



Pre-Permitting Environmental/ Socio-Economic Data Report Series

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# Report Series C-Surficial Geology

## Report C-1 Surficial Geologic Map of the Pebble Project

2007

*Preliminary data. Do not cite or quote.*

The Pebble Partnership is providing environmental and socio-economic baseline data collected in support of the Pebble Project to state and federal agencies, project stakeholders and the general public prior to project permitting as part of its commitment to full and open disclosure.

A comprehensive Environmental Baseline Document (EBD) will subsequently be prepared and appended to future project permit applications. The EBD will also be made publicly available when complete.

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**SURFICIAL GEOLOGIC MAP OF THE  
PEBBLE LIMITED PARTNERSHIP'S  
PEBBLE PROJECT**

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## EXECUTIVE SUMMARY

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The Pebble Project map area was affected by Pleistocene-age glaciers from two sources. Ice flowed southwestward down the Lake Clark structural trough then split into separate ice tongues that followed the present-day Chulitna and Newhalen drainages; these glaciers penetrated the map area from the north and northeast, respectively. A second major ice body that probably overflowed westward from Cook Inlet filled the broad basin of Iliamna Lake and expanded northward into southern parts of the map area. At various times, these glaciers blocked each of the three major drainages in the Pebble project area—Upper Talarik Creek and the North and South Forks of Koktuli River. The resulting ice-dammed lakes filled lowlands in headward parts of each drainage. Subsequent ice wastage was by stagnation rather than retreat of glacial termini, resulting in extensive areas of ice-contact meltwater deposits and in numerous meltwater channels that today are abandoned or contain only very small streams. Lakes enclosed behind moraine dams persisted in some lowlands.

The surficial geology of the map area is dominated by arcuate end moraines, meltwater deposits with abundant kettle depressions, broad outwash aprons and elongate valley trains, and striking meltwater channels. Former glacier-dammed lakes are marked by broad expanses of unusually smooth, poorly drained, and gently sloping terrain that terminate abruptly upslope at consistent altitudes and are commonly bordered by beach and deltaic deposits.

At least four episodes of glaciation are recognized in the map area. The oldest, which

preceded the Brooks Lake glaciation of Detterman and Reed (1973), is marked by ice-abraded uplands with thin patches of drift and by a conspicuous moraine in the southwest part of the map area. Both North and South Forks of Koktuli River were dammed by glaciers during this time. The younger three glacial advances correspond to the three oldest stades of the Brooks Lake glaciation, which Detterman and Reed (1973) equate with the late Wisconsin glacial substage of the standard North American glacial succession. This interval is dated at about 26,000 to 10,000 radiocarbon years before present ( $^{14}\text{C}$  yr BP) elsewhere on the Alaska Peninsula (Stilwell and Kaufman, 1996) and at about 25,000 to 10,000  $^{14}\text{C}$  yr BP in the upper Cook Inlet region (Reger and Pinney, 1997). During each of the two oldest stades, termed Kvichak and Iliamna, by Detterman and Reed (1973), ice filled the Lake Clark trough and coalesced with the huge glacial lobe that filled the basin of Iliamna Lake. Glaciers entered the map area from both north and south at those times. During the subsequent Newhalen stade, glaciers no longer filled the basin of Iliamna Lake and extended only short distances southwest and south of Lake Clark. Glacier ice penetrated into only the extreme northeast corner and east-central margin of the map area at that time. Although no radiocarbon dates could be obtained from the map area, broadly limiting dates elsewhere on the Alaska Peninsula and correlations with upper Cook Inlet suggest that Newhalen stade glaciation may have occurred about 14,000 to 13,500  $^{14}\text{C}$  yr BP. The final meltout of stagnating glacier ice in the map area probably was complete by 10,000  $^{14}\text{C}$  yr BP.

## INTRODUCTION

The area covered by the accompanying surficial geologic map (hereafter termed the “map area”) includes nearly all of the Pebble Project claim block and extends for several miles beyond its eastern and northern boundaries (Figure 1). The map area has been strongly affected by late Pleistocene glaciation. Only very small cirque glaciers were generated within the area itself, but much larger glaciers repeatedly flowed into it from the north, east, and south. These glaciers blocked drainages, forming glacial lakes and causing probable drainage reversals. During warming episodes that followed glacial advances, the melting glaciers tended to stagnate, downwaste, and disintegrate in place, rather than retreat while remaining active (as is more common in steep mountain valleys). This downwasting led to massive outpourings of glacial meltwater that eroded

steep-sided channels that today are abandoned or carry only very small streams.

The map and accompanying report are based on airphoto interpretation, subsequent field examination of deposits utilizing shallow auger borings and test pits, then further examination of large-scale airphotos to refine unit contacts and identify small units and features that were not investigated in the field. The map and report are designed to 1) depict the unconsolidated deposits present at and very close to the surface of the study area, 2) explain the origin of those deposits, and 3) reconstruct the sequence of events by which they were formed. They are not designed to explain the entire sequence of deposits present above bedrock throughout the study area, but should be used in conjunction with drill-hole, test-pit, and groundwater hydrologic data to arrive at that determination.

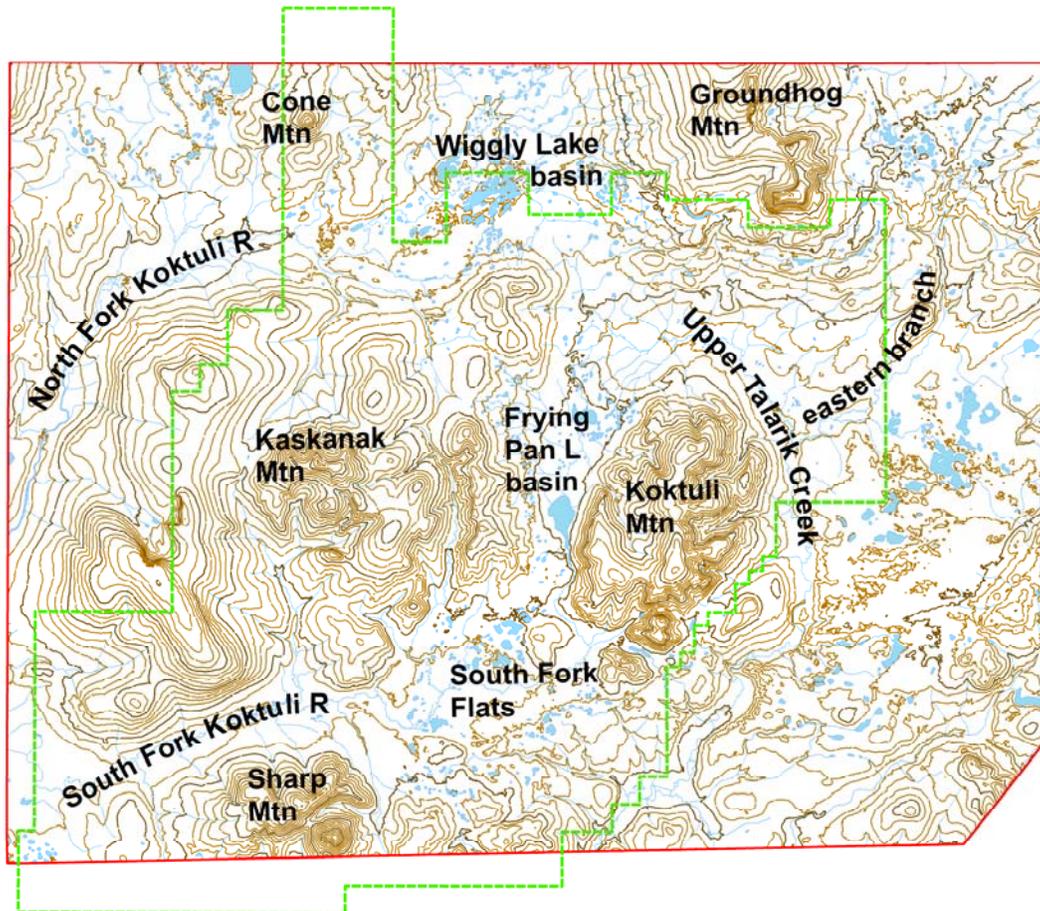


Figure 1. Pebble Project claim block (dashed line), showing boundary of surficial geologic map (in red) and place names used in the text.

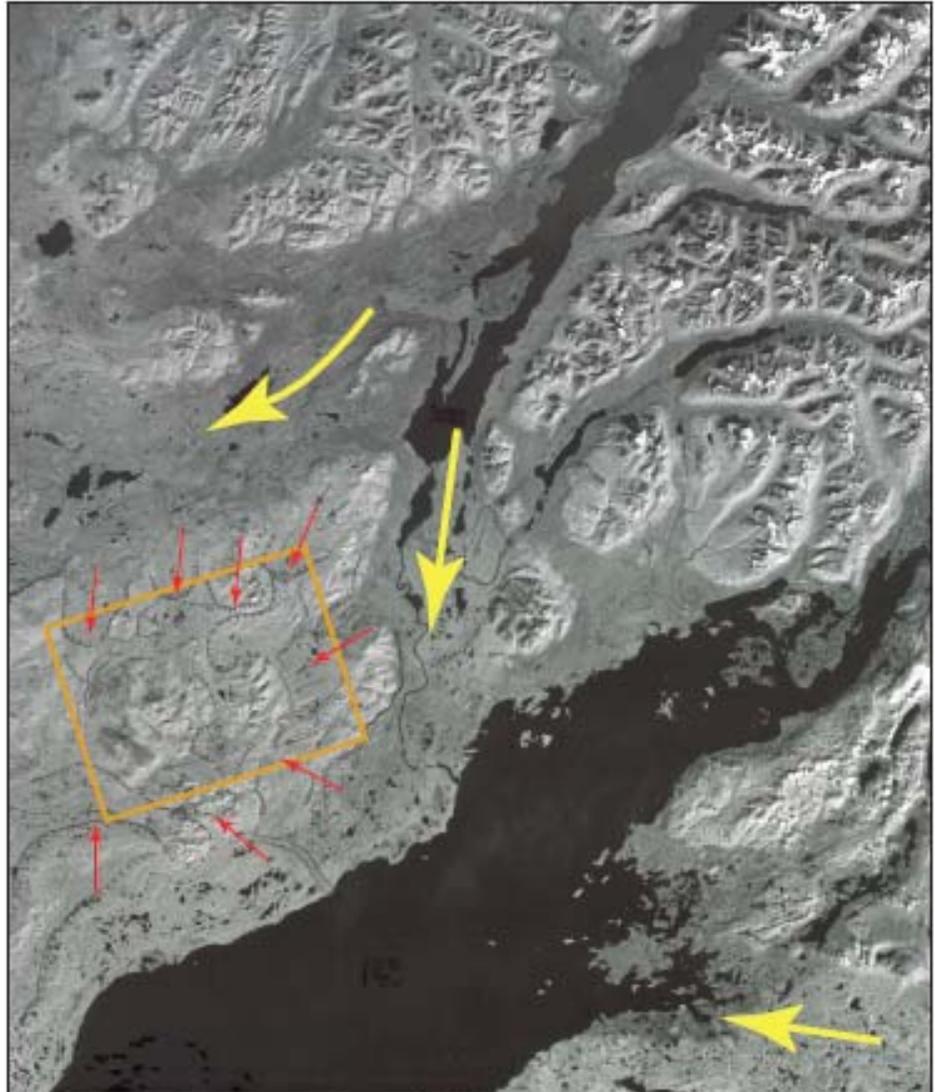
## REGIONAL SETTING

The map area is situated near the southwest end of Lake Clark, which fills a remarkably straight-sided and elongate trough (Figure 2) carved by glaciers along a zone of crustal fracture—the Lake Clark fault. This trough served as a major conduit for glaciers that originated in icefields around its headwaters. Large glaciers from those icefields repeatedly flowed south-southwest down Lake Clark trough, bifurcating near its southwest end into separate bodies that flowed 1) southwest into the Iliamna Lake area via the lowlands now occupied by the Newhalen River and 2) west-southwest toward Bristol Bay through the broad trough now occupied by the Chulitna drainage.

Iliamna Lake, which is situated immediately south of the map area, occupies a large basin that is enclosed at its west end by a very large end-moraine complex (Detterman and Reed, 1973). The origin of the successive glaciers that built that complex is not immediately obvious. Their magnitude is greater than the size of any Pleistocene glaciers known on the Alaska Peninsula (as illustrated in Detterman, 1986), and the

west-southwest (WSW) to east-northeast (ENE) orientation of Iliamna Lake differs markedly from the north-northeast (NNE) to south-southwest (SSW) orientation of Lake Clark and other fault-controlled troughs elsewhere throughout the northern Alaska Peninsula. Only limited source areas of low to moderate relief enclose the head of Iliamna Lake, so their contribution to the huge glaciers that filled its basin and constructed the massive moraines that enclose it may have been relatively minor. Ice from a large glacier complex on the continental shelf southeast of the Alaska Peninsula (Mann and Peteet, 1994) probably overflowed westward to build the moraine system that dams the present-day lake, as advocated by Stilwell and Kaufman (1996). A probable route for that overflow was west-northwest across a broad, low-lying, drift-filled trough that crosses the Aleutian Range at altitudes close to sea level and intersects the southeastern shore of Iliamna Lake (Figure 2).

The map area lies within the zone of sporadic permafrost as mapped by Ferrians (1965) and Brown and others (1997), although it is very close to that zone's southern limit. Apparent thaw lakes in some poorly drained lowlands suggest that permafrost is present locally there. Auger tests in June 2007 encountered frozen ground at very shallow depths (30 centimeters) in those areas, but relict seasonal frost could not be distinguished from permafrost early in the summer.



*Figure 2. Satellite image of Lake Clark-Iliamna Lake area. Large yellow arrows show principal routes followed by glaciers issuing from Lake Clark trough and flowing westward from Cook Inlet into Iliamna Lake basin. Small red arrows show routes of glacier flow into surficial geologic map area (enclosed by solid line).*

## LOCAL GEOGRAPHIC SETTING AND NOMENCLATURE

The map area is drained by three principal stream systems (see Figure 1). The North and South Forks of Koktuli River drain the western half; Upper Talarik Creek and an eastern branch near its head drain the eastern half. Numerous lakes are present, many of which occupy kettle depressions in glacial deposits. Several lakes have informal names, but only three have agreed-upon general usage: Frying Pan Lake at the center of the map area, Wiggly Lake in the north-central area, and Cone Lake near the northwest corner.

Uplands form individual mountain blocks that rise to altitudes of 2,000 to 3,000 feet and control the patterns of both present-day drainage and late Pleistocene glacier flow. Because of their importance to this report, we have taken the liberty of extending the names of their most prominent peaks or bench marks on them to the mountain blocks as a whole. Accordingly, the massifs east and west of Frying Pan

Lake are termed the Koktuli and Kaskanak Mountain blocks, respectively. The Cone Mountain block stands near the northwest corner of the map area and the Sharp Mountain block near the southwest corner. Because “Pig Mountain,” in the northeast sector of the map area, is not a generally accepted name, and because that peak is subordinate to the higher and more extensive Groundhog Mountain, the entire massif is termed the “Groundhog Mountain block.”

Glacier inflow into the map area repeatedly dammed the three major drainages, creating lake-filled basins that are occupied today by poorly drained lowlands with numerous ponds and silty to clayey subsoils. Four principal basins are recognized in the map area: 1) the South Fork Flats at the head of South Fork Koktuli River, 2) the Wiggly Lake basin at the head of the Koktuli’s North Fork, 3) the Frying Pan Lake basin north of the lake with that name, and 4) lowlands at the head of Upper Talarik Creek.

## THE GLACIAL RECORD

### Glacier Distribution and Flow Patterns

The surficial geology of the map area is dominated by the direct and indirect effects of a series of late Pleistocene glaciations. Glaciers flowed into the map area from four directions. Overflow from the Chulitna arm of the Lake Clark glacier entered northern parts of the map area west of the Cone Mountain block, east of the Groundhog Mountain block, and between those two upland areas

(Figure 3). A broad trough carved into bedrock in the east-central part of the map area reflects the influx of southwest-flowing glacier ice derived from the Newhalen fork of the Lake Clark glacier. The massive Iliamna Lake glacial lobe also encroached on the extreme southwest corner of the map area and extended into south-central and southeastern areas of the map as well.

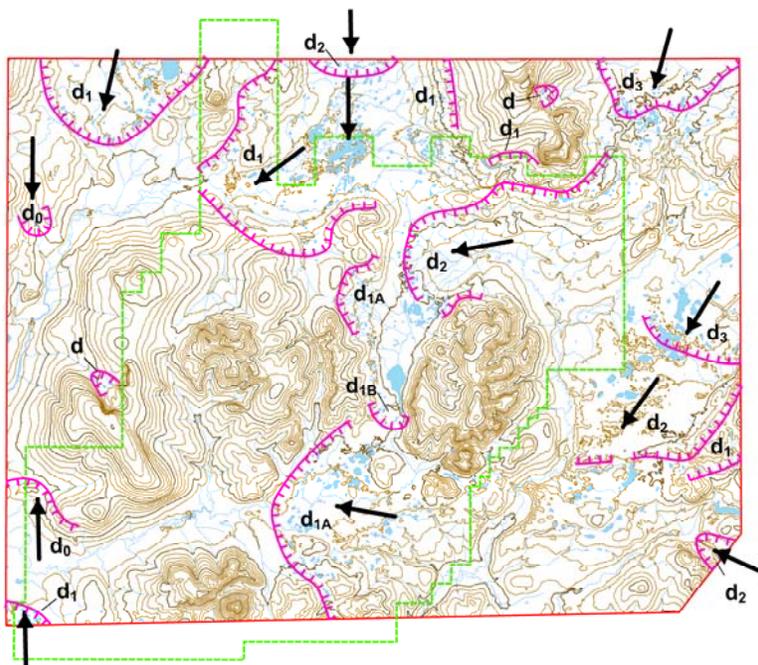


Figure 3. Pebble Project map area, showing principal end moraines deposited by glaciers of middle to late Pleistocene age ( $d_0$ , oldest;  $d_3$ , youngest). Discontinuous moraine fragments not shown.

Small glaciers issued from a cirque on the Groundhog Mountain block and from a pair of cirques on the western flank of the Kaskanak Mountain block. A small ice cap above the Kaskanak

cirques must have existed at one time and been the source for morainal deposits and trains of erratic boulders in the south-trending valley that bisects the Kaskanak Mountain block.

### Glacial Sequence and Correlations

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Surficial deposits relating to four glacial intervals are recognized in the map area. The oldest deposits (designated **d<sub>0</sub>**) reflect one or more glaciations that preceded the last glacial maximum. These deposits generally are restricted to isolated erratic boulders and cobbles and to thin and discontinuous patches of drift that overlie bedrock at altitudes above the limits of younger glacial advances. However, a well-defined moraine is associated with those bedrock features in the southwest corner of the map area, and a probable end moraine occurs near the mouth of an unnamed northern tributary to North Fork Kaktuli River near the map's northwest corner. These moraines may be assignable to the Mak Hill glaciation, which preceded the Brooks Lake advances (Muller, 1953; Detterman and Reed, 1973). Mak Hill deposits are undated, but known to be older than 39,400 radiocarbon years BP (<sup>14</sup>C yr BP) (Mann and Peteet, 1994).

Three younger glacial advances formed distinctive sets of arcuate end moraines and associated glacial deposits (map units **d<sub>1</sub>**, **d<sub>2</sub>**, and **d<sub>3</sub>**, from oldest to youngest) through most of the lowlands within the map area. Based on prior mapping by Detterman and Reed (1973), these advances, from oldest to youngest, are assignable to the Kvichak, Iliamna, and Newhalen stades of the Brooks Lake glaciation, which they correlate with the Late Wisconsin substage of the standard North American glacial chronology. Although not directly dated within the map area, this episode of glaciation probably falls within the age range of 26,000 to 10,000 <sup>14</sup>C yr BP indicated by radiocarbon dating elsewhere on the Alaska Peninsula (Stilwell and Kaufman, 1996). Radiocarbon dates from Kodiak Island and the Kenai Peninsula suggest a comparable age range of about 25,000 to 10,000 <sup>14</sup>C yr BP for the last glacial succession in that region (Reger and Pinney, 1997). Widespread eolian deposits derived from glacial outwash around the head of Bristol Bay date 25,000 to 12,500 <sup>14</sup>C yr BP (Lea, 1990), suggesting glacial maxima within that general age range as well.

During the Kvichak and Iliamna stades, very large glacier lobes filled the Iliamna Lake basin, and expanded northward into southern parts of the map area. Concurrently, the two arms of the Lake Clark glacier flowed southward to coalesce with the

Iliamna Lake ice and westward to fill the upper valley of Chulitna River. Ice from these sources flowed into northern and northeastern parts of the map area. These advances are undated in the map area, but outwash assigned to the Kvichak stade buried organic deposits dated about 26,500 to 26,000 <sup>14</sup>C yr BP in two nearby drainages (Mann and Peteet, 1994; Stilwell and Kaufman, 1996). The termination of two comparable advances in Cook Inlet is dated by Reger and Pinney (1997) at about 16,500 to 16,000 <sup>14</sup>C yr BP. Ice retreated from most of Cook Inlet at that time, and no longer could have overflowed into the basin of Iliamna Lake.

During the Newhalen stade, the youngest advance recognized in the map area, ice flowed from the Lake Clark region into extreme northeastern and east-central parts of the map area. Moraines assignable to the Newhalen stade have narrower crests and markedly steeper flanking slopes than moraines of the Kvichak and Iliamna stades, suggesting that a considerable time span may have separated the younger event from the two older ones (Stilwell and Kaufman, 1996). Although no radiocarbon dates are available for the Newhalen stade in the map area, its possible correlation with the widespread Elmendorf advance in upper Cook Inlet suggests that an age of about 14,000 to 13,500 <sup>14</sup>C yr is likely (Schmoll and others, 1972; Reger and others, 1995). A terrace around Iliamna Lake that is correlated with the Newhalen stade was deposited sometime before 12,600 <sup>14</sup>C yr BP, (Kaufman and Stilwell, 1997), lending some support to that age inference. The Lethe tephra, a widespread volcanic ash that originated in the Katmai area, occurs on glacial deposits that formed following the Newhalen stade (Pinney and Begét, 1991). Although tephra closely resembling the type Lethe bed are now known to have formed during repeated eruptions (Riehle and others, in press), a single bed dated at about 13,000 <sup>14</sup>C yr BP is most widely present on the Alaska Peninsula north of the Katmai area. This tephra therefore may provide a further minimum limiting age on deposits of the Newhalen stade.

Glaciers in upper Cook Inlet had retreated into mountain valleys by 10,000 <sup>14</sup>C yr BP (Reger and Pinney, 1997), and the warmest postglacial temperatures in Alaska were recorded during that time and shortly thereafter (Kaufman and others, 2004). Final meltout of stagnating glaciers in the map area must have taken place by that time.

## Glacial Morphology

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Glacial deposits within the map area form generally arcuate end moraines that enclose areas of irregular hummocky drift (sometimes termed “ground moraine”) with abundant dry to water-filled kettle depressions. Sharp linear moraine crests (linear stippled symbol on map) are common but not universally present. Outwash gravel forms broad aprons and linear belts (valley trains) that extend downslope or downvalley from terminal moraines (map units **o<sub>1</sub>**, **o<sub>2</sub>**, and **o<sub>3</sub>**, from oldest to youngest). Outwash segments close to moraine fronts commonly are kettled, indicating that meltwater streams developed headward above stagnant and downwasting glacier ice. These kettled segments are

designated by compound units (**o/d**, with appropriate subscripts). Ice-contact meltwater deposits that formed as glaciers downwasted (unit **i-c**) are represented by irregular terrain with conical to subdued mounds, short ridges, abundant dry to water-filled kettle depressions, and meltwater channels that contain little or no modern drainage. Meltwater deposits in the South Fork Flats and east of the Upper Talarik drainage contain numerous small kettle depressions 20 to 30 meters in diameter and generally 3.0 to 3.5 meters deep. These features may have been formed by meltout of icebergs carried from disintegrating glacier termini, perhaps by periodic floods that burst out from beneath those glaciers.

## Glacier-Dammed Lakes

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Influx of glaciers into the map area disrupted pre-existing drainage patterns. Glaciers impounded lakes as they advanced to their maximum positions, then built moraines that enclosed additional lakes during subsequent glacial downwastage and retreat. Most of these former lakes are now dry, but are represented by smooth-surfaced, poorly drained expanses of silt-rich sediment with negligible to moderate slope. These deposits terminate abruptly upslope at consistent altitudinal limits. Distinctive linear beach ridges fronting on wave-planed platforms (unit **b**) also define lake limits, and delta and fan-delta deposits (units **dt** and **fd**, respectively) are distinctive landforms at places where meltwater streams entered the lakes. Deposits are rare where the lakes lapped up against areas of more rugged relief, but erosional morphology smooths bedrock outcrops and modifies glacial deposits in those areas. The modified terrain commonly terminates upslope at wave-eroded notches, also at consistent altitudinal limits. The former lake limits define generally horizontal planes through the central part of the map area, but appear to rise by 100 feet or more toward its northeast corner. This tilting of the lake planes is a common response to isostatic rebound, which is greatest where former glaciers were thickest and most extensive.

Three major lake stages are recognized within the map area. The oldest (unit **gl<sub>1</sub>**) rises to altitudes of about 1,170 feet in the Wiggly Lake basin and may

occur locally around the basin north of Frying Pan Lake. This former lake was enclosed within deposits of Kvichak-stade glaciers (unit **d<sub>1</sub>**), and therefore, dates from the deglaciation phase of that event. The next younger lake deposits (unit **gl<sub>2</sub>**) formed during and after the Iliamna-stade advance. These deposits rise to maximum altitudes of about 1,060 feet in the basin north of Frying Pan Lake and across the broad valley floor at the head of Upper Talarik Creek. They may rise higher farther to the northeast near the headwaters of the Talarik’s eastern branch. Deposition of the youngest lake sediments (unit **gl<sub>3</sub>**), which rose from 800 to 900 feet altitude northeastward along the drainage of Upper Talarik Creek, followed the Iliamna stade later during its deglaciation and continued during and after the Newhalen stade. The lake surface progressively lowered with time as Upper Talarik Creek eroded downward through the moraine complex along the north margin of Iliamna Lake that had confined that drainage. Based on presence of the Lethe tephra, Kaufman and Stilwell (1997) determined that Iliamna Lake (which serves as base level for the Upper Talarik) would have been lowered to within 100 feet of its present surface by 12,600 <sup>14</sup>C yr BP. The last large glacial-age lakes in the map area must have been drained by that time.

## SYNTHESIS

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The Pebble Project map area and its drainage system have been strongly impacted by the effects of repeated late Pleistocene glaciations. During the oldest of these advances, which preceded the Brooks Lake glaciation of late Wisconsin age, glaciers expanding northward from Iliamna Lake dammed the South Fork of Koktuli River near the southwest corner of the map area (Figure 4). Glacier ice also approached the Koktuli’s North Fork, and that glacier

or its outwash may have dammed that drainage as well. A probably contemporaneous south-flowing glacier penetrated the valley complex that divides the Kaskanak Mountain block into eastern and western halves, and a small ice cap may have formed on the western part of the Kaskanak block at that time. Through central and eastern parts of the map area, evidence for pre-Brooks Lake

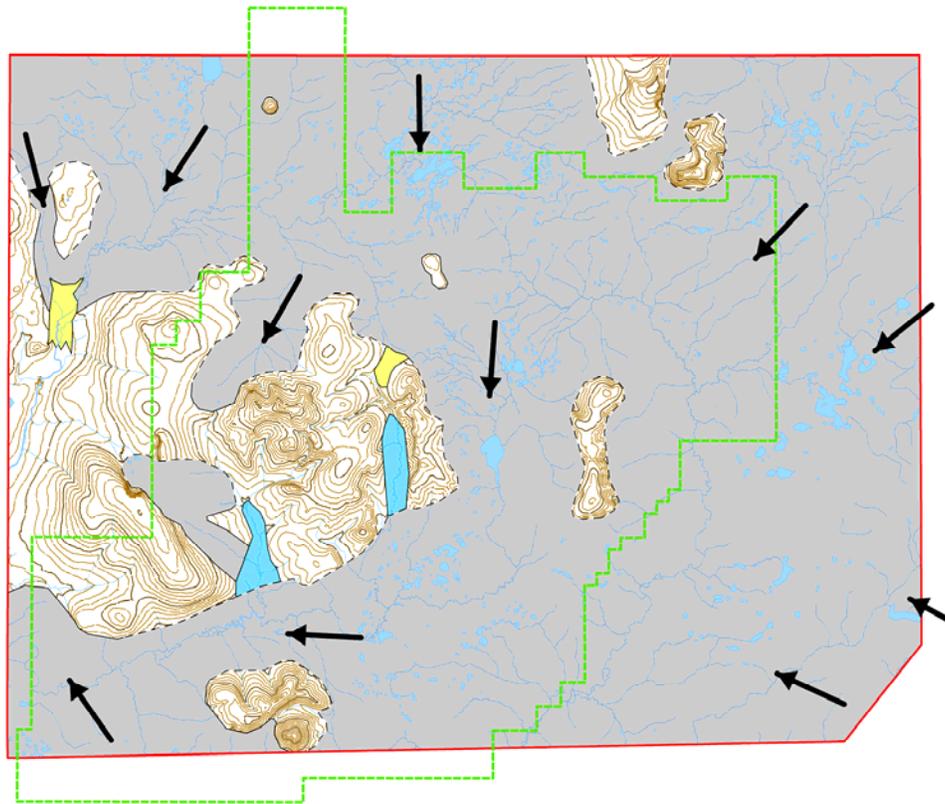


Figure 4. Pebble Project map area, showing distribution of glaciers (light gray), outwash (yellow), and glacial lakes (blue) during pre-Brooks Lake glaciation(s). Unit boundaries dashed where speculative. Thick arrows, glacier flow directions.

glaciation is preserved primarily on uplands above the limits of extensive younger glacial advances. Erratic boulders and dispersed patches of drift occur along the west flank of Groundhog Mountain to nearly 2,000 feet altitude. Similar erratics and drift patches occur to about 1,500 feet in north-central parts of the map area and to perhaps 1,400 feet in south-central parts. These limits appear to define a coalescent glacier complex with surface gradient inclined toward the southwest that covered all but upper parts of the major mountain blocks.

During the Kvichak stade, the initial and most extensive advance of the Brooks Lake glaciation, glaciers entered western parts of the map area from both north and south, but they did not coalesce there (Figure 5). Farther east, large glaciers penetrated the map area from the north, south, and east; and these glaciers coalesced through most lowlands. Ice covered all but the highest mountain blocks through eastern parts of the map area, and extended for short distances farther west into headwaters of the North and South Forks of Koktuli River. Cirques on the Groundhog Mountain and Kaskanak Mountain blocks probably were active at this time, generating small glaciers.

During the succeeding Iliamna stade, glaciers penetrated the map area primarily from the northeast; they coalesced into a large mass that then bifurcated into a western lobe that filled the headwaters of

Upper Talarik Creek and a southern lobe that extended down that creek (Figure 6). Both lobes probably terminated in lakes that had been dammed behind end moraines deposited during the preceding Kvichak stade. At that time, smaller glaciers entered the north-central and southeastern parts of the map area, but they did not extend far into it.

Two separate glaciers entered the eastern part of the map area for short distances during the Newhalen stade (Figure 7). An arcuate end moraine in the northeast corner of the map area forms the drainage divide at the head of Upper Talarik Creek's eastern fork. A second glacier entered the east-central part of the map area from the valley of Newhalen River, but its moraine and outwash are discontinuous. The glacier probably terminated in a glacial lake whose surface stood at about 800 to 850 feet above sea level in that part of the map area, as defined by wave-cut notches, beach complexes, and deltas.

The Brooks Lake glaciation probably began about 26,000 <sup>14</sup>C yr BP. Its two oldest stades, Kvichak and Iliamna, had terminated by about 16,500 to 16,000 yr BP, and the glaciers during the subsequent Newhalen stade may have been at their maximum extent about 14,000 to 13,500 yr BP. Deglaciation of the study area probably was complete by 10,000 yr BP.

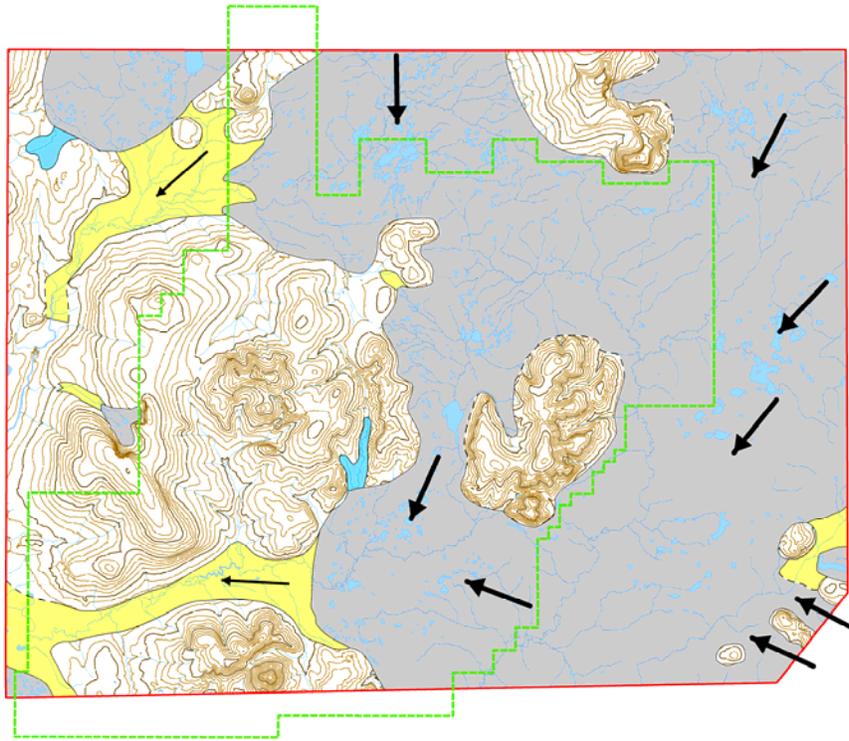


Figure 5. Distribution of glaciers and related features during Kvichak stade of Brooks Lake glaciation. Colors as in Figure 4. Thick arrows, glacier flow directions; slender arrows, meltwater flow directions.

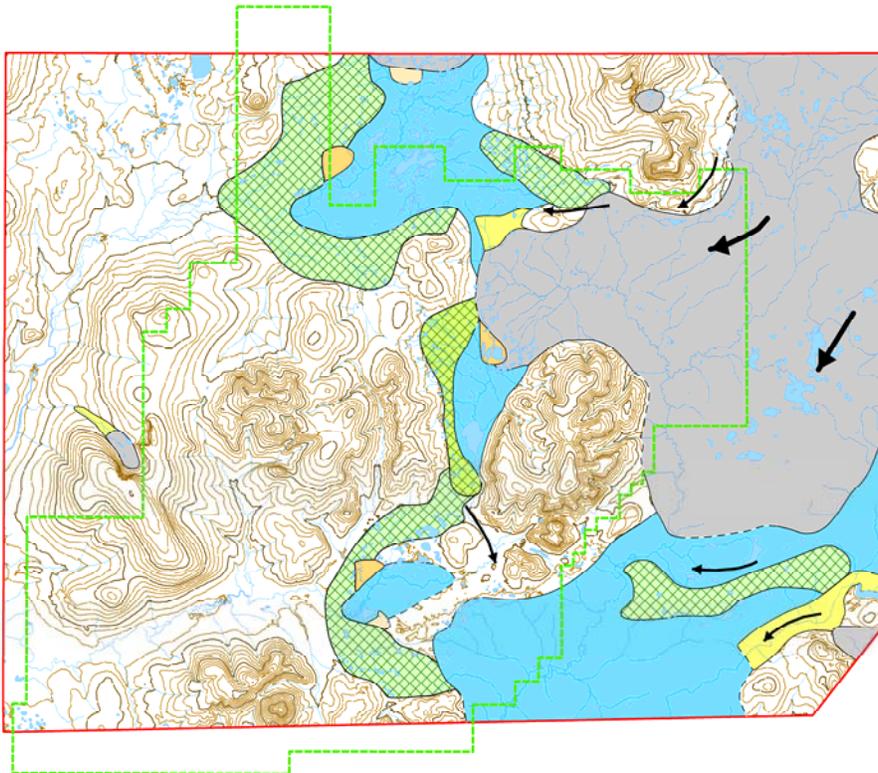


Figure 6. Distribution of glaciers and related features during Iliamna stade of Brooks Lake glaciation. Colors and symbols as in figs. 4-5. Moraine dams green with cross-hatched pattern; delta and fan-delta deposits orange.

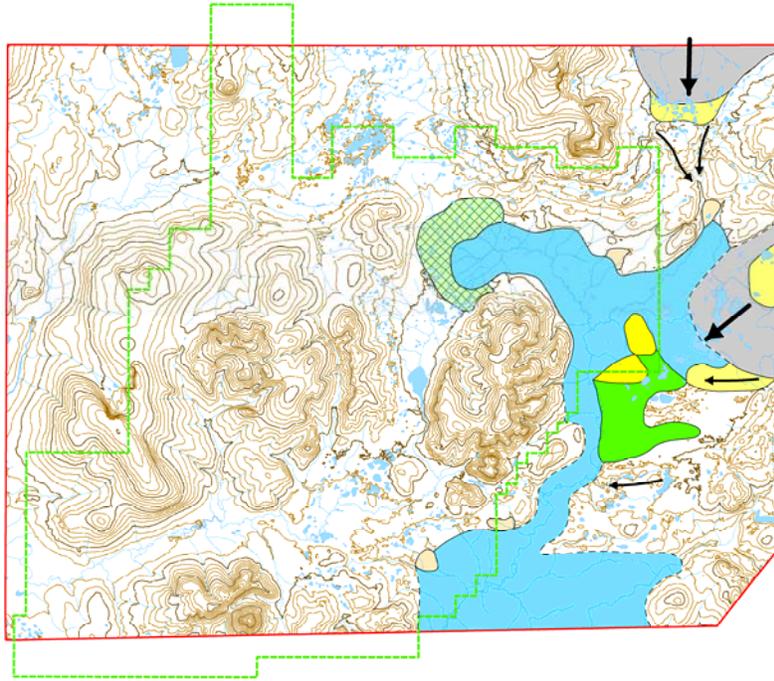


Figure 7. Distribution of glaciers and related features during Newhalen stade of Brooks Lake glaciation. Colors and symbols as in figs. 4-6. Stagnant-ice deposits green.

## REFERENCES CITED

- Brown, J., Ferrians, O.J., Jr., Heginbottom, J.A., and Melnikov, E.S., 1997, Circum-Arctic map of permafrost and ground-ice conditions: U.S. Geological Survey, Circum-Pacific Map Series CP-45, scale 1:10,000,000, 1 sheet.
- Detterman, R.L., 1986, Glaciation of the Alaska Peninsula, in Hamilton, T.D., Reed, K.M., and Thorson, R.M., eds., *Glaciation in Alaska—The geologic record*: Anchorage, Alaska Geological Society, p. 151-170.
- Detterman, R.L. and Reed, B.L., 1973, Surficial deposits of the Iliamna quadrangle, Alaska: U.S. Geological Survey Bulletin 1368-A, p. A-1-A-64.
- Ferrians, O.J., Jr., 1965, Permafrost map of Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-445, scale 1:2,500,000, 1 sheet.
- Kaufman, D.S., and Stilwell, K.B., 1997, Preliminary evaluation of emergent postglacial shorelines, Naknek and Iliamna Lakes, southwestern Alaska, in Doumoulin, J.A., and Gray, J.E., eds., *Geologic Studies in Alaska by the U.S. Geological Survey, 1995*: U.S. Geological Survey Professional Paper 1574, p. 73-81.
- Kaufman, D.S., and 29 others, 2004, Holocene thermal maximum in the western Arctic (0-180°W): *Quaternary Science Reviews*, v. 23, p. 529-560.
- Lea, P.D., 1990, Pleistocene periglacial eolian deposits in southwestern Alaska: Sedimentary facies and depositional processes: *Journal of Sedimentary Petrology*, v. 60, p. 582-591.
- Mann, D.H., and Peteet, D.M., 1994, Extent and timing of the last glacial maximum in southwestern Alaska: *Quaternary Research*, v. 42, p. 136-148.
- Muller, E.H., 1953, Northern Alaska Peninsula and eastern Kilbuck Mountains, Alaska, in Péwé, T.L., and others, *Multiple glaciation in Alaska, a progress report*: U.S. Geological Survey Circular 289, p. 2-3.
- Pinney, D.S., and Begét, J.E., 1991, Late Pleistocene volcanic deposits near the Valley of Ten Thousand Smokes, Katmai National Park, Alaska, in Reger, R.D., ed., *Short Notes on Alaskan Geology 1991*: Alaska Division of Geological & Geophysical Surveys Professional Report 111, p. 45-54.
- Reger, R.D., Combellick, R.A., and Brigham-Grette, Julie, 1995, Late-Wisconsin events in the upper Cook Inlet region, southcentral Alaska, in Combellick, R.A., and Tannian, Fran, eds., *Short Notes on Alaskan Geology, 1995*: Fairbanks, Alaska Division of Geological & Geophysical Surveys Prof. Report 117, p. 33-45.
- Reger, R.D., and Pinney, D.D., 1997, Last major glaciation of Kenai Lowland, in Karl, S.M., Vaughn, N.R., and Ryherd, T.J., eds., 1997 guide to the geology of the Kenai Peninsula, Alaska: Anchorage, Alaska Geological society, p. 54-67.
- Riehle, J.R., Ager, T.A., Reger, R.D., Pinney, D.S., and Kaufman, D.S., in press, Stratigraphic and compositional complexities of the late Quaternary Lethe tephra in south-central Alaska: *Quaternary International*, doi:10.1016/j.quaint.2006.09.006
- Schmoll, H.R., Szabo, B.J., Rubin, Meyer, and Dobrovolny, Ernest, 1972, Radiometric dating of marine shells from the Bootlegger Cove Clay, Anchorage area, Alaska: *Geological Society of America Bulletin*, v. 83, p. 1107-1113.
- Stilwell, K.B., and Kaufman, D.S., 1996, Late-Wisconsin glacial history of the northern Alaska Peninsula, southwestern Alaska, U.S.A.: *Arctic and Alpine Research*, v. 28, p. 475-487.