned channels. Are both processes going on such that the sediment input in the northern part of the map area overwhelms the uplift signal?

Acknowledgements

We gratefully acknowledge significant impact of the financial aid, Park visits, and encouragement of Page Spencer of the National Park Service in our effort to produce this map. Sharing field-time with Jon Harvey in the Park was enjoyable, instructive, and helped to improve the map. Data derived from that fieldwork as well additional fieldwork by Jon and Nathaniel J. Wilson have been a positive contribution to this product. Additionally, Bruce Giffen of the National Park Service provided administrative support and encouragement. Discussions with Tina Neal of the Alaska Volcano Observatory and Patricia Heiser of the University of Alaska (Anchorage) were helpful. Discussions with Tom Hamilton greatly contributed to our thinking and to the language used for describing the features. Cindi Preller and Ed Klimasauskas contributed to this mapping effort by cheerfully retrieving and indexing air photos from our archives and Cindi by digitizing some areas of the map coverage. Digitizing of the northern part of LCNP was by Shaun Peterson.

Text from source map: [Quaternary Geologic Map of Lake Clark National Park and Preserve](#)

Index Map

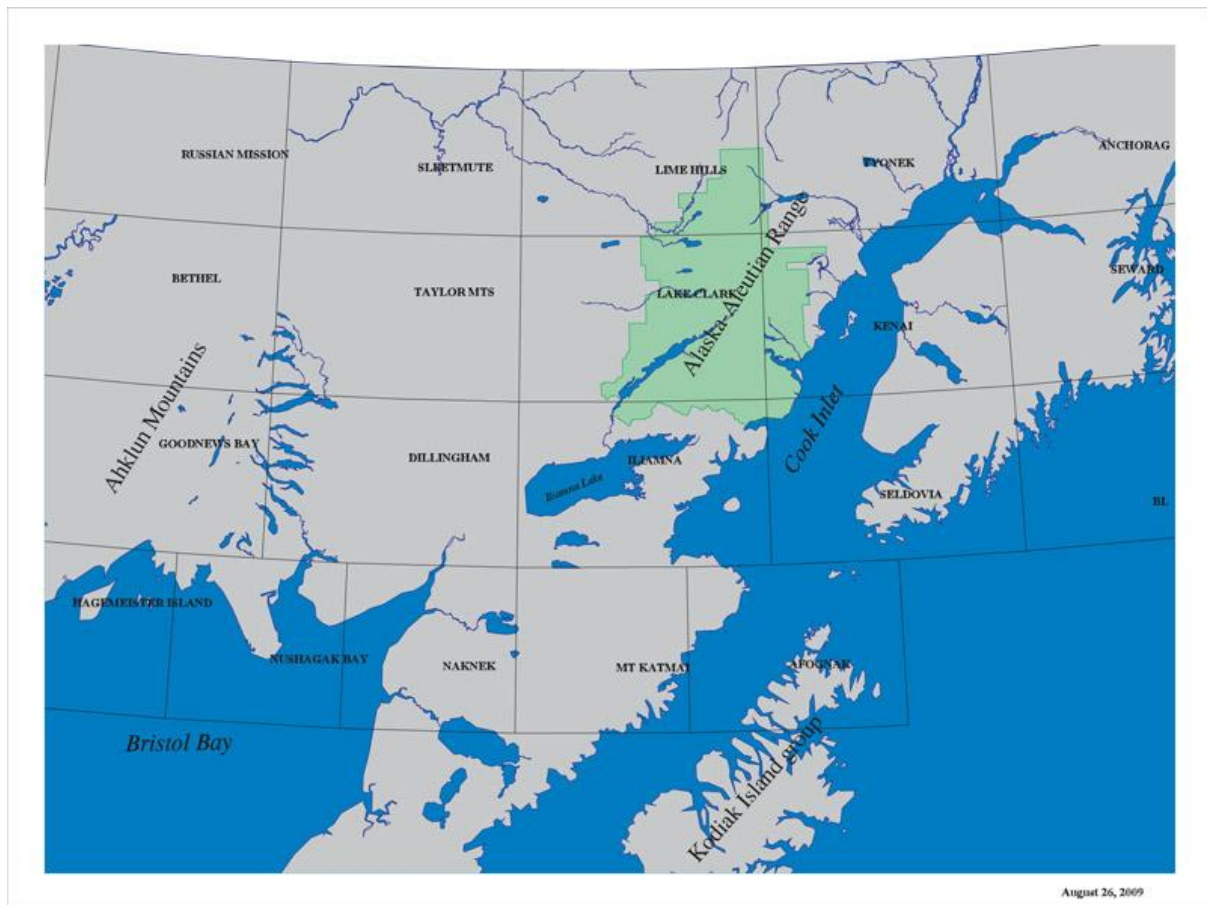


Figure 1. Index map showing boundaries of the Dillingham, Taylor Mountains, Iliamna, Lake Clark, Kenai, and Seldovia quadrangles, major regional features, and named features outside of map area.

Graphic from source map: [Quaternary Geologic Map of Lake Clark National Park and Preserve](#)

Index Map of Weather Stations

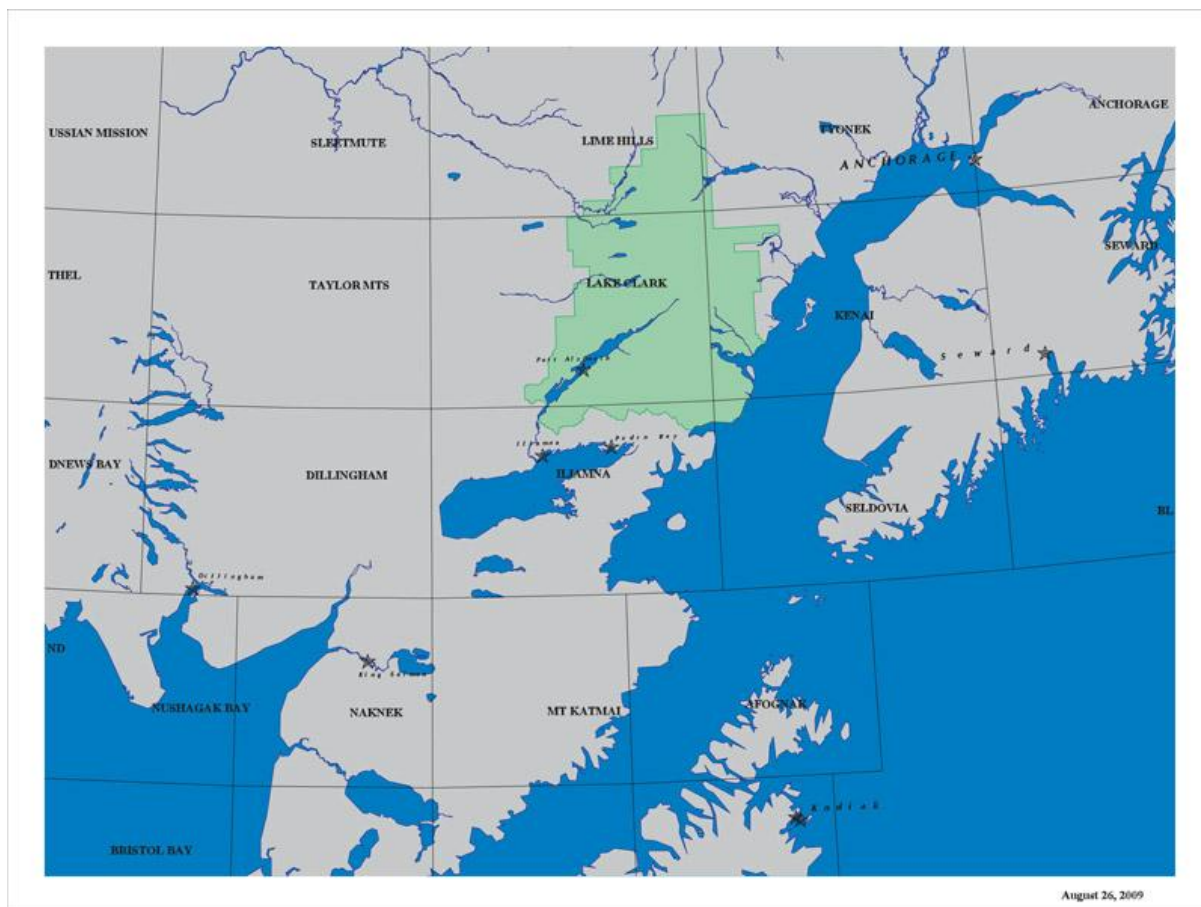


Figure 2. Index map showing locations of weather stations in table 1.

Graphic from source map: [Quaternary Geologic Map of Lake Clark National Park and Preserve](#)

Fan Deposits

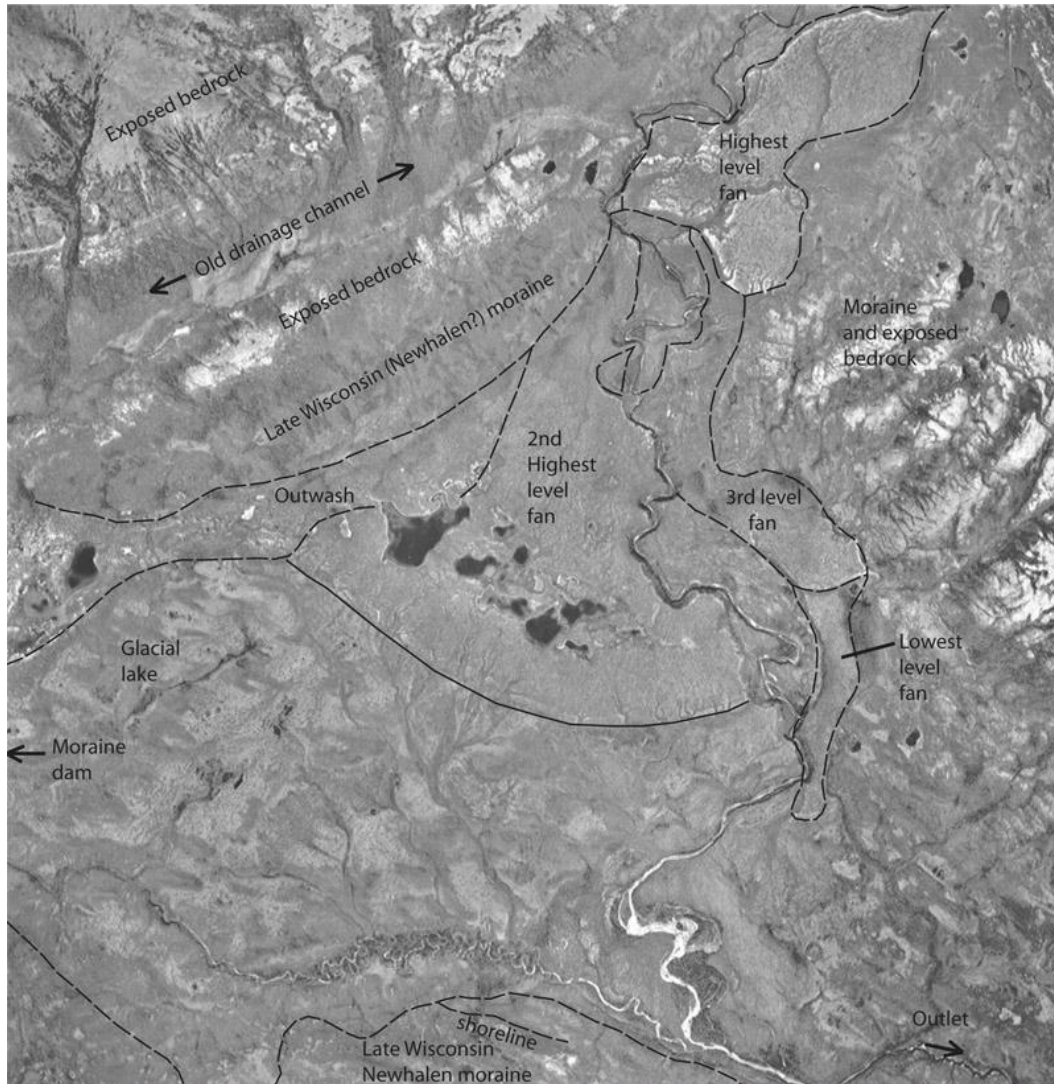


Figure 3. Last glacial maximum fan-like deposits along the Koksetna River. A large volume of glacially derived sediment was deposited a succession of fan-like forms into an ephemeral lake. This lake was dammed behind a probable Newhalen(?) advance glacial moraine (west of image). The lake apparently drained along the present east flowing path of the Koksetna River, which we interpret was temporarily blocked by a glacier in the Lake Clark basin to the southeast. As the glacier to the southeast receded, it allowed successive episodes of drainage from the lake and therefore lowering of lake level, resulting in the construction of a series of fan-like deposits at different levels. Finally, the entire lake drained, as the Koksetna River continued to flow to the southeast, down cutting through bedrock, leaving entrenched meanders, before finally turning west again (south of this image). These fan-like deposits, representing as much as 1.5 km³ of sediment were deposited in a relatively short time interval between the last two major advances of the Brooks Lake Glaciation (Photo 4155, Mission M-217, July 10, 1957).

Graphic from source map: [Quaternary Geologic Map of Lake Clark National Park and Preserve](#)

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The information contained here was compiled to accompany the digital geologic-GIS map(s) and other digital data for Lake Clark National Park and Preserve, Alaska (LACL) developed by Ron Karpilo (Colorado State University) with additional support and cooperation from Ric Wilson (U.S. Geological Survey, Alaska Science Center), Page Spencer (Lake Clark National Park and Preserve), and Bruce Giffen (NPS Alaska Regional Office). GIS data quality control by Jim Chappell and Stephanie O'Meara (Colorado State University).

GRI finalization by Stephanie O'Meara and Ron Karpilo (Colorado State University).

GRI program coordination and scoping provided by Bruce Heise and Tim Connors (NPS GRD, Lakewood, Colorado).