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Reconnaissance Engineering Geology of the Petersburg Area, Southeastern Alaska, with Emphasis on Geologic Hazards

by

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RECONNAISSANCE ENGINEERING GEOLOGY OF THE PETERSBURG AREA, SOUTHEASTERN ALASKA, WITH EMPHASIS ON GEOLOGIC HAZARDS

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ABSTRACT

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

Landscape of the northern end of Mitkof Island on which Petersburg is situated is characterized by a gently sloping, muskeg-covered terrain, with altitudes mostly less than 30 m. In contrast, much of the rest of the island is composed of mountainous terrain with many steep valleys.

During the Pleistocene Epoch, the Petersburg area presumably was covered by ice several times; glaciers deeply eroded many valleys on Mitkof Island and adjacent areas. The last major deglaciation probably was largely completed by 12,000 years ago. Delayed rebound of the earth's crust, after the melting of large amounts of ice, permitted extensive inundation of land in the Petersburg area. Subsequently, emergence has elevated marine deposits to a present-day altitude of at least 65 m and probably to 75 m.

Bedrock in the Petersburg map area is composed of relatively hard metamorphic rocks, chiefly phyllite and probably some graywacke. Rocks are of Middle(?) Jurassic to Early Cretaceous age. Five types of surficial geologic material of Quaternary age were recognized: (1) mixed deposits consisting of diamicton, silt-clay, and sand or sandy pebble gravel, (2) alluvial deposits, (3) shore and delta deposits, (4) organic deposits, and (5) artificial fill.

Geologic structure in southeastern Alaska is complex because several cycles of tectonic deformation since at least early Paelozoic time have affected different parts of the region. The latest of the major tectonic events in southeastern Alaska occurred in Tertiary time, with some minor activity continuing into the Quaternary Period. Along the outer coast of southeastern Alaska, active strike-slip movement is occurring along the Chichagof-Baranof and Queen Charlotte faults. A segment of the prominent Coast Range lineament, part of which may be a fault, lies 18 km northeast of Petersburg.

Many earthquakes occur along the outer coast of southeastern Alaska. Most of these shocks are associated with movements along the Chichagof-Baranof, Queen Charlotte, and Transition faults. A few small earthquakes occur in the region between the outer coast and the southern part of the Coast Mountains. Only a few earthquakes have been recorded as felt at Petersburg; these shocks and others possibly felt in the Petersburg region are tabulated. Among the recorded earthquakes the highest intensity (about V-VI) was the magnitude 7.1 earthquake of October 24, 1927, that occurred probably along the Chichagof-Baranof fault, and about 225 km northwest of Petersburg; damage was reported as minor. Other large earthquakes along the Chichagof-Baranof fault that affected or probably affected the Petersburg area in a minor way occurred on August 22, 1949, (magnitude 8.1) and on July 30, 1972 (magnitude 7.25).

From a consideration of the tectonics and earthquake history of the region, earthquakes similar to the 1927, 1949, and 1972 shocks are expected to recur on segments of the Chichagof-Baranof or Queen Charlotte faults. The closest of these fault segments is about 170 km southwest from Petersburg. The likelihood of destructive earthquakes being generated along faults closer to Petersburg is unknown.

A very generalized discussion of possible geologic effects that could occur in the area during a postulated, theoretically reasonable worst case earthquake of magnitude 8 occurring along the outer coast about 170 km southwest from Petersburg notes that ground shaking probably would be strongest on organic deposits and least on bedrock and on firm, compact diamicton. Among other effects that could happen are: (1) liquefaction of some of the few delta and alluvial deposits, (2) ejection of water and sediment from some of the few alluvial and delta deposits, (3) compaction and differential subsidence of some of the few alluvial and delta deposits, (4) local landslides, (5) perhaps, minor alterations in the movement of ground water within alluvial and delta deposits, and (6) earthquake-induced water waves including tsunamis, seiches, and local waves generated by landslides; waves could develop to heights possibly 1-2 m above normal tide level. Earthquakes of lesser magnitude and/or at greater distance along the same fault structure would, of course, affect the area less strongly.

Geologic hazards not necessarily related to earthquakes include: (1) high water waves, (2) landslides in areas of steep slopes, (3) drifting icebergs, and (4) stream floods and erosion of deposits by running water and sheet floods.

Recommended additional investigations in the Petersburg area and region include:

1. Continued geologic work in order to determine (a) physical properties of special surficial deposits like the silt-clay of the mixed deposits, (b) potentially liquefiable geologic materials, (c) areas most suitable for construction, and (d) potentially unstable slopes especially in the region along the northeast shore of Frederick Sound and at the Crystal Lake hydroelectric power facility.
2. Determination of the approximate location of possible future large earthquakes through use of geophysics, tectonic analysis, and high-sensitivity seismologic instruments.
3. Examination of the potential for large-scale failure of underwater slopes along the rapidly extending Stikine River delta.
4. Determination of the oscillation period of large bodies of water like Frederick Sound in order to help predict possible wave heights during seiching. A companion study should determine tsunami travel times along the several routes from the open ocean.
5. Studies of the fluctuations of growth and retreat of tidal and near-tidal glaciers, to assist prediction of regional iceberg abundance in waterways.

INTRODUCTION

Soon after the great Alaska earthquake of 1964 (March 28, u.t.[1]), the U.S. Geological Survey began a program of geologic study and evaluation of earthquake-damaged cities in Alaska. Subsequently, the Federal Reconstruction and Development Planning Commission for Alaska recommended that the program be extended to other communities in Alaska that had a history of earthquakes, especially communities near tidewater. As a result, Petersburg and several other cities in southeastern Alaska were selected for investigation. Reports have been completed for (1) Haines (Lemke and Yehle, 1972a),[2] (2) Juneau (Miller, 1972), (3) Ketchikan (Lemke, 1975), (4) Metlakatla (Yehle, 1977), (5) Sitka (Yehle, 1974), (6) Skagway (Yehle and Lemke, 1972), (7) Wrangell (Lemke, 1974), and (8) Yakutat (Yehle, 1975, 1978); a generalized regional report was prepared for southeastern Alaska (Lemke and Yehle, 1972b). This report on the Petersburg area highlights the geology, emphasizes the evaluation of potential effects from major earthquakes, and describes other geologic hazards, including high water waves, stream flooding, and erosion. Although geologic descriptions and evaluations of hazards are preliminary, they should be helpful in some measure in land-use planning for Petersburg and nearby areas on Mitkof Island.

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

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

Mapping and collection of geologic information were done in the Petersburg area for short periods during 1965 by R. W. Lemke and L. A. Yehle, during 1968 by L. A. Yehle, and during 1972 by R. W. Lemke (R. W. Lemke, unpub. data 1965, 1972; written commun., 1966; L. A. Yehle, unpub. data, 1968). Approximately 2 weeks were spent in the study area. In addition this study was supplemented by geologic work of others (cited where referred to in the report) and by interpretation of airphotos by L. A. Yehle using year 1963 U.S. Forest Service airphotos. A large part of the mapping should be considered of a reconnaissance nature.

Several U.S. Geological Survey colleagues gave important help during phases of the study; sample analyses were done by E. E. McGregor, P. S. Powers, Meyer Rubin, R. A. Speirer, and R. C. Trumbly. In addition, helpful information was obtained from Federal, State, and city of Petersburg officials, private citizens, and personnel of engineering and construction companies who have worked in the Petersburg area.

A glossary is included near the end of the report to assist readers who may be unfamiliar with some of the geologic terms used.

GEOGRAPHY

Petersburg is situated on northernmost Mitkof Island in the east-central part of southeastern Alaska, 195 km south-southeast of Juneau (fig. 1; fig. 2, in pocket) at lat 56°49' N. and long 132°57' W. The Petersburg area is considered in this report as the area shown in figure 3 (in pocket); it includes the city of Petersburg and vicinity. The Petersburg region is herein considered to be the region shown in figure 2 and includes Mitkof Island and the eastern parts of Kupreanof and Woewodski Islands in addition to many smaller islands and a part of the Coast Mountains on the mainland. Principal waterways surrounding Mitkof Island are (1) along the east and northeast, the mostly very deep water Frederick Sound, (2) along the west and northwest, the constricted, relatively shallow Wrangell Narrows, and (3) along the south, the mostly deep water Sumner Strait.

Petersburg is located on the gently sloping margins and upper surface of a low-relief muskeg terrain that covers chiefly an emerged marine-shore zone whose altitude mostly is below about 30 m; few large areas of similarly low-relief terrain occur elsewhere on Mitkof Island. Most of the remainder of the island consists of gentle- to steep-sided glaciated valleys and moderately rugged to rugged mountains that have a maximum altitude of 1,011 m on the southwest part of the island near Crystal Lake (at desig. 5, fig. 2). The large delta of the Stikine River is the dominant geographic feature adjacent to the easternmost part of Mitkof Island. The major distributaries, designated 1, 2, and 3 in figure 2, carry vast amounts of sediments which are deposited in the shallowing heads of Frederick Sound and Sumner and Dry Straits.

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

Petersburg and its harbor facilities front northwestward onto Wrangell Narrows; at the city the narrows are about 0.8 km wide and have depths averaging 9 m. There is no continuous-recording tidal gage at Petersburg Harbor; tidal benchmarks were installed and tidal levels measured in 1910, 1917, 1958, and 1960 (U.S. Coast and Geod. Survey, 1960; Hicks and Shofnos, 1965). From the latest (1960) data the mean tide range is given as 4.5 m, the estimated highest tide is 6.2 m, and the estimated lowest tide is minus 1.4 m.

Despite its 130-km direct distance from the outer coast of the Pacific Ocean, Petersburg has a maritime climate because of the large numbers of wide, tidal waterways. Climatological data for Petersburg for 1973 list a mean annual temperature of 4.6° C. and precipitation of 2,743 mm/yr (U.S. Natl. Weather Service, 1973). Miller (1963) estimated that the theoretical maximum 100-year rainfall in any 24-hour period for northern Mitkof Island is about 200 mm.

Petersburg was founded in 1897, but continuous occupation did not begin until 1905 (Alaska State Housing Authority, 1966, p. 10). The first dwellings were established near the mouth of Hammer Slough (fig. 3). Locations of some of the municipal and transportation facilities that serve the Petersburg area are shown in figures 2 and 3; the main water-supply reservoir is about 7 km southeast of Petersburg (desig. 4, fig. 2) and the Crystal Lake portion of the hydroelectricity system is located 26 km south-southeast of the city (desig. 5, fig. 2).

GLACIATION AND ASSOCIATED LAND- AND SEA-LEVEL CHANGES

The Petersburg area probably was covered by glacier ice during several different intervals of the Pleistocene Epoch when huge icefields developed and valley glaciers flowed outward from the Coast Mountains. During the culmination of the last major glacial advance, ice overlying the site of Petersburg may have been between 1,160 and 1,220 m thick (Østrem, 1972; U.S. Geol. Survey, 1965). Near the close of the Pleistocene Epoch, glaciers melted and retreated because of worldwide, major climatic warming; most glacier ice probably disappeared from the Petersburg area between 13,000 and 12,000 years ago. In many low areas of southeastern Alaska and coastal British Columbia, as the ice became relatively thin and sea level rose, the ice floated. In the Petersburg area, floating or shelf ice probably was very common for several thousand years near the end of the last major deglaciation. The glaciomarine sediments deposited in this environment beneath the floating ice were of several types representative of ice, marine, and submarine landslide origins. Locally, marine life was abundant; table 1 lists marine megafossil shells from four collecting localities on Mitkof Island. Armstrong and Brown (1954) and Miller (1973, 1975) described similar glaciomarine environments for the Vancouver, British Columbia, and Juneau, Alaska, areas respectively.

Following major deglaciation, numerous glacial erosional landforms were exposed in the mountainous parts of Mitkof Island; characteristic landforms such as large, partly rounded knobs of bedrock and U-shaped valleys are common. Locally, constructional landforms of glacial origin probably are present. Below an altitude of about 75 m glacial erosional and glacial depositional landforms are mostly overlain by glaciomarine, marine, and relict shore and delta deposits. All deposits generally are obscured by a mantle of organic deposits.

Table 1.--Cenozoic marine megafossils collected from Mitkof Island, southeastern Alaska
[See fig. 2 for collection localities; ----, not found]

Fossil type	U.S. Geol. Survey Cenozoic collection designation; location in fig. 2			
	M2543; A	M3944; B[1]	M2542; C	M2541; D[1]
Gastropoda (Snails)				
Acmaea cf. *A. mitra* Eschscholoitz	----	----	----	X
Buccinum plectrum Stimpson	----	X	----	----
Colus sp.	----	X	----	----
Fissurellid?	----	X	----	----
Lepeta concentrica Middendorf	----	----	----	X
Margarites sp.	----	----	----	X
Neptunea cf. *N. decemcostata* (Say)	----	X	----	----
Neptunea cf. *N. lirata* (Gmelin)	----	X	----	----
Oenopota? sp.	----	----	----	X
Pyramidellid, worn	----	----	----	X
Serpulorbis sp.	----	X	----	----
Pelecypoda (Bivalves)				
Astarte fabula Reeve	----	----	----	X
Chlamys rubida hindsii (Carpenter)	X	----	----	----
Chlamys cf. *C. rubida hindsii* (Carpenter)	----	X	X	----
Clinocardium?	----	X	----	----
Mytilus sp.	----	----	----	X
Protothaca staminea (Conrad)	----	----	----	X
Saxidomus giganteus Deshayes	----	----	----	X
Cirripedia (Barnacles)				
Balanus crenatus Bruguiere	----	X	----	----
Balanus sp.	----	----	----	X
Amphineura (Chitons)				
(fragments only)	----	----	----	X

SAMPLE DESCRIPTIONS

M2543 - collected by R. W. Lemke, 1965, field loc. N-7, L-23, alt. 16 m ; identification by F. S. MacNeil (written commun., 1965).

M3944 - collected by L. A. Yehle, 1968, field loc. 68AYe-P2b, alt. 38 m ; identification by W. O. Addicott (written commun., 1968).

M2542 - collected by R. W. Lemke, 1965, field loc. N-6, L-22, alt. 14 m ; identification by F. S. MacNeil (written commun., 1965).

M2541 - collected by R. W. Lemke, 1965, field loc. N-1, L-21b, alt. 8 m ; identification by F. S. MacNeil (written commun., 1968).

[1] Some of the fossils from this locality dated by radiocarbon method. See table 2.

During the Holocene Epoch (about the last 10,000 years), minor fluctuations of climate caused advances and retreats of glaciers that are well documented elsewhere in southeastern Alaska (Barnwell and Boning, 1968; Goldthwait, 1963, 1966; Heusser, 1960; McKenzie, 1970; Péwé, 1975). For Mitkof Island, it seems likely that a few glaciers re-formed in some of the heads of the highest valleys of the island and advanced and retreated in a similar manner. At the present time there are no glaciers on Mitkof Island, but, in the Coast Mountains northeast and east of Petersburg, glaciers form a prominent part of the terrain; icebergs from one of the glaciers are a common sight in parts of Frederick Sound.

The absolute ages of Quaternary deposits in the Petersburg region are unknown. However, three radiocarbon dates on marine megafossil shells from several localities on Mitkof Island (desigs. B, D, and E, fig. 2; table 2) were determined that provide a minimum age for some marine, glaciomarine(?), and relict shore and delta deposits. Fossils from locality E (fig. 2) at an elevation of 65 m on northern Mitkof Island were altitudinally the highest fossils observed; they dated as 12,400±800 years B.P. (before present) (table 2).

The position of level of land in relation to sea level in the Petersburg area has changed greatly within the past tens of thousands of years, and it apparently is continuing to change. The primary cause of change has been the response of the earth's crust to expansion and advance, and then the contraction and retreat, of large glaciers during the Pleistocene and Holocene Epochs. The weight of large volumes of glacier ice depresses land; Gutenberg (1951, p. 172) noted that 205 m of ice is theoretically capable of causing a depression of the earth's crust of 83 m. Melting of ice permits land to rebound. In most areas, however, there is enough of a time lag between melting and complete rebound to allow marine waters to cover low areas for

Table 2.--Radiocarbon determination of age of marine megafossil shells, Mitkof Island, southeastern Alaska [See fig. 2 for location of shell samples]

Location (fig.2) and altitude	U.S. Geol. Survey field no. and radiocarbon lab. no.	Age, yrs. B.P. (before present)	Type or part of fossil shell dated; paleontological data	Enclosing sediment	Environment of deposition	Underlying deposit
[1]B; 38	N-6; 68AYe-P2a; W-2327	12,170 ± 400	Barnacle plates; see table 1 for identification of fossils at loc. B	Fine sand	Shore	Mixed, grading from diamicton to stone-free silt; contains microfossils
[2]D; 8	N-1; L-21a; W-1738	9,970 ±300	Pelecypod shells; see table 1 for identification of fossils at loc. D	Fine sand	Shore	Diamicton with numerous shell fragments
[3]E; 65	N-18; N-28b; W-1734	12,400 ±800	Fossil shells of small bivalves	Clay	Marine	Diamicton?

[1]Information from R. C. Trumbly (written commun., 1968), Meyer Rubin (written commun., 1969), and from R. W. Lemke (unpub. data, 1965), and L. A. Yehle (unpub. data, 1968.

[2]D, R. W. Lemke (*in* Ives and others, 1967, p. 523-524) and Unpub. data: R. W. Lemke, 1965.

[3]E, R. W. Lemke (*in* Ives and others, 1967, p. 524) and Unpub. data: R. W. Lemke, 1965.

several thousands of years (Andrews, 1976; Clague, 1975). Only an approximation of the total amount of relative emergence of Mitkof Island can be made. The approximation is provided by the maximum altitude (about 75 m) of diagnostic landforms or deposits, namely, (1) the upper limit of gentle slopes along mountain sides, (2) the presence of marine and glaciomarine deposits of silt and clay that include variable amounts of stones and marine fossils, or (3) the presence of small, relict shore and delta deposits of shell-bearing sand and/or pebble gravel. The highest known, readily accessible deposit of assuredly marine origin near Petersburg is at an altitude of 65 m (loc. E, fig. 2; table 2). At lower altitudes in the Petersburg area occurs a scattering of other small, relict shore deposits, mostly of sand and some pebble gravel, which mantle chiefly marine and glaciomarine deposits. At Twin Creek (fig. 2) about 11 km south-southeast of Petersburg is a relict delta; the outer margin of the delta lies at an altitude of about 60 m and the inner margin lies at about 75 m. On southern Mitkof Island relict shore deposits, many of which contain fossil shells (table 1), are well exposed in several places near the highway; the altitudinally highest deposit was at 38 m (loc. B, fig. 2). Shells from this deposit and a nearby one (loc. D, fig. 2) have been radiometrically dated (table 2). Along the part of the northeastern shore of Frederick Sound shown in figure 2, and farther northward and northwestward along the same shore, several relict shore and delta deposits were noted by Buddington and Chapin (1929, p. 277-278) at altitudes between 4 and 18 m.

Many places in southeastern Alaska and nearby British Columbia have been described by Twenhofel (1952) where emerged shore, marine, and glaciomarine deposits are present. The maximum recorded altitude of marine fossil-bearing deposits is near Juneau where A. C. Spencer noted (Buddington and Chapin, 1929, p. 278; Smith, 1965, p. 27) beach deposits and megafossil shells at altitudes of 193 m or more, and Miller (1975) showed microfossil locations in glaciomarine deposits at altitudes as high as 192 m.

Land at Petersburg is thought to have emerged relative to sea level at a rate of 0.37 cm/yr between 1910 and 1960, the most recent period of study (Hicks and Shofnos, 1965). Closer to large areas of melting glaciers than Petersburg, emergence rates should be higher; at Thomas Bay, 26 km northeast of Petersburg, an emergence rate of 0.79 cm/yr was determined for the period of 1887-1906 (Hicks and Shofnos, 1965). The most rapid rate of emergence known in southeastern Alaska is at Glacier Bay (fig. 1) where the rate was determined to be 3.96 cm/yr for the period 1938-1959 (Hicks and Shofnos, 1965). If the rate of emergence and other physical factors such as tidal currents remained constant for a period of 50 years, theoretically, at Petersburg the harbor would shallow 19.8 cm and the shoreline where sloping gently (1°, 1.75 percent) would be displaced outward 11 m.

The above discussion of relative land- and sea-level changes treats mean sea level as a long-term fixed level. This is only an approximation, because many factors may combine to slowly change the level of water in the oceans. A major factor is the worldwide relationship of sea level to the melting and nourishment of glaciers throughout the world (Higgins, 1965; Shepard and Curray, 1967).

DESCRIPTIVE GEOLOGY

Formal studies of the geology of that part of the Petersburg region that includes Mitkof Island have been conducted on only a limited scale since the early 1900's. The few reports available provide a general view of the framework of the geology of the region (Berg and others, 1972; Brew and others, 1976; Buddington and Chapin, 1929; Page and others, 1977; Taylor, 1967). The various types of bedrock and surficial deposits and their distribution in the Petersburg area are largely the result of several cycles of sedimentation, intrusion, deformation, and erosion that took place since Middle(?) Jurassic time. The major geologic faults and other possible discontinuities in bedrock of the region are described under "Structural geology."

Bedrock forming most of Mitkof Island is grouped within the Gravina-Nutzotin belt of rocks that parallels the coast of southeastern Alaska and extends northwestward to central Alaska (Berg and others, 1972). Bedrock on Mitkof Island consists chiefly of metamorphosed, fine-grained sedimentary and some interbedded volcanic rocks of Middle(?) Jurassic to Early Cretaceous age. Intrusive activity occurred during part of the same time interval and continued until somewhat later. The closest known igneous rocks on Mitkof Island to Petersburg are granodiorite rocks exposed in a quarry about 1.6 km south-southeast of Sandy Beach and about 0.8 km south of the map area (fig. 3). Some of the intrusive rocks on Mitkof Island are ultramafic (Berg and others, 1972, fig. 2; Page and others, 1977, p. 632; Taylor, 1967, p. 97, 111). During Tertiary and earlier times, extensive erosion and deposition by streams profoundly modified the land surface. These processes continued and were supplemented during the Quaternary Period by extensive glacial erosion and deposition.

Generalized information on the probable types of bedrock in the Petersburg area is available from the few known outcrops in my mapped area and from interpretation of geologic mapping by others in the surrounding region. Bedrock in the mapped area is composed mostly of very thin bedded or foliated phyllite[1] (fig. 3, in pocket), a rock type characteristic of slight to moderate regional metamorphism; such rocks form originally as fine-grained sediments. Locally, lenses of quartz are prominent within the phyllite. Although not known to be exposed in the map area, it is likely that there is some concealed bedrock that is composed of graywacke and lesser amounts of argillite and slate. Outside the mapped area, graywacke is well exposed about 0.8 km south of the airport in a quarry from which most of the fill for the airport was obtained. Bedrock may lie concealed at shallow depth (1.5 m) beneath the organic or other surficial deposits at several places in the Petersburg area. Where such thinly covered outcroppings of bedrock are thought to be present, the bedrock map unit designation on the geologic map bears a query . Bedrock exposed in the Petersburg area is relatively hard when fresh, but upon weathering, locally, it breaks down readily into very thin beds or foliations. Data on jointing and attitudes of bedding or foliation are given under "Local structure." The age of bedrock is interpreted as Middle(?) Jurassic to Early Cretaceous. None of the bedrock exposed in the Petersburg map area (fig. 3) is known to have been utilized for construction purposes.

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[1]Where map units are first described, the name is underlined.

To indicate the distribution of surficial geologic deposits in the Petersburg map area, several mapping units were established on the basis of geologic considerations and airphoto interpretation. The units in approximate ascending order of age are, oldest to youngest: mixed deposits, chiefly diamicton and silt-clay; alluvial deposits; modern shore and delta deposits; organic deposits; and artificial fill. The total thickness of surficial deposits is variable and ranges from a few meters to as much as 44 m (Kenneth Welde, oral commun. to R. W. Lemke, 1965), the thickness reported in the city's test well No. 1, south of Lumber Street (fig. 3).

The geologic map unit mixed deposits is a complex of several types of surficial geologic materials. Deposits may be considered in three different groups. These include (1) stony diamicton, which probably is the most prevalent type of deposit at depth; (2) stone-free silt-clay; and (3) uniform sand or sandy pebble gravel. Fossils of marine organisms, some of which have been identified and dated from elsewhere on Mitkof Island (tables 1 and 2), are present in several deposits.

The different types of mixed deposits are not differentiated on the geologic map because of (1) lack of exposures because deposits are commonly obscured by overlying thick organic deposits, and (2) evidence, where deposits are visible, of changes in textures and materials by intergrading of deposits both laterally and vertically. Deposits of groups 1 and 2 (diamicton and silt-clay) are widely distributed; their combined thickness may average 15 m and have a maximum of about 60 m. Deposits of group 3 (sand and gravel) are very spotty in distribution. They are as much as 2 m thick at the few places where they have been observed both in the area mapped geologically and nearby: (1) along roads southwest of the north point of Mitkof Island, and (2) about 0.4 km south of the map area (fig. 3) in abandoned borrow and test pits (loc. E, fig. 2).

Most geologic materials of groups 1 and 2 were deposited in a glacio-marine or marine environment in which icebergs were abundant during most of the time before emergence of the region. Diamicton deposits of direct glacial origin prevail at altitudes higher than about 75 m, and they probably are common, locally, at lower altitudes. Included in the materials may be a few deposits of sandy pebble gravel. Deposits of group 3 were deposited in a shore environment. In places where waves and tidal currents could have eroded stony diamicton deposits or bedrock, group 3 deposits would tend to be coarsest.

Mixed deposits are underlain by bedrock and overlain almost everywhere by an obscuring mantle of organic materials. Where the mantle of organic materials is thought to be thicker than about 2 m, organic deposits, instead, are shown on the geologic map.

Use of mixed deposits for construction purposes has been limited. Some diamicton deposits have been used as fill. The stony diamicton group of deposits should make a good foundation because of its firmness and compactness. Silt-clay deposits are moderately soft in consistency and generally only fair for foundations even where surface drainage is adequate; some deposits provide very poor foundations, because of extreme softness, poor drainage, and probably a very high content of clay-sized particles. The sand and gravel deposits are generally excellent as construction materials and foundations. The age of mixed deposits is Pleistocene and Holocene.

Alluvial deposits probably consist chiefly of sand and pebble gravel with some cobbles and boulders. The distribution of deposits shown on the geologic map (fig. 3) was determined exclusively by airphoto interpretation of stream courses. Alluvial deposits merge into deltas. Thickness of deposits may average 1.5 m and reach a maximum of 4.5 m. The underlying geologic materials are interpreted as being mostly diamicton and some silt and clay. Organic materials overlie the alluvial deposits in many places, especially in upper reaches of small valleys. At some locations organic materials may be more than 1 m thick.

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

The alluvial deposits are entirely of Holocene age. No engineering use is known to have been made of alluvial deposits in the area.

The map unit modern shore and delta deposits consists of two components--a shore component and a delta component, neither of which is separately delineated on the geologic map (fig. 3). Both components are largely intertidal. The shore component includes the berm of the storm beach and materials along the modern shore that are moderately well sorted and characterized chiefly by pebbles and (or) cobbles with lesser amounts of sand and boulders; the storm beach contains cobbles, pebbles, and some boulders and driftwood. Near bedrock outcrops and southeast of the north point of Mitkof Island there is less sand and pebbles, and there are more cobbles and boulders along the shore.

Diamicton underlies most of the modern shore area at depths that probably average 1.5 m. Maximum thickness of deposits may be 3 m. In some places bedrock is probably the underlying material.

The delta component consists of deposits in small modern deltas that are developed at the mouths of the small to moderate streams that drain the area. The most prominent deltas are at Hammer Slough and Long Pond. Deposits of most deltas probably consist chiefly of pebbly sand and sand containing some silt, especially near Hammer Slough and Long Pond. Diamicton probably underlies most of the modern delta deposits at depths averaging 2 m. In some places bedrock probably is the underlying material. Maximum thicknesses of deposits may be 6 m at the outer edges of some deposits. The origin of delta deposits is largely by a settling-out process of stream sediments as they enter bodies of relatively quiet water and are reworked and sorted by tidal currents and waves and progressively enlarged by growing outward into the more or less quiet water.

Use of modern shore and delta deposits may be limited to a few areas near Hammer Slough, Long Pond, Sandy Beach, and near the north point of Mitkof Island. As a foundation material, the deposits of this map unit may be well suited for structures adequately protected from waves and tides.

The map unit <u>organic deposits</u> has as its uppermost (surface) part the readily visible organic material, muskeg. Only those deposits 2 m or more thick are mapped. Where organic materials are considered to be of lesser thickness, the underlying material, mainly silt-clay, is shown on the map. Collectively, the organic deposits are called peat. At the ground surface, organic materials consist of wet ground dominated by sphagnum and other mosses, various sedges and other moisture-loving plants, plus several types of heaths and other small woody plants; included within the map unit are numerous small ponds. At depth are interstratified organic materials, mostly sedges, plus a variable amount of woody fragments (Dachnowski-Stokes, 1941, p. 19); all materials are in varying states of decomposition and consolidation. Fragments of volcanic glass were noted at depths of 0.5, 1.0, and 1.1 m within peat from one test hole intensively studied by Heusser (1952, p. 341); glass was also present at similar depths in peat from a second hole about 16 km south of Petersburg.

Thickness of deposits may average 2.5 m (Kenneth Welde, oral commun. to R. W. Lemke, 1972); the maximum thickness possibly is 7.5 m.

Physical properties of peats have been investigated intensively in several northern hemisphere areas. Characteristic features are high porosity, ease of consolidation, and a very high moisture content. Moisture retention capability is very high; moisture contents ranging from 180 to 860 percent of dry weight of solid material were determined by the Alaska Highway Department in the generally similar Sitka area, Alaska (Franklet, 1965). Because of very high moisture and porosity, most peat can be compressed. Other testing of peat by the Alaska Highway Department indicated 75-95 percent compression of the material beneath load; compression value depended upon the percentage of wood fragments in the particular deposit. Shear strength of peat is usually variable, though low; the range of sample-in-place values reported by MacFarlane (1969, p. 96) from areas in Canada varies from 0.05 to 2.0 g/cm^2. Peat may lose its coherence and approach a physical state resembling liquefaction during times of heavy construction activity because of the generation of certain types of vibrations by power equipment.

Muskeg deposits overlie map unit mixed deposits (diamicton, silt-clay, and sand and sandy pebble gravel), alluvial deposits, and bedrock. In some places, muskeg is overlain to a depth of ~~less than 0.9~~ as much as 1 m by artificial fill.

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

No commercial use is known to have been made of peat in the Petersburg area, although studies of the material as a resource were accomplished by Dachnowski-Stokes (1941, p. 18-22). Road, airport, and building construction in areas of thick muskeg must employ various techniques to partially overcome the problems of the softness and ease of consolidation of the material. At a construction site, it is preferable to remove most of the peat, but, except where peat is less than about 3 m thick, removal is generally impractical. Where peat is thick, foundations for buildings usually are set on piles placed through the peat and resting on or within the underlying material. Roads or airport runways designed to cross thick peat can be planned so as to consolidate peat uniformly, by correctly placing a fill that is specific in thickness for the type and thickness of peat to be overlain. MacFarlane (1969, p. 106) noted the desirability of using no more than 2.4 m of fill over peat deposits more than 4.6 m thick to achieve a uniform flotation of the fill without foundering or without excessive lateral flowage of the peat. A new method of supporting roads constructed over thick organic deposits has been tried successfully by the U.S. Forest Service at Ideal Cove, Mitkof Island (fig. 2), about 26 km southeast of Petersburg. Their procedure was to directly cover the deposits with foamed-in-place urethane, which in turn was covered by road fill (Selkregg, 1976, p. 113). Controlled flowage (resembling liquefaction) of peat has been used as an excavation method near Prince Rupert, British Columbia (fig. 1; Stanwood, 1958). There, in areas where slopes were moderate to relatively steep and underlying materials were firm, large bulldozers pushed and were able to liquefy masses of peat as much as about 3.5 m high and 75 m in longest dimension. The age of organic deposits is Holocene.

Artificial fill as shown on the geologic map includes (1) those materials that have been used to cover natural ground, and (2) those areas of ground that have been modified during construction; thus, their origin cannot be readily determined. Only large joined-areas of fill and modified ground are shown on the map; neither separate minor fills nor most road embankments are mapped. Several varieties of geologic materials have been used for fill in the Petersburg map area. In decreasing order of volume used, fill includes: (1) rock quarried from south of the airport and mapped area, for use as unclassified fill for airport construction; (2) rock quarried from south of Sandy Beach and the map area; (3) sandy pebble gravel from modern shore and delta deposits, probably from several localities; (4) sand and pebble gravel from emerged shore deposits south of Sandy Beach and the mapped area; and (5) pebbly sandy silt from diamicton deposits, probably from several localities.

Thick fills placed over thick organic deposits are susceptible to subsidence and lateral flowage because of compaction of the underlying, easily compressible organic deposits.

Thickness of artificial fill deposits may average 1.5 m, and the maximum, at the airport, possibly is 9 m.

STRUCTURAL GEOLOGY

Regional setting

Southeastern Alaska is a segment of a belt of active tectonic regions that rims a large part of the Pacific Ocean. From time to time, at least since the late Mesozoic, geologic events such as large-scale plutonic intrusions, widespread metamorphism, and large-scale structural deformation have taken place in that segment of the belt which includes southeastern Alaska (Berg, 1972b; Berg and others, 1972; Brew and others, 1966; Buddington and Chapin, 1929). The latest major tectonic events in southeastern Alaska occurred in Tertiary time, some minor activity continuing into the Quaternary Period. Most structural features such as fold axes and faults trend northwesterly, but some trend northerly and a few trend northeasterly (Reeves, 1976; Twenhofel and Sainsbury, 1958). Prominent among structural features are several faults along which considerable movement is suggested. Some of these major fault zones and lineaments in southeastern Alaska and nearby regions are shown in figure 4. The most significant are: Queen Charlotte fault and adjoined(?) fault segments to the northwest; namely, Transition, Chichagof-Baranof, Fairweather, and Chugach-St. Elias faults (nos. 1-5, respectively, fig. 4); Chatham Strait fault and adjoined(?) fault segments to the north and northwest; namely, Lynn Canal, Chilkat River, Dalton, Duke River, Totschunda, Shakwak Valley, and Denali faults (nos. 6-13, respectively, fig. 4); Clarence Strait lineament (no. 15, fig. 4); and Coast Range lineament (no. 16, fig. 4). The position of offshore and most onshore segments of faults shown in figure 4 is generalized within zones that probably range from several meters to possibly as much as 5 km wide; it is based upon (1) ideally, the locations of detectable earthquakes caused by recurrent faulting; (2) limited geophysical data; (3) topographic data or limited sounding data; and (4) theoretical considerations of geologic structure.

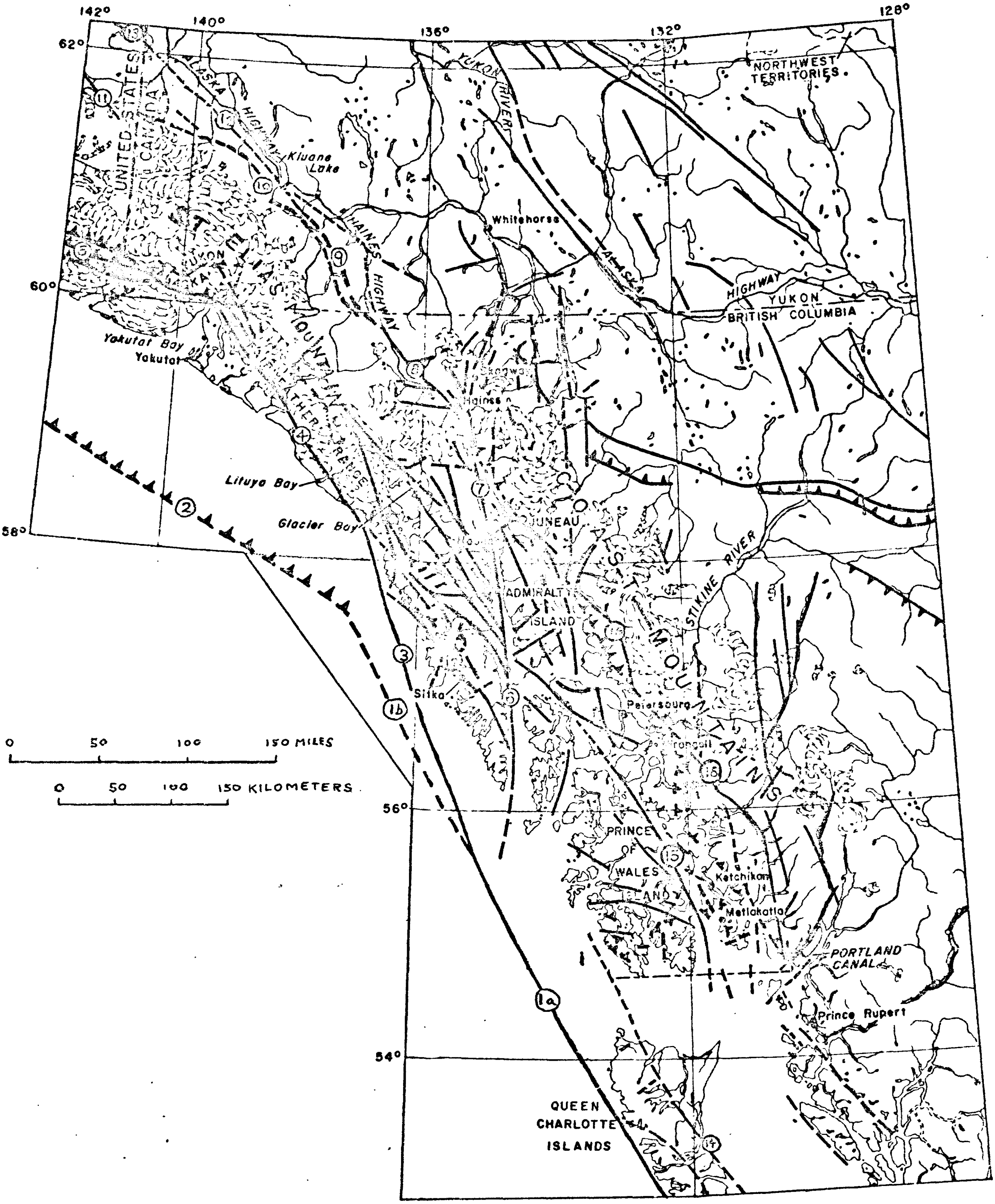


Figure 4.--(See following page for caption and explanation.)

EXPLANATION

Known — Inferred

High-angle fault or lineament

Known — Inferred

Thrust fault; sawteeth on upper plate

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

Figure 4.--Map of southeastern Alaska and adjacent regions showing major faults and selected lineaments that may be possible faults, shear zones, or joints (Beikman, 1975; Berg and others, 1972; Brew and others, 1966; Canada Geol. Survey, 1969a, b; Gabrielse and Wheeler, 1961; Johnson and Couch, 1973; King, 1969; Loney and others, 1975; Plafker, 1969, 1971; Plafker and others, 1976; Read, 1976; Richter and Matson, 1971; Souther, 1970; Tobin and Sykes, 1968; Twenhofel and Sainsbury, 1958; with additions and modifications by the writer).

The Queen Charlotte and adjoined (?), probably related faults, are tectonic features that probably consist of (1) several linear zones of vertical to steeply dipping fault segments along the Queen Charlotte, Chichagof-Baranof, and Fairweather faults (St. Amand, 1957; Plafker, 1967; Tobin and Sykes, 1968; Page and Lahr, 1971; Page, 1973; Page and Gawthrop, 1973; Silver and others, 1974; Beikman, 1975), and (2) adjoined zones of thrust faults, the Transition fault and the Chugach-St. Elias fault (Plafker, 1969, 1971; Gawthrop and others, 1973; Plafker and others, 1975). Movement along the Queen Charlotte, Chichagof-Baranof, and Fairweather faults is thought to be similar in style to movement along the San Andreas fault system in California which is a dominantly horizontal northwestward movement of that part of the earth's crust lying southwest of the fault, relative to fixed points lying across the fault. This is termed right-lateral strike-slip faulting. Both groups of faults are thought to be manifestations of the same apparent tectonic movement of a large plate (block) of the earth, called the Pacific Plate, past an adjacent plate termed the North American Plate (Isacks and others, 1968; Le Pichon, 1968; Morgan, 1968; Atwater, 1970). A popular account of plate motion is given by Yanev (1974, p. 25). Theoretical calculations indicate that relative motion between the plates may average 5.8 cm/yr, which rate is generally supported by geologic studies of Plafker and others (1976), who indicated, further, that this relatively high rate of horizontal displacement might have begun as recently as 100,000 years ago. Right-lateral slip along the Fairweather fault of as much as 6.6 m was measured after the southeastern Alaska earthquake of July 10, 1958 (Tocher, 1960, p. 280). Cumulative horizontal movement along the offshore Queen Charlotte and Chichagof-Baranof faults is unknown but probably is very large.

Significant vertical movements along the Queen Charlotte, Chichagof-Baranof, and Fairweather faults may have occurred, although substantially less than the horizontal movements. Grantz (1966) suggested that the northeast side of the fault zone might have been relatively uplifted a total of 4.8 km or more.

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

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

The Chatham Strait and adjoined(?), probably related faults to the north and northwest (fig. 4) may comprise part of a series of fault segments that extend for a great distance subparallel to and inland from the Gulf of Alaska (Berg and Plafker, 1973; Berg and others, 1972; Grantz, 1966; Read, 1976; St. Amand, 1957; Twenhofel and Sainsbury, 1958). Along the Chatham Strait segment, cumulative right-lateral offset of 205 km is considered likely (Ovenshine and Brew, 1972). The Chatham Strait fault was active after Miocene time and part of it might be active at present.

The number and distribution of faults in the Petersburg region is almost entirely unknown because of the limited amount of detailed geologic mapping in the region. Numerous faults have been mapped elsewhere within the Gravina-Nutzotin belt of rocks (Berg, 1972a, b, 1973; Berg and others, 1972). They include both high-angle normal or strike-slip faults and low-angle thrust faults; zones of sheared rock comprising the fault zones vary from several centimeters to about 1.6 km wide. Most faulting in the region probably took place during middle Tertiary time.

Lineaments are straight or gently curved features that are prominent enough to be expressed, generally in a topographic sense, on airphotos or other imagery, and on some topographic maps and hydrographic charts, depending upon scale. In many cases, lineaments reflect underlying geologic features. In the Petersburg region and in much of the rest of southeastern Alaska, many lineaments are alined waterways or vegetation-clad valleys that conceal bedrock and surficial deposits. Consequently, the origin of most lineaments is largely speculative. Some may be faults, but other lineaments may be intersections of the ground surface with planes of bedding or foliation of bedrock. Other lineaments may be joints, while still others may be depositionally alined surficial deposits or may be features formed by glacial erosion independent of bedrock structure. In many places, lineaments are greatly emphasized topographically because of differential erosion by streams or by former glaciers along these features. Two prominent lineaments that cross the east-central part of southeastern Alaska are the Clarence Strait and the Coast Range lineaments.

The Clarence Strait lineament is a major feature that coincides with a waterway of the same name (Grantz, 1966; Twenhofel and Sainsbury, 1958; (no. 15, fig. 4). Northwestward from Clarence Strait, alined stream courses on several islands, including Kupreanof (fig. 1), may constitute an extension. Total length of the lineament plus the extension is about 350 km. At its northwest end, the lineament appears to merge with Chatham Strait. The origin of the Clarence Strait lineament is uncertain. Large-scale fault offset in a right-lateral sense has been postulated (Turner and others, 1974); however, near Metlakatla (fig. 1) many of the same types of rocks were mapped on both sides of the lineament, thus indicating no apparent offset between them. Thus, large-scale lateral movement along a postulated fault seems unlikely (H. C. Berg, oral commun., 1974). I speculate that the lineament is a rift or graben that developed slowly since the major tectonic deformations of middle Tertiary time and probably is not currently active. Similar rifts or grabens were interpreted by Souther (1970, 1974) to be developing along north-south-trending lines at several places in British Columbia east of the Alaskan border.

The Coast Range lineament (no. 16, fig. 4) is a northwest-trending feature that crosses much of southeastern Alaska within the Coast Mountains (Twenhofel and Sainsbury, 1958; fig. 4). The lineament has not been studied in detail, but in general it appears to consist of several different segments that vary from wide, alined waterways and stream valleys to single or multiple narrow zones of sheared rock. The closest segment to Petersburg is the broad, lower valley of Muddy River (fig. 2); upper Frederick Sound, Horn Cliffs, and several small valleys near Le Conte Bay (fig. 2) have alinements that parallel lower Muddy River, thus indicating a possibly similar origin. Paralleling and close to the lineament along at least a part of its length north of Petersburg is a possibly related sill of graphitic rock that is 3-8 km wide (Brew and others, 1976). The origin of the Coast Range lineament is unclear, but it seems likely that some segments of the lineament may be steeply dipping faults. If the lineament is a major fault, most movement may have occurred after Late Cretaceous time. The level of present-day activity is unknown. It is suggested here, however, that those parts of the lineament that are faults probably are currently inactive.

Local structure

Bedrock exposed in the Petersburg area (fig. 3) exhibits a variety of attitudes that reflect the several tectonic deformations to which the area has been subjected. The occasional outcrops of bedrock in the Petersburg area have bedding that varies in strike from N. 60° W. to N. 40° E., and varies in dip from vertical to about 40° in an easterly direction.

Most joints are very small fractures developed during the cycles of strain that accompany multiple tectonic deformation of a region throughout its history. In the Petersburg area most bedrock probably is moderately jointed as exposed at the ground surface. At depth joints probably are tight.

GEOLOGIC HAZARDS DUE TO EARTHQUAKES

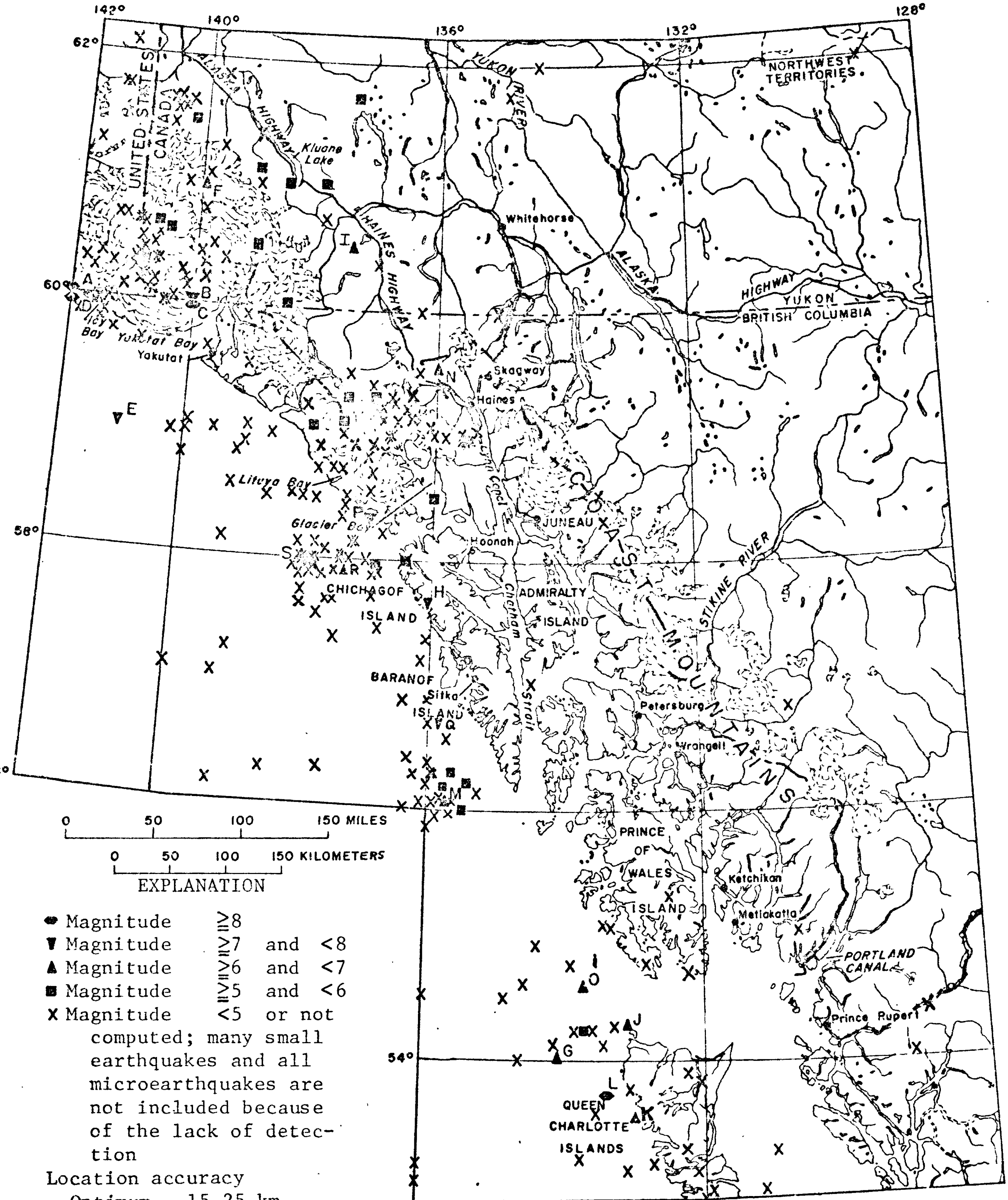
Earthquakes and their possible effects constitute the most important geologic hazard to the Petersburg area. To be considered first are seismicity, relation of earthquakes to faults, and earthquake potential; earthquake effects are discussed in the latter part of this section. Effects are considered, for the purpose of discussion, from the standpoint of a postulated, theoretically reasonable, worst case earthquake of magnitude 8 occurring about 170 km southwest from Petersburg. Earthquakes of lesser magnitude along the same fault structure and/or occurring at greater distance would, as in the past, affect the area less strongly. Information on geologic effects is based both on observations from historic earthquakes felt in southeastern Alaska and on very generalized estimates of the possible response of local geologic materials as inferred from the known response of similar materials during earthquakes elsewhere. Effects discussed include: (1) ground shaking, (2) liquefaction, (3) ground fracturing and water-sediment ejection, (4) compaction and related subsidence, and (5) landsliding. Also considered is the effect of earthquake shaking on ground water and streamflow, and on glaciers. Separately discussed are tsunamis, seiches, and other earthquake-related water waves.

Seismicity

Individual destructive earthquakes cannot as yet be predicted accurately as to place and time of occurrence. However, the likely location, size, and frequency of earthquakes can be estimated on the basis of a region's historic and current seismicity and its geologic or tectonic setting.

Petersburg lies within a broad region of relatively high earthquake activity that includes much of coastal southeastern Alaska, southwestern Yukon Territory, and northwestern and coastal British Columbia. Unfortunately, the written record of earthquakes in this region is meager because the population is sparse, the time since settlement is short, and only one permanent seismologic station exists within the region.

The earthquakes in southeastern Alaska and adjacent regions that have been instrumentally recorded and located during the period 1899 through 1977 are plotted in figure 5. These earthquakes are thought to be of shallow origin, less than about 30 km. Because techniques of earthquake detection and recording



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 - 15-25 km
Minimum -~110 km

Figure 5.--(See following page for caption and additional explanation.)

Dates and magnitudes of some earthquakes of magnitude ≧6

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

Figure 5.--Map showing location of earthquakes in southeastern Alaska and adjacent regions, 1899-1977 (Davis and Echols, 1962; W. H. Gawthrop, oral commun., 1975; Internat. Seismol. Centre, 1967-1973; Lander, 1973; Meyers, 1976; Page and Gawthrop, 1973; R. A. Page and W. H. Gawthrop, written commun., 1973; Rogers, 1976b; Seismol. Service of Canada (Bashaw and others, 1977; Horner and others, 1974, 1975, 1976; Meidler, 1962; Milne, 1956, 1963; Milne and Lombardo, 1953a, b, 1955a, b; Milne and Lukas, 1961; Milne and Smith, 1961, 1962, 1963, 1966; Smith, 1961; Smith and Milne, 1969, 1970; Stevens and others, 1972, 1973, 1976; Wetmiller, 1976a, b, 1977); Tobin and Sykes, 1968; U.S. Coast and Geod. Survey, 1930-1970; U.S. Natl. Geophys. and Solar-Terrestrial Data Center, 1969, 1973, 1975, 1976, 1977; U.S. Natl. Oceanic and Atmospheric Adm., 1971-1973, 1974; U.S. Natl. Oceanic and Atmospheric Adm. and U.S. Geol. Survey, 1975-1977; Wood, 1966).

have improved over the years, it is probable that figure 5 is complete for all magnitude 5 and greater earthquakes since April 1964, for all magnitude 6 and greater earthquakes since the early 1930's, and for all magnitude 7.75 and greater earthquakes since 1899 (Page, 1975). Extremely small earthquakes, termed microearthquakes, are not shown in figure 5 because of the difficulty of detection; knowledge of their distribution is of importance, however, because their occurrence may provide additional information on the tectonics of an area by indicating the location of unknown active faults that may be capable of causing large earthquakes. Data on some of the microearthquakes occurring in southeastern Alaska have been presented by Rogers (1972, 1973, 1976a). These seismic events were detected during parts of June and July 1969, when several portable seismological instruments were operated, one of which was at Petersburg. The closest events were restricted to an area 30 to 55 km east of the city near Le Conte Glacier which flows into Le Conte Bay (fig. 2). Rogers concluded (1972, 1973) that these events probably were related to movements of large, partly floating glaciers. Some of the other microearthquakes recorded in the region may have tectonic origins.

As noted, no permanent seismologic stations exist in the vicinity of Petersburg; the closest is at Sitka, 145 km to the west-northwest. Strong motion accelerographs capable of accurate recording of strong shaking from potentially damaging earthquakes have been installed at several locations in southeastern Alaska; two instruments are at Sitka, and one each at Ketchikan (175 km to the southeast), Juneau (195 km to the north-northwest), and Snettisham Dam (170 km to the north-northwest) (Nielson and Ellis, 1976).

The following large- and moderate-sized earthquakes have occurred within 240 km of Petersburg (fig. 5): two of magnitude 7 but less than 8 (nos. H and Q, fig. 5), one of magnitude 6 but less than 7 (no. M, fig. 5), and four of magnitude 5 or greater but less than 6. In addition, about 23 smaller earthquakes have been instrumentally recorded within 240 km of Petersburg.

Table 3 is a listing of earthquakes felt or large enough to have been felt at the location of Petersburg from 1847 through 1977 as compiled and interpreted from readily available published reports and from instrumental records. Only minor damage has occurred since Petersburg was founded in 1897. Among the major and moderate-sized earthquakes felt, several have been assigned intensity values (Modified Mercalli scale; table 4). Apparently, the highest intensity (interpreted as V to VI) was from the magnitude 7.1 earthquake of October 24, 1927 (desig. H, fig. 5), when several windows were broken. During three other seismic events, none of which, apparently, caused damage, intensities of as much as V occurred: (1) the magnitude 7.9 earthquake of July 10, 1958 (desig. P, fig. 5), (2) the magnitude 7.25 earthquake of July 30, 1972 (desig. M, fig. 5), and (3) the magnitude 5.8 earthquake of August 4, 1972. The only earthquake-induced effect reported in bodies of water in the area took place probably during the passage of earthquake waves of the Alaska earthquake of 1964, when a surge of water about 0.9 m high, probably a seismic seiche, was observed at the harbor (table 3).

Table 3.--Partial list of earthquakes felt or large enough to have been felt in the Petersburg area, Alaska 1847 - 1977

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

Date[1]	Effects and intensity (table 4) of earthquake at Petersburg[2]	Distance, kilometers, and direction to earthquake if instrumentally located (fig. 5)	Magnitude of instrumentally located earthquake[3]	Radius of perceptibility for given magnitude, kilometers (table 4)	Distance, kilometers, direction, and locality (if any) nearest Petersburg at which earthquake felt. Data on earthquake	Reference[4]
Apr. 6, 1847	Felt?-------	n.a.	unk.	n.a.	145 WNW, Sitka; generally felt along coast	1
Oct. 26, 1880	----do------	n.a.	unk.	n.a.	55 NNW; mainland E of SE end of Admiralty Island	2
Oct. 5, 1907	----do------	n.a.	unk.	n.a.	120 NW, near Angoon	3
Apr. 10, 1921	----do------	320 SSW	6.5	290	155 SE, Loring	4
Oct. 24, 1927	V-VI	225 NW	7.1	415	Several windows broken; earthquake intensity VII on Rossi-Forel scale	1, 5
Nov. 13, 1927	Felt?-------	195 WSW	unk.	n.a.	145 WNW, Sitka	1
Nov. 30, 1948	----do------	n.a.	unk.	n.a.	120 SW, Little Port Walter	4
Aug. 22, 1949	Felt--------	355 SSW	8.1	>575	Generally felt southern part southeastern Alaska. Water agitated in harbor, telephone poles swayed (Bernice Stokke, [illegible]	6
Oct. 31, 1949	Felt?-------	255 SW	6.25	240	145 WNW, Sitka	1
Nov. 17, 1956	IV	250 SSW	6.5	290	N.a.----------------------------	1
May 5, 1958	III	250 NW	unk.	n.a.	N.a.----------------------------	1
July 10, 1958	V	280 NW	7.9	560	Felt by and alarmed many people	1
Mar. 28, 1964	II-III	980 NW	8.4	>575	Felt by several; two jiggling motions about 4 minutes apart. Wave in harbor (Fred Magill and Dick Miller, oral communs., to R. W. Lemke, 1965)	1, 7
July 30, 1972	V	185 W	~7.25	~450	Agitation of water in ponds------	1
Aug. 4, 1972	V	170 WSW	5.8	200	N.a.----------------------------	1
Aug. 15, 1972	Felt?-------	175 WSW	5.0	145	145 WNW, Sitka	1
Nov. 17, 1972	III	195 SW	5.0	145	N.a.----------------------------	1
July 1, 1973	Felt?-------	290 NW	6.7	320	145 WNW, Sitka	1

Table 3.--Partial list of earthquakes felt or large enough to have been felt in the Petersburg area, Alaska 1847-1977--Continued

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

[1]Dates are u.t. (universal time) except first entry.

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

Felt?, Earthquake possibly felt somewhere at Petersburg but so far as can be determined there is no readily available published report of the event being felt at Petersburg. An earthquake is known to have occurred, however, because (1) there is a published report of its being felt elsewhere, and (or) (2) there exists an instrumental record and epicenter plot (fig. 5) of the earthquake. (Tabulation based on (1) radius of average distance of perceptibility of earthquakes as described by Gutenberg and Richter (1956, p. 141; table 4) if epicenter and magnitude are known, and (2) general evaluation of regional geologic structure.)

Roman numeral, Published report of earthquake intensity, Modified Mercalli scale (see table 4).

[3]Magnitude, Richter (1958)

[4]1 Lander (1973), Meyers (1976), Meyers and others (1976), U.S. Coast and Geodetic Survey (1930-1970), U.S. National Geophysical and Solar Terrestrial Data Center (1976), U.S. National Oceanic and Atmospheric Administration (1971-1973 and 1974), U.S. National Oceanic and Atmospheric Administration and U.S. Geological Survey (1975-1977), Wood (1966).

2 Rockwood (1881) or U.S. War Department (1881).
3 Tarr and Martin (1912).
4 U.S. Weather Bureau (1918-1958) or Olson (1949).
5 Sommer (1931).
6 Milne (1956).
7 Cloud and Scott (1969, p. 40).

Table 4.--Description of Modified Mercalli intensity scale of earthquakes[1] and approximate distance of perceptibility of earthquakes of various magnitudes[2]

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

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DISTANCE, IN KILOMETERS	15	80	150	220	400	600
MAGNITUDE	3	4	5	6	7	8

[1]Adapted from Wood and Neumann (1931).

[2]From Gutenberg and Richter (1956, p. 141) and Hodgson (1966,p. II-9).

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

In some earthquake-prone regions, a close relation can be established between earthquakes and specific faults. In most of southeastern Alaska, however, such relationships cannot as yet be established because (1) most earthquake epicenters are located at best within an accuracy of only 15-25 km and (2) the location of many faults is not precisely known because of concealment by water, vegetation, or thick surficial deposits. There appears, nevertheless, to be a general correlation between the wide, irregular belt of epicenters shown in figure 5 and the zones of faults that roughly parallel the coast of the Pacific Ocean. These earthquakes appear to be associated with movement, chiefly at depth, along individual faults within the Queen Charlotte, Chichagof-Baranof, Fairweather, and the connecting Transition fault and the Chugach-St. Elias fault zones.

The magnitude 7.25 Sitka earthquake of July 30, 1972 (desig. Q, fig. 5), 185 km west of Petersburg, represents the most recent large-scale motion along faults offshore from southeastern Alaska. Faulting during this event occurred offshore. Aftershocks following the main shock were recorded on portable seismologic instruments installed for a month (Page, 1973; Page and Gawthrop, 1973; R. A. Page and W. H. Gawthrop, written commun., 1973). The epicenters of the aftershocks defined a linear zone about 190 km long and less than 10 km wide. The closest of the aftershocks to Petersburg was about 170 km to the west-southwest. Frequent but minor activity along other segments of the faults offshore from southeastern Alaska and Queen Charlotte Islands is suggested by the widespread distribution of earthquakes shown in figure 5.

The most recent activity along the Chatham Strait fault (fig. 4) is uncertain because earthquakes in its vicinity are rare (fig. 5). In addition, no local microearthquakes were recorded (1) during a brief microearthquake survey in July 1970 (Johnson, 1971; Johnson and others, 1972), (2) during a total of about twelve months of intermittent study (1968-1971) by the Seismological Service of Canada (Rogers, 1972, 1973, 1976a), nor (3) during the August 1972 study by Page and Gawthrop (1973; R. A. Page and W. H. Gawthrop, written commun., 1973). However, possible Holocene offset has been interpreted from seismic profiles for the area at the south end of the Chatham Strait fault west of Coronation Island (fig. 1), where deformation, including faulting of sediments, is suggested (Ovenshine and Berg, 1971; Ovenshine and Brew, 1972).

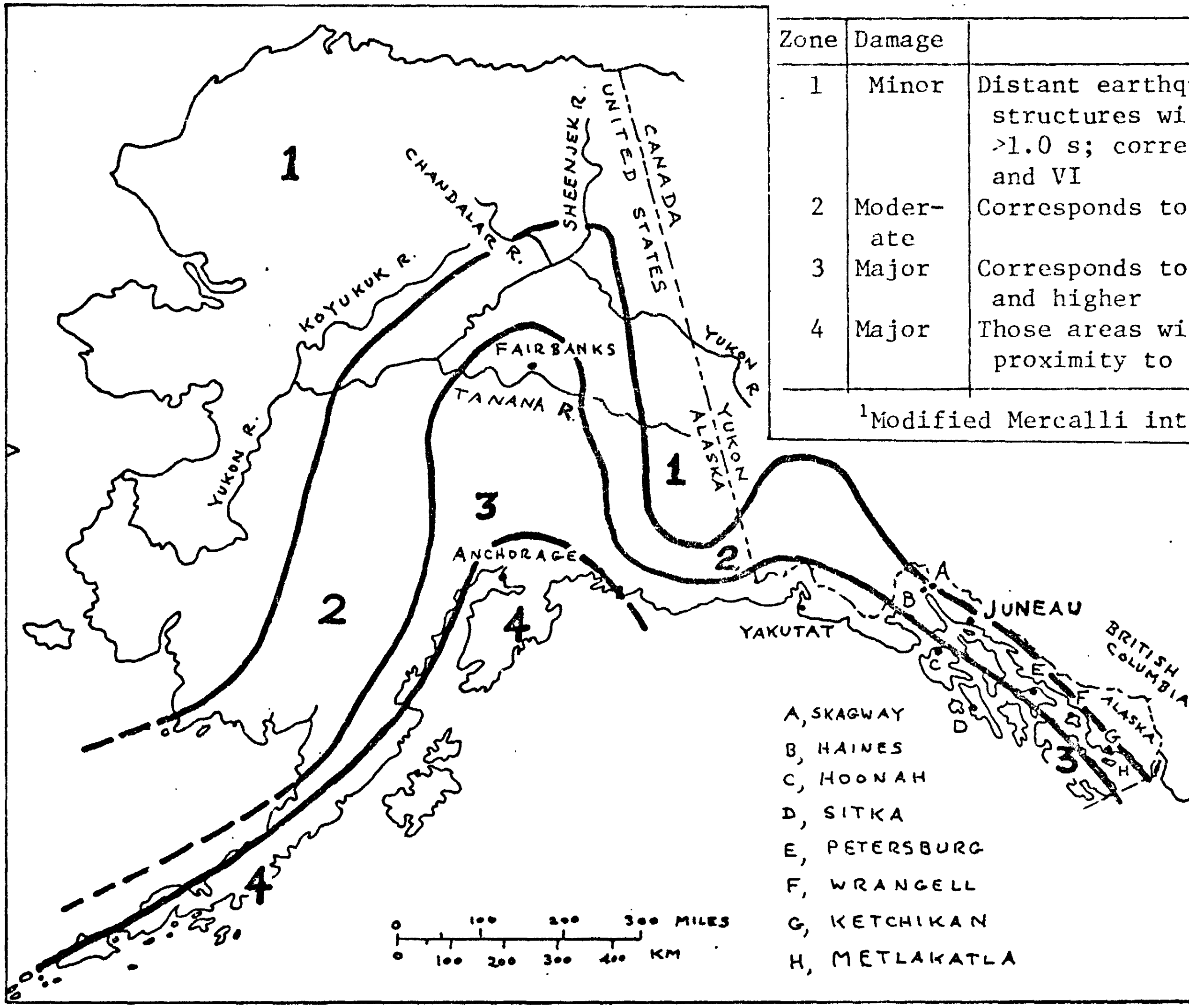
The most recent activity along possible faults that may be associated with the Clarence Strait and Coast Range lineaments is unknown. It is suggested that faults related to these features are currently inactive.

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

Earthquake potential in the Petersburg area

Only a general discussion of earthquake potential can be made for the Petersburg area, because data on many aspects of seismicity and the tectonic framework of southeastern Alaska are limited. To portray the earthquake hazard for the region, two types of maps are available. One type considers only the maximum level of shaking that can be expected to occur in a region sometime in the future; the second type considers the expectable levels of shaking with regard to specific periods of time. Both types of maps generally are derived from analysis of the historic seismicity and some consideration of the tectonic framework.

The Petersburg area is shown on two examples (figs. 6 and 7) of the first type of earthquake hazard map that estimates only the maximum shaking to which a region is subject. The first example is a redrawn, enlarged rendition of the seismic zone map included in the 1976 edition of the Uniform Building Code (fig. 6; Internat. Conf. Building Officials, 1976). The map relates a particular zone to the Modified Mercalli intensities of earthquakes expected to affect that zone. The Petersburg area is shown as being in the zone of moderate expectable earthquake damage, one which might experience Modified Mercalli intensities of as much as VII (table 4). For the Petersburg area, the map depiction is identical to that shown on seismic zone maps in the 1973 edition of the Uniform Building Code and in publications by Johnson and Hartman (1969, pl. 49), and Alaska Industry (1970).



EXPLANATION

Zone	Damage	Comment
1	Minor	Distant earthquakes may cause damage to structures with fundamental periods >1.0 s; corresponds to intensities[1] V and VI
2	Moderate	Corresponds to intensity[1] VII
3	Major	Corresponds to intensity[1] VIII and higher
4	Major	Those areas within zone 3 determined by proximity to certain major fault systems

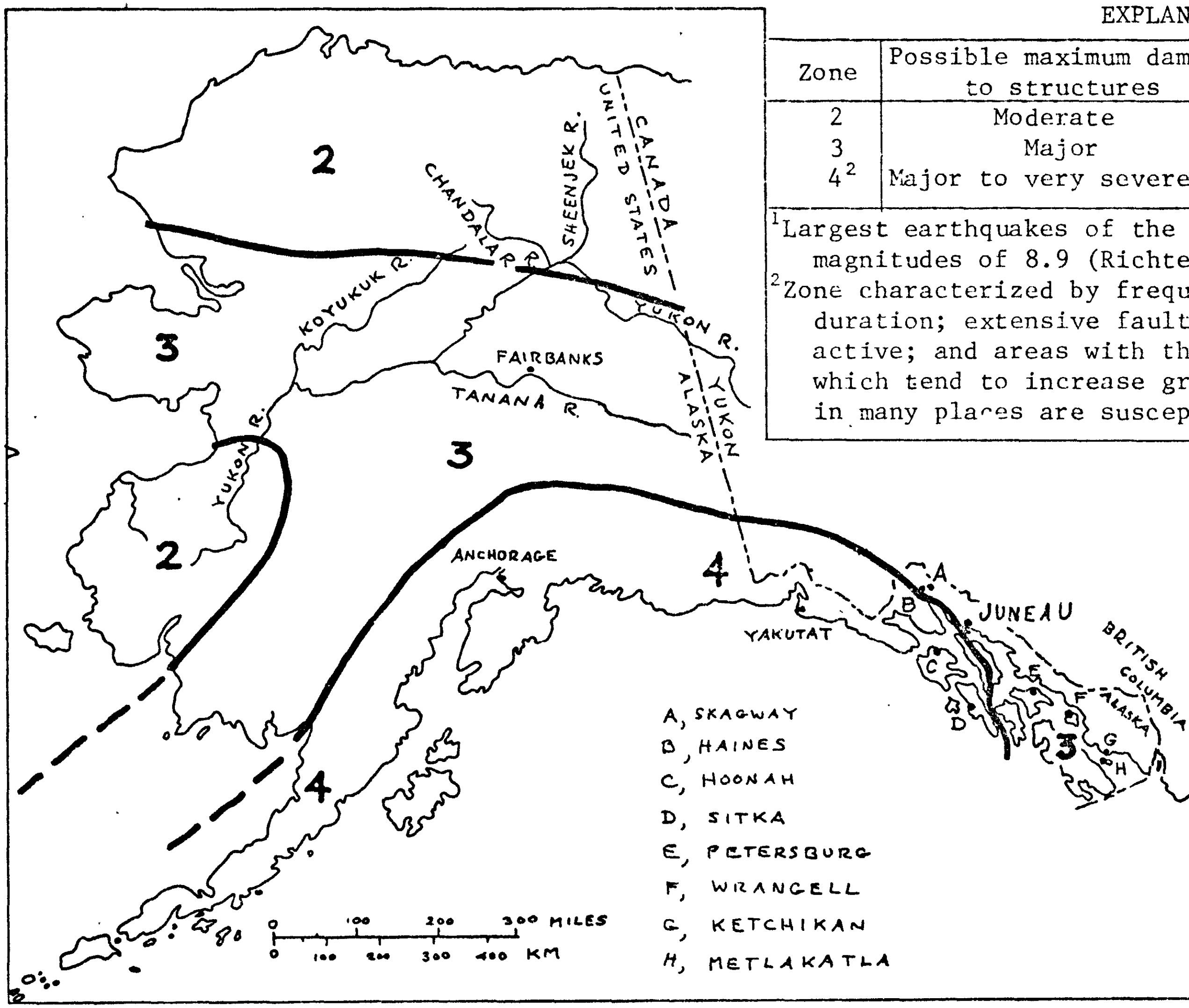
[1]Modified Mercalli intensity scale (table 4)

Figure 6.--Seismic zone map of Alaska modified from Uniform Building Code, 1976 edition (Internat. Conf. Building Officials, 1976).

The second example of the first type of earthquake hazard map is a suggested preliminary map, termed a seismic risk map (fig. 7), that was prepared by the U.S. Army Corps of Engineers, Alaska District, in 1973 (H. W. Holliday, written commun., 1975; Selkregg, 1974, 1976). The map relates possible damage during earthquakes to the magnitude of the largest probable earthquake and it shows the Petersburg area subject to major damage from earthquakes which would have magnitudes equal to or greater than 6.

The Petersburg area also is depicted on the second type of seismic hazard map (fig. 8) which shows probable peak acceleration of earthquakes as a percent of gravity during any period of one hundred years (Milne and Davenport, 1969; Klohn, 1972). For the Petersburg area, the map indicates that a peak acceleration of as much as 15 percent gravity might be expected within any one-hundred-year period. That section of the map showing the contour of 6 percent of gravity is the same contour used for part of the 1970 Seismic Zoning Map of Canada (Whitham and Hasegawa, 1975).

Any detailed discussion of earthquake potential for specific sites must await more detailed geologic, seismologic, and related geophysical studies in the east-central part of southeastern Alaska. Problems to be resolved are (1) precise location of major faults in the Petersburg region, (2) degree of activity along the various parts of the Queen Charlotte and Chichagof-Baranof faults, and (3) significance of the relatively widespread microearthquakes that have been reported on Prince of Wales Island, near Ketchikan, and in the Coast Mountains (fig. 1; Rogers, 1976a).



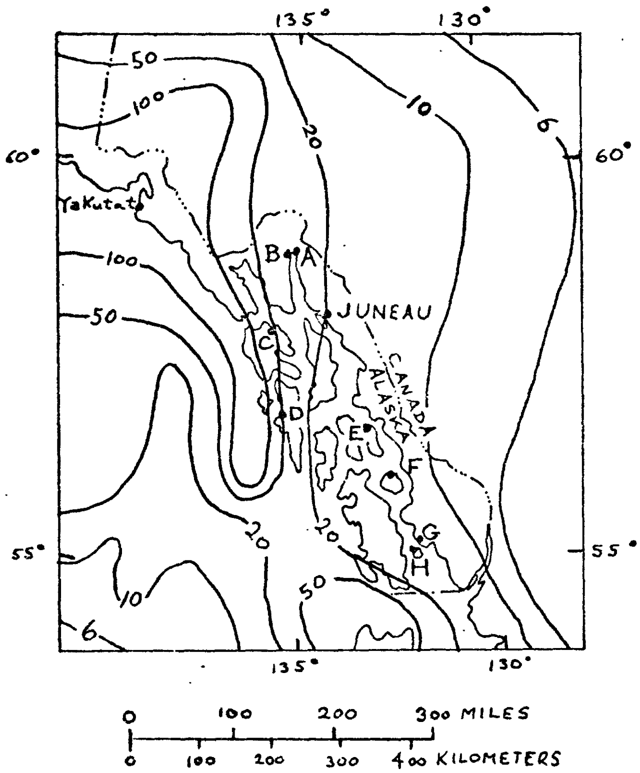
EXPLANATION

Zone	Possible maximum damage to structures	Magnitude[1] of largest probable earthquake
2	Moderate	<6.0
3	Major	⩾6.0
4[2]	Major to very severe	⩾6.0

[1]Largest earthquakes of the world have had recorded magnitudes of 8.9 (Richter, 1958, p. 711-712).

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

Figure 7.--Suggested preliminary seismic risk map of Alaska by U.S. Army Corps Engineers, Alaska District. Modified from description developed by E. L. Long and G. H. Greeley (H. W. Holliday, written commun., 1975).



EXPLANATION

Contours show peak accelerations from earthquakes as a percentage of gravity.

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

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

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

General agreement as to the level of earthquake hazards in the Petersburg area exists among the three described seismic hazard maps. Full agreement is not possible because of different assumptions used in developing the maps. It is clear, however, that earthquakes of relatively large size will continue to affect the Petersburg area. Of importance is the expectation that sometime in the future, earthquakes similar in size to the August 22, 1949, and the July 30, 1972, shocks will occur along the Queen Charlotte or Chichagof-Baranof faults at a minimum of 170 km southwest from Petersburg. Important but unknown is the potential occurrence of smaller but closer earthquakes along faults related to the southern part of Chatham Strait fault zone or to the Clarence Strait or Coast Range lineaments or along unknown faults in the Petersburg region.

Ground shaking during earthquakes

Ground shaking causes most of the damage to buildings and other structures during earthquakes. At a given locality, the severity of ground shaking is controlled by several factors. Major factors include (1) the amount of earthquake energy released during the earthquake, (2) the distance of the particular locality from the fault that caused the earthquake, and (3) the response of surficial deposits to the motion of the bedrock beneath the locality (Page and others, 1975a, b). Other factors of possible significance are the earthquake mechanism and the type of fault motion.

During the postulated theoretically reasonable worst case magnitude 8 earthquake that could occur offshore and about 170 km southwest of Petersburg, ground shaking probably would be most severe on geologic materials that are loose, fine grained, water saturated, and thick. Conversely, shaking probably would be least severe on geologic materials that are hard, firm, and unfractured.

A grouping of the geologic map units (fig. 3) by their inferred relative response to bedrock shaking during this possible earthquake is given below. The grouping is based on very generalized observations of the physical characteristics of the map units, mainly thickness and firmness, and comparison with the response of similar materials elsewhere. (The total thickness of surficial deposits probably averages 15 m; maximum known thickness is 44 m.) A generally similar scheme of grouping and classification of geologic materials elsewhere that is based on much more extensive data than are available in the Petersburg area was completed for parts of the San Francisco Bay region, California, by Lajoie and Helley (1975).

As far as possible, the geologic map units (fig. 3) are arranged within categories in order of decreasing inferred response to shaking; the position of units in these categories is very tentative.

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

A. Organic deposits

B. Artificial fill

C. Soft silt and clay of the mixed deposits

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

A. Delta component of shore and delta deposits

B. Alluvial deposits

C. Shore component of shore and delta deposits

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

A. Firm, compact diamicton of the mixed deposits

B. Metamorphic rocks

Earthquake-induced liquefaction

During large earthquakes in other areas, ground shaking has caused liquefaction of certain types of saturated unconsolidated surficial deposits. Especially susceptible are deposits that contain sediments with very low cohesion and uniform, well-sorted, fine- to medium-grained particles such as fine sand and coarse silt (Seed and Idriss, 1971). A major consequence of liquefaction is that sediments that are not confined at the margin of the body of sediment will tend to flow or spread toward those unconfined margins, and the sediments will flow or spread as long as pore-water pressures remain high and shaking continues (Youd, 1973; Youd and others, 1975). If liquefaction occurs in saturated sediments that are confined at the margin of the sediment, the result is the familiar quicksand condition. A preliminary analysis of the potential for liquefaction of mapped geologic deposits in the Petersburg area indicates that some deposits are present that might liquefy if the amplitude and duration of ground shaking were sufficient during the postulated magnitude 8 earthquake that could occur off the coast about 170 km southwest from Petersburg. However, extensive deposits of uniform fine sand or coarse silt apparently are lacking in the area and thus there is only a minimum likelihood of liquefaction being a major effect during earthquakes. Of the liquefiable deposits the possible fine sand in the small deltas is the most significant because it would have a moderate to high likelihood of liquefying. The deltas, however, are apparently thin and damage to structures founded on them probably would be only slight to moderate. Organic deposits in the area probably would not liquefy.

Earthquake-induced ground fracturing and water-sediment ejection

Ground fracturing and ejection of water or slurries of water and sediments from certain deposits are common during the strong shaking that accompanies many large earthquakes (Davis and Sanders, 1960, p. 243; Waller, 1966, 1968). The ejection process is called fountaining; compaction and differential subsidence of ground commonly accompany ejection. Ejection takes place most often where loose, sand-sized materials are dominant in a deposit and where the water table is shallow and restricted by a confining layer--which can be seasonally frozen ground. Seismic shaking of confined ground water and sediment causes pore-water pressure to increase and then liquefaction may occur. If liquefaction does occur and the confining layer ruptures, the water and sediment erupt from point sources or along ground fractures.

In the Petersburg area the only deposits that contain sediments of the appropriate size range that might be subject to ground fracturing and water-sediment ejection during the postulated magnitude 8 earthquake that could occur offshore about 170 km southwest of Petersburg are parts of some of the few alluvial deposits and some of the delta component of the few modern shore and delta deposits. On these deposits there is only a slight to moderate likelihood of the occurrence of ground fracturing and water-sediment ejection.

Earthquake-induced compaction and related subsidence

Strong shaking of loose geologic materials during large earthquakes may result in compaction and volume reduction of deposits containing such materials. Compaction is often subsequent to liquefaction and ejection of water and water-sediment mixtures. As a result of these processes the surface of the ground locally may settle differentially by as much as a few meters.

In the Petersburg area during the postulated magnitude 8 earthquake there is only a very slight likelihood of extensive compaction and subsidence of deposits. Only local areas of the few alluvial and delta deposits have even a slight to moderate likelihood of compacting an appreciable amount during severe ground shaking.

Earthquake-induced subaerial and underwater landslides

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

In the Petersburg area, during the postulated magnitude 8 earthquake, earthquake-induced landsliding probably would be relatively uncommon because very few steep slopes occur. Of those slides that might occur on land, most of them probably would be of the thin, earthflow type and would develop in water-saturated silt and clay materials of the mixed deposits; locally, a few large landslides might develop. On the steep slopes of mountain valleys in the Petersburg region, landsliding of several types would be of a moderate likelihood. Some of this activity could damage parts of the water-supply reservoir or hydroelectric facilities of the city. Steep areas of particular susceptibility to landslides probably would be the areas of ground that have been newly disturbed by heavy equipment during forest-cutting. Offshore, most slopes as shown on U.S. National Ocean Survey charts 17360 and 17375 (20th ed., May 15, 1976, and 16th ed., May 26, 1973, respectively) are gentle on the floor of Wrangell Narrows but slopes are relatively steep along the margin of the floor of Frederick Sound in the map area. Although the specific types of geologic materials beneath the floor of Frederick Sound in the map area are unknown, it is likely that they are at least in part composed of bedrock and probably not subject to extensive landsliding. Sliding of the fronts of deltas in the area during ground shaking probably would be minor because of short slopes and the small size of the deltas.

Effects of earthquake shaking on ground water and streamflow

The flow of ground water may be changed by strong ground shaking and by the permanent ground displacement that might result. Examples of changes reported by Waller (1966, 1968) from south-central Alaska show that the 1964 Alaska earthquake especially affected semiconfined ground water in alluvial and delta deposits. After the earthquake, ground-water levels locally were raised because of (1) subsidence of ground, (2) increase in hydrostatic pressure, or (3) compaction of sediments. Other ground-water levels locally were lowered because of (1) pressure losses, (2) rearrangement of sediment grains, (3) lateral spreading of deposits, or (4) greater discharge of ground water after sliding of delta fronts. In the Petersburg area the ground-water table is very near the surface. The strong shaking accompanying the postulated magnitude 8 earthquake has a moderate likelihood of altering the level of the water table and altering some ground-water flow especially in permeable horizons containing mixed, alluvial, and delta deposits.

Alterations to streamflow can be important consequences of large earthquakes. Streams flowing on alluvial and delta deposits can experience a temporarily diminished flow because of water loss into fractures opened by shaking. In the Petersburg area these effects would likely be slight because of the presumed thinness of alluvial and deltaic deposits.

Effects of earthquake shaking on glaciers

Although no glaciers occur on Mitkof Island, the response to earthquakes by nearby glaciers might affect the Petersburg area. Strong ground shaking and tectonic change of land levels during earthquakes have caused short- and long-term changes in glaciers and related drainage features in some regions in southeastern Alaska, especially in the Yakutat region (fig. 1) (Tarr and Martin, 1912, 1914; Post, 1967). The triggering of large numbers of avalanches and landslides that can spread over extensive areas on glaciers is one of the important results of ground shaking. However, advances of glaciers, postulated by Tarr and Martin as having been caused by extensive avalanching during and following the very large September 1899 earthquakes, are thought not to have been controlled by effects of the earthquake. During the postulated magnitude 8 earthquake that could occur offshore about 170 km southwest of Petersburg there is a slight to moderate likelihood of strong ground shaking causing extensive formation of icebergs by breakage of the the termini of floating glaciers in the Coast Mountains. If a large number of icebergs broke from Le Conte Glacier, waterways like Le Conte Bay, Frederick Sound, and Wrangell Narrows probably would be subjected, temporarily, to more iceberg-caused restrictions to navigation and fishing than are usual.

Tsunamis, seiches, and other earthquake-related water waves

Earthquake-induced water waves often develop during major earthquakes. Such waves may affect shore areas, even at great distances, for several days thereafter. Types of waves include: (1) tsunamis (seismic sea waves), (2) seiches, and (3) waves generated by subaqueous and subaerial landslides.

Tsunamis are long-period water waves that are caused by sudden displacement of water. The largest tsunamis originate where large vertical displacements of the sea floor and vast displacements of water occur; such displacements have resulted chiefly from major underthrust faulting. Horizontal offsets that accompany strike-slip faulting cause much smaller movements of water and smaller waves.

In the deep ocean, trains of tsunami waves travel long distances at high speed (550-800 km/h) but with low heights; however, as the waves approach shallower water of the Continental Shelf and nearshore areas their speeds decrease greatly and the energy is transformed into a manyfold height increase. Many tsunami waves that have struck coastal areas along the Pacific Ocean have been as high as 12 m (Wiegel, 1970, 1976). Wilson and Tørum (1968) noted that in shallow water the wave height and wave type are controlled largely by (1) initial size of the tsunami wave, (2) depth and configuration of the sea floor, (3) configuration of the shoreline, (4) natural period of oscillation of the water on the shelf or coastal indentation, and (5) tidal stage.

Seiches are water waves that are set in motion as induced oscillations or sloshings of closed or semiclosed bodies of water. They are set in motion by (1) passage of air-pressure disturbances or seismic waves, (2) tilting of the basins, or (3) impact of large landslides into bodies of water. Although seiches commonly are small and masked by other types of waves, there were reports of seiches or possible seiches as much as 7.6 m high occurring during the 1964 Alaska earthquake (McCulloch, 1966; McGarr and Vorhis, 1968, 1972; U.S. Geol. Survey, unpub. field data, 1964).

Table 5 lists the tsunamis and other earthquake-induced waves that affected or possibly affected the Petersburg area from 1880 through 1975. Because the U.S. National Ocean Survey has no continuous-recording tidal gage at Petersburg, the table is based mainly upon my interpretation of known occurrences of waves that reached at least some part of the central outer coast of southeastern Alaska chiefly from distant generating areas in the Pacific Ocean. Most tabulated data were derived from records of the continuous-recording tidal gage at Sitka (Yehle, 1974, table 8). For the Petersburg area, table 5 lists only a single wave about 1 m high which was observed in the harbor about the time of the 1964 Alaska earthquake. The wave probably was a seiche caused by the passage of seismic waves; a wave about 4.5-6 m high struck the community of Baranof, 130 km (fig. 1) west-northwest of Petersburg (Mrs. William Short, in Cloud and Scott, 1969, p. 40). The tsunami waves from the 1964 Alaska earthquake that reached some of the cities in southeastern Alaska at a somewhat similar distance from the open ocean as Petersburg (145 or 225 km, depending upon which waterway is postulated for wave travel) are as follows: (1) Juneau, at 195 or 225 km from the ocean, had a maximum wave of 2.5 m (Wilson and Tørum, 1968, p. 100), and (2) Skagway, at about 255 km, had a maximum wave of 5 m high (J. C. Lee, in Cloud and Scott, 1969, p. 37).

Table 5.--Tsunamis and other earthquake-induced waves that affected or possibly affected the Petersburg area, Alaska, 1880-1975[1]

Date, local time	General region of earthquake and area of generation of tsunami	Distance, km, direction, and locality nearest Petersburg at which wave experienced	At nearest locality, max. runup height or amplitude[2], max. rise or fall of wave[3]; comment. (meters)
Oct. 26, 1880--	Northeastern North Pacific Ocean-------	130 W; Whale Bay. 320 or more SE; British Columbia coast	"Huge"[4]
Nov. 10, 1938--	Western Gulf of Alaska near Alaska Peninsula.	145 WNW; Sitka	0.2[2]
Apr. 1, 1946---	Northern North Pacific Ocean near Aleutian Islands.	145 WNW; Sitka	0.4[2]; 0.8[3]
Dec. 20, 1946--	Northwestern North Pacific Ocean near Japan.	Wave possibly from this event, 145 WNW; Sitka	Max. height 0.3[5]
Aug. 21, 1949--	Northeastern North Pacific Ocean near Queen Charlotte Islands, British Columbia.	175 SE; Ketchikan	0.1[2]; 0.6[6]. Probable seiche.
Mar. 4, 1952---	Northwestern North Pacific Ocean near Japan.	145 WNW; Sitka	0.1[2]
Nov. 4, 1952---	Northern North Pacific Ocean near U.S.S.R.	145 WNW; Sitka	0.3[2]; 0.4[3]
Mar. 9, 1957---	Northern North Pacific Ocean near Aleutian Islands.	145 WNW; Sitka	0.4[2]; 0.8[3]
May 22, 1960---	Southeastern South Pacific Ocean near Chile.	145 WNW; Sitka	0.6[2]; 0.9[3]
Mar. 27-28, 1964	Northwestern Gulf of Alaska along south coast of Alaska.	145 WNW; Sitka	2.4[2]; 4.4[3]. At Petersburg Harbor, wave about 0.9[7]; probable seiche.

Table 5.--Tsunamis and other earthquake-induced waves that affected or possibly affected the Petersburg area, Alaska, 1880-1975[1]--Continued

Date local time	General region of earthquake and area of generation of tsunami	Distance, km, direction and locality nearest Petersburg a which wave experienced	At nearest locality, max. runup height or amplitude[2], max. rise or fall of wave[3]; comment. (meters)
Feb. 3, 1965---	Northern North Pacific Ocean near Aleutian Islands.	145 WNW; Sitka	0.2[8]
May 16, 1968---	Northwestern North Pacific Ocean near Japan.	145 WNW; Sitka	less than 0.1[2]
July 30, 1972--	Northeastern North Pacific Ocean near Sitka	145 WNW; Sitka	0.2[2]
Nov. 29, 1975--	Hawaii------------------------------	145 WNW; Sitka	Possible tsunami wave 0.06[9]

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

[2]Cox and others (1976).

[3]Spaeth and Berkman (1967).

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

[5]Dames and Moore (1971).

[6]Olson (1949).

[7]Fred Magill and Dick Miller (oral communs. to R. W. Lemke, 1965).

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

[9]U.S. National Oceanic & Atmospheric Administration and U.S. Geological Survey (1977, p. 115)

Massive underwater and subaerial landslides generated by shaking during earthquakes have caused small to very large waves in some bodies of water in Alaska. Although some waves were local and dissipated within short distances, others traveled far. Sliding of delta fronts especially can generate waves. Several deltas that failed elsewhere in Alaska during the 1964 earthquake generated waves as much as 10 m high (Kachadoorian, 1965; Coulter and Migliaccio, 1966; Lemke, 1967; Von Huene and Cox, 1972). Subaerial landsliding triggered by earthquake shaking also generated large waves. The world's record height of wave runup is probably 530 m triggered by a landslide in Lituya Bay (fig. 1) near the epicenter of the magnitude 7.9 southeastern Alaska earthquake of July 10, 1958 (Miller, 1960). As far as is known, no waves have reached the Petersburg area that are attributable to earthquake-triggered subaerial or underwater landslides. It must be noted, however, that some of the underwater slides that have occurred along that part of the large Stikine River delta at the head of Frederick Sound about 22 km southeast of Petersburg (fig. 2) have been of sufficient size to break submarine communication cables (Heezen and Johnson, 1969, p. 414-419). Approximately one-half of the breaks occurring between November 19, 1912, and July 10, 1958, happened at the time, or soon after, major earthquakes were reported. The possibility exists that very large slide failures of the Stikine or other large deltas in the region might occur during future large earthquakes that could result in far-reaching waves. In like manner, massive subaerial landslides and resultant waves might develop locally along the steeper slopes that form the northeast shore of Frederick Sound, especially the area 11 km east northeast of Petersburg and near Horn Cliffs (fig. 2). Waves from that source could have a nearly immediate effect on some shores. In similar geographic settings along Norwegian fiords massive failures of slopes have developed even in the absence of earthquakes (Jørstad, 1968).

Damage to low-lying areas at Petersburg from tsunamis and seiches is one of the possible consequences of earthquakes. The occurrence of such waves should be anticipated at Petersburg as at other cities connected by tidal waterways to the Pacific Ocean. However, the exact heights of waves and the amounts of damage cannot be estimated. If all tsunamis were of the nonbreaking (swell) type, and of low height, and occurred at low tide, no damage would result. On the other hand, if a group of moderately high, breaking-type waves were to strike at highest high tide, damage probably would result to boats, harbor facilities, and other low-lying areas. Seiching of lakes in the region might damage outlet works of structures that are parts of the water-supply and hydroelectricity systems for Petersburg (fig. 2).

One may speculate on several possible heights of tsunamis that might reach the Petersburg area from the Pacific Ocean either by way of Sumner Strait or Frederick Sound (fig. 1). When considering possible heights, one must consider that wave focusing and sympathetic resonance of local waves might tend to increase the height of waves in a body of water. Tending to greatly reduce the height of waves are (1) the large number of reefs and the circuitous channel of Wrangell Narrows at Petersburg and vicinity, and (2) the considerable distance from the Pacific Ocean: (a) 145 km, by way of Sumner Strait (fig. 1), and (b) 225 km, by way of Frederick Sound (fig. 1).

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

For the earthquake-related waves originated by the 1964 Alaska earthquake, personnel of the Juneau office of the U.S. Weather Bureau (now U.S. Natl. Weather Service) predicted (J. P. Bauer, written commun., 1964) a maximum wave height for most inner waterways of southeastern Alaska of 1 to 2 m above normal tide levels. Actual wave heights were approximately the values predicted. It is here concluded that these values for the Petersburg area probably are reasonable.

Warnings to coastal Alaska regarding the arrival time of potentially damaging tsunamis are issued by the Tsunami Warning System of the U.S. National Weather Service (Butler, 1971; Cox and Stewart, 1972; Cox and others, 1976; Haas and Trainer, 1974). For Petersburg, such warnings about tsunamis originating at great distances probably will allow ample time to evacuate the harbor and low-lying areas.

Substantial wave damage to shore areas at Petersburg from massive, earthquake-triggered submarine and subaerial landslides is thought to be unlikely, but cannot be ruled out because of the relatively great likelihood of landslides developing in the region even during moderate shaking and especially developing during the postulated magnitude 8 earthquake. If waves were generated by earthquake-triggered landslides, it is likely that most of the waves probably would dissipate to low heights before reaching Petersburg.

Wave damage to shores of lakes and reservoirs from earthquake-triggered landslides might occur, locally, during strong earthquake shaking.

OTHER GEOLOGIC HAZARDS

In addition to the hazard from earthquakes, a potential exists for damage to the Petersburg area and region from other geologic hazards. These hazards include (1) high water waves not associated with local or distant earthquakes, (2) landslides, (3) icebergs, and (4) stream floods and erosion of deposits by running water and sheet floods.

High water waves

Nonearthquake-related water waves high enough to affect some shores occasionally may occur in the Petersburg area, especially along the southeast shore of Frederick Sound. Waves of two origins are possible; those generated by impact of either subaerial or of underwater landslides entering large bodies of water. A brief discussion of landslide-generated waves is given in the preceding section, "Tsunamis, seiches, and other earthquake-related water waves."

Landslides

Some of the steep slopes of Mitkof and nearby islands and on the mainland probably are subject to landsliding. Although many failures of steep slopes, especially those slopes underlain by thin unconsolidated geologic materials, occur during earthquakes, most failures probably occur at other times--during (1) heavy rainfall, (2) rapid snowmelt, (3) seasonal freezing and thawing, or (4) as a result of overloading or alteration of slopes during construction or following intensive timber cutting. Although slopes near the margin of the lakes and reservoir used for Petersburg's water supply and generation of hydroelectricity (fig. 2) were not examined, it is anticipated that landslides will occur near the margins of these bodies of water because of steep slopes and some slide-prone surficial deposits. Massive landslides along the steep to very steep slopes constituting the margins of waterways like Frederick Sound may occur. If such slides occurred, they might cause waves as they dropped into the deep water characteristic of near-shore areas in some places. As noted above in the discussion of earthquakes, the Horn Mountain and Horn Cliff area (fig. 2) would seem to be susceptible to landsliding on the basis of steepness of slopes that range up to 200 percent (63°) (as measured on 1:63,360-scale topographic maps). Landsliding in the city of Petersburg probably is not common, because most slopes are gentle to moderate; small slides could occur, however, in some of the fine-grained unconsolidated geologic materials along the steeper but short slopes bordering the small streams in the area, especially those tributary to Hammer Slough, Long Pond, and other streams directly to the west.

An example of construction activity that resulted in slope failure is along the north side of the west end of the airport runway. There, fill and the underlying organic(?) and soft, fine-grained deposits became saturated and gravitationally unstable, and a landslide developed. Subsequently, additional fill was placed along that part of the runway.

Examples of landslides of several types being caused indirectly by intensive timber cutting and related land-surface modification have been given by Swanston (1969, 1974).

The steep underwater slopes of active deltas and even some slowly extending spits may fail. No failures, however, have been documented in the Petersburg region except along the delta of the Stikine River, where numerous failures, both earthquake and nonearthquake related, have broken submarine communication cables laid across offshore parts of the delta (Heezen and Johnson, 1969, p. 414-419).

Icebergs

Icebergs from tidal glaciers form a hazard to navigation. In the Petersburg region, icebergs from Le Conte Glacier leave Le Conte Bay (fig. 2) and are generally present in the northeast part of Frederick Sound and sometimes present in the southwest part as far northwestward as Frederick Point (U.S. Coast and Geod. Survey, 1969, p. 131; fig. 2). Occasionally, on rising tides, icebergs move into constricted Wrangell Narrows where they constitute both a hazard to navigation and, at certain tidal stages, restrict full usage of Petersburg harbor. Concern about a substantial increase in forward movement of the terminus of Le Conte Glacier that could increase the number of icebergs and the hazard to navigation seems unfounded. From observations made of the glacier in 1974, it is thought that the production of icebergs will continue in the near future at about the same rate as in the recent past (Austin Post, oral commun., 1977).

Stream floods and erosion of deposits by running water

Extensive muskegs, ponds, and small streams easily accommodate and adequately carry normal rainfall and melting snows in the Petersburg area. Thus, the possibility of erosion by stream flooding and sheet flooding is rare. In the moderately steep to steep terrain of most of the rest of the region, however, erosion, especially of thin surficial deposits stripped of vegetation, may occur because of the steeper slopes and greater precipitation of higher altitudes. The 100-year probable maximum rainfall in any 24-hour period is about 200 mm (Miller, 1963); Childers (1970, p. 19) listed the maximum discharge of the creek flowing into Hammer Slough as 17.0 m^3/s during the period 1964 through 1967; maximum occurred on October 22, 1965, when precipitation was recorded as 80 mm (U.S. Weather Bureau, 1965).

RECOMMENDATIONS FOR ADDITIONAL STUDIES

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

1. Detailed geologic mapping and field study utilizing current air-photos and updated geologic maps and hydrographic charts should be undertaken. This work should include the collecting of data on distribution and physical properties of surficial geologic materials in the area. Such an undertaking would lead to a better understanding of the general geology, and probably would result in locating specific zones subject to slope failure and identifying areas most suitable for construction.

2. In order to help indicate possible locations of future large earthquakes, the types of potential movements along known faults and inferred faults in the region and especially along the Chatham Strait fault and along the Coast Range lineament should be determined. To accomplish this and to help locate any presently unknown active faults, geophysical studies should be undertaken and permanent, high-sensitivity seismological instruments should be installed in the region in cooperation with the Seismological Service of Canada.

3. A general reconnaissance of the steepest and potentially most unstable slopes in the region should be made. For initial study the following are suggested: (1) the northeast margins of Frederick Sound, (2) tributary bays and inlets to Frederick Sound that have been recently deglaciated, and (3) the rapidly extending margins of the Stikine River delta.

4. Because of the potential for some wave damage in the Petersburg area, the potential travel time of tsunamis from the Pacific Ocean should be determined, and the configuration and natural oscillation periods of basins that hold large bodies of water in the region (especially Frederick Sound) should be determined. This knowledge would assist in the prediction of possible wave heights resulting from seismic seiching and landslide-caused seiching.

5. A general reconnaissance study should be undertaken of the accumulation areas and rates of movement of tidal and near-tidal glaciers in the region to assist prediction of iceberg abundance in heavily used waterways.

GLOSSARY

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

Argillite: A dense, slightly metamorphosed rock formed from shale or mudstone.

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

Drift: A general term for earth materials of any kind that have been transported from one place to another by glacial ice or associated streams. Material may range in size from clay to boulders and may be sorted or unsorted.

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

Fault: A fracture along which there has been relative displacement of the two blocks parallel to the fracture. There are several kinds of faults: A normal fault is one in which the hanging wall (the block above the fault plane) has moved downward in relation to the footwall (the block below the fault plane). A thrust fault is a low-angle fault in which the hanging wall has moved upward relative to the footwall. A strike-slip fault involves lateral displacement.

approximately parallel to the strike of the fault. If one of the fault blocks has moved relatively to the right, the fault is a right-lateral strike-slip fault; relative movement to the left defines a left-lateral strike-slip fault. The term active fault is in common usage, but agreement is lacking as to the meaning of the term in relation to time. In general, an active fault is one along which intermittent movement can be expected.

Graben: A relatively depressed, elongate tract of land that is bounded by normal faults on its long sides.

Granodiorite: A coarse-grained plutonic igneous rock composed of quartz, plagioclase, and potassium feldspar with biotite and hornblende.

Graywacke: A hard, fine- to medium-grained sandstone composed of fragments of principally quartz and feldspar and, locally, argillite, slate, and fine-grained rocks of volcanic origin; may include some lenses of finer or coarser rock fragments. Slightly metamorphosed.

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

Lineament: A linear feature of the landscape, such as alined valleys, streams, rivers, shorelines, fiords, scarps, and glacial grooves that may reflect faults, shear zones, joints, beds, or other structural geologic features; also, the representation of such a ground feature on topographic maps, airphotos, or on other remote-sensing imagery.

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

Magnitude: A measure of the strength of an earthquake or the strain energy released by it, as determined by seismographic observations. As originally defined, refers to the logarithm of the maximum amplitude on a seismogram written by a standard-type seismograph 100 km from the epicenter of an earthquake (Richter, 1958). Although magnitude does not directly relate to seismic energy, a 1-unit increase in magnitude correlates with a 32-fold increase in seismic energy.

Microearthquake: An earthquake too small to be felt and that can be detected only instrumentally, generally considered to be less than magnitude 2 or 3.

Phyllite: A fine-grained argillaceous rock formed by regional metamorphism.

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

Seismicity: A term used to denote the occurrence of earthquakes.

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

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

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

Ultramafic: An igneous rock that is rich in iron and magnesium minerals.

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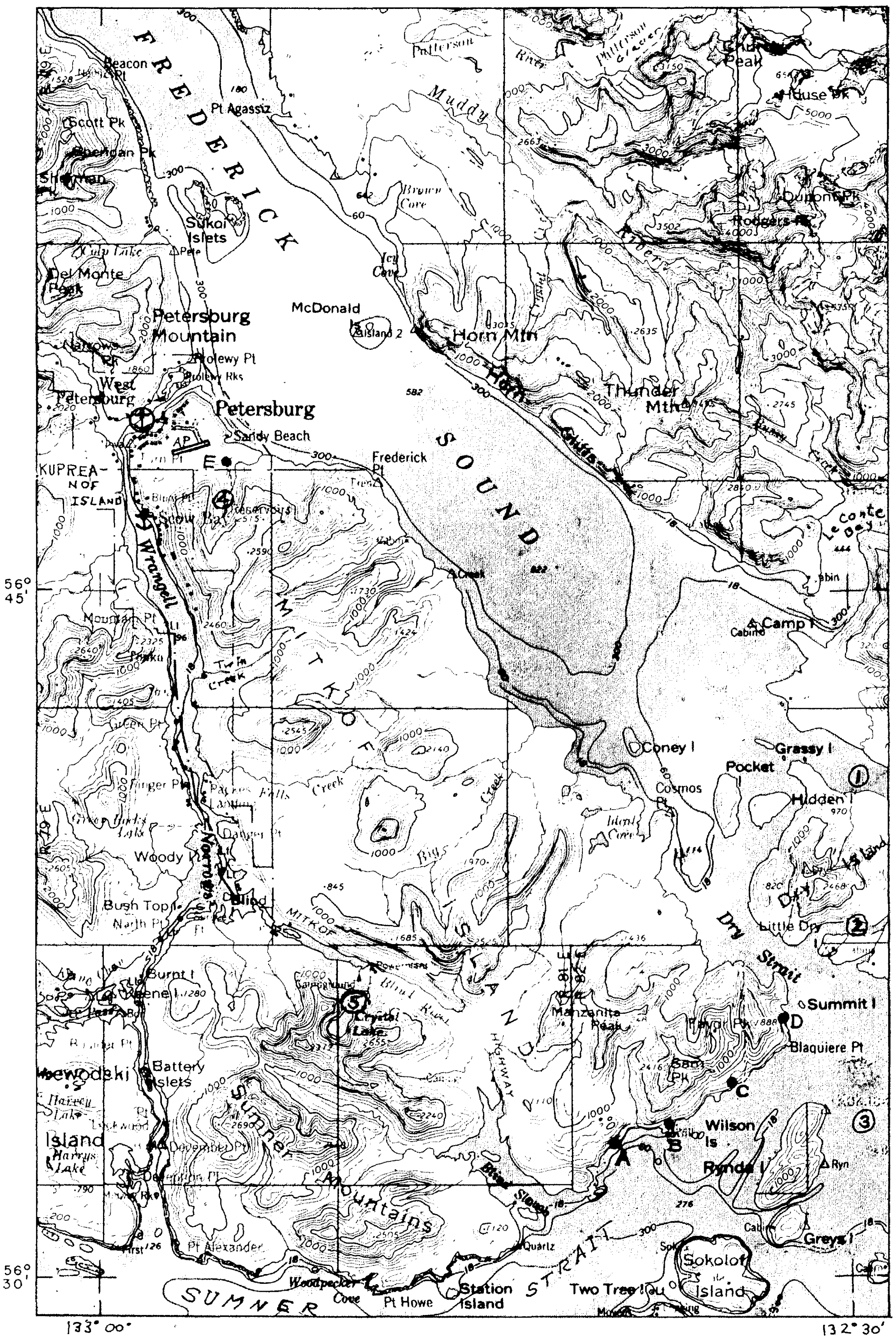
FIGURE 2



EXPLANATION

Collecting site of Cenozoic marine megafossils: A-D. (See table 1.)

Collecting site of radiocarbon-dated fossils: B, D, and E. (See table 1 and text section entitled, "Glaciation and associated land- and sea-level changes.")

①②③: Outer parts of distributaries of Stikine River (approx. flow direction from east to west).

④ Water reservoirs

⑤ Hydroelectric facility

AP Airport

WT Water tank

Scale 1:250,000

0 5 Miles

0 5 Kilometers

Land contour interval 200 ft; datum mean sea level

Water depth curves: 18, 60, and 300 ft; datum, mean lower low water. 1 ft = 0.305 m

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

Figure 2.--Topographic map of Mitkof Island and adjacent areas, southeastern Alaska, showing geographic features and collecting sites of Cenozoic marine megafossils and radiocarbon-dated fossils. Base from U.S. Geological Survey Petersburg, Alaska-Canada, 1960.