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

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

By Richard W. Lemke

ABSTRACT

The Alaska earthquake of March 27, 1964, dramatically emphasized the need for engineering geologic studies of urban areas in seismically active regions. A reconnaissance study of the Ketchikan area in southeastern Alaska is part of a program to evaluate earthquake and other geologic hazards in most of the larger Alaska coastal communities. These evaluations in the Ketchikan area should provide broad guidelines useful in city and land-use planning.

Ketchikan, which had a population of approximately 7,000 in 1970, is built on the southwestern end of Revillagigedo Island along the northeastern coastline of Tongass Narrows. Altitudes reach 1,000 feet (305 m) within half a mile (0.8 km) of the coast and near-vertical cliffs characterize the terrain in places. The climate is predominantly marine. Average precipitation is approximately 152 inches (386 cm).

The Ketchikan area was covered by glacier ice at least once and probably several times during the Pleistocene Epoch. The present topography, characterized by elongate lakes, U-shaped valleys, fiords, inlets, and passages, clearly reflects the effects of glaciation. The presence of emergent marine deposits, at least 300 feet (91 m) above sea level, shows that the land has been uplifted relative to sea level since the last deglaciation of the region.

Bedrock is exposed or is near the surface throughout most of the mapped area. The bedrock consists chiefly of metamorphic rocks. In a few places these rocks have been intruded by igneous rocks. Exposed metamorphic rocks are mostly thinly foliated schists and phyllites, metamorphosed to greenschist facies. Foliation generally strikes northwest with moderate to steep dips to the northeast. Most of the rock is fairly competent and near-vertical cuts tend to be stable. The more indurated metamorphic rock can be used for riprap, but more durable blocks generally can be obtained from the igneous rock.

The surficial deposits have been divided into the following map units on the basis of their time of deposition, mode of origin, and grain size: (1) undifferentiated drift (Qd), (2) elevated marine deposits (Qm),

(3) stream alluvium (Qa), (4) fan-delta deposits (Qf), and (5) modern beach deposits (Qb). Manmade fill (f) also is mapped as a separate unit. Muskeg, colluvium, and offshore deposits are not included as map units but are discussed in the report under the heading "Surficial deposits (not shown on map)." The undifferentiated drift deposits consist mostly of till or other diamictons, generally less than 25 feet (7.6 m) thick. Exposed elevated marine deposits (Qm) generally consist of sand and gravel less than 5 feet (1.5 m) thick. Stream alluvium (Qa) is chiefly sand, gravel, cobbles, and boulders probably everywhere less than 15 feet (4.6 m) thick. Fan-delta deposits (Qf) consist mostly of loose sand, gravel, and boulders as much as 50 feet (15 m) thick. Modern beach deposits (Qb) are mostly loose sand and gravel generally less than 10 feet (3 m) thick. Two basically different types of manmade fill are present: (1) large fills along the waterfront, commonly 5 to 15 feet (1.5-4.6 m) thick, consisting of silt, sand, gravel, rock, and diverse other materials, and (2) fills, generally less than 10 feet (3 m) thick and consisting of sand, gravel, or crushed rock, placed inland from the waterfront and used as pads for buildings and parking areas. Fairly thick deposits of muskeg may be present in the southeastern part of the mapped area but have not been examined in the field. Colluvial deposits, locally 5 to 8 feet (1.5-2.4 m) thick, consist mostly of decomposing bedrock fragments. Offshore deposits are poorly known; near-shore loose sand and gravel rest on a sloping bedrock surface.

Southeastern Alaska lies within the circum-Pacific seismic belt that rims the northern Pacific Basin and has been tectonically active since at least early Paleozoic time. Large-scale faulting has been common. The two most prominent fault systems in southeastern Alaska and surrounding regions are (1) the Denali fault system, and (2) the Fairweather-Queen Charlotte Islands fault system. Of the two, the Fairweather-Queen Charlotte Islands fault system is the more active and of most significance in relation to the Ketchikan area. Ketchikan lies within the northwest trend of the Gravina-Nutzotin belt of fault thrusting. The trends of at least some of the linear fiords near the mapped area are controlled by faults. However, it is not known whether a major fault extends up Tongass Narrows offshore from Ketchikan.

Between 1899 and 1970, five earthquakes having magnitudes of 8 or greater occurred in or near southeastern Alaska or in adjacent offshore areas; three have occurred having magnitudes of between 7 and 8, at least eight with magnitudes of between 6 and 7, 15 with magnitudes of between 5 and 6, and about 140 have been recorded with magnitudes of less than 5 or of unassigned magnitudes. All of the earthquakes with magnitudes greater than 8, and a large proportion of the others, appear to be related to the Fairweather-Queen Charlotte Islands fault system or to the connecting Chugach-St. Elias fault to the northwest. Within a 50-mile (80-km) radius of Ketchikan, epicenters of three earthquakes with magnitudes of 5 or less have been recorded. Within a radius of 100 miles (160 km), 10 epicenters have been recorded, two with magnitudes between 6 and 7 and eight with magnitudes of 5 or less. Although no instrumentally recorded earthquakes had epicenters in the mapped area, at least 32 earthquakes that had epicenters elsewhere were felt or possibly felt in Ketchikan. Most of these earthquakes probably had epicenters along the Queen Charlotte Islands fault.

Ketchikan is tentatively assigned by me to seismic zone 2. This is a zone in which magnitudes of the largest expectable earthquake would range from 4.5 to 6.0 and where moderate damage could be expected. Large earthquakes of magnitude 8 or greater, however, can be expected to occur from time to time along the Queen Charlotte Islands fault. Ground motion from these earthquakes, although attenuated with distance, may still be sufficiently strong at Ketchikan to cause substantial damage.

Possible future earthquake effects include: (1) land-level changes caused by local faulting or by large-scale regional deformation, (2) ground shaking, (3) compaction, (4) liquefaction, (5) subaerial and submarine sliding, (6) water-sediment ejection and ground fracturing, (7) reaction of sensitive and quick clays, and (8) effects of tsunamis, seiches, and other abnormal water waves. Although land-level changes due to local faulting are unlikely, large-scale regional deformation may cause uplift or subsidence in Ketchikan. Adverse effects would be confined mainly to the waterfront area. This area also would be most heavily damaged if Ketchikan were strongly shaken by an earthquake. Nonengineered, loose, manmade fills and fan-delta deposits in this area probably would be subject to the strongest shaking. These deposits probably also are most subject to compaction, liquefaction, sliding, and water-sediment ejection. Earthquake effects expectably would be considerably fewer and less severe for the part of Ketchikan upslope from the harbor area because bedrock is at or near the surface in large parts of the area. No sensitive clays have been identified but, if present, they probably are confined to the till and other diamicton deposits in the northeastern part of the mapped area. Tsunami waves are not expected to have a local generation source. Those arriving from a distant source, although potentially highly destructive, probably would be greatly attenuated before arriving at Ketchikan. Seiche waves may develop on lakes near the mapped area and possibly cause failure of earth-fill dams. Destructive waves generated by earthquake-induced local submarine sliding appear to be unlikely in the Ketchikan area.

Geologic hazards in the area that are not caused by earthquakes are believed to be relatively minor. They include: (1) landsliding and subaqueous sliding, and (2) flooding. Only minor landsliding has occurred in the mapped area, but the potential for sliding may increase as the city expands and heavily timbered areas are cleared, with attendant accelerated erosion and mass wasting. The greatest potential for subaqueous sliding is along the shoreline, where fairly thick fan-delta deposits rest on a sloping bedrock surface. Periodic flooding has occurred on some creeks in the mapped area and can be expected to occur from time to time in the future.

In order that more accurate evaluations of geologic hazards can be made in the future, several recommendations are made for additional studies.

INTRODUCTION

Purpose of study

The Alaska earthquake of March 27, 1964, dramatically emphasized the need for engineering geologic studies of urban areas in seismically active regions. A reconnaissance study of the city of Ketchikan and adjacent areas in southeastern Alaska (fig. 1) constitutes part of an overall program to evaluate earthquake and other geologic hazards in most of the larger Alaska coastal communities.

Methods of study and acknowledgments

Approximately 2 weeks of fieldwork were spent in the Ketchikan area during 1965 and 1 week in 1972. Reconnaissance studies extended northwest from Ketchikan as far as Ward Cove and as far southeast as Saxman (fig. 2). The area of Ketchikan Airport on Gravina Island also was studied briefly. The main studies, however, were directed toward the city of Ketchikan, with emphasis on delineating and studying the surficial deposits and areas of manmade fill. The areal extent of the geologic map (fig. 3, in pocket) is roughly the area included within the boundaries of the city limits. Laboratory analyses of samples of surficial deposits were made in the Denver laboratories of the U.S. Geological Survey. Bedrock samples, collected by the writer, were studied by R. A. Sheppard of the U.S. Geological Survey. Lynn A. Yehle of the U.S. Geological Survey prepared table 1 listing felt and possibly felt earthquakes at Ketchikan; he also assisted in the compilation of the base used for the geologic map.

The evaluations presented in this report should provide broad guidelines useful to engineers, planners, and architects; to Federal, State, and city officials; and to the public. However, because of the short period of study and the reconnaissance nature of mapping, assessments of the geologic hazards of the area, as they affect man and his facilities, should not be rigorously interpreted. Evaluation of a specific site for a particular use will require more detailed geologic and engineering studies.

A number of technical terms used have been defined in a glossary at the end of the report. For more complete definitions of these terms or for definitions of other terms, the reader is referred to standard textbooks on geology, soil mechanics, and seismology, and to references cited in this report.

A report by Lemke and Yehle (1972a), entitled "Regional and other general factors bearing on evaluation of earthquake and other geologic hazards to coastal communities of southeastern Alaska," provides regional background information for evaluating earthquake probability in southeastern Alaska. It also cites numerous examples of effects of past large earthquakes in different parts of the world in relation to how coastal communities in southeastern Alaska might be similarly affected by future earthquakes. The reader also is referred to reports on the Haines area (Lemke and Yehle, 1972b), the Skagway area (Yehle and Lemke, 1972), the Wrangell area (Lemke, 1974), and the Sitka area (Yehle, 1974). These reports furnish

Figure 1.--Map of Southeastern Alaska and adjacent Canada showing pertinent geographic features.

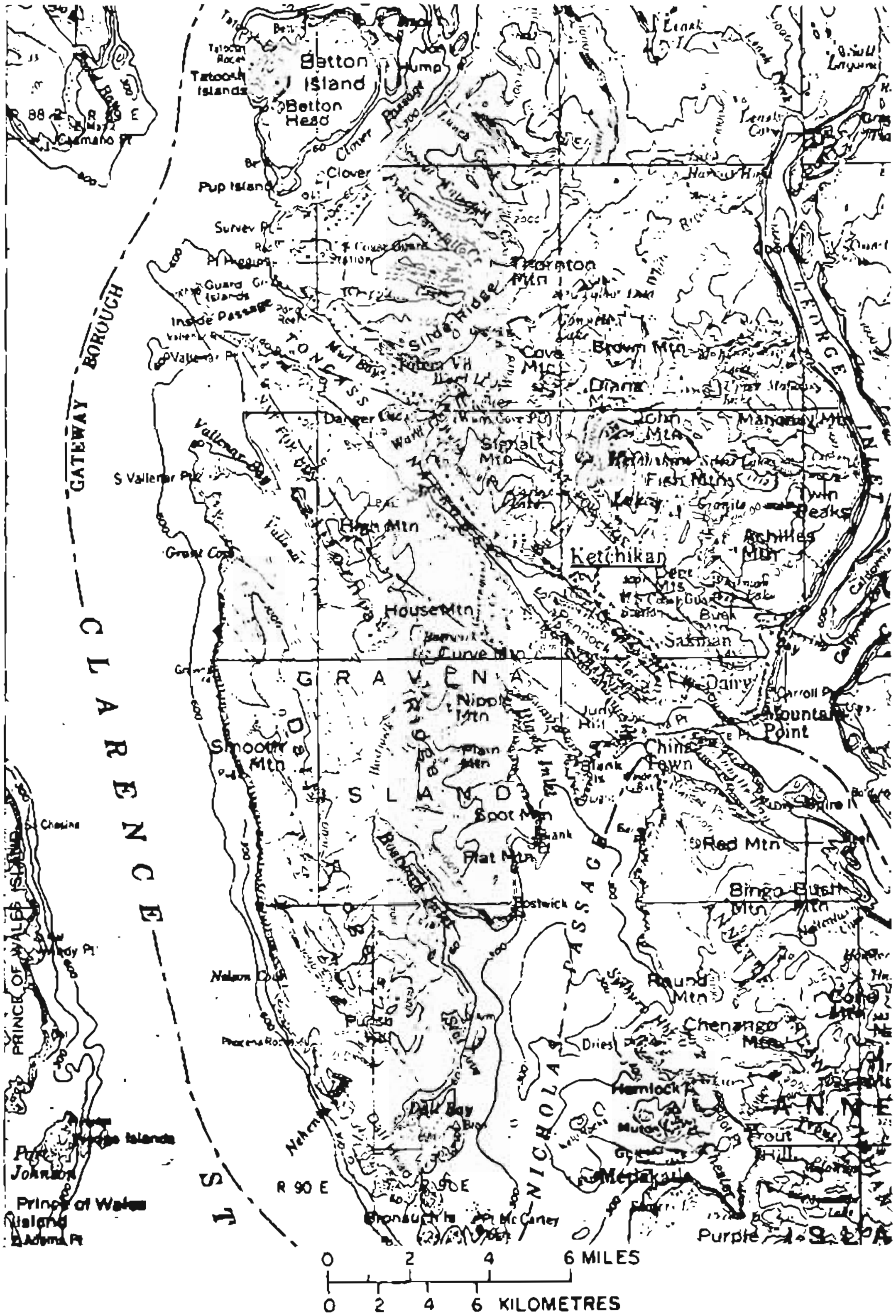

Figure 2.--Location map of Ketchikan and surrounding region, Alaska.

information on the evaluation of earthquakes and other geologic hazards in geologic environments that are somewhat different from those of the Ketchikan area.

GEOGRAPHY

Ketchikan, approximately 235 miles (378 km) southeast of Juneau, is built at the southwestern end of Revillagigedo Island along the northeastern coastline of Tongass Narrows (fig. 2). It is the largest city in southeastern Alaska; in 1970 it had a population of 6,994 (U.S. Bur. Census, 1971). Because of the steep and rocky nature of the terrain extending inland from the coast, much of the development of the city is restricted to a narrow strip about 3.5 miles (5.6 km) long bordering the coast. Altitudes reach 1,000 feet (305 m) within half a mile (0.8 km) of the coast, and near-vertical cliffs characterize the terrain in places. Ketchikan Creek, Schoenbar Creek, Carlanna Creek, and Hoadley Creek are the main drainage courses.

The climate is predominantly marine, and is characterized by mild winters, cool summers, and very heavy precipitation. Average annual precipitation is approximately 152 inches (386 cm). Because of the large amount of rainfall, most undeveloped areas are covered with a heavy growth of trees and dense underbrush.

The economy of Ketchikan depends largely upon timber processing, fishing, and tourism. The city is served by air and water forms of transportation. The recently completed airport on Gravina Island, directly across Tongass Narrows from Ketchikan, offers vastly improved air transportation. The Alaska Marine Highway System, started in 1963, connects Ketchikan with Wrangell, Petersburg, Sitka, Juneau, Haines, and Skagway to the northwest and with Prince Rupert (in British Columbia) to the southwest. No roads connect Ketchikan with the mainland. On Revillagigedo Island, roads are limited essentially to one segment extending about 16 miles (26 km) northwesterly from Ketchikan and a second segment extending from Ketchikan around the southeast end of the island to as far as the Beaver Falls Power House near Silvis Lakes (fig. 2).

Tongass Narrows appears to be part of the glacially scoured fiord system that characterizes southeastern Alaska. Bathymetric contours indicate a fairly flat floor with depths ranging from about 100 to 180 feet (30-55 m). On the basis of 19 years of records (1941-1959) of the U.S. Coast and Geodetic Survey, the diurnal tidal range at Ketchikan is 15.30 feet (4.66 m). The highest tide observed was 20.8 feet (6.4 m) above mean lower low water; the lowest tide observed was 5.2 feet (1.6 m) below mean lower low water.

GLACIATION AND ASSOCIATED LAND- AND SEA-LEVEL CHANGES

Although the glacial geology of the Ketchikan area is poorly known, regional studies of southeastern Alaska indicate that glaciers advanced over the area at least once and probably several times during the Pleistocene Epoch. Inasmuch as glaciers attained altitudes of between 3,000 and 4,000 feet (914 and 1,219 m) in the area (Coulter and others, 1965), even the higher peaks in the vicinity of Ketchikan were covered by ice at least once. The mountains on Revillagigedo Island and adjacent islands descend steeply to a highly indented coastline. The present topography, characterized by elongate lakes, U-shaped valleys, and deep, glacially scoured fiords, inlets, and passages, clearly reflects the effects of glaciation of the area.

During deglaciation, which probably was completed by 13,000 years ago, the land was still depressed from the effects of former glacier loading. Marine waters extended into low areas formerly occupied by glaciers, and marine sediments were laid down. As load effect of the ice slowly diminished, the land began to emerge above sea level, and shore processes began to modify preexisting deposits.

On the basis of fossil evidence, the land in the general area of Ketchikan is indicated to have been uplifted at least 300 feet (91 m). Fossil clam shells were reported to have been found at an altitude of about 300 feet (91 m)[1/] at the northeastern end of Revillagigedo Island (Tobin, 1969). Marine fossils also have been found at an altitude of about 80 feet (30 m) near the southern end of Gravina Island (Chapin, 1918) and by me at an altitude of 85 feet (26 m) in the city of Ketchikan. Other occurrences of fossil shells at altitudes of 60 to 100 feet (18-30 m) have been reported in the vicinity of Saxman and Mountain Point at the southeastern end of Revillagigedo Island (fig. 2).

Parts of southeastern Alaska are presently undergoing one of the most rapid rates of uplift of any place in the world. The fastest rate is in the Glacier Bay area (fig. 1), where the land is being uplifted approximately 1 1/2 inches (3.9 cm) per year (Hicks and Shofnos, 1965). However, the rate of uplift decreases progressively to the southeast, and is nearly zero at Ketchikan.

DESCRIPTIVE GEOLOGY

Bedrock (bex and bc)

Bedrock is exposed or is near the surface throughout much of the mapped area (fig. 3). Except for manmade fill (f) along the waterfront, it is essentially the only map unit in the business district of the city. Exposed bedrock is shown in figure 3 as bex; thinly covered bedrock or areas of small scattered exposures are shown as bc. The map units are most accurately delineated in the developed parts of the city; they are

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[1/] This was an estimate only and may be in considerable error.

least accurately delineated in the heavily timbered northwestern and southeastern parts of the mapped area.

The bedrock in the mapped area consists chiefly of metamorphic rocks. In a few places these rocks have been intruded by igneous rocks.

The metamorphic rocks of this part of Revillagigedo Island were assigned by Buddington and Chapin (1929) to the Wrangell Revillagigedo belt of rocks. More recently, Berg, Jones, and Richter (1972) placed these rocks in the Gravina-Nutzotin belt and assigned an upper Mesozoic age to them. Berg (1973), in mapping the geology of Gravina Island directly across Tongass Narrows from Ketchikan, assigned the rocks of that area to the Gravina Island Formation of Jurassic age. The rocks of this formation are highly deformed, commonly phyllitic, and are metamorphosed to greenschist facies (Berg and others, 1972).

As indicated from mapping by Berg (1973) on Gravina Island, the metamorphic rocks in the mapped area (fig. 3) of Ketchikan probably belong to the Gravina Island Formation. Thinly foliated schists and phyllites, metamorphosed to greenschist facies, constitute most of the exposures in the downtown parts of Ketchikan. The general strike of the foliation tends to be to the northwest with moderate to steep dips to the northeast, but local variations in attitude are common. The rocks are basically similar in composition from exposure to exposure but range substantially in degree of weathering and competence. The critical factor affecting these characteristics is the degree of schistosity of a rock at any particular locality. Increased schistosity tends to produce small platy fragments upon weathering and markedly lower competence. In the main business district of Ketchikan, most of the exposed rocks are grayish-green phyllites that are tough, unweathered, and competent. Fractures tend to be widely spaced, and near-vertical cuts generally are stable. In some other places in the mapped area, the rocks are more schistose, fractured, and subject to weathering, but in general fairly competent metamorphic rock prevails throughout the area.

Igneous rocks are exposed in only a few places in the mapped area. Most are diorites; however, a sample from an outcrop at the northeast end of town was classified as a gabbro by R. A. Sheppard (U.S. Geol. Survey, written commun., 1965). As indicated from mapping by Smith (1973), these igneous rocks probably are part of the Coast Range batholithic complex and are of Cretaceous age or younger. They tend to be hard and resistant to weathering.

All the quarries shown in figure 3 are in metamorphic rocks, but igneous rock can be obtained from quarries outside the mapped area. The quarried rock is used for general purpose fill and also as riprap (armor rock) along the shoreline.

The rock for general purpose fill, used in the construction of roads, parking areas, and fill areas along the waterfront, generally does not need to be as competent as that used for riprap. Therefore, rock that is fairly schistose and weathered and that tends to break into small fragments can be used. In larger fills, however, emplacement of continuous layers of highly schistose or weathered rock should be avoided because of the potential for slide failure. Also, the end dumping from trucks of poor-quality rock should be particularly avoided in thicker fills (Dames and Moore, 1970a).

The better quality metamorphic rock of the area is suitable for riprap, although larger and more durable blocks generally can be obtained from the igneous rocks. In a study of the design of the fill areas of the Ketchikan Airport on Gravina Island, metamorphic rock was found on the site that would break into blocks as large as 5 feet (1.5 m) in diameter. This was larger than was needed, inasmuch as it was concluded that, for an approximate design wave 7 feet (2 m) high, blocks of rock 2 feet (0.6 m) on a side, weighing no less than 1,200 pounds (545 kg) and 2 units thick, would provide ample protection against wave attack (Dames and Moore, 1970a). In the mapped area, breakwaters for Thomas Basin and Bar Harbor have been constructed of blocks of metamorphic rock commonly 3 to 4 feet (0.9-1.2 m) long and 1 foot (0.3 m) thick. Similar size or smaller blocks of rock have been used as riprap along the shoreline edges of some larger fills.

Surficial deposits (shown on map)

The surficial deposits have been divided on the map into the following units on the basis of their time of deposition, mode of origin, and grain size: (1) undifferentiated drift (Qd), (2) elevated marine deposits (Qm), (3) stream alluvium (Qa), (4) fan-delta deposits (Qf), and (5) modern beach deposits (Qb). Manmade fill (f) also is mapped as a separate unit. Muskeg, colluvium, and offshore deposits are not included as map units but are discussed in the report under the heading "Surficial deposits (not shown on map)."

Undifferentiated drift (Qd)

The deposits consist mostly of till or other diamictons. However, because exposures are few, and, therefore, little is known about the area, the mapped unit may include some "Elevated marine deposits (Qm)," or thinly concealed bedrock (bc). As mapped, the units are confined mostly to undeveloped areas, shown in the northwest part of figure 3.

The deposits generally consist of unstratified mixtures of clay, silt, sand, and gravel-size materials. Cobbles and boulders are sparingly present in places.

Unoxidized material commonly is bluish gray, fairly compact and impermeable, and of high strength. The upper 3 to 5 feet (0.9-1.5 m) generally is oxidized to a tan or brown color and is somewhat less compact. Analysis of a sample taken at the Ketchikan Airport on Gravina Island, which probably is fairly typical of the deposits in the mapped area, showed the grain sizes to be 36 percent sand, 35 percent silt, 19 percent clay, and 10 percent gravel (Dames and Moore, 1970b). The shrinkage limit of the material was 15, the liquid limit was 19, the plastic limit was 15, and the plasticity index was 4. In the Unified Soil Classification System, the material would be classified CL-ML. Moisture content of the material at the site generally was in excess of optimum moisture for compaction.

The deposits in the mapped area probably are less than 25 feet (7.6 m) thick in most places. In all places observed, they are directly underlain by bedrock.

Marine shells were not found in the deposits. Their absence suggests, but does not prove, that the deposits are till laid down under subaerial conditions rather than being deposited in a marine environment and subsequently elevated.

Because the deposits are fairly dense and are of high strength, they probably are suitable as foundations for most building purposes. They also can be used as competent fill material, although they may have to be dried somewhat before maximum compaction can be achieved.

Elevated marine deposits (Qm)

The map unit is interpreted to be a near-shore marine deposit that subsequently has been elevated. The deposits are shown on the map as extending up to an altitude of approximately 225 feet (69 m). Higher deposits may be present but have not been identified because of the general absence of exposures.

In the western half of the map area, the deposits consist chiefly of sand and fine gravel; in a few places, silt is the dominant size. The sand and gravel generally are clean and fairly well sorted. Most exposures are oxidized to a reddish-brown color. The deposits in this area generally occur as a thin veneer less than 5 feet (1.5 m) thick overlying "Undifferentiated drift (Qd)," or "Bedrock (bc)." Exposures are few and, because of spotty distribution and general thinness, the deposits may not be present everywhere as shown on the map.

Little is known of the distribution or the nature of the deposits in the southeastern part of the mapped area. Most of this area is heavily timbered or covered with muskeg deposits (unmapped). Therefore, knowledge of the deposits in this area is based upon those exposures near Deermont Street and upon a few exposures outside the mapped area to the southeast. However, it seems likely that elevated marine deposits, similar to those in the northwestern part of the mapped area, mantle the rather conspicuous southeast-trending topographic bench between altitudes of 80 and 100 feet (24 and 33 m) north of Stedman Street. The deposits are inferred to be thin, patchy in distribution, and to be underlain in most places by "Undifferentiated drift (Qd)." Bedrock probably directly underlies the deposits along their margins.

The three exposures of deposits near Deermont Street probably typify those inferred to be present in other places in the southeastern part of the map area. One exposure is in a roadcut along Deermont Street, approximately 600 feet (183 m) north of Stedman Street and at an altitude of 85 feet

(26 m). Ten feet of tannish-brown, fine-grained sand overlying bedrock is exposed. The sand is well sorted, faintly crossbedded, and compact. Near the top of the exposure are fairly numerous casts of marine shells. Pelecypoda *Hiatella arctica* (Linne) and barnacles were identified from these casts by F. S. MacNeil of the U.S. Geological Survey. The deposits at this locality indicate a near-shore environment. The second exposure is about 150 feet (46 m) east of Deermont Street along the road leading up the hill to the sanitary landfill and is at an altitude of about 80 feet (24 m). Here, 3 feet (0.9 m) of thinly bedded grayish sand overlies bedrock. No shells were found in the deposits but near-vertical, orange, pipe-shaped concretionary bodies, 2 to 4 inches (5-10 cm) long and approximately 1/2 inch (1.3 cm) in diameter, may represent former marine organisms. The third exposure, farther up the hill along the road to the sanitary landfill and at an altitude of about 200 feet (61 m), shows about 10 feet (3 m) of stratified coarse sand and fine gravel overlying bedrock. Although no shells were found in this exposure, the sand and gravel probably represent deposits similar to those in the first-described exposure and indicate that other unexposed elevated marine deposits may be present at least to this altitude in the heavily wooded areas to the south and southeast.

The deposits probably are too thin in most places to be used as a source of sand and gravel. Outside the mapped area, deposits 25 to 40 feet (7.6-12.2 m) thick offer sources of sand and gravel for base course for roads and for other purposes. Permeability of deposits generally is high and surface and subsurface drainage is good. Slope stability probably is moderate to fairly high, depending upon grain size. Erosion of finer material on steeper slopes can be expected.

Stream alluvium (Qa)

The deposits, as mapped, consist chiefly of sand, gravel, cobbles, and boulders deposited by Ketchikan Creek and Schoenbar Creek. Boulders, 1 to 4 feet (0.3-1.2 m) in diameter, are locally abundant along the streambed of Ketchikan Creek. Some stream alluvium also is present along Carlanna Creek and other creeks but has not been mapped because of spotty distribution and thinness.

Mapped deposits probably do not exceed 15 feet (4.6 m) in thickness and everywhere appear to rest directly on bedrock. The deposits generally are poorly sorted but are fairly permeable. The water table is fairly high, particularly near the creekbeds. There are no pits in the mapped deposits and none are likely in the future because of prior land use and the generally poor quality of the deposits for most purposes.

Fan-delta deposits (Qf)

The mapped deposits have been laid down at the mouths of Ketchikan, Carlanna, and Hoadley Creeks and some other smaller watercourses. Their outer edges, which extend out into Tongass Narrows, have been reworked by wave action and are gradational in composition with modern beach deposits (Qb).

The deposits consist mostly of poorly sorted sand, gravel, and boulders. The size fractions generally are coarsest near the apex of the fans and become increasingly finer grained seaward. In most places the deposits are less than 15 feet (4.5 m) thick but are considerably thicker at the mouths of the larger streams. The thickness of the deposits near the intersection of Mill Street and Front Street at the mouth of Ketchikan Creek, for example, ranges from 20 to 50 feet (6-15 m) (State of Alaska Dept. Highways, 1966a.[1] The deposits are loose and permeability is high. Their outer edges are completely saturated most of the time and the water table is high in the remainder of the deposits. They appear to lie generally on a seaward-sloping bedrock surface and in most places are overlain by fill of varying thicknesses. A limited amount of sand and gravel has been excavated for commercial use from the deposits at the mouth of Carlanna Creek. However, most parts of the deposits are no longer accessible for further exploitation because they are covered by buildings or fill.

Modern beach deposits (Qb)

The modern beach deposits are intertidal deposits laid down along the shoreline of Tongass Narrows. In many places they have been covered by manmade fill (f) and, as mentioned previously, are gradational with fan-delta deposits (Qf).

The deposits consist chiefly of loose sand and gravel; cobbles are present locally. They generally are less than 10 feet (3 m) thick but locally may be considerably thicker. Inasmuch as the deposits are intertidal, they are completely saturated part of every day. The mapped portions probably everywhere lie on a seaward-sloping bedrock surface. Farther offshore they may be underlain by till in places.

The deposits are not used as a source of sand and gravel because of their general thinness and because they are covered in most places by buildings or manmade fill. Piles for larger wharves and other structures generally are driven through the deposits to bedrock for greater stability.

Manmade fill (f)

Two basically different types of fill are included in this map unit: (1) thick fills emplaced along the waterfront to elevate low-lying land above high tide, and (2) thin fills placed some distance inland from the waterfront and used as pads for buildings and adjacent parking areas. Many small areas of fill, such as used in street and road construction, have not been differentiated on the map. Also, some larger fills may have been placed along the waterfront and elsewhere since mapping was completed.

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[1] The fan-delta deposits almost everywhere underlie the manmade fill at this locality, although exposed in only one small area.

The fills along the waterfront, whose outer edges extend into Tongass Narrows, consist of a variety of materials. Intermixed silt, sand, gravel, and crushed rock are probably the most common materials, but some fills contain tree limbs, sawdust, muskeg, concrete slabs, junked cars, and other trash. Riprap consisting of broken rock, commonly 3 to 4 feet (1-1.2 m) long and 1 foot (0.3 m) thick, has been placed along the seaward side of some of the fills and also constitutes the breakwater for Thomas Basin and Bar Harbor. Some fills are loose, whereas others are moderately dense. Probably only a few have been compacted to maximum density during emplacement. Most of the fills along the waterfront are 5 to 15 feet (1.5-4.6 m) thick but some are considerably thicker. They have been placed on seaward-sloping surfaces of fan-delta deposits, beach deposits, and bedrock.

Probably the thickest fill along the waterfront is in the area of Mill Street and the Ketchikan Spruce Mills. Here, drilling by the State of Alaska Department of Highways (1966a) in connection with construction of a new highway alinement disclosed that the fill is 15 to 20 feet (4.6-6.1 m) thick and lies on 15 to 50 feet (4.6-15.2 m) of fan-delta deposits, which in turn rest on bedrock. However, one drill hole near the alley northeast of the intersection of Front Street and Mill Street penetrated 68 feet (20.7 m) of fill and 7 feet (2 m) of bedrock. The fill in this area is mainly fine sandy gravel but also contains wood, glass, and boulders as much as 4 feet (1.2 m) in diameter. The material generally is loose to medium dense and represents at least in part hydraulic fill material derived from dredging operations in Thomas Basin. The surface of the site occupied by the Ketchikan Spruce Mill originally was about 8 feet (1.4 m) lower than the present fill surface. The first fill consisted of a layer of sandy gravel, wood, and sawdust; later this was covered by a layer of sandy gravel and silt. Earlier fill in this area apparently was not compacted during placement. However, during construction of the new highway along Mill Street and Front Street, fine-grained material first was washed into the void spaces between the abundant boulders present and then the fill was raised to street level in lifts not exceeding 8 inches (20 cm), brought to near-optimum moisture content, and compacted to at least 95 percent of maximum dry density (State of Alaska Dept. Highways, 1966b).

Fills placed inland from the waterfront and used as pads for buildings or for surrounding parking areas consist either of selected material (sand and gravel or crushed rock) hauled into the area or of material obtained on or near the site. Thicknesses generally are less than 10 feet (3 m). Permeability varies widely, depending upon the composition of the fill.

Surficial deposits (not shown on map)

Muskeg, colluvium, and offshore deposits are described herein but are not differentiated on the map because they are not exposed, are too poorly exposed, or are too small in areal extent to be mapped separately.

Muskeg

As indicated from the vegetation pattern on aerial photographs, probably the largest and thickest deposits of muskeg are present along the 80- to 100-foot (24- to 30-m) -high bench in the southeastern part of the mapped area. Larger trees are sparse in this area as compared with adjacent areas, and the surface drainage is poor--characteristics which in the Wrangell area, Alaska (Lemke, 1974), and elsewhere suggest substantial thicknesses of muskeg. However, future delineation of the deposits must await better exposures than are now indicated. The deposits in this area are interpreted to be underlain by elevated marine deposits (Qm).

Muskeg deposits, as much as 3.5 feet (1.1 m) thick and generally overlying undifferentiated drift (Qd) or elevated marine deposits (Qm), are exposed in a few places in the northwestern part of the mapped area. The muskeg consists chiefly of fragmented remains of decayed vegetable matter also known as peat. Its appearance is nearly identical to much thicker deposits described in the Wrangell area (Lemke, 1974). If similar, it probably has an exceptionally high moisture content, high shrinkage upon drying, a high void ratio, and an exceptionally high compressibility. Muskeg deposits encountered in road construction in the Ketchikan area generally are wasted unless they are very thick (State of Alaska Dept. Highways, 1963). In the construction of the Ketchikan Airport on Gravina Island it was determined that muskeg would compress under the contemplated fill loads. Most of the settlement would occur soon after emplacement of the fill, but secondary compression would continue for several years. For example, a layer of muskeg 5 feet (1.5 m) thick and a fill thickness of 20 feet (6.1 m) probably would settle initially 1.5 to 2.0 feet (0.5-0.6 m) and, over a long term, 3 to 6 inches (7.6-15.2 cm) of settlement could be expected (Dames and Moore, 1970b).

Colluvium

Colluvium is the general term given to surficial material, including rubble, that has moved downslope, principally under the influence of gravity. Colluvial deposits, generally less than 2 feet (0.6 m) thick, are sparingly present in the business district of Ketchikan, where they consist chiefly of fragments of decomposing bedrock. In the northwestern part of the mapped area, the colluvial deposits are locally 5 to 8 feet (1.5-2.4 m) thick and, in addition to decomposing bedrock fragments, consist of undifferentiated drift (Qd) and elevated marine deposits (Qm). Farther up the slopes, where bedrock is near the surface, the colluvial deposits consist chiefly of large blocks of detached bedrock.

Offshore deposits

Knowledge of offshore deposits within the area of figure 3 is limited to some seismic traverses and bottom sampling by the U.S. Geological Survey, to some information obtained offshore in the immediate vicinity of the Ketchikan Airport, and to data related to construction along the waterfront at Ketchikan. As used here, offshore deposits are those below mean lower low water.

Some information is provided on the thicknesses and size fractions of sediments in Tongass Narrows as a result of seismic traverse data and bottom sampling done by the U.S. Geological Survey in 1967. Limited preliminary interpretations of the records made by S. C. Wolf (written commun., 1973) indicate that the principal sediment accumulation is in depressions on an irregular bedrock surface. Bedrock is at or near the surface in many places. Some steep-sided bare bedrock projections, such as Idaho Rock and California Rock offshore from Saxman, project to within 2 fathoms (3.7 m) of the surface and constitute navigational hazards. Bottom sampling (S. C. Wolf, unpub. data, 1967) showed that the sediments were largely of sand and silt size with abundant shell material. Rock fragments predominated in some samples. The greatest range in grain size and composition was from a sample taken offshore from Thomas Basin. This sample contained much wood and other organic debris and probably represents deposition from Ketchikan Creek, particularly during flood stage.

Offshore studies were made in Tongass Narrows by Dames and Moore (1970a, b) in connection with construction of the Ketchikan Airport. Although these studies were made outside the mapped area and were of limited extent, some extrapolation of information into the mapped area seems justified. Three sediment units were delineated in the studies by Dames and Moore: (1) sand and angular gravel believed to overlie bedrock and to be continuous throughout the study area; (2) deltaic deposits, consisting of sand and gravel and occurring in lobes near the mouths of two creeks; and (3) a deposit of silt, sand, and wood occurring in a narrow band a short distance offshore and probably representing clearing and stripping operations on the site. Unit 1, the dominant offshore deposit, is dense and contains shells in addition to the sand and angular gravel derived chiefly from bedrock. The angular gravel is described as consisting of platy fragments of schist that lie essentially flat on the sea floor and form a bottom "pavement" to at least 70 feet (21 m) below mean lower low water. Thickness of the unit is variable, ranging from about 5 feet (1.5 m) near shore to about 20 feet (6 m) about 800 feet (244 m) offshore. A similar pavement may characterize the floor of Tongass Narrows in places offshore from Ketchikan, as indicated from some bottom samples previously described. Unit 2, which in addition to sand and gravel consists of some silt and organic debris, is described as not as dense as Unit 1 but nevertheless is of rather high strength and of low to moderate compressibility. It is about 5 to 10 feet (1.5-3 m) thick and everywhere is underlain by Unit 1. In the buried channels at the mouths of two creeks, Unit 2 and Unit 1 also are underlain in the more offshore part of the channels by dense till of high strength which is essentially incompressible. The combined thickness of the three kinds of material was shown in one drill hole to be as much as 37.5 feet (11.4 m). Similar buried channels containing substantial thicknesses of sediments and till may be present in the mapped area offshore from larger streams such as Ketchikan Creek and Carlanna Creek. Unit 3 apparently results from construction and has no significance in the mapped area.

A limited amount of information was obtained regarding offshore deposits along the Ketchikan waterfront in connection with construction of a new segment of highway along Mill and Front Streets. As discussed previously, drill-hole data indicate that 20 to 50 feet (6-15 m) of loose sand and gravel rests on a fairly steeply sloping bedrock surface. Because of the indicated instability of the deposits on this surface, it was recommended that all piles or caissons used to support the highway penetrate at least 3 feet (1 m) of bedrock to prevent lateral translation of load (State of Alaska Dept. Highways, 1966a).

STRUCTURE

Summary of regional structure

Southeastern Alaska lies within the active tectonic belt that rims the northern Pacific Basin. It has been tectonically active since at least late Paleozoic time, and the bedrock outcrop pattern is the result of late Mesozoic and Tertiary deformational, metamorphic, and intrusive events (Brew and others, 1966). Large-scale faulting, mostly with strong right-lateral strike-slip movement, has been common.

The trends of many linear fiords of southeastern Alaska are believed to be controlled by major faults or fault zones (Twenhofel and Sainsbury, 1958); other fiords, such as the northeast-trending ones across Baranof Island (fig. 1), are believed to be controlled by joints (Brew and others, 1963). The fiords are formed along faults or joints chiefly as a result of outlet glaciers scouring and deepening preglacial river valleys whose courses followed, at least in part, the more easily erodible fault or joint planes. Many other linear features such as straight valleys, coastlines, and troughlike depressions reflect faults, shear planes, and joints. The more conspicuous of these lineaments, most of which are believed to be fault traces, are shown in figure 5.

Two of the most prominent fault systems in southeastern Alaska and surrounding regions are (1) the Denali fault system, and (2) the Fairweather-Queen Charlotte Islands fault system. Also, of major tectonic importance are the Totschunda fault system and the Chugach-St. Elias fault, which join the northeastern end of the Fairweather fault. These major fault systems, as well as inferred connections between individual fault segments, are shown in figures 4 and 5. Two other prominent lineaments in southeastern Alaska, which are near Ketchikan and which may be faults, are the Clarence Strait lineament and the Coast Range lineament. Recency of faulting in relation to earthquake risk is discussed under the heading "EARTHQUAKE PROBABILITY."

Denali fault system and associated faults

The Denali fault system (fig. 4) is a great arcuate series of related faults and branches, more than 1,000 miles (1,600 km) long, subparallel to the Gulf of Alaska (St. Amand, 1957; Twenhofel and Sainsbury, 1958; Grantz, 1966; Berg and others, 1972). The Totschunda fault system is indicated to be a part of the Denali fault system (Berg and Plafker, 1973). These fault systems, although of great regional importance, probably are too far away from the Ketchikan area to be of great seismic importance to that area and are not discussed further here.[1]

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[1] For additional detail regarding these tectonic elements, the reader is referred to a regional report by Lemke and Yehle (1972a) and a report on the Wrangell area by Lemke (1974).

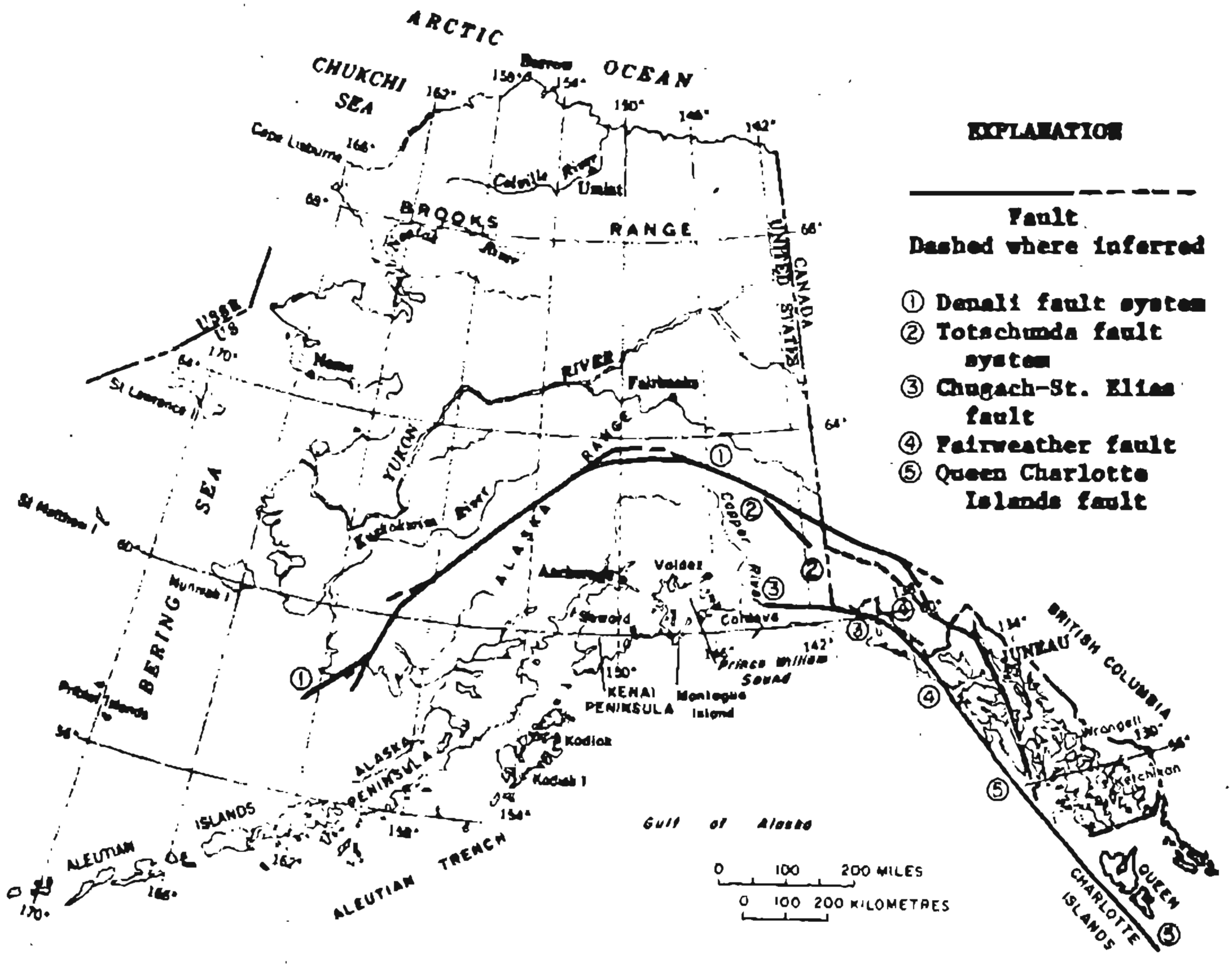

Figure 4.--Map of Alaska showing major elements of the Denali and Fairweather-Queen Charlotte Islands fault systems. Modified from Grantz (1966), Tobin and Sykes (1968), Plafker (1969, 1971), Richter and Matson (1971), Berg, Jones, and Richter (1972), Berg and Plafker (1973), and Page and Gawthrop (1973).

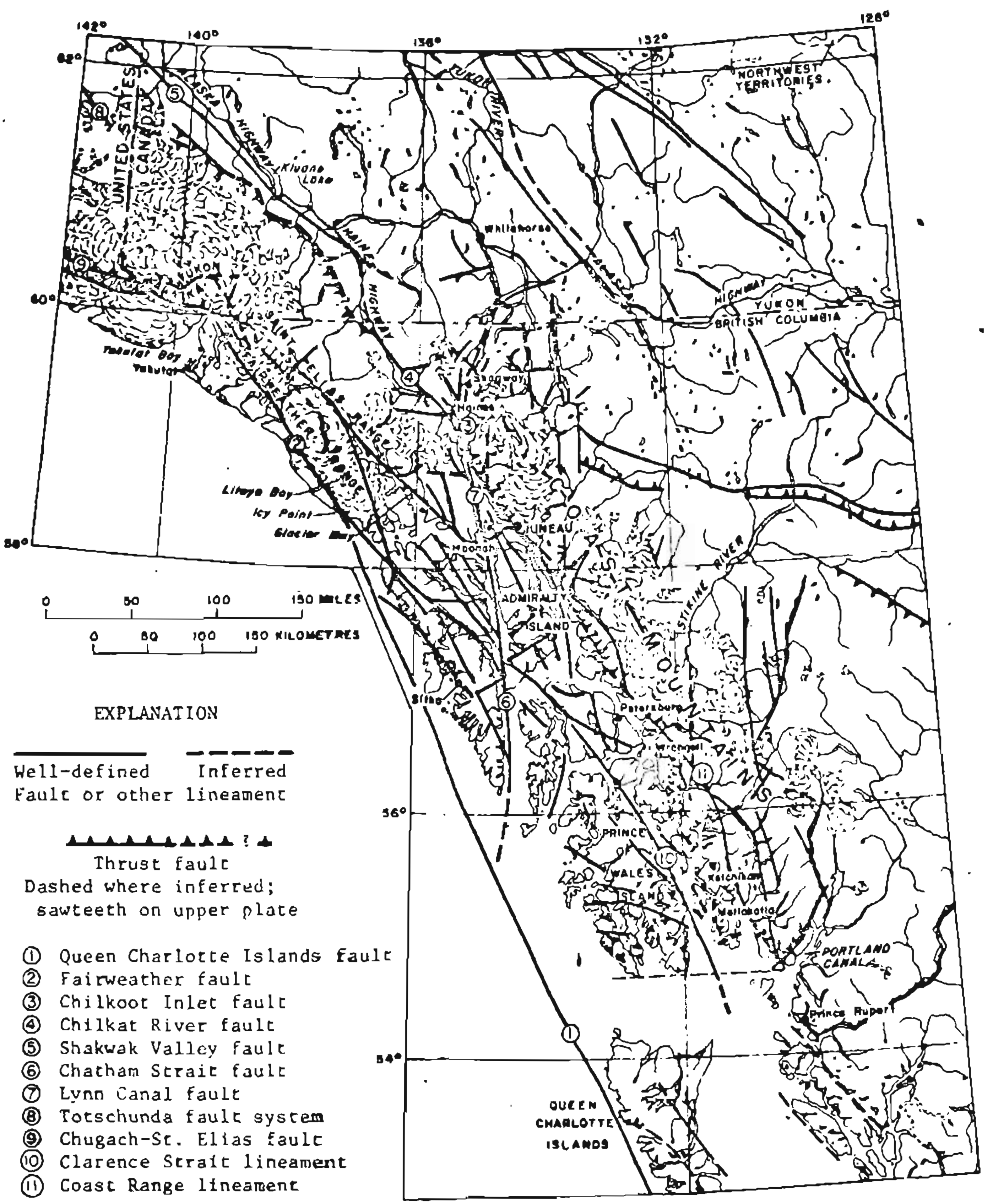

Figure 5.--Map of southeastern Alaska and adjacent Canada showing major faults and selected other lineaments interpreted to be probable or possible faults, shear zones, or joints. Taken from St. Amand (1957), Twenhofel and Sainsbury (1958), Gabrielse and Wheeler (1961), Brew, Loney, and Muffler (1966), Tobin and Sykes (1968), Canada Geological Survey (1969a, b), King (1969), Plafker (1969, 1971), Souther (1970), Richter and Matson (1971), and Berg, Jones, and Richter (1972), with additions and modifications by the writer.

Fairweather-Queen Charlotte Islands fault system

The Fairweather fault and the Queen Charlotte Islands fault probably are part of the same tectonic element but are generally described separately (St. Amand, 1957; Grantz, 1966; Tobin and Sykes, 1968; Page, 1969; George Plafker, written commun., 1971; Richter and Matson, 1971; Page and Gawthrop, 1973). The onland part of the Fairweather fault is a segment about 125 miles (200 km) long that extends southeastward from Yakutat Bay to Icy Point (figs. 4, 5); here, the fault lies largely in a linear valley partly filled by glaciers and separates crystalline rocks of the Fairweather Range from partly younger and less altered rocks of the coastal region (Miller, 1960). As mapped by Plafker (1969, 1971), the northwestern end of the Fairweather fault joins the eastern end of the Chugach-St. Elias thrust fault (figs. 4, 5). The offshore southeastern extension of the fault follows the continental slope off southeastern Alaska and, for purposes of discussion here, joins the Queen Charlotte Islands fault at latitude 55°30' N. The Queen Charlotte Islands fault is inferred to continue southeastward along the southwest side of the Queen Charlotte Islands on the basis of the configuration of offshore topography and the presence of a belt of high seismicity (Menard and Dietz, 1951; St. Amand, 1957; Wilson, 1965; Brown, 1968; Chase and Tiffin, 1972). Because of its closer location, the Queen Charlotte Islands fault is of greater tectonic importance to the Ketchikan area than is the Fairweather fault.

Clarence Strait lineament

This prominent lineament (fig. 5), which probably reflects faulting along part or all of its length, is at least 218 miles (350 km) long (Grantz, 1966) and may be more than 250 miles (400 km) long (Twenhofel and Sainsbury, 1958). It extends northwesterly from the mouth of Clarence Strait in Dixon Entrance to at least Kupreanof Island (fig. 1). If the Clarence Strait lineament is a fault, the northeast side is indicated to have been uplifted (probably during late Early Cretaceous and Late Cretaceous time) at its southeast end, with displacement decreasing to the northwest (Grantz, 1966). Evidence for lateral slip, according to Grantz, is lacking.

Coast Range lineament

This lineament (fig. 5), according to Twenhofel and Sainsbury (1958), is 370 miles (595 km) long and extends from the southern border of southeastern Alaska to Lynn Canal (fig. 1). At least part of the lineament represents faulting, but precise data on amount and type of movement on the structure are lacking. Buddington and Chapin (1929, p. 291), in describing a part of the lineament southeast of Juneau, noted that "a highly mashed overthrust fault zone is indicated by the cataclastic texture of the rocks in a belt on the mainland adjacent to Stephens Passage."

Local structure

Although recent detailed mapping of the structure has been done on the adjacent islands of Annette (Berg, 1972) and Gravina (Berg, 1973), detailed information on the structure of Revillagigedo Island is not available. Some information, however, is available from recent regional studies (Berg and others, 1972) and some extrapolations can be made from detailed studies made nearby.

Berg, Jones, and Richter (1972) showed that the Ketchikan area lies within the Gravina-Nutzotin belt. This is a narrow belt of middle(?) Jurassic to middle Cretaceous sedimentary and volcanic rocks that extends almost continuously in a northwesterly direction from southeastern Alaska to the Alaska Range in eastern Alaska. In southeastern Alaska, rocks of late Paleozoic and early Mesozoic age are believed to structurally overlie the younger Gravina-Nutzotin rocks. Major imbricate thrust faulting is assumed to have produced the inverted sequence, and it is felt that the belt is a part of the deformed upper Mesozoic arc. On Annette and Gravina Islands, thrust faults of this zone displace bedded rocks as young as late Mesozoic and are offset by high-angle faults, probably mainly of middle Tertiary age (Berg, 1972).

At least two lineaments in the area indicate major faulting. One, which has been mapped by Berg (1973) as an alluvium-covered inferred fault on Gravina Island, extends northwestward from Bostwick Inlet to Vallenar Bay (fig. 2). The other extends northwestward from the northern end of Annette Island up Tongass Narrows on the southwest side of Pennock Island. Along this lineament, Berg (1972) showed a fault extending northwestward across the northern tip of Annette Island and into Annette Bay. However, in his mapping of Gravina Island (Berg, 1973), he did not show this fault as continuing northwestward up Tongass Narrows. Perhaps when detailed mapping is extended onto Revillagigedo Island additional information may become available as to whether or not an inferred continuation appears warranted.

Many smaller faults have been mapped by Berg (1973) on Gravina Island across from Ketchikan, and doubtless many are present within the Ketchikan area itself. I noted several high-angle faults in the course of my reconnaissance studies but lack of time and poor exposures in large parts of the area precluded a systematic examination.

EARTHQUAKE PROBABILITY

Assessment of the earthquake probability of an area is dependent upon the determination of two factors: (1) the seismicity or historical record of earthquakes in and adjacent to the area, and (2) the degree of tectonic activity in the area and surrounding region.

Seismicity

Southeastern Alaska lies in one of the two most seismically active zones in Alaska, a State where 6 percent of the world's shallow earthquakes have been recorded (St. Amand, 1957; Wood, 1966). Between 1899 and 1970, five earthquakes having magnitudes of 8 or greater have occurred in or near southeastern Alaska or in adjacent offshore areas, three have occurred having magnitudes of between 7 and 8, at least eight with magnitudes of between 6 and 7, 15 with magnitudes of between 5 and 6, and about 140 have been recorded with magnitudes of less than 5 or of unassigned magnitudes (fig. 6). All of the earthquakes with magnitudes greater than 8, and a large proportion of the others, appear to be related to the Fairweather-Queen Charlotte Islands fault system or to the connecting Chugach-St. Elias fault to the northwest.

There are no recorded epicenters of earthquakes in the Ketchikan mapped area. Within approximately a 50-mile (80-km) radius of Ketchikan, epicenters of three earthquakes with magnitudes of 5 or less have been recorded (fig. 6).[1] Within a radius of 100 miles (160 km), 10 epicenters have been recorded. Two of these had magnitudes between 6 and 7, and eight had magnitudes of 5 or less. The epicenter of the closest earthquake of magnitude 8 or greater is about 140 miles (224 km) southwest of Ketchikan and offshore from the Queen Charlotte Islands (designated L on fig. 6). It occurred August 22, 1949, and had a magnitude of 8.1.

Although no instrumentally recorded earthquakes had epicenters in the Ketchikan mapped area, at least 32 earthquakes that had epicenters elsewhere were felt or possibly felt in Ketchikan (table 1). Probably many more earthquakes have been felt in the Ketchikan area, but they have not been reported or the publication source is obscure.

Of the earthquakes felt at Ketchikan, the one of July 30, 1972, in the vicinity of Sitka (about 180 miles (282 km) from Ketchikan, designated Q on fig. 6, magnitude 7.1-7.6) was the most recent and one of those most strongly felt. It was assigned an intensity of V (Modified Mercalli scale) at Ketchikan (Lander, 1973). Another earthquake that was felt fairly strongly at Ketchikan occurred November 17, 1956, about 100 miles (160 km) to the southwest (designated O on fig. 6) and had a magnitude of 6.5. It was assigned an intensity of IV at Ketchikan (Wood, 1966). The large Queen Charlotte Islands earthquake (magnitude 8.1) of August 22, 1949, 140 miles (224 km) to the southwest (designated L on fig. 6) is inferred to have been felt at Ketchikan, but there are no reports to substantiate this inference. However, at Ward Lake,

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[1] Because of the difficulty of accurately determining the location of epicenters (particularly of early historic earthquakes), assigned locations probably are at least 10-15 miles (16-24 km) in error and in some instances may be mislocated by as much as 70 miles (112 km).

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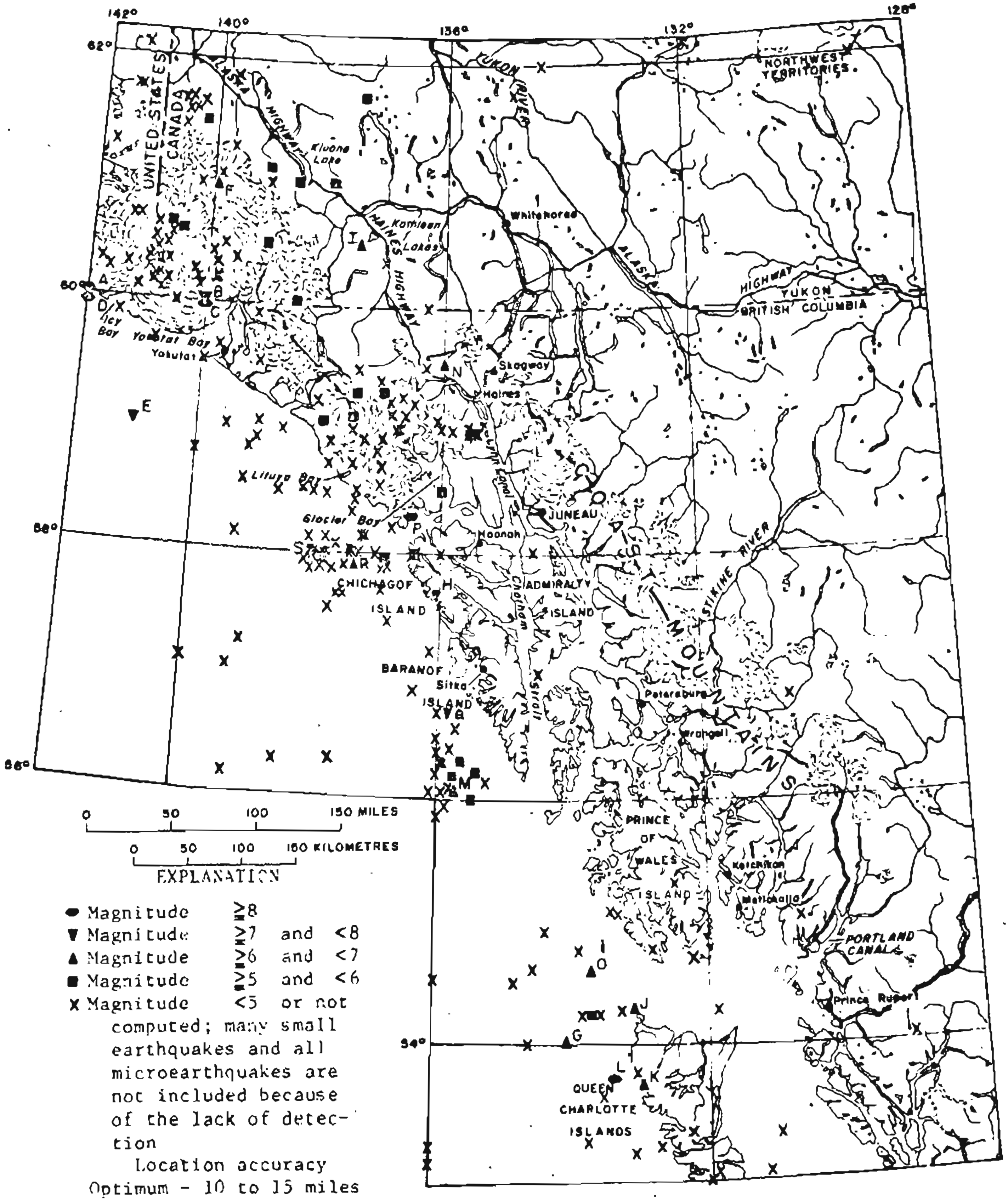


EXPLANATION

- ● Magnitude ≥8
- ▼ Magnitude ≥7 and <8
- ▲ Magnitude ≥6 and <7
- ■ Magnitude ≥5 and <6
- X Magnitude <5 or not computed; many small earthquakes and all microearthquakes are not included because of the lack of detection

Location accuracy
Optimum - 10 to 15 miles
Minimum - about 70 miles

Figure 6.--(See facing page for caption.)

Dates and magnitudes of some earthquakes of magnitude ≧6

Designation on map	Date (universal time)	Magnitude
A	September 4, 1899	8.2-8.3
B	September 10, 1899	7.8
C	September 10, 1899	8.5-8.6
D	October 9, 1900	8.3
E	May 15, 1908	7
F	July 7, 1920	6
G	April 10, 1921	6.5
H	October 24, 1927	7.1
I	February 3, 1944	6 1/2
J	August 3, 1945	6 1/4
K	February 28, 1948	6 1/2
L	August 22, 1949	8.1
M	October 31, 1949	6 1/4
N	March 9, 1952	6
O	November 17, 1956	6 1/2
P	July 10, 1958	7.9-8.0
Q	July 30, 1972	7.1-7.6
R	July 1, 1973	6.7
S	July 3, 1973	6.0

Figure 6.--Map showing locations of epicenters and approximate magnitudes of earthquakes in southeastern Alaska and adjacent areas, 1899-1972 and July 1, 1973. Data from Canada Dept. Energy, Mines and Resources, Seismological Service (1953, 1955, 1956, 1961-1963, 1966, 1969-1973); Davis and Echols (1962); Internat. Seismological Centre (1967-1972); Milne (1963); Tobin and Sykes (1968); U.S. Coast and Geodetic Survey (1930-1970, 1964-1970, 1969); Wood (1966); U.S. Natl. Oceanic and Atmospheric Adm. (1971, 1972, 1973a, b); Lander (1973); and Page and Gawthrop (1973; written commun., 1973).

Table 1.--Partial list of earthquakes felt and possibly felt at Ketchikan, Alaska, 1847-1972

[Compiled by Lynn A. Yehle, U.S. Geological Survey]

Date[1]	Perception[2]	Epicentral location from Ketchikan (see fig. 6)	Magni- tude	Radius of perceptibility[3]	Location nearest Ketchikan at which known to have been felt	Comment	Reference[4]
Apr. 6, 1847	Felt?	-------------	?	--------------	See comment	Generally felt along coast	1
Oct. 26, 1880	Felt?	-------------	?	--------------	---do---------------------	Felt Sitka, SE part Admiralty Island, and along Britsh America coast where accompanied by "tidal" wave.	2
Fall 1900 or spring 1901	Felt?	-------------	?	--------------	Central Prince of Wales Island, 45 mi. (72 km) W.	Frequent light tremblings	3
Aug. 7, 1906	Felt?	-------------	?	--------------	Loring, 17 mi. (27 km) N.	2 shocks felt	3
Sep. 24, 1907	Felt	-------------	?	--------------	--------------------------		1
Apr. 10, 1921	Felt?	135 mi. (216 km) SW.	6 1/2	180 mi. (288 km)	Fortmann Hatchery (SE end Heckman L.), 17 mi. (27 km)	-----do------------------	4
Apr. 29, 1925	Felt	295 mi. (472 km) NW.	?	---------------	--------------------------	The felt shock was 3 1/2 minutes later than the time of the epicenter-located earthquake; possibly different event.	5
Oct. 24, 1927	Felt?	235 mi. (376 km) NW.	7.1	260 mi. (416 km)	Wrangell, 80 mi. (128 km) NW.	All of SE Alaska south of Cape Spencer (~58°15'N.) was shaken	1
May 26, 1929	Felt	~300 mi. (480 km) S	?	240 mi. (384 km)	--------------------------	Four-foot (1.2 m)-high tidal wave at Queen Charlotte City 150 mi. (240 km) to SSW.	6
May 30, 1936	Felt?	-------------	?	---------------	Bell Island, 40 mi. (64 km) N.	2 slight shocks	1
Aug. 2, 1945	Felt?	95 mi. (152 km) SW.	6 1/4	150 mi. (240 km)	?	-------------------------	5
Apr. 1, 1946	Felt	-------------	?	---------------	--------------------------	Light shock	1
Feb. 3, 1947	Felt	-------------	?	---------------	--------------------------	3 light shocks	1
Apr. 26, 1947	Felt?	-------------	?	---------------	Bell Island, 40 mi. (64 km) N.	Mild earthquake	4
Feb. 28, 1948	Felt?	185 mi. (296 km) SW.	6 1/2	180 mi. (288 km)	Annette Island, 20 mi. (32 km) SSE.	Light shock	1
Nov. 30, 1948	Felt?	-------------	?	---------------	Craig, 60 mi. (96 km) W.	-------------------------	4
Aug. 22, 1949	Felt?	140 mi. (224 km) SW.	8.1	~400 mi. (640 km)	----------do--------------	At Craig brick chimneys tumbled. At Ward Lake, 5 mi. (8 km) NW of Ketchikan, there was a 2-foot (0.6 m)-high seiche.	4

Aug. 23, 1949	Felt?	185 mi. (286 km) SSW.	~6 1/2	~180 mi. (288 km)	?	------------------------	5
Aug. 26, 1949	Felt?	95 mi. (152 km) SW.	?	----------------	?	------------------------	5
Sep. 2, 1949 Sep. 2, 1949	Felt? Felt?	110 mi. (176 km) SW.	?	----------------	Tamgas Harbor, Annette Is., 20 mi. (32 km) SSE	------------------------	1
Sep. 12, 1949	Felt?	35 mi. (56 km) WSW.	?	----------------	?	------------------------	7
Oct. 31, 1949	Felt?	165 mi. (264 km) WNW.	~6 1/2	~180 mi. (288 km)	Sitka, 185 mi. (296 km) NW.	------------------------	5
Sep. 28, 1950	Felt?	180 mi. (288 km) SW.	?	----------------	Annette Island, 20 mi. (32 km) SSE.	2 shocks	6
Nov. 17, 1956	IV	100 mi. (160 km) SW.	6 1/2	180 mi. (288 km)	------------------------	Buildings shook	1
July 10, 1958	Felt?	280 mi. (448 km) NW.	8	360 mi. (576 km)	Wrangell, 80 mi. (128 km) NW; Prince Rupert, B.C. 95 mi. (152 km) SE	Wrangell V Prince Rupert III	1 8
Mar. 28, 1964	Felt?	710 mi. (1136 km) NW.	8.4	~450? mi. (720 km)	Prince Rupert, 95 mi. (152 km) SE	Prince Rupert I-III Tsunami wave 2 feet (0.6 m) high at Ketchikan	1
Aug. 3, 1964	Felt?	80 mi. (128 km) S	4.9	85 mi. (136 km)	?	------------------------	6
Sep. 5, 1965	Felt?	50 mi. (80 km) SE.	4.5	70 mi. (112 km)	?	------------------------	6
29 min. later, on Sep. 5, 1965	II-IV	----------------	?	----------------	------------------------	Felt by a number of people in Ketchikan; some strongly.	9
Feb. 11, 1971	Felt?	40 mi. (64 km) SW	4.6	74 mi. (118 km)	?		6
Jul. 15, 1971	Felt	110 mi. (176 km) SW	5.2	100 mi. (160 km)	------------------------		6
Jul. 30, 1972	V	195 mi. (312 km) NW.	7.1-7.6	280 mi. (448 km)	------------------------		6

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

2/Felt — Published report of single or multiple earthquake shock of unknown intensity at Ketchikan.
Felt? — Earthquake possibly felt at Ketchikan but not known to have been reported there 5/. The "felt?" evaluation is based upon the known occurrence of an earthquake elsewhere combined with its possible radius of perceptibility and general evaluation of regional geologic structure.
I, II, III, IV, or
V, Published report of earthquake intensity, Modified Mercalli scale (see table 2).

3/Gutenberg and Richter (1956, p. 141).

4/1. U.S. Coast and Geodetic Survey (1930-1969), Heck (1958), Eppley (1965), Wood (1966), U.S. National Oceanic and Atmospheric Administration (1973a, b) or Lander (1973)
2. Rockwood (1881).
3. Tarr and Martin (1912).
4. U.S. Weather Bureau (1918-1958).
5. Davis and Echols (1962).
6. Milne, (1956), Smith and Milne (1969, 1970).
7. Tobin and Sykes (1968).
8. Davis and Sanders (1960).
9. Reported in : : Ketchikan News, Sept. 5, 1965.

6/Newspapers printed at Ketchikan were not examined; these may provide additional accounts of earthquakes felt at Ketchikan.

5 miles (8 km) to the northwest, it was reported (U.S. Weather Bur., 1918-1958) that 2-foot (0.6-m) -high seiche waves were generated. Water was reported to have first rushed to the west and then upon rushing back "the bottom of the lake began to boil, like gas or air escaping from the lake bed"; in addition, a tsunami wave 0.3 foot (0.1 m) high was generated in Tongass Narrows at Ketchikan (Cox and Pararas-Cayayannis, 1969). The earthquake of September 5, 1965, about 50 miles (80 km) southeast of Ketchikan, had a magnitude of only 4.5 but was moderately to strongly felt at Ketchikan. R. C. Wright, QM2 of the U.S. Coast Guard (oral commun., 1965), stationed at the southeast end of Ketchikan, stated that windows vibrated so hard that they nearly broke and that the desk he was sitting at noticeably bounced. He further stated that a noise like a moving truck immediately preceded the shaking. Both the large Lituya Bay earthquake of July 10, 1958, and the large earthquake of March 27, 1964, probably were felt at Ketchikan but there are no reports at either time of strong shaking. However, tidal records show that a tsunami wave 2 feet (0.6 m) high was generated at Ketchikan during the 1964 earthquake (Cox and Pararas-Cayayannis, 1969).

Microearthquakes, which commonly, but probably not always, reflect small movements along faults at depth, are not shown in figure 6 owing to their small size and general lack of detection. Special microearthquake studies have been made in recent years in southeastern Alaska and adjacent parts of Canada (Boucher and Fitch, 1969; Rogers, 1969, 1972a, b, 1973; Johnson, 1972; Johnson and others, 1972). Swarms of microearthquakes were recorded during these studies at a number of places but none were detected in the vicinity of Ketchikan.

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

All of the large and many of the moderate and smaller size earthquakes in southeastern Alaska and adjacent areas appear to be related to the Fairweather-Queen Charlotte Islands fault system and the connecting Chugach-St. Elias fault or to their branches (figs. 4, 5). Thus, most have epicenters close to the outer coast.

The onland segment of the Fairweather fault, as well as probably its western extension, the Chugach-St. Elias fault (fig. 5), has been very active tectonically during Quaternary time (Grantz, 1966; Page, 1969; George Plafker, written commun., 1971). The epicenter of the great Yakutat earthquake of September 10, 1899 (magnitude 8.6), was not accurately located. However, it is believed to have been near the head of Yakutat Bay, where there was movement on portions of the Fairweather fault or on one of its western extensions (Tarr and Martin, 1912). During the Lituya Bay earthquake of 1958 (magnitude 8.0), there was movement along the entire onland length of the Fairweather fault. Right-lateral slip of 21 1/2 feet (6.5 m) and associated dip slip (up on the south) of 3 1/2 feet (1.1 m) were measured in one place (Tocher and Miller, 1959; George Plafker, written commun., 1971). From late Pliocene or early Pleistocene to Holocene time, the land northeast of the fault is thought to have been uplifted more than 3 miles (5 km).

The fault also has undergone associated right-lateral slip of unknown magnitude (Grantz, 1966).

That the southeastern offshore extension of the Fairweather fault is also active is indicated by the fairly large number of earthquake epicenters in that area (fig. 6). Although the assigned epicentral locations are not well alined, probably most of the earthquakes are related to movement along this fault. Lack of alinement can be explained by inaccurately located epicenters or by the epicenters being along more than one branch of the fault system.

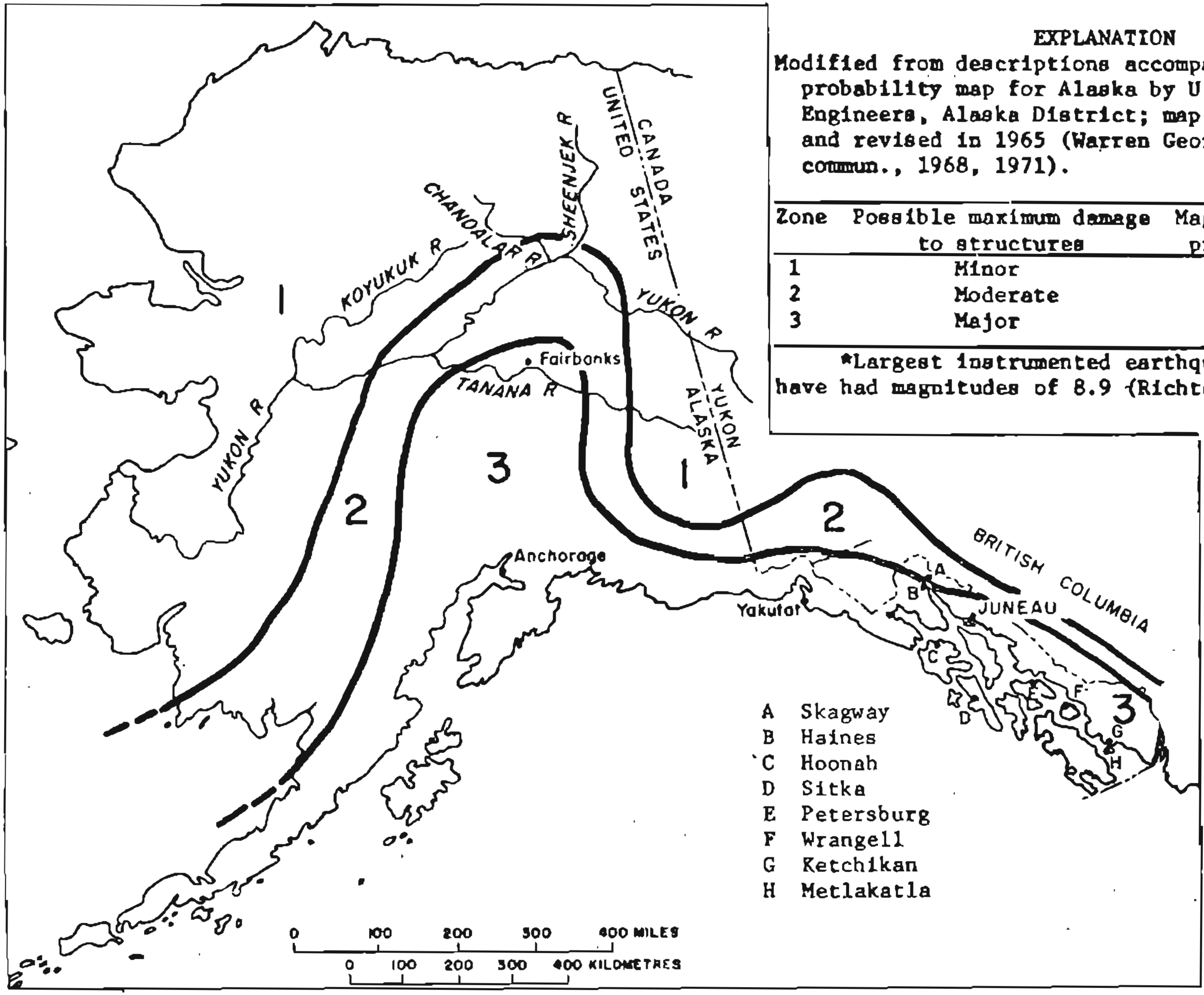
Very active faulting along the entire length of the concealed Queen Charlotte Islands fault (as far south as Vancouver Island) is well documented by the large number of earthquakes that appear to be related to the fault. These earthquakes have ranged in size from the large earthquake (magnitude 8.1)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

No evidence of faulting during Pleistocene or Holocene time has been found in the Ketchikan area. If there has been any fault displacement on the Clarence Strait lineament, it probably took place during late Early Cretaceous or Late Cretaceous time (Grantz, 1966). Data on the amount and time of movement on the Coast Range lineament are largely lacking. On Annette and Gravina Islands near Ketchikan, thrust faults associated with the Gravina-Nutzotin belt have displaced bedded rocks as young as late Mesozoic and are offset by high-angle faults, probably mainly of middle Tertiary age (Berg, 1972). The high-angle faults in the Ketchikan mapped area probably also are of middle Tertiary age and represent the youngest faulting that has been found.

Assessment of earthquake probability in the Ketchikan area

Only a general assessment can be made of earthquake probability in the Ketchikan area. A more definitive assessment must await a longer record of seismic events and a better knowledge of the tectonic framework of the area.

Several types of maps have been prepared to show earthquake probability that applies to the Ketchikan area. One type, prepared by the U.S. Army Corps of Engineers (fig. 7; Warren George, written commun., 1968, 1971), divides Alaska into three seismic zones and relates possible damage to earthquake magnitude for each zone. On this map, Ketchikan is shown as in zone 3, which is the highest zone, where magnitudes of the largest earthquakes are expected to exceed 6 and where major damage to manmade structures can be expected. A seismic zone map (fig. 8) in the 1970 edition of the Uniform Building Code (Internat. Conf. Building Officials, 1970) places Ketchikan in zone 2, where moderate damage to manmade structures is possible, corresponding to intensity VII (Modified Mercalli scale). On a



EXPLANATION

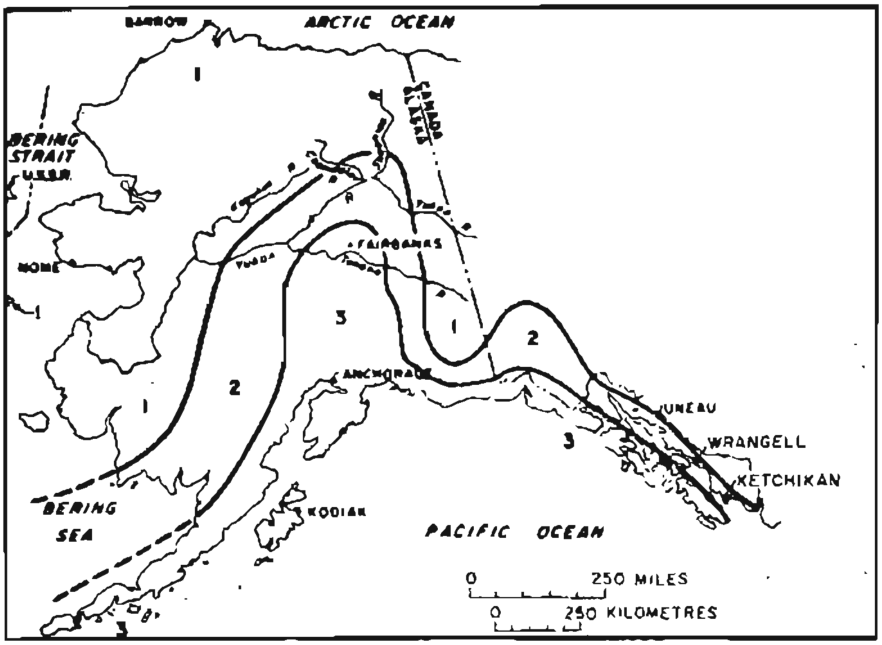
Modified from descriptions accompanying the seismic probability map for Alaska by U.S. Army, Corps of Engineers, Alaska District; map prepared in 1957 and revised in 1965 (Warren George, written commun., 1968, 1971).

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

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

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

Figure 7.--Seismic probability map for most of Alaska as modified from U.S. Army Corps of Engineers, Alaska District.



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

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

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

*Modified Mercalli Intensity Scale of 1931

Figure 8. Seismic zone map of Alaska. Modified from the 1970 edition of the Uniform Building Code (International Conference of Building Officials, 1970).

seismic zone map of Canada (fig. 9), all the coastal region of western Canada and all of southeastern Alaska are shown as being in zone 3, where destructive earthquakes may occur (Hasegawa, 1971). According to a strain-release map (fig. 10) of Milne (1967), Ketchikan lies on contour 1, which indicates that a single earthquake of magnitude 5 would be necessary to release all the energy that accumulates in 100 years. A 100-year probability map (fig. 11) of Milne and Davenport (1969) shows that Ketchikan is in an area in which a peak acceleration of about 8 percent of gravity is probable. Thus, on the basis of table 2, which shows approximate relations between acceleration, magnitude, and intensity,[1/] an earthquake of magnitude 4 and with an intensity on firm ground of IV is expectable within a 100-year period in the Ketchikan area according to this probability map.

The lack of agreement between the above-described maps as to the earthquake probability in the Ketchikan area is due, at least in part, to the different parameters used in making the evaluations. The difference in assessment of seismic risk between the U.S. Army Corps of Engineers map (fig. 7) and the Uniform Code seismic zone map (fig. 8) probably results because the Corps of Engineers attempts to assess the overall earthquake probability of the area in relation to maximum expectable damage whereas the Building Code seismic zone map is used to set up minimum building standards to be met by industry. The Uniform Building Code seismic map and the seismic zone map of Canada (fig. 9), although similar in some respects, apparently differ in some of their derivative factors. The lower seismic risk indicated by the strain-release map of Milne (1967) and the earthquake acceleration map of Milne and Davenport (1969) apparently is due to the fact that these maps are based solely upon the seismicity of the area since 1898. As discussed previously, the seismic record of southeastern Alaska is far too short to permit an assessment of earthquake probability on this basis alone. In this respect, it should be pointed out that the earthquake most strongly felt in the Ketchikan area did not occur until July 30, 1972, and that the one having probably the closest epicenter to Ketchikan and that was also strongly felt there did not occur until September 5, 1965 (see previous discussion).

It also should be noted that the absence of known active faulting in an area does not always indicate that the area will be earthquake free in the future. It has been amply demonstrated by the occurrence of a number of large earthquakes in the past that: (1) faults that long have been inactive may suddenly become reactivated, and (2) large earthquakes may occur

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[1/] Ambraseys (1973) pointed out that there appeared to be a fairly good relationship between acceleration and magnitude when there were just a few records. However, as more data became available he found that "for all practical purposes, there is no significant correlation between magnitude, distance, and acceleration in the near field. At large distances or for small accelerations, these three variables become more interdependent."

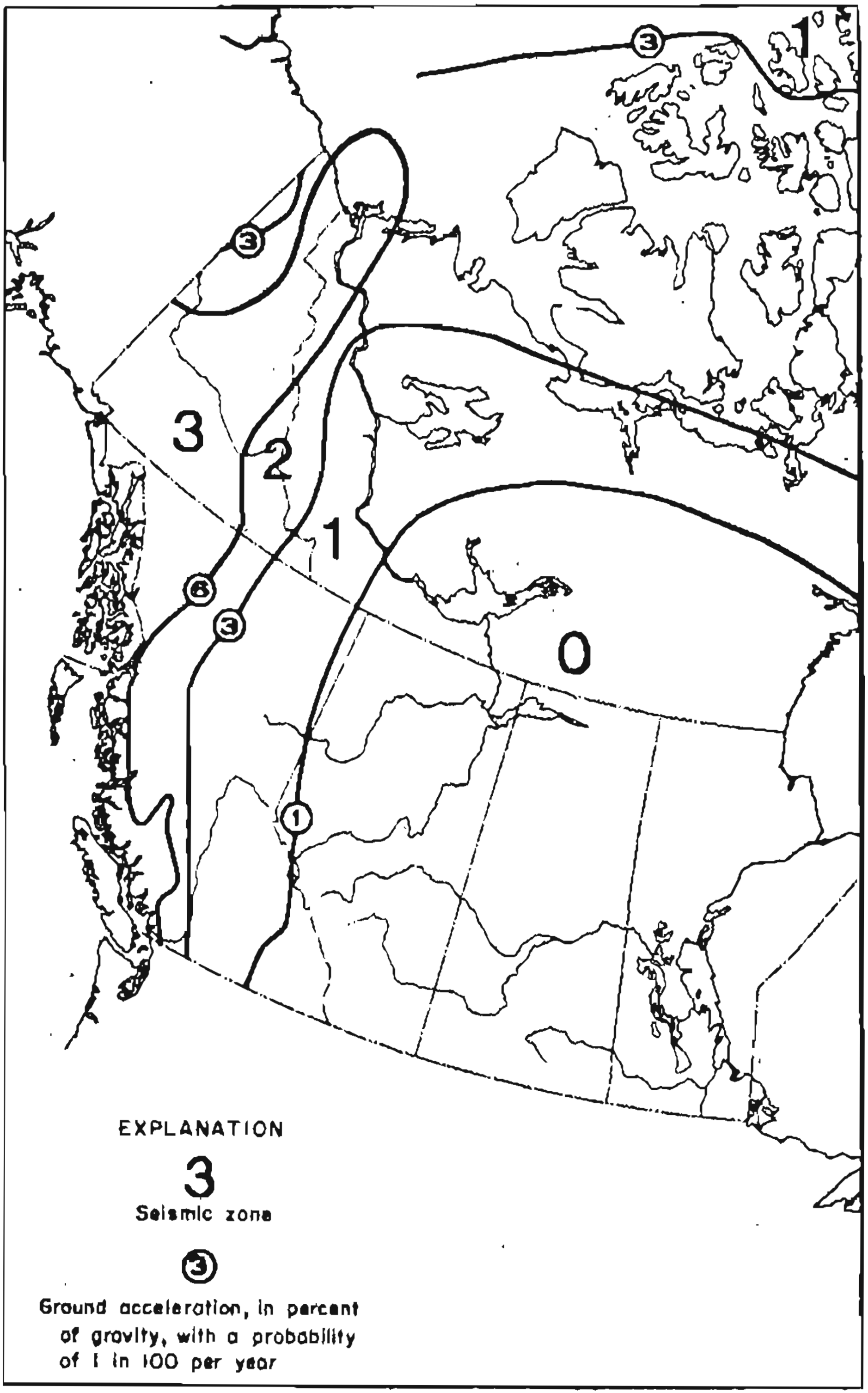


Figure 9.--Seismic zone map of western Canada. Modified from National Research Council of Canada (1970).

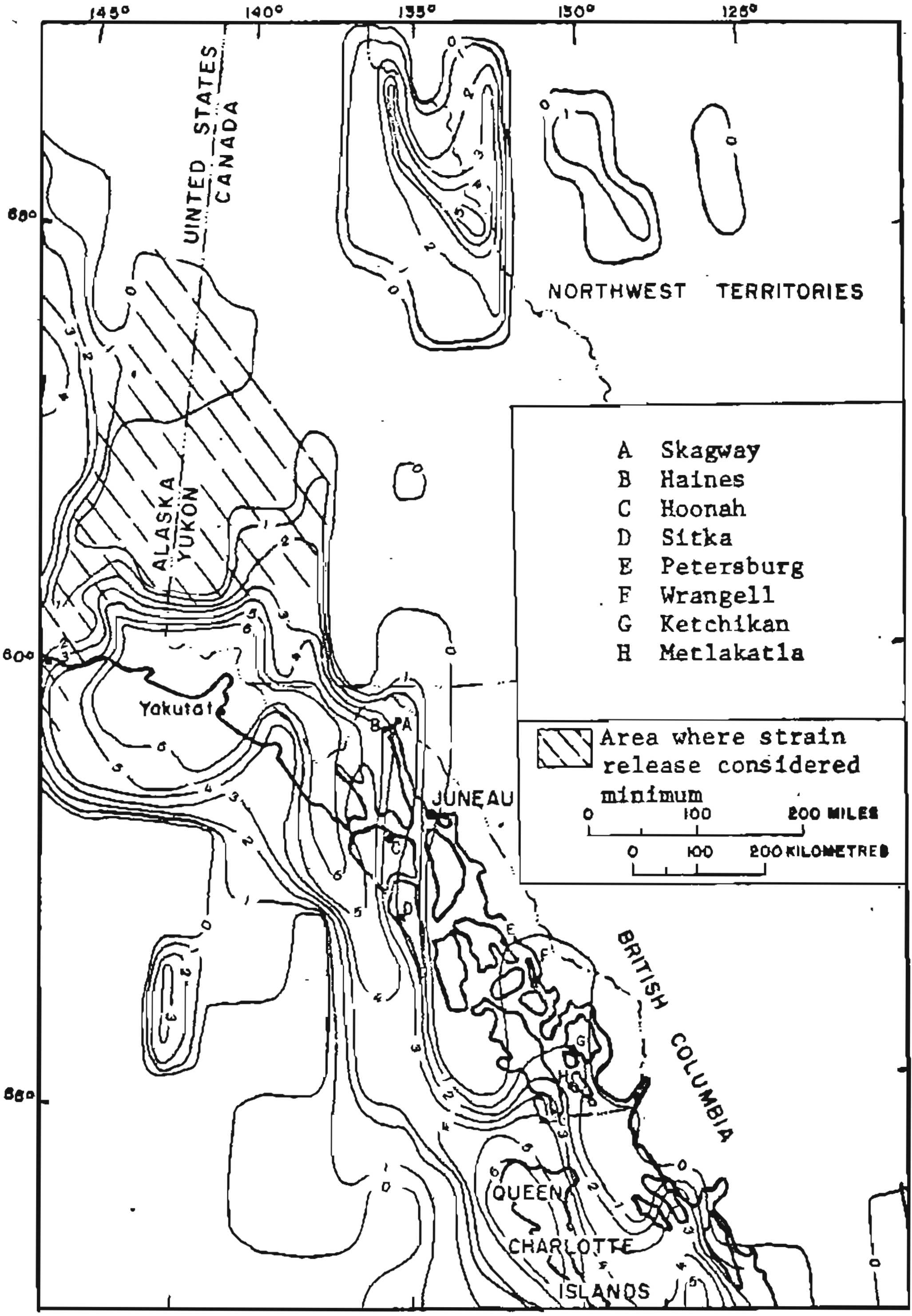


Figure 10.--Strain-release map of seismic energy 1898-1960, inclusive, in southeastern Alaska and part of adjacent Canada with explanation showing interpreted frequency of energy release. Modified from Milne (1967).

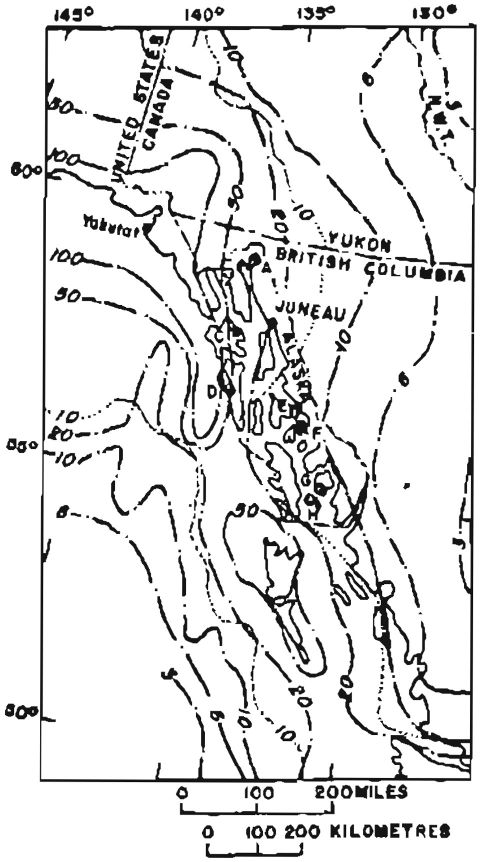
EXPLANATION FOR FIGURE 10

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

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

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

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



EXPLANATION

3
6
·····10······ ←——10
Average-value method
20
50
100

—·—·—6 Extreme-value method

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

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

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*See table 2 showing relations between acceleration units, energy, magnitude, and intensity.

Figure 11.--One-hundred-year probability map showing peak earthquake accelerations for southeastern Alaska and part of adjacent Canada. Modified from Milne and Davenport (1969). Based upon earthquake strain release from 1898-1960 (extended to a 100-year interval) as interpreted by an extreme-value method and using data from all instrumented earthquakes. For comparison of method, another interpretation is offered through an average-value method (dotted contour on map) which uses only earthquakes having an acceleration of 10 percent gravity.

Table 2.--Approximate relations between earthquake magnitude, energy, ground acceleration, acceleration in relation to gravity, and intensity (modified from U.S. Atomic Energy Commission, 1963)

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

These relations until 1971 are believed to have applied fairly well in southern California, where the average focal depth of earthquakes has been about 10 miles (16 km). (See Gutenberg and Richter, 1956; Hodgson, 1966.) However, revisions of these relations may be necessary because of the exceptionally high accelerations resulting from the San Fernando, Calif., earthquake of February 9, 1971, as well as other recent earthquakes. Also see discussion by Ambraseys (1973) in the text.

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

in areas where there has been a record of only minor seismicity previously and no obvious major tectonic structure that would result in a large earthquake. The catastrophic Alaska earthquake of March 27, 1964, was such an example (U.S. Coast and Geod. Survey, 1964; Eppley, 1965; Tobin and Sykes, 1966).

In summary, there is some question as to whether Ketchikan should be placed in seismic zone 3, where earthquakes of magnitudes greater than 6 can be expected and major damage can occur, or in zone 2, where magnitudes of the largest expectable earthquakes would range from 4.5 to 6.0 and where moderate damage could be expected. Certainly, the seismic risk in the Ketchikan area appears to be considerably less than for Sitka, which was assigned to seismic zone 3 by Yehle (1974). Therefore, on this basis and with consideration of other factors previously discussed, a tentative assignment to seismic zone 2 seems the more reasonable to me. However, the possibility of an earthquake of magnitude greater than 6 occurring sometime in the future within a 50-mile (80-km) radius of Ketchikan should not be entirely ruled out. Moreover, it should be emphasized that large earthquakes of magnitude 8 or greater can be expected to occur from time to time along the Fairweather-Queen Charlotte Islands fault system. The ground motion from these earthquakes will be attenuated with distance but still may be sufficiently strong at Ketchikan to cause heavy damage. This would be particularly true for those earthquakes whose epicenters are along the closer part of the Queen Charlotte Islands fault.

INFERRED EFFECTS FROM FUTURE EARTHQUAKES

Because of the reconnaissance nature of this study and the sparsity of laboratory data on physical properties, the discussion of the inferred geologic effects from future earthquakes in the mapped area and immediately adjacent areas must of necessity be largely empirical and generalized. Therefore, the assumptions that follow should not be rigorously interpreted or applied. Rather, they are intended as broad guidelines useful in assessing the kind and degree of hazard that may be present in the Ketchikan area and leading toward minimizing those hazards as they affect man and his structures. As such, they are directed to structural and civil engineers, city and regional planners, public and private utility companies, and all other public and private groups or individuals who are responsible for the safety and welfare of Ketchikan, now and in the future.

The inferred earthquake effects described below generally should be considered to be expectable maximum effects. It should be emphasized, however, that for every major destructive earthquake[1/] that occurs anywhere, a large

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[1/] Major damage generally is associated with earthquakes having a magnitude of about 7 or greater. Exceptions of lower magnitude generally are earthquakes having a very shallow depth of focus, in which instances there may be catastrophic damage from earthquakes with magnitudes not much greater than 5. Earthquakes with magnitudes between 7 and 8 commonly are referred to as major earthquakes and those with magnitudes of 8 or larger as great earthquakes.

number of smaller earthquakes generally occur that have little or no effect upon man. The inferences, by and large, are based upon effects of destructive earthquakes on similar-appearing geologic units in other places, particularly the effects of the Alaskan earthquake of 1964 (Lemke and Yehle, 1972a). It should be noted, though, that the geologic units in the mapped area (fig. 3) may not be the same as those being compared from other areas even though they superficially may resemble them.

Surface displacement on faults and other tectonic land-level changes

Two kinds of land-level changes caused by faulting are possible in the Ketchikan area: (1) sudden local uplift or subsidence produced along a reactivated fault in the area, and (2) large-scale regional deformation resulting from a large earthquake along a more distant major fault system.

Future land-level changes due to local faulting are unlikely to occur in the mapped area but cannot be entirely discounted. Surface faulting generally does not occur for earthquakes having magnitudes of 6 or less, although there have been some exceptions in California in recent years (Tocher, 1958; Brown and others, 1967; Brune and Allen, 1967; Bonilla, 1967). As discussed previously, it seems unlikely that earthquakes having magnitudes greater than 6 will occur in or near the mapped area.

Large-scale regional deformation resulting from a large earthquake occurring along the Queen Charlotte Islands fault probably offers the most likely possibility for land-level changes in the Ketchikan area. During the great Alaska earthquake of 1964 (magnitude 8.5), the land was warped along a belt nearly 600 miles (965 km) long and at least 200 miles (320 km) wide (Plafker, 1969). The maximum measured uplift was approximately 38 feet (11.6 m), and the maximum subsidence was approximately 7 1/2 feet (2.3 m). At a distance of 100 miles (approximately the minimum distance from Ketchikan to the Queen Charlotte Islands fault), the maximum uplift was more than 30 feet (9.1 m) and the maximum subsidence exceeded 6 feet (1.8 m). It should be emphasized, however, that there is no evidence that large-scale regional deformation has resulted from historic earthquakes with magnitudes as great as 8 along the Qheen Charlotte Islands fault, probably because movement along the fault has been chiefly strike slip. Therefore, it probably is not valid to try to predict potential land-level changes resulting from movement along the Queen Charlotte Islands fault on the basis of that which occurred during the Alaska earthquake of 1964.

In the unlikely probability that displacement along a fault does occur in the mapped area, it probably will be along the Tongass Narrows lineament. This is the only inferred major tectonic feature, although, as has been discussed previously, the existence of a major fault along this segment of the lineament has not been documented.

If there were tectonically induced land-level changes in the mapped area, the shoreline area probably would be most affected. Here, owing to the fairly steep slopes adjacent to the shoreline, the extent of land affected would be small. Adverse effects of land uplift or subsidence of less than a foot (less than 0.3 m) probably would be limited mostly to places where there is a critical relation between height of land and sea level. Uplift or subsidence of as much as 5 feet (1.5 m), however, would produce adverse effects throughout a large part of the waterfront area. Particularly affected would be boat harbors, docks, piers, and related buildings; streets and bridges; sewer, water, and other pipelines; and other miscellaneous structures. An uplift of 5 feet (1.5 m) would result in shoaling of Thomas Basin, Bar Harbor, and other docking areas, with attendant navigational problems. Higher projecting offshore rocks also would create additional navigational hazards. Some docks and piers would be too high to permit normal loading and unloading operations. A subsidence of 5 feet (1.5 m) would result in some docks and piers being too low to be operative at high tide and of flooding of some manmade fill areas, as well as inundation of some waterfront buildings and streets. Subsidence of this amount would result in wave erosion extending to a correspondingly greater height, which in some instances would render present protective riprap embankments ineffectual.

Ground shaking

The direct effects of ground shaking during an earthquake generally cause most of the damage to manmade structures. The intensity of ground shaking at any one location is governed by a number of variables.[1/] However, the variable most responsible for the degree of shaking from a particular earthquake at any epicentral distance is the type of ground (Barosh, 1969). A surficial deposit amplifies the shaking of underlying bedrock when one or more of the natural vibrational frequencies of the deposit coincide with the predominant frequencies of bedrock shaking (H. W. Olsen, written commun., 1973). Maximum amplification usually occurs when the fundamental, or lowest, vibrational frequency of a deposit coincides with the predominant frequency of bedrock shaking. On the other hand, no amplification occurs when all the natural vibrational frequencies of the deposit are appreciably higher than the predominant frequencies of bedrock shaking. This condition exists when the thickness of the unit is less than one-fourth the length of the shear waves entering the unit from the bedrock. The variables that govern the natural frequencies of a surficial unit, and hence the potential for ground amplification, are (1) the thickness of the unit, and (2) the stiffness of the unit. Stiffness, in turn, varies with the physical properties and degree of saturation of the materials. Generally, the finer the grain and the looser the deposit, the lesser the stiffness. Water saturation has a more pronounced effect upon fine-grained cohesive deposits such as clays than upon noncohesive deposits such as clean sands because of the much greater range in stiffness between wet and

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[1/] See Lemke and Yehle (1972a) and Lemke (1974) for more detailed discussion of factors affecting ground shaking.

dry clay. Instrumental records show that an area of unconsolidated deposits may have as much as a 10- to 15-fold greater acceleration than an adjoining rock outcrop such as granite (Neuman and Cloud, 1955). Gutenberg (1957), also, for example, found that the ratio of amplitudes at sites on fairly dry alluvium more than 500 feet (152 m) thick to those on crystalline rock was 5:1 or more for earthquake waves having periods of 1 to 1 1/2 seconds. Moreover, amplitudes of earthquake waves on water-saturated alluvium or other soft ground may be 10 times or more greater than those in bedrock.

Considerably more geological and seismological data are needed to accurately assess the amount of shaking of the different geologic units in the Ketchikan area during a particular earthquake. However, it is felt that reasonable inferences can be made on relative variations in intensity between the geologic units. Toward this end, the units have been tentatively divided into the following three categories on the basis of their expectable comparative shaking:

Category 1. Strongest expectable shaking:

- a. Manmade fill, f (part of unit).
- b. Fan-delta deposits, Qf.
- c. Modern beach deposits, Qb.
- d. Stream alluvium, Qa.
- e. Muskeg (not shown on map).

Category 2. Intermediate expectable shaking:

- a. Manmade fill, f (part of unit).
- b. Elevated marine deposits, Qm.
- c. Undifferentiated drift, Qd.

Category 3. Least expectable shaking:

- a. Bedrock, bex and bc.

Geologic units in category 1 (strongest expectable shaking)

Manmade fill, f (part of unit).--As described previously, two basically different types of fill are included in the map unit: (1) thick fills placed along the waterfront to elevate low-lying land above high tide, and (2) thin fills placed some distance inland from the waterfront and used as pads for buildings and adjacent parking areas. The first type of fill is placed in Category 1.[1/]

[1/] Wood's study (1908) of the San Francisco earthquake of 1906 showed that the most severe damage was on manmade fill, generally being 5 to 10 times greater on fill than on hard bedrock. During the Chilean earthquake of 1960, damage to buildings constructed on manmade ground was conspicuously greater than to those on any other type of ground (Barozzi and Lemke, 1966).

The first type of fill consists of materials that generally are susceptible to large amplification of ground motion unless the fill is engineered (properly compacted according to standard engineering methods) or is not thick enough to amplify underlying bedrock motions.[2] The thick fill along the waterfront in the area of Mill Street and the Ketchikan Spruce Mills probably is particularly subject to large ground-motion amplification, for two reasons: (1) the generally loose nature and composition of the fill, and (2) the fill in most places overlies fan-delta deposits that themselves are subject to considerable ground-motion amplification. Other large fill areas probably having similar characteristics and where large amplification of ground motion can be expected are at Bar Point and in the vicinity of Charcoal Point. Large amplification of ground motion also should be expected in smaller fill areas, especially where logs, sawdust, and other miscellaneous debris have been dumped. A number of smaller fills, however, have been placed directly on bedrock and may be too thin to amplify ground motion from the bedrock.

Fan-delta deposits, Qf.--The deposits at the mouths of Ketchikan, Carlanna, and Hoadley Creeks probably are most likely to amplify ground motion to a considerable extent. They generally are loose, largely water saturated, and in most places are thick enough to amplify ground motion arriving from the underlying bedrock. They also are overlain nearly everywhere by substantial thicknesses of manmade fill--the two units together causing a composite amplification greater than would result from a thinner single unit.

Modern beach deposits, Qb.--The deposits in most places are less than 10 feet (3 m) thick and may be generally too thin to amplify ground motion arriving from the underlying bedrock. Locally, however, they probably are of sufficient thickness, which together with their looseness and high degree of water saturation would make them susceptible to considerable ground amplification.

Stream alluvium, Qa.--Probably only the deposits along Ketchikan and Shoenbar Creeks are thick enough to amplify ground motion from the underlying bedrock. Amplification in these areas may not be as great as for other units in Category 1 because of the general coarseness of the deposits. However, their water table is fairly high, and thus they probably are more subject to shaking than deposits assigned to Category 2.

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[2] No amplification occurs when the deposits are sufficiently thin so that all the natural vibrational frequencies of the deposit are higher than the predominant frequencies of bedrock shaking. H. W. Olsen of the U.S. Geological Survey prepared a chart (see Yehle, 1974) showing the relation of fundamental frequency to thickness for three types of deposits, in increasing order of firmness. This chart is used as a very general guide for the Ketchikan area, but it cannot be interpreted rigorously because of the considerable number of unknown variables.

Muskeg (not shown on map).--It is not known whether there are muskeg deposits in the mapped area that are thick enough to amplify ground motion. Probably the only area where they may be sufficiently thick is along the 80- to 100-foot (24- to 30-m) -high bench in the southeastern part of the mapped area. If sufficiently thick there, they can be expected to shake very strongly in relation to most other deposits because of very low rigidity. In addition, large lateral deformation of the deposits can be expected, which could be particularly damaging to buildings or other structures built on muskeg-covered slopes.

Geologic units in Category 2 (intermediate expectable shaking)

Manmade fill, f (part of unit).--Most of the fills placed inland from the waterfront and used as pads for buildings or for surrounding parking areas probably are too thin to significantly amplify ground motion of underlying material or are too coarse textured to provide large amplification. Some additional total amplification may be expected, however, where the fill rests on surficial deposits that themselves may amplify the ground motion, thus providing a minimum thickness necessary for amplification.

Elevated marine deposits, Qm.--Where sufficiently thick, the deposits, because of their looseness, could be expected to moderately amplify ground motion. However, except perhaps locally, they probably are too thin to cause amplification.

Undifferentiated drift, Qd.--Although these deposits generally are considerably thicker than the elevated marine deposits (Qm) that stratigraphically overlie them, they also are much firmer and have higher vibrational frequencies. Therefore, in most places they also may be too thin to amplify ground motion from the underlying bedrock.

Geologic units in Category 3 (least expectable shaking)

Bedrock, bex and bc.--Damaging intensities on bedrock in the Ketchikan area probably can be reached only during the unlikely probability of a major nearby earthquake or a distant great earthquake such as along the Queen Charlotte Islands fault. Inasmuch as bedrock is exposed at the surface or lies at shallow depth throughout much of the mapped area, overall damage from shaking of an earthquake of certain size can be expected to be comparatively small in relation to most other cities studied in southeastern Alaska. Also, most of the bedrock is fairly hard and little weathered. However, somewhat stronger shaking can be expected on topographic highs and steep slopes (Davis and West, 1973), as well as where the rocks are characterized by closely spaced joints and shear zones.

Compaction

When loose cohesionless soils (those containing no significant clay content) are shaken during a major earthquake, the materials tend to compact with associated settlement of the ground surface. The resulting densification of the materials may be accompanied by liquefaction and water-sediment ejection. Only the effect of settlement will be discussed here.

The greatest compaction in the Ketchikan area probably would occur in thick nonengineered fills (f) where large amounts of loose cohesionless materials have been emplaced. Fills in the areas of the Ketchikan Spruce Mills, Bar Point, and Charcoal Point, as well as in several other areas of smaller extent, might be subject to settlement and possible damage to structures placed thereon. Likewise, fan-delta deposits (Qf) underlying the fills in these same areas could be expected to compact and settle during strong ground motion. The resulting combined settlement from compaction of both types of materials present could be considerable. Piers, docks, and other harbor works would be the facilities most affected. Some settlement resulting from compaction of thicker deposits of stream alluvium (Qa) might be expectable, but it probably would be considerably less than for the generally looser and thicker fill and fan-delta deposits. Settlement of the modern beach deposits (Qb) and elevated marine deposits (Qm), both of which are loose and ordinarily are susceptible to comparatively large amounts of compaction, probably would be small to negligible in the mapped area because of their general thinness. Undifferentiated drift (Qd) is of considerable thickness in some areas, but little settlement is expectable because of the general cohesiveness and firmness of the deposits. Because of the unknown thickness and nature of the muskeg, assessment of amount of potential settlement can only be surmised. However, it probably is reasonable to assume that if the muskeg is loaded, for example, with fill for roads and parking areas, comparatively large amounts of differential settlement and resultant damage can be expected.

Liquefaction in cohesionless materials

Loose to medium-dense materials that are saturated and virtually cohesionless tend to compact when subjected to strong ground shaking. As a result of the closer packing of the solid particles, there is an increased pore-water pressure and the load is transferred from the solids to the fluid. The resulting transformation of a granular material from a solid state into a liquid state is known as liquefaction (Youd, 1973). Other factors being equal, fine sands and coarse silts are most subject to liquefaction (Terzaghi and Peck, 1948). Also, the higher the void ratio the greater is the tendency for the material to liquefy. Three basic types of ground failure are associated with liquefaction (Seed, 1968): (1) flow landslides, (2) landslides with limited displacement, and (3) quick-condition failures. Examples of these three types of failures were described in more detail by Youd (1973). Ejection of water and sediment (discussed later) also may occur in conjunction with liquefaction during an earthquake.

In the Ketchikan area, the fan-delta deposits (Qf) and some of the offshore deposits (not shown on the map) near the shoreline probably are most subject to liquefaction and resulting damage to manmade structures. These deposits are loose, mostly of a grain size favorable for liquefaction, and are nearly or completely saturated. The inferred effects of liquefaction of these deposits, as well as of other units, are discussed under the headings "Earthquake-induced slides and slumps" and "Water-sediment ejection and associated subsidence and ground fracturing." Some manmade fill (f) may be sufficiently loose and of favorable grain size to liquefy. Beach deposits (Qb) probably are subject to liquefaction in many places but generally are too thin to be significant in respect to damage. Stream alluvium (Qa) may be subject to liquefaction in places but probably is too coarse grained in most places. Elevated marine deposits (Qm) are too well drained and too thin in most places to be significantly affected. Undifferentiated drift (Qd) is unlikely to liquefy in most places because of its small grain size and fairly high density. Muskeg deposits (not shown on map) probably are not subject to liquefaction because of their composition and internal structure.

Earthquake-induced slides and slumps

Earthquake-induced slides and slumps may occur both on land and under water. Most are confined to steep slopes, but some take place on moderate to nearly flat slopes if the underlying deposits liquefy. Larger submarine slides commonly occur along the foreslopes of deltas, expecially when sliding is due to liquefaction. Slide material, as a result of liquefaction, may travel considerable distances as liquefied flows or as intact materials riding on liquefied flows. Numerous examples of this kind of ground failure, accompanied by heavy destruction of property along waterfront areas, occurred during the great Alaska earthquake of 1964 (Hansen, 1965; Coulter and Migliaccio, 1966; Lemke, 1967).

In the Ketchikan area, the fan-delta deposits (Qf) and the manmade fill (f) overlying these deposits probably are most susceptible to earthquake-generated sliding. If the fan-delta deposits liquefy, the slide material probably will travel some distance out into Tongass Narrows, partly as liquefied flows representing the fan-delta deposits and partly as debris flows representing unliquefied portions of the overlying manmade fill. Sliding of this nature could cause exceptionally heavy damage to piers, wharves, and other facilities along the waterfront. Modern beach deposits (Qb) and elevated marine deposits (Qm) probably would be little affected (except for minor slumping) because of their general thinness. Also, other than minor slumping along walls of larger stream channels, stream alluvium (Qa) is not expected to be affected. Some minor slumping and sliding may occur in undifferentiated drift (Qd), particularly on steeper slopes from which timber has been cleared. Also, debris flows may occur on some colluvium-covered steep slopes. Rockfalls probably would be limited to small areas where bedrock exposures are near vertical and the rock is jointed or otherwise fractured.

Water-sediment ejection and associated subsidence and ground fracturing

Water and sediment commonly are ejected from surficial deposits during strong ground motion. The ejection phenomena, which are a consequence of liquefaction of the deposits (Ambraseys and Sarma, 1969), have been called fountaining, sand spouts or sand boils, mud or sand craters, and blowouts. The ejecta may range from clear water to material as large as coarse gravel, but sand is a common size fraction. The ejections are associated with surface or near-surface deposits where there is a high water table or a confined water condition. Associated fractures commonly form an intricate mosaic pattern of ground breakage, and generally range in width from hairline cracks to 1 or 2 feet (0.3 or 0.6 m). The water-sediment ejecta and ground fractures can cause damage by filling of basements and other low areas with ejected material and by surface collapse owing to removal of material from beneath the surface by ejection.

In the Ketchikan area, the fan-delta deposits (Qf) probably are most likely to be affected if ground motion is sufficiently strong to produce water-sediment ejection and ground fracturing. The manmade fill (f) that overlies the fan-delta deposits probably would not itself be greatly subject to water-sediment ejection. However, some of the fill material would tend to provide a confined water condition for the underlying deposits and, hence, increase the probability of ejection and ground fracturing in these deposits, which in turn would be manifested in the fill. Ground fracturing along the outer edges of both kinds of material would be expectable owing to lateral seaward translation of the fan-delta deposits upon liquefaction. Some water-sediment ejection and ground fracturing might occur in the thicker stream alluvium (Qa) deposits. Ground fracturing in these areas probably would be limited to fractures paralleling the walls of the larger stream channels. Modern beach deposits probably would not be greatly affected because of their general thinness and because, in most places, they do not have a confined water condition. Thicker deposits, however, may undergo a "quick" condition (Youd, 1973), where upward-percolating water during liquefaction tends to reduce the sand to a liquefied material. Loss of bearing strength results, causing settlement or tilting of structures built on the deposits. Little or no effects from water-sediment ejection and associated ground fracturing are expected in other deposits in the Ketchikan area.

Reaction of sensitive and quick clays

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

Sensitive or quick clays are not known to be present in the mapped area. However, some portions of the undifferentiated drift (Qd) may contain sensitive clays but have not been recognized because of the relative lack of exposures. No clay probably is sufficiently sensitive to be classed as a quick clay.

Effects of tsunamis, seiches, and other abnormal water waves

Abnormal water waves associated with large earthquakes have caused vast property damage and heavy loss of life in a number of places throughout the world.[1] Tsunami effects can be highly damaging to coastal areas many thousands of miles from the generation source. Seismic seiche effects generally are confined to inland bodies of water or to relatively enclosed coastal bodies of water. Other abnormal waves, generated by submarine sliding or by subaerial landsliding into water, generally produce only local effects; nevertheless, they may be highly devastating.

Inasmuch as the magnitude of an earthquake generally has to be 7 or greater to produce a noticeable tsunami and 8 or greater to produce a disastrous tsunami (Wiegel, 1964), it is highly unlikely that a generation source for a large tsunami would be closer to Ketchikan than the Queen Charlotte Islands fault. Tsunami waves originating from the area of this fault or from a more distant source expectably would be greatly attenuated during travel up the straits and inlets before reaching Ketchikan. It should be noted, however, that under certain conditions tsunami waves can travel up long narrow inlets and attain runups of 5 to 10 feet (1.5-3 m). (See discussion in Lemke and Yehle (1972a).) Height of tsunami wave runup and resultant damage at Ketchikan would depend in large part upon the arrival time of the waves in relation to the phase of the tide. For example, a wave 15 feet (4.5 m) high could crest during lower low tide and still not have a runup above normal higher high water. On the other hand, a 5- to 10-foot (1.5- to 3-m) -high wave arriving at Ketchikan during high tide could cause devastating damage to the harbor area, particularly if it came crashing into shore as a breaker. It should be noted, however, that only two tsunamis with low wave heights have been recorded on mareograms for the Ketchikan area: (1) a 0.3-foot (0.1-m) -high wave resulting from the Queen Charlotte Islands earthquake of August 22, 1949, and (2) a 2-foot (0.6-m) -high wave resulting from the great Alaska earthquake of March 27, 1964[2] (Cox and Pararas-Cayayannis, 1969). Therefore, on the basis of past known wave heights,

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[1] See Lemke and Yehle (1972a), Lemke (1974), and Yehle (1974) for more detailed descriptions of wave types and effects from them. Also see "GLOSSARY" for definitions of "tsunami" and "seismic seiche."

[2] J. Barry of Ketchikan reported (oral commun., 1965) that the U.S. Coast Guard stationed at the southeastern end of Ketchikan recorded abnormal surges of the tide up to a maximum of 7 feet (1.2 m) above normal tide level.

it seems unlikely that a tsunami wave as much as 10 feet (3 m) high would arrive at Ketchikan.

There are no bodies of water in the Ketchikan mapped area where seismic seiches are likely to develop. However, seiching upon nearby lakes, such as upon Ketchikan No. 1 and No. 2 Lakes, Carlanna Lake, and Ward Lake (fig. 2) could affect water supplies by causing failure of earth-filled dams impounding these lakes. Power facilities possibly also could be affected by seiching upon Upper and Lower Silvis Lakes, about 5 miles (8 km) northeast of Ketchikan. Height of seiche waves that might be generated upon these lakes during an earthquake cannot be estimated with any degree of assurance. The highest seiche wave reported in the Ketchikan area was during the earthquake of August 22, 1949, when a 2-foot (0.6-m) -high seiche wave was generated on Ward Lake (U.S. Weather Bur., 1918-1958). However, seiche waves as much as 6 feet (1.8 m) high were recorded during the great Alaska earthquake as far away from the epicenter as the coastal regions of Louisiana and Texas (McGarr and Vorhis, 1968). Also, 20- to 30-foot (6- to 9-m) -high runups from seiche waves were documented on Kenai Lake, about 60 miles (48 km) from the earthquake epicenter (McCulloch, 1966). Because the seismic waves travel so much faster than tsunami waves, they can cause damage in an area before any tsunami waves could arrive.

It is unlikely that destructive waves will be generated in the Ketchikan area by earthquake-induced local submarine sliding or by subaerial landsliding into water. Other than the fan-delta deposits (Qf) and associated manmade fill (f), no masses of slide-prone material large enough to generate significant wave action are known to be present in the area. Even these deposits are believed to be fairly small, and sudden displacement of large volumes of water by slide material, with subsequent wave generation, seems unlikely. The potential for slide-generated waves from a somewhat more distant source cannot be fully evaluated. However, no slide-prone foreslopes of large deltas, such as are believed to exist in the Wrangell area (Lemke, 1974), are known to be present in the general area of Ketchikan. Any waves that might be generated, though, can be highly destructive, because they generally hit the shore suddenly during or immediately after an earthquake and because their occurrence and runup height at any particular locality are largely unpredictable.

Effects on ground water and streamflow

It is well known that large earthquakes can affect ground and surface water regimens. Waller (1966) noted several short-term effects of the great Alaska earthquake of 1964 on ground water. Surface-water changes included diminished or increased streamflow. Changes in streamflow commonly were controlled by ground fracturing in or near streambeds and by snow and rock avalanching. Most landslides blocked streams for only short periods, but effects from some persisted for months (Waller, 1966; Lemke, 1967).

Inasmuch as Ketchikan obtains its entire water supply from surface sources, any changes in ground-water flow or quality are not presently pertinent. It seems unlikely that the quantity of the surface supply would be significantly affected unless large-scale landsliding occurred along the valley walls of the stream channels or the slopes above the reservoirs and either temporarily blocked the streamflow or diminished the holding capacities of the reservoirs. Earth dams impounding the reservoir waters might also fail as a result of landsliding above or onto the dams.

Summary of inferred effects from future earthquakes

Land-level changes due to local faulting are unlikely in the Ketchikan area. However, large-scale regional deformation resulting from a large earthquake along the Queen Charlotte Islands fault could possibly result in land-level changes at Ketchikan. Uplift or subsidence of as much as 5 feet (1.5 m) could produce adverse effects throughout a large part of the waterfront area. If Ketchikan were strongly shaken by an earthquake, it seems likely that the harbor and other waterfront facilities would be most heavily damaged. Nonengineered loose manmade fills (f), which have been placed along the shore to elevate low-lying areas above high tide, are expected to be subject to comparatively strong shaking; they also may be subject to settlement, possible liquefaction, and to sliding. The fan-delta deposits (Qf) also are expected to be subject to comparatively strong ground shaking, as well as to settlement, liquefaction, water-sediment ejection and associated ground fracturing, and sliding. Offshore deposits probably are subject to liquefaction and on sloping bedrock surfaces are subject to submarine sliding. Modern beach deposits (Qb) probably are too thin in most places to be significantly affected.

Earthquake effects expectably would be considerably fewer and less severe for the part of Ketchikan upslope from the harbor area. Ground shaking would be much less strong for most of this part of the city because bedrock is at or near the surface in large parts of the area; in most other places ground motion would be less amplified by the surficial deposits present than by those along the shoreline. Ground motion, however, probably would be amplified in thicker stream alluvium (Qa) and possibly in some muskeg deposits; some settlement, liquefaction, water-sediment ejection, and slumping may occur in these deposits.

Effects from abnormal water waves are not expected to be large. Tsunami waves are not expected to have a local generation source. Those arriving from a distant source, although potentially highly destructive, probably would be greatly attenuated in traveling up inlets to Ketchikan from the open ocean. There are no bodies of water in the mapped area where seismic seiche waves are likely to develop. Seiching upon some nearby lakes, however, may affect water supplies if earth-filled dams impounding these lakes should fail. It is unlikely that destructive waves will be generated by earthquake-induced local submarine sliding because no masses of slide-prone material large enough to generate significant wave action are known to be present in the area.

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

Geologic hazards other than those caused by earthquakes are believed to be minor in the Ketchikan area. They probably are restricted primarily to (1) nonearthquake-induced landsliding and subaqueous sliding, and (2) flooding.

Landsliding and subaqueous sliding

Other than a few small debris slides on some colluvium-covered steeper slopes and minor local slumps in some manmade cuts, no landsliding has been found in the mapped area. However, in addition to the large landslide that buried the hydroelectric power plant in the Lake Silvis area (fig. 2) in 1970, several fairly large debris-type slides have occurred in nearby areas.[1/] As pointed out by Swanston (1969), most landslides of this type in southeastern Alaska are the direct manifestation of natural mass wastage and slope reduction; some, however, result from logging and logging-road construction.

No significant cutting of trees on steeper slopes is presently being done in the Ketchikan mapped area. However, as the city expands, additional heavily timbered areas on moderately steep slopes will be cleared. Denudation of these areas, together with street and road construction, will tend to accelerate erosion and produce mass wasting and debris slides where surficial deposits mantle the bedrock. Bedrock, however, forms the steepest slopes and, other than minor rockfalls, little or no slope failures are anticipated in those areas.

Although no sliding is known to have occurred, the greatest potential for nonearthquake-triggered sliding probably is along the shoreline, where fairly thick fan-delta deposits (Qf) rest on a sloping underwater bedrock surface. Of special consideration is the area in the vicinity of the intersection of Mill Street and Front Street, where 20 to 50 feet (6.1-15 m) of fan-delta deposits, overlain by 15 to 20 feet (4.6-6.1 m) of fill, lies on a moderately steep seaward-sloping bedrock surface. In recognition of the potential instability of this area, the State of Alaska Department of Highways (1966a) recommended that all piling and caissons placed in connection with street construction in this area should penetrate at least 3 feet (0.9 m) of bedrock. Other fan-delta areas, such as at Bar Point and Charcoal Point as well as at other shoreline areas where surficial deposits may lie on a moderate to steeply sloping bedrock surface, should be carefully investigated before major construction is undertaken. Shoreline slopes, now stable, may become unstable as a result of constructing heavy structures and adding to the surcharge of the area.

[1/] Large slides were observed from a distance or seen on aerial photographs.

Flooding

The potential for damage from flooding appears to be limited chiefly to floods that may occur along Ketchikan, Schoenbar, and Carlanna Creeks. Ketchikan Creek, which is fed by two earth-dammed lakes, has been subject to periodic flooding, and on at least one occasion in 1963 floodwaters topped Stedman Street (State of Alaska Dept. Highways, 1966b). On October 26, 1974, the earth dam impounding Carlanna Lake ruptured following heavy rains, sending a torrent of water, mud, and logs down Carlanna Creek (Alaska Magazine, 1974). The force of the water destroyed the bridge along the main highway, disrupting traffic between Ketchikan and the area to the northwest for several days. Floodwaters also surged through a mobile home court built on fan-delta deposits (Qf) near the mouth of Carlanna Creek. Drinking water was temporarily cut off for part of the city, and electrical utilities were damaged. City officials estimated loss of the dam and damage to other utilities at $1.2 million and private property losses at more than $300,000.

Future flooding in the Ketchikan area may occur because of: (1) periods of exceptionally heavy rainfall, such as have occurred in the past; (2) failure of upstream earth dams; (3) construction of stream channels (flood plains) by emplacement of manmade fill or other obstructions; or (4) by increased surface runoff due to cutting of timber upstream or of paving of large surface areas. It should be noted that the last three are in large part man induced and can be controlled.

RECOMMENDATIONS FOR ADDITIONAL STUDIES

Because of the reconnaissance nature of the studies, there was insufficient time to make many of the geologic studies necessary to fully evaluate the geologic hazards of the area. Listed below, in approximate order of importance, are some of the additional studies that I believe should be made by geologists or specialists in other disciplines to more fully make these evaluations:

1. In order to permit a more adequate assessment of the earthquake probability of the area, studies should be made to locate more accurately all the major regional and local faults and to determine if possible the degree of activity along their lengths. Sophisticated instrumentation studies, particularly, should be made on the Queen Charlotte Islands fault. Also, it would be important to determine whether the known fault along the southeastern end of the Tongass Narrows lineament on Annette Island extends northwestward up Tongass Narrows offshore from Ketchikan and, if so, the time of latest movement on it.

2. Additional analyses are needed to more adequately determine the physical properties of the surficial deposits in order to better evaluate their behavior in respect to earthquake and other hazards. Onshore and offshore drilling and geophysical work are needed to determine thicknesses of geologic units and the topographic relations of the units to bedrock, especially of shore and nearby offshore areas.

3. Geologic mapping and related studies should be made of additional areas outside the city of Ketchikan where future development can be expected, such as the area of Ward Cove and Saxman.

GLOSSARY

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

Acceleration: The time rate of change of velocity in either speed or direction. The force imposed on structures by ground shaking varies with the acceleration of ground shaking. The acceleration reaches a maximum during each shaking cycle when the direction of ground movement reverses. The maximum acceleration varies with the change in velocity that occurs and the elapsed time during which the change in velocity takes place. Maximum accelerations are commonly expressed as a percentage of the acceleration of gravity. For example, an acceleration of 16.1 feet (4.9 m) per second per second may be expressed as 50 percent g where g is the acceleration of gravity, 32.2 feet (9.8 m) per second per second.

Amplitude: In relation to ground motion caused by earthquakes, refers to the maximum value of the displacement in an oscillatory motion.

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

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

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

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

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

Ground amplification: The amount by which the amplitude of ground motions at the surface of a surficial unconsolidated deposit exceeds the amplitude of ground motions at the surface of the underlying bedrock. Amplification arises from the multiple (successive) reflection of seismic waves between the ground surface and the bedrock surface underlying the unconsolidated deposit. Maximum amplification occurs when the internal deformations induced by the reflected waves augment the deformations induced by the incoming waves from underlying bedrock; in other words, when the reflected waves are in phase with the incoming waves.

Ground shaking: The severity of ground shaking at a specific location during an earthquake is defined qualitatively in terms of intensity scales (see Intensity) and quantitatively in terms of instrumental observations of ground motions. The latter permits ground shaking to be characterized by three factors: (1) the amplitude of the strongest ground motions which may be expressed in terms of accelerations, velocities, or displacements; (2) the predominant frequency or period of the strongest motions; and (3) the duration of strong shaking.

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

Intensity: Refers to the severity of ground motion (shaking) at a specific location during an earthquake and is based on the sensations of people and visible effects on natural and manmade objects. The most widely used intensity scale in the United States is the Modified Mercalli intensity scale. (See table 2.)

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

Liquefaction: The transformation of a granular material from a solid state into a liquefied state as a consequence of increased pore-water pressure (Youd, 1973).

Liquid limit: The water content in percent of dry weight at which soil passes from the liquid state into the plastic state (Terzaghi and Peck, 1948, p. 32-36).

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

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

Moisture content: The loss in weight when a material is dried to a constant weight; ~~and~~ expressed as a percentage of the dry material.

Muskeg: Muskeg is a term commonly used to designate organic terrain. However, for purposes of this report the term "muskeg" will be used in more or less of an engineering sense and with the material itself being emphasized more than the landform. Thus, muskeg is defined here as "Organic-rich deposits consisting of peat and other decaying vegetation that are commonly found in swamps and bogs." The term "peat" is used more or less interchangeably with the word "muskeg" in this report.

Plasticity index: The numerical difference between the liquid limit and the plastic limit. Represents the range of moisture content within which a soil is plastic (U.S. Bur. Reclamation, 1968, p. 8, 28).

Plastic limit: The water content of a soil in percent of dry weight at the boundary between the plastic state and the solid state (Terzaghi and Peck, 1948, p. 32-36).

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

Schistosity: The property of a foliated rock to split into thin layers or flakes.

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

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

Shrinkage limit: The water content below which further loss of water by evaporation does not result in a reduction of volume of a soil (Terzaghi and Peck, 1948, p. 33).

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

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

Tsunami: A sea wave, otherwise known as a seismic sea wave, generated by sudden large-scale vertical displacement of the ocean bottom as a result of submarine earthquakes or of volcanic action. Tsunamis in the open ocean are long and low, and have speeds of 425-600 miles (680-960 km) an hour. As they enter shallow coastal waters they can greatly increase in height and also in height and distance of runup onto land.

Void ratio: The ratio of the volume of the voids to the volume of the solids.

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