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RECONNAISSANCE ENGINEERING GEOLOGY OF THE HAINES AREA, ALASKA, WITH EMPHASIS ON EVALUATION OF EARTHQUAKE AND OTHER GEOLOGIC HAZARDS

By

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ABSTRACT

The Alaska earthquake of March 27, 1964, brought into sharp focus the need for engineering geologic studies in urban areas. Study of the Haines area constitutes an integral part of an overall program to evaluate earthquake and other geologic hazards in most of the larger Alaska coastal communities. The evaluations of geologic hazards that follow, although based only upon reconnaissance studies and, therefore, subject to revision, will provide broad guidelines useful in city and land-use planning. It is hoped that the knowledge gained will result in new facilities being built in the best possible geologic environments and being designed so as to minimize future loss of life and property damage.

Haines, which is in the northern part of southeastern Alaska approximately 75 miles northwest of Juneau, had a population of about 700 people in 1970. It is built at the northern end of the Chilkat Peninsula and lies within the Coast Mountains of the Pacific Mountain system. The climate is predominantly marine and is characterized by mild winters and cool summers. The mapped area described in this report comprises about 17 square miles of land; deep fiords constitute most of the remaining mapped area that is evaluated in this study.

The Haines area was covered by glacier ice at least once and probably several times during the Pleistocene Epoch. The presence of emergent marine deposits, several hundred feet above sea level, demonstrates that the land has been uplifted relative to sea level since the last major deglaciation of the region about 10,000 years ago. The rate of relative uplift of the land at Haines during the past 39 years is 2.26 cm per year. Most or all of this uplift appears to be due to rebound as a result of deglaciation.

Both bedrock and surficial deposits are present in the area. Metamorphic and igneous rocks constitute the exposed bedrock. The metamorphic rocks consist of metabasalt of Mesozoic age and pyroxenite of probable early middle Cretaceous age. The igneous rocks consist of diorite and quartz diorite (tonalite) of Cretaceous age. Sedimentary rocks of Tertiary age may be present in the mapped area but are not exposed. The surficial deposits, of Quaternary age, have been divided into the following map units on the basis of time of deposition, mode of origin, and grain size: (1) undifferentiated drift deposits, (2) outwash and ice-contact deposits, (3) elevated fine-grained marine deposits, (4) elevated shore and delta deposits, (5) alluvial fan deposits, (6) colluvial deposits, (7) modern beach deposits, (8) Chilkat River flood-plain and delta deposits, and (9) manmade fill. Offshore deposits are described but are not mapped.

Southeastern Alaska lies within the tectonically active belt that rims the northern Pacific Basin and has been active since at least early Paleozoic time. The outcrop pattern is the result of late Mesozoic and Tertiary deformational, metamorphic, and intrusive events. Large-scale faulting has been common. The two most prominent inferred fault systems in southeastern Alaska and surrounding regions are: (1) The Denali fault system and (2) the Fairweather-Queen Charlotte Islands fault system.

In the general area of Haines, rocks of Mesozoic age northeast of Chilkat River have a simple monoclinal structure. Paleozoic-Mesozoic rocks southwest of Chilkat River are gently to rather complexly folded. Several major and numerous minor faults probably transect the general area of Haines but their exact location and character can only be inferred because their traces are coincident to the long axes of fiords and river valleys, where they are concealed by water or by valley-floor deposits. Inferred faults in or near the Haines mapped area are: (1) Chilkat River fault, (2) Chilkoot fault, (3) Takhin fault, and (4) faults in the saddle area at Haines.

Southeastern Alaska lies in one of the two most seismically active zones in Alaska, a State where 6 percent of the world's shallow earthquakes have been recorded. Between 1899 and 1970, five earthquakes of magnitude 8 or greater have occurred in or near southeastern Alaska or in adjacent offshore areas, three have occurred having magnitudes between 7 and 8, at least eight with magnitudes between 6 and 7, 15 with magnitudes between 5 and 6, and about 140 have been recorded with magnitudes less than 5 or of unassigned magnitudes. All of the earthquakes with magnitudes greater than 8, and a large proportion of the others, appear to be related to the Fairweather-Queen Charlotte Islands fault system or to the Chugach-St. Elias fault.

Although there are no known epicenters of earthquakes in the Haines mapped area, more than 100 earthquakes having epicenters elsewhere have been felt or were possibly felt at Haines. Microearthquake studies along a segment of the Denali fault system between Mount McKinley and Haines (about 400 miles) indicate that during the period of investigations the Haines area had one of the highest rates of microearthquake activity anywhere along that segment. On the basis of the seismic record alone, the largest expectable earthquakes in the Haines area would be of only moderate size (between magnitudes 6 and 7) and at only infrequent intervals. However, because of the high activity of the Fairweather-Queen Charlotte Islands fault system as well as the presence of other nearby faults of large size and of unknown activity, the possibility of an earthquake as great as magnitude 8 cannot be ruled out. Inferred effects from future earthquakes are based on this assumption.

Possible earthquake effects include: (1) surface displacement along faults and other tectonic land-level changes, (2) ground shaking, (3) compaction, (4) liquefaction in cohesionless materials, (5) reaction of sensitive and quick clays, (6) water-sediment ejection and associated subsidence and ground fracturing, (7) subaerial slides and slumps, (8) subaqueous slides, (9) effects on glaciers and related features, (10) effects on ground water and surface water, and (11) tsunamis, seiches, and other abnormal waves.

Facilities that probably would be affected most by surface displacement of faults would be those along inferred faults in the saddle area at Haines. These might include roads and streets, buildings, port facilities, waterlines, sewerlines, a petroleum pipeline, and an aircraft landing strip. About the only facilities that might be affected by movement on the Chilkat River fault are short segments of the Haines Highway, a petroleum pipeline, and a segment of a proposed highway across the Chilkat River. The Chilkoot fault probably is too far offshore to affect facilities other than, possibly, underwater communication cables. Sudden regional tectonic uplift or subsidence could produce a number of adverse effects, particularly along the shorelines of the inlets.

Although the amount of shaking (intensity) associated with an earthquake is dependent upon a great many variables, the variable most responsible at any epicentral distance is the type of ground. Generally the shaking is considerably greater in poorly consolidated deposits than in hard bedrock, particularly if the deposits are water saturated. In the Haines area, the geologic units are divided tentatively into three general categories on the basis of comparative degrees of expectable shaking: (1) strongest shaking, (2) intermediate shaking, and (3) least shaking.

Compaction and resulting settlement could cause some damage in the Haines area. Roads and streets, the aircraft landing strip, buildings, and other facilities built of or founded wholly or partly on manmade fill might be damaged. Piers, docks, and other harbor works may be affected by compaction of loose sandy beach deposits. Any appreciable settlement of the Chilkat River flood-plain and delta deposits or of the low-lying parts of the elevated fine-grained deposits would result in these areas being inundated by the sea.

Liquefaction in cohesionless materials resulted in catastrophic flow slides, heavy loss of life, and great property damage during some past earthquakes in Alaska and in other parts of the world. Other factors being equal, fine sands and coarse silts are most subject to liquefaction. In the Haines area, the Chilkat River flood-plain and delta deposits probably would be most affected.

Sensitive and quick clays, which lose a considerable part of their strength when shaken, commonly fail during an earthquake and become rapid earthflows. In the Haines area, preliminary data indicate that the elevated fine-grained marine deposits are most likely to contain sensitive clays, but more information is needed.

Water-sediment ejection and associated subsidence and ground fracturing are common effects during major earthquakes. The ejections are associated with surface or near-surface unconsolidated deposits where there is a high water table and a confined-water condition. In the Haines area, the Chilkat River flood-plain and delta deposits probably are the most likely to be subject to these effects.

Earthquake-triggered slides on land are confined most commonly to steep slopes and may involve either bedrock or surficial deposits. On moderately to nearly flat slopes, sliding is generally confined to fine-grained plastic surficial deposits or to materials that are subject to liquefaction. In the Haines area, an earthquake could trigger new rockslides or accelerate the movement of presently active to semiactive talus deposits on steep slopes. Facilities that might be affected include roads northwest and north of Haines, the water facilities for Haines, a segment of a petroleum pipeline, and dwellings close to steep slopes. Surficial deposits that might slide on moderate to nearly flat surfaces are: (1) Chilkat River flood-plain and delta deposits, (2) elevated fine-grained marine deposits, (3) elevated shore and delta deposits, (4) modern beach deposits, and (5) manmade fill. Facilities affected would depend upon which deposits slide.

In assessing the potential for earthquake-induced submarine sliding in the Haines mapped area, it is concluded that the deltaic deposits at the mouth of the Chilkat River probably have the greatest potentiality. There seems little likelihood of major submarine sliding in Portage Cove because no steep underwater slopes are indicated. However, if the offshore deposits are subject to liquefaction, slides can be generated on gentle slopes and the resulting slurrylike mass can move a considerable distance offshore.

There are no glaciers in the Haines mapped area. Adverse effects from nearby glaciers probably would be minimal. Snow and debris avalanching on steep slopes might constitute a hazard within the Haines area during winter months.

It seems unlikely that long-term supplies of ground water would be greatly affected although there might be temporary changes in flow and the water might be turbid for a period of time. Short-term effects on surface water may include increased flow of Chilkat River unless tributary stream channels are blocked by snow or rockslides and debris slides. If a slide dam is breached suddenly, the flow of water that was impounded can be large and heavy damage can ensue downstream.

Abnormal water waves associated with large earthquakes elsewhere have caused vast property damage and heavy loss of life. Maximum height of tsunami waves and of runup on land cannot be predicted for the Haines area. Whether seiche waves can be generated in the inlets near Haines also cannot be ascertained. Local waves generated by earthquake-induced submarine sliding or by subaerial landsliding into water probably have the greatest destructive potential of any type of abnormal wave because of possible high local runup and because they can hit the shore almost without warning during or immediately after an earthquake.

Geologic hazards in the area that are not caused by earthquakes are believed to be relatively minor. However, effects from hazards of this type may occur so much more frequently than effects from very infrequent large earthquakes that their aggregate effects could be significant. They include: (1) effects of landsliding and subaqueous sliding, (2) effects of flooding, and (3) effects of relative uplift of land.

Because of the reconnaissance nature of the study, the evaluations of geologic hazards described in this report must be regarded as tentative and subject to revision. In order that more rigorous interpretations can be made in the future, several recommendations are made for additional studies.

INTRODUCTION

Purpose and scope of study

The great Alaska earthquake of March 27, 1964, trought into sharp focus the need for engineering geologic studies of urban areas in seismically active regions. As a result, Haines was one of several communities in southeastern Alaska selected for reconnaissance investigation as part of an overall program of earthquake studies recommended by the Federal Reconstruction and Development Commission for Alaska. Initiation of the studies was based on the premise that some Alaskan communities, which were too far from the area of strong ground motion to be affected by the 1964 earthquake, may have geologic settings similar to those of towns that were heavily damaged by that quake. The earthquake hostory of Alaska strongly argues that some of these communities will be adversely affected by future large earthquakes. The study of Haines attempts to evaluate future effects of earthquake hazards as well as other geologic hazards. The resulting evaluations should be useful in city and regional land-use planning so that new facilities can be built, as nearly as possible, in the best geologic environment and can be designed so as to minimize future damage and loss of life.

Methods of study and acknowledgments

Approximately 2 man-weeks of fieldwork were spent during July 1965 and June 1968 in reconnaissance studies and mapping of the Haines area (fig. 3). Mapping was done on aerial photographs and on topographic base maps. The study was directed mainly to collecting data on physical characteristics of the surficial deposits in the immediate area of Haines and in areas of outlying associated facilities. Knowledge of the surficial geology in the less accessible areas shown on figure 3 was based largely upon photo interpretation. The bedrock part of the geologic map (fig. 3) is credited to Eugene C. Robertson of the U.S. Geological Survey and was modified from an open-file report (1956) and from an unpublished report and maps by him (written commun., 1966). Several bedrock samples, collected by us, were studied by R. A. Sheppard of the U.S. Geological Survey. Subsurface data were obtained from many helpful individuals and organizations. Some of the water-well data are from the files of the Geological Survey; the U.S. Army, Corps of Engineers, Alaska District, provided unpublished subsurface data for the Tanani Point area. Geophysical studies were made by E. E. McGregor and R. A. Farrow of the U.S. Geological Survey. Laboratory analyses of samples of surficial materials were made in the Denver laboratories of the U.S. Geological Survey.

The writers also gratefully acknowledge the many sources of information and the complete cooperation from Federal, State, and city organizations and individuals. The Alaska State Housing Authority was especially helpful in furnishing background information, much of which is published in their (1964) Comprehensive Plan of Haines and Port Chilkoot. The numerous reports of the Alaska Department of Highways furnished valuable

data on soils and materials site investigations related to road construction. City officials and other local individuals, particularly Edward Novak (former Mayor of Haines), Carl W. Heinmiller (former Mayor of Port Chilkoot), and Martin A. Cordes, Alaska Department of Highways, were most helpful in providing additional information.

It should be emphasized that, because of the short period of study in the area and the reconnaissance nature of the mapping, this report must be regarded as preliminary. Our assessments of the geologic hazards of the area, as they affect man and his facilities, should not be rigorously interpreted. Data on the physical properties of the geologic units are so few that only broad generalizations can be made and even some of these must be regarded as tentative. Evaluation of specific land use or of a specific locality will require more detailed geologic and engineering studies. Also, it should be emphasized that responsibility for final site selection and design of a specific structure rests with the engineer. In spite of these limitations, it is our hope that the information and evaluations contained herein will provide broad guidelines useful to engineers, planners, and architects; to Federal, State, and city officials; and to the public.

In order to try to make the information as understandable as possible to a wide range of users, a number of the more frequently used technical terms have been defined in a glossary at the end of the report. For definition of other terms or for more complete definitions, the reader is referred to standard textbooks on geology, soil mechanics and seismology and to references cited in this report.

Also, the reader is referred to the report by Lemke and Yehle (1972) entitled "Regional and other general factors bearing on evaluation of earthquake and other geologic hazards to coastal communities of southeastern Alaska." This report provides regional background information for evaluating earthquake probability in southeastern Alaska. In addition, it cites numerous examples of effects of past large earthquakes in different parts of the world in relation to how coastal communities in southeastern Alaska might be similarly affected by future earthquakes.

GEOGRAPHY

Location and extent of area

Haines is in the northern part of southeastern Alaska--the so-called Alaska Panhandle. It is approximately 75 airline miles northwest of Juneau and 16 miles south of Skagway (fig. 1). The mapped area (fig. 3) described in this report, which surrounds Haines, comprises about 17 square miles of land. The remaining map area is water or intermittently exposed river bars in the Chilkat River.

Topographic setting

Haines, which is built at the northern end of the Chilkat Peninsula, lies within the Coast Mountains of the Pacific Mountain system. Northeast of town the snow- and glacier-clad peaks of the Coast Mountains rise in scenic splendor in the vicinity of the International Boundary. Southwest, west, and northwest of town are the impressive Chilkat Range and Takshanuk Mountains with their large snowfields and outlet glaciers (fig. 2). Many of the mountains in southeastern Alaska descend steeply to the highly indented coastlines (fig. 1), characterized by deep and picturesque fiords. Offshore, a large number of islands, both large and small, help form the famous "Inside Passage."

Haines occupies low-lying land at the northern end of the Deshu Isthmus that hereafter will be referred to as the saddle, at the northern end of the Chilkat Peninsula (figs. 2 and 3). The peninsula is bounded on the northeast by Chilkoot Inlet and on the southwest by Chilkat Inlet. These two waterways form the northwest continuations of Lynn Canal. The Takshanuk Mountains (fig. 2), immediately northwest of Haines, constitute a steep-sided northwest-trending ridge, which rises 3,000-6,000 feet above the Chilkat River on the southwest and the Chilkoot River on the northeast. The Chilkat River, a broad braided stream, empties into Chilkat Inlet about 1 mile southwest of Haines. The Chilkoot River flows into Chilkoot Lake, which in turn empties into Lutak Inlet--one of the northerly continuations of Chilkoot Inlet (fig. 2).

Mount Ripinski (altitude approximately 3,680 ft) is the highest point in the mapped area (fig. 3). The lowest part of the saddle, separating the Chilkat River from Chilkoot Inlet, is at an altitude of approximately 40 feet, about one-half mile west of Portage Cove. The highest point in the southern part of the mapped area is at an altitude of approximately 900 feet.

The Chilkat River, Johnson Creek, Mink Creek, and several unnamed creeks (along the southwest side of Lutak Inlet), are the only significant drainage courses in the mapped area. Several small intermittent creeks drain southward from the mountain front northwest of Haines. Much of the low area in Haines and to the west is poorly drained.

Figure 1.--Map of southeastern Alaska and adjacent Canada showing pertinent geographic features. CRV, Chilkat River Valley

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Base from U.S. Geological Survey
Skagway, Alaska - Canada, 1961

0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS
CONTOUR INTERVAL: 200 FEET

Figure 2.--Location map of Haines and surrounding region, Alaska.

Bathymetry and tides

Chilkoot Inlet, Chilkat Inlet, Lutak Inlet, and associated inlets near Haines are good examples of deep glacially scoured fiords. East of Haines, Chilkoot Inlet reaches a depth in excess of 300 feet. Portage Cove, part of Chilkoot Inlet, slopes gently from shore to a depth of about 300 feet (fig. 3). Near the mouth of the Chilkat River, water depths range from shoaling water in McClellan Flats to depths of less than 100 feet for a distance of several miles to the south in Chilkat Inlet. Chilkat Inlet is more than 300 feet deep a few miles south of the mapped area (fig. 2) and more than 600 feet deep south of the southern tip of the Chilkat Peninsula (fig. 2). Still farther to the south, Lynn Canal reaches a depth of approximately 2,500 feet (U.S. Coast and Geodetic Survey chart 8202).

The following tidal data for Haines are taken from records of the U.S. Coast and Geodetic Survey, based on 2 years of records, 1949-1950, reduced to mean values:

	Feet
Mean higher high water	16.80
Mean high water	15.80
Mean tide level	8.70
Mean low water	1.60
Mean lower low water	0.00

The estimated highest water level to the nearest one-half foot is 22½ feet above mean lower low water. The estimated lowest water level to the nearest one-half foot is 6 feet below mean lower low water.

Climate and vegetation

The climate is predominantly marine and is characterized by mild winters and cool summers. The maximum temperature recorded was 90°F; the minimum was -16°F. Mean temperature is approximately 40°F. Average precipitation is approximately 60 inches and average snowfall is 133 inches. Winds, chiefly southeast and west, have been reported at 54 mph with gusts estimated to 65 mph (Alaska State Housing Authority, 1964).

Thick vegetation, which consists of trees and brush, covers most of the area to an altitude of about 3,000 feet. A fairly large stand of commercial timber is being exploited in the vicinity. Muskeg forms an organic mat several feet thick in most low-lying areas.

Historical background and population

The area was first inhabited by the Chilkat Indians, a branch of the Tlingit Indians of southeastern Alaska. Permanent settlement by white men began in 1879. The Haines Post Office, second oldest in the State, was established in 1883. During the famous gold strike in the Klondike, Yukon Territory, Canada, which began in 1896, Haines grew rapidly as one of the terminal points for bringing in supplies and men to be transported over trails to the Yukon. Following the gold rush, the population decreased to 85 people in 1900.

In 1903, Fort Seward was established one-half mile south of Haines. During World War II, the fort, then called Chilkoot Barracks, became headquarters for construction of part of the Alaska Highway as well as an induction and rest camp for military personnel. During this period and lasting until 1946, Haines experienced its greatest economic boom. In 1946, Chilkoot Barracks, consisting of 381 acres of land and 85 buildings, was purchased by a group of military veterans and the town of Port Chilkoot (see fig. 3) came into existence.

According to the 1960 census, Haines had a population of 392 and Port Chilkoot had 120. Census figures for 1970 gave Haines a population of 463 and Port Chilkoot a population of 220 (U.S. Bur. Census, 1971). In March 1970, the towns of Haines and Port Chilkoot were merged to become the City of Haines and approximately 1,700 acres were included in the new corporate limits (Martin A. Cordes, Alaska Department of Highways, written commun., 1970). The census figures indicate that the newly incorporated City of Haines (hereafter referred to as Haines) has a population of about 700 people. Port Chilkoot will be referred to hereafter in this report as a place name.

Transportation and other facilities

Haines lies at the southern terminus of the Haines Highway, which extends northwestward for 159 miles to connect with the Alaska Highway in Yukon Territory, Canada. The 42 miles of highway in Alaska is paved; the remainder is gravel surfaced. Two other roads, both unpaved, extend short distances from Haines. Lutak Road (fig. 4), along the southwest side of Lutak Inlet, furnishes access to the dock of the Alaska State Ferry Terminal and to a recreational area near the mouth of Chilkoot Lake (fig. 2)--a total length of about 11 miles. Mud Bay Road, about 8 miles long, extends southeastward from Haines to furnish access to a cannery built in 1917 at Letnikof Cove and continues as far as Flat Bay (fig. 2).

The Alaska Marine Highway System, started in 1963, connects Haines with Skagway to the north and with Juneau, Sitka, Petersburg, Wrangell, Ketchikan, and Prince Rupert (in British Columbia) to the southeast. The docking facilities for the Haines area are on Lutak Inlet, about 4 miles north of Haines (fig. 3). This location, which provides a deep-water port with less wind problems than in Portage Cove at Haines, can accommodate large seagoing vessels as well as ferry boats of the Alaska Marine Highway System. Part of the docking facility is a former cargo and possible evacuation dock built in 1953 and used then by the U.S. Army.

A small-boat harbor, which can accommodate 90 small fishing and pleasure boats, was built by the Alaska Public Works Department on Portage Cove at the end of Main Street in Haines at the approximate location of a former dock. The rock breakwater for the boat harbor was completed in 1958 and the moorage ramps in 1959. There also is a wharf at Port Chilkoot, which is used by seagoing vessels.

Commercial planes make daily flights from a landing strip built along the edge of the Chilkat River, about $2\frac{1}{2}$ miles northwest of Haines. The landing strip consists of a single gravel-surfaced runway, 4,200 feet long. Charter flights by private planes also are made from the landing strip.

A U.S. Army petroleum products tank farm has been built near Tanani Point, 3 miles north of Haines. Petroleum products, pumped from seagoing vessels which dock at a small nearby wharf, are stored in the tank farm or pumped through a pipeline to Fairbanks, Alaska.

Haines obtains most of its water supply from streams and springs issuing from the mountainside northwest of town. The 1964 production rate was approximately 120 gpm (Alaska State Housing Authority, 1964). Water is stored in a 50,000-gallon tank; there also is a 5,000-gallon aeration tank (Edward Novak, former Mayor, oral commun., 1965). Studies for additional water supplies were made in 1966 and 1967 by the U.S. Geological Survey (McConaghy, 1970).

GLACIATION AND ASSOCIATED LAND- AND SEA-LEVEL CHANGES

The Haines area was covered by glacier ice at least once and probably several times during the Pleistocene Epoch. Large erratic boulders on rounded glacially scoured bedrock surfaces, as high as 3,000-5,000 feet in altitude near the mapped area, demonstrate the height and the wide extent of glaciation (Knopf, 1911, 1912; Eakin 1919; Buddington and Chapin, 1929; Robertson, written commun., 1959). Fiords, U-shaped valleys, rouche moutonee topography, cirques, and other glacially modified landforms clearly portray the effects of valley glaciation in the region.

Landforms near the study area that may be related to the last major glaciation of the Pleistocene are: (1) a moraine in Ferebee Valley, which nearly closes Taiyasanka Harbor, (2) an elevated delta, which apparently buries a Chilkoot Valley moraine at the mouth of Chilkoot Lake near the upper end of Lutak Inlet, (3) a broad, shallow ridge in the vicinity of Indian Rock in Chilkoot Inlet, which may represent the terminus of a former glacier near the mouth of Taiya Inlet, and (4) a possible moraine buried beneath marine sediments at the upper end of Chilkat Inlet near Pyramid Island and Green Point (see figs. 2 and 3 for locations). About 60 miles to the southeast, in the Juneau area (fig. 1), marine shell fragments from elevated deltaic deposits, dated by radiocarbon methods, indicate that by 10,000 years ago the lowland near Juneau was free of Pleistocene glacier ice (Miller, R. D., 1972). It is likely that the last major deglaciation in the Haines area also had been completed by about this time.

There have been several minor advances and retreats of glaciers in southeastern Alaska during Holocene time, but these have not significantly modified the landforms of the Haines area. Additional ice load upon the land during minor ice advances probably slacked or reversed for a time the overall rate of land emergence. During the latest period of glacier growth (Neoglaciation), glaciers advanced at least once, as shown by glacially overridden and sheared tree stumps near the terminus of Davidson Glacier (fig. 2). As reported by Egan, Miller, and Loken (19th Alaska Science Conference, written commun., 1968), the trees were sheared about 800 years ago.

There are no glaciers at present in the mapped area. However, valley glaciers and icefields are fairly numerous in the mountains west of Chilkat Inlet, northwest of Haines, and east of Chilkoot Inlet. Most are retreating from their Neoglacial terminal positions but some are in equilibrium or are advancing. Of 22 glaciers studied in the Chilkat River area during the period 1946-1962, the termini of seven were dominantly shrinking, five were gradually shrinking, six were in equilibrium, and four were gradually expanding (Miller, M. M., 1970).

During deglaciation in late Pleistocene time, the land was still depressed from the effect of former glacier loading. Marine waters extended into low areas formerly occupied by glacier ice, and marine sediments were laid down. As load effect of the ice slowly diminished, the land began to emerge above sea level, and shore processes began to modify preexisting deposits.

In the mapped area, the land has been uplifted at least 300 feet relative to present sea level and perhaps as much as 600 feet or more[1] during approximately the last 10,000 years. As indicated from tidal records during the period 1922-1959, the land in the Haines area is emerging from the marine waters at the rate of 2.26 cm per year or 0.074 foot per year (Hicks and Shofnos, 1965). Whether some of the present emergence, as well as past emergence, may be due to tectonic activity is not known. It seems likely, however, that most of it can be attributed to rebound of the land as a result of deglaciation.

Concomitant with land uplift in the Haines area, worldwide (eustatic) sea level is believed to have risen approximately 100 feet during the past 10,000 years (Shepard, 1963; Shepard and Curray, 1967; Redfield, 1967). Redfield (1967) concluded that between 10,000 years ago and 4,000 years ago the rate of rise was 3.4 mm (0.13 inch) per year but that during the past 4,000 years the rise was only 0.76 mm (0.03 inch) per year. Although these figures may be subject to revision as more data become available, nevertheless it is important to consider the rise of eustatic sea level when calculating the actual amount of land uplift in the Haines area during approximately the last 10,000 years. The point is that, with sea level used as a datum, the amount of eustatic sea-level rise must be added to the apparent uplift of land to obtain the absolute amount of land uplift.

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[1]There is a suggestion of a marine limit at an altitude of 600 feet near the upper end of Lutak Inlet (fig. 2). In support of this higher marine limit, fossiliferous marine deposits of Quaternary age are present to an altitude of at least 750 feet 60 miles to the southeast in the Juneau area (Miller, R. D., 1972).

DESCRIPTIVE GEOLOGY

Bedrock

Exposed bedrock in the mapped area (fig. 3) consists of metamorphic and igneous rocks. The metamorphic rocks are of two types: metabasalt and pyroxenite. Igneous rocks consist of diorite and quartz diorite (tonalite). Sedimentary rocks may directly underlie surficial deposits in the saddle area between Chilkoot Inlet and Chilkat River but are not exposed in the mapped area.

Bedrock of the area is described only briefly because: (1) Robertson (1956; unpub. data) previously studied and mapped the bedrock, and (2) all the exposed bedrock is expected to behave in a fairly similar manner with respect to the geologic hazards.

Nearly all bedrock descriptions that follow are those of Robertson (1956; unpub. data). Also, the bedrock part of the map (fig. 3) of this report is credited to Robertson. Bedrock studies by Barker (1952), in an adjoining and slightly overlapping area to the north, provide additional regional background information. Additional information also was obtained on the pyroxenites of the mapped area from Taylor and Noble (1960).

Metamorphic rocks

Metabasalt (Mzm).--These rocks, which were not examined by the writers, were described by Robertson (1956; unpub. data) as dark-green fine-grained metamorphosed volcanic rocks of Mesozoic(?) age consisting chiefly of hornblende and plagioclase feldspar. Their outcrops form the mountainous mass northwest of Haines, including Mount Ripinski. Observed attitudes show that the rocks strike northwest and dip northeast.

Pyroxenite (Mzp).--Magnetite-bearing pyroxenite crops out both north and south of the saddle where Haines is located. One body forms part of the south slope of Mount Ripinski north of the landing strip and rises to an altitude of about 1,500 feet. North of Haines, in the area between Portage Cove and Tanani Bay, a second body of pyroxenite attains an altitude of about 700 feet. South of the saddle, the pyroxenite forms several hills, streamlined by glacial action and with glacial deposits forming the surface mantle between these hills. The separate outcrops of pyroxenite may be exposed parts of one large mass.

As described by Robertson (1956; unpub. data), the pyroxenite consists chiefly of augite, is dark green to black, medium to coarse grained, and massive. Magnetite was found in nearly all samples examined by Robertson (1956).

Robertson estimated that several billion tons of low-grade magnetite-bearing pyroxenite may be present in the Haines area. Although sampling was limited, apparently the grade is lower than in magnetite-bearing pyroxenite bodies near Klukwan (about 25 miles northwest of Haines) where Robertson (1956) estimated that there are between 1 and 5 billion tons of rock (assuming an average depth of 1,000 ft) containing an average of about 13 percent magnetic iron. Directly north of the landing strip, a 100-foot tunnel reportedly was driven into the pyroxenite body by the Alaska Iron and Steel Company, who abandoned their claims in 1911. Other individuals staked claims in the pyroxenite bodies through 1916, but only a few briefly held claims have been staked since then (Robertson, 1956).

According to Taylor and Noble (1960), the magnetite-bearing pyroxenite near Klukwan and Haines, are part of a linear zone of ultramafic bodies in southeastern Alaska of probable early middle Cretaceous age. The zone is about 30 miles wide, 400 miles long, and parallels the major structural features of the region.

Igneous rocks

The igneous rocks consist of diorite and quartz diorite (tonalite) of Cretaceous age and are exposed in the mountains north and northwest of Haines.

Diorite (Ked).--Diorite is well exposed in steep cliffs north and northwest of Haines. It also forms a large area west of the Alaska State Ferry Terminal. The diorite, as described by Robertson (1956; unpub. data) is light to medium gray, coarse grained, and consists chiefly of plagioclase, hornblende, and epidote.

Quartz diorite (tonalite) (Kt).--The Haines area lies near the southwestern limit of a region of quartz diorite constituting a large percentage of the Coast Mountains and the Coast Range batholith. In the map area, these rocks are exposed along part of the southwestern shore of Lutak Inlet and as high as about 2,200 feet altitude (Robertson, 1956; unpub. data). Robertson describes the quartz diorite as light gray, medium grained, and massive, consisting of plagioclase, quartz, orthoclase, hornblende, biotite, sphene, and a few accessory minerals.

Sedimentary rocks (not shown on map)

Sedimentary rocks are not exposed in the mapped area but they may underlie surficial deposits in the saddle between Haines and the Chilkat River.

Sedimentary rocks of Tertiary age are present northwest and southeast of the mapped area (Robertson, 1956; unpub. data). Along the Kelsall River, about 35 miles northwest of Haines, well-indurated slate (containing fossil leaves) and conglomerate, about 2,000 feet thick, of Tertiary age are exposed discontinuously for a distance of about 9 miles. Conglomeratic rocks of Tertiary age also make up Kochu Island (about 6 miles south of Haines) in Chilkat Inlet as well as the southern part of the Chilkat Peninsula and islands to the southeast. Interbedded slate and limestone on the southwest side of the Chilkat Peninsula, as well as fresh-appearing volcanic rocks (andesite) on the peninsula and on the islands to the southeast, also are believed to be of Tertiary age by Robertson (written commun., 1968).

The possibility that sedimentary rocks of Tertiary age may underlie surficial deposits in the saddle at Haines is based upon the following indications: (1) "soft" bedrock penetrated by a water well, (2) low seismic velocity of possible bedrock indicated by geophysical studies, and (3) the possibility of downdropping of sedimentary rocks by faulting in the saddle area.

As shown in the driller's log below, nearly 100 feet of "rock" was penetrated in a water well drilled near the northwest limits of Haines (location N of fig. 4). Part of the "rock" penetrated is described as soft and porous and part is described as water bearing. Unless this section represents highly weathered metamorphic or igneous rocks, which seems unlikely in view of the shallow depth of weathering in exposed rocks, the strong possibility exists that sedimentary rocks were penetrated. On the other hand, compact till might have been mistakenly identified as "rock."

Data resulting from a north-south seismic profile (fig. 10), made transverse to the saddle (fig. 4) and coincident along part of its length with Fourth Street in Haines, support the possibility that sedimentary rocks may underlie surficial deposits in that area. An average velocity of 10,500 feet per second was obtained for a unit (V_1 of fig. 10) 300-400 feet thick, which underlies a unit (V_0) of surficial deposits and which has a velocity of 5,100-6,250 feet per second and overlies a bedrock unit (V_2) having a velocity of 24,350 feet per second. Unit V_1 might be sedimentary rocks. The velocity of that unit seems too high for most surficial deposits and too low for metamorphic or igneous rocks unless weathered. Till possibly could have a velocity that high but, for comparison, hard compact subsurface till at Seward, Alaska, has velocities ranging from 6,700 to not more than 7,500 feet per second (Lemke, 1967, pl. 2).

As will be discussed later (see "STRUCTURE") the saddle area may reflect a grabenlike structure. This speculation is supported by the seismic profile (fig. 10), which indicates that faults cut the inferred sediments in the approximate middle part of the supposed fault trough. If Tertiary rocks were downthrown by faulting in the saddle area, they would have been fairly well protected from glaciofluvial and glacial erosion and, therefore, could still be present. In support of this possibility, rocks of Tertiary age are present to the northwest in British Columbia in downthrown fault blocks (Watson, 1948, p. 35). Verification that Tertiary rocks underlie surficial deposits in the saddle, however, must await drilling, sampling, and rock identification.

Driller's log of test well drilled by Foley Brothers, Inc.

[August-September 1943 at Haines, Alaska (location N of fig. 4). Collar of well, according to driller's log, is at an altitude of 92.8 ft]

	Thickness (feet)	Depth to bottom of stratum (feet)
[Surficial deposits][1]		
Surface gravel	1	1
Blue-gray clay	79	80
Gravel; slight water content	1	81
Sand and gravel; small amount of water	7	88
Coarse gravel and fine sand	8	96
Blue-gray clay	2	98
Coarse gravel; very little sand	8	106
Large gravel and boulders as much as 6 in. size; some sand	5	111
Gravel with some fine sand	7	118
Fine to large gravel with some fine sand--Stopped drilling at 122 feet. Casing was perforated with 7 holes at 115 feet, then casing was perforated to within 32 feet of the top with 180 perforations; cleaned out the well, and installed test pump. Test showed about 15 gpm.	4	122
Blue-gray clay	2	124
Fine gravel and sand	6	130
[Bedrock(?)][1]		
Hard rock	7	137
Rock; slightly water bearing	38	175
Rock	7	182
Soft rock	5	187
Soft porous rock	20	207
Soft porous rock with seams of fine clay	17	224
Soft porous rock. Drilled to 236 feet and then pumped well for 4 hours; average yield was 16 gpm with drawdown to 166 feet	12	236

1/Interpretation by us.

Surficial deposits

The surficial deposits are most accurately delineated on the map (fig. 3) in the vicinity of Haines, Port Chilkoot, Haines aircraft landing strip, Tanani Point, and in the vicinity of roads. In less accessible areas, mapping was done chiefly by airphoto interpretation and, therefore, may be considerably less accurate.

General description of geologic units

The surficial deposits have been divided on the map into the following units on the basis of time of deposition, mode of origin, and grain size: (1) undifferentiated drift deposits (Qd), (2) outwash and ice-contact deposits (Qo), (3) elevated fine-grained marine deposits (Qem and Qemy), (4) elevated shore and delta deposits (Qeb), (5) alluvial fan deposits (Qaf), (6) colluvial deposits (Qc), (7) modern beach deposits (Qb), (8) Chilkat River flood-plain and delta deposits (Qr), and (9) man-made fill (Qf). Some units have been deposited more or less contemporaneously and have gradational contacts. Insofar as possible, map units are described from oldest to youngest. Offshore deposits are also described but are not shown on the map.

Offshore marine deposits, as well as marine deposits that have now been elevated above sea level, are characterized by great local variations in grain size and other physical properties, reflecting in large measure different modes of origin. Many of these deposits closely resemble till that has been deposited on land. Because of the marked variations in engineering properties of these deposits, particularly as they may affect nearshore and onshore facilities, it is desirable to discuss the relation of these deposits to each other as well as their modes of origin. Discussion also should help clarify the reasons for separating map unit "Undifferentiated drift deposits (Qd)" from map unit "Elevated fine-grained marine deposits (Qem and Qemy)."

The characteristics of glacial deposits laid down on lower mountain slopes, in valleys leading to fiords, and in the fiords themselves depend chiefly on whether: (1) the depositing glacier was advancing on land, (2) the glacier was advancing in a fiord but its base was grounded, or (3) the glacier was floating in a fiord. In the first instance, typical till would be deposited; in the second, material identical or similar to till would be deposited; in the third, material of diverse sizes is dropped from the floating glacier ice or is derived from underwater slopes and, upon settling to the bottom, becomes mixed with or forms a mantle over the normal fine-grained marine sediments. Where large amounts of coarse material have been intermixed with the fine-grained marine deposits, the resulting product also greatly resembles till. For clarity in this report, the unsorted glacially derived deposits that were laid down subaerially (on land) will be called "till," whereas unsorted or poorly sorted glacial deposits or deposits of unspecified origin that were laid down in fiords will be called "diamicton."

With increased distance down a fiord away from an ice front, glacially derived diamicton would be expected to constitute correspondingly lesser amounts of the fiord sediments. However, a similar-appearing diamicton of a different origin might be present in places. This type of diamicton is the product of the mixing of normal fine-grained marine sediments with material derived from onshore landsliding into a fiord, from submarine sliding, from the action of turbidity currents, or by wave erosion of shoreline deposits. Deposition of these sediments has continued from the time of deglaciation to the present.

Various aspects of the problem of distinguishing till from other diamictons have been considered by D. J. Miller (1953), Armstrong and Brown (1954), Carey and Ahmad (1961), Easterbrook (1963; 1964), Ferrians (1963), and Harland, Herod, and Krinsley (1966). Easterbrook distinguishes glacially derived diamicton in a marine environment from till by the presence of fossils, by higher void ratios, and by lower bulk densities for the diamicton in a marine environment. It should be noted, however, that not all diamictons deposited in a marine environment contain fossils.

In summary, there are several types of deposits in the Haines area whose end members range from till at one end to fine-grained sediments deposited in water at the other end with all gradations between. The mixed deposits of coarse material and fine-grained marine sediments, deposited in water under one of the conditions described above and subsequently elevated above sea level, have been included in the map unit "Elevated fine-grained marine deposits (Qem and Qemy)."

Undifferentiated drift deposits (Qd)

As mapped (fig. 3), the undifferentiated drift deposits (Qd) consist mostly of till or other diamictons. However, the map unit also includes some fluvioglacial and ice-contact deposits not specifically included in the unit "Outwash and ice-contact deposits (Qo)," as well as some undifferentiated "Elevated fine-grained marine deposits (Qem and Qemy)" and possibly other deposits of small areal extent.

The surface deposits north of Haines are mostly above an altitude of about 300 feet; south of Haines they are exposed at lower altitudes. Till or another kind of diamicton is well exposed along the north side of the Haines Highway, about one-half mile east of the aircraft landing strip. Other good exposures of similar material are southeast of Johnson Creek near Tanani Bay.

The section exposed about one-half mile east of the aircraft landing strip is about 50 feet thick, of which the upper 10 feet is well exposed. Gravel, sand, and silt constitute the most common particle sizes with clay-size material and cobbles constituting minor amounts (sample B of table 1). The gravel- and cobble-size material is subrounded to subangular and strongly reflects local bedrock types. Approximately the upper $1\frac{1}{2}$ feet of the exposure is oxidized to a yellowish-orange color; the unoxidized part is light to medium gray. The deposits are compact and are generally unsorted except for a faint horizontal banding, which may represent a textural change.

Exposures along Lutak Road southwest of Nukdik Point differ from the one described above by having a considerably greater abundance of gravel and larger size material. The upper several feet are oxidized to orange brown in contrast to the unoxidized greenish gray part of the section. The gravel, cobbles, and boulders are angular to subangular. Northward the deposit may grade to a kame(?) deposit mapped as (Qo) at Nukdik Point.

Size analyses, liquid limits, plastic limits, and plasticity indexes for three samples of till or other kinds of diamicton (locations on fig. 4), are shown on table 1. An average of the three size analyses shows 37 percent sand, 30 percent silt, 24 percent gravel, and 9 percent clay.

Outwash and ice-contact deposits (Qo)

These stratified glacial materials, which have been deposited by glacial melt water, generally are coarse grained, and are poorly to moderately well sorted. Gravel (subrounded) and sand sizes predominate with varying lesser amounts of silt and cobble sizes.

The outwash deposits are associated with morainal deposits in valleys along the southwest side of Lutak Inlet. They generally are mantled by elevated marine deposits or other deposits below an altitude of 300 feet (possibly as high as 600 ft[2/]) that, for the most part, postdate them but which in part are contemporaneous. Two probable kame deposits, however, are exposed pits below that altitude. One exposure is at Nukdik Point and the other at Kaskulu Point (fig. 3).

The deposits at Nukdik Point consist of intermixed gravel and sand with some silt and cobbles. Larger size fractions are subrounded to subangular. The upper 2 feet in the pit is well compacted and may form part of a fairly well defined surface that represents shore processes active during land emergence in late Pleistocene and (or) Holocene time. This supposition is supported by the nearby presence on the surface of scattered boulders (possibly a lag concentrate), which lie on a thin layer of sand.

2/Locally, toward the head of Lutak Inlet, a marine limit of 600 feet altitude is suggested from airphoto interpretation.

Table 1.--Analyses of samples of till or other kinds of diamicton from the Haines area, Alaska

[See fig. 4 for sample locations. Analyses by E. E. McGregor, U.S. Geological Survey]

Sample Location on fig. 4	USGS Eng. Geology Lab. No.	Collector's No.	Approx. alt of sample (feet)	Macrofossils or Microfossils observed	Particle size distribution, in percent; after Natl. Research Council (Lane, 1947)				Atterberg limits		
					Clay[1/]	Silt[2/]	Sand[3/]	Gravel[4/]	Liquid limit[5/]	Plastic limit[6/]	Plasticity index[7/]
A[8/]	8-112	68AYe-H5a	25	No	7	27	38	28	14	13	1
B	8-113	68AYe-H9a	40	No	7	28	36	29	16	15	1
C[9/]	9-114	68AYe-H10a	60	No	14	35	38	13	----	----	----

1/Clay, <0.00015 in. (<0.0039 mm).

2/Silt, 0.00015-0.0025 in. (0.0039-0.0625 mm).

3/Sand, 0.0025-0.079 in. (0.0625-2.0 mm).

4/Gravel, 0.079-2.52 in. (2.0-64 mm). (No material coarser than very coarse gravel included in laboratory processed samples.)

5/Water content in percent of dry weight at which soil passes from the liquid state into the plastic state (Terzaghi and Peck, 1948, p. 32-36).

6/Water content of the soil in percent of dry weight at the boundary between the plastic state and the solid state (Terzaghi and Peck, 1948, p. 32-36).

7/Numerical difference between the liquid limit and the plastic limit. Represents the range of moisture content within which the soil is plastic (U.S. Bur. Reclamation, 1960, p. 8, 28).

8/Sample taken from trench; overlain by Qeb.

9/Sample taken where the till or other kind of diamicton is less than 5 feet thick and, therefore, the unit is not differentiated on figure 3 at this locality.

Approximately 50 feet of stratified deposits has been exposed near Kaskulu Point in connection with construction of a sawmill. The deposits exhibit abrupt lateral and vertical changes in grain size, stratification, sorting, and compactness. Grain size ranges from clay to boulders but gravel and sand sizes probably predominate. A section measured in 1965, which may or may not be representative of the deposit, follows:

(top to bottom)	Thickness (feet)
Gravel, poorly sorted; iron-stained	4.0
Sand, well-sorted, clean; fairly well bedded	7.0-8.0
Gravel, with lesser amounts of sand, silt, and clay; some cobbles and boulders as much as 3 feet in diameter; poorly sorted and stratified except near base where gravel is well stratified and contains lenses of blue-gray till-like material (diamicton) and fine sand lenses	40.0

The lower 40 feet of the section is believed to be kame deposits. Whether the upper 11 or 12 feet are kame deposits or represent elevated shore deposits (Qeb) is not clear. However, for purposes of mapping, the kame deposits are shown as extending to the surface.

Elevated fine-grained marine deposits (Qem and Qemy)

The deposits, for the most part, are marine sediments that were laid down in fiords by settling of fine-grained material derived from glaciers, rivers, and streams. Subsequently, the sediments have been elevated above sea level by rebound of the land owing to deglaciation of the area and possibly by tectonism. As discussed previously, land emergence in the area has been at least 300 feet and maybe as much as 600 feet. The deposits generally form flat to gently sloping surfaces.

The deposits have been subdivided on the map into two subunits: (1) older sediments (Qem), and (2) younger sediments (Qemy). In places, the older or higher lying sediments are overlain by elevated shore and delta deposits (Qeb) and, where less than 5 feet thick, they are included with the (Qem) deposits. One to several feet of muskeg also commonly overlies the elevated fine-grained marine deposits in most places but it is not mapped as a separate unit.

Older elevated fine-grained marine deposits (Qem).--The largest area of this subunit is in the central part of the saddle between Haines and the Chilkat River. This area, which lies below an altitude of about 125 feet, is for the most part poorly drained and swampy, except where ditched. The water table is generally less than 5 feet below the surface and in places reaches the surface. The thickest known deposits in this area are near the northwest outskirts of the built-up part of Haines.

Here, logs of test wells and auger holes, made by the U.S. Geological Survey, indicate that 80 to approximately 100 feet of soft plastic sediments underlie one to several feet of muskeg or other material. This thick sequence of fine-grained marine sediments is underlain by sand and gravel (boulders locally), which in turn is intercalated with other beds or lenses of fine-grained marine deposits. A similar thickness of deposits is present in the southern part of the mapped area northeast of Chilkat (A. Butz, Haines, oral commun., 1968). The greatest known thickness of sediments is near Tanani Point in the area of the U.S. Army petroleum tank farm. Here the sediments are at least 108 feet thick (U.S. Army Corps Engineers, unpub. data, 1951 and 1957). The emergence sequence of these sediments is illustrated in figure 5.

The sediments, which are medium gray, consist predominantly of silt- and clay-size fractions. Sand constitutes the remaining size fraction except for a low percentage of local gravel. Organic-rich zones, as much as a few feet thick, locally constitute the upper part of the deposits. Grain-size analyses of seven samples (locations D, E, F, G, J, K, and L) are given in table 2. Bedding is indistinct to absent and the sediments tend to break in a blocky pattern.

The sediments have low to medium plasticity (table 2). In the Unified Soil Classification (U.S. Bur. Reclamation, 1960), they are in the CL Group. In the soil classification for highway purposes (American Society for Testing Materials, 1951), most of the sediments probably would fall in Group A-6. Some, however, fall in Group A-4, on the basis of tests on samples from near the western outskirts of the built-up part of Haines (Munson, 1962); frost susceptibility was determined to be in Group F-4[3].

A sample (no. 7-324, table 2), was analyzed by E. E. McGregor, U.S. Geological Survey, for percentage of voids. This value, in which porosity is expressed in percentage, was 36.5. The void ratio (ratio of the volume of voids to the volume of the solid substance) was 0.575.

Both marine megafossils and microfossils are present in most places. Marine megafossils, collected from several exposures in the mapped area as well as southeastward along the Chilkat Peninsula (fig. 2), were identified by F. S. MacNeil and W. O. Addicott (U.S. Geol. Survey, written commun., 1965; 1968) and are listed in table 3.

The deposits were studied by Eugene C. Robertson (unpub. data, 1959) to assess their commercial possibilities for clay; also, the chemical and mineralogical composition of one sample, collected from the business district of Haines, was determined. Material from near Flat Bay (fig. 2) was used to a very limited extent in 1910 for the manufacture of bricks. Also, in official recognition of the commercial possibilities

[3]Soils in Group F-4 are of especially high frost susceptibility as defined by the U.S. Army Corps Engineers (1962, p. 7-8).

Table 1.--Cenozoic marine megafossils in elevated fine-grained marine deposits from the Haines area, Alaska (See fig. 4 for locations of all collecting sites except M3941 which is 3.2 miles southeast of Haines.)

[Identification by F. S. MacNeil (M2539, M2540) and W. P. Addicott (M3940, M3939, M3941, M3942), U.S. Geological Survey (written commun., 1965, 1968)]

Fossil form	U.S. Geological Survey Cenozoic locality				
	M2539 M3940	M2540	M3939	M3942	M3941
Gastropoda:					
Cryptonatica?	X	-----	-----	-----	-----
Serpulorbis sp	-----	-----	-----	X	-----
Pelecypoda:					
Astarte sp	-----	-----	X	-----	-----
Chlamys sp	-----	-----	X	-----	-----
Cyclocardia ventricosa (Gould)	-----	-----	-----	-----	X
Macoma incongrua von Martens	-----	X	X	-----	-----
Mya truncata Linné	-----	-----	X	-----	-----
Mytilus fragments	X	-----	-----	-----	-----
Nucula sp. fragment	-----	X	-----	-----	-----
Nuculana fossa (Baird)	X	X	-----	-----	X
Polynemamussium alaskense (Dall)	-----	-----	-----	-----	X
Saximodus	-----	-----	X	-----	-----
Tresus?	-----	-----	X	-----	-----
Cirripedia: (barnacles)					
Balanus sp	-----	-----	X	-----	-----
Balanus cariosus (Pallas)	X	-----	-----	-----	-----
Balanus crenatus Bruguiere	-----	-----	-----	-----	X
Fish otoliths:[1] (part of earbone structure)					
Gadus macrocephalus	X	-----	-----	-----	-----

[1] Identification by J. E. Fitch, California State Fisheries Laboratory, Terminal Island, Calif. S0731.

M2539, M3940 - 0.5 mile northeast of Haines, alt 50 ft, $NE\frac{1}{4}SW\frac{1}{4}$ sec. 26, T. 31 S., R. 59 E.; Locality L, fig. 4.
M2540 - 1 mile west-southwest of Haines, alt 15 ft, $NE\frac{1}{4}NE\frac{1}{4}$ sec. 33, T. 31 S., R. 59 E.; Locality N, fig. 4.
M3939 - 0.8 mile west-southwest of Haines, alt 35 ft, $NW\frac{1}{4}NW\frac{1}{4}$ sec. 34, T. 31 S., R. 59 E. [illegible]; Locality M, fig. 4.
M3942 - 3.5 miles northwest of Haines, alt 50 ft, $NE\frac{1}{4}SE\frac{1}{4}$ sec. 9, T. 30 S., R. 59 E.; Locality K, fig. 4.
M3941 - 3.2 miles southeast of Haines, alt 100 ft, $NW\frac{1}{4}NW\frac{1}{4}$ sec. 13, T. 31 S., R. 59 E.

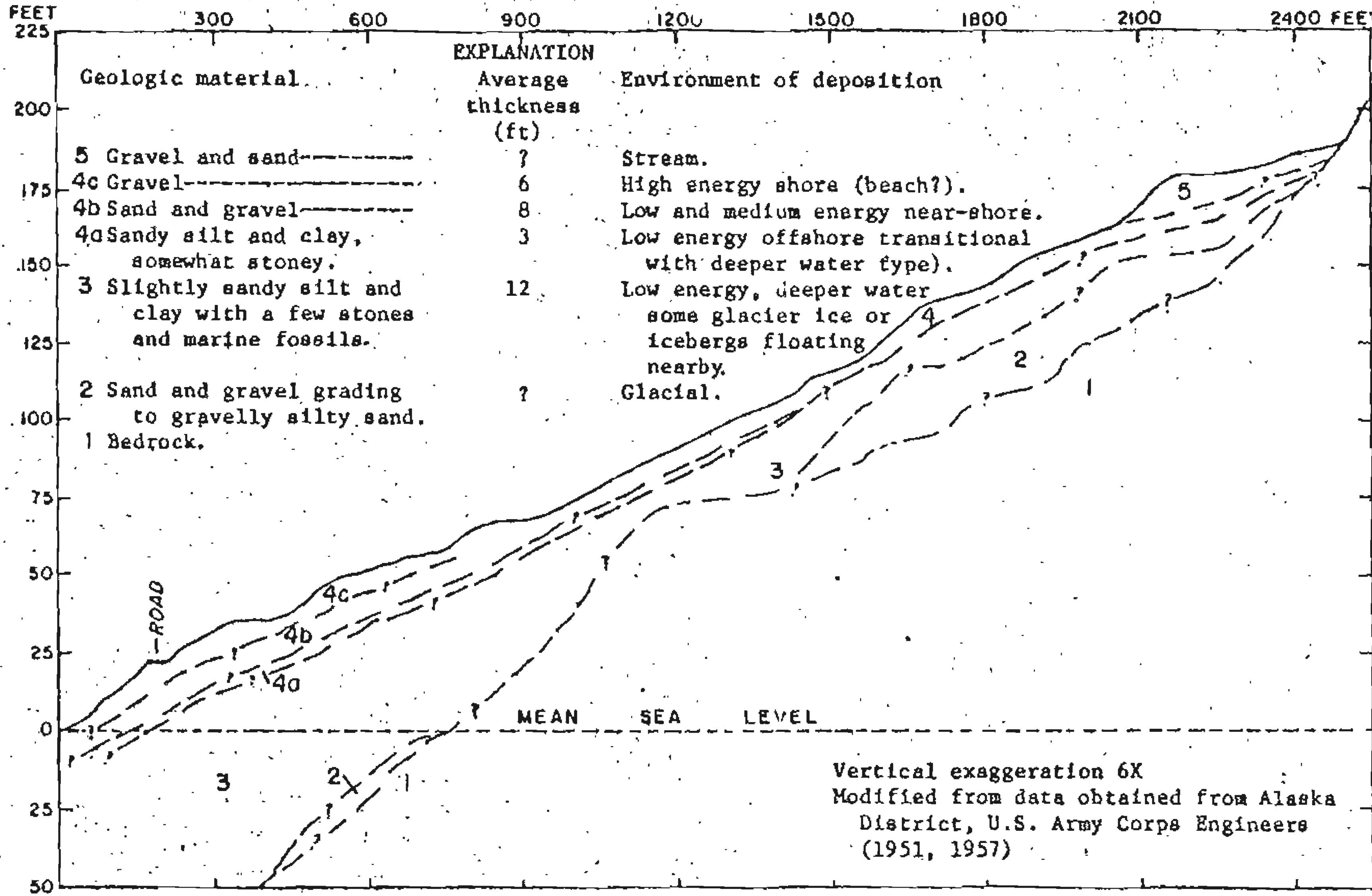


Figure 5.--Generalized section illustrating emergence sequence of elevated marine and shore deposits near Tanani Point, 2.5 miles north of Haines.

of the clay, a "Military Clay Reserve" was set aside in 1914 at the western edge of Haines. Results of firing tests by T. A. Klinefelter, U.S. Bureau of Mines, on samples collected by Robertson from these localities, showed a great similarity of test results (Robertson, unpub. data, 1959). Working properties of the clay were good and there was low shrinkage and no defects upon drying. At about 1000°C, the color of the product was reddish brown, the structure was relatively soft and porous, and the shrinkage low. At 1150°C, the material bloated and was sticky, whereas, at 1200°C, it became molten. Robertson concluded that common bricks and similar products could be made from materials like the samples but that it was not suitable for lightweight aggregate.

Younger elevated fine-grained marine deposits (Qemy).—This subunit underlies a roughly arcuate area west of Haines that forms the western part of the saddle area adjacent to the Chilkat River. Formerly an intertidal flat, the area has only recently been elevated above sea level. Most or all of the area is less than 6 feet above mean higher high water. It is reported (Martin A. Cordes, Alaska State Department of Highways, written commun., 1967) that the part of the area between Kaskulu Point and the aircraft landing strip is normally flooded once or twice a year by 20-foot-high (above mean lower low water) tides. This flooding probably occurs at times of exceptionally high tides concurrent with high streamflow from the Chilkat River. Marsh grass covers the surface except where shallow tidal runs and rills modify the otherwise nearly flat terrain.

Little is known about the (Qemy) deposits because of the fewness of exposures. However, based on the depositional history of the area and on nearby drill-hole data obtained in connection with the proposed Chilkat River bridge (Migliaccio and Slater, 1968), the deposits probably are 100 or more feet thick and are underlain by drift that forms the basal surficial deposits of the former fiord area. On the basis of analyses of two samples (H and I of table 2), it is likely that the deposits are similar in composition to the (Qem) unit which consists chiefly of marine silt- and clay-size material with lesser amounts of sand. However, somewhat coarser sediments, representing deltaic deposits and alluvium of the Chilkat River, probably interfinger in the upper parts of the deposits. The interfingering would have occurred when the Chilkat River delta, whose front is now in the vicinity of Pyramid Island (see fig. 2), advanced down the river to the vicinity of the (Qemy) area and laid down somewhat coarser deposits. Subsequently, as the surface of the deposits rose to approximate sea level, as a result of continued land uplift and sedimentation, more and more river-deposited alluvium probably was carried into the (Qemy) area. These somewhat coarser sediments, like the deltaic deposits, probably also were intercalated with the marine deposits.

Elevated shore and delta deposits (Qeb)

Widespread deposits of elevated shore and delta sediments (Qeb) in the Haines area consist chiefly of gravel, sand, and cobbles and are moderately well sorted and stratified. They are analogous to the partly contemporaneous elevated fine-grained marine sediments (Qem and Qemy) described above, because both have been elevated above sea level mainly as a result of land uplift during regional deglaciation.

As the land began to emerge from the sea in the Haines area, it was first subjected to increasing longshore and tidal current activity and finally to direct wave action as it passed through the surf zone. Depending upon: (1) local sediment supply, (2) longshore current sediment supply, (3) tidal current direction, and (4) vigor of wave attack, shore deposits of varying thicknesses and sizes were deposited. A complete sequence of shore emergence deposits from near Tanani Point indicates from bottom to top: (1) a transitional zone (unit 4a of fig. 5) of offshore winnowing of preexisting deposits (stony to stone-free silt and clay of marine origin), (2) nearshore sand and gravel deposits (unit 4b of fig. 5), and (3) high-energy shore deposits (unit 4c of fig. 5) of gravel.

The upper limit of the elevated shore and delta deposits in the Haines area, as indicated from the topography and from aerial photos, reaches an altitude of at least 300 feet. The deposits appear to be well developed along the mountain front near the Haines aircraft landing strip, near the Alaska State Ferry Terminal, and along the upper end of Lutak Inlet in the mapped area. Also, a massive elevated delta deposit, which reaches an altitude of 300 feet, probably buries a moraine forming the dam for Chilkoot Lake (fig. 2).

Actually, the highest elevated shore and delta deposits (representing the marine limit in the area) might be at an altitude of about 600 feet. This assumption is based upon a break in slope at this altitude along the upper part of Lutak Inlet, which is interpreted to be a possible elevated shoreline. The assumption also seems reasonable on the basis of high-level marine deposits in the Juneau area, 64 miles to the southeast, where fossiliferous marine deposits have been identified up to an altitude of 750 feet (Miller, R. D., oral commun., 1967; and Miller, R. D., 1972).

Downslope from the indicated marine limit, variably thick accumulations of elevated shore and delta deposits parallel the present shoreline. Some of the deposits consist of irregular mantles over older deposits; others form well-developed ridges or benches. Such depositional forms may have resulted from: (1) a series of storms during time of deposition, (2) changes in sediment supply or character of waves and currents during time of deposition, (3) slackening or "reversal" of land emergence, or (4) tectonic deformation.

In many places, the deposits are absent owing to the slopes being too steep, to an inadequate sediment supply, or to former current action. Deposits less than 5 feet thick, which are not shown on the map, overlie much of the undifferentiated drift deposits (Qd) and the elevated fine-grained marine deposits (Qem) below the marine limit. Especially extensive are thin elevated shore deposits overlying undifferentiated drift deposits south of Port Chilkoot. Alluvial fan deposits (Qaf) and colluvium (Qc) merge with or cover elevated shore and delta deposits.

Much of the business district of Haines has been built on an elevated beach whose crestline approximately parallels part of the present shore of Portage Cove. Deposits of this former beach extend from an altitude of about 150 feet near the mountain front at the north edge of the city to an altitude of about 60 feet between Haines and Port Chilkoot. Fifteen feet of clean-bedded mixed sand and gravel with some cobbles and a few boulders are exposed in the northern part of Haines. Here the gravel and larger clasts are well rounded to subangular and consist of local bedrock types. Overall color is tan gray except for the upper 1-2 feet, which is oxidized to a reddish brown.

The deposits, as indicated from drill-hole data, probably are less than 20 feet thick under the main part of Haines. Westward they thin to extinction between Third and Fourth Streets (fig. 4) where they are stratigraphically underlain by elevated fine-grained marine deposits. Toward Portage Bay, the deposits thicken to as much as 68 feet or more, as indicated in a drill hole (see following log), and are underlain or intercalated with elevated fine-grained marine deposits. Slumping along the slope facing the bay, however, has complicated the stratigraphic relations.

The beach deposits upon which Haines is built are interpreted to have formed as a spit during land emergence and when shorelines were developing parallel to the mountain front north of Haines. If this interpretation is correct, a water connection at the south end of the spit existed at that time between Chilkoot Inlet and ancestral Chilkat Inlet, and the present Chilkat Peninsula was an island.

A lower lying elevated beach (altitude about 30 ft), present between Haines and Port Chilkoot, is considerably narrower than the one upon which much of Haines is built. It probably represents a somewhat later phase of beach deposition when the water connection between Chilkat and Chilkoot Inlets was closed by beach deposits to form a more or less continuous barrier beach rimming Portage Cove. The deposits are poorly exposed but appear to be considerably finer grained than those underlying the business district of Haines. Grain-size analysis of a sample from a pit at the south end of Port Chilkoot, made by the Alaska Department of Highways (unpub. data, 1962), shows the following percentages: finer than sand, 4 percent; sand, 90 percent; and gravel, 6 percent; none of the gravel was more than 1 inch in size. According to the soil classification for highway purposes, this material is in Group A-1-b(0); in the Uniform Soil Classification it belongs to the SW Group.

Driller's log of test hole in elevated beach deposits at Haines

[See locality O, fig. 4. Altitude about 82 ft.]

	Thickness (feet)	Depth (feet)
[Elevated beach deposits][1]		
Gravel and cobbles mixed with sand; gravel is very well rounded and composed mostly of greenstone and "quartzite"(?)	15	15
Cobbles	4	19
Gravel and sand; dirty	6	25
Gravel and cobbles	5	30
Sand and gravel	3	33
Gravel and cobbles	3	36
Sand, coarse, and gravel, very fine	12	48
Gravel, fine to medium, and sand, coarse; gravel is well rounded	11	59
Gravel	9	68
[Elevated fine-grained marine deposits][1]		
Sand, fine, silty; wood chips	14	82

[1]Interpretation by us.

Elevated shore deposits on the Chilkat River side of the saddle are not as conspicuously developed as those rimming Portage Cove. However, two gravel pits (northeastern pit known as Philpott Pit; southwestern pit known as Lapham Pit), about one-half mile northeast of Kaskulu Point, expose a total thickness of about 15 feet of gently dipping moderately well sorted gravel and sand. The upper 3-4 feet is iron stained. Grain-size analyses of samples from the two pits, made by the Alaska Department of Highways (written commun., 1962) showed almost identical grain-size percentages: smaller than sand size, 2-3 percent; sand, 25 percent; and gravel 72-73 percent; none of the gravel was larger than 1½ inches. The deposits are underlain by elevated fine-grained fossiliferous marine sediments containing a few pebbles. There also is a well-developed series of beach ridges about three-quarters of a mile northeast of Kaskulu Point, which has successive crests at altitudes of 34, 32, and 28 feet. Other beach ridges, with crests at an altitude of approximately 22 feet, are flanked by younger elevated fine-grained deposits directly northeast of Kaskulu Point and near the Haines aircraft landing strip.

Three elevated beach strandlines were identified, on the basis of topographic map expression, between Mink Creek and Tanani Point, at approximately the following altitudes: (1) 80 feet, (2) 60 feet, and (3) 40 feet. A gravel pit in the deposit at an altitude of 60 feet, exposes about 12 feet of medium-grained gravel and sand. The upper 3 feet is oxidized to an orange brown, is well stratified, and dips gently toward Tanani Bay.

The elevated shore and delta deposits furnish much of the local sand and gravel demands of the area although the demands have not been great. Borrow pits are shown by symbol on the geologic map. The chief use has been for road surfacing; probably the next most abundant use has been for asphalt and concrete aggregate.

Alluvial fan deposits (Qaf)

Steep-gradient streams, mostly confined to the northern part of the mapped area, have deposited alluvial fan deposits at breaks in slope. These breaks in slope are chiefly along the northern edge of the saddle north and northwest of Haines, where the streams emerge from the precipitous mountain front, and along the southwest coastline of Lutak Inlet, where a narrow strip of flatter terrain commonly borders the inlet. Most depositing streams are intermittent or have a small perennial flow. During spring runoff and at times of heavy precipitation, however, streamflow is large and most fan material is deposited then. Fan surfaces, particularly near their apexes, generally are fairly steep. Little is known of the composition and thickness of the deposits because of a fairly thick tree cover and a mantle of muskeg.

Judged from limited exposures along Tanani Bay, Lutak Inlet, and the northern edge of the saddle between Haines and Chilkat River, the deposits appear to consist of poorly sorted and poorly stratified mixtures of gravel, cobbles, and boulders. Locally, sand and some silt are present, generally as a matrix to coarser material. Angular to subangular boulders, as much as several feet in longest dimension, are derived chiefly from local upslope rocks. The deposits probably are 30 or more feet thick in places and are underlain by elevated fine-grained marine deposits (Qem), elevated shore and delta deposits (Qeb), and undifferentiated drift deposits (Qd). Some older distal parts of large alluvial fans may merge with elevated shore and delta deposits.

Fifty feet of poorly sorted gravel, cobbles, boulders, and lesser amounts of sand is exposed in a gravel pit adjacent to the cargo dock on Lutak Inlet. The abundant cobbles and boulders (as large as 8 by 5 by 4 ft) are mostly diorite; nearly all are subangular to angular. The coarser material is in the upper part of the exposure and probably represents fan material. Finer and better stratified deposits in the lower part of the pit probably are elevated beach or delta deposits. The pit material was used in part for filling cells of the cargo dock.

A pit in another alluvial fan deposit along the mountain front northwest of Haines exposes angular to subangular rubble and cobbles, gravel, and boulders in a sandy matrix. The deposit, as is characteristic of most fan deposits, is much less coarse toward its distal margin than headward. Seeps are present in places where the deposits are in contact with elevated fine-grained marine deposits of low permeability.

Colluvial deposits (Qc)

Colluvium is the general term given to surficial material, including rubble, that has moved or is moving downslope, principally under the influence of gravity. Movement may range from very slow to rapid. Very slow-moving colluvial deposits generally are vegetated below regional timberline; faster moving deposits, such as landslides and talus deposits, tend to be more free of vegetation. Because of the difficulty of determining the origin of each deposit of colluvium, the unit is not further divided on the map as to type.

Slowly moving types of colluvium are especially prevalent in the Haines area where surficial deposits are thin and overlie steep bedrock slopes. Steep, glacially smoothed bedrock slopes of valley walls of fiords are especially susceptible to this downslope process whereby undifferentiated drift deposits, elevated fine-grained marine deposits, and elevated shore and delta deposits become intermixed. As a result of this diversity of source material the colluvium ranges in composition from silty gravel and cobbles to sand, silt, or silty rubble--all with varying amounts of organic material.

The fast to moderately fast moving types of colluvium include landslide deposits, mixed snow and avalanche debris deposits, and active to semiactive talus deposits. Rapid sliding is especially prevalent during periods of heavy precipitation when the contact between the surficial deposits and the bedrock is well lubricated. Rockfall, rockslide, and rockflow deposits, which constitute the talus slopes, consist of coarse rubble generally in a sandy matrix, nearly all of which is derived from upslope bedrock.

Active to semiactive talus deposits, which are common along the precipitous mountain front north and northwest of Haines, are well exposed in a borrow pit at the end of the road leading north from Second Street. Here, the face of the deposits has a slope of approximately 40° and is about 125 feet high. Nearly vertical bedrock cliffs, which extend 100-150 feet above the talus, furnish most of the source material. Angular cobble- to boulder-size pieces of rubble constitute the more common sizes, but smaller fractions down to silt size also are present. Some subrounded boulders, approximately 6 feet in diameter that constitute a part of the slide debris, are believed to be either glacial erratics derived from upslope till or they are derived from elevated beach deposits. All of the slide material is loosely packed and the void ratio is high. Some of the rubble in the face of the pit is in unstable equilibrium and, although it is not thick (bedrock is exposed in several sectors of the pit), sliding probably will be reactivated as material is removed from the base of the rubble face.

Large, bare talus deposits form the steep mountain slope less than a mile north of the airstrip. The talus is derived from vertical to nearly vertical cliffs consisting of metabasalt (Mzm). The bareness and steepness of the talus slope indicate that the deposits are in unstable equilibrium and are moving slowly downslope as more slide and rockfall material is being added at their apexes.

Very large landslides have not been recognized in the mapped area. However, the steepness of the south flank of the upper part of Mount Ripinski, together with the presence of a large, flat to slightly hummocky surface below this steep slope, are topographic features that are sufficiently anomalous regionally as to require some special explanation as to origin. One might postulate that the steep slope is the back scarp of a very large landslide block, part of whose upper surface is the flat to slightly hummocky area below the scarp. If so, the areal extent of the slide block might be a mile or more in length in an east-west direction and possibly as much as 1 mile long in a north-south direction (as far south as the mountain front along the north side of the saddle northwest of Haines). On the other hand, the area may represent a tectonically downdropped block. In support of this second supposition, aerial photographs indicate that several lineations—possibly faults--bound the northern and eastern margins of the area. It also should be noted that the area rather closely coincides with the areal limits of one type of bedrock (pyroxenite (Mzp)) and thus might be a reflection of different rates of erosion of rock types. Still another possible explanation is that the flat to slightly hummocky area is the surface expression of a lateral moraine. However, the presence of the steep upslope scarp is not well explained in this manner nor are there other similar flat areas in the vicinity as one would expect if this were the case. Unfortunately, time was not available for us to make a field examination of this area.

Small landslide deposits and snow avalanche debris accumulations occur along the steep mountain front north and northwest of Haines and along fiord walls of Chilkoot and Lutak Inlets as evidenced by several vegetation discontinuities along steep slopes. These deposits undoubtedly contribute source material to downslope talus and alluvial fan deposits.

There are several landslides of considerable extent just outside of the mapped area. One example where a landslide is well defined topographically is along the east side of Taiyasanka Harbor fiord northeast of Lutak Inlet (unmapped part of fig. 3). Other evidences of landslides or snow avalanches are on the northeast side of Lutak Inlet fiord (also in the unmapped area) where the entire mantle of surficial deposits has been removed. The largest indicated landslide tract lying just outside of the mapped area is along the east shore of Taiya Inlet, about 3 miles northeast of Haines (fig. 2). Here, on the basis of aerial photo interpretation, deposits in parts of four sections (SW part of sec. 17, SE part of sec. 18, NE part of sec. 19, and the western part of sec. 20, T. 30 S., R. 60 E.) are thought to show evidence of sliding. A large unvegetated scar on the side of a cliff shows that sliding has been active in that area in recent years although most of the total slide tract is vegetated and probably is partly to largely inactive. The slide tract is bounded on the landward sides by two well-developed intersecting lineations, which are part of a series that characterize the region. As discussed under "STRUCTURE," at least some of these lineations are believed to be faults. Thus, the landslide area may be bounded on the landward side by a fault and the tract itself may represent a tectonically downdropped block that has slid.

Colluvial deposits have been used for riprap for the small-boat harbor at Haines and for other limited use.

Modern beach deposits (Qb)

Modern beach deposits flank Chilkoot Inlet and Lutak Inlet in the mapped area. For mapping and discussion purposes, the modern beach is defined as the strip of land extending from mean lower low water to the upper limits of present-day wave action.

Along Portage Cove, the modern beach in most places is 300-500 feet wide. Surface deposits close to Port Chilkoot consist chiefly of fine gravel and coarse sand. Cobbles, gravel, and numerous isolated boulders, together with some sand and silt, constitute the deposits elsewhere along Portage Cove. The widest extent of beach in Portage Cove is southwest of Nukdik Point where bluffs of very stony diamicton provide large quantities of gravel, cobbles, and boulders. Thicknesses of the deposits in Portage Cove are not known. However, because of the relatively rapid rate of land emergence, the deposits probably are only a few feet thick. Underlying deposits in most places likely are fine-grained marine deposits or diamicton. Near the rock promontory southeast of Port Chilkoot, bedrock probably underlies boulder and cobble beach deposits at shallow depth.

North of Portage Cove, the beach deposits in most places are narrower and are characterized by abundant local concentrations of cobbles, gravel, and boulders. Bedrock probably is at shallow depth. Directly north of Nukdik Point, beach deposits are nearly absent and a wave-cut bedrock surface extends at least to mean lower low water. Along the shore of Tanani Bay, a special combination of sediment supply and wave and current action, which, in the past, formed well-developed elevated shore and delta deposits, is also today responsible for well-sorted beach gravel. Along the steep fiord walls of Lutak Inlet, modern beach deposits are gravelly to cobbly with numerous local concentrations of cobbles and boulders near the mouths of numerous short streams.

The modern beach along the northeast shore of Chilkat Inlet south of Kaskulu Point is approximately the same width as in Portage Cove, except across from Pyramid Island (fig. 2) where an expance of beach nearly 1,000 feet wide is exposed at mean lower low water. The deposits of the Chilkat Inlet beach consist chiefly of clean well-sorted sand and fine gravel, mostly less than 1 inch in longest dimension. Adjacent to bedrock exposures southeast of Kaskulu Point and for a distance of about $1\frac{1}{2}$ miles southeastward, cobbles and boulders are abundant locally. A gravel pit, approximately $1\frac{1}{4}$ miles southeast of Kaskulu Point, exposes a minimum thickness of 15 feet of fine gravel and sand and a few cobbles and boulders. The sand and fine gravel is used locally in the Haines area for road construction and other purposes. Additional reserves of similar-size material are indicated in the vicinity of the pit.

Chilkat River flood-plain and delta deposits (Qr)

These deposits are confined to sediments laid down on the flood plain at and near the mouth of the Chilkat River and to associated intertidal deltaic sediments being laid down at the head of Chilkat Inlet. They include all the surface deposits of the area shown on figure 3 as McClellan Flats. At tidewater they grade into deltaic deposits of Chilkat Inlet (see "Offshore deposits").

Near the mouth of the Chilkat River, the flood plain is 2-3 miles wide, and the river flows in a highly braided channel system. During spring runoff, at other times of large discharge down the river, and during high tides, the flood plain within the mapped area is completely or largely covered with water. During periods of low streamflow, the river flows in bifurcating channels between bars a few feet or less above stream level.

The flood-plain and delta deposits are fine grained. A single sample collected from the surface near the Haines aircraft landing strip consisted of 64 percent sand (of which 70 percent was fine to very fine), 35 percent silt, 1 percent gravel, and less than 1 percent clay size (E. E. McGregor, U.S. Geol. Survey, written commun., 1968).

Composition of flood-plain deposits and stratigraphic relations at depth were revealed by test holes (fig. 6) drilled at the west edge of the mapped area (about one-half mile northwest of the aircraft landing strip) in connection with a proposed highway crossing over the Chilkat River. Here, a maximum of approximately 40 feet of flood-plain deposits, consisting mostly of fine sand, was penetrated by the drill holes. Underlying these deposits, at the locations of the test holes, are at least 100 feet of somewhat finer grained deltaic deposits, consisting chiefly of a silty fine sand in the upper part of the section and a sandy silt in the lower part. Along at least the eastern edge of the valley at this site, the deltaic deposits are underlain by about 80 feet of clayey silt, which we interpret to be marine deposits. These in turn are underlain by at least 15 feet of dense intermixed silty sand, gravel, and cobbles, which we interpret to be drift (possibly till). It is likely that drift extends entirely across the valley as the basal surficial deposit and may constitute a large part of the total valley fill. It should be noted, however, that the drill holes extend across only the eastern half of the Chilkat River valley and, even there, they are too shallow in most places to indicate the varying thicknesses of the different units constituting the valley fill. E. C. Robertson (unpub. data, 1959) estimated an average thickness of valley fill of 800 feet, on the basis of several cross-valley projections between Haines and an area about 19 miles up the Chilkat River. We cannot assess how valid this estimate might be other than to say that the valley fill immediately west of Haines probably is several hundred feet thick.

Manmade fill (Qf)

Eight areas of man-emplaced fill are shown on figure 3. These are relatively small areas, mostly on or near the shore. Not shown, because of their even smaller size, are road and street fills, building site fills, and other miscellaneous types.

The largest area of artificial fill is the aircraft landing strip. Here the fill, which probably consists of intermixed gravel and sand emplaced on elevated fine-grained marine deposits (Qem and Qemy), has been built to a height of only a few feet above the Chilkat River. Boulders, emplaced behind a limited diking of piles, help protect the main part of the fill from river erosion. It is not known whether or not the fill was engineered (compacted to maximum density during emplacement).

Sand and gravel, several feet thick, have been emplaced on elevated shore deposits (Qeb) and elevated fine-grained marine deposits (Qemy) for construction of a sawmill and parking area at Kaskulu Point. The fill was obtained from a nearby ice-contact deposit (Qo).

The riprap constituting the breakwater of the Haines small-boat harbor is a special type of fill. The breakwater is L-shaped, each arm being approximately 400 feet long and extending several feet above higher high water. It is constructed of angular pieces of rock 2-4 feet in maximum dimension with a core of finer grained material in the nearshore segment. The riprap is from talus (colluvial deposits) obtained from the mountain front directly north of Haines.

The local headquarters of the Alaska Department of Highways covers a large part of the northern part of a mapped fill area at the western edge of Haines. In most places, the fill is about 5 feet thick and consists mostly of loose sand and gravel. It is underlain by clayey silt of the elevated fine-grained marine deposits (Qem).

Two small areas of artificial fill, one just south of the small-boat harbor and the other one near Nukdik Point have no facilities built upon them. The fill south of the small-boat harbor consists of fine-grained material a few feet thick. The one near Nukdik Point is an abandoned dump.

Two areas of fill have been mapped along Lutak Inlet. The larger area constitutes the interior of the cargo dock adjacent to the Alaska State Ferry Terminal. Here the fill consists chiefly of blocks of rock taken from a nearby outcrop of fine-grained metamorphosed volcanic rock (Mzm), with a topping of sand and gravel taken from a pit just north of the dock in an alluvial fan deposit (Qaf). This latter material also was used for filling the cells (caissons) along the deepwater side of the dock. The fill, which rises to a height of 26 feet above mean lower low water, may be as much as 40-50 feet thick on the seaward side. Jet probe holes, put down in connection with constructing the Alaska State Ferry Terminal, indicate that 20 or more feet of coarse gravel with small boulders underlies the fill (Toner and Nordling, Engineers, Juneau, written commun., 1962). The second area of fill is about one-half mile northwest of the cargo dock. Here, an area has been modified by highway relocation, construction of a timber chipper mill and dock, and emplacement of fill obtained from elevated fine-grained marine deposits topped with sandy gravel. The fill is underlain, at least near the shore, by loose sandy gravel of modern beach deposits (Qb).

<u>Offshore deposits (not shown on map)</u>

The deposits that are described in this section are those that, by definition, lie below mean lower low water. They include normal marine bottom sediments, offshore deltaic deposits, submerged glacial deposits, and other miscellaneous types. Data as to the nature and thickness of the deposits are meager.

Some data are available regarding the nature of offshore deposits in Portage Cove. As shown on Hydrographic Survey chart no. H-6942, compiled by the U.S. Coast and Geodetic Survey in 1943, "gray mud" is the common floor material. The thickness of the material, however, is not known. Some data also are available immediately offshore from Haines based on drilling in connection with the construction of the small-boat harbor. In 1957 five holes were churn drilled, in what is now the small-boat harbor, by the present firm of Toner and Nordling, Engineers, Juneau, Alaska. Two of these holes, drilled near the shoreward margin of the harbor, were 32 feet deep and penetrated a variable sequence of silt, sand, and fine gravel. One hole, farther offshore and nearer the outer margin of the breakwater, penetrated 12 feet of firm clay underlying 2 feet of sand and clay.

The composition of material penetrated in the other three holes (located between the breakwater and shore) also was variable and ranged from clay to gravel in size. No bedrock or boulders were penetrated in any of the holes.

Some indication of the nature of the marine deposits outside of Portage Cove can be gained from seismic traverse studies made in 1965 near the head of Chilkoot Inlet and in inlets to the north. These studies were made by Gene A. Rusnak of the U.S. Geological Survey, using the barge Don J. Miller. The closest traverse to the Haines area was one that was run east from Nukdik Point to the eastern shore of Chilkoot Inlet; a second one was run from the middle of Chilkoot Inlet to about 1 mile offshore from Haines where the 300-foot-depth contour "bulges" outward from Portage Cove (see fig. 2). According to Rusnak (written commun., 1966), the outward "bulge" of the 300-foot-depth contour reflects topographically high bedrock virtually free of sediment cover. A grab sample taken by Rusnak at this site indicates that the small amount of sediment that is present consists of a coarse "muddy" gravel containing shells. That bedrock knobs exist in Chilkoot Inlet is shown by the presence of Indian Rock, which is awash at lower low water, $1\frac{1}{2}$ miles east of Tanani Point (fig. 2).

Bedrock crops out onshore at Nukdik Point and little or no sediment is present seaward along the steeper underwater slopes. However, toward the middle of Chilkoot Inlet, where the sediments form the relatively flat floor of the inlet at a water depth of about 400 feet, a seismic profile indicates a maximum thickness of approximately 500 feet of sediments, assuming an acoustic velocity of 4,800 fps (feet per second) for the sediments (Gene A. Rusnak, written commun., 1966). According to Rusnak, the sediments appear to be essentially uniform in composition but, locally, irregular bodies of glaciofluviatile(?) deposits underlie the softer marine sediments.

Limited information on bottom sediment and depths is available for Lutak Inlet from the U.S. Coast and Geodetic Survey chart no. 8303 (1945, minor revisions, 1966). The chart shows a steep-sided cross-sectional profile typical of a fiord with a fairly flat floor and shoaling at its upper end. Offshore sediments near the upper end of Lutak Inlet probably are derived largely from elevated delta and buried morainal deposits that serve as the dam for Chilkoot Lake (fig. 2). Thus, the floor sediments, indicated by U.S. Coast and Geodetic Survey chart no. 8303 as "mud," and "mud and clay" sediments, probably form only a thin layer overlying older prodeltaic deposits of fine sand and silt. Most of the present-day coarse and fine sediment of the Chilkoot River is deposited in Chilkoot Lake and does not reach Lutak Inlet.

Some information is available on nearshore sediments near the Alaska State Ferry Terminal from jet probings in 1962 by Toner and Nordling, Engineers (written commun., 1965), prior to construction of the terminal. These probings indicate the presence of coarse gravel and small boulders. Bottom slopes, between 15 and 65 feet below sea level in this locality, were determined to be about 20°.

Thick sediments are present off the face of the Katzehin River delta in Chilkoot Inlet, about 4 1/2 miles southeast of Haines (fig. 2). Here, about midway across Chilkoot Inlet, at a water depth of approximately 250 feet, the deltaic sediments are more than 1,500 feet thick, assuming a seismic velocity of 4,800 fps (Gene A. Rusnak, written commun., 1966).

No definitive data are available as to the nature and thickness of subaqueous deposits in Chilkat Inlet. Some speculation, however, is possible on the basis of materials that are now being deposited or that have been deposited recently in the inlet. There are two main sources for these sediments: (1) the Chilkat River, and (2) glacial melt-water streams from Davidson Glacier and the glacier whose melt waters empty into Chilkat Inlet just south of Pyramid Harbor (fig. 2). Of the two main sources, the Chilkat River is by far the largest contributor. At one time the mouth of the river was several miles farther up the valley, but owing to deposition of large quantities of fine-grained fluvial material and to land emergence, the river is rapidly extending its delta into Chilkat Inlet.

Judged from material penetrated in drill holes for the proposed bridge upstream (fig. 6), the deltaic foreset beds probably consist of fine sand, silt, and some clay-size material. Also, the deposits in the deeper water in front of the delta probably consist chiefly of clay and silt-size material.

Between Pyramid Island and Chilkat Peninsula (fig. 2), Chilkat Inlet is very shallow. The inlet also is shallow on its west side for some distance offshore from Green Point. The position of Pyramid Island and the associated offshore shallows suggests the presence of a largely submerged end moraine, marking the frontal position of a former Chilkat valley glacier. An end moraine also is indicated by the presence of plentiful boulders and cobbles, both on the Pyramid Island tidal flats and along the shore at Green Point; the cobbles and boulders may have been wave concentrated by winnowing out of the fines of the morainal material. No obvious lateral morainal features, however, are visible along the adjacent valley walls. Because the subaerial part of Pyramid Island consists of elevated fossiliferous fine-grained marine deposits, the submerged portion of the postulated moraine probably also is buried beneath a mantle of marine deposits.

The Glacier River is another substantial contributor of sediments to Chilkat Inlet. The river, which is on the west side of the inlet (fig. 2), is only about 1½ miles long, but it carries most of the melt water of Davidson Glacier to the inlet. The terminus of Davidson Glacier extends only a couple of thousand feet beyond the mouth of the valley whereas the fan delta of the river extends more than a mile farther out into the inlet to constrict the width of the navigable waters of the inlet in this area to about one-half mile. However, the middle part of the channel is 450-500 feet deep. The fan delta of the Glacier River was not visited by us. However, from somewhat scanty descriptions by Gilbert (1903), Wright and Wright (1960), and Egan, Miller, and Loken (19th Alaska

Sci. Conf., oral commun., 1968), Alaska Highway Department investigations (Rasmussen and Franklet, 1969), and from a study of aerial photographs by us, we conclude that the surface deposits of the fan probably consist chiefly of sand and gravel outwash from Davidson Glacier and of associated morainal deposits. On the basis of this assumption, the foreset beds of the delta probably are coarser grained than those at the mouth of Chilkat River. However, considerable rock flour (clay- and silt-size material) probably is being carried into the deeper offshore parts of the inlet. Therefore, the prodeltaic deposits in that area probably do not differ greatly from those offshore from the mouth of the Chilkat River.

STRUCTURE

Summary of regional structure

Southeastern Alaska lies within the active tectonic belt that rims the northern Pacific Basin. It has been tectonically active since at least late Paleozoic time and the bedrock outcrop pattern is the result of late Mesozoic and Tertiary deformational, metamorphic, and intrusive events (Brew, Loney, and Muffler, 1966). Large-scale faulting, mostly with strong right lateral strike-slip movement, has been common. Two of the most prominent fault systems in southeastern Alaska and surrounding regions are: (1) the Denali fault system, and (2) the Fairweather-Queen Charlotte Islands fault system. Also, of major tectonic importance are the Totschunda fault system, which appears to connect with the Denali fault system, and the Chugach-St. Elias fault, which joins the northwestern end of the Fairweather fault. These fault systems, as well as inferred connections between individual fault segments, are shown in figures 7 and 8 and are described in more detail in our regional report (Lemke and Yehle, 1972).

As first reported by St. Amand (1954) and by Sainsbury and Twenhofel (1954), and later described in more detail by St. Amand (1957), and Twenhofel and Sainsbury (1958), the "Denali fault" is a great arcuate series of related faults and branches about 1,300 miles long. The "fault" was described as extending from the Bering Sea across the northern flank of Mount McKinley, through northernmost British Columbia, and thence down the Chilkat River valley and Chilkat Inlet to Lynn Canal and Chatham Strait (fig. 7). Thus, in Canada and southeastern Alaska, it included the Shakwak valley, Chilkat River, Chatham Strait, and Lynn Canal fault segments (fig. 8). Grantz (1966) called this series of related faults and branches the Denali fault system but restricted the Denali fault itself to that part of the Denali fault system that extends from the Kuskokwim River drainage east of Bethel to northernmost British Columbia (a length of about 870 miles).

Some doubt was expressed by Hamilton and Myers (1966) on the continuity of the Denali fault into British Columbia and southeastern Alaska, as described by St. Amand (1957) and others. Instead, they suggested that the Denali fault system extends southeastward along a lineament that Richter and Matson (1971) named the Totschunda fault system. Furthermore, they noted that this fault was alined with the Fairweather fault to the southeast and assumed that the two faults connect. Richter and Matson (1971) left open the question of whether or not there was a connection between the Denali fault and the Totschunda fault system and only suggested that the Totschunda fault might connect with the Fairweather fault. As discussed below, Plafker (1971; written commun., 1971) does not believe that the Totschunda fault is a continuation of the Fairweather fault.

The Fairweather fault and the Queen Charlotte Islands fault probably are a part of the same tectonic element (St. Amand, 1957; Grantz, 1966;

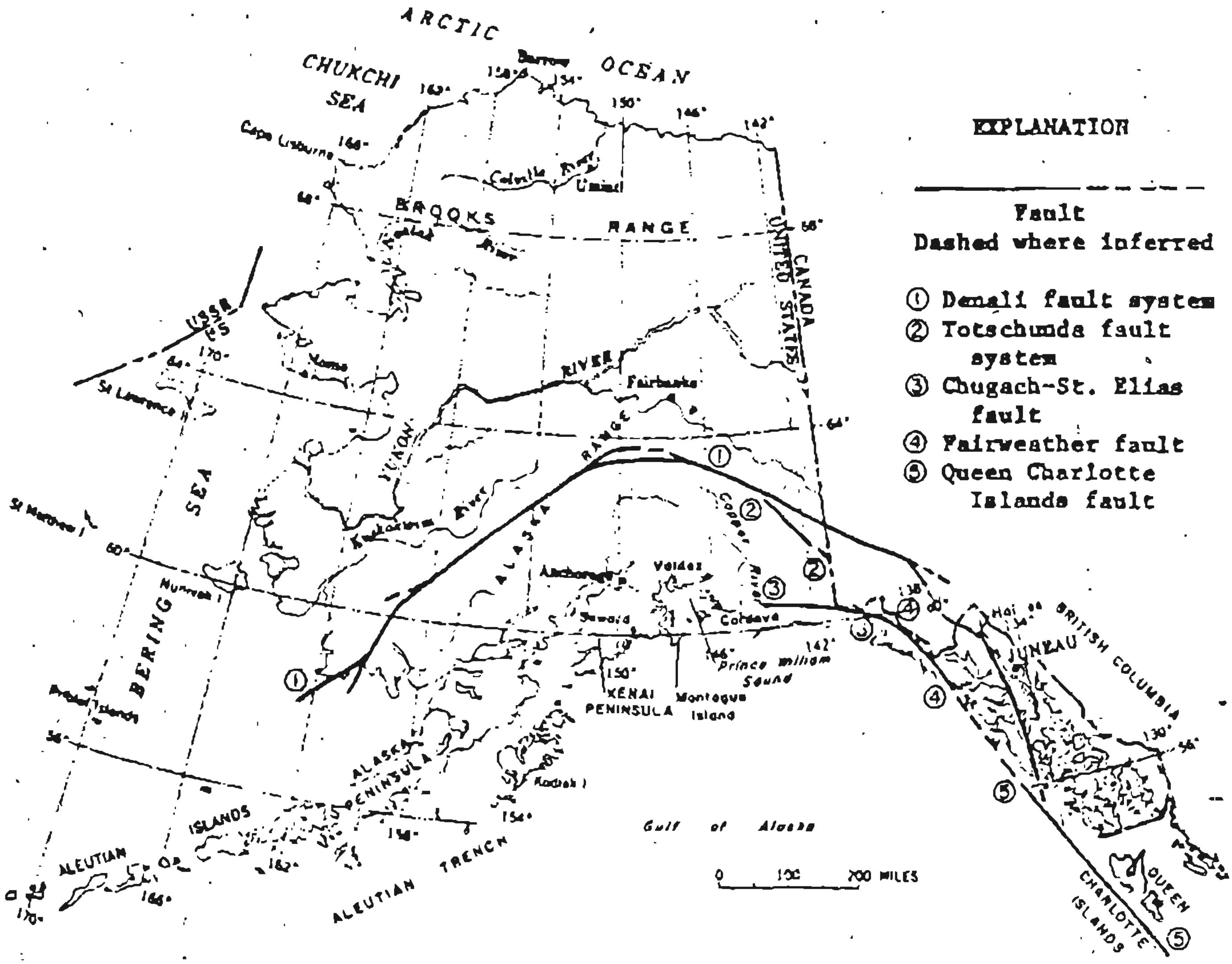


Figure 7.—Map of Alaska showing major elements of the Denali and Fairweather-Queen Charlotte Islands fault systems. Modified from Grantz (1966), Tobin and Sykes (1968), Plafker (1969; 1971), Richter and Matson (1971).

Tobin and Sykes, 1968; Page, 1969; George Plafker, written commun., 1971; and Richter and Matson, 1971). The onland part of the Fairweather fault is a segment about 125 miles long extending southeastward from Yakutat Bay to Icy Point (figs. 7 and 8). Here, the fault lies largely in a linear valley partly filled by glaciers and separating crystalline rocks of the Fairweather Range from partly younger and less altered rocks of the coastal region (Miller, 1960). The offshore southeastern extension of the fault follows the continental slope off southeastern Alaska and probably joins the Queen Charlotte Islands fault off the coast of British Columbia. The Queen Charlotte Islands fault was inferred on the basis of the configuration of offshore topography and the presence of a belt of high seismicity (Menard and Dietz, 1951; St. Amand, 1957; and Wilson, 1965). As mapped by Plafker (1969; 1971), the northeastern end of the Fairweather fault joins the eastern end of the Chugach-St. Elias thrust fault (figs. 7 and 8). Plafker (written commun., 1971) states that "Despite numerous published statements to the contrary, our data preclude the possibility that the Fairweather fault, or a major splay of it, extends northwestward along the Artlewis Glacier to link up with the Totschunda fault system." His reasons for this belief are given in more detail in our regional report (Lemke and Yehle, 1972).

These differences in interpretation as to the true trend of the Denali fault system, as well as possible connections between the Denali and Fairweather-Queen Charlotte Islands fault systems cannot be resolved by us. However, for purposes of discussion here, the Shakwak valley fault, Chilkat River fault, Lynn Canal fault, and the Chatham Strait fault (fig. 8) will be included as probably an older part of the Denali fault system and the Totschunda fault system as a younger part of that system. The Fairweather-Queen Charlotte Islands fault system will be considered to be more or less separate from the Denali fault system but one which merges to the northwest with the Chugach-St. Elias fault.

Local structure

Knowledge of structure in and adjacent to the Haines area is based in large part upon studies by Robertson (1956; unpub. data, 1959). According to Robertson (unpub. data, 1959), rocks of Cretaceous and Mesozoic age northeast of Chilkat River in the general area of Haines have a simple monoclinal structure. Layering of flow structures in metabasalt and foliation of dioritic rocks strike northwest, roughly parallel to the Chilkat River and dip moderately to steeply northeast. Major joints also strike northwest and dip northeast. Paleozoic-Mesozoic rocks southwest of the Chilkat River exhibit in places a rather complex isoclinal folding with vertical axial planes and bedding whereas in other places they are gently folded.

Several major and numerous minor faults probably transect the Haines mapped area and vicinity. They are indicated by numerous lineaments (figs. 8 and 9) and, in some places, by differences in lithology on opposite sides of river valleys or fiords. However, the actual existence of the faults and location of their traces are difficult to determine because most appear to be coincident with the long axes of fiords and river

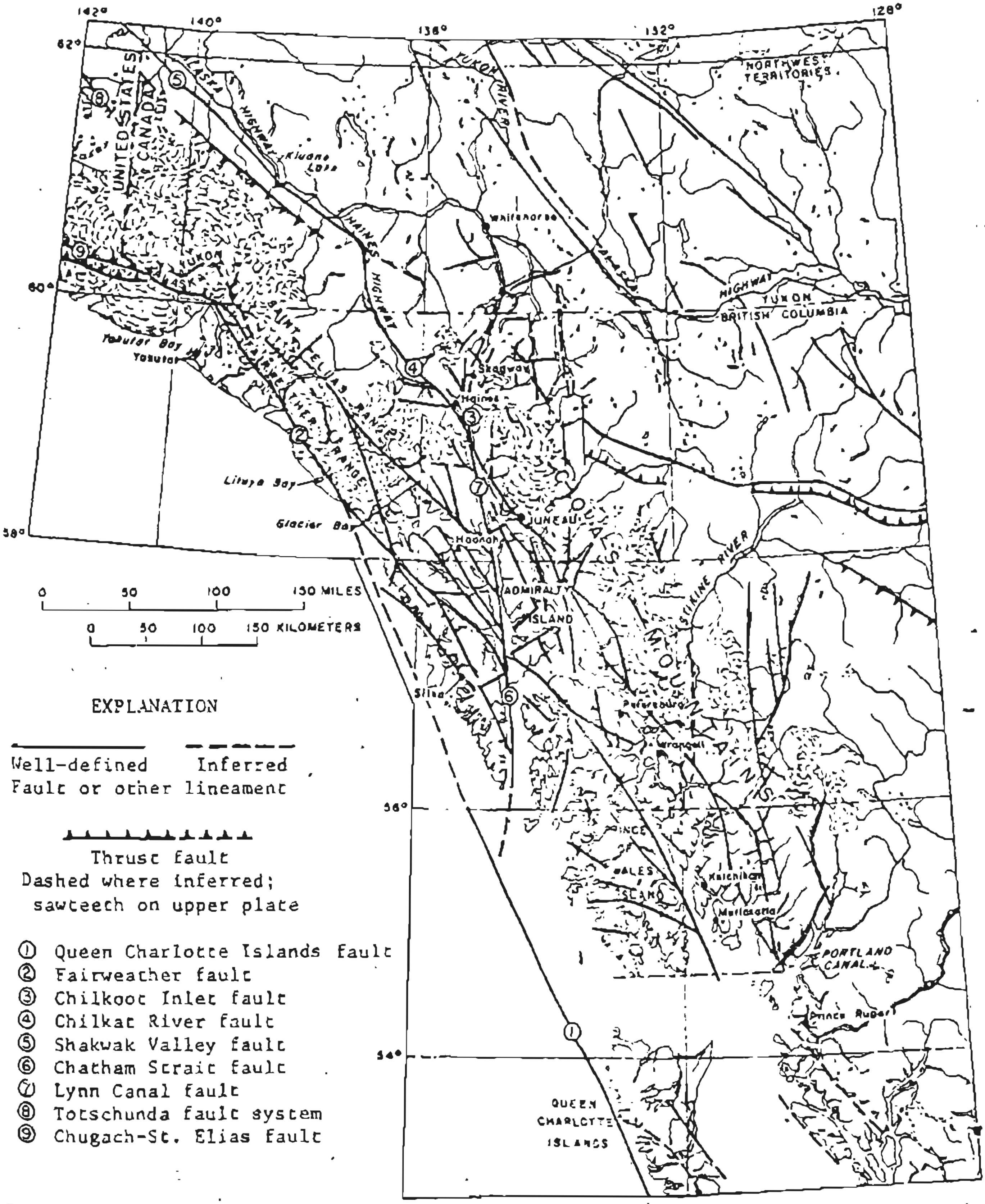


Figure 8.--Map of southeastern Alaska and adjacent Canada showing major faults and selected other lineaments interpreted to be probable or possible faults, shear zones, or joints. Taken from St. Amand (1957), Twenhofel and Sainsbury (1958), Gabrielse and Wheeler (1961), Brew and others (1966), Tobin and Sykes (1968), Geological Survey of Canada (1969a; 1969b), King (1969), Plafker (1969), Souther (1970), Plafker (1971), and Richter and Matson (1971); and with additions and modifications by the writers.

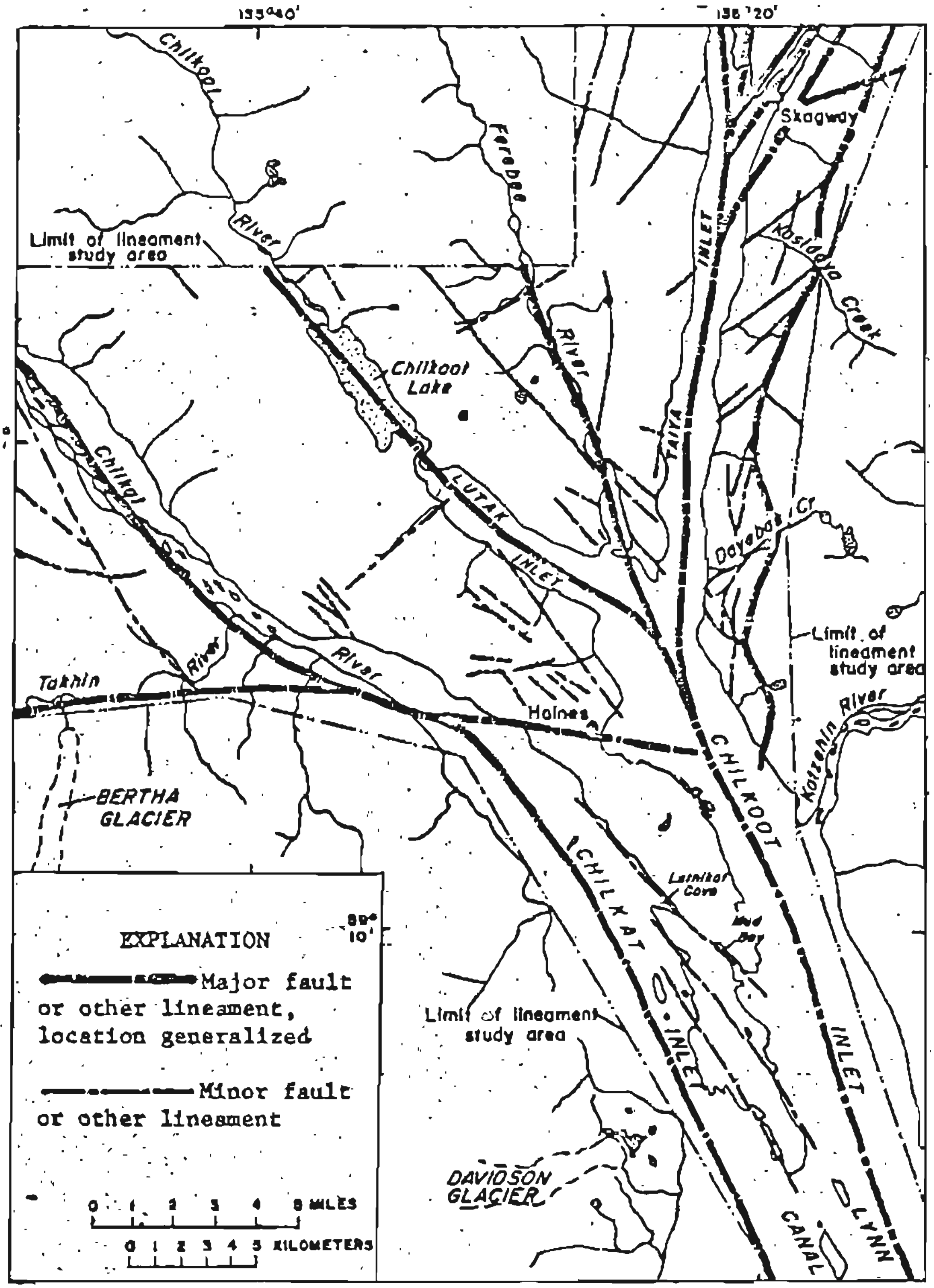


Figure 9.—Map of Haines area and vicinity showing faults or other lineaments. Taken from Twenhofel and Sainsbury (1958), Robertson (1959; unpub. data), Gabrielse and Wheeler (1961), and with additions by the writers based upon airphoto and map interpretation.

valleys, where they are concealed by water or by valley fill. Some lineaments in the area are not due to faults but their origin is obscure. The more prominent of the indicated faults are discussed below.

Chilkat River fault

The Chatham Strait-Lynn Canal fault (figs. 8 and 9), which has been described by St. Amand (1957), Twenhofel and Sainsbury (1958), Grantz (1966), and Brew, Loney, and Muffler (1966), splits into two branches at the northern end of the Lynn Canal. The branch that extends up Chilkat Inlet, Chilkat River valley, and Kelsall River valley is known as the Chilkat River fault. It has a length of about 90 miles (figs. 8 and 9), and connects with the Shakwak Valley fault to the northwest (Robertson, unpub. data, 1959; Grantz, 1966). Differences in lithology on either side of these two river valleys (Robertson, unpub. data, 1959) plus the linearity and continuity of the valleys provide strong evidence for the existence of this unexposed fault. As stated by Grantz (1966), "The character of the fault and the amount of displacement are not known but, if a fault exists, movement may be partly Early and Late Cretaceous, partly post-Paleocene to Miocene." The exact trace of the fault in the Haines mapped area (fig. 3) is not known but it must extend up the Chilkat River valley and, therefore, must lie somewhere beneath McClellan Flats. Because it is not now possible to more precisely locate the fault, it is not shown on figure 3; however, its generalized trace is shown on the smaller scale map of figure 9.

Chilkoot Inlet fault

The branch of the Chatham Strait-Lynn Canal fault that is believed to extend up Chilkoot Inlet is known as the Chilkoot Inlet fault (see figs. 8 and 9). As indicated by linear trends of fiords and valleys, the Chilkoot Inlet fault probably further splits northward into several branches (fig. 9). Twenhofel and Sainsbury (1958) show conspicuous lineaments as extending up the following river valleys: (1) Chilkoot River, (2) Ferebee River, (3) Taiya River (at head of Taiya Inlet), and (4) Skagway River (north of Skagway). Many other minor linear trends, which generally indicate faults or joints, have been mapped in the Skagway area (Yehle and Lemke, 1972). All branches of the Chilkoot fault probably lie east of the mapped Haines area except the inferred branch that extends up Lutak Inlet. The location of the inferred Lutak Inlet branch is not shown on figure 3 because of lack of knowledge as to the probability of its existence or location.

Faults in southern part of Chilkat Peninsula

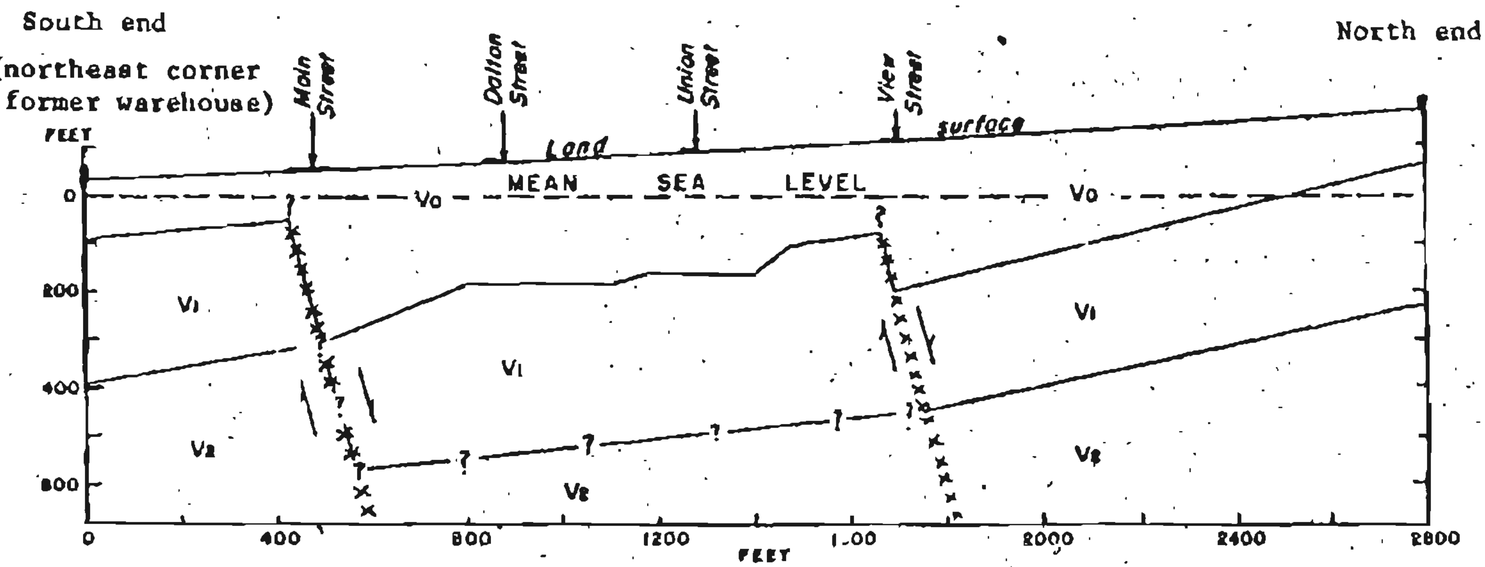
The en echelon pattern of lineaments in the southern part of the Chilkat Peninsula and of islands to the south suggest several northwest-trending faults (fig. 9). Particularly suggestive of a fault is a conspicuous topographic offset of Chilkat Peninsula marked by Letnikof Cove and Mud Bay (fig. 2). Both bodies of water are elongated and aligned in a northwest direction and are land-connected by a low swale.

Takhin fault

Robertson (unpub. data, 1959) inferred that a fault, which he named the Takhin fault, follows the Takhin River valley and connects with the Chilkat fault 3 or 4 miles west of Haines (fig. 9). The existence of this fault is suggested mainly by the linearity of the Takhin River valley.

Faults in the saddle at Haines

In the mapped area (fig. 3), the most likely area of major faults other than McClellan Flats where the Chilkat River fault must lie, is the low saddle in which Haines is built. The possibility that rocks of Tertiary age occupy a downdropped block bounded by faults has already been discussed (see section on "Bedrock"). A seismic profile (fig. 10), run transverse to the saddle, suggests that the more middle part of the saddle is cut by two normal faults, which may have displacements of as much as 140 feet. The abrupt bedrock escarpment that forms the northern side of the saddle may mark the trace of a much larger east-west-trending fault. This supposition is supported by the fact that, if the postulated Takhin fault is extended eastward across the Chilkat River fault, its strike would be approximately along the northern escarpment of the saddle. Evidence that the saddle is bounded by a fault on its southern side, to form a grabenlike structure, is largely lacking. Because more subsurface data are needed before the number and orientation of the faults that may be present in the saddle area can be determined, no attempt has been made to show these faults on figure 3. However, a major northwest-southeast lineament (representative of all possible faults) is shown on figure 9 as traversing the saddle area and connecting with both the Chilkat and Chilkoot lineaments.



EXPLANATION

Velocity interface		Vo	5,100-6,250 fps (feet per second) velocity. Possibly bedded clay, gravel, and gravelly sand, silt, and clay.
Shallowest position for interface		V1	10,000 fps velocity. Possibly indurated glacial drift(?) or soft rock(?) with some hard rock and clay seams.
Central sector		V2	24,350 fps velocity. Bedrock.
Hypothetical fault showing relative sense of possible movement			

Figure 10.--Seismic profile approximately along Fourth Street, Haines. (See fig. 4 for location.) Modified from profile by R. A. Farrow and E. E. McGregor, U.S. Geol. Survey (written commun., 1968).

EARTHQUAKE PROBABILITY

As yet it is not possible to predict when or where the next destructive earthquake will strike in the world or what its size and other characteristics will be. We do know, however, that some regions are much more likely to have destructive earthquakes in the future than other regions. The degree of likelihood is based upon two factors: (1) the seismicity or historical record of earthquakes in a certain region or area, and (2) the degree of tectonic activity of the region or area, as indicated chiefly by the recency of fault movement. Assessment of these two factors affords a means of determining the earthquake probability of an area.

Seismicity

A large part of Alaska lies in the circum-Pacific earthquake belt—one of the world's greatest zones of seismic activity. Six percent of the world's shallow earthquakes are recorded in the State, chiefly in two seismic zones (St. Amand, 1957; Wood, 1966). One of these zones includes the Aleutian Islands, Aleutian trench, Alaska Peninsula, Alaska Range, and eastward as far as the Copper River (fig. 7). The second zone, which encompasses the Haines area (fig. 3), includes southeastern Alaska, southwestern Yukon, and the coastal areas of British Columbia.

The historical record of earthquakes in southeastern Alaska and adjacent areas is so short that most of the data are limited to that obtained in the present century. These data show that five earthquakes of magnitude 8 or greater have occurred offshore or on land in southeastern Alaska and adjacent Canada (fig. 11). During this time, there also have been three earthquakes with magnitudes between 7 and 8, at least eight with magnitudes between 6 and 7, more than 15 with magnitudes between 5 and 6, and about 140 have been recorded with magnitudes less than 5 or of unassigned magnitudes in this region. In addition there undoubtedly have been many additional unrecorded earthquakes since 1899. All five of the earthquakes with magnitudes greater than 8 were offshore or near the coast and appear to be related to movement along the Fairweather-Queen Charlotte Islands fault system and the connecting Chugach-St. Elias fault or to their splays and extensions (figs. 8 and 11). Most of the other larger earthquakes (magnitudes greater than 6) and a large proportion of the smaller ones also appear to be related to these tectonic features.

There are no recorded epicenters of earthquakes within the Haines mapped area (fig. 3). The closest epicenter for any earthquake of magnitude 6 or greater is about 30 miles[4] northwest of Haines in the Chilkat River valley (designation N in fig. 11). This earthquake occurred March 9, 1952, and had a magnitude of 6. Epicenters of only 12 other earthquakes

[4]Because of the difficulty of accurately determining the location of epicenters (particularly of early historic earthquakes), assigned locations probably are at least 10-15 miles in error and may in some instances be mislocated by as much as 70 miles.

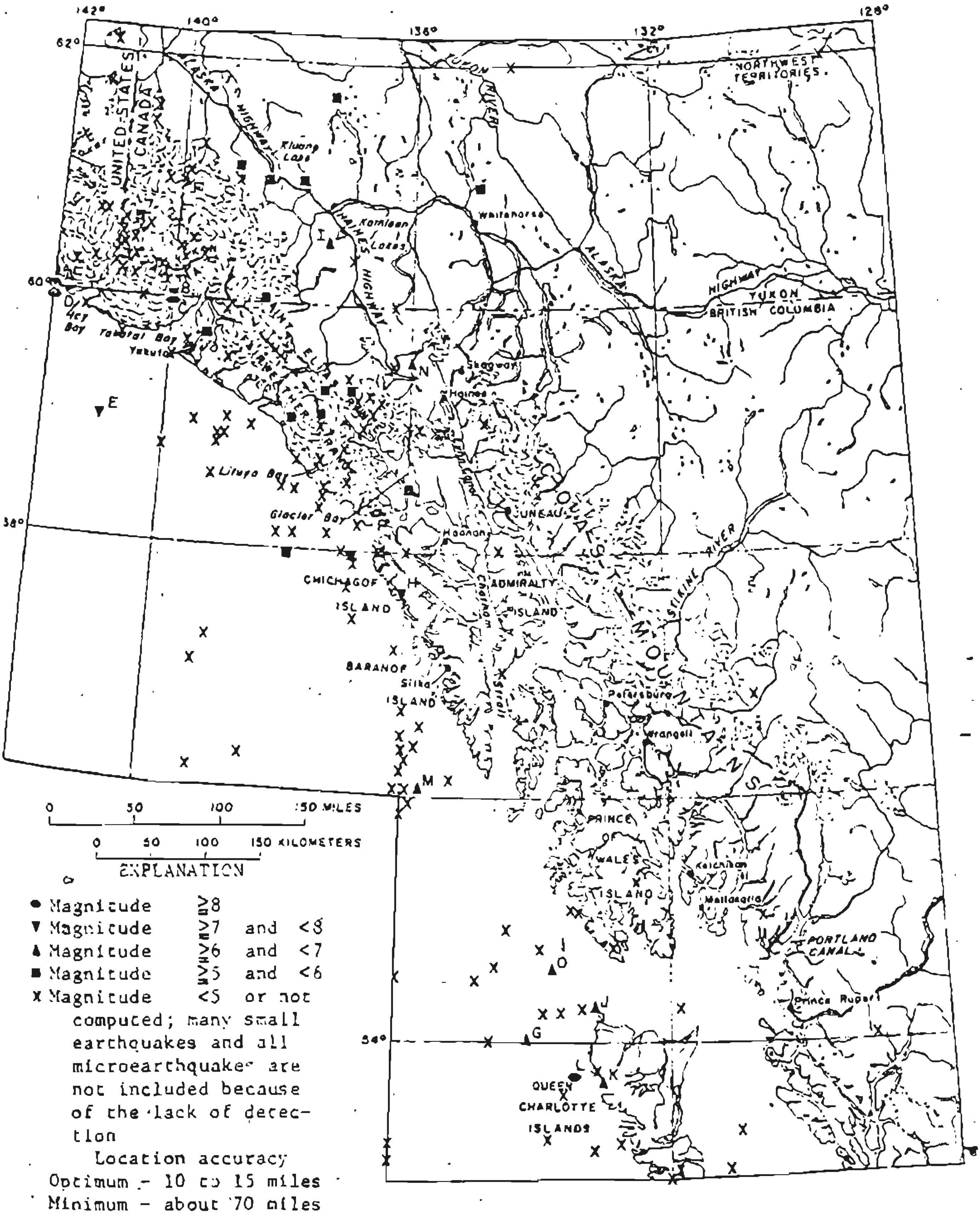


Figure 11.--Map showing locations of epicenters and approximate magnitude of earthquakes in southeastern Alaska and adjacent areas for period 1899-1969 inclusive. Data from Canada Dept. of Energy, Mines and Resources, Seismological Service (1953, 1955, 1956, 1961-63, 1966, 1969, 1970), Davis and Echols (1962), International Seismological Centre (1967-1970), Milne (1963), Tobin and Sykes (1968), U.S. Coast and Geodetic Survey (1930-1969, 1964-1970, 1969), and Wood (1966)

Dates and magnitudes of some earthquakes of magnitude ≥6

Designation on map	Date (Universal Time)	Magnitude
A	September 4, 1899	8.2-8.3
B	September 10, 1899	7.8
C	September 10, 1899	8.5-8.6
D	October 9, 1900	8.3
E	May 15, 1908	7
F	July 7, 1920	6
G	April 10, 1921	6.5
H	October 24, 1927	7.1
I	February 3, 1944	6 1/2
J	August 3, 1945	6 1/4
K	February 28, 1948	6 1/2
L	August 22, 1949	8.1
M	October 31, 1949	6 1/4
N	March 9, 1952	6
O	November 17, 1956	6 1/2
P	July 10, 1958	7.9-8.0

are recorded as being within about 50 miles of Haines. Magnitudes for these earthquakes were less than 5 or were not computed. Thirty-nine earthquakes within 100 miles of Haines have been instrumentally recorded. One of these, the Lituya earthquake of July 10, 1958, (designation P of fig. 11) had a magnitude of 8, one had a magnitude of 6 (described above), six had magnitudes between 5 and 6, and 31 had magnitudes less than 5 or were not computed.

Although no instrumentally recorded earthquakes had epicenters in the mapped area, more than 100 earthquakes, which occurred between 1847 and 1969 and had epicenters elsewhere, have been felt and reported in Haines or were possibly felt at Haines but not reported (table 4). There probably have been many more felt quakes in the mapped area but they have not been reported or the published source is obscure. Most of the information available to us is from scattered newspaper accounts, oral accounts, and other sources of varying reliability. There is little doubt but that, in many instances, major earthquakes felt in nearby areas and presumably felt in the Haines area, have not been reported in that area or are unknown to us.

Felt earthquakes reported in the Haines area have ranged from slight tremors to severe shocks (table 4). The two earthquakes of 1899 in the Yakutat Bay area that had magnitudes greater than 8 were strongly felt in the Haines area. Based upon newspaper accounts, the Yakutat Bay earthquake of October 9, 1900, had intensities (Modified Mercalli scale) of VI to VII at Skagway (Eppley, 1965). Because of a similar distance from the epicenter to Haines, intensities in Haines probably were similar to those in Skagway in those places where geologic conditions were similar. One account of the Yakutat Bay earthquake of September 4, 1899, taken from the San Francisco Chronicle September 22, 1899, and published in Tarr and Martin (1912) is as follows:

"At Haines Mission near Skagway the shocks were accompanied by the moving of furniture, swaying of trees, rolling of logs, difficulty in standing and walking, etc. The ground is said to have cracked open in places * * * natives in utmost panic * * *."

Several earthquakes that occurred during 1907, 1909, 1910 were moderately to strongly felt in or near Haines (Davis and Echols, 1962). During an earthquake on September 24, 1907 (epicenter probably somewhere in Lynn Canal area), clocks stopped at Haines as well as at Skagway. Many people were awakened and the intensity was estimated by the U.S. Coast and Geodetic Survey at V (Modified Mercalli intensity scale) at Klukwan, about 20 miles northwest of Haines. A strong earthquake on February 16, 1909, probably was felt at Haines and at widely scattered other towns. Two moderately strong shocks on March 14, 1910, 1 hour apart and probably having epicenters in the area of Icy Straits (50-75 miles southwest of Haines) probably also were felt at Haines. Still another earthquake on July 7, 1910, which is thought to have had its origin near Skagway, was felt at that town for perhaps 28 seconds (Tarr and Martin, 1912) and presumably was felt also at Haines.

Table 4.—Partial list of earthquakes felt and possibly felt at Haines, Alaska, 1847-1969

Apr. 9(?), 1847	felt?	July 7, 1910	felt?	Apr. 10, 1930	felt?†	July 17, 1946	felt?†	July 25, 1954	felt?†	Oct. 14, 1960	felt[2]
Oct. 27, 1880	felt?	Dec. 15, 1919	felt?†	Feb. 24, 1932	felt[2]	Oct. 3, 1946	felt?†	Mar. 30, 1955	felt?†	Aug. 15, 1961	felt?
Oct. or Nov. 1898	felt?	Mar. 22, 1920	felt?	May 7, 1932	felt[1]	Apr. 2, 1947	felt?†	July 11, 1955	felt?†	June 24, 1963	felt?
Aug. 10, 1899	felt?	Feb. 5, 1923	felt?	May 27, 1932	felt[2]	Apr. 30, 1947	felt?†	July 16, 1955	felt?†	Oct. 15, 1963	felt?
Sept. 4, 1899	heavy* shocks	Apr. 22,24,1923	felt?	Aug. 31, 1933	V[2]	June 29, 1947	felt?†	July 24, 1955	felt?†	Oct. 16, 1963	felt?†
Sept. 10, 1899	felt*	Apr. 25, 1923	felt?	Sept. 19, 1933	felt?	Nov. 18, 1947	felt?†	July 31, 1955	felt?	Oct. 19, 1963	felt?
Sept. 16, 1899	felt?	Apr. 30, 1923	felt?	Dec. 19, 1933	felt[2]	Nov. 28, 1947	felt?†	Oct. 28, 1955	felt?	Oct. 24, 1963	felt?†
Sept. 17, 1899	felt?	Feb. 23, 1925	felt[2]	Jan. 5, 1935	felt[2]	May 17, 1948	felt?†	Nov. 30, 1955	felt?	Dec. 20, 1963	felt?†
Sept. 23, 1899	felt?	Apr. 29, 1925	felt?	Jan. 13, 1935	felt[2]	May 28, 1948	felt?†	Nov. 3,4,1956	felt?	Dec. 23, 1963	felt?†
Sept. 26, 1899	felt?	Jan. 24,26,1927	felt[1]	July 6, 1935	felt[2]	June 6, 1948	felt?†	June 21, 1957	felt?†	Jan. 15, 1964	felt?
Sept. 30, 1899	felt?	June 29, 1927	felt[1]	June 11, 1938	felt[1]	Dec. 28, 1948	felt?†	June 23, 1957	felt?†	Mar. 28, 1964	VII[2]
Oct. 9, 1900	felt?	Oct. 24,25,1927	felt?	Oct. 14, 1938	felt?	Mar. 23, 1949	felt?†	Aug. 18, 1957	felt?†	Apr. 26, 1964	felt?†
Aug. 17, 1902	felt?	Nov. 12, 1927	felt[2]	Aug. 10, 1941	felt?	Aug. 22, 1949	felt?	Dec. 9, 1957	felt?†	Apr. 30, 1964	felt[2]†
Sept. 24, 1907	felt[2]	Nov. 21, 1927	felt[1]	June 12, 1942	felt?	Jan. 4, 1950	felt[1]	May 5, 1958	felt[2]	June 13, 1964	felt?
May 15, 1908	felt?	Dec. 31, 1927	felt[2]	Feb. 3, 1944	felt?	July 28, 1950	felt?†	June 19, 1958	felt?	Oct. 7, 1966	felt?
Feb. 16, 1909	felt?	Feb. 1, 1928	felt[2]	Oct. 15, 1945	felt?	Aug. 10, 1950	felt?†	July 10, 1958	VI?[3]	Oct. 17, 1967	felt?
Oct. 26, 1909	felt?	Apr. 27, 1928	felt[2]	Nov. 16, 1945	felt?	Mar. 9, 1952	felt?†	July 13, 1958	felt?		
Mar. 14, 1910	felt?	Nov. 12, 1929	felt[1]	May 4, 1946	felt?†	Sept. 27, 1952	felt?†	July 18, 1958	felt?		
				May 6, 1946	felt?†	Sept. 28, 1952	felt?	Nov. 29, 1958	felt[2]		

Dates are U.T. (Universal Time, or Greenwich Mean Time)

felt Report of single or multiple earthquake shock of unknown intensity

felt? Earthquake possibly felt at Haines but not reported (earthquake known to have occurred elsewhere in region and (1) reported there as felt, or (2) recorded only instrumentally)

III,V,VI Reported intensity using Modified Mercalli earthquake intensity scale (see Table 5)

* Data from Tarr and Martin (1912)

† Report of earthquake being felt along or near the Chilkat River fault but not reported as being felt at Haines

1 Report from weather observer, 1908-1958, U.S. Weather Bureau, Monthly Climatological Data Summaries

2 Data from U.S. Coast and Geodetic Survey (U.S. Earthquakes, yearly publication since 1928), Heck (1958), Eppley (1965) or Wood (1966)

3 Intensity estimated by authors from data by Davis and Sanders (1960)

The Lituya Bay earthquake of July 10, 1958 (designation P in fig. 11), was felt strongly at Haines and reportedly alarmed everyone. Hairline cracks reportedly were formed in the dock of the U.S. Army tank farm, 3 miles north if Haines, and slides were triggered near Pyramid Harbor (fig. 2), about 4 miles southwest of Haines (Harry Young, Haines, Alaska, oral commun., 1965). Underwater communication cables were broken near Haines by submarine slides. A few toppled chimneys that we observed in Port Chilkoot may have fallen during this quake. Intensity at Skagway was given as VI (Davis and Sanders, 1960). The same or a slightly higher intensity for similar geologic units in Haines seems reasonable.

The great Alaskan earthquake of March 27 (Mar. 28, Greenwich Mean Time), 1964, of magnitude 8.3 to 8.4 presumably was only weakly felt by a few at Haines. However, an underwater communication cable along the face of the Katzehin River delta (about 5 miles southeast of Haines) broke 8 hours after the shock, probably by a submarine slide that may have been induced by the shock (Alford, U.S. Alaska Communication System, written commun., 1966). The U.S. Coast and Geodetic Survey (Wood, 1966) assigned an intensity of III at Haines. It is interesting to note from table 4 that there are intervals covering a considerable period of time when no earthquakes reportedly were felt in the Haines area. One such interval extends from October 17, 1967, to the end of 1969 (last date for which epicenter data are plotted on fig. 11).

Microearthquake seismicity studies, made along a major part of the Denali fault system by Boucher, Matumoto, and Oliver (1968) and Boucher and Fitch (1969), show that during the periods of investigations the Haines area had one of the three highest rates of microearthquake activity anywhere along the studied part of the fault system. Rates of local microearthquake activity along different segments of the fault ranged from 0 to 40 events per day. About 32 shocks a day were recorded near Haines by Boucher and Fitch (1969). As they further point out, limited evidence lends support to the idea that these microearthquakes were generated preferentially along the fault zone and that the activity near Haines seemed to be localized along the Chilkat River fault.

Relation of earthquakes to known or inferred faults and recency of fault movement

The variable accuracy of locating earthquake epicenters, particularly during the 19th century and early 20th century, plus incomplete knowledge of fault locations, make it difficult to directly relate seismicity in southeastern Alaska to known and inferred faults. In spite of these difficulties, most of the larger and many of the smaller earthquakes probably can be related to the faults shown in figures 7, 8, and 9 in the section entitled "STRUCTURE."

All of the large and many of the moderate and smaller size historical earthquakes in southeastern Alaska and adjacent areas appear to be related to the Fairweather-Queen Charlotte Islands fault system and the connecting Chugach-St. Elias fault or to their branches (fig. 8). Thus, most have epicenters close to the coast or offshore in Gulf of Alaska and in the northern Pacific Ocean. Although late Pleistocene movement is well defined along the Totschunda fault system (fig. 7), evidence of very recent movement is lacking (Richter and Matson, 1971) and few if any historical recorded earthquakes have epicenters that appear to be related to movement along this fault system.

The onland segment of the Fairweather fault, as well as probably its western extension, the Chugach-St. Elias fault (fig. 7), has been very active tectonically during Quaternary time (Grantz, 1966; Page, 1969; George Plafker, written commun., 1971). The epicenter of the great Yakutat earthquake of September 10, 1899, (magnitude 8.6) was not accurately located but is believed to have been near the head of Yakutat Bay where there was movement on portions of the Fairweather fault or on one of its western extensions (Tarr and Martin, 1912). Likewise, during the Lituya Bay earthquake of 1958 (magnitude 8.0), there was movement along the entire onland length of the Fairweather fault, with 21 1/2 feet of right-lateral slip and 3 1/2 feet of associated dip-slip (up on the south) measured in one place (Tocher and Miller, 1959; George Plafker, written commun., 1971). From late Pliocene or early Pleistocene to Holocene time, the land northeast of the fault is thought to have been uplifted more than 3 miles (5 km) and the fault has undergone associated right-lateral slip of unknown magnitude (Grantz, 1966).

That the southeastern offshore extension of the Fairweather fault, which appears to connect with the Queen Charlotte Islands fault, is also active is indicated by the fairly large number of earthquake epicenters in that area (figs. 8 and 11). Although the assigned epicentral locations are not well alined, probably most of the earthquakes are related to movement along the Fairweather fault. Lack of alinement can be explained by inaccurately located epicenters or by the epicenters being along more than one branch of the fault system. That there is branching and splaying along at least part of the fault system is verified by the fault pattern on land in the Yakutat-Lituya Bay area (Grantz, 1966; Plafker, 1969; 1971).

High seismicity along the entire length of the concealed Queen Charlotte Islands fault (as far south as Vancouver Island) is well documented by the large number of earthquakes that appear to be related to the fault. These earthquakes have ranged in size from the large earthquake (magnitude 8.1) of August 22, 1949 (L in fig. 11), through several earthquakes of magnitude 6 to 7, to numerous earthquakes of smaller magnitude. Here, also, the epicenters are not well alined but they do fall, nevertheless, along a fairly definite offshore northwest-southeast belt that strongly suggests a relation to an active fault zone (Gutenberg and Richter, 1954; St. Amand, 1957; Wilson, 1965; Tobin and Sykes, 1968).

As shown by figure 11, the number of earthquakes related to the Shakwak valley, Chilkat River, Lynn Canal, Chatham Strait segments of the Denali fault system (fig. 8) is small as compared to the number along the Fairweather and Queen Charlotte Islands faults. The reason for the relatively low seismicity on these fault segments may be due to the fact that this part of the Denali fault system amy have been rendered relatively inactive tectonically in favor of movement along the newer Totschunda fault system. As suggested by Richter and Matson (1971) the Totschunda fault system may represent part of a new transform fault segment of the Denali fault system, which bypasses the Denali fault system in Canada and southeastern Alaska and leaves it as a more passive tectonic segment. However, that this part of the Denali fault system is not everywhere passive is evident from the number of earthquake epicenters that appear to be related to segments of it.

Only two earthquakes appear to be related to the Chatham Strait fault. This may be due to the fact, as pointed out by Grantz (1966), that movement along this fault probably occurred mostly during Tertiary time.

Historic movement along the Chilkat River fault in the vicinity of Haines and possibly along the northern part of the Lynn Cánal fault appears to be greater than along the Chatham Strait fault. This is indicated by the occurrence on or near the fault system of one earthquake of magnitude 6 (N of fig. 11) and several earthquakes of magnitude less than 5 or of uncomputed magnitude. Also, numerous small shocks (table 4), probably mostly of local origin, were reported (U.S. Weather Bureau, Climatological Data, various years) by volunteer weather observers stationed during intermittent periods at Moose Valley (25 miles northwest of Haines), at Porcupine Creek (30 miles west-northwest of Haines), and at Linger Longer (a roadhouse or lodge about 35 miles west-northwest of Haines). Felt shocks were reported from time to time during the period 1930-1935 at Porcupine Creek, during 1946-1957 at Moose Valley, and during 1963-1964 at Linger Longer--periods when observers were present at these locations. There also were a number of small earthquakes that were felt at Haines but not reported from elsewhere—particularly during the period 1947-1950. Many or most of these small earthquakes felt at Haines and to the northwest may have had their origin along the Chilkat River fault or a branch of that fault, or they may have been due to tectonic changes resulting from the relatively rapid glacio-isostatic rebound of the land. Also, as previously discussed, microearthquake activity near Haines was high during about 7 hours of observation in 1967 and appeared to be localized along the Chilkat River fault (Boucher and Fitch, 1969).

As discussed previously, most of the movement along the Chilkat River fault may have occurred partly during Early and Late Cretaceous and partly during post-Paleocene to Miocene time (Grantz, 1966). Boucher and Fitch (1969) concluded, however, on the basis of their microearthquake studies, that "the Denali fault is active in some sense along its entire length east of Mount McKinley * * * and it probably should not be dismissed as a relic fault of no current tectonic importance." The high microearthquake activity, they suggest, may document the occurrence of very large earthquakes in the past. A possible alternate explanation, given by them, is that the microearthquakes are signatures of some kind of background seismicity such as that associated with a creep phenomenon.

The Shakwak valley fault segment of the Denali fault system, northwest of Kluane Lake (fig. 8), is believed to have moved in recent centuries (Bostock, 1952). Its prominent topographic trace along the Shakwak valley is marked locally by fault scarps of Holocene age and by right-laterally offset topographic features. Right-lateral offsetting of 1 mile, and perhaps as much as 3 miles, of the glaciated Shakwak valley is suggested to have occurred since early Pleistocene time. The northeast side of the fault is indicated to have been upthrown more than one-half mile since Oligocene time and large strike-slip displacement movement is believed to have taken place in Miocene to early Pliocene time or later (Grantz, 1966). Several earthquakes that occurred in historical time may be related to the more recent movement. The epicenters for three earthquakes of magnitudes between 5 and 6 and of several others of magnitudes less than 5 or uncomputed are located in the vicinity of Kluane Lake (see figs. 8 and 11) and may be related to movement along the fault. An earthquake of magnitude 6 1/2, on February 3, 1944, had its epicenter in the vicinity of Kathleen Lake (about 40 miles southeast of Kluane Lake). This may indicate movement along the southeast extension of the fault near its indicated juncture with the Chilkat River fault.

Assessment of earthquake probability in the Haines area

As indicated in a regional report by us (Lemke and Yehle, 1972), data still are too few to permit more than a general assessment of earthquake probability in southeastern Alaska. Therefore, a rigorous evaluation of earthquake probability in the much smaller Haines area must await a longer record of seismic events and a better knowledge of the tectonic framework of the area. However, some generalizations, based upon the present state of knowledge, appear warranted.

Seismic probability maps, as well as strain-release and earthquake acceleration probability maps, compiled for southeastern Alaska and adjacent Canada, permit a general assessment of earthquake probability in the Haines area. A seismic probability map (fig. 12), prepared by the U.S. Army Corps of Engineers in 1957 and revised in 1965 (Warren George, U.S. Army Corps of Engineers, written commun., 1968; 1971) places Haines in zone 3—a zone where the largest expectable earthquakes would have magnitudes greater than 6.0[5] and where major damage to manmade structures could be expected. A seismic zone map (fig. 13) in the 1970 edition of the Uniform Building Code (International Conference of Building Officials, 1970) places Haines in zone 2—a zone where moderate damage to manmade structures is possible. On the other hand, a recent detailed study of earthquakes in Canada has led to the development of a new seismic zone map, which shows all of the coastal region of western Canada, all of southeastern Alaska, the northwest part of British Columbia, and most of

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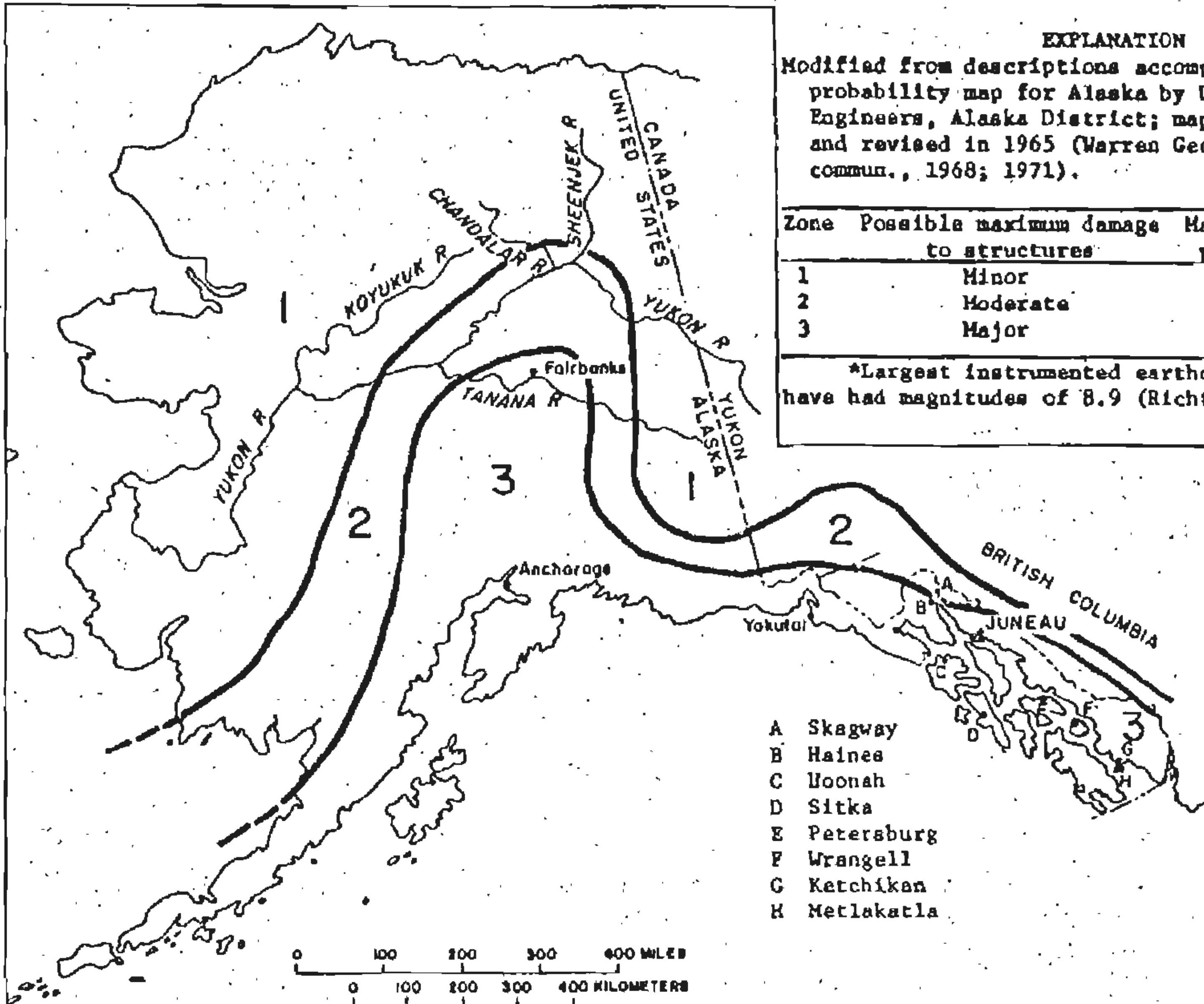
[5] The largest instrumented earthquakes of the world have had magnitudes of 8.9. Therefore, earthquakes of magnitude as great as 8.9 could conceivably occur in zone 3.



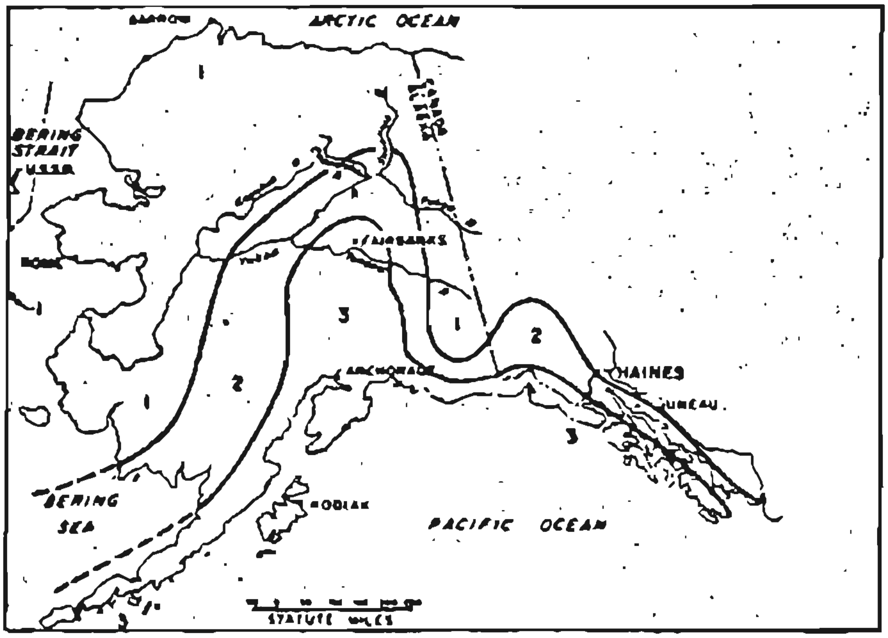
EXPLANATION

Modified from descriptions accompanying the seismic probability map for Alaska by U.S. Army, Corps of Engineers, Alaska District; map prepared in 1957 and revised in 1965 (Warren George, written commun., 1968; 1971).

Zone	Possible maximum damage to structures	Magnitude of largest probable earthquake
1	Minor	3.0-4.5
2	Moderate	4.5-6.0
3	Major	>6.0*

*Largest instrumented earthquakes of the world have had magnitudes of 8.9 (Richter, 1958).

Figure 12.--Seismic probability map for most of Alaska as modified from U.S. Army Corps of Engineers, Alaska District.



ZONE 1 - Minor damage: distant earthquakes may cause damage to structures with fundamental periods greater than 1.0second; corresponds to intensities V and VI of the MM* Scale

ZONE 2 - Moderate damage: corresponds to Intensity VII of the MM* Scale

ZONE 3 - Major damage: corresponds to Intensity VIII and higher of the MM* Scale

*Modified Mercalli Intensity Scale of 1931

Figure 13. Seismic zone map of Alaska. Modified from the 1970 edition of the Uniform Building Code (International Conference of Building Officials, 1970).

the Yukon Territory as being in zone 3 (National Research Council of Canada, 1970). Zones are similar to those prepared for the United States, ranging from 0, where no damage is expected, to 3, where major destructive earthquakes may occur (Hasegawa, 1971). In zone 3 of this map the estimated maximum intensity, as measured on the Modified Mercalli scale, falls between VIII and IX and the corresponding horizontal ground acceleration may be taken as 50 percent of gravity (Ferahian, 1970). According to a strain-release map (fig. 14) of Milne (1967), Haines falls on contour 4 of his map, which indicates that a single earthquake as great as magnitude 6.7 would be necessary to release all the energy that accumulates in 100 years, or 3.5 earthquakes of magnitude 6, or 20 earthquakes of magnitude 5. A 100-year probability map (fig. 15) of Milne and Davenport (1969) shows that Haines is in an area in which a peak earthquake acceleration of 40 percent of gravity is a possibility. Thus, on the basis of table 5, which shows approximate relations between acceleration, magnitude, and intensity, an earthquake of magnitude 6.9 and with an intensity on firm ground of IX is possible in a 100-year period in the Haines area.

It is obvious that agreement is not close between the above-described maps as to earthquake probability in the Haines area. At least part of this divergence is due to the fact that some of the maps, such as the strain-release map of Milne (1967) and the earthquake acceleration map of Milne and Davenport (1969), are based solely upon the seismicity of the area since 1898. As discussed previously, the seismic record of southeastern Alaska is far too short to permit an assessment of earthquake probability on this basis alone. Also, the seeming differences in assessment of seismic risk between the U.S. Army Corps of Engineers' map (fig. 12), the Uniform Building Code map (fig. 13), and the seismic zone map of Canada may be more apparent than real because the three maps are not assessing all the same factors. The Uniform Building Code seismic zone map sets up only minimum building standards to be met by industry. The earthquake probability map of the Corps of Engineers (fig. 12), on the other hand, attempts to assess the overall earthquake probability of the area, and thus, expectedly would show a higher risk value. The Uniform Building Code seismic zone map and the seismic zone map of Canada, although similar in some respects, apparently differ in some of their derivative factors.

In addition to assessing the earthquake probability of the Haines area on the basis of the above-described maps, a number of specific geologic factors, whose pertinency has been demonstrated in studies of earthquakes in numerous other places, also have to be considered. Some of these factors are: (1) faults that long have been inactive may suddenly become reactivated, (2) faults active during Quaternary time may be inactive during most of historical time but suddenly become reactivated, (3) certain presently inactive segments of otherwise active fault systems can be expected to become active in the future, (4) the occurrence of small earthquakes is not necessarily an indication of where large earthquakes may occur or vice-versa, and (5) large earthquakes may occur in areas where there is little or no record of seismicity and no obvious tectonic structure that would result in an earthquake. These five factors,

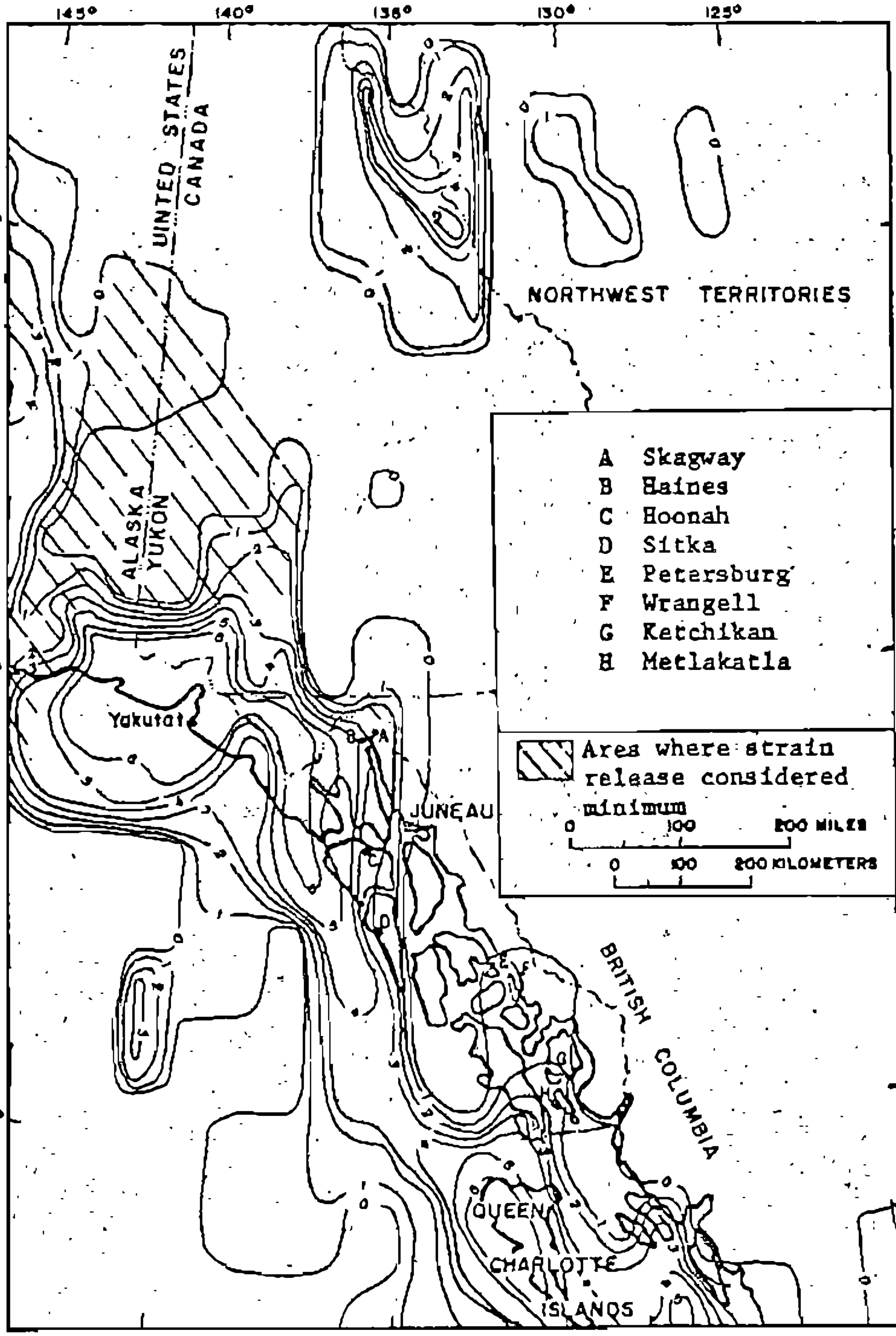


Figure 14.—Strain-release map of seismic energy 1898-1960, inclusive, in southeastern Alaska and part of adjacent Canada with explanation showing interpreted frequency of energy release. Modified from Milne (1967).

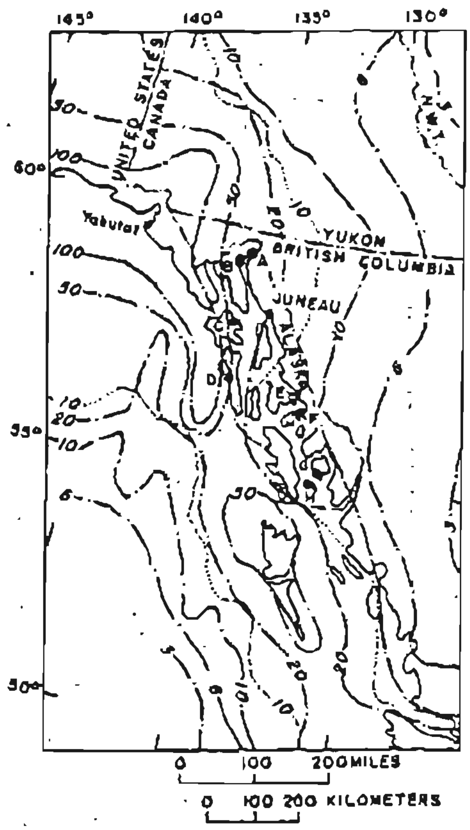
EXPLANATION FOR FIGURE 14

Map contour	Energy level in strain release units[1]	Interpreted frequency per 100 yrs of certain magnitudes (M)[2] necessary to release all of energy level				Interpreted magnitude necessary to release all of energy level in a single event per 100 yrs
		M 5	M 6	M 7	M 8	
0	0.1	---	-----	----	----	3.7
1	1	1	-----	----	----	5.0
2	5	5	-----	----	----	5.9
3	10	10	1.8	----	----	6.3
4	20	20	3.5	----	----	6.7
5	50	50	8.9	1.6	----	7.3
6	100	100	17.8	3.1	----	7.7
[3] 7	200	200	36	6.5	1.03	8.1
8	500	500	90	15	2.5	8.6
9	700	700	120	21	3.5	8.7

[1]Energy level, strain-release (Benioff, 1951) unit here defined in terms of energy of a magnitude 5 earthquake $(10^{1.5(M-5)/2})$ per area $(10^4\ km^2)$ based on earthquakes 1898–1960 inclusive, extended to a 100-year base.

[2]A one-unit increase in magnitude is about a 30-fold increase in energy release and a two-unit increase is a 900-fold increase (Steinbrugge, 1968).

[3]Northern area of contour 6 has a maximum energy of 700 strain-release units; southern area of contour 6 has 236 units. Contours 7, 8, and 9 are not shown on map; tabular data for 7, 8, and 9 have been extended by the writers.



EXPLANATION

Average-value method		Extreme-value method
	3	
	6	
10 ←	10	6
	20	
	50	
	100	

Contours showing peak earthquake acceleration as a percent of gravity (about 982 cm/sec^2 for southeastern Alaska at sea level*)

A	Skagway	E	Petersburg
B	Haines	F	Wrangell
C	Hoonah	G	Ketchikan
D	Sitka	H	Metlakatla

*See table 5 showing relations between acceleration units, energy, magnitude, and intensity.

Figure 15.—One-hundred-year probability map showing peak earthquake accelerations for southeastern Alaska and part of adjacent Canada. Modified from Milne and Davenport (1969). Based upon earthquake strain release from 1898-1960 (extended to a 100-year interval) as interpreted by an extreme-value method and using data from all instrumented earthquakes. For comparison of method, another interpretation is offered through an average-value method (dotted contour on map) which uses only earthquakes having an acceleration of 10 percent gravity.

Table 5.—Approximate relations between earthquake magnitude, energy, ground acceleration, acceleration in relation to gravity, and intensity (modified from U.S. Atomic Energy Commission, 1963)

M[1]	E[2]	a[3]	a/g[4]	I[5]	
	10^{14}			I	Detected only by sensitive instruments
	10^{15}	2, 3		II	Felt by a few persons at rest, especially on upper floors; delicate suspended objects may swing
3	10^{16}	4, 5, 6, 7	.005g	III	Felt noticeably indoors, but not always recognized as a quake; standing autos rock slightly, vibration like passing truck
4	10^{17}	8, 9, 10	.01g	IV	Felt indoors by many, outdoors by a few; at night some awaken; dishes, windows, doors disturbed; motor cars rock noticeably
	10^{18}	20		V	Felt by most people; some breakage of dishes, windows, and plaster; disturbance of tall objects
5	10^{19}	30, 40, 50, 60	.05g	VI	Felt by all; many frightened and run outdoors; falling plaster and chimneys; damage small
6	10^{20}	70, 80, 90, 100	.1g	VII	Everybody runs outdoors; damage to buildings varies, depending on quality of construction; noticed by drivers of cars
	10^{21}	200, 300		VIII	Panel walls thrown out of frames; fall of walls, monuments, chimneys; sand and mud ejected; drivers of autos disturbed
7	10^{22}	400, 500, 600	.5g	IX	Buildings shifted off foundations, cracked, thrown out of plumb; ground cracked; underground pipes broken
		700, 800, 900, 1000	1g	X	Most masonry and frame structures destroyed; ground cracked; rails bent; landslides
8	10^{23}	2000, 3000		XI	Few structures remain standing; bridges destroyed; fissures in ground; pipes broken; landslides; rails bent
	10^{24}	4000, 5000	5g	XII	Damage total; waves seen on ground surface; lines of sight and level distorted; objects thrown up into air

These relations until 1971 are believed to have applied fairly well in southern California where the average focal depth of earthquakes has been about 10 miles (16 km). (See Gutenberg and Richter, 1956; Hodgson, 1966.) However, revisions of these relations may be necessary because of the exceptionally high accelerations resulting from the San Fernando, Calif., earthquake of February 9, 1971, when the earthquake, of magnitude 6.6, produced accelerations of as much as 1 g (Maley and Cloud, 1971).

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[1] M, magnitude scale, according to Richter (1958). [2] E, energy, in ergs. [3] a, ground acceleration, in centimeters per second^2. [4] a/g, ground acceleration shown as a percent of the acceleration of gravity (about 981 cps^2 or about 32.2 fps^2; adopted as a standard by the International Committee on Weights and Measures). [5] I, Modified Mercalli intensity scale (abridged from Wood and Neumann, 1931); complete description of scale units given in Richter (1958).

most of which cannot now be properly evaluated locally, are discussed in our regional report of southeastern Alaska (Lemke and Yehle, 1972); also, a number of worldwide earthquake examples are given in that report to illustrate how the factors apply.

In summary, it is not now possible to assess with any great degree of precision the earthquake probability of the Haines area. Seismic records alone indicate that the largest expectable earthquakes for the Haines area would be of only moderate size (between magnitudes 6 and 7) and at only infrequent intervals. It must be remembered, however, that the Haines area is in the second most seismically active region in Alaska and that the region constitutes a part of the highly active circum-Pacific seismic belt where earthquakes of magnitude 8 and greater have occurred. In fact, five earthquakes of magnitude 8 or greater have occured in southeastern Alaska and vicinity in historic time along or near the tectonically active Fairweather-Queen Charlotte Islands fault system (fig. 7) or along the Chugach-St. Elias fault. Therefore, the Haines area may well have a higher earthquake probability than that indicated solely by the historic seismic record. The possibility of an earthquake as great as magnitude 8, or even greater, in the general area of Haines cannot be ruled out. For these reasons, the placing of Haines in seismic zone 3, as assigned (fig. 12) by the U.S. Army Corps of Engineers, seems reasonable to us. Moreover, it should be emphasized that intensities from fairly distant large earthquakes, such as may occur along the Fairweather-Queen Charlotte Islands fault, will be attenuated with distance from the epicenter but still may be sufficiently high at Haines to cause damage either directly or indirectly from shaking (see Lemke and Yehle, 1972, for discussion of attenuation of earthquake intensity with distance).

INFERRED EFFECTS FROM FUTURE EARTHQUAKES

As discussed previously, lack of knowledge of a number of geologic factors that are critical in considering the earthquake potential of the Haines area necessitates evaluating the possible effects on the basis of the highest expectable possibility. Therefore, it will be assumed that earthquakes of magnitude as great as 6 may occur in the area or vicinity from time to time and that an earthquake of magnitude as great as 8, or perhaps even larger, may sometime occur.

Because of the reconnaissance nature of the study and sparsity of laboratory data on physical properties of geologic units, the discussion of inferred geologic effects from future earthquakes in the mapped area and immediately adjacent areas must of necessity be largely empirical and generalized. The inferences, by and large, are based upon the effects of major earthquakes on similar-appearing geologic units in other places, particularly the effects of the Alaskan earthquake of 1964 (see Lemke and Yehle, 1972). It must be emphasized, however, that the properties of the geologic units in the mapped area (fig. 3) may not be the same as those being compared from other areas even though they superficially may resemble them. Moreover, the physical setting and other factors, which could markedly influence the effects, also may differ. For these reasons, the assumptions that follow should not be rigorously interpreted or applied. Rather, they are intended as broad guidelines useful in assessing the kind and degree of hazard that may be present in the Haines area and leading toward minimizing these hazards as they affect man and his structures. As such they are directed to structural and civil engineers, city and regional planners, and public and private utility companies, and all other public and private groups or individuals who are responsible for the safety and welfare of Haines and its environs, now and in the future. However, the interpretations that follow are in no way intended to preclude the making of additional detailed geologic and engineering studies, particularly those studies that pertain to small tracts or individual sites. In fact, we recommend that such additional studies be made whenever possible.

Surface displacement on faults and other tectonic land changes

In attempting to assess the damage potential from tectonic land changes in the Haines area, the location of faults in respect to present or planned facilities is an important consideration. However, as stated previously, the presence and locations of faults are known only in a general way, the faults being for the most part concealed beneath water of fiord inlets or of valley fill, and in some instances the very existence of a fault is speculative.

The Chilkat River fault or fault zone, as discussed previously, is believed to trend up the Chilkat Inlet and the Chilkat and Kelsall River valleys (figs. 8 and 9). The almost total absence at the present time of manmade structures along the inferred trace of the fault in the Haines area makes it unlikely that there would be significant damage from the direct effects of surface displacement of the fault. About the only present facilities that might be affected would be short segments of the highway and the petroleum pipeline north of Haines and then only if the fault location is such that it impinges against the northeast wall of the Chilkat River valley. One place where the topography suggests that the fault might impinge against the northeast valley wall is about 7 miles northwest of Haines, opposite the mouth of Kicking Horse River (see fig. 2). If the Haines-Juneau highway is built across the Chilkat River, as now proposed, displacement along the Chilkat River fault probably would affect that segment of the highway that crosses the river and associated river flats less than one-half mile upstream from the aircraft landing strip. The proposed highway project includes approximately 3,925 feet of causeways and three bridges with a total footage of approximately 1,111 feet (Franklet, 1968). Because the trace of the fault or fault zone in this area can only be inferred as being some place between the valley walls, one cannot speculate whether the causeway or the bridges would be most affected if there is future horizontal or vertical movement along the fault.

The location of the inferred Chilkoot Inlet fault or fault zone in the vicinity of Haines is even more speculative than that of the Chilkat River fault. If, as shown on figure 9, its trend is about 2 miles east of Haines, surface breakage along its length would not directly affect the onshore facilities unless accompanied by regional tectonic uplift or subsidence. The only offshore facilities that might be affected are the communication cables between Skagway and Haines as well as those cables that extend down Chilkoot Inlet toward Juneau. Significant vertical or horizontal ground displacement could break the cables where they cross the fault.

As discussed previously, the inferred Takhin fault or fault zone may extend eastward down the Takhin River valley and through the saddle where Haines is built. The abrupt northern escarpment of the saddle may mark the northern side of the fault or, as seems more likely, a fault zone. A second parallel fault may bound the southern side of the saddle and additional faults (see fig. 10) are indicated in the more central part of the saddle. These series of faults may form a grabenlike structure. If this structural picture is correct, surface fault breakage during an earthquake, along one or more of these postulated faults, could directly affect facilities built athwart these structures. Facilities affected by either horizontal or vertical displacement causing dislocation or rupture might include roads and streets, buildings, port and communication facilities, the petroleum pipeline along the base of the northern escarpment of the saddle, waterlines and sewerlines, and the aircraft landing strip northwest of Haines.

In addition to damage to manmade structures directly from fault displacement, sudden tectonic regional uplift or subsidence of the land resulting from an earthquake could produce adverse effects in the Haines area. In general, the amount of land-level change would determine the amount of expectable damage. The greatest damage probably would be to facilities along the waterfront.

Based upon amounts of land-level changes associated with large earthquakes elsewhere, uplift or subsidence greater than 10 feet is possible but unlikely in the Haines area. Therefore, effects from land-level changes greater than 10 feet will not be discussed here. It is interesting to note, however, that if the land subsided 30-40 feet a sea connection at high tide would exist between McClellan Flats and Chilkoot Inlet.

A hypothetical regional uplift of 10 feet would produce several significant changes along the shorelines of Chilkoot Inlet and Chilkat Inlet. The Haines small-boat harbor would be rendered useless without additional dredging in the harbor itself and in the channel leading to it. The water also would be too shallow adjacent to other docks in the area (including the ferry terminal in Lutak Inlet north of Haines) to permit docking of larger boats. Considerable additional beach area would be exposed along much of the shoreline of Portage Bay. On the Chilkat Inlet side, all of McClellan Flats would be raised several feet above high tide and newly emergent deposits would be exposed some distance farther down the inlet. The uplifted Chilkat River would soon erode to grade in the alluvium of McClellan Flats and probably would be confined for awhile to one or a few channels in that area rather than flowing in the present braided channel system.

A tectonic subsidence of 10 feet also would produce significant changes. The Haines small-boat harbor would be rendered ineffectual because the breakwater walls would be too low to prevent overtopping by larger waves. The decks of docks would be too low to allow unloading at high tide. The shoreline of Portage Bay would advance inland so that the waterfront area of Haines would be subject to erosion from storm waves, especially at high tide. Likewise, lower lying segments of the road leading north to the ferry terminal could be damaged in a similar manner. Whether sewers would be impaired by their outlets into Portage Bay being too low cannot be evaluated by us. A substantial amount of presently low-lying land would be inundated adjacent to Chilkat Inlet. All of McClellan Flats would be covered by marine water even at low tide, and high tides would extend up the Chilkat River valley probably to about the mouth of the Kicking Horse River (about 6 miles northwest of Haines). Deposits, similar to those forming McClellan Flats, would be built at the new mouth of the river and eventually cover the lower part of the valley floor in that area. Large segments of the Haines Highway, from the vicinity of the mouth of the Kicking Horse River to near Haines, would be inundated at high tide or subject to bank erosion. The aircraft landing strip northwest of Haines would be completely covered at high tide, even if the subsidence were on the order of 5 feet. Likewise, the low-lying area southeast of the aircraft landing strip (area shown by symbol (Qemy) on fig. 3) would be inundated even with 5 feet of subsidence.

Ground shaking

The amount of ground shaking (intensity) at any one place is dependent upon a great many variables, including: magnitude of the earthquake, distance from the epicenter, acceleration, period, duration of shaking, amplitude of the seismic waves, physical properties of the ground, geologic structure, and ground water (Barosh, 1969). The variable most responsible for the range of shaking at any epicentral distance, however, is the type of ground.

Although much remains to be learned and many effects are not clearly understood, it is generally found that ground vibration (shaking) is considerably greater in poorly consolidated deposits than in hard bedrock. Moreover, in poorly consolidated deposits, the thicker the beds and the finer the grain of the deposits, the more subject the deposits generally are to destructive ground motion. This is particularly true if the deposits are water saturated. For example, Neumann and Cloud (1955) state that a rock outcrop (such as granite) and an adjoining area of unconsolidated deposits may have as much as a 10-15-fold difference in acceleration. Gutenberg (1957), in comparing relative amplitudes of earthquake motion for different types of ground, assigned the following amplitude factors, using solid rock as 1: sandstone as much as 3; dry sand, about 3 1/2; and marshy land, 12. Except for some types of manmade fill, alluvium is generally subject to the strongest shaking of any type of deposit, particularly if water saturated or in those places where seismic waves emerge abruptly from rock into alluvium (Richter, 1959). In such cases, it has been estimated that [illegible] ~~amplitude~~ may increase as much as 22-fold or a rise from VI to X on the Modified Mercalli scale (Neumann, 1954).

Sufficient geological and seismological data are not available for the Haines area to assess the amount of expectable shaking of the geologic units during an earthquake other than to make rough comparisons of degree of shaking between the geologic units. In attempting to make such comparisons, we have tentatively divided the geologic units into three general categories: (1) those units where the strongest shaking is expected, (2) those units where shaking is expected to be intermediate between the other two categories, and (3) those units where the least shaking is expected. In some cases, one unit may fall into more than one category.

On this basis the geologic units in the Haines area are tentatively assigned to the following categories:

Category 1: strongest expectable shaking
- A. Manmade fill, Qf
- B. Chilkat River flood-plain and delta deposits, Qr
- C. Modern beach deposits, Qb
- D. Colluvial deposits, Qc (part of unit)
- E. Alluvial fan deposits, Qaf (part of unit)
- F. Elevated fine-grained marine deposits, Qem and Qemy

Category 2: intermediate expectable shaking
- A. Colluvial deposits, Qc (part of unit)
- B. Alluvial fan deposits, Qaf (part of unit)
- C. Elevated shore and delta deposits, Qeb
- D. Outwash and ice-contact deposits, Qo
- E. Drift deposits, undifferentiated, Qd

Category 3: least expectable shaking
A. Igneous rocks, Kc and Ked
B. Metamorphic rocks, Mzm and Mzp

It should be emphasized that, although the above categories show comparative amounts of expectable shaking of the different geologic units, the amount of expectable damage to manmade structures built upon these units may not be directly related. There are several other factors, mostly pertaining to differing engineering aspects of the structures that may markedly affect the amount of ensuing damage and even may be the dominant factor. Whether a structure is built of wood, cinder blocks, bricks, or concrete (reinforced or nonreinforced) can markedly affect the amount of damage. Likewise, the design of the building in relation to the foundation conditions and whether it is built to be earthquake resistive or not are significant factors. Also the height and rigidity of the building, particularly in respect to the natural frequency of the building in comparison to the period of the seismic waves, are factors that may significantly affect the damage potential. Thus, a more or less direct comparison between amount of ground shaking and ensuing damage to structures can be made only between similar structures. It, therefore, is the responsibility of the engineer to be as aware as possible of the comparative ground intensities of the different geologic units, to collect additional data on soil properties whenever necessary, and to design in conformity with the ground conditions.

Geologic units in Category 1 (strongest expectable shaking)

Shaking of geologic units in this category is expected to be stronger than shaking of geologic units in categories 2 and 3 in the same locality for a specific earthquake.

Manmade fill (Of).--It has been dramatically illustrated during past large earthquakes that manmade fill is generally subjected to strong shaking, commonly with resultant heavy damage to structures built upon it. The strong ground motion is due in large measure to the composition of material constituting the fill, to the looseness of the emplaced material, and to emplacement of the fill upon poorly consolidated and fine-grained deposits that themselves are subject to strong shaking. It should be noted, however, that engineered fills (those properly compacted by standard engineering methods) may not be subject to such a degree of shaking.

Wood's study (1908) of the San Francisco earthquake of 1906 showed that the most severe damage was on manmade fill, with damage successively less severe on alluvium, conglomerate, shale, and hard rock. Damage was 5 to 10 times greater on fill than on hard rock. Although some of the damage undoubtedly was due to associated effects, such as ground fracturing and differential settlement, the effect of shaking probably was the dominant cause. The same trend has been found for earthquakes in eastern Canada, Germany, Chile, Turkey, Greece, Algeria, and China (Duke, 1958). During the Chilean earthquake of 1960, damage to buildings constructed on manmade ground was conspicuously greater than that on any other type of ground (Barozzi and Lemke, 1966).

Eight areas of artificial fill, mostly small, are shown on the map (fig. 3). Not shown because of their small size, are road and street fills and other small miscellaneous types of fills.

The largest areal extent of artificial fill is the aircraft landing strip. The sand and gravel fill is only a few feet thick and has been emplaced on elevated fine-grained marine deposits (Qem and Qemy). The only manmade structures on this fill, other than the runway itself, are a couple of small plane hangars. Comparatively strong ground motion can be expected mainly because of the probable high susceptibility to shaking of the underlying fine-grained deposits.

A small area of manmade fill near Kaskulu Point is mostly sand and gravel from nearby ice-contact deposits. The fill is underlain in part by thin sand and gravel deposits (Qeb) and in part by fine-grained marine deposits (Qemy). Relatively strong shaking is indicated because of the probable looseness of the fill and the nature of the underlying deposits.

Fill covers an area about 1 mile northeast of Kaskulu Point upon which are constructed several shop buildings of the Alaska Department of Highways. In most places the mapped part of the fill is only about 5 feet thick and consists mostly of sand and gravel from nearby elevated shore deposits (Qeb). Inasmuch as the fill presumably is loose and is underlain at shallow depth by fine-grained marine deposits (Qem), it probably is susceptible to strong shaking.

Riprap surrounding the small-boat harbor consists of angular blocks of igneous rock (Ked) over a core of fine-grained material at the shoreward end. The fill overlies beach deposits (Qb), elevated fine-grained marine deposits (Qem), and offshore marine deposits. Although the riprap itself should not be subject to strong shaking, the fine-grained material of the core and the deposits underlying the core probably would subject the entire fill to strong ground motion.

Two small areas of artificial fill, one just south of the small-boat harbor and the other one to the north near Nukdik Point, are not significant to this evaluation because no facilities are built on the fills. The fill south of the small-boat harbor consists of fine-grained material. The one near Nukdik Point is an abandoned dump.

The cargo dock next to the Alaska State Ferry Terminal dock, north of Haines, appears to consist chiefly of blocks of rock topped with sand and gravel. The fill of the dock, which rises to a height of 26 feet above mean lower low water, may be as much as 50 feet thick toward the seaward side. Probe holes, jetted nearby in connection with construction of the Alaska State Ferry Terminal (firm of Toner and Nordling, Juneau, Alaska, written commun., 1962), indicate that 20 or more feet of coarse gravel and small boulders underlies the fill. The general coarseness of the fill combined with the somewhat coarser nature of the underlying deposits, suggest that the degree of shaking may be somewhat less here than for areas of manmade fill discussed above. Effects of shaking, other than to the cargo dock itself and to the ferry dock, would be limited chiefly to cargo stored intermittently on the dock area and to automobiles on the adjacent parking platform.

An area of artificial fill a few hundred feet northwest of the cargo dock, upon which is constructed a chip mill, appears to consist mostly of fine-grained elevated marine deposits (Qem). Relatively strong shaking probably could be expected because of the composition of the fill and the probable looseness of the underlying beach deposits (Qb).

Chilkat River flood-plain and delta deposits (Qr).--Except for some types of manmade fill, alluvium generally is subject to the strongest ground motion of any type of deposit, particularly if water saturated. The smaller the grain size of the alluvium and the thicker the deposit, the more subject the alluvium generally is to the generation of destructive seismic shock waves (Millikan, 1933; Omote, 1949). This is particularly evident where seismic waves emerge abruptly from rock into alluvium (Richter, 1959). As noted previously, amplitude may increase as much as 22 times (Neumann, 1954). Gutenberg (1957) noted that the ratio of amplitudes at seismological sites on fairly dry alluvium that was more than 500 feet deep, compared to a site (Seismological Laboratory of the California Institute of Technology, Pasadena) on crystalline rock is frequently 5:1 and that the amplitudes on water-saturated alluvium may be 10 times greater. He also noted that strong shaking lasts several times as long on alluvium as on crystalline rock and that this ratio usually decreases with decreasing thickness of the alluvium. Other examples of severe shaking of alluvial deposits during a large earthquake are described in our regional report (Lemke and Yehle, 1972).

In comparing the Chilkat River flood-plain and delta deposits with alluvial deposits in other parts of the world in respect to earthquake shaking, it seems reasonable to suppose that shaking of these deposits will be as great as or greater than in most of the other alluvial deposits. The deposits are fine grained, loosely consolidated, fairly thick, and are completely saturated to the surface or to a few feet of the surface--all factors that make them susceptible to strong ground motion. Moreover, as will be discussed later, they may be subject to significant secondary effects of shaking such as landsliding into Chilkat Inlet, lurching and other types of ground fracturing, liquefaction, fountaining and attendant effects, and subsidence due to compaction.

No manmade structures are built presently upon these deposits. In the event that the proposed highway bridge is built across the Chilkat River and the alluvial flood plain in the vicinity of the airstrip, the probability of the alluvium being subject to strong ground motion during a large earthquake should be carefully considered in the design of the bridge and of the associated road fill.

Modern beach deposits (Qb).--These deposits, in general, are considerably coarser grained than the Chilkat River flood-plain and delta deposits and, in most places, they probably are thinner. On the basis of these two factors, one might expect the deposits to be less subject to heavy shaking than the flood-plain and delta deposits. The deposits, however, are loosely consolidated, are saturated to or nearly to the surface, and, except where directly underlain by bedrock, may lie on other deposits that themselves are subject to strong ground motion. Expectable degree of shaking, therefore, probably would be high but not as high as the Chilkat River flood-plain and delta deposits. Manmade structures built on these deposits are limited essentially to sewerline outlets, the small-boat harbor dock and breakwater wall at Haines, the freight dock at Port Chilkoot, and the cargo dock and associated ferry dock north of Haines.

Colluvial deposits (Qc) (part of unit).—The deposits range considerably from place to place in grain size, looseness, and thickness; underlying material also differs markedly from one place to another. Therefore, the susceptibility of the deposits to shaking can be expected to differ from place to place. Consequently, part of the deposits probably should be placed in category 1 and part in category 2.

Most of the deposits are considerably coarser grained than others described in category 1 and, therefore, on this basis alone, one might expect that they would be less subject to strong ground motion. Also, in most places they are less saturated than most of the other deposits previously described. On the other hand, most are very loose (particularly the actively moving types) and resemble manmade fill in this respect. Some lie directly on bedrock on steep slopes and, therefore, may be subject to increased shaking as a result of seismic waves emerging abruptly from hard rock into the deposits (Neumann, 1954; Richter, 1959). Also, some are directly underlain by fine-grained marine deposits (Qem), which themselves are subject to strong ground motion; where thin, these colluvial deposits could be expected to largely reflect the shaking of the underlying deposits.

In summary, thin colluvial deposits resting directly on bedrock or on fine-grained marine deposits probably should be placed in category 1. Thicker deposits, particularly those underlain by coarser grained surficial deposits probably should be placed in category 2. As will be discussed later, the colluvial deposits may be particularly susceptible to other earthquake effects such as rock sliding and other forms of landsliding. Because of the steepness of the slopes, virtually no manmade structures have been built on the deposits. However, the pipeline from the tank farm north of Haines extends across some of the colluvial deposits at the base of the steep mountain front north and northwest of Haines.

Alluvial fan deposits (Qaf) (part of unit).—These deposits are similar in many respects to colluvial deposits and can be expected to be subject to about the same amount of shaking from a specific earthquake. In general, though, they are somewhat finer grained, particularly toward their termini and may be somewhat more consolidated owing to deposition by water rather than chiefly by gravity. Also, most fans spread out farther downslope across fine-grained deposits and do not as commonly directly overlie bedrock.

Those parts of the deposits that are thin, fine grained, and are underlain by fine-grained sediments, such as the fine-grained marine deposits (Qem), probably should be placed in category 1. Thicker and coarser deposits (such as those farther up the slope and particularly those not underlain by fine-grained deposits) probably should be placed in category 2.

Present manmade structures built on these deposits are confined mostly to a few houses, to the petroleum products pipeline built at the base of the mountains directly north and northwest of Haines, and to the water line extending from the mountain front toward Haines. More structures may be built in the future on the deposits as Haines expands toward the more mountainous areas.

Elevated fine-grained marine deposits (Qem and Qemy).--The generally small grain size, considerable thickness, and high degree of saturation of the deposits are factors that make the deposits susceptible to strong shaking during a large earthquake.

Shaking of most parts of the elevated fine-grained marine deposits in the Haines area might be nearly as great or as great as that of the Chilkat River flood-plain and delta deposits (Qr). The most severe shaking might be in the thick (Qemy) subdivision of the unit, where the water table is virtually at the surface and the deposits appear to consist mostly of silt- and clay-size particles. One foot to several feet of muskeg, which it is believed would be particularly susceptible to shaking, mantles large parts of the older (Qem) deposits.

The western part and some of the eastern part of the city of Haines, as well as waterlines and sewerlines, primary and secondary roads, and other manmade structures (such as the tank farm north of Haines) are constructed on or in these deposits. Inasmuch as the surface of these deposits constitutes some of the most level land in the mapped area, it is likely that this terrain will be considered for future expansion for dwellings and other types of construction.

Geologic units in category 2 (intermediate expectable shaking)

Elevated shore and delta deposits (Qeb).—These deposits, which consist mostly of gravel, sand, and cobbles, are considerably coarser grained than the elevated fine-grained marine deposits (Qem and Qemy) and the Chilkat River flood-plain and delta deposits (Qr). Also in most places, because of their greater permeability and because they are topographically higher, they are not nearly as water saturated as the other two types of deposits or as the modern beach deposits (Qb). They probably also are more compact than manmade fill (Qf), colluvial deposits (Qc), and alluvial fan deposits (Qaf). For these reasons it is not expected that this unit would be subject to as great a degree of shaking as those units placed in category 1. It should be pointed out, however, that the unit is underlain in many places by fine-grained marine deposits, which have been placed in category 1. In such areas and particularly where the unit is thin, shaking probably would be the same as or similar to that of the underlying deposits.

Most of the business district of Haines and virtually all of Port Chilkoot are built on these deposits. Other manmade structures are largely limited to road segments, waterlines and sewerlines, and scattered dwellings.

Outwash and ice-contact deposits (Qo).--Ground motion of this unit is expected to be similar to that of the elevated shore and delta deposits (Qeb) because of similarity in grain size and thicknesses. Both, also, are fairly well drained and probably are about equally consolidated. Near Lutak Inlet, the outwash deposits lie mostly on bedrock or on surficial deposits that are less subject to strong ground motion than deposits in category 1.

At the present time only a few single-dwelling structures have been built on the deposits. Because of the general inaccessibility of the areas, it is unlikely that many structures will be built in the foreseeable future.

Drift deposits, undifferentiated (Qd).--In the mapped area, these deposits consist chiefly of compact till or other types of diamictons lying mostly on bedrock in fairly to moderately well drained areas. Therefore, expectable ground motion probably would be considerably less than for deposits in category 1. Where the unit consists of fluvioglacial deposits (sand, gravel, and cobbles), it is fairly well drained, and in most places, probably rests on bedrock. Thus, expectable ground motion in these deposits probably would be considerably less than for units in category 1.

Manmade structures on these deposits are confined to a few scattered dwellings southwest of Port Chilkoot.

Colluvial deposits (Qc); alluvial fan deposits (Qaf) (part of each unit).--As previously discussed, part of each of these units is assigned to category 1 and part to category 2. The reader is referred to the previous discussion (see "Geologic units in category 1").

Geologic units in category 3 (least expectable shaking)

Igneous rocks (Kt and Ked); metamorphic rocks (Mzm and Mzp).--Because of the expectable similarity in degree of shaking, all the exposed bedrock is treated as one unit. Some other earthquake effects, however, as will be discussed later, may differ from one rock type to another.

Historical records of earthquake damage generally show that shaking in hard dense bedrock is much less than in poorly consolidated surficial deposits. There may be as much as 10-15-fold difference in acceleration (Neumann and Cloud, 1955) and amplitudes recorded over granitic bedrock may be only one-tenth that recorded over water-saturated soft ground

(Richter, 1959). All this implies that manmade structures built on bedrock generally undergo considerably less damage from shaking during an earthquake than similar structures built on water-saturated soft ground. All other conditions being equal, this generally has been found to be true. However, as discussed previously, other factors, mainly of structural engineering nature, may markedly affect the amount of damage.

Compaction

When loose cohesionless soils (those containing no significant clay content) are shaken by strong ground motion during an earthquake, there is a tendency for them to compact with associated settlement of the ground surface. Also, the resulting densification of the materials, under some conditions, produces liquefaction and water-sediment ejection. Only the associated effect of settlement will be discussed here.

Settlement of the ground surface, where underlain by loose cohesionless materials, probably has accompanied every severe earthquake. The amount of settlement generally is dependent upon: (1) the looseness of the material, (2) the intensity of shaking, (3) the length of time of strong ground motion, and (4) the relation between the natural frequency of the material when vibrated and the frequency of the impulse vibrations of the seismic waves. Thus, the higher the void ratio of the material, the greater the intensity of shaking, the longer the length of time of strong ground motion, and the closer the frequency of the seismic waves is to the natural frequency of the material, the greater the expectable compaction and resulting ground settlement. Although the vibration effects on clays are considerably less than for cohesionless materials like sand, even soft clay compacts to some extent when subjected to intense vibrations having a frequency close to the natural frequency of the clay (Terzaghi and Peck, 1948).

Except possibly for local areas of manmade fill, the Chilkat River flood-plain and delta deposits (Qr) probably would be subject to the greatest amount of compaction in the Haines area during a severe earthquake. Factors which favor this assumption are: (1) the loose cohesionless nature of the deposits, and (2) the considerable indicated thickness of the deposits. The sediments are believed to consist chiefly of sand and silt with a fairly high void ratio. In most places, it is likely that they exceed 150 feet in thickness and toward the face of the delta they may be considerably thicker. Inasmuch as most of the ground surface is now just barely above sea level, settlement of only a few feet would result in a considerable area being inundated by the sea.

Settlement of manmade fill (Qf) could cause damage in the Haines area to roadbeds (especially bridge approaches) and to buildings and other facilities whose foundations are founded wholly or partly in fill. If the sediments underlying the manmade fill also are subject to compaction or to liquefaction, settlement could be considerable. For example, a roadbed built on the Chilkat River flood-plain and delta deposits (Qr) might actually settle below the level of the deposits, such as occurred at the Snow River crossing during the Alaskan earthquake of March 27, 1964 (observation by senior author, 1964). The aircraft landing strip might also be subject to this kind of settlement and result in it being inundated at times of high tide or during periods of high water on the Chilkat River.

The loose sandy modern beach deposits (Qb) probably are susceptible to considerable compaction, if strongly shaken. However, in most places, they are believed to be fairly thin and total settlement probably would not be appreciable unless the underlying deposits also are subject to compaction. Piers, docks, and other harbor works would be the main facilities affected by settlement.

The elevated shore and delta deposits (Qeb) might undergo some compaction during strong ground motion. Most or all of the deposits, however, are sufficiently above sea level not to be inundated. Some damage might ensue to buildings and other facilities due to differential settlement.

Little compaction of the elevated fine-grained marine deposits (Qem and Qemy) is expectable because of their generally cohesive nature. However, where the deposits are more sandy or where they are underlain by more cohesionless materials, some compaction and associated settlement might take place. If they also are subject to liquefaction, then material may move by lateral extension toward a free face and considerable settlement of the surface could ensue. Most of the younger deposits (Qemy) are now just barely above high tide. Any appreciable settlement would cause this area to be inundated by the sea.

Other surficial deposits, where the materials are loose and cohesionless, also may be susceptible to compaction if there is strong shaking for a considerable time. The resulting differential settlement could damage manmade structures built upon them.

Liquefaction in cohesionless materials

If loose to medium-dense materials that are saturated and virtually cohesionless, loaded and confined by impermeable material are subject to strong shaking, the resulting tendency to compact increases the pore-water pressure. The resulting upward flow of water may turn the materials into a "quick" or liquefied condition; hence, the term "liquefaction" (Seed, 1970). As a result of closer packing of the solid particles, there is an excess of water and the load is transferred from the solids to the fluid. Other factors being equal, fine sands and coarse silts are most subject to liquefaction (Terzaghi and Peck, 1948). Also, the higher the void ratio, the greater is the tendency for the materials to liquefy. When part of a sloping soil mass liquefies, the entire mass can undergo catastrophic failure and can flow as a high-density liquid. The resulting flows can move down even nearly flat slopes and can cause heavy loss of life and property destruction.

In the Haines area, the Chilkat River flood-plain and delta deposits (Qr) probably are the most susceptible to liquefaction during an earthquake because of their small grain size (sand and silt) and because of their high degree of saturation. During investigation for the proposed Chilkat River highway crossing, one-half mile northwest of the aircraft landing strip, a "quicksand" condition developed in the deposits during movement of heavy equipment (Migliaccio and Slater, 1968). Moderate to large-size sliding due to liquefaction of the deposits, originating along the frontal face of the deltaic deposits and extending upstream into the flood-plain deposits, must be considered a distinct probability in the event of a moderate to large earthquake. Also, water-sediment ejection (sand and mud boils) and accompanying ground fracturing, due wholly or in part to liquefaction, would be expectable in these deposits during a moderately large to large earthquake. The possibility of earthquake-induced sliding and of water ejection in these deposits, as well as other deposits, will be discussed later under the respective subject headings.

The elevated fine-grained marine deposits (Qem and Qemy) are chiefly of silt and clay size, are fairly plastic, and have a high degree of water saturation. Insufficient data are available to ascertain whether they are subject to liquefaction. However, unless the deposits contain fairly numerous lenses of coarser material (sand and silt), they probably are considerably less likely to liquefy than the Chilkat River flood-plain and delta deposits (Qr). It should be emphasized though that deposits having a greater susceptibility to liquefy may underlie the elevated fine-grained marine deposits and that both deposits could be adversely affected, if the underlying deposits liquefy.

The elevated shore and delta deposits (Qeb) are considerably coarser grained than the elevated fine-grained marine deposits and, where they form the surface unit, are in most places much better drained. Liquefaction seems unlikely except where there may be intercalated lenses of fine sand and silt or where the deposits underlie other deposits and have a higher degree of saturation.

The modern beach deposits (Qb) may be susceptible to liquefaction during an earthquake because they are saturated to or nearly to the surface and in places may contain a fairly high percentage of sand and silt. However, because they are of fairly small areal extent and generally are not thick, liquefaction effects probably would be considerably less than for the Chilkat River flood-plain and delta deposits (Qr). Nearshore subaqueous deposits, however, may be considerably thicker but, because of insufficient data, their liquefaction potential cannot be evaluated.

Parts of other mapped deposits, where grain size is favorable and where there is a high degree of water saturation, may be susceptible to liquefaction. However, data are too few at present to attempt to evaluate this possibility.

Reaction of sensitive and quick clays

Sensitive clays are those clays that lose a considerable part of their strength when shaken. During an earthquake such clays commonly fail and become rapid earthflows that can cause heavy damage and loss of life. Sensitivity of a clay is defined as the ratio of undisturbed shear strength of a clay to remolded shear strength of the same specimen (Terzaghi and Peck, 1948). The term "quick" clay denotes a clay of such high sensitivity that it behaves as a viscous fluid in the remolded state (Mitchell and Houston, 1969).

In the Haines area, the elevated fine-grained marine deposits (Qem and Qemy) appear to be the most likely deposits to contain sensitive clays. Although available data are too few to actually confirm the presence of these clays, our comparison of the few pertinent data available with sensitivity analyses made for the Bootlegger Cove Clay in Anchorage (see Hansen, 1965) indicates that parts of the elevated fine-grained marine clays may have moderate to high sensitivity.

Sufficient data are available from analyses of 11 samples of fine-grained marine deposits for us to calculate the liquidity indexes.[6] Six samples were analyzed by the U.S. Army Corps of Engineers (Warren George, written commun., 1968) in connection with construction of the petroleum tank farm near Tanani Point, four samples were collected by the Alaska Department of Highways (Munson, 1962), and one sample was collected by us. Thus, because of the diversity of conditions under which the samples were collected and analyzed, rigid comparisons probably are not possible. Likewise, the liquidity indexes obtained in the Haines area probably cannot be compared directly to sensitivity values obtained in the Anchorage area. In addition to probable difference in collection and analysis procedures, the samples in the Haines area were all collected from depths of less than 8 feet whereas samples from the Anchorage area were collected from an average depth of 50 feet. In spite of these difficulties, we feel that some indication of the degree of sensitivity of the deposits can be obtained from the data available.

The liquidity index results are as follows: (1) in three of the samples the plastic limit exceeded the natural water content and, therefore, a negative value for the liquidity index resulted, (2) four of the samples showed liquidity indexes of less than 1 indicating sensitivities of less than 15, (3) two of the samples had liquidity indexes of 1.07 and 1.10 indicating sensitivities of about 16 and 17, respectively; two of the samples had liquidity indexes of 2.10 and 2.12, respectively, indicating sensitivities greater than 50. As described by Mitchell and Houston

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[6] The sensitivity of a clay has been found to correlate fairly well with the water-plasticity ratio of the clay or the so-called liquidity index. This ratio, as defined by Casagrande and Fadum (1944) is equal to the natural water content of the soil minus the plastic limit divided by the liquid limit minus the plastic limit.

(1969), clays having sensitivities of 16 to 17 are regarded as medium to quick clays (high to very high sensitivity); clays having sensitivities of 50 are regarded as very quick clays (extremely high sensitivity).

Salinity tests were made on two samples that we collected to see if salts had been leached from the material—a factor that might increase the sensitivity of the materials. No salt was found in either sample indicating that it had been leached from the sediments since deposition. Both samples, however, were collected from within a few feet of the surface and may not be representative of the conditions at greater depth.

In summary, we tentatively conclude that some parts of the elevated fine-grained deposits may contain moderately to highly sensitive clays subject to failure and resultant damage to manmade structures when subjected to shaking during an earthquake. Much additional data need to be obtained to support or negate these tentative conclusions and to accurately delineate, both areally and stratigraphically, any sensitive clays that may be present.

Water-sediment ejection and associated subsidence and ground fracturing

In at least half of approximately 50 major earthquakes, water and sediment have been ejected from surficial deposits (Waller, 1968). The ejection phenomena have been called fountaining, sand spouts or sand boils, mud or sand craters, blowouts, and other names. The ejecta may range from clear water, through mud, to water containing material as large as coarse gravel. Sand, however, is a common size fraction. Ejecta heights of several feet are common but fountaining to a height of as much as 100 feet has been reported. The ejections are associated with surface or near-surface unconsolidated deposits where there is a high water table or a confined-water condition (where the top of the water zone is in contact with an overlying, relatively impervious zone). Associated fractures commonly form an intricate mosaic pattern of ground breakage and generally range in width from hairline cracks to 1 or 2 feet wide but some have been reported to be as wide as 30 feet and open to a depth of 25 feet (Foster and Karlstrom, 1967). The water-sediment ejection and associated subsidence and ground fracturing can cause extensive damage by filling basements with ejecta material, covering agricultural land with a blanket of infertile soil, and filling or making shallow small ponds. Also, where a "quicksand" condition is produced, structures can sink into the liquefied materials. Moreover, where material has been removed from beneath the surface by ejection, the surface collapses and causes heavy damage to structures built thereon.

In the Haines area, the Chilkat River flood-plain and delta deposits (Qr) probably are the most likely to be subject to water-sediment ejection and to associated subsidence and ground fracturing during an earthquake. As discussed previously, these sediments probably are the most likely of any of the deposits to liquefy and the water table is at or near the surface--both factors favoring water-sediment ejection.

However, unless the earthquake occurs in the winter so that a frozen surface crust can furnish a restrictive layer for a confined-water condition, sufficient water pressure may not be built up to produce fountaining or jetting of water and sediment. Instead, the water and sediment may merely well up and overflow the surface to produce a quicksand condition. Local subsidence can be expected whether or not there is jetting, and intense ground fracturing is likely if there is a frozen surface crust.

Insufficient data are available to predict whether the elevated fine-grained marine deposits (Qem and Qemy) are subject to water-sediment ejection. As noted previously, it is not now known whether the deposits are subject to liquefaction although the tendency probably is considerably less than for the Chilkat River flood-plain and delta deposits. Also, as was emphasized, some of the underlying deposits may be subject to liquefaction. If so, the relatively impermeable fine-grained marine deposits might act as a confining restrictive layer and permit sufficient water overpressure to develop to produce fountaining, fracturing, and local subsidence. The fact that the water table in most places is high is a factor favoring this possibility.

The elevated shore and delta deposits (Qeb), as discussed previously, are well drained in most places, are fairly coarse grained, and probably are not highly subject to liquefaction. Therefore, except locally where the deposits may be more saturated and finer grained or where there is a layer permitting a confined-water condition to develop, the phenomenon of water-sediment ejection and associated effects seems unlikely.

Because the modern beach deposits (Qb) have a high water table and may be subject to liquefaction, it is likely that water-sediment ejection might be actuated in the deposits during an earthquake. However, because the deposits in most places are not thick, the effects probably would be relatively small. Also, unless the surface of the deposits are frozen at the time of the earthquake, there probably is no restrictive layer to produce a confined-water condition that would allow fountaining to develop.

Parts of other surficial deposits, where the water table is high and where liquefaction is possible, may be subject to water-sediment ejection and associated effects. The distal parts of some of the alluvial fan deposits (Qaf), particularly, might be subject to these phenomena where conditions are similar to those that produced marked effects on alluvial fans during the Alaskan earthquake of 1964.

Earthquake-induced subaerial slides and slumps

Geologic units on land that probably are most prone to slide as a result of a severe earthquake are: (1) Chilkat River flood-plain and delta deposits (Qr), (2) elevated fine-grained marine deposits (Qem and Qemy), (3) elevated shore and delta deposits (Qeb), (4) modern beach deposits (Qb), and (5) manmade fill (Qf). Other surficial units may be affected locally.

The Chilkat River flood-plain and delta deposits (Qr) probably are the most susceptible to subaerial and submarine landsliding. During strong ground motion, the frontal face of the Chilkat River delta is likely to fail. Moderate to large-size sliding, originating along the frontal face of the delta and progressing upstream into the flood-plain deposits, is probable in the event of a moderate to large earthquake. The deposits are fine grained, are loosely deposited, and probably are barely in a state of equilibrium under present static conditions. If failure is caused at least in part by liquefaction, then headward progression of sliding up the river might continue as long as strong ground motion lasts--a situation analogous to that along the waterfront at Seward and at Valdez during the great Alaskan earthquake of 1964 (Lemke, 1967; Coulter and Migliaccio, 1966). Also, lurching and accompanying fissuring in the fine-grained water-saturated deposits forming McClellan Flats could be expected as these deposits move toward the frontal face of the delta.

Fairly high plasticity and generally high degree of water saturation are characteristics of the elevated fine-grained marine deposits (Qem and Qemy) that favor sliding. If liquefaction of the deposits is also a possibility, the slide potential is further increased greatly. The largest area underlain by the deposits is the nearly flat surface in the saddle west and south of Haines; large-scale landsliding in that area is not probable because of lack of a free face toward which the material can move. The steepest slope of significant size underlain by the deposits is between Portage Bay and the business district of Haines. Landsliding in this area during a large earthquake might range from sliding of moderate-size discrete masses to minor slumping, ground cracking, and lurching toward the free face. A less likely area to slide, because of the more gentle surface slopes, is that underlain by the older deposits (Qem) northwest of Tanani Point.

Because they are coarser grained and in most places are better drained, the elevated shore and delta deposits (Qeb) are less likely to slide than are the elevated fine-grained marine deposits. Unless there are intercalated lenses or beds of fine sand and silt, liquefaction of the deposits is not expected. These characteristics tend to preclude large-scale sliding of the deposits except possibly where they form steep slopes or where they are underlain by more slide-prone deposits, such as the elevated fine-grained marine deposits (Qem) at Haines. Some lurching and associated ground cracking can be expected in those places where the deposits can move toward a free face.

Because the water offshore from the beach deposits (Qb) is fairly shallow in most places, no significant landsliding of the beach deposits is expected unless the deposits are subject to liquefaction. There may be some lurching and accompanying ground cracking, however, where the deposits move toward the free shore face.

Manmade fill (Qf) in the mapped area is not areally extensive nor are there high fills supporting highways or other facilities. Most fills have been emplaced on low-lying ground where there are no nearby high open faces. Therefore, sliding probably would be restricted to local slumping with accompanying lurching and ground cracking. Sliding of this type could be expected to be greatest where fill has been emplaced on more slide-prone deposits such as the Chilkat River flood-plain and delta deposits (Qr) and the elevated fine-grained marine deposits (Qem and Qemy).

Earthquake-induced subaqueous slides

Data are largely lacking to permit an assessment of the amount of submarine sliding that has been triggered by past earthquakes in the vicinity of Haines. That some of the sliding can be attributed to earthquakes is indicated by cable breaks that have been coincident or nearly coincident in time with large earthquakes.

The following information on cable breaks along Lynn Canal and Chilkoot Inlet between Juneau and Haines (60 miles) is furnished in modified form from the records of the Alaska Communication System (D. Alford, written commun., 1966) and from Heezen and Johnson (1969):

Local time of event	Possible cause of break
Aug. 13, 1924	Cable break; cause not given.
Sept. 22, 1927	Submarine slide of silt and debris from Katzehin River; no earthquake reported.
Oct. 24, 1927	Cable break; cause not given.
Feb. 4, 1952	Cable break; cause not given.
June 18, 1952	Cable break; cause not given.
July 16, 1952	Submarine slide; no earthquake reported.
Sept. 1, 1956	Profile of cable route shows break well up the side of Katzehin River delta; break occurred during a windstorm.
Sept. 1 or 2(?), 1956	Submarine slide on Katzehin River delta; no earthquake reported.
July 10, 1958	Four submarine slides within 4 miles of the front of the Katzehin River delta; occurred at time of a great earthquake. Two of these slides along the delta front and two others, 9 miles south of the delta front, may have been caused by Katzehin River delta failures, turbidity currents, direct seismic shaking, or dislocation of unstable perched bodies of glacially derived sediments along fiord walls.
March 27, 1964	Submarine slide along face of Katzehin River delta 8 hours after Alaska earthquake of March 27, 1964.

The above information suggests that some of the cable breaks offshore from the Katzehin River delta (5 miles southeast of Haines) can be correlated with the Lituya Bay earthquake of July 10, 1958. The submarine slide that occurred 8 hours after the Alaska earthquake of March 27, 1964, probably also was due to secondary slumping of the delta front related to that earthquake. Some of the other recorded cable breaks may have been caused by sliding related to earthquakes too small to have been instrumentally recorded whereas others probably were caused by natural oversteepening of delta fronts. Considering the limited extent of fiord bottoms transected by these cables, there probably have been many additional undetected slides in the vicinity along delta fronts and in perched sediments along fiord walls.

In assessing the potential for earthquake-induced submarine sliding in the Haines mapped area, we tentatively conclude that the deltaic deposits are the most likely to slide--particularly the deposits at the mouth of the Chilkat River. The slide potential for deposits at the mouth of the Chilkat River has been discussed in the sections "Liquefaction" and "Earthquake-induced subaerial slides and slumps."

No large-scale submarine sliding seems likely along frontal faces of the fairly small fan deltas built at the mouths of streams along the west side of Chilkoot and Lutak inlets north of Haines unless the deposits are subject to liquefaction. However, in the construction of the large cargo dock adjacent to the Alaska State Ferry Terminal, it is reported that four or five caissons of the dock failed during construction (Harry Young, Chief, Haines tank farm, U.S. Army, oral commun., 1965). We do not know whether the failure was a structural one or whether there was a foundation failure, due possibly to the caissons being placed in unstable deltaic fan deposits or in fine-grained marine sediments.

There seems little likelihood of major submarine sliding in Portage Cove. Bathymetric contours indicate that steep underwater slopes are not present. However, if offshore deposits are subject to liquefaction, slides may be triggered on fairly gentle slopes and the resulting slurry-like slide mass can move a considerable distance from its source and spread out as a relatively thin blanket.

Two fan deltas, a few miles outside the mapped area, appear to have a high potential for earthquake-induced sliding along their underwater frontal faces. One is the fan delta below Davidson Glacier, about 10 miles south of Haines. The other is the fan delta at the mouth of the Katzehin River, which already has been discussed briefly as the locus for previous slides that caused cable breaks. As denoted from bathymetric contours, both deltas have steep frontal slopes that likely will fail during strong ground motion. Judged from previous sliding, triggered either by earthquake shaking or as a result of natural depositional oversteepening of the foreslope, future sliding along the Katzehin River delta front seems a certainty. Major sliding of either the delta front downstream from the Davidson Glacier or of the Katzehin River delta could appreciably affect water depths in immediately adjacent areas of Chilkat and Chilkoot Inlets. However, the inlets are sufficiently deep so that it is unlikely that slide debris could seriously restrict any possible future navigation.

Effects on glaciers and related features

Strong ground motion and land-level changes resulting from earthquakes can affect glaciers and related features in several ways: (1) cause thickening of glacier ice, (2) cause thinning of glacier ice, (3) disrupt glacier-fed streams, (4) change flow characteristics of glacier ice resulting in glacial advance, (5) cause accelerated calving of the termini of tidewater glaciers resulting in possible retreat of glaciers, (6) cause glaciers to advance or retreat due to land-level changes, and (7) produce long-term changes in mass or flow characteristics of glaciers because of tectonic displacement (Post, 1967).

There are no glaciers in the Haines mapped area (fig. 3) and expectable adverse effects in the area from nearby glaciers, in the event of a severe earthquake, probably are minimal. No nearby glaciers terminate in tidewater. Davidson Glacier, one of the largest nearby glaciers, drains into Chilkat Inlet 10 miles south of Haines and terminates slightly more than 1 mile from the inlet. During an earthquake, some of the lower reaches of the glacier may be subject to rock avalanching from bordering steep bedrock walls, but it is unlikely that this would affect the regimen of the glacier sufficiently to cause it to advance to tidewater and discharge icebergs into Chilkat Inlet. Any substantial advance, however, even if the glacier did not reach the inlet, would significantly affect the proposed Haines-Juneau Highway between the glacier and Chilkat Inlet (see Franklet, 1969). It seems unlikely that the regimen of the Garrison Glacier and other glaciers to the west (see fig. 2) would be changed sufficiently to affect significantly the Chilkat River and the Haines area downstream, unless there was a sudden release of a large quantity of water due to the breaking of an earthquake-induced dam of ice or debris. A sudden release of water, however, could cause flooding downstream and, if the volume of water were large, might affect parts of the Haines Highway as well as the proposed highway across the Chilkat River just upstream from the aircraft landing strip. The effects of any tectonic changes, such as uplift or subsidence, resulting from a future earthquake almost surely would be too small to significantly affect the regime of any of the glaciers. Snow and debris avalanching on steep slopes, triggered by strong ground motion during an earthquake, might constitute a hazard within the Haines area itself during winter months.

Effects on ground-water and stream flow

It is well known that large earthquakes can significantly affect ground-water and stream flow.

Waller (1966a, b) noted that short-term effects of the Alaska earthquake of March 27, 1964, on ground water included: (1) surging of water in wells, (2) water-sediment ejection, (3) failure of well systems, and (4) turbidity of water in wells and springs. Long-term effects included temperature changes, chemical quality changes, and the lowering or raising of water levels or artesian pressures. Surface water changes included diminished or increased stream flow. Changes in stream flow commonly were controlled by ground fracturing in or near streambeds and by snow and rock avalanching. Most landslides blocked streams for only short periods but effects from some persisted for months (Waller, 1966a; Lemke, 1967).

It is difficult to evaluate the effects of an earthquake on ground and surface water in the Haines area. Most of the water supply for Haines comes from two springs, a creek, and an old mine tunnel. Whether these supplies would be increased or decreased cannot be ascertained. However, inasmuch as the source is largely on or in bedrock, it seems unlikely that the long-term supply would be greatly affected, although there might be some temporary change in flow and the water might be turbid for a period of time. Water levels in wells dug in loose granular surficial deposits might be lowered owing to compaction of the materials and consequent reduced transmissibility. Failure of well systems due to sanding or silting of the pump column or breaking of the well casing also must be considered a possibility. Other than the Chilkat River, streams are not abundant or large in the mapped area. Short-term effects on the Chilkat River might include increased flow unless tributary stream channels were blocked by snow or rock and debris slides. If a slide dam is breached suddenly, the flow of water that was impounded can be large and heavy damage can ensue downstream. Water is rarely impounded behind a snowslide or rockslide if there is an absence of fine-grained material so that the water can drain through the slide. On the other hand, if the slide material is sufficiently fine grained so that the water cannot drain through fast enough, the dam may fail catastrophically by overtopping and large quantities of water and sediment may pour downstream.

Tsunamis, seiches, and other abnormal water waves

Abnormal water waves associated with large earthquakes commonly cause vast property damage and heavy loss of life. Tsunami effects can be devastating to coastal areas many thousands of miles from their generation source. Seiche effects generally are confined to inland bodies of water or to relatively enclosed coastal bodies of water such as bays. Other abnormal waves, generated by submarine sliding or by subaerial landsliding into water, generally produce only local effects but nevertheless may be highly devastating.

Tsunamis, otherwise known as seismic sea waves and erroneously referred to as tidal waves, are generated by sudden tectonic displacement of the ocean bottom. In the oceanic depths, tsunami waves travel at speeds of about 425-600 miles an hour but in shallower water, such as in bays and inlets, their speeds are considerably less. As tsunami waves near a coast, they greatly increase in height and (or) runup onto land; the waves generally are higher where the offshore zone is gently shelving. Also, tsunami waves running into the heads of funnel- or triangular-shaped bays may be considerably higher than at the mouths of those bays. Wave runup onto shore can range from a barely perceptible abnormal rise in tide level to heights of more than 100 feet (Wiegel, 1964). Damage can be exceptionally great. In addition to heavy loss of life and damage to nearshore buildings, docks, and other harbor and coastal installations, moored boats can be extensively damaged by pounding against each other or by being carried ashore and beached.

It is beyond the scope of this paper to try to predict the maximum height of tsunami waves and of runup on land that might be reached in the Haines area. Situated as the area is along a long fiord system of varying depth and configuration, many unevaluated factors can affect the wave action. The fact that the magnitude of an earthquake generally has to be 7 or greater to produce a noticeable tsunami and generally of magnitude 8 or greater to produce a disastrous tsunami (Wiegel, 1964) tends to markedly lower the probability that the generation source for a large tsunami would be near Haines. Moreover, to generate a tsunami requires a considerable vertical displacement of the ocean bottom such as would occur along a dip-slip fault. Most all of the earthquakes in southeastern Alaska large enough to generate a tsunami have been along the Fairweather-Queen Charlotte Islands fault system, where movement has been chiefly horizontal. However, this does not preclude tsunami waves arriving from a far-distant generation source. Although no accurate figures are available, a tsunami wave may have arrived at Haines as a result of the Lituya Bay earthquake of July 10, 1958; this assumption is based upon a report (Manager, Alaska Power and Telephone Co., Skagway, oral commun., July 21, 1965) that at that time a wave rose 25 feet above tide level (a time of low tide) at Skagway.

Height of wave runup and resultant damage at Haines from a tsunami would depend in part upon the arrival time of the waves in relation to the phase of the tide. Inasmuch as there is a tidal range of approximately 17 feet at Haines, a tsunami wave of this height could crest at lower low tide and still not have a runup above normal higher high water. On the other hand, a 10-foot-high wave arriving at Haines during higher high tide could cause considerable damage along the waterfront, particularly if it came crashing into shore as a breaker. In the rather exposed Chilkat Inlet, it probably would inundate most of the low-lying area mapped as younger elevated fine-grained marine deposits (Qemy) (fig. 3). It probably also would advance over the aircraft landing strip, and tidal waters would be pushed a considerable distance farther up the Chilkat River. A 20-foot-high wave, arriving during higher high tide would be considerably more destructive to facilities along the shorelines than a 10-foot-high wave. In the unlikely event of a 40-foot-high wave, the Haines Highway in the low-lying part of the saddle area west of Haines would be inundated. It would require a wave 60-100 feet high to inundate most of the business district of Haines. Tsunami waves of this height at Haines are considered highly unlikely.

Seiches are periodic oscillations (standing waves) in lakes, bays, inlets, reservoirs, and rivers produced by changes in wind stress, atmospheric pressure, or by earthquakes. Seiches produced by earthquakes are believed to be caused by horizontal acceleration of short-period seismic surface waves (McGarr and Vorhis, 1968). Seiching also may be produced during an earthquake by tectonic tilting of the water basin, which causes periodic wave oscillations (McCulloch, 1966). Because the seismic waves travel so much faster than tsunami waves, seiche waves are operative in an area before the tsunami waves arrive.

In attempting to evaluate the potential effects of seiching in the Haines area, it should be noted that there are no completely enclosed bodies of water of significant size in the mapped area. However, Chilkoot Lake (fig. 2) lies just north of the mapped area and, during a large earthquake, seiching might take place on it such as occurred on Kenai Lake during the Alaskan earthquake of March 27, 1964 (McCulloch, 1966). In such an event it is possible that seiche waves might runup on shore and cause damage and possible loss of life at the campground at the southeast end of the lake. Whether seiching can take place in Chilkat and Chilkoot Inlets, which are open on one end, cannot be ascertained by us. However, answers to questionnaires submitted by the U.S. Geological Survey to Postmasters and others suggest that seiching did take place in some of the long narrow inlets of southeastern Alaska as a result of the Alaska earthquake of March 27, 1964. In at least four places in southeastern Alaska abnormal water waves, as much as 5 feet high and possibly higher, were reported immediately following the earthquake and more than an hour before the arrival of the first tsunami waves. However, no abnormal waves were reported at Haines immediately after the earthquake.

Local waves generated by earthquake-induced submarine sliding or subaerial landsliding into water can be highly destructive. Because they generally hit the shore suddenly, during or immediately after an earthquake, and because their runup height at any particular locality is largely unpredictable, a warning system is not possible. Wave heights have ranged from barely perceptible rises in water levels to a record-breaking height of 1,720 feet during the Lituya Bay earthquake of 1958 (Miller, 1960). Slide-induced waves violently struck a number of coastal communities during or immediately after the Alaska earthquake of 1964 and were a major cause of loss of lives and property.

It seems reasonable to assume that the Haines area has a fairly high potential for damage from slide-induced waves resulting from a large earthquake. It should be emphasized, however, that the potential slide areas where the waves might originate, the number of waves, and the height of wave runup can be assessed only in the most general way. Probably the areas most susceptible to sliding and, therefore, to wave generation are the deltas at the heads of fiords or those deltas that extend into deep water along the valley walls of the fiords. Of these deltas, the Katzehin River delta (fig. 2), as noted previously, probably is the most susceptible to sliding during a large earthquake. In the event of future large-scale sliding of this delta front, slide-generated waves might travel to the opposite shore of the inlet where they could run up on shore and cause damage at Haines. Waves might be generated also by sliding of the Chilkat River delta front or of the delta front near the terminus of Davidson Glacier (fig. 2). As has already been noted, runups of only a few feet could inundate a considerable area near the mouth of the Chilkat River. Waves generated along more distant delta fronts might reach Haines, but they probably would not have as great a damage potential as those originating closer. Waves formed by subaerial and submarine rock and debris slides on steep slopes into water also are possible.

In summary, it seems possible that tsunami, seiche, and slide-generated waves could be produced by a large earthquake in the Haines area and could cause damage and possible loss of life. Of the three types of waves, the slide-generated waves probably would have the greatest destructive potential because of possible higher local runup and because they can hit the shore almost without warning during or immediately after an earthquake.

INFERRED FUTURE EFFECTS FROM GEOLOGIC HAZARDS OTHER THAN THOSE CAUSED BY EARTHQUAKES

Geologic hazards other than those caused by earthquakes are believed to be relatively minor in the Haines area. However, they may occur so much more frequently than those from major earthquakes that their aggregate effects could be significant. Three kinds of geologic hazards are discussed here: (1) effects of nonearthquake-induced landsliding and subaqueous sliding, (2) effects of flooding, and (3) effects of current land uplift.

Landsliding and subaqueous sliding

The potential for nonearthquake-triggered landsliding that would significantly affect man appears to be fairly low in the mapped area. Slow, downslope movement of talus deposits along the precipitous mountain front immediately north and northwest of Haines can be expected to continue. Also there may be, from time to time, fast-moving snow and rock avalanches or debris slides on these slopes as well as on the steeper natural slopes and manmade cuts north of Haines along the west side of Lutak Inlet. In addition, moderately fast to fast moving mudflows and debris slides may develop, after periods of heavy precipitation, along the steep-walled stream valleys between Haines and Tanani Bay and along the southwest side of Lutak Inlet. Small to moderate-size slumps and mudflows also can be expected after heavy rains on steep roadcuts in surficial deposits.

Accelerated slope erosion and debris flows may follow large-scale clearing and cutting of timber. Swanston (1969), who has made an extensive study of this cause and effect relation in southeastern Alaska, states that the erosion occurs mainly as mass soil movements associated with steep slopes and high water levels in the soil. He noted more than 3,800 large-scale debris avalanches and debris flows in southeastern Alaska; although most of these slides are the direct manifestation of natural mass wastage and slope reduction, some are the direct result of logging and logging-road construction. None was noted in the Haines mapped area, but future sliding of this type probably can be expected if logging and clearing take place on steeper slopes.

The Haines area may be affected at some time by damaging waves generated by rockslides moving down steep fiord walls outside of the mapped area. One such potentially unstable steep slope is along the east wall of Taiyasanka Inlet in the northeast unmapped corner of figure 3. A fresh-appearing scar, extending from the top of the inlet wall to the water's edge, shows that a fairly large rockslide has occurred there recently; also, on the basis of aerial photo interpretation, parts of four sections of land adjacent to the slide show evidence of sliding in the past. In the event that large-scale landsliding takes place in this area in the future and that the material slides into the inlet, a sufficiently large slide-generated wave might be produced to travel across Lutak Inlet and damage facilities on the southwest shore. Steep subaerial slopes in other areas also might be subject to failure and to the generation of damaging waves.

It has been noted previously that some of the cable breaks off the front of the Katzehin River delta and elsewhere in nearby inlets were caused by nonearthquake-triggered submarine sliding. There is every reason to believe that sliding will continue in these areas at such times as the fronts of deltas and other underwater slopes become oversteepened by normal depositional processes. Whether the scale of submarine sliding under nonearthquake conditions would be large enough to generate a wave that would cause damage in the Haines area cannot be ascertained. We know of no damage in the Haines area in the past from a wave of this type.

Local small-scale sliding also can be expected on steep underwater slopes along fiord walls where there may be perched bodies of glacially derived sediments. Such materials can fail suddenly when offshore structures, such as docks, are built upon them.

Flooding

A flood in mid-September 1967 illustrates the type and extent of expectable damage that may be incurred in the future in the Haines area and in the area to the northwest during periods of exceptionally heavy rainfall. Approximately 6½ inches of rain fell in the area in 5 days. Information on the effects of the flood was obtained chiefly from the Alaska Department of Highways (Martin A. Cordes, unpub. narrative rept., 1967).

Damage in the Haines mapped area was confined almost entirely to the road system. All streams between Haines and Tanani Point, as well as those along the west shore of Lutak Inlet, overran their channels and left debris on Lutak Road (fig. 4). At mile 7 (7 road miles from Haines) on Lutak Road, a stream along which large rocks reportedly were being tumbled, washed out a culvert as well as about one-quarter mile of the road. There also were several rockfalls on the stretch of road between Haines and the ferry terminal but they were of small size and were easily cleared from the road. A small mudflow partially blocked Mud Bay Road near Letnikof Cove, about 2 miles south of the mapped area. The Chilkat River rose sufficiently to flood the low area between Kaskulu Point and the aircraft landing strip. The aircraft landing strip itself came within a few inches of being inundated.

Approximately a 35-mile stretch of the Haines Highway northwest of the Haines area was affected by the 1967 flood. Highway traffic was stopped for more than 2 days by washed-out bridges, slides and debris on the roadway, and by floodwaters of the Chilkat River. Rocks and other debris were debouched onto the highway to depths of several feet where the road crossed flood-swollen creeks. The Chilkat River rose to a reported height of several feet and flooded the highway between mile 7 (7 miles northwest of Haines) and mile 16 to a depth of several feet in places. A creek at mile 23, besides blocking and damaging the main highway, dumped mud and rocks all around the village of Klukwan. Due to the extreme danger, all the inhabitants of the town, except two families, were evacuated until the water had subsided.

Future heavy rains probably will cause flooding of the same streams and damage to essentially the same stretches of highway as occurred during the floods in 1967 unless additional remedial measures are taken.

Land uplift

The fact that the land in the Haines area is rising in respect to sea level at the appreciable rate of 0.89 inch per year should be borne in mind when considering the long-term effects upon construction on or near the shoreline, such as docks, boat harbors, and other facilities where there is a critical relation between height of land and water. If, as indicated previously, the uplift of land is due chiefly to rebound as a result of deglaciation, then it is unlikely that the rate of uplift during the next 50 years will be appreciably different than it has been during the past 50 years. On the basis of this premise, it can be expected that the land will be uplifted nearly 4 feet (in respect to sea level) during the next 50 years. As discussed previously, however, it should be emphasized that there could be several feet or tens of feet of sudden uplift or subsidence of the land in the event of a large earthquake.

RECOMMENDATIONS FOR ADDITIONAL STUDIES

The reconnaissance nature of our studies in the Haines area did not permit us to make all the geologic studies necessary to fully evaluate earthquake and other geologic hazards of the area. Also, additional geophysical, soils mechanics, and seismological studies are necessary to assess more adequately some aspects of the problems. Listed below in approximate order of importance are some of the additional studies that we believe should be done by geologists or specialists in other disciplines to help fulfill the objective of evaluating the potential geologic hazards and other characteristics of the area that are pertinent to proper land-use planning:

1. In order to permit a more adequate assessment of the earthquake probability of the area, a high priority should be placed on studies that will more accurately locate all the major local and regional faults and determine the kind and amount of their past movement and their present degree of activity. All major lineaments that show on aerial photographs should be studied in the field to differentiate those reflecting faults from those attributable to joints or other causes. Geophysical studies should be made to accurately locate faults where the inferred faults are concealed beneath valley fill, water of inlets, or otherwise are not exposed. Geophysical traverses run across the Chilkat River valley northwest of Haines and additional north-south traverses across the saddle area immediately west of Haines should furnish valuable information on the Chilkat River fault as well as help evaluate the tectonic structure of the saddle area. Additional microearthquake studies should be done in the Chilkat River valley, over a considerable period of time, to ascertain whether the high level of microearthquake activity indicated from recent short-term studies is representative of longer periods of time. Also, additional microearthquake studies should be done along other faults for comparison. Instruments should be set up to measure tectonic creep and other types of movement on the two main indicated fault systems of southeastern Alaska and adjacent areas, namely the Fairweather-Queen Charlotte Islands fault system and the Denali fault system.

2. As part of a recommended detailed geologic mapping and engineering geologic study of the Haines area, a fairly large number of additional analyses are needed to more adequately determine the physical properties of the surficial deposits as they may relate to earthquake and other geologic hazards in the area. Particular emphasis should be directed toward those analyses that will give additional information on: (1) comparative degree of shaking of the different kinds of deposits during a major earthquake, (2) expectable degree of slope stability, (3) liquefaction potential, (4) sensitivity of fine-grained deposits, and (5) compaction and resultant settlement characteristics. The information gained from the studies described above should be supplemented, where needed, by drilling and geophysical work to determine thicknesses of individual units and the characteristics of deposits at depth, as well as the topographic relations of the deposits to bedrock.

3. A long-term program of measuring stream flow, sediment load, and lateral channel cutting of the Chilkat River should be undertaken to determine how fast the delta at the mouth of the river is advancing and to obtain related data useful for construction in the general area of the river.

4. Additional bathymetric data are needed for Chilkat and Chilkoot Inlets as well as data on the nature and thicknesses of bottom and possible underwater fiord-wall sediments. The hydrographic charts of the area should be updated and considerably more control points should be established, particularly to define the configuration of the presumably more slide-prone delta fronts, such as those at the mouth of the Chilkat and Katzehin Rivers. These charts, in turn, should be revised periodically so as to reflect delta growth and submarine landsliding. The resulting data will be useful in predicting location and magnitude of future submarine and onshore landsliding and in assessing the hazard of abnormal waves induced by the sliding.

5. More studies need to be done leading to estimating maximum wave heights and runup of tsunamis in long linear fiords in order to assess the tsunami hazard in the Haines area from waves that originate from a distant source. The resulting studies, particularly if a hydraulic model were constructed, also would furnish information that probably would be helpful in evaluating whether or not seiche waves could be generated in inlets in the vicinity of Haines.

6. In the event of a major earthquake in or near the Haines area, a multidisciplinary team, including geologists, geophysicists, seismologists, and engineers, should study the affected area to determine the actual ground effects and the effects upon the structures built thereon. Such a study not only will add to the overall knowledge of earthquake effects but, in this particular instance, where some previous engineering geology studies have been made, it will afford an opportunity to compare the actual effects with our present assessments. Only in this way will it be possible to assess the accuracy of our evaluations and at the same time to furnish guidelines for increasing the worth of future studies of this nature.

7. Additional drilling and sampling, supplemented by the recommended geophysical work to be done in connection with the recommendation in item 1, should be done to determine whether rocks of Tertiary age underlie the surficial deposits in the saddle area west of Haines. The drilling also should provide additional information on the thickness of the surficial deposits and the ground-water potential of the area, and it should help in the interpretation of the recommended geophysical work to be done in connection with the study of the inferred faults of the area.

8. Studies of present rates of land emergence in Haines and other selected localities in southeastern Alaska should be continued to try to differentiate land rebound caused by deglaciation from land-level changes due to faulting. Also, in order that land-level change due to rebound can be clearly distinguished from land-level changes due to local compaction of surficial deposits, all primary tidal bench marks should be established on bedrock.

GLOSSARY

Technical terms that are used extensively in this report are defined here for readers who may not be familiar with them.

Creep: The slow, generally imperceptible, downslope movement of earth material.

Diamicton: A nonsorted or poorly sorted sediment that consists of particles larger than sand in a matrix of sand, silt, and clay-size particles. The term is noncommittal as to how the deposit was formed.

Dip: The angle which a bed, layer, dike, fault, fissure, or similar planar geologic feature forms with an imaginary horizontal surface when measured at right angle to the strike.

Drift: A general term for rock material of any kind that has been transported from one place to another by glacier ice or associated streams. Material may range in size from clay to boulders and may be sorted or unsorted. It includes till and all kinds of stratified deposits of glacial origin.

Epicenter: The point on the earth's surface directly above the origin point of an earthquake.

Fault: A fracture or fracture zone along which there has been displacement of the two sides relative to one another parallel to the fracture. There are several kinds of faults: A normal fault is one in which the hanging wall (the block above the fault plane) has moved downward in relation to the footwall (the block below the fault plane); on a vertical fault, either side has moved down in relation to the other side. A thrust fault is a low-angle fault on which the hanging wall has moved upward relative to the footwall. A strike-slip fault is a fault on which there has been lateral displacement approximately parallel to the strike of the fault. (If the movement is such that, when an observer looks across a fault, the block across the fault has moved relatively to the right, then the fault is a right-lateral strike-slip fault; if the displacement is such that the block across the fault has moved relatively to the left, then the fault is a left-lateral strike-slip fault.) The term active fault is in common usage in the literature, but there is no general agreement as to the meaning of the term in relation to time. In general, an active fault is one on which continuous or, more likely, intermittent movement is occurring. As used in this report, an active fault is defined as one that has displaced the ground surface during Holocene time.

Foliation: Banding or lamination of crystalline rock that resulted from segregation of minerals during metamorphism or lamellar flow.

Footing: Manmade supporting portions of a structure, placed on the foundation.

Foundation: Natural or artificially emplaced earth material on which manmade structures are placed.

Graben: A fault block, generally long and narrow, that has been relatively downdropped along normal faults bounding each side of the block.

Holocene: The most recent epoch in geologic time; it includes the present. Used interchangeably with the term Recent. As used in this report the Holocene Epoch consists of approximately the last 10,000 years of geologic time.

Hypsithermal: The prolonged interval of mild climate in the Holocene Epoch, which started about 8,000 years ago and may have ended as late as 3,500 years ago in southeastern Alaska.

Intensity: Refers to the severity of ground motion (shaking) at a specific location during an earthquake and is based on the sensations of people and visible effects on natural and manmade objects. The most widely used intensity scale in the United States is the Modified Mercalli intensity scale. (See table 5.)

Joint: A fracture in bedrock along which there has been no movement parallel to the fracture. Movement at right angles to a fracture, however, may take place and produce an open joint.

Kame: A mound, knob, or hillock of fluvioglacial origin in which one or more sizes were in contact with glacier ice. Kames are diverse in size, shape, and composition and generally consist of poorly sorted and poorly stratified material.

Lineament: A linear feature of the landscape, such as alined valleys, streams, rivers, shorelines, fiords, scarps, and glacial grooves which may reflect faults, shear zones, joints, beds, or other structural geological features.

Magnitude: Refers to the total energy released at the source of an earthquake. It is based on seismic records of an earthquake as recorded on seismographs. Unlike intensity, there is only one magnitude associated with one earthquake. The scale is exponential in character, and where applied to shallow earthquakes, an increase of 1 unit in magnitude signifies approximately a 32-fold increase in seismic energy released.

Marine limit: The height to which sea level formerly extended as contrasted with present sea level. It is used to indicate the approximate amount of relative rise of the land surface above present sea level.

Microearthquake: An earthquake that generally is too small to be felt by man and can only be detected instrumentally. The lower limit of magnitude of felt earthquakes generally is between 2 and 3; many microearthquakes, on the other hand, have magnitudes of less than 1.

Moraine: An accumulation of material (mainly till) deposited by glacier ice which has a topographic expression of its own. It includes but is not restricted to ground moraine, end moraine, terminal moraine, medial moraine, and lateral moraine.

Muskeg: Organic-rick deposits consisting of peat and other decaying vegetation; commonly found in swamps and bogs.

Neoglaciation: An episode of relatively cool climate that followed the Hypsithermal, and extended from about 3,500 years ago in southeastern Alaska to the present.

Outwash: Material transported by glacial melt-water streams and laid down as stratified deposits beyond the edge of the glacier.

Pleistocene: An epoch of geologic time characterized by worldwide cooling and by major glaciations; also called the "glacial epoch" or Ice Age. The Pleistocene Epoch denotes the time from about 2 million to 10,000 years ago.

Seismicity: A term used to denote the historical frequency of earthquakes occurring in a certain area.

Seismic seiche: Waves set up in a body of water by the passage of seismic waves from an earthquake, or by tilting of a water-filled basin.

Strike: The compass direction of a line formed by the intersection of a bed, bedding surface, fracture, fault, foliation, or other essentially planar geologic feature with a horizontal plane.

Till: An unstratified and unsorted mixture of clay, silt, sand, gravel, cobbles, and boulder-size material deposited by glacier ice on land.

Tsunami: A sea wave, otherwise known as a seismic sea wave, generated by sudden large-scale vertical displacement of the ocean bottom as a result of submarine earthquakes or of volcanic action. Tsunamis in the open ocean are long and low, and have speeds of 425-600 miles an hour. As they enter shallow coastal waters they can greatly increase in height and also in height of runup onto land.

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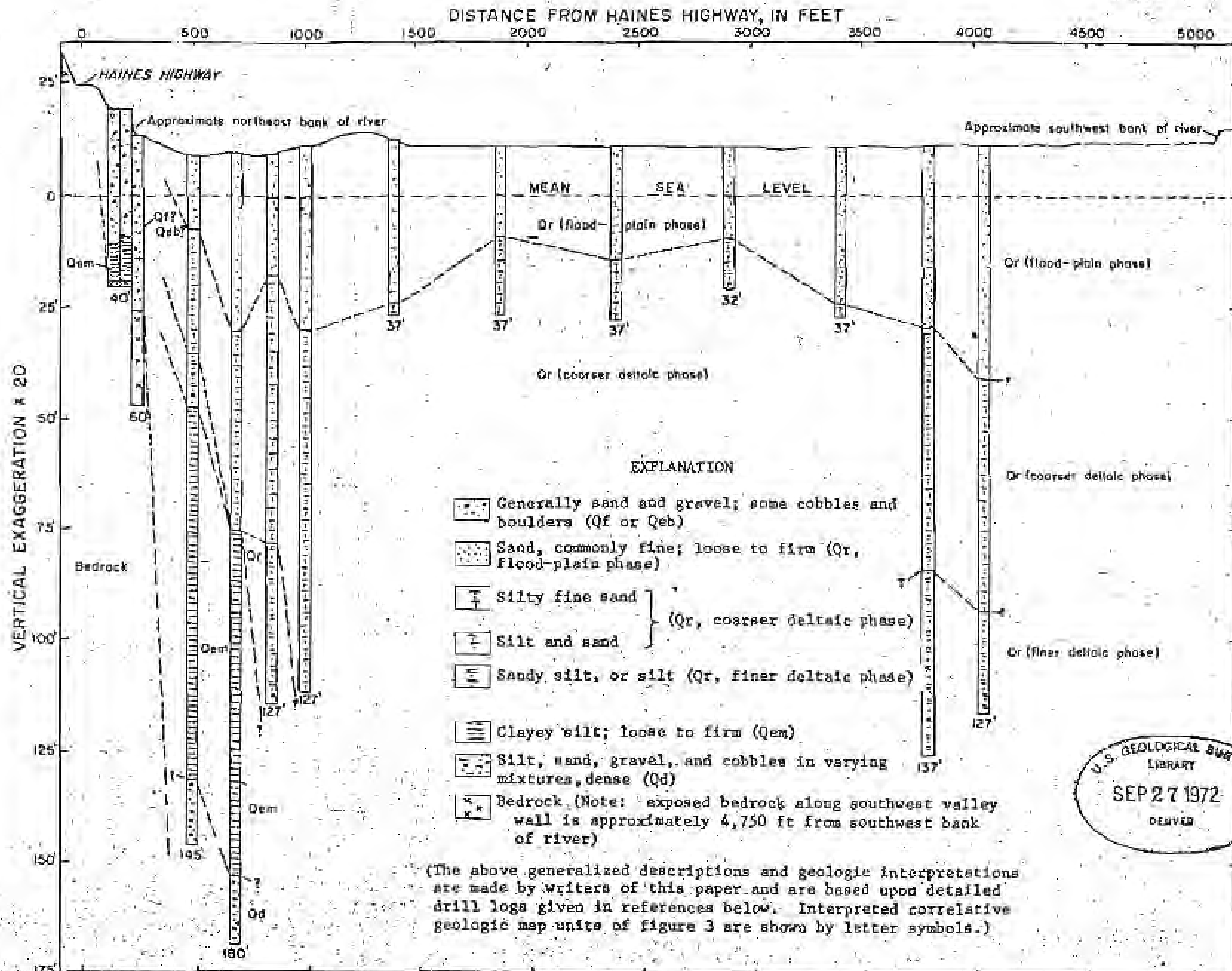

Figure 6.—Section along proposed highway across Chilkat River flood plain (one-half mile northwest of aircraft landing strip) showing drill holes and interpreted geologic units. Modified from Migliaccio and Slater (1968); Franklet (1968).