GEOTECHNICAL HAZARDS ASSESSMENT STUDY

June, 1979

Municipality of Anchorage

GEOTECHNICAL HAZARDS ASSESSMENT
MUNICIPALITY OF ANCHORAGE
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SUMMARY

Of the hazards evaluated in this study, those related to earthquakes are by far the greatest threat to life and property in the Municipality of Anchorage. This was amply demonstrated during the great Alaska earthquake in March, 1964. Ground shaking and seismically-induced ground failure have been and probably will continue to be the cause of most of the damage during future earthquakes. Although relative hazard zones have been delineated for those two hazards, more complete subsurface data are needed to assess this hazard throughout the Municipality. The seismic risk from surface faulting and tsunamis is comparatively small. Further tectonic subsidence could cause local property loss as occurred in 1964.

To perform an accurate overall geotechnical risk assessment, the data for the various significant hazards should be of equal quality. There are several gaps in the data bases for evaluating the non-seismic hazards. The known permafrost and icing conditions are limited to relatively small areas and other areas undoubtedly exist. Groundwater conditions have been assessed in detail in some areas but a more complete and accurate picture of the near-surface groundwater levels is needed.

The mass wasting potential is fairly well defined in the lowlands, but mapping of avalanche and landslide areas in the mountains is incomplete.

Wind conditions are not well-quantified outside the Anchorage bowl, and although this is not presently a serious hindrance to planning, a better data base for the outlying areas should be sought. The accuracy of the coastal erosion potential ratings is adequate for a general risk assessment. However, additional study including ground surveys and

aerial photo interpretation would enable refinement of the present hazard zoning.

The geotechnical hazards can all be evaluated in terms of the risk of loss of human life and property and the resulting economic and social disruption. In making land use policies, geotechnical hazard severity should be considered along with economic, social and environmental factors. Factors including cost, voluntary as opposed to involuntary public use, and comparative hazard risks for alternative development proposals should be considered in determining the acceptable level of risk for a particular proposed development. The required level of hazard investigation can be determined by the mapped hazard level, combined with the proposed type of land use.

A geotechnical hazards mitigation program involves evaluating the hazards prior to approval of development proposals. It must also provide for public awareness of the hazard risks, as well as programs of action for use in the event of natural disaster.

I. INTRODUCTION

A. Object of Study

The object of the geotechnical hazards assessment study for the Municipality of Anchorage is to provide an inventory of all geotechnical data significant with respect to geologic hazards, to analyze the data to provide an indication of the degree of hazard and to designate those areas of potential hazards upon a series of maps of the Municipality. The purpose of the study is to determine which areas of the Municipality have natural features, geologic conditions and/or characteristics which are less tolerant of development or are marginal in nature or possess natural hazards which would preclude or restrict their development potential.

For the purpose of this study, natural hazards are defined as those natural features, conditions, events and/or characteristics which may be hazardous or harmful to the extent that they can result in loss of life or property.

The Anchorage Geotechnical Commission has identified the following hazards to be included in the study. They fall within two broad categories, seismic and non-seismic, as follows:

Seismic Hazards

1. Active or potentially active faults
2. Soil liquefaction
3. Landslides
4. Ground shaking
5. Tsunami Runup

Non-Seismic Hazards

1. Non-seismic landslides
2. Avalanche

3. Icing
4. Ground water
5. Permafrost
6. Subsidence
7. Coastal erosion
8. Wind

B. Scope of Work

The scope of work was determined by the Municipality of Anchorage Planning Department and the Anchorage Geotechnical Commission. This scope of work has consisted of the following basic elements.

1. Research of all geotechnical data from both published and unpublished but recognized public sources which have relevance to the Municipality of Anchorage area
2. Interpretation of aerial photographs with respect to avalanche and mass wasting areas
3. Interviews with geologists, engineers, planners and others with local technical expertise or information in order to provide additional unpublished data and commentary on interpretation and approach in the study
4. Analysis of the data including determination of the degree of hazard and designation of areas in which the potential for the hazard is believed to be nil or in which the data are believed to be insufficient to determine presence or absence of the hazard
5. Preparation of a set of hazard maps together with an explanatory text
6. Preparation of geotechnical guidelines for land use control in the Municipality of Anchorage.

7. Preparation of an annotated bibliography for written or map data sources

8. Compiling an appendix to the text, comprised of copies of hazardous lands ordinances from other local governments faced with seismic and non-seismic hazards similar to those in Anchorage.

C. Geotechnical Hazards Maps

Three topographic base maps have been utilized which cover three sections of the Municipality as determined by the Municipality of Anchorage Planning Department. These are the Anchorage Sheet and the Eagle River Sheet both at scales of 1:25,000, and the Turnagain Arm Sheet at a scale of 1:63,300. Military Reservation land west of the Glenn Highway and north of Ship Creek has been excluded from this study. For each of these three map sheet areas, five maps have been prepared which designate the hazards by degree. Two of the maps present the seismic hazards:

1. Tectonic hazards and maximum expectable earthquake intensities
2. Seismically induced ground failure

Three of the maps present non-seismically related hazards:

3. Non-seismically induced mass wasting
4. Flooding, wind and coastal erosion
5. Ground water, icings and permafrost

The hazards have been grouped on the maps in order to facilitate the use of the maps. The grouping has been determined on the basis of a close interrelationship between the geology or physiography and the hazards. As an example, soil liquefaction and seismically-induced landsliding, resulting in ground cracking and differential subsidence, would tend to occur in geologically similar areas. Avalanches and rockfalls, a type of mass wasting or landslide, would also tend to occur in similar or the same areas.

The maps have all been prepared based upon currently available data; no new data were developed by field investigation for the purpose of this study. Consequently, the quality of the data varies and in turn, the quality of the analysis or degree and location of various hazards will vary. As an example, the geologic mapping in the Anchorage area has been far more detailed with respect to the surficial deposits than in the other study areas. Consequently, the user of the maps should thoroughly recognize the limitations of the data, the analysis, and the inherent uncertainties involved in predicting subsurface geological processes based on surface evidence. The limitations are explained further both upon the maps and in the succeeding paragraphs describing the specific hazards.

D. Definition of Terms

This report contains a glossary attached at the rear which defines the technical terminology contained in the report and on the maps. The definitions used are abstracted primarily from the glossary of geological terms published by the American Geological Institute.

E. Acknowledgements

The writers are indebted to the following individuals and organizations for their assistance in providing information and commentary helpful in the study:

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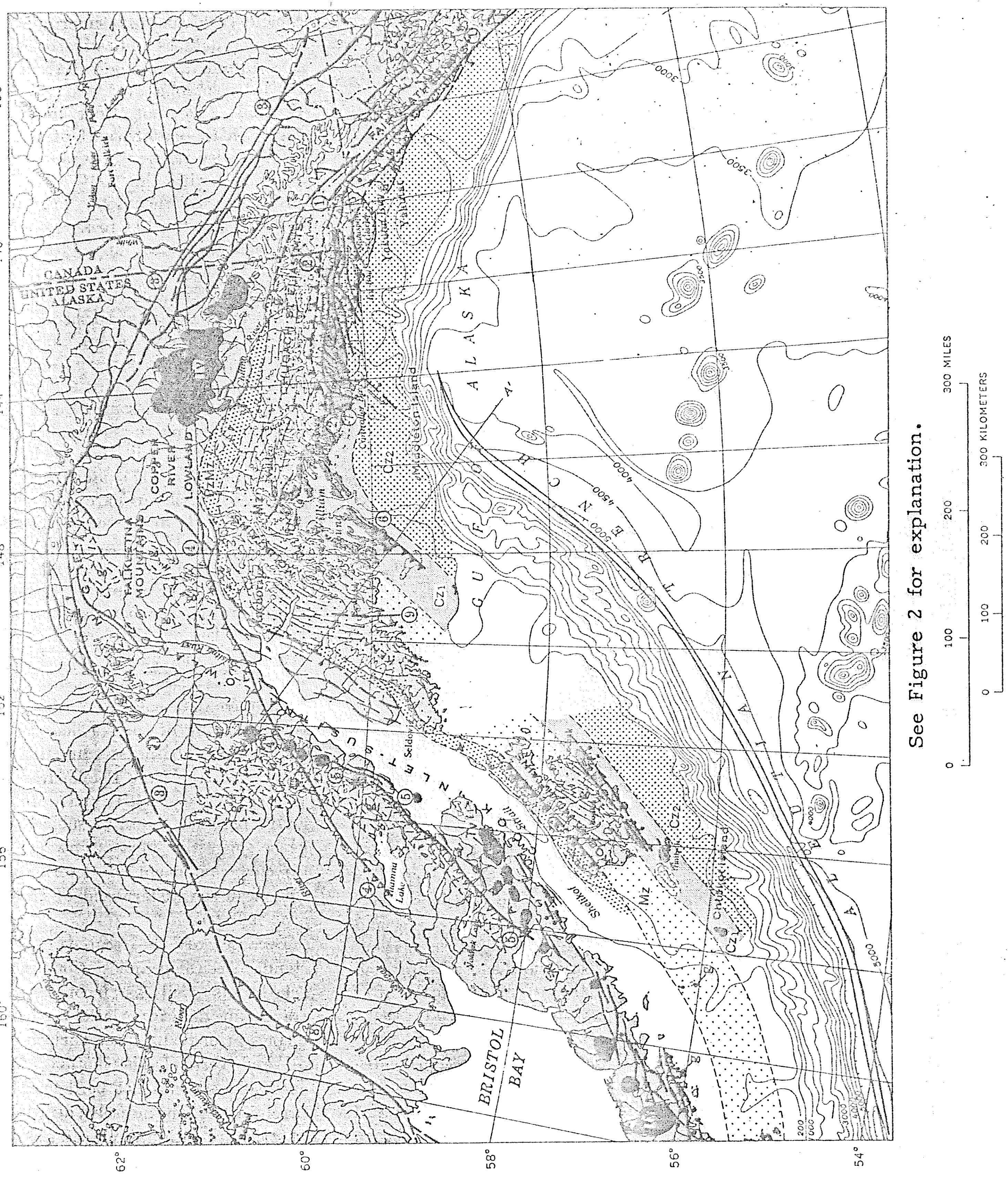
II. GENERAL SETTING

A. Topography

The study area includes the coastal lowlands generally termed the Anchorage basin which is a part of the broader Cook Inlet-Susitna lowlands. These lowlands are bounded on the northwest by the Knik Arm and the southwest by the Turnagain Arm of Cook Inlet. The Chugach Mountains rise to the east with maximum elevations of about 6000 feet above sea level. The major drainages within the Chugach Mountains flow generally westward into Cook Inlet. Several major drainages, including Eagle River, Ship Creek and Campbell Creek, enter onto the coastal lowlands and have carved channels into that surface. The lowlands form a near-level to gently undulating surface with elevations generally in the range of 100 feet near the coastline to about 300 feet near the foot of the range. Above that, the slope is moderate up to about 500 to 800 feet and becomes progressively steeper to precipitous farther east within the mountain range. Topographic features within the range are typical of highly glaciated mountains including U-shaped valleys, steep sided cirques and sharp precipitous peaks and ridges. On the west, the lowlands are bounded generally by steep bluffs which reach their maximum elevations of about 150 to 200 feet at Points Woronzof and Campbell, respectively, at the extreme western tip. At the foot of the bluffs are gently sloping marshlands and tidelands which are all generally below 20 feet elevation above mean sea level.

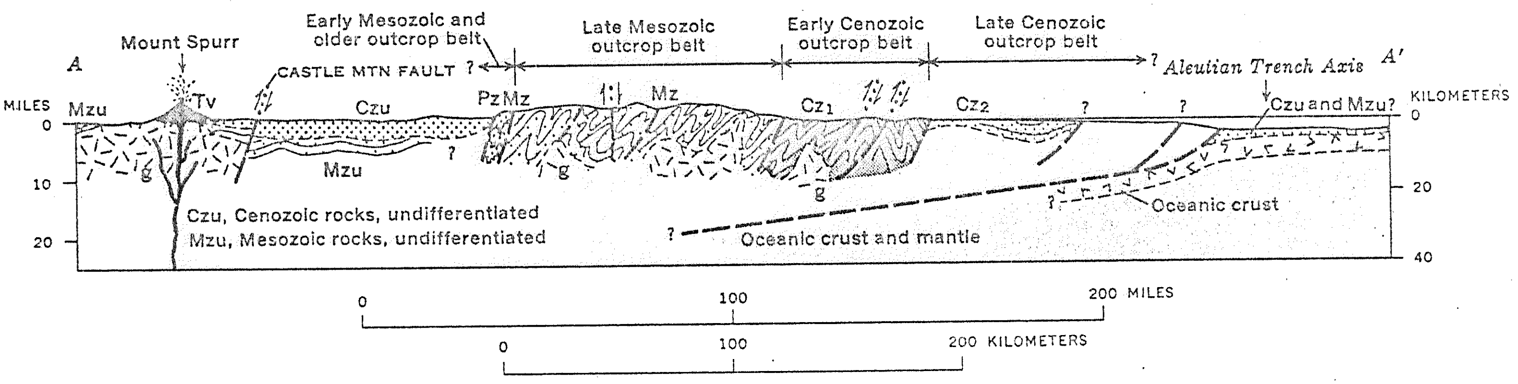
B. Regional Geology

The regional geologic setting in which the study area lies is indicated on the attached Generalized Tectonic Map, Figure 1. The symbols are explained on Figure 2. Anchorage is located northcentrally at about



See Figure 2 for explanation.

Figure 1. Generalized Tectonic Map of Southern Alaska (from Plafker, 1969).



EXPLANATION

Tv
Andesitic extrusive rocks of active or dormant volcanoes

Cz_2
Late Cenozoic bedded rocks
Lighter pattern where projected offshore

Cz_1
Early Cenozoic bedded rocks
Lighter pattern where projected offshore

Mz
Late Mesozoic bedded rocks
Lighter pattern where projected offshore

PzMz
Paleozoic and early Mesozoic bedded rocks
Lighter pattern where projected offshore

g
Granitic plutonic rocks

Undifferentiated rocks

Approximate contact
Includes possible fault contacts, Dashed where inferred or concealed

Thrust or reverse fault
Dashed where inferred. Sawteeth on upper plate. Open teeth indicate major fault

Steeply dipping fault
Dashed where inferred. Arrows indicate relative lateral displacement; bar and ball on relatively downthrown side

Trend lines showing strike of bedding, schistosity, and folds

Major faults and faults with known Holocene movement
Asterisk indicates known Holocene movement; double asterisk indicates historic movement

No	Fault	Data Source
1**	Fairweather	Tocher (1960); Tarr and Martin (1912); Plafker (1967)
2.	Chugach—St Elias (probable Holocene movement)	Miller and others (1959, p. 42); Plafker (1967)
3*	Denali	St. Amand (1957); Hamilton and Myers (1966); Grantz (1966)
4*	Castle Mtn-Lake Clark	Martin and Katz (1912, p. 72-75); Kelly (1963, p. 289); Grantz (1965, sheet 3)
5.	Bruin Bay	Burk (1965, p. 139); R. L. Detterman, (oral commun., 1967)
6**	Patton Bay and Hanning Bay	Plafker (1968)
7*	Ragged Mtn	Miller (1961)
8*	Holitna-Togiak	Hoare (1961, p. 608-610)
9.	Kenai lineament (possible 1964 movement)	This paper

Generalized tectonic map and idealized vertical section showing selected rock units and structural features of south-central Alaska. Indicated displacement direction on faults is the net late Cenozoic movement only. Geology modified from a manuscript tectonic map of Alaska by P. B. King and from unpublished U.S. Geological Survey data; the thickness of crustal layers and the structure shown in the section are largely hypothetical.

Figure 2. Tectonic Map Explanation and Section A-A' (from Plafker, 1969).

61 degrees north latitude and 150 degrees west longitude. As shown, Anchorage lies within the Cook Inlet-Susitna Lowland Basin rimmed on the northwest by the Alaska Range and on the southeast by the Kenai and Chugach Mountains. The geologic basement rocks exposed in the Alaska Range are principally granitic plutonic rocks which have been intruded and overlain locally by andesitic volcanic extrusives from both active and dormant volcanos. In contrast, the Kenai-Chugach Mountain basement rocks are Paleozoic through late Mesozoic bedded sedimentary rocks. (See Table 1 for geologic time divisions). Rock types are principally metamorphosed marine sediments.

As shown by Geologic Section A-A' oriented northwest (see Figure 1) and presented on Plate 2, the bedded rocks within the Kenai-Chugach Mountains have been tightly folded by northwest-southeast compression and intensively faulted by a series of northwest-dipping reverse faults. These rocks are believed to comprise part of the upper plate of an extensive northward-dipping thrust fault system which comes to the surface of the sea floor along the Aleutian Trench. This structural and tectonic setting is typical of the Aleutian Island arc which extends for about 1500 miles to the west and may continue in modified form eastward to the Wrangell Mountains. The arrangement of continental-type rocks including granitic basement and andesitic volcanics on the landward side and intensively deformed marine sediments on the seaward side is believed typical of an actively accreting continental margin in which the oceanic plate is underthrust beneath the continental plate. In this case, the Pacific plate is being underthrust northwestward beneath the North American plate.

To the north, generally separating the marine sedimentary basement from the granitic basement, are the northeast striking Castle Mountain-

MAJOR STRATIGRAPHIC AND TIME DIVISIONS IN USE BY THE U.S. GEOLOGICAL SURVEY

Era or Erathem	System or Period	Series or Epoch	Estimated ages of time boundaries in millions of years
Cenozoic	Quaternary	Holocene Pleistocene	2-3[1]
	Tertiary	Pliocene	12[1]
		Miocene	26[2]
		Oligocene	37-38
		Eocene	53-54
		Paleocene	65
Mesozoic	Cretaceous[4]	Upper (Late) Lower (Early)	136
	Jurassic	Upper (Late) Middle (Middle) Lower (Early)	190-195
	Triassic	Upper (Late) Middle (Middle) Lower (Early)	225
Paleozoic	Permian[4]	Upper (Late) Lower (Early)	280
	Carboniferous Systems Pennsylvanian[4]	Upper (Late) Middle (Middle) Lower (Early)	320?
	Mississippian[4]	Upper (Late) Lower (Early)	345
	Devonian	Upper (Late) Middle (Middle) Lower (Early)	395
	Silurian[4]	Upper (Late) Middle (Middle) Lower (Early)	430-440
	Ordovician[4]	Upper (Late) Middle (Middle) Lower (Early)	500
	Cambrian[4]	Upper (Late) Middle (Middle) Lower (Early)	570
Precambrian	Time subdivisions of the Precambrian: Precambrian Z - base of Cambrian to 800 m.y. Precambrian Y - 800 m.y. to 1,600 m.y. Precambrian X - 1,600 m.y. to 2,500 m.y. Precambrian X - 1,600 m.y. to 2,500 m.y.		3,600+[3]

[1] Holmes, Arthur, 1964, Principles of physical geology: 2d ed., New York, Ronald Press, p. 360-361, for the Pleistocene and Pliocene; and Obradovich, J. D., 1965, Age of marine Pleistocene of California: Am. Assoc. Petroleum Geologists, v. 49, no. 7, p. 1087, for the Pleistocene of southern California.

[2] Geological Society of London, 1964, The Phanerozoic time-scale; a symposium: Geol. Soc. London, Quart. Jour., v. 120, supp., p. 260-262, for the Miocene through the Cambrian.

[3] Stern, T. W., written commun., 1968, for the Precambrian.

[4] Includes provincial series accepted for use in U.S. Geological Survey reports.

Terms designating time are in parantheses. Informal time terms--early, middle, and late--may be used for the eras, for periods where there is no formal subdivision into Early, Middle, and Late, and for epochs. Informal rock terms--lower, middle, and upper--may be used where there is no formal subdivision of an era, system, or series.

From U.S. Geological Survey, Geologic Names Committee, 1972.

Table 1. Geologic Time Scale

Lake Clark (No. 4) and Bruin Bay (No. 5) faults which are part of a broad arcuate fault system including the Fairweather and Denali faults (Nos. 1 and 3) shown on Figure 1. Within this system, the active or geologically young and potentially active faults consist of the Aleutian Trench underthrust, or megathrust, and some of the steeply-dipping faults showing reverse and/or horizontal relative displacement. Typical of the latter are the Denali and Castle Mountain faults as will be discussed in succeeding paragraphs under Seismicity. The Aleutian Trench Megathrust and the Castle Mountain fault represent the greater earthquake potential with respect to the study area.

The unshaded areas on Figure 1 including the Cook Inlet-Susitna Lowland contain younger sediments generally of Tertiary through Recent geologic age as indicated by the Cenozoic bedded rock symbol in Section A-A' on Figure 2. These deposits within the study area include a succession of non-marine coal-bearing sediments, interlayered glacial and lacustrine or shallow marine sediments, and recent alluvium in ascending order. They form a westward thickening wedge beneath the coastal plain and represent the more significant geologic unit with respect to their earthquake response and potential for geologic hazards within the study area.

III. ANCHORAGE AREA GEOLOGY

A. Previous Work

The first comprehensive mapping of the geology with emphasis on the important Cenozoic sedimentary section was conducted by Robert D. Miller and Ernest Dobrovolny of the U.S. Geological Survey and published in their 1959 report entitled Surficial Geology of Anchorage and Vicinity. Immediately following the great Alaska earthquake of March 27, 1964, a number of geologists and geotechnical engineers conducted intensive geological studies in relation to the ground movements and damage occasioned by that earthquake, including the Anchorage area. The results of these studies were published in part as USGS Professional Paper 542, Sections A through G (Hansen, 1965, and Plafker, et al., 1969 apply to the Anchorage area). More recently, the geology and the engineering geology of the Anchorage area have been published by the Geological Survey as Maps I-787-A through E (H. R. Schmoll and E. Dobrovolny, 1972a and b, 1973, 1974a and b, and Freethey, 1976). Similar small-scale maps for the Eagle River and Girdwood areas have been published by the Geological Survey (Zenone, et al., 1974, and Zenone, 1974). Other workers whose mapping and interpretations immediately outside the study area include Karlstrom, who mapped the Quaternary geology of the Kenai lowland as Professional Paper 443, 1964. Most recently, detailed mapping of the marine sedimentary basement rock exposed in the Chugach Mountains has been performed by S.H.B. Clark of the Geological Survey as Map MF-350, 1972. As yet unpublished geologic maps in the Eagle River, Eklutna and Girdwood areas by H. R. Schmoll and E. Dobrovolny have been provided by the Geological Survey for this study.

The basic map of the Anchorage area geology by Schmoll and Dobrovolny plus the unpublished map of the Eagle River and Girdwood areas form the basic geologic data for this analysis of geologic hazards. A single copy of these maps (Plates A, B and C) is attached to the original copy of this report to serve as a reference in any future evaluation of the data and the need for further study in selected areas.

B. Stratigraphy

1. Basement

The bedrock constituting the marine sedimentary basement exposed in the Chugach Mountains ranges in age from late Paleozoic through late Mesozoic. As mapped by Clark (1972), they have been divided into three mappable units all with generally similar engineering properties. These consist of undifferentiated Upper Paleozoic through lower Mesozoic metasediments and volcanics together with plutonic igneous rocks exposed in a relatively small area of the range front near Birchwood and Eklutna. More widespread exposures are of the McHugh Complex of late Jurassic or Cretaceous age exposed in the more westerly portion of the range and along the Turnagain Arm. Rock types are principally graywacke and arkose-type sandstones and conglomerate plus siltstone, metachert, argillite and greenstone. All are weakly metamorphosed and moderately competent. They are highly consolidated, moderately hard and stand moderately well in steep slopes. The third unit is the Valdez group of less competent, thinly bedded siltstone and graywacke. These rocks are more highly metamorphosed and have been intensively deformed by tectonic activity. They are exposed in the eastern and southern parts of the Chugach Range including the Girdwood area. The Mesozoic rocks have been intruded by or have been faulted against small bodies of ultrabasic igneous rocks including serpentinite and dunite. In addition, there are localized dike swarms of felsic to intermediate composition. Because of their similar engineering properties, all of the bedrock formations are shown as a single unit on the Geologic Maps.

2. Kenai Formation

The Kenai Formation of Tertiary age constitutes the major unit of the Cenozoic sequence underlying the Anchorage-Eagle River lowlands. It consists of several hundreds of feet of non-marine sediments, principally sandstone, siltstone and claystone containing localized coal seams. Except for a few small exposures near Eagle River, it is covered by several hundreds of feet of Quaternary age sediments.

3. Quaternary Deposits

a. Glacial Deposits

Quaternary deposition in the area (during the last two million years) includes extensive glacial deposits resulting from at least five known glacial advances into the lowlands from the surrounding ranges. Studies of the sediments in the Anchorage lowlands have identified at least two of the glacial advances: the Eklutna and the Knik. Oxidized drift of the Eklutna Glaciation of Illinoian age is overlain by unweathered drift of the Knik Glaciation of early Wisconsinan age (Miller and Dobrovolny, 1959; Karlstrom, 1964; Trainer and Waller, 1965).

The Bootlegger Cove Clay Formation overlies the Knik Glaciation drift. Karlstrom (1964) believed that the Bootlegger Cove Clay was lacustrine or estuarine, but studies of foraminifera from this unit indicate that it is entirely of marine origin (Hansen, 1965). Schmoll, Szabo, Rubin and Dobrovolny (1972) determined that the deposit is about 14,000 years old, based on radiocarbon and uranium series age dating, and is not of the conventional late Wisconsinan age as documented by Karlstrom (1964).

Glacial sedimentation typically results in heterogeneous deposits of mixed clay, silt, sand and gravel ranging from moderately well stratified to unstratified. The more poorly stratified are glacial moraine deposits of clay to boulder sizes in vast sheets or low ridges typically distributed along the range front or valley slopes. As shown on the Geologic Map, Plates A and B, large areas of morainal deposits extend along the southeast side of Knik Arm and are termed the Elmendorf Moraine. Large areas of mixed coarse and fine-grained moraine deposits from the Eklutna and Knik glacial advances extend along the lower Chugach Range front in a series of lateral moraines. They were deposited by glaciers that advanced both southwestward out of the Matanuska and Knik River drainages, and northwestward along Turnagain Arm.

Coarse-grained sandy and gravelly deposits which underlie the Bootlegger Cove Clay occur extensively in the Point Woronzof and Point Campbell areas. These deposits which extend the full height of the bluffs, are believed by Miller and Dobrovolny (1959) to have been deposited in a delta within a lake formed by glacier damming of Cook Inlet. Alternatively, Karlstrom (1964) believes they are glacio-fluvial channel-fill deposits.

b. <u>Bootlegger Cove Clay</u>

The deposits termed the Bootlegger Cove Clay underlie the lowland area at shallow depth in a north-south zone several miles wide. The zone includes most of the downtown and Turnagain Heights area of Anchorage, the westernmost portion of Elmendorf Air Force Base near the Knik Arm and southward through the Sand Lake and Campbell Lake area near Turnagain Arm. The Bootlegger Cove Clay formation ranges in thickness from zero up to about 300 feet and averages about 100 to 150 feet. The light grey to dark greenish grey deposit varies from clayey silt to lean clay with some occasional layers of fat clay. The clay is laminated to massive, often layered with clean sands and silts. It ranges in consistency from very soft to hard. Upon reworking, it ranges from extra sensitive to normal consistency. In some areas, discrete ice-rafted rock particles are found. Rarely it contains large ice-rafted boulders. The deposit ranges from normally loaded to preconsolidated depending on erosional and other factors.

c. Surficial Deposits

Surficial deposits of non-glacial origin but largely derived from reworked glacial sediments include alluvial fans, wind-deposited silt and sand, sandy and gravelly stream deposits, peat and muskeg plus estuarine silts and clays in the tidal flats along the Knik and Turnagain Arms. Also indicated on the Geologic Map are deposits from mass wasting including talus and colluvium along the steep valley sides in the Chugach Mountain drainages and landslides and colluvium along the coastal bluffs and major stream drainages in the lowlands. There are important differences as to origin and engineering characteristics among these mass-wasting deposits. Most of the deposits, particularly in the mountain areas, are gradual accumulations from the action of mechanical weathering, snow avalanches and running water. The landslides in the bluffs along the Knik Arm and in the Ship and Chester Creek lower drainages, are the result of large block-glide-type landslides with deep seated failure planes in the Bootlegger Cove Clay. These latter types are all believed the result of strong earthquake shaking such as occurred in the great Alaska earthquake of March 27, 1964.

Extensive slumping also occurred in the high bluffs southeast of Point Campbell during the 1964 earthquake. The slumping involved large dune sand accumulations in the upper area of the bluffs. Deeper seated landsliding also occurred near Potter where the Alaska Railroad descends the bluffs. Well logs in the area indicate a blue clay or silt possibly equivalent to the Bootlegger Cove Clay.

C. Structure

Mapping of the basement rocks in the Chugach Mountains by Clark (1972) indicated two main thrust faults separating the Valdez group, McHugh Complex and unnamed upper Paleozoic rocks. These are named the Eagle River thrust fault and they generally strike northeast and dip steeply northwest. At the range front, Clark has mapped the Knik fault zone which also strikes northwest and is buried beneath the Eklutna and Knik lateral moraine deposits. In the Birchwood area, this fault zone extends back into the range where it separates the Paleozoic rocks from the younger McHugh Complex and Valdez Group. Both the Paleozoic and the Kenai Formation rocks are exposed west of this fault. An abrupt increase in depth to the top of the Kenai Formation as indicated by well penetrations west of the exposures near Eagle River have been interpreted by Capps (1940) to indicate possible post-Kenai activity on this fault. Eardley (1951) indicates possible late Pliocene or Pleistocene movements. There are, however, no surface indications of displacement of the Pleistocene glacial deposits or more recent alluvium. No other faults have been mapped in the study area which could reasonably be interpreted as of tectonic origin.

Southwestward in the Kenai lowland across Turnagain Arm, Foster and Karlstrom (1971) mapped extensive areas of ground breakage and other apparent effects of the 1964 earthquake. In summary, the conclusion was reached that this ground breakage occurred in areas underlain by thick deposits of unconsolidated sediments. The principal concentration of breakage was in a northeast trending zone in the northern part of the Kenai lowland. The zone cuts across diverse topography and stratigraphy. It occurs in two principal forms: ". . . 1) fracturing or cracking and the extrusion of sand and gravel with ground water along fractures in various types of landforms; and 2) slumping and lateral extension of unconfined faces, particularly along delta fronts." It is suggested by the authors that ". . . the disruption in this zone may be due to movement along a fault in the underlying Tertiary rocks." There is, however, no published map that indicates a fault within bedrock at this location. Conversely, the dominant northeast topographic trend or lineation represented by the Kenai and Chugach Mountain front suggests at least the possibility of a major northeast striking fault zone bounding the southeast side of the Cook Inlet basin. The age of most recent displacement on this suspected fault zone is unknown.

IV. SEISMICITY

A. Introduction

Seismicity is generally defined as the degree of risk of seismic activity as indicated by the earthquake record and by the geologic record with emphasis on geologically young faulting. Seismic risk typically involves ground shaking, the secondary effects of ground shaking such as landsliding and surface rupturing from active faulting. Subsidence or uplift and tsunami flooding are also typical in some areas including southern Alaska.

Because of the relatively brief span of historical earthquake records in comparison to geologic time and the uncertainties involved in associating older poorly located earthquake epicenters with mapped faults, heavy reliance is sometimes placed upon the geologic and tectonic setting rather than the historical record in order to provide a more complete indication of the expectable future earthquake activity. This is particularly true in areas for which seismograph records from early historical earthquakes do not provide accurate epicenter locations because most recording stations were remote from the earthquake epicenter. Algermissen (1972) states: ". . . only two seismograph stations - College and Sitka - were operated in the state on a routine basis before that (1964 earthquake) time. . . . the small number of seismograph stations before 1964 precluded any detailed study of local seismicity and its relation to the geologic study in the area."

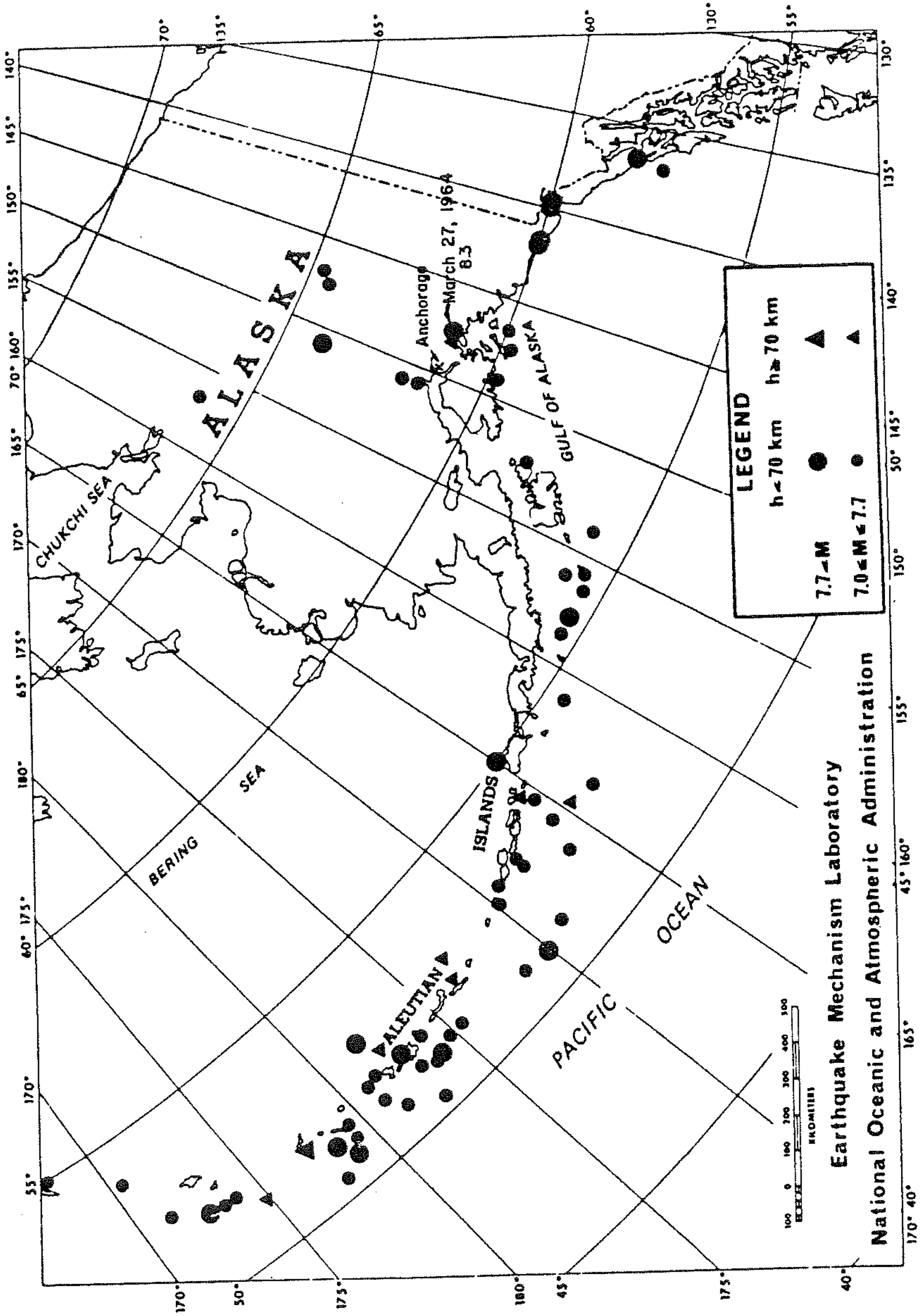
Several large potentially damaging earthquakes have been centered in the general vicinity of Anchorage during historical time. The magnitudes all exceeded seven on the open-ended Richter Scale. Their locations are indicated by symbols on the attached Earthquake Epicenter

Map, Figure 3. Except for the 1964 earthquake centered just north of Prince William Sound and which was caused by a large and extensive displacement of the megathrust, the causative faults for the other events are unknown. As shown on Figures 1 and 2, the extensive Castle Mountain fault system approaches to within about 20 miles of the study area. Although surface mapping along the fault trace indicates Quaternary or Holocene activity, there is no documented record to confirm whether any of the large historical earthquakes in the area were due to displacements on the Castle Mountain fault.

Studies are currently underway by the U.S. Geological Survey (K. Fogleman, et al.), the State of Alaska Division of Geological and Geophysical Surveys (R.G. Updike) and the University of Utah (Ronald Bruhn) to provide a better understanding of tectonic activity in the region and perhaps allow more confidence in locating the older events with respect to the geologically young faults. However, results of these studies that would significantly improve our understanding will not become available for a year or more. Consequently, for the purpose of this present study, some probability judgments based on incomplete information are necessary.

B. Regional Seismicity

Southern Alaska, including the Aleutian Island chain, lies within the Circum-Pacific belt of seismic and volcanic activity. As described previously under Regional Geologic Setting and as shown on Plate 1, the Aleutian Trench contains the submerged trace of an extensive thrust fault system which dips at a low angle northwestward beneath the Gulf of Alaska and the Cook Inlet area. This megathrust is one of many major faults along which displacements have occurred periodically in



Earthquakes in Alaska with magnitude greater than 7.7 during the period 1899-1970 and with magnitude 7.0 or greater during the period 1918-1965.

Figure 3. Major Historical Alaskan Earthquakes.

response to differential movement between the Pacific and North American Plates. The Pacific Plate is rotating counter-clockwise and in this area, is converging northwestward beneath the North American Plate. Earthquakes occur both by displacements on the megathrust and by horizontal slip on the arcuate belt of steeply dipping faults to the north. This tectonic activity is accompanied by volcanic activity including historical eruptions of Mt. Katmai, Mt. Spurr, Mt. Iliamna, Mt. Trident, Mt. Redoubt, Novarupta, and the volcano forming St. Augustine Island near the mouth of Cook Inlet.

In addition to the earthquake shaking and volcanic activity, short and long-term uplift or subsidence of the land areas and sea floor have occurred and will continue to occur. There are indications that the on-land faults such as the Castle Mountain and Denali faults have experienced surface rupturing during very recent geologic time at least in some segments. Conceivably, during historical time, surface rupturing may have occurred on these faults during strong earthquakes but has gone unobserved and unrecorded due to the remoteness and sparse population.

In the Montague Island area south of Prince William Sound, early explorers observed indications of subsidence including drowned forests along the seashore. These same areas experienced up to 38 feet of vertical uplift during the 1964 earthquake. The subsidence was due to the underthrusting which tended to pull the upper plate of the megathrust downward and toward the northwest. When fault rupture occurred at the time of the 1964 earthquake, the upper plate including Montague Island was thrust upward and southward. The subsidence was a relatively short-term effect whereas the uplift is the longer term effect of the tectonic movements in this area. Conversely, farther to the northwest in the Cook Inlet area, the ground surface subsided up to six feet in response to the thrusting which stretched and thinned the upper plate of the megathrust. Conceivably, this area was undergoing gradual short-term uplift prior to the earthquake, however, there are no data such as survey records to confirm this. Neither are there geological indications of gradual long-term subsidence.

C. Earthquake History

Southern Alaska has experienced numerous small to very large earthquakes during historical time. Figure 3 shows the earthquakes greater than magnitude 7.7 during the period 1899 through 1970 and greater than magnitude 7 during the period 1918 through 1965. As shown, most have occurred along the Aleutian Islands Arc and are related to the megathrust. Others in central and southeastern Alaska have occurred along the northwest to west striking faults in those areas. Further studies involving evaluation and age determinations of earthquake-induced features such as lake sediment deformation (Rymer and Sims, 1976), coastal terraces, and landslides will aid in determining the intensity distribution of past earthquakes.

As explained, the earthquake record is insufficient to provide good confidence in predicting future behavior. However, geologic studies of the 1964 earthquake indicate that strain accumulated on the Megathrust for approximately 1000 years (Plafker, 1969). This is not to say that another 1000 years of strain buildup is needed before another great earthquake can occur in the region. Other areas of the Megathrust to the southwest have not experienced very large displacements and earthquakes in recent time and these areas could experience near-future earthquakes with resulting strong ground motion in the study area.

The area between Icy Bay and Kayak Island in the Yakataga region is believed to be a zone of unrelieved strain accumulation between the rupture zones of the 1958 and 1964 earthquakes. The 7.7 magnitude 1979 St. Elias earthquake occurred on the eastern end of this zone, and one or more earthquakes with magnitude near 8 are likely within the next several decades (Menard, 1979). As part of the USGS Earthquake Hazards Reduction Program, monitoring activities in the area are being intensified.

The Castle Mountain fault could also experience large displacements with resulting strong ground motion similar to the 1964 event in the Anchorage area. Based on fault length, the evidence for Holocene activity and the historical earthquake magnitudes in the area, the Castle Mountain fault may be capable of producing a magnitude 7 to 7.5 earthquake.

The March 27, 1964 Alaska earthquake with a magnitude of 8.5 represents the probable maximum earthquake for the study area. Consequently, the shaking intensities that were experienced in the Anchorage area in that event may represent the maximum expectable in a future event. The Castle Mountain fault might produce similar high intensities in the event of a large displacement and earthquake on that fault. The actual intensities would depend on the location of the epicenter and offset with respect to the study area. For a maximum event on either fault system, shaking intensities in the study area will tend to vary more as a result of ground response characteristics rather than fault distance. Typically, areas underlain by a deep section of unconsolidated sediments tend to experience longer period shaking in contrast to shallow bedrock areas. Structures such as highrise buildings with longer fundamental periods tend to experience stronger shaking due to resonance effects. Areas underlain by shallow bedrock tend to experience shorter period shaking with less potential for damage to tall structures.

V. SEISMIC HAZARDS

A. General

Seismic-related hazards include earthquake shaking, the secondary effects of shaking including various types of ground failure such as cracking and landslides, surface rupture from faulting, tectonic uplift or subsidence and inundation of low lying coastal areas from tsunamis or submarine landslide-generated waves, plus seiches in closed bodies of water. The following paragraphs describe the seismic hazards which are believed significant to the study area based on the earthquake history for the region. Two sets of three maps each present the approximate expectable degree of these hazards. The two map sets are titled: Tectonic Hazards and Maximum Expectable Earthquake Intensities, Plates 1A, B and C, and Seismically Induced Ground Failure, Plates 2A, B and C.

B. Tectonic Hazards and Earthquake Intensity Maps

1. Earthquake Intensity

The intensity of an earthquake is a measure of the degree of shaking and its effects upon both the natural features plus any man-made construction. Consequently, it depends upon a number of variables which are not subject to precise measurement. This is unlike earthquake magnitude which is a measurement of the energy release and is the same for any one occurrence regardless of one's point of measurement or observation.

The intensity of an earthquake depends upon:

1. Magnitude of the earthquake
2. Depth of focus
3. Distance from causative fault

4. Duration of shaking
5. The topography and local soil and groundwater conditions which determine ground failure effect
6. The relationship between the predominant period of the ground vibration and the fundamental period of a structure
7. The adequacy of a building design and construction to resist strong shaking

Various scales have been formulated in response to the need to quantify earthquake intensity. In the United States, the currently used scale is the Modified Mercalli scale of 1931 which is presented on the following page. As shown, there are twelve degrees of intensity from barely perceptible shaking to total damage. Significant widespread damage for well-built structures starts at about intensity VIII.

The Alaska earthquake of 1964 produced intensities in the range of VII through XI in the study area. The higher intensities are, however, based upon the damage caused by secondary ground failure in the areas of unusually adverse soil and groundwater conditions. Many structures of ordinary design in the Anchorage area survived the earthquake with negligible damage.

The U.S. Coast and Geodetic Survey conducted studies of intensity following the 1964 earthquake (W.K. Cloud and Nena H. Scott, 1972) and found a wide range of intensities at the same location in the Anchorage area primarily as a result of the greatly increased proportion of long period effects to short period effects. The Anchorage Basin being underlain by a thick section of unconsolidated sediments, experienced long period shaking in contrast to the shallow bedrock areas in the Chugach Range front. They state that ". . . here there was serious

MODIFIED – MERCALLI INTENSITY SCALE OF 1931

I	**Not felt by people, except under especially favorable circumstances. However, dizziness or nausea may be experienced.** Sometimes birds and animals are uneasy or disturbed. Trees, structures, liquids, bodies of water may sway gently, and doors may swing very slowly.
II	**Felt indoors by a few people, especially on upper floors of multi-story buildings, and by sensitive or nervous persons.** As in Grade I, birds and animals are disturbed, and trees, structures, liquids and bodies of water may sway. Hanging objects swing, especially if they are delicately suspended.
III	**Felt indoors by several people, usually as a rapid vibration that may not be recognized as an earthquake at first. Vibration is similar to that of a light, or lightly loaded trucks, or heavy trucks some distance away. Duration may be estimated in some cases.** Movements may be appreciable on upper levels of tall structures. Standing motor cars may rock slightly.
IV	**Felt indoors by many, outdoors by few. Awakens a few individuals, particularly light sleepers, but frightens no one except those apprehensive from previous experience. Vibration like that due to passing of heavy, or heavily loaded trucks. Sensation like a heavy body striking building, or the falling of heavy objects inside.** Dishes, windows and doors rattle; glassware and crockery clink and clash. Walls and house frames creak, especially if intensity is in the upper range of this grade. Hanging objects often swing. Liquids in open vessels are disturbed slightly. Stationary automobiles rock noticeable.
V	**Felt indoors by practically everyone, outdoors by most people. Direction can often be estimated by those outdoors. Awakens many, or most sleepers. Frightens a few people, with slight excitement; some persons run outdoors.** Buildings tremble throughout. Dishes and glassware break to some extent. Windows crack in some cases, but not generally. Vases and small or unstable objects overturn in many instances, and a few fall. Hanging objects and doors swing generally or considerable. Pictures knock against walls, or swing out of place. Doors and shutters open or close abruptly. Pendulum clocks stop, or run fast or slow. Small objects move, and furnishings may shift to a slight extent. Small amounts of liquids spill from well-filled open containers. Trees and bushes shake slightly.
VI	**Felt by everyone, indoors and outdoors. Awakens all sleepers. Frightens many people; general excitement, and some persons run outdoors.** Persons move unsteadily. Trees and bushes shake slightly to moderately. Liquids are set in strong motion. Small bells in churches and schools ring. Poorly built buildings may be damaged. Plaster falls in small amounts. Other plaster cracks somewhat. Many dishes and glasses, and a few windows, break. Knick-knacks, books and pictures fall. Furniture overturns in many instances. Heavy furnishings move.
VII	**Frightens everyone. General alarm, and everyone runs outdoors.** People find it difficult to stand. Persons driving cars notice shaking. Trees and bushes shake moderately to strongly. Waves form on ponds, lakes and streams. Water is muddied. Gravel or sand stream banks cave in. Large church bells ring. Suspended objects quiver. Damage is negligible in buildings of good design and construction; slight to moderate in well-built ordinary buildings; considerable in poorly built or badly designed buildings adobe houses, old walls (especially where laid up without mortar), spires, etc. Plaster and some stucco fall. Many windows and some furniture break. Loosened brickwork and tiles shake down. Weak chimneys break at the roofline. Cornices fall from towers and high buildings. Bricks and stones are dislodged. Heavy furniture overturns. Concrete irrigation ditches are considerably damaged.
VIII	**General fright, and alarm approaches panic.** Persons driving cars are disturbed. Trees shake strongly, and branches and trunks break off (especially palm trees). Sand and mud erupts in small amounts. Flow or springs and wells is temporarily and sometimes permanently changed. Dry wells renew flow. Temperatures of spring and well waters varies. Damage slight in brick structures built especially to withstand earthquakes; considerable in ordinary substantial buildings, with some partial collapse; heavy in some wooden houses, with some tumbling down. Panel walls break away in frame structures. Decayed pilings break off. Walls fall. Solid stone walls crack and break seriously. Wet grounds and steep slopes crack to some extent. Chimneys, columns, monuments and factory stacks and towers twist and fall. Very heavy furniture moves conspicuously or overturns.
IX	**Panic is general.** Ground cracks conspicuously. Damage is considerable in masonry structures built especially to withstand earthquakes; great in other masonry buildings - - some collapse in large part. Some wood frame houses built especially to withstand earthquakes are thrown out of plumb, others are shifted wholly off foundations. Reservoirs are seriously damaged and underground pipes sometimes break.
X	**Panic is general.** Ground, especially when loose and wet, cracks up to widths of several inches; fissures up to a yard in width run parallel to canal and stream banks. Landsliding is considerable from river banks and steep coasts. Sand and mud shifts horizontally on beaches and flat land. Water level changes in wells. Water is thrown on banks of canals, lakes, rivers, etc. Dams, dikes, embankments are seriously damaged. Well-built wooden structures and bridges are severely damaged, and some collapse. Dangerous cracks develop in excellent brick walls. Most masonry and frame structures, and their foundations, are destroyed. Railroad rails bend slightly. Pipe lines buried in earth tear apart or are crushed endwise. Open cracks and broad wavy folds open in cement pavements and asphalt road surfaces.
XII	**Panic is general.** Disturbances in ground are many and widespread, varying with the ground material. Broad fissures, earth slumps, and land slips develop in soft, wet ground. Water charged with sand and mud is ejected in large amounts. Sea waves of significant magnitude may develop. Damage is severe to wood frame structures, especially near shock centers, great to dams, dikes and embankments, even at long distances. Few if any masonry structures remain standing. Supporting piers or pillars of large, well-built bridges are wrecked. Wooden bridges that "give" are less affected. Railroad rails bend greatly and some thrust endwise. Pipe lines buried in earth are put completely out of service.
XII	**Panic is general.** Damage is total, and practically all works of construction are damaged greatly or destroyed. Disturbances in the ground are great and varied, and numerous shearing cracks develop. Landslides, rock falls, and slumps in river banks are numerous and extensive. Large rock masses are wrenched loose and torn off. Fault slips develop in firm rock, and horizontal and vertical offset displacements are notable. Water channels, both surface and underground, are disturbed and modified greatly. Lakes are dammed, new waterfalls are produced, rivers are deflected, etc. Surface waves are seen on ground surfaces. Lines of sight and level are distorted. Objects are thrown upward into the air.

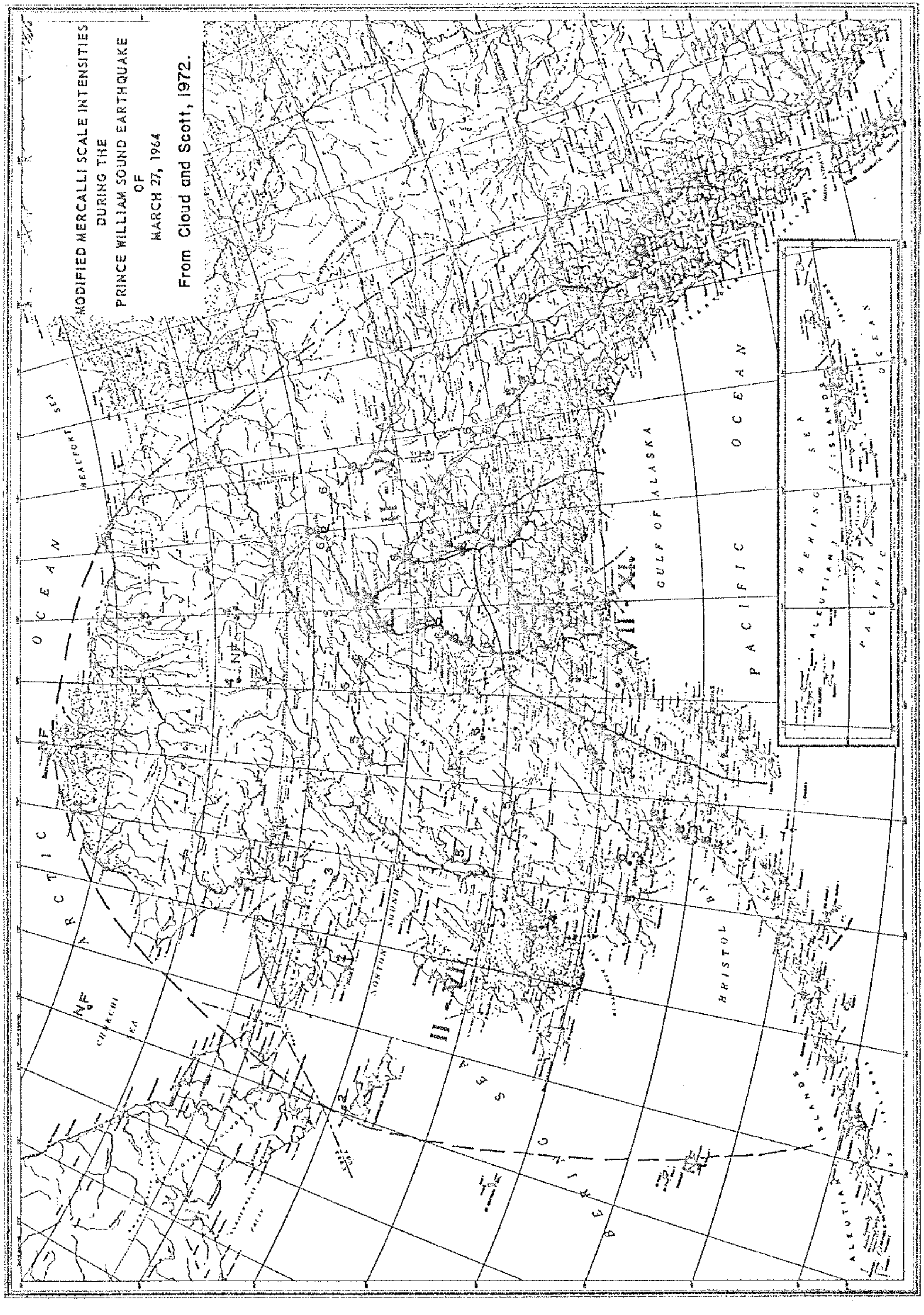
Table 2. Modified Mercalli Intensity Scale

damage to taller buildings and to slide-prone areas, but homes and other small structures, even those adjacent to the taller buildings and slide areas, suffered comparatively little damage. The U.S. Coast and Geodetic Survey's solution to this problem was to assign a range of intensities rather than a single intensity." Their map is reproduced on the attached Figure 4.

In considering the results of the U.S. Coast and Geodetic Survey, for the purpose of this study, we have attempted to roughly delineate the basin area which would tend to be subject to longer period and higher intensity shaking (Plate 1A, B and C). We have further indicated the probable maximum intensity in future earthquakes that would be experienced in either the basin or shallow bedrock areas.

In the basin areas, tall structures with longer fundamental periods would tend to experience higher intensity shaking than low rise structures with shorter periods. The reverse would tend to be true for the upland areas with shorter period ground shaking. However, regardless of structure characteristics, ground shaking intensities would generally be higher in the basin due in most part to amplification effects.

The approach used is inherently imprecise and subject to considerable improvement. The number of variables involved in the prediction of intensity at any particular location is too great to permit any strict appraisal; the map indicates only the smaller probability of damage such as to long period structures in the upland shallow bedrock areas. The possible effects of secondary ground failure on damage potential are not indicated by this map and are presented on Plates 2A, B and C and explained in succeeding paragraphs.



MODIFIED MERCALLI SCALE INTENSITIES
DURING THE
PRINCE WILLIAM SOUND EARTHQUAKE
OF
MARCH 27, 1964

From Cloud and Scott, 1972.

Figure 4. Distribution of Intensities, 1964 Earthquake.

2. Surface Rupture

Tectonic hazards include surface rupture from faulting and tectonically produced subsidence. There are no known active faults which break the surface within the study area. Whereas the Megathrust, which caused the 1964 earthquake, does underlie the study area it is at a depth of approximately 30 miles. The only known possibility for surface faulting would be along the Knik fault zone but as explained, there are no indications for geologically young displacement on this fault.

The usual rationale applied to fault rupture risk involves an approximation of the time of last activity on any faults in the area of interest. Active faults are classified on the basis of indications for historical movements or prehistorical movements during about the past 11,000 years (Holocene geologic time). Faults older than 11,000 years but having experienced displacements one or more times during the last two million years are generally regarded as potentially active. The apparent absence of topographic lineations suggestive of surface displacement of the lateral moraines along the Chugach Range front all of which are much older than 11,000 years, would indicate that the Knik fault zone is not active. Older displacements which have been obscured at the surface by erosion, but which displace the moraine deposits at depth may be present. Intensive subsurface investigation such as by trenching, would be needed to confirm or deny this condition. However, the feasibility of accomplishing this is questionable due to the uncertainty of the actual fault location, the need for investigation at several locations, and the probable presence of numerous fault-like features in the moraine deposits produced by glacial processes. There would have to be a compelling need to locate and evaluate this hazard relative to the Knik fault zone in order to justify the costs involved.

For the purpose of this study, we have indicated the general location of the Knik fault zone as indicated on the smaller scale map by Clark (1972). However, the intent of indicating this zone on the map is to approximately divide the areas of more intensive long period shaking from the lesser intensive short period shaking in shallow bedrock areas; this dividing line would tend to occur near the Knik fault zone. From the standpoint of surface rupture risk, this line should be regarded as tentative until such time as better geologic information becomes available. Except in the case of planning for critical structures such as hospitals or other emergency facilities and highrise or very high use public buildings, the indicated fault zone should have no influence on site development feasibility. In the case where critical structures are planned, further intensive investigations should be conducted relative to the fault rupture risk.

3. Tectonic Subsidence

As explained in a previous paragraph, tectonic subsidence occurred in the study area at the time of the 1964 earthquake. The amounts of subsidence were determined on the basis of tidal level changes, changes in the relative location of microwave relay antennae and so forth. Care was exercised to distinguish between tectonic subsidence of the bedrock as opposed to the numerous and widespread occurrences of differential subsidence due to soil consolidation caused by earthquake shaking and liquefaction. The contours with a two-foot vertical interval indicating two, four and six feet of subsidence increasing southeastward in the study area, are presented on Plates 1A through C. Inasmuch as there has only been one historical occurrence of tectonic subsidence in the study area, it is not possible to evaluate the probability of a reoccurrence or what the short and long-term changes might be. We can only indicate that a reoccurrence of the large magnitude 1964 earthquake would likely produce a similar crustal deformation and a probability of the same order of magnitude of subsidence in the study area. A major displacement on the Castle Mountain fault would be less likely to produce any significant uplift or subsidence in the study area.

C. Seismically Induced Ground Failure Maps

1. Historic Ground Failure

Plates 2A, B and C show the relative potential for seismically induced ground failure such as landsliding, land spreading, surface cracking and liquefaction. Much of the damage to structures in the Anchorage area from the 1964 earthquake was caused by these secondary effects rather than from the actual ground shaking. Significant structural damage resulted from translational (block-glide) type landsliding in which shear failure occurred in the Bootlegger Cove Clay formation which underlies a large portion of the Anchorage lowlands (see Plate 2A). These shear failures are associated with sand layers and sensitive clays within the formation. The major slides are shown on the maps as hazard zone 5 and include the large slides at "L" Street, 4th Avenue, Government Hill and Turnagain Heights.

Land spreading of water-saturated alluvium mobilized horizontally towards topographic depressions was the major cause of surface cracking along river banks and deltas during the 1964 earthquake. Land-spreading damage to highway and railroad systems is documented by Grantz, Plafker and Kachadoorian (1964) and McCulloch and Bonilla (1970).

They concluded that the six principal geologic controls on damage in order of decreasing importance were:

1. The difference in foundation materials.--In areas of exposed till and bedrock, there was no damage, and in areas of young unconsolidated water-laid non-cohesive sediments, all mobilization damage occurred.
2. The total thickness of the sediments.--Other things being equal, damage increased dramatically with sediment thickness.
3. The depth of the ground-water table beneath the surface.--In the most severely damaged areas the water table probably was about 10 feet or less beneath the surface.
4. The distance to a topographically lower area.--The amount of lateral spreading increased toward stream channels, gullies, borrow pits, or adjacent lower terraces.
5. The slope of the ground surface.--Steeper slopes, such as those on deltas and fans have a greater propensity for spreading.
6. The proximity to the area of maximum strain release.--The closer to the source of the seismic energy, the stronger was the ground motion.

Ground cracking occurred throughout the Anchorage lowlands (Hansen, 1965; Engineering Geology Evaluation Group, 1964), particularly in areas underlain by saturated, non-cohesive, unconsolidated deposits with a frozen, brittle upper layer, and in fine-grained surficial deposits such as mud flats and peat bogs. Subsidence and surface cracking was, in general, substantially greater in areas underlain by fine-grained sand and silt as compared with coarse-grained sand and gravel. Few cracks occurred in well-drained, surficial deposits, and few were observed in bedrock areas (Eckel, 1970). Most ground cracking occurred in the areas underlain by the Bootlegger Cove Clay formation.

Seismic vibration caused consolidation of loose, saturated materials in many places. Portage, for example, experienced up to about 2.5 feet of non-tectonic subsidence during the 1964 quake (McCulloch and Bonilla, 1970). Subsidence of up to 0.6 feet was also experienced in the downtown Anchorage and Turnagain Heights areas in close relation to the areas that experienced block-glide slides and surface cracking.

2. Susceptibility Rating

The seismic-related ground failure susceptibility has been rated on Plates 2A, B and C on a one to five scale from low susceptibility to high. The specific criteria for each rating are described in the map legends. These criteria were developed by consideration of observed and expectable seismic response of various combinations of soil, geologic and topographic conditions (based on observations in Anchorage as well as observations and research in areas which have conditions similar to those at Anchorage). In general, the susceptibility is least in areas of exposed bedrock; moderate in areas underlain by dense, coarse-grained, unconsolidated sediments (such as glacial till); and greatest in areas which are underlain by saturated, fine-grained, unconsolidated deposits. Surficial geologic and interpretive maps by Schmoll and Dobrovolny (1972 and unpublished), Schmoll, et al. (1971) and Zenone, et al. (1974) provided the basis for susceptibility rating.

3. Data Gaps and Limitations

The reliability of susceptibility maps such as these is limited by the varying quality of the data, uncertainties in the ground response to seismic shaking at specific locations, seasonal variations in groundwater conditions, etc. Some specific information gaps which exist here include:

a) Maps 2A, B and C are based on generalized maps of surficial geology. There is variation both laterally and with depth in most all of the mapped unconsolidated units, even within the Bootlegger Cove Clay. Therefore, there could be differences in ground shaking response and degree of ground failure within areas mapped as apparently similar geologic units. The need for subsurface data in all of the lowland areas underlain by unconsolidated sediments is the most important data gap. Plans should be developed to acquire existing as well as future subsurface data and incorporate it into hazards maps.

b) The data on response of various alluvial materials are largely limited to those materials in areas which were developed and relatively accessible at the time of the 1964 earthquake. Much of the Chugach Range foothill area currently under heavy development pressure received little or no attention following the 1964 quake due to poor access and the urgent need to evaluate the inhabited areas.

c) Ground failure mechanisms are still not completely understood; for example, there is not complete agreement over the actual mechanism of the slope failures associated with the Bootlegger Cove Clay formation (Seed, 1968, Seed and Wilson, 1966, and Updike, 1978).

Some localized areas may contain conditions which could be susceptible to seismically-induced ground failure but were not included in the generalized maps. These include, but are not limited to:

a) Snow avalanches and rockslides which may be triggered by seismic shaking (refer to Plates 3A, B and C). Many avalanches and rockslides were triggered by the 1964 earthquake (LaChappelle, 1968), and an earthquake during a time of higher avalanche potential could result in avalanches of unprecedented mass and extent. This should be considered in the avalanche risk evaluation for sites in the upland areas (see section VI A). However, the probability of this type of slope failure was not considered great enough to warrant the added complexity that would result from its inclusion.

b) Two adjacent materials which may respond differently to ground shaking. This may result in cracking along the contact or differential settlement between the two materials. Site-specific analyses are required to evaluate the potential for this phenomena.

VI. NON-SEISMIC HAZARDS

A. Mass Wasting

1. Mass Wasting Processes

Mass wasting is a general term for a variety of processes by which masses of earth material are moved by gravity at varying speeds generally in a downslope direction. In Anchorage, the downslope movement of snow (technically an earth material), rock, colluvium and alluvium can create hazards to life and property. The mechanics and hazards associated with snow avalanches and landslides are discussed below.

2. Snow Avalanches

a. General Climatic and Weather Conditions

Most destructive avalanche cycles are caused by periods of heavy and sustained snowfall, especially if accompanied by significant wind drift. Ninety percent of all avalanche activity occurs during or shortly after avalanche path loading.

Factors which govern the density of the snowfall and consequently the instability of the new snow include temperature and wind. In general, snow density increases with air temperature, the highest new snow density being associated with graupel and needle crystals falling at temperatures near freezing. Snow is picked up on the windward side of a hill and is re-deposited on the leeward side. During wind transport, the snow particles are disaggregated and broken so that the re-deposited snow is two to four times denser than newly fallen snow. This dense snow takes on a slab-like cohesive structure, and is highly prone to avalanche failure.

b. Types of Avalanches

There are two distinct processes of avalanche failure. The slab avalanche is caused by brittle fracture of cohesive snow. The point avalanche or loose snow avalanche occurs in relatively cohesionless snow when the critical angle of repose of the snow is exceeded.

Slab avalanches generally start on slopes between 30° and 45°. Shear failure beneath the slab can result from several mechanisms including: snow loading of the slabs, collapse of weak layers, and thaw. In general, slab avalanches are more likely on north-facing slopes during midwinter, and on south-facing slopes during spring and on sunny days. Wind-deposited snow on leeward slopes increases the potential for slab failure.

The critical angle for a point avalanche failure depends on the temperature, wetness and texture of the new snow and to some extent, on the character of the underlying snow pack. Angles of repose for fresh snow can vary from about 30° for slush to about 55° for uncompacted snow. Most point avalanches are small and pose little threat to man-made facilities, however, they are a serious threat to human lives. Point failures may be triggered by an explosive force, a skier's weight, or localized warming of a layer resulting in a large loss in cohesion within the snow.

Dangerously thick layers of snow seldom accumulate on slopes greater than about 50° due to the continual sluffing during the snowfall. Consequently, the snow avalanche hazard is generally low in areas of precipitous slopes.

c. Avalanche Paths

Avalanche paths have a starting zone, a track, and a runout zone. Accumulation and failure of the snow pack occur in the starting zone, which is generally sloped steeper than 30°. The track can be either a channel or an open slope, generally steeper than about 20°. The runout zone is the bottom boundary of known or suspected avalanches. It is usually in a valley floor, but may extend up the other side of the valley. The airblast created by an avalanche may extend up to 100 meters beyond the avalanche path boundary, and should be included in the runout zone.

3. Landslides

Landsliding is the "downward and outward movement of slope-forming material composed of natural rock, soils, artificial fills or combinations of these materials" (Eckel, et al., 1958). Landslides range in volume from minor soil slumps of only a few cubic yards to massive slides involving millions of cubic yards of soil and rock. The main factors that contribute to landslide potential are loose or weakly consolidated rock or soils, steep slopes, and water. Adverse dip angle of bedding planes, fractures or fault zones may also increase landslide potential. Poorly engineered or inappropriate grading and construction often contributes to slope instability. Landslide potential is sometimes increased by septic tank systems and excessive irrigation.

Landslides have been classified according to type of material and type of movement. Table 3 presents D.J. Varnes' classification scheme (Eckel, et al., 1958).

4. Mass Wasting Maps

a. Mass Wasting Potential Rating

Relative slope-stability maps have been prepared by the U.S. Geological Survey for most of the Anchorage sheet (Dobrovolny and Schmoll, 1974) and the northwest portion of the Eagle River sheet (Zenone, et al., 1974). Those maps incorporated both seismically induced and non-seismically induced landslide potential. The 1-5 ratings on their maps were based on slope angle and surficial material and

TYPE OF MOVEMENT		TYPE OF MATERIAL			
		BEDROCK		SOILS	
FALLS		ROCKFALL		SOILFALL	
SLIDES		ROTATIONAL	PLANAR	PLANAR	ROTATIONAL
	FEW UNITS	SLUMP	BLOCK GLIDE	BLOCK GLIDE	BLOCK SLUMP
	MANY UNITS		ROCKSLIDE	DEBRIS SLIDE	FAILURE BY LATERAL SPREADING
FLOWS		ALL UNCONSOLIDATED			
		ROCK FRAGMENTS	SAND UR SILT	MIXED	MOSTLY PLASTIC
	DRY	ROCK FRAGMENT FLOW	SAND RUN LOESS FLOW		
			RAPID EARTHFLOW	DEBRIS AVALANCHE	SLOW EARTHFLOW
	WET		SAND OR SILT FLOW	DEBRIS FLOW	MUDFLOW
COMPLEX		COMBINATIONS OF MATERIALS OR TYPE OF MOVEMENT			

Table 3. Landslide Classification (Eckel, et al., 1958)

provided input for this study. However, the seismically induced ground failure potential is presented separately (on Plates 2A, B and C) since the potential for movement in that case can be unrelated to local slope inclination.

On Plates 3A, B and C, the relative potential for mass wasting in the study area has been rated on a scale of 0 to 3, low to high. Known avalanche paths and landslide areas are included in Zone 3. Zone 2 includes all of the remaining steeply sloping upland areas, as well as lowland areas of low stability such as coastal and stream bluffs. Lowland areas with a small localized potential instability comprise Zone 1. Near-level terrain with no apparent potential is classified as Zone 0. Table 4 shows how the rating scheme applies to combinations of avalanche and landslide potentials. Note that even in areas where the landslide risk is nil, if there is a high avalanche potential, the risk zone is still 3. Conversely, areas having no avalanche potential, but a high landslide potential are also in Zone 3.

	LANDSLIDE AND ROCKFALL POTENTIAL		
SNOW AVALANCHE POTENTIAL	High Potential And Known Slides	Low To Moderate Potential	No Potential
Known Avalanche Path	3	3	3
Low to High Potential (Unassessed)	3	2	-
Very Low To No Potential	3	1	0

Table 4. Mass Wasting Zones

b. Avalanche Potential in Anchorage

The upland areas in the Municipality of Anchorage have a history of high avalanche activity. Of the 33 Alaskan avalanche fatalities recorded since 1952, five were in Chugach State Park from Chugach State Park files. During the past 5 years, 43 people are known to have been caught in avalanches in the Anchorage area. In the spring of 1979, a year of exceptional avalanche activity in the Anchorage area, two homes in the Eagle River area were demolished by avalanches in known avalanche paths.

Records of avalanche frequency vary greatly in quality for each of the hundreds of avalanche chutes in Anchorage. The Department of Transportation maintains careful records of avalanches on the Seward Highway along Turnagain Arm, whereas most avalanche activity in the undeveloped areas in the Chugach Mountains goes unrecorded. Consequently, assignment of comparative severity ratings throughout the study area is subject to considerable uncertainty.

The maps show known avalanche paths including those reported by Chugach State Park and Alaska State Department of Transportation personnel, and other suspected paths which were delineated from vegetation patterns on color infrared and black-and-white aerial photographs. These areas have been assigned a severity rating of 3, the high end of the scale.

Avalanche potential in much of the mountainous areas has not been studied in detail simply because of inaccessibility and low use. Without further study only small areas can be considered to have no potential. Consequently, all of the steep upland areas outside delineated avalanche paths or landslides are designated low to high avalanche potential (Zone 2). Detailed studies should be performed before any specific upland area is designated as having no avalanche potential.

The low lying areas around Anchorage and Eagle River and some areas along Turnagain Arm are essentially free from avalanche threat, so the mass wasting hazard rating there is based on landslide potential.

c. Avalanche Size and Frequency

Most avalanche paths along Turnagain Arm have carried avalanches within the last 30 years and many generate more than one avalanche per year. However, to evaluate the size and frequency of avalanches in any defined path, long-term observations are needed. In the Anchorage area 30 years record is the maximum, and this applies only to transportation routes affected by avalanches. Because of the paucity of data, no attempt has been made in this study to assign a hazard rating based on frequency.

d. Landslide Potential in Anchorage

Rock slides and rockfalls are known to occur every year in the areas designated by overprint on Plate 3C. (Fesler, 1979 and Morrow, 1979). These areas are steep fractured bedrock faces. In making steep cuts into fractured rock, or doing construction at the base of rock faces, the potential for rock slides and rockfalls should be evaluated.

Many snow avalanche paths are also paths for rock avalanches as evidenced by the talus cones formed at the base. Schmoll and Dobrovolny (i.p.) have mapped some of those talus cones. They are not delineated separately on the hazard maps since they coincide closely with the avalanche paths.

Areas of known landsliding (Schmoll and Dobrovolny, 1972 and i.p.) have been shown on Plates 3A, B and C by an overprint symbol. Some locally steep slopes such as coastal bluffs and stream banks are subject to slumping, soil fall and debris sliding. In general, coarse-grained surficial deposits are more stable on these slopes than fine-grained material. In the upland areas, loose surficial deposits on moderate to steep slopes are subject to sliding.

A mudflow is "a flowage of heterogeneous debris lubricated with a large amount of water usually following a former stream course" (Sharpe, 1938). In the Anchorage area, such mudflows occur in steep gullies during spring breakup and heavy summer rains. An area of frequent mudflows (Morrow, 1979) is designated by landslide overprint on Plate 3C. There are undoubtedly other areas of high mudflow hazard in the Municipality, which have not been delineated. It is possible that the mudflow problem could increase as the Anchorage area is developed. Special attention should be paid to preserving natural vegetation on slopes. Denuding slopes tends to increase runoff and erosion, and can result in mudflow-type slides. This is a potential hazard particularly in sloping terrain where there is an upstream source of unconsolidated surface material such as glacial till, colluvium, alluvium or deeply weathered bedrock.

e. Limitations of Mass Wasting Maps

Similar to the seismically induced ground failure hazard, the landslide hazard potential can vary from that indicated by surface mapping. Slope failures can occur due to locally adverse subsurface conditions and due to local topographic features, both natural and man-made. Because the maps are intended for Municipality-wide planning and zoning, many of these local conditions cannot be shown at the small scale, even where they are known. Further investigation and data compilation (particularly subsurface) may indicate modification of the maps are needed in some areas.

Because grading to prepare building, roadway and other sites can have significant influence on slope stability, geotechnical investigation should precede all significant grading of construction sites to assess the existing conditions and the effects of the construction.

B. Coastal Erosion

The rate of coastal erosion depends upon two factors: 1) the intensity of wave action and tidal currents acting on the shoreline, and 2) the erodibility of the materials in the shoreline. Shorelines which are protected from wave attack and those exposing hard, unweathered bedrock are not highly susceptible to erosion. Loose surficial material (for example, alluvium or deeply weathered bedrock), and shorelines which are subject to direct wave attack or strong tidal currents are eroded more quickly.

Erosion susceptibility for the shoreline at high tide in the Anchorage area is rated on a 1 to 3 scale (Plates 4A, B and C). Since no coastal area can be considered to be completely free from coastal erosion, no "0" rating is assigned to any area. Those areas which are not being noticeably eroded are assigned a rating of 1. Coastal exposures of bedrock, and areas where coastal deposition is occurring are included in Zone 1. Some areas which include broad tidal flats rising to above maximum high water are also included in Zone 1, since it is unlikely that these areas would experience significant wave erosion.

It is possible that there are local areas of active erosion in Zone 1. All coastal areas should be studied before they are deemed to be unaffected by erosion.

Coastal stretches in Zone 2 are those which show evidence of erosion, the rate of which is unknown. This includes coastal bluffs, the toes of which are reached by tide or wave action. Zone 3 is limited to Pt. Woronzof where Miller and Dobrovolny (1959) has estimated the retreat at the top of the bluff averages about 2.5 feet per year based on aerial photos and surveys. Under present conditions, this rate is probably the fastest within the Municipality and could be used to estimate setbacks from actively eroding bluff lines. For example, the 50-year bluff would be 125 feet back from the existing bluff line. However, the pre-1964 bluff in the Turnagain Slide area is reported to have been eroding at an average rate of 10 feet per year between 1927 and 1945 (U.S. Army Corps of Engineers, 1966). Rapid shoreline erosion is not occurring there now, but the slide debris in the inlet is probably being eroded. Further study of land survey data and aerial photos as well as monitoring of on-going erosion would aid in establishing present natural erosion rates and further identify problem areas in the municipality.

Changes such as shoreline construction and tectonic subsidence can change coastal erosion and deposition patterns. The effects of such changes should be considered as coastal development proceeds, and in the event of measurable subsidence.

C. Tsunami Hazard and Coastal Flooding

A tsunami is a sea wave generated by a vertical or horizontal motion of the seafloor. Cataclysmic volcanic activity and earthquake triggered subaqueous landslides have also generated large sea waves. The propagation of tsunami waves towards a shoreline depends in part on the depth of the water body and the shoreline configuration.

Because of the narrow mouth of the Cook Inlet, a tsunami generated in the Pacific Ocean would probably not produce significant runup at Anchorage. It is possible but unlikely that an earthquake centered beneath the Cook Inlet would generate a tsunami capable of reaching the upper end of the Inlet, because of the shallow, narrow configuration of the Inlet and the complex tidal regime (Evans, 1972).

The opinion generally held is that the tsunami threat is minimal in the Municipality of Anchorage (Selkregg, 1979). Evans (1972) indicates that a large magnitude local earthquake might damage vessels and coastal facilities in Cook Inlet and pipelines on the bottom of Cook Inlet.

Computer modeling of the propagation and effect of tsunamis in the Cook Inlet have indicated that runup from any conceivable tsunami would be exceeded by the 100-year tidal flood.

The runup of the 100-year runoff/tidal flood has been delineated by the Municipality of Anchorage for Sheets A and B of this study, based on the U.S. Army Corps of Engineers data. The extent of potential flooding from the Inlet is shown on Plates 4A and 4B of this report.

There is a tsunami warning center at Palmer, Alaska, just north of the Municipality of Anchorage. However, because the earthquake which could generate the rare tsunami capable of damaging Anchorage would have to be very close to Anchorage, a tsunami warning could probably not be communicated in time to be fully effective.

D. Wind Hazard

There are two phenomena which can cause high winds in the Anchorage area. The prevailing air flow from the south is frequently channeled by the stream valleys which descend the northwest slope of the Chugach Mountains. This results in southeasterly "Chugach" winds up to 100 miles per hour especially where Chester, Rabbit, Ship and Campbell Creeks exit the Chugach Mountain front (see Plates 4A and B). (Greater Anchorage Area Borough Planning Commission, 1971). Turnagain Arm also provides a large wind channel (Plate 4C) and resulting 50 mile per hour winds are common along the Arm and near Campbell Point. Strong north winds are also experienced in Anchorage as a result of shallow, dense, cold air masses which periodically displace the prevailing warmer southerly flow. These north winds are strongest along the Knik Arm shoreline. Velocities decrease rapidly southward across the Anchorage lowlands. (Diemer, 1979).

The wind record in Anchorage is confined primarily to the measurements at the weather stations at the Anchorage International Airport, Merrill Field and Elmendorf Air Force Base. Anemometers have also been temporarily installed in the Municipality at various locations including Portage and the Anchorage dock. Most evidence for strong winds outside the Anchorage bowl area is subjective being based on observed damages and hearsay (Diemer, 1979).

Maximum recorded or estimated wind velocities and their direction in the Anchorage Municipality are tabulated below.

Table 5. Recorded Maximum Winds

Date	Location	Wind Velocity (mph)	Direction
10/22/45	Merrill Field	70	No Record
10/22/45	Merrill Field	70	SE
11/2-3/67	Anchorage International Airport Outlying Areas?	57 100	SE SE
10/6/69	Elmendorf Air Force Base Portage Site Summit	68 90-100 (est.) 100 (est.)	NE SE SE
1/14-15/71	Anchorage International Airport Merrill Field Anchorage Dock	69 85 115	N N N
5/71	Rabbit Creek	75 (est.)	SE
10/1/74	Anchorage Dock	90	N

From unpublished National Weather Service records (Diemer, 1979).

Plates 4A, B and C show the general strong wind patterns in the Municipality. The Chugach range front affected by the Chugach winds, and the waterfront areas which are subject to the high velocity northerlies are included in Zone 2, the highest designated wind hazard zone. Fifty mile per hour winds, with occasional gusts to 100 mph should be expected in Zone 2.

The central Anchorage lowlands comprise Zone 1. Wind velocities in Zone 1 rarely if ever reach 100 mph, but 70 mph winds have been recorded at Merrill Field (Table 5).

Because of the lack of data, most of the Eagle River and Turnagain Arm areas (Plates 4B and C) have been included in Zone U, an area of unknown hazard. South wind funneling occurs along Eagle River, and northeasterlies come in from the Matanuska Valley, but velocities are not well documented (Wise, 1979). Gusts up to 100 mph from any direction can also be expected in the lowlands. Zone U also includes the Chugach Mountains where very strong funneled winds occur in valleys and passes. Some high areas may experience winds exceeding 100 mph.

E. Groundwater Conditions And Associated Problems

Near-surface unconfined groundwater occurs throughout the Anchorage lowlands in glacial deposits and non-glacial alluvium. Seeps and springs are common in the bluffs along Knik Arm and at many places along the sides of Ship and Chester Creek valleys, generally at the contact between the water bearing alluvium and the underlying clay (Cederstrom, et al., 1964). Groundwater in fractured bedrock in the upland areas also produces springs and seeps.

Several groundwater studies have been done in the Municipality of Anchorage during the last 10 years. As shown on the reference map (Figure 5), the groundwater conditions in the Eagle River, Chugiak, Anchorage bowl, Hillside, Girdwood-Alyeska, and Portage areas have been evaluated by the indicated reports. Most of these studies were done to evaluate the potential for groundwater resource development. The near-surface aquifer conditions which create most drainage and icing problems generally were not evaluated in detail. There is also much water well data available on the Anchorage area (Freethey, 1978), but analyzing the well logs was beyond the scope of this assessment.

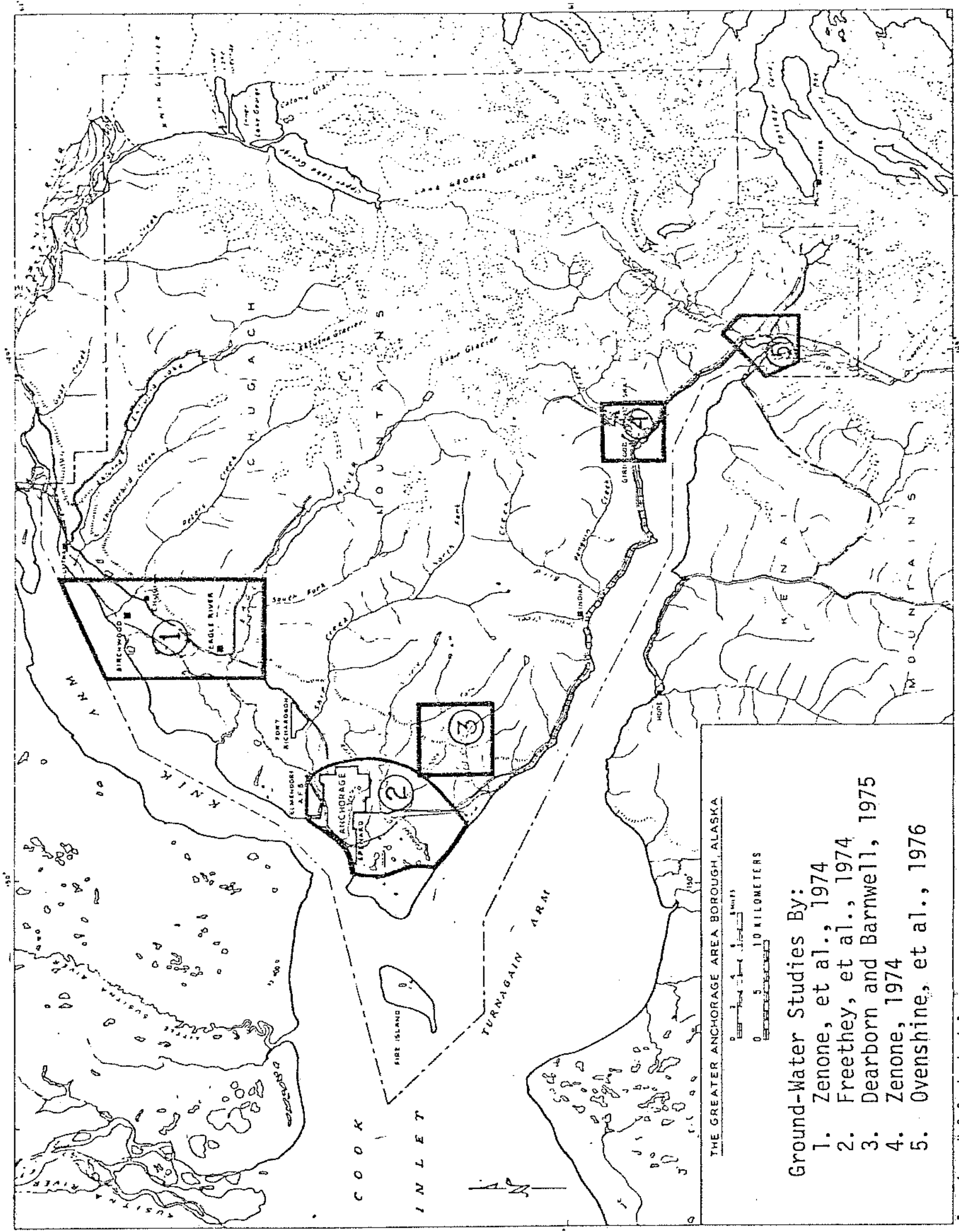


Figure 5. Groundwater Study Areas in the Municipality of Anchorage

Because of the great variation in the permeability of the unconsolidated material, local groundwater conditions are largely unpredictable. An approximately located contour line where the groundwater level is about 20 feet below the surface is shown on Plates 5A, 5B and 5C. The accuracy of this contour, which is based on data from the various published groundwater studies (Dearborn and Barnwell, 1975, Freethey, et al., 1974, Ovenshine, et al., 1976, Zenone, et al., 1974 and Zenone, 1974) is variable. The distribution, density and reliability of the water well data available for the original studies control the accuracy of the water level contour. In general, the water levels are best defined in and around the communities of Anchorage and Eagle River. It must be kept in mind that these maps are not intended for site specific interpretation.

1. Areas of Poor Drainage

Known areas of saturated surficial materials are shown on Maps 5A-C by swamp overprint, and are assigned a severity rating of 3 (the highest potential for near-surface groundwater). The boundaries of these areas are based on maps provided by the Municipality of Anchorage showing wetlands, and USGS topographic quadrangle maps which show swampy areas. Marshy areas in enclosed basins are more difficult to drain and reclaim than those which are contiguous with streams.

The poorly drained peat soils as mapped by the U.S. Soil Conservation Service (Furbush, 1976) generally comprise Zone 3; they occur in Zone 2 in the drainage ways and depressions in the glacial till, and in depressions on nearly level benches and tidal flats.

Zone 1 includes the upland areas underlain by bedrock or glacial deposits, and some lowland areas of Anchorage which have surface elevations greater than 20 feet above the generalized unconfined water table as defined by Freethey, et al. (1974). There are, undoubtedly, some areas included in this zone which have poor drainage.

2. Icing

Formation of surface ice can result from groundwater seepage under several conditions. Springs and seeps from fractures in bedrock cause "aufeisings" which build up at the surface, and can cause structural damage and hazardous road conditions. This type of icing is common along the Seward Highway in the area shown on Map 5C. Seeps and springs in other areas create similar problems. Cuts into slopes in either fractured bedrock or water-bearing alluvium can create an icing problem by intersecting a previously concealed water bearing fracture or aquifer. There are no available records of icings except for the known occurrences on the Seward Highway. A more detailed investigation would be required to provide a numerical rating of the icing potential in the Municipality. Unofficial reports of occurrence in Anchorage indicate that the icing potential must be considered in any hillside development or lowland area having poor drainage.

F. Permafrost

Permafrost occurs throughout much of the Municipality of Anchorage. The definition, occurrence and effects of permanently frozen ground or "permafrost" are presented below.

Permafrost is a stratum of soil which has been continuously frozen for two or more years. In the Anchorage area, it is occasionally encountered to depths of between 15 and 40 feet often with massive ice layers. Permafrost has been encountered at depths greater than 15 feet, commonly overlain by thawed soils. In the Anchorage area, permafrost conditions require a localized microclimate well below the ambient temperature. The conditions which contribute to the necessary microclimate are complex and include: low areas, northern slopes, sparse tree cover, live organic ground cover over peat or fine-grained soils, near-surface static water table, and relict glacial ice. Permafrost cannot be detected from surface features so that subsurface exploration is essential to evaluate permafrost at any specific site.

Permafrost has been found in Anchorage in isolated, discontinuous areas within the zone shown on Map 5A. This area of high incidence of frozen ground has been assigned a severity rating of 3. Deep frozen soils may exist in the lowlands anywhere outside the shaded area on Map 5A, so this area has been assigned a permafrost potential rating of 2. Outside the Anchorage bowl, no assessment of permafrost zones has been made, but areas of permafrost should be expected there. The entire area covered by Plates 5B and C and the upland area on Plate 5A have been classified as Zone U (unknown). Further field investigations and compiling of existing scattered data are needed to define the potential in these areas.

The hazard to structures related to permafrost consists of deep seated subsidence from thawing of permafrost. The severity of the destructive ground movement depends on the amount of ice in the soil. Movements on the order of four feet have been observed in extreme permafrost cases. (Municipality of Anchorage, Geotechnical Commission, unpublished).

VII. GUIDELINES FOR LAND USE PLANNING AND CONTROLS

A. Introduction

The Municipality of Anchorage is situated in a seismically active region. Previous earthquake damage to the Municipality of Anchorage has been well documented and the potential for future damage must be recognized. In addition, within the Study Area are many examples of other geotechnical hazards -- landslides, flooding, permafrost, etc. The geotechnical hazards can all be considered in terms of the risk of direct or indirect loss of human life and property, and the resulting economic and social dislocations.

Geotechnical hazards alone should not determine precisely which land uses will be specified or permitted. Such determination should be based on economic, social and environmental considerations as well. However, the presence, disposition, and severity of geotechnical hazards should play a major part in determining general land use policies. Some uses of land may be inappropriate for the level of acceptable risk in certain hazards areas.

Historical records of earthquakes and other natural hazards in the Anchorage area are brief compared to most other populated areas and the combination of hazards or geologic processes that are active is somewhat unique within the world for a rapidly populating area. The great Alaska earthquake of 1964 was an unusual event in the type and degree of tectonic movement that took place. Hazards mitigation measures learned from experience in other seismically active areas, such as California, do not necessarily apply or provide all of the necessary criteria for hazards assessment and mitigation. Coupled with the other hazards peculiar to the area such as the sensitive glacio-marine clays, permafrost, etc., the combination of hazards present requires special effort to gather and analyze the data, and assess the hazards with appropriate emphasis on each so that a suitable hazards mitigation program is instituted. This study, based only on available data, is but a starting point in that program. Adjustments will become necessary as new data are accumulated and greater experience is gained through application of the program.

Some basic concepts and principals, and suggested planning guidelines based on the San Rafael, California ordinance (see Appendix A), are set forth in the following paragraphs. They have been found applicable in other areas with generally similar seismic risk and are suggested for consideration in the development of geotechnical guidelines most suitable for land use planning and controls in the Municipality of Anchorage.

B. The Concept of Balanced Risk

There are three basic risks to man and the environment from geotechnical hazards: the risk to life, the risk to property and to the natural physical environment, and the risk to social and economic stability.

Public agencies have a clear mandate to protect the public from injury or death, and a definite role in preventing property damage, especially in the case of public buildings where risk should be reduced as much as possible.

There is an inherent degree of uncertainty in using risk as a basis for land use planning. However, land use planning decisions can be made if the hazard risks associated with any proposed development are identified and the risks compared with the risk of alternative development proposals and alternative development locations.

C. Land Use and Site Investigations

The level of geotechnical investigation prior to approval and construction of any development in the various hazard zones, is outlined in Table 5. All the hazard maps must be reviewed in order to determine the highest hazard zone for a particular area. For example, if an area is shown as Zone 1 on the Seismically Induced Ground Failure map and Zone 3 on the Mass Wasting Hazard map, the level of investigation should be for Zone 3.

Preliminary geotechnical evaluation may indicate that the site is stable and a lower level of investigation is required or, conversely, that the area is more unstable than anticipated, and more detailed and specific studies are required. In special situations where the Municipality of Anchorage determines that there is a question as to the necessary degree of investigation, a Geotechnical Review Board should be convened to review the project, establish the required extent of investigation and to advise on the specific hazard level for the property being considered. In making decisions as to the acceptable level of risk and investigation requirements, Municipality of Anchorage officials will want to review the Hazards Zones Maps as well as the risk zone definitions. It should be kept in mind that these maps were prepared from data developed on a Municipality-wide scale and are therefore generalized and not site specific, i.e., there are likely to be exceptions, both better and worse conditions, within each of the risk zones shown on these maps. The property owner or developer should be afforded the opportunity of demonstrating through on-site investigations where these exceptions may lie. In addition, it is recommended that specific consideration be given to the following principles:

1. That the level of acceptable risk be reasonable in terms of the cost of achieving it. The cost may either be direct (potential damage to property or loss of life), or indirect (removing hazardous lands from the tax rolls and placing them in open space). The endeavor to minimize risk may result in higher costs. At some point, it becomes too costly to reduce the risk further and the risk may be considered acceptable.

2. That there be an explicit differentiation between voluntary risk and involuntary risk. Because use of certain public buildings is not voluntary, there is no choice available to the individual whether or not to submit to a given degree of risk. Thus, the level of acceptable risk associated with land or building uses of involuntary public occupancy should be quite low.

3. That there be an explicit differential between unknown risks and known risks. It is the proper function of public agencies to provide information that will make the public fully aware of the risks associated with all known geotechnical hazards. This can be accomplished with the use of hazard maps, public hearings, adoption of high risk development zones, etc.

4. That the acceptable risk level must be commensurate with the benefits accrued. For a given site use, the public should not be exposed to a level of risk which exceeds the corresponding benefits from the selected use.

5. That the balancing of risk not be limited to future planning decisions but also include the evaluation of risks associated with existing land uses and structures.

The Municipality's evaluation of geotechnical hazards and risk levels must be based on the technical judgment of appropriate professionals.

As experience and new knowledge about geologic and seismic events and the response of man-made structures are gained, and as new data in the Study Area become available, the acceptable risk levels and investigation standards may have to be adjusted accordingly.

D. Policies

The following policies underlie and shape the character and orientation of the seismic risk reduction programs.

Policy 1: Evaluate carefully the potential geotechnical hazards before approving public or private development proposals.

Policy 2: Develop procedures for maintaining and disseminating information to the public regarding geotechnical hazards.

Policy 3: Prepare programs of action for use in the event of natural disaster, and attempt to reduce the extent of damage to the public from the recurrence of such disaster.

E. Implementation

The best way to reduce the risk of geotechnical hazards in the long term is to begin regulating new development effectively. Because the Study Area is experiencing strong development pressures, the thrust of a risk reduction program should be toward better land use decision-making. This requires well developed data in terms of geotechnical hazards. However, most existing construction will be little affected by this type of program. In recently developed areas of high risk, the only practical means of lowering the risk may be adequate disaster programs and better evacuation routes. In the older developed areas, redevelopment and structural hazard abatement, where necessary, may be the most practical means of reducing risk.

1. Acceptable Risk

The Municipality should continue to refine the locally acceptable levels of environmental risk (see Table 6). Such levels can guide the Municipality in judging specific applications for land uses within various risk zones, and establish the standards for investigations (within different risk zones) for various land uses or structures. Thus, for example, if overriding public considerations required that a public use structure be built in a Zone 4 seismic risk area, then a very intensive "D" classification investigation would be expected to ensure that the level of risk was reduced as much as possible.

2. Geotechnical Hazards Maps

The Geotechnical Hazards maps should be maintained and updated as new data becomes available. These maps should be on public display at the Municipality for general reference use.

The Public Works Department's responsibility should be the maintenance of copies of all soil reports, and engineering and geologic investigations conducted within the Study Area by or for public and private entities. The geotechnical hazards maps developed as part of the program should be updated as new information becomes available. Property owners and developers should be given the opportunity to demonstrate through on-site investigations whether or not the level of risk described on the geotechnical hazards maps actually exists on individual sites.

LAND USE - BUILDING TYPES / HAZARD ZONES	5	4	3	2	1	O/U
Public, High Occupancy and Critical Use, including: Hospitals Fire and Police Stations Communication Facilities Schools Auditoriums, Theaters Penal Institutions High-rise Hotels, Office & Apartment Buildings (over 3 stories) Major Utility Facilities	E	D	C	C	B	B
Low Occupancy, including: Low-rise commercial & office buildings (1 to 3 stories) Restaurants (except in high-rise category) Residential (over 8 attached units and less than 3 stories)	E	D	C	B	A	A
Residential (less than 8 attached units) and Manufacturing & Storage/ Warehouses (except where highly toxic substances are involved which should be evaluated on an individual basis with mandatory geotechnical review)	E	C	B	B	A	A
Open Space, Parks, Golf Courses, etc.	E	A	A	A	A	A

SUGGESTED SITE INVESTIGATION REQUIREMENTS

A. Current building code requirements must be met, as well as other existing state and local ordinances and regulations. A preliminary geotechnical investigation should be made to determine whether or not the hazards zones indicated by the maps are consistent with the actual site conditions.

B. In addition to the above, sufficient geotechnical investigation and structural analysis to determine structural suitability to the site in terms of proposed use. It may be necessary to extend the investigation beyond the immediate site boundaries in order to evaluate all of the applicable hazards. All critical use structure sites require detailed subsurface investigation.

C. In addition to the above, there must be sufficient surface and/or subsurface investigation and analyses to evaluate liquefaction and related ground failure, mass wasting and/or permafrost potential.

D. In addition to the above, there must be detailed dynamic ground response and stability analyses.

E. In addition to the above, positive stabilization measures must be taken before structures for human occupancy can be considered. In general, public and especially emergency facilities should not be considered. Developments such as golf courses and parks which do not include structures for human occupancy, but where activities such as regrading or irrigation might have adverse effects on stability require careful investigation and analysis to determine whether or not stabilization measures are necessary.

Dangerous or unspecified land uses should be evaluated and assigned categories of investigation on an individual basis.

Table 6. Suggested Site Investigation Requirements In Relation To Land Use

F. Examples of Ordinances

Appendix A consists of hazardous lands ordinances currently used in other localities which are seismically active or have some non-seismic hazard in common with Anchorage. These ordinances provide examples of various approaches to geotechnical hazards mitigation.

GLOSSARY

Alluvial fan: A low, outspread, mass of loose alluvium, shaped like an open fan or a segment of a cone, deposited by a stream where it issues from a narrow mountain valley onto a plain or broad valley, or where a stream channel becomes less steep or less constricted;

Alluvium: A general term for unconsolidated stream deposits of clay, silt, sand and gravel;

Andesitic: Pertaining to andesite, a dark-colored, fine-grained extrusive rock;

Angle of repose: The maximum angle of slope (measured from a horizontal plane) at which loose, cohesionless material will come to rest on a pile of similar material;

Arkose: A feldspar-rich, typically coarse-grained sandstone composed of angular to subangular grains, usually derived from the rapid disintegration of granitic rocks;

Argillite: A compact rock that is more highly indurated than mudstone or shale, but is not fissile like shale and does not have slaty cleavage;

Attenuation: In geologic terms, the decrease in size or amplitude of earthquake waves with an increase in distance from the source;

Aufeis: Thick masses or sheets of ice formed on a river's flood plain in winter, when shoals in the river freeze solid or are otherwise dammed, so that water under increasing hydrostatic pressure is forced to the surface and spreads over the flood plain where it freezes in successive sheets of ice;

Avalanche path: The terrain boundaries of known or suspected avalanches. It is customary to divide an avalanche path into three sections: starting zone, track, and runout zone;

Basement: A complex of undifferentiated rocks that underlies the oldest identifiable rocks in the area;

Block glide: A translational landslide in which the slide mass remains essentially intact, moving outward and downward as a unit, most often along a preexisting plane of weakness, such as bedding, faults, etc.;

Bog: A waterlogged, spongy ground mass, primarily mosses, containing decaying vegetation which may develop into peat;

Cenozoic: The present era of geologic time. See <u>Geologic time scale</u>;

Chert: Hard, siliceous rock, usually reddish colored and thin bedded;

Cirque: A deep, steep-walled, half-bowl-like hollow situated high on the side of a mountain and commonly at the head of a glacial valley, and produced by the erosive activity of mountain glaciers;

Colluvium: A general term applied to any loose, heterogeneous and incoherent mass of soil material deposited chiefly by gravity;

Cone: A land form shaped like a cone, having relatively steep slopes and a pointed top (alluvial cone; talus cone);

Contact: The boundary between two geologic formations;

Cretaceous: A period of geologic time. See Geologic time scale;

Damping: Absorption of mechanical energy by a material with the resulting in a decrease in motion;

Diamicton: A nongenetic term for nonsorted or poorly sorted, nonmarine sediments that contain a wide range of particle sizes, such as rock with sand and/or larger particles in a muddy matrix;

Dike: A tabular igneous intrusion that cuts across the planar structures of the surrounding rock;

Dike swarm: A group of dikes, either radial from a single source or in parallel, linear arrangement;

Displacement: Relative movement along two sides of a fault;

Dunite: A coarse-grained plutonic rock composed almost entirely of olivine;

Epicenter: The exact geographical location on the surface of the earth that is directly above the earthquake focus;

Erosion: The mechanical destruction of the land and the removal of material by running water, waves and currents, moving ice, or wind;

Esker: A long, narrow, sinuous, steep-sided ridge or mound composed of irregularly stratified sand and gravel deposited by a stream flowing beneath a glacier;

Eustatic: Pertaining to worldwide changes of sea level relative to continental glaciation;

Extrusive: Said of igneous rock that has been ejected onto the surface of the earth. Extrusive rocks include lava flows and volcanic rocks;

Fault: A fracture or zone along which the rocks have been displaced in relation to each other;

Fault creep: A series of slow, continuous movements which are not associated with "felt" earthquakes;

Fault trace: The linear expression of a fault on the ground surface;

Felsic: Said of an igneous rock having a high silica content (compare ultrabasic);

Focus: The point of origin of the initial earthquake waves on the fault plane;

Folding: The curving or bending of a planar structure such as rock strata;

Formation: A rock body or an assemblage of rocks which have some character in common such as age or a similar rock type used in mapping;

Fracture: A general term used for any break in a rock, due to mechanical failure or stress;

Frequency: The number of vibrations or cycles per unit of time;

Frost heaving: The uneven lifting and general distortion of surface soils, rocks, vegetation and structures, due to subsurface freezing of water and growth of ice masses;

Fundamental periods: Vibration characteristics of a building;

Geologic time scale: (See Table 1, page 12 of this report);

Geotechnical: Pertaining to the application of scientific methods and engineering principles to the acquisition, interpretation, and use of knowledge of materials of the Earth's crust to the solution of civil-engineering problems; the applied science of making the Earth more habitable. It embraces the fields of soil mechanics and rock mechanics, and many of the engineering aspects of geology, geophysics, hydrology, and related sciences.

Glaciomarine: Said of marine sediments that contain glacial material;

Granitic rock: A term loosely applied to any light-colored coarse-grained plutonic rock containing quartz as an essential component;

Graupel: A soft, usually spherical snow crystal which has been completely engulfed by frozen water droplets;

Graywacke: Hard, and firmly compacted sandstone that consists of poorly sorted, angular to subangular sand grains indicative of rapid deposition;

Greenstone: Compact, dark-green, altered basic to ultrabasic igneous rock;

Ground acceleration: The ground motion due to seismic waves, expressed in percent of gravity, e.g., 0.1g (1 gravity = 32 feet per second);

Ground failure: Disruption of the surface of the earth due to liquefaction, surface faulting, differential settlement and lurching;

Ground response: Reaction of rock and soil materials to earthquake waves;

Ground shaking: Periodic oscillation of the ground resulting from fault movement;

Ground water: All subsurface water;

Holocene: The present epoch of geologic time. See Geologic time scale;

Igneous rocks: Formed as a result of solidification from molten material;

Intensity: Geologically, a Roman numeral ranging from I to XII designating the destructiveness of an earthquake. It is a measure of the damage caused by an earthquake, and will decrease in value with increased distance from the earthquake source. Thus a single earthquake can have many intensities ranging from the high damage level of XII to the low of I;

Intrusion: The igneous rock mass formed by the emplacement of magma in preexisting rock;

Jurassic: A period of geologic time. See Geologic time scale;

Kame: A long, low, steep-sided hill, mound, knob, hummock or short irregular ridge, composed chiefly of poorly sorted and stratified sand and gravel deposited by a subglacial stream;

Lacustrine: Pertaining to, produced by, or formed in a lake;

Landslide: A term covering a wide variety of mass-movement from moderately rapid to rapid downslope transport of soil and rock;

Lateral spreading: Seismically induced lateral flows of soil;

Liquefaction: A process by which water saturated cohesionless soils lose strength and become liquid - caused by ground shaking;

Loose-snow avalanche: An avalanche initiated by a small amount of cohesionless snow slipping out of place and starting down the slope;

Lurching: Yielding of the earth material in the unsupported direction along a stream bank or cliff during an earthquake;

Magnitude: A numeral designating the strength of an earthquake. It is determined by seismographic observations and calculations. An earthquake can have but one magnitude (see Intensity);

Marsh: A water-saturated, poorly drained area, intermittently or permanently water-covered, having aquatic and grasslike vegetation, essentially without peatlike accumulation;

Mass wasting: A general term for the dislodgement and downslope transport of earth material under the direct application of gravitational body stresses;

Megathrust: Refers to the large fault zone along the Aleutian Arc, where the continental plate is overriding the oceanic plate;

Mesozoic: An era of geologic time. See Geologic time scale;

Meta-: A prefix that, when used with a name of a sedimentary or igneous rock, indicates that the rock type has been altered;

Metamorphic: Rocks altered by pressure, heat and solutions, usually at considerable depth in the earth;

Moraine: A mound, ridge, or other distinct accumulation of unsorted, unstratified glacial drift, predominantly till, deposited chiefly by direct action of glacier ice in a variety of topographic land forms that are independent of control by the surface on which the drift lies;

MSL elevation: Mean sea level elevation;

Muskeg: A bog, frequently with firm hummocks of deep accumulations of organic material, growing in wet, poorly drained regions, often areas of permafrost;

Needle crystal: A long slender snow crystal that is at least five times as long as it is broad;

100-year flood: A flood at any given location having an average frequency of occurrence of about once in 100 years, or a one percent chance of occurrence in any one year;

Outcrop: Surface exposure of bedrock;

Outwash plain: A broad alluvial sheet of stratified sediment deposited by meltwater streams flowing in front of or beyond the terminal moraine of a glacier;

Paleozoic: An era of geologic time. See Geologic time scale;

Peat: Unconsolidated deposit of semicarbonized plant remains in a water saturated environment;

Period: A number representing the time between seismic wave peaks usually measured in seconds;

Permafrost: Any soil, subsoil, or other surficial deposit, or even bedrock, in which a temperature below freezing has existed continuously for more than two years;

Permeability: Capability for transmitting a fluid;

Physiographic: The description of natural features and processes;

Pitted: Said of a glacial outwash plain marked by many irregular depressions believed to have formed by the melting of blocks of ice left behind in the outwash material by a retreating glacier;

Plate, Continental or Oceanic: One of the large, nearly rigid, but still mobile segments or thin blocks involved in plate tectonics, with a thickness (50-250 km) that includes both crust and some part of the upper mantle;

Pliocene: An epoch of geologic time. See Geologic time scale;

Pleistocene: An epoch of geologic time. See Geologic time scale;

Plutonic: Pertaining to igneous rocks formed at great depth;

Point avalanche: See Loose-snow avalanche;

Pore water: The water that fills the voids between particles of a soil or rock mass;

Predominant Period: A number representing the time between seismic wave peaks, usually measured in seconds;

Quaternary: The present period of geologic time. See Geologic time scale;

Reverse fault: A fault with a dip of 45° or less in which the upper side appears to have moved upward relative to the lower side;

Riprap: Large, durable rocks used to protect shorelines or embankments from erosion through wave action, tidal forces or strong currents;

Rotational landslide: A landslide in which the shearing takes place on a well defined, curved shear surface, concave upward in cross section;

Runout zone: (Avalanche term) The bottom area of the avalanche path, which is generally less steep than the track. Includes the area affected by the airblast caused by the moving snow;

Runup: The landward advance of water following the breaking of a wave;

Sedimentary: Pertaining to solid fragmental material that originates from weathering of rocks and is transported or deposited by air, water or ice, and forms in layers in a loose unconsolidated form; e.g. sand, gravel, silt, mud, till, alluvium;

Seiche: Periodic oscillations of a generally confined body of water;

Seismic: Pertaining to an earthquake or earth vibration;

Serpentinite: A rock consisting of serpentine-group minerals derived from the alteration of previously existing ferro-magnesium minerals;

Shear zones: Localized zones of rock which have been crushed by past tectonic forces;

Sluff: A small, innocuous loose snow avalanche;

Soil creep: Gradual, slow and steady downhill movement of soil on a slope;

Starting zone: (Avalanche term) The area at the head of an avalanche path, where the accumulation and failure of the snow pack occurs;

Strike: The horizontal course or bearing of a planar feature, measured perpendicular to the direction of the dip;

Subsidence: The sinking of a portion of the ground surface;

Talus: Rock fragments of any size or shape (usually coarse and angular) derived from and lying at the base of a very steep rocky slope;

Tectonic: Pertaining to rock structure and surface forms resulting from deformation of the earth's crust;

Tertiary: A period of geologic time covering the interval from 1½ to 65 million years before the present. See Geologic time scale;

Thrust fault: See Reverse fault;

Till: Unsorted, unstratified, and generally unconsolidated material deposited directly by and underneath a glacier. Consists of a heterogeneous mixture of clay, sand, gravel and boulders varying widely in size and shape;

Track: (Avalanche term) The part of the avalanche path between the starting zone and the runout zone. May be channeled or unconfined;

Translational landslide: A major landslide classification group involving the downslope displacement of soil-rock material on a surface which is roughly parallel to the general ground surface;

Tsunami: A seismic sea wave produced by submarine earth movement, characterized by great speed of propagation, long wavelength, long period, and low observable amplitude on the open sea. It may pile up to great heights and cause considerable damage on entering shallow water along an exposed coast;

Ultrabasic: Said of an igneous rock having a low silica content. (Compare felsic).

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3, 5, 7	Barnwell, W., W. Beaty, L. Dearborn, E. Dobrovolny, R. George, H. Schmoll, L. Selkregg, and C. Zenone, eds. 1973. Road Log and Guide, Geology and Hydrology for Planning, Anchorage Area, Alaska Geological Society. 34 p. Describes areas which have geologic and hydrologic problems including earthquake induced landslides, coastal erosion and surficial drainage problems.
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Contains landslide susceptibility map based in part on observations made after the great Alaska earthquake; shows how topographic and geologic maps may be used to determine possible landslide areas in the event of a strong earthquake.

2, 3 Eckel, E.B. 1970. The Alaska earthquake, March 27, 1964: Lessons and Conclusions. U.S. Geological Survey Professional Paper 546. Washington: Government Printing Office. 47 p. Also in The Great Alaska Earthquake of 1964: Geology. NAS Pub. 1601. Washington: National Academy of Sciences, 1971.

Summarizes geologic and hydrologic findings of the U.S. Geological Survey and includes sections on tectonics, vibration and deformation of the land surface, downslope mass movements, ground cracks and geologic control of vibration damage.

2, 3 Eckel, E.B. 1967. Effects of the earthquake of March 27, 1964, on air and water transport, communications and utilities systems in southcentral Alaska. U.S. Geological Survey Professional Paper 545-B. Washington: Government Printing Office. 27 p. Also In The Great Alaska Earthquake of 1964: Geology. NAS Pub. 1601. Washington: National Academy of Sciences, 1971.

Notes that utilities, communications and all forms of transportation were wrecked or hampered by the 1964 earthquake; several, such as air facilities, were at least partly operational within hours after the earthquake.

2, 3 Eckel, E.D., and W.E. Schaem. 1966. The work of the Scientific and Engineering Task Force - Earth science applied to policy decisions in early relief and reconstruction in the Alaska

earthquake, March 27, 1964: Field investigations and reconstruction effort. U.S. Geological Survey Professional Paper 541. Washington: Government Printing Office, p. 46-69. Revised in the Great Alaska Earthquake of 1964: Human Ecology. NAS Pub. 1607. Washington: National Academy of Sciences, 1970, p. 168-182.
Describes immediate response of the federal government and the work accomplished by the Federal Reconstruction and Development Planning Commission and by the Scientific and Engineering Task Force; gives objectives, accomplishments, and recommendations of the Task Force, which gathered information on parts of earthquake-damaged cities where reconstruction was inadvisable because of land-stability problems.

3 Engineering Geology Evaluation Group. 1964. Geologic report - 27 March 1964 earthquake in Greater Anchorage area: Anchorage, Alaska, prepared for and published by Alaska State Housing Authority and the City of Anchorage. 34 p.
Provides a very early assessment of the geological changes due to the 1964 earthquake, with emphasis on the engineering geology of landslides in the Anchorage area, Bootlegger Cove Clay, and the monitoring of possible ground movements.

1, 2, 7, 8 Evans, C.D., E. Buck, R. Buffler, G. Fisk, R. Forbes and W. Parker. 1972. The Cook Inlet Environment: A Background Study of Available Knowledge. A report by the Resource and Science Service Center, Alaska Sea Grant Program, University of Alaska for the U.S. Army Corps of Engineers, Alaska District.
Discusses the environment, resources and cultural activities in the Cook Inlet that would affect or be affected by petroleum resource development in the Inlet. Of specific interest, are sections on geology (page 1-7) and geologic risk phenomena (page IV-1) which include earthquake, tsunami and volcanic risk in the Inlet.

2, 3 Federal Reconstruction and Development Planning Commission for Alaska. 1964. Response to disaster: Alaska earthquake - March 27, 1964. Washington: Government Printing Office. 84 p.
Describes need for accurate knowledge of the geology and soil conditions of the earthquake area, as well as judgment as to future slides and subsidence and as to precautions to minimize their occurrence.

1, 7 Feulner, A.J., J.M. Childers, and V.W. Norman. 1971. Water Resources of Alaska, U.S. Geological Survey, Open-File report 1971. 60 p.
Presents regional descriptions of water resources in Alaska. Includes discussion of regional geology, permafrost, glaciers, surface water and groundwater occurrence.

Fogleman, K., C. Stephens, J.C. Lahr, S. Helton, and M. Allan. 1978. Catalog of Earthquakes in Southern Alaska. U.S. Geological Survey Open-File Report 78-1097.
Describes the USGS seismograph network in southern Alaska. Includes a quarterly chronological catalog of seismic data.

2, 3 Foster, H.L., and T.N.V. Karlstrom. 1967. Ground breakage and associated effects in the Cook Inlet area, Alaska, resulting from the March 27, 1964 earthquake. U.S. Geological Survey Professional Paper 543-F. Washington: Government Printing Office. 28 p. Abstract In The Great Alaska Earthquake of 1964: Geology. NAS Pub. 1601. Washington: National Academy of Sciences. 1971.

Describes ground cracks and deposits from groundwater eruptions (extrusions) throughout Kenai Lowland; discusses origin by faulting, settling and sliding.

7 Freethey, G.W. 1976. Relative permeability of surficial geologic materials, Anchorage and vicinity, Alaska. Map I-787-F. Lat. 61°04' to 61°20', Long. 149°37' 30" to 150°05'. Scale 1:24,000 (2 inch = 2,000 feet). Sheet 43 by 52 inches.

Shows the relative permeability of surficial material (five categories). Also shows peat, marshland and exposed bedrock area.

7 Freethey, G.W. 1976. Preliminary report on water availability in the lower Ship Creek basin, Anchorage, Alaska -- with special reference to the fish hatchery on Fort Richardson and a proposed fish hatchery site near the Elmendorf AFB power plant; prepared in cooperation with the State of Alaska, Department of Fish & Game, Water Resources Investigations WRI 48-75. 21 p.

Includes a discussion of the unconfined groundwater in lower Ship Creek basin.

7 Freethey, G.W. 1978. Guide to Ground-Water Data, Cook Inlet Basin, Alaska. U.S. Geological Survey Open-File Report 78-439. 200 p.

Describes the types of groundwater data available for the Cook Inlet Area, and the access to that data. Includes maps showing well locations, and a list of USGS publications and personnel having groundwater data.

7 Freethey, G.W., J.W. Reeder, and W.W. Barnwell. 1974. Map showing depth to Water, Anchorage, Alaska, Alaska, open-file report. 1 sheet.

A generalized map showing the approximate depth to the saturated zone beneath the urbanized area around Anchorage. Shows surface water and 10- and 20-foot-depth contours.

1 Furbush, C.E. 1976. Soils of the Anchorage Area, Alaska, Interim Report, Soil Conservation Service, U.S. Department of Agriculture, Palmer, Alaska, 66 p. and maps.

Detailed description and mapping of the surficial soils in the Anchorage Area. Discusses engineering applications of soils maps. The S.C.S. mapping has been transferred to the 1:250,000 base maps of Anchorage and Eagle River which are on file in the Municipality of Anchorage Physical Planning Department.

5 Gatto, L.W. 1976. Baseline data on the oceanography of Cook Inlet, Alaska, U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Report 76-25, Hanover, NH. 84 p.

A compilation of information on ocean circulation in Cook Inlet based on aircraft and satellite imagery.

2, 3 George, W. and R.E. Lyle. 1966. Reconstruction by the Corps of Engineers - Methods and Accomplishments In The Alaska Earthquake, March 27, 1964: Field Investigations and Reconstruction Effort, U.S. Geological Survey Professional Paper 541. Washington: Government Printing Office. p. 81-89.
Details the need for geologic and soil studies, which, when completed, gave conclusions regarding the ground-motion waves, soil failure and future movements of slide areas.

3 Goldthwait, R. 1968. Hydrologic hazards from earthquakes In The Great Alaska Earthquake of 1964: Hydrology, NAS Pub. 1603, Washington: National Academy of Sciences, p. 405-414.
Evaluates hazards to life and property from snowslides, far-traveling debris, avalanches, floods, seiches, and groundwater spouts; suggests 11 steps to prevent or reduce losses.

1 Grants, A., I. Zietz, and G.E. Andreasen. 1963. Geophysical Field Investigations, An Aeromagnetic Reconnaissance of the Cook Inlet Area, Alaska, United States Government Printing Office, Washington, Geological Survey Professional Paper 316-G.
A regional geologic interpretation of the magnetic field over the Cook Inlet area.

2, 3 Grantz, A., G. Plafker and R. Kachadoorian. 1964. Alaska's Good Friday Earthquake, March 27, 1964: A preliminary geologic evaluation, U.S. Geological Survey Circular 491. Washington: U.S. Geological Survey. 35 p.
Describes areas of tectonic uplift and subsidence; effects on land, on coasts; hydrologic effects; and damage to communities, transportation routes, and industries. Outlines areas of landsliding in Anchorage and shows diagrammatic sections through the "L" Street and Turnagain Heights slides. Discusses damage and subsidence in the Portage area.

6 Greater Anchorage Area Borough Planning Commission. 1971. Upper Campbell Creek Area Land Use Plan, Anchorage, Alaska, pp. 15-20.
Describes local climate conditions, including the "Chugach" wind phenomenon.

2, 3 Hansen, R. 1965. Effects of the earthquake of March 27, 1964 at Anchorage, Alaska, U.S. Geological Survey Professional Paper 542-A. Washington: Government Printing Office. 68 p. Also in The Great Alaska Earthquake of 1964, Geology. NAS Pub. 1601. Washington: National Academy of Sciences, 1971.
Describes and analyzes the most damaging ground response, the translatory slides; describes characteristics of Bootlegger Cove Clay in relation to slides, and summarizes vibratory damaging effects.

2, 3 Hansen, R., E.B. Eckel, W.E. Schaem, R.E. Lyle, W. George, and G. Chance. 1966. The Alaska earthquake, March 27,

1964: Field investigations and reconstruction effort. U.S. Geological Survey Professional Paper 541. Washington: Government Printing Office. 111 p.
Summarizes the effects of the great Alaska earthquake and emphasizes field investigations made by the Geological Survey, the work of the Scientific and Engineering Task Force and the reconstruction by the U.S. Army Corps of Engineers. Reviews the contributions of many geologists to solving geologic problems relating to pattern of sea-level changes, outlook for fisheries, effects on water supply and soil environments.

2 Housner, G.W., and P.C. Jennings. 1973. Reconstituted earthquake ground motion at Anchorage in The Great Alaska Earthquake of 1964: Engineering, NAS Pub. 1606. Washington: National Academy of Sciences. (Copy of computer printout for simulated horizontal ground acceleration for 240 seconds of ground shaking at Anchorage, Alaska, during the earthquake of March 27, 1964, on file, Library, National Academy of Sciences--National Academy of Engineering, Washington, D.C.).
Indicates, from the use of a simulated accelerogram of the ground motion at Anchorage during the 1964 earthquake, a maximum acceleration of approximately 15 percent of gravity, with strong ground shaking lasting about 1 minute and lesser shaking for about 3 minutes.

2 Howard, K.A. and others. 1978. Preliminary Map of Young Faults in the United States as a guide to possible fault activity, U.S. Geological Survey. Miscellaneous Field Studies, Map MF-916, 2 sheets.
Includes map of Alaska, scale 1:7,500,000. Shows known young faults and gives age of youngest known displacement. In the Anchorage area, the following faults are shown: Aleutian Arc, Kodiak Island, Fairweather, Castle Mountain, Moquawkie, Bruin Bay, Denali, Hanning Bay.

2 Hudson, D.E., and W.K. Cloud. 1973. Seismological background for engineering studies of the earthquake in The Great Alaska Earthquake of 1964: Engineering, NAS Pub. 1601. Washington: National Academy of Sciences.
Draws attention to the lack of any measurements of strong ground motion at the time of the 1964 Alaska earthquake because of the absence of suitable instrumentation in the area; assists in an engineering interpretation of the damage.

2 Hudson, T., G. Plafker and M. Rubin. 1976. Uplift rates of marine terrace sequences in the Gulf of Alaska. U.S. Geological Survey Circular 733 pp. 11-13.
Describes Holocene tectonic uplift rates based on radiocarbon dating of material from marine terrace sequences.

1, 6, 7 Johnson, P.R., and C.W. Hartman 1969. Environmental Atlas of Alaska: Institute of Arctic Environmental Engineering, Institute of Water Resources, University of Alaska, College, Alaska. 111 p.

A physical description of the entire state. Includes discussion of hydrology, climate and geology.

7 Johnson, P.R. in review. Hydrogeologic Data for the Eagle River-Chugiak Area, Alaska: Open-File Report 78-XXX, XXp. with 2 plates.
Presents water well log data, well locations, and 100-foot depth-to-water contours for the area around Eagle River and Chugiak.

3 Kachadoorian, R. 1960. Effects of the earthquake of March 27, 1964, on the Alaska Highway system. U.S. Geological Survey Professional Paper 545-C. Washington: Government Printing Office. 66 p. Also In The Great Alaska Earthquake of 1964: Geology, NAS Pub. 1601. Washington: National Academy of Sciences, 1971, p. 641-703.
States that the chief engineering characteristics responsible for roadway and bridge damage in the 1964 Alaska earthquake include (1) thickness of roadway fills, (2) type of pile bents and masonry piers, (3) the weight ratio between the substructure and superstructure, and (4) the tie between the sub- and superstructure.

1 Karlstrom, T.N.V. 1964. Quaternary geology of the Kenai Lowland and glacial history of the Cook Inlet Region, Alaska. U.S. Geological Survey Professional Paper 443. 69 p.
Summarizes a glacial chronology of the Kenai Lowland and adjoining areas of Cook Inlet, including the Anchorage area. Includes a map showing the extent of glaciations in Cook Inlet.

2, 3 Kawasumi, H., and E. Shima. 1967. Spectra of microtremors observed in the City of Anchorage and their relation to soils in Volume II-A: The Prince William Sound, Alaska, earthquake of 1964 and aftershocks. Environmental Science Services Administration, U.S. Coast and Geodetic Survey. Washington: Government Printing Office. P. 299-331.
Microtremor analyses were performed at 33 stations in the Anchorage lowlands. Correlation plots of predominant period of microtremors as a function of various subsurface conditions (layer thicknesses) were made.

3 Kerr, P.F. and I.M. Drew. 1965. Quick Clay Movements, Anchorage, Alaska: A preliminary report. Air Force Cambridge Research Laboratories Scientific Report (AFCRL - 66-78). Bedford, Mass: U.S. Air Force, Office of Aerospace Research, 1965. 133 p.
Notes that during the 1964 earthquake, quick clay movement at Anchorage initiated slide action with deformation in overlying silts and gravel; also states that old slide areas along the bluffs contain heterogeneous materials that may form a mass resistant to quick clay flowage.

2, 4 LaChappelle, E.R. 1968. The character of snow avalanching induced by the Alaska earthquake in The Great Alaska Earthquake of 1964: Hydrology, NAS Pub. 1603. Washington: National Academy of Sciences. P. 355-361.

Finds a clear pattern of two separate avalanche cycles generated by the 1964 earthquake, with the first shock triggering the displacement of already unstable surface layers of large cornices and with the fracturing of deep drifts causing the second series of avalanches.

3 Logan, M.H. 1967. Effect of the earthquake of March 27, 1964, on the Eklutna Hydroelectric Project, Anchorage, Alaska (with a section on television examination of earthquake damage to underground communication and electrical systems in Anchorage, by Lynn R. Burton). U.S. Geological Survey Professional Paper 545-A. Washington: Government Printing Office. 30 p. Also abstract in The Great Alaska Earthquake of 1964: Geology, NAS Pub. 1061. Washington: National Academy of Sciences, 1971.
Indicates that the intake structure in Eklutna Lake was damaged by densification of unconsolidated sediments and overburden.

3 Long, E.L. 1973. Earth slides and related phenomena. In The Great Alaska Earthquake of 1964: Engineering, NAS Pub. 1601. Washington: National Academy of Sciences.
States that some of the large destructive slides in the 1964 Alaska earthquake were the consequence of soil liquefaction, which caused a reduction in soil strength and was responsible for large soil movements.

3 Long, E., and W. George. 1967. Buttress design for earthquake-induced slides. Journal of the Soil Mechanics and Foundation Division, American Society of Civil Engineers, vol. 93 (July 1967) p. 595-609.
Explains that stabilization of the Fourth Avenue slide in Anchorage was accomplished by construction of a gravel buttress designed to resist forces caused by sand or clay liquefaction, horizontal or circular sliding, or slumping.

3 Long, E., and W. George. 1967. Turnagain slide stabilization, Anchorage, Alaska. Journal of the Soil Mechanics and Foundations Division, American Society of Civil Engineers, vol. 93 (July 1967), p. 611-627.
Mentions tests conducted in early 1966 that show that soil strength under the seaward toe of the Turnagain slide would not fail in an equivalent future earthquake.

1, 2, 3, 4, 7 Maher, J.C., and W.M. Trollman. 1969. Geological literature on the Cook Inlet Basin and Vicinity, Alaska. Alaska Department of Natural Resources.
An indexed bibliography of most of the geological literature on the Cook Inlet basin and adjacent highlands published prior to May 1, 1969.

3 Marcus, M.G. 1968. Effects on glacier-dammed lakes in the Chugach and Kenai mountains, in The Great Alaska Earthquake of 1964: Hydrology. NAS Pub. 1603. Washington: National Academy of Sciences, p. 329-347.

Considers ice-dammed lakes in which minor disturbances attributed to the earthquake were observed but no major changes were identified.

2, 3 McCulloch, D.S., and M.G. Bonilla. 1970. Effects of the earthquake of March 27, 1964, on the Alaska Railroad, U.S. Geological Survey Professional Paper 545-D. Washington: Government Printing Office. 161 p. Condensed in The Great Alaska Earthquake of 1964: Geology. NAS Pub. 1601. Washington: National Academy of Sciences, 1971.
Stresses that damage to The Alaska Railroad from the earthquake was caused by landslides, regional tectonic subsidence, and landspreading (lateral displacement and distension of mobilized sediments).

2, 3 McCulloch, D.S. 1966. Slide-induced waves, seiching, and ground fracturing caused by the earthquake of March 27, 1964, at Kenai Lake, Alaska. U.S. Geological Survey Professional Paper 543-A. Washington: Government Printing Office. 1966. 41 p. Also in The Great Alaska Earthquake of 1964: Hydrology. NAS Pub. 1603. Washington: National Academy of Sciences, 1968, p. 47-81. Abstract in The Great Alaska Earthquake of 1964: Geology. NAS Pub. 1601. Washington: National Academy of Sciences, 1971.
Describes nine Delta slides and the resulting, long-lasting seiche of the lake. Also describes the deep lateral spreading of sediments toward Delta margins, ground fractures and the permanent tilting of Kenai Lake.

1, 3, 4 Miller, R.D., and Dobrovolny, E. 1959. Surficial geology of Anchorage and vicinity, Alaska: U.S. Geological Survey Bulletin 1093. 128 p.
Describes the surficial geology and presents a geologic history of the Anchorage bowl area. Briefly describes engineering problems with the surficial deposits, including the Bootlegger Cove Clay. Briefly describes the effects of the 1954 earthquake.

1, 3, 4 Mitchell, J.K., W.H. Houston, and G. Yamane. 1973. Sensitivity and geotechnical properties of Bootlegger Cove Clay in The Great Alaska Earthquake of 1964: Engineering. NAS Pub. 1606. Washington: National Academy of Sciences.
Indicates that Bootlegger Cove Clay demonstrates no specific correlation between its mineralogical composition and its sensitivity.

1, 2, 3, 8 National Academy of Sciences. 1971. The Great Alaska Earthquake of 1964, Washington, D.C.
An eight-volume collection of reports relating to various aspects of the 1964 earthquake. Includes volumes on hydrology, geology, engineering, and geodesy and seismicity. Each volume has an annotated bibliography. Reports which apply specifically to Anchorage have been listed separately in this bibliography.

2, 3 National Board of Fire Underwriters and Pacific Fire Rating Bureau. 1964. The Alaska Earthquake, March 27, 1964.

San Francisco: The National Board of Fire Underwriters. 35 p.
Emphasizes the elevation change of large land masses, earthslides, and ground settlements as requiring provisions for earthquake-resistive design and consideration of soil conditions at building sites.

2, 7 Ovenshine, A.T., D.E. Lawson, and S.R. Bartsch-Winkler, 1976. The Placer River Silt--An Intertidal Deposit Caused by the 1964 Alaska Earthquake: U.S. Geological Survey, Journal of Research, v. 4, no. 2, p. 151-162.
Describes the deposition of intertidal sediment resulting from regional tectonic subsidence and local subsidence during the 1964 earthquake. Contains a brief description of the geology and groundwater conditions of the Portage area.

2 Page, R.A., D.M. Boore, W.B. Joyner, and H.W. Coulter. 1972. Ground motion values for use in the seismic design of the Trans-Alaska Pipeline System. Geological Survey Circular 672. 23 p.
Discusses the seismicity of Alaska and the ground-motion values used for the seismic design of sections of the Trans-Alaska Pipeline.

1 Péwé, T.L. 1975. Quaternary Geology of Alaska, U.S. Geological Survey Professional Paper 835. 145 p.
Summarizes the results of many studies of the Pleistocene and Holocene epochs in Alaska. Discusses areas of disagreement. Contains specific references to the Cook Inlet region.

2, 3, 5 Plafker, G., and R. Kachadoorian. 1966. Geological Effects of the March 1964 Earthquake and Associated Seismic Sea Waves on Kodiak and Nearby Islands, Alaska. U.S. Geological Survey Professional Paper 543-D. Washington: Government Printing Office. 46 p. Also in The Great Alaska Earthquake of 1964: Geology. NAS Pub. 1601. Washington: National Academy of Sciences, 1971.
Describes tectonic vertical displacements, subsidence due to failure of noncohesive granular materials, landslides, effects on hydrologic regimen and tsunamis.

2 Plafker, G. 1969. Tectonics of the March 27, 1964 Alaska Earthquake. U.S. Geological Survey Professional Paper 543-I. Washington: Government Printing Office. 74 p. Also in The Great Alaska Earthquake of 1974: Geology. NAS Pub. 1601. Washington: National Academy of Sciences, 1971.
Presents and summarizes available data on the distribution and nature of displacements and effects of tectonic movements that accompanied the Alaska earthquake; suggests that the primary fault motion was along a complex, gently dipping thrust fault beneath the continental margin near the Aleutian Trench.

2, 5 Plafker, G., R. Kachadoorian, E.B. Eckel, and L.R. Mayo. 1969. Effects of the earthquake of March 27, 1964, on various

communities. U.S. Geological Survey Professional Paper 542-G. Washington: Government Printing Office. 50 p. Also in The Great Alaska Earthquake of 1964: Geology. NAS Pub. 1601. Washington: National Academy of Sciences, 1971.
Discusses vertical tectonic displacements over an area in excess of 50,000 m^2, local surface faulting, uplift of Continental Shelf and resultant tsunamis, widespread subaqueous sliding and sedimentation, and local violent surges of water.

3 Post, A. 1964. Influence of the 1964 Good Friday earthquake on Alaskan glaciers. Abstract of paper presented at Symposium on Alaskan earthquake, Fourth Western National Meeting Program. University of Washington, Seattle, December 28-30, 1964. Transactions, American Geophysical Union, v. 45 (December 1964). 610 p.
Reports no notable changes in the glaciers of the Chugach Mountains 5 months after the earthquake.

3, 4 Post, A. 1967. Effects of the March 1964 Alaska earthquake on glaciers. U.S. Geological Survey Professional Paper 544-D. Washington: Government Printing Office. 42 p. Also in The Great Alaska Earthquake of 1964: Hydrology. NAS Pub. 1603. Washington: National Academy of Sciences, 1968, p. 266-308.
Analyzes 1964 earthquake effects, including rock avalanches, changes in ice-dammed lakes, river drainage, and the termini of tidewater glaciers; reviews the Tarr-Martin theory and the problem of surges.

4 Reger, R.D., and C.L. Carver. Unpublished. Geologic Hazards Evaluation of Preliminary General Development Plan for Chugach State Park.
Geologic hazards evaluations based on air photo stereo pairs of 38 acres of planned development in Chugach State Park. Snow and rock avalanches, flood, rockfall, mud flow and erosion potentials are identified at the various sites. Includes 1" = 1 mi. maps showing hazard features.

2, 3 Reimnitz, E., and N.F. Marshall. 1965. Effects of the Alaska earthquake and tsunami on recent deltaic sediments, Journal of Geophysical Research, v. 70 (May 15, 1965), p. 1363-1376. Also in The Great Alaska Earthquake of 1964: Geology. NAS Pub. 1601. Washington: National Academy of Sciences, 1971.
Discusses ground fractures, lake ice fractures, earthquake fountain craters and related phenomena, avalanches, and regional uplift.

3 Ross, G.A., H.B. Seed, and R.R. Migliaccio. In press. Performance of highway bridge foundations during the Alaska earthquake in The Great Alaska Earthquake of 1964: Engineering. NAS Pub. 1606. Washington: National Academy of Sciences.
Reports on the foundation conditions, bridge and channel configurations, and foundation displacements; assess the effects of

foundation support conditions on bridge performance during the earthquake.

1, 3 Schmidt, R., B. Bedford, K.W. Calderwood, G. Ganopole, J.A. Hamilton, D.N. Helmuth, N.J. Moening and D.H. Richter. 1964. Earthquake-triggered landslides in the Anchorage area March 27, 1964, In Science in Alaska, 1964: Proceedings Fifteenth Alaskan Science Conference, College, Alaska, August 31 to September 4, 1964. George Dahlgren, editor. College: Alaska Division American Association for the Advancement of Science, March 15, 1965, p. 239-252.
Describes detailed field mapping of the Anchorage area from air photos; drill sampling program; landslide areas; and weak zones in bluff areas.

8 Schmoll, H.R. and E. Dobrovolny. 1971. Generalized slope map of the Eagle River-Birchwood area, Greater Anchorage Area Borough, Alaska. U.S. Geological Survey Open-file map.
Subdivides the area into five slope angle categories. Scale is 1:63,360. Reproduced in Zenone, et al., 1974.

1 __________. 1972a. Generalized Geologic Map of Anchorage and vicinity, Alaska, Map I-787-A, U.S. Geological Survey.
Geologic units are grouped genetically and by grain size. Scale is 1:24,000.

8 __________. 1972b. Slope Map of Anchorage and Vicinity, Alaska. Map I-787-B, U.S. Geological Survey.
Subdivides the area into 6 slope categories. Scale is 1:24,000.

1, 8 __________. 1974a. Foundation and excavation conditions map of Anchorage and Vicinity, Alaska, Map I-787-D, Lat. 61° 04' to 61° 20', Long. 149° 37'30" to 150° 05'. Scale: 1:24,000.
Five map units describe foundation and excavation conditions.

8 __________. 1974b. Slope-stability map of Anchorage and Vicinity, Alaska, Map I-787-E.
Lat. 61° 04' to 61° 20', Long, 149° 37'30" to about 150° 0.5'. Scale is 1:24,000. Five categories of slope stability.

1 __________. Unpublished. Preliminary surficial geologic map of the southeastern part of Anchorage Borough and Vicinity, Alaska, Open-file report.
A detailed surficial geologic map of the entire area covered by the geotechnical hazards assessment, with the exception of that portion of the Municipality covered by the 1972 Map I-787-A. Scale is 1:63,360.

1 Schmoll, H.R., E. Dobrovolny, and C. Zenone. 1971. Generalized geologic map of the Eagle River-Birchwood Area, Greater Anchorage Area Borough, Alaska, U.S. Geological Survey, Open-file map.
Presents the generalized surficial geology of the Eagle River and Birchwood area. Scale is 1:63,360. Reproduced in Zenone, et al., 1974.

3 Schmoll, H.R., B.J. Szabo, M. Rubin, and E. Dobrovolny. 1972. Radiometric dating of marine shells from the Bootlegger Cove Clay, Anchorage area, Alaska. Geological Society of American Bulletin, V. 83, p. 1107-1114, 3 figs.
Includes a discussion of the seismically-induced failure of the Bootlegger Cove Clay.

2, 3, 4 Scott, R.F. 1966. Soil mechanics and foundation engineering aspects of the Alaskan earthquake of March 27, 1964. Proceedings 3d World Conference on Earthquake Engineering, New Zealand, 1965, Vol. 1. Wellington: New Zealand Institute of Engineers. P. 157-172.
Summarizes the geology and soil profiles of the Anchorage area, describes earthquake effects with respect to soil engineering, and discusses stability of slopes in the region.

2, 3 Scott, R.F. 1973. Behavior of soils during the earthquake in The Great Alaska Earthquake of 1964: Engineering. NAS Pub. 1606. Washington: National Academy of Sciences.
Stresses that adverse behavior of soils during the 1964 earthquake caused extensive damage, that the present knowledge of soil behavior is not sufficient for future earthquake-resistant design, and that additional research on properties of soils is needed.

3 Seed, H.B. 1968. Landslides during earthquakes due to soil liquefaction. Journal of the Soil Mechanics and Foundations Division (American Society of Civil Engineers), v. 94, no. SM5 (September 1968), p. 1053-1122. Also in The Great Alaska Earthquake of 1964: Engineering. NAS Pub. 1606. Washington: National Academy of Sciences, 1973.
Points out the necessity for engineers to study the destructive landslides caused by soil liquefaction in the 1964 earthquake in order to evaluate complex situations in the future.

3 Seed, H.B., and S.D. Wilson. 1966. The Turnagain Heights landslide in Anchorage, Alaska. Soil Mechanics and Bituminous Materials Research Laboratory Report. Berkeley: University of California, Department of Civil Engineering (1966). 55 p. See also Journal of the Soil Mechanics and Foundation Division, 93 (July 1967), p. 325-353. Also in The Great Alaska Earthquake of 1964: Engineering. NAS Pub. 1606. Washington: National Academy of Sciences, 1972.
Analyzes soil conditions in the Turnagain Heights slide area and concludes that the slide developed as a result of a loss in strength of the soils underlying the area.

2, 3, 8 Selkregg, L., E. Crittenden, and N. Williams, Jr. 1970. Urban Planning in the Reconstruction, The Great Alaska Earthquake of 1964. National Academy of Sciences, Washington, D.C., p. 186-242.
Describes the planning and reconstruction after the 1964 earthquake. Discusses some special reconstruction problems and their solutions.

1, 2, 3, 6, 7, 8 Selkregg, L. 1972. Environmental Atlas of the Greater Anchorage Area Borough, Alaska, University of Alaska. 105 p.
A summary of the physical and biological environment of the Greater Anchorage Area Borough. Intended for use by planners, policy makers and the general public. Contains maps, tables and explanatory text. Includes sections on wind, geology, groundwater, flooding and earth movements.

1, 2, 6, 7, 8 Selkregg, L. 1974. Alaska Regional Profiles: Southcentral Region, State of Alaska, Office of the Governor.
Maps, tables and explanatory text summarize scientific and technological data for use by planners, policy makers and the general public. Covers the southcentral region of Alaska. Contains sections on climate, topography, geology, groundwater and soils.

3, 8 Shannon and Wilson, Inc. 1964. Report on Anchorage Area Soil Studies, Alaska. U.S. Army Corps of Engineers, Alaska District, 300 p.
Describes the Anchorage landslides resulting from the 1964 earthquake. Presents the results of soils investigation of those slides. Borings, laboratory tests (including pulsating load and dynamic modulus tests), geophysical investigations, slope indicator measurements, minerology, physico-chemical analyses, paleontology studies, and vane shear tests were performed.

3, 4, 8 Shannon and Wilson, Inc. 1964. Preliminary report to U.S. Army Corps of Engineers on 4th Avenue slide, Anchorage, Alaska. Seattle: Shannon and Wilson, Inc. 10 p.
Summarizes surface observations in area of 4th Avenue slide, outlines subsurface explorations, describes laboratory testing program, summarizes interpretations of soil formations, discusses possible landslide mechanisms, and gives conclusions on the stability of this area, along with forthcoming remedial measures.

3, 4 Shannon and Wilson, Inc. 1964. Preliminary report to U.S. Army Corps of Engineers on Turnagain slide, Anchorage, Alaska. Seattle: Shannon & Wilson, Inc. 10 p.
Presents a summary of findings from subsurface exploration description of soil conditions around the Turnagain slide area and an analysis of the mechanism of failure.

3, 8 Shannon and Wilson, Inc. 1965. Remolding of Bootlegger Cove Clay with explosives. Preliminary stabilization studies for the Turnagain buttress for U.S. Army Corps of Engineers. Seattle: Shannon & Wilson, Inc. 180 p.
Describes field tests with a series of alternating explosive shots of small magnitude, fired with a time delay of more than 0.5 second between shots, is more effective in creating a disturbance to the clay structure and is less likely to cause critical vibrations in the Turnagain residential area.

3, 8 Shannon & Wilson, Inc. 1966. Electro-osmosis Field Test Section. Preliminary stabilization studies for the Turnagain buttress, U.S. Army Corps of Engineers, Alaska District. 153 p.

Presents the results of testing electro-osmosis as a method for stabilizing the Turnagain Landslide. Concluded that electro-osmosis would not be effective.

2 Small, J.B., and L.C. Wharton. 1969. Vertical displacements determined by surveys after the Alaskan earthquake of March 1964 in Volume III: The Prince William Sound, Alaska, earthquake of 1964 and aftershocks. Environmental Science Services Administration, U.S. Coast and Geodetic Survey. Washington: Government Printing Office, p. 21-33. Also in The Great Alaska Earthquake of 1964: Seismology and Geodesy. NAS Pub. 1602. Washington: National Academy of Sciences, 1971.
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2, 3, 5 Stanley, K.W. 1971. Effects of the Alaska earthquake of March 27, 1964, on shore processes and beach morphology. U.S. Geological Survey Professional Paper 543-J. Washington: Government Printing Office, 1968. 21 p. Also in The Great Alaska Earthquake of 1964: Geology. NAS Pub. 1601. Washington: National Academy of Sciences.
Reports that about 10,000 mi of shoreline in southeastern Alaska was affected by subsidence or uplift associated with the great Alaska earthquake; tells of effects on frontal beach ridges and stream mouths.

2, 8 Steinbrugge, K.V., and V.R. Bush. 1965. Review of earthquake damage in the western United States, 1933-1964 in earthquake investigations in the western United States, 1931-1964. U.S. Coast and Geodetic Survey Pub. 41-2. Washington: Government Printing Office. P. 223-256.
Stresses proper earthquake-resistant design of foundations and superstructure of buildings; finds that long-period ground motion has been particularly destructive to multistory structures.

2 Steinbrugge, K.V., J.H. Manning, and H.J. Degenkolb. 1967. Building damage in Anchorage in Volume II-A: The Prince William Sound, Alaska, earthquake of 1964 and aftershocks. Environmental Science Services Administration, U.S. Coast and Geodetic Survey. Washington: Government Printing Office. P. 7-217.
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2, 3 Stephenson, J.M. 1964. Earthquake damage to Anchorage area utilities, March 1964. U.S. Naval Civil Engineering Laboratory Technical Note N-607. Port Hueneme, California: U.S. Naval Civil Engineering Laboratory. 47 p.
Relates the damage suffered by the utilities at Anchorage to shock waves traveling through the soil and to the nature of the Bootlegger Cove Clay, which was responsible for larger landslides.

2, 3 Sturman, G. 1973. The Alaska highway system in The Great Alaska Earthquake of 1964: Engineering. NAS Pub. 1606. Washington: National Academy of Sciences.

Describes the damage to Alaska roads and bridges due to subsidence, high tides, and soil movement on the stream embankments during the 1964 earthquake.

2, 3 __________. 1973. The Alaska Railroad in The Great Alaska Earthquake of 1964: Engineering. NAS Pub. 1606. Washington: National Academy of Sciences.

Assesses the severe damage to The Alaska Railroad in the 1964 earthquake and describes reconstruction of the facilities.

2 Sykes, L.R. 1971. Aftershock Zones of Great Earthquakes, Seismicity Gaps and Earthquake Prediction for Alaska and the Aleutians, Journal of Geophysical Research, Vol. 76, p. 8021-8041.

Discusses tectonic theory, and the prediction of earthquakes in Alaska based on gaps in activity along known faults.

1, 3 Trainer, F.W., and R.M. Waller. 1965. Subsurface stratigraphy of glacial drift at Anchorage, Alaska in Geological Survey Research 1965: Short Papers in the Geological Sciences. U.S. Geological Survey Professional Paper 525-D. Washington: Government Printing Office. P. 167-174.

Indicates that glacial druft at Anchorage reaches a thickness greater than 5000 feet and concludes that disastrous slides during the earthquake were caused by failure of a thick clay unit exposed in the Anchorage bluffs.

5 U.S. Army Corps of Engineers, Alaska District. 1966. Concept Study, Turnagain Area Beach Erosion Stabilization, Anchorage, Alaska. 20 pp.

Discusses the natural buttressing effect of the Turnagain Slide. Includes erosion, slope stability, and slope protection information.

2 U.S. Coast and Geodetic Survey. 1966. The Prince William Sound, Alaska earthquake of 1964 and aftershocks. Fergus J. Wood, editor. Volume I: Operational phases of the Coast and Geodetic Survey program in Alaska for the period March 27 to December 31, 1964. Washington: Government Printing Office. 263 p.

Summarizes USC&GS operations in Alaska between March 27 and December 31, 1964; contains an account of the seismic history and setting of the area.

2 U.S. Coast and Geodetic Survey. 1967. The Prince William Sound, Alaska, earthquake of 1964 and aftershocks. Fergus J. Wood, editor. Volume II-A: Research Studies--Engineering Seismology. Washington: Government Printing Office. 392 p.

Combines nine engineering seismology papers as a study of vibrational effects on various types of building construction, mainly in the Anchorage area.

2 U.S. Coast and Geodetic Survey. 1969. The Prince William Sound, Alaska, earthquake of 1964 and aftershocks. Louis E. Leipold, editor. Volume II-B, C: Research studies--Seismology and marine geology. Washington: Government Printing Office. 350 p.
Gathers 11 seismology papers in Part B and 1 marine geology paper in Part C into a single binding; includes articles on seismological aspects of the Alaska earthquake, the mapping of crustal deformation in the Gulf of Alaska, and focal mechanism studies.

2 U.S. Coast and Geodetic Survey. 1969. The Prince William Sound, Alaska, earthquake of 1964 and aftershocks. Louis E. Leipold, editor. Volume III: Research and interpretive results--Geodesy and photogrammetry. Washington: Government Printing Office. 161 p.
Presents seven geodesy and photogrammetry papers in a single volume that also contains papers on gravity observations, vertical displacements, horizontal crustal movements and strain analyses.

3, 4 Varnes, J.D. 1969. Stability of the west slope of the Government Hill Port area of Anchorage, Alaska. Bulletin 125-D, U.S. Geological Survey. 61 p.
Based on testing of boring samples, the slopes along the west side of Government Hill appear susceptible to failure under seismic activity. Under static conditions, one slope evaluated appears stable, and the other is on the verge of failure. Describes historic evidence of sliding in the Government Hill area.

3 Waller, R.M. 1966. Effects of the March 1964 Alaska earthquake on the hydrology of southcentral Alaska. U.S. Geological Survey Professional Paper 544-A. Washington: Government Printing Office. 28 p. Also in The Great Alaska Earthquake of 1964: Hydrology. NAS Pub. 1603. Washington: National Academy of Sciences, 1968, p. 12-39.
Contains descriptions of water-level fluctuations, ejection of sediment-laden water, seiching of ice-covered lakes and streams, and changes in stream regimen.

3 __________. 1966. Effects of the March 1964 Alaska earthquake on the hydrology of the Anchorage area. U.S. Geological Survey Professional Paper 544-B. Washington: Government Printing Office. 18 p. Also in The Great Alaska Earthquake of 1964: Hydrology. NAS Pub. 1603. Washington: National Academy of Sciences, 1968, p. 82-96.
Describes immediate effects of stream-flow changes and groundwater fluctuations; explains lowered water levels and increased pore pressure.

2, 3 __________. 1966. Effects of the earthquake of March 27, 1964, in the Homer area, Alaska (with a section on Beach changes on Homer Spit, by Kirk W. Stanley). U.S. Geological Survey Professional Paper 542-D. Washington: Government Printing Office. 28 p. Also in The Great Alaska Earthquake of 1964: Geology. NAS Pub. 1601. Washington: National Academy of Sciences, 1971.

Describes geologic and hydrologic effects and relation to damage: tectonic subsidence, subsidence from compaction, submarine slides, postearthquake beach modifications.

2 Whitten, C.A. 1969. An evaluation of the geodetic and photogrammetric surveys in Volume III: The Prince William Sound, Alaska, earthquake of 1964 and aftershocks. Environmental Science Services Administration, U.S. Coast and Geodetic Survey. Washington: Government Printing Office, p. 1-4. Also in The Great Alaska Earthquake of 1964: Seismology and Geodesy. NAS Pub. 1602. Washington: National Academy of Sciences, 1972.

Evaluates geodetic surveys made after the Alaska earthquake and concludes that some postearthquake monitoring is essential for the future economic development of Anchorage.

3, 8 Wilson, S.D. 1967. Landslides in the City of Anchorage in volume II-A: The Prince William Sound, Alaska, earthquake of 1964 and aftershocks. Environmental Science Services Administration, U.S. Coast and Geodetic Survey. Washington: Government Printing Office. P. 253-297.

Gives a digest of the Shannon & Wilson, Inc. (1964) report on Anchorage area soil studies.

7 Zenone, C. 1974. Geology and Water Resources of the Girdwood-Alyeska Area, Alaska. Open-File Report. U.S. Geological Survey in cooperation with the Greater Anchorage Area Borough. 24 p.

Discusses the hydrogeologic setting, occurrence, availability, and quality of groundwater and surface water, and the existing and potential water problems of the Girdwood-Alyeska area. Includes data on selected wells.

1, 7 ___________. 1976. Geohydrology of the lowland lake areas, Anchorage, Alaska. Water-Resources Investigations WRI 76-22, 2 sheets.

Describes the interrelationship of geology and hydrology in the lowland lakes area of Anchorage, Includes geologic map, water table map, and hydrographs.

1, 7, 8 Zenone, C., H.R. Schmoll, and E. Dobrovolny. 1974. Geology and Groundwater for land-use planning in the Eagle River-Chugiak Area, Alaska, U.S. Geological Survey. 25 p.

Describes geologic and hydrologic features and conditions as they relate to development in the Eagle River-Chugiak area. Includes well data and interpretive geologic maps.

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*Subjects

2, 3, 4, 5 — Alaska, State of, Department of Military Affairs, Division of Emergency Services. 1978. Hazard Summary Report for the State of Alaska.
A general overview of disaster problems and their mitigation in Alaska. Includes sections on flooding and geologic hazards.

3 — American Society of Civil Engineers. 1976. Liquefaction Problems in Geotechnical Engineering. ASCE National Convention, Sept. 27 - October 1, 1976. 388 p.
Includes a 104-page state-of-the-art review of soil liquefaction by H.B. Seed, and ten papers on various aspects of liquefaction problems.

2, 3, 4, 5, 6, 7 — Bolt, B.A., W.L. Horn, G.A. MacDonald, R.F. Scott. 1975. Geological Hazards. Springer-Verlag. New York. Heidelberg, Berlin. 328 p.
A textbook-type compilation of descriptions and examples of the various geologic hazards.

7 — Carey, K.L. 1970. Icing Occurrence, Control and Prevention, an Annotated Bibliography, CRREL Special Report 151, U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire. 57 p.
An annotated bibliography on icing, 93 entries.

7 — Carey, K.L. 1973. Icings Developed from Surface Water and Ground Water, Cold Regions Science and Engineering Monograph III-D3, U.S. Army Corps of Engineers, CRREL, Hanover, New Hampshire. 65 p.
Summarizes the existing knowledge of the occurrence, control, and prevention of icings.

2, 3 — Committee on Earthquake Engineering Research. 1969. Earthquake Engineering research. A report to the National Science Foundation prepared by the National Academy of Engineering, Division of Engineering-National Research Council. Springfield [Virginia]: Federal Clearinghouse for Scientific and Technical Information, 1969. 313 p.
Discusses problems of strong-motion seismology; soils, foundations; and earth structures; structural dynamic analysis; and postearthquake study of behavior of structures, to provide evaluation of earthquake engineering effectiveness.

4, 5 — Conservation Foundation. 1977. Physical Management of Coastal Flood Plains: Guidelines for Hazards and Ecosystems Management. Sponsored by U.S. Army Corps of Engineers,

*Reference contains information relating to the subjects keyed: 1-General Geology, 2-Seismicity and Tectonics, 3-Seismically-Induced Ground Failure, 4-Avalanches or Non-Seismic Landslides, 5-Coastal Flooding, Coastal Erosion, or Tsunami, 6-Wind, 7-Groundwater or Permafrost, 8-Hazard Evaluation, Mitigation Measures, or Land Use Planning.

Council on Environmental Quality, U.S. Environmental Protection Agency, Federal Insurance Administration, U.S. Fish and Wildlife Service, and Office of Coastal Zone Management.
Defines nine natural features of coastal zones; including floodlands, wetlands, bluffs, dunes, and beaches, and describes ecological functions, natural resistance to hazards, environmental problems, potential management responses, and conservation guidelines and restoration techniques.

2, 3, 4, 8 Daniel, Mann, Johnson & Mendenhall. 1972. Geophysical Hazards Investigation for the City and Borough of Juneau, Summary Report, 92 p. summary report, 202 p. technical supplement.
Presents discussion severity maps, and recommendations concerning seismic, mass wasting, and snow avalanche hazards in Juneau.

2, 8 Donovan, N.C., and A.E. Bornstein. 1978. Uncertainties in Seismic Risk Procedures, Journal of the Geotechnical Engineering Division, Proceedings of the American Society of Civil Engineers, V. 104, No. GT7, July, 1978, pp. 869-897.
Presents case histories of problems encountered in seismic risk analyses.

7 Ferrians, O.J., Jr., R. Kachadoorian and G.W. Green. 1969. Permafrost and Related Engineering Problems in Alaska. U.S. Geological Survey and Professional Paper 678. 37 p.
Describes the regional and local conditions controlling permafrost occurrence, geomorphic features related to permafrost, and solutions to engineering problems encountered in areas of permafrost.

2, 3, 8 Joint Committee on Seismic Safety. 1974. Meeting the Earthquake Challenge, Final Report to the Legislature, State of California, California Division of Mines and Geology Special Publication 45.
Presents the committee's recommended comprehensive approach to seismic safety in California, including legislative proposals. Includes advisory group reports on Engineering Considerations and Earthquake Sciences, Disaster Preparedness, Postearthquake Recovery and Redevelopment, Land Use Planning, and Governmental Organization and Performance.

4, 8 Martinelli, M. 1974. Snow Avalanche Sites, Their Identification and Evaluation, U.S. Department of Agriculture, Forest Service, Agriculture Information Bulletin 360. 26 p.
Describes avalanche terminology, conditions and evidence, and ways of estimating size and frequency. A nontechnical illustrated booklet.

7 National Research Council of Canada. 1978. Proceedings of the Third International Conference on Permafrost, July 10-13, 1978, Edmonton, Alberta, Canada. Vol. 1, 947 p.
Contains 139 papers submitted by permafrost scientists and engineers from eleven countries. Foreign papers have translations of abstracts.

4, 8 Perla, R.I. and M. Martinelli, Jr. 1976. Avalanche Handbook. U.S. Department of Agriculture, Forest Service, Agriculture Handbook 489. 238 p.

An illustrated handbook describing avalanche mechanisms, and procedures for avoiding avalanche disasters. Methods of control include artificial release, defense structures, public warnings, and land-use mitigation.

2, 3, 8 Proceedings of the Second International Conference on Microzonation for Safer Construction - Research and Application. 1978. San Francisco, California, November 26 - December 1, 1978. Vols. I-III. 1537 p.

A collection of over 100 papers on various aspects of seismic microzonation. Includes papers on seismicity, site response, earthquake insurance, government responsibility in microzonation, examples of seismic zonation schemes, strong motion modeling and prediction, and earthquake engineering mechanics and structural design.

3 Seed, H.B. 1967. Soil stability problems caused by earthquakes. Soil Mechanics and Bituminous Materials Research Laboratory Report. Berkeley: University of California, Department of Civil Engineering, January 1967. 57 p.

Classifies types of soil-instability problems, including settlement of cohesionless soils, liquefaction of saturated sands, and failures of fills on weak foundations.

3 Seed, H.B., and C.K. Chan. 1966. Clay strength under earthquake loading conditions. Journal of the Soil Mechanics and Foundations Division, 91 (March 1966), pp. 53-78.

Presents procedure for determining the combinations of sustained stress and pulsating stress that will cause failure of a given soil.

2, 3, 4, 5 U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of Coastal Zone Management. 1976. Natural Hazard Management in Coastal Areas. Washington, D.C. 261 p. (plus appendices).

A guide for reducing losses due to natural hazards in coastal areas. Includes sections on coastal erosion, landslides, earthquakes, tsunamis, avalanches, and subsidence. Has a 28-page annotated bibliography and a directory of agencies concerned with natural hazards in the coastal zone.

1, 8 Varnes, D.J. 1974. The Logic of Geologic Maps, with Reference to Their Interpretation and Use for Engineering Purposes. U.S. Geological Survey Professional Paper 837. 48 p.

A discussion of the definition and classification of map units, with emphasis on the problems presented by maps intended for use in civil engineering.

AERIAL PHOTOGRAPHS

TYPE	DATE	SCALE	ROLL/ LINE	FRAMES	AREA
U-2 Color Infrared	8/78	1:60,000	02662	6943-6948	Twenty Mile River to Bird Creek
U-2 Color Infrared	8/78	1:60,000	02662	6643-6647	Bird Creek to Potter
U-2 Color Infrared	8/78	1:60,000	02662	6947-6961	Downtown Anchorage
U-2 Color Infrared	8/78	1:60,000	02664	7183-7186	Eagle River to N. End of Knik Arm
U-2 Color Infrared	7/77	1:20,000	364-03	005-011	Girdwood to Fire Island
U-2 Color Infrared	7/77	1:20,000	364-03	086-088	Campbell Lake to Bird Creek
Color	8/78	1:12,000	28	007-008	Indian
Color	8/78	1:12,000	29	002	Indian
Color	8/78	1:12,000	30	001	Indian
Color	8/78	1:12,000	31	001-003	Bird Creek
Color	8/78	1:12,000	35	002-004	Girdwood/Glacier Creek
Color	8/78	1:12,000	36	003-004	Girdwood/Alyeska/ Glacier Creek
Color	8/78	1:12,000	37	005	Alyeska
Color	8/78	1:12,000	37	008	Glacier Creek