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GEOLOGICAL SURVEY

SURFICIAL GEOLOGY OF THE JUNEAU URBAN AREA AND VICINITY, ALASKA WITH EMPHASIS ON EARTHQUAKE AND OTHER GEOLOGIC HAZARDS

By

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

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SURFICIAL GEOLOGY OF THE JUNEAU URBAN AREA AND VICINITY, ALASKA
WITH EMPHASIS ON EARTHQUAKE AND OTHER GEOLOGIC HAZARDS

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INTRODUCTION

This report results from a geologic study of surficial deposits in and near the Juneau urban area. The investigation is part of an earthquake-hazards study in Alaskan coastal communities by the U.S. Geological Survey. The principal objectives of the project are to investigate and evaluate the potential geologic effects of earthquakes and other catastrophic geologic events in the Juneau area.

The accompanying geologic map was compiled on parts of three U.S. Geological Survey quadrangles: Juneau A-2, Juneau B-2, and Juneau B-3. Subsurface geology shown on the cross sections of certain areas of Juneau and Douglas is interpreted from records of drilled test holes. The topography used in constructing the cross sections was obtained from topographic maps prepared by the engineering firm of Wyller, Van Doren, and Hazard, at a scale of 1 inch = 400 feet, for the communities of Juneau and Douglas. The geologic character of each unit shown on the map and cross sections is briefly described in the tables and more extensively discussed in the text of the report.

In order to aid planners, engineers, developers, and others concerned with land use, two transparent overlays are provided to be used in conjunction with the geologic map. One overlay depicts areas known or believed to be susceptible to the effects of landslides. The other shows an interpretation of the relative suitability of geologic deposits for foundations, judged principally from the expected behavior of those deposits during a severe earthquake. These overlays represent the best interpretations I can make of the probable ground response of the various geologic deposits. The interpretations are based on laboratory tests as well as on many field observations of such conditions as ground stability, density, thickness, and saturation. I wish to emphasize that these overlays are only general guidelines for future urban planning and are not intended to take the place of detailed geologic investigations of specific sites.

The map and tables accompanying this report show the distribution of the geologic formations, some of their physical properties, uses, and probable reactions to a severe earthquake. However, it is not the purpose of this study to predict in detail how an earthquake would affect any one place. The unpredictability of magnitude, acceleration, direction, period of seismic energy, and the distance of an earthquake epicenter from Juneau makes an unqualified prediction of ground behavior impossible. The interpretations shown in the accompanying table should be regarded as indications of how certain geologic deposits will behave during an earthquake. Many of the interpretations are based on the behavior of similar deposits during earthquakes elsewhere, and others are based on laboratory tests of the physical properties of certain deposits.

This report includes also a tabular text that briefly summarizes the pertinent characteristics of each geologic formation. Both the text and the tables describe first the geology of each formation and then interpret the probable behavior of each formation under the influence of a severe earthquake, or as a consequence of man's use of the formation.

Juneau is in southeastern Alaska on the northeastern side of Gastineau Channel, a fiord that separates Douglas Island from the mainland. Gastineau Channel joins Stephens Passage to the southeast; it terminates about 8 miles northwest from Juneau near the mouth of the Mendenhall River valley where it merges with Fritz Cove. West Juneau is on Douglas Island near the west end of the bridge from Juneau that crosses Gastineau Channel. The town of Douglas is on Douglas Island about 2 miles southeast from West Juneau.

The Juneau area, as used in this report, consists of that part of the Greater Juneau Borough that adjoins Gastineau Channel, Fritz Cove, Auke Bay, Lena Cove, and Tee Harbor, and includes the small islands in the waterways. Geologic mapping was generally restricted to shore and valley areas, and along mountainsides to altitudes less than 700 feet above sea level.

The coast mountains on the mainland rise sharply from tidewater to an altitude of more than 3,500 feet at Mount Juneau, less than 1 mile from the city of Juneau. About 7 or 8 miles eastward from tidewater lies the Juneau Ice Field, which covers much of the high part of the mountains. Only one glacier, the Mendenhall Glacier, extends into the mapped area; it lies at the head of the Mendenhall River valley, a valley about 4 miles long and from about 1 to 2 miles wide.

In addition to the Mendenhall River valley, the valleys of Salmon, Lemon, and Fish Creeks either are or probably will be used for urban development. Of these, the valleys of Salmon and Lemon Creeks already contain homes or other structures. Fish Creek valley probably will be developed after the proposed road to Cropley Lake and the planned ski development are realities.

Low-lying shorelands provide most of the desirable homesite properties in the mapped area because of the steepness of the mountains. Much of the land along the mainland shore northward from Juneau to Tee Harbor is developed as residential property. Urban development on the east coast of Douglas Island has been slow and sporadic; consequently, there are areas there that remain undeveloped. Lack of large water supplies is one of the causes for the slow urban growth on Douglas Island.

ACKNOWLEDGMENTS

Many organizations and individuals contributed valuable information, advice, and unpublished data on various aspects of the Juneau area. Mr. Felix Toner, of the engineering firm of Toner and Nordling, gave permission to drill on his property and both his firm and that of Wyller, Van Doren, Killewich, and Hazard drew on their knowledge of the area and made their files available to me to provide engineering and design data for the Juneau area. Mr. George Davidson, City of Juneau, provided a large-scale base map of Juneau. Mrs. Margaret Fritsch, Juneau Borough Planning Department, made data from their files available to me. Mrs. Susan H. L. Barrow, Curator, Alaska Historical Library, provided photographs that helped reveal the location and form of geologic and topographic features now obscured by buildings and manmade fill, and made available old newspaper accounts quoted in this report. Special acknowledgment is made of the assistance provided by Ray D. Miller and Robert J. Munson, Juneau District, Alaska Department of Highways, and by Keith Hart, Juneau, who volunteered observations and made special efforts to provide samples of geologic deposits that were not accessible to me.

C. C. Fenn, U.S. Army Corps of Engineers, helped coordinate the test-drilling program undertaken as part of this study by R. S. Velikanje, Geologist, U.S. Army Corps of Engineers. L. E. Jack and K. J. Metcalf, U.S. Forest Service, provided copies of unpublished reports on the glacier and vegetation in the Mendenhall valley. In addition, F. R. Stevens and D. N. Swanston, Institute of Northern Forestry, U.S. Forest Service, discussed soils and debris flows with me both in the office and in the field.

L. A. Yehle assisted for several weeks in the field. A Geological Survey mobile laboratory under the direction of R. A. Farrow and E. E. McGregor was used for about 1 month to provide selected soil tests, and for geophysical traverses using seismic and resistivity techniques. Members of the Geological Survey's office in Juneau provided logistic support and made available unpublished well records for critical areas; in particular I want to acknowledge the assistance of V. K. Berwick, C. H. Clark, C. W. Boning, J. A. McConaghy, R. L. Cartmill, L. J. Whistler, and Jessie Skrzynski. D. A. Brew and A. B. Ford, U.S. Geological Survey, provided data collected in connection with their studies of the bedrock geology of the Juneau region, which was most helpful to me.

GLOSSARY

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

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

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

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

Fault. A fracture or fracture zone along which there has been structural displacement of the two sides relative to one another parallel to the fracture.

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

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

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

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

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

Infiltration. The slow entry of water from the ground surface into surficial deposits or into bedrock.

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

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

Joint set. A group of joints parallel in strike and dip with each other.

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

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

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

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

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

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

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

Talus. Accumulated heap of rock fragments derived from and lying at the base of a cliff or very steep slope. The term applies to the body of rock fragments as a unit. The heap usually has a form determined by gravity and the angle of rest of the material (Varnes, 1958).

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

FAULTS

Faults record ground movement that occurred in the past, and indicate the possibility of renewed movement in the future. Consequently, one of the objectives of the field mapping was to determine if recent movement on any faults could be established in the Juneau area. Particular attention was given to a search for geomorphic features that might indicate fault displacement of the relatively young deposits of Pleistocene or Holocene age. Broad flattish surfaces on surficial deposits and terraces were examined on the ground for evidence of vertical or horizontal movement, and aerial photographs were inspected for linear features in the surficial materials, which might indicate fault traces. In addition, exposures of glaciomarine deposits were examined for any internal evidence of fault movement. I have concluded that in the area mapped no recent fault activity has displaced surface deposits of Pleistocene or Holocene age. Whether there has been fault movement beneath the waters of Gastineau Channel during that time, however, is not known. Thus, all the faults shown on the geologic map (pl. 1, sheets I and II) probably are of pre-Pleistocene age.

Faults have been recognized in southeastern Alaska and in and near the Juneau area for many years (fig. 1). The faults shown on figure 2 have been plotted from earlier work by others. F. E. and C. W. Wright (1908, p. 21-22; pl. IV) proposed that the fiord marked by Lynn Canal and its southern extension, Chatham Strait, existed because of a major fault (see fig. 1, this report). This fiord, which is only 3-6 miles wide along most of its length is more than 250 miles long and trends at an angle of about 30° to the strike of the bedrock. Buddington and Chapin (1929, p. 291) also considered the Lynn Canal-Chatham Strait fiord to be the result of erosion along a fault zone. St. Amand (1954, p. 1350; 1957, p. 1357, fig. 7) concluded that the Lynn Canal segment is part of the Denali fault and postulated it to be a strike-slip fault with right-lateral movement. This means, in effect, that the parts of the earth on different sides of the fault moved in opposite directions and basically in a horizontal plane, with the western side of the fault moving northwestward relative to the eastern side. He also suggested that the nearly straight alignment of Cowee and Boulder Creeks (northwest of the mapped area) along with Windfall and Montana Creeks and Gastineau Channel, may mark an important fault branch of the Denali fault. Twenhofel and Sainsbury (1958, fig. 2) show an inferred fault trending southeastward from the main Lynn Canal-Chatham Strait fault through Berners Bay as the Gastineau Channel fault (?) (fig. 2, this report). The trace of this inferred fault is believed to be represented by deformed rocks in the saddle in the ridge northeast of the Juneau airport (C. L. Sainsbury, oral commun., 1966). Subject to controversy, the existence of a fault along Gastineau Channel is given support by seismic data that show a V-shaped rather than U-shaped valley at depth (Gene Rusnak, written commun., 1967). Twenhofel and Sainsbury (1958, fig. 2) also show an inferred fault trending northwest-southeast that approximately bisects Douglas Island and follows Fish Creek on the northern part of the island (fig. 2). Barker (1957) mapped shear zones along Windfall and Montana

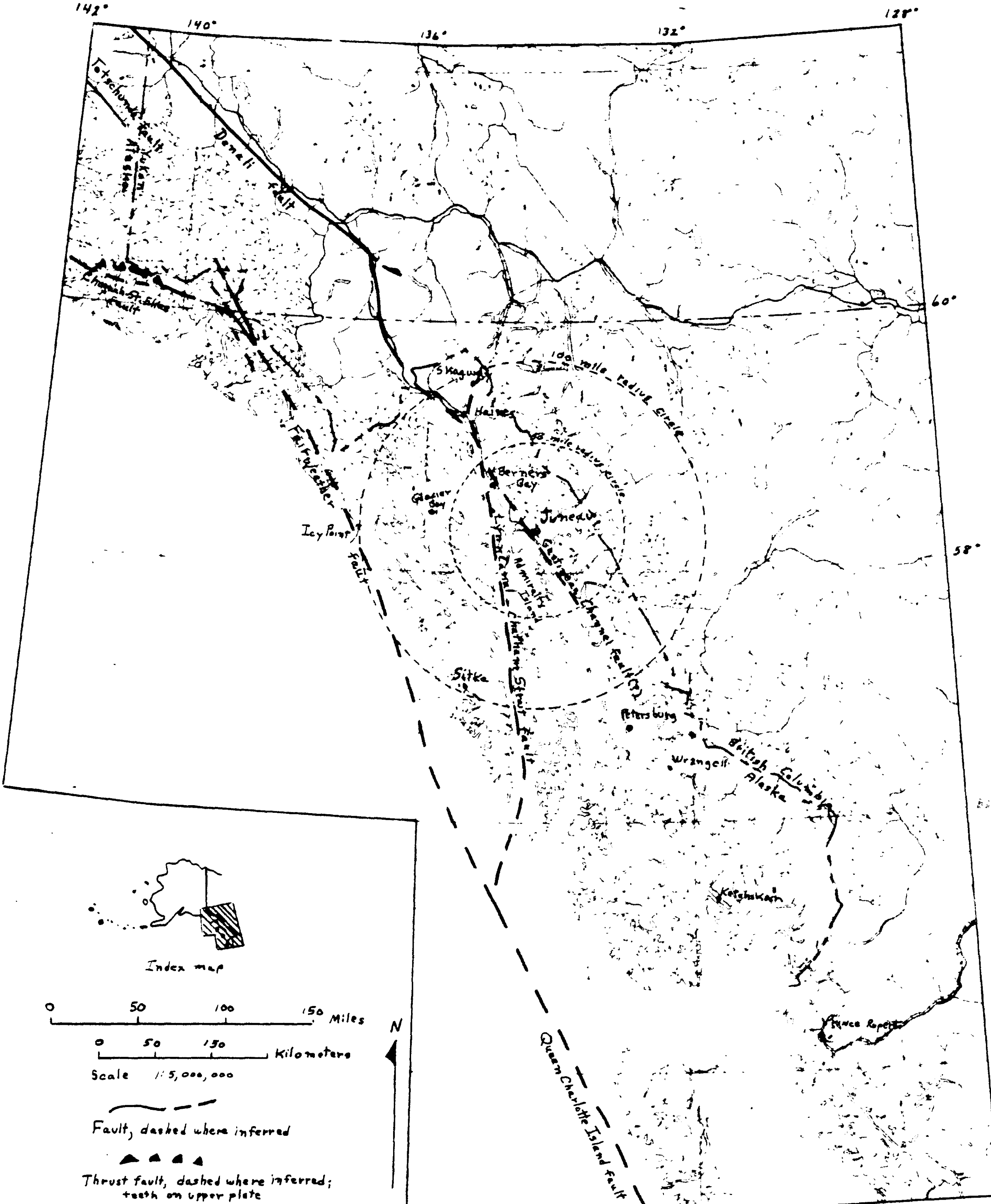


Figure 1.--Location of selected major faults in southeastern Alaska that might cause earthquakes that could affect the Juneau area. Fault locations from Twenhofel and Sainsbury (1958), Tobin and Sykes (1968), and Richter and Matson (1971).

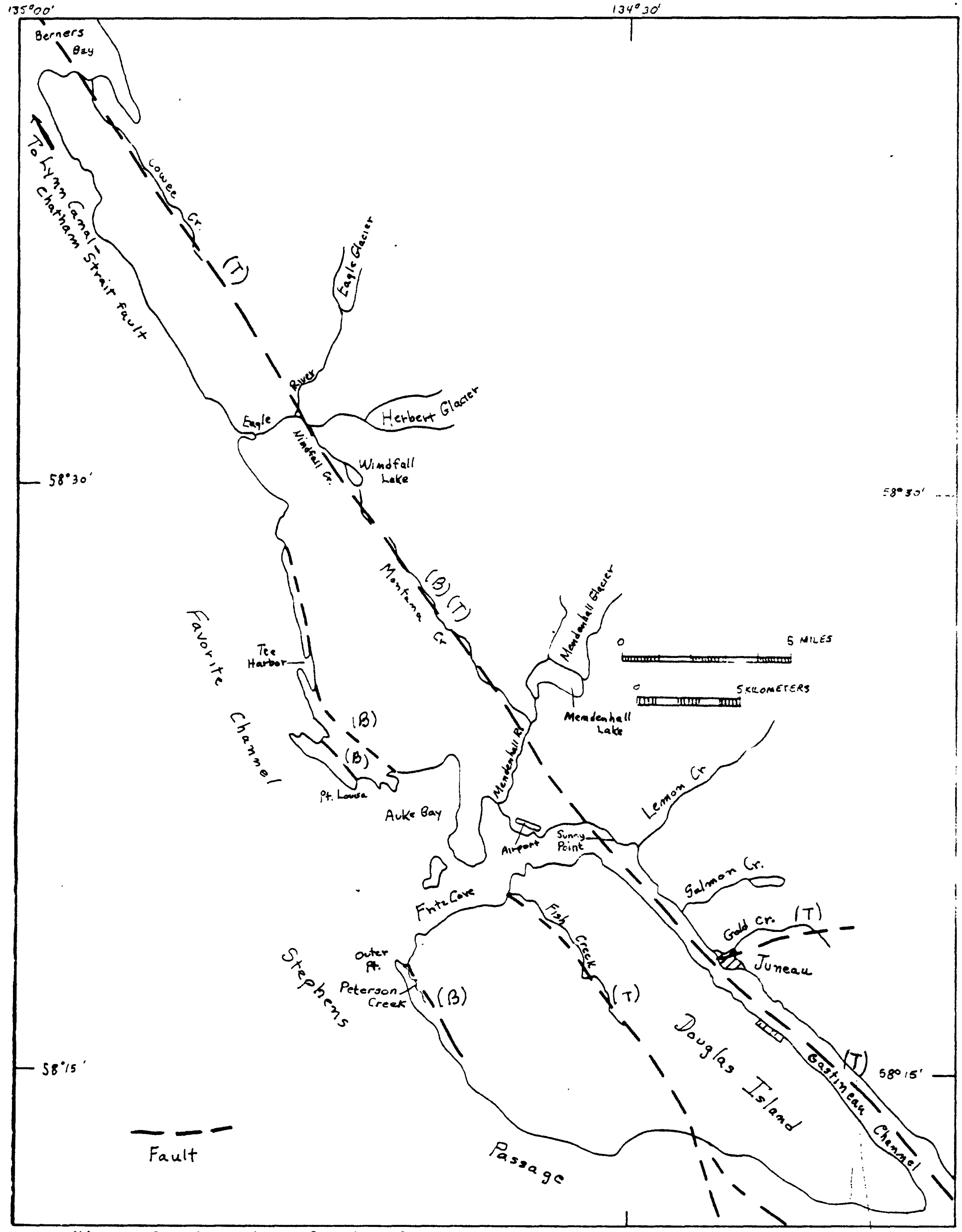


Figure 2.--Location of major faults in the Juneau area as mapped by Twenhofel and Sainsbury (1958) indicated by (T), and by Barker (1957) indicated by (B).

Creeks, showed a fault along Peterson Creek on the western part of Douglas Island, and showed possible faults at the base of and parallel to Auke Mountain, north of Auke Bay, and from Lena Cove to near Point Louisa on Auke Bay (fig. 2 this report). Brew and others (1966, fig. 8-5) also show a major fault or lineament trending northwest along Gastineau Channel and Montana Creek. The steeply dipping beds at Sunny Point also may be related to a fault or faults along the channel. In addition, a water well drilled just northeast of the bedrock ridge that forms Sunny Point did not penetrate bedrock until it reached the depth of 105 feet (Andrew Haskins, Alaska Drilling Corp., Juneau, Alaska, oral commun., 1965). This suggests to me that the bedrock at the Sunny Point promontory may be a bedrock remnant contained between faults. Spencer (1906, pl. IV) first mapped the Silverbow fault along Snowslide Gulch, adjacent to Gold Creek, which trends Gastineau Channel. The fault location shown on the geologic map, plate 1, sheet I, of this report, was provided by A. B. Ford and D. A. Brew, U.S. Geological Survey. Although Brew and others (1966, p. 167) consider that post-Tertiary movements along existing faults in southeastern Alaska helped to develop the present-day configuration of the land, evidently no such movements have occurred near Juneau. The nearest known example of historic fault movement occurred about 100 miles west of Juneau in 1958 (Tocher and Miller, 1959; D. J. Miller, 1960; Page, 1969) along the Fairweather fault (fig. 1).

EARTHQUAKES

Although movement has not occurred along faults in or near Juneau in historic time, the area has been repeatedly shaken by earthquakes from more distant epicenters. Furthermore, the type and distribution of some of the geologic deposits at Juneau leads me to believe that in prehistoric time, the area was seismically active. The geologic evidence in support of this conclusion includes the rockslide-avalanche deposits and some of the other landslide deposits. The rockslide-avalanches along lower Gold Creek and on Douglas Island and the landslides in Lemon and Salmon Creeks and along Nugget Creek reflect catastrophic events of the fairly recent past. Other conditions could have triggered these slides, but recurring seismic activity seems to be the most likely cause. Because of Juneau's location at the base of steep mountain slopes, there is an ever-present risk from falling and sliding rock. This risk is greatly increased during a severe earthquake, and hence, rockfalls should be considered in long-range planning for urban development.

Although damage to buildings from seismic shaking is not solely a geologic effect, the period and amplitude of ground motion depend on geologic factors. It is generally known that vibration is more intense in thick unconsolidated materials than in bedrock. This report in part discusses the probable response of the various geologic materials to the effects of a hypothetical nearby severe earthquake.

Newspaper and scientific accounts record the occurrence of earthquakes of various intensities since about 1900. Table 1 is a compilation of earthquakes since 1847 that various sources reported as felt in Juneau or that possibly should have been felt in the Juneau area. Table 2 is the Modified Mercalli intensity scale, which classifies the severity of earthquakes by a numerical rating that is based on ground behavior, human reactions, and damage. On September 10, 1899, miners working underground on Douglas Island and in the Silverbow Basin rushed to the surface after the strongest earthquake to occur that day at Yakutat, Alaska (The Alaska Miner, Sept. 16, 1899). Tarr and Martin (1912, p. 48) refer to reports that fractures or furrows occurred in "incoherent sand flats in the Lynn Canal region * * *," and (p. 82) to eyewitness accounts that reported ground waves, dishes being broken, and boulders rolling down the mountainsides from the shocks in the Berners Bay area. The direction of motion and severity of the quake at Berners Bay is suggested by a person who stated that "It seemed to come from the northwest. If walking northwest one staggered forward, and if walking northeast one staggered sidewise." (Tarr and Martin, 1912, p. 82). Another eyewitness reported that icebergs filled the nearby waterways of Taku Inlet and Stephens Passage, as well as Gastineau Channel, from the shattering of Taku Glacier. Buildings along the Juneau waterfront shook and swayed and windows rattled during an earthquake in 1909 (Daily Alaska Dispatch, Feb. 16, 1909). A large earthquake that occurred February 12, 1934, on the northern part of Admiralty Island (fig. 3) had an intensity of 5 at Juneau; it caused the rock dump at the A-J mill to settle in places and tipped over a stacker. An earthquake shook Juneau on September 23, 1934, and caused furniture to move (Davis and Echols, 1962, no. 224). Another earthquake shook buildings in Juneau on September 27, 1947 (Davis and Echols, 1962, no. 246). As a result of the earthquake along the Fairweather fault near Icy Point on July 10, 1958, Juneau shook and merchandise fell to the floor, minor rockslides occurred in the highland part of town, and people fled to the streets as the 12-story Mendenhall apartment building and private homes swayed (Daily Alaska Empire, July 10, 1958). As a result of the great Alaska earthquake on March 27, 1964, a float plane on the water in the harbor at Douglas flipped over "as a result of unusual tidal action" (Juneau-Daily Alaska Empire, Mar. 29, 1964). Von Hake and Cloud (1966, p. 54) state that the 1964 earthquake was felt principally in the northwest part of Juneau, especially in the Gastineau Channel area, but with "the heaviest rolling shocks apparently concentrated in the Mendenhall valley."

Probability

The historical record indicates that earthquakes strong enough to affect Juneau most likely would occur along the Fairweather-Queen Charlotte Islands fault, and that their direct effects on Juneau would depend on the epicentral distance, magnitude, and focal depth and on the acceleration, amplitude of the ground waves, and duration of shaking at Juneau. A long duration of shaking even from an earthquake of fairly low magnitude can result in greater damage than one might predict from the magnitude alone.

Table 2.--*Abridged Modified Mercalli intensity scale*[1]

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

[1] Abridged from Wood and Neumann (1931)

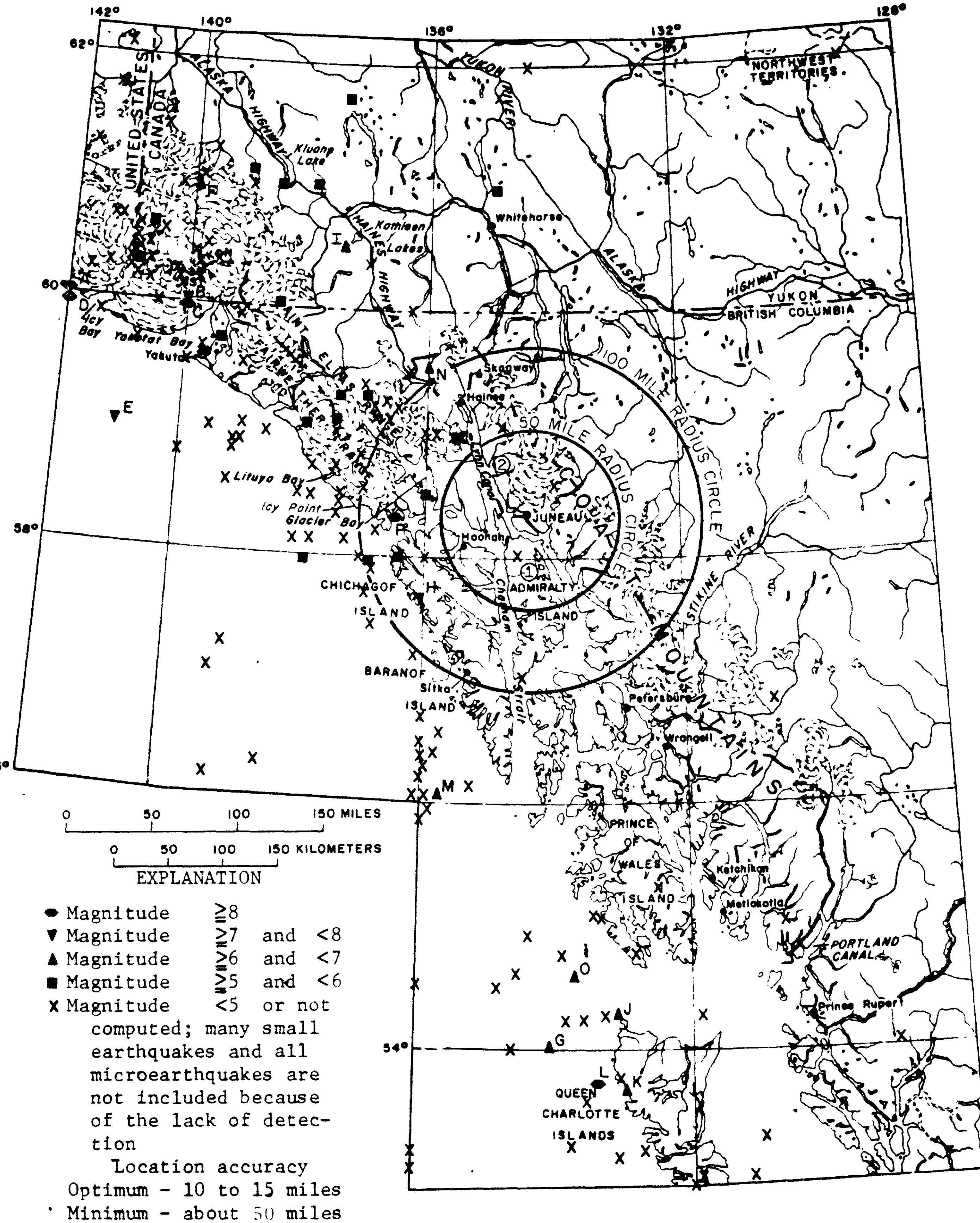


Figure 3.--Location of epicenters and approximate magnitude of earthquakes in southeastern Alaska and adjacent regions for the period 1899-1969 inclusive. (Data from Davis and Echols, 1962; Tobin and Sykes, 1968; U.S. Coast and Geodetic Survey; Canada Dept. Energy, Mines, and Resources; and Internatl. Seismol. Centre.) Compiled and drawn by L. A. Yehle (Lemke and Yehle, 1972a). 1 Admiralty Island, 2 Berners Bay.

Dates and magnitudes of some earthquakes of magnitude ≥ 6

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

 (no page 14)

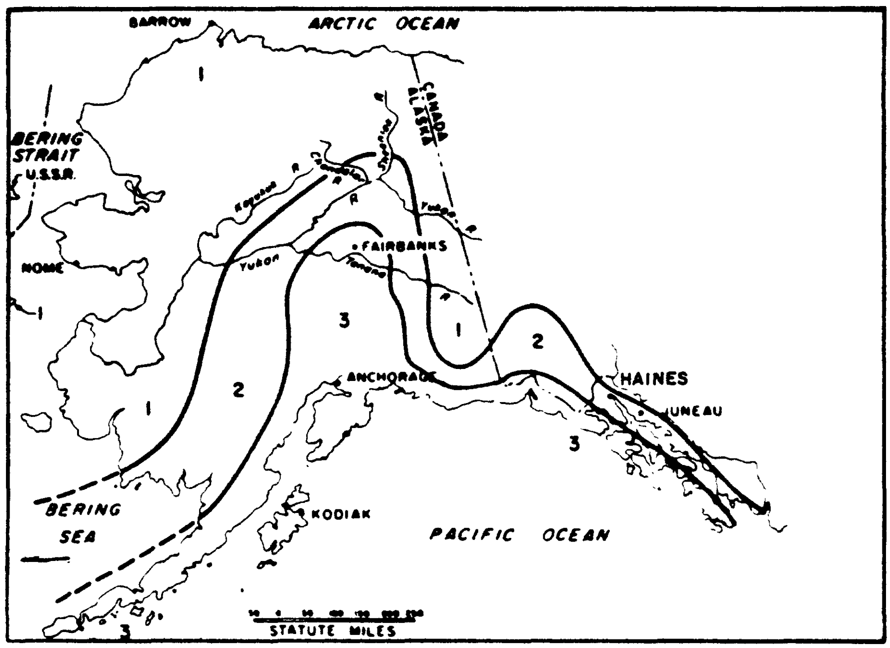
Prediction of the size and location of future earthquakes and their effects is difficult and tenuous. Figure 3 shows the location of epicenters and approximate magnitude of most of the recorded earthquakes that occurred between 1899 and 1969 in, or adjacent to, southeastern Alaska. Circles of 50- and 100-mile radii give some idea of the historical occurrences of earthquakes in location and magnitude within a distance that could strongly affect the Juneau area. Earthquakes beyond the 100-mile circle probably would not seriously affect Juneau. It is interesting to note that only two recorded earthquakes originated within 50 miles of Juneau since at least the turn of the century. The epicenter of one of these earthquakes, which occurred on January 20, 1964, lies about 25 miles northeast of Juneau. Although this earthquake was not felt at Juneau, it was recorded at Edinburgh by the International Seismological Centre (1967). As noted on figure 3, the optimum accuracy of the epicentral locations is within 10-15 miles, but some of the epicenters of the early 1900's may be misplaced as much as 50 miles or more; nevertheless, this 1964 earthquake apparently originated closer to Juneau than any other known at present.

An attempt to predict statistically the probability, or recurrence intervals, of earthquakes that might affect the Juneau area or their potential magnitudes can be based only on historical records, and at Juneau those records extend back only to near the turn of the century. A record of no less than several centuries is regarded by Lomnitz (1967) as necessary for computer predictions of earthquake recurrence intervals. In an attempt to provide a research guide for design and insurance uses, Milne (1967) compiled all of the recorded earthquakes in Canada. One result of the study was a computer print-out based on records from 1898 through 1960 that provided the data for compilation of a strain-release map designed principally for western Canada, but including coastal Alaska (Milne, 1967, fig. 11, p. 809). On this map energy release is shown by contours numbered from 0 to 6. Because each contour is based on the maximum strain that has been released in the historical past, the contours can be used to suggest the potential size of future earthquakes. Juneau lies between the 0 and 1 contours on Milne's strain-release map. According to Milne (1967, table II, p. 805) the 0 contour requires a magnitude 3.7 earthquake once every 100 years to release the accumulated strain, and the 1 contour indicates that a magnitude 5 earthquake every 100 years is needed to totally release the strain. Earthquakes of these magnitudes are generally not considered to be destructive in areas of well-designed and properly built structures. These magnitudes are theoretically the most severe earthquake anticipated per 10,000 km^2 per 100 years, based on the historical data available to Milne. It should be pointed out, however, that the highest strain-release contour plotted, the 6 contour, is only about 80 miles from Juneau where it extends north from a point south of Icy Point (shown on fig. 1). This strain-release contour indicates a magnitude 7.7 earthquake as the theoretical maximum; more events of lesser magnitude would be needed to release the accumulated strain. For example, 3.1 events of magnitude 7 or 100 events of magnitude 5 would be needed to release the strain per 100 years. The Icy Point area was near the epicenter of the 1958 Fairweather fault earthquake that so dramatically affected Lituya Bay (D. J. Miller, 1960); this earthquake had a magnitude of about 8 (see fig. 3).

Some workers believe that the seismic activity in this part of southeastern Alaska has moved westward, away from the Lynn Canal-Chatham Strait fault during Pleistocene and Holocene times. Lemke and Yehle (1972a) summarize the regional tectonics concerning southeastern Alaska in more detail than this paper permits. Briefly, the tectonic thinking relative to the Juneau area is reflected in the following statements. Grantz (1966, p. 52, 76) suggests that the main seismic activity in southeastern Alaska now occurs along the Fairweather-Queen Charlotte Islands fault, and the related Chugach-St. Elias fault (fig. 1). Richter and Matson (1971, p. 1533) consider that "Movement, and especially lateral movement, along that part of the Denali fault southeast of the Totschunda fault system and the remainder of the faults in the Denali system extending into Canada and southeast Alaska may have been negligible since middle Pleistocene time." Figure 3 shows the concentration of seismic activity west and northwest of Juneau, near the coast and in the areas traversed by the Fairweather and Chugach-St. Elias faults, shown on figure 1.

The seismic status of the southeast part of the Denali fault system, however, remains unresolved. Although the Lynn Canal-Chatham Strait fault has shown no detectable seismic activity during the past 60 years, according to Tobin and Sykes (1968, p. 3839), or during recent microearthquake studies by Rogers (1972, p. 226), interpretations differ as to the meaning of this lack of activity. Richter and Matson (1971, p. 1534) believe that the Totschunda fault system shows Holocene right-lateral displacement; this, coupled with lack of evidence of such movement southeast of the Denali-Totschunda junction, suggests to them that the Totschunda fault system may extend to the Fairweather fault, and seismic activity may be bypassing the southeastern part of the Denali fault, including the Lynn Canal-Chatham Strait fault. Evaluating the absence of seismic activity, Tobin and Sykes (1968, p. 3840) suggest that prolonged quiet periods over part of an otherwise active earthquake belt might be a guide to the accumulation of strain which might be released suddenly as an earthquake. Boucher and Fitch (1969, p. 6648), summarizing their microearthquake seismicity studies along the Denali fault system, state that " * * * the results of this study indicate that the Deanli fault is active in some sense along its entire length east of Mount McKinley, the westernmost point visited in this survey, and it should probably not be dismissed as a relic fault of no current tectonic importance." On the basis of these statements, I feel that the Lynn Canal-Chatham Strait fault cannot be ignored merely because of the lack of historical earthquakes having epicenters related to it.

Attempts have been made by others to zone portions of the earth's surface according to the probable maximum magnitudes of earthquakes that might affect the various areas. The purpose of such zoning is to aid in development of design criteria and insurance rates, and is not to aid in prediction of the specific size or frequency of earthquakes. A seismic zone map (fig. 4) from the 1970 edition of the Uniform Building Code (Internatl. Conf. Building Officials, 1970) places Juneau in zone 2, a zone where the largest expectable earthquakes would have magnitudes of



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

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

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

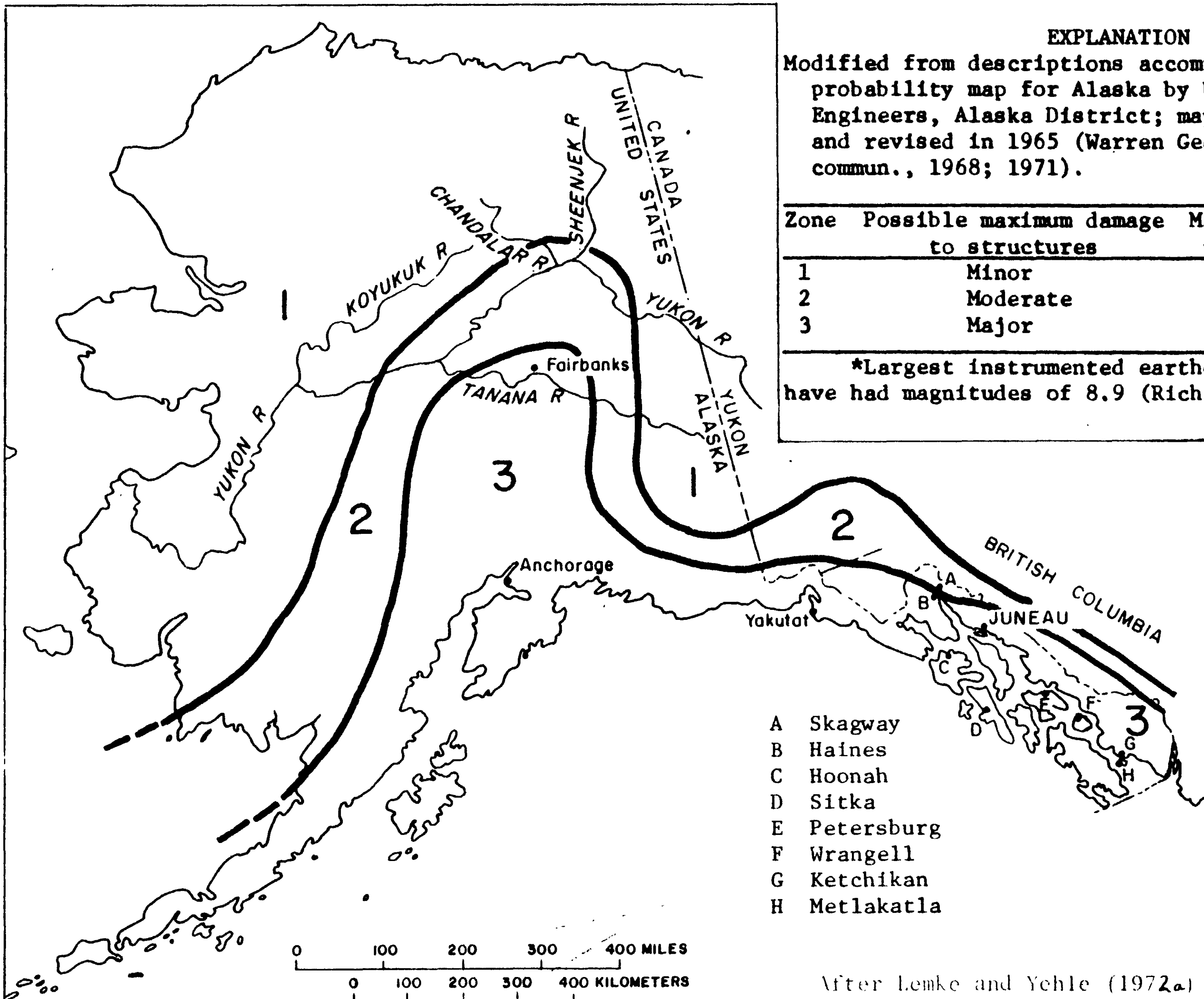
*Modified Mercalli Intensity Scale of 1931

Figure 4.--Seismic zone map of Alaska. Modified from the 1970 edition of the Uniform Building Code (International Conference of Building Officials, 1970). After Lemke and Yehle (1972a).

between 4.5 and 6 and where moderate damage to manmade structures is possible. On the other hand, figure 5 of this report is a seismic probability zone map currently used by the U.S. Army Corps of Engineers for design requirements (Alaska District, written commun., June 13, 1968). On this map Juneau lies within zone 3, which consists of the area in which an earthquake greater than magnitude 6.0 might occur and where major damage to manmade structures might occur. Thus, this map places Juneau in a considerably higher category of risk than either Milne's (1967) strain-release map or the seismic zone map in the Uniform Building Code. The higher risk assignment by the Corps of Engineers seems reasonable to me, until the seismic activity, or lack of it, in the Lynn Canal area is better understood. The hazard evaluations that are discussed for the various geologic deposits are based upon the assumption that a magnitude 6 or stronger earthquake could occur in the Juneau area. A magnitude event with an epicenter within 10 miles of Juneau could cause more shaking and resulting damage than a much stronger earthquake 100 miles away. Thus, in the tabular text the column titled "Probable ground response to a severe earthquake" discusses the *probable* reaction to a severe earthquake on the premise that, *if* such an earthquake occurs, part or all of the responses probably will occur.

TSUNAMIS

The possibility that the Juneau area is susceptible to tsunamis, or seismic sea waves, must be considered. It is highly unlikely that tsunamis from the ocean would cause spectacularly damaging effects in the Juneau area, such as those experienced elsewhere by the tsunamis caused by the 1964 Alaska earthquake. The previous discussion of faults points out that the Lynn Canal-Chatham Strait fault (fig. 1) is probably a strike-slip fault that had right-lateral movement (see p. 7). Tsunamis are not known to be caused by such horizontal fault movements; vertical displacement is considered necessary for their generation (Plafker, 1969, p. 138). Consequently, strike-slip movement along the Lynn Canal-Chatham Strait fault probably would not cause a tsunami. However, Plafker (1969, p. I39) mentions that unusual water disturbances in lakes, fiords, and rivers not physically related to the epicenter of the 1964 Alaska earthquake" * * * may have been generated by inertial effects of the water bodies as the land mass was displaced horizontally beneath them. Horizontal movement of a deep steep-sided basin or fiord, if it occurred fast enough, would be expected to impart potential energy to a contained water mass by changing its surface configuration * * *. Thus, because of its inertia, water would tend to pile up above its original level along shores opposite to the direction of displacement, and it would simultaneously be lowered along shores in the direction of displacement." Plafker states further "For a given amount and rate of displacement, the effect of horizontal movement on the water mass would be proportionally greatest where orientation of shores is normal to the direction of horizontal movement and relatively steep basin sides permitted the maximum energy to be transferred from the basin to the water mass."



EXPLANATION

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

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

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

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

After Lemke and Yehle (1972a)

Figure 5.--Seismic probability map for most of Alaska as modified from U.S. Army Corps of Engineers, Alaska District.

In effect, then, the Juneau area cannot be considered free from abnormally high and destructive water waves if, in the future, there is a severe earthquake centered along the Lynn Canal-Chatham Strait fault. Although the preceding discussions of faults suggest that the Lynn Canal-Chatham Strait fault may no longer be active, the historical seismic record for this area is so short, and the capability of predicting earthquakes and their effects so uncertain, that recognition of the possibility of abnormal water waves occurring in the area is only prudent. The National Ocean Survey maintains a net of observation stations that permit warnings to the residents of areas expected to be affected by tsunamis from distant sources, but only the individuals' awareness of the potential danger from abnormal water waves caused by relatively near severe earthquakes can help prevent damage from such waves.

SUMMARY EVALUATION OF RELATIVE PROBABILITY OF OCCURRENCE OF CERTAIN HAZARDOUS GEOLOGIC EVENTS

The foregoing discussions make it obvious that there are no criteria established at the present time that will reveal the specific form, time, or place of occurrence of hazardous geologic events. Judgments on my part, however, based partly on quantitative tests and partly on subjective reasoning as a result of studying the geologic materials in the Juneau area, place selected geologic hazards into five categories of relative probability of occurrence. The general range of probability from almost impossible to almost certain is arbitrarily indicated by the numbers 1 to 5, respectively. Within the detailed discussions that follow in the remainder of the report certain hazards are discussed regarding their relationships to each geologic formation. Table 3 lists what in my judgment are the relative probabilities of occurrence of selected geologic events.

GEOMORPHOLOGY

Physiographically, the Juneau area consists of three units--mountains, coastal benches along the fiords and bays, and floors of stream and river valleys. The slopes of the mountains are generally steep; 35°-45° slopes are prevalent, but even steeper slopes are common. The steep slopes merge into more gentle slopes near sea level along the fiords, so these valleys have the appearance of having recently been glacially shaped and smoothed. The U-shape, however, was developed as a result of the lower mountain slopes being covered by valley-filling surficial deposits. These deposits fill the deep bedrock-walled fiord containing Gastineau Channel and provide the valley with a flat floor. Glacial ice did smooth at least the upper part of the fiord walls, but seismic data indicate that the mountainsides continue downward at the same slope angle to form a V-shaped bedrock trough at depth (Gene Rusnak, written commun., 1967). The original floor of the valley is shown to be as much as 600 feet below the floor of the modern channel.

Well-defined and prominent topographic benches extend from south of the town of Douglas northward to Outer Point. Two surfaces separated by bedrock ridges or knobs that project through the surficial deposits

Table 3.--*Relative probability of occurrence of earthquakes and selected hazardous geologic events in the Juneau area within 100 years*

Earthquakes	*Probability*[1]
Earthquake of magnitude 6 or greater with epicenter at Juneau	1
Earthquake of magnitude 6 or greater with epicenter within 50 miles of Juneau	3
Earthquake of magnitude 6 or greater with epicenter within 100 miles of Juneau	5
Type of hazard	
Movement along faults in Juneau area	1
Massive landslides in glaciomarine deposits similar to landslides that occurred in the Bootlegger Cove Clay in the Anchorage area during the March 1964 earthquake	1
Delta-front slides into water as result of earthquake, causing waves with rapid runups in excess of 5 feet	3
Tsunamis in Gastineau Channel with rapid runups in excess of 5 feet	2
Tsunamis in Lena Cove, Auke Bay, Fritz Cove, Tee Harbor, and along North Douglas Island and rapid runups in excess of 5 feet	3
Debris flows along existing or new channels on mountain slope above the Gastineau Avenue-Franklin Street area	5
Massive rockslide-avalanches along mountain fronts	4
Isolated rockfalls along existing talus cones, and as unexpected occurrences elsewhere	5
Damage from severe shaking caused by earthquake of magnitude 6 or greater with epicenter within 100 miles of Juneau	3
Compaction and settlement of water-saturated deposits from shaking of ground in response to earthquake of magnitude 6 or greater with epicenter within 100 miles of Juneau	3

[1]Probability ranges from 1 (almost impossible) to 5 (almost certain)

provide a stairstep appearance to the lower slopes of the mountains on Douglas Island along Gastineau Channel. The lower surface extends to altitudes of about 200 feet above sea level. These benches are the result of deposition of subaqueous sediments over ancient wave-cut surfaces on bedrock followed by uplift of the land as the weight of melting glaciers decreased.

The large tributary streams on the mainland, such as Salmon, Lemon, and Montana Creeks, generally have broad evenly sloping alluvium-filled valleys at their lower ends. Upstream, however, the streams flow through narrow bedrock gorges, which more or less mark the present limit of possible urbanization.

GEOLOGY AND ENGINEERING INTERPRETATIONS

The following discussion consists primarily of information supplementary to that presented in tabular form. For this reason, the geologic formations are discussed in the same order in which they appear in the table.

The distribution and nature of the surficial deposits in the vicinity of Juneau are shown on plate 1, sheets I and II. Regional bedrock studies currently are being made by D. A. Brew and A. B. Ford, U.S. Geological Survey; consequently, for the purposes of this report the bedrock is undifferentiated on the accompanying geologic map. Southeastern Alaska, which lies within an active tectonic belt that extends around the Pacific Ocean, has been tectonically active since the early Paleozoic. It was subject to "intermittent marine detrital clastic, carbonate, and volcanic deposition from early Paleozoic through late Mesozoic time" (Brew and others, 1966, p. 149). The Juneau area is immediately underlain by layered greenstone, graywacke, slate, greenschist, and metavolcanic flow breccia that are "mostly of Mesozoic age, perhaps as young as Early Cretaceous" (Loney and others, 1967, p. 521). These rocks lie exposed where Quaternary glaciers have scraped and removed residual soils from along the mountain slopes. At lower altitudes, however, the bedrock is generally obscured by overlying unconsolidated materials of late Pleistocene and Holocene age.

The unconsolidated materials of Quaternary age are subdivided in this report into groups of deposits of similar origins, though possibly of different ages. These groups are manmade fill, muskeg, mass-wasting deposits, glacial deposits, alluvial deposits, deltaic deposits, beach deposits, marine deposits, and glaciomarine deposits. With the exception of the first five categories named, all or part of the other deposits originated because of deposition related to changes in sea level resulting first from the depression and then from the subsequent rebound of land owing to the advance and retreat, respectively, of the last widespread glaciation in southeastern Alaska.

Sometime prior to 12,000 years ago, the land was depressed at least 500 feet and, locally, as much as 700 feet below modern sea level in the

Juneau region. Micro- and macrofossils in the glaciomarine deposits, and radiocarbon dates determined from them, provide the evidence and time of such submergence. Pebbles, cobbles, and boulders, in a sandy matrix containing the shells, constitute much of the glaciomarine deposits preserved in the Juneau area. Deltas and beaches accumulated from streams and tidal waters; these are preserved today as deposits raised several hundred feet above modern sea level.

Holocene materials in the Juneau area, as shown on the geologic map, are both glacial and nonglacial in origin. Ice-laid as well as fluvial deposits represent the materials that accumulated as a result of the presence of piedmont or valley glaciers. These deposits are found along major streams on the mainland and Douglas Island. Nonglacial deposits include alluvium underlying flood plains and terraces, and in deltas building into Mendenhall and Auke Lakes, and into Gastineau Channel. Beach and bar deposits occur in some places along the shores of the channel, bays, and coves. Intertidal materials are along the present shores in areas of moderate or weak offshore currents, and also underlie surfaces lifted slightly above high tide level since the turn of the century. Muskeg overlies and obscures portions of some of the Pleistocene and Holocene deposits in the Juneau area.

Deposits accumulated from mass-wasting processes are widespread and are evidence of a continued potential major geologic risk in the Juneau area. Landslides that include rockslide avalanches and debris flows, and accumulations of talus near the base of slopes suggest that unstable mountain slopes surround the Juneau urban areas. Loose and weathered rock, and residual debris, lie on steep slopes awaiting some trigger to send them moving toward the foot of the slopes.

Bedrock

Bedrock, shown on map as unit (b), of the Juneau area includes layered greenstone, graywacke, slate, greenschist, and metavolcanic flow breccia (Knopf, 1912; Buddington and Chapin, 1929; Barker, 1957; and D. A. Brew, written commun., 1965). Upvalley from the Mendenhall Glacier and beyond my mapped area is one major source for the pieces of metamorphic schists, gneisses, and a coarse-grained hornblende quartz diorite contained in the surficial deposits (D. A. Brew, written commun., 1965). A similar suite of rocks, east of Juneau, lies adjacent to or in the Gold Creek drainage (Sainsbury, 1953).

The age of the layered rocks in the Juneau region ranges from late Triassic to Early Cretaceous (Plafker, 1962, pl. 10; Brew and others, 1966, figs. 8-2, 8-10, and 8-11). The intrusive rocks east of the area mapped in this report are of Early Cretaceous age (Brew and others, 1966, fig. 3 and p. 153) and Eocene age (Forbes and Engels, 1970, p. 583).

Two principal rock groups are present on the mainland and Douglas Island, according to Buddington and Chapin (1929, pl. I). Graywacke, slate, and conglomerate extend along the entire length of the eastern side of

Douglas Island and along the mainland northwestward from Juneau. Greenstone and greenschist (green phyllite) are interbedded with black and gray slaty phyllite along the mainland shore of Gastineau Channel south of Juneau. The islands in Auke Bay and Fritz Cove and the mainland north from Auke Bay have been mapped as augite-bearing volcanic flow breccia of Jurassic(?) to Cretaceous(?) age by Barker (1957).

The bedrock tends to form nearly vertical bluffs along shores and moderately steep slopes along much of the mountainsides. Mass wasting and heavy rainfall have removed most of the glacial deposits from these slopes so that rock is generally at the surface at most places above 500 feet above sea level. Steep to vertical alcoves are common on slopes above areas of rockfalls, rock avalanches, and some talus cones.

The physical properties of the bedrock influence the stability of the mountain slopes and use of the land at the base of the mountains. Several broad generalizations may call attention to what I consider to be critical aspects of land use along or below steep bedrock slopes. The foliation or bedding of the layered rocks on the mainland strike nearly parallel to the trend of the steep slopes along Gastineau Channel. These planar features generally dip northeastward into the mountainside from about 30° to 75°. A joint set that strikes almost perpendicularly to the foliation or bedding is well developed, and generally dips northwestward at between 55° and 80°. Another important joint set strikes nearly parallel to the foliation and layering, but dips southwestward at about 65°. The result of the combination of planar features and joints is that the bedrock readily breaks into large blocks which can become loosened and unstable on the steep slopes. Such large blocks formed by these intersecting fractures are loosened even further by tree roots that grow in the openings and push the blocks apart.

On Douglas Island, the layering of the rocks which is somewhat easier to see because of the conspicuous partings in slate, also strikes to the northwest and dips northeastward about 60° to 65° in many places; the dip is locally steeper. These beds are cut by joint sets that have variable directions; some strike northeast and dip southeastward, others strike northeast and dip northwestward.

Erosion of the bedrock is generally controlled by weathering along the planar features, which are the weakest aspect of most of the bedrock. Weathering generally progresses along these incipient fractures, and developes openings and zones of weakness along which water and gravity, singly or in combination, can loosen and erode the rock. The micaceous greenschist above Juneau weathers and erodes easily, and schistose particles accumulate as clayey colluvium. The bedrock on the steep mountain slopes has been scraped by past glaciers that moved across the area. Sainsbury (1953) reports residual soils on bedrock at interstream divides at altitudes of 3,000 feet and higher, but the bedrock is scarcely weathered on the glaciated mountainsides.

Bedrock is more resistant to shaking from earthquakes than any of the other geologic materials in the Juneau area. Although damage to buildings from seismic vibration is not a geologic effect along, the frequency and amplitude, which affect buildings, depend on geologic factors. The subsoil is important in this respect, and, other things being equal, it is widely accepted that vibration is less in areas of bedrock than in areas of thick unconsolidated materials. Direct seismic damage is highly selective, and poor construction practices and structural weaknesses are quickly revealed by earthquakes (Berg and Stratta, 1964, p. 58), whether on bedrock or on unconsolidated materials.

The wave-cut benches on bedrock along the channel, bays, and coves are in areas that are susceptible to tsunami waves. The low flat bedrock benches along the shore of Auke Bay, on Mendenhall Peninsula, and on Auke Cape are particularly susceptible because of their openness to the waters extending north and northwest. The bedrock bench bounding the Lena Cove area on Point Lena is also exposed to open waters. Waves that originated to the north or northwest probably would strike these areas with full force.

Large rockslide- avalanche deposits in the Juneau area are proof of past rockfall activity, but rockfall potential along the mountains varies from place to place. Most previous rockfalls originated on slopes generally free of dense vegetation and left scars that coincide with planes of weakness along joint sets or at boundaries between different rock types. Some mountain areas are underlain by rocks that have tight joints and smooth debris-free slopes. Such slopes are more stable than slopes where broken rock is being pushed apart by tree roots or is slowly moving downhill.

While most of the bedrock slopes in the Juneau area lie some distance from Gastineau Channel, large rockfalls could reach the water and cause waves. The fiord country of Norway is noted for nonearthquake-related massive rockfalls and slides that have caused giant waves and destruction along shores. In places in Norway the risk of rockfalls is of such concern that large loose rocks, many of which are being pushed apart by tree roots (as in the Juneau area), have been secured by cables anchored to solid rock (Bjerrum and Jorstad, 1968, p. 7). Inspection of the slopes above the urbanized areas of the Juneau Borough probably would locate similar large and unstable fragments that well could be secured in a similar manner.

Surficial deposits

Manmade fill

Manmade fill, as used in this report, consists of earth materials reworked by man, and solid waste discarded by man. These materials are mapped as debris from mining and milling operations that have been placed in dumps (md), undifferentiated materials generally used for highway and construction fill (mf), and accumulations of solid waste and rubbish placed in dumps (mw).

Mine dumps (md)

Mine dumps consist of waste from mining and milling operations. They are primarily mixtures of angular fragments of slate, greenstone, diorite, greenschist, and vein quartz. Many of the pieces are 4-10 inches in longest dimension; other pieces came through the stamp mill and range in size from less than 2 inches in diameter to sand.

The mine dumps along Gold Creek are related to mills, many of which have disappeared. The dumps along Gastineau Channel near the Alaska-Juneau mill are the largest in the area. Smaller dumps are near the Treadwell property on Douglas Island southeast of Douglas. Piles of rock that form elongate terraces or multiple ridges and mounds are characteristic of the mine dumps. The beach at Douglas is made up mostly of mill tailings.

The Alaska-Juneau tailings dump in Gastineau Channel is the thickest mine dump in the area. Fathometer traverses revealed that the margin of the A-J dump extends about 100 feet below sea level (Robert D. Miller, 1967). The thickness of the dump above high tide is not definitely known but it exceeds 20 feet in most places. Other dumps are thinner and probably veneer hillsides to a thickness of 20-50 feet but extend several hundred feet down slope. Small isolated dumps along Gold Creek and on Douglas Island are probably less than 40 feet thick.

Much of the debris in mine dumps is weathered and decomposed. The larger fragments in the A-J dump were not processed through the stamp mill, and pieces 4-6 inches and larger are common. Mine dumps on nearly level ground are composed of weathered rock fragments, and fine-grained material seems to be distributed throughout the deposit.

Infiltration is generally good to excellent in the coarser mine dumps, and poor in the intensely weathered dumps. The surface of the large A-J dump is generally sandy, but apparently the bulk of the dump consists of blocky fragments, so there probably are openings between rock fragments which allow free flow of water. Runoff is good on the fine-grained dumps with steep slopes and fair to poor on the large dumps along Gastineau Channel.

The fine-grained dumps are easily eroded by concentrated flow but resist sheet wash. The large dumps along Gastineau Channel resist sheet wash and wave erosion. Tidal currents have winnowed the dump material and formed broad flats that can be seen at low tide between the large A-J mine dump and Snowslide Creek dump.

The large A-J dump provides satisfactory foundations for oil tanks and other structures under static conditions. The general coarseness of the material, coupled with compaction and settlement over many years, seems to have resulted in a good foundation. The fine-grained dumps probably are less satisfactory foundation materials, and differential settlement should be expected.

Severe vibration shakes loosely consolidated materials more than densely compacted materials. Material in mine dumps is generally loosely placed, only moderately compacted, and contains many openings between rock fragments. During an earthquake on February 12, 1934, the A-J dump settled in several places and waste conveyors were wrecked, apparently by shaking (U.S. Coast and Geodetic Survey, 1934, p. 38). Profiles across Gastineau Channel from the slopes of the A-J dump show slope configurations that may indicate subaqueous sliding of blocks marginal to the dump (Robert D. Miller, 1967). A severe earthquake might result in marginal slumping and sliding, as well as settlement from compaction, of dump deposits otherwise stable under quiet conditions.

The large dumps of the A-J mine and smaller dumps of the Treadwell mine southeast of Douglas are all at or near shoreline. The impact of wave runup on these deposits would be similar to that discussed under younger delta deposits (p. 67). A low runup would rise on the slopes of the dumps but probably would not overtop them. If the rock fragments in the A-J dumps are in point-to-point contact, these deposits should be highly permeable, and high pore pressures would be unlikely to develop within the dump as a result of rapid drawdown of water level as part of violent oscillations of the channel waters during seiche or tsunami activities. If the deposit is not relatively permeable, pore pressure will increase as a result of any drawdown.

Field examinations of the slopes of mine dumps showed little evidence of slumps or slides. If steep cuts are made in dumps, however, raveling and slumping would probably occur. The mine dumps along the steep mountain slopes are potentially unstable and any disruption of the toes of these deposits probably will cause slumps and slides.

The large A-J mine dump is used in part as a golf course; the dump by the mill on the slopes near Juneau has been used as a source of fill. The mine dump overlying the Snowslide Creek delta is used as a trash and garbage dump.

Undifferentiated fill (mf)

The composition of undifferentiated fill is highly variable from place to place. Most highway fills are mixtures of rock, silty sand, gravel, and soil obtained from nearby cuts and borrow pits; many of these fills were emplaced years ago. Modern construction practices wherever feasible now restrict fill to materials that are not susceptible to frost action; sandy gravel and other materials having a low silt content are now commonly used. In some localities, glaciomarine deposits have been used for fill because of lack of other types of materials nearby; such an area is between Fritz Cove and Peterson Creek on Douglas Island. Angular framments from the A-J dump constitute the most common fill material beneath much of Juneau, but other readily available materials, including sawdust in the sawmill area along part of the Juneau waterfront, are also present. The fill under the airport is mostly fine grained and much of it was obtained from borrow pits in sandy younger delta deposits (Qdy) adjacent to the runway.

Most of the areas of fill are on nearly flat lying or gently sloping ground. These deposits should have good slope stability and should not fail by landsliding. The margins of thick fills having steep embankments, however, may slump or slide owing to overloading that would exceed the shear strength of the fill material. An example of poor fill material with low slope stability is a sawdust fill in the SE¼SE¼ sec. 23, T. 41 S., R. 67 E., along Gastineau Channel. Sawdust accumulated on the tidal flats over many years of sawmill operation. New earth fill from the A-J dump was placed at the site of the timber pile-supported sawmill during construction of the new freight distribution depot of the Alaska Steamship Co. About 4 feet of the sawdust and other debris lying on the tidal flats was buried by the new fill (Robert Killewich, oral commun. to J. A. McConaghy, U.S. Geol. Survey, Nov. 15, 1966). Four to six thousand cubic yards of the new fill at this site slid out on the sawdust into 40 feet of water in Gastineau Channel on Oct. 15, 1966 (Daily Alaskan Empire, Oct. 15, 1966). A severe earthquake would probably cause fill deposits to shake violently, fracture in places, and slide on steep slopes or where the embankments of thick fills are unsupported, or where fill is on weak material.

The largest amount of manmade fill underlies the Juneau airport and shopping area where it forms a large flat pad. Around Juneau, undifferentiated fill was placed around structures originally built on piles driven into intertidal flats, beach deposits, and younger delta deposits. The original shoreline as determined from older topographic maps and turn-of-the-century photographs matches the shoreward boundary of the fill as shown on the geologic map. The fill extends channelward around the docks and buildings along Gastineau Channel, and covers the lower part of the Gold Creek fan and is emplaced over the younger delta. Elsewhere in the area, only large or very prominent areas of fill are mapped; innumerable small fills have been emplaced along roads, streets, and building pads. Filled areas are generally flat where used for buildings but form terraces or ramps under roadways.

Thickness of fill varies from place to place. Fills only a few feet thick emplaced as a pad for construction are not mapped. In some parts of the fill on the Gold Creek fan delta, where the A-J dump material was used, the thickness exceeds 25 feet (Franklet and Swedell, 1969).

Physical properties of the fill vary from place to place, depending on materials used and method of emplacement. The density is variable. Older fills were placed without compaction, whereas new fill is generally compacted during placement by use of smooth-wheeled vehicles and sheepsfoot rollers. Some areas needing fill have been used to dispose of trees, soil, and muskeg removed from cleared areas. Such practices, which result in differential densities and strengths of fill, seem to be confined to small nonprofessional operations by individuals.

In most places, other than areas of coarse angular rocks obtained from the A-J dump, excavation and drilling in fill is generally very easy. The coarser materials make drilling difficult because of the looseness of the individual pieces in the fill.

Coarse fill has excellent infiltration characteristics. Fine fill generally has poorer infiltration characteristics, and water stands after rains. Surface runoff is slow over broad areas of nearly level fill.

Where fill is dominantly coarse material, erosion seems to be slight; finer grained materials seem subject to sheet wash and gullying where flow is concentrated. Fill that is subject to lateral scour by streams is easily eroded unless protected by riprap.

Most areas of fill that were observed during this study seem to provide stable foundations for light structures if properly compacted. In areas where glaciomarine deposits are used for fill, stability seems better if fill is emplaced and compacted with optimum moisture in dry weather.

Response of fill to seismic vibrations (shaking) will vary from place to place. Studies of damage in areas specifically affected by the 1964 Alaska earthquake revealed that areas of filled ground generally were more severely affected than were adjacent natural surficial deposits. Highway fills of coarse-grained sand and gravel were generally more stable than those composed of fine-grained sand and silt. Fills placed over fine-grained sediments subsided more than those on coarse-grained sediments. The fill deposit placed at the southern end of Auke Lake overlies swampy peaty deposits, and it probably would be deformed and contorted if a strong earthquake occurred in the Juneau area. Cracks as wide as one-half inch in the runway at the Juneau airport were reported to have developed as a result of the 1964 Alaska earthquake (Von Hake and Cloud, 1966, p. 54). The seismic response of fill underlain by intertidal deposits (Qts) and younger delta deposits (Qdy) will be similar to that of those deposits (see p. 68, 81).

Most of the manmade fill deposits are placed at or near water level along Gastineau Channel and Fritz Cove and adjacent to Auke Lake. If seiche waves or seismic sea waves affected these areas the fills would be inundated (see p. 69).

Waste dump (mw)

Three deposits of solid waste and rubbish are shown on the map; (1) the dump near the mouth of Lemon Creek, (2) the wrecked-auto dump along Gastineau Channel southeast of Salmon Creek, and (3) the old A-J dump on the Snowslide Creek delta. A fourth area, the Glory Hole at Treadwell, southeast of Douglas, was being considered by local authorities for waste disposal at the time of mapping. The Lemon Creek deposit is landfill and has a nearly level surface. The other two areas are surface deposits, and have a hummocky surface composed of junk. The thickest deposit is a dump covering most of the Snowslide Creek delta, where as much as 25 feet of trash has accumulated. The other deposits probably are thinner. Many small waste piles were not mapped.

Sanitary landfill is formed by the burial beneath soil of loosely compacted waste materials. Surface waste deposits are extremely loose and voids are abundant between pieces. The deposits consequently have a low density and are extremely compressible.

Sanitary landfill dumps vary from easy to difficult to excavate with heavy power equipment. The surface accumulations are easily moved and excavated by heavy power equipment. Drilling ranges from easy to difficult because of buried concrete, cars, and logs.

Infiltration is slow to rapid depending on type of earth used for burial; it is extremely rapid in surface waste piles. Runoff is generally slow because of the nearly level surface of landfill areas, the loosely compacted nature of the buried deposits, and the jumbled nature of surface accumulations. Erosion is high if landfill sites are subjected to stream or concentrated surface runoff.

Waste dumps generally provide very poor foundations. Settlement is excessive, and differential movement could cause structural damage to buildings placed on waste dumps. These materials are probably as loosely compacted as any deposit in the area and would thus be severely affected by earthquake vibration. The Lemon Creek and Snowslide Creek dumps are placed over water-saturated fine-grained deltaic deposits. The expectable intense shaking of these underlying deposits will be transferred to and perhaps amplified within the waste-dump materials. Also to be expected would be differential settlement caused by shaking.

Loosely compacted waste deposits have very poor slope stability in cuts and excavations, and dumps placed along bluffs are highly susceptible to landsliding because of very low shear strength.

Waste dumps can be converted to recreational use after the land is reclaimed. The low density and uncompacted nature of waste dumps makes them unsuitable for general construction uses.

Muskeg

Muskegs around Juneau are commonly referred to as slope muskeg, raised muskeg, and flat muskeg. Slope muskegs result from the accumulation of vegetative material on sloping land under extremely wet conditions and develop best where the terrain is low and hilly (Dachnowski-Stokes, 1941, p. 3-4; Heusser, 1960, p. 47). Sedge marshes are generally the parent material of the slope muskegs. The valley of Kowee Creek on Douglas Island contains slope muskegs. Raised muskegs develop under less wet conditions in a strongly acid environment and the absence of mineral nutrients so that moss can grow and accumulate as peat (Dachnowski-Stokes, 1941, p. 4). Convex surfaces are typical. Moisture falls on the muskeg surface rather than being supplied from the water table or from streamflow (Heusser, 1960, p. 48). Raised muskegs occur in the Montana-Windfall Creek area, at Sunny Point, in the flat areas above the town of Douglas along Lawson and Paris Creeks, and on the flats near

Johnson Creek near the north end of Douglas Island. Small shallow pools are scattered throughout these muskegs. Flat muskegs are closely related to slope muskeg but are limited to lowlands, edges of lakes, and valleys where the stream water is slightly acid and poor in soluble minerals (Dachnowski-Stokes, 1941, p. 4; Heusser, 1960, p. 49). Their surfaces are flat to slightly concave.

Peat (Qmk)

Peat and other plant debris in various stages of decay constitute the muskegs in the Juneau area. These muskegs contain very dark brown woody, fibrous peat and humus, as well as vegatative layers that contain pieces of wood. Peat on the edge of ponds or overlying beach deposits is silty. Plant seeds and pollen spores are locally well preserved. Detailed botanical and stratigraphic descriptions of selected peat deposits in the Juneau area are reported by Dachnowski-Stokes (1941, p. 24-32), Rigg (1937, p. 194-195), and Heusser (1960, fig. 24, p. 154). Ages of the peats in different muskegs vary. The oldest is basal peat from the divide between Montana Creek and Windfall Creek, which is dated at 10,000±400 years B.P. (Heusser, 1960, p. 97). This deposit is at an altitude of about 800 feet, as determined from the altimeter in a helicopter used in the course of my mapping, and is one of the topographically highest peat samples dated. Muskegs are scattered throughout most of the mapped area on top of the glaciomarine and glaciofluvial deposits, bedrock, and less commonly on younger outwash and other deposits. Peat in the muskegs is covered by mosses, tussocks of sedges, and scattered growths of scrubby timber. Beds of peaty material less than 5 feet thick generally are not mapped, especially where muskegs overlie most older raised beach deposits, thin and continuous (Qbe) on Douglas Island and the mainland. The muskeg tends to form rather flat to slightly domed surfaces.

The deepest muskegs contain more than 10 feet of peat and are those domed or raised muskegs on the Montana Creek-Windfall Creek divide, at Sunny Point, in the Lena Beach area, in the flat areas above the town of Douglas, especially along Lawson and Paris Creeks, in the broad muskeg area near Johnson Creek near the northern end of Douglas Island, and in the muskeg area near the north end of Auke Lake. Muskegs generally less than 6 feet deep occur in mountain valleys, such as the Kowee Creek valley on Douglas Island. These peat deposits generally are mapped wherever they are extensive, regardless of their thickness. Peat on the wide flats on the east side of Douglas Island is generally 2-3 feet thick and overlies thin sandy gravelly beach deposits; these areas of shallow muskeg are not mapped because portrayal of the underlying geologic units there is more important for construction and planning.

No physical-property tests were made of peat as part of this study. Field observations indicate that almost everywhere it is saturated, soft, spongy, and subject to high compaction under loads. Field and laboratory tests made by the Alaska Highway Department, as part of a materials investigation in the Mendenhall valley, showed that undisturbed peat in the muskeg on the northern side of Auke Lake contained more than 500 percent moisture (expressed as a percentage of the dry weight) (Ray D. Miller, District Materials Engineer, Juneau District, Alaska State Highway Dept., written commun., 1964). The dry weight of this peat was 11.5 lbs per cu ft and the wet weight was 60.7 lbs per cu ft. Such a high water content permits a high degree of compaction and flowage of the peat under loads. Peat is commonly removed and the excavation backfilled with gravel so as to avoid frost heaving.

Peat can easily be excavated with hand or power equipment. Deep excavations tend to have wet floors and water seeps from the walls. Where earthmovers have moved over muskeg areas repeatedly, the bearing strength of the peat diminishes and a muskeg-quagmire can result. Thin deposits of peat can be removed by tractor-drawn scrapers and earthmovers or by dozers; thicker deposits require backhoe or dragline. Peat is easily drilled but support is required for the drill rig and the drill hole requires casing.

Muskegs are generally wet, except during periods of prolonged drought when the water table is lowered. When the peat is wet, infiltration through it is slow and standing water is common; seeps are generally found at the contact with the underlying deposits. Surface runoff is slow because of the nearly flat or very gently sloping surface. When the peat is dry, infiltration into it is more rapid, but quick saturation of the upper part of the peaty material slows further infiltration. Although the small streams that cross some muskegs are slightly incised, lateral drainage through the upper part of the peaty material is slow and the muskeg area remains wet.

Peat has little bearing strength, especially when saturated. Differential compaction could cause structures built on platforms on thick muskeg to settle unevenly. In areas of thin peat deposits, excavation and backfilling with more stable material are advisable; caisson or pile footings should be used. Road constructors generally use excavation and backfilling methods in muskeg areas; but in areas where muskeg is over 10 feet deep and the peat is not excavated, gravel blankets 4-5 feet thick are placed over the muskeg to avoid roadbed problems (Munson, 1964, p. 5-6).

Each muskeg and its organic content should be evaluated individually as to its probable behavior during an earthquake because of the many types of underlying deposits, each of which has a different seismic response that would be transmitted to the muskeg. The response of a muskeg area to a severe earthquake commonly would be intense because it is loose, porous, and generally saturated. Seismic shaking generally is much more intense in loose sediments than in bedrock, and it lasts longer in unconsolidated wet materials than in unconsolidated dry sediments. Peat deposits underlain by unconsolidated materials, such as outwash, are more susceptible to vibration than peat underlain by bedrock. Road embankments and other fill material placed on thick peat probably would crack in response to vibration, as would peat reclaimed by draining the muskeg areas (Hansen, 1965, p. A27). Dense materials tend to subside into less dense underlying sediments when shaken (Kachadoorian, 1968,

p. C19). Highway fill placed over muskeg thus could be expected to fracture, compact differentially, flow laterally, and bulge upward around the edges of the fill material as a result of prolonged shaking during earthquakes. If frozen, muskeg over unconsolidated deposits that were saturated but not frozen would act as a coherent and competent layer, a condition found to be typical of fractured ground during the 1964 earthquake (Coulter and Migliaccio, 1966, p. C23). The muskeg would then be more likely to fracture and eject water and sediment as spouts or boils (Lemke, 1967).

Peat deposits generally are sufficiently above sea and lake levels to be out of danger of tsunamis or seiches. If a tsunami or seiche invaded Gastineau Channel, a low runup on shore could inundate the margin of the muskeg flat on Douglas Island opposite Sunny Point.

Peat stands in nearly vertical cuts when freshly excavated, even when wet. Water drips and seeps down cut faces in saturated peat; larger seeps are common at the base of muskeg in a cut, and highly decomposed peat layers slump or flow in time. Drier fibrous peat will stand indefinitely in vertical cuts. Peat deposits tend to be undercut by wave or current erosion of underlying unconsolidated materials, and in such cases fall as blocks. Peat does not as a rule slide of its own accord, because the fibrous material generally holds the deposit together.

Sphagnum moss is generally the peat commercially preferred as a humus-forming product, although sedge peats also are used. Fibrous and sedge peats consist of underground stems of grasslike plants and have horizontal lamination, whereas those derived from sphagnum moss are characterized by small columnar lumps and vertical aggregates and are preferred for use as stable bedding or for packing and shipping small plants (Dachnowski-Stokes, 1941, p. 7). Slope muskegs do not develop a continuous cover of sphagnum moss, but instead are composed of sedges, heaths, and patches of sphagnum moss. Raised muskegs generally have sedge in the lower part and layers of sphagnum moss at the top, locally separated by wood (Dachnowski-Stokes, 1941, p. 26-27); the sphagnum moss is considered by Dachnowski-Stokes (1941, p. 30-31) to be well suited for commercial use. He evaluates the Montana Creek muskeg deposit as exceeding in extent and amount the moss peat available at either the Sunny Point muskeg or the Lena Beach muskeg. Flat muskegs generally have little commercial use.

Mass-wasting deposits

Mass-wasting deposits, as mapped in the area of this study, include colluvium (Qc), talus (Qta), debris-flow deposits (Qfl), rockslide-avalanche deposits (Qra), undifferentiated landslides (Qsl), and colluvial(?) diamicton (Qud). While some of these deposits are contemporaneous in age, in total they span the time interval from very recent to prehistoric, and probably extend back as far as early Holocene or late Pleistocene times. As used in this study, mass-wasting deposits include deposits some authors would separate into materials originating from mass movement and mass transport, as well as from mass-wasting (Fairbridge, 1968

p. 688-700). In each of the above-mentioned geologic deposits gravity plays an important part in the accumulation of materials into mappable deposits. Water, snow, and possibly air also were involved in the transport of some or all of these deposits to a greater or lesser degree.

Weathering weakens the materials exposed at the surface of the earth, thereby allowing these materials to be more susceptible to gravitational influence resulting in downslope movement. Colluvium (Qc), rockslide-avalanche deposits (Qra), undifferentiated landslides (Qsl), and colluvial(?) diamicton (Qud) are most strongly influenced solely by gravity. Talus (Qta) and debris-flow deposits (Qfl) represent deposits that are influenced also in part by water and(or) snow.) All of these deposits represent accumulations of geologic materials after transport.

Transport can be slow or fast, the materials dry or wet, the areas involved large or small, and the movement can be represented by creep, slide, flow, or fall. Colluvium (Qc) in the Juneau area represents slow transport of weathered or unconsolidated materials to the lower parts of slopes by gravity, supplemented by moisture in the form of water, snow, or ice resulting in some movement by slope or sheet wash, and soil creep. Talus (Qta) here includes rockfall talus (individual pieces that fall, bounce, and roll to the bottom of slopes), alluvial talus (particles of all sizes transported by water; the talus accumulates generally as a result of heavy rains and melting snow and commonly displays narrow flow channels, natural levees, and gouged channels through brushy vegetation), and avalanche talus (generally as a result of snow avalanches in the Juneau area). Debris-flow deposits (Qfl) for the most part represent water-saturated loose residual materials that moved rapidly from steep slopes. Rockslide-avalanche deposits (Qra) generally represent extremely rapid downslope transport from steep bedrock cliffs. Joint sets seem to be important in the weakening and ultimate release of masses of bedrock; stress release may be the dominant factor in the rockslide avalanches. The large mass of rock slowly slides downward along dipping joint planes as a unit, but breaks into large and small fragments as the mass accelerates down the steep mountain slope. Slopes as steep as 70° are common at the source of these rockslide avalanches. Undifferentiated landslides (Qsl) are generally believed to be of a rapidly moving but basically dry type. They are formed by the downward and outward movement of slope-forming materials composed of natural rock, soils, manmade fills, or combinations of these materials (Varnes, 1958, p. 20). Colluvial(?) diamicton (Qud) is the mass-wasting deposit least understood by me. The origin of these deposits is problematical, but I believe that most of them were formed by colluvial processes, including creeping, flowing, and sliding.

Colluvium (Qc)

The composition of colluvium varies from place to place. The areas mapped as colluvium include talus and waterborne slope-wash deposits that are too small to show separately at the scale of the map, as well as soil and rock fragments. The bedrock that underlies the slopes provides most of the larger fragments in colluvium, and soil and glacial or glaciomarine surficial deposits mixed with the pieces of bedrock make up the colluvium on the lower mountain slopes in the Juneau area. In general, greenstone and mica-rich greenschist are the most common bedrock types in the deposits along Gastineau Channel on the mainland. At the northern end of Douglas Island, colluvium contains fragments of greenstone, slate, and volcanic flow breccia. Of particular interest is the colluvium covering the slopes in the vicinity of Nelson Street in Juneau. The matrix of the deposit here is rich in mica, much of it weathered to clay, which was derived from a greenschist that forms the westward face of the ridge between Mount Roberts and Mount Maria. An exposure along the Glacier Highway across from the Childrens' Home reveals greenschist fragments accumulated over a peaty humus layer. Age is Holocene.

The areal extent of colluvium is largely arbitrary as mapped. Only sizable deposits of colluvium are mapped; smaller deposits exist but are not mappable at the scale of the map. Much of the delineation of colluvium was done by interpretation of aerial photographs. Slopes underlain by colluvium are generally steep at the top and curve and become flatter downward. Deposits were mapped on the slopes to an arbitrary height where the bedrock appeared to be free of surficial cover. The thickness of colluvium is highly variable and is more than 15 feet in some places. Deposits on steep slopes are thinner.

Large rock fragments in colluvium lie near the angle of repose on steep slopes, with the flat sides of the fragments parallel to each other; spaces between fragments may be filled with clayey or humic matter, or by smaller pieces of rock. On lower, more gentle slopes the colluvium contains a greater amount of fine-grained matrix; much of this fine material has been altered to a clayey mixture of humus and silt and sand. This kind of colluvium overlies the mica-rich greenschist on hillsides south of Mendenhall valley.

The looseness of most colluvium permits rapid infiltration of water. In some places where bedrock or other impermeable layers underlie thin colluvium, springs and seeps appear, especially in road cuts. Runoff is rapid on upper slopes, but becomes much slower on the lower slopes. Erosion in colluvium is rapid where water flows down slopes free of vegetation. The fine-grained colluvium derived from greenschist is especially susceptible to such erosion.

Colluvium is a poor foundation material; it tends to creep downslope even on the more gentle lower mountain slopes. The high rainfall in the Juneau area lubricates the platey fragments in colluvium, and light structures founded on such material move out of plumb over a period of time. Thin colluvium should be removed and buildings placed on firmer underlying materials.

Colluvium is generally unstable even under earthquake-free conditions because of the steep slopes on which it occurs and because of the platy nature of the fragments in the deposit. Creep, a very slow downward movement shown by tree trunks bent downslope, is the norm rather than the exception. Weathered mica plates in colluvium on the hillsides south of Mendenhall valley are stacked as a deck of cards and have a tendency to slide over each other. Heavy rainfall can cause slumps and rapidly moving slides and debris flows in colluvium. Colluvium on slopes steeper than 37° is in danger of sliding when the cohesiveness of the material is destroyed or disrupted, whatever the cause (Swanston, 1970, p. 14). Excavations in colluvium create potentially unstable conditions upslope and result in raveling, washing, or sliding.

Strong earthquake vibrations will increase the gravitational effects on the colluvial deposits, could cause some displacement downslope, and might even cause quick-moving landslides. The debris flows on Mount Roberts originated in part in colluvium that became extremely saturated and that lost internal cohesion. Consequently, colluvium on steep slopes would be very susceptible to earthquake-induced sliding, especially if the earthquake occurred during or after periods of prolonged heavy rains.

Danger from isolated rockfalls is high along slopes covered by colluvium. Numerous large angular rock fragments lying within the trees bear testimony to the susceptibility to rocks falling from the higher slopes. See the discussion under debris flow (Qfl) and bedrock (b).

Talus (Qta)

Rock fragments in taluses are locally derived and consist of micaceous greenschist, greenstone, slate, and metavolcanics that range in size from 1/4 inch where derived from slate or schistose rocks to 10 feet where derived from harder blocky rocks. All of the taluses are of Holocene age, and most taluses are still accumulating debris today. Some taluses, however, are inactive. Such taluses are generally covered with trees 60-150 years old. These taluses are not completely stabilized, however, as indicated by some trunks as large as 40 inches in diameter that are bent upslope as the tree attempts to maintain a vertical trunk. Being relatively inactive, these deposits are not receiving present-day accumulations of rock fragments by any of the talus processes described earlier (p. 34). Such inactive taluses are shown on the geologic map by a diagonally lined overprint.

An area of inactive talus is well exposed in an excavation for a home in the NE¼SW¼ sec. 15, T. 41 S., R. 67 E., and along the Glacier Highway northwest from Norway Point. This area is currently stable, but several layers of platy greenschist-rich talus between at least two peat and woody beds suggest recurrent cycles of talus accumulations. The ground there is generally wet, and springs seep on the slope. The peaty beds are as thick as 2 feet but contain greenschist fragments in layers 2 inches thick. The old age of this talus is indicated by the large 40-inch-diameter trees growing on the deposit, as well as the interlayering of talus and peaty beds, which suggest depositional conditions that no longer exist.

There are many taluses at the base of steep slopes in the mapped area. Taluses elsewhere in the area are fewer and less conspicuous. Some large taluses have coalesced along the steep slopes to form continuous aprons that cover broad areas of mountainside. Smaller taluses are restricted to narrow troughlike or ribbonlike deposits on forested slopes. Taluses range in thickness from a few feet in the upslope part of the deposit to probably more than 10 feet at the base. Exposures along Gold Creek and Gastineau Channel reveal thicknesses of 8-10 feet.

The taluses along part of Gold Creek and south from Juneau along Gastineau Channel are mica rich, and rock fragments lie with flat surfaces parallel with each other. Some deposits have interlocking blocky pieces, but open spaces are abundant between larger fragments in nearly all taluses.

Rock fragments fall or roll from cliffs and steep slopes to the base of slopes where they generally lie at the angle of repose. Source areas for some of the taluses are shown on the geologic map by a scarp symbol. Arrows shown below some of the scarps indicate known or anticipated paths of falling rock fragments. The rocks generally are released unexpectedly from high on the slopes, so the rock fragments can have an extremely high velocity that carries some of them beyond the mapped extent of the deposit. Taluses are mapped above undifferentiated landslide deposits (Qls) in some places where the rocks continue to ravel from bedrock faces even though most of the original debris moved as a landslide. Taluses composed of small fragments can be easily excavated and generally drilled without trouble. The deposits having coarser fragments would be moderately difficult or difficult to excavate with power equipment and difficult to drill because of the large loose pieces.

The coarseness and hardness of rock fragments generally makes taluses only slightly susceptible to erosion in the portions low on the slopes. Taluses that have a fine-grained matrix, such as those along the slopes of Mount Roberts south of downtown Juneau, are more susceptible to erosion from heavy rainfall and are gullied. Creep is common; slopes formed by excavations ravel and slide. Excavations in active or inactive taluses generally will exceed the natural angle of repose of the material, reduce the stability, and may cause slides.

Taluses are unsuitable locations for structures because they are unstable and because blocks of rock still fall on most of them from time to time. In case of a strong earthquake rock fragments on slopes above taluses probably would be dislodged and would roll and bound down the steep mountainside. The talus itself is unstable, and shaking during earthquakes elsewhere has caused taluses to move downslope. Roads at the lower margins of talus could be blocked by slides of talus. Structures such as water troughs, built across taluses, probably would be damaged. The water flowing from such a broken trough would saturate the material below and probably cause a debris slide or debris flow.

Debris-flow deposits (Qfl)

Debris-flow deposits, as mapped in the Juneau area, include deposits of debris flows or debris avalanches, one debris slide, and one sand flow, and all consist of materials of various size gradations that moved rapidly under wet conditions (Varnes, 1958). Four of the five mapped debris flows along the slopes of Mount Roberts are dark gray and consist of locally derived tabular greenschist fragments mixed with a few rounded boulders of granitic rock in a matrix of finer material. The other mapped debris flow was derived largely from colluvium and soil and added debris from houses, retaining walls, and other structures. The debris slide, located in the Salmon Creek valley, consists of shell-rich diamicton. The sand flow, located along lower Salmon Creek, is entirely brownish-gray sand and sandy gravel. The age of all these deposits is Holocene, and all the debris flows but one occurred during historic time.

The debris-flow deposits along the slopes of Mount Roberts near First Street in southeast Juneau and along Gastineau Avenue and Franklin Street include at least four flows. One of the four deposits mapped includes two flows that occurred 32 years apart. The deposits form narrow bands of rubble that have a bulbous to fan-shaped lower terminus where not modified by construction. The flows extend down the 35°-45° slope of Mount Roberts in narrow gullies or tree-cleared flow tracks. At their heads some of the gullies bifurcate near the sloping ridge top, 1,000-1,500 feet above Gastineau Channel. The debris-flow deposits form ridges in the lower part that are distinctly different from the generally smooth steep slopes of the mountainside. These deposits vary in thickness, but range from 5 to at least 20 feet.

The debris slide is along the southern side of Salmon Creek valley and extends from below the flume to creek level. The path of the debris slide is floored by smooth bedrock. Large isolated masses that moved as units remain in the upper part of the trough, but saturated material formed a hummocky lobe at the base. The thickness of this flow is about 10-12 feet. The sand flow is near the mouth of Salmon Creek along an old road alinement and at the northern end of an old bridge. The present slope is near the angle of repose, 30°-35°, but seems to be stable now and is covered by shrubbery. Thickness of the flow is unknown.

Density of the debris-flow deposits along Mount Roberts probably is greater than that of the materials from which the flows were derived. The relatively undisturbed source materials--colluvium, broken rock, and soil--generally contain numerous voids. After water drains from a debris flow, the deposit becomes stabilized, compacts, and is firmer and less porous than the undisturbed materials. The sand in the flow along lower Salmon Creek, however, probably is about as loose as the undisturbed sand in the bluff. The material in the debris slide in Salmon Creek came from a glaciomarine deposit that is firm and hard when dry, but which flows easily when wet. As it dries the material seems to become as firm as the original deposit.

All the debris flows recognized in the Juneau area occurred after sudden or unusual amounts of water were added to the material forming the steep slopes. Those along Mount Roberts moved after being subjected to prolonged and intensive rainfall. A debris flow on Sept. 28, 1918, followed 7.45 inches of rain in 3 days, and the flow on Jan.22, 1920, followed 6.30 inches of rain in 3 days. A catastrophic debris flow on Nov. 22, 1936, that caused 14 deaths followed 3.85 inches of rain in 24 hours, and followed a period of heavy rains that amounted to 18 inches in October and provided an additional 25 inches through November. A debris flow on Oct. 31, 1949, followed 2.55 inches of rain within 24 hours, and one in late October 1952 followed a prolonged period of rain during which time only five of 77 days had no precipitation (U.S. Weather Bur., 1918-58).

The slopes of Mount Roberts are covered by broken rock, colluvium (which here is a mixture of rock fragments and weathered and loosened debris from past glaciations), and soil. The lower slopes are mostly between 35° and 45°, the upper slopes are commonly 50° or steeper, and gravity normally causes colluvium on such steep slopes to move slowly downslope. In addition, the joints in the slaty shistose rocks form planes of weakness that dip steeply outward from the mountain and provide loose pieces of rock. Saturation of such materials results in sudden movements as debris flows.

The 1968 debris slide in the Salmon Creek valley probably resulted from water escaping from a flume that crosses a ravine at the head of the debris slide. The glaciomarine diamicton there became saturated and moved down a 28° bedrock slope to creek level.

The rains on Nov. 22, 1936, also caused the sand flow downstream from the bedrock gorge near the mouth of Salmon Creek. Two sand flows came down in about the same area, but the second filled and blocked the channel of Salmon Creek so that the water swept around the bridge and over the road. The bridge was swept away during the night of Nov. 23 (The Daily Alaska Empire, Nov. 23 and 24, 1936).

The debris flow along Gold Creek and in Evergreen Bowl apparently occurred before Juneau was settled; this assumption is based on the presence of mature trees interspersed with decaying logs on the deposit. The debris flow seems to have been derived from the material brought down from Mount Juneau as part of the rockslide avalanche.

The debris-flow deposits have a high affinity for water. They would be extremely unstable in the event of strong seismic shaking in the Juneau area while the deposits were saturated. The upper parts of the flow deposits probably would move downslope and conceivably could override or even extend beyond the lower parts of the deposits. In addition, loose surficial deposits high on the slope would be shaken loose if the vibrations were of long duration, causing new flows or slides to move down the tracks of previous debris flows. The area adjacent to South Franklin and Gastineau Avenues in Juneau probably is especially susceptible to earthquake-induced flows. If the deposits were dry at the time of an earthquake, there probably would be some shifting and differential compaction, and possibly some movement downslope. The sand deposit along Salmon Creek is particularly susceptible to dry flowage from shaking.

The recurrence of debris flows along the lower slopes of Mount Roberts suggests that upslope conditions favor the occurrence of similar flows in the future. In an effort to better understand the slope conditions, especially the stability, along the mountainside, I made a traverse downward from about 1,000 feet above Gastineau Avenue. The mountainside, which is commonly as steep as 50° by measurement, also includes small cliffs that required rapelling in order to descend safely. Even the tree-covered portions of the upper 400 feet of the slope were so steep that ropes were used for safety.

In addition to the steepness of the mountainside, two geologic factors contribute significantly to the high slope instability. These are the type of rock and the fractures related to weak zones in the rock. Soft platy mica-rich greenschist underlies most of the upper part of the mountainside. This rock disintegrates when weathered, and the small flat mica flakes accumulate with windblown silt to form a thin loose cover on the bedrock. Pieces of broken rock, from 6 inches to 5 or 6 feet in length, lie precariously on the steep slopes in the mixture of mica flakes, smaller rock pieces, and silt. The foliation or layering of the in-place soft rock dips generally away from Gastineau Channel at about 47°, but in the nearly vertical faces of the small cliffs the layers are bent outward and in places actually dip about 10° toward the channel (fig. 6). Where the layers are bent, they part and the rock becomes extremely susceptible to weathering and dislodgment.

Fractures consisting of joints or sets of joints also weaken the rock and reduce slope stability. I hypothesize that the fractures in this slope may be the result of continuing release of stress confined in the rock. The absence of confining pressure in the direction of Gastineau Channel may allow the rock to expand about parallel to the existing slope and open cracks along planes of weakness in the rock. If the stress-release concept applies to this slope, the cracks may continue to enlarge and new ones develop over the years as the stress is slowly released.

The joint fractures intersect the layering of the rock to form a crisscross set of cracks. Three joint sets seem to be dominant in the area above Gastineau Avenue. One joint set strikes N. 80° W. and has a nearly vertical dip. Another set strikes N. 85° E. and dips 80° northward; the last of these dominant joint sets strikes N. 35° W., almost parallel to the mountainside, and dips southwestward at 75°. Some of the pieces of rock between these numerous intersecting fractures are loose, and others will loosen with time. Moisture moving along the open cracks between rock fragments helps weaken the rock, and trees send roots into the cracks and thereby tend to accelerate the separation of the rock fragments. Figure 6 shows also the relationship of some of the joints to the foliation or layering and the characteristic pattern that results from the intersecting fractures.

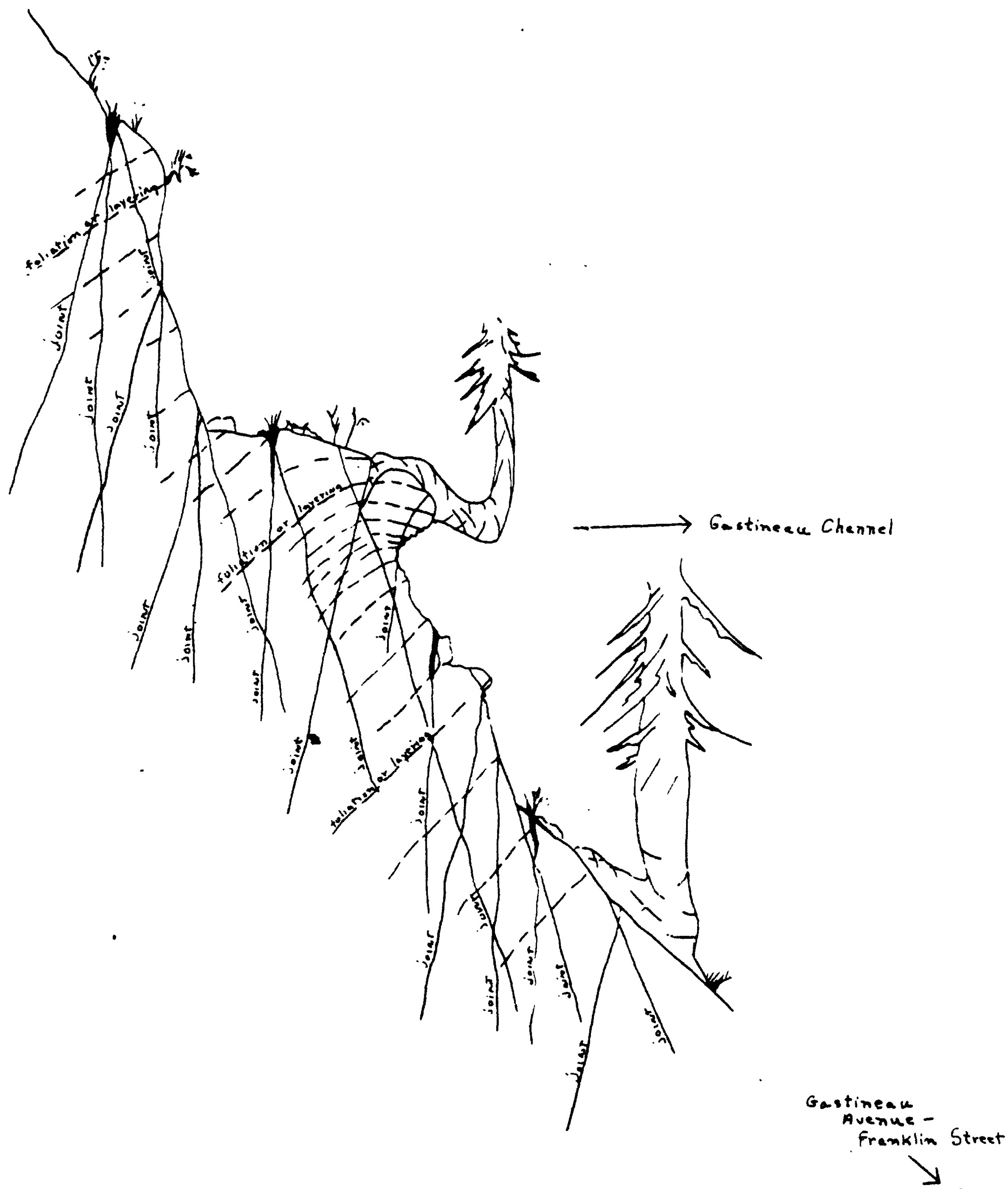


Figure 6.--Sketch showing relationships of foliation and layering and joint sets to each other in the mountain slope above the Gastineau Avenue-Franklin Street area, Juneau, Alaska. The numerous fractures shown tend to weaken the bedrock slope and to provide access routes for ground water and roots. Tree roots can push the rock pieces apart and increase the instability of the mountainside.

Troughs 10-20 feet deep and 15-30 feet wide originate near the ridge above the Gastineau Avenue-Franklin Street area. Several of these troughs merge and extend down the fall-line to the base of the mountain. These troughs mark areas where the earth materials of the mountainside have slid or flowed downslope toward Juneau. Fractures along sets of joints seemingly control development of these troughs, and the walls are generally joint surfaces. Intensely cracked and broken rocks project from the walls; similar pieces have fallen and have accumulated on the bedrock floors of the troughs. Numerous large blocks of rock lie in a rubbly mixture of smaller rock fragments, silt, soil, and fallen trees. Most of this debris lies at angles steeper than the angle of repose, and consequently the rubble is very unstable. Pieces of tree trunks, limbs, and roots apparently act to restrain the mass from moving downslope. This debris is so loose, and lying on such steep slopes, that my assistant and I avoided walking on it for fear of starting rockslides.

On the lower part of the mountainside, the troughs are partially filled with the uppermost portions of debris flows that moved down into the residential area below. Along Gastineau Avenue, ridges mark the historical debris flows; between these ridges are older tree-covered prehistoric transported material, here mapped as undifferentiated landslide deposits (Qsl), indicating that slides and flows have occurred over a long period of time.

It is difficult to predict whether future flows will move exclusively along the paths established by earlier flows. Tracks of previous flows, as marked by the troughs, would help concentrate heavy rainfall. However, to my knowledge, only the 1952 flow followed a path established by an earlier flow, in this case one that occurred in 1920. All other flows apparently originated in material that apparently had not previously failed by debris flowage.

It is even more difficult to predict specifically when the flows will occur. Heavy prolonged rainfall preceded each of the known debris flows. The fall of the year is the most common season for the flows to move. The recorded amount of rainfall for different occurrences of debris flows, however, ranged from about 2½ inches in 24 hours, near the end of almost 2 months of continuous rainfall, to 7½ inches of rain in 3 days. Swanston (1970, p. 14) studied the mechanics of debris flows in shallow permeable till soils in Maybeso Creek valley on Prince of Wales Island, southeast of the Juneau area. He considered a slope angle of 37° to be critical and that materials in slopes steeper than that are in imminent danger of sliding when the cohesiveness of the soil is destroyed or disrupted. I consider slope stability of the thin colluvial material over the bedrock to be of special concern, and a careful evaluation should be made of the possible effect construction might have on the stability of the slope-covering deposits, especially in the areas between the tracks of known flows.

As the above discussion brings out, the mountainside above the Gastineau Avenue-Franklin Street area seems to exist under geologic and topographic conditions that, in time, reduce the cohesiveness of the soil or rock, and that result in the accumulation of loose rubble on extremely steep slopes. Specific triggering actions that cause debris flows remain unknown. Physical and environmental conditions do change with time, however. Periodic heavy rains permeate the rubble, and the moisture content may reach the point of extreme saturation where the rubble will flow of its own weight. Trees grow on the mountainside, but eventually die. Though the roots of a growing tree can push rock slabs apart and cause pieces to fall, many roots bind large slabs of bedrock and help stabilize the slope. Death and decay of such a tree removes any strength from intertwined roots and reduces slope stability. Wind that commonly accompanies heavy autumn rains may be an important triggering action. Slabs of rock as large as 10 feet long were seen held in place by fine-grained mixtures of weathered rock, silt, and humus filling cracks. These massive rocks also act as walls to restrain loose material lying upslope. If a tree growing from a crack is blown down during a heavy windstorm, it seems conceivable to me that the rock slab might be dislodged and fall, thereby allowing the loose material to move down the mountainside. Some of the slabs would fall free as much as 50 feet before landing on the accumulation of saturated rubble. The weight and striking force of a large falling rock could start the debris flowing downslope.

The brief examination of the mountainside above south Juneau reinforces my belief that detailed examination of the slope should be a prerequisite before any major urban changes are made in the Gastineau Avenue-Franklin Street area. Excavations for low-grade fill material will reduce the stability of the upslope material. The high affinity of the deposits for water makes any such fill material susceptible to slumping with saturation. No practical use is known for the debris-flow deposits, especially where on the lower slopes of the mountain. Open green space probably is the best use for the debris-flow deposits, because of the possibility that future flows may move down the same routes.

Rockslide-avalanche deposits (Qra)

As used in this report, a rockslide-avalanche is a rock avalanche that either falls a short distance and then avalanches downslope, or starts as a slide and becomes an avalanche. The rock that falls may start as one block, or several, but repeated impact generally causes it to disintegrate as it moves downslope. It quickly becomes a mass of sliding, rolling, and bounding rock debris. Rockslide-avalanche deposits consist of jumbled rock fragments of many sizes. Some are as large as 30 feet across,but 5- to 8-foot sizes are most common. Each avalanche deposit is principally of one rock type; the deposit on Douglas Island is composed mostly of blocks of a greenish metamorphosed porphyritic dike rock; the surface part of the greenish rock weathers to a reddish-brown rind about ¼ inch thick that is coated by a light-brown layer. The deposits on the mainland were derived from greenstone or greenschist. All of the rockslide-avalanche deposits apparently are of Holocene age.

There are five rockslide-avalanche deposits in the vicinity of Juneau. One is on the outskirts of Juneau; the rockslide-avalanche started on the side of Mount Juneau, where a large scar can be seen, crossed the Gold Creek valley, and rose more than 180 feet on the opposite slope where the deposit now partly covers a bedrock ridge that connects Mount Maria to Mount Roberts. Spencer (1906, p. 83) recognized the large deposit in Gold Creek valley as an ancient slide or avalanche that dammed Gold Creek. This deposit in Gold Creek valley is at least 38 feet thick and is so massive and the fragments so large that to the casual observer the debris looks like knobs of bedrock surrounded by surficial material. High on the bedrock ridge large scattered blocks form a deposit about 300 feet wide. The absence of a continuous cover of debris leads me to conclude that these very large pieces bounded up the slope as a result of energy provided from falling, rather than from being carried on an air cushion. A distinct and abrupt margin is typical of the deposit. The leading edge of the avalanche projected off the Mount Maria-Mount Roberts ridge and continued down to the site of Juneau. Isolated angular fragments 2 feet or more in largest dimension provide evidence that the avalanche reached at least as far as the upper part of 6th Street. Building and grading over the years probably removed or buried most of the fragments.

This massive rockslide-avalanche blocked Gold Creek completely and formed a lake (Spencer, 1906, p. 84). The avalanche deposit extends about 38 feet above the concrete flume at the lower end of Last Chance Basin. Terrain on the south side of Gold Creek consists of ridges and elongate channels in the valley and large boulders covering the slope of Mount Maria. The ridges and channels are interpreted as being caused by erosion as Gold Creek overflowed the avalanche dam.

The debris flow deposit along Gold Creek near and in Evergreen Bowl is interpreted as being the result of breakthrough of the avalanche dam and rapid drainage of the lake behind the dam causing a debris flow. Large 8-foot boulders in the debris-flow material are not greenschist, but are fine-grained rock similar to that found in the avalanche deposit along Gold Creek and on the ridge between Mount Maria and Mount Roberts.

Joint fractures on the slopes of Mount Juneau apparently weakened the rock and provided the proper circumstances for a massive rockslide-avalanche. Examination on the ridge just below the top of Mount Juneau did not show any zones of mineralization that might have weakened the rock. Instead, the rock is hard and firm but fractured along well-defined joint sets. The joints that apparently are most related to the rockslide avalanche are those that strike N. 65° W. and dip 83° NE, strike N. 85° W. and dip 75° S., and that strike N. 50° E. and dip 75° SE. These joints are either parallel to the face of the avalanche scar on the mountain, or intersect each other or the foliation to provide fracturing of the rock underlying the slope. The cause of such rockslides may be weathering along these fractures over long periods of time, or may be continued expansion of the fractures as a result of possible stress release active since deglaciation of the Juneau area. One trigger may have been a strong earthquake in prehistoric time that involved what is now the Juneau area.

The specific age of this rockslide-avalanche is unknown. Trees 15-20 inches in diameter that are growing on rotting trunks are about 60 years old. Larger diameter stumps, in various stages of decay, also are on the avalanche deposit. Photographs of Juneau taken near the turn of the century suggest that the ridge between Mount Maria and Mount Roberts was probably logged about 60 years ago, thus accounting for the relatively young trees growing on the avalanche deposit. Some of the older tree trunks are in advanced stages of decay. Assuming that at least 150 or 200 years are required in the Juneau area for decay, a very rough estimate for the rockslide-avalanche is about 200-250 years.

A large and impressive rockslide-avalanche temporarily dammed Lemon Creek in prehistoric time. This slide had its source on the southeastern flank of Heintzleman Ridge. A jumbled mass of rock fragments, some as large as 50 feet in length, lies on the northern end of a bedrock ridge and extends southward to fill part of the valley behind the ridge. Canyon Creek was also blocked, and a temporary lake probably filled part of the valley upstream from the avalanche; however, no deposits were located that might represent the remnants of such a lake. Rock spines stand prominently at the south edge of the avalanche deposit, and they form conspicuous landforms when viewed from the Lemon Creek trail where it traverses a bedrock ridge. The foliation in the spines matches that of the bedrock in the ridge west of the avalanche deposit. Consequently, these spines are really bedrock in place and apparently reflect erosion along foliation and joint fractures by waters that overflowed from the dammed lake. The strikes of the large fragments in the avalanche mass, however, vary and includes N. 50° W., N. 40° E., and N. 45° W., and the dips also are variable and in both eastward and westward directions. The age of this rockslide-avalanche deposit is not known, but seemingly mature trees cover the surface of the debris; thus it is at least several hundred years old.

An equally impressive rockslide-avalanche deposit lies on the northwest side of Salmon Creek, near the junction of the trail and foot bridge over the creek, where blocks of rock 5-6 feet across cover the surface. Spaces between the blocks are generally open but some contain fine sand and silt. The terminus of the deposit extends along Salmon Creek for about 2,000 feet. The avalanche extended into the creekbed downstream from the foot bridge but has been largely removed by the stream. The deposit apparently came from a scarred area on the lower slope of Blackerby Ridge. Mature trees cover the slide debris.

The avalanche deposit near the airport is relatively small but extends as far downslope as the Glacier Highway. The source area is a nearly vertical 400-foot bedrock cliff above a bench that is 70 feet above the road. The material in this deposit probably fell free from the face of the cliff and became a rockfall-avalanche. Large angular fragments as large as 30 feet across rest on the bench. A lobe of the deposit which contains fragments as large as 10 feet can be seen at the edge of the road. Mature trees also cover this deposit.

On Douglas Island, a large rockslide-avalanche deposit extends 2,500 feet outward from a scar on Mount Anderson and ends on a flattish bench. A series of lobate ridges confines swamps and small ponds within the avalanche deposit. Blocks of moss-covered rock as large as 10 feet form grotesque shapes in the dim light of the dense forest. The avalanche deposit ends abruptly with distinct edges. The roots of a partially decayed tree found on this deposit were entwined around the avalanche fragments; growth and decay of the tree probably represents several hundred years. The oldest living tree found in the same area of the avalanche deposit, however, is only about 60 years old. Attempts to find long-time residents who might remember the rockslide-avalanche were unsuccessful.

This rockslide-avalanche apparently resulted from the separation of dike rock from adjoining black slate. The dike approximately paralleled the face of the cliff. The weathering rind suggests prolonged weakening of the rock, but the trigger for the avalanche is unknown.

Infiltration in rockslide-avalanche deposits is generally good in the areas of large fragments, but fair to poor in areas where many small pieces or fine material partially fill large voids in the avalanche deposit. The swamps and ponds on the Douglas Island deposit probably lie on very thin avalanche debris and reflect the more impermeable nature of the deposits underlying the rockslide-avalanche. Runoff on all deposits is fair to very good, depending on particle size, infiltration rate, and slope configuration.

Severe ground vibration associated with a major earthquake could cause rock falls from the cliffs above the four known avalanche deposits and possibly also on steep slopes elsewhere in the fiord areas. A strong shock can be expected to send either individual fragments or large masses down the slopes. All steep unvegetated slopes especially should be considered potentially hazardous.

Because the pieces and fragments within rockslide-avalanche deposits are mostly loose and jumbled, the deposits generally are unstable. The upslope parts of the deposits are probably less stable than the lower parts. Excavation can result in embankments that will ravel, and it may loosen large rock fragments. Excavation and other earth-moving activities can alter the equilibrium in the deposits.

Undifferentiated landslides (Qsl)

Undifferentiated landslides in the Juneau area consist of large and small deposits of heterogeneous mixtures of earth materials. Included are deposits of rock debris that moved downslope as part of massive snow avalanches and that lie beyond the margins of talus deposits, or directly at the base of steep talus-filled chutes. Most of the landslide deposits are mixtures of bedrock fragments in a silty sand matrix of mostly soil and other surficial deposits. Blocks of rock as large as 30 feet across occur individually or in clusters at the base of some mountain slopes, and rocks 5-10 feet long are common in slide debris in the valleys of Gold, McGinnis, and Nugget Creeks. The slide in Lemon Creek valley, and most of the slide deposits in south Juneau, include pieces of greenschist 6 inches to 4 feet in length in a matrix of sand-rich organic material. The age of these slides is Holocene, and some are historically young.

Some landslide deposits occur in places along slopes bordering Gastineau Channel, but most seem to be along the northern slopes of Gold, Salmon, Lemon, and Nugget Creek valleys. The large slide on McGinnis Mountain, however, lies on the east side of McGinnis Creek. Small landslides along Gastineau Channel have arcuate debris ridges that seem to merge upslope into talus or are bounded by bedrock slopes. The elongate slides along Lemon and Salmon Creeks are narrow and have flat to concave surfaces that extend upslope behond the mapped area. The large slides along Nugget and Gold Creeks are fan-shaped and extend upslope to fill narrow bedrock troughs or chutes.

Most landslides in the Juneau area apparently result from loss of shear strength by loosening of rock along joint fractures in response to stress release continuing since retreat of the glacial ice in late Pleistocene time. Other factors that may be important are weathering of joint surfaces or of mineralized zones parallel to cliffs or steep slopes and loss of friction because of water filling joint fractures. The landslide deposit along McGinnis Creek lies below a V-shaped scar on the slope leading down to the slide deposit. Some of the joint sets on the ridge above the cliff are almost parallel to the cliff face. The joint sets that strike N. 43° W. and dip 78° NE. and those that strike N. 35° W. and dip 55° SW. are almost parallel to the vertical cliff face at the top of the landslide area. Another set strikes N. 45° E. and dips 75° SW. and transects the other joints allowing the freeing of large blocks of rock.

The McGinnis Creek slide may have started as a rockfall when part of the rock in the steep west face of McGinnis Mountain fell freely for some distance before sliding down the mountain. This slide apparently is in an area of recurring rockfalls and slides; the last major slide reported was about 1949 when blocks 10-15 feet long dammed a lake 30-40 feet wide and about 300 feet long, according to Mr. R. E. Reed (oral commun., 1968) who was operating a mining claim along McGinnis Creek at the time. Dust was seen along the steep face on Mount McGinnis during my mapping in 1968 and may have been caused by small rockfalls. Similarly, the slides on the slopes of Bullard Mountain along the Lower Basin of Nugget Creek may also have started as rockfalls.

Bullard Mountain was not visited on the ground, but as seen from an airplane, the face of the cliff on the mountain seems to be controlled by joint planes. The strike of the cliff apparently is roughly parallel to the N. 43° W. and N. 35° W. joint sets that seemingly control the development of the cliff on McGinnis Mountain. Landslide scars are well developed on Bullard Mountain and have narrow V-shaped funnels that lead to the slide debris below.

A similar V-shaped scar is upslope from the slide in Gold Creek that occurred in September 1901. This slide apparently was caused by heavy rainfall, and probably was a wet slide or debris avalanche. It may have been triggered by blasting at the Ebner Mine (Daily Alaska Dispatch, Sept. 24, 1901). The relationship of this slide to joint sets is not known, but the trend of one of the cliff faces above the slide nearly matches the N. 65° W. strike of one of the controlling joint sets of the Mount Juneau rockslide-avalanche source area.

The development of a cliff above the slide in Lemon Creek also seems to be related to the joint sets in the rock at the southwest end of Heintzleman Ridge, between Mendenhall and Lemon Creek valleys. One joint set strikes N. 73° E. and is almost parallel with the face of the cliff in sec. 22, T. 40 S., R. 66 E., indicated by a hachure on the geologic map.

The age of this large slide in Lemon Creek valley can be estimated as being over 500 years old. One of the stumps of a tree logged since 1962 is well preserved and reveals more than 512 rings. This stump was rooted in the slide deposit rich in greenschist and greenstone fragments that cover older delta deposits (Qdo). The mature forest covering the slide track on the slopes of Heintzleman Ridge also supports such an age.

The undifferentiated landslide deposits exposed between the debris-flow deposits along Gastineau Avenue and Franklin Street may be older debris-flow deposits. Because these materials are mostly buried by the historical debris-flow deposits their origin can only be assumed. For this reason, these deposits, though rich in large angular greenschist fragments as are the debris-flow deposits, are grouped with the undifferentiated landslides. The stability of the surficial deposits and bedrock upslope from Gastineau Avenue is described in detail under debris-flow deposits (Qfl).

Some of the small slide deposits elsewhere along Gastineau Channel may have been transported as a part of snow avalanches or as debris that slid down the snow-covered surfaces of the avalanche tracks. The isolated arcuate ridges at the bottom of the bedrock slopes or slide scars suggest such methods of movement to me. The lack of mature trees in slide scars above some of the slide deposits suggests recurring snow or rock avalanches that prevent tree growth. Snow avalanches frequently move downslope from Mount Juneau and terminate in the Highland area. The last large one in that area occurred on March 22, 1962 (Daily Alaska Empire, Mar. 22, 1962). Older snow avalanches have extended beyond the houses in the Highland area and onto the former tide flats of Gastineau Channel in an area now occupied by a motel.

Gentle slopes on landslide deposits are slightly susceptible to sheetwash or gully wash; vegetation cover helps protect slopes. Some of the steeper slopes erode by gully wash, especially those slopes near active taluses. Narrow rock troughs concentrate runoff coming from high on the slopes into small streams which erode the landslide deposits. Landslide deposits that blocked streams, such as Salmon and Gold Creeks, have been extensively eroded.

Landslide deposits are loosely compacted. Those lying on steep slopes probably will settle or slide downslope if a severe earthquake shakes the area; and some rock masses or individual rocks high on the slopes may fall (see overlay 1, sheets 1 and 2).

The upper slopes of slides are unstable. However, the lower slopes are flatter and are usually more stable. Where springs develop, the slope stability decreases. Excavations in the lower parts of the landslide deposits can further reduce stability and may reactivate that part of the slide above the cut. Excavations that leave large blocks hanging in the walls of the cuts are especially hazardous. Heavy rainfall can cause these large fragments to loosen and fall. Removal of the lower part of any slide deposit on a steep slope can cause renewed slide movement; such reactivation would be especially likely during heavy rainfalls.

The abundance of landslide deposits points out the tendency for rocks to fall and slide in the Juneau area. Overlay 1 shows areas of past and potential landslide hazards.

Colluvial(?) diamicton (Qud)

The colluvial(?) diamicton consists of pale-yellow (5Y 7/3)[1] dry, to olive (5Y 5/3) wet, cohesive heterogeneous mixtures of silt, clay, sand, pebbles, and scattered cobbles (table 4, no. 7). Slate is the most common rock type, and the slate fragments have random orientations in the deposits. Judged from small and scattered exposures, the deposits seem to be massive. Surfaces on broken pieces of the diamicton are rough and porous, and angular fragments of slate 1/4-1/2 inch long protrude from the surface. Dry bulk density determined for one sample is 130 pcf.

The age of the deposits may range from late Pleistoce to late Holocene.

These deposits are shown on the geologic map only along Lawson, Kowee, and Eagle Creeks on Douglas Island. The deposit along Kowee Creek was the only one examined; it forms a ridge 50 feet high along the northwest side of the creek. The other deposits shown on the map were recognized on aerial photographs.

As mentioned under "Mass wasting," I believe that most of these deposits were formed by colluvial processes, including creep, flowing, and sliding. The yellowish color extends throughout the material, and probably represents oxidation of the parent material before that material was reworked into this deposit. The absence of macro- or microfossils, the fact that the deposit can be traced upvalley as high as 1,000 feet above sea level, and the apparent absence of fluvial or lacustrine bedding eliminate most alternate origins, except possibly glacial.

A glacial origin is less satisfactory than the concept of formation by colluvial processes. The colluvial(?) diamicton does not seem to contain

[1] Color codes from Munsell Soil Color Charts, 1954 ed., Munsell Color Co., Inc., Balto., Md. Color numbers are used in the descriptions of selected deposits where such designation is an aid to field identification.

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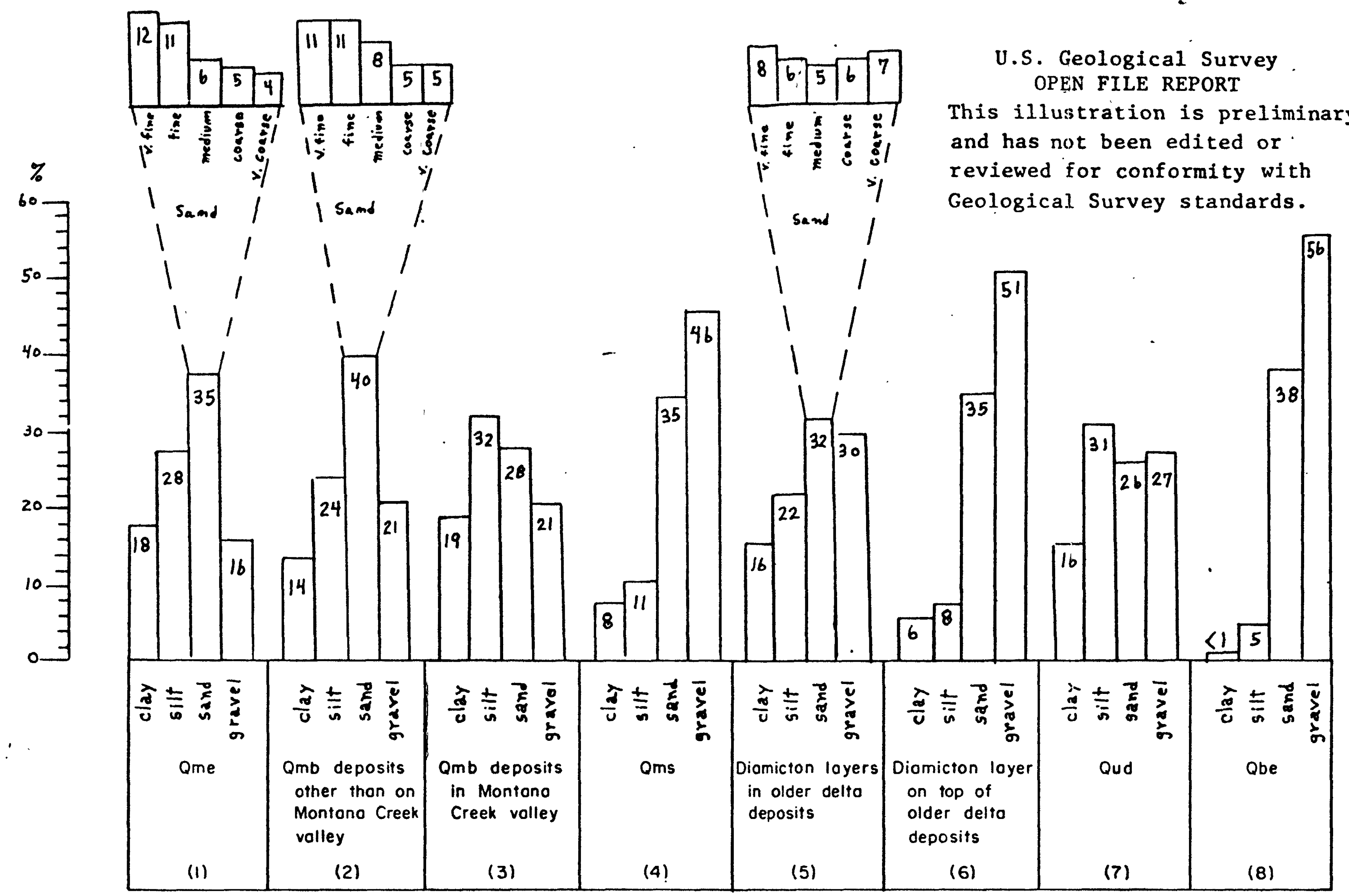

SIZE RANGE OF CLAY, SILT, SAND, AND GRAVEL

Clay	<0.004 mm		very fine	0.0625-0.125 mm
Silt	0.004-0.0625 mm		fine	0.125-0.25 mm
Sand	0.0625-2.0 mm	Sand	medium	0.25-0.5 mm
Gravel	2.0-32 mm		coarse	0.5-1.0 mm
			very coarse	1.0-2.0 mm

Table 4.--Average percentage of particles passing 1¼-inch screen from selected geologic units. Units Qme and Qmb are composite results of 10-15 samples; other units are composite results of 1-5 samples.

stones larger than pebbles. In contrast, glacial till typically has a wide assortment of coarse materials. Such a wide size range would be expected on Douglas Island because of the vast number of granite-boulder erratics elsewhere on the island. The surface of the deposit has a ridge form but it is more likely erosional than depositional. The ages of the glaciomarine deposits and older delta deposits, which are topographically lower, require that if this deposit is, however, glacial it is related to the waning phases of the Cordilleran ice sheet, and is older than 10,000 years.

Glacial deposits

Glacial deposits in the Juneau area include pitted outwash deposits (Qop), moraine (Qm), younger outwash deposits (Qoy), late glacial-outwash deposits (Qol), older glacial(?) alluvium (Qpm), and older till (Qpt). Mendenhall valley contains the largest amount of glacial deposits mapped in the Juneau area, but other valleys, such as those of Fish Creek and Kowee Creek on Douglas Island, contain a larger variety of deposits. Similarly, the valleys of Gold, Lemon, Salmon, Nugget, Montana, Eagle, and Falls Creeks, on the mainland and Douglas Island, contain some or all of the above deposits. These deposits range in age from late Pleistocene to Holocene. The older till (Qpt) is probably the oldest surficial deposit mapped; it probably was deposited prior to and overridden by the late Pleistocene ice sheet. The older glacial(?) alluvium (Qpm) underlies deposits that are older than 10,000 years. The late glacial-outwash deposits (Qol) consist of materials that are related to the depositional alluvial cycle that followed the deglaciation of the Juneau area in late Pleistocene or early Holocene time. The moraine (Qm) was deposited by ice and the younger outwash deposits (Qoy) and pitted outwash deposits (Qop) were deposited by glacial meltwater during Neoglacial or younger times.

Pitted outwash deposits (Qop)

Pitted outwash deposits consist of light-brownish-gray (2.5Y 6/2) medium to coarse sand and fine to medium gravel containing pebbles and cobbles. Granules and pebbles 1/2-1 inch in diameter are the most prevalent sizes, and cobbles and boulders are scarce. Broken pieces of granite, gneiss, and greenstone, and grains of quartz and dark micas and hornblendes give a salt-and-pepper appearance to the deposits. The pitted outwash deposits are of very late Holocene age and were formed during a very recent retreat of the Mendenhall Glacier. Ice covered the area behind the third morainal ridge from the front (see geologic map, pl. 1) in 1909-10 (Knopf, 1912). Part of the area now underlain by this outwash deposit was still covered by ice in 1942 (U.S. Geol. Survey topographic map, Juneau B-2, 1947 ed.). By 1948, the area was ice free (U.S. Geol. Survey topographic map, Juneau B-2, 1962 ed.); consequently most of the pitted outwash deposits accumulated between 1942 and 1948.

As the ice terminus of Mendenhall Glacier retreated from its 1909-10 position, Nugget Creek apparently flowed from beneath the glacier, as it does today, and deposited sand and gravel over stagnant glacial ice. The 1909-10 map of Knopf (1912) shows such a subglacial flow, as does the map showing the 1942 ice position (U.S. Geol. Survey topographic map, Juneau B-2, ed. 1947). Mendenhall Lake has expanded since 1942 and Nugget Creek now flows into the lake. The pitted outwash deposits were abandoned as a channel and became part of the shore on Mendenhall Lake. Ice blocks buried by the outwash sand and gravel slowly melted and formed depressions in an otherwise relatively smooth surface.

This single deposit of pitted outwash occurs along Mendenhall Lake near the U.S. Forest Service Visitors' Center at the upper end of Mendenhall valley. Moss and flowers cover the deposit discontinuously along with isolated clumps of alder and small evergreens. The surface of the deposit is graded to the channel used by Steep Creek in 1948. Steep Creek has been diverted northward since that time and now flows from near the powerhouse across the pitted outwash into Mendenhall Lake. An ice-cored steep-sided kame (not differentiated on the map) still existed in 1971 at the edge of the pitted outwash deposit on the shore of the lake.

Moraine (Qm)

Moraine is an accumulation of glacial drift with a distinctive and characteristic topographic expression. As mapped in the Juneau area, moraines are composed of loose till and stand as arcuate ridges across Mendenhall valley, and extend as elongate ridges laterally along the mountainsides. In addition, moraines form smaller arcuate ridges in cirques; such moraines are mapped in cirques at the heads of streams tributary to Fish Creek and in the cirque at the head of Kowee Creek, both on Douglas Island. The moraines in Mendenhall valley are predominantly unsorted mixtures of light-gray silt-rich gravelly sand to sandy coarse gravel containing rounded cobbles and boulders; in a few places, however, the moraines consist mostly of boulders. The cirque moraines are composed almost entirely of boulders.

The moraines in Mendenhall valley have textures in part dependent upon the position of the moraine relative to ancient streamflow. The matrix of most of the deposits in the arcuate morainal system has a salt-and-pepper appearance caused by numerous dark minerals. Dioritic and granitic fragments, as well as greenstone, gneiss, schist, and quartz make up most of the materials in the moraines. The variable texture of these materials ranges from silty gravelly sand to scattered boulders 6-10 feet across and is characteristic of much of the western and central morainal arc. The deposits in this portion probably were dropped directly from the ice with little modification or sorting by flowing water. A cobble-rich sandy gravel, blanketed by a concentration of semiround boulders 6-12 feet in diameter, forms a nearly continuous boulder ridge as part of the morainal arc on the east side of the valley. Similar concentrations of large boulders form the lateral moraine along the mountain slope, and, in fact, mark the highest morainal ridge near Nugget Creek. These boulder accumulations are shown on the geologic map by an overprint. The presence of gravel within part of this boulder-ridge area indicates water sorting; the large boulders probably rolled down from the mountainsides, but I believe they were concentrated by streams flowing on or marginal to the ice at those places.

The largest moraines mapped are in Mendenhall valley. The outermost two moraines form distinct and prominent ridges separated by outwash. These ridges can be traced to the valley walls and into conspicuous lateral moraines. A third, inner moraine, is less prominent, but also is arcuate. A broad area of mounds, ridges, and kettles, locally interrupted by outwash channels, extends upvalley from the third moraine. There, ridges trend almost at right angle to the arcuate trend of the outer moraines and give the inner moraines a distinctive striped appearance. Kettle lakes generally lie on the crests of all the arcuate ridges.

Smaller and less distinct moraines lie in the alpine cirques; only those on Douglas Island at the head of Kowee Creek and in cirques at the heads of streams tributary to Fish Creek were mapped. In general, the small cirque moraines consist of boulder ridges made distinctive by tree growth. These ridges are low, only about 1-3 feet high; the trace of the moraines is most visible after a light snowfall that blankets the shallow troughs between moraines.

The thickness of the moraines varies from place to place in Mendenhall valley. Ridges forming the end moraines are some of the thicker deposits, and the till is at least 80 feet thick in some parts of the end moraine area where it overlies buried peaty woody beds (see fig. 7).

The minimum age of the moraines in the Mendenhall valley is based on the date of reestablishment of vegetation and the inferred stabilization of the moraine as the ice retreats. Lawrence (1950, p. 203) considers that the outermost moraine became stabilized about 1767-69. There is no morainal material downvalley from the outermost moraine, and this moraine apparently represents the farthest advance of the Mendenhall Glacier of Neoglacial age.

The Neoglaciation is believed to have started in the Juneau area about 3,500 years ago (Heusser, 1953, p. 637; 1960, p. 186). A radiocarbon date of 2,800±200 B.P. (sample W-2379, Meyer Rubin, written commun., 1970) from one of several stumps deposited in morainal debris on the west side of Mendenhall Lake suggests that the Mendenhall Glacier advanced from an earlier upvalley position prior to 3,000 years ago and had reached within 2 miles of the position of its mid-18th-century terminus at least by about 2,800 years ago. A radiocarbon date of 1,970±250 B.P. (sample W-1989, Meyer Rubin, written commun., 1968) was obtained from peat in a horizon containing logs and stumps which underlies the morainal deposits and overlies late glacial outwash (Qol) and is exposed along the south bank of Mendenhall Lake. Thus, the ice apparently reached a point about 1-1/2 miles upvalley from the 18th-century terminal moraine about 2,000 years ago. It is not known when the glacier reached the terminal moraine or how long the ice front was at that position before the glacier started to recede.

The total recession of the glacier as of 1962 from the outermost moraine since about 1767-69 was about 2 1/4 miles. Knopf (1912) showed the 1909-1910 position as being about 1 mile upvalley from the mid-18th-century moraine. The withdrawal of an additional 1 mile to the 1948 position reflects a much-accelerated retreat. Lawrence (1950, p. 202) pointed out that "The 1931 position. . . stands about halfway between that of 1909-1910 and that of 1948, an indication of a rather uniform rapid rate for the past 40 years." Between 1948 and 1962, the latest position shown on the geologic map, the ice front retreated an additional quarter of a mile. The morainal debris lying above the approximately 2,000-year-old peat along the south edge of Mendenhall Lake was still covered by ice until 1942. In 1968, only the eastern one-half mile of the glacier front still extended into Mendenhall Lake; the remainder of the ice front was on land, and sandy bouldery morainal debris was accumulating over the recently uncovered smoothed-bedrock surface.

The ages of the moraines in the cirques on Douglas Island are based on the growth rings in trees growing on the boulder ridges; on that basis, the outermost moraines in the cirques seem to be older than the moraines in Mendenhall valley. Those moraines at the head of Kowee Creek and the trees growing on the muskeg-covered till along the shore of Cropley Lake are at about 1,700 feet above sea level. Cores of trees on moraines in the cirque at the head of Kowee Creek reveal rings that suggest that the trees on the outermost boulder ridge started growing about 400-435 years ago; cores of trees on the next ridge upvalley indicate an age of about 300 years for the start of tree growth. A tree on the shore of Cropley Lake revealed rings suggesting growth started at least 400 years ago.

Trees in cirques above Cropley Lake show older ages in a cirque at 2,300 feet than in a cirque at about 3,000 feet above sea level. The 2,300-foot cirque contains several boulder ridges; the outermost ridge near the bedrock threshold at the outlet of the cirque supports trees that are at least 400 years old. Trees on the outermost moraine in the 3,000-foot cirque started growing only about 270 years ago, and the trees on the next moraine upvalley started growing about 100 years later.

Absence of a permanent icefield on Douglas Island, such as is found on the mainland, suggests that the glaciers of late Pleistocene age did not survive through the prolonged warm cycle preceding the Neoglacial glaciation. The boulder ridges accumulated at the margins of snow or ice that developed during Neoglacial time in these alpine cirques. Whether these cirques contained only permanent snow fields or actively moving glaciers is not known. It is possible that the ridges may be accumulations of boulders that fell from the cirque walls and rolled across the snow fields to accumulate as low morainelike ridges called protalus ramparts. If small cirque glaciers developed, the ridges represent debris dropped along the margins of slowly retreating glaciers.

A severe earthquake in the Juneau area probably would cause the moraines in the Mendenhall valley to ravel, slump, and compact differentially. In areas where the water table is near the surface, prolonged shaking of the deposits probably would cause ground fracturing and might produce sand spouts and sand boils. Large boulders lying on the morainal slopes could be expected to roll. Homes built on the slopes of morainal ridges might be damaged by differential compaction of the morainal deposits and by rolling boulders.

If an earthquake caused landslides and ice falls into Mendenhall Lake, large waves might result. Also, an earthquake might cause the fronts of deltas to slide and create waves that could cross the lake and inundate the west shore area. The waves could reflect back toward the campground area built on low-lying glacial moraine deposits (see p. 69).

Glacier faces were shattered and ice was thrown outward elsewhere in Alaska during the 1964 earthquake (Waller, 1966, p. 4). Large masses of glacial ice falling into an ice-free lake could cause waves that might cross the lake and rise onto the opposite shore. The shore directly opposite the portion of the Mendenhall Glacier reaching into Mendenhall Lake includes a high morainal bluff and the much lower pitted outwash deposit (Qop). A U.S. Forest Service campground is situated on low morainal topography along the southwestern shore, but is protected somewhat by the younger delta deposit (Qdy) that projects into the lake between the campground area and the ice front. Nevertheless, a wave capable of a 15-foot runup could overtop the water-level delta and continue on to the campground, though in a somewhat attenuated form. The continued retreat of the Mendenhall Glacier assures the complete grounding of the ice front in the foreseeable future, which will reduce the chance of such waves.

Slope stability of the glacial moraine deposits is generally good. Slopes range from 10° to as much as 60° in the bluffs along the shore of Mendenhall Lake; the general range is between 20° and 35° most places. The measured angle of repose of these deposits is generally between 30° and 35°; consequently, slopes steeper than 35° along the lake constantly ravel and slump. The waves on the lake tend to remove the debris, keeping the slope steep and unstable.

Younger outwash deposits (Qoy)

The younger outwash deposits consist principally of gray silty fine sand. Boulders 7-12 feet in diameter are present in the outwash deposits near the moraines in Mendenhall valley. Dioritic rock, granite, gneiss, schist, with their contained dark minerals such as mica and hornblende, and greenstone and quartz are the principal constituents of the deposits. Particle size varies with location; the coarsest size generally is nearer the glacier and along modern channels that follow ancient paths of larger streams. The coarsest outwash deposits bound the eastern side of the broad Mendenhall valley, where they grade from cobble and coarse pebble gravel to boulders near the lake, to pebble gravel and sandy cobble gravel near Mendenhaven, and to fine or medium sand near the Glacier Highway. Several depositional surfaces rise above the modern stream channels. One such surface is 4 feet higher than the cobble-gravel surface near Mendenhaven and is underlain by gray medium sand with pebbles. A still higher surface along the Mendenhall River near Montana Creek is underlain by very fine sand and silt interlayered with peat and humus beds. An excellent exposure of such a deposit is along the Mendenhall River channel at a bend west of Mendenhaven.

Materials in the outwash channels within the Mendenhall moraines are coarser and younger than the outwash deposits in front of the outermost moraine. Outwash deposits between the morainal ridges generally are composed of cobbles and scattered boulders in coarse sand, and are well exposed near the junction of the Montana Creek Road and the road to Mendenhall campground. The deposit in the channel on the edge of the Mendenhall River is a fine to medium sand. Similar grading occurs on the other side of the river where meltwater channels represent old channels of Nugget and Steep Creeks.

Outwash deposits in the valley of Nugget Creek seem to be lithologically very similar to those in Mendenhall valley. Texturally, they seem to be mainly sandy pebble gravel that contains some cobbles and a few boulders.

Records of test wells and water wells in Mendenhall valley (J. A. McConaghy, U.S. Geol. Survey, written commun., 1967) indicate that a relatively widespread peat or carbonaceous layer separates the younger outwash deposits from an older outwash deposit that is somewhat coarser. The peat layer extends beneath part if not all of the moraines as well, and is shown on the fence diagram, figure 7.

Upright sheared trees rooted in peat or carbonaceous material are exposed beneath 12 feet of outwash deposits along the Mendenhall River. A radiocarbon determination on wood from one of these trees shows a death date of 860±260 B. P. (about 1,100 A.D.) (sample W-1947, Meyer Rubin, U.S. Geol. Survey, written commun., 1968). The location is shown on the geologic map. The outwash deposits in channels within the moraines are younger; most of the area was covered by ice as late as 1900-1910, and Steep Creek and Nugget Creek flowed along some of the inner-moraine outwash channels as late as 1942.

The outwash deposits slope downvalley with a more or less even surface. Outwash channels within the moraines in the upper Mendenhall valley trend parallel to arcuate ridges. Outwash deposits in front of the moraines form a broad sheet that underlies the valley floor as far as Gastineau Channel. The Mendenhall River, entrenched into the outwash deposits about 12 feet, and smaller streams have left several surfaces across the valley which are bounded by scarps 1-4 feet high.

A small amount of younger outwash deposits is mapped in the valley of Nugget Creek, east of Mendenhall Glacier. It has a flat surface slightly incised by Nugget Creek.

The younger outwash deposits apparently accumulated during the final Neoglacial ice surge as a result of the increased carrying capacity of the streams flowing from advancing glaciers. The outwash buried humus layers and forest growing on older outwash deposits that had accumulated before the latest Neoglacial advance. Streams flowing from the Mendenhall Glacier, from glaciers at the heads of Nugget and McGinnis Creeks, as well as glaciers tributary to Montana Creek, carried sand and fine gravel onto the broad surface of the older outwash deposits. The silt, fine sand, and muskeg in the area above the confluence of Montana Creek and the Mendenhall River probably accumulated from overbank flooding along Montana Creek. The presence of the late Neoglacial Mendenhall Glacier probably stabilized the deposition in the main valley, whereas the absence of large valley-filling glaciers within the Montana Creek drainage resulted in seasonal floods or extremely high runoffs. Preliminary examination of seeds and plants from several peat beds within the Mendenhall valley indicates a fresh-water and terrestrial environment (Estella Leopold, written commun., 1969). These fossils indicate that the valley floor was above sea level throughout late Neoglacial time.

The radiocarbon age of one of the buried trees along the Mendenhall River channel (p.56) restricts the start of rapid deposition of the younger outwash to about 860 years ago (about 1,100 A.D.) Whether this deposition started before the Neoglacial Mendenhall Glacier reached the position of the end moraine is not known. The age of termination of most outwash deposition in the Mendenhall valley is apparently indicated by two widely separated trees that started growing about 290-300 years ago. One of the oldest stands of trees on the outwash is along the channel of the Mendenhall River, in the SE1/4SW1/4SW1/4 sec. 18, T. 40 S., R. 66 E., where one spruce about 38 inches in diameter was cored and revealed 250 growth rings with the center at least 2 inches farther into the tree from the end of the core. Judged from the closeness of the rings in the last 1 1/2 inches of the core, about 50 rings are probably represented by the missing 2 inches of core. Thus, an age of about 300 years seems reasonable for this tree. A similar age was reported by Lawrence (1950, p. 203) as being represented by a tree cut in 1948 in the SW1/4 sec. 30, T. 40 S., R. 66 E., where the Mendenhall Loop Road crosses Duck Creek. The growth of that tree started about 290 years ago as of 1971. These old trees were growing before the ice retreated from the end moraine; however, the radiocarbon age of the tree along the Mendenhall River channel and the ages of these cored trees restric deposition of the widespread younger outwash sheet in front of the moraines to about a 560-year interval.

The water table in areas underlain by the younger outwash deposits ranges from 2 to about 10 feet below the ground surface. Although the deposits are easily excavated by hand tools and power equipment, draglines and backhoe trenchers are used to excavate below the water table. It is easy to drill through the fine-grained materials but holes need to be cased.

Infiltration into outwash deposits is generally good, except where the water table is extremely high or barriers of lenses of silt-size or clay-size material are present. Surface runoff ranges from poor to good, depending on slope and amount of vegetation. The gentle slope of the valley confines extremely rapid runoff to established stream courses. After periods of extreme and continuous rainfall or snowmelt, water stands in many places having a relatively thick cover of vegetation.

Most erosion takes place in banks of streams, where the younger outwash deposits are very susceptible to undercutting and caving; such erosion is common along the Mendenhall River. The deposits generally absorb sheetwash runoff and usually are not eroded where the surface is flat. Vegetation cover also reduces the tendency to erode, but where the deposits are clear of vegetation and near the terrace scarps, gullies may be eroded by running water.

Many of the reactions of water-saturated fine-grained alluvial deposits to the 1964 Alaska earthquake elsewhere, reactions such as compaction, fracturing of ground, and spouting of ejected water rich in sand and silt, could occur in Mendenhall valley in the event of a strong earthquake (see p.69). The Mendenhall valley consists of more than 100 feet of thick valley fill beneath the younger outwash (fig. 7). Mendenhall valley should be considered highly susceptible to damage from severe earthquakes because shaking is much greater and damage more widespread in areas of thick unconsolidated deposits than in bedrock areas (see overlay 2). I was told that ground waves were visible in Mendenhall valley during the 1958 Lituya Bay earthquake and the 1964 earthquake, but this could not be confirmed. In the lower part of the valley the outwash grades into the Mendenhall River delta that extends into Gastineau Channel and Fritz Cove. Any large lateral movement of the outer slope of the delta would probably cause lateral spreading and fracturing in the ground surface upvalley.

Younger outwash deposits are near sea level in the lower part of the Mendenhall valley. If large tsunamis were to enter Fritz Cove and Gastineau Channel, they probably would cover that part of the outwash deposits near the Glacier Highway. In 1964, some deltaic deposits elsewhere in Alaska were engulfed by seiche and tsunami waves; in addition, backfill waves from sliding of delta faces swept upvalley over the land. (See p. 69 .)

Vertical to nearly vertical slopes as much as 10 feet high are common in gravel pits in the younger outwash deposits. Slumping and raveling occur where the deposits stand unsupported. Slope stability is poor in cuts below the water table, and the outwash deposits tend to slump or wash. The deposits are not susceptible to large landsliding.

Late glacial-outwash deposits (Qol)

Late glacial-outwash deposits consist of light-gray (N7 to 5Y 6/1) sand and pebble to cobble gravel, silty sand, and locally, brownish silt and very fine sand. Most of the rocks in the deposits were derived locally; slate is the dominant rock type on Douglas Island, and greenschist, greenstone, and granite are the dominant rock types on the mainland. The larger fragments of greenstone and granite are generally subround to round, and those of slate and greenschist are tabular; pieces smaller than cobbles are generally subangular to subround. The deposits at some localities, such as in the Salmon Creek valley, contain only silt, but elsewhere they include firmly cemented crossbedded sand and gravel. Most bedding is even and parallels the surface of the deposit. Sand underlies a layer of humus, peat, and wood beneath the youngest glacial moraine at the north end of Mendenhall valley. Peat from this layer was dated as 1,970±250 years old (sample W-1989, Meyer Rubin, U.S. Geol. Survey, written commun., 1968). Most of the other late glacial-outwash deposits are probably much more than 2,000 years old; in many places they are graded to, and apparently contemporaneous with, the older delta deposits (Qdo) of late Pleistocene or early Holocene age.

The late glacial-outwash deposits are conspicuous in the valleys of Fish, Lawson, Kowee, Eagle, Falls, Gold, Lemon, and Salmon Creeks, and are present in one exposure near the upper end of Mendenhall valley. Most of these deposits extend upvalley from the older delta deposits, apparent~~ly~~ to altitudes well above 600 feet. The downvalley-sloping surfaces of the deposits are relatively smooth and in most places uneroded. The deposit near Kowee Creek is higher than the adjacent muskeg-covered bedrock, and forms an anomalous topographic feature within the valley. The deposits mapped along Gold Creek lie behind and are graded to bedrock-risers. The shape of the deposit along upper Gold Creek in Silver Bow Basin is partly obscured by an alluvial fan deposited by Icy Creek. Both the Lemon and Salmon Creek deposits have smooth surfaces graded downstream. A series of terraces has been cut into this deposit along Lemon Creek, the highest of which is at the same altitude as the older delta surface below the bedrock gorge. The Salmon Creek deposit lies upvalley from bedrock ridges and has flat-surfaced channels that wind around bedrock hills.

The largest expanse of late glacial-outwash deposits is mapped along Fish Creek on Douglas Island. Examined only by reconnaissance, this water-deposited material apparently covers most of the valley floor. Numerous boulders, many of granite, cover the eroded surface of the deposit. Part of this deposit may consist of deltaic beds. A scarp over 70 feet high (shown on the geologic map by a terrace-scarp symbol in secs. 13 and 24, T. 41 S., R. 66 E.) is a prominent topographic feature in the lower part of Fish Creek valley and may be the terminus of a delta. Channels 10-25 feet deep are eroded into the otherwise level surface upstream from the scarp. Below the scarp, the outwash is rich in cobble- and boulder-sized rocks on the surface. No deep exposures of material were found.

The late glacial outwash probably accumulated from reworking of older valley fill by water flowing from melting remnants of the late Pleistocene ice. This wasting ice probably had been part of a broad ice sheet, an extension of the Juneau Icefield, that by nature was basically clean ice.

In late Pleistocene time as the ice margin retreated toward the present icefield locality, an isolated and rapidly melting icefield was left on Douglas Island. The melting ice on the mainland provided the water for the conspicuous late glacial-outwash deposits in Gold Creek, Lemon Creek, and Salmon Creek valleys. The deposits in Last Chance Basin, along Gold Creek, are interbedded gravel and silt beds that overlie fossil-bearing glaciomarine deposits. The uppermost beds there may have been deposited in a basin dammed by the prehistoric rockslide-avalanche, as Spencer postulates (1906, p. 79), but I feel that the rockslide-avalanche is much too young to have dammed the late glacial-outwash deposits. Test wells drilled in the basin penetrated two layers of gravel separated by a clayey silt that may be part of a lake deposit (Waller, 1959, p. 3). Gravels behind a bedrock barrier in Lemon Creek valley also overlie silt (Spencer, 1906, p. 119). Salmon Creek flows entirely on bedrock below the concrete dam forming Salmon Reservoir, but sand and silt are abundantly exposed at altitudes as high as 500 feet above sea level where the Salmon Creek trail and powerhouse flume are located in cuts into or through deposits of the late glacial outwash.

Whether all the deposits mapped as late glacial outwash are of the same age or are even necessarily part of the same depositional cycle is not known. The outwash in the valleys of Lemon and Salmon Creeks on the mainland, and in the valleys of Kowee, Eagle, and Lawson Creeks, on Douglas Island, all seem to be graded to the older delta deposits (Qdo). The late glacial outwash along Fish Creek on Douglas Island, does not grade to such a delta. The scarp in the lower part of Fish Creek valley may represent the outer boundary of a deposit that may be an older delta deposit (Qdo), but if so, this particular deposit is at least 100 feet higher than older delta deposits mapped elsewhere on Douglas Island. The older delta deposits have been dated at about 10,000-12,000 years old (see p.70); thus, the late glacial outwash is latest Pleistocene in age if it is graded to older delta deposits.

Older glacial(?) alluvium (Qpm)

The older glacial(?) alluvium generally consists of a brownish-gray very fine sand interlayered with sandy pebble gravel that is reddish to yellowish brown. No shells or shell fragments were seen in outcrops of the unit. The gravel is older than the overlying diamicton in the glaciomarine deposit, first phase, and thus is more than about 10,000 years old.

The older glacial(?) alluvium is exposed only upvalley from the bedrock gorge on Montana Creek but south of the mouth of McGinnis Creek. It disconformably underlies the glaciomarine deposits, first phase (Qmb), and the contact slopes downstream.

An exposure of the older glacial(?) alluvium in the bluff along Montana Creek in the SW1/4SW1/4NE1/4 sec. 2, T. 40 S., R. 65 E., reveals 9 feet of sandy gravel beneath the glaciomarine diamicton, but even more importantly, shows the gravel overlying a 2-foot-thick intensely compacted peaty, woody zone. The exposure was discovered by Carl Blanchard, U.S. Geological Survey, and called to my attention. It may be one of the most geologically significant exposures relative to the glacial history in the Juneau area. The compressed peat suggests a surface that predates the depression and submergence of the land owing to the weight of glacial ice. Whether the gravel above the peat is outwash deposited in advance of the ice encroachment, outwash deposited as the ice retreated, or some other form of alluvium is not known. Peat samples have been submitted to U.S. Geological Survey laboratories for C_{14} and pollen and seed determinations.

Possible older glacial(?) alluvium is reported from test wells elsewhere in the Juneau area. Sand and gravel deposits underlie glaciomarine diamicton in Last Chance Basin along Gold Creek valley (Waller, 1959, table 1) and underlie silty clayey glaciomarine deposits in lower Salmon Creek valley (J. A. McConaghy, written commun., 1967) and along Auke Creek near the beach at Auke Bay (C. L. Sainsbury, written commun., 1964).

The bedrock at the gorge along lower Montana Creek rises above an older valley floor, and perhaps was a barrier to deposition of the alluvium. Similar bedrock ridges occur at the mouths of all major streams (other than the Mendenhall River) in the Juneau area. It is possible that the older glacial(?) alluvium accumulated in a lake dammed behind the ridge. Little is known about the depositional environment of this deposit.

Older till (Qpt)

Older till is mapped only along the valleys of Kowee and Fish Creeks and in the cirques of streams tributary to Fish Creek on Douglas Island. The till consists of a greenish- to brownish-gray clayey, silty, sandy, and pebbly material. The till lies plastered against bedrock along the slopes of the valleys. Rock types are predominantly local; greenstone, argillite, and graywacke are most common; isolated pebbles or cobbles of grainite are included in the deposit.

The till has no distinctive land form. Tightly plastered till is exposed in Kowee Creek valley along the ski trail, and in slump scars along the valley wall near the cirque. This till seems to represent deposition by an older ice before the westward expansion of the ice moving from the Juneau Icefield.

A similarly hard and intensely compacted till lies plastered above bedrock in the cirque holding Cropley Lake, and against the valley wall above the lake and in two much higher cirques that hang above the valley. Exposures are rare; two of the best exposures are in excavations made during construction of the two small dams built to raise the level of the naturally dammed Cropley Lake. About 3 feet of peaty material overlies the till in these excavations. Bedrock is not exposed beneath the 2-3 feet of till, and the thickness of the older till is unknown.

Though not everywhere exposed, the older till apparently underlies many of the muskegs in Kowee and Fish Creek valleys. Probes penetrated only about 3 feet of peat in muskegs between Cropley Lake and Fish Creek before meeting refusal. The hollow end of the probe contained till. Scattered exposures in Kowee Creek valley suggest that the older till extends nearly to the lower end of the valley; the location of the lower boundary of this deposit is arbitrary.

Alluvial deposits

Alluvial deposits, as mapped, consist of materials that are interpreted as having generally accumulated from flowing water. Modern alluvium (Qal), fan deposits (Qf), and terrace deposits (Qt) are found along flowing streams, but not necessarily along the same streams. Rubble deposits (Qar) are accumulations of coarse fragments of rock filling or blocking dry gullies or flowing streams that are much too weak to move such large pieces.

Modern alluvium (Qal)

Modern alluvium is derived from bedrock and surficial deposits within the drainage basin of each stream, and thus its composition varies from place to place. Alluvium along the Mendenhall River consists mostly of granite and diorite pebbles, cobbles, and small boulders that form point-bars along the river channel. Alluvium along Duck and Jordan Creeks, within Mendenhall valley, ranges from pebble gravel upstream to coarse sand near the Glacier Highway. The streams flow on sand and gravel in most other places on the mainland, except for segments of steep gradient along mountain streams where boulders are dominant and generally lie directly on bedrock. Cobbles and boulders of granitic rock as large as 3 feet make up most of the alluvium along Fish Creek. Much of Fish Creek is entrenched in bedrock gorges where the alluvium is nearly absent. Elsewhere on Douglas Island streams are short, steep, and swift; only scattered cobbles and boulders accumulate along these streams. Age of the modern alluvium is late Holocene.

Thickness of modern alluvium is variable and ranges from a few feet to probably several tens of feet. Alluvium at the mouth of the Mendenhall River is more than 6 feet thick. Remnants of alluvium 3 feet or more thick are preserved as broad flats in the lower part of Fish Creek valley marginal to the boulder concentrations along the stream channel. Modern alluvium along Lemon Creek varies in thickness but is probably more than 5 feet thick.

Modern alluvium generally is a poor foundation material (see overlay 2); it forms a broad plain, which has a low gradient. It generally is composed of relatively loose deposits that have a high water table. Some alluvium is entrenched slightly by streams and has a water table lower than deposits where streams flow directly on the surface of the plain. Alluvium with such a lower water table would provide slightly better foundation conditions, but it is less desirable for building sites than drier and more compacted deposits.

Very thin deposits of coarse modern alluvium on bedrock probably would respond to an earthquake by transmitting the waves with little internal displacement. Thick, water-saturated deposits, however, like those deposits mapped along lower Lemon Creek and at the lower end of the Mendenhall valley, would fracture, compact, and possibly eject sediment-laden water as described under the younger outwash deposits (Qoy) (see p. 58) and especially under the younger delta deposits (Qdy) (see p. 69).

The lower parts of large stream valleys that enter tidewaters are susceptible to seiche waves or tsunamis. Entrenched stream channels and low terrain adjacent to the streams make easy paths for seismic sea waves.

Fan deposits (Qf)

Alluvial fans form at the mouths of most streams that flow from steep mountain slopes onto flatter ground on the mainland and Douglas Island. Fans form where streams enter a body of water only if there is an onland break in slope from steep to more gentle gradient. The fans are composed of sand and pebbles mixed together in varying amounts. Slate and other foliated rocks seem to be the most prominent rock types and form tabular angular fragments 1-3 inches across; silty sand, coarse sand, or granules fill the spaces between rock fragments. Granite fragments locally seem to be present in amounts out of proportion to the relative extent of granite in the source areas and may reflect reworking of upstream glacial deposits. This is especially true of the fan of Auke Nu Creek near Mendenhall valley and the fan of Fish Creek on Douglas Island. Material from Lake Creek, which shares a fan with Auke Nu Creek, is composed almost exclusively of platy slate fragments with no granite boulders. The fan deposits are all of Holocene age and the deposits are accumulating at the present time.

Large deposits which extend landward from deltas are mapped as fan deposits in this report. Gold Creek fan and the fan of Lake and Auke Nu Creeks are such fans. Figure 8 shows the relationships between fans, deltas, and fan deltas. The geologic map shows only the prominent fan deposits; some small fans are not mapped. Almost all fans slope 5°-10° downslope. The front of the delta portion of the fan along Lake and Auke Nu Creeks slopes 25°. The subaerial slope of each fan, however, depends on the abruptness of change in gradient where the stream exits from the mountain slope, as well as on the volume and velocity of the stream. Some fans extend upward into the mountain valleys as alluvial cones where they have steeper gradients. Most of the deposits shown on the map are individual fans, but along the eastern side of Mendenhall valley the fans have coalesced to form a series of undulating surfaces.

The larger the fan and steeper the upstream gradient, the thicker is the fan deposit. A test hole drilled into deposits of the Lake Creek alluvial fan penetrated 80 feet of gravel before entering glaciomarine deposits (J. A. McConaghy, written commun., 1967). The deposits accumulate to build the fan shape as streams wander from side to side; the stream channels become blocked as material is dropped and the stream shifts

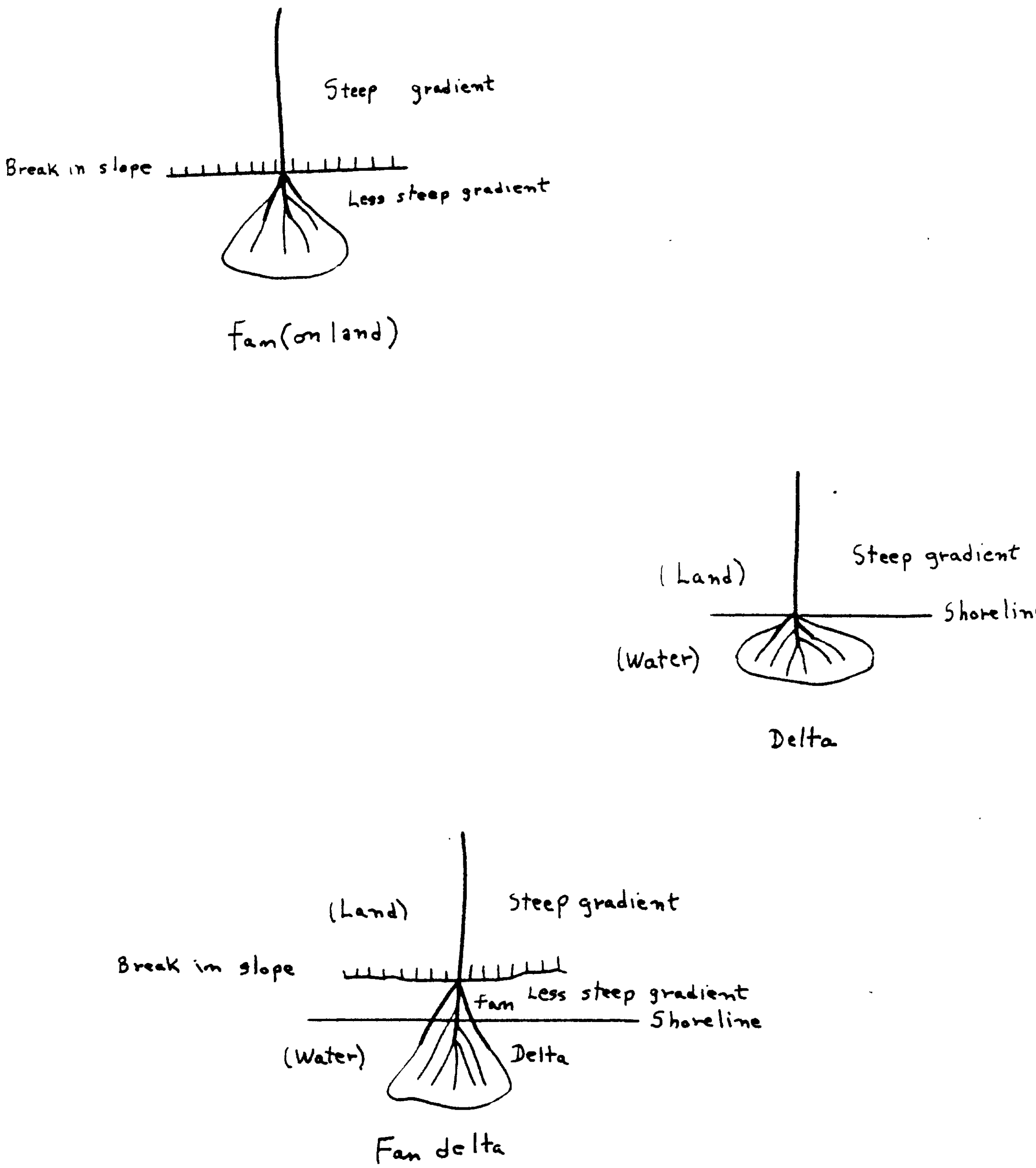

Figure 8.--Diagrammatic sketches showing the relationships between fans, deltas, and fan deltas.

from place to place. If an active stream channel is shortened or otherwise steepened, the stream will erode the fan to adjust to the new gradient.

Rock types in fans vary according to the rocks in the drainage area through which the streams flow. The deposits are saturated below the water table, which varies in depth from place to place. In deposits that consist chiefly of angular slate fragments, plates or chips of slate tend to lie flat like cards in a deck or are stacked like shingles and inclined against the direction of flow. The voids between slate fragments generally are only partially filled by finer material. The looseness permits rapid infiltration under normal conditions. Streams on alluvial fans are generally confined to a single channel during normal flow, but at times of high discharge the channel may shift, be abandoned in favor of a new one, or flow in several channels.

Under normal conditions the foundation capability of alluvial fan deposits is good. Heavy structures commonly require spread footings or driven-friction piles; light structures generally are placed on concrete mats or footings. The extremely loose character of the deposit decreases with depth, and generally excavations 5 or 6 feet deep for houses find firmer ground for footing. Basements are impractical in deposits having a high water table.

The looser fan deposits would react violently to shaking caused by a severe earthquake (see overlay 2). The parts of fans that are near a stream or lake or form the apex would be very susceptible to shaking, fracturing, and perhaps water-sediment ejection. Most susceptible would be such parts of the Gold Creek fan, the Lake Creek-Auke Nu Creek fan, and the Fish Creek fan. Strong shaking could cause liquefaction and(or) slides in sandy deposits along fan-delta fronts. The water table is unusually high in the alluvial fan deposits along the eastern side of Mendenhall valley and along Montana Creek. The conditions at these places are similar to those of Forest Acres near Seward, Alaska, where sand boils, sand spouts, and ground fracturing damaged homes during the 1964 earthquake (Lemke, 1967, p. E34-E40). There is less probability of such violent fracturing and spouting in fans with lower water tables. Nevertheless vibration would be higher on fan deposits than on better consolidated deposits, and strong shaking, fracturing, differential settling, and compacting should be expected.

Slopes in excavations in fan deposits will ravel if vertical cuts are made. This is especially true of the upper 15 or 20 feet of the fan deposit. At greater depths a more compact deposit is reached that probably would stand better in steeper excavations if the water table is below the floor of the excavation. Because the fan materials vary from place to place, as does the water table, individual sites should be carefully investigated before excavations are planned. Sliding of the subaqueous delta fronts of fans is discussed on p. 68.

Terrace deposits (Qt)

Terrace deposits are alluvial deposits that stand above the surface of modern alluvium (Qal) along entrenched stream channels. In general, the terrace deposits are lithologically similar to alluvium, but may be somewhat coarser. In most places, the terrace deposits are rich in hard granitic rocks. The terrace deposit near the mouth of Lemon Creek is a silty fine sand; farther upstream near the bedrock gorge, the terrace deposit is sandy cobble gravel. The terrace deposits along upper Montana Creek are mostly rounded boulders and cobbles, and those along the lower part of Fish Creek consist of well-sorted cobble and boulder gravel. The age of the deposits is late Holocene.

Although terrace deposits are shown on the geologic map only along Montana, Peterson, Gold, Lemon, and Fish Creeks, similar deposits too small to map also are present along other streams. Some terrace deposits form two or more distinct surfaces that are separated by scarps 1-4 feet high.

Streams of the Juneau area are now graded to tidewater. As the land in the Juneau area rose following the last major regional glaciation, streams cut into their own alluvium. The time and rate of the rise of the land that caused this downcutting are discussed on p. 82.

Rubble deposits (Qar)

The rubble deposits generally consist of angular, locally derived blocks of slate, greenstone, and metavolcanic rocks, and round to subround boulders of granite. Some of the pieces are as large as 12 feet across. Rock fragments in the deposit lie against each other, and the spaces between large fragments are only partly filled with smaller rocks. The age probably is Holocene.

These rubble deposits probably represent more than one depositional origin and age, but it seems likely that most of them were formed by torrential floods. The large granite boulders probably are glacial erratics. The large stream discharge required to form the deposits could be related to an episode of greater precipitation than characterizes the present climate. Some of the deposits extend downslope to altitudes below 500 feet, and thus are below the marine limit. These rubble deposits must have accumulated after the land had started to rebound isostatically and had risen relative to modern sea level.

The deposits cover the floors of narrow ravines and blanket some of the slopes at the north end of Douglas Island and the mainland between Lemon Creek and Tee Harbor. The jumbled landform is unmistakable and bears no resemblance to the smoother slopes developed on the adjacent deposits. Lena Creek flows almost exclusively through such a rubbly deposit. The rubble deposits along Gold Creek northeast of Juneau start abruptly where the ravines steepen toward Gold Creek. Deposits on the Mendenhall Peninsula also seem to have abrupt margins near the upper ends of ravines.

Deltaic deposits

A delta is an alluvial deposit that forms where streams drop their loads of solid particles as the result of decreased stream velocity where the flowing water enters a body of water. Deposition is greatest when the stream load is highest and least when the stream load is lowest. As the delta slowly builds outward, the uppermost beds generally remain above high water. Streams flowing on deltas generally wander and change channels unless artificially confined, such as Gold Creek which is restricted to a flume. Channel change generally takes place during periods of high stream flow. As a delta grows, the landward portions tend to enlarge and a combination fan and delta is built (fig. 8). Gold Creek has such a fan delta.

Deltaic deposits, those sediments that form a delta, are separated into two groups in this report. Younger delta deposits (Qdy) are those sediments in modern deltas, whereas the older delta deposits (Qdo) are those sediments that formed deltas during the time when the land was still depressed from the weight of the late Pleistocene ice cover and sea level was higher relative to the land than at the present time. Consequently, these older deltas now are found several hundreds of feet above modern sea level.

Younger delta deposits (Qdy)

The younger delta deposits range from fine to coarse material. Slate, greenstone, and granite are the most common rock types. The younger delta deposits are generally overlain by intertidal silts or fill material; consequently, they are not easily seen. Test holes drilled and augered by the Materials Division of the Alaska Highway Department as part of several roadway and bridge investigations show that most delta deposits are generally composed of fine sand or sandy gravel mixed with small amounts of silt, and that they become finer and more dense with depth (Munson and Slater, 1963; Munson and Rasmussen, 1966; Franklet and Rasmussen, 1969; Slater and Grahek, 1970; Slater and Palczer, 1970).

The larger deltas, such as those of Mendenhall River, Salmon Creek, Lemon Creek, and Gold Creek, contain materials which have a wide range in texture and lithology. Light-gray granitic rock fragments are very common in most of the delta deposits along the mainland. Dark slates and greenstones are dominant in the Douglas Island younger delta deposits, whose texture ranges from fine sand to a pebble gravel that locally contains cobbles and boulders. Where slate predominates, more than 60 percent of the pieces are thin and platy. The greenstone fragments generally are more blocky and subrounded. Cobbles and boulders are common in the younger delta of Eagle Creek, whereas the delta of Lawson Creek is mostly sandy gravel (Munson and Franklet, 1963a). These deltas are Holocene and are growing and enlarging at present.

Deltas are mapped along Gastineau Channel and Fritz Cove and Mendenhall Lake. The deltas have a typically triangular or fan shape in plan. The upper surface of the delta slopes gently toward the water, and the modern stream channel may be incised from 1 to 5 feet. During periods of high discharge, streams may erode laterally and shift their channels. New channels are also formed when the stream shifts position at the apex of the delta. The front of the delta is below water. The deltas in Gastineau Channel and Fritz Cove are encroaching on the channelways in the fiord and have so filled the constricted north end of the channel that dredging is necessary from time to time to maintain a boat channel usable at high tide.

The arcuate distal outline and broad lateral extent of most of the deltas are well exposed at minus tides, except for the Mendenhall River delta, which remains obscured. Fathometer traverses across fronts of deltas in Gastineau Channel show slopes of about 25° (R. D. Miller, 1967). Bathymetric contours on topographic maps suggest similar slopes.

Most of the information available concerning the thickness of the younger delta deposits comes from drilling already cited. Judging from interpretation of drill records, I think that the large deltas near water level are more than 50 feet thick.

Sliding of delta fronts was common during the 1964 Alaska earthquake. Large slides occurred at Seward (Lemke, 1967, p. E30); Valdez (Coulter and Migliaccio, 1966, p. C15); and Whittier (Kachadoorian, 1965, p. B16-B17). Ground vibration of sufficient strength and duration in fine-grained saturated deposits can increase pore pressure, produce liquefaction, and reduce the shear strength of the deltaic materials. Massive slides may result.

Saturated unconsolidated materials similar to those of the younger deltaic deposits responded during the 1964 earthquake by compacting and subsiding, lateral spreading, fracturing, and spouting sediment-laden water. Compaction of silt and sand near Portage resulted in land subsidence of 4-5 feet (Seed, 1964, p. 37). Writing of subsidence, probably of about 2-3 feet in Snow River valley north of Seward, Lemke (1967, p. E40) also mentions that some of the subsidence in the Snow Creek valley near Seward may have been caused by lateral spreading from the outward movement of a delta in nearby Kenai Lake. Similar lateral spreading of flat or nearly flat ground toward an unconfined delta face is believed by Coulter and Migliaccio (1966, p. C21) to have caused fractures that trended across the valley parallel to the delta face at Valdez during the 1964 earthquake. In addition, ground fissures develop when seismic energy is transmitted through sediments and is transformed into surface waves which stretch and compress the surface materials until they fracture. Fissures caused in this way occurred in frozen ground at Valdez (Coulter and Migliaccio, 1966, p. C25).

Sediment-laden water spewed from the ground at various places in Alaska during the 1964 earthquake. Vibratory compaction of saturated sediments forced water freed from the intergrain voids to the surface as sand spouts and boils (Seed, 1964, p. 37). Such emissions generally occurred at isolated points during the earthquake. In addition, continued undulatory ground movement pumped sand, silt, and water upward, where it emerged along fissures in a series of pulsating surges (Macelwane, 1947, p. 17; Coulter and Migliaccio, 1966, p. C25; Lemke, 1967, p. E39). Buildings on or near such fissures were structurally damaged at Valdez (Coulter and Migliaccio, 1966, p. C30-C35), and Seward (Lemke, 1967, p. E13), and several homes in Forest Acres, near Seward, were partly filled by sand from spouts, boils, and fissures.

Most of the damaging water waves during the 1964 Alaska earthquake have been ascribed to subaqueous slides or tsunamis. Waves generated locally that were apparently not related to tectonic movement, tsunamis, or subaqueous slides were reported over much of the area affected by the earthquake. How many of these waves were seismic seiches are not known, and the importance of seismic seiches relative to shoreline inundation is not specifically understood.

Juneau apparently was but slightly affected by the tsunami caused by the earthquake in 1964. A resident living on the bluff above Auke Bay noted that the water oscillation at Auke Bay was out of phase with that being reported from Gastineau Channel at Juneau (Keith Hart, oral commun., 1968). Spaeth and Berkman (1967, table 4) show 7 feet as being the maximum rise of the water above anticipated tidal heights over a period of many hours of fluctuations at the tide gage along Gastineau Channel at Juneau.

Another incident was attributed to a tsunami in Gastineau Channel. A float plane flipped over in the water and sank in the harbor at Douglas as a result of the unusual tidal action (Juneau Daily Alaska Empire, Mar. 29, 1964). Thus, although well within the sheltered waters of the Inside Passage, Gastineau Channel at Juneau was evidently affected by sea waves originating many miles away.

Wilson and Tørum (1968, p. 363-372) discuss the ability of structures to withstand tsunamis, damage to harbor structures, protective measures, and safety standards in areas that may be affected by tsunamis. They report that old, one-story wooden frame buildings had poor resistance to tsunamis in coastal communities hit by the seismic sea waves in 1964. Concrete block and reinforced concrete structures, on the other hand, generally withstood the tsunamis. Wave damage can also be reduced if buildings have deeply embedded footings.

A dramatic consequence of subaqueous sliding of delta fronts during the 1964 earthquake was backfill waves. These waves formed as water rushed into the void created when the material slid out. Backfill waves caused much of the damage to buildings and other structures on the deltas at Valdez (Coulter and Migliaccio, 1966, p. C14) and Seward (Lemke, 1967, p. E4-E5; p. E41). Water from a backfill wave ran up as high as 30 feet above a slide scarp in Kenai Lake (McCulloch, 1966, p. A7, A17). Slide-induced waves also move outward and inundate low shores opposite the slide. Such waves on Kenai Lake ran up to a height of 25-35 feet in the center of the wave-washed area, and to heights of 11-13 feet on the sides (McCulloch, 1966, p. A8).

Mendenhall Lake contains a potential danger in the form of slide-induced waves from earthquakes. The lake has a depth of 200 feet and covers a surface area of slightly more than 1 square mile (Barnwell and Boning, 1968, p. 1). Slides could occur in the delta of Nugget Creek at the northeast edge of the lake, and in the old Steep Creek outwash delta along the south-central shore of the lake. The latter delta is opposite a forested shore, and waves created by a slide probably would cause no serious damage. The area opposite the Nugget Creek delta includes the U.S. Forest Service Visitors' Center and parking lot. If the delta front slid out, waves could endanger the campground, which is located on land that in many places is less than 15 feet above lake level. Although Mendenhall Lake is smaller than Kenai Lake, it is deeper, and waves at least as high as those at Kenai Lake probably could be developed from slides.

Older delta deposits (Qdo)

The older delta deposits consist of olive-gray (5Y 5/2) sandy gravel and gravelly sand, containing variable amounts of silt and clay. The deposits are made up mostly of deltaic foreset beds that contain cobbles, boulders, and shell fragments. Layers of gray diamicton 2-10 feet thick are interbedded with foresets of gravel that are exposed in a pit in the SW1/4SE1/4 sec. 21, T. 40 S., R. 65 E., near the Auke Bay ferry terminal (table 4, no. 5). Shells and shell fragments are widespread, and many unbroken barnacles are attached to cobbles in natural growth positions. The interlayered diamicton beds are texturally similar to those described under glaciomarine deposits. These diamictons form ledges having nearly vertical faces. The delta deposit at the gravel pit mentioned above has an eroded surface that truncates the gravel; this surface is overlain by a massive diamicton rich in barnacle shells which, in turn, is overlain by a second sequence of deltaic gravels.

Barnacle shells attached to cobbles in this upper diamicton have a radiocarbon age of 12,730±500 years (sample W-1830), and shells within the diamictons in the lower deltaic beds have an age of 12,880±500 years (sample W-1831, Meyer Rubin, U.S. Geol. Survey, written commun., 1966). These ages, though from materials separated by an erosional surface, suggest that all of the deposits are of about the same age.

The older delta deposit near the mouth of Gold Creek, in Juneau, contains similarly interlayered beds of grayish diamicton. The age of barnacle shells in these beds is 10,880±340 years (sample W-1829, Meyer Rubin, written commun., 1966).

A well-developed layer, 4 feet thick, of gray very compact and indurated diamicton in a gravel pit at Eagle Creek, on Douglas Island, contains boulders, cobbles, and shells (table 3, no. 6) and unconformably overlies deltaic sand and gravel. This layer appears to be horizontal and blankets an eroded surface that truncates the underlying foreset beds. Boulders and cobbles seem to be concentrated in the lower two-thirds of the diamicton. Shells in the diamicton are 9,150±800 years old (sample W-2395; Meyer Rubin, written commun., 1970).

The older delta deposits occur primarily along Gastineau Channel at the mouths of some tributary valleys. In addition, an extensive older delta deposit is preserved in the lower part of Montana Creek valley. A small delta exposed in the gravel pit near the Alaska ferry terminal apparently is related to an earlier drainageway that has since been abandoned. Surprisingly, no delta deposit was found in the lower part of the Fish Creek valley, which is one of the larger valleys on Douglas Island, even though deltas exist on some of the smaller valleys of Douglas Island. The deltas occur at heights of as much as 500 feet above sea level.

Many analyses of the older delta deposits are included in project reports of the Alaska State Highway Department. Most deltaic deposits are loose and variable in composition. Boulders as large as 2 feet across and isolated fragments as large as 10 feet make up about 20 percent of the older delta deposits. Silt and clay generally make up less than 10 percent of any deposit. Samples from diamicton layers had dry bulk densities of as much as 140 lbs per cu ft. The diamicton on top of the foreset beds at Eagle Creek on Douglas Island is even more dense, and has a dry bulk density of 150 lbs per cu ft.

The older delta deposits in the Juneau area accumulated in the marine waters of Gastineau Channel and Auke Bay when the land was lower relative to sea level (fig. 10). The land subsequently rose relative to sea level and left these deposits perched along mountain fronts as high as 250 to about 500 feet in altitude. Such heights indicate the position of the ancient sea level relative to modern sea level at the time the deltas were formed. The maximum height of the deltas does not represent the marine limit, which is believed to be considerably higher, but apparently represents one of perhaps several temporary and relatively stable positions during isostatic rebound. The diamictons interbedded with the foreset beds of the delta may have settled out of marine water during intervals when streams were not bringing coarse material to the delta, or they may represent mudflows derived from saturated glaciomarine deposits upstream. At Eagle Creek, the materials in the layer that is draped over the truncated deltaic beds appears to be graded; the coarser material is concentrated in the lower two-thirds of the deposit. Such grading has been described as being characteristic of mudflows elsewhere (Crandell, 1952; Mullineaux and Crandell, 1962, p. 857-858). Such an origin, however, would require that the mudflow came to rest on a slope of 30°-35°. The diamictons on top of the deltaic sand and gravel may also represent a period when the rise of eustatic sea level exceeded that of isostatic rebound of the land

and the tidal waters temporarily submerged the deltaic deposit. If this occurred, the coarse materials in the diamictons could have been derived from melting ice blocks floating in the fiord. The relatively young age of 9,150±800 years B.P. (sample W-2395, Meyer Rubin, U.S. Geol. Survey, written commun., 1970) for the blanket-forming diamicton at Eagle River supports the concept of a temporary eustatic rise of sea level.

The older deltas that lie at an altitude of about 250 feet, or slightly lower, are the deltas that contain the upper blanket-forming diamictons. These diamictons are believed to relate to a pause in the rebound of the land during isostatic readjustment. This 250-foot level is consistent throughout the Juneau region for deltaic preservation and appears to be regional in nature. Deltas occur at a similar altitude in the Skagway and Haines areas (Yehle and Lemke, written commun., 1972; Lemke and Yehle, 1972b). This pause in rebound is discussed in somewhat more detail under glaciomarine deposits.

Prolonged shaking from a severe earthquake near Juneau could cause compaction and differential settlement in parts of the relatively loose older delta deposits. Some of the frontal slopes of these older deltas are at angles of 30°-35°, about the angle of repose for sand and gravel. Such slopes could slide or flow from prolonged shaking, and headward stoping by these slides could destroy parts of the older delta deposits near these steep slopes.

Rockfalls and other types of landslides have encroached upon some of the older delta deposits in the past. Blocks of bedrock have fallen or rolled onto the older delta along Auke Bay. A prehistoric landslide covers part of the older delta at Lemon Creek. Heintzleman Ridge is the apparent source and should be examined before residential development of the Lemon Creek delta.

The older delta deposits are potential sources of good quality gravel. Tests for specific uses are necessary for each delta deposit. The older delta deposit at Eagle River is now being utilized and site reports of the Alaska State Highway Department show that texture and composition are variable, and that weathering and decomposition are extensive in some zones. Materials from this pit have been used for portions of the North Douglas Road and the small-boat harbor at Douglas (Munson, 1963). The older delta deposit at Gold Creek has also been developed but was not being used at the time of this investigation. An inactive gravel pit is located in the older delta deposit at Montana Creek.

The broad flat surfaces and easy excavation make several of the older delta deposits attractive sites for urban expansion. It should be noted, however, that the permeable nature of the deltaic sands and gravels could permit waste fluids to move through the deposit and to contaminate wells.

Beach deposits

Beach deposits, as mapped in the Juneau area, include modern beach deposits (Qby), spit deposits (Qb), young raised beach deposits (Qrb), older raised beach deposits (thin, continuous) (Qbe), and older raised beach deposits (thick, local) (Qbo). A beach is a "zone of unconsolidated material bounded to seaward by the junction of land and sea at low tide and, to landward, by a definite change in material or physiographic form, such as a sea cliff, or by a line of permanent vegetation" (Stokes and Varnes, 1955, p. 13). Beaches are ephemeral constructional shoreline features whose form and size can change as the direction and intensity of waves and long-shore currents change and as the amount of transportable material changes.

Beach deposits formed by wave and shore currents that carried and deposited material. Rivers and streams brought some of the material in from distant sources, but some came from the erosion of adjacent deposits. Most of the boulders and cobbles and some large blocks were eroded from nearby glaciomarine deposits or other coarse surficial materials. A few of the very large blocks probably fell from nearby bedrock cliffs or promontories.

Beaches formed at different times after the glacier ice left the Juneau area. As a result, there are beach deposits at different altitudes above present sea level; these reflect deposition during isostatic uplift in response to the removal of the weight from glacial ice. The modern beach deposits (Qby) and the spit deposits (Qb) are being deposited at the present time at the modern sea level. The young raised beach deposits (Qrb), reflect beaches that have been raised above sea level by rebound in the last few hundred years. The older beach deposits (thin and continuous) (Qbe), and the older raised beach deposits (thick and local) (Qbo) probably accumulated in part contemporaneously but, also, in part sequentially. The older raised beach deposits underlie peat beds dated at from about 8,200 to 5,700 years old. The oldest raised beach deposits underlie peat dated at about 7,200 years old on the Mendenhall Peninsula; they are believed to be older at other localities. Both older raised beach deposits overlie glaciomarine deposits dated as being about 10,000 years old.

Separation of the two older raised beach deposits (Qbe) and (Qbo) in the field, and as shown on the geologic map, is based mostly on landform and distribution. The older raised beach (thin and continuous) formed as broad expanses on gently sloping surfaces of the underlying glaciomarine deposits. Such deposits extend for miles along the shoreline; their broad lateral extent as a continuous blanket reaching from the sea cliffs to as high as 600 feet above sea level apparently reflects a uniform accumulation during rebound. This deposit, in the broad sense, is easily traced along the shoreline and raised seacoast and is recognizable from place to place by its almost uniform thickness and brown to reddish color. The older raised beach deposits (thick and local), however, are more restricted in their occurrence; they are found in narrow topographic settings that are conducive to gravelly accumulations from high-energy waves. These older raised beach deposits (thick and local) are at different altitudes at different places, which suggests to me that these deposits accumulated at different times in places where sea level, terrain, and wave direction and energy were all balanced. Whereas some of these older thick and local deposits are truly beaches, as along the eastern shore near Tee Harbor, some of the deposits may be bay-mouth bars that accumulated between headlands, such as the deposits on Mendenhall Peninsula and near Auke Lake.

Modern beach deposits (Qby)

Modern beach deposits consist of brownish to dark-grayish fine sand and pebble- to boulder-size gravel. Some deposits are composed almost entirely of whole and broken shells. Slate, greenstone, and flow breccia are the predominant rock types. Granitic rocks, generally of boulder or cobble size, are scattered along the beaches. Overprints are used on the map to show predominant fragment size where accumulations are uniform in size. Some beach slopes consist entirely of beveled bedrock; these areas are mapped as bedrock extending seaward from the shoreline. The beach deposits are of Holocene age and are accumulating today.

Beaches occur sporadically along most of the shores in the Juneau area. Very steep bluffs and deep channels are not conducive to beaches, but most shorelines have beach deposits that can be seen at least during low tide. Beaches are well developed at bays and coves but are less persistent along elongate channels. Beach slopes average about 10°.

Fine-grained deposits are loose and uncompacted. The cobbles and pebbles are wedged together in a matrix of sand and silt. Broken shells loosely fill the spaces between stones on some beaches. Stones are tightly wedged together in beaches of large boulders, but some boulders roll under foot and with the tide. Blocks 10-20 feet on a side are scattered on the beaches.

Deposition and erosion are in balance along most modern beaches away from the mouths of rivers. Beaches can be eroded by strong tidal or long-shore currents, or by waves during storms. Large boulders or angular blocks fallen from nearby bedrock outcrops may shift in response to storm waves and tides, but do not move significant distances. Construction of harbors, docks, etc., can change the shore currents and alter the previous balance between erosion and deposition.

Beach deposits provide a poor foundation. Where there are large boulders, their looseness results in an unstable foundation. Most beach deposits are less than 5 feet thick and can be readily removed so that footings can be placed on bedrock. Bedrock generally provides an excellent foundation, but there are other problems in building structures on beaches. In addition to periodic inundation by high-high tides and storm waves, beaches are susceptible to tsunamis and to slide-generated and other abnormal waves.

Localities most likely to be affected by a tsunami are those that are exposed to broad areas of open water. Auke Bay and the northern end of Douglas Island are exposed to long reaches of open water, and Tee Harbor, which faces northward, would be extremely susceptible if waves approached from the north. The prediction of tsunamis or other abnormal waves is beyond the scope of this report; the fact that such waves can be caused by earthquakes makes beach deposits unsuitable for residences (see p. 69).

The boulder and cobble beaches probably would respond strongly to severe seismic vibration. The rounded and ovoid fragments could roll and move but the general thinness of the beach deposits would prevent much compaction or severe shaking. Where beach deposits are thicker in sheltered inlets or coves, they might be severely shaken and compacted, and they might slide or flow.

Spit deposits (Qb)

Spits are embankments built by waves and currents extending from land and terminating in open water. Because spits are closely related to beaches, spit deposits are included with beach deposits.

Most spit deposits are gray pebbly sand and sandy gravel. In places they are composed of pebble to boulder gravel. The rock types are mostly argillite and flow breccia in spits in the North Douglas Island-Outer Point area, and mostly argillite and greenstone elsewhere. Locally the deposits contain some boulders of granitic rock. Overprints are used on the geologic map to show the predominant fragment size where accumulations are uniform in size. Spits are forming now.

Spit deposits are best developed near points of land, along irregular shorelines near the mouths of streams, and between shore and offshore rock promontories. Several spits are on the north portion of Douglas Island along Fritz Cove near Outer Point. The largest deposit is a concentration of pebbles and cobbles that extends outward from the mainland near Fish Creek to Entrance Point, a bedrock promontory. Though mapped as a spit, this deposit forms a barrier beach between the mainland and Entrance Point. The largest mainland spit is on the south side of Lena Point. All spits are asymmetrical ridges, generally less than 12 feet high above mean sea level, that have a steeper landward slope and more gentle seaward slope. The crestlines range from a few inches to several feet in width.

The thicknesses of spit deposits are variable. Some bars on tidal flats are only a few feet thick; others are in locations subject to stronger currents and are larger and thicker. The thickest deposit known is in the bar along the south side of Lena Point and consists of about 16 feet of sandy gravel that overlies bedrock.

Spits form where tidal shore currents and storm waves move sand and gravel laterally along shore to an area where transport energy is decreased for some reason and part of the load is dropped. Generally the material is provided by streams entering the body of water; thus, most spits are near the mouths of streams. Strong shore currents and tidal currents also rework and transport beach deposits laterally and form spits at jutting points of land that affect current flow, or where two shore currents meet. Spit deposits are eroded as well as deposited by shore and storm waves. Strong storm waves can modify the shape and size of a spit bar, or even remove the bar temporarily. Strong runoff in streams near spits can cause lateral scour of the spits, especially during low tides.

Spit deposits are a rather minor geologic unit in the Juneau area and not generally utilized for construction sites. If spits are used, however, their looseness and nearness to sea level require understanding of the deposits' shortcomings. Besides being easily reshaped or completely removed during storms or strong shore-current activity, the deposits are susceptible to inundation from large storm waves or seismically induced sea waves. The surface of a spit deposit is close to sea level and thus has little protection from abnormal waves. Such loose deposits would be highly susceptible to shaking and compaction during a strong earthquake in the Juneau area. Fractures that might provide outlets for water and sediment ejection might form, though the relative thinness of the deposit might reduce the amount of compaction and fracturing. However, some of the spits overlie thick tidal deposits whose reactions to a strong earthquake might overshadow the reactions of the spit deposits.

Young raised beach deposits (Qrb)

Young raised beach deposits are generally composed of brown to gray fine sand and pebble to cobble gravel. Fragments of platy slate make up the deposits at most places, but broken shell fragments are common; graywacke supplements slate in deposits on Spuhn Island, and rounded pieces of greenstone and flow breccias make up deposits near Outer Point and Tee Harbor. Well-developed podzol soils having an A_2 horizon (a bleached white ashy-appearing layer) are found on some, but not all, of the raised beach deposits. A well-developed yellowish-brown to reddish clay-enriched B horizon underlies the A_2 horizon in deposits along Peterson Creek, near Outer Point on Douglas Island. All of the raised beaches are of late Holocene age, but not all deposits were formed at the same time. The access road to the beach at Lena Cove lies between two raised beach ridges, the inner (shoreward) of which has a better developed soil than does the seaward ridge (Freeman Stevens, oral commun., 1968). Trees on the seaward ridge are about 175 years old, whereas a mature forest covers the inner ridge. A tree growing between the two ridges was cored and is more than 398 years old; thus, the inner beach ridge is more than 400 years old.

Raised beach deposits in the Juneau area are at the heads of Tee Harbor and Lena Cove, and near Outer Point on the northern part of Douglas Island. Raised beach deposits have two topographic forms. Some are narrow beach ridges, asymmetrical, and have the steeper slope on the leeward side.

Others are broad expanses with relatively smooth surfaces that slope gently upward and extend inland near Outer Point and on Spuhn Island.

These deposits accumulated by normal wave and shore current action and by occasional storm waves. All of these deposits in the Juneau area face an open or semi-open expanse of water. The asymmetrical beach ridges developed at the heads of coves, where waves deposited material in elongate arcuate ridges more or less parallel to the shape of the cove. The two ridges at Lena Cove are examples. Both of these ridges may be storm beaches, but the great age difference suggests that at least the inner ridge is a normal beach that reflects uplift of the land in relation to water level during the last few hundred years. The deposits near Outer Point are exposed to many miles of open water to the north and probably represent storm-beach accumulations that have been elevated since they were formed.

Raised beach deposits face open or nearly open waters to the north. These broad expanses of water provided the fetch for waves to develop the energy to form deposits near Outer Point and on Spuhn Island, but they also expose the deposits to possible tsunamis coming from the north. Most of the young raised beaches are less than 20 feet above water level and would be very susceptible to inundation by large tsunamis. The nearest known subaqueous earthquake epicenter is off Icy Point along Icy Straits, about 100 miles from Juneau (fig. 3). Admiralty Island lies between the Juneau area and Icy Straits, which is the main opening to the Gulf of Alaska to the west. Presumably, then, any seismic sea wave coming from the open sea or the Gulf of Alaska would be attenuated by the time it reached the Juneau-Douglas Island area. The possibility of tsunamis caused by horizontal movement along the Lynn Canal-Chatham Strait fault was discussed on p. 18.

<u>Older raised beach deposits, thin and continuous, (Qbe)</u>

Older raised beach deposits, thin and continuous, consist of very-dark-reddish-brown (10YR 3/2) to yellowish-brown (10YR 4/5) pebble gravel containing some sand but very little silt, and practically no clay (table 4, no. 8). The color of moist material is black (10YR 7/1). Individual pieces of slate, greenstone, and graywacke are generally tabular and lie with their flat sides parallel to each other and to the surface of the underlying deposit. Subangular to subround edges are typical, but a few fragments have sharp edges. Sand and some silt mixed with peat from the overlying thin muskeg fill the spaces between the pieces. This organic matter obscures the natural dark-gray and green colors of the rocks and gives the deposits a reddish hue. Light-gray (10YR 8/1) layers apparently related to podzolic soil development are conspicuous in some exposures. Medium to fine sand that underlies the gravel is generally yellowish brown (10YR 4/5) but is locally gray (N 4/0). These older raised beach deposits, thin and continuous, are commonly underlain by glaciomarine deposits.

These beach deposits were lifted as the land emerged in response to isostatic rebound during and after the late Pleistocene retreat of the glaciers. Their ages may be almost as great as those of the underlying glaciomarine deposits. Judged from radiocarbon dates from peaty material overlying these beach deposits, however, the earliest dated accumulation of older thin and continuous raised beach gravel, along the shore of Auke Lake, is older than 8,280±350 years B.P. (sample W-2258; Meyer Rubin, written commun., 1969), and the youngest dated gravel, near Douglas, accumulated along the rising shorelines about 5,730 years ago (sample W-1949; Meyer Rubin, written commun., 1968).

Such radiocarbon dates suggest beach development throughout the entire period of shore erosion and uplift in Holocene time. As the land rebounded isostatically, the glaciomarine deposits were eroded and the coarse fragments collected to form beach deposits. That the surfaces on the beach deposits are generally evenly sloping suggests a uniform rate of land uplift and a rate of beach deposit accumulation that kept pace with the uplift. The peat may or may not have started to accumulate immediately as the tidal waters receded from the rebounded land; consequently, there may be unknown time intervals between the formation of the dated peats and the underlying beach gravels. Evidence that peat does accumulate quickly on still-active beaches is suggested by the plant material filling the spaces between pebbles and cobbles on the modern beach along Auke Bay near the outlet of Auke Creek. Salt-tolerant plants there grow below mean sea level and are inundated daily by tides; such plants probably grew in earlier times, and thus the altitudes of basal peat samples and their dates <u>may</u> closely represent the position of sea level and the time of beach development at that altitude.

Older raised beach deposits, thin and continuous, are found along both sides of Gastineau Channel, along Fritz Cove, Auke Bay, Lena Cove, and along the lower reaches of Montana Creek. Their surfaces slope gently, 10°-15°, but locally are interrupted by scarps less than 10 feet high. The deposits extend from the seabluff, or stream channel, to the mountainside. The surfaces on these deposits approximately reflect the surfaces on the underlying deposits (profile C-C', fig. 9). The deposits extend more than 600 feet above sea level near Kowee Creek on Douglas Island, and elsewhere have been mapped to an altitude of 500 feet. Peat (Qmk) and forest humus overlie these beach deposits, so that the thin beach deposits are exposed only along bluffs or in excavations.

Bedrock along the shoreline prior to and during isostatic rebound provided some of the fragments found in the older raised beach deposits, thin and continuous, as did the glaciomarine deposits whose coarse fragments were reworked into the beach deposits. The preponderance of local rocks in these raised beach gravels, however, suggests that bedrock was the prime source of the gravel. Some of the peaty humus that is intermixed with the platy pebbles and sand sifted down from above into open spaces, but some also accumulated as part of the beach gravel.

Older raised beach deposits, thin and continuous, are generally loose and uncompacted and are thus very susceptible to shaking during an earthquake. Broad deposits probably would react by some lateral movement of the platy pieces and, possibly, some compaction. The deposits are thin, so compaction would be slight. It is unlikely that a large building would be founded entirely on or in such a thin deposit, but if it were, ground cracking and differential settling might result.

Older raised beach deposits, thick and local, (Qbo)

The older raised beach deposits, thick and local, consist of olive-gray (5Y 5/2) to pale-brown (10YR 6/3) pebble, cobble, or boulder gravel in a sand matrix. Slate, graywacke, greenstone, flow breccia, and granite are dominant rock types. This coarse material locally overlies a medium to coarse sand which contains abundant shell fragments scattered through the sand and also concentrated in layers. Beach deposits in areas exposed to long expanses of open water have the coarsest materials; the deposit extending along the east side of Tee Harbor is the coarsest in the Juneau area. Here, subround to round locally derived greenstone and flow-breccia boulders 2-3 feet in diameter are concentrated in a conspicuous deposit. The broad deposit near Outer Point on Douglas Island is stained a very dark brown (10YR 3/2), but the cobbles bleach almost white after the overlying thin muskeg is scraped from the deposit. Elsewhere, most of the deposits are pebble to granule size and contain isolated granite cobbles and boulders. The deposit between Auke Lake and Montana Creek has numerous cobbles and boulders of granite; they are especially abundant along the base of a bedrock knob that extends above the surface of the older beach deposit.

These deposits are of early Holocene age. They are younger than the 10,630±500 B.P. radiocarbon date obtained from shells in the underlying glaciomarine deposits, third phase (Qme) (sample W-2263, Meyer Rubin, written commun., 1969) and older than the 7,210±300 year B.P. date obtained on peat that overlies the older raised thick and local beach deposits 180 feet above MLLW along the Engineers Cutoff on Mendenhall Peninsula (sample W-1832, Meyer Rubin, written commun., 1966).

Except for the deposit in Juneau below Mount Maria, the older raised beach deposits, thick and local, occur only in the northern part of the mapped area. The most extensive deposit forms a broad surface near Outer Point. It extends upslope to heights of as much as 200 feet above sea level. At Tee Harbor, a similar deposit consists of conspicuous coarse boulders that lie along the mountain slope as high as 50 feet above the Glacier Highway. Farther north, the deposit forms a series of benches. A finer textured equivalent deposit underlies much of the surface between Tee Harbor and Lena Cove. Older thick and local raised beach deposits occur on Coghlan Island and Mendenhall Peninsula and have steep slopes to the north. The deposit at the southern edge of Auke Lake slopes from a crest gently southward toward the Mendenhall valley, and more steeply northward on a gradient of about 20° to the shore of Auke Lake.

The deposit shown on Plate 1, sheet I, below Mount Maria in Juneau merges with the older delta deposit that forms Evergreen Bowl. It is interpreted as a raised beach deposit rather than part of the delta because it lies higher than the delta deposit, and because its surface is graded toward the delta deposit. These two conditions suggest to me that this older thick and local raised beach deposit accumulated from a source different from that of the delta. The two deposits may have been nearly contemporaneous, but the older delta was deposited by waters flowing from Gold Creek, and the older thick and local raised beach deposit was formed by waves and currents from Gastineau Channel. This particular raised beach deposit slopes from the base of the ridge between Mount Maria and Mount Roberts toward downtown Juneau. The material in this deposit is generally pebble size or smaller. Cobbles occur but rarely, and then in discrete layers rather than within sandy beds. Shell fragments occur in the deposit. Figure 9 shows the relationship of this deposit to the older delta deposit, and the lithology as recorded from drill hole no. 1.

Elsewhere, the older raised beach deposits, thick and local, were formed by waves and currents along shore and in shallow water between highland promontories. Bedrock and glaciomarine deposits were the source materials. The coarse deposits on the east side of Tee Harbor probably originated in rockfalls from the adjoining cliffs. At some other localities, such as along the bedrock hill near Auke Lake, granite boulders were concentrated after being eroded from nearby glaciomarine deposits. Some of the gravels mapped as older raised beach deposits, thick and local, may have been formed as nearshore bay-mouth bars. The asymmetrically shaped older raised beach deposits, thick and local, on Coghlan Island, Mendenhall Peninsula, and at the southern end of Auke Lake may be examples of such bars. Their asymmetry may be due to the direction of strong-energy waves.

Marine deposits

Marine deposits include the modern intertidal deposits (Qts) that extend from below the edge of the water at low tide shoreward to the beach, and the emergent intertidal deposits (Qe) that have been raised by rebound of the land in response to modern isostatic uplift apparently centered around Glacier Bay (Hicks and Shofnos, 1965, p. 3318). Intertidal deposits are formed by tidal currents which transport sediment from the mouths of rivers to the margins and floors of channels and bays. High tides and waves related to storm tides locally erode these unconsolidated deposits and redistribute the material.

Intertidal deposits (Qts)

Intertidal deposits are composed of gray to dark-gray sandy silt, silty gravelly sand, and sandy gravel; shells are scattered throughout the deposits. The coarser parts of the deposits are mostly near the mouths of streams. The deposits are accumulating at the present time.

The intertidal deposits extend along the shores of the fiords and bays of the Juneau area. Broad gently sloping tidal flats are revealed at low or minus tides, and are generally obscured at high tides. The intertidal deposits extend outward under water. The deposits shown on the geologic map are those exposed during normal high tides. The surface on the intertidal deposits slopes toward the center of Gastineau Channel at about 5° near shore, and steepens offshore to about 17° (R. D. Miller, 1967). The broadest expanse of the deposits is near the mouth of the Mendenhall River.

The materials in the intertidal deposits differ from place to place; they are generally nonplastic silt to sandy gravel. At many places the upper 5-20 feet is loose, whereas in many other places the material is compact and dense from the surface downward. Material selected as representing the poorest foundation conditions along the proposed Glacier Expressway shows a void ratio of 1.405 (Franklet and Rasmussen, 1969, p. 15). Such a void ratio indicates that the voids make up more than half of the volume of the deposit; thus, it is a very loose porous material. The same sample had a natural moisture content of 53 percent, a liquid limit of 33 percent, and a natural dry density of 72 pcf. This sample was collected from 2 feet below the ground surface. Samples collected elsewhere contained less water and had a greater density.

Variations in texture and density make this deposit a poor foundation (see overlay 2). Most of the intertidal deposits in downtown Juneau are covered by manmade fill (mf) on which commercial and private buildings have been constructed. The results of tests made by the Alaska State Highway Department of fill emplaced over the intertidal deposits showed a maximum settlement of 3 1/2 feet and an average of 2.9 feet settlement under 26 feet of fill (Franklet and Rasmussen, 1969, p. 9-27).

Intertidal deposits were compacted and fractured elsewhere in Alaska during the 1964 earthquake. Compaction of materials similar to the intertidal deposits caused power poles to tilt or fall (Eckel, 1967, p. B19) and highways to fracture or subside. Long-continued shaking caused centerline fractures in highways where dense roadway material subsided into less dense underlying sediments which then flowed out from beneath the fill (Kachadoorian, 1968, p. C19). Fractures along the edges of the roadway and parallel to the road were also caused by this compaction and flowage. The roadway fill locally subsided differentially and fractures transverse to the roadway displaced the road, caused waves in the roadway, and dropped the filled approaches to bridges. Fill placed over the intertidal deposits at Juneau probably would react in a similar manner. Some places in the Juneau area have fill emplaced with an abrupt edge 10 feet high or more standing above the intertidal surface. Lateral spreading of the fill from overloading and compaction of the intertidal deposits by the fill during construction should be expected.

The location of the intertidal deposits at sea level makes them highly susceptible to inundation by seiches or tsunamis (see p. 58).

Footings of many buildings are founded in the intertidal deposits along Gastineau Channel. Most buildings are on piles, others are on filled ground placed over intertidal deposits. The deposits south of Juneau have slopes that abruptly steepen outward from the shoreline (R. D. Miller, 1967). A dock built on piling between the present A-J dump and the Snowslide Creek delta slid into the channel on Jan. 15, 1930 (Daily Alaskan Empire, Jan. 16, 1930); a submarine landslide was given as the cause. The same article referred to a similar "cave-in" 700 feet farther north 2 years earlier. Such occurrences suggest that the intertidal deposits are highly susceptible to sliding.

Emergent intertidal deposits (Qe)

Emergent intertidal deposits are composed of gray (5YR 6/1) cohesive sandy silts that contain some clay-size particles but little coarse material. Plant roots and occasional shells help typify the deposit as an older intertidal deposit. The color of moist material is very dark gray (5Y 3/1) but appears greenish to the eye. This deposit is generally massive but locally has thin laminations. A "swampy" appearance of the surface of the deposit is characteristic and, when moist, the material generally bends before breaking with subangular or subconchoidal fractures. The age of this deposit is late Holocene.

Emergent intertidal deposits occur near the mouths of major streams. Their surfaces generally slope gently to mean tide level and are commonly covered by grass. These deposits extend to about 30 feet above mean lower low water in the Mendenhall valley, and about 20 feet elsewhere. Small spruce trees dot this emerged surface near the Mendenhall River. Runoff paths form dendritic patterns cut as much as 2 feet into the deposits.

The deposits are probably less than 10 feet thick at most places. They overlie the younger outwash and younger delta deposits in the lower part of Mendenhall valley, as well as the glaciomarine deposits along the western part of the valley north of the Glacier Highway. Test holes at the site of a sand pit near the airport showed a maximum of only 2 feet of tidal material above 47 feet of sand of the younger delta deposits (Munson and Rasmussen, 1966, p. 15).

Silt is the predominant size composing the emergent intertidal deposit; sand and clay-size particles make up most of the remainder of the material in the deposit. Silt averages 61 percent, sand 22 percent, clay-size particles 15 percent, and gravel only 2 percent in samples tested. It is the high silt content that causes the material to bend before breaking. Although the deposit becomes slippery when wet, the two samples tested were too sandy for their plasticity index to be determined.

The emergent intertidal deposits accumulated in the intertidal zone just as modern intertidal deposits are forming today. The emergent intertidal deposits probably are in part estuarine because many streams carry sand and gravel into the fiords. Maps prepared in the early 1900's show the areas now covered by these emergent deposits to have been subjected to daily tidal inundations (Spencer, 1906; Knopf, 1912). Thus, the deposit apparently accumulated between lower low tide and mean high tide prior to 1900. Uplift of the Juneau area relative to sea level has been calculated to be 1.31 cm per year (Hicks and Shofnos, 1965, p. 3318). Accordingly, the intertidal flats should have been elevated about 2.5 feet since 1909, which appears to be about the amount of actual emergence as based on the depth of channels eroded by streams into the intertidal deposits.

The emergent intertidal deposits are thin and cover thicker unconsolidated materials. These underlying deposits, the younger delta deposits (Qdy) at the mouths of streams entering Gastineau Channel, and the younger outwash (Qoy) upstream from the mouth of the Mendenhall River, will control the response of the emergent intertidal deposits to an earthquake.

Glaciomarine deposits

The glaciomarine deposits are the most widespread but geologically the lease understood materials in the Juneau area. The deposits normally are composed of heterogeneous till-like mixtures of clay, silt, sand, and gravel-sized particles and abundant remains of broken and unbroken molluscs, barnacles, and foraminifera; in places, they also contain scattered cobbles and boulders. Because of the general lack of sorting and bedding, and because of the presence of scattered boulders of local and foreign rock types in a matrix of fossiliferous silty sand, these materials have been called marine till in the past. In this report, however, the deposits are called diamictons. A diamicton is a poorly sorted or unsorted sediment that consists of particles larger than sand in a matrix of sand, silt, and clay-sized particles; the term is noncommittal as to how the deposit was formed. It was originally devised (Flint and others, 1960a, 1960b) to provide a descriptive term for deposits of unsorted texture; that is, deposits containing a heterogeneous mixture of particle sizes as described above, which cannot be shown to have been deposited by glaciers.

Diamictons similar to those in the Juneau area occur at altitudes of less than 700 feet along the coasts of southeastern Alaska, British Columbia, and the State of Washington. Armstrong and Brown (1954) and Easterbrook (1963), among others, have discussed the possible origins for these deposits. Armstrong and Brown (1954, p. 357-358) suggest that plowing of the sea floor by glacial ice, deposition of debris from floating ice, and submarine landslides, slope wash, or turbidity currents could account for the combination of coarse gravel, stones, and fossils in a fine-grained matrix. They consider self-ice, berg-ice, and sea-ice as types of floating ice that could transport sand and gravel into marine waters where living shellfish could be buried by materials from melting ice.

The submarine landslide and slope-wash theory requires sliding or washing of previously deposited materials, and would result in intermittent deposition and perhaps even a distinctive layering of deposits. Transport by turbidity currents would satisfy the textural requirements for diamicton, but such deposits probably would be confined to small areas.

Easterbrook (1963, p. 1474) evaluated these processes and concluded that the fossiliferous diamictons in the northern part of the Puget Lowland near Seattle, were formed beneath shelf-ice and berg-ice. Shelf-ice is one of the results of thinning of a broad ice sheet along a seacoast. The ice sheet is assumed to have originally been grounded on the sea floor, but as the ice thinned it lost contact with the floor and became a floating mass, similar to the ice fringing the Antarctic Continent. Berg ice is ice that calves from valley glaciers wherever the ice reaches the sea or other body of water.

Certain limitations apply to the origin of the glaciomarine deposits at Juneau and possibly throughout much of southeastern Alaska. First the similarity of ages for the glaciomarine diamictons, for the older delta deposits perched along the slopes of the fiords, and for the peat in alpine valleys requires that the Gastineau Channel area and the mountain valleys were glacier free at the time of deposition. Second, the presence of vast amounts of coarse material over a broad region requires an effective process by which the sand, gravel, and boulders could be transported and deposited. Third, most of these deposits are massive, dense, and compact. Fourth, a marine or fiord environment is necessary because all of the diamictons contain marine fossils.

The acceptance of an open-water environment along Gastineau Channel and other fiords in this region imposes problems regarding the distribution of large amounts of coarse materials found in the widespread glaciomarine diamictons. One of the most obvious solutions to the problem of transport of such material--large valley-filling glaciers that moved through the fiords of southeastern Alaska--does not fit the known environmental conditions. The numerous older deltas that are preserved to heights of 200-250 feet or more above modern sea level attest that the fiords were free of glaciers when the deltas formed. The ages of the deltas and the diamictons overlap. Nevertheless, some form of ice transport seems necessary to move and distribute the coarse debris throughout so much of the region. This would seem to leave us with shelf-ice or berg-ice for transport and deposition.

During a discussion with D. M. Hopkins in July 1971, in which Hopkins emphasized that a fiord environment does not lend itself to development of classical floating shelf-ice, it was concluded that a seasonal development of sea-ice, or ice that builds outward from the shores each winter and that locally covers small lagoons and coves, could provide similar depositional results. Rather than carrying debris from a large land-bound ice mass, however, the sea-ice would carry the material deposited by streams flowing from the land onto the ice. This debris of all sizes would be accumulated during early spring runoff before the shore-ice breaks up. Eventually the ice would separate from shore, float away, and when it melts or breaks, the debris would drop into the marine waters of the fiords. Thus coarse material would be intermixed with the soft, saturated, finer-grained bottom deposits in the fiord.

Transport by seasonal sea-ice supplemented by contributions from berg-ice might have provided the coarse particles found in the glaciomarine deposits now exposed along Gastineau Channel and elsewhere along the shores of the Juneau area. The utilization of berg-ice requires that certain of the large valley glaciers of the region continued to terminate in the open waters of fiords. These valley glaciers may have been the late Pleistocene or earliest Holocene ancestors of some of the glaciers presently flowing from icefields in parts of southeastern Alaska.

It is not known which valleys entering Lynn Canal contained these ancient glaciers. The large valleys in the Juneau area do not contain lateral moraines, or any other geomorphic evidence that the Mendenhall, Herbert, or Eagle Glaciers could have been sources for such berg-ice. If much of the coarse debris in the diamicton came from berg-ice, the glaciers must have been heavily laden with gravel, and there must have been numerous active glaciers terminating in the sea in order to provide the vast amount of coarse material found in the glaciomarine deposits.

The hypothesis of transport of coarse debris by either sea-ice or berg-ice, or both, is not free of problems. The principal problem with each type of ice is the seasonal and therefore expected cyclic nature of the deposition. Sea-ice seemingly would drop its load during late spring and summer; subsequent deposition would tend to be relatively free of coarse fragments. Berg-ice seemingly would drop its load as localized accumulations of coarse material. Neither situation is reflected in either the texture or distribution of the coarse material throughout the diamicton in the Juneau area. At this time, however, there seems to be no better explanation of the presence of the coarse fragments than by their transport and deposition by sea- and berg-ice.

The glaciomarine diamictons are subdivided into four units on the geologic map. Three of these glaciomarine deposits are recognizable mappable materials. The boundaries between these deposits are somewhat arbitrary because of the lack of continuous exposures. These three units are identified in exposures on the basis of their texture and sequence of deposition relative to the emerging of land in response to isostatic adjustment after the massive late-Pleistocene ice cover had melted. They are designated as glaciomarine deposits, first phase (Qmb); glaciomarine deposits, second phase (Qms); and glaciomarine deposits, third phase (Qme). The fourth unit is undifferentiated glaciomarine deposits (Qmu). All of these deposits apparently accumulated between about 12,000 and 9,800 years ago. Figure 10 provides diagrammatic sketches interpreting the manner of accumulation of the three phases of glaciomarine deposits.

Judging from available field and laboratory data, I currently visualize the accumulation of the different phases of the glaciomarine deposits as being generally sequential, but also in part simultaneous. The first phase of glaciomarine deposition was the accumulation of stony diamicton during the maximum late Pleistocene depression of the land and during the first part of emergence of the land after the ice sheet had retreated

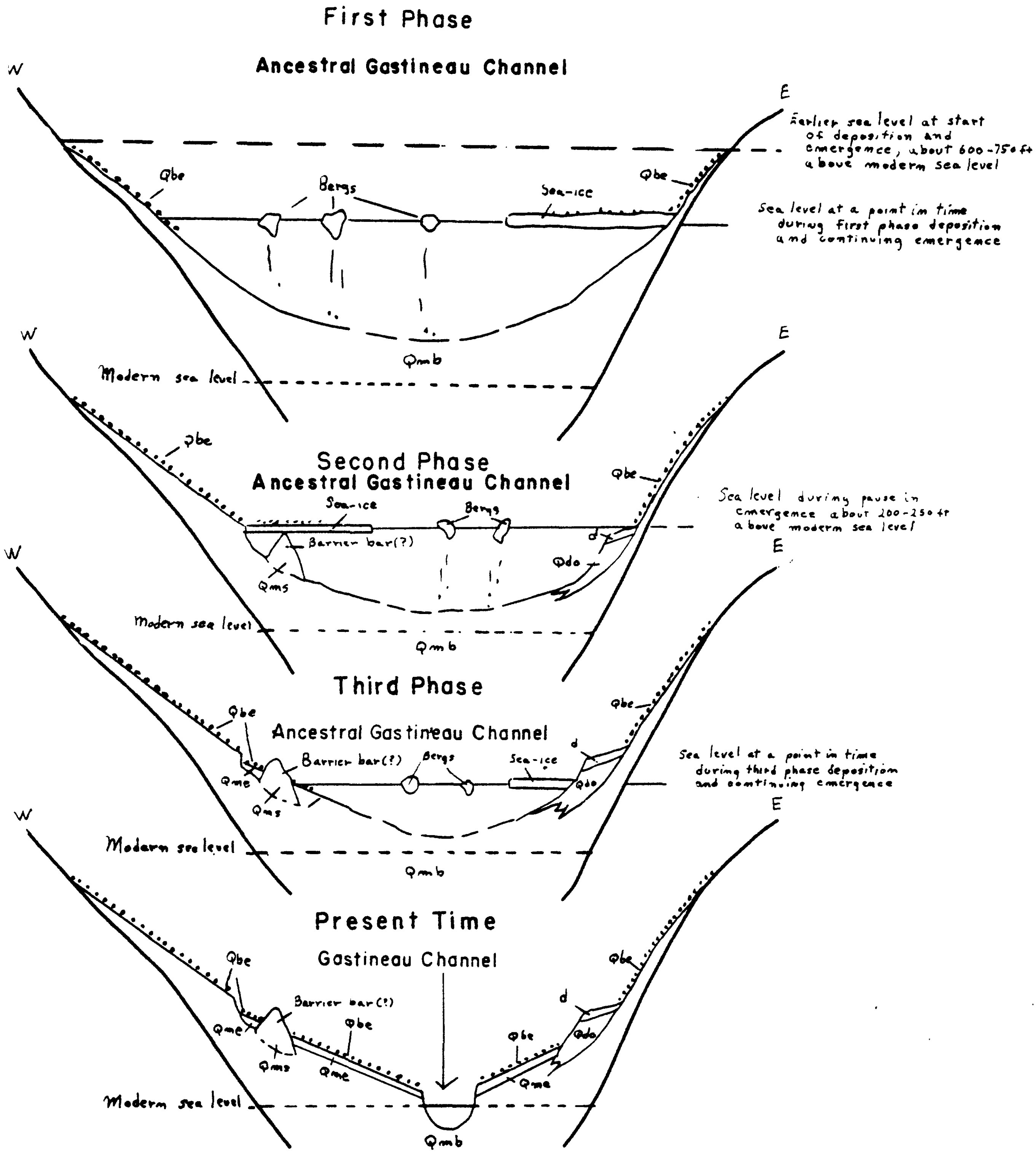

Figure 10.--Diagrammatic sketches showing interpretations of manner of glaciomarine deposition and accumulation of related deposits during the three depositional phases of the glaciomarine deposits in the Juneau, Alaska, area. Qmb, glaciomarine deposits, first phase; Qms, glaciomarine deposits, second phase; Qme, glaciomarine deposits, third phase; Qdo, older raised delta; Qbe, older raised beach deposits (thin and continuous); d, diamicton layer on top of delta deposits.

and marine waters were reoccupying the fiords in the Juneau region. As the land slowly rebounded and the higher parts of the glaciomarine deposits gradually emerged above water, waves reworked the material and deposited a thin blanket of beach gravels (Qbe) on the emerged depositional surface. Slightly more than midway through the total amount of emergence a slowing or halt of unknown duration apparently occurred. The older delta deposits (Qdo), now about 200-250 feet above present sea level, probably were graded to the sea level at that time. Also, during this pause, waves eroded the glaciomarine deposits, first phase, and formed low risers or small escarpments along the shoreline. Although the glaciomarine deposits, second phase, probably were formed during this still stand, their exact mode of origin is not clear. They are believed to represent chiefly local depositional features related to higher energy waves than were the first and third phase glaciomarine deposits, and hence, they are interpreted as having formed as barrier bar deposits. The possibility that these second phase deposits, however, also may have formed in other ways is briefly discussed under glaciomarine deposits, second phase.

While the rise in sea level apparently exceeded land uplift, relatively quiet waters existed along the shores. It was at this time that the diamicton on top of the older deltas described earlier and shown on figure 10 was deposited. The glaciomarine deposits, third phase, accumulated as land uplift accelerated and exceeded the rise of sea level. Eventually the land rose at least 500 feet and locally as much as 750 feet above present sea level. The third phase deposits are generally more fine grained than the first phase deposits, and probably represent a nearshore or tidal zone depositional environment. The third phase deposits are in part reworked from the first phase deposits.

The undifferentiated glaciomarine deposits (Qmu) are deposits that are not exposed but whose surfaces appear to be continuous with the surfaces of either the first or third phase deposits.

Marine fossils occur in deposits of all three phases. Unbroken as well as broken pelecypods and other molluscs, as well as barnacles, have been recovered from the first and third phase deposits. Only broken fragments of such shells have been recovered from the second phase deposits. Interpretations of the environment of the molluscs and of the foraminifera by Warren Addicott (written commun., 1966) and Ruth Todd and Doris Low (written commun., 1967), respectively, indicate shallow water ranging between low tide and a maximum depth of 50 fathoms. Lists of these fossils are shown in table 5.

In 1958, the late Don J. Miller collected molluscan and foraminiferal samples from deposits in the Juneau area. The fossils identified from these samples are listed in tables 6 and 7. The collection sites are shown on the geologic map by the numbers listed in the tables. In her evaluation of the foraminifera in those samples, Ruth Todd (written commun., 1959) considered the assemblages to indicate marine deposition, and at that time believed that the foraminifera "could have lived at depths from 0 to 100 fathoms or even more."

Table 5.--*Fossils collected from massive glaciomarine deposits in the Juneau, Alaska, vicinity by R. D. Miller*

[Numbers in columns indicate phase of glaciomarine deposition as used in this report]

	Localities 3/				
	M2650	M2652	273	487	DH4 4/
Pelecypods 1/:					
Chlamys rubida hindsi (Carpenter)	3	1			
Clinocardium ciliatum (Fabricius)	3	1			
Hiatella arctica forma *pholadis* (Linné)	3				
Hiatella sp. (?)		1			
Macoma calcarea Gmelin	3	1			
Mya truncata Linné	3	1			
Gastropods 1/:					
Buccinum sp.	3				
Cryptonatica clausa (Broderip and Sowerby)	3				
Fusitriton oregonensis (Redfield)		1			
Neptunea lyrata (Gmelin)		1			
Vermetid		1			
Barnacles 1/		1			
Foraminifera 2/:					
Cassidulina teretis Tappan			1		
Elphidium clavatum Cushman			1	1	1
Elphidium frigidum Cushman				1	
Pyrgo lucernula (Schwager)			1	1	
Virgulina (?)					1

1/ Identifications by W. O. Addicott (written commun., 1966)

2/ Identifications by Ruth Todd and Doris Low (written commun., 1967)

3/ Locality numbers starting with M refer to U.S. Geol. Survey Cenozoic locality numbers on file with the U.S. Geol. Survey. Other numbers are U.S. Geol. Survey station numbers as referred to in the field notebooks of this study.

4/ Sample collected from Drill Hole 4, at 12.7 feet below the surface. Drill Hole 4 is shown on the cross sections in figure 9.

Table 6.--*Molluscan fossils collected from glaciomarine deposits in 1958 in the Juneau, Alaska, vicinity, by Don J. Miller*

[Numbers in columns indicate phase of glaciomarine deposition as used in this report.

	Localities							
	M210	M211	M212	M214	M216	M217	M242	M243
Pelecypods:								
Astarte alaskensis Dall				3				3
Axinopsida serricata (Carpenter)								3
Cardid			2					
Chlamys rubida (Hinds)			2					
Chlamys rubida hindsi (Carpenter)				3	1	3		
?*Clinocardium ciliatum* (Fabricius)	1							
Clinocardium ciliatum (Fabricius)		1		3		3		
Clinocardium nuttalli (Conrad)								3
Cyclocardia ventricosa (Gould)			2	3				3
Hiatella arctica (Linné)		1		3	1	3		3
Macoma cf. *M. calcarea* Gemlin		1						
Macoma calcarea Gmelin			2	3				3
Macoma inquinata (Deshayes)								3
Macoma incongrua (Martens)				3	1	3		3
Macoma brota Dall								3
Macoma brota lipara Dall								3
Mya truncata Linné		1		3	1	3		
Nuculana fossa (Baird)	1	1	2					3
Nuculana sp.							1	
Nucula cf. *N. tenuis* (Montagu)			2					
Panomya ampla Dall				3	1	3		3
Polynemamussium alaskense (Dall)			2					3
Polynemamussium davidsoni (Dall)								3
Protothaca cf. *P. staminea* (Conrad)								3
Saxidomus giganteus (Deshayes)								3
Serripes grönlandicus (Bruguiere)		1		3	1			3
Tresus capax (Gould)								3

Table 6.--*Molluscan fossils collected from glaciomarine deposits in 1958 in the Juneau, Alaska, vicinity, by Don J. Miller*--Continued

	M210	M211	M212	M214	M216	M217	M242	M243
Gastropods:								
?Buccinum glaciale Linné	1							
Buccinum glaciale Linné				3	1	3		
Buccinum glaciala Linné--weakly sculptured form					1			
Colus sp.			2					
Colus cf. *C. halli* Dall				3				
Cryptonatica clausa (Broderip and Sowerby)				3	1	3		3
Fusitriton sp.			2	3				
Lepeta concentrica (Middendorff)								3
Littorina sitkana Phillipi								3
Neptunea lirata Gmelin			2	3		3		3
Neptunea sp.	1				1			3
Odostomia sp.								3
?Polinices sp.		1						3
Polinices sp.		1						
Propebela sp.			2		1	3		3
Puncturella major Dall				3				
Trichotropis borealis (Broderip and Sowerby)				3	1	3		
Trophonopsis pacificus (Dall)				3				
Trophonopsis? cf. *T. latus* (Dall)						3		
Turbonilla sp.								3

Table 7.--*Foraminifera collected from glaciomarine deposits in 1958 in the Juneau, Alaska, vicinity by Don J. Miller*

[Numbers in columns indicate phase of glaciomarine deposition as used in this report. Fossils identified by Ruth Todd (written commun., 1959) *Tentative identification]

	58AMr 1B	58AMr 2B	58AMr 7B	58AMr 8B	58AMr 11B	58AMr 88A	58AMr 277	58AMr 276B	58AMr 11C	58AMr 280B
BENTHONIC										
ASTRORHIZIDAE										
genus?										3
MILIOLIDAE										
Quinqueloculina agglutinata Cushman									1*	
Q. akneriana d'Orbigny		1	2		1				1	
Q. frigida Parker		1	2							
Q. stalkeri Loeblich and Tappan		1	2	3	1			1		3
T. tricarinata d'Orbigny					1					
Pyrgo lucernula (Schwager)			2		1					3
LAGENIDAE										
Lagena gracillima (Seguenza)							1			
BULIMINIDAE										
Buliminella elegantissima (d'Orbigny)										3
Globobulimina auriculata (Bailey)										3
Virgulina fusiformis (Williamson)		1	2	3			1	1	1	3
Bolivina decussata Brady										3
B. pacifica Cushman and McCulloch				3					1	3
Fissurina sp. (globular, slit aperture)	1									
ROTALIIDAE										
Buccella frigida (Cushman)	1	1	2	3	1		1	1	1	3
ELPHIDIIDAE										
Elphidium bartletti Cushman			2		1		1	1		3
Elphidium clavatum Cushman	1	1	2	3	1	1	1	1	1	3
Elphidium frigidum Cushman	1	1	2	3	1				1	
Elphidiella nitida Cushman										3

Table 7.--*Foraminifera collected from glaciomarine deposits in 1958 in the Juneau, Alaska, vicinity by Don J. Miller*--Continued

	58AMr 1B	58AMr 2B	58AMr 7B	58AMr 8B	58AMr 11B	58AMr 88A	58AMr 277	58AMr 276B	58AMr 11C	58AMr 280B
ANOMALINIDAE										
Cibicides lobatulus (Walker and Jacob)					1					3
Dyocibicides biserialis Cushman and Valentine									1	3
NONIONIDAE										
Nonion labradoricum (Dawson)		1	2	3			1	1	1	3
Nonionella turgida Williamson, var.								1		
digitata Nørvang										
Pseudononion auricula (Heron-Allen and Earland)	1		2	3					1	3
Astrononion gallowayi Loeblich and Tappan									1	
A. stelligerum (d'Orbigny)				3						
CASSIDULINIDAE										
Cassidulina islandica Nørvang		1	2	3	1		1	1		
C. teretis Tappan	1	1	2	3			1	1	1	3
Epistominella exigua (Brady)									1	
PLANKTONIC										
GLOBIGERINIDAE										
Globigerian bulloides d'Orbigny			2					1		

As a result of a regional study of foraminifera in southeastern Alaska and British Columbia, Roberta K. Smith (1970, p. 692) concluded that water depths were more restrictive, and that the foraminifera faunas she collected were representative of water "probably less than 30 meters deep * * *."

On the basis of the paleontologic evaluations, I interpret the depth of water in the Juneau area to have been relatively shallow at the time of the deposition of all of the glaciomarine diamictons, probably less than the 30 meters suggested above.

Glaciomarine deposits, first phase (Qmb)

The glaciomarine deposits, first phase, consist of gray (N5) to light-gray (5Y 7/1) cohesive compact diamicton. They are heterogeneous mixtures of sand, silt, gravel, and clay (table 4, no. 2) which contain pebbles, cobbles, and boulders, some as large as 10 feet across. They also contain broken and whole shells of marine molluscs, some of which are articulated. Foraminifera abound, as do barnacles, many of which are attached to rocks in the original position of growth. The material when moist is dark gray (N 3/0) or very dark gray (5Y 4/1) and appears dark bluish or black on the outcrops. These deposits form most of the material that local well drillers call "blue clay." Rock types include greenstone, slate, graywacke, metavolcanics, and granite; most of the larger pieces are either granite or dense metavolcanic rock. In the deposits above the confluence of Montana Creek with McGinnis Creek, clay and silt averages 51 percent, and the clay-silt-sand sizes are more evenly distributed than in other deposits in the area (table 4, no. 3). Below the confluence with McGinnis Creek, the deposit along Montana Creek valley coarsens to a gravel in a clay and silt matrix.

Several radiocarbon dates were obtained on shells from the glaciomarine deposits, first phase. One shell sample, from near the base of the deposit at an altitude of about 80 feet near the junction of Fritz Cove Road and the Glacier Highway, is 10,640±300 years old (sample W-1827, Meyer Rubin, written commun., 1966). Another shell sample, taken from an outcrop at an altitude of about 400 feet in the Salmon Creek valley, has an age of 11,920±1,000 years (sample W-2396, Meyer Rubin, written commun., 1970).

This diamicton crops out along the sides of Gastineau Channel, along Fritz Cove, Auke Bay, Lena Cove, and the Tee Harbor area, and underlies much of downtown Juneau. In addition, it extends along Montana Creek upvalley from Tolch Rock, as well as up the Fish Creek valley. Fossiliferous clay, assumed to be part of the first phase deposits, is found 110 feet below the ground surface in Last Chance Basin at an altitude of 280 feet (Waller, 1959, test hole no. 4, table 1), and beneath a gravel in the lower-middle part of the Lemon Creek valley (Spencer, 1906, p. 119).

The surface of the diamictons adjacent to Gastineau Channel slopes 10°-15° upward toward the mountainsides from sea bluffs or from scarps that separate the first phase diamicton from the overlying younger third phase diamicton that extends downslope. Locally, hills of bedrock project through this surface and interrupt the broad even slope. Most of the scarps between the two diamictons are composed of first phase diamicton, but locally the scarps may be bedrock or bedrock mantled by the diamicton.

In most places this diamicton is mapped generally to a height of about 500 feet above sea level as determined from very poor and sporadic exposures and inferred from pronounced changes in topography. However, material that contains shell fragments and that is thought to be a part of this first phase diamicton extends up to an altitude of 750 feet in the SW1/4SW1/4 sec. 27, T. 39 S., R. 65 E., in a bluff along upper Montana Creek. This is the highest fossiliferous glaciomarine deposit recognized in the Juneau area. Elsewhere on the mainland and at some places on Douglas Island, first phase diamicton may be as high as 600 feet above sea level.

The diamicton in the first phase is more massive than that in the third phase, and layers and lenses of fine sand are rare. Sand in the first phase deposits also is slightly coarser than that in the third phase diamicton, and gravel is more common (table 4, no. 2). Cores from test holes drilled into the first phase diamicton revealed an extremely dense and tight material. Core recovery was almost 100 percent in this material, but no size gradation or depositional breaks were seen. Foraminifera were found in all of the holes at all depths. Although sand is the principal particle size (table 4, no. 2), combined clay and silt averages 38 percent, and the material tends to become slippery when wet, even though the plasticity index is generally 8 or less. Liquid limits are as high as 22 percent, but in 13 samples the average is 19 percent. The physical properties of the unit are not uniform and show both lateral and vertical variations. For example, samples tested show extremes of clay size from 7 to 21 percent, silt size 11 to 33 percent, sand size 20 to 65 percent, and gravel size 5 to 38 percent. The Proctor dry density determined for one outcrop sample was 127.5 pcf, with an optimum moisture of 10 percent; the sample became mushy at 16-percent moisture content. The optimum moisture is near the average natural moisture content of 12.5 percent, as determined from 12 other samples. Samples collected from slumping and flowing diamicton contained about 25 percent moisture. Dry bulk densities of 15 samples collected from outcrops along the shore of the Gastineau Channel average 129.1 pcf but range from 112.1 to 143.2 pcf. A sample from along Montana Creek, below its confluence with McGinnis Creek, had a dry bulk density of 127.2 pcf. Samples of cores from test holes indicate a higher density and a lower moisture content than from outcrop samples. Cores from drill hole 3, which was located behind the elementary school at the northern edge of Douglas, had a maximum density of 149.6 pcf at 11 feet below the surface, but had an average dry bulk density of 136.9 pcf. The lowest bulk density was found in the core sample at 22 feet below the surface. The average natural moisture content was 7.4 percent. Numerous samples of cores from drill hole 4, by the Methodist Church in Juneau, had an average dry bulk density of 146.1 pcf and an average moisture content of 5.8 percent; a sample from about 24.5 feet had less than 1 percent natural moisture, while samples near the bottom of the hole, between 61 and 61.5 feet, had natural moisture contents of only about 2-4 percent. Two samples of core material obtained from this test hole between 19-22 feet, and at 54 feet below the surface, in confined compression tests showed angles of internal friction of 55° and 63° respectively. The sample cores from drill hole 5, behind the State Capitol Building, showed an average dry bulk density of 146.1 pcf and an average moisture content of 7.3 percent.

The reason for the increased denseness of the materials in the lower part of the test holes is not known. It could be the result of tidal sifting during deposition, which caused very fine material to displace water and fill most voids; it might be repeated vibration, possibly from earthquakes; it might be the result of normal consolidation from the weight of overlying material, dessication of diamicton, or it might be that this denser diamicton is an older glaciomarine deposit that was overridden by a Pleistocene ice sheet and thereby overconsolidated.

The compactness, cohesiveness, stony character, and density of the diamicton, along with the abundance of large boulders, makes excavation difficult even by heavy power equipment. In some places the toughness of the material and the tendency for the material to break into large cohesive masses makes excavation extremely difficult. Drilling is slow because of the large number of cobbles and boulders.

Concentrated flows of water, such as from broken flumes or diversion of stream channels, cut into and deeply erode the diamicton. Very steep sided gullies, 5-20 feet deep, have been formed by this kind of concentrated flow. Just such a gully has been cut along Gold Creek near Evergreen Bowl where water from a flume has eroded through the older delta deposits, and the gully is entrenched into the glaciomarine deposits, first phase. Sheet wash, however, erodes the deposits only slightly, even on steep slopes.

Seismic response of the undisturbed glaciomarine deposits, first phase, to a severe earthquake probably will be essentially like that of nearby bedrock, chiefly because of the natural dryness and high bulk densities of the deposits. The high angles of internal friction suggest that the material is stable under static conditions and that it would probably remain so if shaken by an earthquake. A sample from a drill hole was determined sonically to have a shear modulus of 89,910 psi, which is nearer that of solid rock than any other unconsolidated surficial deposit in the Juneau area.

Diamicton used for fill, however, might react differently. Disturbance of the material by excavation, dumping, and improper compaction could easily increase the affinity for water of such poorly sorted deposits. Such an affinity could raise the natural moisture content far above the normal range of 5-7 percent so that the liquid limit would be approached or exceeded. In such a state the material very likely would compact, and subside or flow if subjected to strong seismic shaking, as did poorly sorted and poorly compacted material elsewhere during the 1964 Alaska earthquake (Kachadoorian, 1968, p. C43).

Dry diamicton of the glaciomarine deposits, first phase, is very stable in natural or cut slopes. Saturated diamicton is very unstable and tends to slump, flow, or move as small slides. The debris slide in Salmon Creek below the flume vividly indicates how the material behaves when saturated. Slides and slumps of the first phase diamicton have locally blocked the Glacier Highway after heavy rains.

Glaciomarine deposits, second phase (Qms)

The glaciomarine deposits, second phase, are very hard compact cohesive diamictons that are gray (5Y 6/1, 2.5Y 6/1) when dry and very dark gray (N 3/0) when moist. Texturally, they are heterogeneous and consist dominantly of gravel, with lesser amounts of sand, silt, and clay that contain boulders as large as 15 inches in diameter (table 4, no. 4). Although fragments of shells are widely scattered through the deposit, no complete shells were found. Weak stratification is evident in some places but the deposits are generally massive. Unmapped thin sandy gravel, which may be a beach deposit, locally overlies the glaciomarine deposits, second phase. A radiocarbon date of 9,800±300 years B.P. (sample W-2392, Meyer Rubin, written commun., 1970) determined from shells in a deposit at the mouth of Cove Creek, in the northern part of Douglas Island, suggests that the time of formation of these deposits may have overlapped that of the third phase deposits.

The second phase deposits are not as widespread as the other glaciomarine deposits. They occur only in several separate areas. Most are found along the shores of Gastineau Channel, Auke Bay, Auke Lake, and Fritz Cove; deposits also occur near Indian Cove and extend between Lemon and Salmon Creeks. The largest deposit accumulated as a series of knobs and ridges at the northern end of Douglas Island, south of Outer Point near Peterson Creek. Between Lemon and Salmon Creeks, second phase deposits form a ridge that is more or less sinuous; a smaller ridge projects away from the main ridge to form Vanderbilt Hill. The deposits at Cove Creek, on northern Douglas Island, and along Montana Creek are of limited areal extent and are more deltaic in form.

Gravel is the principal size of material in the 1 1/2-inch or smaller sizes in the glaciomarine deposits, second phase, although the sand content may be nearly as high (table 4, no. 4). Textural extremes of the samples collected show particle ranges as follows: clay, 0-26 percent; silt, 1-24 percent; sand 16-62 percent; and gravel 17-63 percent. Because the fine-grained particles fill the spaces between the coarse fragments, the deposit is hard and firm. These fines may have been the result of sifting by waves or tidal waters. The outer 1-2 inches of the surface of outcrops is characteristically hardened by dry sandy silt, which resists penetration when struck with a pick. The material is nonplastic because of the relatively low silt and high sand content. The

Proctor dry density of two samples from second phase material is 141.7 pcf and 142.0 pcf. One characteristic in particular sets these second-phase deposits apart from the other materials; this material has an extreme affinity for water and, when wetted, quickly loses cohesion and internal strength. The natural moisture content of two samples from the same outcrop is 2.98 percent and 3.00 percent. Optimum moisture content of other samples from two localities was about 6.5 percent, and these samples became wet and soupy with only 7-8 percent moisture; thus, this material has a very critical moisture point. As a result, artificial or natural overwetting of the material causes loss of internal cohesion, and any unconfined material either flows or turns into a soupy mass. If such a deposit is left undisturbed to drain, the surface of the material first hardens, and with continued drying the remainder of the material slowly regains enough internal cohesion to be almost as firm as undisturbed material.

The mode of origin of the glaciomarine deposits, second phase, is still somewhat enigmatic. Their coarse-grained nature, their apparent proximity to areas of either prior high wave energy or to the vicinity of streams capable of providing large supplies of coarse gravel, their content of scattered broken shells and their characteristic depositional landforms led me to consider these deposits to be old barrier bars (fig. 10). The finer particles probably accumulated by sifting into and filling open spaces between the gravel particles either during intervals of relatively quiet water or because of the fluctuating currents of daily tides. It is also recognized that these second phase deposits could be remnants of an older, late Pleistocene glaciomarine deposit or, perhaps, eroded remnants of till that project through the glaciomarine deposits, first phase. If these are older deposits, apparently they were deposited either from ice into marine water, as evidenced by the broken shells, or they represent eroded remnants of reworked glacial deposits. Absence of recognizable till elsewhere in the Juneau area below at least 500 feet above modern sea level, and the close association of the glaciomarine deposits, second phase, to those deposits of the first and third phases, leads me to discount the till origin of the diamicton in the glaciomarine deposits, second phase.

Second phase deposits where dry probably would react to shaking much like bedrock. Although the glaciomarine deposits, second phase, have been used for road fill and embankments, after prolonged rainfall parts of these fills have become saturated and have flowed laterally. Prolonged strong seismic vibration of poorly compacted wet material probably also would result in similar flowage and compaction and subsidence of the fill material.

Glaciomarine deposits, third phase (Qme)

The third phase of glaciomarine deposits consists of light-gray (5Y 7/1) massive compact to punky diamicton; specifically it is a heterogeneous mixture, in order of abundance, of sand, silt, clay, and gravel (table 4, no. 1). Isolated cobbles and boulders are scattered throughout the deposits locally. Stems and leaves, some of which are carbonized, are conspicuous in some places, as are shell fragments and whole molluscan shells, many of which remain articulated; foraminifera are also common. The color of moist material is very dark gray (5Y 4/1) and appears dark blue or black on the outcrop. This diamicton is also a part of the material that local well drillers call "blue clay." Rock types include locally derived greenstone, slate, graywacke, granite, and some erratic pieces of sandstone and limestone, or marble. Most of the large boulders are either granite or dense metavolcanic rocks. Shells collected from the diamicton in the glaciomarine deposits, third phase, near Auke Lake have a radiocarbon age of 10,630±500 years B.P. (sample W-2263, Meyer Rubin, written commun., 1969). Shells from a diamicton that partly underlies an undated older delta deposit (Qdo) near Kowee Creek, were also dated by radiocarbon methods, and gave an age of 9,700±800 years (sample W-2393, Meyer Rubin, written commun., 1970); this is the youngest radiocarbon date on glaciomarine deposits at Juneau. This young date from a third phase diamicton that is now close to sea level suggests that the rise of sea level occurred at nearly the same rate as the rise of the land.

The glaciomarine deposits, third phase, crop out intermittently along both sides of Gastineau Channel, along Fritz Cove, Auke Bay, Lena Cove, Tee Harbor, and the lower reaches of Montana Creek in Mendenhall valley. These deposits generally veneer preexisting surfaces that slope upward at about 10°-15° from the modern beaches or seabluffs to the mountainsides. The surface of the deposit along lower Montana Creek slopes downstream under a cover of muskeg and forest. Scarps that are generally no more than 10 feet high commonly separate the third phase deposits from the somewhat older, higher, and more extensive glaciomarine deposits, first phase, (Qmb). The third phase deposits reach an altitude of about 200 feet. Thin and continuous other raised beach deposits (Qbe) and muskeg (Qmk) of variable thickness overlie and generally obscure this glaciomarine material almost everywhere except in bluffs or excavations. The third phase deposits are generally 4-12 feet thick.

The third phase diamicton differs from the other diamictons in several ways: thin laminations occur locally, plant remains are common, and the bulk density is lower. The third phase diamictons generally appear massive in outcrop, but some exposures show the materials to consist of laminae and thin layers of very fine sand that parallel the slope of the surface. Although composed principally of fine sand (table 4, no. 1), these deposits show an average clay and silt content of 46 percent; consequently, the material becomes unctuous when wet, even though the plasticity index is less than 8.

The physical properties of the third phase deposits vary somewhat from place to place. Samples tested during this investigation show extremes of clay from 0 to 32 percent, silt 4 to 49 percent, sand 26 to 57 percent, and gravel 0 to 66 percent; generally gravel is rare, however. A Proctor dry density of 118.0 pcf was determined, which for one sample collected about 3 feet below the top of the deposit along the southern shore of Auke Lake, is the lowest dry density of any of the glaciomarine deposits. This sample also had an optimum moisture content of 12.5 percent and became mushy at 18 percent. Surprisingly, both of these percentages are less than the average natural moisture content of this sample, which was 21-24 percent. Dry bulk densities of other samples average 116.8 pcf and show extremes of 108.4 and 123.3 pcf. Ten samples collected 3-4 feet below the top of the glaciomarine deposits, third phase, elsewhere in the Juneau area revealed an average natural moisture content of about 17 percent, with extremes of 6.2 percent and 42 percent. Several samples collected from the surface of wet and flowing material contained 35-55 percent moisture. Thus, some samples can retain moisture in excess of 50 percent even though the liquid limit, the arbitrary limit between the plastic and liquid states of a material, as determined from nine samples is generally considerably less, averaging about 21 percent. These data show this deposit to be extremely sensitive to moisture.

The upper few inches of an undisturbed deposit can become saturated rather easily, but excess moisture apparently does not readily penetrate below these few inches. For example, one sample collected from stable material immediately below the flowing material contained only 19 percent natural moisture. Disturbed material becomes saturated easily, however, and when this happens flowage can result.

The low density and high silt and sand content of this deposit generally permit very easy excavation and drilling as compared to the other glaciomarine deposits; occasional large boulders may be encountered, however. If wet, the deposit becomes very soft and heavy equipment can become bogged down. Drilling equipment generally needs a platform to hold the rig. Wet materials removed from excavations as spoil drain readily and become hard and firm in dry weather but will flow during wet weather.

Natural exposures of diamictons in the glaciomarine deposits, third phase, resist sheetwash, but gullies develop where the materials are exposed to concentrated running water. Most undisturbed deposits are covered by vegetation, which helps reduce erosion. Sheetwash erosion is minor along slopes of artificial cuts. When excavated material is piled or dumped, its high affinity for water causes saturation during periods of wet weather, and flowage can occur.

The foundation stability of these deposits is poor to fair. Observations of buildings under construction show that some structures are built on concrete footings placed directly on the 4-12-foot-thick deposits, other structures are placed on piles or concrete-filled caissons drilled to firmer underlying materials.

Low density of this material, together with a relatively high natural moisture content and low optimum moisture, suggests that this material would be potentially unstable in its natural state if placed under dynamic conditions, and it would be subject to damaging reactions when subjected to prolonged shaking from a severe earthquake in the Juneau area. Sediments that have been excavated and used for fill, if poorly compacted, may subside, fracture, and fail by flowage if subjected to strong seismic shaking (Kachadoorian, 1968, p. C43). The average natural moisture of 17 percent is near the average liquid limit of 21 percent. As interpreted from the Proctor test, the broad optimum moisture curve slopes gently to the mushy point (there is no sharp steep-sided break) so that fracturing and compaction would be more likely than massive sliding. In addition, the general thinness of the deposit helps reduce the risk of massive block slides, such as those that occurred at Anchorage during the Alaska earthquake of 1964.

Field observations of this diamicton reveal that it stands well under static condition in natural exposures and in nearly vertical walls of shallow excavations when dry or moist, but not when wet. Gentle slopes permit greater infiltration and wetting of the deposits, and flowage may result. If infiltration of water can be prevented, the risk of flowage should be reduced. Slumps and small slides are rare in natural material because of its cohesiveness. Slumps along bluffs have occurred where waste materials overloaded the edges of the bluffs. In addition, loose excavated material that was pushed over bluffs has become saturated with water and has flowed and slumped.

Glaciomarine deposits, third phase, on Douglas Island apparently were used to produce bricks during the early days of Juneau. The beach along the northeastern part of Douglas Island contains many fragments of these bricks.

Undifferentiated glaciomarine deposits (Qmu)

Areas in which there are no exposures, but which are thought to be underlain by diamicton of either first or second phase glaciomarine deposits, or both, are shown on the geologic map as undifferentiated glaciomarine deposits. These areas also may locally include surficial deposits of other kinds, as well as bedrock.

Undifferentiated glaciomarine deposits are present on the Mendenhall Peninsula, north of Auke Bay and Auke Lake, and in the Lena Cove area, where they lie upslope from the glaciomarine deposits, third phase (Qme), or between the shore and the mountainside. The deposits generally lie below the 300-foot contour, but in the Waydelich Creek area north of Auke Bay, undifferentiated deposits are mapped to an altitude of about 500 feet.

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