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Preliminary Report on the Reconnaissance Engineering Geology of the Yakutat Area, Alaska, with Emphasis on Evaluation of Earthquake and Other Geologic Hazards

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

By LYNN A. YEHLE

ABSTRACT

Yakutat, situated about 225 miles northwest of Juneau, Alaska, near the shores of the Gulf of Alaska, has a setting that calls for superlatives. Within the Yakutat region are some of the tallest mountains, some of the heaviest snowfalls, and the largest glacier in North America. Between the abrupt mountain front and the Gulf of Alaska lies a very gently sloping plain of outwash derived from repeated cycles of advance followed by melt and retreat of glaciers during the Quaternary Period. The latest melting probably took place 500 to 600 years ago. Yakutat is built upon the moderately steep moraine that is the product of melting of one of these glaciers. Near Yakutat, surficial deposits are as much as 700 feet thick and probably overlie siltstone, sandstone, and mudstone. The eight general categories of mapped surficial deposits include artificial fill, organic, eolian, beach, delta-estuarine, alluvial, and outwash deposits, and deposits of the outer Yakutat Bay moraine complex.

The Yakutat region is part of an active tectonic belt that rims most of the North Pacific Ocean. The latest period of activity probably began in Late Mesozoic and Tertiary time. Many faults are active as indicated by numerous earthquakes in the area. A few of them are known to have broken the ground surface in historic time, notably the nearly vertical Fairweather fault, whose closest segment is about 33 miles northeast of Yakutat. Movement along this fault caused the major earthquake of July 10, 1958 (magnitude 7.9 to 8.0). The great earthquake of September 10, 1899 (magnitude 8.5 to 8.6), probably was caused by tectonic uplift within a broad area centered about 30 miles north of Yakutat. Uplift averaged between 5 and 10 feet; one small area shows uplift of about 47 feet, the greatest uplift ever measured for an earthquake sequence. A sequence of earthquakes in July 1973, centered offshore, southwest of Yakutat, has been related to a postulated fault.

Many earthquakes have been felt at Yakutat since written historic records were first kept. Five very large earthquakes (magnitude 7.0 to 8.6) occurred within a radius of 80 miles from Yakutat in the period from 1893 through 1974. Of these earthquakes, those of September 10, 1899, and July 10, 1958, were the strongest, causing some damage to buildings at Yakutat. Earthquakes of equally large size undoubtedly will shake the Yakutat area in the future.

Several geologic effects that have characterized large earthquakes in the past may be expected to accompany large earthquakes in the future. These effects include (1) tectonic uplift; (2) severe ground shaking; (3) liquefaction of some delta-estuarine, alluvial, and fine-grained outwash deposits; (4) ejection of water and sand as fountains from individual craters; (5) compaction and differential subsidence of some materials, especially young and intermediate delta-estuarine deposits and some artificial fills; and (6) landslides, where terrain is steep or where beach spits and delta-estuarine deposits are newly deposited and poorly consolidated.

Large water waves commonly are formed during large coastal earthquakes. Tsunami (seismic sea) waves arriving from large earthquakes at great distances can be forecast, but advanced warnings of locally formed waves cannot be provided. To date, the highest recorded earthquake-related waves at Yakutat were about 15 feet high and occurred during the largest earthquake of the sequence during September 10, 1899.

Geologic hazards in the Yakutat region not necessarily associated with earthquakes include (1) subaerial and submarine landsliding, (2) stream flooding and erosion of surficial deposits, (3) high waves, and (4) glacier advances and breakout of glacier dammed lakes.

Recommended future geologic and geophysical studies in the Yakutat area and surrounding region could provide additional information needed for land-use planning. Expansion of general and detailed geologic mapping and collection of data on geologic materials, joints, faults, and stability of slopes are strongly recommended to help delineate areas of economic mineral deposits, to identify hazardous slopes, and to locate suitable areas for construction. There should be expansion of the studies of earthquakes in the region. Such work might lead to prediction of the location of future large earthquakes. Installation of additional seismological instruments would provide information on the location of any unknown active faults and an index of the overall tectonic activity of the region. Additional offshore geophysical studies are needed to determine the nature and position of faults and their relationship to the stability of sediments on the sea floor. Determination of the natural periods of oscillation of Yakutat Bay and adjoining fiords as well as the nearby Continental Shelf would assist in the prediction of heights of tsunami and other water waves that might be associated with seismic shaking.

Other studies might concentrate on analysis of slopes that appear unstable and possibly subject to landsliding. Finally, glaciers that are (1) advancing rapidly, (2) appear likely to form glacier-dammed lakes, or (3) appear susceptible to sudden breakage should be studied.

INTRODUCTION

Soon after the great Alaska earthquake of 1964, the U.S. Geological Survey started a program of geologic study and evaluation of earthquake-damaged cities in Alaska. Subsequently, the Federal Reconstruction and Development Planning Commission for Alaska recommended that the program be extended to other communities in Alaska that had a history of earthquakes, especially those near tidewater. As a result, Yakutat and eight other communities in southeastern Alaska were selected for reconnaissance investigation. Reports were previously completed for the communities of Haines (Lemke and Yehle, 1972a),[1] Juneau (Miller, 1972), Ketchikan (Lemke, 1975), Sitka (Yehle, 1974), Skagway (Yehle and Lemke, 1972), and Wrangell (Lemke, 1974); a generalized regional report was prepared for southeastern Alaska (Lemke and Yehle, 1972b).

This preliminary report concerning the Yakutat area describes highlights of the geology and emphasizes the evaluation of hazards associated with large earthquakes and of other geologic hazards, including subaerial landsliding, submarine landsliding, and high water waves of several types. These descriptions and evaluations, even though intended only as preliminary and tentative, should be helpful in some measure to land-use planning.

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[1]Complete data on titles of reports mentioned in the text are given in the section "References cited."

Values for length, area, and volume used in the report are given in English units. To convert to metric units, the following conversions may be used:

Multiply English units	By	To obtain metric units
feet (ft)	0.3048	metres (m)
miles (mi)	1.609	kilometres (km)
square miles (mi^2)	2.590	square kilometres (km^2)
cubic feet (ft^3)	0.0283	cubic metres (m^3)
cubic mile (mi^3)	4.168	cubic kilometres (km^3)

Several U.S. Geological Survey colleagues gave assistance during different phases of the study: R. W. Lemke gathered data during the initial phase of the work; George Plafker and Austin Post, and W. H. Gawthrop and R. A. Page, contributed information on regional geology and seismicity, respectively; R. C. Trumbly, E. E. McGregor, and P. S. Powers analyzed samples; Meyer Rubin dated wood and shell samples by radiocarbon methods; R. P. Maley and B. L. Silverstein furnished information on earthquake-detection instruments; and V. K. Berwick and S. L. Obernyer prepared data on water wells and test borings. Information also was obtained through interviews and through correspondence with residents of Yakutat and with Federal, State, and city officials who were familiar with the Yakutat area. Especially acknowledged is the help of Byron Mallott and John Williams, former Mayors of Yakutat; personnel of the Alaska Departments of Highways and Game and Fish; the U.S. Forest Service; and the U.S. Bureau of Public Roads.

GEOGRAPHY

Yakutat lies at 59°33′ N. lat and 139°44′ W. long; it is situated on the shore of Monti Bay, along an outer part of Yakutat Bay, about 225 miles northwest of Juneau, Alaska (figs. 1; 2, in pocket). For purposes of discussion in this report, the Yakutat region is defined as extending to the boundaries shown in figure 3, and the Yakutat area is defined as extending to the boundaries shown in figure 2, encompassing most of the B-5 and C-5 quadrangles. Four principal concentrations of population exist in the area: (1) at Upper Yakutat, centered near the head of Monti Bay and containing the civic center of Yakutat; (2) at Lower Yakutat or Old Village, centered about 1 mile to the northwest; (3) near the airport; and (4) near Ocean Cape (McCabe, 1971; Sealaska Corporation, 1973). Landscape in the region near Yakutat is characterized by the spectacular peaks of the Saint Elias Mountains, which rise above large glaciers and icefields, and by Yakutat Bay and its connecting waterways. Close to the city the major geographic features include (1) the low hills and small lakes of the end and recessional moraines that rim outer or lower Yakutat Bay; and (2) the nearly flat plain of outwash deposits and shallow-water marine deposits, part of the Yakutat Foreland, extending from the city to the Gulf of Alaska where there are several types of shore features.

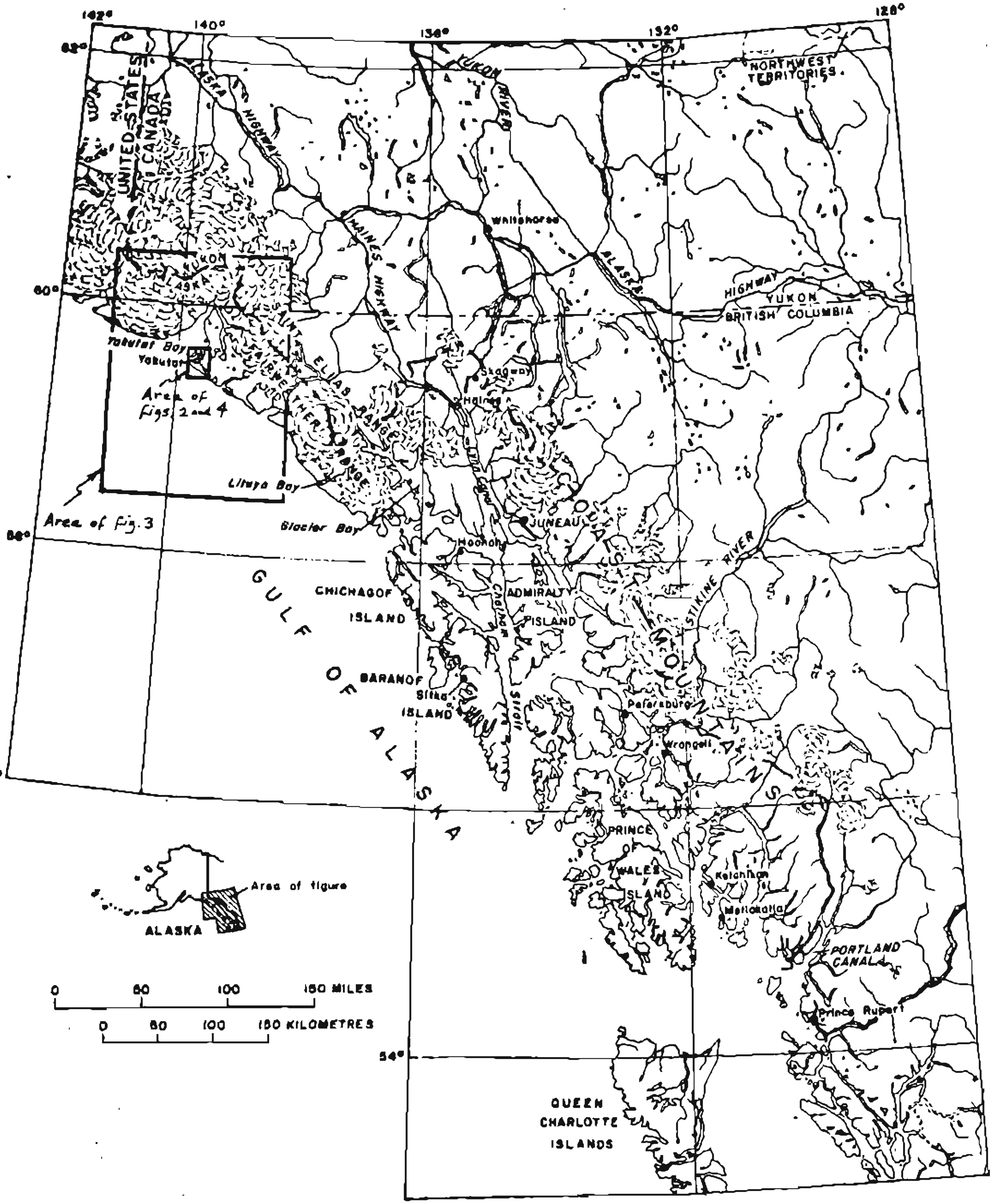

Figure 1.--Index map of southeastern Alaska and adjacent Canada showing location of Yakutat.

Land near Yakutat has been subaerially exposed for only a relatively short period of time (Billings, 1970, p. 7). Land formed directly from glaciers probably is no older than about 500 to 600 years. Some land has emerged above tidal levels within only the last several hundred years, while other areas, notably the older beaches and deltas, might have had their beginnings as long ago as several thousands of years.

GLACIATION AND ASSOCIATED LAND- AND SEA-LEVEL CHANGES

Glaciers in the Yakutat region were vastly expanded on several occasions during the Pleistocene Epoch; during the Holocene Epoch they were moderately expanded at least several times. Most evidence of glacial erosion and deposition is obliterated by later glacial advances, especially in lowland areas. In a few places along mountain valleys and mountain fronts, however, evidence is preserved that is thought to be a record of glacial events rather than other processes, such as tectonic uplift. Such places are the prominent, relatively gently sloping topographic surfaces at about 1,600 to 2,000 feet altitude along the steep mountain front between Yakutat Bay and Russell Fiord and at about 1,200 to 1,500 feet altitude southeast of Russell Fiord. These surfaces probably attest to the importance of glacial erosion in sculpting the mountains northeast of Yakutat. Surfaces at lower altitudes along the mountain front may owe their origin to glacial erosion, glacial deposition, or wave action.

Glacial drift deposits are abundant on the floor of Yakutat Bay and along adjacent lowland areas and have been studied by several investigators (Tarr, 1909; Plafker and Miller, 1958; Miller, 1961; Plafker, 1967; Wright, 1972). At least three groups of moraines, and possibly a fourth, have been recognized. The group of moraines looping along the southeast side of the outer part of Yakutat Bay is subaerially the most prominent of the groups. It probably was deposited about 500 to 600 years ago, according to interpretations of several radiocarbon dates. (See discussion of outer Yakutat Bay moraine complex in section called "Description of geologic map units.")

The most recent major glacial event in the region was the sudden breakup or retreat in the mid-1800's of a glacier in southern Russell Fiord that fronted southward into a large lake about 20 mi^2 in size and having a maximum depth of about 1,000 feet. The lake apparently drained suddenly as the glacier retreated. These combined events drastically reduced the flow of the Situk River (fig. 2) (de Laguna, 1964, p. 17). Before these events, the river carried the outflow of the dammed lake.

Numerous glaciers and icefields still exist in the region. Although most of these features are in a state of near equilibrium or are melting or otherwise retreating, several glaciers are advancing.

The position of land in relation to sea level in the Yakutat area has changed greatly within the past tens of thousands of years; at present, land is emerging. One of the causes of change is the expansion and contraction of glaciers, which affects sea level throughout the world as well as locally; other causes are considered below. The weight of thick glacial ice depresses land; 500 feet of ice, theoretically, is capable of causing a land depression of 136 feet (Gutenberg, 1951, p. 172). Melting of ice causes land to slowly rebound; however, in most areas there is a time lag between melting and rebound, and thus marine waters temporarily may occupy low areas. Each cycle of glacial advance and retreat, theoretically, is accompanied by a relative subsidence and then an emergence of land.

Other possible causes for the relative emergence of land near Yakutat are not related to deglaciation but are related to active tectonic movements, presumably mostly uplift, which result from release of stresses deep within the western part of the North American Continent and the adjacent Pacific Ocean.

The most recent sudden tectonic uplift in the region resulted in a large zone of emergence having an average uplift of about 5 to 10 feet and maximum uplift at the surface of about 47 feet. This value was recorded about 32 miles north of Yakutat after the earthquakes of September 1899 (Tarr and Martin, 1912; Plafker, 1974). Tectonic uplift probably is the cause of most of the relative emergence of the prominent surfaces mapped by Miller (1961) along the mountain front east-northeast and east of Yakutat.

Measurements of the relative emergence of land at Yakutat indicate an average emergence of 0.21 ± 0.02 inch per year, on the basis of readings of the Yakutat tidal gage during the period 1940 through 1972 (Hicks and Crosby, 1974). Using that value and projecting it to a 50-year period, there is, in theory, a possible emergence of 10.5 inches, which could result in 50 feet of new land where shore areas slope very gently (1°, 1.75 percent).

DESCRIPTIVE GEOLOGY

Regional setting

Several reconnaissance as well as detailed studies have been completed that deal with various aspects of the geology of the Yakutat region. Of primary importance are reports by Tarr (1909), Tarr and Butler (1909), Plafker and Miller (1957, 1958), Miller (1961), Plafker (1967, 1971), Stoneley (1967), and MacKevett and Plafker (1970). Distribution of major groupings of bedrock and generalized locations of major faults in the region, as shown in figure 3, are based on these reports. Consideration of structure is given in the section "Structural geology."

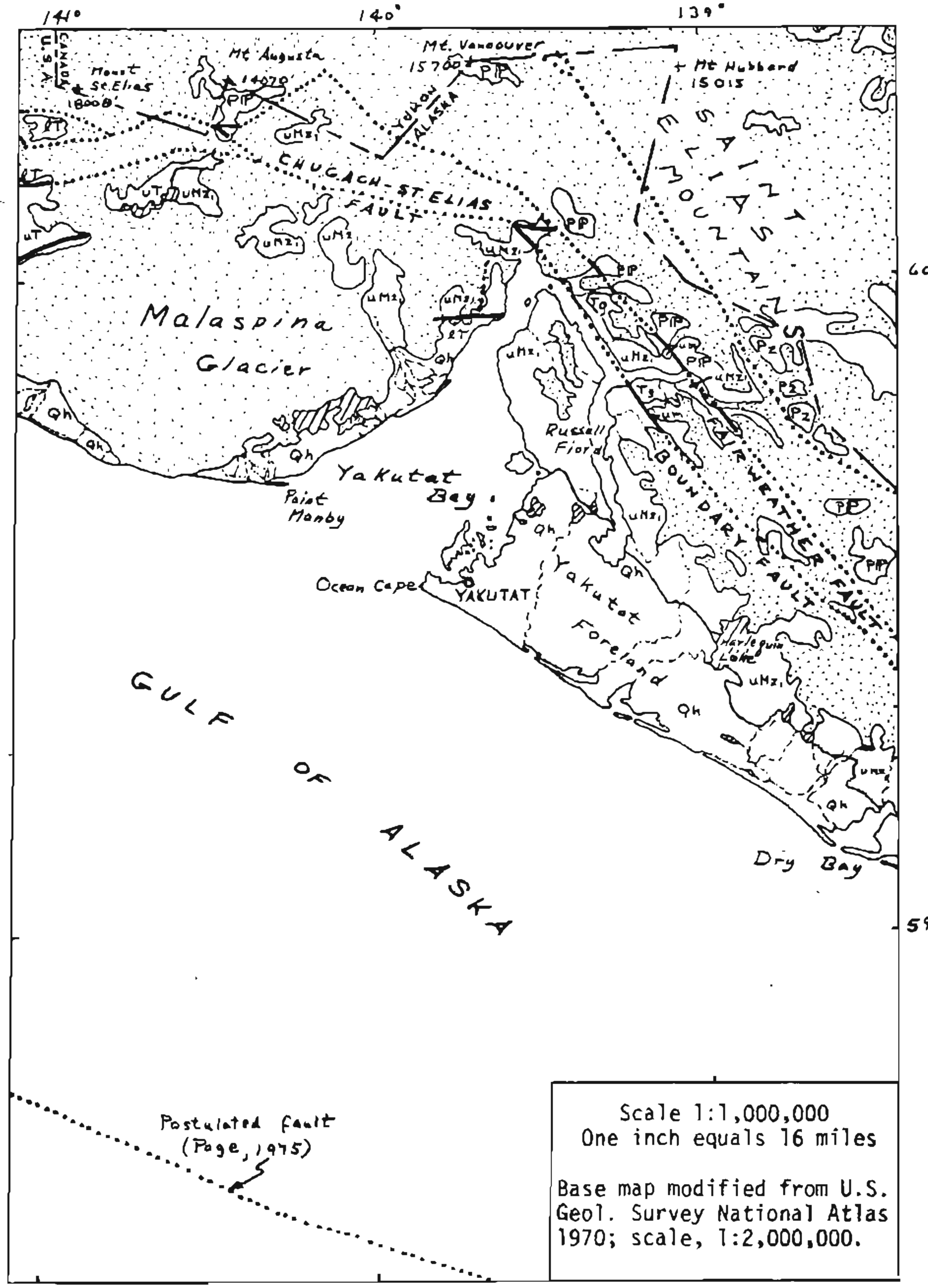

Figure 3.--(See following page for caption.)

DESCRIPTION OF MAP UNITS

Qh — HOLOCENE DEPOSITS--Alluvial, glacial, lacustrine, swamp, landslide, and beach deposits.

uT — UPPER TERTIARY ROCKS--Mostly siltstone, sandstone, and conglomeratic sandy mudstone (marine tillite).

lT — LOWER TERTIARY ROCKS--Probably chiefly arkose, siltstone, coal, and some sandstone.

uMz — CRETACEOUS AND UPPER JURASSIC(?) ROCKS--Interbedded graywacke, siltstone, conglomeratic sandstone, conglomerate, and greenstone.

PP — PERMIAN AND PENNSYLVANIAN ROCKS--Probably chiefly slate, phyllite, mica schist, migmatite, amphibolite, greenschist, and marble.

Pz — PALEOZOIC ROCKS--Mostly marble, metavolcanics, and mica schist.

Tg — TERTIARY GRANITIC ROCKS--Mainly quartz diorite, granodiorite, and quartz monzonite.

um — ULTRAMAFIC ROCKS OF UNCERTAIN AGE--Probably mostly dunite, serpentinized dunite, and peridotite.

SYMBOLS

Contact between map units.

Major fault, approximately located; dotted where concealed, inferred, or postulated.

Glacier

Lake

Stream

Figure 3.--General geologic map of Yakutat region, Alaska. (Modified from Richter, 1958, p. 599; Plafker, 1967, 1974; MacKevett and Plafker, 1970; Beikman, 1974; and Page, 1975).

The known bedrock exposures closest to Yakutat are at the abrupt mountain front, about 15 miles northeast of the city. These rocks are part of the Yakutat Group of Cretaceous and Upper Jurassic(?) age that includes several types of interbedded, hard, generally metamorphosed sedimentary and volcanic rocks; namely, graywacke, siltstone, conglomeratic siltstone, conglomerate, and greenstone. Beneath the thick unconsolidated Holocene deposits forming the Yakutat Foreland are Tertiary sedimentary rocks penetrated by exploratory test wells during oil exploration (Plafker, 1967). These rocks probably are similar to rocks exposed west of Yakutat Bay, where there are moderately soft siltstone and sandstone, and various types of mudstone. The thickness of surficial deposits and depth to bedrock at Yakutat probably average more than 335 feet, because the city water well drilled to that depth did not reach bedrock (V. K. Berwick, written commun., 1965); depth to bedrock near the airport may be more than 700 feet (B. L. Silverstein, written commun., 1975).

Local geologic setting

The reconnaissance geologic map (fig. 4, in pocket) prepared for this report shows the distribution of geologic materials in the Yakutat area. Materials were examined in reconnaissance near roads, along some trails, along the Gulf of Alaska or outer coast, and along the northern and southern ends of Khantaak Island. Elsewhere, information was obtained largely by interpretation of airphotos, supplemented by data from borings for water wells and highway locations (U.S. Army Corps of Engineers, 1959; Franklet, 1970; U.S. Bureau of Public Roads, written commun., 1962). Seventeen types of geologic materials in eight categories of map units were recognized and mapped. Units are artificial fill, two types of organic deposits, eolian sand deposits, three types of beach deposits, four types of delta-estuarine deposits, three types of alluvial deposits, two types of outwash deposits, and deposits of the outer Yakutat Bay moraine complex. Detailed descriptions of the geologic materials composing the map units follow. Information on selected characteristics and physical properties of deposits is given in table 1. These include slopes, permeability, surface drainage, ground-water level, compactness, and frost susceptibility. Table 2 lists the suitability of deposits for selected construction purposes; namely, as construction aggregate, as fill, and as foundations for roads and large structures.

Table 1.--Characteristics of geologic map units

Geologic unit and map symbol	Slopes	Permeability; surface drainage; ground-water level	Compactness	Frost susceptibility
f artificial fill	Nearly flat, except in Upper Yakutat where commonly steep near margin of Monti Bay.	Generally good, but locally poor where content of silt is high; surface drainage good for well-constructed, gently to steeply sloping fills; water table dependent upon height of fill over natural terrain (much natural terrain has very high water table).	Well-constructed fills generally firm; many small fills probably loose.	Generally low where silt content low and fill height greater than frost penetration. (Probably about 4 ft.)
wc organic deposits underlain by coarse-grained deposits	Nearly flat to very gentle.	Low; surface drainage poor; ground-water table at surface or at very shallow depths.	Loose to very loose, but many sectors are fibrous and thus relatively firm.	High to very high.
wf organic deposits underlain by fine-grained deposits	Nearly flat	Very low; surface drainage very poor; ground-water table at surface or at very shallow depths.	Loose to extremely loose; a few sectors fibrous and thus relatively firm.	Probably very high.
e eolian sand deposits	Mostly gentle to moderately steep.	Excellent to good; drainage excellent; ground-water table probably at depth of 5-15 ft.	Very loose to loose.	Very low.

Table 1.--Characteristics of geologic map units--Continued

Geologic unit and map symbol	Slopes	Permeability; surface drainage ground water level	Compactness	Frost susceptibility
by young beach deposits	Gentle to nearly flat.	Excellent; drainage excellent, dependent upon tidal stage.	Moderately firm to loose, except very loose where newly deposited, as near ends of lengthening spits.	Not applicable.
bi intermediate beach deposits	Gentle to locally moderate, especially in direction perpendicular to shore.	Excellent; drainage excellent; water table probably at depth of 5-10 ft.	Moderately firm.	Very low.
bo old beach deposits	Gentle to moderate.	Excellent; drainage excellent; water table probably at depth of 5-15 ft.	Moderately firm.	Very low.
dy young delta-estuarine deposits	Very gentle to nearly flat.	Fair; drainage fair to good dependent upon stage of tide.	Very loose.	Not applicable.
di intermediate delta-estuarine deposits	Very gentle except along stream banks where gentle to moderately steep.	Fair to good; drainage fair; water table within several inches to a few feet of surface.	Loose.	Very high.

Table 1.--Characteristics of geologic map units--Continued

Geologic unit and map symbol	Slopes	Permeability; surface drainage ground water level	Compactness	Frost susceptibility
do old delta-estuarine deposits	Gentle.	Probably good to fair; drainage probably good; ground water probably more than 5 ft beneath surface, except shallower near margin of deposits.	Probably varies from somewhat loose to moderately firm.	Moderate to low.
ds clayey silt delta-estuarine deposits	Generally exposed only in stream cuts, most of which are moderately steep.	Extremely low; other aspects not applicable because of intertidal position.	Dense.	Not applicable.
ac coarse-grained alluvial deposits	Mostly gentle; locally, moderately steep along margins of some streams and between stream channels. Steep along shores of Yakutat Bay.	Moderately good; drainage mostly good except in some former stream channels where poor; water table within a few feet of surface.	Loose.	Moderately high.
af fine-grained alluvial deposits	Mostly gentle; moderately steep along some streambanks and between some stream channels of different ages. Steep along shores of Yakutat Bay.	Probably fair to good; drainage fair, except poor along floors of abandoned stream channels; water table within a few inches to a few feet of surface.	Mostly loose.	High.

Table 1.--Characteristics of geologic map units--Continued

Geologic unit and map symbol	Slopes	Permeability; surface drainage ground water level	Compactness	Frost susceptibility
ao old alluvial deposits	Gentle to very gentle.	Probably fair; drainage fair; water table within a few inches to a few feet of surface.	Loose to somewhat firm.	Moderately high.
oc coarse outwash	Gentle to moderately steep along margins of active and abandoned channels.	Excellent; drainage very good except locally where minor swales poorly drained (much drainage is subsurface); ground-water level within several feet to 15 feet of surface.	Loose.	Low, but locally moderate, close to moraine where some silt probably present.
of fine outwash	Gentle.	Probably good to excellent; drainage good; ground-water level probably within a few to several feet of surface.	Generally loose.	Low to moderate.
m outer Yakutat Bay moraine complex	Possibly averages moderately steep, but widely variable, ranging from gentle to locally very steep.	Probably averages moderate, but varies widely from poor, (where silt-rich) to very good (where sandy till and ice-contact deposits abundant); drainage variable from good to poor; water table variable and within a few feet of surface in many places.	Varies widely from deposit to deposit, ranging from firm to loose.	Moderate, locally high.

Table 2.--Suitability of geologic map units for certain construction purposes

Geologic unit and map symbol	Construction aggregate	Fill	Foundation for roads and large structures
f artificial fill	Not applicable.	Not applicable.	Not applicable.
wc organic deposits underlain by coarse-grained deposits	Unsuited.	Unsuited.	Generally unsuited unless overlain by filter blanket and several feet of granular fill.
wf organic deposits underlain by fine-grained deposits	Unsuited.	Unsuited.	Unsuited unless overlain by filter blanket and many feet of granular fill.
e eolian sand deposits	Limited suitability because of lack of coarse-sized rock fragments.	Fair.	Excellent where thick, shore position probably not appropriate for some uses.

Table 2.--Suitability of geologic map units for certain construction purposes--Continued

Geologic unit and map symbol	Construction aggregate	Fill	Foundation for roads and large structures
dy young delta-estuarine deposits	Unsuited.	Generally unsuited.	Unsuited.
di intermediate delta-estuarine deposits	Generally poorly suited because of relative lack of coarse-grained rock fragments and abundance of fines.	Poor.	Poor to fair.
do old delta-estuarine deposits	Probably poorly suited because of probable low content of coarse-sized material.	Poor.	Good to fair.

Table 2.--Suitability of geologic map units for certain construction purposes--Continued

Geologic unit and map symbol	Construction aggregate	Fill	Foundation for roads and large structures
by young beach deposits	Limited suitability depending upon % of appropriate grain sizes.	Generally good, very good where full range of rock-fragment sizes present.	Excellent, but shore position not appropriate for some uses.
bi intermediate beach deposits	Limited suitability because of general lack of coarse-sized rock fragments.	Good.	Limited suitability where less than 5 ft thick; excellent where thicker. Position along outer coast not appropriate for some uses.
bo old beach deposits	Limited suitability because of general lack of coarse-sized rock fragments.	Fair to good.	Generally excellent.

Table 2.--Suitability of geologic map units for certain construction purposes

Geologic unit and map symbol	Construction aggregate	Fill	Foundation for roads and large structures
ds clayey silt delta-estuarine deposits	Unsuited.	Unsuited.	Poorly suited because of exposure to sea and very high % of fine-grained constituents.
ac coarse-grained alluvial deposits	Good to excellent.	Excellent.	Generally good, poor where water table high and wet abandoned stream channels exist.
af fine-grained alluvial deposits	Generally poor, locally good.	Poor to good.	Fair to poor.
ao old alluvial deposits	Probably good.	Excellent.	Fair to good.

Table 2.--Suitability of geologic map units for certain construction purposes--Continued

Geologic unit and map symbol	Construction aggregate	Fill	Foundation for roads and large structures
oc coarse outwash	Generally excellent after removal of cobbles.	Excellent.	Excellent.
of fine outwash	Good to locally excellent where some pebbles present in the sand.	Excellent.	Good to excellent where water table at least several feet deep.
m outer Yakutat Bay moraine complex	Generally poor; locally, excellent when screened.	Very good.	Very good except where drainage poor and directly exposed to sea.

Description of geologic units

Artificial fill

This unit, designated f on the geologic map, includes the larger areas of fill and also most of the areas of ground extensively modified during construction. Materials chiefly consist of pebble gravel and sand, some silty, pebbly sand, and cobbles. The thickness ranges from 2 to 30 feet. Many of the active and abandoned borrow pits used as sources of fill and construction aggregate are shown on the map. Locally, materials probably have been obtained from intertidal areas, but evidence of such exploitation is quickly obliterated by the action of longshore currents and waves.

Organic deposits

Areas that were interpreted using airphotos as being wet and containing considerable amounts of organic materials are placed in this map unit. Materials probably are derived from the decomposition of small woody plants, mosses, and sedges and other water plants. Areas denoted as marshes and swamps on the published topographic map delineate only a part of the total area of mapped organic deposits. Thickness of deposits probably is between 2 and 5 feet. The area covered by organic deposits has been broken down into two subunits that interpret the type of underlying material. Mapped subunit wc is thought to be underlain chiefly by coarse rock fragments; namely, sandy pebble gravel or silty, sandy pebble gravel deposited by streams. Cobbles form a part of the constituents near the outer Yakutat Bay moraine. Near the airport and northeastward, the subunit merges with mapped subunit wf. This latter subunit is defined as organic deposits underlain by fine- grained, stream-deposited materials, chiefly sand and silty sand, locally including silt. The silt probably owes its origin to wind and subsequent deposition in quiet waters of ponds, small lakes, and former tidal lagoons.

Eolian sand deposits

The eolian deposits, designated *e* on the geologic map, are composed of windblown sand, mostly in the form of dunes. Principal locations are near the estuary of the Situk River. Deposits probably range from 5 feet to as much as 20 feet thick. The underlying materials may include at least two types of delta-estuarine deposits. Eolian sand merges laterally with mapped young beach and delta-estuarine deposits.

Beach deposits

Three subunits of beaches are shown on the geologic map on the basis of differences in age. The *first* subunit, young beach deposits, designated *by*, includes materials between the line of mean lower low water and the berm of the storm beach. Along most of the outer coast near the Gulf of Alaska, these young deposits consist of sand and some pebbly sand, while along the remainder of the gulf and among the islands, bays, and coves of Yakutat Bay, deposits consist, overall, of mixtures of sandy, pebbly cobble gravel with some boulders and driftwood. Areas that consist mostly of sand are symbolized , and areas that consist of abundant cobbles, boulders, and pebbles and some driftwood are symbolized . Thickness of the deposits probably averages 7 feet and ranges from a few feet to 10 feet. These deposits chiefly overlie deposits of the outer Yakutat Bay moraine complex and, in part, the clayey silt subunit of delta-estuarine deposits.

The <u>second</u> subunit of beach deposits, designated <u>bi</u> on the geologic map, is intermediate in age. It consists of sand and some pebbly sand; deposits extend along the coast of the Gulf of Alaska. Thickness of the deposits probably averages 15 feet and ranges from 5 to 20 feet. Generally, moraine deposits or clayey silt of the delta-estuarine deposits underlie these beaches, but near Aka and Summit Lakes they probably are underlain by intermediate or older delta-estuarine deposits. A timbered mound area characterizes most of the deposits; more prominent linear ridges on the mound are symbolized ·······, and some crests are as much as 15 feet above adjacent parts of the deposits. Origin and emergence of the intermediate beaches probably occurred mostly following formation of the outer Yakutat Bay moraine.

The <u>third</u> subunit of beaches that has been recognized and mapped is the old beach deposits, designated <u>bo</u> on the geologic map. The deposits are composed of sand and pebbly sand; thickness probably averages 15 feet and ranges from 5 to 20 feet. These form a series of low, gently sloping, timbered ridges that are inland from intermediate beaches near Tawah Creek and Lost and Situk Rivers. The more pronounced individual ridges are symbolized ········ . Crests of some ridges probably rise to as much as 20 feet above adjacent parts of the deposits. The underlying geologic materials are possibly the clayey silt subunit of the delta-estuarine deposits. Formation of the old beach deposits probably was largely completed a few thousand years before development of the beach deposits of intermediate age.

Delta-estuarine deposits

Four subunits of delta and estuarine deposits are recognized and shown on the geologic map on the basis of apparent differences in age. The first subunit, dy on the geologic map, is the young deposits. It comprises the active deltas and estuaries of Lost, Situk, and Ahrnklin Rivers. Geologic materials are chiefly silty sand or fine sand; these are symbolized  . Thickness of the deposits possibly averages 20 feet, ranging from 15 to 50 feet. Merging with these deposits are young beach and intermediate delta-estuarine deposits; underlying the deposits are sediments of older cycles of delta-estuarine deposition.

The second subunit is the intermediate delta-estuarine deposits, designated di. They form a small, low-relief plain inland from deposits of the first subunit and generally are located near Tawah Creek and Lost, Situk, and Ahrnklin Rivers. Geologic materials are largely sand and include some silt and small pebbles. Thickness of the deposits possibly averages 20 feet and ranges from 10 to 40 feet. Most mapped deposits are timbered. Organic deposits wf locally overlie intermediate delta-estuarine materials to thicknesses exceeding 2 feet. Several such areas are near the airport. Toward the outer shore intermediate deposits merge with young delta-estuarine deposits, and landward they merge very gradually with alluvial and some outwash deposits. The origin and emergence of these intermediate delta-estuarine deposits probably followed development of the outer Yakutat Bay moraine complex.

The third subunit, old delta-estuarine deposits, designated do, occurs near Ophir Creek and the Situk River. Constituents probably are mostly sand and include some pebbles and silt. Total thickness possibly is 30 feet. The deposits appear to form low mounds related topographically to the intermediate delta-estuarine deposits. Some linear ridges are present within the area of the deposits. These are symbolized .... The deposits are older than the intermediate deposits and probably originated a few thousand years ago from limited wave action on coarse-grained delta deposits.

The fourth subunit of delta-estuarine deposits, designated ds on the geologic map, is composed of firm clayey silt exposed on the intertidal shore area between mean lower low water and several feet above mean high water in the estuary of Lost River and southeastward. The greatest observed thickness of the deposit is about 7 feet. In the upper part of one exposure of the deposit, lenses of pebbly silt included marine mollusk shells and some fragments of wood. Although the relationship of the fourth subunit to other deposits is not clear, it is speculated that the subunit underlies much of the southern part of the map area at a depth of from 50 to a few hundred feet and is similar to marine deposits that probably underlie much of the outer Yakutat Bay moraine complex. The age of at least a part of the clayey silt, as interpreted from a radiocarbon date on marine shells (loc. ⌒ on the geologic map), is about 2,180±250 years before the present (U.S. Geol. Survey sample W-2598; Meyer Rubin, written commun., 1971).

Alluvial deposits

Geologic materials composing the alluvial deposits are located chiefly near the Situk River; they consist of pebble gravel, sand, and some cobble gravel, the percentage of sand increasing toward the south. Deposits are in beds as much as several feet thick. Thickness of the deposits may average 25 feet but varies greatly; the maximum probably is as much as 100 feet. Organic materials locally overlie alluvial deposits. Alluvial deposits probably overlie delta-estuarine deposits. Larger alluvial deposits merge toward the present shore of the Gulf of Alaska with delta-estuarine deposits and merge very gradually away from shore with outwash deposits. Alluvial sediments originate by deposition from streams; most sediments are not directly related to glacier melting but do include large quantities of reworked glacial outwash. Three subunits of alluvial deposits are recognized on the basis of differences in grain size and age. The first subunit is coarse grained and designated ac on the geologic map. It is composed mostly of pebble gravel and includes some sand, cobbles, and silty sand in abandoned stream channels. The materials of the subunit merge gradually with those of the second subunit, which is fine grained and designated af on the map. Geologic materials of this subunit are mostly sand and include some pebble gravel and silt. A few small deposits are mapped near the shores of Yakutat Bay. The third subunit, the oldest, is designated ao; it probably is composed of sand and silty sand that includes sandy pebble gravel near its base. The deposits are related mostly to streams draining from the glacier-dammed lake that existed in the southern part of present Russell Fiord until the mid(?)-1800's.

Outwash deposits

Melting and retreat of the glacier that deposited the outer Yakutat Bay moraine about 500 to 600 years ago released vast quantities of frozen-in rock fragments termed, collectively, outwash, which was carried outward from the glacier by numerous streams. Individual streams developed, shifted, and were abandoned as the various sectors of the glacier melted. Some of the abandoned stream channels are symbolized by →⇨. Two subunits of outwash that gradually merge into one another are shown on the geologic map. The first, heavily timbered, is the coarse-grained subunit of the deposit, situated within a few miles of the outer Yakutat Bay moraine and consisting mostly of sandy pebble gravel. It is designated oc on the geologic map. Close to the moraine, cobble gravel is a major constituent of the outwash, and some silty, sandy gravel is present, derived from direct melting of the glacier ice to form kame and other types of ice-contact deposits too small to show on the geologic map. Deposits of the subunit are bedded and moderately well sorted within individual beds. Coarse rock fragments at many places are silt coated. The overall thickness of the coarse-grained outwash subunit may average 20 feet and range from 3 feet to as much as 50 feet. Deposits are thought to overlie delta-estuarine and probably some deposits related to buried parts of the moraine complex. In many places organic deposits cover the coarse outwash.

The <u>second</u> subunit, designated <u>of</u> on the geologic map, is the fine-grained outwash deposits. These deposits are chiefly sand, varying from pebbly sand to silty sand. The thickness of the subunit may average 20 feet and range from a few to as much as 40 feet. Underlying the fine-grained outwash are intermediate and old delta-estuarine deposits and, locally, coarse-grained outwash. Commonly, small to very large sized organic deposits cover the fine-grained outwash deposits. In many places organic materials cover the deposit.

The outwash deposits are contemporaneous with the outer Yakutat Bay glacier from which the deposits issued. This is corroborated by a generalized study of the ages of trees rooted on the surface of the outwash; these averaged 550 years old (Plafker and Miller, 1958).

Outer Yakutat Bay moraine complex

The map area is topographically dominated by the large group of crude morainal loops near the shores of Yakutat Bay. These are part of an outer Yakutat Bay moraine complex, while a group of cross-bay probable moraines about 20 miles to the north are considered an inner complex. The most prevalent type of deposit within the largely timbered moraine complex is a heterogeneous mixture called diamicton, or till. This mixture consists mostly of granule- and pebble-laden silt or sand, in varying proportions; subordinately, the mixture includes cobbles, clay, some boulders, and, rarely, organic material. The less prevalent deposits are quite variable in grain size; they range from sandy pebble gravel or sandy cobble gravel to silty, fine sand. Locally, sorting is very good, in beds that may be as much as 10 feet thick. Although deposits generally are firm, in many places they are loosely consolidated. Groups of curvilinear ridges that are oriented perpendicular to the direction of flow of glacier ice are a characteristic feature of the moraine complex. These may represent sequential thrusting during advance of the glacier. A differing orientation to some ridges may indicate a minor readvance of the glacier, as is true northeast of Redfield Cove. The more prominent ridges are symbolized ·–·–·–; crests of some ridges are as much as 30 feet above adjacent parts of deposits. Interridge areas commonly contain organic materials. Locally, the organics may overlie deposits of former ponds or small lakes, as indicated by deposits containing more silt or sand than those in the ridges.

Subordinate landforms in the moraine complex are mostly kames, eskers, crevasse fillings, and some outwash. These forms may contain mostly pebble gravel, sand, and silt; silty, sandy pebble gravel commonly is contained in kames. Small areas of linear, fluted landforms, mostly parallel to the direction of movement of the glacier, are symbolized .... on the geologic map. They are relatively common on Khantaak Island. Most forms probably contain sandy or silty pebble gravel. The thickness of the deposits of the moraine complex, as interpreted by me from a few logs of drill holes (provided by V. K. Berwick, written commun., 1965), may average 75 feet and be a maximum of as much as 200 feet. The base of the moraine overlies former marine sediments of sand, silt, clay, and organic material.

A large part of the moraine was formed about 500 to 600 years ago, on the basis of interpretation of radiocarbon dates of samples of wood from three locations (A, B, C on geologic map). The sample from A was dated as 560±75 years before the present (I-439; Miller, 1966); it was collected from a stump that was mostly sheared off by the glacier that deposited the outer Yakutat Bay moraine. The other dates are B, 830±160 years before the present (U.S. Geol. Survey sample W-559; Hartshorn, 1960), and C, 500±250 years before the present (U.S. Geol. Survey sample W-2167; Meyer Rubin, written commun., 1968).

STRUCTURAL GEOLOGY

Regional setting

The Yakutat region is part of an active tectonic belt that rims the Gulf of Alaska and much of the rest of the North Pacific Ocean. Since early Paleozoic time, profound tectonic deformation, plutonic intrusion, and widespread metamorphism have occurred in this belt. The latest major events in the Yakutat region probably began in late Mesozoic and Tertiary time and have continued to the present, as evidenced by frequent earthquakes that have produced uplift as well as lateral offsets along faults in the region (Tarr and Butler, 1909; Stoneley, 1967; Plafker, 1967, 1971, 1974; MacKevett and Plafker, 1970).

The areas that contain the most prominent zones of faults in the region are shown in figure 3. Most of the indicated faults consist of groups of closely spaced subparallel zones of fractured bedrock that extend to great depth and may total as much as several miles in width. Areas of prominent faults are (1) generally northeast of Yakutat Bay, where the group includes the northwest-trending, nearly vertical Boundary and Fairweather faults, and, farther to the northeast, a lineament, possibly a fault, that is alined along a major glacier; (2) northwest of Yakutat Bay, the Chugach-St. Elias and other generally west trending thrust faults, most of which dip gently northward (Plafker, 1971, 1972a, b). The broad area of uplift, probably related to the second of the two large earthquakes of September 10, 1899, is about 18 by 30 miles in size and centers about 30 miles north of Yakutat (Plafker, 1974). Uplift averages between 5 and 10 feet, although one small area, presumably bounded by faults, shows greater uplift and a maximum of about 47 feet, the greatest uplift ever measured for an earthquake sequence (Tarr and Martin, 1912); and (3) offshore southwest of Yakutat and beneath the floor of the Gulf of Alaska, a postulated thrust fault that is northward dipping (Gawthrop and others, 1973; Chandra, 1974; Page, 1975). In the same general region of the Gulf of Alaska, Naugler and Wageman (1973, p. 1577) identified an area roughly parallel to the fault where the magnetic field is abruptly different from the magnetic field to the southwest.

Active faults close to Yakutat

Many of the prominent faults in the Yakutat Region are thought to be active. An active fault, in general, is considered to be a type of fault along which continuous or intermittent movement is taking place; motion may be abrupt or, in some cases, may be very slow. The active fault nearest to Yakutat on which historic surface displacements have been measured is the Fairweather fault, whose closest segment is about 33 miles to the northeast. From the historic record of earthquakes, other active faults, including those that moved during the September 1899 earthquakes, are inferred to exist, but they have not as yet been located and, possibly, either have not ruptured the surface or are concealed by glaciers or large bodies of water.

The type of movement along the Fairweather fault is known to be similar to the movement along the San Andreas fault system in California; namely, right-lateral, strike-slip faulting, with northwestward movement of that part of the earth's crust lying on the southwest side of the fault relative to points on the other side of the fault. Both fault systems are thought to be part of the same tectonic movement of a large block, termed the Pacific plate, past an adjacent plate, termed the North American plate (Isacks and others, 1968; Atwater, 1970; Plafker, 1972a). (A popularized account of these plate movements is presented by Yanev, 1974, p. 26.) Northwest of Yakutat Bay, motion between these plates changes from lateral side-by-side to an oblique underthrusting where the Fairweather fault merges with the Chugach-St. Elias group of faults on the Pacific plate beneath the North American plate. Theoretical calculations indicate that the rate of horizontal motion along the Fairweather fault and associated connections to the southeast may average 2.25 inches per year. Total distance of movement along the Fairweather fault may be as much as 150 miles (Plafker, 1972b, 1973; Berg and others, 1972, p. D18).

The surface offset reported in the geologic literature (Tocher, 1960, p. 289) as closest to Yakutat along the Fairweather fault was at a locality about 110 miles southeast of Yakutat, where, following the earthquake of July 10, 1958, u.t.[1], 21.5 feet of right-lateral movement was measured. Plafker (1972b), however, suggested that during this earthquake movement occurred along much of the Fairweather fault northwestward to Yakutat Bay; he reports (oral commun., 1975) an area about 36 miles north-northeast of Yakutat that is 3 miles long and indicative of about 5 feet of right-lateral offset during the earthquake. The ground cracks along the Fairweather fault near 139° W. longitude that were reported by Tarr and Martin (1912) as active surface faults are now considered to be massive landslides of bedrock (Plafker, 1974).

[1]The dates of all earthquakes in this report are given in universal time whenever possible; for the Yakutat area, universal time is local standard time plus 9 hours.

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EARTHQUAKE PROBABILITY

Accurate prediction of the place and time of occurrence of destructive earthquakes is not yet possible. However, broad regions can be outlined by geologists, geophysicists, and seismologists where damaging earthquakes probably will occur in the future. One such region is the wide belt that roughly parallels the coast of the Gulf of Alaska. For the Yakutat area, an evaluation of earthquake probability is based on two factors: (1) the local seismicity as determined largely from historic records of earthquakes, and (2) the local geologic and tectonic setting.

Seismicity

The Yakutat area lies within the earthquake region along the Gulf of Alaska and outer coast of southeastern Alaska. Unfortunately, the written record of earthquakes in this region is meager. There are three reasons: (1) the relatively short time that written records have been kept, (2) the sparse population, and (3) the absence of permanent seismograph stations in the region prior to 1973.

The earthquakes that have been instrumentally recorded and located by seismologists during the period 1899 through 1974 are shown in figure 5. Because detection and recording techniques have improved over

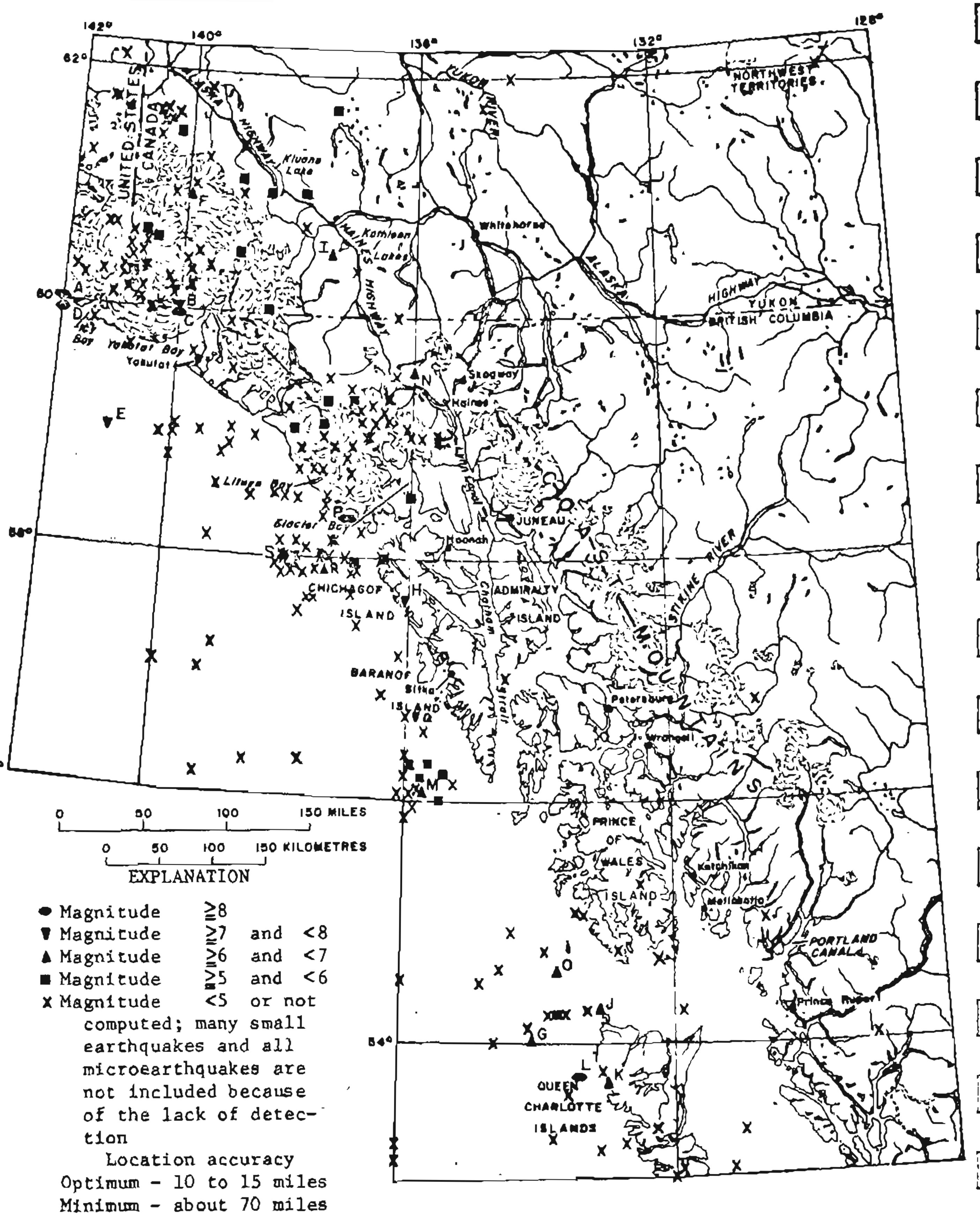

Figure 5.--(See following page for caption.)

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
Q	July 30, 1972	7.1-7.6
R	July 1, 1973	6.7
S	July 3, 1973	6.0

Figure 5.--Map showing locations of epicenters and approximate magnitude of earthquakes in southeastern Alaska and adjacent areas, 1899-1974. Data from Canada Department of Energy, Mines and Resources Seismological Service (1953,1955, 1956, 1961-1963, 1966, 1969-1974), Davis and Echols (1962), International Seismological Centre (1967-1973), Milne (1963), Tobin and Sykes (1968), U. S. Coast and Geodetic Survey (1930-1970), Wood (1966), U. S. National Geophysical and Solar-Terrestrial Data Center (1969, 1973, 1975), U. S. National Oceanic and Atmospheric Administration (1971-1975), Lander (1973), Page and Gawthrop (1973; written commun., 1973), and W. H. Gawthrop (oral commun., 1975).

the years, it is probable that the record is complete in the Yakutat region for all magnitude 5 and greater earthquakes since April 1964, for all magnitude 6 and greater earthquakes since the early 1930's, and for all magnitude 7 3/4 and greater earthquakes since 1899 (Page, 1975). The earthquakes shown in figure 5 are thought to be of shallow origin (typically less than 18 miles) and to have similar properties to shallow-focus earthquakes occurring elsewhere. Figure 5 indicates that within about 80 miles of Yakutat at least 13 earthquakes of magnitude 5 or greater are known to have occurred since 1899, and that earthquakes of lesser or unknown magnitudes are widespread. Considering the same-sized earthquakes within a radius of 130 miles, the total is 26, only 4 of which are west of 142° long and which are, thus, not shown in figure 5. More than one earthquake of magnitude 5 or larger have occurred, on an average, each year within about the last 10 years of record.

Extremely small earthquakes, or microearthquakes, though not shown in figure 5 because of the difficulty of detection, are nevertheless very important, because they may indicate the location of unknown active faults that may be capable of causing large earthquakes sometime in the future.

Permanent seismograph stations, some of which have been operating intermittently and some of which have been operating continuously in the region west, north, and east of the Yakutat area since 1973, should provide extensive data on many sizes of earthquakes after a few years of continuous recordings. Other types of seismological instruments, namely, a strong-motion accelerograph and six seismoscopes, were installed in the Yakutat area in 1965 (fig. 2; B. L. Silverstein, written commun., 1975). These seven instruments respond only to earthquake ground motions of relatively large size or of certain frequencies. Two of the seismoscopes are on deposits of the outer Yakutat Bay moraine complex at Upper Yakutat; two other seismoscopes are on intermediate beach deposits; and the remaining two are on sandy, small-pebble gravel at the airport. The strong-motion accelerograph also is housed at the airport. At all locations the surficial deposits probably are at least 100 feet thick.

A list of earthquakes that were felt or were large enough to be felt at Yakutat from 1893 through 1974 is given in table 3. The list was compiled and interpreted from the more readily available published reports and from instrumental records from seismological stations. Among the major earthquakes listed are the earthquakes of September 1899, October 1900, May 1908, July 1958, and March 1964. Other earthquakes, mostly small, undoubtedly could be added to the list if the population of the region were more widespread and thus able to report earthquakes over a larger area.

Table 3.--Partial list of earthquakes felt or large enough to be felt at Yakutat, Alaska, 1893-1974

Date[1]	Comment[2]	Distance (mi) and direction to epicenter if shown on fig. 5	Magnitude	Calculated radius of perceptibility (mi) (table 4)	Distance (mi), direction, and locality nearest Yakutat at which felt; data on earthquake	References[3]
Mar 1893	Felt	--	?	-----------	-----------	1
Nov 3, 1894	Three light shocks	--	?	-----------	-----------	1
Late May 1896	Felt?	--	?	-----------	225 WNW, near Orca, very severe, shaking about 25 sec.	1
Jan 11, 1897	Severe	--	?	-----------	-----------	1
May 6, 1897	Felt?	--	?	-----------	240 NNE, Fort Selkirk, Yukon.	1
Sep 4, 1899	Severe. Lasted 2-5 min	75 WNW	8.2-8.3	430?	-----------	1, 2a
Sep 10, 1899	Severe? Lasted about 3 sec. Several long aftershocks.	35 NNW	7.8	350	-----------	1, 2a
Sep 10, 1899	Severe. Lasted 5 sec-5 min	35 NNW	8.5-8.6	500?	-----------	1, 2a
Sep 16, 1899	Severe	--	?	-----------	-----------	1
Sep 23, 1899	Moderately severe	--	?	-----------	-----------	1
Dec 14, 1899-Aug 10, 1900	12 shocks. Most shocks light, a few shocks long or heavy.	--	?	-----------	-----------	1
Oct 9, 1900	Two shocks	75 WNW	8.3	430?	-----------	1, 2a
Dec 17, 1900-Sep 28, 1901	Five shocks. Slight(?)	--	?	-----------	-----------	1
Aug 17, 1902	Felt?	--	?	-----------	80 SE(?)	1
Mar 10, 1903	Felt	--	?	-----------	-----------	1
Jul 26, 1903	Felt?	--	?	-----------	50 SE, Dry Bay	2a
Sep 10, 1903	Felt	--	?	-----------	-----------	1
Summer 1905	Several felt; slight	--	?	-----------	-----------	1
Aug 30, 1905	Slight shock	--	?	-----------	-----------	1

Table 3.--Partial list of earthquakes felt or large enough to be felt at Yakutat, Alaska, 1893-1974--Continued

Summer 1906	A few shocks felt?	--	?	----------	Near shores of Yakutat Bay, slight.	1
May 15, 1908	Felt?	60 SW	7	240	100 WNW, Yakataga, felt from Sitka to Seward.	2a
Feb 16, 1909	Moderate, stopped clocks	--	?	----------	----------	1
May 6, 1909	Felt	--	?	----------	----------	1
Jul 16, 1909	Felt?	--	?	----------	~25 NE, Russell Fiord, slight.	1
Aug 5, 1910	Felt. Shook up bldgs along shore, but no damage.	--	?	----------	----------	1
Early Sep 1911	Severe	--	?	----------	----------	1
Jul 7, 1920	Felt?	100 NNW	6	130	----------	2a
Apr 25, 1923	----do----	70 SE	5 3/4	125	215 SE, Juneau. (In opposite direction from Yakutat.)	3
Feb 23, 1925	----do----	275 NW	?	----------	155 ESE, Haines	2a
Oct 24, 1927	Felt?	185 SE	7.1	260	140 SE, Cape Spencer	2a
Nov 13, 1927	----do----	260 SE	?	----------	155 ESE, Haines	2a
Mar 2, 1933	Felt	--	?	----------	----------	2a
Mar 17, 1933	Felt, lasted 45 sec	--	?	----------	----------	2a
May 6, 1933	Felt	--	?	----------	----------	4
Aug 31, 1933	Felt?	95 ESE	5 1/4	105	155 ESE, Haines. (In opposite direction from Yakutat.)	2a
Sep 16, 1933	Felt	--		----------	----------	4
Sep 19, 1933	Felt?	85 ESE	~5.6	120	160 E, Skagway. (In opposite direction from Yakutat.)	2a
Oct 14, 1938	Felt	150 SE	5	90	----------	3, 4
Aug 10, 1941	Felt?	80 ESE	5 1/4-5 1/2	110	160 E, Skagway. (In opposite direction from Yakutat.)	2b
Jun 12, 1942	----do----	120 NE	5 3/4	125	----------	3
Feb 3, 1944	----do----	105 NE	6 1/2	180	165 NE, Aishihik, Yukon	5
Aug 17, 1945	----do----	45 NNW	?	----------	----------	5
Oct 15, 1945	----do----	37 S	?	----------	165 SE, Gull Cove	4
Apr 30, 1947	----do----	45 SE	?	----------	135 E, Mosquito Lake	4

Table 3.--Partial list of earthquakes felt or large enough to be felt at Yakutat, Alaska, 1893-1974--Continued

Mar 12, 1949	Felt?-------------------------	140 W	?	-----------	360 NW, Anchorage. (Epicenter probably poorly located.)	2a
Mar 9, 1952	----do------------------------	130 E	6	130	165 NE, Aishihik, Yukon--	5
Sep 9, 1952	Felt--------------------------	--	?	-----------	------------------------	6
Oct 3, 1954	----do------------------------	420 WNW	~6 3/4	200	------------------------	2a
Jul 31, 1955	Felt?-------------------------	--	?	-----------	340 WNW, Seward. (Possibly different earthquakes.)	2a
Oct 28, 1955	----do------------------------	95 SE	?	-----------	220 SE, Sitka-----------	2a
May 3, 1956	----do------------------------	60 S	?	-----------	------------------------	3
Nov 3, 1956	----do------------------------	110 NNE	5.7	125	110 NE, Haines Jct., Yukon. (Felt location near epicentral region.)	5
Nov 4, 1956	----do------------------------	115 NNE	5.4	110	------------------------	5
Jun 1, 1957	----do------------------------	130 SE	?	-----------	------------------------	7
Jun 23, 1957	----do------------------------	125 SE	5 1/2-5 3/4	120	130 E, Moose Valley------	4
Feb 1, 1958	----do------------------------	75 NW	?	-----------	------------------------	3
Apr 9, 1958	Felt, V-----------------------	235 S	?	-----------	------------------------	2a
Apr 29, 1958	Felt?-------------------------	85 NW	?	-----------	------------------------	7
Jul 10, 1958	Felt; VIII-IX, XI. Numerous aftershocks during next few months, but no written record of the total number felt; only magnitude given (Wood, 1966) is for aftershock of July13, 1958 (M 5 1/2-5 3/4); others probably less than magnitude 5.	140 SE	7.9-8.0	360	------------------------	2b, 8

Table 3.--Partial list of earthquakes felt or large enough to be felt at Yakutat, Alaska, 1893-1974--Continued

Sep 24, 1958	Felt?------------------------	115 W	6.3	160	------------------------	7
Nov 26, 1958	Felt, V----------------------	--	?	----------	------------------------	2a
Jan 9, 1959	Felt, IV, trembling and swaying motion.	--	?	----------	------------------------	2a
Feb 4, 1959	Felt, IV, trembling motion followed by sharp jar.	22 E	?	----------	------------------------	2a
Oct 17, 1959	Felt?------------------------	50 NE	5.6	120	------------------------	5
Oct 14, 1960	Felt, moderate earth noises heard by a few persons before shock.	120 ENE	?	----------	------------------------	2a
Mar 26, 1962	Felt, IV, strong jolt, abrupt onset.	--	?	----------	------------------------	2a
Jun 17, 1963	Felt?------------------------	75 NW	5.4	110	------------------------	7, 2c
Jun 27, 1963	----do-----------------------	75 NW	4.6	75	------------------------	7, 2c
Nov 19, 1963	----do-----------------------	40 WNW	4.2	60	------------------------	2c
Mar 28, 1964	Felt, IV-VI, east-west rolling or swaying motion, 5±1 min.	300 NW (not on fig. 5)	8.4	450?	------------------------	2a, 2b 9
Apr 1, 1964	Felt?------------------------	75 NW	4.4	70	------------------------	2
Apr 3, 1964	----do-----------------------	85 NW	4.5	75	------------------------	2c
Apr 8, 1964	----do-----------------------	80 NW	4.3	65	------------------------	2c
Apr 13, 1964	----do-----------------------	120 W	5.1	195	------------------------	2c
Apr 28, 1964	----do-----------------------	55 SE	4.6	75	------------------------	2c
Apr 30, 1964	Three felt?------------------	50 SE 50 SE 95 NW	4.4 4.4 4.9	70 70 90	------------------------	2c 10
May 17, 1964	Felt?------------------------	105 WSW	5.1	115	------------------------	2c
May 18, 1964	----do-----------------------	105 W	4.9	85	------------------------	2c
May 23, 1964	----do-----------------------	55 WSW	?	----------	------------------------	10
Jul 18, 1964	----do-----------------------	55 N	3.8	40	------------------------	2c, 10
Sep 4, 1964	----do-----------------------	50 SE	3.8	40	------------------------	2c
Apr 26, 1965	Felt. Moderate tremor---------	115 SW	5.3	105	------------------------	2b

Table 3.--Partial list of earthquakes felt or large enough to be felt at Yakutat, Alaska, 1893-1974--Continued

		65 NW	5.3	105		
Jun 27, 1965	Three felt?	65 NW	4.8	85	-------------------------	2c
		70 NW	4.3	65		
Dec 23, 1965	Felt	80 NW	5.8	125	-------------------------	2b
Feb 8, 1966	Felt?	60 NW	3.8	40	-------------------------	2c
Jun 19, 1966	Felt?	80 E	4.4	70	-------------------------	2c
Nov 27, 1967	----do	65 NW	4.6	75	100 WNW Yakataga	2b
Aug 27, 1968	----do	70 SSE	4.3	65	-------------------------	2c
Aug 29, 1968	----do	10 N	4.4	70	Epicenter possibly poorly located.	2c
Sep 22, 1968	----do	70 WNW	3.9	45	-------------------------	2c
May 27, 1969	----do	75 NW	4.3	65	-------------------------	2c
Apr 11, 1970	Felt, III	(100 WNW, not on fig. 5)	~6.2	150	-------------------------	2d
Apr 16, 1970	----do	--do----	~6.8	220	-------------------------	2d
Apr 19, 1970	Felt	(110 W, not on fig. 5)	~5.8	125	-------------------------	2d
Sep 6, 1970	Felt?	65 NW	4.7	80	-------------------------	2c
Mar 26, 1971	Felt, IV	70 NW	5.7	120	-------------------------	2d
Apr 24, 1971	Felt?	70 NE	5.1	100	-------------------------	2c
Jul 30, 1972	Felt, V-VI	240 SE	(7.1-7.6)	290	-------------------------	2d
						--
			7.3			11
Jul 1, 1973	Felt, V	150 SE	6.7	200	-------------------------	11
Jul 3, 1973	Felt, IV	125 SE	6.0	130	-------------------------	11
Sep 12, 1973	Felt?	50 NW	3.9	45	-------------------------	2c
Jan 6, 1974	Two shocks felt?	40 SW	4.1	55	-------------------------	2c
Feb 21, 1974	Felt?	60 NW	3.9	45	-------------------------	2c
Mar 4, 1974	----do	45 NW	3.6	35	-------------------------	2c
Apr 18, 1974	Felt, II	35 SW	4.4	70	-------------------------	12

Sep 28, 1974	Felt?--------------------------	55 NW	4.6	75	------------------------------	2c
Nov 5, 1974	----do-------------------------	55 NW	4.1	55	------------------------------	2c

[1]Dates are intended as u.t. (universal time) except first five entries and 11th, 13th, 18th, 20th, 26th, and 47th, which are local time.

[2]Felt--published report of single or multiple earthquake shock of unknown intensity at Yakutat.

Felt?--earthquake possibly felt at Yakutat, but as far as can be determined there is no readily available published report of the event being felt at Yakutat. The occurrence of the earthquake is known, however, because of (1) a published report of its being felt elsewhere in region, and (or) (2) an instrumental recording and an instrumentally determined epicenter. (Tabulation based on (1) radius of average distance perceptibility of earthquakes, as described by Gutenberg and Richter (1956, p. 141), if epicenter and magnitude are known, and (2) general evaluation of regional geologic structure.)

Roman numeral--published report of earthquake intensity, Modified Mercalli scale. (See table 4.)

[3] 1 Tarr and Martin (1912).
2a Wood (1966).
2b U.S. Coast and Geodetic Survey (1930-1970).
2c U.S. National Geophysical and Solar-Terrestrial Data Center (1969, 1973, 1975).
2d U.S. National Oceanic and Atmospheric Administration (1971-1975).
3 Davis and Echols (1962).
4 U.S. Weather Bureau (1918-1958).
5 Canada Department of Energy, Mines and Resources Seismological Service (1953, 1955, 1956, 1961-1963, 1966, 1969-1974).
6 de Laguna (1972, p. 793).
7 Tobin and Sykes (1968).
8 Davis and Sanders (1960).
9 Plafker and others (1969).
10 International Seismological Centre (1967-1973).
11 U.S. Geological Survey (1975).
12 R. B. Simon (written commun., 1975).

Table 4.--Description of Modified Mercalli intensity scale of earthquakes (a) and approximate distance of perceptibility of earthquakes of various magnitudes (b).

I	Detected only by sensitive instruments.
II	Felt by a few persons at rest, especially on upper floors; delicate suspended objects may swing.
III	Felt noticeably indoors, but not always recognized as a quake; standing autos rock slightly, vibration like passing truck.
IV	Felt indoors by many, outdoors by a few; at night some awaken; dishes, windows, doors disturbed; motor cars rock noticeably.
V	Felt by most people; some breakage of dishes, windows, and plaster; disturbance of tall objects.
VI	Felt by all; many frightened and run outdoors; falling plaster and chimneys; damage small.
VII	Everybody runs outdoors; damage to buildings varies, depending on quality of construction; noticed by drivers of cars.
VIII	Panel walls thrown out of frames; fall of walls, monuments, chimneys; sand and mud ejected; drivers of autos disturbed.
IX	Buildings shifted off foundations, cracked, thrown out of plumb; ground cracked; underground pipes broken.
X	Most masonry and frame structures destroyed; ground cracked; rails bent; landslides.
XI	Few structures remain standing; bridges destroyed; fissures in ground; pipes broken; landslides; rails bent.
XII	Damage total; waves seen on ground surface; lines of sight and level distorted; objects thrown up into air.

(a)

(abridged from Wood and Neumann, 1931)

distance (mi)	9	18	90	132	240	360
magnitude	3	4	5	6	7	8

(b)

(Gutenberg and Richter 1956, p. 141; Hodgson, 1966, p. II-9)

Among the group of most severe earthquakes, only the 1899, 1958, and 1964 earthquakes will be considered here, because data on the 1900 and 1908 earthquakes are too limited. The group occurring in September 1899 included one of the largest earthquakes known to have happened in the world. Despite the severity of the earthquakes, very little damage was done to the few buildings at Yakutat.

Shaking from the earthquake of September 4, 1899 (desig. A, fig. 5), lasted about 2 to 5 minutes; the magnitude of the earthquake is estimated as 8.2-8.3 (Tarr and Martin, 1912; Wood, 1966). Tarr and Martin (1912) reported that one informant noted ground motion consisting of a general "shivering" that ended with a "jerk" from west to east. Another observer noted the violent rocking and shaking of buildings, with earth vibrations being 2 to 3 seconds in duration and traveling from northwest to southeast.

Shaking from the first of the large earthquakes that occurred on September 10, 1899 (desig. B, fig. 5), lasted about 3 seconds, with several long aftershocks. The main earthquake had a magnitude estimated as 7.8. Tarr and Martin (1912) reported one observer as noting that ground movement initially was north-south but that, as motion continued, movement swung around to west-east. During ground shaking, buildings creaked and groaned.

The second earthquake of September 10, 1899 (desig. C, fig. 5) was the most severe felt earthquake of the group and presumably was the one responsible for most of the earthquake effects reported at later dates by observers and presented by Tarr and Martin (1912). Reports of the duration of the earthquake varied, depending on the observer, with estimates ranging from 5 seconds to 5 minutes. The earthquake had a magnitude estimated as 8.5-8.6. Figure 2 shows areas along the shores of Yakutat Bay having uplift or subsidence; extremes were 3 feet of uplift and 4 feet of subsidence, both of which were measured on Otmeloi Island. Of special note were two possible submarine landslides(?)--one along the south end of Khantaak Island, where 25 acres of land subsided 20 feet (desig. A, fig. 2; Tarr and Martin, 1912), and the other along the northern end of the island (desig. B, fig. 2). It seems likely that both slide areas are zones of rapid deposition of loose beach spit sediments of pebbly sand and, as such, are not firm and are easily disturbed by earthquake shaking. In the same general areas, sliding apparently also occurred during the July 10, 1958, earthquake. Another earthquake effect, namely, fountaining and ground fissuring or fracturing, was inferred from the presence of craters and lines of ground cracks on (1) Blacksand Island (southeastern part of the map area, fig. 2), where a crack at an unspecified locality developed that was 400 feet long in a north-south direction, 10 feet wide, and 10 feet deep; and (2) near The Ankau on Phipps Peninsula, where fissures and sand fountains occurred (fig. 2) (Tarr and Martin, 1912). Emitted sand covered several acres to a depth of 1/2 foot; craters were 4 to 5 feet deep. Fissures in this vicinity affected about 10 acres; cracks were about 4 to 5 feet deep and about 4 feet apart (Martin, 1910, p. 362-363). Fissures also were reported at a few places near Lower Yakutat (de Laguna, 1972, p. 288).

High waves and great fluctuations in level of water were observed in Monti Bay in response to the earthquake (Tarr and Martin, 1912). Apparently there was a heavy flow of water out of Monti Bay during the earthquake, but the water returned in a short time as a strong current and big swell that washed around (some of?) the houses at Lower Yakutat. Most houses probably were situated about 5 feet to possibly as much as 10 feet (my estimate) above present high tide. There were three large waves in Monti Bay at intervals of about 5 minutes. The total rise was about 15 feet, extending from near or somewhat below low tide to about 1 foot above highest tide. Wave action tore away a sawmill chute; trees, driftwood, and lumber were rapidly churned and whirled around in the bay.

The earthquake of July 10, 1958 (desig. P, fig. 5), had a magnitude of between 7.9 and 8.0 and, although strongly felt in the Yakutat area, structural damage to buildings was generally slight. The Modified Mercalli intensity was VIII-IX, although some estimates were XI (table 3).

The most prevalent permanent effects were formation of fountains and fractures. The most complete account of earthquake effects in the area was by Tocher (1960), much of which is abstracted here. Ground shaking lasted for 3 to 4 1/2 minutes at Yakutat, the most intense shaking being felt for at least 1/2 minute near the mouth of the Situk River. Fountains ("sand blows") of sand and water were especially common on the Yakutat Foreland area, where generally fine grained sediments are abundant. Most areas in which fountains formed also experienced some ground fracturing. The eruptions of sand and water from craters and fractures were restricted mainly to lower lying ground where the water table was high; some fountains were located in stream valleys. Sand cones remaining after fountaining ceased had volumes of between a few and several hundred cubic feet. Some fountains commenced at the same time as the beginning of earthquake ground motion, while others started 1 to 2 minutes after motion had begun. There were two principal size groupings of craters formed by the fountains. The first group contained randomly spaced craters from a few inches to several feet in diameter, whereas the second included craters from 10 to 20 feet in diameter, frequently in linear or near-linear configurations. Figure 2 shows areas near the outer coast that are thought to have developed fountains as determined from inspection of airphotos taken about 1 month after the earthquake. One of the principal areas of occurrence was near the mouth of the Situk River.

Ground motion and various earthquake effects at several locations in the map area were reported by observers:

1. Descriptions of the actual ground shaking near the mouth of the Situk River varied slightly. One account described the motion as beginning with a slight shaking that increased in intensity, the duration of intense shaking lasting about 30 seconds. Another observer estimated the duration of intense shaking to be 30 to 45 seconds.
2. One person noted that the first earthquake tremors near the railroad trestle over the Situk River appeared to be vertical and lasted for about half a minute; they were followed without letup by what appeared to be horizontal motion with possibly some vertical movement. Another observer in the same general area thought that the first motion was vertical and that it was followed 2 or 3 seconds later by violent horizontal movement. Water waves seen moving in the Situk River caused dirty water to roll several feet up the steep riverbanks. The water became generally muddy, and mounds of sand were built up from the river bottom to above the water level. Water waves continued to travel along the the river with decreasing amplitudes for some minutes after ground motion had ceased.

3. Ground shaking near the intermediate beach and Summit Lake was reported to be mainly in an east-west direction, the earth pulsating like ground swells in the ocean. In a water well thought to be approximately 100 feet deep, the water remained murky for 36 hours after the earthquake.

4. Small ponds in the general vicinity between Ocean Cape and the airport showed evidence of seiching, where some water sloshed up banks for several feet.

5. At the airport the onset of the earthquake was reported by one person as being very abrupt and developing within 4 seconds to full intensity, which continued for about 4 minutes. The airport is built mostly on sandy pebble gravel, except for the southwestern part of the northeast-southwest runway, which is built mostly on sand but contains increasingly large amounts of silt toward the southwest end. The ramp in front of the airport hanger, near the junction of the runways, undulated during ground shaking, individual concrete slabs rising and falling in a wavelike motion. The hanger, a large steel building, swayed violently, the huge doors rolling back and forth. Walls of the hanger buckled, and many windows cracked. Another observer thought that the greatest intensity of shaking was attained in approximately 6 to 10 seconds and lasted 4 1/2 minutes. Another person observed ground waves. Frame buildings near the airport suffered minor cracking of paint seals and plasterboard.

The most severe damage to the airport area was to the southwestern 2,000 feet of the northeast-southwest runway, where sand and silty sand are present. That runway, the northwest-southeast runway, and the aircraft parking area were all constructed with 12-foot-square concrete slabs 7 inches thick. Individual slabs were separated by asphalt-filled cracks 1/2 inch wide, and larger asphalt-filled cracks 1 inch wide were spaced 8 blocks (96 feet) apart. Relative movement occurred between all blocks on the 1-inch joints, but only those in the southwestern 2,000 feet of the northeast-southwest runway acquired permanent offsets greater than 1/2 inch; maximum net displacement on any joint was 3 inches. The compacted soil near the airport did not crack; however, slumping did occur in the reworked gravel near a small (lumber) millpond several hundred yards northeast of the northwest-southeast runway. Seiches in the pond tossed some logs 4 feet up the north bank. The U.S. Coast and Geodetic Survey (1960) reported numerous small ground cracks at some places near the airport; cracks trended west-northwest.

6. At Upper Yakutat the most intense ground motion was estimated by observers as having lasted 3 or more minutes. The U.S. Coast and Geodetic Survey (1960) reported surface fissures that trended west-northwest. Damage to most commercial and residential buildings was slight; many of the buildings were small frame structures without plaster and were well able to withstand fairly severe ground motion. In the general store of the former cannery, almost all canned goods and other merchandise on the third story fell to the floor. On the first floor of the other general store in Yakutat, there was little damage to merchandise and the structure was not damaged. However, on the second floor lamps crashed to the floor and half the water in a large fish tank spilled out.

Near the head of Monti Bay, a large wooden water tank collapsed; the tank was 12 feet high by 15 feet in diameter and built on a platform 40 feet above the ground surface.

The 3-foot-high waves reported in Monti Bay probably were due to the submarine landslide on the south end of Khantaak Island. However, the tidal gage recorded a 2/3-foot wave at the time of the earthquake, plus a 1-foot wave at an unspecified time (table 7).

7. Khantaak Island experienced two large submarine landslides. Both apparently were in areas of rapid deposition and loose sediments and perhaps occurred in the same areas that slid during the earthquakes of 1899. The slide at the southern end of the island (desig. C, fig. 2) encompassed an area about 150 feet wide and 1,000 feet long, and involved most of Point Turner, the southernmost end of the island. The slide caused a wave estimated to be at least 15 to 20 feet high as seen by an observer at Lower Yakutat; however, by the time the wave reached upper(?) Monti Bay it was reported as only 3 feet high. Two later waves also were reported as about 3 feet high. Total amount of material involved in the submarine landslide was estimated to be at least 500,000 cubic yards; the nearly vertical cliff left by the slide was approximately 12 feet high and trended about parallel to the former shoreline. Behind the cliff there were several cracks subparallel to the shore and several grabens, some as deep as 4 feet. Other cracks were as much as 6 feet deep and 1 foot wide.

Near the slide two other areas were heavily fissured. One was at the easternmost part of Point Turner and the other was approximately 200 yards to the northwest. The northwest area contained individual fissures that reached depths of 3 feet and indicated a relative downward motion to the west.

The other area of submarine landslides was on the northern end of Khantaak Island (desig. D, fig. 2). There, an unknown amount of subsidence left a cliff estimated to have been 10 to 15 feet high. Many small fissures were in evidence back from the cliff and on the northeasternmost 1/2 mile of the island. In addition, an area near the southern end of Gilbert Spit was extensively fissured, mostly in a northeast-southwest direction; a graben that developed was 15 feet wide and 3 feet deep.

The great Alaska earthquake of 1964 (the March 28 or Good Friday earthquake), with an epicenter about 300 miles west-northwest of Yakutat, was felt strongly in parts of the Yakutat area, especially on the Yakutat Foreland. Estimates of the Modified Mercalli intensity ranged from IV to VI (table 3). The earthquake shaking lasted between 4 and 6 minutes depending on the observer (Plafker and others, 1969, p. G35). One observer reported an east-west rolling or swaying motion that built to a peak in about 1/2 minute and lasted a total of 6 minutes (timed). Damage in the area as a whole generally was very minor; no structural damage to buildings was reported, although small items were thrown from shelves in stores and in some homes. In addition, ice on many lakes was broken and some lakes were drained (Plafker and others, 1969, p. G35).

At the airfield there was some damage to the parking ramp and runways built of concrete slabs; ground motion was strong enough to cause parked trucks on the ramp to roll back and forth as much as 10 feet. The damage to the slabs apparently was caused by differential up-and-down movement of the slabs, resulting in cracking of some of them. Damage to the ramp and runways was considered somewhat greater than the damage that occurred during the July 10, 1958, earthquake.

Several earthquake-related water waves affected shore areas during and after the 1964 Alaska earthquake; none of the waves reached above extreme high water level or caused damage in the vicinity of Yakutat (Plafker and others, 1969, p. G35). At Yakutat during the earthquake, a single wave was observed along the shore of Monti Bay. The churned, muddy water seen in the vicinity the next day indicated the possibility that the wave had been caused by a submarine slide near the southern end of Khantaak Island (Pt. Turner), probably close to where slides occurred during the July 10, 1958 (desig C. fig 2), and September 1899 earthquakes (Plafker and others, 1969, p. G35). Some slumping of a beach near Pt. Turner was observed (desig. E, fig. 2; U.S. Coast and Geodetic Survey, 1966, p. 56). About 1 hour and 25 minutes after the earthquake started, the far-reaching tsunami waves, generated by movement of the earth's crust near the earthquake epicenter, began arriving in Monti Bay. These waves were recorded on the tidal gage and were interpreted as showing a maximum wave height of about 7.6 feet (table 7) (Wilson and Tørum, 1968; Cox and Pararas-Carayannis, 1969). The series of tsunami waves continued for at least 7 hours, and erratic tides continued for several days.

The most recent relatively large earthquakes felt at Yakutat were the earthquakes of July 30, 1972, and July 1 and 3, 1973. The one of July 30, 1972 (desig. Q, fig. 5), with its main shock of magnitude between 7.1 and 7.6 and centered offshore from Sitka, Alaska, was distinctly felt in the Yakutat area and had a Modified Mercalli intensity of V-VI (table 3); damage was light. Among the effects noted were the following: water in some wells became muddy, trees swayed, hanging objects swayed violently, and part of a sewage facility was damaged. This earthquake probably was the first recorded by the seismoscopes and strong-motion accelerograph in the Yakutat area (fig. 2). Only two of the six seismoscopes in operation had a measurable response to the earthquake, and those were on the relatively less firm foundations of water-saturated, sandy, small-pebble gravel at the airport. Seismoscopes on firmer ground of the intermediate beach deposits and those on deposits of the outer Yakutat Bay moraine complex at Upper Yakutat had responses that were too small to be measured accurately. Of the two seismoscopes at the airport, one registered a relative displacement of 0.19 inch in the principal direction S. 75° W., and the other registered 0.22 inch in the principal direction S. 40° E. (Maley and Silverstein, 1973). On the component oriented N. 53° E., the strong-motion accelerograph registered a value of 1 percent gravity and a period of 1.7 seconds (U.S. National Oceanic and Atmospheric Administration, 1974); neither of the other components had responses that were large enough to measure accurately.

This earthquake involved horizontal strike-slip faulting of the sea floor and did not generate a tsunami significant enough to register on the tidal gage at Yakutat.

The earthquakes of July 1 and 3, 1973 (desigs. R and S, respectively, fig. 5), with magnitudes of 6.7 and 6.0, respectively, were felt in the Yakutat area (table 3). The earlier shock had a Modified Mercalli intensity of V (U.S. National Oceanic and Atmospheric Administration, 1975). There was rattling of doors, windows, and dishes, and there were reports of buildings creaking loudly and hanging objects swinging moderately (U.S. Geological Survey, 1975). The earthquake of July 3, 1973, had a Modified Mercalli intensity of IV (U.S. National Oceanic and Atmospheric Administration, 1975).

Any tsunami waves generated by these earthquakes were not prominent enough to be detected on the Yakutat tidal gage.

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

In some earthquake regions of the world, a close spatial relation has been demonstrated between earthquakes and specific faults. In most of southeastern Alaska, however, such relationships cannot yet be established for two reasons: most earthquake epicenters are located, at best, with an accuracy of only 10 to 15 miles, and exact location of many faults is unknown because of concealment by water or surficial deposits. There appears, however, to be a general relationship between some extensive groups of earthquakes and certain zones of faults. Despite the widespread distribution of earthquakes (fig. 5) in the Yakutat region, it is thought that many of the earthquakes probably are caused by fault movements within zones a few miles wide along the Fairweather fault and zones many miles wide along the Chugach-St. Elias and associated faults. Because of the type of fault movement (underthrusting) attributed to the postulated fault offshore from Yakutat, that fault, too, probably would exhibit a broad zone of earthquakes if additional data on earthquakes were available.

The Fairweather and Chugach-St. Elias faults are active, and at some localities they rupture the ground surface. The most recent known surface breaks reported in the geologic literature (Tocher, 1960) occurred at several locations along the Fairweather fault during the earthquake of July 10, 1958. Plafker (1972a) suggested that during the earthquake movement occurred along much of the fault northwestward to Yakutat Bay; he reports (oral commun., 1975) an area about 36 miles north-northeast of Yakutat that is 3 miles long and indicative of about 5 feet of right-lateral offset during the earthquake. Minor amounts of movement appear to be continuing along the Fairweather fault, as interpreted from the occurrence of localized microearthquakes during a few days in 1968 (Page, 1969). As permanent earthquake-detection instruments are installed and operated in the region, movement along faults will be more clearly defined.

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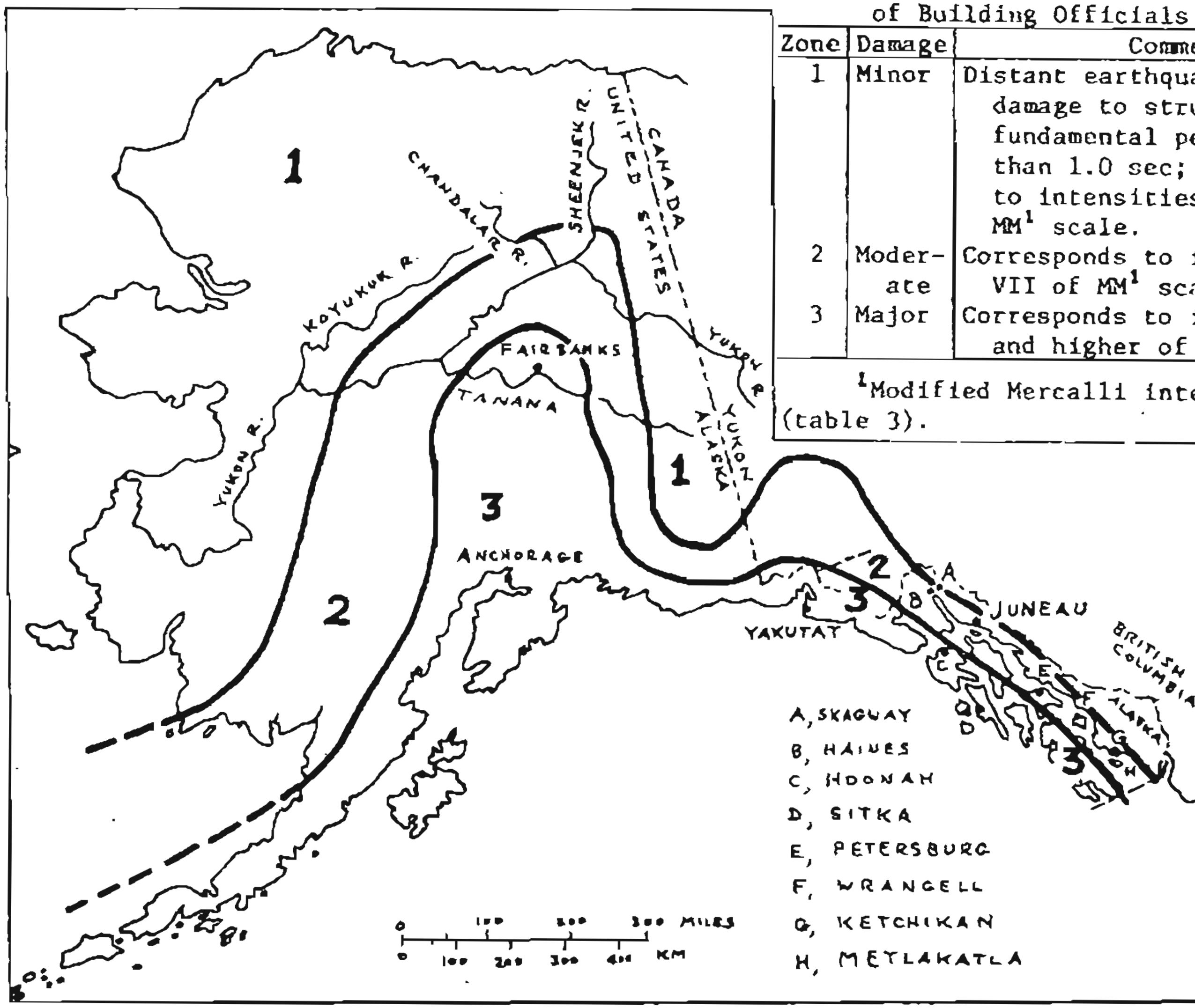
Assessment of seismic risk in the Yakutat area

Only a general assessment of seismic risk can be made for the Yakutat area, because information on many aspects of seismicity is limited. Details still must be studied that concern geologic structure and the tectonic framework of much of the region as it relates to Yakutat. To portray the seismic risk for an area, two basic types of maps have been developed. One type considers only the likelihood that earthquakes of a certain size might occur sometime in the future; the second type considers the number of earthquakes of a certain size that are expected to occur during a specific period of time.

As noted, in southeastern Alaska the historic record is short, and geologic and, especially, tectonic information for many areas is known only in general terms. As a result, the risk maps here described (figs. 6 through 8) are based largely on the record of instrumentally located earthquakes and secondarily for figure 7 on a generalized consideration of geology and tectonics.

The Yakutat area is shown on two examples of the first type of seismic risk map. These maps do not predict the frequency of earthquake occurrence. The first example is a redrawn, enlarged rendition of the map included in the 1973 edition of the Uniform Building Code (fig. 6; International Conference of Building Officials, 1973). The map legend relates possible damage within a particular zone to Modified Mercalli intensities of earthquakes and shows the Yakutat area as being in the highest zone, one in which the maximum probable earthquakes might have Modified Mercalli intensities of VIII or higher (table 4). This map portrays the area west of Yakutat as subject to larger earthquakes and greater possible damage than do maps of seismic probability that appeared in publications by Johnson and Hartman (1969, pl. 49) and Alaska Industry (1970).



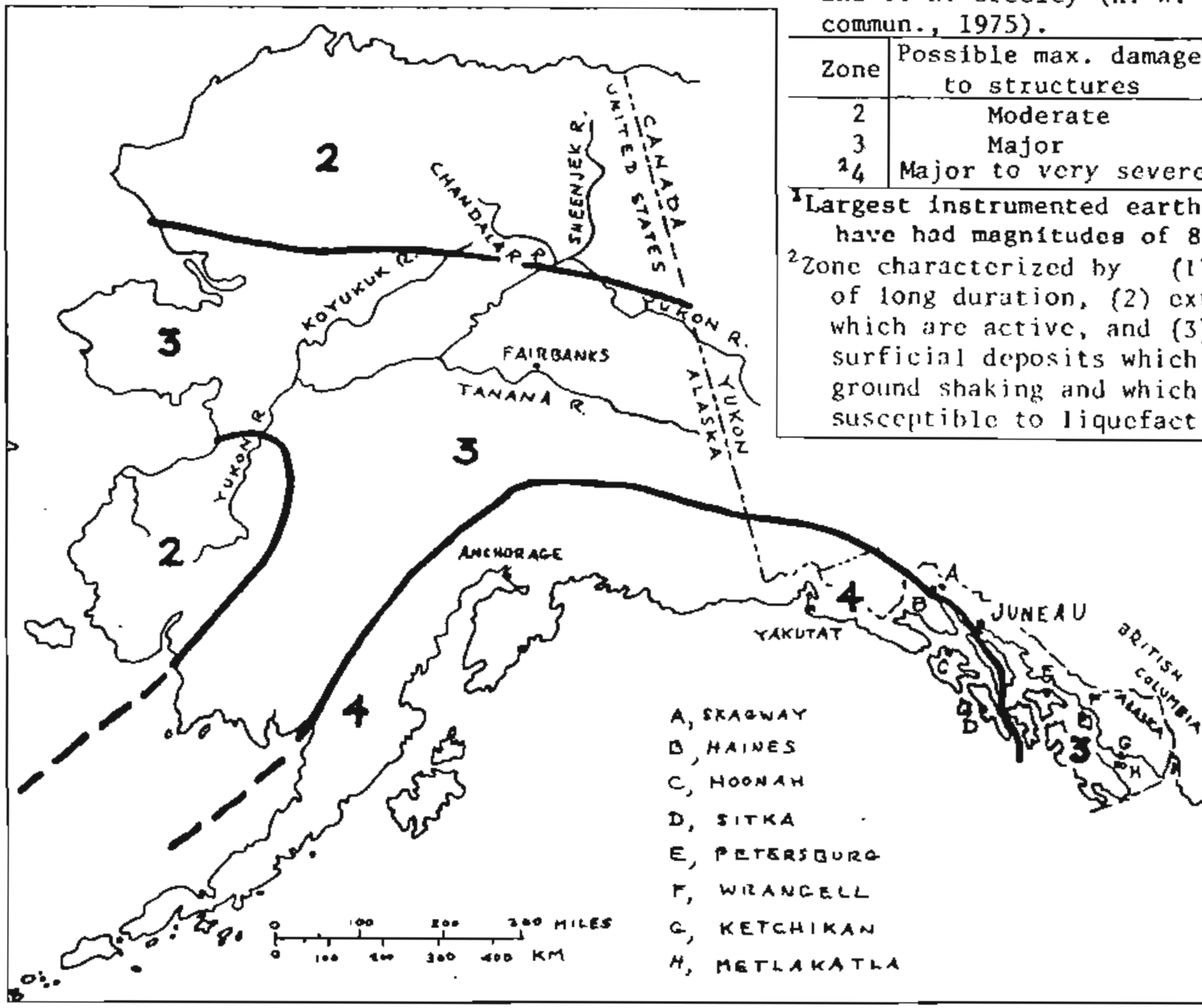
EXPLANATION
Modified from International Conference of Building Officials (1973)

Zone	Damage	Comment
1	Minor	Distant earthquakes may cause damage to structures with fundamental periods greater than 1.0 sec; corresponds to intensities V and VI of MM[1] scale.
2	Moderate	Corresponds to intensity VII of MM[1] scale.
3	Major	Corresponds to intensity VIII and higher of MM[1] scale.

[1]Modified Mercalli intensity scale (table 3).

Figure 6.--Seismic zone map of Alaska as shown in Uniform Building Code, 1973 edition.

The second example is a suggested preliminary seismic risk map (fig. 7) prepared by the U.S. Army Corps of Engineers, Alaska District, in 1973 (H. W. Holliday, written commun., 1975) (Selkregg, 1974). The map is a modification of seismic risk maps prepared in the past by the U.S. Army Corps of Engineers, Alaska District. The newer map relates possible damage during earthquakes to the magnitude of the largest probable earthquake and shows the Yakutat area in the highest zone, one in which major to very severe damage is possible and maximum probable earthquakes would have magnitudes greater than 6. The highest zone was developed after a generalized consideration of certain geologic factors, most of which can be related to regional patterns of earth movements and the response of ground to shaking during earthquakes. Factors include (1) presence of extensive faults in the region, some of which are active, (2) probable duration of earthquake shaking, and (3) presence of thick unconsolidated deposits, many of which are subject to liquefaction.



EXPLANATION

Modified from description developed by E. L. Long and G. H. Greeley (H. W. Holliday, written commun., 1975).

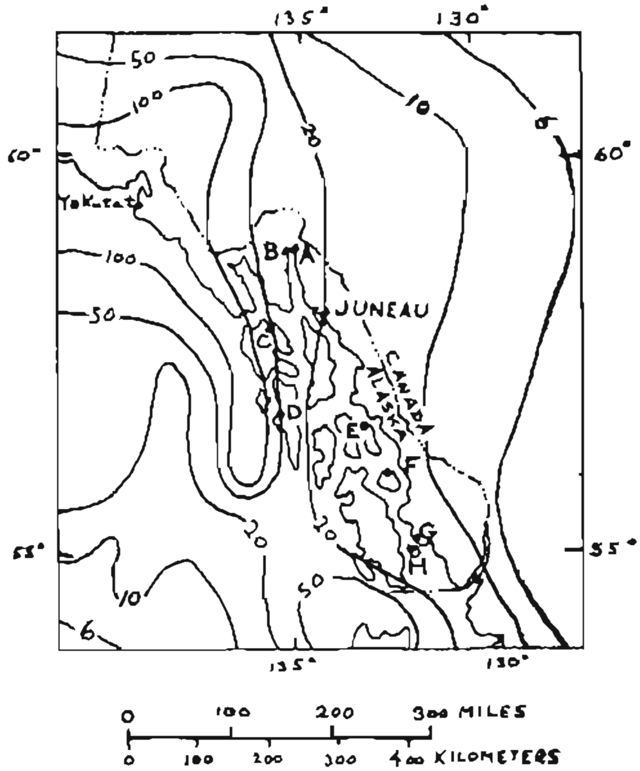
Zone	Possible max. damage to structures	Magnitude[1] of largest probable earthquake
2	Moderate	Less than 6.0
3	Major	6.0 or more
[2]4	Major to very severe	6.0 or more

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

[2]Zone characterized by (1) frequent earthquakes of long duration, (2) extensive faults, some of which are active, and (3) areas with thick surficial deposits which tend to increase ground shaking and which in many places are susceptible to liquefaction.

Figure 7.--Suggested preliminary seismic risk map of Alaska provided by U.S. Army Corps of Engineers, Alaska District.

The Yakutat area also is shown on the second, or frequency, type of seismic risk map. The example of such a map (fig. 8) shows probable peak acceleration of earthquakes as a percent of gravity per 100 years (Milne and Davenport, 1969; Klohn, 1972). For the Yakutat area, the map indicates that a peak acceleration of as much as 100 percent gravity might be expected within any 100-year period. For part of the same area shown in figure 8, Stevens (1974) and Stevens and Milne (1974) extended the data to a longer time period and used a slightly different basis for analysis of earthquakes.



EXPLANATION

——— 10 ———

Contour, showing peak earthquake acceleration as a percent of gravity.

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

Map is based upon the amount of energy released by the largest earthquake (above magnitude 2.5) that occurred each year in a unit area of 3,860 mi^2 (10,000 km^2) during the period from 1899 through 1960, projected to a 100-year interval.

Figure 8.--One-hundred-year probability map showing distribution of peak earthquake accelerations as percents of gravity for southeastern Alaska and part of adjacent Canada. Modified from Milne and Davenport (1969).

Any evaluation of earthquake risk for specific sectors of land smaller than the Yakutat area must await expanded as well as more detailed geologic and related geophysical studies in the region. Of special importance are studies of (1) the degree of activity along the Fairweather fault and along faults of the Chugach-St. Elias complex of faults (Plafker, 1974), (2) the lack of very large earthquakes in the recent past in the area west of Yakutat (Sykes, 1971; Kelleher and others, 1974; Plafker, 1974; Page, 1975), and (3) the nature of the postulated fault offshore from Yakutat. Concerning the last, it is important to know the fault's relationship to regional movement of the earth's crust and to know whether the postulated fault can generate very large earthquakes and tsunamis or only moderate to large earthquakes, such as those of July 1973 (Gawthrop and others, 1973).

INFERRED EFFECTS FROM FUTURE EARTHQUAKES

The following discussion and evaluation of the geologic effects of future large earthquakes in the Yakutat area are based upon the assumption that large earthquakes will continue to affect the Yakutat area.

Specific evaluation of possible geologic effects in the Yakutat area is based partly on observations by others during earthquakes felt in the area and partly on estimates of the response of local geologic materials, inferred from the response of similar materials during earthquakes elsewhere.

Evaluations are given in tables 5 and 6 for several geologic factors, including (1) sudden tectonic uplift, (2) sudden tectonic subsidence, (3) ground shaking, (4) liquefaction, (5) ground fracturing and water and slurry fountains, (6) compaction and related subsidence, and (7) landsliding. These factors and several others are discussed briefly below.

Effects from surface movements along faults and other tectonic land-level changes

In southeastern Alaska and along the Gulf of Alaska coast, movements of surface faults have been documented for only a few of the considerable number of earthquakes in historic time. During the more numerous small earthquakes, displacement along faults occurs mostly at depth; however, during the less frequently occurring moderate and large earthquakes, there is movement along faults at depth as well as up to the ground surface. At Yakutat the likelihood of faults breaking the surface during a nearby major earthquake is unknown.

Tectonic land-level changes such as sudden uplift or subsidence have happened infrequently during historic earthquakes, although the Yakutat region does bear ample evidence of tectonic uplift having occurred as part of the large earthquakes of September 1899. If a sudden, vertical change in level of land of several inches took place, the change would cause no adverse effects in the Yakutat area; however, a change in level of a few feet, in theory, might affect the area greatly. The effect of such changes in level on geologic deposits is given in table 5.

Table 5.--Possible effect of sudden tectonic uplift or subsidence of a few feet on geologic materials near Yakutat Bay or the outer coast

Geologic unit and map symbol	Sudden tectonic uplift	Sudden tectonic subsidence
f artificial fill	Uplift would promote better drainage; tidewater access to some fills would be disrupted.	Margins of some deposits near tidewater would be flooded.
wc organic deposits underlain by coarse-grained deposits	Probably none.	Probably none.
wf organic deposits underlain by fine-grained deposits	Locally, drainage would be better following uplift and there would be increased erosion by streams.	Flooding would occur in many places near outer coast.
e eolian sand deposits	Uplift would promote enlargement of several deposits.	Flooding of some deposits near Situk.

Table 5.--Possible effect of a sudden tectonic uplift or subsidence of a few feet on geologic materials near Yakutat Bay or the outer coast--Continued

Geologic unit and map symbol	Sudden tectonic uplift	Sudden tectonic subsidence
by young beach deposits	Along gentle slopes, a few feet of uplift would greatly enlarge deposits.	There would be an increase in wave erosion of deposits especially during storms.
bi intermediate beach deposits	Probably none.	Some deposits along outer coast might be within zone of wave erosion during storms.
bo old beach deposits	Probably none.	Margin of some deposits would be flooded.

Table 5.--Possible effect of a sudden tectonic uplift or subsidence of a few feet on geologic materials near Yakutat Bay or the outer coast -- Continued

Geologic unit and map symbol	Sudden tectonic uplift	Sudden tectonic subsidence
dy young delta-estuarine deposits	Uplift would greatly enlarge deposits.	There would be a large inland shift of all tidal stages and an increase in erosion by storm waves.
di intermediate delta-estuarine deposits	Uplift would increase drainage and promote stream downcutting.	Several areas of deposits would be inundated and drainage would be worsened.
do old delta-estuarine deposits	Probably none.	Margins of a few deposits would be inundated.

Table 5.--Possible effect of a sudden tectonic uplift or subsidence of a few feet on geologic materials near Yakutat Bay or the outer coast--Continued

Geologic unit and map symbol	Sudden tectonic uplift	Sudden tectonic subsidence
ds clayey silt delta-estuarine deposits	Uplift would result in further stream downcutting of deposits.	Subsidence would result in burial of some deposits by young delta sediments.
ac coarse-grained alluvial deposits	Probably none.	Probably none.
af fine-grained alluvial deposits	Uplift would tend to improve drainage because of accelerated stream downcutting.	There would be flooding of lower margins of small deposits.

Table 5.--Possible effect of a sudden tectonic uplift or subsidence of a few feet on geologic materials near Yakutat Bay or the outer coast--Continued

Geologic unit and map symbol	Sudden tectonic uplift	Sudden tectonic subsidence
ao old alluvial deposits	Probably none.	Probably none.
oc coarse outwash	Probably none.	Probably none.
of fine outwash	Probably none.	Probably none.
m outer Yakutat Bay moraine complex	Uplift of a few feet would disrupt some shore facilities.	Subsidence would disrupt some shore facilities and would cause increased wave erosion of many deposits.

Ground shaking

Ground shaking is recognized as causing most of the damage to buildings and other structures during earthquakes. At a given locality, ground shaking is controlled by several factors (Page and others, 1975, p. 601). Major factors are (1) the earthquake energy released, (2) the distance of the particular locality from the causative fault, and (3) the response of geologic materials to the motion of the bedrock beneath the locality. Other factors of importance are the earthquake mechanism and type of fault motion. The severity of ground shaking during earthquakes largely is determined by three aspects of motion: amplitude, frequency content, and duration.

During a single large earthquake occurring outside, but near, the Yakutat area, ground shaking probably would be most severe on geologic materials that are loosely consolidated, fine grained, water saturated, and thick. Conversely, shaking probably would be less severe on geologic materials that are hard, firmly consolidated, and unfractured. However, even for a moderate-sized earthquake occurring within the area, distance from the causative fault may be an overriding factor. The possible characteristics of ground shaking of mapped geologic materials during large earthquakes occurring near the Yakutat area are presented in table 6.

Table 6.--Evaluation of map units for certain geologic effects during earthquakes

Geologic unit and map symbol	Ground shaking	Liquefaction	Ground fracturing and water and slurry fountains	Compaction and related subsidence	Landsliding
f artificial fill	High to moderate, especially around periphery of upper part of fill if poorly compacted during emplacement and if water table very high.	Low; may respond to liquefaction of underlying deposits.	Low to moderate; may be affected by fracturing of underlying material.	Low to high; high where overlies (at shallow depth) saturated silty sand or if fill is not compacted to optimum density during emplacement.	High along margins of fills; might be involved in movement of underlying deposits.
wc organic deposits underlain by coarse-grained deposits.	Severe.	Generally low, moderate in some localities.	Moderate to low; fractures may open where certain types of horizontally moving landslides occur. Very low potential for fountaining.	Low.	Low; locally some horizontally moving landsliding might be expected toward bodies of water.

Table 6.--Evaluation of map units for certain geologic effects during earthquakes--Continued

Geologic unit and map symbol	Ground shaking	Liquefaction	Ground fracturing and water and slurry fountains	Compaction and related subsidence	Landsliding
wf organic deposits underlain by fine-grained deposits	Severe to very severe.	High because of generally high water table and the fine grain size of underlying materials.	High because of fine-grained size of underlying material and relation to high water table.	Expected to a moderate degree in underlying material. This action should affect these organic deposits.	Probably moderate with horizontally moving slides spreading toward bodies of water.
e eolian sand deposits	Probably moderate to severe, locally, where thin and overlying saturated young delta-estuarine deposits.	Very low; except high where thin and overlies saturated delta-estuarine deposits.	Very low; where thin, may be fractured along with underlying deposits.	Low.	Low; possibly moderate where newly deposited.

Table 6.--Evaluation of map units for certain geologic effects during earthquakes --Continued

Geologic unit and map symbol	Ground shaking	Liquefaction	Ground fracturing and water and slurry fountains	Compaction and related subsidence	Landsliding
by young beach deposits	Moderate to severe depending upon stage of tide and degree of saturation.	Low to moderate.	Low.	Low to moderate; probably higher where newly deposited; however, such deposits even more subject to submarine landsliding.	Low; locally very high where newly deposited.
bo old beach deposits	Moderate.	Low.	Very low.	Very low.	Very low.
dy young delta-estuarine deposits	Very high.	High, locally very high.	Very high; emitted sediments might cover large areas.	High to moderate, especially near newly deposited materials.	Very high because of saturation, looseness, and fine-grained nature of deposits. Submarine landslides probably common.

Table 6.--Evaluation of map units for certain geologic effects during earthquakes--Continued

Geologic unit and map symbol	Ground shaking	Liquefaction	Ground fracturing and water and slurry fountains	Compaction and related subsidence	Landsliding
di intermediate delta-estuarine deposits	Very high.	High.	Moderate to high.	Moderate to high.	Moderate to low; some horizontally moving slides may progress toward streambanks.
do old delta-estuarine deposits	Moderate to high.	Low to moderate at lower margins where thinnest and probably saturated.	Probably low.	Probably low to moderate.	Moderate at margins of some deposits.
ds clayey silt delta-estuarine deposits	Probably moderate to high.	Low because deposit well compacted.	Low because deposit well compacted.	Low because deposit well compacted.	Probably low to moderate.

Table 6.--Evaluation of map units for certain geologic effects during earthquakes--Continued

Geologic unit and map symbol	Ground shaking	Liquefaction	Ground fracturing and water and slurry fountains	Compaction and related subsidence	Landsliding
ac coarse-grained alluvial deposits	High to moderate.	Probably moderate to high.	Moderate.	Low.	Probably low except along banks of streams.
af fine-grained alluvial deposits	Very high.	High.	High, especially near abandoned stream channels.	Moderate.	Low except along streambanks. Massive, horizontally moving slides are a possibility.
ag old alluvial deposits	Very high.	Probably high.	High, especially near channels of formerly active streams.	Probably low.	Low except along streambanks. Massive, horizontally moving slides are a possibility.

Table 6.--Evaluation of map units for certain geologic effects during earthquakes--Continued

Geologic unit and map symbol	Ground shaking	Liquefaction	Ground fracturing and water and slurry fountains	Compaction and related subsidence	Landsliding
oc coarse outwash	Low to moderate.	Probably none.	Probably very low.	Low.	Low.
of fine outwash	Moderately high because well saturated.	Probably moderate to high because of saturation and fineness of deposit.	Moderate to low.	Possibly moderate to low.	Probably low, but horizontally moving slides might occur.
m outer Yakutat Bay moraine complex	Relatively low to moderate.	Very low; locally moderate where deposits are saturated and have a large content of fine sand.	Low.	Generally low.	Probably moderate to high, especially in steep-sloped areas of the deposits.

Liquefaction

Ground shaking during major earthquakes in other areas has caused liquefaction of certain types of saturated, unconsolidated deposits. Especially susceptible are those deposits that contain materials of very low cohesion and uniform, well-sorted, fine- to medium-grained particles, like coarse silt and fine sand. A major consequence of liquefaction is that sediments that are not confined at the margin of the body of sediment will tend to flow or spread toward those unconfined margins and will continue to flow or spread as long as pore-water pressures remain high and shaking continues (Youd, 1973).

If liquefaction occurs in saturated sediments that are confined at the margin of the body of sediment, the result is the familiar quicksand condition. A generalized evaluation of the potential for liquefaction of the various geologic deposits in the Yakutat area is shown in table 6, based in part on analysis of effects during the July 10, 1958, earthquake. To develop detailed maps showing liquefaction potential during large earthquakes (Youd and others, 1975, p. A70), additional data on physical properties, especially on density of geologic materials, are required in the Yakutat area.

Ground fracturing and water-sediment ejection

Ground fracturing and ejection above the ground surface of water or slurries of water and sediments from certain deposits are common during the strong shaking that accompanies many large earthquakes. The ejection process is called fountaining, or spouting; compaction and differential subsidence of ground often accompany ejection. Ejection takes place most often where loose, sand-sized materials are dominant in a deposit and where the water table is shallow and restricted by a confining layer--which can even be seasonally frozen ground. Seismic shaking of confined ground water and sediment causes hydrostatic pressure to increase and liquefaction to occur. If the confining layer ruptures, the water and sediment erupt from point sources or along ground fractures. In the Yakutat area, ejected material during the July 10, 1958, earthquake covered some areas to depths of a few feet (fig. 2), and the craters and fractures may have been many feet deep. Table 6 lists the relative susceptibility of mapped deposits in the Yakutat area to ground fracturing and fountaining.

Compaction and related subsidence

Strong shaking of loose geologic materials during major earthquakes may result in volume reduction and compaction of some deposits. Compaction often is accompanied by ejection of water or water-sediment mixtures, sometimes in the form of fountaining or spouting. As a result of such combined processes, the surface of the ground locally may settle differentially as much as a few feet. The greatest settlement of ground probably will occur where (1) the ground-water table is high and some of the water can be expelled, (2) the deposits are loose and thick and consist of silt to small pebble-sized materials, and (3) strong shaking persists for at least a few minutes. The possibilities of compaction and subsidence of deposits in the Yakutat area are evaluated in table 6.

Earthquake-induced subaerial and underwater landslides

During earthquake-caused ground shaking, geologic materials may experience a variety of downslope mass movements termed, collectively, "landslides." Movements may consist of single or multiple sliding events that include failures of active delta fronts or extending spits, land spreading, small-scale slumping, earth flowage, and minor creep (Eckel, 1970). Loose, water-saturated deposits on steep slopes are especially prone to downslope movement. Liquefaction may trigger sliding and flowage of material even on very gentle slopes.

Steep delta fronts, because of their large content of loose material, are particularly susceptible to sliding during the strong shaking that accompanies major earthquakes. Shaking during the 1964 Alaska earthquake triggered landsliding of delta fronts at numerous places in southern Alaska. Some of the slides, in turn, triggered large waves that swept onto the land. Rapidly extending beach spits are another geologic setting where submarine landsliding probably is frequent during earthquakes. For the Yakutat area, susceptibility of mapped deposits to landsliding during earthquake shaking is shown in table 6.

Effects of shaking on ground water and streamflow

The flow of ground water may be altered considerably by strong ground shaking during an earthquake and by any resultant permanent ground displacement. Examples of alterations reported by Waller (1966, 1968) from south-central Alaska show that the 1964 Alaska earthquake especially affected semiconfined ground water in alluvial and delta deposits. After the earthquake, ground-water levels locally were raised because of (1) subsidence of ground, (2) increase in hydrostatic pressure, or (3) compaction of sediments. Other ground-water levels locally were lowered because of (1) pressure losses, (2) rearrangement of sediment grains, (3) lateral spreading of deposits, or (4) greater discharge of ground water after sliding of delta fronts. Waller reported that some changes in hydrostatic pressure and ground-water level were temporary, while others lasted for at least a year; some changes may be permanent.

In the Yakutat area,the ground-water table and ground-water flow are very near the surface in alluvial and young and intermediate delta-estuarine deposits. Intense shaking and earthquake effects that would alter ground-water flow include water-sediment ejection, ground compaction, and large-scale sliding or spreading of these deposits south and southwestward toward the outer coast.

Alterations to streamflow often are important consequences of major earthquakes. Streams flowing on alluvial and deltaic deposits can experience a temporarily diminished flow because of water loss into fractures opened by ground shaking. The sediment load of streams often will be increased temporarily following a major earthquake. Streams may be dammed by earthquake-caused landslides and, if the dams break suddenly, downstream flooding can result.

Effects of earthquake shaking on glaciers

Strong ground shaking and tectonic change of land levels during earthquakes have caused short- and long-term changes in glaciers and related drainage features in the Yakutat region (Tarr and Martin, 1912, 1914; Post, 1967). However, the extensive advances of glaciers, postulated by Tarr and Martin as having followed the September 1899 earthquakes, are thought more likely to have been controlled by climatic factors, even though large amounts of snow, avalanches, and landslide debris were spread over extensive areas on glaciers and icefields. Other results of ground shaking are massive icefalls from hanging glaciers and extensive icebergs formed by breakage from floating glaciers. In upper Yakutat Bay and adjacent fiords during the September 1899 earthquakes, enough icebergs were produced to block passage of boats for a considerable time in upper Yakutat Bay and the western part of outer Yakutat Bay. Waves generated by ice breakage probably would be mostly dissipated before arriving at Yakutat.

Tsunamis, seiches, and other earthquake-related water waves

Earthquake-induced water waves often develop during major earthquakes and may affect shore areas, even at great distances, for several days thereafter. Types of waves include tsunamis (seismic sea waves), seiches, waves generated by subaqueous and subaerial landslides, and waves generated by local tectonic displacement of land. The following discussion considers each of these types of earthquake-induced waves and the likelihood that they may develop to heights that might affect the Yakutat area.

Tsunamis are long-period water waves that are caused by sudden displacement of water. The largest tsunamis originate where widespread vertical offsets of the sea floor occur, such as those accompanying major underthrust earthquakes around the rim of the Pacific. In the deep ocean, groups of tsunami waves travel long distances at great speed and with low height, but as they approach the shallower water of the Continental Shelf and shore areas their speed decreases greatly and their height increases manyfold. In shallow water, wave height and type are controlled largely by the initial size of the wave, the configuration of the ocean bottom, the shoreline configuration, the natural period of oscillation of the water on the shelf or bay, and the stage of the tide (Wilson and Tørum, 1968). Wiegel (1970) noted that many waves that strike Pacific Ocean coastal areas have been as high as 40 feet and that a few waves have been as high as 100 feet.

At Yakutat and in Yakutat Bay and adjoining fiords, several tsunamis and other earthquake- and non-earthquake-induced waves have been experienced in the last about 130 years. Some of these events are listed in table 7, along with wave heights as noted by eyewitnesses or as interpreted from records derived from tidal gages maintained by personnel of the former U.S. Coast and Geodetic Survey, now the National Oceanic and Atmospheric Administration. There undoubtedly are many tsunami and other waves that are not included. At Yakutat the highest earthquake-related wave originating nearby was caused by tectonic uplift in the upper Yakutat Bay area that occurred as part of the earthquake of September 10, 1899. Although estimates varied, the wave may have had a height of about 15 feet. The highest tsunami wave originating at a considerable distance from Yakutat in part of the Pacific Ocean was the wave, about 7 feet high, that arrived March 27, 1964 (local time), as one of the group of tsunami waves resulting from the 1964 Alaska earthquake.

Table 7.-- Partial list of tsunami and other earthquake and non-earthquake-related waves that reached or possibly reached Yakutat, Alaska, or elsewhere in the region, 1845 through 1973[1]

Date, local time	Max. runup height or amplitude,[2] max. wave height,[3] or max. rise or fall of wave[4] (feet)	General region of earthquake and generation of tsunami; comments
1845	[2] [3] 115---------------------	Probably not earthquake related; icefall into Yakutat Bay; 100 deaths.
Mid-1800's	Unknown--------------------	Probably not earthquake related; breakup of glacier damming very large lake, Russell Fiord(?).
Sep. 10(?), 1899.	[3] 60 in upper Yakutat Bay; local waves, [3] 15 Yakutat.	Upper Yakutat Bay and adjoining fiords; many waves caused by landslides.
July 4, 1905	[2] 12 in fiord adjoining upper Yakutat Bay.	Probably not earthquake related; icefall.
((Nov. 10, 1938))	(([2] 2/3 at Sitka, 230 miles to southeast; [2] 1/3 at Seward, 350 miles to west.))	Western Gulf of Alaska near Alaska Peninsula.
Apr. 1, 1946	[2] 2/3 Yakutat---------------	Northern North Pacific Ocean near Aleutian Islands.
Nov. 4, 1952	[2] 1 Yakutat; [4] 1.8 Yakutat--	Northern North Pacific Ocean near U.S.S.R.
Mar. 9, 1957	[2] 1.3 Yakutat; [4] 2.2 Yakutat.	Northern North Pacific Ocean near Aleutian Islands.
July 9, 1958	[2] ⅔-1 Yakutat; [5] 3 Yakutat; probably from local waves generated in Yakutat Bay.	Northeastern Gulf of Alaska, southeast of Lituya Bay.
May 22, 1960	[2] 3 Yakutat; [4] 5.2 Yakutat--	Southeastern South Pacific Ocean near Chile.
Mar. 27, 1964	[2] 6.7 Yakutat; [4] 7.6 Yakutat. Seiche waves to about 0.5.[6]	Northwestern Gulf of Alaska along south coast of Alaska.
((Feb. 3, 1965))	(([7] 0.5 at Sitka, 230 miles to southeast.))	Northern North Pacific Ocean near Aleutian Islands.
((May 16, 1968))	(([7] 0.2 at Sitka, 230 miles to southeast.))	Northwestern North Pacific Ocean near Japan.

[1]Other tsunami or special waves, especially those of low height, undoubtedly have occurred but were not listed in publications about tsunamis because of the difficulty of detecting such events on tidal records in general, and because of the scarcity of observers.

[2]Cox and Pararas-Carayannis (1969).

[3]Tarr and Martin (1912).

[4]Spaeth and Berkman (1967).

[5]Tocher (1960).

[6]McGarr and Vorhis (1972).

[7]U.S. Coast and Geodetic Survey (1967, 1970).

(( ))Far-reaching tsunamis apparently not detected at Yakutat; however event was recorded at possibly similar location(s) indicated.

Seiches are water waves that are set in motion as sympathetic oscillations or sloshings of closed or semiclosed bodies of water; they are caused by (1) the passage of air-pressure disturbances or seismic waves, (2) the tilting of enclosing basins, or (3) the impact of large landslides into bodies of water. The natural period of oscillation of a water body is controlled by the configuration of the enclosing basin. Although seiches often are small and masked by other types of waves, there were reports of seiches or possible seiches as much as 25 feet high occurring during the 1964 Alaska earthquake (McCulloch, 1966; McGarr and Vorhis, 1968; U.S. Geological Survey unpub. field data, 1964). At Yakutat, a seismically induced seiche developed about 4 minutes after the initial shock and was about 0.5 foot high, as recorded on the tidal gage; it had a duration of 14 minutes (McGarr and Vorhis, 1972). Another of the set of waves affecting the Yakutat tidal gage was interpreted by Wilson and Tørum (1968, p. 100) as having developed a maximum height of 5 feet with a period of 30 minutes. Earthquakes originating in other regions may generate different seismic waves and thus cause higher or lower oscillations of water.

Massive underwater and subaerial landslides related to shaking during earthquakes have caused small to very large waves in some bodies of water in Alaska. Although some waves were local and dissipated within short distances, others traveled far. Delta fronts, especially, can respond to shaking by extensive landsliding and generation of waves. Several deltas that failed elsewhere during the 1964 Alaska earthquake generated waves as much as 30 feet high, including one wave that had a maximum vertical runup of 170 feet (Kachadoorian, 1965; Coulter and Migliaccio, 1966; Lemke, 1967; Von Huene and Cox, 1972). Subaerial landsliding triggered by earthquake shaking also generated high waves. The world's record height of wave runup is probably 1,740 feet, triggered by a landslide in Lituya Bay, southeast of Yakutat, during the July 10, 1958, earthquake (Miller, 1960). Along the steep walls of upper Yakutat Bay and adjoining fiords, numerous waves formed because of earthquake-generated landsliding and, undoubtedly, submarine landsliding. The highest known waves occurred during the earthquake of September 10(?), 1899, and washed to heights of as much as 60 feet (table 7) (Tarr and Martin, 1912).

Some of the locally generated waves that caused damage in southern coastal Alaska during the 1964 Alaska earthquake apparently were triggered neither by earthquake-induced landslides nor by seiches or tsunamis. Instead, Plafker (1969) and Von Huene and Cox (1972) suggested that these local waves were generated by sudden, direct tectonic displacement of the land; wave height probably was controlled by bottom configuration, shore orientation, and the direction and amount of land displacement. In the Yakutat area, earthquake-induced waves of this type have not been recognized but may have been included as part of the complex of waves developed during the September 1899 earthquakes.

Damage to Yakutat from tsunamis and seiches is one of the most likely consequences of earthquakes. The occurrence of such waves should be anticipated at Yakutat as at other coastal cities. Unfortunately, wave heights and amount of damage related to hypothetical waves cannot be predicted. If all tsunamis were of the nonbreaking type and of low height and occurred at low tide, no damage would result. On the other hand, if a group of moderately high, breaking-type waves were to strike at highest high tide, locally, intensive damage probably would result.

One may speculate on several possible wave heights of tsunamis that might strike the Yakutat area. When considering these heights, the reader must bear in mind that wave focusing and sympathetic resonance of local waves in a particular bay, cove, or fiord could increase wave heights by many feet.

The U.S. Coast and Geodetic Survey (1965) cautioned that all land less than 50 feet above sea level and within 1 mile of the coast should be considered potentially susceptible to tsunamis generated at considerable distance. Fortunately, most of Upper Yakutat and much of the shore area along Monti Bay are above an altitude of 50 feet and have steep slopes down to tidewater (fig. 2).

A somewhat less conservative approach is indicated by the data of Wiegel (1970), who noted that many Pacific Ocean tsunamis have been about 40 feet high. If a 40-foot wave (one in which amplitude is 20 feet) spread into Monti Bay at midtide, there would be flooding of some land (1) at Lower Yakutat, (2) along parts of some nearby islands, (3) at the small-boat harbor area, (4) along a narrow strip of the Monti Bay shore, including some harbor facilities, and (5) along part of The Ankau on Phipps Peninsula. Along the outer coast of the Gulf of Alaska, and especially near the estuaries of Lost, Situk, and Ahrnklin Rivers, waves possibly would spread inland as much as 1 mile.

Another evaluation of the height of tsunamis that could affect Yakutat is available from a study by Dames and Moore (1971, p. B5-B6) on potential damage to the airport at Sitka, Alaska, (fig. 1) from tsunamis generated in the Pacific Ocean. Because of the somewhat similar positions of Yakutat and Sitka relative to the Pacific Ocean and because of the use by Dames and Moore of similar data on tsunamis generated in the Pacific Ocean, their study is thought to be applicable in general to Yakutat. The principal conclusion of Dames and Moore was that "there is a 65-percent chance that a tsunami will hit Sitka in a 100-year interval with a maximum wave height of at least 20 feet * * *, a 25-percent chance that such [a] wave will occur in 29 years, and a 10-percent [chance] that such a wave will hit * * * in 10 years."

Warnings to coastal Alaska regarding the arrival time of potentially damaging tsunamis are issued by the International and the Alaska Regional Tsunami Warning System of the National Oceanic and Atmospheric Administration (Butler, 1971; Cox and Stewart, 1972; Haas and Trainer, 1974). For Yakutat, such warnings about tsunamis that are generated at great distances should allow sufficient time to move ships and evacuate the harbor and other low-lying areas. However, it is doubtful that the warning time would be sufficient for tsunamis or other potentially destructive waves that might be generated in Yakutat Bay and adjoining fiords or generated relatively close offshore in the Pacific Ocean.

Wave damage to shore areas from earthquake-triggered subaerial and submarine landslides may occur at several places in the Yakutat region. The potential for damage is high along the shores of narrow upper Yakutat Bay and adjoining fiords, where there are steep slopes, deep water, and probably steep-fronted deltas. Most waves should dissipate as they travel into the much wider expanse of outer Yakutat Bay.

INFERRED FUTURE EFFECTS FROM GEOLOGIC HAZARDS OTHER THAN EARTHQUAKES

In addition to the hazards from earthquakes, a potential for damage in the Yakutat area from other geologic hazards exists. These include (1) subaerial and underwater landslides, (2) stream floods and erosion of deposits by running water and sheet floods, and (3) high water waves not associated with local or distant earthquakes.

Subaerial and underwater landslides

Numerous slopes in the Yakutat region are subject to various types of subaerial and underwater landsliding. Although many slope failures occur during earthquakes, as discussed previously, most occur at other times--on steep subaerial slopes during heavy rainfall, rapid snowmelt, and seasonal freezing and thawing, or as a result of man's alteration of slopes. The underwater slopes of active deltas and extending spits fail during normal oversteepening by deposition.

Subaerial landslides in the Yakutat area are rare, because most slopes are gentle; some shore areas of outer Yakutat Bay, where slopes are steep (table 1), are an exception. Such places that do slide probably are characterized by loose, unconsolidated geologic materials that are saturated. Relative susceptibility of various geologic deposits to general landsliding is presented in table 8.

Table 8.--Evaluation of geologic map units for degree of susceptibility to certain non-earthquake-related geologic hazards: landsliding, erosion by running water and sheet floods, and damage by high water waves

Geologic unit and map symbol	General susceptibility to all types of landsliding	Ease of erodibility by running water & sheet floods	Susceptibility to damage from high water waves
f artificial fill	High where slopes of margins are steep and saturation is great; low elsewhere.	Low to moderate; high on steep margins if compaction was minimal at time of emplacement.	Greatly variable, depending in part on (1) compaction at time of emplacement and (2) direction of exposure and relation to pileup or focusing of waves.
wc organic deposits underlain by coarse-grained deposits	None because of lack of steep slopes.	Moderate where fibrous.	Moderate, for a few deposits near Summit Lakes.
wf organic deposits underlain by fine-grained deposits	None because of lack of steep slopes.	Moderate where very fibrous; usually not developed where large amounts of water occur.	High for deposits near estuaries of Lost Creek and Situk River.
e eolian sand deposits	Low where not actively developing; high elsewhere.	Very high.	Very high.

Table 8.--Evaluation of geologic map units for degree of susceptibility to certain non-earthquake-related geologic hazards: landsliding, erosion by running water and sheet floods, and damage by high water waves--Continued

Geologic unit and map symbol	General susceptibility to all types of landsliding	Ease of erodibility by running water & sheet floods	Susceptibility to damage from high water waves
by young beach deposits	Very low to very high; highest where newly deposited, as at ends of lengthening spits.	Not applicable.	Very high.
bi intermediate beach deposits	Very low.	Moderate.	High.
bo old beach deposits	Very low.	Moderate.	Low.
dy young delta-estuarine deposits	Moderate to very high; highest where newly deposited.	Very high; major changes can take place in channel configuration within short time.	Very high; many deposits directly exposed to waves.

Table 8.--Evaluation of geologic map units for degree of susceptibility to certain non-earthquake-related geologic hazards: landsliding, erosion by running water and sheet floods, and damage by high water waves--Continued

Geologic unit and map symbol	General susceptibility to all types of landsliding	Ease of erodibility by running water & sheet floods	Susceptibility to damage from high water waves
di intermediate delta-estuarine deposits	Low because of gentleness of slopes.	Probably moderate to high.	Low for most deposits; high where merge with delta-estuarine deposits.
do old delta-estuarine deposits	Low.	Moderate to low.	Low for those deposits near Ophir Creek.
ds clayey silt delta-estuarine deposits	Probably low but difficult to evaluate because of position and relation to fluctuations of tide-water.	Low.	Low because of high degree of compaction.
ac coarse-grained alluvial deposits.	Low.	Moderately high; frequent shifting of channels.	Inapplicable.
af fine-grained alluvial deposits	Low.	High.	Low.

Table 8.--Evaluation of geologic map units for degree of susceptibility to certain non-earthquake-related geologic hazards: landsliding, erosion by running water and sheet floods, and damage by high water waves--Continued

Geologic unit and map symbol	General susceptibility to all types of landsliding	Ease of erodibility by running water & sheet floods	Susceptibility to damage from high water waves
ao old alluvial deposits	Low.	High.	Inapplicable.
oc coarse outwash	Very low.	Moderately high.	Low for those deposits near Aka Lake.
of fine outwash	Very low.	High.	Inapplicable.
m outer Yakutat Bay moraine complex	Probably moderate because of abundance of steep slopes and a generally high level of saturation.	Moderate to low.	High only along some low, shore-exposed parts of deposits and at heads of bays and coves; mostly low susceptibility because of deposit height of more than 50 to 100 feet.

In much of the Yakutat region north and northeast of Yakutat, slopes commonly are steep to very steep, especially along (1) the mountain front, (2) margins of most valleys, and (3) the margins of upper Yakutat Bay and adjoining fiords. In this region, subaerial landslides probably are relatively frequent. Noteworthy are the massive slides and fissured bedrock of the valley sides of upper Beasley Creek valley, east of the south end of Russell Fiord. Some of the slides may have originated because of the loss of lateral support when Beasley (or Fourth) Glacier, which feeds the creek, melted back rapidly within the last hundred (?) years.

Although earthquake shaking undoubtedly contributes to the frequency of sliding, the extensive research by Miller (1960) regarding the history of landslide-generated waves in Lituya Bay strongly indicates a high degree of hazard from landslides along the steep walls of fiords, even without earthquakes.

Intermittently occurring submarine landslides of various sizes in Yakutat Bay probably characterize fronts of (1) actively growing deltas and (2) extending beach spits that are located in down-current directions from shore areas being rapidly eroded by wave action. Some of the more prominent spits in the Yakutat area are Point Carrew on Phipps Peninsula and the north and south ends of Khantaak Island. Large deltas are present only southeast of Yakutat, where Lost, Situk, and Ahrnklin Rivers enter the Gulf of Alaska. Fronts of these deltas are continually being modified by the powerful longshore current of the gulf; thus, their fronts rarely become oversteepened. In contrast, in upper Yakutat Bay and adjoining fiords and along the west side of outer Yakutat Bay, the fronts of the large deltas formed by predominantly glacial streams probably are very susceptible to submarine landslides. Some slides might be capable of generating waves of moderate size.

Stream floods and erosion of deposits by running water

Extensive marshland and a locally well developed and integrated system of small and large streams easily accommodate or adequately carry most rainfall and melting snows in the Yakutat area; only occasionally will stream flooding occur. In a like manner, because vegetation covers most of the ground, sheet flooding will probably occur only locally during exceptionally heavy rainfall. The susceptibility of the various geologic map units to erosion by running water and sheet floods is given in table 8.

High water waves

Non-earthquake-related water waves high enough to damage some harbor structures occasionally might strike shores in the Yakutat area. Three types of waves are possible: (1) waves generated by underwater landslides or subaerial landslides into bays and fiords (noted above, in relation to landslides themselves), (2) glacier-related waves, and (3) storm and other waves originating in the Pacific Ocean. The susceptibility of parts of the Yakutat area to high water waves is given in table 8.

Glacier-related high water waves in upper Yakutat Bay and connecting fiords have been caused by breakout of glacier-dammed lakes and by breakage and falling of huge pieces of ice from "hanging" glaciers perched along steep walls of fiords (table 7). In many places in the region, glaciers dam ice-free tributary valleys. If drainage becomes blocked in the tributary valleys, large lakes can form and break out suddenly at regular or irregular intervals. This situation presumably has occurred in the past in several places in the region, notably in Russell Fiord.

Breakage and sudden falling of glacier ice into the deep waters of the fiords connecting to upper Yakutat Bay caused locally high waves in 1905 and possibly in 1845 (table 7).

Glacier advances, development of glacier-dammed lakes, and large scale cracking of hanging glaciers probably could be detected by monitoring of selected glaciers in the Yakutat region (Post and Mayo, 1971). Resulting waves probably would dissipate to a large extent as they traveled into the wide outer part of Yakutat Bay.

Waves from most storms in the Pacific Ocean weaken somewhat after moving into Yakutat Bay. Even after being weakened, however, waves from some storms could be very large and could cause damage to the more exposed shore areas. One set of destructive storm waves was noted by Tarr and Martin (1912, p. 47) as having occurred November 18, 1907.

A study by Watts and Faulkner (1968) was carried out to determine the height of the probable maximum 100-year storm waves in the Pacific Ocean west of British Columbia. The value they determined was 70 feet, which may be valid as a possible maximum wave height for areas of the Gulf of Alaska near Yakutat Bay. Studies presently being conducted concerning specific heights of waves in the Gulf of Alaska are reported by McLeod, Adams, and Hamilton (1975).

The origins of other types of Pacific Ocean waves that rarely may affect the Yakutat area are unknown, and time of occurrence or wave height cannot be predicted. Waves reached heights of 18 feet above mean high water on March 30-31, 1963, along the north coast of the Queen Charlotte Islands and near Prince Rupert, British Columbia (fig. 1; U.S. Coast and Geodetic Survey, 1965, p. 46). It has been speculated that the waves were caused by a massive submarine slide along part of the continental slope or by some special long-period ocean wave similar to waves described by Munk (1962) and Rossiter (1971). Another type of wave may have been the cause of the "freak" waves and heavy surf that struck part of the Oregon and Washington coast on November 25-26, 1972, as reported in the Denver [Colorado] Post for November 27, 1972. On Khantaak Island, a wave of unknown origin, though described as a tidal wave, did strike and remove at least a part of the beach at the southern end of the island in 1889 (Tarr and Butler, 1909, p. 165).

Whether or not the few low-lying areas at Yakutat could be damaged by slide-generated waves or special long-period ocean waves is not known. It seems plausible to expect, however, that sometime in the future such waves will reach Yakutat without warning.

RECOMMENDATIONS FOR ADDITIONAL STUDIES

The reconnaissance nature of this geologic investigation did not permit more than a brief evaluation of the general geology, potential geologic hazards, and other geologic factors that would be helpful to land-use planning in the Yakutat area. Therefore, the following recommendations for additional investigations are listed in a generalized order of importance.

1. Additional geologic mapping and field study of the Yakutat region, utilizing current airphotos and updated topographic maps, should be performed, including collection of data on the distribution and physical properties of geologic materials and the plotting of data concerning joints and faults. Such work might lead to discovery of economic mineral deposits, a better understanding of geologic structure of potentially oil-bearing areas, the locating of generalized zones of potentially unstable slopes and zones of geologic materials subject to liquefaction, and the identifying of areas most suitable for construction.

2. In order to help indicate the possible location of future large earthquakes, the type of movement along known faults and inferred and postulated faults in the region should be determined. To accomplish this work, and to delineate any unknown active faults, records of earthquake events detected by seismological instruments in the region will have to be analyzed for a period of at least several years. Also important are measurements of the slow, very small vertical changes in ground levels in the region; these measurements assist in determining the rate of rebound of land following glacial retreat and provide an indication of possible future earthquakes.

3. Offshore geophysical studies should be continued and expanded. These studies should help determine the configuration of the sea floor, the nature of faults, and their relationship to the stability of geologic materials on the sea floor. Such work might result in the location of potential submarine landslides that might be triggered by movement along the faults.

4. Because of the potential for extensive wave damage in the Yakutat area, there should be a study of the natural oscillation periods of basins enclosing or related to large bodies of water in the region, to assist in prediction of possible wave heights. Basin areas include Yakutat Bay, adjoining fiords, and the Continental Shelf and associated sea-floor valleys of the Gulf of Alaska near Yakutat. In conjunction with the study, a probability analysis of tsunami frequency should be undertaken, similar to the analysis described above that was developed by Dames and Moore (1971) for the airport at Sitka, Alaska.

5. Stability of steep subaerial slopes, especially along upper Yakutat Bay and adjoining fiords, should be analyzed to determine the areas of greatest probability of landslides and any associated high waves. Although initial detection of the most unstable slopes should be accomplished during areal geologic mapping, a separate analysis of slopes would permit a more thorough evaluation of those factors considered most responsible for the instability.

6. The advance and retreat of glaciers in the region should be monitored because of the potential for (a) large, local waves from massive breakage of ice or from breakout of glacier-dammed lakes, and (b) blockage of navigation by glacier advances or greatly increased calving of tidal glaciers. A generalized surveillance of glaciers could be accomplished by periodic inspection from aircraft.

GLOSSARY

Accelerograph: An instrument designed to record the time history of ground acceleration for strong ground shaking generated by a nearby earthquake. The instrument records motion in three mutually perpendicular directions, one vertical and two horizontal directions.

Diamicton: A nonsorted or poorly sorted, unconsolidated sedimentary deposit that contains a mixture of wide-ranging particle sizes (boulders, cobbles, pebbles, and sand) dispersed in a finer grained matrix, generally silt and sand. The term may be applied to deposits of any origin.

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 initial point of subsurface fault rupture that generates earthquake waves.

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, one 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 one on which there has been lateral displacement approximately parallel to the strike of the fault. If the block across the fault has moved relatively to the right, the fault is a right-lateral strike-slip fault; relative movement to the left defines a left-lateral strike-slip fault. The term active fault is in common usage, but there is not complete 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.

Graben: A relatively depressed, elongate tract of land owing its origin to spreading of adjacent land in a direction perpendicular to the long sides of the tract, thus resulting in normal faults bounding those sides.

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 on visible effects on natural and manmade objects. The most widely used intensity scale in the United States is the Modified Mercalli intensity scale (table 4).

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; also the representation of such a ground feature on topographic maps or on airphotos or other remote-sensing imagery.

Liquefaction: The transformation of a material having very low cohesion from a solid state to a liquid state by a process of shock or strain that increases pore-fluid pressure.

Magnitude: As originally defined, refers to the logarithm of the maximum amplitude on a seismogram written by a standard type seismologic instrument 60 miles from the epicenter of an earthquake (Richter, 1958). Although magnitude does not directly relate to seismic energy, a 1-unit increase in magnitude is correlated to a 32-fold increase in seismic energy.

Microearthquake: An earthquake too small to be felt that can be detected only instrumentally. The range for the lower limit of magnitude of felt earthquakes generally is considered to be approximately 2 to 3.

Moraine: A landform that is an accumulation of material deposited by glacier ice and composed mostly of till, a diamicton of glacial origin.

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

Seiche: Water waves set into motion by sympathetic response of water in a closed or semiclosed basin to passage of air pressure disturbances, seismic waves, or impact of landslides.

Seismograph: An instrument designed to record the time history of small ground motions generated by small local earthquakes as well as distant large earthquakes.

Seismoscope: An instrument that records strong horizontal ground motion from earthquakes and whose response models that of common small buildings to the same earthquake.

Tectonics: The part of geologic study dealing with origin, development, and structural relations of large-sized blocks of the earth's crust.

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

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 earthquakes or of volcanic action. Tsunamis in the open ocean are long and low and have speeds of 425 to 600 miles an hour. As they enter shallow coastal waters, they move more slowly and can increase greatly in height.

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