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# Review of the Origin of the Braid Scarp near the Pebble Prospect, Southwestern Alaska

Open-File Report 2011–1028

**U.S. Department of the Interior**
**U.S. Geological Survey**

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# Conversion Factors and Datum

## Conversion Factors

| Multiply | By | To obtain |
|---|---|---|
| centimeter (cm) | 0.3937 | inch (in.) |
| meter (m) | 3.281 | foot (ft) |
| kilometer (km) | 0.6214 | mile (mi) |

## Datum

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

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## Abstract

A linear geomorphic scarp, referred to as the “Braid Scarp,” lies about 5 kilometers north of Iliamna Lake, Alaska, and has been identified as a possible seismically active fault. We examined the geomorphology of the area and an 8.5-meter-long excavation across the scarp. We conclude that the scarp was formed by incision of a glacial outwash braid plain into a slightly older outwash plain as ice stagnated in the region during deglaciation 11–16 thousand years ago. We found no evidence for active faulting along the scarp.

## Introduction

An assessment of seismic hazards is needed prior to any significant industrial development, particularly in Alaska, where the frequency of large magnitude earthquakes is high. We were made aware of an excavation across a linear geomorphic feature, proposed as a seismically active fault trace, located about 5 km north of Iliamna Lake, near the headwaters of the east fork of Lower Talarik Creek (fig. 1). This feature is about 8 km from a large gold and copper prospect, referred to as the Pebble Project or Pebble claim block (fig. 1). The purpose of this report is to discuss our assessment of the linear geomorphic feature, comment on its likely mode of origin, and discuss what future work can be done to better understand seismic hazards in the region. The Alaska Division of Geological and Geophysical Surveys (ADGGS) completed an independent review of the Braid Scarp (Koehler, 2010). The ADGGS report reaches an identical conclusion to ours on the proposed origin of the scarp.

Our assessment of the geomorphology of the Braid Scarp and the deposits and features exposed in the excavation is based on standard practices in paleoseismology (the study of ancient earthquakes; see McAlpin, 1996). Large earthquakes commonly produce a surface rupture where the land surface is displaced across the causative fault trace. Thus, to find earthquake-producing faults, it is common practice to look for linear scarps that displace drainages and geomorphic surfaces underlain by surficial deposits. One such feature near the Pebble prospect was identified by a geological consultant (Bretwood Higman) and is referred to as the “Braid Scarp.” Higman and a crew hand excavated two trenches across the scarp in the summer 2009, and another deeper and longer trench in the summer 2010. The purpose of the excavations was to investigate the origin of the Braid Scarp, and in particular to determine if the scarp was caused by prehistoric surface rupture. Higman’s discussion and interpretation of this feature can be found at *http://www.groundtruthtrekking.org/Reports/FaultHunt01/BraidScarpTechnicalNotes.html* (last accessed: January 20, 2011). Higman asked the Alaska Division of Geological and Geophysical Surveys to review his findings, which supported evidence for active faulting across the Braid Scarp. Because of the importance of seismic hazards to possible development in the region, the U.S. Geological Survey (USGS) was asked to review Higman’s findings by the State

Geologist and Director of the Alaska Division of Geological and Geophysical Surveys. We examined the scarp and the surrounding area from a fixed-wing aircraft and spent about 6.5 hours on the ground investigating the trench on August 4, 2010.

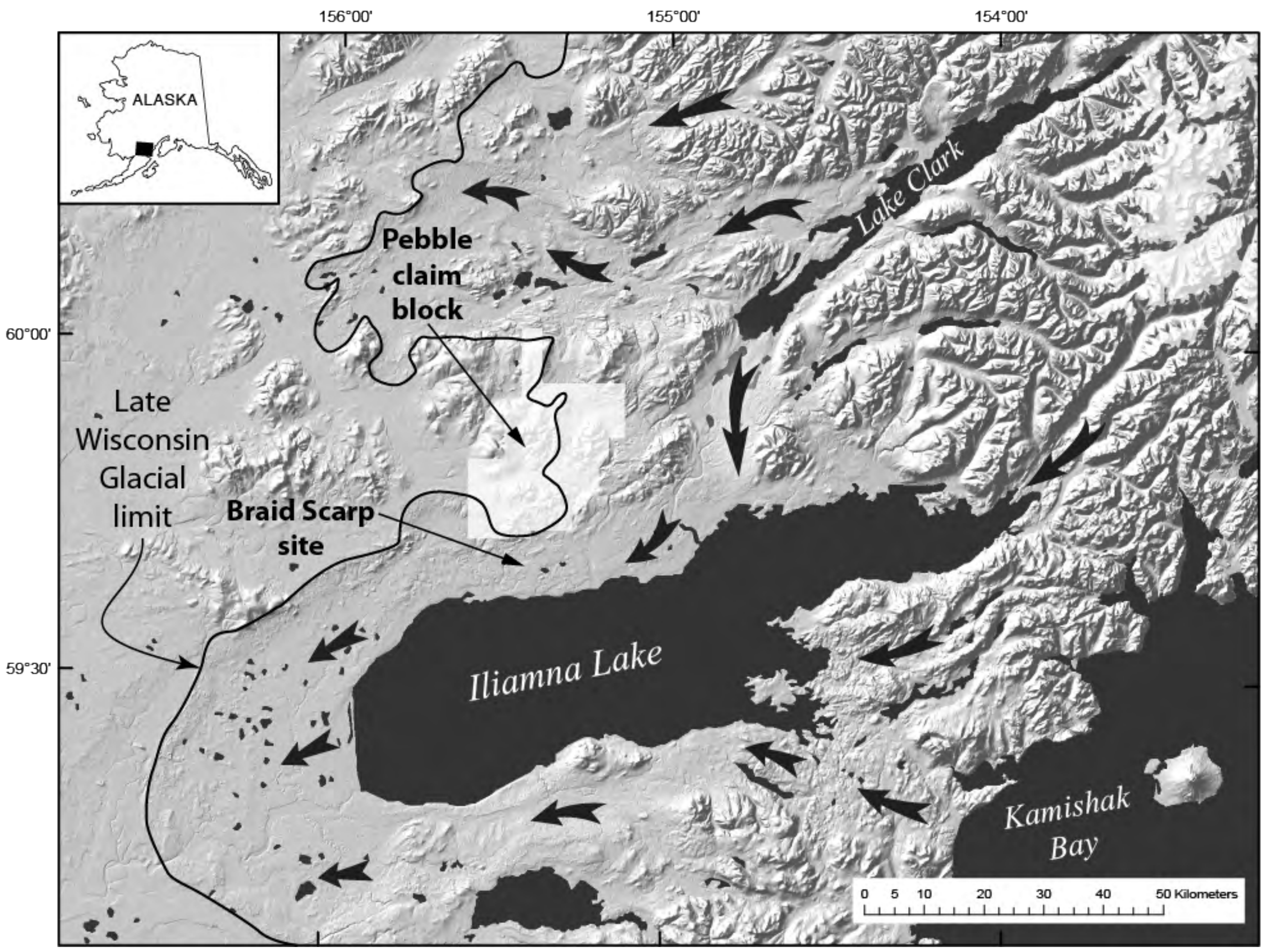


Figure 1. Overview of glacier flow directions near Braid Scarp site near Pebble Prospect, southwestern Alaska. Thick black arrows show glacier flow directions from Hamilton and Klieforth (2010). Black line shows limit of late Wisconsin glaciation from Detterman and Reed (1973), Kaufman and Stillwell (1997), Hamilton and Klieforth (2010), and F.H. Wilson (USGS, unpub. data). White polygon shows approximate area of Pebble claim block. Note that the Braid Scarp area was completely covered by glacial ice at the last glacial maximum, so all features post-date this glacial episode.

# Quaternary Geology and Geomorphology of the Braid Scarp

## Regional Setting

The Quaternary geology and geomorphology near the Braid Scarp was described in a USGS Bulletin by Detterman and Reed (1973), which included a 1:250,000-scale geologic map of surficial deposits in the Iliamna quadrangle. Their report described the surficial geology of the region, and determined that Iliamna Lake and Lake Clark were the main troughs that conveyed westward flowing glacier ice into the area during the late Pleistocene (Brooks Lake) glaciation of southwestern Alaska. The ice lobe that issued from the Lake Clark trough bifurcated, with one lobe flowing north of the Braid Scarp area, and the other flowing to the east, which eventually joined with ice in the Iliamna Lake trough. End moraines of late Pleistocene age are located west of Iliamna Lake (fig. 1). During the last glacial maximum, the entire Iliamna Lake lowland region was ice covered, including the Braid Scarp area. Following ice retreat, numerous small lakes formed in kettles in areas of melting stagnant ice. Glacial lakes also formed in areas of deep glacial scour, such as Iliamna Lake, the largest lake in Alaska. As the ice melted and isostatic rebound occurred, the level of Iliamna Lake fluctuated and lowered toward the present day lake level. Stilwell (1995) and Kaufmann and Stilwell (1997) examined beach ridges and wave-cut terraces at several locations around the lake, obtained age control for some of the shoreline features, and made correlations with glacial deposits and features elsewhere in the region. They conclude that the highest lake terrace, 40 m above the present lake level, likely formed during the Newhalen stade of the Brooks Lake glaciation of Detterman and Reed (1973), about 13,000–14,000 years ago. Hamilton and Klieforth (2010) made the first detailed (1:50,000-scale) Quaternary geologic map in the region. Although the southern boundary of their map area lies about 10 km north of the Braid Scarp, their conclusions about the glacial history of the region apply to the Braid Scarp site.

Given this regional understanding of the Quaternary history, the Braid Scarp site was completely covered by ice during the Newhalen stade of the Brooks Lake glaciation of Detterman and Reed (1973). Although there are no direct dates on the Newhalen stade in the area of the Braid Scarp, Hamilton and Kleiforth (2010) infer a correlation with the Elmendorf moraine, which was the last major ice advance in the upper Cook Inlet region (Schmoll and others, 1972; Reger and others, 1995). In previous studies, $^{14}C$ ages were obtained from the lowermost deposits that overlie the Elmendorf moraine. Using new $^{14}C$ calibrations, these deposits are between 11,300 and 15,200 calendar years B.P. (see discussion in Willis and others, 2007). More recent work by Kopczynski (2009) pushes the time of deglaciation back to 18,800 to 16,700 calendar years B.P., with retreat from the maximum by 16,400 calendar years B.P. Kaufman and Stilwell (1997) dated one of the higher lake terraces around Iliamna Lake at 12,600 $^{14}C$ years B.P., which broadly supports a correlation with the Elmendorf moraine and the Newhalen stade. These age relations and correlations suggest that the area near the Braid Scarp was covered by glacier ice until about 11,000 to 16,000 calendar years B.P. and the features and surfaces shown in figure 2 (with the exception of glacially scoured older surfaces) must have formed since then.

The geomorphology of the Braid Scarp area shows abundant evidence for glacial stagnation. Numerous kettle lakes and a sequence of abandoned braided outwash plains demonstrate that the topography was strongly shaped by melting ice (fig. 2). Near the Braid Scarp, there is only one large area 1–3 km south of the site that does not exhibit evidence for extensive erosion by meltwater (labeled Qg in fig. 2). This area is a low, level upland surface with drumlin-like ice-molded surface features, indicating a relict surface reflecting the glacial flow direction. Although we did not examine this feature in the field, we infer that it is mantled by till. This surface stands out relative to the surrounding terrain, which consists of kettle and kame topography and abandoned braided outwash surfaces.

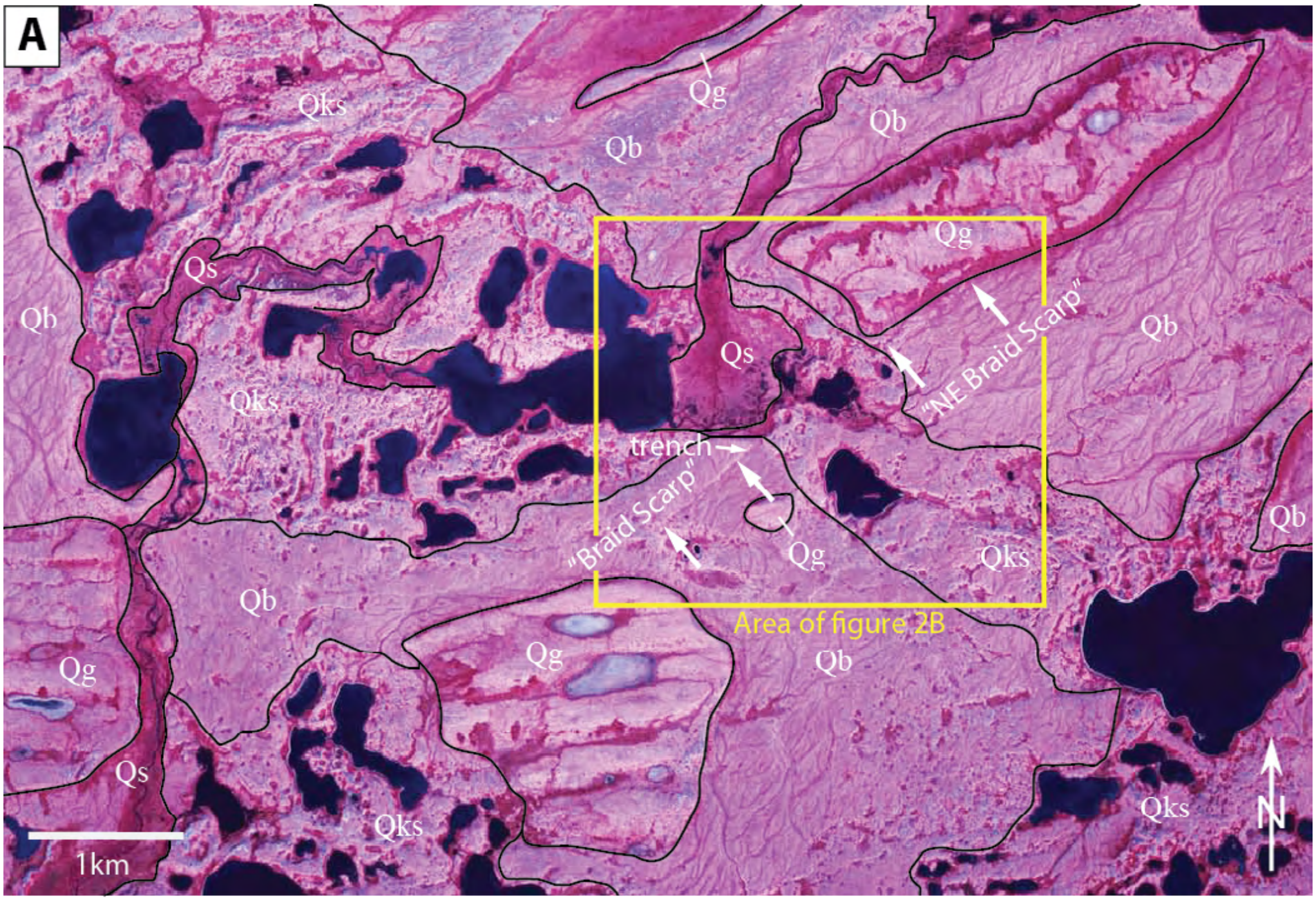


Figure 2. Color infrared photograph and simplified Quaternary geologic map of Braid Scarp area near Pebble Prospect, southwestern Alaska. (A) Overview and (B) detailed view of simplified Quaternary geology. Numerous kettle lakes characterize the geomorphology of the kame and kettle deposits (Qks), whereas older surfaces (Qg), show broad grooves that are evidence of glacial scour. Arrows show the Braid Scarp, as well as another linear feature in the area that we refer to as the northeastern Braid Scarp, which are developed in well-drained braid plain (outwash) deposits (Qb). Holocene stream deposits (Qs) post-date the glacial sediments, which likely date to the last glacial period to affect the area, locally known as the Brooks Lake glaciation of Detterman and Reed (1973). All contacts between units are approximate and some are gradational. The Braid Scarp is not expressed in the kame and kettle terrain (Qks) between the two scarp segments, and does not cross the older glacially scoured surface (Qg) to the southwest. These relationships indicate the scarp formed after ice retreat from the area, but before final melting of stagnant ice beneath the kame and kettle terrain (Qks) that may have obscured the connection between the two scarps. The limited lateral extent of the scarp is in contrast to known active faults that typically have much longer fault scarps and cross multiple geomorphic surfaces. Unit definitions: Qg, older Quaternary glacially scoured surface; Qks, Quaternary kame and kettle deposits; Qb, Quaternary braid plane deposits; Qs, Quaternary stream deposits.

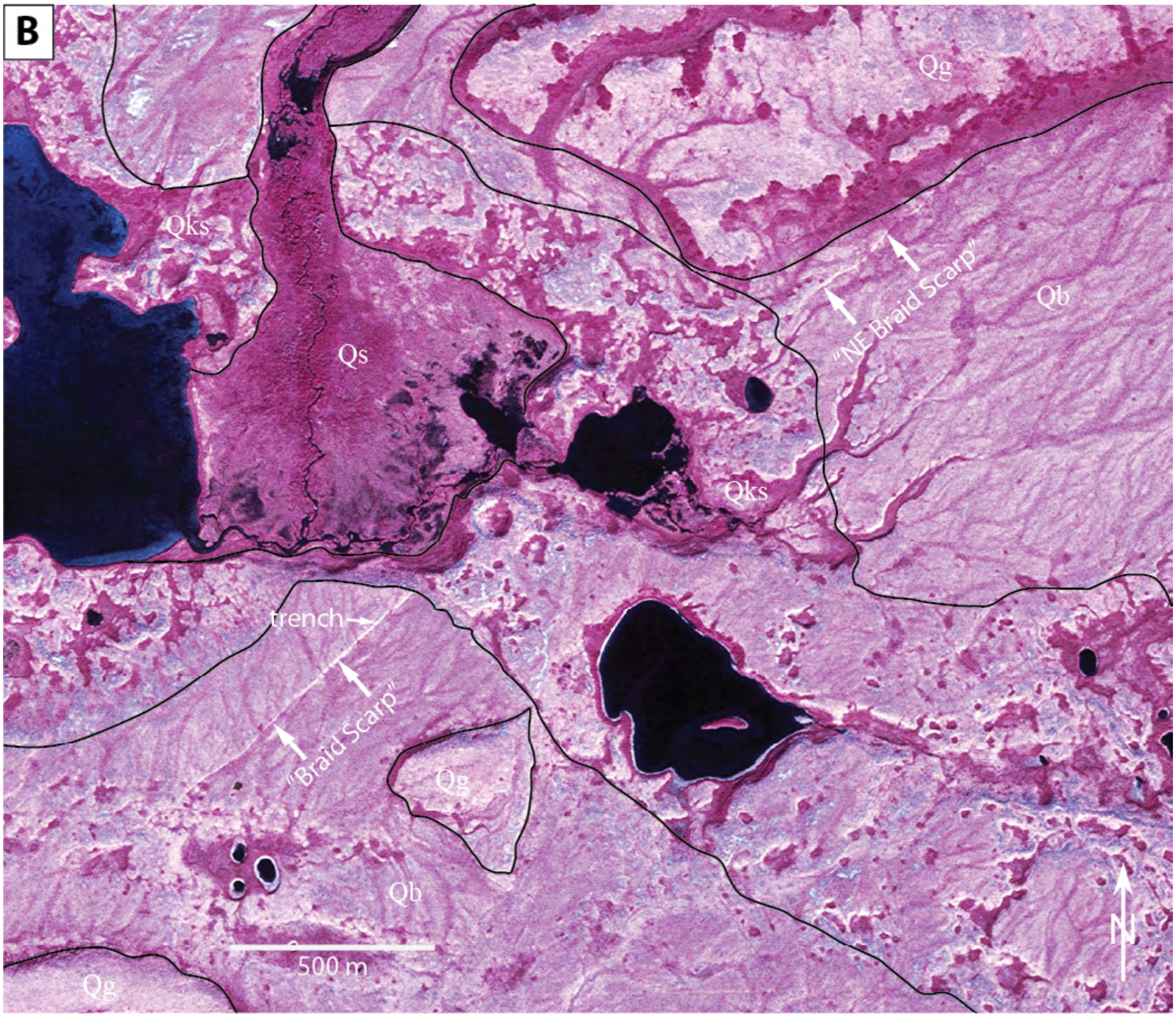


Figure 2.—Continued

## Geomorphic Characteristics of the Braid Scarp

The Braid Scarp consists of a northeast-trending, linear, 800-m-long, 1-m-high east-side-down scarp. The slope of the scarp is gentle—we estimate a maximum slope angle of less than 15 degrees (fig. 3). The scarp is linear but gently scalloped along its trace, and is quite distinct when viewed from the air (fig. 4). Another similar east-side-down linear scarp that begins about 900 m to the northeast of the Braid Scarp (herein informally termed the northeast Braid Scarp) extends about 700 m to the northeast. We observed no topographic expression of a scarp in the kettled area between these two linear features. The Braid Scarp does not cross the relict glacial surface (Qg) or the kettled surface (Qks) to the southwest (fig. 2). A wind-deflated and frost-mixed cover of reddish-brown to yellow-orange-brown silt, probably loess, mantles the braid plain (Qb) surfaces cut by the Braid Scarp and parts of the scarp itself. The area supports herbaceous shrub tundra, and local stands of willow and alder.

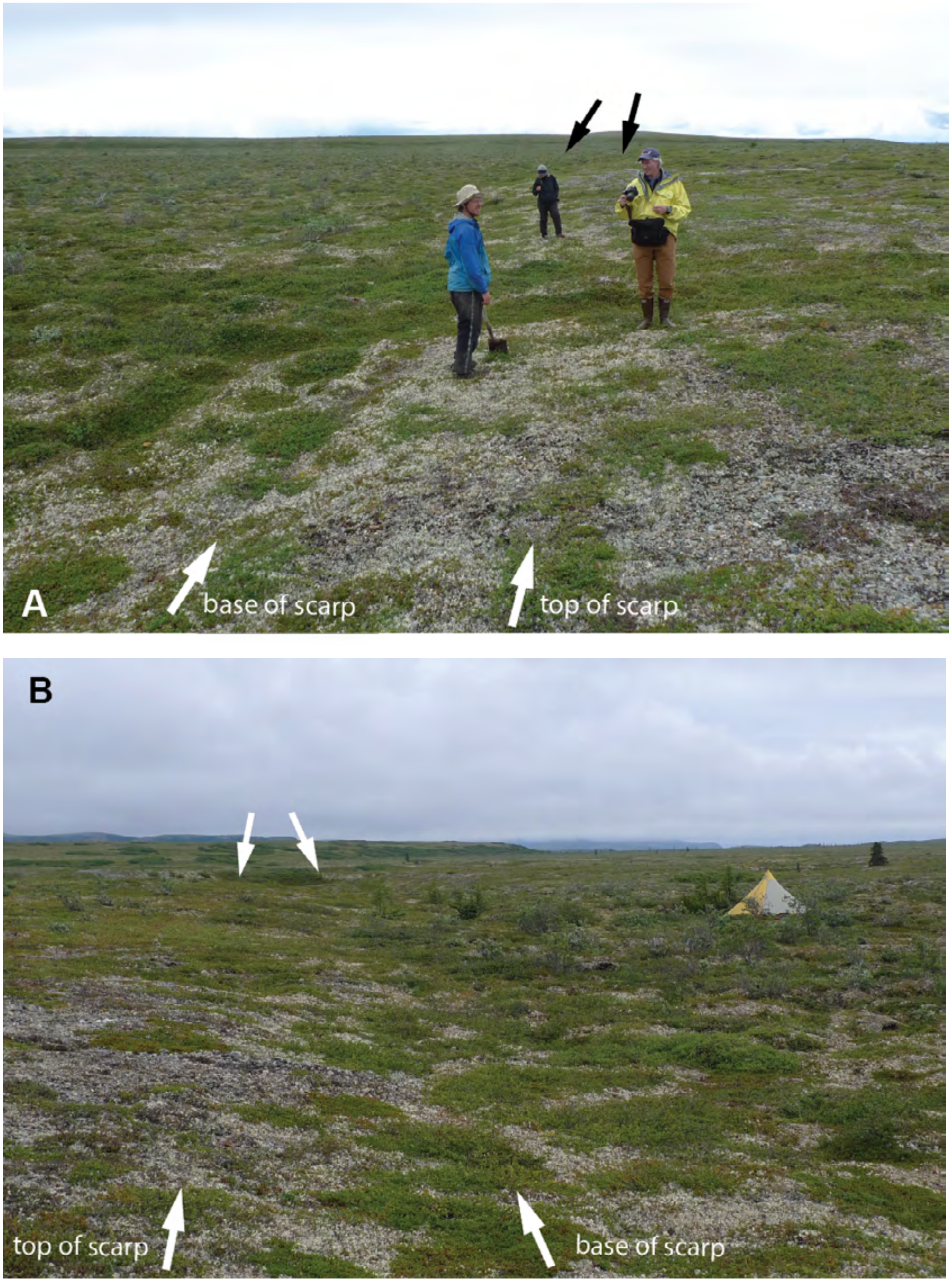


Figure 3. Ground level views of the Braid Scarp near Pebble Prospect, southwestern Alaska. The scarp is southeast side down, about 1 m high, and has a gently sloping (less than 15 degrees) scarp face. The arrows, regardless of color, denote either the top or base of the scarp. A. View to the southwest. Two persons on the left standing on scarp surface; person on right standing on top of scarp. The relict glacially molded surface is on the horizon about a kilometer away. B. View to the northeast. Tent is about 2-m high and is on the lower braided surface.

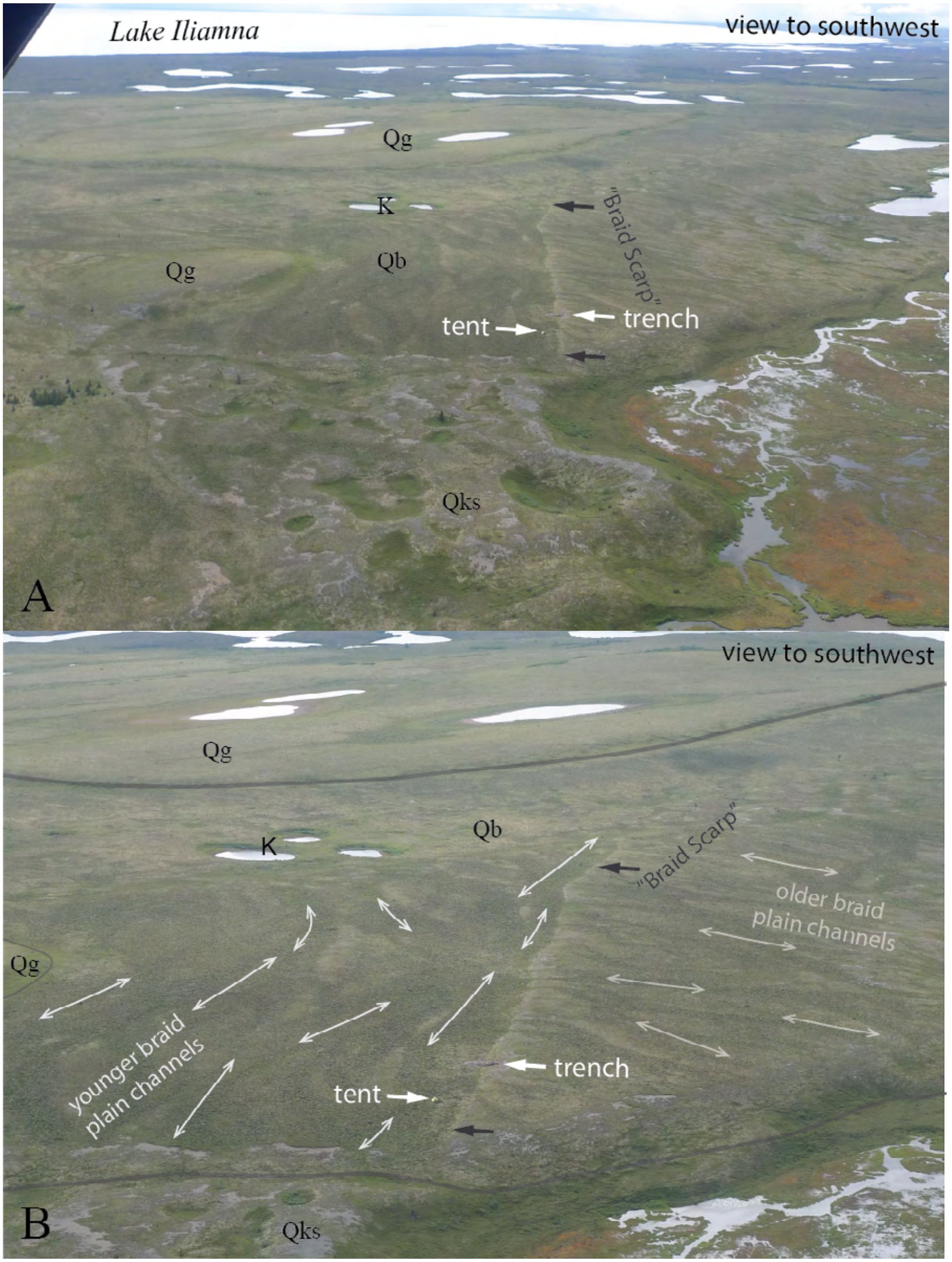


Figure 4. Oblique aerial views of the Braid Scarp looking southwest. The Braid Scarp is marked with black arrows. Unit labels are the same as those in figure 2. K marks kettles in braid plain. (A) The scarp is well expressed in braid plain deposits (Qb) but does not extend into the older glacially carved and grooved surface (Qg) in the middle distance. Also note that the scarp is truncated by the kame and kettle topography (Qks) in the foreground,

indicating that the Qks deposit post-dates formation of the scarp. However, the presence of the northeast Braid scarp and similar channel patterns in Qb deposits northeast of the Qks deposit (fig. 2) suggest that the scarp and braided channel topography may have been continuous across this area prior to meltout of stagnant glacial ice underlying the Qks terrain. Iliamna Lake in the distance, about 7 km away. (B) Closeup view showing the scarp in more detail. Arrows show the orientation of prominent braid channels. Note that relict channels on the higher, older braid plain on the northwest (right) side of the Braid Scarp trend northwest-southeast and are truncated by the lower, younger surface, which is marked by northeast-southwest trending channels that parallel the Braid Scarp. This relationship strongly suggests that the scarp formed by fluvial incision during the abandonment of the higher braid plain and deposition of the lower braid plain. Channel arrows have heads on both ends, indicating uncertainty in the direction of paleoflow. We consider it likely that the water flow direction was to the left, or to the southeast, on the older braid plain. We are less certain of the paleoflow direction on the younger braid plain, but favor an interpretation where paleoflow was away from the viewer, toward Iliamna Lake.

## Deposits Exposed in Braid Scarp Trench

The trench across the Braid Scarp excavated in 2010 was located at latitude N59.68018 and longitude W155.41000 (NAD27 datum) near the north end of the scarp. The trench was about 8.5 m long, 2 m deep, and oriented perpendicular to the scarp (figs. 5, 6, and 7). Most of the sediment exposed in the trench consists of unconsolidated gravel and sand. These deposits had very little cohesiveness and the trench walls were prone to slumping, which made it difficult to get complete views of the exposure. Despite the slumping, interpreting the stratigraphy and sedimentology of the deposits was straightforward.

We observed two main stratigraphic units in the trench, a lower unit of fluvial gravel and gravelly sand, and an upper unit of reddish-brown loess with frost-heaved pebbles and small cobbles. The gravel and gravelly sand was faintly bedded and lacked sharp contacts between sedimentation units. We noted few well-defined beds or subunits with sharp contacts, but most horizons were delineated by varying amounts of cobbles. Cobbles typically were less than 15 cm in diameter (intermediate axis), and the largest observed cobble was about 25 cm in diameter. Some beds exhibited faint festoon cross bedding, typically confined to bed segments up to 1.5 m long and 25 cm thick. In a few places, cross bed sets included both foreset and topset beds. The topsets were parallel to the ground surface. The gravels in the lower part of the trench were similar in all aspects to those in the upper part of the trench and there were no obvious vertical or lateral breaks or discontinuities. The gravel deposits were horizontally stratified beneath the upper, or northwest, surface. This stratification was truncated against the scarp (fig. 7). Cobbles in the main deposit showed no unusual orientations, and only a few cobbles near the top of the trench had steeper orientations where they were frost heaved and slightly mixed with the loess deposits that mantle the surface.

The top of the trench exposed a reddish-brown to yellow-brown silt unit that is up to 40 cm thick. The silt was thickest on the lower surface and thinned and pinched out upward against the scarp. This silt unit contained pebbles up to 3 cm in diameter, with the greatest concentration of pebbles near the lower contact with the gravels.


Figure 5. Overview of Braid Scarp trench. View is toward the southeast. The left, or northeast wall, was cleaned off fairly well, but the right, or southwest, wall was sloping and not as well exposed. Length of excavation was about 8.5 m and the depth was about 2 m.

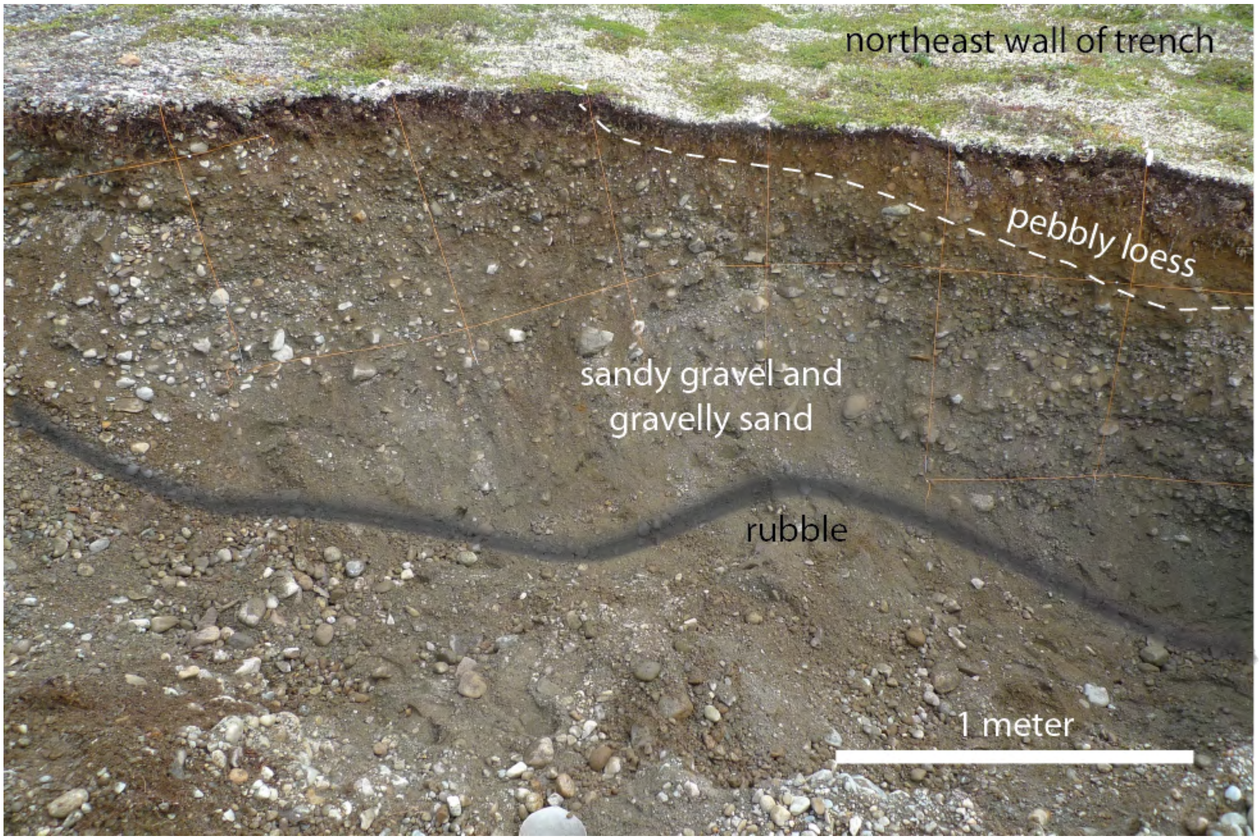


Figure 6. View of the northeast wall of trench. A tagline grid, shown by orange string, has 1 m spacing. Rubble lies below the grey line. There were two stratigraphic units in the trench: (1) the lower fluvial sandy gravel and gravelly sand and (2) the upper pebbly loess that had a reddish brown color.

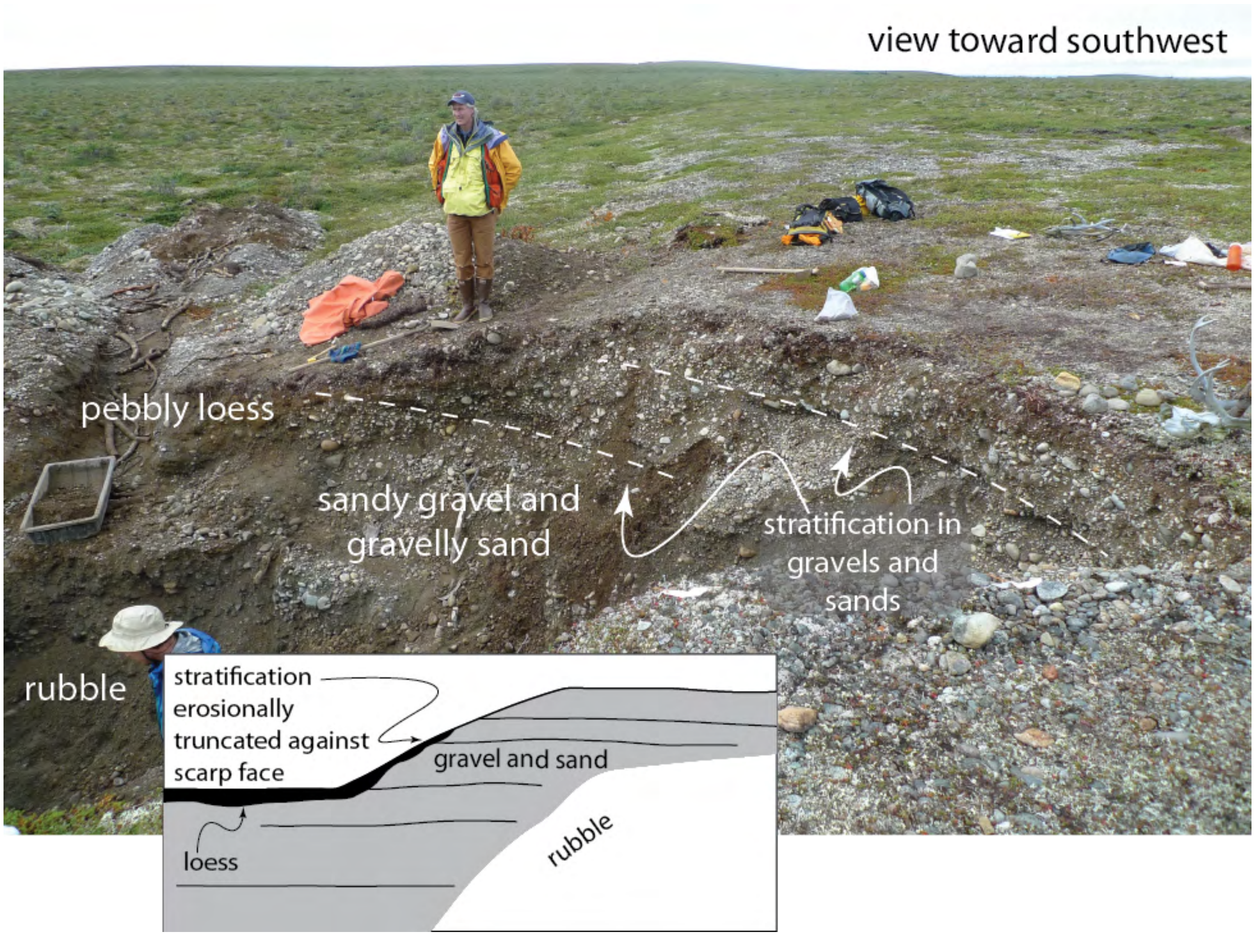


Figure 7. View of the upper southwest part of the trench along the scarp trace. In the photograph, the dashed white lines show horizontal stratification within the gravels. The flat-lying beds in the fluvial gravels beneath the highest surface are truncated at the scarp, where the person in yellow is standing. The pebbly loess onlaps the lower part of the scarp. The same relationships are shown in the schematic cross section, at bottom.

## Interpretation of Trench Deposits and Surface Features

The gravel deposits exposed in the trench are fluvial in origin and appear to have been deposited in a braided stream environment. Such gravel sequences are common in proglacial environments and are typically associated with outwash deposits where they may form valley-filling sequences and outwash terraces. We interpret the silt deposits (loess) at the top of the sequence as eolian in origin. These deposits are similar to post-glacial loess deposits seen throughout Alaska and in other paleoseismic trenches in south-central Alaska (Haeussler and others, 2002). The geometry of the silty sediments indicates they probably were deposited after formation of the scarp. The pebbles in the loess appear to have either rolled off the scarp and into the deposit, or in some cases may have been frost-heaved upward and mixed into it.

We found no evidence for faulting or fault-related deformation in the trench. We observed no fault traces, offsets of stratigraphy, aligned cobbles indicating a fault plane, slickensided surfaces, and no displaced buried soils. The overall sedimentary architecture of the gravel deposits is consistent with deposition by a relatively high-energy braided stream, and the somewhat uniform coarse-grained nature of the gravels indicates that they were deposited relatively close to source. Although some of the fluvial bedforms appeared discontinuous, it was difficult to identify specific subunits bounded by sharp, easily identifiable contacts because of the loose, noncohesive nature of the deposits and relatively uniform grain size. We attempted to trace individual beds across the exposure face, but found this difficult and uncertain because of the poorly developed bedding. Some of the better-defined beds appeared to be laterally discontinuous at scales of 5–10 cm, but this probably resulted from minor scour and fill of the aggrading gravel deposit associated with short-term fluctuations in discharge that are characteristic of braided streams. The quality of the exposure was not good enough to be able to explain all lateral changes in particle size and every bed termination, but we found no compelling reason to invoke faulting to explain the sedimentological relationships in the trench exposure.

The morphology of the surfaces across which the scarp extends indicates that the scarp formed by incision of a braided stream into an older braided stream deposit. The higher surface is marked by relict channels oriented at nearly right angles relative to those on the lower surface (fig. 4). This relationship resulted from changes in meltwater flow direction caused by changes in position (probably retreat) of the ice margin. The channels on the lower surface are subparallel to the Braid Scarp, and we infer that the scarp is a terrace riser formed during a brief episode of incision of the upper surface followed by channel aggradation and formation of the lower surface.

The apparent continuation of the Braid Scarp to the northeast suggests that the braid plains (Qb, fig. 2) to the northeast and southwest of the kame and kettle terrain, which presently separate the two scarps, once formed a continuous outwash surface. This surface, and a presumably continuous Braid Scarp with a total length of 2.4 km, was subsequently disrupted by melting of a band of stagnant ice that now forms the Qks deposits. Whether or not the two scarps were once continuous, restriction of the Braid Scarp to outwash deposits constrains scarp formation to a narrow time window during the waning stages of the last glacial period.

## Discussion

We found no aspects of this scarp that are consistent with an origin by faulting and surface rupture. The scarp has limited lateral extent and is present only on the local outwash surfaces. Active fault scarps produced by surface-rupturing earthquakes are typically distinct, through-going features that can be traced for tens to hundreds of kilometers and typically cross-cut various types and ages of surficial deposits. If this were a fault scarp, we would expect it to extend considerably beyond the area where it is currently observed, and it should offset other surficial deposits and drainages in the area. As mentioned previously, the Braid Scarp has a lateral extent of about 800 m, and if the 700-m-long colinear scarp 900 m to the northeast of the Braid Scarp is related (the “northeastern Braid Scarp” on fig. 2), the entire feature is only 2.4 km long. If this was an active fault scarp, it would be one of the shortest ever observed. Wells and Coppersmith (1994) compiled information on 244 subsurface and surface rupturing earthquakes, and 14 of these (5.7 percent) had a documented surface rupture shorter than 10 km, 8 (3.2 percent) had a surface rupture shorter than 5 km, and only two were shorter than the 2.4 km. Those surface ruptures less than 10 km long had an average earthquake magnitude of 5.7.

In the trench across the Braid Scarp, we also found no evidence indicating it formed by faulting. We found no evidence the gravel deposits exposed in the trench were disturbed or offset by faulting. Analysis of the geomorphology of the outwash surfaces associated with the Braid Scarp indicates that the scarp formed by fluvial erosion during deglaciation and ice wastage, after a higher, slightly older outwash surface was incised during the development of a lower outwash surface. This hypothesis is confirmed by the sedimentary architecture of gravel deposits in the trench exposure, where horizontally bedded gravels are erosionally truncated at the scarp face, and show no evidence of displacement, rupture, or disruption.

## Recommendations for Future Work

A broader evaluation of potential seismic hazards in this region would be useful prior to preparation for future developments. The surficial geology of this area is ideal for identifying active fault traces—if they exist. Most surficial features and deposits developed during the stagnation of glacial ice that occurred toward the end of the last major period of glaciation to affect the region. Although the geochronology of glacial and other surficial deposits in the area has not been completely determined, most of the deposits near the Braid Scarp are likely 11,000 to 16,000 years old. If there have been surface faulting events within this time period, traces of active faults should be easily observed. Thus far, no active fault traces have been identified in the region, although it is possible that some active fault traces are obscured beneath vegetation, talus, alluvial deposits, and other mass-wasting deposits. A detailed topographic survey of the area using LiDAR technology combined with focused field analyses would reveal the presence or absence of possible fault traces in the Lake Clark–Lake Iliamna region. If faults are discovered, they could be characterized with site-specific paleoseismic analyses. The most important objectives of such a study would be to evaluate the ages of faulting, frequency of paleoearthquakes, fault slip rates, and estimated earthquake magnitudes associated with the surface displacements. We do not think that further investigation of the Braid Scarp site is warranted. Excavation of additional trenches is unlikely to change the interpretation that the scarp is an erosional feature.

The only fault that has been identified as having possible Neogene (that is, in the last 23 million years) activity in the region is the Lake Clark fault. Haeussler and Saltus (2005) found that the Lake Clark fault has had about 26 km of offset in the last 34–39 million years, but that conclusion does not mean the fault is active today. In their compilation of active and Neogene fault traces in Alaska, Plafker and others (1994) categorized the Lake Clark fault as a fault trace of pre-Pleistocene age. In other words, they found no evidence that there had been offset along the Lake Clark fault within the past 1.8 million years. Several studies that focused on the Lake Clark fault in the region northeast of Lake Clark found no evidence for movement along the fault since the last glaciation, around 11,000–12,000 years ago (Plafker and others, 1975; Detterman and others, 1976; Reger and Koehler, 2009). Thus, there is no evidence for active faulting or seismic hazard associated with the Lake Clark fault. In summary, if further geologic studies find no evidence for surface faulting, it would be difficult to conclude that a significant seismic hazard exists from crustal faults in the area.

## Acknowledgments

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