A guide to the late Quaternary History of the Southeast Alaska: Yakutat Block and Alexander Archipelago

Cathy L. Connor and Roman J. Motyka

Cover Photo The June 2008 receding terminus of the Herbert Glacier visited during Juneau Icefield Research Program Student Field Trip (Connor photo, Connor, 2008 in review).

Acknowledgements

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A Guide to the Late Quaternary History of the Alexander Archipelago: Yakutat to Dixon entrance, Alaska

By Cathy Connor and Roman Motyka

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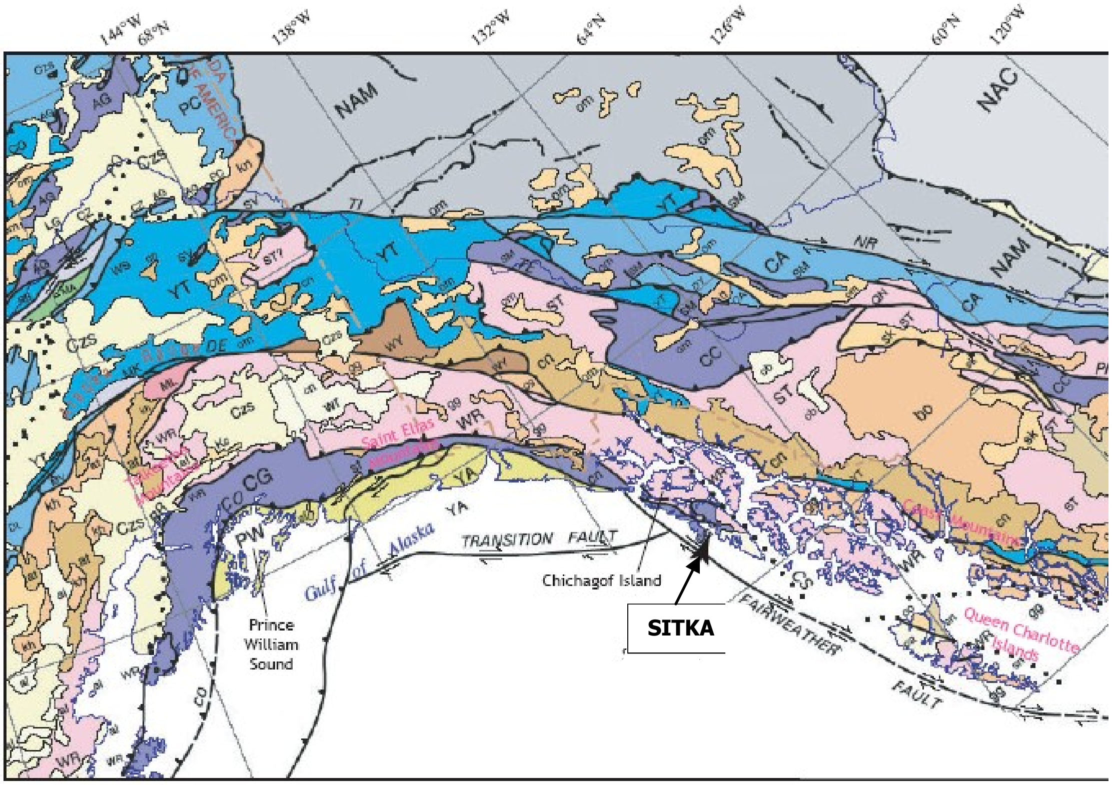
INTRODUCTION

Southeast Alaska is dominated by the St. Elias Range, which trend along the coast of the Gulf of Alaska into Cross Sound, and by the Coast Range, which trend southeast to Dixon Entrance and southward (Figure 1). These mountains are the products of immense tectonic forces which led to the amalgamation of a complex of fault-bounded bedrock terranes (Figure 2). This landscape together with moisture from the North Pacific, provides the platform for the generation of extensive coastal glaciers and glaciations that have profoundly influenced and shaped this region.

Researchers from a variety of disciplines have studied this interplay between tectonics and climate. The Late Quaternary history of Southeast Alaska has been recorded in many ways: in muskegs, in fluvial, lacustrine, glacial, beach, estuarine, continental shelf, and abyssal fan sediments, in subfossils (pollen, microfauna, macro-biota), in biogeochemical signatures, and in the landscape. Features such as uplifted coastal terraces and marine shell beds, abandoned cirques, offset glacier valleys, subglacial lava flows, and unglaciated refugia from the broad Yakutat forelands southeast along the continental shelf edge bordering the modern shorelines of Baranof, Heceta, Suemez, and Prince of Wales Islands (Figure 1, Carrara et al. 2007, Karl et al. 2008) record the interplay of tectonics, volcanism, glacial loading of the crust, and lowered sea levels as climate changed throughout the Pleistocene. Repeated glaciations and interstadial interludes have resulted in periodic erasure and reestablishment of terrestrial and intertidal flora and fauna. A complex island biogeography has been established since the end of the Last Glacial Maximum (LGM) in part from animals and plants that existed in ice-free refugia on the continental shelf and on alpine nunataks. These habitats supported the first human occupants of the region (Cook et al. 2006).

In 2008 the Alaska cell of the Friends of the Pleistocene (FOP) held their annual weekend field trip, in the Juneau Area. In this Field Guidebook from that gathering we provide a brief overview of regional neotectonics and geodynamics; surface processes including glaciology and glacial geology; paleoecology, palynology, and dendrochronology; anthropological studies; soils and landscape development; biogeography; and 20th-21st century climate warming. We also provide the details of our field trip stops during August 30-Sept 1, 2008, during which we visited some of the Southeast Alaska Quaternary sites in the Juneau area.

Figure 1 Map of southeastern Alaska showing geographic features.
(http://www.alaskais.com/akse.htm)



Gulf of Alaska area, showing location of study area and tectonostratigraphic terranes of Alaska, Yukon Territory, and British Columbia (from Nokleberg and others, 1998). The Sitka Graywacke, the Valdez Group, and the McHugh Complex are all parts of the Chugach accretionary complex. Terranes: CG, Chugach; ST, Stikine; YT, Yukon-Tanana. Faults: *BR*, Border Ranges; *CS*, Chatham Straight; *DE*, Denali; *TI*, Tintina.

Figure 2 Map of Southeast Alaska showing bedrock terranes (Nokleberg et al 1998).

Northern Cordillera Tectonics

Rupture zones of major earthquakes have been mapped for twentieth century earthquakes around the Northern Gulf of Alaska Figure 3 (Plafker and Thatcher, 2008).

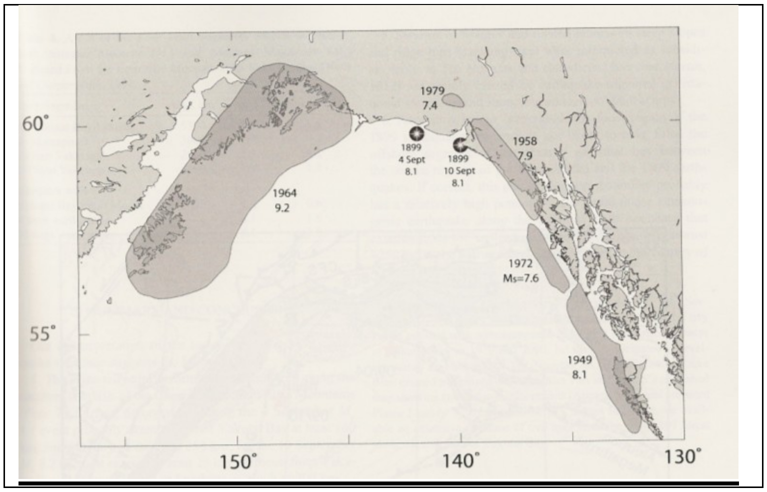


Figure 3. Twentieth century rupture zones of major northern Gulf of Alaska earthquakes 1899-1979 (Plafker and Thatcher, 2008)

Two great earthquakes (M_W=8.1 and 8.2) occurred in September 1899 in Yakutat Bay. These ruptures are related to the ongoing collision of the Yakutat block with North America in this region Figure 4 (Plafker and Thatcher, 2008). Data from Leonhard et al. (2007) infer that relative Yakutat–North America motion is accommodated across the eastern collision boundary by right-lateral motion (~40 mm/a), mainly on the Fairweather fault with minor shortening (~6 mm/a). To the northwest, collision is taken up by shortening (~31 mm/a) mainly on the Chugach–St. Elias fault system, with westward extrusion and possible counterclockwise rotation of the Yakutat block and Alaskan fore arc. This rotation is facilitated by ~23 mm/a right-lateral motion that is shared by several faults. Glacier redistribution of eroded material resulted in progradation of the continental shelf edge southward, shifting the location of deformation centers and changing collision dynamics across the region (Figures 4a, 4b, and 5, Gulick et al, 2007, Chapman et al, 2008). Strain from this collision has resulted in "escape tectonics" in the form of movement of western interior Alaska toward Russia (Redfield et al. 2007), a rotation of the Kenai Peninsula crust clockwise and westward, uplift of Denali and Foraker mountains as well as the Central Alaska Range, and has produced strain throughout eastern Alaska, Yukon, and western Northwest Territories, at least 400 km from the Yakutat collision front (Leonhard et al, 2007).

Photo 2. Yakataga Formation west of Yakutat From Alaska Airlines 737 (Connor 2006).

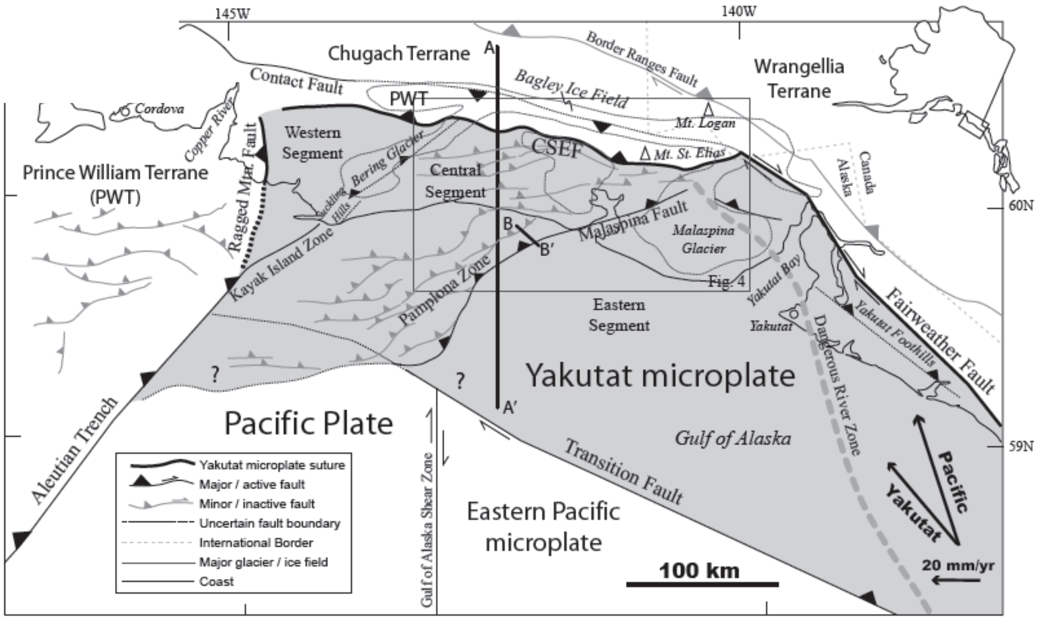


Figure 4a Overview Map of Yakutat Block with plate motion velocities (Fig 1 in Chapman et al, 2008). Locations of N-S cross section A-A’ in Figure 4 below.

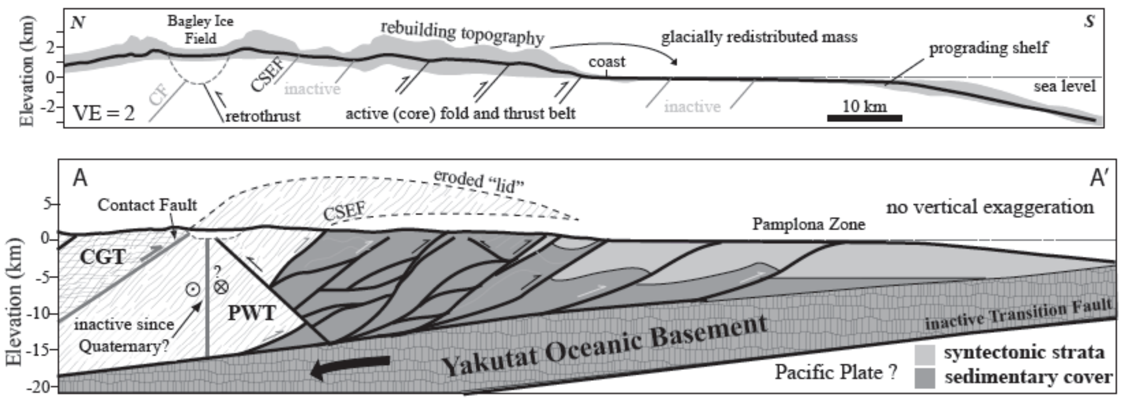


Figure 4b Shallow (-2 km) along line A-A′ (N-S) cross-section showing the average topography and areas of redistribution of mountain mass by glaciers (Vertical Exaggeration=2, Chapman et al. 2008). 4b. Deeper cross section (-20 km) along line A-A^1 shown in Figure 4a. indicates topographic change and subsurface tectonics across a 50 km transect without vertical exaggeration (Chapman et al. 2008).

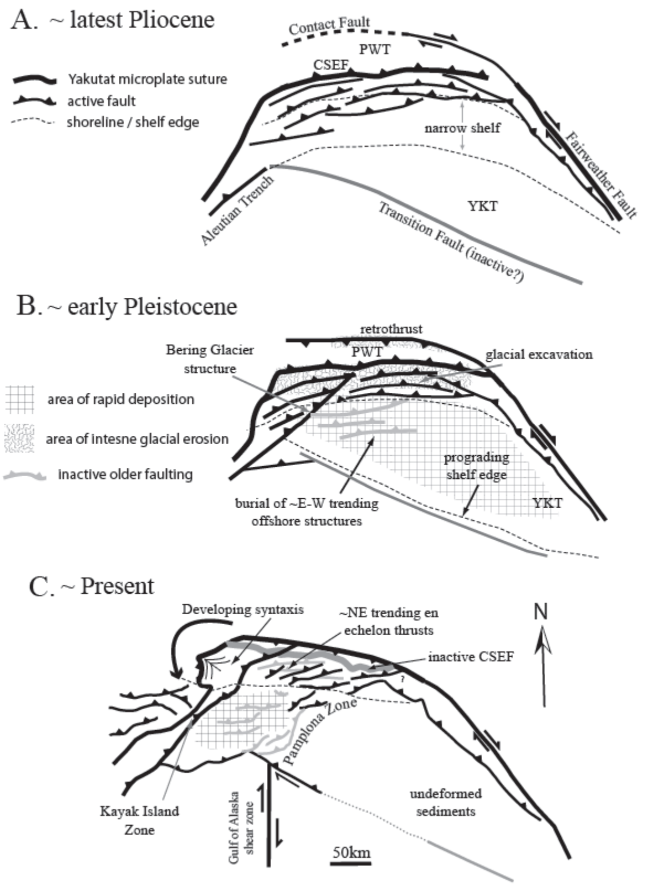


Figure 5 Reconstruction of tectonics and glaciation from Late Pliocene to Recent in the Gulf of Alaska region during deposition of the Yakataga Formation (Chapman et al. 2008).

The Miocene Onset of Glaciation

By the late Miocene, deformation from a converging Yakutat block had already produced the high elevation ranges of the St. Elias and Coastal Mountains (Fig. 5). These ranges hosted a series of expanding ice caps that flowed to the ocean and eroded troughs across the continental shelf while blocking the courses of interior rivers flowing such as the Alsek, Tatshenshini, Chilkat, Taku, and Stikine to the coast (Carlson et al 1982, Molnia, 1986, Templeman-Kluit 1980). During this time the southern and headwater region of the Yukon River watershed was located in the central Yukon Territory Figure 6). In Pliocene time it began drainage basin expansion to the south through headward erosion. This campaign of stream piracy facilitated the loss of of the upper watershed tributaries of many coastal rivers, reversing their flow into the Yukon and into to Bering Sea (Templeman-Kluit, 1980).

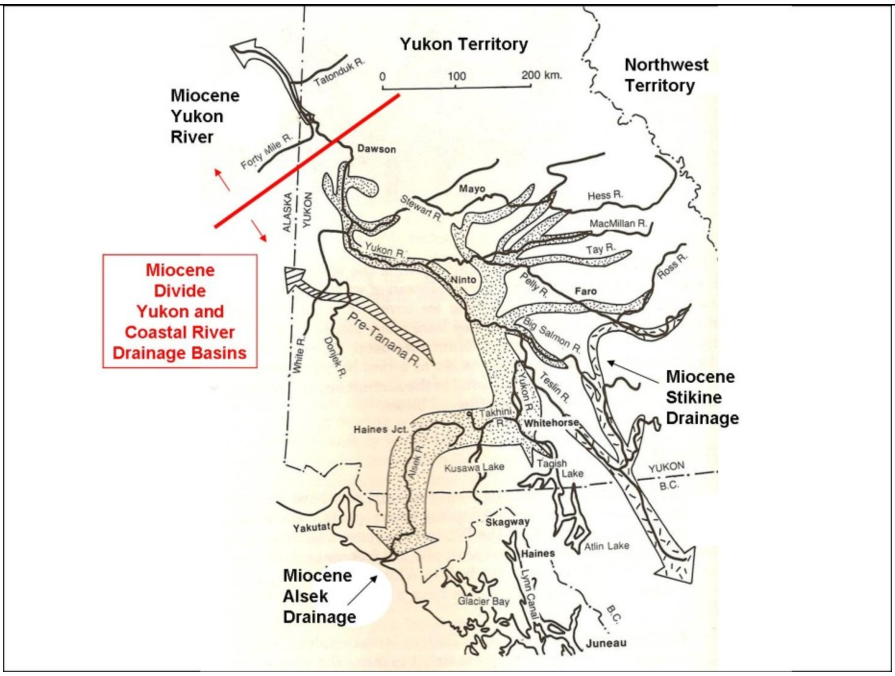


Figure 6. Ancient Alsek and Stikine River drainage basin patterns prior to Miocene glaciation in the St Elias and Coast Ranges and Yukon River expansion (after Templeman-Kluit, 1980)

Alaska's first tidewater glaciers deposited the basal glacial-marine unit of the Yakataga Formation between 6.0 and 5.0 Ma (Miller, D.J., 1957, Eyles et al 1991, Lagoe et al, 1993). Sediments eroded by glaciers on these high peaks were redeposited offshore, prograding the shelf seaward during late Pliocene and Pleistocene glacier cycles (Hallet et al. 1996, Meigs and Sauber, 2000, Chapman et al, 2008). A 6,000 m thick sequence of inter-bedded, glaciomarine and marine sediments is well exposed in the Robinson Mountains west of Yakutat (Photo 2) and has been recovered from cores in continental shelf sediments and on

Middleton Island in Prince William Sound. From west to east the Yakataga formation extends 400 km along the Gulf of Alaska and inland 100 km; it is at least 1150 m thick under Prince William Sound (Molnia, 1986). Following a mid Pliocene warming, glaciation intensified from 3 to 2 Ma. Deep Sea Drilling cores from Site 178 (von Heune, 1973, 1976), on the abyssal plain 400 km south of the coast, contain ice-rafted debris of middle Pliocene age. Paleomagnetic reversals in Yakataga Formation sediments record deposition during the Olduvai Normal Polarity Subchron of 1.8 to 1.6 Ma through the Matuyama-Reversed Polarity Subchron 1.6-0.8 Ma (Fig. 6) (Allison, 1976, Lagoe et al 1993). Ice-rafted debris from Gulf of Alaska marine or nearshore ice lobes have been found as far south as Lat 44°, offshore of Oregon, some 2000 km south of the Alaskan coast (Griggs and Kulm, 1969).

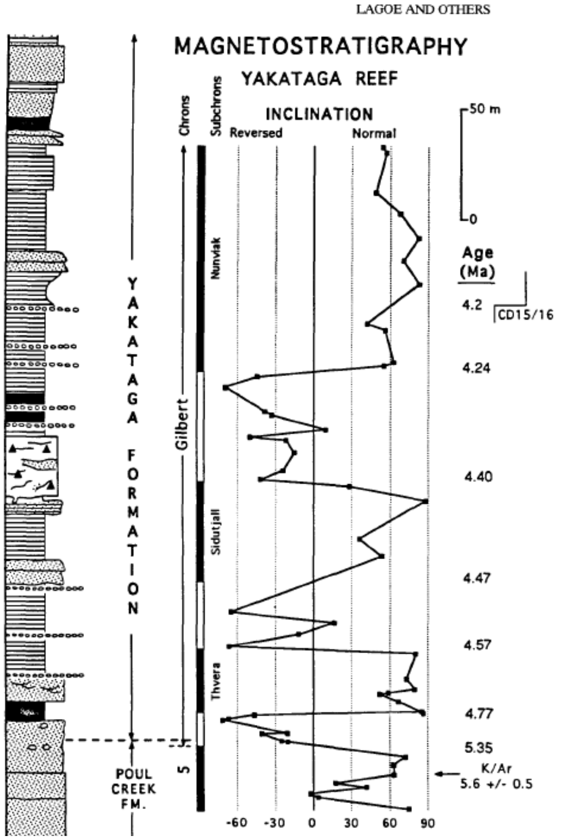


Figure 7 Generalized stratigraphy of the Yakataga Formation and underlying and Poul Creek Formation with magnetostratigraphy (Lagoe et al, 1993).

The upper 100 m of the Yakataga Formation sediments indicate a second phase of glaciation began about 2.5 Ma. The sediment record also indicates an intensification in glacier cycling, presumably from repeated advances and retreats, between 100 ka and 40 ka. Glacier activity and not tectonic exhumation is responsible for these sediments as revealed by high resolution seismic data (Gulick et al. 2007).

The Northern Cordilleran Volcanic Complex

Following subduction of the Resurrection and Essamy ridges beginning 50 Ma, (Figure 8a; Madsen et al. 2006) the Queen Charlotte-Fairweather transform fault was formed and began the right lateral translation of the Pacific Plate to the NW past the North American Plate Margin Figures 8a and 8b. To the south of Dixon Entrance, subduction of the present day Explorer ridge system has propagated a slab window under northern BC and southern Southeast and is exposing crustal rocks directly to the upper mantle (Figure 8c).

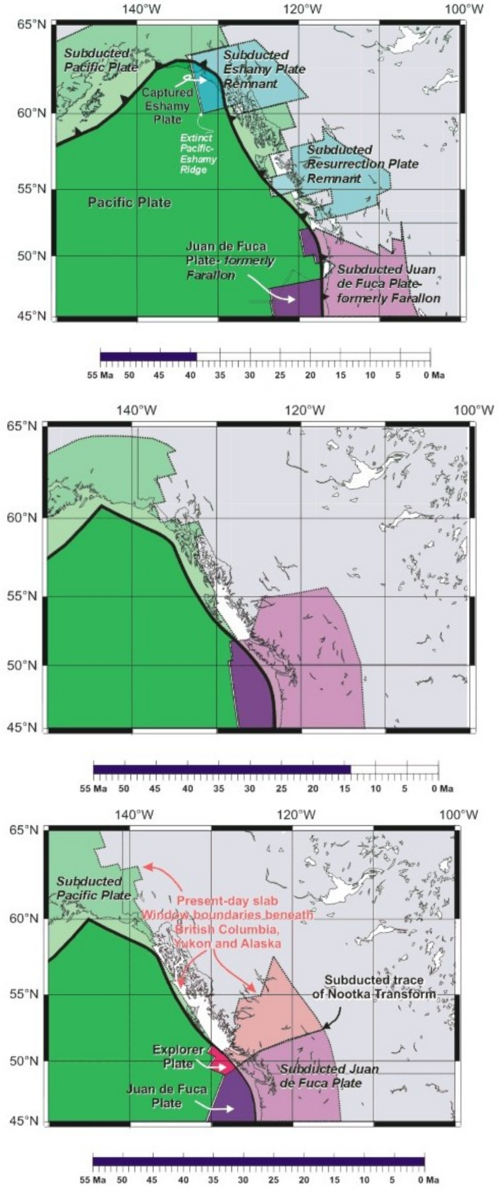


Figure 8a. Forty million years ago a model of slab-window boundaries beneath the Yukon, BC and SEAK related to subduction of Resurrection and Essamy Ridges. 8b. Subducted Pacific Plate beneath SEAK at 14 mya, 8c. Present day slab window boundaries related to migration of the Explorer, North American, and Pacific Plate Triple Junction and oblique subduction of Pacific Plate along the Queen Charlotte Fairweather Fault. (Madsen et al, 2006)

Extension and right lateral offset between the inland Tintina strike-slip fault, to the Queen Charlotte-Fairweather transform fault, has created an extensive fracture system and widespread magmatism resulting in eruptions of the Northern Cordilleran Volcanic Province (Karl et al, 2008). Neogene-Quaternary magmas have surfaced through the fracture systems mostly in two distinct pulses (8-4 Ma and 2-0 Ma), and the mean rate of magma production was higher from 7 to 5 Ma than from 2 to 0 Ma (250 km ^{3} /m.y. vs. 100 km ^{3} /m.y.; Edwards and Russell, 2000).The first pulse of magmatism correlates with a period of net extension along the Pacific-North American plate margin. The second pulse (2-0 Ma) resulted from local domains of extension during a period of net compression between the Pacific and North American plates (Edwards and Russell, 2000).

Ice loading and migration of glacial forebulges during successive glaciations may have influenced the timing of eruptive phases from Yakutat to Suemez Island resulting in earthquakes and subglacial eruptions (Baichtal and Karl, 2009, Sauber and Ruppert, 2008; Greene et al. 2007). Alkaline and bimodal volcanoes such as Tseax Cone north of Prince Rupert, and the 2,787 m Mt. Edziza volcano shield volcano in the upper Stikine River watershed (Photo 3) have all formed since Miocene time. Volcanic Hawaiite basalts from Suemez Island near Obsidian Bay have yielded ages of about 684,000 years ago (Karl et al. 2008). Subglacial eruptions of obsidian are likely on Suemez Island (Baichtal and Karl, 2009) and on the mainland near Ketchikan, forming an important resource and trade item for early southeast Alaskan coastal residents. Additional obsidian sources have been found ~80 km from tidewater up the Stikine River at Mt Edziza (Photo 3; Moss et al, 2001). Young lava flows (100 to 300 years in age) can be found at Lava Falls in the Bradfield Canal area east of Ketchikan and Wrangell (Photo 4).

 **Photo 3** Mt Edziza from the Cassiar Highway (Connor 2005)	 **Photo 4** Lava Falls in the Bradfield canal area on the mainland in central southeast Alaska. (Stephen B. Lewis 2004)

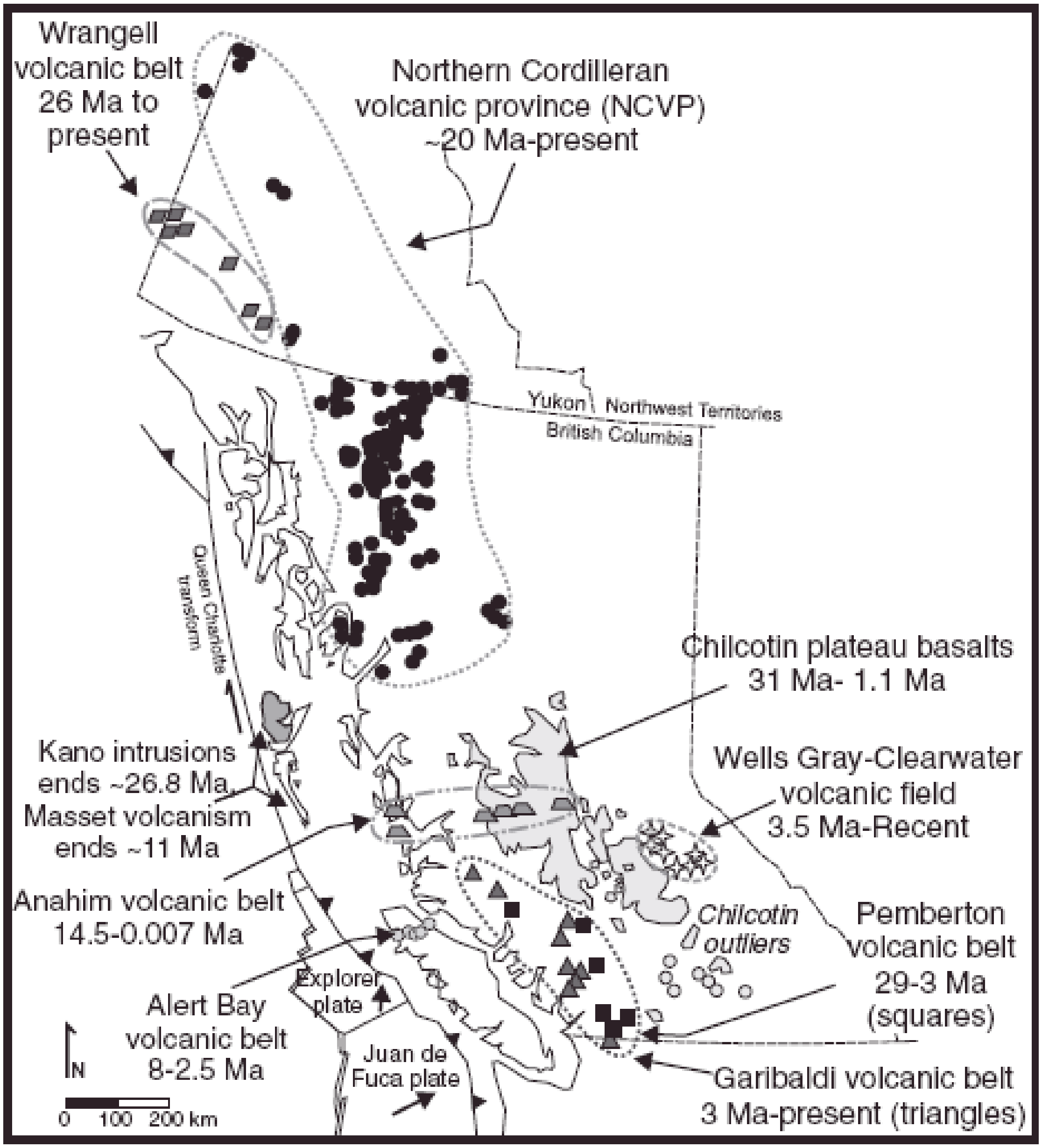


Figure 9. Late Oligocene to Recent Northern Cordilleran Volcanic Province volcanic regions in British Columbia, Southeast Alaska and the Yukon (Edwards and Russell, 2000). Southeast Alaska volcanic localities are not shown in this Canadian dataset.

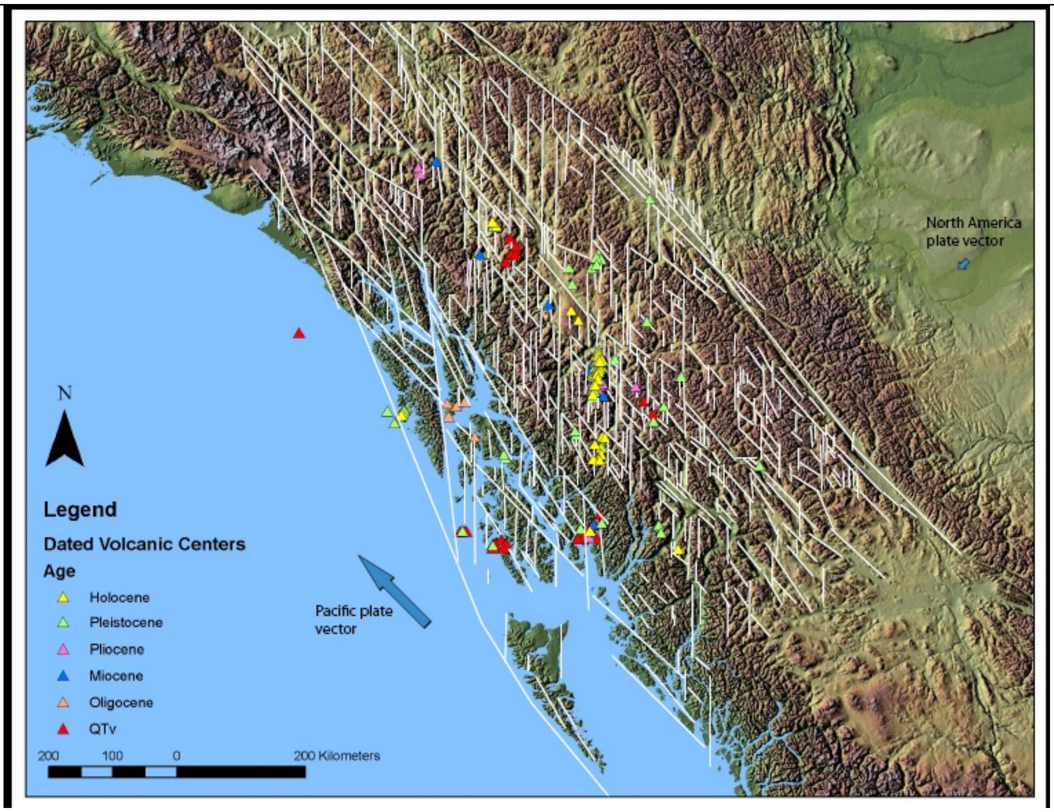


Figure 10. Dated Southeast AK Volcanic Centers shown with regional fracture pattern (Karl et al. 2008)

The Edgecumbe volcanic field (Photos 5, 6) is identified by the prominent stratocone on Kruzof Island as viewed from Sitka's western skyline. The field formed initially as basaltic aquagene tuffs emerged onto the continental shelf beginning about 600,000 YA near Krestoi Point (Photo 5; Riehle, 1996). Explosive dacitic and rhyolitic eruptions began about 14,000 YA following withdrawal of glacier ice (Figure 10; Riehle, 1996). Ash layers ~1m thick can be seen around Sitka, and are 100m thick on Kruzof Island. An eruption which occurred 11,250 BP was recorded widely in tephra layers around northern Southeast AK (Mann and Streveler, 2008; Beget and Motyka, 1998; Riehle, 1996).

The extensive Mt Edgecumbe volcanic field erupted about 600 km^2 of pahoehoe and aa lavas flows, lobate lavas, collapsed lava tubes and vesiculated basalts about 7,000 years ago across the continental shelf along the west side of Kruzof Island (Greene et al. 2007). The lack of pillow basalts in the presently submerged portions of the lava field suggest it was either formed subaerially, subglacially, or in shallow marine water and that it has subsided 300 m since its formation (Greene et al. 2007).

Photo 5 Mud Bay, Kruzof Island 600,000 YA aquagene tuffs erupted atop glaciated Cretaceous Sitka graywacke bedrock. (Jess Parks Photo 2008)

Photo 6 Mt Edgecumbe and Crater Ridge Peaks on Kruzof Island NW of Sitka (Jess Parks Photo 2008)

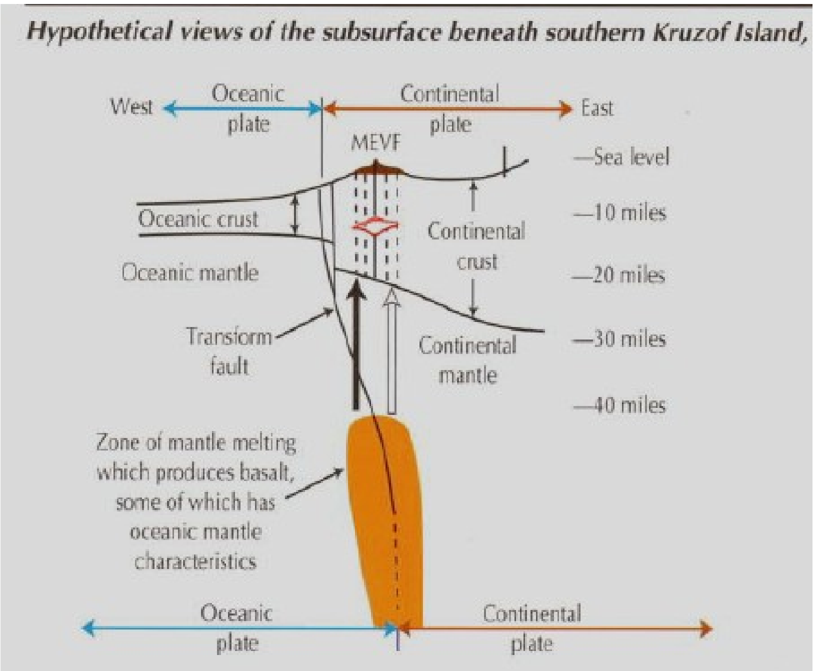


Figure 11. Mt. Edgecumbe volcano sources relative to Queen Charlotte-Fairweather Transform Fault boundary (Riehle 1996)

<u>The Pleistocene Climate in Southeast Alaska</u>

Middle Pleistocene (700,000-130,000 YA)

On Prince of Wales Island and elsewhere carbonate bedrock of the Alexander Archipelago, rainwater and low pH muskeg waters have dissolved Silurian and Devonian aged limestones to form an extensive karst landscape with abundant caves formed along the regional vertical bedrock fracture system. Many caves have been mapped and inventoried by volunteers with the Tongass Cave Project

(1970-2009). Uranium-thorium dates on speleothems in On Your Knees Cave (49-PET-408) on Northern Prince of Wales Island (POW) indicate that by 185,000 YA, caves were already well-developed (Dorale, 2003). Subfossils recovered from deposits in these caves represent a variety of plant and animal remains, including the oldest human remains found to date (10,300 calender years). Radiocarbon ages range from >40,000, to middle Wisconsin and late Holocene (Heaton and Grady, 2003; Dixon, 2001), and provide a chronology for this globally significant archive. Obsidian, Rhyolite, and Hawaiite were erupted subglaciialy on Suemez Island off of the Southwest Coast of POW about 684,000 years ago (Karl et al., 2008).

Middle Wisconsin Interstadial (70,000 to 20,000 YA)

Remains of mammals, birds, fish and pollen from cave sediments over time represent multiple environments ranging from cold Arctic tundra, to drier and warmer fire-prone pine forests, to cool and wet maritime rainforests (Table 1.) Caves such as El Capitan (Photo 7) contained the remains of arctic mammal faunas that thrived during the LGM when local sea ice expansion supported Arctic fox (*Alopex lagopus*) and ringed seal (*Phoca hispida*). Alpine fauna that are found in caves but were extirpated from Prince of Wales Island during the LGM include hoary marmot (*Marmota),* heather vole *(Phenocomys intermedius),* lemming *(Lemmus sibericus),* red fox (Vulpes vulpes), and steppe antelope (*Saiga)*. In addition northern sea lion (*Eumetopias jubatus)* and harbor seal (*Phoca vitulina*) were present. Ringed seals disappeared with glacier retreat but arctic foxes were present an additional 2,000 years after the end of the Pleistocene (Heaton and Grady, 2003). Brown bear (*Ursus arctos),* American black bear *(Ursus americanus),* river otter*(Lontra sp.), and* caribou (*Rangifer tarandus)* were present both before and after the LGM (Fig. 12). Brown bear and caribou are no longer present on POW island. The cave remains reveal that during the LGM, parts of the southern Alexander Archipelago were nonglaciated refugium which supported Arctic and temperate terrestrial mammal populations, supported primarily through abundant marine food resources (Heaton and Grady, 2003).

In the northern archipelago radiocarbon ages >49,000 radiocarbon years on Juneau area sediment from the east side of Montana Creek, record a pollen assemblage of sage (*Artemisa,* 35% of total) and sedge (25% of total), with pine (Pinus, 14%), fir (Abies 6 %) and hemlock (Tsuga 1%), spruce (Picea), and alder (Alnus) and reflects ice withdrawal from interior valleys prior to the LGM. (Leopold and Mann, 1986; Ager, personal comm. 2008)

Timeline for selected species from Prince of Wales Island.

```
            --------Middle Wisconsin-------||---Glacial Maximum---||-------Postglacial------|

14C Age (KY BP)   40      35      30      25      20      15      10      5      0
            |      |      |      |      |      |      |      |      |
Species
Brown Bear       ---------*------*----------*------- - - - - - - - - - -****-**----*
Black Bear      *****-*------------*--*--------- - - - - - - - - - - -*******---**---*--------

Arctic Fox      --------*-*-----*---------------------*--*-----------*-*
Red Fox                          ? --*------*-----------------*-- ?
Wolf                                                        ? --

River Otter     ------------------------------- ?               ? ---*--*-*------*-*---
Ringed Seal                        ****-*-********----*-*
Harbor Seal      -----*-------------------*-----------*--*-----------------------------------
Steller's Sea Lion -*-----------------------------------*-*--------------------------*-----------

Saiga (or goat)   ------------*---*--------------- ?
Caribou         ----*-*-------------------*------- - - - - - - - - ---*-*--
Black-tailed Deer                                        --**---**-----*--*-

Hoary Marmot      *------------**---------**-------*
Heather Vole      ---------------------------------
Brown Lemming      ----------------------------------
Long-tailed Vole  ------------------------------              -----------------------

Man & Artifacts                                         *-*------*-----*------

Birds           *-------------*------------*----------*---------------------*-----------------
Fishes          -------------------------------------------------------------*--*-*-----------

All 14C Dates     ***** * *** *** *   *  ******   **** **********    * * **************** *
**** *


            |      |      |      |      |      |      |      |      |
14C Age (KY BP)   40      35      30      25      20      15      10      5      0

            --------Middle Wisconsin-------||---Glacial Maximum---||-------Postglacial------|
```

Table 1 Heaton and Grady radiocarbon dates on POW Cave Fauna
http://www.usd.edu/esci/alaska/dates.html

Photo 7 Ice and Karst: LGM morainal deposits lie at the entrance to El Capitan Cave on Northern POW (Connor Photo 2005) below.

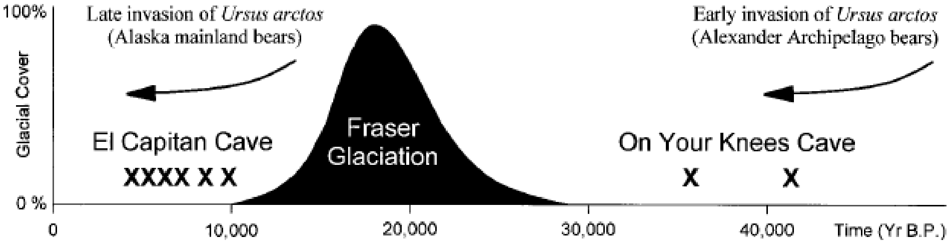


Figure 12 Timeline of interpreted events 50,000 years ago to present from bear fossils in Prince of Wales Island Caves and Admiralty Island, SE Alaska (Heaton, Talbot, & Shields, 1996).

The Last Glacial Maximum in Southeast Alaska 22, 000-17,000 BP

The high mountains bordering the Gulf of Alaska, combine cool temperatures and prodigious precipitation from the Northern Pacific Aleutian Low to support the largest glacier systems outside of the Polar Regions. These glacier systems extend from Yakutat Bay to Dixon Entrance, and profoundly influence the extant maritime rainforest (Carrara et al, 2006).

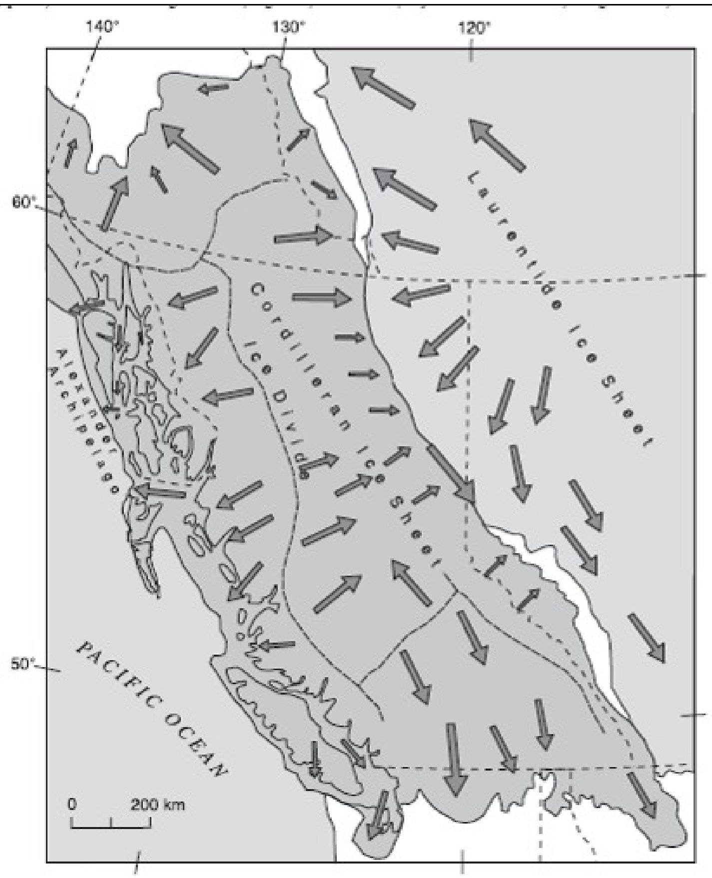


Figure 13 Map of the LGM Cordilleran ice Sheet in central and southern southeast and BC without refugia (Carrara et al 2006)

During the LGM, Cordilleran ice flowing out of icefields in the St Elias, Fairweather, and Coast Mountains, coalesced with local valley glaciers and filled fjords to flow seaward (Figure 13; Kaufman and Manley, 1996, Carrara, et al. 2006). The North Pacific was relatively ice free during this time (Mann and Hamilton, 1995). Maximum glacier extents were out of phase from north to south. Northern glaciers on Shelikof Strait and Cook Inlet reached their outer limits between 23,000 and 16,000 BP. In southeast AK, the Cordilleran Glaciers expanded and flowed into fault-formed valleys such as Cross Sound, Lynn Canal, Chatham Strait, Gastineau Channel, Stephens Passage, Clarence Strait, and Frederick Sound (Figures 14 and 15).

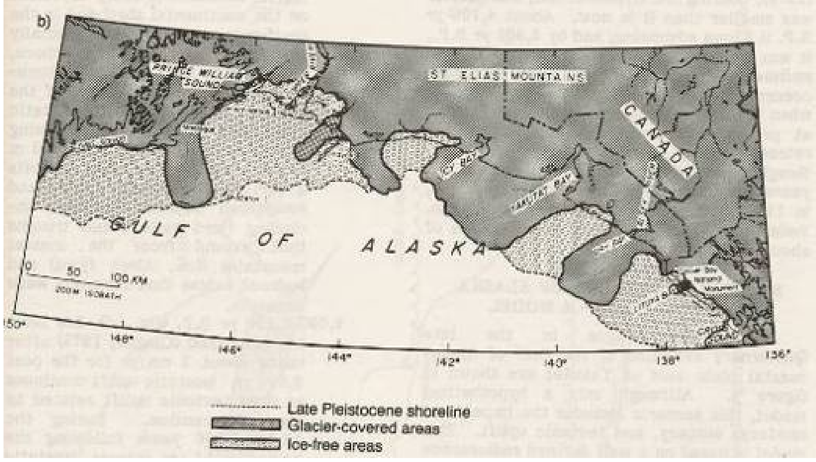


Figure 14. Expansion of piedmont glacier lobes across the continental shelf in the northe6n Gulf of Alaska (Molnia, 1986)

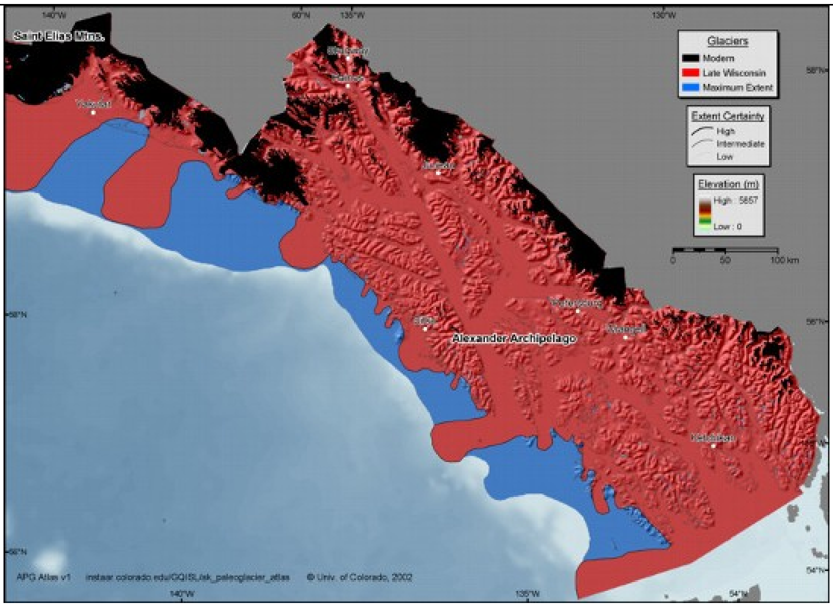
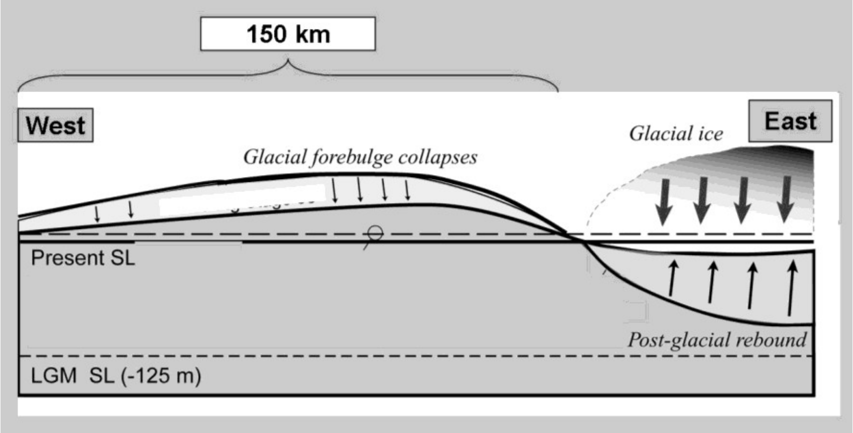


Figure 15 Paleoglacier Atlas of Alaska Southeast during the Late Wisconsin glacier Maximum (Manley & Kaufman, 1996; http://instaar.colorado.edu/QGISL/ak_paleoglacier_atlas/index.html)

At high elevations in the Alexander Archipelago and coastal British Columbia, ice thickened to the 1829 m level between 28,000 and 17,000 BP. To the far south, the ice formed a lobe that filled Puget Sound and flowed over Seattle by 17,000 BP (Carrara et al, 2003; Clague et al, 2004). Glacier retreat was also time-transgressive; 16,000 BP in south-central Alaska and 14,000-13,000 in the southeast Alaska and BC (Mann and Hamilton, 1998).

Sea Level Change

The history of sea level change is complicated in this region. Globally the eustatic sea level was 125 m lower during the LGM, 24,000-16,000 years BP (Yokoyama et al, 2000) but locally, variations in ice loading and the visco-elastic response of the underlying crust significantly affected relative sea levels (Figure 16a,16b). Glacier limits in this region show up best in continental shelf bathymetry where piedmont lobes expanded onto and across an emergent continental shelf, and carved U-shaped submarine troughs that transect the continental shelf between Cape Suckling and Dixon Entrance (Figure 14 and 15; Greene et al. 2007). Onshore piedmont glacier lobes align seaward with these erosional geomorphic features from major fjord mouths or river valleys (Carlson et al, 1982, Molnia, 1986). The presently submerged shelf platform varies from 100 km wide near Cross Sound narrowing to 50 km near the Queen Charlotte Islands (Figure 15; Carrara et al, 2006). On the mainland, glaciers also carved grooves into bedrock pavements (Miller, D.J. 1953), formed alpine cirque basins (Miller, M.M., 1961) and scoured trimlines into areas like the upper Juneau Icefield (Photo 8), the Alsek River Valley, Lynn Canal, and Glacier Bay National Park and Preserve (McKenzie and Goldthwait, 1971)



16a. Schematic profile of flexure and migration of glacier forebulge in southern Southeast AK

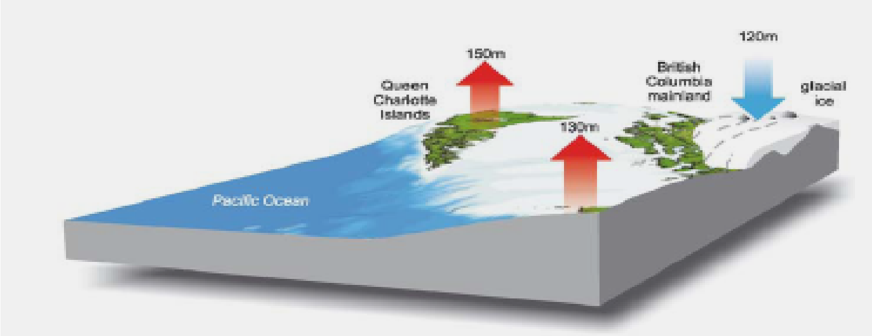


Figure 16b. Ice Sheet over flexible lithosphere with forebulge loading forward of ice terminus near the Queen Charlotte Islands (Hetherington et al. 2003)

Photo 8. Juneau Icefield nunataks extend above glacially sculpted bedrock of the Kakuhan Range where exposures of the Paleocene "Great Tonalite Sill" form the eastside of Lynn Canal (fjord) along the proposed Juneau Access Road corridor (Connor 2005)

In the Gulf of Alaska glacially-derived sediments have created a depositional record that includes Late Pleistocene and Holocene offshore marine sediments. These sediments can be traced back to their specific bedrock terrane by using the sediments magnetic properties (e.g., Cowan et al, 2006) or the lithology of terrestrial morainal clasts (e.g., Glacier Bay, Ovenshine, 1967).

In Northern British Columbia, seismic surveys on the continental shelf primarily for oil exploration yielded information from sediment cores that have newly expanded our understanding of the LGM bathymetric, archeological and sea level history of this region (Carrara et al, 2006; Fedje and Mathewes, 2005).

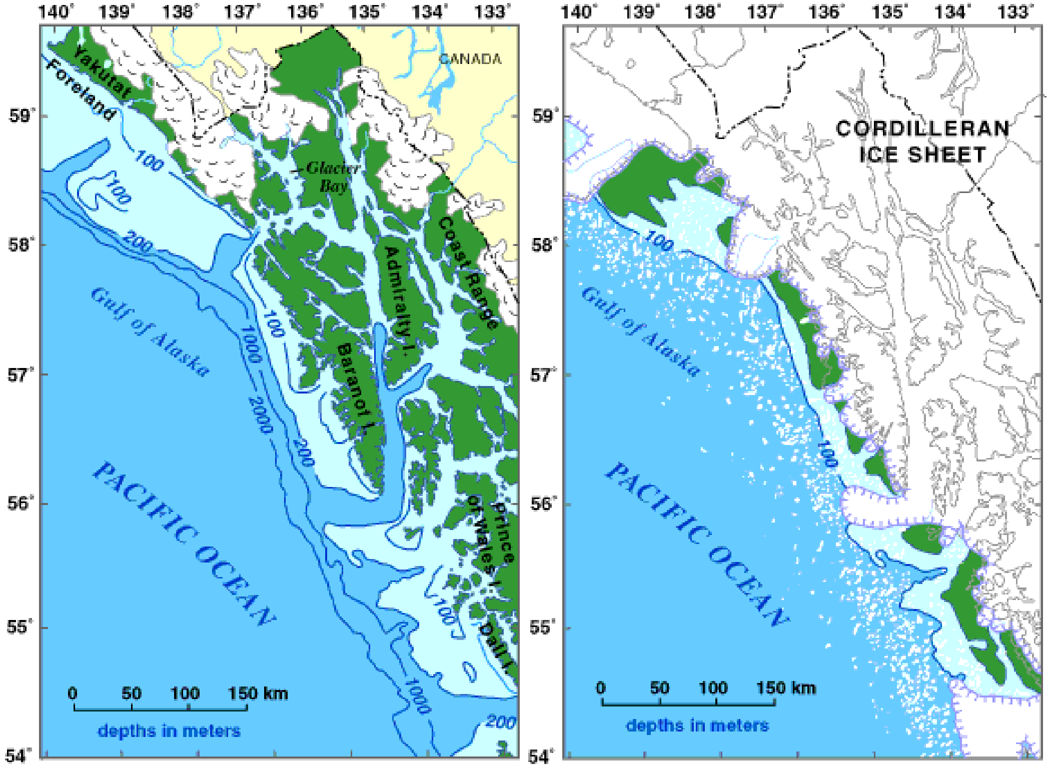


Figure 17a Right map of part of southeastern Alaska showing **Present-day** distribution of major glacier systems. Dark green areas are possible lands that escaped glaciation. These refugia supported tundra, shrub and subalpine vegetation. **17b** Left map shows many white dots in the Gulf of Alaska indicating abundant icebergs during the late **LGM** (Carrara et al 2003).

Important paleoecological evidence comes from subfossil plant distributions, pollen records and marine invertebrate and vertebrate remains from continental shelf cores, uplifted marine shell beds and fjordal sediments (Ager, 1998; Baichtal, 2008, Barnwell and Boning 1968, and R.D. Miller, 1975). Sediments from freshwater lakes and bogs now well below sea level, reveal the existence of Late Wisconsin refugia in these once emergent regions of the continental shelf (Heaton et al, 1996; Mann and Hamilton, 1995; and Kondzela et al, 1994, Baichtal, 2008, Greene et al., 2009). Genetic studies of mammals now living in the Alexander Archipelago reveal ancient separations in gene flow across this island biogeography (Figure 16; Cook et al. 2009).

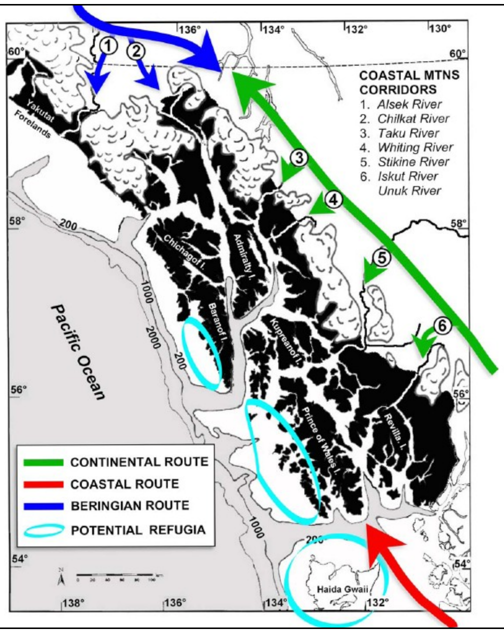


Figure 18. Possible recolonization routes into Southeast Alaska following LGM based on phylogenetic data from modern species (Cook et al, 2006).

The Coastal Migration Theory

The Cordilleran Ice Sheet, formed multiple times over the central and southern Yukon, southeast Alaska, and British Columbia. Glaciers filled interior river channels that once flowed through the coastal mountains and created challenging barriers for Beringian interior humans and animals from accessing the coast (Figure).

Archeological evidence has emerged for the late Pleistocene or Early Holocene coastal migration of ancient seafaring Asians who followed the coastline from the northwestern Pacific, along the Aleutian Islands in to southeast Alaska. Fifteen thousand years or so ago these first Alaskan people utilized nearshore marine routes and marine food sources to immigrate into the unglaciated landscapes around the North Pacific. Their food preferences were recorded in the stable carbon and nitrogen isotopes that built the bones of a 20 year old male found on northern POW. At this time sea level was 125-130 m lower and the emergent continental shelf provided refugia between piedmont glacier lobes along the Gulf of Alaska, southeast Alaska and in northern British Columbia (Molnia, Kaufman, Carrera et al. 200X, Dixon, 2009) Newly published genetic information from the remains of a single 23 year old male human recovered from a cave in southern southeast Alaska, suggest a link between these maritime people with the Chumash of Southern California, Tarahumara, Zaptec in Mexico, and in South America Quechua, Mapuche, Yaghuri, and Tierra del Fuegans who share Haplotype Group D, subhaplogroup QM-3 (Kemp et al. 2007). With access to the deglaciated Queen Charlotte Islands (Haida Gwaii), and to Vancouver Island, WA, OR and the CA coast as well as Central America and South America, ancient Asian mariners discovered the "new world" before 15,000 BP years ago, creating important archeological sites at Monte Verde, Chile by 12,500 (Madsen, 2004).

Oral Histories and Changing Landscapes

Tlingit, Haida, Tsimshian, and other northwest cultures have oral histories that record human observations of this late Pleistocene dynamic landscape. As glaciers receded to the mainland and their crustally depressed and raised forebulge troughs and rises followed, shorelines were first drowned and then uplifted. This flooding ecology and climate transformation bordering the northeastern Pacific basin shores were recorded by uplifted marine shell beds, and submerged freshwater lakes and artifacts (Baichtal and karl, 2009; Dixon, 1999), and by place names in the ancient languages and ethnohistory of Alaska Native and Canada First Nation peoples (Fedje and Mathewes, 2005, Huna Tribe placename map), and by their cultural artifacts, dating back to at least 9,400 BP at sites such as Groundhog Bay, Hidden Falls, and On Your Knees Cave (Ackerman, 1966).

Researchers in Haida Gwaii (the Queen Charlotte Islands) have identified emergent regions on the continental shelf that were subject to variable loading and unloading by glacier ice and transgressions and regressions, moving glacier forebulges and dynamic sea levels locally (Hetherington et al. 2003).

This region served as a southern leg of a circum-North Pacific margin coastal migration route from Asia provided early human entry into North American by the end of the LGM (Dixon, 2001, Clague et al 2004). Molnia (1986) created a post LGM sea level landscape isostatic dynamism model scenario above from Alaska Gulf Coast data (Fig. 14). Lower Cook Inlet by was ice free by 16,000 to 14, 700 BP (Reger et al, 2007) and by 15,000 BP in the Queen Charlotte Island. McKenzie and Goldthwait, (1971) and Goldthwait (1987) found that ice had retreated to near modern positions by 13,500 BP in the inner fjords of Muir Inlet in Glacier Bay. Mann and Streveler (2008) constructed a relative sea level (RSL) curve for northern southeast using marine shells and terrestrial vegetation in the Icy strait and Glacier Bay region. They found that regional deglaciation following the LGM was completed by 13, 900 cal yr BP and that sea level remained several meters below modern levels until middle Holocene time. Readvance of Glacier Bay ice beginning 6,000 cal yr BP created local sea level fluctuations as ice loaded and unloaded the crust triggering isostatic rebound and uplift.

Uplift and Sea level Rise following LGM Deglaciation

Marine transgression was as great as 350 m in the Juneau area (R.D. Miller, 1972, 1973a,b, 1975, Baichtal, 2008) when 125m of sea level rose over aonce heavily iceloaded (-230m) crust 12,000 to 10,000 BP. The southern end of the Chilkat Peninsula near Excursion Inlet has 3 raised marine terraces that show human occupation dating to 9,200 years BP which suggest a complex uplift history during early human occupation of the region (Ackerman, et al, 1979). Modern sea level was attained by 9,000 BP in northern SEAK (Mann and Hamilton, 1995).

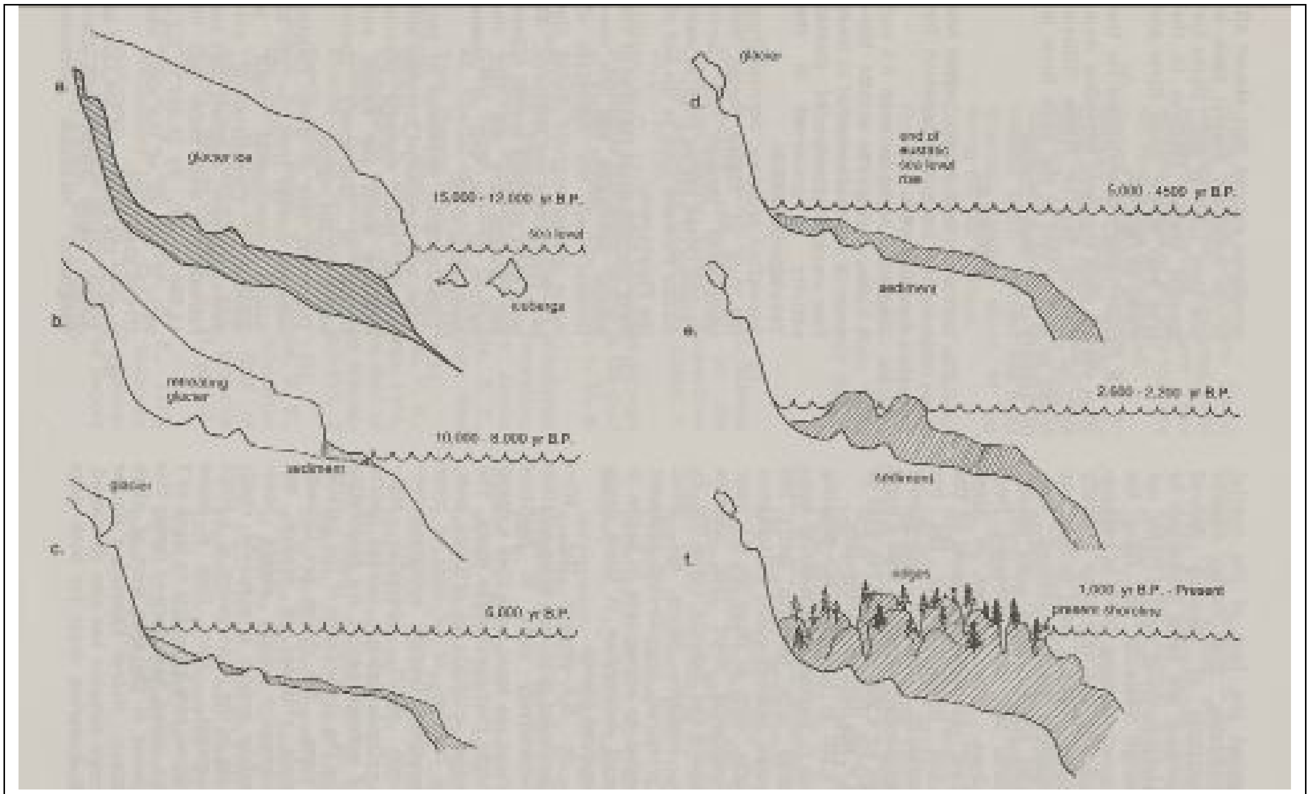


Figure 19. Model for inundation and uplift sequence along the Gulf of Alaska following the LGM (Molnia, 1986).

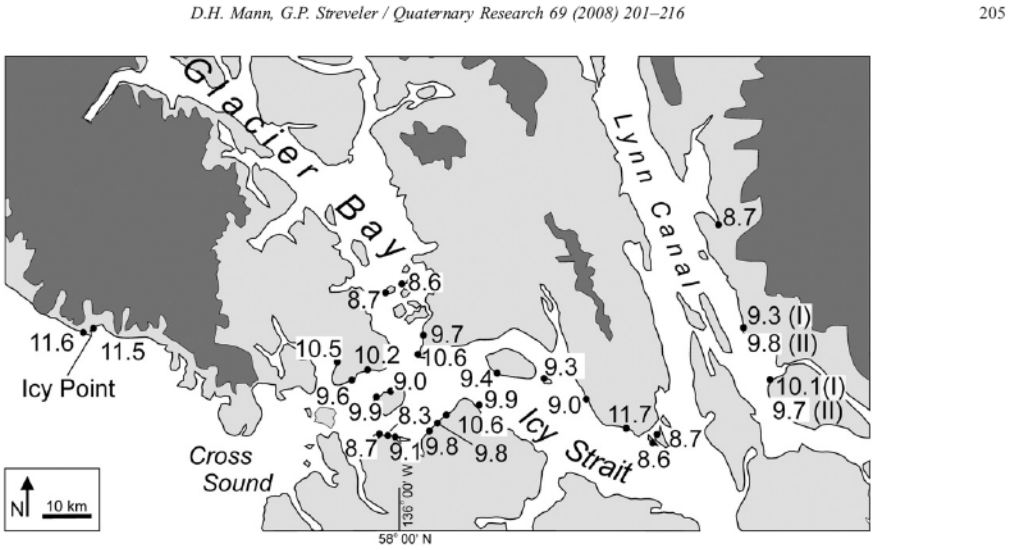


Figure 20. Elevations (in meters) of vegetated and raised barrier beach crests above MLLW along eastern Lynn Canal (Mann and Streveler, 2008).

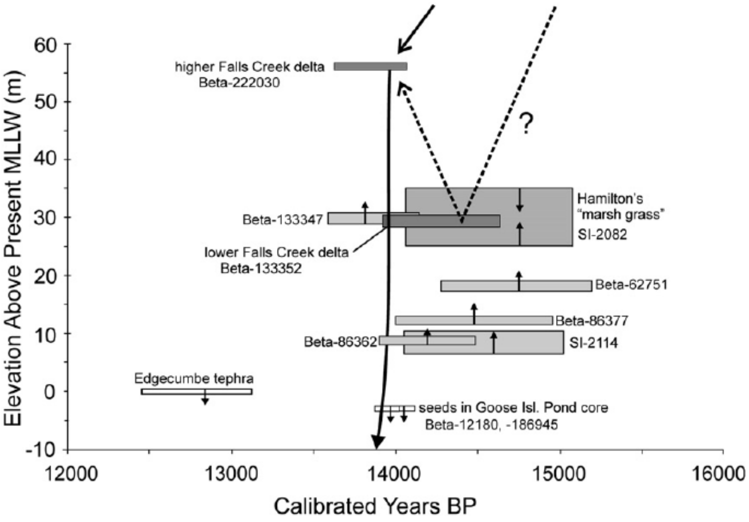


Figure 21. Relative Sea Level history in Icy Strait 15,500 to 1, 500 cal yr BP (Mann and Streveler, 2008).

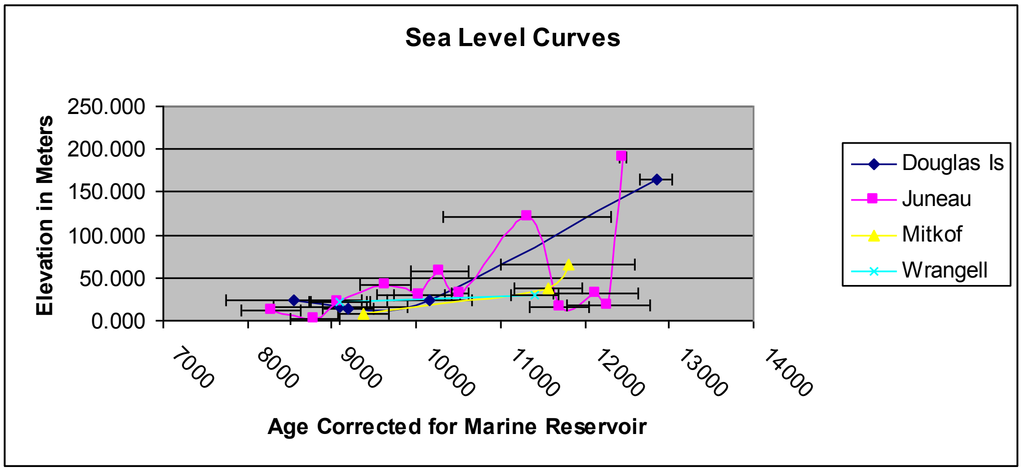


Fig 22. Composite of northern southeast sea level curves (Baichtal 2008).

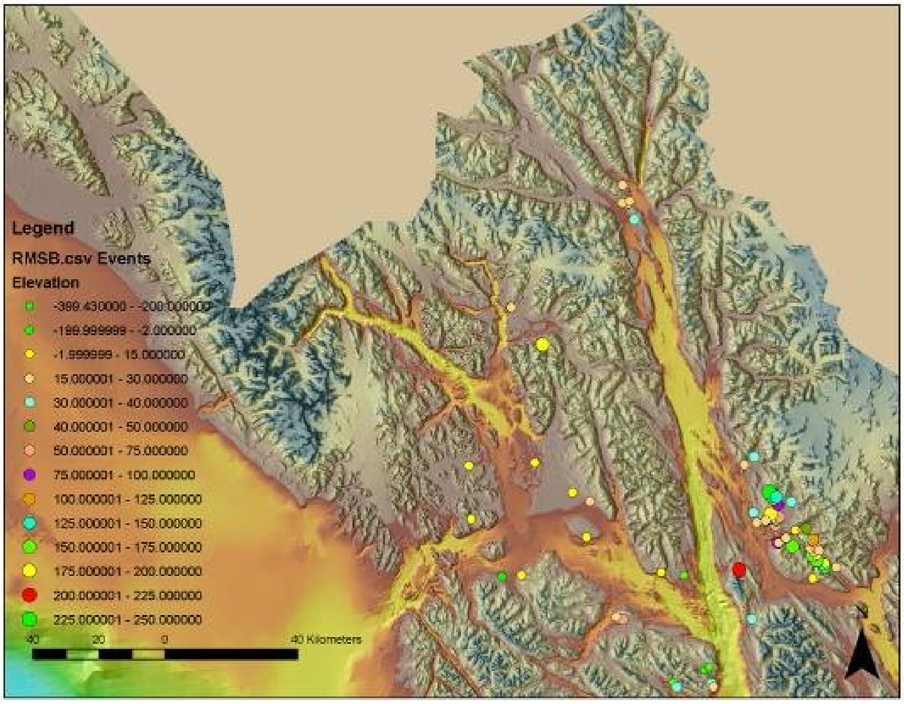


Figure 23. Deglaciated by approximately 13,000 B.P, these shorelines rose to a height of 54 meters on Revillagigado Island above present sea level as is evidenced by uplifted, shell-bearing strata dating to between 12,650 to 12,840 C14 YBP. Similar shell-bearing strata on other Islands in the Archipelago and the mainland are as follows: Chichagof Island at 35 meters ASL, 12,640 YBP; Douglas Island, at 164 meters a.s.l., 12,850 C14 YBP; Juneau Mainland, at 191 meters a.s.l., C14 12,460 YBP; Kuperanof Island at 30 meters a.s.l., 12,670 C14 YBP; Mitkof Island at 10 and 65 meters a.s.l., 12,680 and 11,800 C14 YBP; On Wrangell Island at 30 meters a.s.l., 11,410 C14 YBP. Though not dated, shell-bearing strata has been reported from elevations of 145 to 211 meters on Admiralty Island, 175 to 345 meters on the Canadian Mainland, 229 meters on the Juneau Mainland, and 103 meters from Cleveland Peninsula all a.s.l.
(All C14 dates discussed indicate a marine reservoir correction of 600 years for shell dates.

Figure 24. The highest shell bearing sites in the Juneau area are Upper Montana Creek at 228 meters ASL (750 feet) and on Admiralty Island at 212 meters (695 feet). If you assume an approximate date of 13,000 years for these deposits and consider that sea level was approximately 100 meters lower at that time, you have somewhere about 328 meters of isostatic uplift, an adjustment of 1076 feet. (Baichtal, 2008)

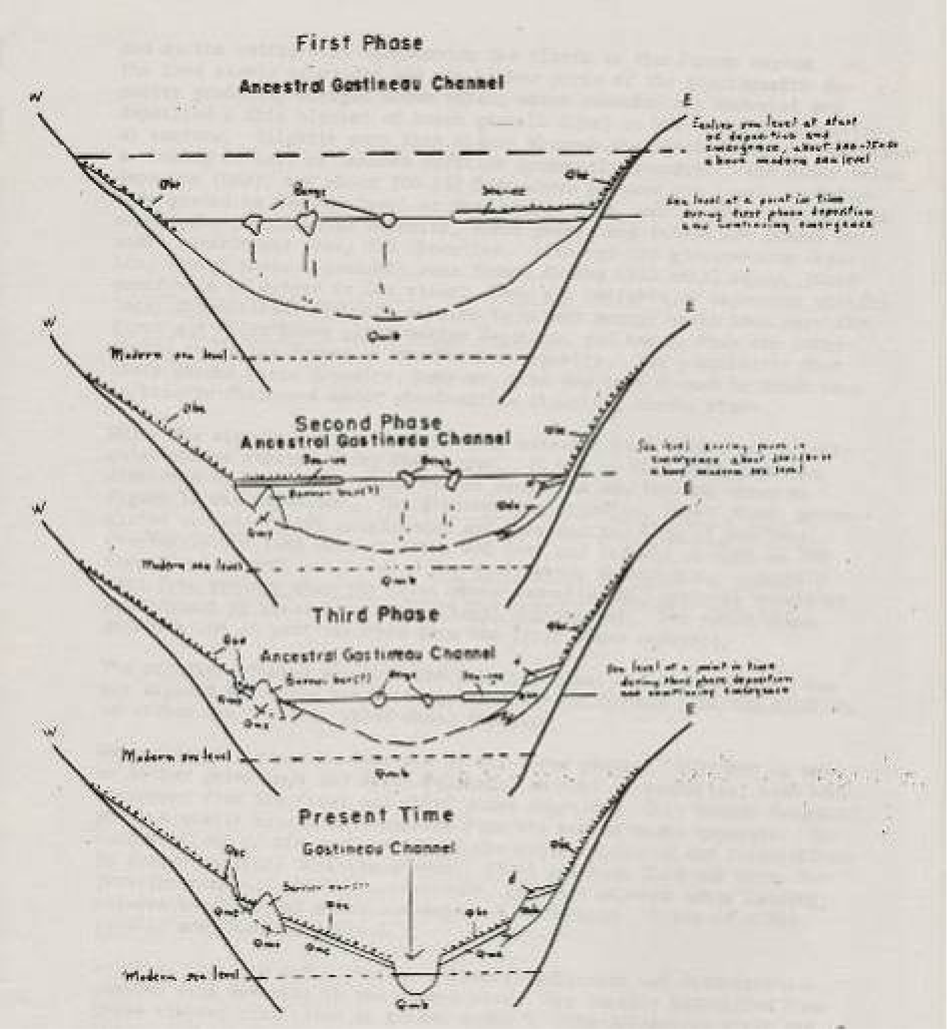


Figure 25. Glaciomarine, beach, and deltaic deposits and their subsequent uplift in Gastineau Channel in Juneau following the LGM (R.D. Miller, 1973)

R.D. Miller (1971, 1973, 1975) studied and mapped glaciomarine sediments, uplifted deltaic and beach deposits throughout the Juneau region and divided them into three facies of the Gastineau Formation. He used their elevations and locations to construct an uplift scenario following the LGM for this area Figure 22. Lemke and Yehle (1978) mapped similar uplifted glaciomarine diamicton sediments in upper Lynn Canal and around Petersburg on northern Mitkof island.

In the southern archipelago and northern QCI, glacier loading depressed the crust and locally raised sea level during the LGM. Large regions of emergent outer continental shelf provided refugia and formed a prominent terrace at -165m. These were subsequently inundated when the rising forebulge collapsed and the sea flooded over. Uplifted marine shell beds (Figure 23) record high sea stands on POW. (Baichtal, 2008). Tlingit Oral history addresses flooding through many narratives and identifies islands from that time period that have since been inundated (Monteith, pers comm). Raised marine shell beds throughout

Southeast record shoreline uplift and subsidence during deglaciation that in southern southeast may have as high as 5 cm/yr (Baichtal 2008). During the life span of a 50 year old person living along this dynamic coastline, sea level change could have been as great as 2.5 m (Baichtal, 2008). Evidence for human habitation of the archipelago (Dixon, 1999) following deglaciation has been found in the form of microblade tradition obsidian, faunal, and human remains at Ground Hog Bay in Icy Strait (9, 130 +- 130 BP Ackerman, 1996), Hidden Falls on Baranof Island (>9,000 BP), On Your Knees Cave (49-PET-408, 9,200 BP, Dixon, 1999) and Thorne River (7,500 BP) on Prince of Wales Island, and at Chuck Lake/Rice Creek on Heceta Island (8,200 BP). Ancient obsidian trade routes using Suemez Island and Stikine River (Edziza) bedrock sources have been documented (Erlandson and Moss, 1996) Figure 23?.

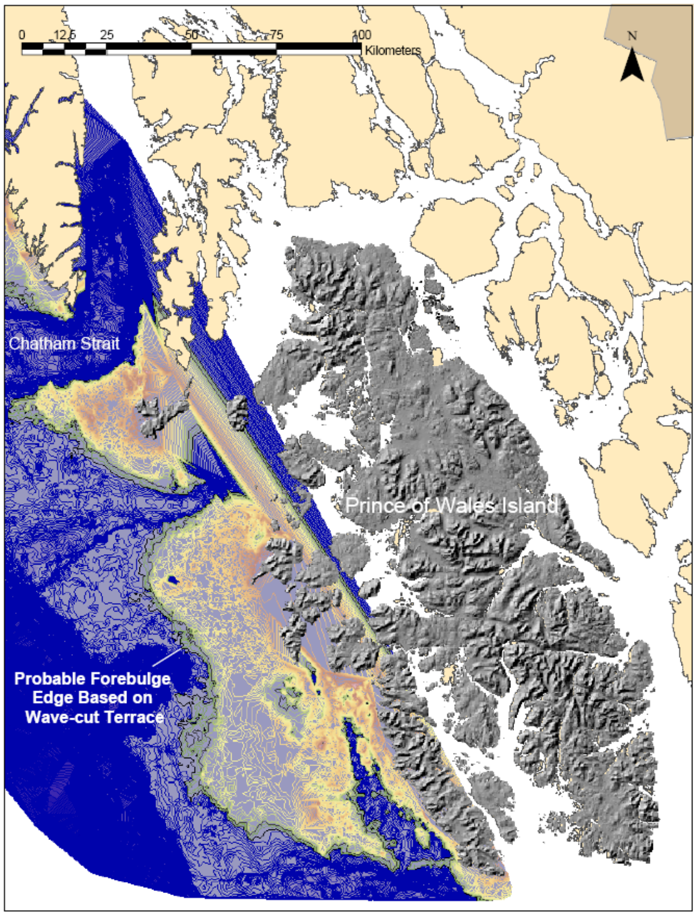


Figure 26. Now submerged (-165m) wave cut terraces offshore of western Prince of Wales Island suggest the locations of ice termini and later migrating glacier forebulges during the LGM and Early Holocene (Baichtal 2008)

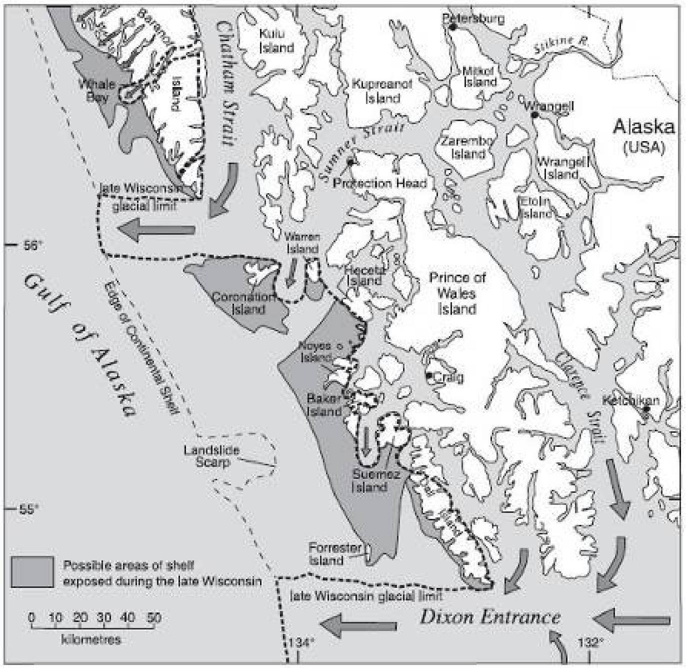


Figure 27. Map of southern southeast Alexander Archipelago showing locations of Cordillera Ice on the continental shelf and ice-free refugia (Carrara et al 2006)

Evidence from Palynology

Pollen evidence from cores obtained from the continental shelf in the Queen Charlotte Islands indicate that arboreal species did not survive in offshore refugia through the LGM, but herb and shrub tundra did (Fedje and Mathewes, 2005) Figure 25?. Hansen and Engstrom, 1996 took cores on Pleasant Island in Icy Strait near the entrance to Glacier Bay and found that by 12,500 BP Lodgepole pine and alder were growing on the island. A Younger Dryas Reversal 10,800-9,800 BP showed vegetation change to a shrub and herb tundra replacing the lodgepole pine/alder. Much charcoal on Prince of Wales Island and abundant fish remains of Pacific Sardines suggest a change in rainfall as well as ocean conditions (Baichtal 2008). By 10,000 BP Sitka Spruce, Western Hemlock, and mountain hemlock were growing on Pleasant island. During the Hypsithermal 9,000 to 6,000 BP Heusser et al (1985) found a precipitation minimum at 8,000 BP in Montana Creek near Juneau. Western red cedar reached its modern northern extent on southern Mitkof island by middle Holocene, migrating from the south.

Evidence from Archeology and Ethnohistory:The Neoglacial

Glacial evidence shows a readvance of glaciers out of the Fairweather Mountains into western Glacier Bay beginning 6,000-5,000 BP in Reid Inlet (McKenzie and Goldthwaite, 196X, Goodwin 1988) The Neoglacial transformation of the bay to an ice-filled fjord by 3500-3500 BP is recorded in Beardslee Formation sediments

(Connor et al 2008 in press). Huna Tlingit ethohistory and place names record the impact of these cooling conditions on the people living on the glacier forefield that filled the lower bay at this time (Dauenhauer and Dauenhauer, 1987, Monteith et al 2007, Connor et al, 2008 in press).

The Little Ice Age

Glacier Bay Tlingit people were forced out of the bay by an advancing glacier around 1760 (Dauenhauer and Dauenhauer, 1987, Monteith et al 2007, Mann and Streveler, 2008, Connor et al. 2009). By 1794, George Vancouver had explored the region and documented ice terminus positions especially in Glacier Bay, where a calving retreat had begun following the destabilization of LIA shoal and tidewater terminus in Icy Strait (Mann and Streveler, 2008). In the Mendenhall Valley, the terminal Little Ice Age moraine of the Mendenhall Glacier was positioned over Back Loop Road and occupied the upper Mendenhall Valley (R.D. Miller, 1975). Finney and others (2000) have utilized fish weir records and nitrogen isotopes in lake sediments to reconstruct salmon population histories in the region. The 35 year fish weir record in Auke Lake maintained by the NOAA Auke Bay Lab (Taylor, 2008) has the potential to support similar studies of paleo-salmon productivity in lake cores for this locality. Calkin et al (1988, 2001) and Barclay et al (2006) have summarized the Holocene and LIA history of the Gulf Coast region.

Studies in the Mendenhall Valley include dendrochronology (Lawrence, 1950; Lacher, 1999), valley stratigraphy (Barnwell and Boning 1968; R.D. Miller, 1975), soils (Heusser, 1960; Alexander and Burt, 1996), fluvial and groundwater hydrology (Neal and Host, 1999; Hood and Scott, 2008), glacial history (R.D. Miller, 1975; M.M. Miller 1986; Motyka et al 2002), and current glacier recession (Boyce et al, 2007). A fishtrap buried near the confluence of the Mendenhall and Montana Creek Rivers was dated at ~1252 AD (Moss, 2004).

Alexander and Burt, (1996) studied soils on the sequence of well drained Neoglacial moraines up to 240 years-old in the Mendenhall Valley, plus an older soil, to investigate soil development through the initial stages of podzolization. Pebbles and cobbles in the moraines are about 75 to 80% granitic rock. Computations based on minerals observed optically and on chemical analyses indicate that plagioclase and quartz are the predominant minerals in the fine-earth. The climate is perhumid. Leaching of the moraines may have begun before they were free of glacial ice, but little organic matter accumulated under the initial vegetative cover of sparse dwarf fireweed (10-year site). As alder thicket developed, organic matter accumulated rapidly in Oi, Oe, and A horizons (38-year site). As spruce trees began to replace alder, organic matter was lost from the surface mineral soil to form an E horizon and an incipient Bs horizon formed below it, an Oa horizon formed, and the A horizon disappeared (70- and

90-year sites). Organic acid leaching continued, to form a spodic Bhs horizon in spruce forest (240-year site) and a spodic Bh horizon in spruce−hemlock forest (>240-year site). Hornblende has been etched slightly within 240 years, apatite has been lost from E horizons and free-Fe, presumeably in ferrihydrite, has accumulated in B horizons. The younger moraine soils, both with and without incipient Bs horizons, are Typic Cryorthents and the 240-year-old and older soils with spodic Bhs and Bh horizons are Typic Haplocryods. They are expected to accumulate more organic matter and become Andic Humicryods, which is the most common subgroup of soils in the area (Alexander and Burt, 1996).

Ongoing Change

Motyka and Beget (1996) and Post and Motyka (1995) documented calving advance and retreat of the Taku glacier across Taku Inlet. Nolan et al. (1996) used geophysical methods to determine that the Juneau Icefield's largest glacier, the Taku Glacier, was 1477 m thick in its lower regions and found that for over half the length (35/55 km) it lies well below sea level. Studies by the Juneau Icefield research Program for the past 60 years in the region measured 7.5 km of advance on the Taku Glacier, Glacier thickening, and equilibrium flow for the past 50 years (Pelto et al. 2008). Ongoing measurements collected by a distributed sensor network have documented the timing and subglacial discharge of glacial lake outburst floods on the Lemon Creek Glacier system (Heavner et al. 2008). Arendt et al. (2002) have measured ice loss and glacier thinning along Alaska's coastal glaciers and attribute 0.27 mm/yr of global sea level rise to Alaskan glacier ice loss. Hood and Scott (2008) found the concentration of nutrients entering coastal watersheds in southeast Alaska is in part controlled by the extent of glacial coverage in the river catchment area. Changing amounts of glacial coverage in southeast Alaska watersheds could affect nutrient concentrations and change the nutrient cycling in coastal ecosystems along the Gulf of Alaska.

Larsen et al. (2005) measured the highest rates of uplift anywhere on Earth in the Yakuktat and lower Glacier Bay regions at ~30 mm/yr (Figure 28). Since 1770 AD, following the rapid post-LIA tidewater glacier calving retreat and ice loss (60km/120 years), relative sea level has changed as much as 5.7 m in the region. A new golf course in Gustavus was created from accretionary lands gained from the sea over the last century. In the Juneau region uplift rates are lower at 10-18 mm/yr. South of Sitka and Petersburg rates diminish to less than 2 mm/yr.

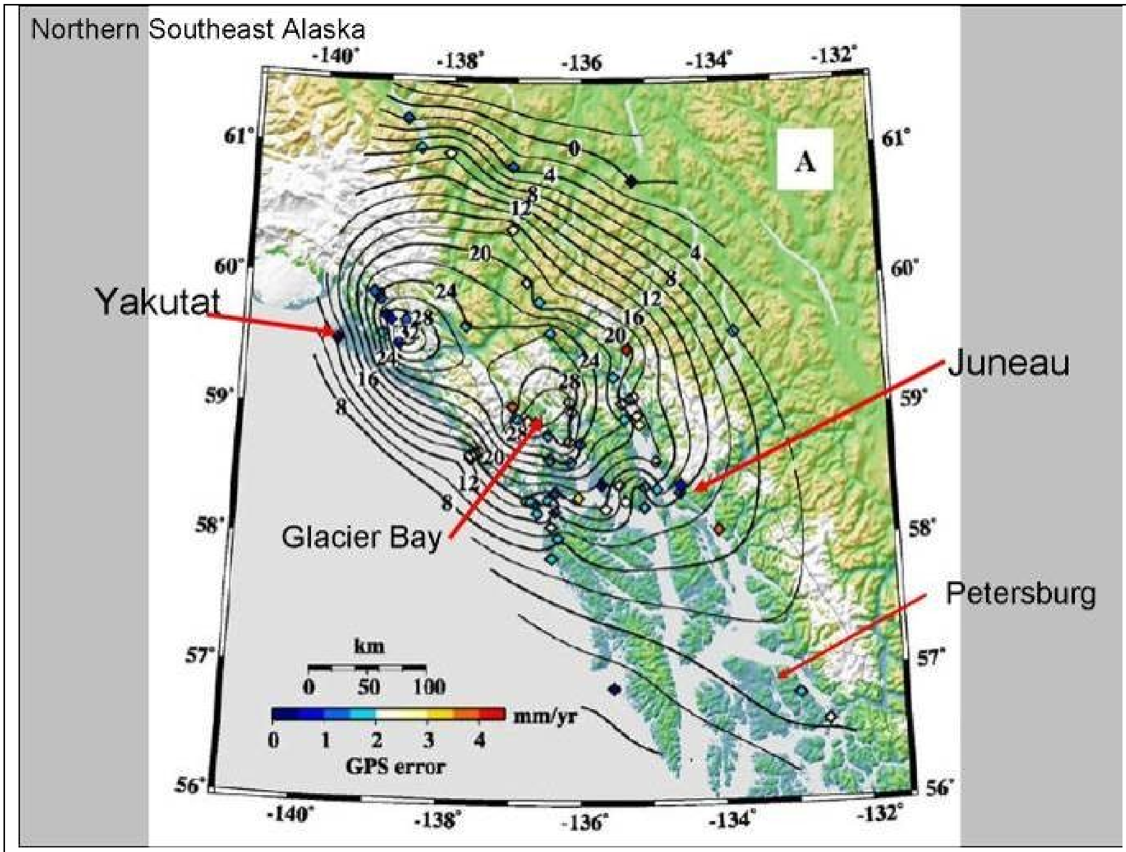


Figure 28. Uplift Observations from GPS uplift rates (Larsen et al, 2005)

Landslides, Cruiseships, Powerlines,

Southeast Alaska's over-steepened fjords are vulnerable to mass wasting following deglaciation, seismic and storm events. In Glacier Bay the Tidal Inlet landslide could fail and generate large period impulse waves in the west arm of the bay imperiling cruise ship traffic (Wieczorek et al. 2007, Photo 9).
In Juneau avalanche paths have been mapped and monitored above the city. On April 16, 2008 and again in Jan xx, 2009 heavy snowfall generated avalanches that knocked down hydropower transmission lines about 3 miles from the Snettisham Powerhouse, 40 miles to the south of Juneau. This required the local power company to run expensive diesel generators until repairs could be made. Record-breaking snow fall at high elevations in 2007-2009 suggest an ongoing shift in snowfall regime.

Photo 9 Tidal Inlet Landslide from Blue Mouse Cove Glacier Bay National Park (Connor 2008).

Stringent cruise ship wastewater discharge quality regulations for the US were first developed in Alaska (1999-2003) by the US Coast Guard in conjunction with the Alaska State Department of Environmental Conservation to protect important fisheries and avoid solid waste, dry cleaning solvents, and other pollutants in the deep fjords of the Inside Passage.

Ship routes are inferred from reported start and stop locations of discharge events. Some vessels may be certified by the USCG to discharge at speeds less than six knots and within one nautical mile of shore. Width of symbolization is not proportional to discharge. To accurately assess cumulative impacts, flushing rates and residence times in individual basins should be evaluated.

Figure 29. Large Cruise ship discharge events (UAS Spatial data: Ostman, 2002,.)

Field Trip Guide

August 30, 2008 Saturday Stops

9 am: Mendenhall Lake/Skaters Cabin Orientation

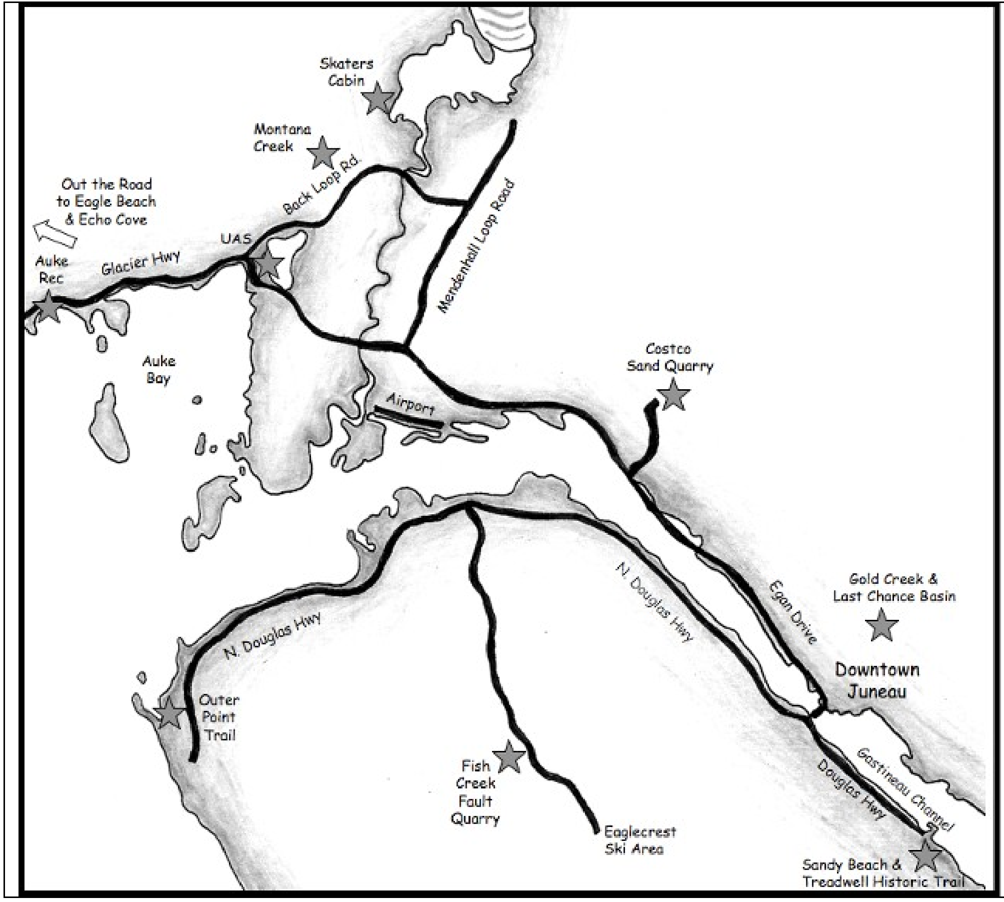


Figure 30. FOP field trip stops around the City and Borough of Juneau (CBJ).

Connor and Motyka gave an overview of the late Quaternary history of the Juneau Ice field and its outlet glaciers including the Mendenhall glacier and the Taku glaciers. Holocene ice recession and post LIA uplift has changed the hydrology of Mendenhall Valley drainages. Changes during 1975-1980s following the discovery of oil at Prudhoe Bay and statewide prosperity lead to growth in Juneau into the Mendenhall Valley. The growth of cruise ship tourism in the 1990s through present has focused the use of fossil fuel by summer visitors on and around the Mendenhall Glacier. Pertinent references include; Alexander and Burt 1996; Barnwell and Boning, 1968; Boyce et al, 2006; Coulter et al 1965; Hood et al 2008; Kuriger et al, 2006; Lacher 1999;Lawrence, 1950 and 1958; M.M. Miller,1961, 1963 & 1985; R.D. Miller 1972, 1973 & 1975; Molnia, 2008; Motyka, 1999 & 2003; Motyka et al, 1995, 1996, 2003a, 2003b, & 2006; Neal et al 1999; 2002; Nolan et al, 1996; O'Clair et al, 1992; Pelto et al, 2008; and Post et al 1995.

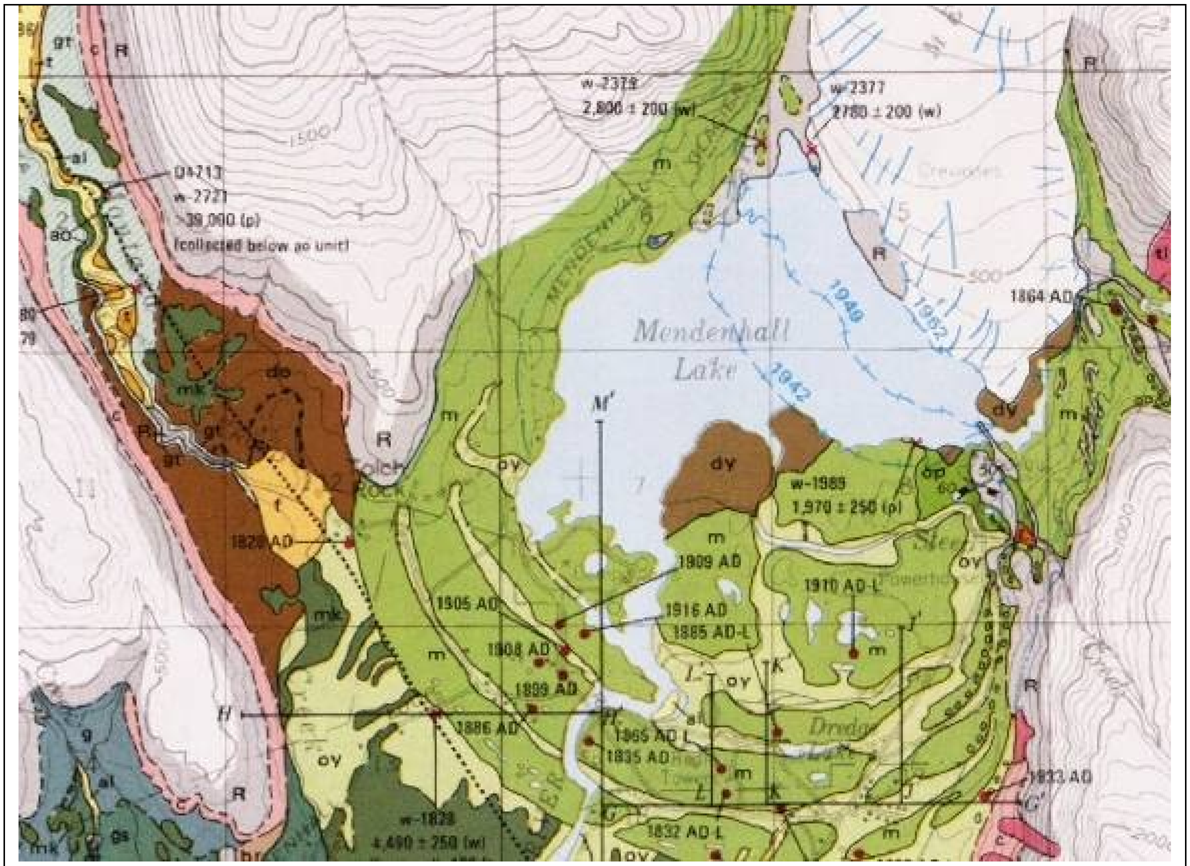


Figure 31. Quaternary Geology of upper Mendenhall Valley and Montana Creek (R.D.Miller, 1975)

Photo 10. Skaters Cabin originally built by U.S. Civilian Conservation Corps in the 1930s (Santosh Panda, 2008)

Photo 11. Mendenhall Lake and Glacier from Skaters Cabin (Santosh Panda, 2008)

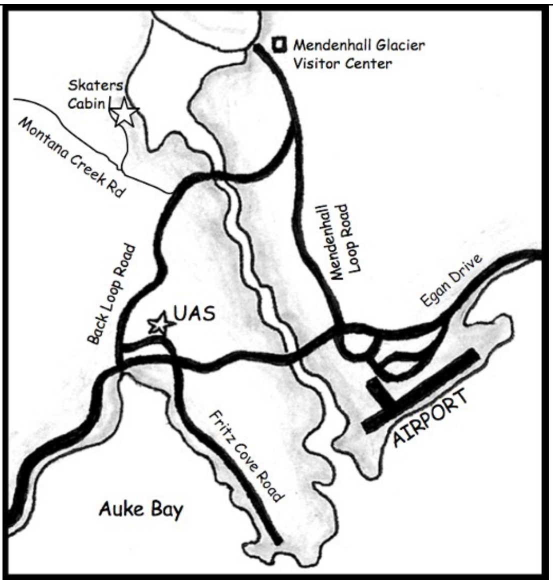


Figure 32. Map to Stops 1 and 2 (J. Parks)

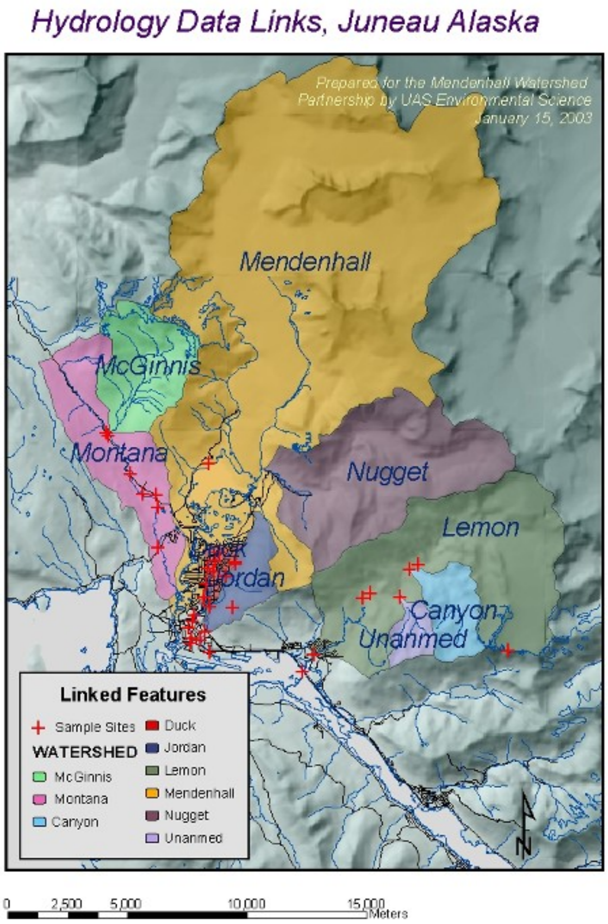


Figure 33. Map of Mendenhall Valley watersheds (UAS Spatial data and Juneau Watershed Partnership, Byers and students, 2003)

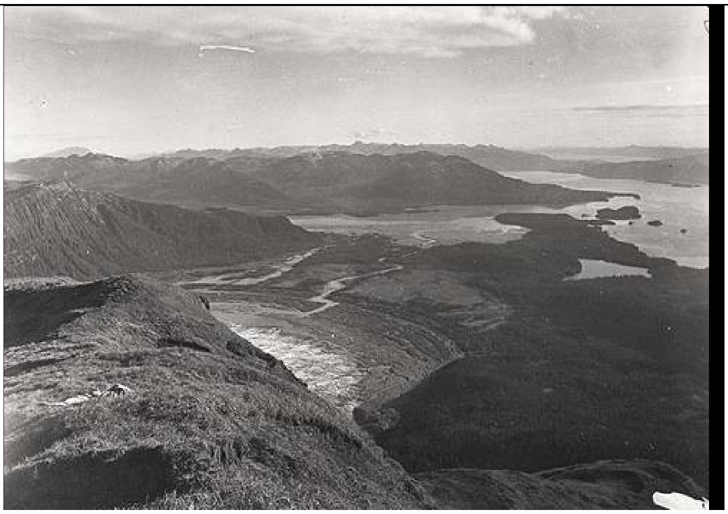


Photo 12. View of1894 Mendenhall valley and Auke Bay from atop McGinnis Mountain (Willliam Olgilvie photo, NSIDC)

Photo 13. 1902 terminus of Mendenhall Glacier view from the River (C. Wright photo, NSIDC)

Photo by R.E. Johnson, Yakutat

Photo 14. Mendenhall Glacier LIA Features

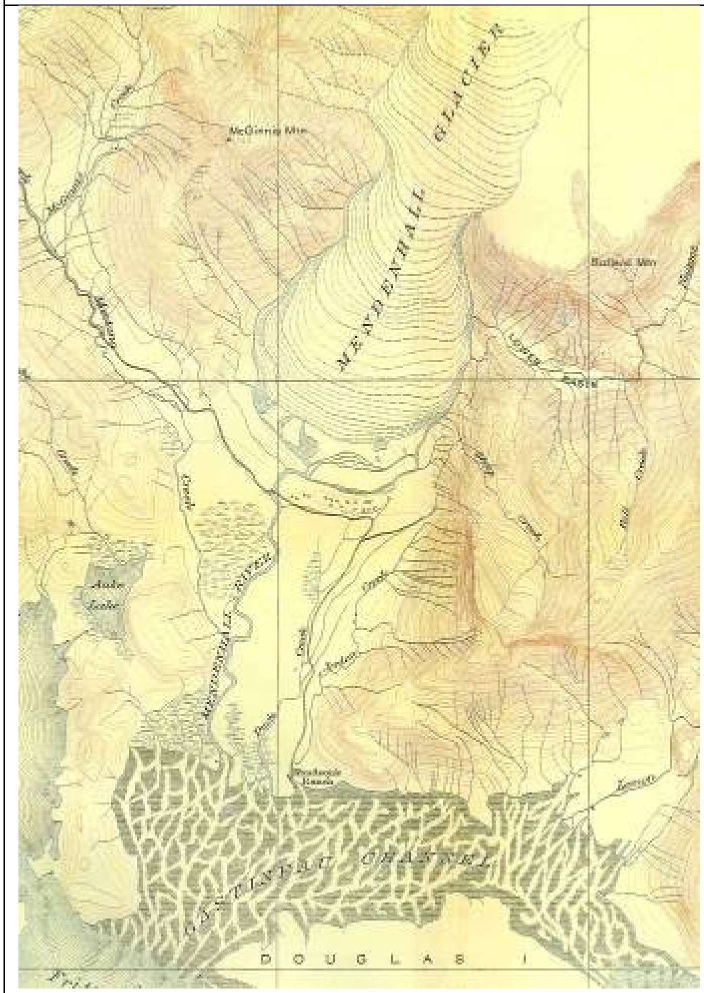


Figure 34. Mendenhall Valley Topography by (Knopf circa 1912 USGS)

	**Photo 15.** Tree slab cut from Montana Creek along Back Loop Road-south of the LIA Terminal moraine of the Mendenhall Glacier.Tree age is circa 1300 AD (R.D. Lawrence sample, courtesy of R. Carstensen)

10 am Montana Creek Peat, Volcanic Ash, and Gastineau Formation. Dave D'Amore gave us a soil scientist's hydrological view of the fen in upper Montana Creek. We followed Montana Creek Trail beyond the road's end past the large cutbank containing 11,250 ± 50^{14}C yr B.P volcanic ash from Mt. Edgecumbe in Sitka (Beget and Motyka, 1998). We talked about the Northern Cordilleran Volcanic Province and about the early Holocene during which time the Mendenhall Glacier was a tidewater glacier and Montana Creek flowed into Mendenhall Bay. Mid-Wisconsin interstadial/Pollen studied by Heusser (1960) dated by R.D. Miller (1971, 1973, 1975).

 Photo 16. Peat in upper Montana Creek (Krista Koehn photo 2008)	 Photo 17. Early Holocene Gastineau Formation Third Facies exposed in Montana Creek Bluffs with Edgecumbe ash atop (Steffi Schrieber photo 2008).

Photo 18. Tom Ager USGS samples 11,250 ± 50^{14}C yr B.P Edgecumbe Ash atop Montana Creek Bluff (Connor photo circa 1999)

Photo 19. Four meter section reveals LGM till overlying interstadial sediments along upper Montana Creek (Connor 2001 photo)

We drove by Auke Lake just over the Goat Hill divide between the Mendenhall system and the Auke Bay watershed. The Auke Lake basin was probably formed by the Fish Creek fault, plucked out by repeated advances of the Mendenhall glacier and drowned by transgressive Auke Bay about 10 Kya. Post LIA uplift has elevated the lake out of the reach of saltwater. It’s surface is presently 17 m above msl. Pertinent references include: Barnwell and Boning 1968; Connor et al 2005; Miller, R.D. 1971, 1973, 1975; and Thilennius et al 2007.

Figure 35. Post LGM evolution of the Mendenhall Valley 10kya, 6kya, and 250 ya (Barnwell and Boning 1968)

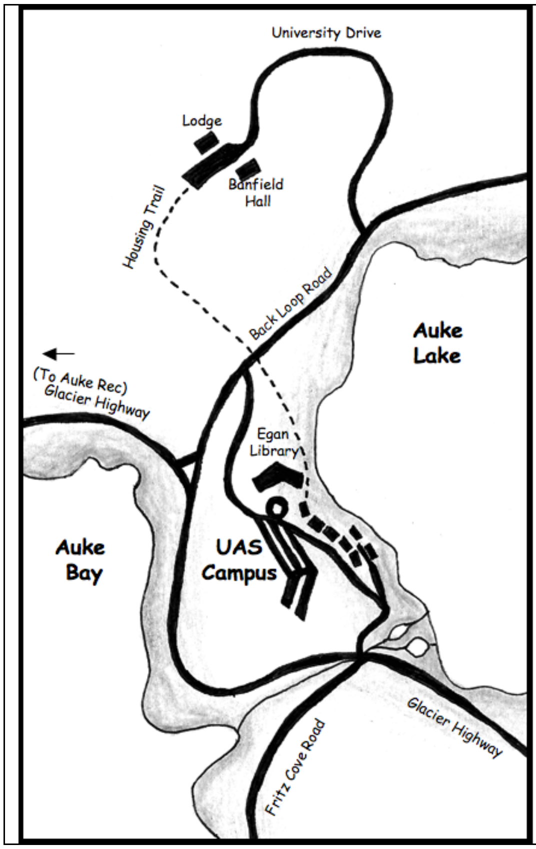


Figure 36. Map of Back Loop Road Auke Lake Area showing location of UAS campus.

11:00 Auke Lake

The origin of Auke Lake's basin is related to the Fish Creek fault which from northern Douglas Island trends just west and sub-parallel to the Fanshaw/Gastineau channel fault in the Auke Lake area. During repeated Pleistocene glacial maxima, Mendenhall Glacier ice over-rode the divide at Goat Hill and flowed into the Auke Lake/Bay area. Ice quarrying and extraction of the faulted bedrock deepened the basin. Bathymetric surveys by the UAS Environmental Science program faculty and students determined the maximum basin depth at 34 meters.

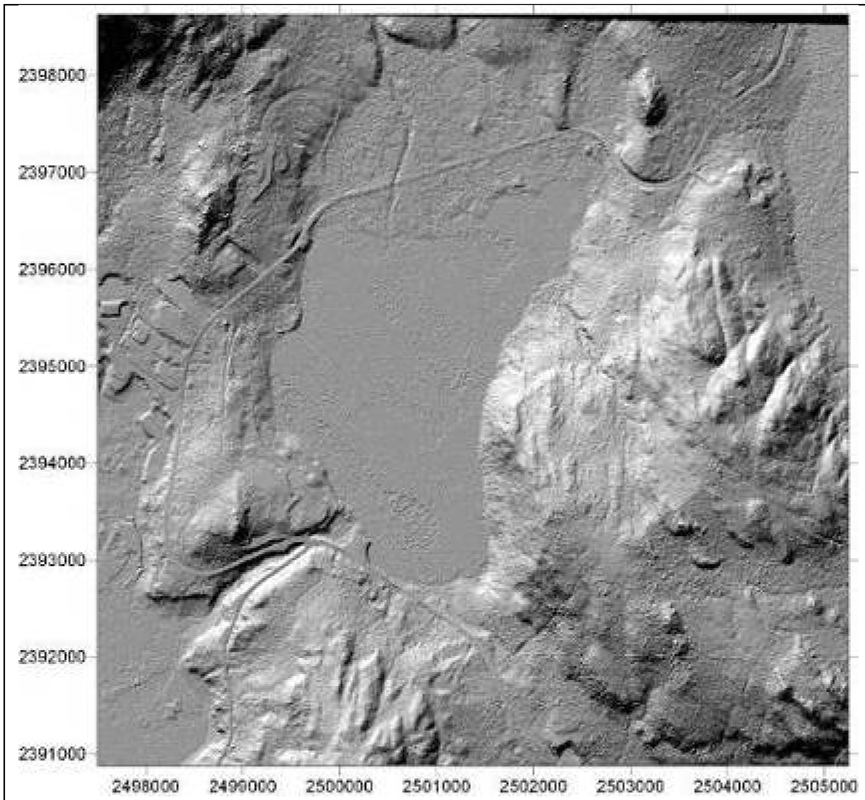


Figure 37. LIDAR Image of Auke Lake Courtesy of Gary Vetesey CBJ

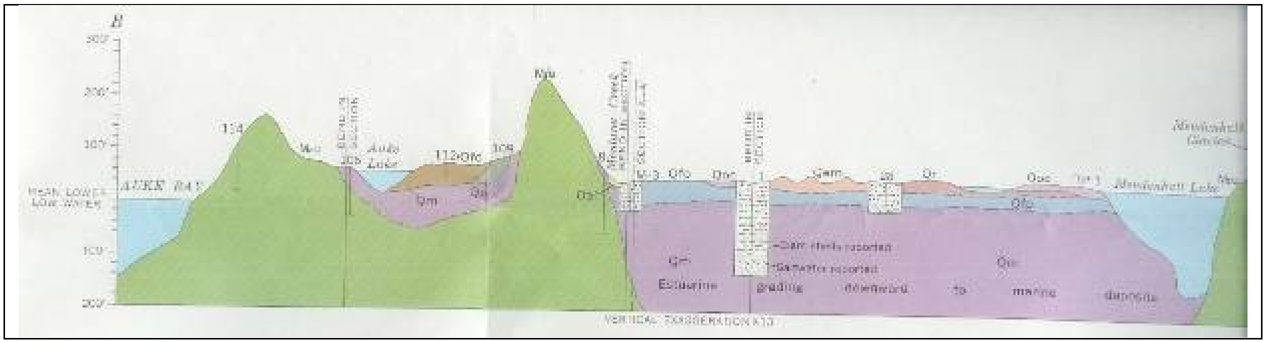


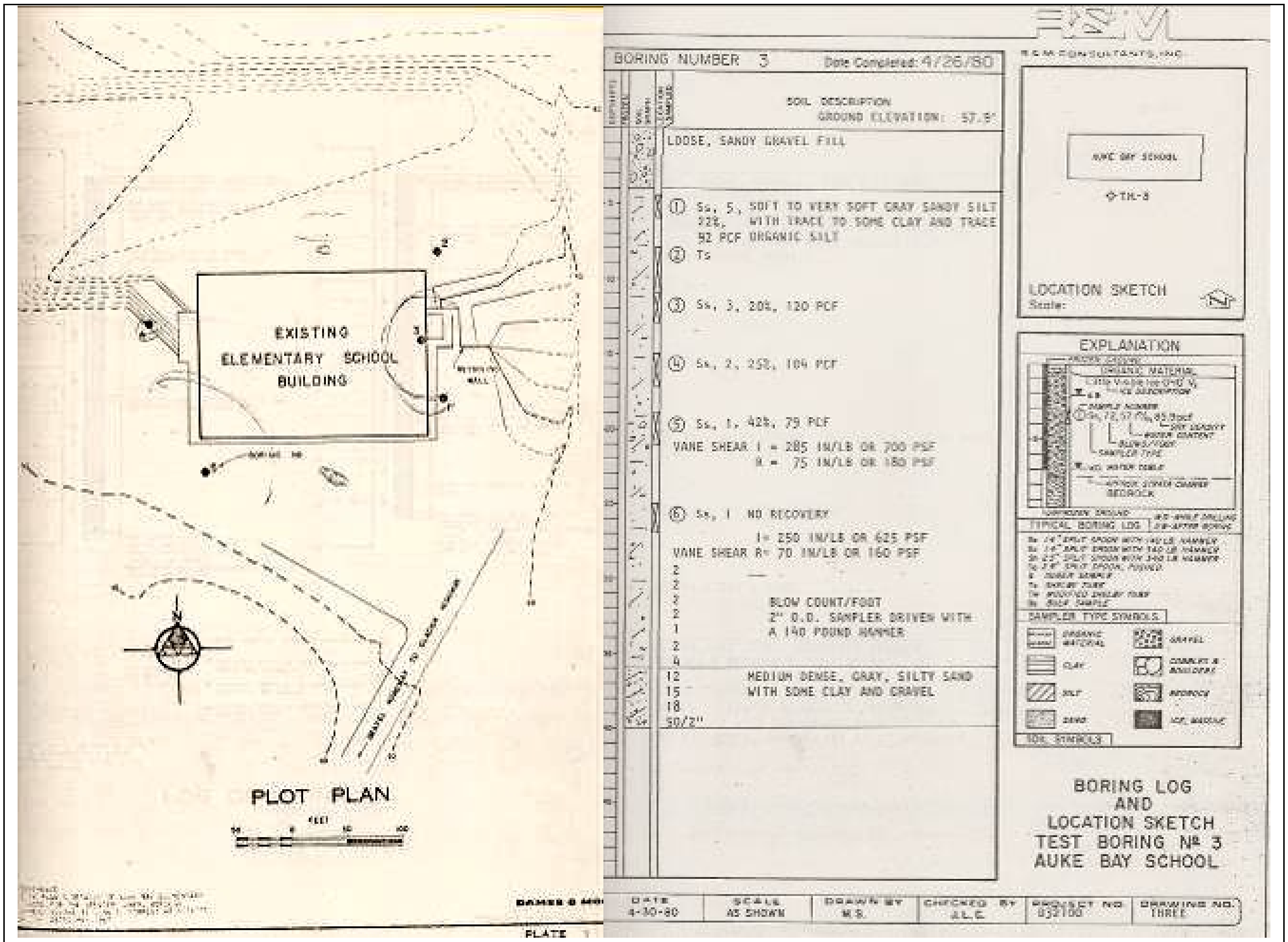
Figure 38. South to North bedrock profile from Auke Bay to Mendenhall Glacier through the central Mendenhall valley. Green rocks are Cretaceous Gravina Belt basin volcanics and turbidites and purple sediments are the Late Holocene Gastineau Formation with younger fluvial and deltaic sediments atop. Bedrock at the north end of the profile is Devonian to Mississippian Yukon Tanana terrane amphibolite facies metamorphic rock. Auke Lake has not been overrun by ice for ~13,000 years (Barnwell and Boning, 1968)

11:45 Auke Bay School Gastineau Formation-Sinking Building History

On Saturday August 30, Mike Blackwell, (UAF geology program graduate and Dames and Moore Engineering Geologist, ret.) helped us to celebrate the 40th anniversary (almost to the day) of the opening of Auke Bay School. The geo-engineering story of this site began during the mid-1960s as Juneau's population began to sprawl out of the downtown area into the Mendenhall Valley and Auke Bay areas. No large structures had been built in Auke Bay up until this time. By 1965 the Auke Bay School site was being investigated for construction and planning for a school was underway.

Geo-engineering pre-construction assessment consisted of some shallow soil probing and plate bearing (load) tests which saved the City and Borough of Juneau (CBJ) ~$1,000. Between 1967 and 1968 Construction took place concurrent with some more site investigation, saving the CBJ several more $1,000. The organic mat, peat, and underlying silts were scraped off of the site surface and replaced by much heavier sand and gravel. The Auke Bay School opened in September 1968 with the building already showing signs of distress. The foundation had been structurally "floated' on the site but tied to a heavy boiler-heating system at the southeast end of the building. Differential settlement occurred as the imported gravel building pad and the school building exceeded the bearing capacity of the underlying (and previously undetected) Early Holocene glaciomarine Gastineau Formation. Geo-engineering preceding site preparation had focused on the shallow and cheaper style of investigation and not detected the weakness of the site's deeper substrate. In May 1969 borings were cored to bedrock. The CBJ opted to watch and wait. From 1970-1980, the building showed continued distress with wracking doors and windows while columns and beams had actually twisted. Building distress and settlement had been observed for 12 years before action was taken.

The CBJ options were to tear the building down ($5,931,530...replacement costs), move it to another portion of the site ($1,750,000), upgrade the building structure, or underpin the building (~$2,152,004). In the 1980s the students were sent on a split-schedule to Glacier Valley Elementary School, as engineers drilled pilings through the gym floor to pin the structure to bedrock through some 40 feet of glacier-marine silt. Auke Bay citizens and the CBJ learned the lessons to pay for the site geo-engineering assessment upfront before construction rather than after the building was been built. (R&M Engineering, 1980)



BORING NUMBER 3 Date Completed: 4/26/80

SOIL DESCRIPTION
GROUND ELEVATION: 57.9'

LOOSE, SANDY GRAVEL FILL

① Ss, 5, 22%, 92 PCF SOFT TO VERY SOFT GRAY SANDY SILT WITH TRACE TO SOME CLAY AND TRACE ORGANIC SILT

② Ts

③ Ss, 3, 20%, 120 PCF

④ Ss, 2, 25%, 104 PCF

⑤ Ss, 1, 42%, 79 PCF
VANE SHEAR I = 285 IN/LB OR 700 PSF
R = 75 IN/LB OR 180 PSF

⑥ Ss, 1 NO RECOVERY
I= 250 IN/LB OR 625 PSF
VANE SHEAR R= 70 IN/LB OR 160 PSF

2
2
2
2
1
2
4

BLOW COUNT/FOOT
2" O.D. SAMPLER DRIVEN WITH
A 140 POUND HAMMER

12
15
18
50/2"

MEDIUM DENSE, GRAY, SILTY SAND WITH SOME CLAY AND GRAVEL

BORING LOG
AND
LOCATION SKETCH
TEST BORING Nº 3
AUKE BAY SCHOOL

DATE	SCALE	DRAWN BY	CHECKED BY	PROJECT NO.	DRAWING NO.
4-30-80	AS SHOWN	M.S.	J.L.C.	832100	THREE

Figure 39. Auke Bay Elementary School Site investigation: Location Map of Borehole 3 and core log location near heavy school boiler (R& M Engineering Report, 1980).

12:30 pm Human Occupation of Southeast: USFS Auke Village Recreation Site Aukwan History

Daniel Monteith, UAS Social Science Department summarized the archeological and ethnographic evidence from POW caves, Alexander Archipelago village and shell midden sites, and obsidian trade discoveries which support the Coastal Migration theory for early human occupation of North America. Useful references include those by Ackerman, 1996; Baichtal, 2007a,b & 2008; Carrara et al, 2003 & 2007; Cook et al 2006; Connor et al. (2009); Cruickshank, 2001; Dauenhauer and Dauenhauer, 1989; DeLaguna, 1972; Dixon et al. 1997, 1999, 2001; Emmons, 1991; Fedje et al. 200X; Fetter et al. 2008; Heaton et al. 1996, 2007, Manley et al. 2002; Monteith et al. 2007, and Moss et al. 2001.

We also discussed Lynn Canal and it's geomorphic evidence as a southern extension of the Denali Fault which is though to have switched from a position along Gastineau Channel. Motyka guided a discussion of Glacier Bay climate history coupled with the rise of Mt Fairweather and the interplay with the southwestern Yakutat block, and North America Plate tectonics. Pertinent references include Hicks et al, 196X, Hudsen et al 198X; Larsen et al 2003, 2005, &, 2007; Lawson et al 2002 & 2004; Mann et al 2008,

We visited outcrops of the Gastineau Formation where it lies unconformably atop Cretaceous Gravina Belt turbidites along Auke Village Recreation bypass highway section. Subfossils of the Gastineau Formation are delineated by Miller, 1973 and Thilenius et al. 2007.

Photo 20. Auke Village (site of USFS Auke Village Recreation Site, Case and Draper Photo 1888).

Alaska State Library - Historical Collections

Photo 21. Beach edge petroglyph in the Auke Bay area (Connor photo)

Photo 22. The most abundant foraminifera *Elphidium clavatum,* many subfossils were recovered from Early Holocene Gastineau Formation along the Glacier Highway near Auke Village recreation Site (Thilenius, 2005).

Photo 23. Motyka and D'Amore search for the Gastineau Formation (a favorite substrate for stabilizing by hydroseeding for AKDOTPF) along the highway above the Auke Village Recreation site.

2 pm Eagle Beach-LIA deglaciation history, uplift along river

Motyka and Connor described the post-Little Ice age accretionary lands that are especially evident in the uplift meadows of this region. The rapid deglaciation of

Glacier Bay beginning about 1760 resulted in XXx km3 of ice loss in XX years with XX km of terminus retreat. The highest uplift rates in the world are currently occurring in northern Southeast Alaska. At the same time warming climate is contributing to great ice loss in non-tidewater glaciers around the southern Alaska coast from the Kenai Peninsula, through Prince William Sound, across the Gulf of Alaska and into the Alexander Archipelago. Global Sea level rise can attribute 7% of input in 2002 to Alaska glacier meltwater (Arendt et al 2002). Oral histories of many Alaska Native groups in the region record glacier crossings, glacier advances, and deteriorating conditions during the Little Ice Age. Pertinent papers include Connor et al in press 2008; Cowan et al, 200X;, Lawson, Larsen 2002, 2005, 2007; Mann et al, 1995, 1998, 2008; McKenzie et al; Miller, D.J. 1958; Monteith et al 2007, Powell et al, 1984, 200X. Palynology from cores in Lily Lake, Mosquito Lake, and bogs on Pleasant Island provide additional records of changing vegetation and climate throughout Holocene time. Pertinent references include Ager, 1998; Barto, 2007; Cwynar, 1990; and Hansen et al, 1996.

Connor next described the Late Cenozoic to Quaternary tectonic and volcanic history of the region as we looked out at the Denali fault trace where it forms the axis of the Lynn Canal fjord separating the Chilkat Peninsula on the west from the Kakuhan Range north of Berners Bay and the Juneau road system on the east. The North American, Pacific Plate and Yakutat block intersect at a triple junction west of Sitka. The Fairweather-Queen Charlotte transform fault slices inland at Palma Bay and swings northwesterly across the head of Lituya Bay, across Alsek Lake and into the St Elias Mountains to join the Contact fault. Ongoing studies by the STEEP project have identified the relationship between plate collision, glacier erosion, bedrock exhumation and transfer of glacier sediments. Pertinent references include Chapman et al 2008, Edwards and Russell, 1999, Haeussler et al 2006; and Madsen et al, 2006.

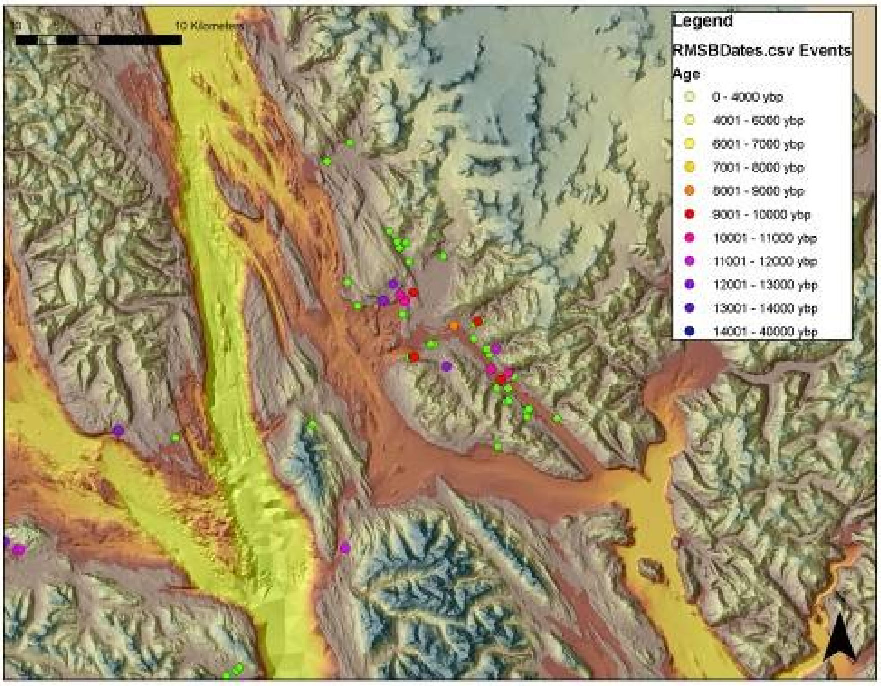


Figure 40. Locations and elevations of raised marine shell beds (Baichtal 2008).

Photo 24. View to Northwest across Lynn Canal to the Chilkat Peninsula Range from Eagle Beach, Juneau.

4 pm Echo Cove: North End of the Juneau Road System

The planned route for Juneau Access Road from Berners Bay to the Katzehin River past the Kensington Mine is located at the base of the Kakuhan Mountains which form the steep terrain on the east side of the fjord. The greatest safety issue associated with this East Lynn Canal Highway route are the frequent mass-wasting events from mudslides, to landslides, to rockfalls, to avalanches. A total of 58 avalanche paths intersect with the proposed road path. While avalanches often stop before reaching the proposed road alignment, not all will. In some cases avalanches have been observed that swept over a proposed site and displaced debris up to a half mile offshore. Some large avalanches are expected to cross the road alignment each year. These avalanches could be of a magnitude to push automobiles in the pathway into Lynn Canal if no avalanche mitigation measures are put into effect. (Golder Report to CBJ 2007; Steininger et al 2003). Juneau experienced avalanche difficulties in April 2008 when snowslides destroyed two support towers that hold the power cable fro Snettisham generator to downtown Juneau.

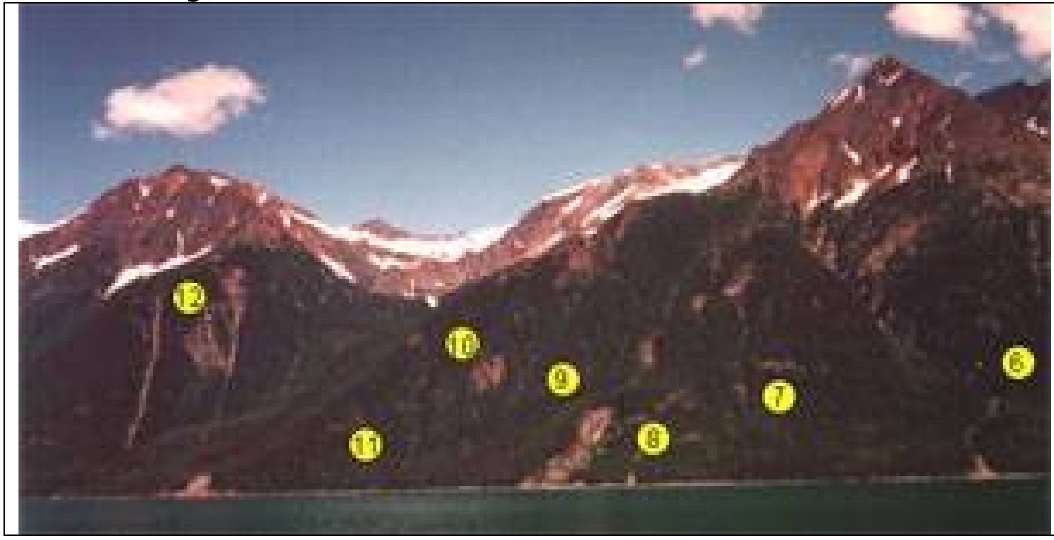


Fig 41. Yellow dots denote an avalanche path and its corresponding number in the Juneau Access Draft Environmental Impact Statement (Steininger et al 2003)

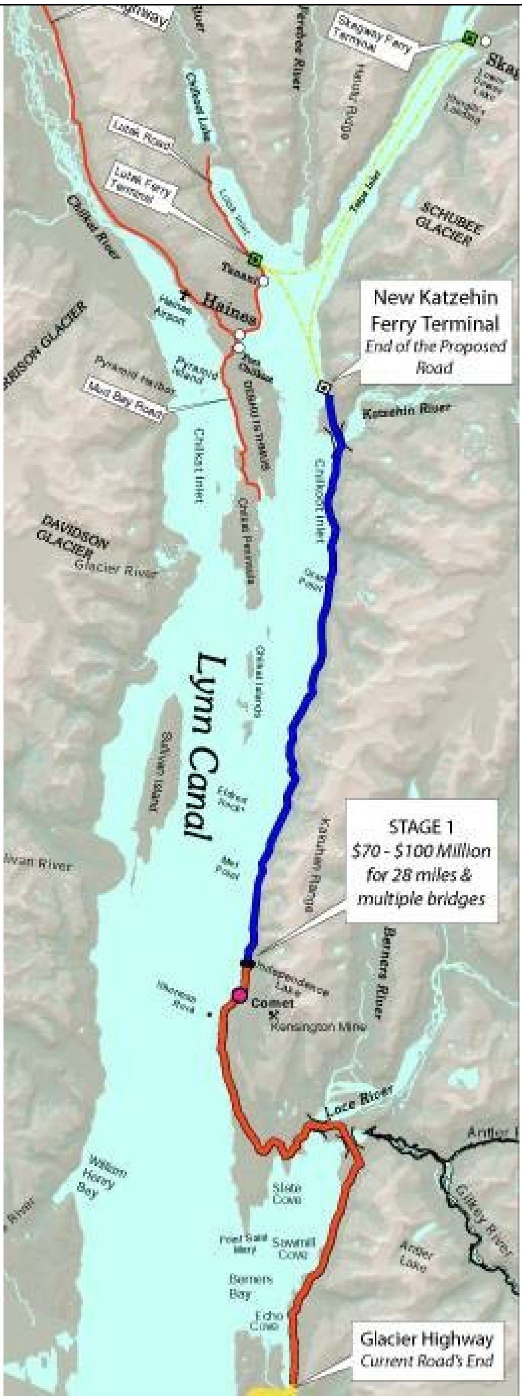


Figure 42. Proposed route for Juneau Access Road along the east side of the Lynn Canal fjord Linking Juneau with the Katzehin River valley east of Haines.

Figure 43. Location of Coeur Alaska Kensington Gold Mine north of Berners Bay (Juneau Empire). Presently the mine development has been slowed down pending a U.S. Supreme Court Decision on tailings disposal in Slate Lake.

5 pm return to Auke Bay/Mendenhall Valley for dinner.

Sunday August 31

Low tide -2.4' at 8:06 am

Drive to Downtown Juneau and cross Gastineau Channel at the Douglas Bridge. Turn Right to North Douglas and Drive to Mile 11.4 mile North Douglas Highway. Park at Outer Point trailhead.

Fig 35 Location Map False Outer Point trail area

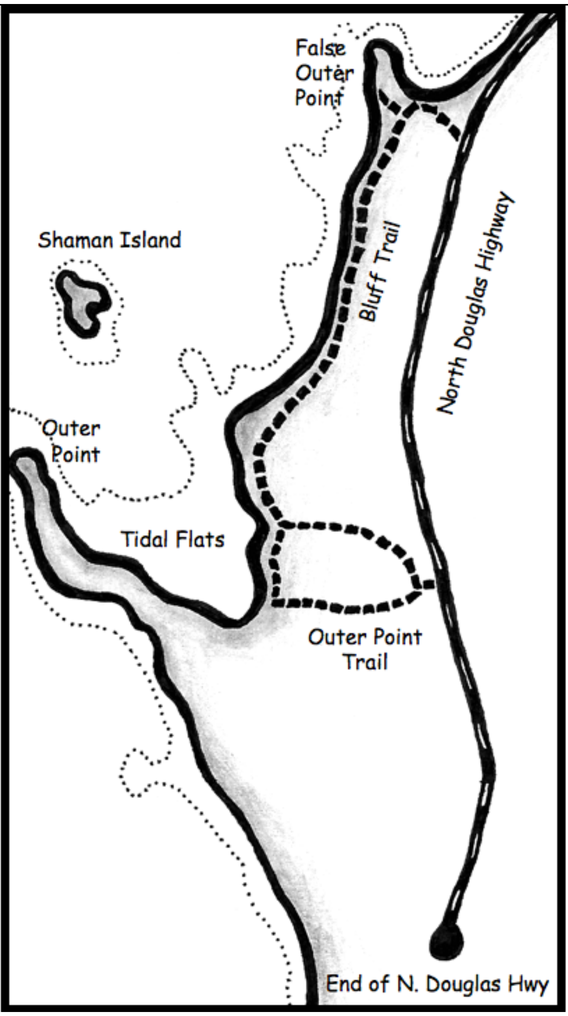


Figure 44. North Douglas Island Route

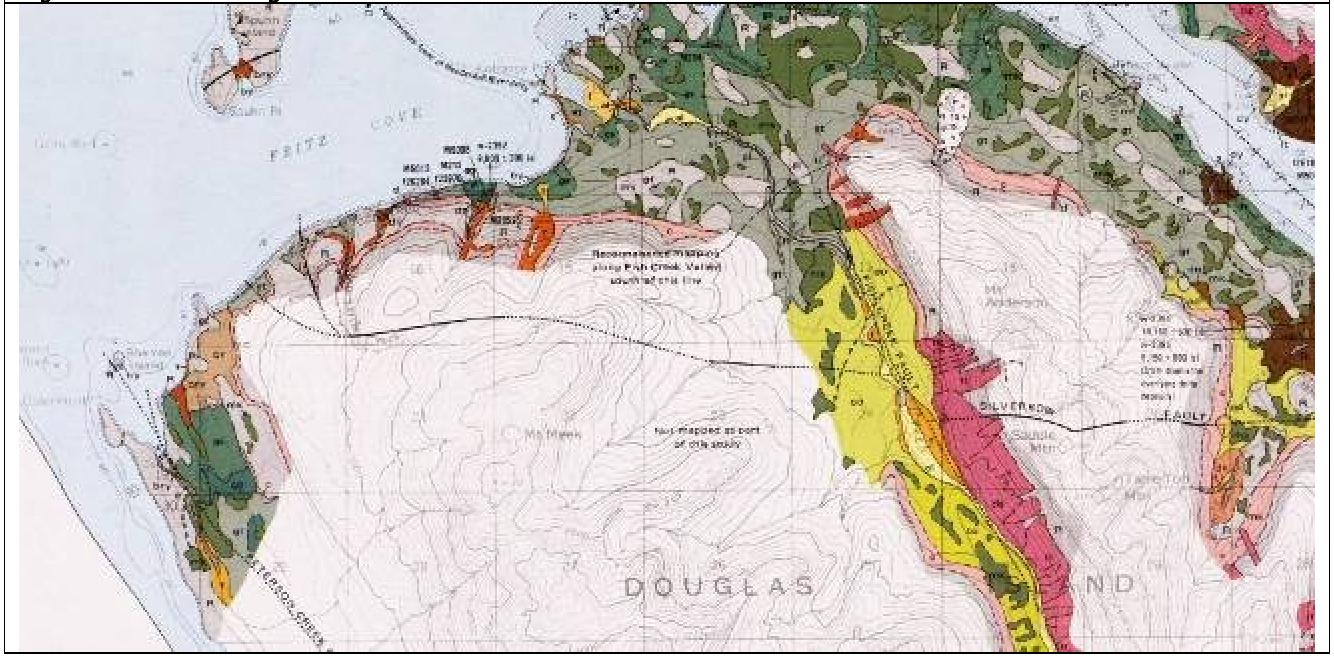


Figure 45. Surficial Deposits of North Douglas Island (R.D. Miller, 1975)

8 am False Outer Point-Post LIA Uplift History (Motyka)
We begin our exploration of the Douglas Island and downtown Juneau areas with a hike to Shaman Island across an emergent at low tide only tombolo. Motyka and D'Amore led a discussion of early Holocene uplift followed by post LIA uplift and the the development of landform and peat bogs, and the forest's response. Pertinent references include D'Amore 200, 200, 2000 Miller, 1973 and 1975; Motyka, 2000, and

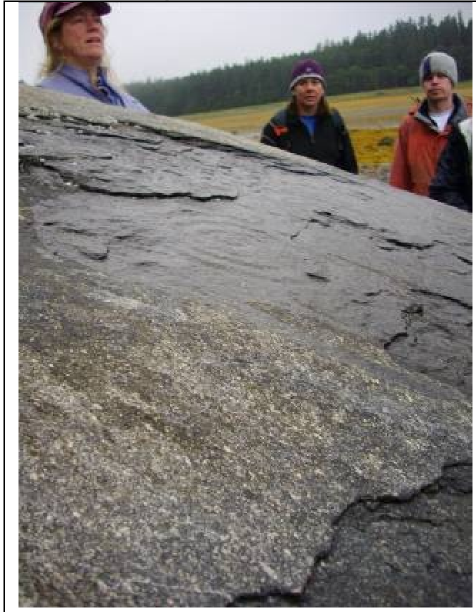


Photo 25. Petroglyph on glacial erratic boulder

Photo 26. Motyka and D'Amore lay out glacial landscape and forest response.

Photo 27. Shaman Island FOP rock and uplift inspectors

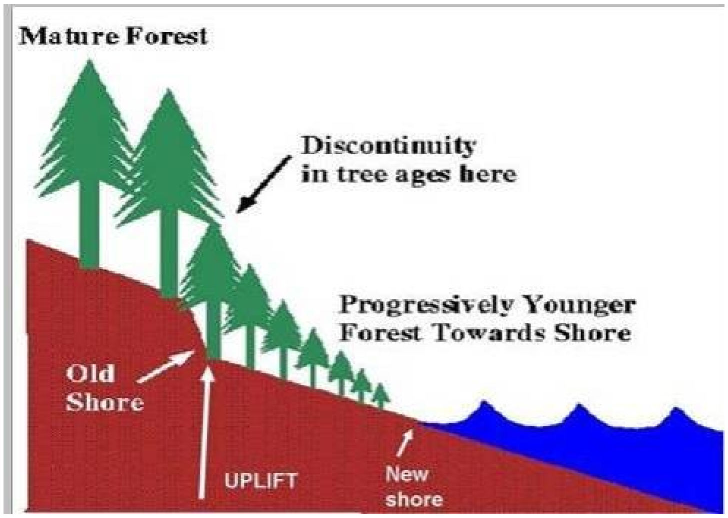


Figure 46. Spruce trees growing seaward on accretionary lands following uplift. (Motyka 2003)

Photo 28. Spruce growing on riser with pine bog to the south and uplift beach to the north.

10 am Eaglecrest Older Outwash and Morainal Sediments underlie forested wetlands. Dave D'amore led us to his soil study sites along Fish Creek and into interested discussions about the age and movement of soils formed on glacial morainal sediments here.

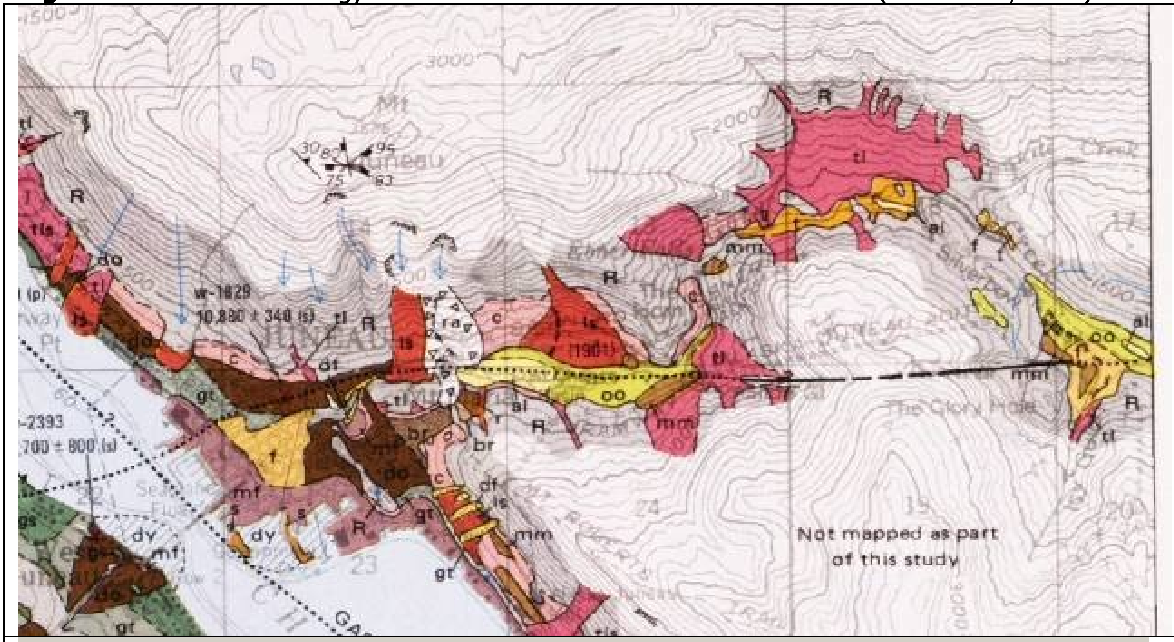
Damore and others (2004) characterized soil type, storage, and export of carbon in a bog (peatland) and a forested wetland to investigate carbon storage in wetland soils and its export to streams in Southeastern Alaska. The majority of terrestrial carbon in southeast Alaska is stored in extensive wetlands dominated by peat. This carbon stock is believed to contribute much dissolved organic carbon (DOC) to streams. Wetland soils in southeast Alaska vary widely in organic matter depth and decomposition that influence both carbon and nutrient cycles within these different soils. The bog had a deeper peat accumulation compared to the forested wetland, although DOC concentrations were higher in lysimeters in the forested wetland (70 to 90 mg C/L) than the peatland (20 to 49 mg C/L). DOC concentration in wells (15 to 45 mg C/L) and export from tributaries (5 to 41 mg C/L) draining both the forested wetland and peatland was similar with peak DOC concentrations and export linked to high soil temperatures and storm flushing in mid-summer. This relationship would support a positive feedback of increased DOC export with warmer temperatures and higher rainfall in the hypermaritime ecosystem of coastal North America (Damore et al, 2004).

Photos 29a Muskeg Meadows on glacier till, **29b** Eaglecrest Soil pit.

11 am West Juneau
From North Douglas Head to Downtown Douglas easing ¼ turn CCW on Douglas Roundabout (rotary). Turn Right at crosswalk onto and head up the hill. Turn Left onto Pioneer Ave. and continue up the hillside to a good viewing spot.

Here, at an overlook of downtown Juneau, we observed Gastineau Channel's tectonic geomorphology, glacial features, and Juneau's notorious avalanche paths and landslide slopes within residential areas. Cruise ship emissions, tourism impacts and use of fossil fuels were also pertinent topics at this site.

Figure 47. Surficial Geology of the Downtown Juneau-Gold Creek Area (R.D. Miller, 1975)



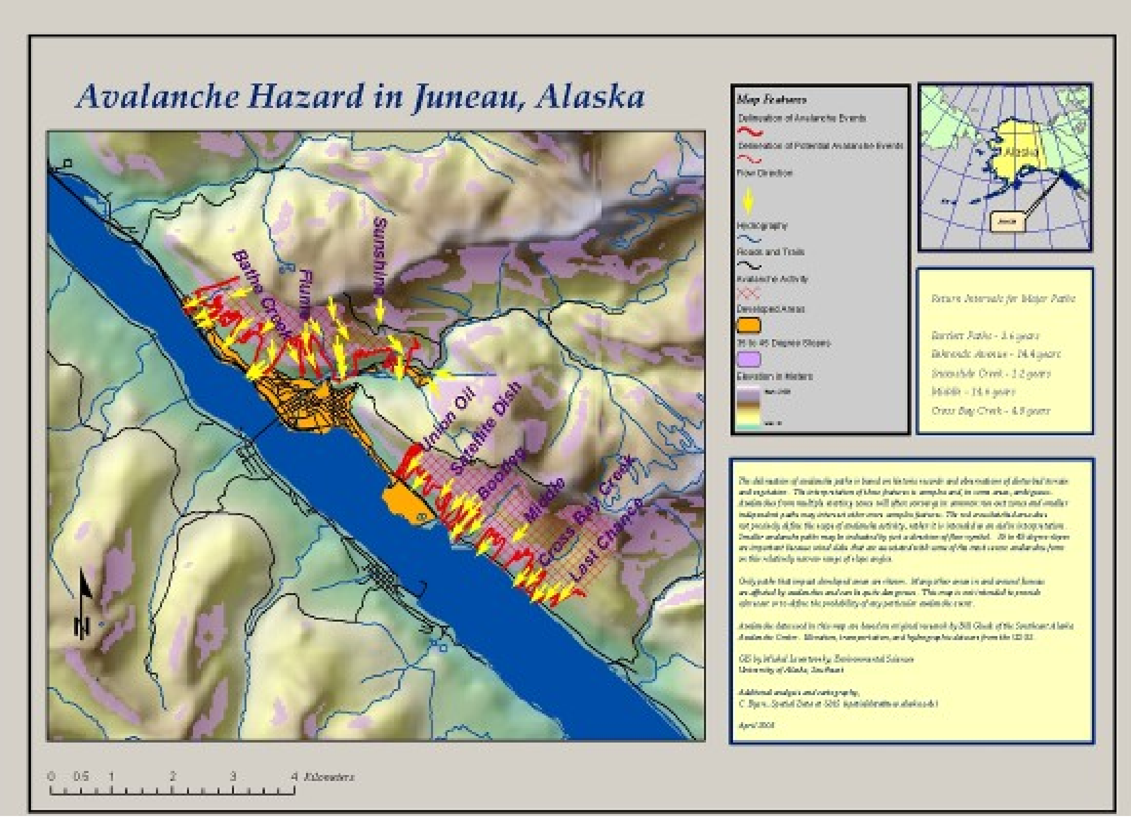
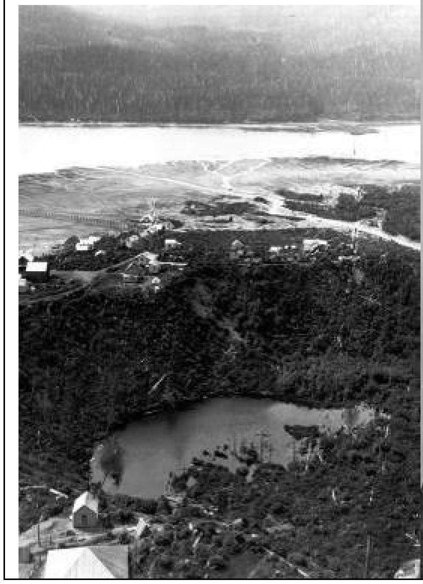


Figure 48. Avalanche paths in downtown Juneau (UAS Spatial Data: Byers and Levartosky, 2002).

Photo 30. Courtesy Of Mike Laudert / Alaska Electric Light & Power Co.
Electric rates in Juneau are expected to rise sharply as Alaska Electric Light & Power Co. switches to diesel power while the structures are repaired. Juneau homeowners' and some renters' electricity rates will likely quintuple next month (May 2008). The city's electric utility will resort to running on diesel as the result of an avalanche Wednesday morning that cut hydroelectric power to the area (Juneau Empire).

Photo 31a) Cope Park Bowl and Gold Creek's delta before later mine-tailings fill and residential and commercial construction. View is southwesterly toward Douglas Island.
31**b**) G.K. Gilbert, USGS Geologist who traveled with the Harriman Expedition through Juneau in 1899.



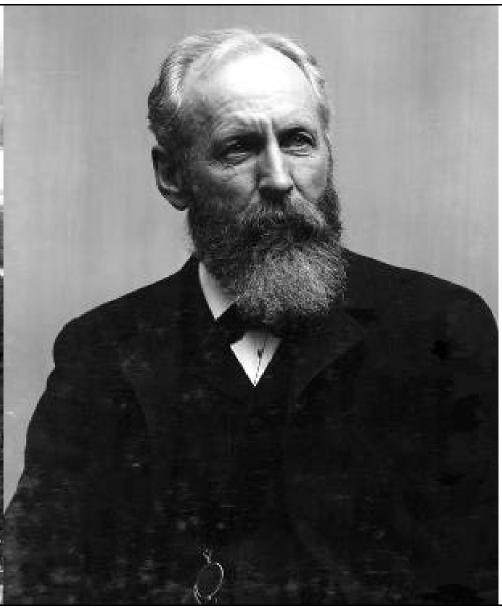


Photo 32a,b. Views from Douglas Island (west Juneau) of Gold Creek, downtown Juneau and Cruiseship haze.

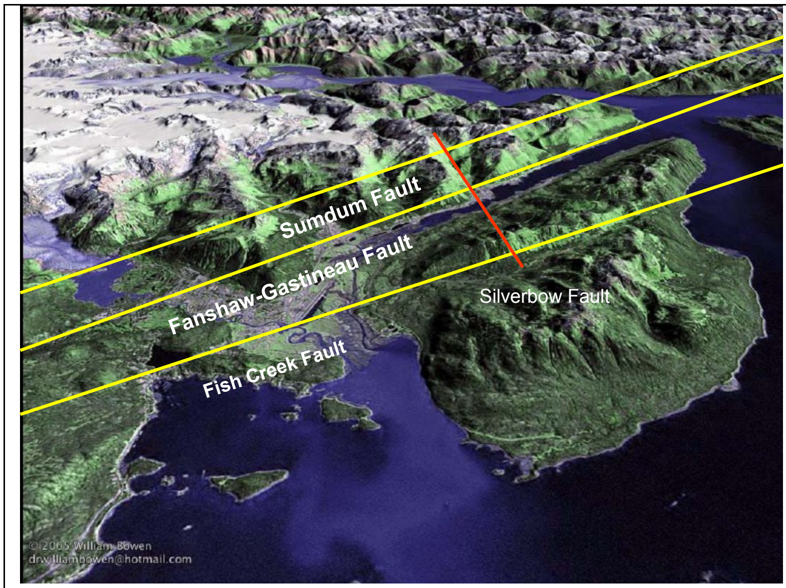
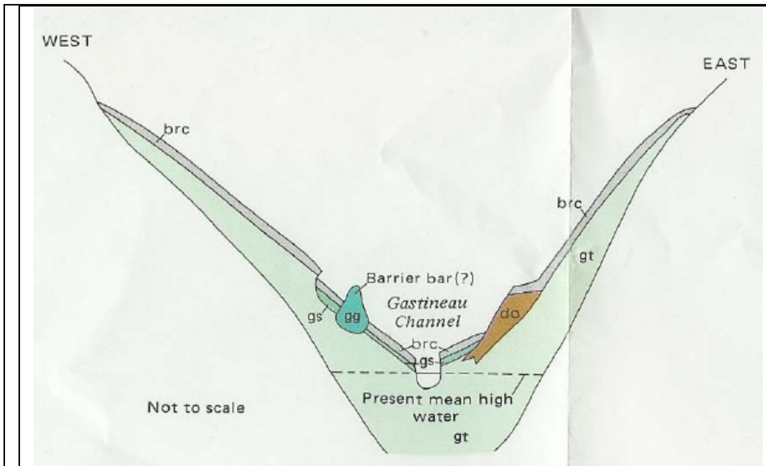


Figure 49. Approximate locations of Fanshaw/Gastineau Channel Fault, Sumdum faults, Silverbow faults, and Fish Creek Faults along the Coast Range Shear Zone after Gehrels and Stowell (2000)**.** William Bowen image used for basemap.



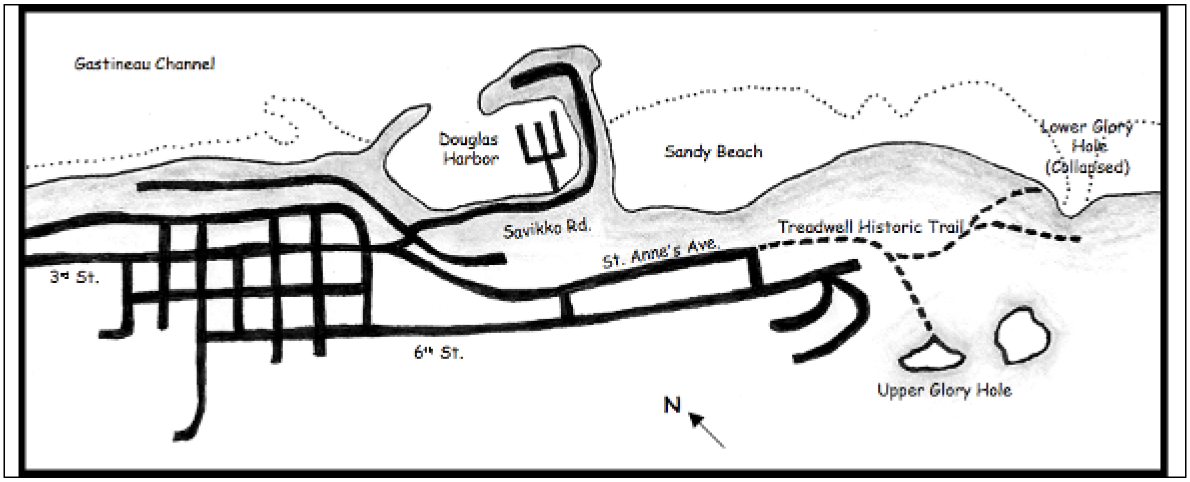
DIAGRAMMATIC CROSS SECTION OF THE GASTINEAU CHANNEL FIORD

Shows relation of glaciomarine, beach, and deltaic deposits. (See Miller, 1973b.) First facies (gt) of Gastineau Channel Formation ranges through almost entire age span of second (gg) and third (gs) facies as controlled by sequential deposition during uplift of land relative to sea level following deglaciation of the Gastineau Channel area.

Figure 50. Cross Section of Gastineau Channel showing glaciomarine, beach and deltaic deposits Gastineau Channel Formation Facies are first facies (gt), second facies (gg) and third facies (gs), providing information about uplift following deglaciation (R.D. Miller, 1975)

Noon Sandy Beach-Lunch

Gastineau Formation on Gravina Bedrock Treadwell Mining History-Cave In: Walk along the channel to the southeast to see the first Facies of Gastineau Formation unconformably overlying Cretaceous Gravina belt rocks that are well-exposed at the beach level, lower glory hole or Cave-in site.



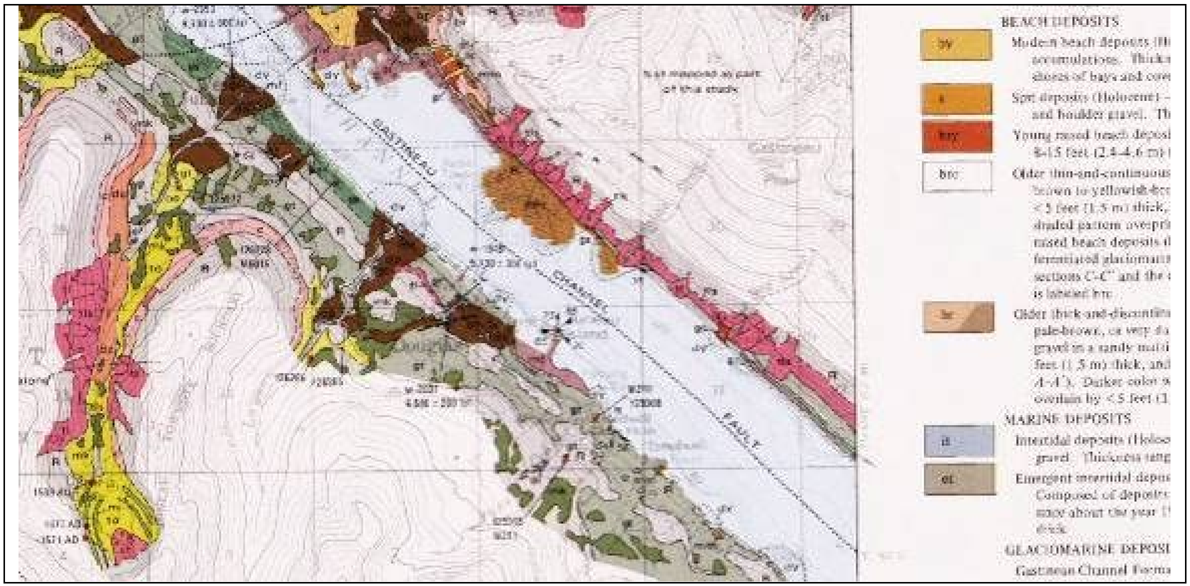


Figure 51a. A Map of Downtown Douglas-Sandy Beach area.
51b. Surficial deposits by R.D. Miller 1975


Alaska State Library - Historical Collections

Photo 33. Canoeing to Juneau before the bridge
Alaska State Library Digital Archives


Photo 34. Microfaunal washed out ofGastineau Formation third facies *Elphidium* species foraminifera (C. Thilenius, 2007)


Photo 35. Treadwell Ditch 1905
Alaska State Library Digital Archives


Photo 36. Douglas 1899
Alaska State Library Digital Archives

Photo 37. Mine Workers pick white, gold-bearing quartz rock off the sorting belt. AJ mine.
Alaska State Library Historical Collections

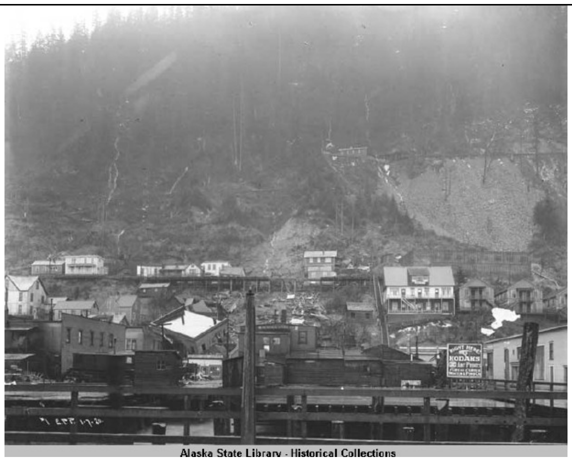


Photo 38. Gastineau Avenue Landslide in 1920s Juneau. Alaska State Library Historical Collections

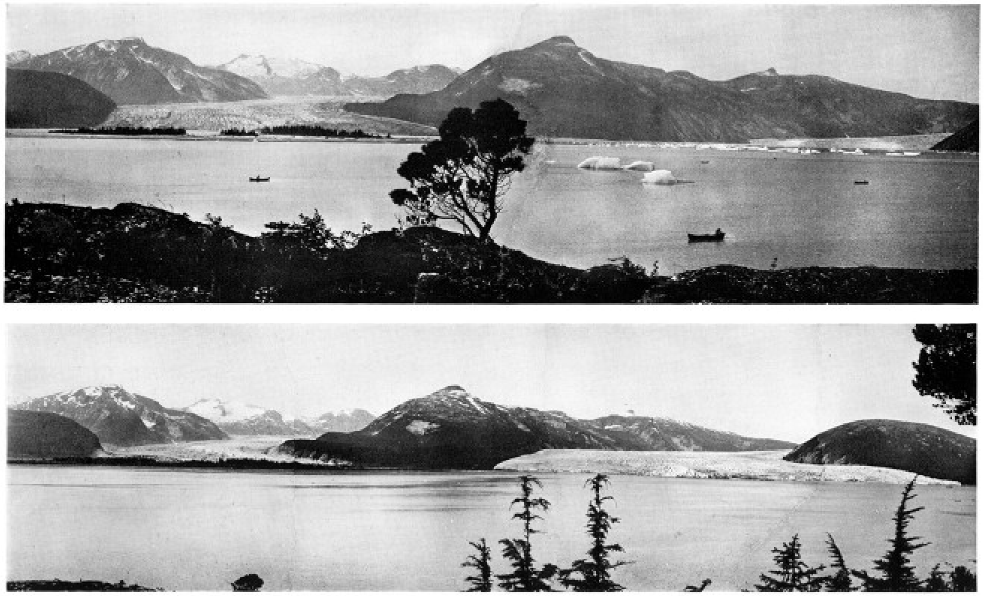


Photo 39. Repeat photography of Taku Glacier taken by William S. Cooper in 1916 and R. Lawrence in 1949. Note growth of Taku Glacier (right) and reduction in Norris Glacier (Left). (Lawrence, 1950)

After Lunch and beach walk

Lemon Creek-Older Deltaic Deposits

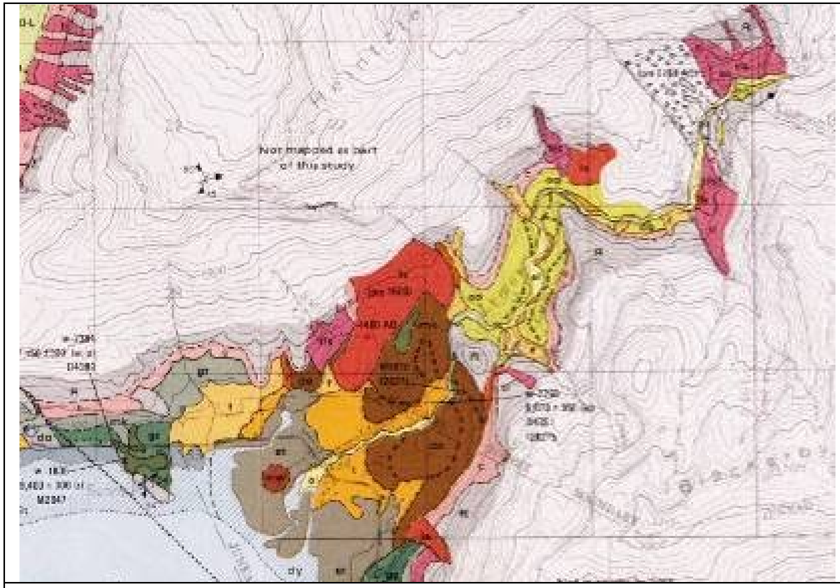


Figure 52. Lemon Creek Quaternary Sediments (R.D. Miller, 1975)

Photo 40a., b., c., Early Holocene Lemon Creek delta deposits
The early Holocene deltaic deposits of Lemon Creek now mined by the City and Borough of Juneau. Sand quarry allows observation of channel-ward dipping foreset beds which have been uplifted relative to modern sea level between Home Depot and the AK State Prison at the end of Anka Street. These sands have been excavated for construction projects around the Capital City.

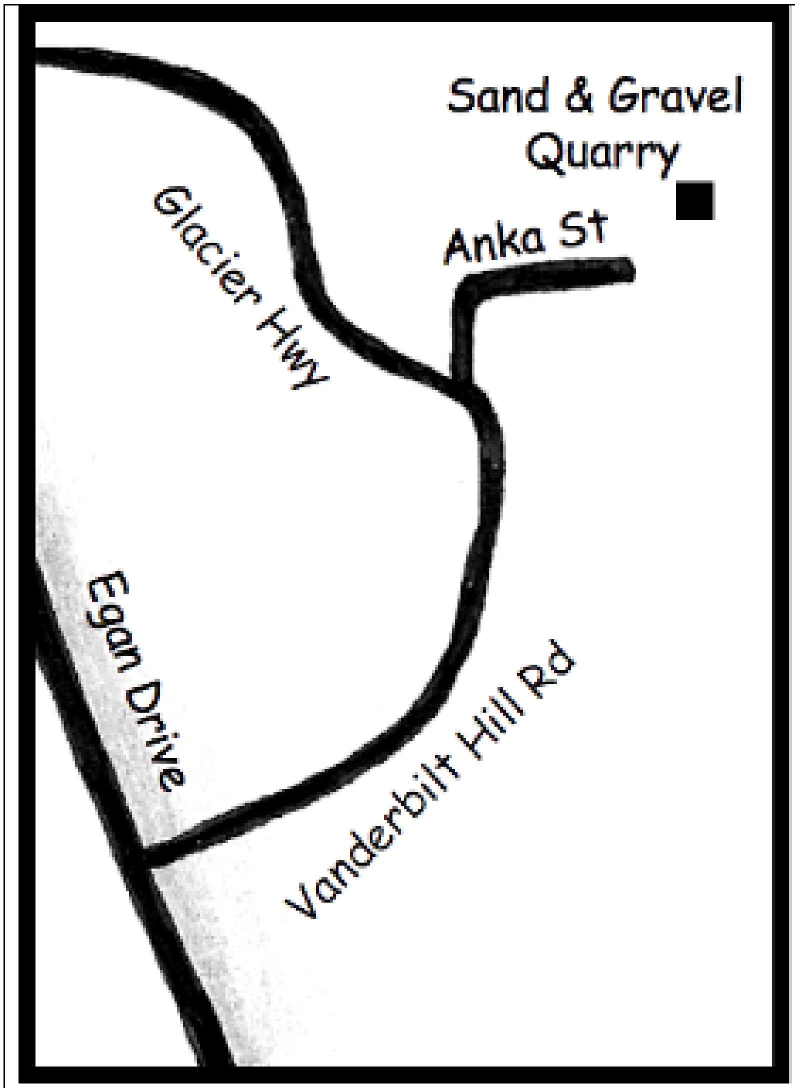


Figure 53. Lemon Creek Stops

Eran Hood UAS Hydrology professor and his student Joshua Jones describe ongoing sensor networks that are monitoring the glacier-hydrology of the Lemon Creek Glacier System. Eran also described his work with nutrient cycling in deglaciating watersheds along the Juneau road system (Hood and Scott , 2008)

End of Field trip

After dinner we returned to the Mendenhall Campground for our traditional Evening FOP fireside festivities, FOP Trowel Exchange Ceremony, and songfest. FOP 2009 will return to the north and may include an exploration of the Dalton Highway and southern Brooks Range Quaternary led by Tom Hamilton USGS.

Monday Sept 1 Optional Field trip East Mendenhall Glacier trail Hike.

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