OBSERVATIONS OF PLEISTOCENE FEATURES IN THE BERING STRAIT REGION OF SEWARD PENINSULA, ALASKA

Travis Hudson

Preliminary Interpretive Report 2024-5

This publication has not been reviewed for technical content or for conformity to the editorial standards for DGGS.

2024
STATE OF ALASKA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL & GEOPHYSICAL SURVEYS

STATE OF ALASKA
Mike Dunleavy, Governor

DEPARTMENT OF NATURAL RESOURCES
John Boyle, Commissioner

DIVISION OF GEOLOGICAL & GEOPHYSICAL SURVEYS
Melanie Werdon, State Geologist & Director

Publications produced by the Division of Geological & Geophysical Surveys are available to download from the DGGS website (dggs.alaska.gov). Publications on hard-copy or digital media can be examined or purchased in the Fairbanks office:

Alaska Division of Geological & Geophysical Surveys (DGGS)
3354 College Road | Fairbanks, Alaska 99709-3707
Phone: 907.451.5010 | Fax 907.451.5050
dggspubs@alaska.gov | dggs.alaska.gov

DGGS publications are also available at:

Alaska State Library, Historical
Collections & Talking Book Center
395 Whittier Street
Juneau, Alaska 99801

Alaska Resource Library and
Information Services (ARLIS)
3150 C Street, Suite 100
Anchorage, Alaska 99503

Suggested citation:
Hudson, Travis, 2024, Observations of Pleistocene features in the Bering Straight region of Seward Peninsula, Alaska: Alaska Division of Geological & Geophysical Surveys Preliminary Interpretive Report 2024-5, 20 p.
https://doi.org/10.14509/31055

Contents

OBSERVATIONS OF PLEISTOCENE FEATURES IN THE BERING STRAIT REGION OF SEWARD PENINSULA, ALASKA

Travis Hudson[1]

ABSTRACT

Observations of the 210 m (650 ft) high York terrace and other wave-cut surfaces, the distribution of distinctive erratics, and the distribution and nature of both onshore and offshore sediments suggest that one or more high sea level stands are the primary control on Pleistocene landforms of the western Seward Peninsula. The widespread erratics of the region are thought to have been mobilized and dispersed by shore-ice rafting and sea ice movements rather than by movement of glacial ice accumulations. Glaciers do not appear to have developed in the York Mountains and the few local surface features previously mapped as moraine are thought to be erratic accumulations, stream terrace deposits, or talus and landslide deposits. Pleistocene to Recent faulting likely contributed to some landform elevations and possibly to discontinuities in their present distribution. At the time of the high sea level stand that created the York terrace, the York Mountains would have been an island archipelago; a cape analogous to the present Cape Prince of Wales was present along the southwest flank of the York Mountains, and much of the area west of the York Mountains was below sea level and scoured by north-flowing currents. These currents appear to have removed bottom sediments, transported them northward, and deposited them in a shoal in the Chukchi Sea analogous to today's active Prince of Wales shoal. Cape Mountain would have been an isolated island at this time. The York terrace high sea level stand could have affected other parts of Seward Peninsula, such as the Pilgrim River gap (elevation of 60 m [200 ft]). Flooding of this pass would have created a seaway between the estuary of the Niukluk River drainage and the now intertidal Imuruk Basin. Sea levels higher than those forming the York terrace seem to be indicated in some areas. This study synthesizes observations incidental to reconnaissance geologic investigations for other purposes and its principal interpretations and conclusions need to be more completely evaluated and tested. Hopefully, this report will help foster future investigations of the Pleistocene history of Seward Peninsula.

INTRODUCTION

Bering Strait, about 90 km (50 mi) wide, separates Alaska's westernmost mainland of Seward Peninsula from Russia's eastern Chukotka Peninsula (fig. 1). Parts of Seward Peninsula adjacent to Bering Strait include the coastline from Brevig Mission west to Cape Prince of Wales and the coastline northeast from Cape Prince of Wales (fig. 2). Quaternary sea level changes significantly influenced land exposure in this region (e.g., Hopkins, 1959), and the importance of western Seward Peninsula to understanding the Pleistocene history of land submergence and emergence helped to establish the Bering Land Bridge National Preserve (fig. 1).

The first geologic reconnaissance of Seward Peninsula (Brooks and others, 1901) and its western regions (Collier, 1902) recognized landforms (such as the York plateau, below) that could be attributed to marine erosion processes, although at the time land elevation changes rather than sea level changes were thought to be the general control. Sainsbury (1967a) mapped and described the well-developed marine terraces along the south side of the York Mountains and considered their possible correlatives

[1] Applied Geology, Inc., 701 Alice Loop, Sitka, Alaska 99835; travishudson2016@outlook.com

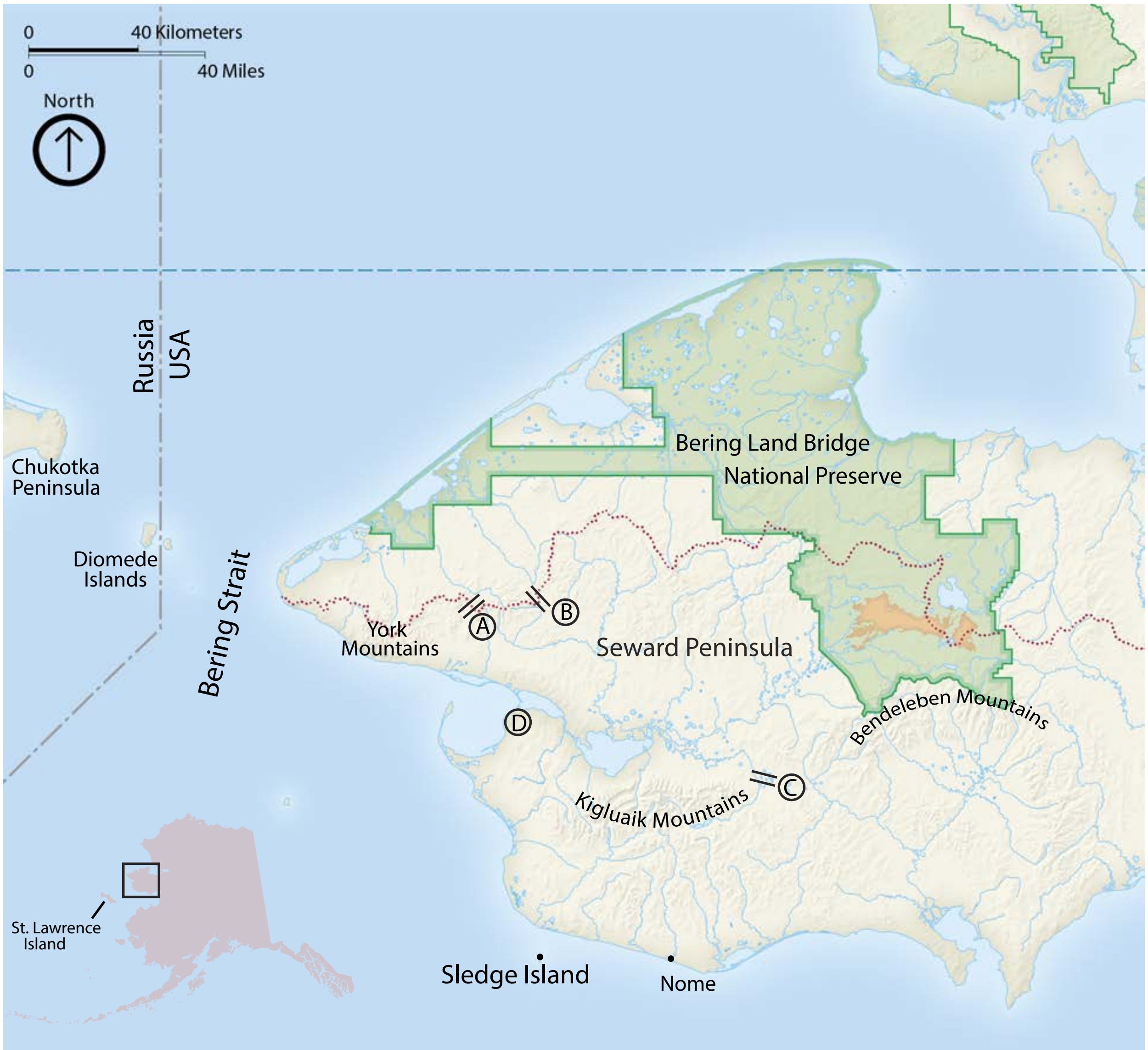

Figure 1. Map of Seward Peninsula, Alaska (location shown by box on inset map). This report's area of interest is adjacent to Bering Strait and south of the westernmost Bering Land Bridge National Preserve. Localities discussed in the text include the Don River gap (A), Nuluk River gap (B), Pilgrim River gap (C), and a marine terrace south of Teller (D). The continental divide is shown by the dotted red line. The location of St. Lawrence Island is also shown on the inset map.

elsewhere on Seward Peninsula, but his subsequent investigations focused on identifying and mapping features he considered indicative of glacial processes in the region (Sainsbury, 1967b). Hopkins and others (1974) identified Pleistocene fossils from two localities on marine terrace surfaces and considered their implications for possible submergence of the Bering Strait region during parts of the Pleistocene.

This report summarizes observations of certain Pleistocene features of western Seward Peninsula, generally covering the onshore area from the York Mountains west to Cape Prince of Wales (fig. 2). These features include marine terraces, stream terraces, plateau uplands, alluvial deposits, onshore and offshore gravel deposits, materials previously mapped as moraine, erratics, and onshore and offshore faults. These observations were mostly made incidental to geologic field studies of Cretaceous granites

Figure 2. Map of western Seward Peninsula showing localities and features discussed in this report, including Lost River terrace (A; fig. 3), Fish Creek terrace (B; figs. 4 and 5), Brevig scarp (C; figs. 4 and 5), York terrace (D; figs. 6 and 7), York plateau (E; figs. 9 and 10), Pleistocene gravels (F and G), granite erratic of lower Anderson Creek (H; fig. 12), Kanauguk River moraine (I; fig. 14), Lost River moraines (J; fig. 15), East Fork of Grouse Creek moraine (K; fig. 16), moraines of upper Anderson Creek (L; fig. 13), buried beach deposits on Boulder Creek (M), Sainsbury's (1967b) erratic locality A (N), and Sainsbury's (1967b) erratic locality B (O). The base map (from U.S. Geological Survey's 1950 Teller quadrangle 1:250,000 topographic map [contour interval 200 ft]) shows many geographic features, such as Cape Mountain, Boulder Creek, Cape York, Potato Mountain, York Mountains, Brooks Mountain, Anderson Creek, and Don River, also referred to in this report.

(1977) and mineral deposits (1982 and 2010) but also included foot traverses in 1998 from Tin City to the mouth of Lost River and along parts of lower California River and Fish Creek (fig. 2). Photographs of some physiographic features were obtained from the air and in the lower Anikovik River area in 2021. These observations, data from topographic and bathymetric maps, and previous work provide a basis for evaluating the role of higher sea levels and related processes in developing the landforms of the region. This integration of observations and relationships is not a comprehensive study and the interpretations presented here need additional evaluation and testing. Hopefully, this work will help foster future investigations of the Pleistocene history of Seward Peninsula.

MARINE TERRACES

Three well-defined marine terraces west of Brevig Mission and along the south flank of the York Mountains provide direct evidence of high sea level stands in the study area. From lowest to highest, these are the Lost River, Fish Creek, and York terraces (fig. 2).

Lost River Terrace

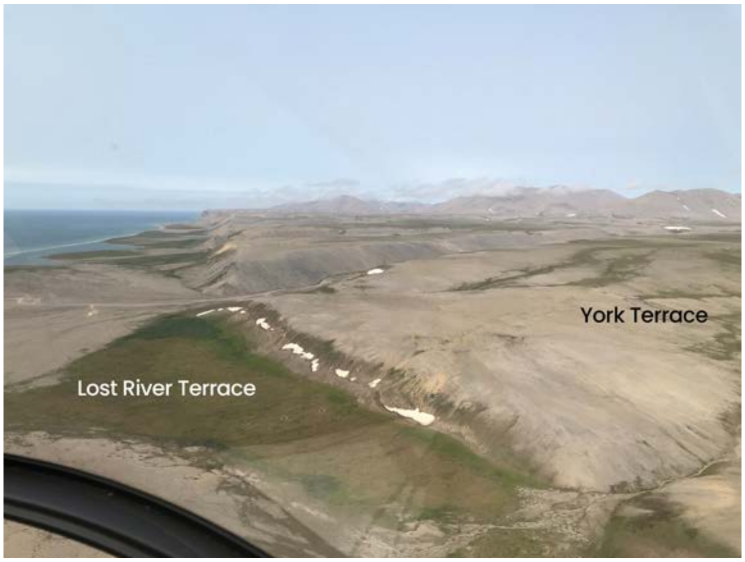

Figure 3. Photograph looking west (from near locality A, fig. 2) showing the Lost River terrace and its abandoned sea cliff adjacent to the bare limestone bedrock platform of the York terrace. Colluvial aprons and alluvial fans are well developed along the base of the abandoned sea cliff.

The Lost River terrace is very well defined from the mouth of Lost River east for about 10 km (6 mi), where its inner margin is marked by an abandoned sea cliff locally over 120 m (390 ft) high (fig. 3). Colluvial aprons and alluvial fans are well developed along the base of the abandoned sea cliff, and only very locally do surface elevations (about 15 m; 50 ft) approximate original shoreline angle elevations (9 to 12 m; 30 to 40 ft, Sainsbury, 1967a). East of the abandoned sea cliff, the Lost River terrace is eroded by fluvial processes in the lower Don River area (fig. 4), but a correlative surface appears to be present further east, seaward of the Fish Creek terrace (pg. 6). Narrow remnants of the Lost River terrace and its abandoned sea cliff are locally preserved from Lost River west to the Kanauguk River, seaward of the York Mountains and York terrace (fig. 2). A slope break at about 30 m (100 ft) surface elevation along the inner margin of a narrow and discontinuous coastal plain identifies the correlative surface from the Kanauguk River west to Cape Mountain (fig. 2).

The broader coastal plain northeast of Cape Prince of Wales that includes beach deposits, large lagoons, many small lakes, and extensive fluvial deposits, with an inner margin along a discontinuous, subdued slope break at about 30 m (100 ft) elevation, is likely correlative with the Lost River terrace (fig. 2; Sainsbury, 1967a, fig. 1). A buried beach present on Boulder Creek at a bedrock elevation of about 20 m (65 ft; locality M, fig. 2; Mulligan and Thorne, 1959) could be correlative with the Lost River terrace high stand.

The Lost River terrace is correlative with other terraces and coastal plains well-developed elsewhere along the present coastline of Seward Peninsula and Saint Lawrence Island (Brooks and others, 1901; Sainsbury, 1967a; Hopkins, 1973; Hudson and Saltus, 2000, fig. 5). These coastal features developed during the last Pleistocene interglacial high sea level stand, about 125,000 years BP (Pelukian transgression, Brigham-Grette and Hopkins, 1995), and they are spatially related to present shorelines and commonly oriented similarly to them.

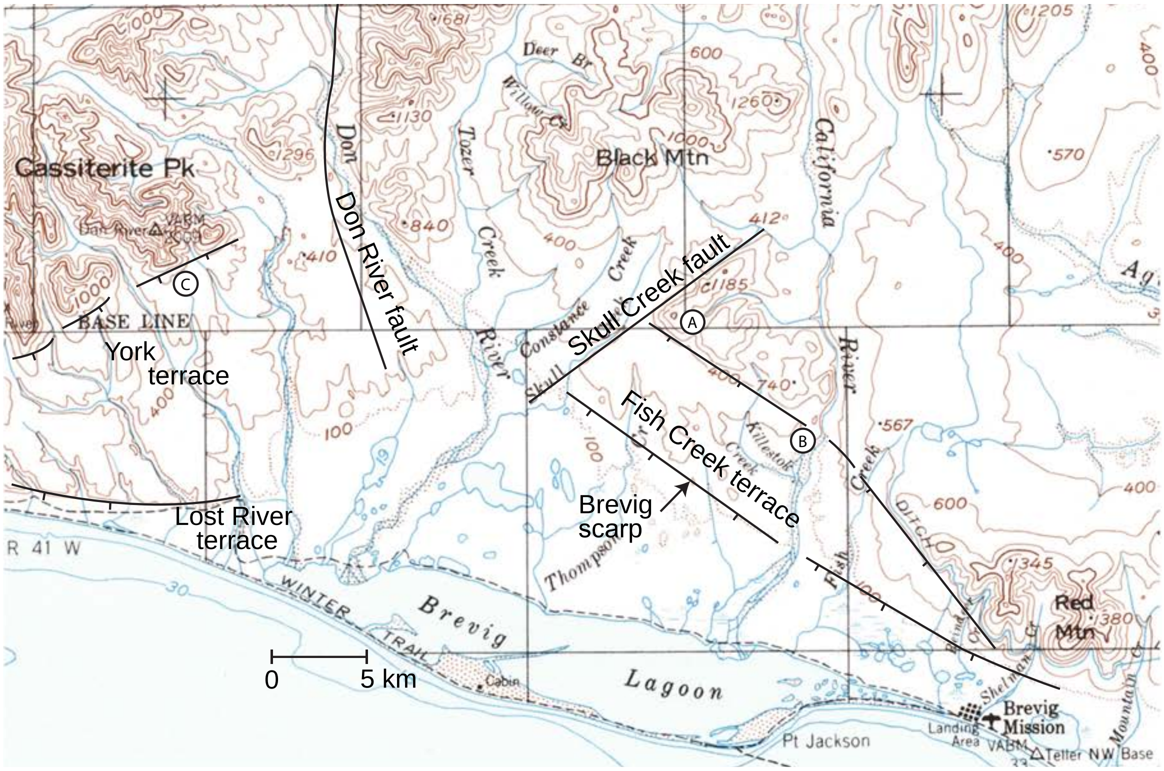

Figure 4. Map showing Pleistocene features of the Don River area including the Lost River, York, and Fish Creek terraces, the Don River and Skull Creek faults, the Brevig scarp, and localities discussed in the text, including (A) Sainsbury's (1967b) Skull Creek erratic locality, (B) nearshore marine sediment exposures along the California River, and (C) fossil locality of Sainsbury (1967a). Base map is U.S. Geological Survey's 1950 Teller quadrangle 1:250,000 topographic map (contour interval 200 ft).

Figure 5. Photograph looking north showing the Brevig scarp slope break (black arrow) in the vicinity of the braided flood plain of the California River. Nearshore marine sands and gravels are exposed on the Fish Creek terrace along the west side of the California River. The platform between the Brevig scarp and the distant light-colored limestone uplands is the Fish Creek terrace. The red arrow marks the slope break along the inward margin of the Fish creek terrace. Fish Creek is in the foreground.

Fish Creek Terrace

The Fish Creek terrace is between the coastal plain and higher uplands east of the Don River valley (fig. 4). It is about 15 km (9 mi) long and best defined between Skull Creek and California River where its inland margin is marked by a distinct slope break at about 120 m (350 ft) surface elevation (fig. 5). The inland margin between California River and Fish Creek is subdued and modified, but from Fish Creek southeast to near Brevig Mission it is better defined.

Unconsolidated nearshore marine deposits are present on this terrace (Sainsbury, 1967b) and its uneven surface between Skull Creek and California River could reflect variably deposited and subsequently eroded marine sediments. These sediments were examined and described by Sainsbury (1967b) from exposures on both the California River and Fish Creek. The author examined the two exposures along the west side of California River in 1998 (locality A, fig. 4). The upstream exposure reveals fine-grained, clean, tannish to gray sand with broken pelecypod shells in surface float. L. Marincovich (written communication, 1998) identified these shells as *Mytilus sp.* (mussels), indicating the sediments were deposited close to a shoreline. Downstream exposures, interpreted as beach gravel, include about 1 m (3 ft) of pebble–cobble gravel with pelecypod shells, porphyritic granite cobbles, and discontinuous sand and pebble layers. The beach gravel section is capped by partly cemented alluvial gravel, underlain by fine- to medium-grained sand with iron-stained zones and pebble layers, and appears to dip slightly north. Fossils (mollusks, ostracods, and foraminifera) collected from the California River exposures are reported to include extinct species and be early Pleistocene in age (Hopkins and others, 1974).

The seaward margin of the Fish Creek terrace is a slope break called the Brevig scarp by Sainsbury (1967b; figs. 4 and 5). The Brevig scarp is a subdued slope break that continues southeast from near Skull Creek to near Brevig Mission where it appears to truncate the eastern limits of the Fish Creek terrace (fig. 4). The surface elevation at the base of the Brevig scarp is between 15 and 30 m (50 to 100 ft), where it is better preserved near the California River (fig. 5). Because these elevations are similar to those at the base of the abandoned sea cliff along the inboard margin of the Lost River terrace to the west (figs. 3 and 4), the Brevig scarp appears to be the lateral equivalent of the abandoned sea cliff on the Lost River terrace. Consistent with this reinterpretation, the coastal plain seaward of the Brevig scarp was correlated with the Lost River terrace by Sainsbury (1967b).

Hopkins and others (1974) considered the Fish Creek terrace correlative with the York terrace, although fossils from the latter (locality C, fig. 4) indicate a middle Pleistocene or younger age (Sainsbury, 1967a) and fossils from the Fish Creek terrace (locality B, fig. 4) indicate an early Pleistocene age (Hopkins and others, 1974). The Fish Creek terrace occupies the same physiographic position as the York terrace west of the Don River (between the Lost River terrace and inland uplands), but its shoreline angle elevation is only about half that of the York terrace. Sainsbury (1967b, p. D209) noted these elevation differences and the challenge they present to a Fish Creek and York terrace correlation but suspected their equivalence. Combinations of erosion and faulting may be needed to explain the location, character, and height of the Fish Creek terrace (see faulting section below).

York Terrace

The York terrace, a conspicuous bedrock platform along the south flank of the York Mountains (figs. 6A and B), was recognized to be the product of marine erosion by Brooks and others (1901), who included it as part of their York plateau, and by Collier (1902), who referred to it as the York Bench. It is the highest well-defined marine terrace on western Seward Peninsula (fig. 2), with shoreline angle elevations of about

Figure 6. Photographs of the bare limestone bedrock platform of the York terrace. **A.** View looking west from about 3 km (2 mi) west of the mouth of Lost River. **B.** View looking west from near Cape York. The dark level upland surface in the distance of fig. 6B is the York plateau of Brooks and others (1901) and Collier (1902), as expressed along the west side of the lower Kanauguk River valley.

200 m (650 ft) in many areas. Larger drainages, such as Lost River, mark significant gaps in this terrace, and both its western and eastern limits are at the large valleys of the Kanauguk and Don rivers, where fluvial processes have significantly eroded it (fig. 2). In some places east of Lost River, the terrace's inner margin is observed to trend inland along smaller valley margins for short distances. Drainages whose headwaters are on the terrace platform are graded to present sea level. Where it is present, the abandoned sea cliff along the inner margin of the Lost River terrace marks the seaward margin of the York terrace.

The inner margin of the York terrace is marked by a distinct slope break that is not strongly modified by colluvial or alluvial deposits. Shoreline angle elevations estimated from topographic maps vary from about 165 m (550 feet) at its eastern limit, about 230 m (750 feet) in the vicinity of Lost River, to about 200 m (650 feet) at its western limit overlooking the Kanauguk River valley. The inner margin slope break shifts from a generally east-west trend along the south flank of the York Mountains to a northerly trend along the west flank of the mountains (fig. 7). At the time of the York terrace high sea level stand, the southwest corner of the York Mountains was a cape like today's Cape Prince of Wales. Previous workers, as early as Collier (1902), recognized that the changes in elevation along the York terrace's inner margin reflected warping of the marine terrace. In addition, the presence of recent normal faulting offshore suggests that the preservation and height of the York terrace platform could also reflect tectonic uplift of western Seward Peninsula (see faulting section below).

Figure 7. Photograph of the bare limestone platform of the York terrace looking west from the southwest corner of the York Mountains (photograph taken at locality F, fig. 8). Onuteshuik Creek is in the foreground and the mouth of the Kanauguk River and the York plateau are in the distance. The inland margin of the York terrace changes from an east-west to a northerly trend in this area.

Patches of nearshore marine sediments, locally fossiliferous, are present along the inner margin of the York terrace's eastern segment (Sainsbury, 1967a, fig. 1). Fossils collected from the gravels are thought to be middle Pleistocene or perhaps late Pleistocene (locality C, fig. 4; Sainsbury, 1967a, p. 131). The marine gravels contain pebbles and cobbles of lithologies not found in the York Mountains, including gneiss, schist, and basalt, that Sainsbury (1967a, p. 128) recognized required longshore drift or ice rafting. Sainsbury also noted distinctive iron oxide pebbles in the marine sediments.

York Plateau

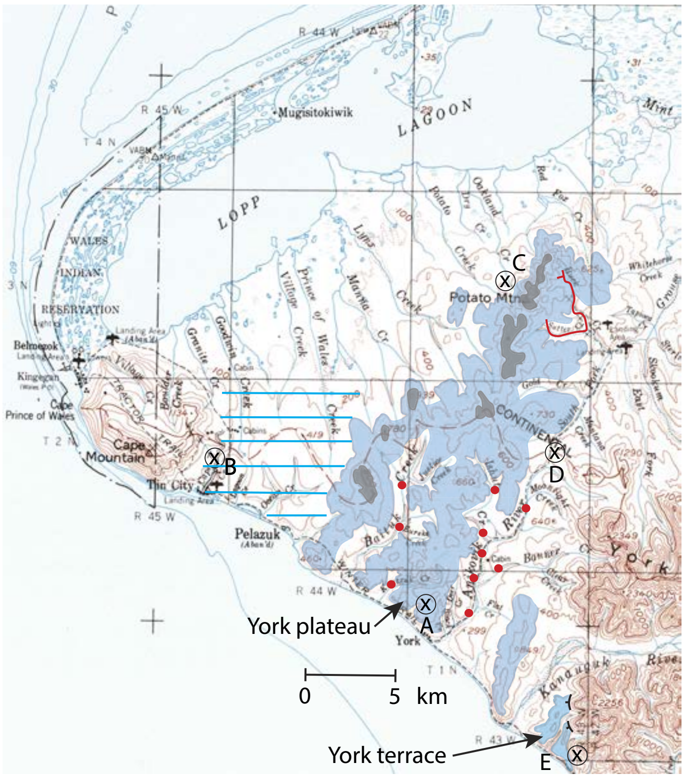

Figure 8. Map showing extent of the York plateau (light blue) and related surface features west of the York Mountains. Areas within the York plateau that have elevations of 230 m (750 ft) or more are shaded gray. Western areas where continued marine erosion or re-submergence may have occurred (elevations less than 130 m [430 ft]) are shown with horizontal blue lines. Localities discussed in the text include the location for photographs in figures 9 and 10 (A), Cape Creek marine sediments (B), 10 m (30 ft) thick gravels at about 70 m (230 ft) bedrock elevation on upper Oakland Creek (C), 120 m (400 ft) high pass at head of Anikovik River (D), and the location of figure 7 (E). Red dots and lines are the locations where the U. S. Bureau of Mines determined alluvial gravel thicknesses. Base map is the USGS's 1950 Teller quadrangle 1:250,000 topographic map (contour interval 200 ft).

The York plateau is the upland between the York Mountains and Cape Mountain and extends north to Lopp Lagoon (figs. 2 and 8). It was first described by Brooks and others (1901), who included the York terrace with the level upper surface of the plateau (fig. 7) and concluded marine processes were responsible for its origin. Collier (1902) distinguished the York terrace (his York Bench) separately and recognized the York plateau to include large areas north and east of the York Mountains. Collier (1902) concluded that the York plateau resulted from a combination of marine and subaerial erosion processes, as some uplands, such as Potato Mountain (427 m [1,400 ft]), reached elevations much higher than that characteristic of the plateau (150 to 215 m [500 to 700 ft]).

The uplands between the York Mountains and Cape Mountain commonly have broad, approximately level summits at elevations of 150 to 215 m (500 to 700 ft; fig. 8). The level upper surfaces are evident in photographs (figs. 9 and 10) taken from the summit south of Kigezruk Creek (locality A, fig. 8). The distinctive plateau features of this area and their ties to the York terrace and terrace remnants on the east side of Cape Mountain are what convinced Brooks and others (1901) of their shared marine origin. The parts of the York plateau that have elevations greater than 230 m (750 feet) are commonly places where more resistant bedrock is present; for example, mafic metaigneous rocks in the Baituk Creek drainage (Sainsbury, 1974) and hornfels at Potato Mountain (Mulligan, 1965).

Figure 9. View looking east from locality A in figure 8. The York Mountains are in the distance. The lower Anikovik River is in the foreground and one of the U.S. Bureau of Mines churn drill locations (fig. 8) is just upstream out of view.

Figure 10. View looking west from locality A in figure 8. This level summit is at 180 m (600 ft) elevation. Cape Mountain, partly cloud-covered, is in the far distance.

The York plateau summits are lower at its western limits near Cape Mountain, where the pass between Goodwin and Cape creeks is at 52 m (171 ft) elevation. The uplands here also differ from those of the York plateau to the east in that they are more subdued and elongate in a north-south direction. This lower area may reflect continued or subsequent marine erosion after the York terrace high stand, as marine sediments have been identified in placer workings along Cape Creek at bedrock elevations of about 30 m (100 ft; locality B, fig. 8; Mulligan and Thorne, 1959; Hudson and Reed, 1997, fig. 4). This western plateau area is identified separately in figure 8 because of its differences with the York plateau to the east. The distinct slope break at 45 to 60 m (150 to 200 ft) north of Potato Mountain on the north flank of the York plateau (fig. 8) appears to reflect a high sea level stand intermediate between that of the Lost River and York terraces, another indication that the York plateau at least locally retains evidence of a composite submergence history.

The northwest flank of the York plateau has many north-flowing drainages, and fluvial processes have significantly modified it between the uplands and Lopp and Ikpek lagoons (figs. 2 and 8). The south-flowing Anikovik River is in a large valley (fig. 9), but many smaller drainages of the southern plateau area are in narrow, deep valleys graded to present sea level. These drainages on the plateau west and northwest of the York Mountains are all weakly alluviated with thin, angular gravels derived from nearby bedrock that is dominantly dark, fine-grained siliciclastic rocks. The gravel thicknesses, commonly only 1 to 2 m (3 to 7 ft) and almost everywhere less than 3 m (10 ft), are known from U.S. Bureau of Mines' churn drilling at many locations in the Anikovik River valley, Kigezruk Creek, Baituk Creek, and drainages on the east side of Potato Mountain (fig. 8; Heide and Rutledge, 1949; Mulligan, 1959).

Pleistocene gravel deposits are present near the mouth of the Mint River and along lower Pinguk River (localities C and D, fig. 11; Sainsbury, 1967b), north of the weakly alluviated drainages of York plateau. A 10-m- (30 ft) thick gravel section at 70 m (230 ft) bedrock elevation on Oakland Creek (locality C, fig. 8; Heide and Rutledge, 1949) may be another occurrence of these gravels. These gravel deposits may have originally formed on the seafloor and been related to the sediments that formed a large northerly trending shoal on the Chukchi seafloor (feature B, fig. 11). This large north-trending shoal is inferred to be a constructional sediment lobe like the Prince of Wales shoal now developing north of Bering Strait today (fig. 2; feature A, fig. 11; McManus and Creager, 1963; Creager and McManus, 1967; Hopkins and others, 1976). If this is the case, sediment scoured from the York plateau sea floor (as indicated by the weak and recent alluviation on the plateau) could have been transported north by bottom currents and become deposited to form the Chukchi shoal (feature B, fig. 11) at the time of the York terrace high sea level stand.

As originally concluded by Brooks and others (1901), the York plateau appears to be a landform created by marine erosion processes. Brooks and others (1901) also concluded that the York plateau is correlated with terrace remnants on the east flank of Cape Mountain, the York terrace, a terrace south of Port Clarence (locality D, fig. 1), and the upper surface of Sledge Island northwest of Nome—all with approximately level surface elevations of 120 to 180 m (400 to 600 ft). Although tectonic influences on western Seward Peninsula terrace height are likely (see faulting section below), these appear to be valid correlations. The high sea level stand that produced the York plateau and terrace is expected to be observed elsewhere on Seward Peninsula and Saint Lawrence Island (see Discussion section).

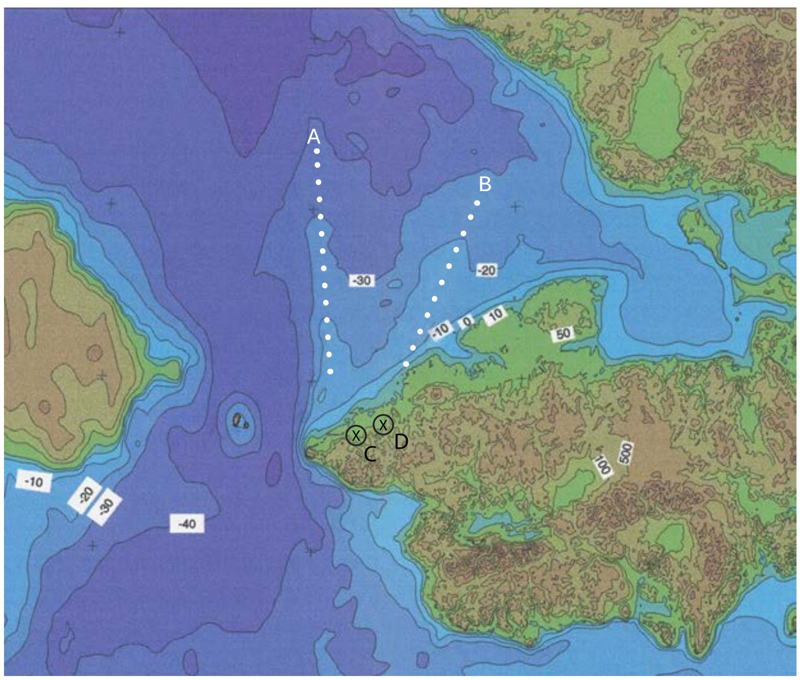

Figure 11. Map showing general topography and bathymetry of Seward Peninsula, Bering Strait, and eastern Chukotka. Contour labels are in meters. Prince of Wales shoal, an actively developing constructional sediment lobe on the sea floor, is marked by the dotted white line labeled A. The dotted white line labeled B marks a bathymetric feature inferred to be a Pleistocene constructional sediment lobe like Prince of Wales shoal. Onshore Pleistocene gravel localities discussed in the text include the Mint River (locality C) and the Pinguk River (locality D). Map compiled by R. Saltus (written communication, 2000).

ERRATICS

After describing and mapping the Lost River, Fish Creek, and York terraces, Sainsbury focused on identifying what he considered to be Wisconsin glacial features of the York Mountains and western Seward Peninsula (Sainsbury, 1967a, 1967b, 1969a, 1969b). His older York glaciation was centered on the York Mountains, but covered a large area extending north to Lopp Lagoon and east to Brevig Lagoon—across large parts of the York plateau as well as parts of the Lost River, Fish Creek, and York terraces (Sainsbury, 1967a, fig. 1). Ice of his younger Mint River glaciation covered northern valleys of the York Mountains and stream valleys north of them. The key evidence Sainsbury used to define and map his Mint River and York glaciations was the nature and distribution of distinctive erratics.

The bedrock geology of the York Mountains is especially suited to confidently identify and map erratics across western Seward Peninsula. Large areas are underlain by Lower Paleozoic (mostly Ordovician) limestones that are commonly exposed on bare frost-riven surfaces (fig. 6). Structurally underlying the light-colored limestones are dark-colored, pelitic and siliciclastic sedimentary rocks, many with a well-developed slaty character. Upper Cretaceous granites intrude the limestones and slaty rocks at several places, but the largest exposed granite body is at Brooks Mountain (fig. 2). This 4 km^2 (1.5 mi^2) composite stock is mostly porphyritic granite (Hudson and Arth, 1983). The distinctive Brooks Mountain granite is a key source of erratics widely distributed throughout the region. Hornfels and tactite, which developed adjacent to the granite intrusions, are also a source of distinctive erratics. Sainsbury (1969a, 1969b) mapped the location of granite and other erratics and used their distribution to interpret the glacial history of the northwestern Seward Peninsula (Sainsbury, 1967a, 1967b). He also noticed that some erratics were faceted and striated, some limestone bedrock was scoured and grooved, and the erratic debris included polished quartz pebbles (interpreted to be waterworn along subglacial streams; Sainsbury, 1967b).

Observations of granite erratics on a limestone platform on the south side of lower Anderson Creek (a west tributary to the upper Don River, fig. 2) first suggested to the author that erratics interpreted by Sainsbury to be glacially distributed were instead rafted and distributed by shore ice during high sea level stands. A granite erratic boulder locality observed in 1982 on the limestone platform, but not subsequently relocated by the author and further documented as to location and character, seems especially important. It is an accumulation of cannonball-shaped granite boulders up to about a meter (3 ft) in diameter that form a pavement in a surface swale on the limestone platform. This locality is evidence of the repeated wave-working of the granite erratics and shows that the limestone platform on the south side of lower Anderson Creek (shown in figs. 12A and 12B) was wave-worked.

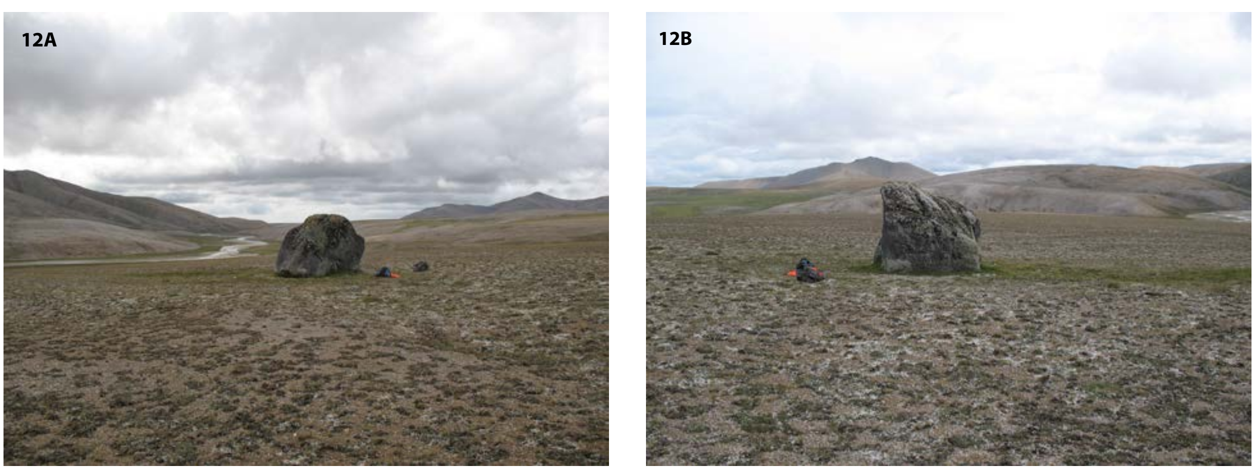

Figure 12. Photographs of granite monolith on the wave-cut platform near the confluence of Anderson Creek and the Don River (N 65 32.054, W 166 54.198; locality H, fig. 2). This granite erratic originated at Brooks Mountain in the headwaters of Anderson Creek (fig. 13). **A.** View looking south down Don River valley. **B.** View looking northeast towards pass in headwaters of the Don River (Don River gap, fig. 1).

A large granite erratic on this limestone platform near the confluence of Anderson Creek and the Don River (mapped by Sainsbury, 1969b) was first observed in 1982 and then again located in 2010 (figs. 12A and 12B; locality H, fig. 2). This large, angular, solitary monolith of Brooks Mountain granite has K-feldspar phenocrysts up to 4 cm (2 in) long and rests on the same gently sloping wave-worked limestone platform as the well-rounded granite boulders described above. It is at an elevation of about 115 m (380 ft).

Shore and sea ice processes could produce some of the same characteristics on entrained debris and bedrock as glacial ice processes—faceted and striated erratics, scoured or grooved bedrock, and widely distributed water-worn pebbles or cobbles, for example. Sainsbury (1967a, p. 128) noted that some pebbles and cobbles of schist, gneiss, and basalt in marine gravels on the York terrace are exotic to western Seward Peninsula and are evidence of longshore drift or ice rafting.

If erratics were distributed by shore and sea ice movements, then their elevations would be evidence of former sea levels. For example, Sainsbury's (1967b) Skull Creek erratics (hornfels, locality A, fig. 4) at 235 m (770 ft), tactite erratic locality A (locality N, fig. 2) at 320 m (1,050 ft), and granite erratic locality (locality O, fig. 2) at about 300 m (980 ft) on the north flank of the upland between Clara Creek and upper Yankee River (Sainsbury, 1969b) could be evidence for sea levels higher than that indicated by the York terrace (200 to 215 m [650 to 700 ft]). Small iron oxide pebbles were observed in 1982 at an elevation of about 400 m (1,300 ft) on a small ridgetop gap on the south side of upper Anderson Creek (near a small Kg exposure and MB locality, fig. 13). These pebbles are of unknown origin and may not have any relationship to marine processes, but they are apparently similar to iron oxide pebbles noted by Sainsbury (1967a, p. 128–130) in marine gravels on the York terrace. The possibility that sea levels influenced elevations higher than those of the York terrace and plateau is discussed below (see Discussion section).

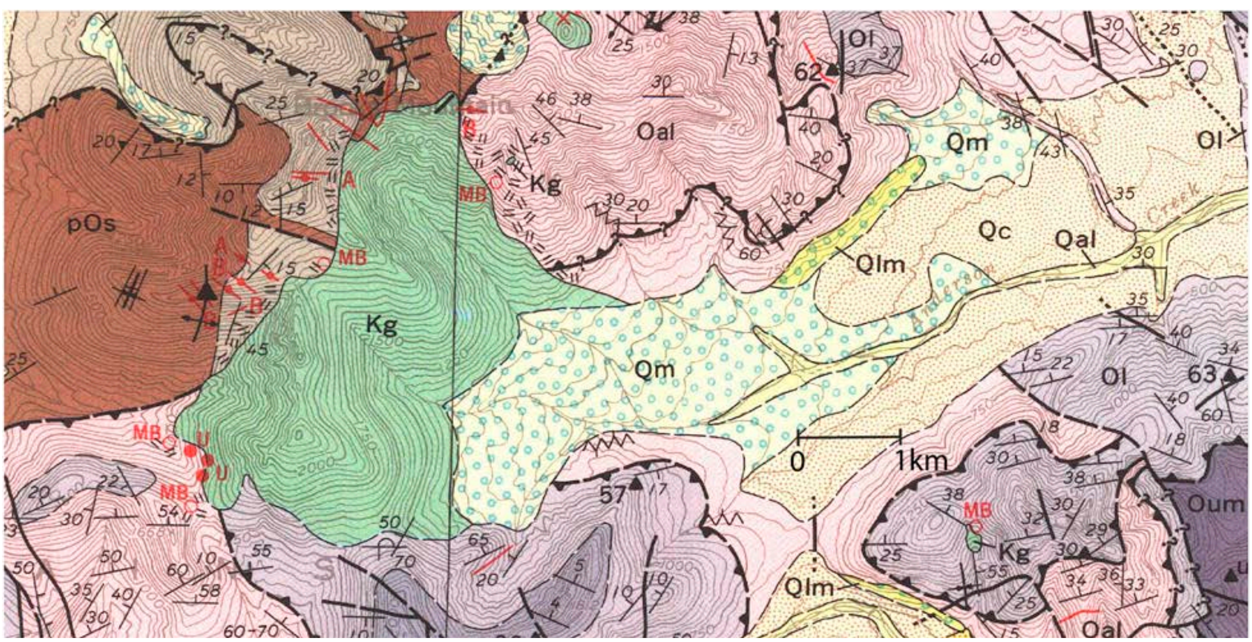

Figure 13. Geologic map of the upper Anderson Creek area (locality L, fig. 2; map from Sainsbury, 1969a, plate 1). Sainsbury's map units include: Qal – Alluvium, Qc – Surficial cover, Qm – Ground moraine, Qlm – Lateral moraine, Kg – Brooks Mountain granite. Brown colors (unit pOs) are pelitic rocks converted to tactite adjacent to Brooks Mountain granite and Oal and Ol units are Ordovician limestone. Iron oxide pebbles were observed in 1982 at locality MB adjacent to a small Kg (granite) exposure at 380 m (1,250 ft) south of Anderson Creek.

MORAINES?

Sainsbury (1967b) noted the paucity of conspicuous moraines and related glacial features in the region, but he did map local moraine deposits at several places in the York Mountains (Sainsbury, 1969a, 1969b). Observations of mapped moraines along the south side of Kanauguk River and near the mouth of Lost River were made in 1998.

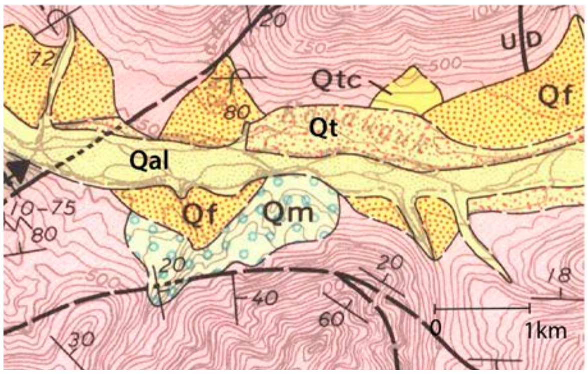

Figure 14. Geologic map of the Kanauguk River moraine locality (locality I, fig. 2; map from Sainsbury, 1969a, plate 1). Sainsbury's Quaternary map units include: Qm – Moraine, Qf – Alluvial fans, Qt – Stream terraces, Qal – Alluvium, and Qtc – Talus. Bedrock is Ordovician limestone (light pink units). This area of hummocky material (Qm) is at the base of steep slopes and is instead interpreted to be a landslide (partly onto stream terrace deposits). Sequences of up to three stream terraces (some cut in bedrock) are present in the southwestern York Mountains.

The Kanauguk River locality is a hummocky mass of angular limestone fragments with diameters up to 1 meter (3 ft) across (fig. 14). Sainsbury (1967a, fig. 9) discusses this deposit and its relation to stream terraces that are well-developed here and elsewhere in the western York Mountains. (The stream terraces are potentially important to understanding the uplift history of this area.) This deposit is interpreted to be a landslide because of its chaotic mix of angular locally derived debris, location at the base of steep slopes, deposition across and on young alluvial fans, and lack of any lateral equivalents elsewhere in the Kanauguk River valley.

The deposits mapped as morainal near and along lower Lost River include gravels and erratics. The low area on the west side of lower Lost River (locality A, fig. 15) is a poorly sorted boulder–cobble gravel with a muddy to silty matrix. Surface elevations are less than 30 m (100 feet), and the deposits could be marine. Stream terrace deposits, rather than moraine, appear to be present along both sides of lower Lost River (locality B, fig. 15). The slopes (locality C, fig. 15) and the York terrace platform surface (locality D, fig. 15) on the east side of lower Lost River valley are rubble crop over limestone bedrock with scattered erratics of subrounded to rounded granite cobbles and more angular tactite fragments. These are lithologies native to Lost River valley.

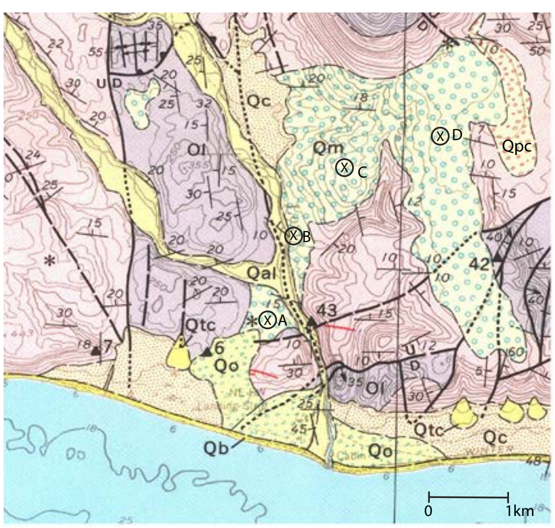

Figure 15. Geologic map showing moraines and outwash deposits mapped by Sainsbury (1969a) in the lower Lost River area (locality J, fig. 2; map from Sainsbury, 1969a, plate 1). Sainsbury's Quaternary map units include: Qo – Outwash, Qm – Moraine, Qc – Surficial cover, Qtc – Talus, Qpc – Conglomerate, and Qb – Beach deposits. Bedrock is Ordovician limestone (light pink units). Localities where observations were made in 1998 include (A) poorly sorted boulder gravel with a muddy to silty matrix (porphyritic granite boulders common), (B) stream terrace deposits, and (C and D) erratics of granite and calc-silicate rock scattered on frost-riven Ordovician limestone bedrock. As discussed in the text, none of these materials are thought to be glacial in origin.

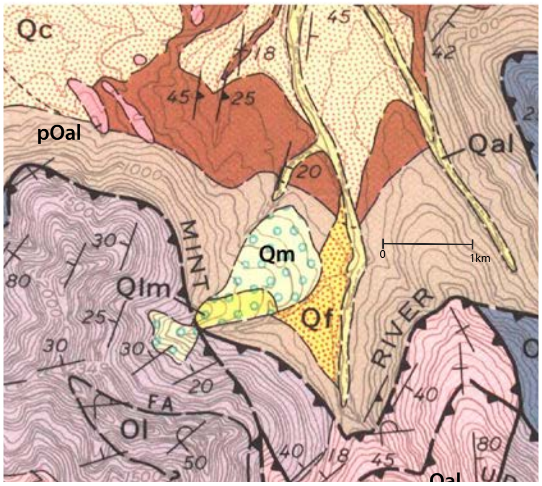

Figure 16. Geologic map of the Mint River glaciation type locality along the upper East Fork of Grouse Creek (locality K, fig. 2; map from Sainsbury, 1969a, Plate 1). Sainsbury's Quaternary units include: Qm – Moraine, Qlm – Lateral moraine, Qf – Alluvial fan, and Qal – Alluvium. Brown unit is pelitic rocks and other light pink bedrock units are Ordovician limestone. The mapped moraine is a hummocky mass about 500 m (1600 ft) across in an east-west direction. It contains large angular limestone blocks and could be a landslide like that at the Kanauguk River locality (fig. 14).

Sainsbury's type locality for the Mint River glaciation is a mapped moraine in the northern York Mountains adjacent to the upper East Fork of Grouse Creek (Sainsbury, 1967a, 1969a). This hummocky feature (fig. 16) has a lower part of frost-riven limestone rubble overlain by coarser limestone rubble with blocks up to 4 m (13 ft) across (Sainsbury, 1967a, p. 140). This very local feature at the base of very steep slopes could be a landslide deposit like that along the Kanauguk River (fig. 14) rather than moraine.

The largest area of moraine mapped in the York Mountains is in the headwaters of Anderson Creek along the east flank of the Brooks Mountain granite stock (fig. 13; Sainsbury, 1969a). This is a key area for future evaluation of the possible role of shore and sea ice rather than glaciers in the dispersal of granite erratics down Anderson Creek valley (fig. 12) and elsewhere throughout the Don River drainage. If ice rafting was the erratic dispersal mechanism, then (1) evidence of these processes should be present in the headwaters of Anderson Creek, and (2) the mapped moraines may instead be other surficial materials such as talus and landslide deposits.

In summary, distinct lateral or terminal moraines are not present on western Seward Peninsula, and the very local features mapped as moraine can be explained in other ways (e.g., talus, landslides, stream terraces, or erratic accumulations). These features do not preclude the interpretation that high sea levels and associated processes are the primary control on Pleistocene landforms of western Seward Peninsula.

FAULTING

Tectonic displacements of parts of western Seward Peninsula are likely. A young normal fault system is present offshore of the York Mountains (Johnson and Holmes, 1978). The faults mapped offshore (fig. 17) have well-developed seafloor scarps up to 15 m (50 ft) high. The Bering Strait fault, the longest mapped, extends 90 km (56 mi) west-southwest from offshore to the mouth of Lost River (fig. 17). These faults appear to be a western part of the active normal fault systems of Seward Peninsula that are responsible for recent uplift of the Kigluaik and Bendeleben mountains (Hudson and Plafker, 1978; Plafker and others, 1994). The faults offshore of western Seward Peninsula have not had nearly as much total displacement as the Kigluaik and Bendeleben faults, but they may have played a role in uplifting, preserving, and deforming the York plateau and terrace. It is possible that the present general height of the York terrace and plateau reflects at least some regional uplift, and correlative surfaces elsewhere may not be as high. Uplift related to the offshore fault system could also have played a role in developing the stream terrace sequences in the York Mountains and perhaps the stepped emergence history of the Lost River terrace west of Lost River (Hopkins, 1973, fig. 6).

The York terrace is warped (higher near Lost River than elsewhere, Brooks and others, 1901; Sainsbury, 1967a, p. 126), but significant discontinuities, possibly related to tectonic displacements, are

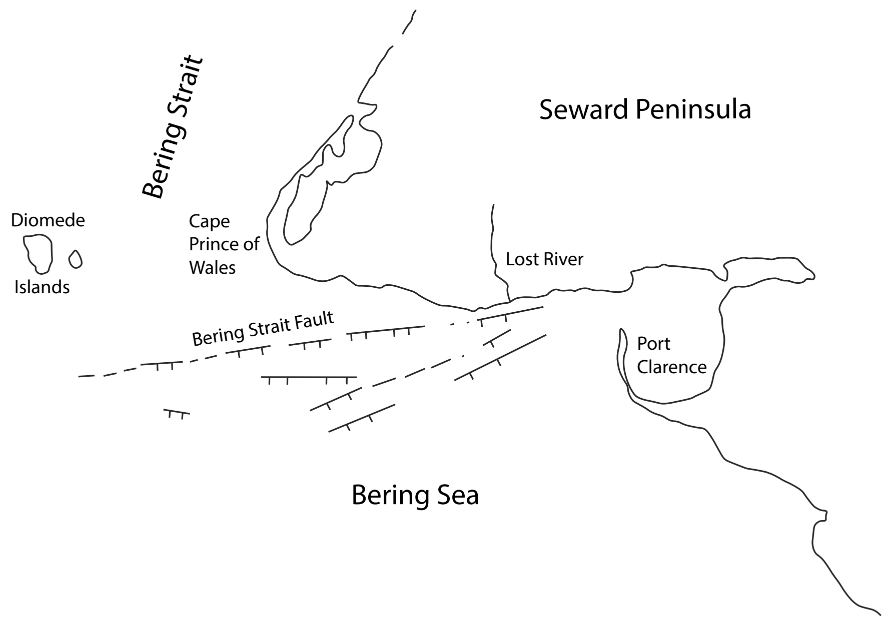

Figure 17. Map showing recent faults offshore of western Seward Peninsula as identified by Johnson and Holmes (1978, fig. 3). These normal faults (down-to-the-south) display seafloor scarps up to 15 m (50 ft) high. Johnson and Holmes (1978) identify many smaller recent faults including some down-to-the-north that are not shown. The Bering Strait fault, the longest mapped, extends from near the mouth of Lost River 90 km (56 mi) to the west-southwest, subparallel to the western Seward Peninsula coastline.

not recognized where it is well preserved along the south flank of the York Mountains. Sainsbury (1967b, fig. 1) and Hopkins and others (1974) correlated the York terrace (shoreline angle elevations of about 200 m or 650 ft) with the Fish Creek terrace east of the Don River (shoreline angle elevations of about 90 m or 300 ft). If this correlation is valid, a significant change in terrace height across the lower Don River valley is indicated. Faults, such as a northwest-trending bedrock fault in the Don River drainage (fig. 4) and a northeast-trending bedrock fault along Skull Creek (fig. 4; Sainsbury, 1969b), are candidates for helping create terrace discontinuities throughout this area. Determining the influence of Pleistocene to Recent faulting on the landforms of western Seward Peninsula will require better understanding of the location, height, and age of the Pleistocene landforms.

DISCUSSION

Sainsbury (1967b, p. D205) and Hopkins and others (1974) both recognized that the presence of the York terrace indicates that a seaway was present in the Bering Strait region during parts of the Pleistocene. The interpretation here that Pleistocene high sea level(s) is the primary control on landforms of the western Seward Peninsula started with a few observations of erratics in the Don River drainage system. The additional observations presented above strengthen this interpretation, but further evaluation and testing is needed. It is especially important to examine the surficial deposits in the headwaters of Anderson Creek and adjacent to the Brooks Mountain granite stock (fig. 13). If shore-ice rafting rather than glaciation is responsible for mobilization and dispersal of Brooks Mountain granite erratics, then evidence for these processes should be present in the headwaters of Anderson Creek.

If the role of nearshore and other marine processes becomes better supported, then efforts to identify and correlate old shorelines and marine-eroded surfaces in the study area and elsewhere on

Seward Peninsula are needed. For example, the 120 m (400 ft) high passes at the head of the Don and Anikovik rivers (figs. 2 and 8) would have allowed the York terrace high stand to flood north through and along the York Mountains. The lower areas in the Don River valley extend north across its headwaters as a break in the general altitude of this part of the York Mountains (Don River gap, locality C, fig. 1). The York Mountains would have become an archipelago of small islands with a sea level stand at 150 m (500 ft) elevation. Surfaces at elevations less than that of the York terrace high stand would not only have been eroded by shoreline transgressions with rising sea level but bottom currents as well once the seaway was fully established.

Several correlations of the York terrace were made by Brooks and others (1901), and equivalent surfaces are likely elsewhere. These include a terrace south of Teller along the coast from Port Clarence that extends south to at least the Tisuk River area in the Nome quadrangle (locality D, fig. 1) and lies inboard of the coastal plain and terrace (equivalent to the Lost River terrace). Surface elevations on this inboard terrace surface are commonly 120 to 180 m (400 to 600 ft).

Another terrace, possibly equivalent to the York terrace, is present on Saint Lawrence Island. This terrace—known as the Putgut Plateau, with surface elevations of 60 to 90 m (200 to 300 ft)—is inboard of a very well-defined terrace equivalent to the Lost River terrace (fig. 18). An abandoned sea cliff more than 20 m (70 ft) high, and like that of the Lost River terrace, is well preserved along the southeastern boundary of the Putgut Plateau. The Putgut Plateau is generally lower than the York terrace but about the same height as the Fish Creek terrace. Such differences could reflect tectonic uplift of the York terrace and plateau area. The Putgut Plateau is a very well-preserved bedrock platform that will be important to better correlate regionally.

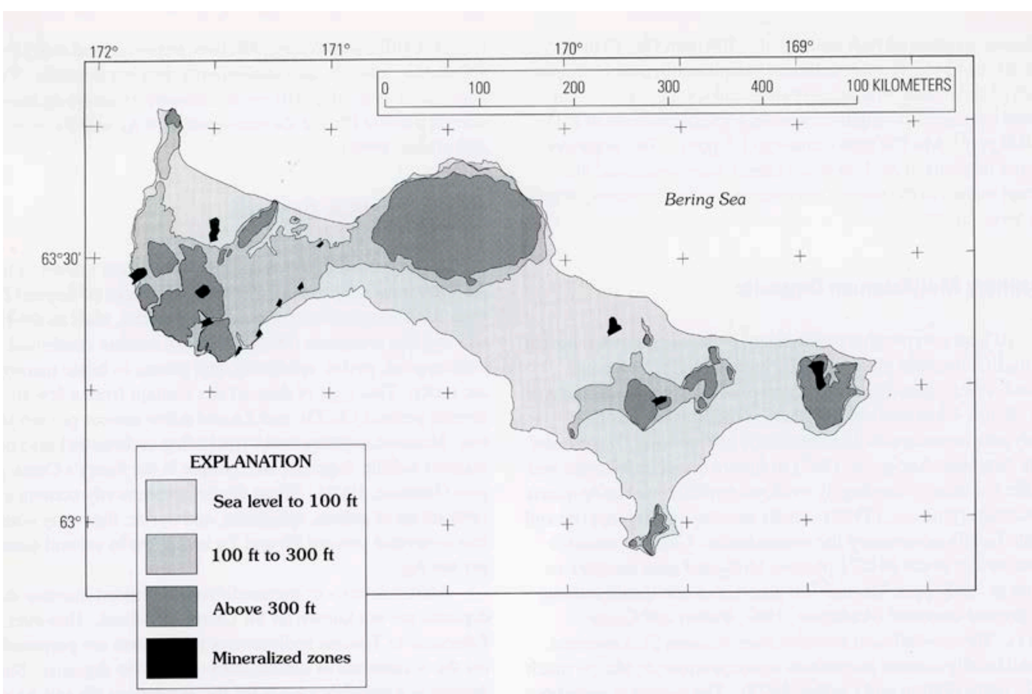

Figure 18. Map of St. Lawrence Island showing areas of different surface elevations (fig. 5 of Hudson and Saltus [2000]). The area with surface elevations less than 30 m (100 feet) is a marine terrace platform correlative with the Lost River terrace. The area with surface elevations between 30 to 90 m (100 to 300 ft) includes the Putgut Plateau, a marine terrace bedrock platform with level upper surfaces commonly at least 60 m (200 ft) high.

The pass between the Kigluaik and Bendeleben mountains (Pilgrim River gap, locality C, fig. 1), connecting the lowlands of the Pilgrim River and the intertidal Imuruk Basin to the north with lowlands of American Creek and the Niukluk River drainage to the south, is only about 70 m (250 ft) in elevation. Brooks and others (1901) and Collier (1902) both drew attention to this low elevation, and Brooks and others (1901), accepting that submergence of Seward Peninsula was an important part of its Late Cenozoic history, proposed that a seaway once connected the drowned estuary of the Niukluk River drainage with the now intertidal Imuruk Basin. The Pilgrim River gap is low enough that sea levels as high as those forming the Fish Creek terrace could have led to a seaway in this area.

The possibility that there were Pleistocene sea levels higher than those forming the York terrace and plateau needs to be considered because York Mountain erratics are present at elevations higher than the York terrace. Other possible evidence of higher sea level stands in the Bering Strait region is provided by resistant uplands, including Little Diomede Island, 41 km (25 mi) west of Cape Prince of Wales. This island has an approximately horizontal upper surface at about 360 m (1,180 ft) elevation. Gaultieri and Brigham-Grette (2001) suggested this surface could be correlated with the York terrace, but it is significantly higher—unless tectonic uplift is also significant in this area. Big Diomede Island has a more irregular upper surface, as does Cape Mountain at Cape Prince of Wales, but both of these uplands have subdued upland summits or benches surrounded by steeply sloped flanks suggestive of wave-cut surfaces at about 300 m (1,000 ft) elevation.

Collier (1902) described upland surfaces at about 300 m (1,000 ft) and 490 to 550 m (1,600 to 1,800 ft), his Kugruk and Nuluk plateaus, respectively, that are well defined in the limestone bedrock areas of the central Teller Quadrangle east of the York Mountains. The origin of these surfaces is not clear, and subsequent workers have generally not studied them. (Altiplanation processes and their influence on upland surfaces are important in many places on Seward Peninsula.) However, Collier (1902) specifically identifies a lower area between the headwaters of the Nuluk River and Arctic Creek (headwater tributary to the Agiapuk River) as a distinct gap (Nuluk River gap, locality B, fig. 1) in the continuity of the upland surface in this area (a key part of his Kugruk plateau). Level summits through this gap are generally at 300 m (1,000 ft) elevation. If sea levels higher than the York terrace become verified, then the origin of the Nuluk River gap and its adjacent uplands would seem to warrant further investigation.

Finally, what if the high-level gravels and placer gold deposits, like those in the headwaters of Dexter Creek in the Nome C-1 Quadrangle (at about 170 m [560 ft] elevation; ARDF localities NM246, NM247, and NM248, for example, in Hawley and Hudson [2002]), formed through higher sea level processes and not glaciation? This possibility has been recognized as potentially influencing placer gold deposits in the region (Hawley and Hudson, 2002; Hudson, 1999) but has not been investigated, although a project to do so on the Nome coastal plain was proposed to the U.S. Geological Survey in 2006 (available online at the author's ResearchGate publications page).

CONCLUSION

The principal conclusions of this investigation of the Pleistocene landforms of the western Seward Peninsula, all of which need to be further evaluated and tested, are: (1) distinctive erratics were mobilized and dispersed by shore and sea ice processes rather than glaciers originating in the York Mountains, (2) surficial materials previously mapped as moraine appear to be very local erratic accumulations, stream terrace deposits, or talus and landslide deposits, (3) the York terrace and other marine erosion surfaces are evidence that sea levels were as high as 110 m (350 ft) and up to 210 m (700 ft), although at least some of this present height is likely due to tectonic uplift, and (4) at the time of the high sea level stand that formed the York terrace:

- Seas flooded through the York Mountains and created an archipelago of small islands.
- The southwest flank of the York Mountains, in the vicinity of the western limits of the York terrace, was a cape like Cape Prince of Wales today.
- The area west of the York Mountains to Cape Mountain and Lopp Lagoon, the York Plateau, was mostly below sea level. The weak alluviation now present here suggests that bottom currents scoured this region.
- Bottom currents transported sediment northward to be deposited in the Mint River to Pinguk River area and offshore to a large north-trending constructional sediment shoal on the Chukchi seafloor that is like the Prince of Wales shoal forming today.
- Cape Mountain was an island.

Large parts of Seward Peninsula could have been affected by the high sea levels that controlled landform development near the Bering Strait. If future research verifies the conclusions of this study, then investigations of the role of high sea levels in shaping landforms in other regions such as the Pilgrim River gap are needed. As sea level stands higher than that forming the York terrace are possible, future investigations should also consider the origin of such features as the Nuluk River gap. I hope this collection of observations and syntheses of previous work helps justify and foster future studies.

ACKNOWLEDGMENTS

Figure 19. Photograph of the memorial plaque placed by C.L. "Pete" Sainsbury's family commemorating his life and work in the York Mountains and western Seward Peninsula. The plaque is in Lost River valley near the mouth of Camp Creek. A specimen of fluorite-rich rock from Camp Creek is embedded in the upper right-hand corner of the memorial. Photograph taken on July 9, 2011.

C.L. "Pete" Sainsbury's contributions to understanding the many aspects of western Seward Peninsula geology are exemplary and a foundation for all subsequent investigations in this region. The scope of his studies was exceptional, including such diverse investigations as water–rock chemical reactions, magma mixing and assimilation, geochemical cycles, mineralogy, underground geologic mapping, and the discovery of unusual beryllium-fluorite deposits. All these investigations were in turn built upon strong stratigraphy and petrology studies important to his geologic mapping of the region. Pete would not be stopped by inclement weather or other handicaps as he ventured on foot over this large area, diligently recording observations and reporting his findings. The York Mountains became a special place in Pete's life that his family was able to commemorate with a memorial plaque (fig. 19) placed near the mouth of Camp Creek in Lost River valley. This synthesis and interpretation would not have been possible without the important foundations Pete provided, and I will always be deeply grateful to Pete for his personal and professional help early in my career. Reviews by F.H. (Ric) Wilson (USGS) and Amanda K. Lanik (NPS) were very helpful and much appreciated—Amanda's assistance obtaining figure 1 is also very much appreciated.

REFERENCES

Brigham-Grette, Julie, and Hopkins, D.M., 1995, Emergent marine record and paleoclimate of the last interglaciation along the northwest Alaskan coast: Quaternary Research, v. 43, no. 2, p. 159–173.

Brooks, A.H., Richardson, G.B., Collier, A.J., and Mendenhall, W.C., 1901, Reconnaissances in the Cape Nome and Norton Bay Regions, Alaska, in 1900: U.S. Geological Survey, 222 p., 9 sheets, scale 1:250,000.

Collier, A.J., 1902, A reconnaissance of the northwestern portion of Seward Peninsula, Alaska: U.S. Geological Survey Professional Paper 2, 1 sheet, scale 1:250.000, 70 p.

Creager, J.S., and McManus, D.A., 1967, Geology of the floor of the Bering and Chukchi seas – American studies, *in* D.M. Hopkins, ed., The Bering Land Bridge: Stanford University, Stanford, California, Stanford University Press, p. 7–31.

Gaultieri, Lyn, and Brigham-Grette, Julie, 2001, The age and origin of the Little Diomede Island upland surface: Arctic, v. 54, no. 1, p. 12–21.

Hawley, C.C., and Hudson, T.L., 2002, Alaska Resource Data File – Nome Quadrangle: U.S. Geological Survey Open-file Report 01-113, 735 p.

Heide, H.E., and Rutledge, F.A., 1949, Investigation of Potato Mountain tin placer deposits, Seward Peninsula, northwestern Alaska: U.S. Bureau of Mines Report of Investigations 4418, 21 p.

Hopkins, D.M., 1959, Cenozoic History of the Bering Land Bridge: Science, v. 129, no. 3362, p. 1,519–1,528.

———1973, Sea level history in Beringia during the past 250,000 years: Quaternary Research, v. 3, p. 520–540.

Hopkins, D.M., Nelson, C.H., Perry, R.B., and Tau Rho Alpha, 1976, Physiographic subdivisions of the Chirikov basin, northern Bering Sea: U.S. Geological Survey Professional Paper 759-B, 3 plates, 7 p.

Hopkins, D.M., Rowland, R.W., Echols, R.E., and Valentine, P.C., 1974, An Anvilian (early Pleistocene) marine fauna from the western Seward Peninsula, Alaska: Quaternary Research, v. 4, no. 4, p. 441–470.

Hudson, Travis, 1999, Alaska Resource Data File – Solomon Quadrangle: U.S. Geological Survey Open-File Report 99-573, 360 p.

Hudson, Travis, and Arth, J.G., 1983, Tin granites of Seward Peninsula, Alaska: Geological Society of America Bulletin, v. 94, p. 768–790.

Hudson, Travis, and Plafker, George, 1978, The Kigluaik and Bendeleben faults, Seward Peninsula, Alaska: U.S. Geological Survey Circular 772-B, p. B47–B50.

Hudson, T.L., and Reed, B.L., 1997, Tin deposits in Alaska, *in* Goldfarb, R.J., and Miller, L.D., eds., Mineral Deposits of Alaska: Economic Geology Monograph 9, p. 450–465.

Hudson, T.L., and Saltus, R.W., 2000, Bedrock assemblages of the Bering Strait region: Implications for offshore metal sources in the marine environment: U.S. Geological Survey Professional Paper 1615, p. 111–125.

Johnson, J.L., and Holmes, M.L., 1978, Surface and subsurface faulting in Norton Sound and Chirikov Basin, Alaska, *in* Environmental Assessment of the Alaskan Continental Shelf, Annual Report of Principal Investigators for the year ending March 1978: U.S. Department of Commerce National Oceanic and Atmospheric Administration, v. 12, p. 203–227.

McManus, D.A., and Creager, J.S., 1963, Physical and sedimentary environments on a large spit-like shoal: Journal of Geology, v. 71, p. 498–512.

Mulligan, J.J., 1959, Sampling stream gravels for tin near York, Seward Peninsula, Alaska: U.S. Bureau of Mines Report of Investigations 5520, 23 p.

———1965, Tin lode investigations, Potato Mountain area, Seward Peninsula, Alaska: U.S. Bureau of Mines, Report of Investigations 6587, 85 p.

Mulligan, J.J., and Thorne, R.L., 1959, Tin-placer sampling methods and results, Cape Mountain district, Seward Peninsula, Alaska: U.S. Bureau of Mines Information Circular 7878, 69 p.

Plafker, George, Gilpin, L.M., and Lahr, J.C., 1994, Neotectonic map of Alaska, *in* Plafker, George, and

Berg, H.C., eds., The Geology of Alaska: Geological Society of America, 2 sheets, scale 1:2,500,000.

Sainsbury, C.L., 1967a, Quaternary geology of western Seward Peninsula, Alaska, *in* Hopkins, D.M., ed., The Bering Land Bridge: Stanford, California, Stanford University Press, p. 121–143.

———1967b, Upper Pleistocene features in the Bering Strait area: U.S. Geological Survey Professional Paper 575-D, p. D203–D213.

———1969a, Geology and ore deposits of the central York Mountains, western Seward Peninsula, Alaska: U.S. Geological Survey Bulletin 1287, 101 p., 1 plate, scale 1:63,360.

———1969b, Geologic map of the Teller B-4 and southern part of the Teller C-4 quadrangles, western Seward Peninsula, Alaska: U.S. Geological Survey Miscellaneous Investigations Map I-572, scale 1:63,360.

———1974, Geologic map of the Teller quadrangle, western Seward Peninsula, Alaska: U.S. Geological Survey Miscellaneous Investigations Map I-685, scale 1:250,000, 4 p.