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Reconnaissance Engineering Geology of the Metlakatla Area, Annette Island, Alaska, With Emphasis on Evaluation of Earthquakes and Other Geologic Hazards

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This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards or nomenclature.

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RECONNAISSANCE ENGINEERING GEOLOGY OF THE METLAKATLA AREA, ANNETTE ISLAND, ALASKA, WITH EMPHASIS ON EVALUATION OF EARTHQUAKES AND OTHER GEOLOGIC HAZARDS

By LYNN A. YEHLE

ABSTRACT

A program to study the engineering geology of most larger Alaska coastal communities and to evaluate their earthquake and other geologic hazards was started following the 1964 Alaska earthquake; this report about the Metlakatla area, Annette Island, is a product of that program. Field-study methods were of a reconnaissance nature, and thus the interpretations in the report are tentative.

Landscape of the Metlakatla Peninsula, on which the city of Metlakatla is located, is characterized by a muskeg-covered terrane of very low relief. In contrast, most of the rest of Annette Island is composed of mountainous terrane with steep valleys and numerous lakes.

During the Pleistocene Epoch the Metlakatla area was presumably covered by ice several times; glaciers smoothed the present Metlakatla Peninsula and deeply eroded valleys on the rest of Annette Island. The last major deglaciation was completed probably before 10,000 years ago. Rebound of the earth's crust, believed to be related to glacial melting, has caused land emergence at Metlakatla of at least 50 ft (15 m) and probably more than 200 ft (61 m) relative to present sea level.

Bedrock in the Metlakatla area is composed chiefly of hard metamorphic rocks: greenschist and greenstone with minor hornfels and schist. Strike and dip of beds are generally variable and minor offsets are common. Bedrock is of late Paleozoic to early Mesozoic age. Six types of surficial geologic materials of Quaternary age were recognized: firm diamicton, emerged shore, modern shore and delta, and alluvial deposits, very soft muskeg and other organic deposits, and firm to soft artificial fill. A combination map unit is composed of bedrock or diamicton.

Geologic structure in southeastern Alaska is complex because, since at least early Paleozoic time, there have been several cycles of tectonic deformation that affected different parts of the region. Southeastern Alaska is transected by numerous faults and possible faults that attest to major movements of the earth's crust. The latest of the major tectonic events in the Metlakatla region occurred in middle Tertiary time; some minor fault activity probably continues today at depth. Along the outer coast of southeastern Alaska and British Columbia, major faulting activity occurs in the form of active, strike-slip movement along the Queen Charlotte fault about 100 mi (160 km) west-southwest of Metlakatla. Some branching subsidiary faults also may be active, at least one of which may be the Sandspit fault.

Many major and smaller earthquakes occur along the outer coast. These shocks are related to movements along the Queen Charlotte fault. A few small earthquakes occur in the region between the outer coast and the Coast Mountains, which includes Metlakatla. Only a few earthquakes have been reported as felt at Metlakatla; these shocks and others felt in the region are tabulated. Historically, the closest major earthquake was the magnitude 8.1 Queen Charlotte Islands earthquake of August 22, 1949, which occurred along the Queen Charlotte fault 125 mi (200 km) southwest of Metlakatla. No damage was reported at Metlakatla.

The probability of destructive earthquakes affecting Metlakatla is unknown. A consideration of the tectonics and earthquake history of the region, however, suggests that sometime in the future an earthquake with a magnitude of about 8 will occur along that segment of the Queen Charlotte fault nearest to Metlakatla. Smaller earthquakes with magnitudes of 6 or more might occur elsewhere in the Metlakatla region or south-southeastward near Dixon Entrance or Hecate Strait.

Several geologic effects that have characterized large earthquakes elsewhere may be expected to accompany some of the possible major earthquakes that might affect the Metlakatla area in the future. Evaluation of effects indicates that fault displacement and tectonic uplift or subsidence are probably unlikely, and ground shaking in general probably would be strongest on muskeg and other organic deposits and least on bedrock. Other possible effects include: (1) liquefaction of some muskeg and a few alluvial and delta deposits, (2) ejection of water and sediment as fountains from some alluvial and delta deposits and emerged shore deposits, (3) compaction and differential subsidence in some of the few alluvial and delta deposits and in some artificial fills, (4) some landslides in the region, and (5) minor alterations, possibly in the movement of ground water within alluvial deposits in the area.

Water waves commonly are generated by earthquakes and include (1) tsunamis, (2) seiches, and (3) local waves produced by landslides and tectonic displacement of land. Tsunami waves are the most significant waves; the largest ones have been generated in offshore regions where underthrust faulting occurs. Such waves are capable of traveling great distances across oceans and striking shore areas with destructive effect. A wave 20 ft (6 m) high at Metlakatla is a distinct possibility. Arrival times can be forecast with some accuracy for distantly generated waves, but for waves that are generated locally forecast cannot be made.

Geologic hazards not necessarily related to earthquakes include (1) occasional high water waves, (2) some landslides on steep slopes, and (3) rare stream floods and erosion of deposits by running water and sheet floods.

Recommended additional investigations in the Metlakatla area and region include (1) determination of the approximate location of future large earthquakes through use of tectonic analysis, geophysics, and high-sensitivity seismologic instruments in cooperation with the Seismological Service of Canada; (2) determination of the gravitational stability of underwater slopes along fiords in order to help identify areas of potential submarine landslides; (3) determination of the oscillation period of Port Chester in order to help predict possible wave heights, and a companion study to analyze tsunami frequency for the region; and (4) additional geologic work to (a) determine physical properties of surficial deposits, (b) help identify potentially liquefiable geologic materials, (c) identify areas most suitable for construction, and (d) identify potentially unstable slopes in the region.

INTRODUCTION

Soon after the great Alaska earthquake of 1964 (March 28, u.t.[1]), the U.S. Geological Survey began 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 communities near tidewater. As a result, Metlakatla and several other cities in southeastern Alaska were selected for investigation. Reports have been completed for Haines (Lemke and Yehle, 1972a),[2] Juneau (Miller, 1972), Skagway (Yehle and Lemke, 1972), Sitka (Yehle, 1974), Wrangell (Lemke, 1974), Ketchikan (Lemke, 1975), and Yakutat (Yehle, 1975); a generalized regional report was prepared for southeastern Alaska (Lemke and Yehle, 1972b). This report on the Metlakatla area highlights the geology; emphasizes the evaluation of potential damage from major earthquakes; and describes other geologic hazards, including high water waves, landsliding, and stream flooding and erosion. These geologic descriptions and evaluations of hazards are only preliminary; however, they should be helpful in some measure to land-use planning in the Metlakatla area and nearby areas on Annette Island.

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[1]The dates of all earthquakes in this report are given in universal time whenever possible; for the Metlakatla area, universal time is local standard time plus 8 hours.

[2]Complete data on title and publisher of reports mentioned in the text are given in the section "References cited."

Collection of geologic data in the Metlakatla area and region was limited to a total of about 1 1/2 weeks during 1965. These data were supplemented extensively by the geologic work of others and by interpretation of airphotos in order to prepare a reconnaissance geologic map of the Metlakatla area, an integral part of this report.

Several U.S. Geological Survey colleagues gave valuable assistance during different phases of the study: R. W. Lemke, H. C. Berg, and M. V. Marcher contributed extensive geologic data; and E. E. McGregor, P. S. Powers, R. A. Sheppard, and R. A. Speirer analyzed samples of rock and surficial deposits. In addition, information was obtained through interviews and correspondence with Federal, State, and city of Metlakatla officials, private citizens, and personnel of engineering and construction companies who have worked on Annette Island. Especially acknowledged is the help of Russell Hayward, City Clerk of Metlakatla in 1965.

Because of the short period of field study and the reconnaissance nature of geologic mapping, it is emphasized that this report discusses subjects only in general terms.

GEOGRAPHY

Metlakatla is on the west coast of Annette Island in the southern part of southeastern Alaska, 15 mi (25 km) south-southeast of Ketchikan (figs. 1; 2, in pocket) at lat 55°08' N. and long 131°34' W. The Metlakatla area is considered in this report as the area shown in figure 3 (in pocket); it includes the city of Metlakatla and vicinity. The Metlakatla region is herein considered to be the region shown in figure 2, and includes Annette Island and parts of Prince of Wales, Gravina, Revillagigedo, and Duke Islands plus the principal waterways of Clarence Strait, Nichols Passage, and Revillagigedo Channel.

Metlakatla is situated on an emerged former shore zone on the north end of Metlakatla Peninsula (fig. 2). The peninsula bounds the south side of Port Chester, an eastern embayment of Nichols Passage. Most of the peninsula has a low relief, its muskeg-covered surface averaging about 100 ft (30 m) in altitude. The rest of Annette Island is a great topographic contrast to the peninsula, with generally rugged mountains, steep valleys, and numerous lakes. Some of the mountains rise to over 2,000 ft (610 m).

Metlakatla fronts on Port Chester. The waterway is characterized by numerous shoals and islets except offshore from Village Point, where an east-trending channel more than 200 ft (61 m) deep extends to about the longitude of the cargo dock (fig. 3).

There is no continuous-recording tidal gage at Metlakatla; tidal bench marks were installed in 1883, 1914, 1920, and 1969 (Woodworth and Haight, 1927, p. 73; U.S. Coast and Geod. Survey, 1951a; U.S. Natl. Ocean Survey, 1971). From the latest data, the mean tide range is given as 14.6 ft (4.4 m) and the estimated highest tide is 19.5 ft (5.9 m).

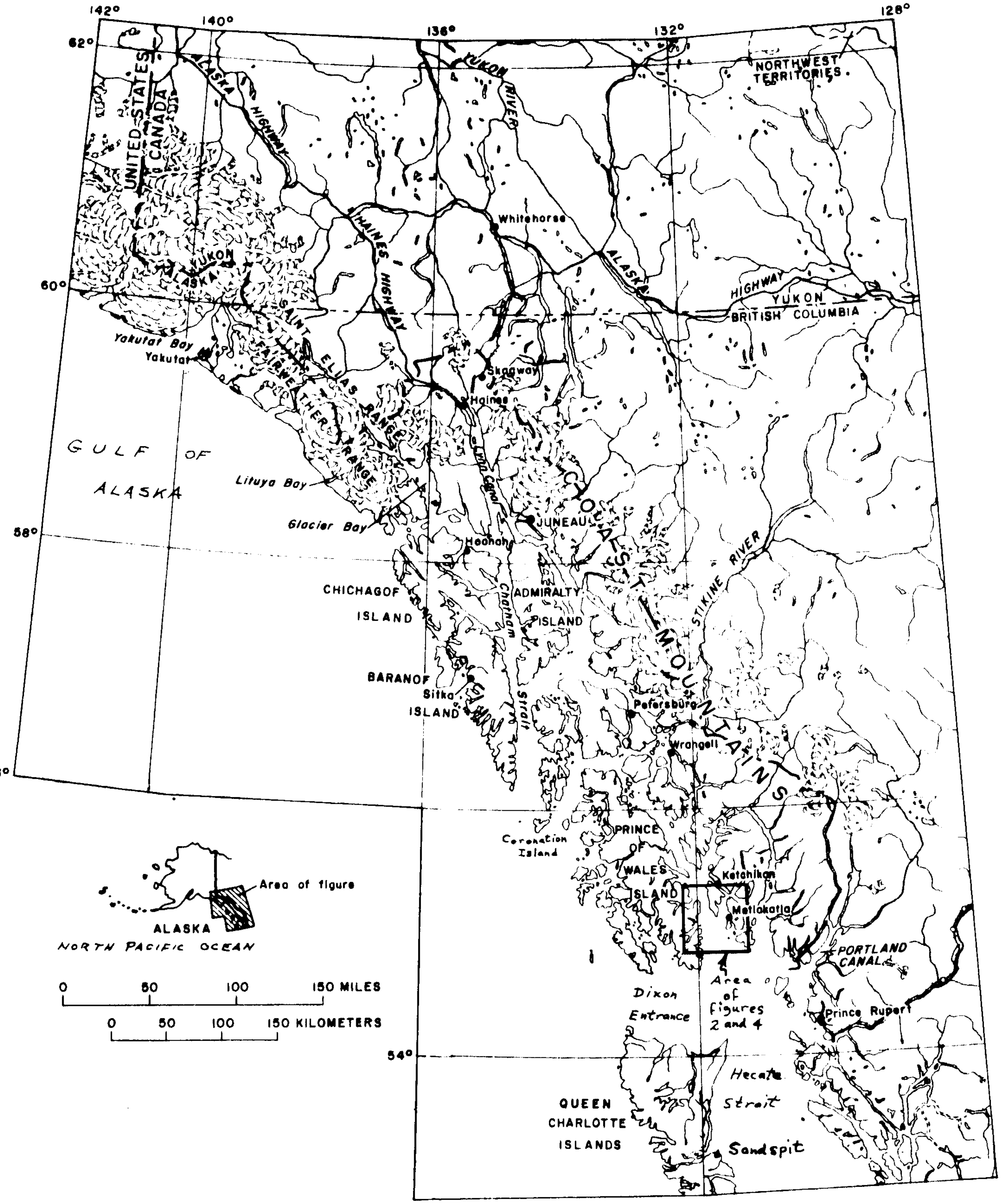


Figure 1.--Index map of southeastern Alaska and adjacent Canada showing location of Metlakatla, Annette Island.

Metlakatla has a strongly maritime climate typical of its latitude in southeastern Alaska (U.S. Natl. Weather Service, 1973). Data from the Annette Island airport, 6 mi (10 km) south of Metlakatla, indicate that the mean annual temperature is 45.6°F (7.6°C). Precipitation averages 118 in/yr (2,997 mm/yr); that is 65 percent of the precipitation at the city of Ketchikan, which is adjacent to mountainous terrane. Precipitation at Annette Airport occurs throughout the year, with minimums in June and July. Miller (1963) considered that the maximum theoretical 25-year rainfall in 24 hours for Annette Island is about 8 in. (203 mm). Winds are very strong at times, with maximum velocities of more than 50 mi/h (80 km/h) recorded in several months; prevailing winds are from the south-southeast (U.S. Natl. Weather Service, 1973).

Metlakatla has a unique history. The city was established in 1887 by Father William Duncan and a large group of Tsimshian Indians who emigrated from a city in British Columbia about 20 mi (32 km) northwest of present Prince Rupert (Metlakatla Indian Community and Environmental Concern, Inc., 1972). In 1891 all of Annette Island became the Annette Island Reserve.

The location of some of the municipal and transportation facilities that serve the Metlakatla area is shown in figures 2 and 3.

GLACIATION AND ASSOCIATED LAND- AND SEA-LEVEL CHANGES

The Metlakatla area probably was covered by glacier ice during several different intervals in the Pleistocene Epoch. During the culmination of the last major glacial interval, ice overlying the site of Metlakatla may have been between 3,500 and 3,900 ft (1,065-1,190 m) thick (Østrem, 1972; U.S. Geol. Survey, 1965). Early in an interval of major glaciation, ice in the form of small valley glaciers developed in the mountainous parts of Annette Island and flowed outward; later, most of the valley glaciers were overwhelmed by glacier ice that spread outward from the Coast Mountains (fig. 1). The ice thinned as it flowed toward Hecate Strait, Dixon Entrance, and the narrow Continental Shelf, and it probably formed a very large ice shelf. Near the close of the Pleistocene Epoch, the valley glaciers and shelf ice melted because of major climatic warming; most ice probably disappeared from the Metlakatla region before 10,000 years ago.

Following the last major deglaciation, numerous erosional landforms of glacial origin were exposed, especially in the mountainous parts of Annette Island. Characteristic landforms such as large, partly rounded knobs of bedrock and U-shaped valleys are common. Offshore, some drowned valley floors are from several hundreds of feet to more than 1,000 ft (100-305 m) deeper than the adjacent sea floor. Lack of time prohibited observation of large-scale constructional landforms of glacial origin, many of which have been modified by erosion or concealed by thick muskeg deposits.

During the Holocene Epoch (about the last 10,000 years), minor fluctuations of climate caused advances and retreats of glaciers that are well documented elsewhere in southeastern Alaska (Barnwell and Boning, 1968; Goldthwait, 1963, 1966; Heusser, 1960; McKenzie, 1970; Péwé, 1975).

For Annette Island, I interpret that small glaciers may have re-formed in some of the heads of the highest valleys and advanced and retreated in similar manner. No analyses of airphotos were made, however, to confirm this interpretation. At the present time there are no glaciers on Annette Island.

The position of land in relation to sea level in the Metlakatla area has changed greatly within the past tens of thousands of years, and apparently it is continuing to change. The primary cause of change has been the expansion and advance and then contraction and retreat of glaciers during the Pleistocene and Holocene Epochs. The weight of thick glacier ice depresses land; Gutenberg (1951, p. 172) considered 525 ft (205 m) of ice capable of causing a depression of 275 ft (83 m). Melting of ice permits land to slowly rebound. In most areas, however, there is a time lag between melting and rebound, and thus marine waters temporarily may occupy low areas. As a result, marine processes may greatly alter or cover older geologic materials (Armstrong and Brown, 1954; Miller, 1973).

Another possible cause for the relative emergence of land near Metlakatla is related not to deglaciation but to tectonic movements which result from stresses deep within the western part of the North American Continent and the adjacent Pacific Ocean.

Only the minimum amount of relative emergence of land at Metlakatla can be determined; total possible emergence is much greater. The minimum is provided by the altitude (about 50 ft (15 m)) of diagnostic landforms and deposits; namely, (1) the relict wave-cut bluff north of Hillcrest Avenue, (2) the relict shore deposits of sand and pebble gravel developed as a result of wave action and longshore currents that spread materials northeast and eastward from the former bluff, and (3) some diamicton deposits that locally exhibit sorting characteristics indicative of a marine or shore environment of deposition. On the southern half of Metlakatla Peninsula, using a 1:20,000-scale topographic map (U.S. Geol. Survey, 1940), I have interpreted three groups of marine-planation terraces at 30-35 ft (9-11 m), 50-55 ft (15-17 m), and 95-110 ft (29-33 m) above mean sea level (reported _in_ Marcher, 1971, p. D202).

Some shore deposits and underlying diamicton deposits are clearly marine because they contain marine fossils. The closest locality to Metlakatla at which marine fossils (in a probable diamicton) were noted was in a drill hole (loc. 4, fig. 2) approximately at the level of mean sea level, on the west shore of Tamgas Harbor (Marcher, 1971, p. D203). On southern Gravina Island (loc. 5, fig. 2), similar fossil-bearing deposits and overlying shore deposits at an altitude of 87 ft ($\sim$26 m) were noted by Chapin (1918, p. 99). The highest emerged shore deposits in the Metlakatla region probably are on eastern Gravina Island (loc. 6, fig. 2) at an altitude of 200-300 ft (60-90 m), where a large area of marine planation and shore deposits was interpreted by W. H. Condon (_in_ Berg, 1973, p. 34). Shore deposits of marine origin are recorded at similar and higher altitudes elsewhere in the southern part of southeastern Alaska and nearby British Columbia (Dolmage, 1923; Twenhofel, 1952; Clague, 1975).

None of the emerged Quaternary deposits in the Metlakatla region have been radiometrically dated. The closest samples that have been dated are marine fossils within late Quaternary deposits on Revillagigedo Island, 33 mi (53 km) north of Metlakatla at about 33 ft (10 m) above mean sea level (8,420±130 years B.P. (before the present), SI-905; Stuckenrath and

Mielke, 1973, p. 395), and from the central part of the east coast of Prince of Wales Island, 50 mi (80 km) northwest of Metlakatla at an altitude of about 30 ft (9 m) (9,510±280 years B.P., I-1621; Swanston, 1969a).

In modern times, land at Metlakatla is thought to have emerged relative to sea level at the very slow rate of 0.001 ft/yr (0.30 mm/yr) between 1883 and 1914 (Woodworth and Haight, 1927, p. 73) and at a rate of 0.002 ft/yr (0.61 mm/yr) between 1920 and 1969 (based upon my interpretation of altitudes of tidal bench marks determined by the U.S. National Ocean Survey (1971)). At Ketchikan, 15 mi (25 km) to the north-northwest (fig. 1), a continuous-recording tidal gage indicated similar miniscule relative emergence at the rate of 0.00001±0.001 ft/yr (0.003±0.31 mm/yr) for the period 1919-1972 (Hicks and Crosby, 1974); more recent data indicate that this trend continued through 1975 (S. D. Hicks, oral commun., 1976). Northward from Metlakatla, rates of emergence are progressively greater (maximum, 0.13 ft/yr (39.6 mm/yr)) with diminishing distance to Glacier Bay and its rapidly melting glaciers (fig. 1; Hicks and Shofnos, 1965).

DESCRIPTIVE GEOLOGY

Regional setting

Formal study of the complex geology of the Metlakatla region began in the late 1800's and continues today. During this time, many geologic reports and specialized analyses of mineral deposits were completed, so that, at present, the basic framework of the geology of the region is known (Berg, 1972a, 1973; Brooks, 1902; Buddington and Chapin, 1929; Chapin, 1918; Condon, 1961; Irvine, 1974; MacKevett, 1963; Smith, 1973; Taylor, 1967).

The distribution of the various types of bedrock in the Metlakatla region is largely the result of the several cycles of sedimentation, intrusion, deformation, and erosion that have taken place between probably Ordovician or earlier time and the present. Distribution of rocks and their ages are shown on the generalized geologic map (fig. 4, in pocket); although surficial deposits form an extensive cover, they are not shown on the map because of relative thinness and spotty distribution. Surficial deposits in the Metlakatla area are described in the succeeding section of the report entitled "Local geologic setting." Some of the major geologic faults and other possible discontinuities in bedrock of the region are described under "Structural geology."

Bedrock of Gravina and much of Annette and nearby small islands is grouped within the Gravina-Nutzotin belt of rocks that parallels the coast of southeastern Alaska and extends northwestward to central Alaska (Berg and others, 1972). Types of bedrock in the belt are chiefly interbedded volcanic and fine-grained sedimentary rocks of Middle(?) Jurassic to Early Cretaceous age. Intrusive activity occurred during part of the same time span, and continued until somewhat later. Some of the intrusive rocks are ultramafic and consist of dunite (Berg, 1972a; Taylor, 1967), which has been quarried extensively on Metlakatla Peninsula about halfway between Metlakatla and Tamgas Harbor (fig. 2). The remainder of Annette Island is chiefly underlain by plutonic rocks of leucotrondhjemite and quartz diorite composition and of Silurian or earlier Paleozoic age.

Most of the parts of Duke and Revillagigedo Islands shown in figure 4 are underlain by plutonic and variably metamorphosed volcanic and sedimentary rocks of Paleozoic to Cenozoic age (Irvine, 1974; Smith, 1973; H. C. Berg, unpub. data).

Bedrock on Prince of Wales Island consists of diverse igneous, sedimentary, and metamorphic rocks that range in age from Ordovician or older Paleozoic to Mesozoic(?); the results of detailed recent geologic work are being incorporated in maps at a scale of 1:250,000 (H. C. Berg, Michael Churkin, Jr., and G. D. Eberlein, unpub. data).

The youngest bedrock in the southern part of southeastern Alaska consists of volcanics, mostly of basaltic composition. These rocks are present in several locations west, north, and northeast of Metlakatla (Buddington and Chapin, 1929, p. 278; Eberlein and Churkin, 1970). Most exposures show no evidence of having been glaciated (Smith, 1973, p. 411), and thus are probably of Holocene age and were extruded less than about 10,000 years ago. The known outcroppings of these rocks closest to Metlakatla are about 5 mi (8 km) east of the northeast corner of figure 4. Possibly related basaltic andesite rocks are present at Sylburn Harbor, about 3 mi (5 km) north of Metlakatla (H. C. Berg, oral commun., 1970; Berg, 1972a), but the outcrops are too small to be shown in figure 4.

A generalized geologic history of the Metlakatla region is as follows: Early Paleozoic rocks, mostly of marine origin, were intruded in Silurian or earlier Paleozoic time by granitic plutons. The next moderately well dated event was in late Paleozoic and early Mesozoic time, when volcanic rocks were extruded and fine-grained sediments were deposited. A younger Mesozoic event included volcanism, sedimentation, and roughly contemporaneous intrusion of granitic to ultrabasic plutons of the Gravina-Nutzotin belt. Paleozoic and Mesozoic rocks were variably metamorphosed, probably in late Mesozoic or Cenozoic time. Major faulting affected the region in late Mesozoic time and continued probably into late Tertiary time (Berg, 1972b; H. C. Berg, unpub. data). Also in

Tertiary time, intrusion of granitic plutons and minor extrusion of volcanic rocks occurred in several nearby regions. During Quaternary time, extensive erosion and deposition by streams and glaciers profoundly modified many parts of the region; minor volcanism continued in a few places.

Local geologic setting

Bedrock underlying the surficial deposits in the Metlakatla area probably originated in late Paleozoic or early Mesozoic time as volcanic and sedimentary strata. Rocks were recrystallized possibly as late as Late Cretaceous time during metamorphism related to intrusion of plutonic rocks exposed on southern Metlakatla Peninsula (Berg, 1972a, b; 1973). Numerous small offsets of bedding and minor flexures of bedrock attest to a period of deformation probably related to major regional faulting that culminated in middle Tertiary time. The minor topographic irregularities of the present landscape (beneath the cover of muskeg) largely owe their origin to erosion and deposition by glacier-, glaciomarine-, and shore-related processes in Quaternary time. Artificial fill and construction-related modification of the ground surface have changed land configuration in several places in the Metlakatla area.

Description of geologic map units

The geologic map (fig. 5, in pocket) shows the distribution of geologic materials in the Metlakatla area. Several types and subtypes of surficial deposits and bedrock were either directly observed or inferred to exist in the mapped area. These geologic materials were grouped into the following seven map units in approximate order of decreasing age: metamorphic rocks (Pzmr), diamicton deposits (Qd), emerged shore deposits (Qes), modern shore and delta deposits (Qsd), alluvial deposits (Qa), muskeg and other organic deposits (Qm), and artificial fill (Qf). Map units are considered to be

4 ft (1.2 m) or more thick and to be covered by no more than about 3 ft (0.9 m) of other geologic materials. I used a combination map unit (dr) to indicate areas that may be underlain by diamicton deposits or by metamorphic rocks within limits of the mapping thickness.

The geology of the mapped area of figure 5 was examined in reconnaissance during about 1 1/2 weeks' time in 1965 along marine shores, near roads, and at several locations in the more developed parts of the city. Work was supplemented by geologic investigations by R. W. Lemke (written communs., 1965, 1972) and by Berg (1972a). For other areas of the map, information was gained largely by geologic interpretation of airphotos supplemented by data from (1) Robert Rehfeld (written commun., 1970) and (2) surveys for highway locations by the U.S. Bureau of Indian Affairs (written communs., 1965, 1966, 1969). One of the difficulties of geologic study in the Metlakatla area is the presence of a variably thick cover of muskeg and other organic materials, which obscures most other deposits except near marine shores and, locally, elsewhere. Predictions of the types of underlying geologic materials were developed by the use of several techniques, including (1) extrapolation from visible geologic exposures, (2) interpretation of preconstruction surveys for roads by highway engineers of the U.S. Bureau of Indian Affairs (written communs., 1965, 1966, 1969), (3) interpretation of landforms, and (4) use of general knowledge of growth habits of certain types of vegetation.

Descriptions of the geologic materials composing the map units follow; these are given in a generally decreasing order of age; the combination map unit (dr) is considered last.

Metamorphic rocks (Pzmr)

Metamorphic rocks of several types and attitudes are present in the Metlakatla area. Exposures are especially prominent along intertidal shores west and southeast of the city (fig. 5). Most commonly, rock types are greenschist and greenstone, with lesser amounts of phyllite and fine-grained schist and some hornfels. Hornfels and other more intensely metamorphosed rocks such as schist and gneiss are increasingly abundant in a southwesterly direction, especially southwest of an imaginary line from the proposed harbor to Skaters Lake (fig. 3; Berg, 1972a).

Bedrock is thinly to thickly layered; most layers probably cannot be traced for more than a few hundred feet ($\sim$100 m). The strike and dip of layers (fig. 5) are variable and reflect tectonic deformation of the rocks. Numerous minor offsets of layering are evident; some offsets are very small faults. Minute amounts of pyrite and lesser amounts of copper-bearing sulfide minerals are sparsely disseminated throughout bedrock in several localities.

No detailed physical-property tests are known to have been conducted on bedrock in the map area. However, most types of rock are hard and firm. Jointing of most bedrock is moderately well developed; where readily observable, joints are seen to dip steeply (fig. 5).

Bedrock within the Metlakatla map area originated in late Paleozoic to early Mesozoic time as a sequence of lava flows, related volcanic sediments, and some fine-grained sediments (Berg, 1972b, p. C80; 1973). These rocks probably were recrystallized to various types of low- to moderate-grade metamorphic rocks in late Cretaceous time (Berg, 1973, p. 18).

Where bedrock is not directly exposed at the ground surface, it is overlain by surficial deposits estimated to average possibly 10 ft ($\sim$3 m) in thickness; maximum overburden may be as much as 100 ft ($\sim$30 m). Surficial deposits are mapped where they are thought to be 4 or more feet (1.2 m) thick. Large areas of bedrock are covered by muskeg deposits that are too thin to map separately.

A high percentage of the geologic materials included in the combination map unit (dr) is bedrock.

For purposes of construction use, none of the metamorphic rocks within the map area have been directly exploited; however, bedrock serves as the foundation for part of the cannery and for the lumber mill (fig. 3). A quarry in metamorphic rocks about 0.2 mi (0.3 km) southeast of Skaters Lake has been used extensively as a source of fill for general construction purposes in the Metlakatla area.

Diamicton deposits (Qd)

Diamicton is a two-component (bimodal) surficial deposit (fig. 5) mostly of direct glacial origin; it underlies low and moderate relief areas in much of the Metlakatla area, especially southwest of the built-up part of the city. Deposits are mixtures consisting generally of a matrix component commonly of rock fragments that range in size from silt and clay to sand and a clast component mostly of rock fragments that range in size generally from pebbles to sand and, in some places, boulders; locally the percentage of clasts probably is very low. Most deposits are compact, resulting in fair to poor internal drainage.

Sorting of diamicton deposits generally is lacking, although parts of some deposits are sorted. Locally, below altitudes of 50 ft (∿15 m) above mean sea level, there is evidence of sorting of the upper part of some deposits. This localized sorting consists either of concentrations of pebbles, or possibly some horizons of silt and clay which in a few places may contain marine fossils. The closest locality to Metlakatla at which fossils were noted was in a drill hole near Tamgas Harbor (loc. 4, fig. 2).

Thickness of diamicton deposits is variable but probably averages 15 ft (4.6 m); the maximum is possibly 100 ft (∿30 m).

Diamicton deposits are thought to directly overlie bedrock in most places. In turn, diamicton may be overlain by all other types of surficial deposits. Muskeg and other organic deposits too thin to show on the map cover large areas of diamicton deposits.

Most of the diamicton is of direct glacial origin; commonly it is called till. Some of the diamicton deposits, however, are of glaciomarine origin and are related to the submergence and gradual emergence of land, processes that occurred during the latter part of the glacial and the early part of the postglacial intervals of time. During these intervals, marine currents and waves were able to either modify or cover the upper part of some of the deposits with other sediments. Other parts of the diamicton deposits were formed by downslope mass-wasting processes active on steep slopes, especially after emergence of the Metlakatla area.

Age of diamicton deposits is problematical. Although the bulk of diamicton probably is of Pleistocene age, the nature and origin of the deposits is such that parts of some deposits may be of Holocene age.

There has been large-scale use of diamicton as fill for general construction purposes in Metlakatla. As a foundation for buildings and other structures, most diamicton is well suited in areas where adequate surface drainage is provided.

Some of the geologic materials included in the combination map unit (dr) consist of diamicton.

Emerged shore deposits (Qes)

The sand and pebble gravel deposits comprising this map unit as shown in figure 5 are chiefly below an altitude of 50 ft (15 m) above mean sea level and underlie most of the city of Metlakatla. These materials occur in a gently shoreward sloping area adjacent to the modern marine shore. Well-exposed materials south of the schools, south of 4th Avenue, were studied in 1965. Deposits also occur as a zone about 300 ft (∿90 m) wide along the road to the cemeteries southwest of Metlakatla. Looseness and good internal drainage characterize the emerged shore deposits. They generally are well bedded; some contain only sand. No marine fossils were observed, although they probably are abundant locally. In some of the fossil-bearing emerged shore deposits elsewhere in southeastern Alaska high percentages of the marine fossils apparently have been eroded from underlying glaciomarine deposits, some of which are diamictons.

Thickness of the deposits probably averages about 4 ft (1.2 m), and the maximum possibly is 20 ft (6 m). Minimum thickness is at the landward edge of deposits, where they grade to diamicton both laterally and vertically. Principally, muskeg and some alluvium are the materials that overlie emerged shore deposits.

Most of the emerged shore deposits were derived from diamicton by marine planation through processes such as wave and tidal current action that are characteristic of a shore environment. These processes were active during the slow emergence of the region after deglaciation in late Pleistocene time. Below an altitude of about 50 ft (15 m) above mean sea level, the majority of deposits probably are of Holocene age; scattered remnants possibly at higher altitudes in the map area and elsewhere on Metlakatla Peninsula may be of late Pleistocene age. On Gravina Island, areas thought to be emerged shores were noted by Chapin (1918; loc. 5, fig. 2) and Condon (in Berg, 1973; loc. 6, fig. 2).

Emerged shore deposits south of the schools, south of 4th Avenue, have been used as construction materials on a limited basis. The deposits also provide the foundation upon which construction of Metlakatla was started in 1887.

Modern shore and delta deposits (Qsd)

This map unit consists of two components, a shore component and a delta component, neither of which is separated on the geologic map (fig. 5). Both components are mostly intertidal; the shore component includes the berm of the storm beach. The first to be considered is the shore component. Near Village Point, and especially westward, materials of the shore component are moderately well sorted and characterized by mostly pebbly sand except near the numerous bedrock outcrops, where cobbles and pebbles are common; the storm beach contains cobbles, pebbles, and some boulders and driftwood. Elsewhere along the modern shore, southeast of Village Point, deposits are chiefly pebbles and (or) cobbles with lesser amounts of sand and boulders; the storm beach contains some driftwood.

Bedrock underlies most of the modern shore area at depths probably averaging 4 ft (1.2 m). Maximum thickness of deposits may be 10 ft (3 m). In some places diamicton probably is the underlying geologic material.

Modern shore deposits are the present-day counterpart of the adjacent emerged shore deposits; their origins are similar.

The delta component of the map unit consists of small modern deltas and their deposits that are developed at the mouths of small streams draining the area. Deposits consist chiefly of pebbly sand.

Bedrock underlies most of the modern delta deposits at depths probably averaging 4 ft (1.2 m). Maximum thickness of deposits may be 10 ft (3 m). In some places diamicton probably is the underlying geologic material.

Delta deposits originate largely by a settling-out process of stream sediments which enter the sea and then are washed and sorted by tidal currents and waves.

No large-scale use of modern shore and delta deposits for construction purposes is known, although some material was removed from directly east of Village Point for surfacing of streets in the early 1960's (Carl Cook, oral commun., 1965). Since that time a large quantity of artificial fill has been added to the locality. As a foundation, the deposits of this map unit are well suited for structures that are adequately protected from waves and tides.

Alluvial deposits (Qa)

Geologic materials of this map unit (fig. 5) probably consist principally of pebble gravel and sand. The distribution of deposits was determined almost exclusively by airphoto interpretation of probable courses of streams and associated sediments except at marine shores, where some deposits were observed directly. At shores, deposits merge into small deltas. Thickness of deposits may possibly average 5 ft (1.5 m); the maximum may be 15 ft (4.6 m). The underlying geologic materials are interpreted as mostly diamicton and, locally, bedrock. Alluvial deposits are covered to a very large extent by muskeg that is locally thicker than 3 ft (0.9 m).

Origin of the deposits is by stream erosion of underlying and adjacent materials in upstream areas and, ultimately, deposition of these materials in downstream areas.

Alluvial deposits in the area are entirely of Holocene age; no use is known to have been made of these deposits.

Muskeg and other organic deposits (Qm)

Within the Metlakatla map area, the most readily visible geologic material is muskeg. Determination of the distribution of mappable deposits was difficult, and boundaries shown on the map (fig. 5) are very approximate. At the ground surface the material consists of wet ground with sphagnum and other mosses, various sedges, and other moisture-loving plants, plus several types of heaths and other small woody plants. Included within the map unit are many small ponds that overlie the deposits. At depth within the deposit there are interstratified organic materials, probably mostly sedges, some mosses, plus a variable amount of woody fragments; all materials are in varying states of decomposition and consolidation. These materials are collectively called peat.

Thickness of these deposits may average 5 ft (1.5 m), and the maximum may be 25 ft (7.6 m).

Physical properties of peats have been investigated intensively in several Northern Hemisphere areas. Characteristic features are high porosity, ease of consolidation, and very high moisture content. Moisture contents ranging from 180 to 860 percent of dry weight of solid material were determined by the Alaska Highway Department in the generally similar Sitka area, Alaska (Franklet, 1965). Other testing of peat indicated 75-95 percent compression of the material beneath a load. Compression values depended upon the percentage of wood fragments in a particular deposit. Shear strength of peat is usually variable; the range of sample-in-place values reported by MacFarlane (1969, p. 96) from areas in Canada varies from 0.69 to 2.8 lb/in^2 (0.05-2.0 g/cm^2). Liquefaction of peat may occur during times of heavy construction activity because of the generation of certain types of vibrations by power equipment.

The muskeg deposits overlie diamicton, alluvial deposits, and bedrock. In some places muskeg is overlain to a depth of less than 3 ft (0.9 m) by artificial fill.

Muskeg and peat develop where the climate is cool and moist and subsurface drainage is generally poor (Dachnowski-Stokes, 1941; Neiland, 1971; Stephens and others, 1970). Although the rate of accumulation of peat varies, an average rate of peat accumulation using estimates from elsewhere may be 1 ft (0.3 m) per 1,000 years (Cameron, 1970, p. A23).

The age of these muskeg and peat deposits is Holocene.

No commercial use is known to have been made of peat in the Metlakatla area. Road and building construction in areas of thick muskeg must employ various techniques to partially overcome the problem of the softness and ease of consolidation of the material. At a construction site, it is a desirable practice to remove most of the peat but, except where peat is less than about 10 ft (∿3 m) thick, removal is generally impractical. Where peat is thick, foundations for buildings usually are set on piles placed within the geologic material underlying the peat. Roads designed to cross thick peat can be planned so as to consolidate peat uniformly by correctly placing a fill that is specific in thickness for the type and thickness of peat to be overlain. MacFarlane (1969, p. 106) noted the desirability of using no more than 8 ft (2.4 m) of fill over peat deposits more than 15 ft (4.6 m) thick to achieve a uniform flotation of the fill without failure of the peat. Controlled liquefaction of peat has been used as an excavation method near Prince Rupert, British Columbia (fig. 1; Stanwood, 1958). There, in areas where slopes were gentle and underlying materials were firm, large bulldozers pushed and liquefied masses of peat as much as a few hundred feet (∿100 m) long.

Artificial fill (Qf)

The large areas of ground in Metlakatla that have been filled over or otherwise modified in a major way are included in this map unit (fig. 5). Not included are the minor fills in the more intensely developed parts of the city and most road embankments. Several varieties of geologic materials have been used as artificial fill in the Metlakatla map area. From the standpoint of commonness of use, these materials, in descending order, include the following: (1) irregular-size pieces of quarried rock, mostly from the quarry directly south of the map area, for use as unclassified fill for large areas; (2) riprap consisting of large-size blocks of mostly dunite from the quarry on central Metlakatla Peninsula (fig. 4), for use as armor rock for the breakwater protecting the small-boat harbor; and (3) lesser amounts of pebble gravel, from the emerged shore deposits and modern shore and delta deposits, for use in miscellaneous small fills. Muskeg excavated from some construction sites has been dumped in certain areas near marine shores. Where these areas are known, they are mapped in figure 5 as artificial fill and shown by a ruled pattern.

Physical properties of those types of bedrock used as fill material were investigated only by generalized observation. Detailed information about these properties can be obtained from (1) the city of Metlakatla; (2) the Engineering Division, U.S. Bureau of Indian Affairs, Juneau, Alaska; and (3) the Alaska District, U.S. Army Corps of Engineers, Anchorage, Alaska.

The thickness of artificial fill deposits may average 4 ft (1.2 m), and the maximum, at the breakwater, may be 30 ft (9.1 m).

Interpretations as to the type of geologic material (in order of decreasing abundance) underlying the larger areas of fill in the Metlakatla area were made. These show that (1) the large area of fill at the lumber mill is underlain probably by diamicton deposits, muskeg deposits, and bedrock; (2) the fill area near 8th Avenue and Milton Street is underlain by diamicton; an average of probably 8 ft (2.4 m) of muskeg was excavated before emplacement of fill; (3) fills northeast and east of Skaters Lake are underlain by muskeg and diamicton; and (4) the fill area southeast of the cannery is underlain by diamicton, bedrock, and modern shore deposits.

The breakwater was emplaced upon offshore sediments probably similar to sediments revealed in exploratory holes made by the U.S. Army Corps of Engineers (1970, p. A-11--A-14) in the proposed harbor area west of Village Point (fig. 3). These sediments consisted in general of about 8 ft (2.4 m) of pebble gravel to sand overlying diamicton or bedrock. In many of the holes, an intermediate bed of clay 1-5 ft (0.3-1.5 m) thick was noted.

Diamicton deposits or metamorphic rocks (dr)

This map unit is a combination of two regular geologic map units (fig. 5) that are not clearly separable on the basis of airphoto interpretation. The geologic material underlying the ground surface may be (1) diamicton deposits mostly of glacial origin, or (2) bedrock consisting of some type of metamorphic rock. The lack of certainty is due primarily to a lack of test holes that might be used to establish the kind of geologic material in the areas in question and, secondarily, to the limitations of airphoto interpretation.

A high percentage of areas bearing the designation "dr" probably is underlain by bedrock within several feet (∿1 m) of the ground surface. The remainder of the areas, of course, is underlain by diamicton.

STRUCTURAL GEOLOGY

Regional setting

Southeastern Alaska is a segment of a belt of active tectonic regions that rims a large part of the Pacific Ocean. From time to time, at least since the early Paleozoic, profound tectonic deformation, large-scale plutonic intrusions, and widespread metamorphism have taken place in that segment of the belt which includes southeastern Alaska (Berg, 1972b; Berg and others, 1972; Brew and others, 1966; Buddington and Chapin, 1929). The latest major events in southeastern Alaska occurred in Tertiary time; some minor activity continued into the Quaternary Period. Most structural features such as fold axes and faults trend northwesterly, some trend northerly, and a few trend northeasterly (Reeves, 1976; Twenhofel and Sainsbury, 1958). Prominent among structural features are several faults along which considerable movement is suggested. Some of the major fault zones and lineaments in southeastern Alaska and nearby regions are shown and named in figure 6; fault zones and lineaments near Metlakatla are shown in figure 4. The most significant features are the following: Queen Charlotte fault and adjoined(?) fault segments to the northwest; namely, Transition, Chichagof-Baranof, Fairweather, and Chugach-St. Elias faults (desigs. 1-5, respectively, fig. 6); Chatham Strait fault and adjoined(?) fault segments to the north and northwest; namely, Lynn Canal, Chilkat River, Dalton, Duke River, Totschunda, Shakwak Valley, and Denali faults (desigs. 6-13, respectively, fig. 6); Sandspit fault (desig. 14, fig. 6); Clarence Strait lineament (desig. 15, fig. 6; fig. 4); and Coast Range lineament (desig. 16, fig. 6). The position of offshore and most onshore segments of faults shown in figure 6 is generalized within zones from several hundreds of feet (∿100 m) to several miles (∿5 km) wide and is based upon (1) ideally, the locations of detectable earthquakes caused by recurrent faulting; (2) limited geophysical data; (3) topographic or limited sounding data; and (4) theoretical considerations of geologic structure.

The Queen Charlotte and adjoined(?), probably related faults are tectonic features that probably consist of (1) several linear zones of vertical to steeply dipping fault segments along the Queen Charlotte, Chichagof-Baranof, and Fairweather faults (Beikman, 1975; Page, 1973; Page and Gawthrop, 1973; Page and Lahr, 1971; Plafker, 1967; St. Amand, 1957; Silver and others, 1974; Tobin and Sykes, 1968); and (2) adjoined zones of thrust faults--the Transition fault and the Chugach-St. Elias fault (Gawthrop and others, 1973; Plafker, 1969, 1971; Plafker and others, 1975). Movement along the Queen Charlotte, Chichagof-Baranof, and

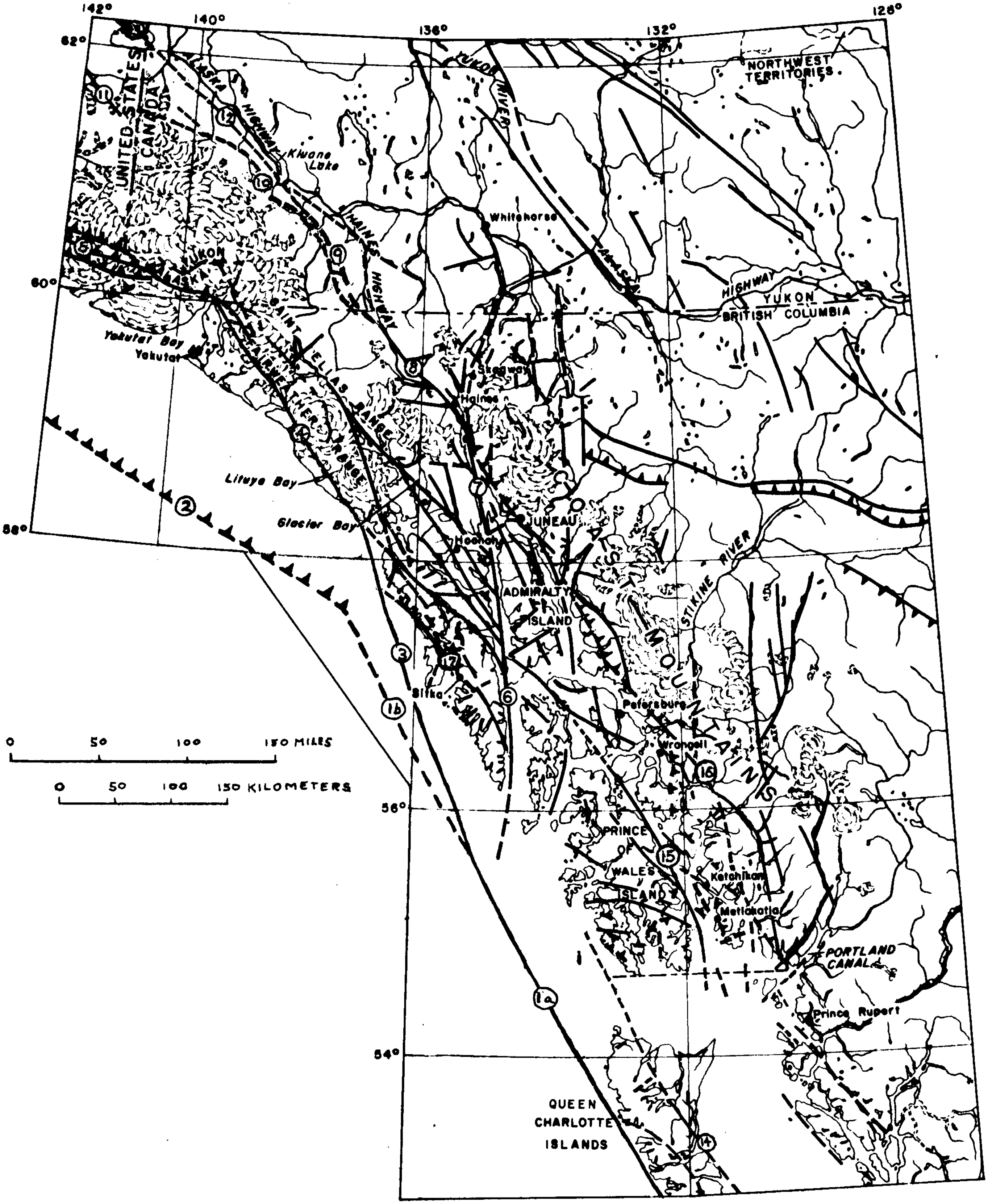


Figure 6.--(See following page for caption and explanation.)

EXPLANATION

Known Inferred

High-angle fault or other lineament

Known Inferred

Thrust fault; sawteeth on upper plate

1a, b	Queen Charlotte fault
2	Transition fault
3	Chichagof-Baranof fault
4	Fairweather fault
5	Chugach-St. Elias fault
6	Chatham Strait fault
7	Lynn Canal fault
9	Chilkat River fault
10	Duke River fault
11	Totschunda fault
12	Shakwak Valley fault
13	Denali fault
14	Sandspit fault
15	Clarence Strait lineament
16	Coast Range lineament
17	Sitka fault

Figure 6.--Map of southeastern Alaska and adjacent regions showing major faults and selected other lineaments that may be possible faults, shear zones, or joints (Beikman, 1975; Berg and others, 1972; Brew and others, 1966; Canada Geol. Survey, 1969a, b; Gabrielse and Wheeler, 1961; Johnson and Couch, 1973; King, 1969; Loney and others, 1975; Plafker, 1969, 1971; Plafker and others, 1976; Read, 1976; Richter and Matson, 1971; Souther, 1970; Tobin and Sykes, 1968; Twenhofel and Sainsbury, 1958; with additions and modifications by the writer).

Fairweather faults is thought to be similar to movement along the San Andreas group of faults in California, which is a dominantly horizontal northwestward movement of that part of the earth's crust lying southwest of the fault relative to fixed points across the fault. Both groups of faults are thought to be manifestations of the same apparent tectonic movement of a large plate (block) of the earth called the Pacific Plate past an adjacent plate termed the North American Plate (Atwater, 1970; Isacks and others, 1968; LePichon, 1968; Morgan, 1968). A popular account of plate motion was given by Yanev (1974, p. 25). Theoretical calculations indicate that motion between the plates may average 2.25 in/yr (5.8 cm/yr). This rate is generally supported by work of Plafker, Hudson, and Rubin (1976), who indicated, further, that this relatively high rate of horizontal displacement might have begun as recently as 100,000 years ago. After the southeastern Alaska earthquake of July 10, 1958, which was caused by activity along the Fairweather fault, 21.5 ft (6.6 m) of right-lateral movement was measured at one place along the fault (Tocher, 1960, p. 280). Total horizontal movement along the offshore Queen Charlotte and Chichagof-Baranof faults is unknown but probably is large.

Vertical movements along the Queen Charlotte, Chichagof-Baranof, and Fairweather faults probably have been locally extensive, although of subordinate importance to horizontal movements. For the Fairweather fault, Grantz (1966) suggested that the northeast side of the fault zone might have been relatively uplifted a total of 3 mi (4.8 km) or more.

An area of active thrust faulting at depth along the Transition fault is indicated by the Cross Sound sequence of earthquakes having major shocks on July 1 and 3, 1973, about 35 mi (56 km) offshore from the northwestern part of Chichagof Island (Gawthrop and others, 1973; Plafker and others, 1975). The zone of faulting underlies the Continental Slope. Thrust-fault motion along the Transition fault is similar to movement along the Chugach-St. Elias group of faults.

The initiation of movement along the Queen Charlotte, Chichagof-Baranof, and Fairweather fault zones may have been in middle Eocene time (Plafker, 1972, 1973).

The Chatham Strait and associated faults to the north and northwest (fig. 6) may constitute part of a series of fault-zone segments that extends more than 1,000 mi (1,600 km) subparallel to and inland from the Gulf of Alaska (Berg and others, 1972; Berg and Plafker, 1973; Grantz, 1966; Read, 1976; St. Amand, 1957; Twenhofel and Sainsbury, 1958). Along the Chatham Strait segment, right-lateral movement of 12 mi (20 km) is considered likely (Ovenshine and Brew, 1972). The Chatham Strait fault was active after Miocene time.

The Sandspit fault (fig. 6) along the eastern part of the Queen Charlotte Islands is the closest fault to Metlakatla that apparently is active. It possibly is a branch of the Queen Charlotte fault. For part of its distance, the Sandspit fault separates rocks of Tertiary age from older rocks (Sutherland Brown, 1968, p. 152). The existence of an inferred extension of the fault that heads northwestward to a point west of Prince of Wales Island is based upon consideration of geophysics (Johnson and Couch, 1973), topography, and offshore soundings. Movement along the fault may have begun in Cretaceous time and may have continued intermittently to the present. Steep dips probably characterize the fault surface. Three styles of movement are indicated: (1) (the oldest) a relative downdrop of many thousands of feet (about a kilometer) for some areas east of the fault (Stacey, 1975, p. 727); (2) locally, minor movement in the opposite direction, upward on the east; and (3) lateral strike-slip movement as evidenced near the fault trace by offset channels of many small streams. Near the channels there are partly breached linear ponds and small fault scarps which are only partly eroded (Sutherland Brown, 1968, p. 152).

Faults abound in the Metlakatla region. The distribution of major faults is shown in figure 4, which is a generalized depiction based in part upon the portrayal of the faults on primary source maps (referenced in fig. 4), each of which has a different scale and a different date of mapping. Most faults shown in figure 4 are thought to be high-angle normal faults or strike-slip faults. The amounts of displacement, however, are largely unknown. Most large-scale movements along these faults probably ended by middle Tertiary time.

Several significant thrust faults on Gravina and Annette Islands have been studied by Berg (1972a, b; 1973; fig. 4). The thrust faults have many characteristics in common. They dip gently eastward or northeastward and cut rocks as young as Jurassic in age; many of them exhibit wide areas of intensely sheared rock along the zone of faulting. Some of the shearing may be due to later normal or strike-slip faulting. A zone of shearing about 1 mi (1.6 km) wide marks the major fault along the isthmus between Metlakatla Peninsula and the main part of Annette Island. Along this fault, Berg (1972b) estimated a minimum net slip of 5-6 mi (8-10 km) of relative eastward displacement of the peninsula toward the main part of the island. The age of thrust faulting on Gravina and Annette Islands probably is sometime between late Jurassic and middle Tertiary time; most normal faulting and strike-slip faulting probably took place during the latter part of middle Tertiary time.

Lineaments are straight or gently curved geologic features that are prominent enough to be expressed, generally in a topographic sense, on airphotos or other imagery and on some topographic maps and hydrographic charts, depending upon scale. A study of the geology in the vicinity of a lineament can usually determine the origin of the feature, but in the Metlakatla region and in much of the rest of southeastern Alaska many lineaments are alined waterways that conceal bedrock and surficial deposits. Consequently, the origin of many lineaments is largely speculative. Most lineaments shown in figures 4 and 6 are probably faults. At least some of the lineaments may be intersections of the ground surface with planes of bedding or foliation of bedrock. Other lineaments may be joints or alined surficial deposits, while still others may have been formed by glacial erosion independent of bedrock structure. In many places lineaments are greatly emphasized because of differential erosion by streams or by former glaciers along these features. Two prominent lineaments that cross the southern part of southeastern Alaska are the Clarence Strait and the Coast Range lineaments.

The Clarence Strait lineament is a major geographic feature, most of which coincides with the waterway of the same name (Grantz, 1966; Twenhofel and Sainsbury, 1958; figs. 4, 6). Northwestward from Clarence Strait, alined stream courses on several islands may constitute a possible extension. Total length of the lineament plus the extension is about 220 mi (350 km). At its northwest end the lineament is thought by some geologists to merge with the Chatham Strait fault. The apparent southeast end of the lineament is the junction of Clarence Strait with Dixon Entrance (fig. 1). Several short linear features are present on the floor of the strait; some of these features may be faults, whereas others may be alined glacial or landslide deposits. Several less prominent lineaments appear to branch from the Clarence Strait lineament. The origin of the Clarence Strait lineament is problematical. Extensive fault offset in the right-lateral sense has been postulated (Turner and others, 1974); however, many of the same types of rocks are present in the Metlakatla region on both sides of the lineament without apparent offset between them. Thus, large-scale lateral movement along a postulated fault seems unlikely (H. C. Berg, oral commun., 1974). I speculate that the origin of the lineament is a rift, graben, or tear fault that has been developing slowly since the major tectonic deformations of middle Tertiary time. Similar types of fault structures developing along north-trending lines were interpreted by Souther (1970, 1974) at several places in British Columbia east of the Alaskan border.

The Coast Range lineament is an enigmatic northwest-trending geographic feature that crosses much of southeastern Alaska within the Coast Mountains (Twenhofel and Sainsbury, 1958; fig. 6). Along its route the lineament consists of several different segments that vary from wide, alined waterways and stream valleys to narrow zones of sheared rock. Paralleling and close to the lineament along at least a part of its length is a sill of granitic rock that is probably related; it is in part quartz diorite and is 2-5 mi (3-8 km) wide (Brew and others, 1976). The origin of the Coast Range lineament is unclear. Some segments of the lineament may be steeply dipping faults. If the lineament is a major fault, movement may have occurred principally after late Cretaceous time.

Local structure

Bedrock exposed in the Metlakatla area (fig. 5) exhibits a variety of attitudes that reflect the several tectonic deformations to which the area has been subjected. One of the major intervals of deformation is thought to have occurred between late Mesozoic and late Tertiary time (Berg, 1972b; H. C. Berg, unpub. data). Outcrops of bedrock in the Metlakatla area are not common except along the coast, where numerous short minor offsets are readily visible. Most offsets probably are faults. Because of their minor nature, none of the offsets are shown on the geologic map (fig. 5). Many measurements of the dip and strike of bedding or foliation of bedrock were made by Berg (1972a). As a generalization, dips are quite variable; many of them range from vertical to about 45°. Strikes also are variable; many of them are within 30° of north (fig. 5).

Most joints are very small fractures that develop during the cycles of strain that accompany multiple tectonic deformation of a region throughout its history. In the Metlakatla area, most bedrock is moderately jointed as exposed at the ground surface. Where readily measurable, joints are steep, more than 70°, and more than one joint set may be present. At depth, joints probably are tight.

EARTHQUAKE PROBABILITY

Accurate prediction of the place and time of occurrence of destructive earthquakes is not yet possible. Broad regions, however, can be outlined by geologists and seismologists in which damaging earthquakes probably will occur in the future. One such region forms a wide irregular belt that roughly parallels the coast of the Pacific Ocean. For the Metlakatla area, the evaluation of earthquake probability is based on two factors: (1) regional and local seismicity as determined principally from the records of historic earthquakes, and (2) the regional and local geologic setting and the tectonic setting.

Seismicity

The Metlakatla area lies within the broad region of earthquake activity that includes much of southeastern Alaska, southwestern Yukon Territory, and northwestern and coastal British Columbia. Unfortunately, the written record of earthquakes in this region is meager, for three reasons: (1) the relatively short time that written records have been kept, (2) the sparse population, and (3) the absence of permanent, fully instrumented seismologic stations in the region.

The earthquakes that have been instrumentally recorded and located by seismologists during the period 1899 through 1975 are shown in figure 7. All earthquakes are thought to be of shallow origin, less than about 18 mi (30 km). Because techniques of earthquake detection and recording have improved over the years, figure 7 is probably complete 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). Extremely small earthquakes (microearthquakes) are not shown in figure 7 because of the difficulty of detection; knowledge of them is of importance, however, because they may indicate the location of unknown active faults that may be capable of causing large earthquakes.

As noted above, there are no permanent, primary seismologic stations in the vicinity of Metlakatla. Within 130 mi (209 km), however, three strong-motion accelerographs capable of accurate recording of magnitude about 6 and larger earthquakes are present. One is installed at Ketchikan (Nielson and Ellis, 1976) and one each is installed at Prince Rupert and

Sandspit, British Columbia (Horner and others, 1976; fig. 1). In addition, a secondary seismologic station has been operating at or near Sandspit since April 1970.

In figure 7 the following large- and moderate-size earthquakes are located within 125 mi (200 km) of Metlakatla: one of magnitude 8 or greater (desig. L), none between magnitudes 7 and 8, four between magnitudes 6 and 7 (desigs. G, J, K, and O), and one between magnitudes 5 and 6. In addition, about 20 smaller earthquakes have been instrumentally recorded within 125 mi (200 km) of Metlakatla.

Table 1 is a listing of earthquakes felt or large enough to have been felt on Metlakatla Peninsula from 1847 through 1975, as compiled and interpreted from readily available published reports and from instrumental records developed at permanent seismologic stations. Among the major earthquakes listed, only one of them--the magnitude 7.25 Sitka earthquake of July 30, 1972 (desig. Q, fig. 7)--has been assigned an intensity value (Modified Mercalli scale; table 2) by seismologists: III for Metlakatla and IV for Annette (table 1). Thus, on Metlakatla Peninsula many people probably felt the earthquake, and if they were in or near buildings they probably noticed a rattling of windows and doors. Other earthquakes both closer and larger have occurred in the Metlakatla area but have not been assigned intensity values, probably because (1) ground response was such that the shocks were not felt, or (2) the shocks were felt, but so slightly that a report by observers of the occurrence was considered of no importance. Summarized information on some of the important earthquakes that might have been felt is given here. Earthquakes include (1) the Queen Charlotte Islands earthquake of August 22, 1949, and (2) the eastern Queen Charlotte Islands or Hecate Strait earthquake of May 26, 1929. The

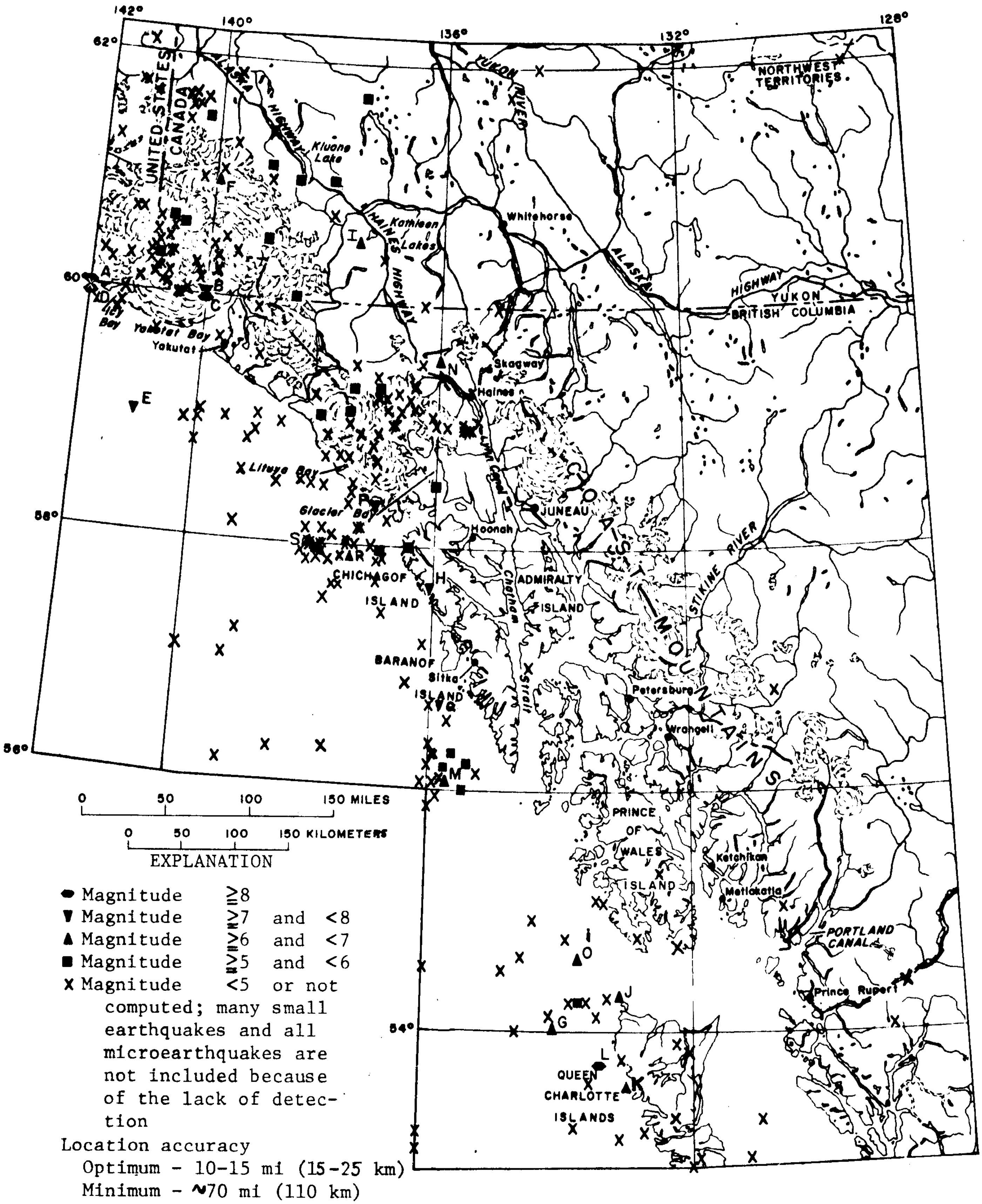


Figure 7.--(See following page for caption and additional explanation.)

Dates and magnitudes of some earthquakes of magnitude ≥ 6

Designation on map	Date (universal time)	Magnitude
A	September 4, 1899	8.3
B	September 10, 1899	7.8
C	September 10, 1899	8.6
D	October 9, 1900	8.3
E	May 15, 1908	7.0
F	July 7, 1920	6.0
G	April 10, 1921	6.5
H	October 24, 1927	7.1
I	February 3, 1944	6.5
J	August 2, 1945	6.25
K	February 28, 1948	6.5
L	August 22, 1949	8.1
M	October 31, 1949	6.25
N	March 9, 1952	6.0
O	November 17, 1956	6.5
P	July 10, 1958	7.9
Q	July 30, 1972	7.25
R	July 1, 1973	6.7
S	July 3, 1973	6.0

Figure 7.--Map showing location of earthquakes in southeastern Alaska and adjacent regions, 1899-1975 (Davis and Echols, 1962; Internat. Seismol. Centre, 1967-1973; Lander, 1973; Meyers, 1976; Page and Gawthrop, 1973; R. A. Page and W. H. Gawthrop written commun., 1973; Rogers, 1976b; Seismol. Service of Canada (Horner and others, 1974, 1975, 1976; Meidler, 1962; Milne, 1956, 1963; Milne and Lombardo, 1953a, b, 1955a, b; Milne and Lukas, 1961; Milne and Smith, 1961, 1962, 1963, 1966; Smith, 1961; Smith and Milne, 1969, 1970; Stevens and others, 1972, 1973, 1976; Wetmiller, 1976a, b); Tobin and Sykes, 1968; U.S. Coast and Geod. Survey, 1930-1970; U.S. Natl. Geophys. and Solar-Terrestrial Data Center, 1969, 1973 1975, 1976; U.S. Natl. Oceanic and Atmospheric Adm., 1971-1974; U.S. Natl. Oceanic and Atmospheric Adm. & U.S. Geol. Survey, 1975, 1976; W. H. Gawthrop, oral commun., 1975; and Wood, 1966).

Table 1.--Partial list of earthquakes felt or large enough to have been felt on Metlakatla Peninsula, Annette Island, Alaska, 1847-1975

[n.a. - not applicable; unk. - unknown]

Date[1]	Effects and intensity (table 2) of earthquake on Metlakatla Peninsula[2]	Distance, mi (and km), and direction to earthquake if instrumentally located (fig. 7)	Magnitude of instrumentally located earthquake[3]	Radius of perceptibility for given magnitude, mi (and km) (table 2)	Distance, mi (and km), direction, and locality (if any) nearest Metlakatla Peninsula at which earthquake felt. Data on earthquake	Reference[4]
Apr. 6, 1847	Felt?-------	n.a.	unk.	n.a.	205 (330) NW, Sitka; generally felt along coast.	1
Oct. 26, 1880	----do------	n.a.	unk.	n.a.	British America coast (no specific locality).	2
Fall 1900 or spring 1901	----do------	n.a.	unk.	n.a.	Prince of Wales Island (no specific locality); frequent light tremblings.	3
Aug. 7, 1906	----do------	n.a.	unk.	n.a.	35 (55) NNW, Loring; 2 shocks.	3
Sept. 24, 1907	----do------	n.a.	unk.	n.a.	15 (25) NNW, Ketchikan; shock.	1
Apr. 10, 1921	----do------	130 (210) SW	6.5	180 (290)	35 (55) N, SE end Heckman Lake; shock.	4
Apr. 29, 1925	----do------	310 (500) NW(?)	unk.	n.a.	15 (25) NNW, Ketchikan (felt earthquake, possibly different from the one recorded instrumentally).	5
Oct. 24, 1927	----do------	255 (410) NW	7.1	260 (415)	100 (160) NW, Wrangell--------	1
May 26, 1929	----do------	185 (300) SE	7.0	240 (380)	15 (25) NNW, Ketchikan--------	1, 6
May 30, 1936	----do------	n.a.	unk.	n.a.	60 (95) N, Bell Island; 2 slight shocks.	1
Mar. 22, 1938	----do------	200 (320) SSW	6.25	150 (240)	Southernmost southeastern Alaska (no locality given).	6
Aug. 2, 1945	____do------	85 (135) SW	6.25	150 (240)	Unk--------------------------	5
Apr. 1, 1946	----do------	n.a.	unk.	n.a.	15 (25) NNW, Ketchikan; light shock.	1

Feb. 3, 1947	Felt?-------	n.a.	unk.	n.a.	15 (25) NNW, Ketchikan; 3 light shocks.	1
Apr. 26, 1947	----do------	n.a.	unk.	n.a.	60 (95) N, Bell Island; mild earthquake.	4
Feb. 28, 1948	Light shock felt, Annette.	130 (210) SW	6.5	180 (290)	N.a--------------------------	1
Nov. 30, 1948	Felt?-------	n.a.	unk.	n.a.	65 (105) NW, Craig------------	4
Aug. 22, 1949	----do------	125 (200) SW	8.1	>360 (>575)	65 (105) NW, Craig; series of sharp shocks lasting about 5 min, several persons knocked down.	4
Aug. 23, 1949	----do------	170 (270) SSW	6.5	∿180 (∿290)	Unk--------------------------	5
Aug. 26, 1949	----do------	95 (150) WSW	unk.	n.a.	----do-----------------------	7
Sept. 2, 1949	Felt a slight swaying of bldgs., Tamgas Harbor.	105 (170) SW	unk.	n.a.	N.a--------------------------	1
Sept. 5, 1949	Felt?-------	110 (175) SW	unk.	n.a.	Unk--------------------------	7
Sept. 12, 1949	----do------	40 (65) WNW	unk.	n.a.	----do-----------------------	7
Oct. 31, 1949	----do------	180 (290) NW	6.25	150 (240)	205 (330) NW, Sitka-----------	5
Sept. 28, 1950	Two shocks felt, Annette.	125 (200) WSW	unk.	n.a.	N.a--------------------------	5
Nov. 17, 1956	Felt?-------	95 (150) WSW	6.5	180 (290)	15 (25) NNW, Ketchikan; IV.	1
July 10, 1958	----do------	295 (470) NW	7.9	350 (560)	75 (120) SE, Prince Rupert, B.C.; III.	8
July 4, 1960	----do------	21 (35) S	∿6.6	∿200 (∿320)	75 (120) SE, Prince Rupert, B.C.; III.	6
Mar. 28, 1964	----do------	730 (1,110) NW	8.4	>360 (>575)	75 (120) SE, Prince Rupert, B.C.; I-III.	1
Aug. 3, 1964	----do------	95 (150) SW	4.9	85 (135)	Unk--------------------------	6
Sept. 5, 1965	----do------	35 (55) E	4.5	70 (110)	15 (25) NNW, Ketchikan; shock felt in several parts of city	6, 9

Table 1.--Partial list of earthquakes felt or large enough to have been felt on Metlakatla Peninsula, Annette Island, Alaska, 1847-1975--Continued

Date[1]	Effects and intensity (table 2) of earthquake on Metlakatla Peninsula[2]	Distance, mi (and km), and direction to earthquake if instrumentally located (fig. 7)	Magnitude of instrumentally located earthquake[3]	Radius of perceptibility for given magnitude, mi (and km) (table 2)	Distance, mi (and km), direction, and locality (if any) nearest Metlakatla Peninsula at which earthquake felt. Data on earthquake	Reference[4]
Apr. 17, 1966	Felt?-------	90 (145) SW	4.9	85 (135)	Unk--------------------------	10
Feb. 11, 1971	----do------	40 (65) SW	4.6	74 (120)	----do-----------------------	1
July 15, 1971	----do------	105 (170) SW	5.2	100 (160)	15 (25) NNW, Ketchikan--------	1
July 30, 1972	III, Metlakatla; IV, Annette.	210 (340) NW	∿7.25	∿280 (∿450)	N.a--------------------------	1, 11

(See following page for footnotes)

[1]Dates are u.t. (universal time) except first and third entries.

[2]Felt, Published report of single or multiple earthquake shocks of unknown intensity.

Felt?, Earthquake possibly felt somewhere on Metlakatla Peninsula but so far as can be determined there is no readily available published report of the event being felt on Metlakatla Peninsula. An earthquake is known to have occurred, however, because (1) there is a published report of its being felt elsewhere, and (or) (2) there exists an instrumental record and epicenter plot (fig. 7) of the earthquake. (Tabulation based on (1) radius of average distance of perceptibility of earthquakes as described by Gutenberg and Richter (1956, p. 141) (table 2) 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 2).

[3]Magnitude, Richter (1958).

[4]
1 U.S. Coast and Geodetic Survey (1930-1970), U.S. National Geophysical and Solar Terrestrial Data Center (1976), U.S. National Oceanic and Atmospheric Administration (1971-1973 and 1974), U.S. National Oceanic and Atmospheric Administration and U.S. Geological Survey (1975, 1976), or Wood (1966).
2 Rockwood (1881) or U.S. War Department (1881).
3 Tarr and Martin (1912).
4 U.S. Weather Bureau (1918-1958) or Olson (1949).
5 Davis and Echols (1962).
6 Milne (1956), Milne and Smith (1961), or Smith and Milne (1969 or 1970).
7 Tobin and Sykes (1968) or Sykes (1971).
8 Davis and Sanders (1960).
9 Reported in Ketchikan [Alaska] Daily News for September 7, 1965.
10 International Seismological Centre (1970).
11 Lander (1973).

Table 2.--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 slight.
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 (km)

Distance, mi (km)	9 (15)	48 (80)	90 (150)	132 (220)	240 (400)	360 (600)
Magnitude	3	4	5	6	7	8

Magnitude

(b)

(Gutenberg and Richter, 1956, p. 141; Hodgson, 1966, p. II-9) distant 1964 Alaska earthquake (May 28, 1964) (730 mi (1,175 km) northwest of Metlakatla) caused noticeable effects on some bodies of water in the Metlakatla region. These are described in the section on "Tsunamis, seiches, and other earthquake-induced water waves."

Principal among the earthquakes that affected the Metlakatla and adjacent regions was the magnitude 8.1 Queen Charlotte Islands earthquake of August 22, 1949. The epicenter of the main shock was 125 mi (200 km) southwest of Metlakatla (desig. L, fig. 7). Although the shock was not reported as felt on Metlakatla Peninsula, it was strongly felt and caused damage at several more distant localities in southeastern Alaska and British Columbia (Ketchikan [Alaska] Daily News for August 22, 1949; Milne, 1956, p. 140; Olson, 1949). Of these localities, the closest one to Metlakatla was the city of Craig in the central part of the west coast of Prince of Wales Island (fig. 1), where several people were knocked down, brick chimneys tumbled, and at least one building shifted on its foundation; the earthquake was reported by some people as consisting of a series of sharp shocks that lasted for a total of about 5 minutes (Olson, 1949).

The magnitude 7.0 eastern Queen Charlotte Islands or Hecate Strait earthquake of May 26, 1929, is probably one of the more significant earthquakes that have occurred near the southern part of southeastern Alaska. Its importance is based on the possibility that the earthquake developed along the Sandspit fault, apparently the active fault closest to Metlakatla. If this relationship is correct, it could help strengthen the suggestion, made here, that the Sandspit fault (in addition to the assuredly active Queen Charlotte fault) may be a major contributor to the seismicity of the Metlakatla region. Thus, there might be a higher possibility of larger and more frequent earthquakes in the region than have heretofore been suggested. There is no readily available written record that the earthquake was felt on the Metlakatla Peninsula, although it was felt at Ketchikan, which is even farther from the epicenter (table 1; fig. 7). The epicenter of the earthquake was located at approximately 52.8° N. lat and 129.5° W. long (Milne, 1963, p. 22), about 185 mi (300 km) southeast of Metlakatla and 15 mi (25 km) south of the southern limit of figure 7. Many of the surface effects of the earthquake occurred near the designation number for the Sandspit fault shown in figure 6. The maximum Modified Mercalli intensity of the earthquake was VI-VII; at one locality a beach about 500 ft (152 m) long was reported to have "disappeared," and at another place fissuring of a beach was noted (Milne, 1956, p. 134-135). In addition, two localities reported a tsunami wave, which at one place reached a height of 4 ft (1.2 m). At a town near the north shore of Queen Charlotte Islands, 80 mi (129 km) southwest of Metlakatla, houses were reported to have been shaken violently.

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

In some earthquake regions of the world, a close relation has been established between earthquakes and specific faults. In most of southeastern Alaska, however, such relationships cannot as yet be established because (1) most earthquake epicenters are located, at best, within an accuracy of only 10-15 mi (15-25 km), and (2) the exact location of many faults is unknown because of concealment by water or thick surficial deposits. There appears, nevertheless, to be a general relationship between some extensive groups of earthquakes and certain zones of faults. One example is the wide irregular belt of epicenters of large earthquakes and many moderate and small earthquakes, shown in figure 7, that roughly parallels the coast of the Pacific Ocean. These earthquakes apparently are caused by movement, chiefly at depth, along faults within the Queen Charlotte, Chichagof-Baranof, and Fairweather fault zones and the connecting Transition and Chugach-St. Elias faults. Movements along some of these faults, in part, might possibly be a fault-creep type of motion unaccompanied by earthquakes.

Relative to the geographic position of Metlakatla, the most recent large-scale motion along faults offshore from southeastern Alaska occurred during the magnitude 7.25 Sitka earthquake of July 30, 1972 (desig. Q, fig. 7). Faulting apparently did not extend up to the sea floor; movement at depth was indicated in a linear zone about 118 mi (190 km) long and less than 6.2 mi (10 km) wide by the main shock and by more than 100 aftershocks, some as small as microearthquakes. The southeasternmost of the aftershocks in the zone occurred about 170 mi (275 km) northwest of Metlakatla. The aftershocks were recorded on portable seismologic instruments installed for a month following the main shock (Page, 1973; Page and Gawthrop, 1973; R. A. Page and W. H. Gawthrop, written commun., 1973). Minor activity along other segments of the faults offshore from southeastern Alaska and Queen Charlotte Islands probably occurs at relatively frequent intervals, as indicated by the widespread distribution of earthquakes shown in figure 7.

The most recent movement along the major Chatham Strait fault (fig. 6) is uncertain, because instrumented earthquakes in the vicinity are rare (fig. 7). In addition, no local microearthquakes were recorded (1) during a detection study in July 1970 (Johnson, 1971; Johnson and others, 1972), (2) during a total of about 12 months of intermittent study (1968-1971) by the Seismological Service of Canada (Rogers, 1972, 1973, 1976a), nor

(3) during the August 1972 study by Page and Gawthrop (1973). The only known indication of possible Holocene movement is along the south end of the Chatham Strait fault west of Coronation Island (fig. 1), where deformation, including faulting of sediments, has been interpreted from seismic profiles (Ovenshine and Berg, 1971; Ovenshine and Brew, 1972).

The fault closest to Metlakatla that may be active is the Sandspit fault of eastern Queen Charlotte Islands (fig. 6). The most recent earthquake that is thought to have occurred at depth along a subsidiary of this fault happened on May 26, 1929 (Milne, 1956, p. 134; 1963, p. 22). Ground-surface effects from the earthquake other than shaking occurred as far north as the area of the designation number shown in figure 6 for the Sandspit fault.

None of the widely distributed microearthquakes reported on Prince of Wales Island, and near Ketchikan, and elsewhere in the Coast Mountains northward to the Juneau area (fig. 1; Rogers, 1976a; Stevens and others, 1976) have been related to specific faults or lineaments.

Evaluation of seismic risk in the Metlakatla area

Only a general evaluation of seismic risk, especially of the probability of destructive earthquakes, can be made for the Metlakatla area, because data on many aspects of seismicity are limited. Studies of geologic structure and of the tectonic framework of the southern part of southeastern Alaska as they relate to the Metlakatla region are especially needed. 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 earthquakes of a certain size that might occur during a specific period of time. Both types of maps generally are based upon the premise that future earthquakes are most likely to occur where past earthquakes have occurred. Therefore, the longer the period of record, the greater is the total number of known earthquakes and the greater is the probable accuracy of prediction.

As noted, in southeastern Alaska the historic record of earthquakes is short, and geologic and tectonic information for many areas is known only in general terms. As a result, the seismic risk maps here described (figs. 8-10) are based primarily on the record of instrumentally located earthquakes and secondarily (for fig. 9) on a very generalized consideration of geology and tectonics.

The Metlakatla area is shown on two examples (figs. 8, 9) 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 a seismic zone map that was included in the 1973 edition of the Uniform Building Code (fig. 8; Internat. Conf. Building Officials, 1973). The map legend relates possible damage within a particular (derived) zone to the Modified Mercalli intensities of earthquakes expected to occur within that zone. The Metlakatla area is shown as being in the zone of moderate expectable earthquake damage, one in which the maximum probable earthquakes might have Modified Mercalli intensities of as much as VII (table 2). The Uniform Building Code portrayal of the Metlakatla area is identical to that shown on seismic probability maps in publications by Johnson and Hartman (1969, pl. 49), and Alaska Industry magazine (1970).

The second example of the first type of seismic risk map is a suggested preliminary seismic risk map (fig. 9) prepared by the U.S. Army Corps of Engineers, Alaska District, in 1973 (H. W. Holliday, written

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	Moder-ate	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 2).

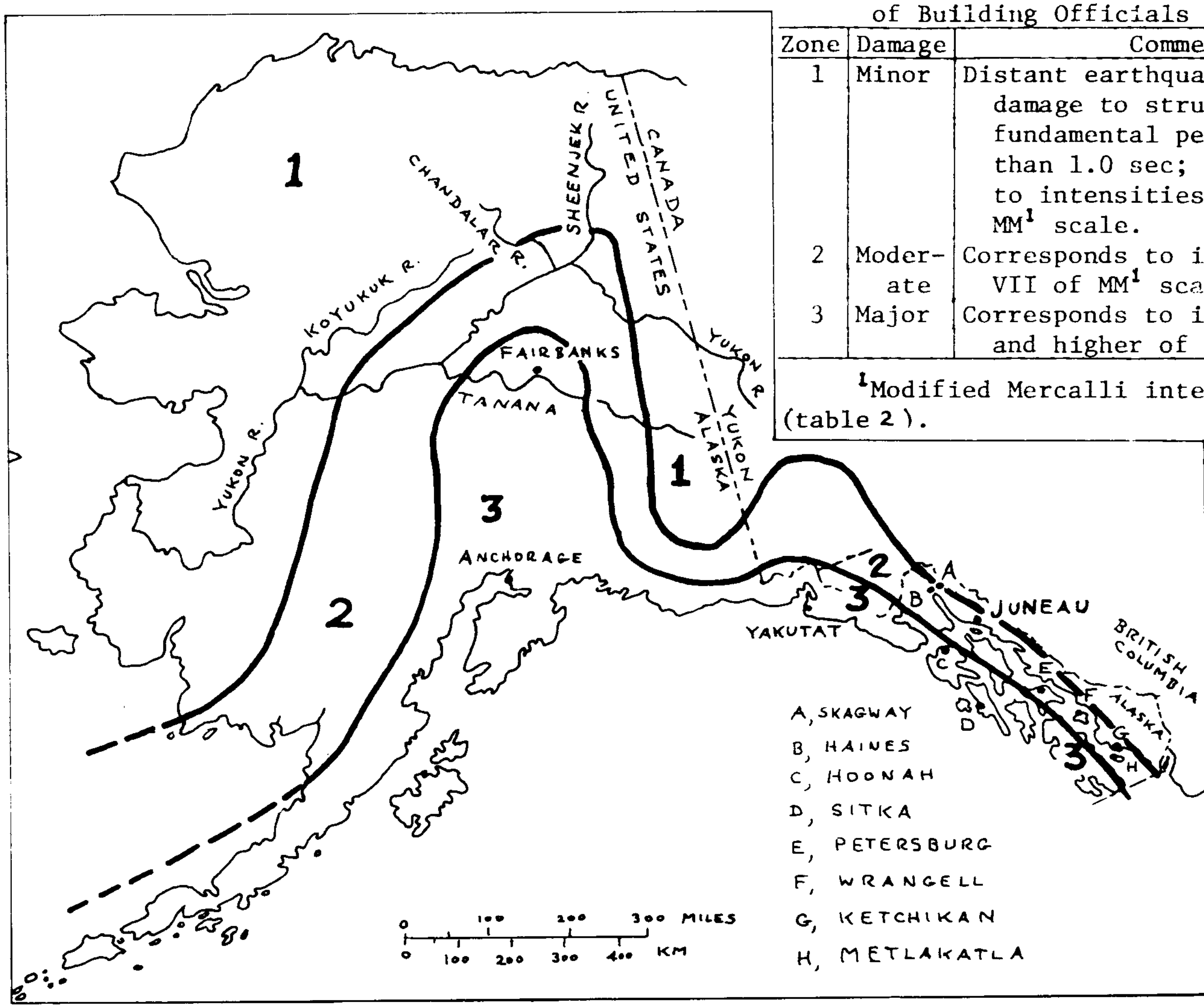


Figure 8.--Seismic zone map of Alaska as shown in Uniform Building Code, 1973 edition.

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.

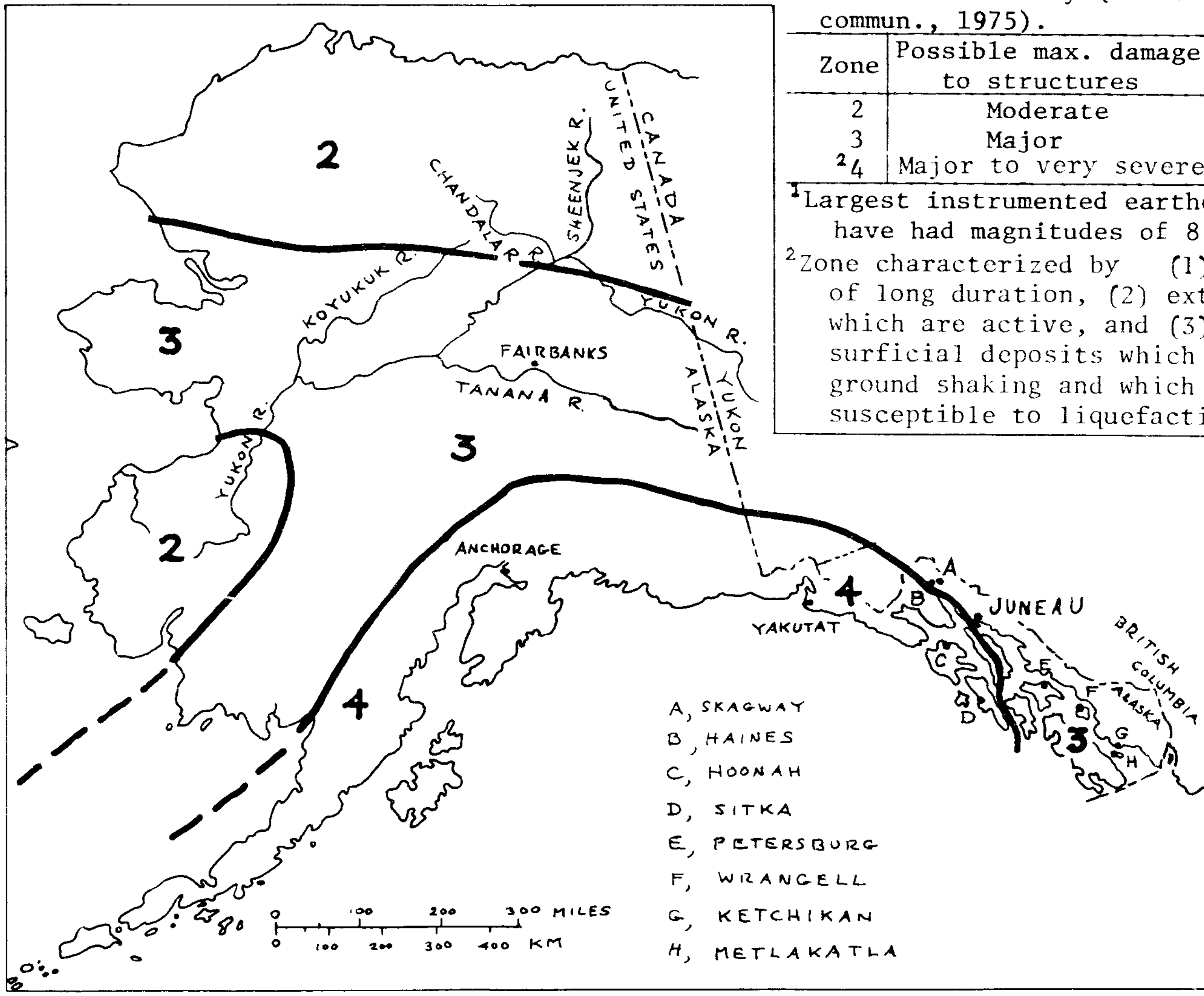
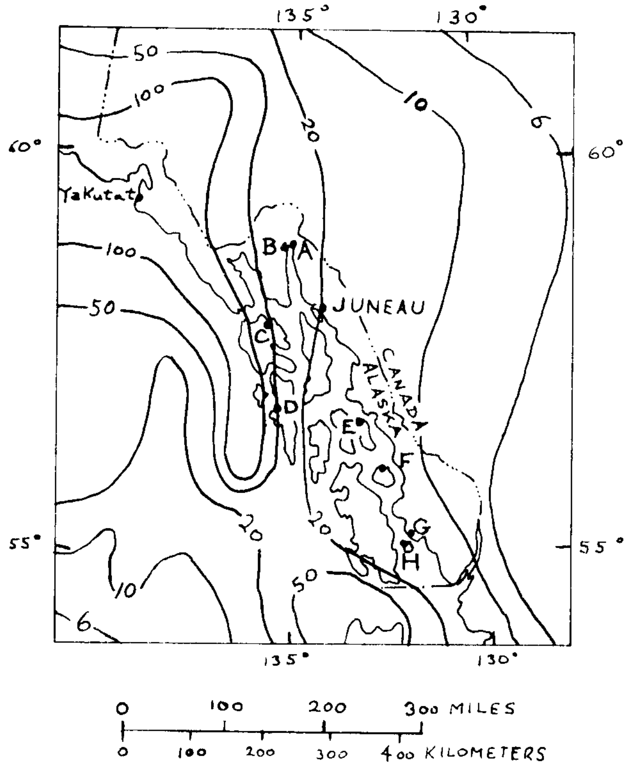


Figure 9.--Suggested preliminary seismic risk map of Alaska provided by U.S. Army Corps of Engineers, Alaska District.

commun., 1975; Selkregg, 1974, 1976). 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 it shows the Metlakatla area in the next to the highest zone, one in which major damage is possible and maximum probable earthquakes would have magnitudes equal to or greater than 6. The highest seismic risk zone was derived after a generalized consideration of certain geologic factors, most of which can be related to regional patterns of fault movements and to the response of ground to shaking during earthquakes. These factors include (1) the presence of extensive faults, some of which are active; (2) the probable duration of earthquake shaking; and (3) the presence of thick unconsolidated deposits, many of which are thought to be subject to liquefaction.

The Metlakatla area also is shown on the second, or frequency, type of seismic risk map. The example of such a map (fig. 10) shows probable peak acceleration of earthquakes as a percent of gravity during any period of 100 years (Klohn, 1972; Milne and Davenport, 1969). That section of the map showing the contour of 6 percent of gravity is used for part of the 1970 Seismic Zoning Map of Canada (Whitham and Hasegawa, 1975). For the Metlakatla area, the map indicates that a peak acceleration of as much as 15 percent gravity might be expected within any 100-year period.

Any detailed evaluation of earthquake risk for specific parcels of land must await expanded as well as more detailed geologic, seismologic, and related geophysical studies in the region. Of special importance are studies of (1) location of major faults in the region, (2) degree of activity along the Queen Charlotte and Sandspit faults, and (3) significance of widespread microearthquakes that have been reported on Prince of



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 10.--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).

Wales Island, near Ketchikan, and in the Coast Ranges (Rogers, 1976a; Stevens and others, 1976; table 1).

General agreement as to the level of seismic risk in the Metlakatla area exists among the three described seismic risk maps. Full agreement is not possible because of different periods of time and different assumptions used in developing the maps. It is clear, however, that earthquakes of relatively large size will continue to affect the Metlakatla area in the future, as they have in the past. There is a likelihood that sometime in the future a magnitude 8 earthquake will occur somewhere along the Queen Charlotte fault near the mouth of Dixon Entrance, about 100 mi (160 km) west-southwest of Metlakatla. Such an event would be in keeping with conclusions drawn by others (Kelleher, 1970; Kelleher and others, 1974; Kelleher and Savino, 1973; Sykes, 1971), who predicted the location of future large earthquakes along major fault zones such as the Queen Charlotte and Chichagof-Baranof faults at sites between epicenters of earlier large earthquakes.

INFERRED EFFECTS FROM FUTURE EARTHQUAKES

The following discussions and evaluation of the geologic effects of possible future large earthquakes in the Metlakatla area are based on the assumption that an earthquake of magnitude 6 or more might occur in the southern part of southeastern Alaska or nearby sometime in the future. Specific evaluation of possible geologic effects in the Metlakatla area is based partly on observations by others during earthquakes felt in southeastern Alaska and partly on estimates of the response of local geologic materials, inferred from the response of similar materials during earthquakes elsewhere.

Evaluations are given below for several geologic effects, including (1) sudden lateral offsets along faults, (2) sudden tectonic subsidence or uplift, (3) ground shaking, (4) liquefaction, (5) ground fracturing and water and slurry fountains, (6) compaction and related subsidence, and (7) landsliding. Of these effects, ground shaking is of greatest importance to Metlakatla; only one geologic unit (muskeg and other organic deposits) is highly susceptible to shaking. Effects of tsunami, seiche, and other earthquake-related water waves are considered separately; tsunami waves are most important and may reach heights of 20 ft (6 m).

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

In southeastern Alaska, movements of surface faults have been documented for only a few of the considerable number of earthquakes in historic time. During the numerous small earthquakes, displacement along faults occurs mostly at depth; however, during the less frequent moderate and large earthquakes there is movement at depth along faults, and the movement along the fault may extend up to the ground surface. At Metlakatla the likelihood of faults breaking the surface during a nearby major earthquake is unknown but probably is unlikely.

Large-scale subsidence or uplift has occurred elsewhere during some large earthquakes. The Metlakatla area shows little evidence of tectonic subsidence; evidence of uplift, however, is widespread, but it can be more readily related to glacio-isostatic rebound. If sudden tectonic subsidence or uplift of a few inches (several centimeters) did occur, the city would not be affected seriously. However, subsidence or uplift of a few feet ($\sim$1 m) would greatly affect some aspects of the life of the city; mainly, harbor operations.

Ground shaking

Ground shaking causes most of the damage to buildings and other structures during earthquakes. At a given locality, ground shaking is controlled by several factors. Major factors include (1) the amount of earthquake energy released during the earthquake, (2) the distance of the particular locality from the causative fault, and (3) the response of surficial deposits to the motion of the bedrock beneath the locality (Page and others, 1975a, b). Other factors of significance are the earthquake mechanism and the type of fault motion. Severity of ground shaking during earthquakes is largely dependent upon three aspects of motion: amplitude, vibrational frequencies, and duration.

During a major earthquake occurring beyond but near Metlakatla, ground shaking probably would be most severe on geologic materials that are loose, fine grained, water saturated, and thick. Conversely, shaking probably would be least severe on geologic materials that are hard, firm, and unfractured. Even for a moderate-size earthquake occurring within the region, however, the distance from the causative fault may be an overriding factor.

A very tentative grouping of the geologic map units in the Metlakatla area (fig. 5) by their probable relative severity of shaking during major earthquakes is given below. The grouping is based on generalized observations of the physical characteristics of the map units, mainly thickness and firmness, and comparison with the response of similar materials elsewhere. (Most surficial deposits probably average 15 ft (4.6 m) or less in thickness.) A generally similar scheme of grouping and classification of geologic materials elsewhere which is based on much more extensive data than available in the Metlakatla area was completed for parts of the San Francisco Bay region, California, by Lajoie and Helley (1975, p. A49-A51).

As far as possible, the geologic map units (fig. 5) are arranged within categories by decreasing anticipated severity of response to shaking. The position of units in these categories is very tentative.

Category 1.--Strongest expectable shaking in the map area:

A. Muskeg and other organic deposits (Qm)

B. Artificial fill (Qf) that contains a relatively large amount of muskeg

Category 2.--Intermediate expectable shaking in the map area:

A. Most of the alluvial deposits (Qa)

B. Most of the artificial fill deposits (Qf)

C. Thickest modern shore and delta deposits (Qsd)

D. Thickest emerged shore deposits (Qes)

Category 3.--Least expectable shaking in the map area:

A. Thinnest alluvial deposits (Qa)

B. Most of the modern shore and delta deposits (Qsd)

C. Most of the emerged shore deposits (Qes)

D. Diamicton deposits (Qd)

E. Combination unit; diamicton deposits or metamorphic rocks (dr)

F. Metamorphic rocks (Pzmr)

Liquefaction

During major earthquakes in other areas, ground shaking has caused liquefaction of certain types of saturated unconsolidated surficial deposits. Especially susceptible are deposits that contain sediments with very low cohesion and uniform, well-sorted, fine- to medium-grained particles such as fine sand and coarse silt (Seed and Idriss, 1971). 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 the sediments will flow or spread as long as pore-water pressures remain high and shaking continues (Youd, 1973; Youd and others, 1975). If liquefaction occurs in saturated sediments that are confined at the margin of the sediment, the result is the familiar quicksand condition. A generalized evaluation of the potential for liquefaction of mapped geologic deposits in the Metlakatla area indicates that only some deposits--namely, parts of thick muskeg deposits--might liquefy under certain frequencies of ground motion. Extensive onland deposits of easily liquefiable fine sand or coarse silt apparently are lacking in the area. In addition, it is unlikely that extensive deposits of such sediments occur in nearshore areas, although detailed analyses of areas other than those close to the proposed harbor have not been accomplished.

Ground fracturing and water-sediment ejection

Ground fracturing and ejection of water or slurries of water and sediments from certain deposits are common during the strong shaking that accompanies many large earthquakes (Davis and Sanders, 1960, p. 248; Waller, 1966, 1968). The ejection process is called fountaining; compaction and differential subsidence of ground often accompany ejection. Ejection takes place most often where loose, sand-size materials are dominant in a deposit and where the water table is shallow and restricted by a confining layer--which can be seasonally frozen ground. Seismic shaking of confined ground water and sediment causes hydrostatic pressure to increase, and then liquefaction may occur. If liquefaction does occur and the confining layer ruptures, the water and sediment erupt from point sources or along ground fractures.

In the Metlakatla area, the only deposits that contain sediments of the appropriate size range that might be subject to ground fracturing and water-sediment ejection are some parts of alluvial deposits and possibly the topographically lower part of some emerged shore deposits.

Compaction and related subsidence

Strong shaking of loose geologic materials during major earthquakes may result in compaction and volume reduction of deposits containing such materials. Compaction is often accompanied by liquefaction and ejection of water or water-sediment mixtures. As a result of the operation of these processes, the surface of the ground locally may settle differentially by as much as a few feet (∿1 m).

The possibility of compaction and subsidence of deposits in the Metlakatla area is limited. Only some alluvial deposits and possibly some emerged shore deposits might compact an appreciable amount during severe seismic shaking.

Earthquake-induced subaerial and underwater landslides

During ground shaking, geologic materials may experience a variety of downslope mass movements termed, collectively, "landslides" (Nilsen and Brabb, 1975). Movements may consist of single or multiple sliding events that include rockslides, earthslides, land spreading, small-scale slumping, earth flowage, minor creep, and failures of rapidly extending active delta fronts or spits (Eckel, 1958, 1970). Loose, water-saturated, unconsolidated deposits on steep slopes are especially susceptible to downslope movement. Liquefaction may trigger sliding and flowage of materials even on very gentle slopes of less than 1° (1.75 percent).

During the shaking accompanying a major earthquake in the Metlakatla area, landsliding probably would be uncommon, because there are very few steep slopes in the area and landslides might occur in only a few places. Of those slides that might occur on land, most would probably be of the thin earthflow type and would develop in water-saturated diamicton deposits. Offshore, most slopes as shown in figures 3 and 5 are gentle except near the cannery and small-boat harbor, where they are relatively steep. Although the types of geologic materials in this area are unknown, it is likely that they are, at least in part, composed of bedrock, because of the presence of bedrock nearby on land. It is thought unlikely that massive slides will occur in this area during major earthquakes because of the probably relatively large extent of bedrock. Another area of offshore interest, although of relatively gentle slopes, is the spit extending northeastward from Village Point. Such an area is characterized typically by relatively rapid deposition of sediments which consequently are loose and prone to slide during the shaking accompanying a major earthquake. Other offshore areas of rapid deposition near Metlakatla are the very small deltas, none of which are near the developed part of the city.

Effects of shaking on ground water and streamflow

The flow of ground water may be changed by strong ground shaking and by the permanent ground displacement that might result. Examples of changes 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 lower 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. In the Metlakatla area, the ground-water table and ground-water flow are very near the surface in alluvial and delta deposits. Intense shaking during earthquakes might alter some ground-water flow, especially near Skaters Lake.

Alterations of streamflow often are important consequences of major earthquakes. Streams flowing on alluvial and delta deposits can experience a temporarily diminished flow because of water loss into fractures opened by shaking. In the Metlakatla area these effects might occur on a limited scale during shaking accompanying major earthquakes.

Tsunamis, seiches, and other earthquake-related water waves

Earthquake-induced water waves often develop during major earthquakes. Such waves may affect shore areas, even at great distances, for several days thereafter. Types of waves include (1) tsunamis (seismic sea waves), (2) seiches, and (3) local waves generated by subaqueous and subaerial landslides and local tectonic displacement of land. The following section of this report considers each of these types of earthquake-induced waves and the likelihood that they may develop to such heights that they might affect the Metlakatla area.

Tsunamis are long-period water waves that are caused by sudden displacement of water. They form trains of waves, of which the first several probably include the highest waves of the train. The largest tsunamis originate where large vertical offsets of the sea floor and vast displacements of water occur; such offsets result from major underthrust faulting. Horizontal offsets that accompany strike-slip faulting cause much smaller displacements of water.

In the deep ocean, trains of tsunami waves travel long distances at great speed (350-500 mi/h (565-805 km/h)) (Wiegel, 1970, p. 257) and with low height, but as the waves approach shallower water of the Continental Shelf and nearshore areas their speed decreases greatly but their height increases manyfold. In shallow water the wave height and wave type are controlled largely by (1) initial size of the tsunami wave, (2) configuration of the sea floor, (3) configuration of the shoreline, (4) natural period of oscillation of the water on the shelf or bay, and (5) tidal stage (Wilson and Tørum, 1968). Wiegel (1970, p. 255) noted that many tsunami waves have struck coastal areas along the Pacific Ocean and have been as high as 40 ft (12 m); a few waves have been as high as 100 ft (30 m).

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) passage of air-pressure disturbances or seismic waves, (2) tilting of the basins, or (3) impact of large landslides into bodies of water. The natural period of oscillation of a water body is controlled by the configuration of its enclosing basin. Although seiches commonly are small and masked by other types of waves, there were reports of seiches or possible seiches as much as 25 ft (7.6 m) high occurring during the 1964 Alaska earthquake (McCulloch, 1966; McGarr and Vorhis, 1968, 1972; U.S. Geol. Survey, unpub. field data, 1964). During the August 22, 1949, earthquake, probable seiches in the tidal waterway at Ketchikan caused waves as much as 2 ft (0.6 m) high; and waves probably several feet ($\sim$1 m) high formed in a lake about 6 mi (10 km) northwest of the city (Olson, 1949, p. 86).

In the Metlakatla region, no seiche waves are known to have developed during earthquakes in the past.

The tsunamis and other possibly earthquake induced waves that may have reached the Metlakatla region between 1880 and 1974 are listed in table 3. The list is based upon known occurrences of similar waves that reached at least some part of central or southern southeastern Alaska or nearby British Columbia. Tsunami waves associated with the 1964 Alaska earthquake were relatively high in many areas in southeastern Alaska, but at Metlakatla the earthquake produced neither unusual high tides nor damage, despite the high tide level at about the time of the calculated arrival of the first wave of the train of tsunami waves. At Tamgas Harbor(?), however, a reported tsunami wave was 3-4 ft (0.9-1.2 m) high (V. L. Simords, in Cloud and Scott, 1969, p. 40). A similar height (3.7 ft (1.1 m)) developed at Ketchikan (Wilson and Tørum, 1968, p. B-1); locally, higher waves, to 7 ft (2 m), and abnormal tide surges were reported (J. Barry, oral commun., in Lemke, 1975, p. 47). The highest wave in the southern part of southeastern Alaska and nearby British Columbia from the 1964 Alaska earthquake was at Prince Rupert, British Columbia, where the maximum tsunami wave developed to a height of 8.9 ft (2.7 m). This height was 0.6 ft (0.2 m) higher than the level of mean higher high water (Wilson and Tørum, 1968, p. B-1).

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

Table 3.--Tsunamis and other possibly earthquake-induced waves that may have reached the Metlakatla Peninsula, Alaska, 1880-1974[1] and November 29, 1975

Date, local time	General region of earthquake and area of generation of tsunami	Distance, miles (and km), direction, and locality nearest Metlakatla at which wave experienced	At nearest locality, max. runup height or amplitude,[2] max. rise or fall of wave [3] (ft (and m))
Oct. 26, 1880--	Northeastern North Pacific Ocean[4] -----	50 (80) or more SE; British Columbia coast.	
May 26, 1929---	Northeastern North Pacific Ocean near Queen Charlotte Islands.	130 (210) SSW; Queen Charlotte City.	Wave height(?), 4.0 (1.2)[5]
Nov. 10, 1938--	Western Gulf of Alaska near Alaska Peninsula.	205 (330) NW; Sitka.	0.6 (0.2) [2]
Apr. 1, 1946---	Northern North Pacific Ocean near Aleutian Islands.	205 (330) NW; Sitka.	1.3 (0.4);[2] 2.6 (0.8)[3]
Dec. 20, 1946--	Northwestern North Pacific Ocean near Japan.	Wave possibly from this event, 205 (330) NW; Sitka.	Max. height 1.0 (0.3)[6]
Aug. 21, 1949--	Northeastern North Pacific Ocean, near Queen Charlotte Islands, British Columbia.	15 (25) NNW; Ketchikan.	0.3 (0.1).[2] Wave height 2.0 (0.6)[7]
Mar. 4, 1952---	Northwestern North Pacific Ocean near Japan.	205 (330) NW; Sitka.	0.3 (0.1) [2]

Table 3.--Tsunamis and other possibly earthquake-induced waves that may have reached the Metlakatla Peninsula, Alaska, 1880-1974[1] and November 29, 1975--continued

Date, local time	General region of earthquake and area of generation of tsunami	Distance, miles (and km), direction, and locality nearest Metlakatla at which wave experienced	At nearest locality, max. runup height or amplitude,[2] max. rise or fall of wave [3] (ft (and m))
Nov. 4, 1952---	Northern North Pacific Ocean near U.S.S.R.	205 (330) NW; Sitka.	1.0 (0.3); [2] 1.3 (0.4) [3]
Mar. 9, 1957---	Northern North Pacific Ocean near Aleutian Islands.	205 (330) NW; Sitka.	1.3 (0.4); [2] 2.6 (0.8) [3]
July 9, 1958---	Northeastern North Pacific Ocean, northwest of Chichagof Island, southeastern Alaska.	205 (330) NW; Sitka.	0.3 (0.1) [2]
May 22, 1960---	Southeastern South Pacific Ocean near Chile.	205 (330) NW; Sitka.	2.0 (0.6); [2] 3.0 (0.9) [3]
Mar. 27-28, 1964-	Northwestern Gulf of Alaska along south coast of Alaska.	4.5 (7.2) S(?); Tamgas Harbor(?).	Wave height(?), 3-4 (0.9-1.2)[8]
Feb. 3, 1965---	Northern North Pacific Ocean near Aleutian Islands.	205 (330) NW; Sitka.	0.6 (0.2)[9]
May 16, 1968---	Northwestern North Pacific Ocean near Japan.	205 (330) NW; Sitka.	<0.3 (<0.1)[2]

Table 3.--Tsunamis and other possibly earthquake-induced waves that may have reached the Metlakatla Peninsula, Alaska, 1880-1974[1] and November 29, 1975--continued

Date, local time	General region of earthquake and area of generation of tsunami	Distance, miles (and km), direction, and locality nearest Metlakatla at which wave experienced	At nearest locality, max. runup height or amplitude,[2] max. rise or fall of wave[3] (ft (and m))
July 30, 1972--	Northeastern North Pacific Ocean near Sitka.	205 (330) NW; Sitka.	0.6 (0.2)[2]
Nov. 29, 1975---	Hawaii	205 (330) NW; Sitka	Maximum amplitude 0.6 (0.2)[9]

[1]Newspapers were not published in southeastern Alaska; these papers might provide accounts of additional tsunamis and other earthquake-induced waves.

[2]Cox, Pararas-Carayannis, and Calebaugh (1976).

[3]Spaeth and Berkman (1967).

[4]U.S. War Department (1881).

[5]Milne (1956).

[6]Dames and Moore (1971).

[7]Olson (1949).

[8]V. L. Simords, *in* Cloud and Scott (1969, p. 40).

[9]U.S. Coast and Geodetic Survey (1967).

[10]Tilling and others (1976, p. 15).

that failed elsewhere during the 1964 Alaska earthquake generated waves as much as 30 ft (10 m) high (Coulter and Migliaccio, 1966; Kachadoorian, 1965; Lemke, 1967; Von Huene and Cox, 1972). Subaerial landsliding triggered by earthquake shaking also generated large waves. The world's record height of wave runup is probably 1,740 ft (530 m), triggered by a landslide in Lituya Bay (fig. 1) near the epicenter of the magnitude 7.9 southeastern Alaska earthquake of July 10, 1958 (Miller, 1960). As far as is known, no waves have occurred in the Metlakatla region that are attributable to earthquake-triggered subaerial or underwater landslides.

Another group of earthquake-induced local water waves is the type generated by sudden direct tectonic displacement of the land (Plafker, 1969; Von Huene and Cox, 1972). The height of the waves probably is controlled by configuration of the sea floor, shore orientation, and the direction and amount of land displacement. In the Metlakatla region, earthquake-induced waves of this type have not been recognized.

Damage to Metlakatla and its water-related facilities from tsunamis and seiches is one of the most likely consequences of earthquakes. The occurrence of such waves should be anticipated at Metlakatla as at other coastal cities. Unfortunately, the heights of waves and the amounts of damage cannot be predicted. If all tsunamis were of the nonbreaking type, were 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, extensive damage probably would result to boats, harbor facilities, other low-lying areas, and above-ground fuel tanks. Seiching of some of the lakes of the region might seriously affect outlet works of structures that are parts of the water-supply and hydroelectricity systems of Metlakatla (fig. 2).

One may speculate on several possible heights of tsunamis that might strike the Metlakatla area from the Pacific Ocean, Dixon Entrance, or Hecate Strait. When considering these heights, it must be borne in mind that wave focusing and sympathetic resonance of local waves that might develop in a particular inlet could increase wave heights by several feet ($\sim$1 m). Tending to reduce the height of waves are the islets and large number of reefs in Port Chester, especially those reefs between southern Gravina Island and Metlakatla Peninsula.

The U.S. Coast and Geodetic Survey (1965a) cautioned that all land with direct access to the open ocean and that is less than 50 ft (15 m) above sea level and within 1 mi (1.6 km) of the coast should be considered potentially susceptible to tsunamis generated at considerable distances.

A somewhat less cautious approach is indicated by the data of Wiegel (1970), who noted that many of the large Pacific Ocean tsunamis have been about 40 ft (12 m) high.

Another evaluation of the height of tsunamis that might affect Metlakatla is available from a study by Dames and Moore (1971, p. B5-B6) of potential wave damage to the low-lying airport at Sitka, Alaska (fig. 1), from tsunamis generated at considerable distance from Sitka. Despite the difference in distance of the two communities from the open ocean, the study is applicable in general to Metlakatla. The principal conclusion of Dames and Moore was that "there is about a 63 percent chance that a tsunami will hit Sitka in a 100-year interval, with a maximum wave height of at least 20 ft [6 m]. . . . a 25 percent chance that such a wave will occur in 29 years and 10 percent [chance] that such a wave will hit . . . in 10 years." It is here concluded that the possibility of a 20-ft (6-m) wave striking Metlakatla sometime in the future is equally reasonable.

Warnings to coastal Alaska regarding the arrival time of potentially damaging tsunamis are issued by the Tsunami Warning System of the U.S. National Weather Service (Butler, 1971; Cox and others, 1976; Cox and Stewart, 1972; Haas and Trainer, 1974). For Metlakatla, such warnings about tsunamis originating at great distances should allow sufficient time to move boats and to evacuate the harbor and low-lying areas. However, warning times probably would be insufficient for tsunami or potentially destructive waves that might be generated close to the outer coast of southeastern Alaska and Queen Charlotte Islands, or in Dixon Entrance or Hecate Strait.

Wave damage to shore areas at Metlakatla from massive earthquake-triggered subaerial and submarine landslides is thought to be relatively unlikely but cannot be ruled out because there is a strong possibility of local landsliding during major earthquakes. If waves were generated, most of them probably would dissipate to low heights before reaching Metlakatla.

Wave damage to lakeshore areas from earthquake-triggered landslides may occur locally, in the generally steep terrane of the main part of Annette Island. Thus, there is a potential for damage to the water-supply and hydroelectricity facilities (fig. 2) serving Metlakatla.

INFERRED FUTURE EFFECTS FROM GEOLOGIC HAZARDS OTHER THAN EARTHQUAKES

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

High water waves

Nonearthquake-related water waves high enough to damage some harbor structures occasionally may strike shores in the Metlakatla area. Two types of waves are possible: (1) waves generated by the impact of submarine landslides or subaerial landslides entering large bodies of water (described below under "Landslides"), and (2) waves generated by storms or other means and originating most likely in the North Pacific Ocean or Dixon Entrance.

Waves formed by severe storms over ocean regions can be especially destructive. Such waves have been studied for many years (Bretschneider, 1967; Welander, 1961). For the Pacific Ocean west of British Columbia, the height of the theoretical maximum 100-year storm wave has been calculated by Watts and Faulkner (1968) to be 70 ft (21 m) and the height of the maximum annual storm wave to be 45 ft (14 m). In the Metlakatla region, storm waves gradually weaken as they move into Nichols Passage and Port Chester from the Pacific Ocean, Dixon Entrance, and Clarence Strait (figs. 1, 2). This weakening occurs because of shallowing of water, extensive bottom irregularities, and the great number of shoals and islets. Even after being weakened, however, some sets of waves may still be very large and cause damage to shore areas in the Metlakatla area. An illustration of the weakening of storm waves from the Pacific Ocean is shown by an analysis of Dames and Moore (1971, p. B9) for the airport near Sitka (fig. 1). The study gives the maximum height of the 100-year storm wave from the Pacific Ocean as 27.5 ft (8 m).

The origin of the other types of waves from the Pacific Ocean or Dixon Entrance that may affect the Metlakatla area at rare intervals is unknown, and time of occurrence or wave height cannot be predicted.

Waves of unknown origin reached heights of 12-18 ft (4-5 m) above mean high water on March 30-31, 1963, at several places along the north coast of the Queen Charlotte Islands and near Prince Rupert, British Columbia (fig. 1; U.S. Coast and Geod. Survey, 1965, p. 46). It is speculated that the waves were caused by (1) a massive submarine slide along part of the Continental Shelf in or near Dixon Entrance, or (2) some special long-period ocean wave similar to waves described by Munk (1962) and Rossiter (1971).

Additive waves are another type of wave that cannot be predicted. They develop by coalescence of several small waves to produce multiple forms of large size. These waves break substantially higher on beaches than do so-called normal storm waves. Large-size additive waves are thought to have occurred along the Oregon coast on February 19, 1973 (Schlicker and others, 1973, p. 108).

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

Landslides

Some of the steep slopes on Prince of Wales Island and on the main part of Annette Island probably are subject to landsliding from time to time (Swanston, 1969b; U.S. Forest Service, undated). Although many failures of steep slopes, especially those slopes underlain by thin unconsolidated geologic materials, occur during earthquakes, most failures probably occur at other times--during (1) heavy rainfall, (2) rapid snowmelt, (3) seasonal freezing and thawing, or (4) as a result of alteration of slopes during construction or timber cutting. Although slopes near the margins of the lakes on Annette Island that are used for Metlakatla's water supply and hydroelectricity (fig. 2) were not examined, it is anticipated that from time to time landslides will occur near the margins of these lakes. Landslides in the city of Metlakatla probably are rare, because most slopes are gentle; some small slides may occur, however, in some of the unconsolidated geologic materials along the steep but short slopes southwest of the small-boat harbor and north of Hillcrest Avenue.

The steep underwater slopes of some bays, inlets, and active deltas, and of even some slowly extending spits such as the one northeast of Village Point, may fail locally from time to time. No failures, however, have been documented in or near Metlakatla. In part, this lack is caused by a general sparseness of steep slopes both under water in Port Chester and on land, where the few steep slopes are short and probably commonly underlain by bedrock. In addition, most active deltas are very small. The types of geologic materials that underlie the relatively steep slopes offshore from the area of the cannery and small-boat harbor (figs. 3, 5) are unknown, but the presence of bedrock outcroppings on the shore nearby indicates that the offshore area probably is underlain, at least in part, by bedrock.

Stream floods and erosion of deposits by running water

Extensive muskegs, ponds, and small streams easily accommodate and adequately carry normal rainfall and melting snows in the Metlakatla area. Thus, there is very little possibility of erosion by stream flooding and sheet flooding. In the moderately steep to steep terrane of most of the rest of the region, however, erosion, especially of surficial deposits by running water, may occur because of the steeper slopes and greater precipitation at higher altitudes. The 25-year probable maximum rainfall in any 24-hour period is about 8 in. (203 mm) (Miller, 1963).

RECOMMENDATIONS FOR ADDITIONAL STUDIES

The reconnaissance nature of this geologic investigation did not permit a thorough examination of all aspects of the general geology and potential geologic hazards in the Metlakatla area. Therefore, the following recommendations for additional investigations, in general order of decreasing importance, are listed below.

1. In order to help indicate possible locations of future large earthquakes, the type of movement along known faults and inferred faults in the southern part of southeastern Alaska, in northern Queen Charlotte Islands, and in outer coastal areas should be determined. To accomplish this and to help delineate any unknown active faults, geophysical studies should be continued; and permanent, high-sensitivity seismological instruments should be installed in the region in cooperation with the Seismological Service of Canada. Records derived from these instruments must be analyzed for at least several years before preliminary results can be made available.
2. The configuration of the major fiords and the sea floor adjacent to southeastern Alaska should be mapped in greater detail. Such studies would help to determine the gravitational stability of geologic materials on margins of fiords and on the sea floor. In addition, such work might result in the location of potential submarine landslides that could be triggered by earthquakes.

3. Because of the potential for extensive wave damage in the Metlakatla area, a study is recommended of the natural oscillation periods of basins that hold large bodies of water in the region, such as Port Chester, to assist in prediction of possible wave heights. In conjunction with the study, a probability analysis of tsunami frequency is suggested, similar to the analysis described above that was developed by Dames and Moore (1971) for the airport at Sitka, Alaska.
4. Additional geologic mapping and field study utilizing current airphotos and updated topographic maps and hydrographic charts should be undertaken, including collecting of data on distribution and physical properties of surficial geologic materials in the region. Such work would lead to a better understanding of the general geology, and probably would result in locating specific zones subject to liquefaction, identifying areas most suitable for construction, and locating potentially unstable slopes. In conjunction with the study of the potential for wave damage, an analysis of shore sediments and their stability and transport is recommended. Such work should include determination of the rate of extension of the spit northeast of Village Point.

GLOSSARY

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

Agglomerate: A rock composed of coarse fragmental material ejected from volcanoes.

Clinopyroxenite: A rock formed dominantly of monoclinic pyroxene minerals.

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 earth material of any kind that has been transported from one place to another by glacial ice or associated streams. Material may range in size from clay to boulders and may be sorted or unsorted.

Dunite: An olivine-rich ultrabasic rock.

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 relative displacement of the two blocks 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); in a vertical fault, one side has moved down in relation to the other side. A thrust fault is a low-angle fault in which the hanging wall has moved upward relative to the footwall. A strike-slip fault is one in which there has been lateral displacement approximately parallel to the strike of the fault. If one of the fault blocks 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 in 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.

Greenschist: A green-colored schist with abundant amounts of the minerals chlorite, epidote, or actinolite.

Greenstone: A dark-green, dense, basic rock.

Hornfels: A dense, tough, fine-grained, metamorphic rock.

Joint: A fracture in bedrock along which there has been no movement parallel to the fracture.

Leucotrondhjemite: A plutonic rock very rich in sodic plagioclase and quartz and almost devoid of alkali feldspar and ferromagnesian minerals.

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 geologic 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 mi (100 km) from the epicenter of an earthquake (Richter, 1958). Although magnitude does not directly relate to seismic energy, a 1-unit increase in magnitude correlates with a 32-fold increase in seismic energy.

Microearthquake: An earthquake too small to be felt and 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.

Plutonic: A word used to refer to igneous rocks that have cooled at considerable distance below the ground surface.

Schist: A well-foliated metamorphic rock.

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

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

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

Till: An unstratified and unsorted mixture of clay, silt, sand, pebble, cobble, and boulder-size material deposited by glacial ice on land; a diamicton deposited directly by glaciers.

Ultramafic: An igneous rock that is rich in ferromagnesian minerals.

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