The ORE BIN
Volume 26, No. 12
December, 1964

EARTHQUAKE GEOLOGY OF THE PORTLAND AREA, OREGON

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The Alaska Good Friday earthquake of March 27, 1964, was one of the most severe ever recorded on the North American continent. The vast damage caused by this quake emphasizes anew the importance of seismic considerations in the location and design of public buildings and other civil works.

In this report the authors point out that the Portland area has had a long history of earthquakes and can expect more; they summarize the information on the Alaska earthquake in the belief that knowledge gained from that catastrophe can be applied to earthquake resistance considerations for the Portland area; and they discuss the geologic and engineering factors that could influence the type and extent of damage in the event of a major local earthquake.

Emphasized is the need for the installation of a sufficient number of strong-motion seismographs in the Portland area to record the reaction of the various geologic units to earth movement, so that this information can be made available to those concerned with locating and designing civic structures.

Acknowledgments

The authors are very grateful to the following persons who generously contributed their time and experience by critically reading the manuscript and offering many helpful suggestions to the benefit of this paper: Mr. F. W. Libbey, mining engineer; Mr. Rowland S. Rosé, consulting structural engineer; Mr. Kurt H. Siecke, consulting engineer; and Mr. Ronald McReary, civil engineer, all residents of the Portland area.

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Introduction

History of Oregon earthquakes

Oregon has experienced many more earthquakes than is generally realized, and a good share of them have occurred in the vicinity of Portland. Since 1841, at least 160 earthquakes have been recorded in Oregon, not including those originating out of the state or at sea but felt here. Prior to 1900, only about 30 quakes had been known. Undoubtedly many more occurred but were not reported because of the scattered population, poor communications, and lack of instrumentation.

Earthquakes having intensities of VIII on the modified Mercalli scale have been reported for Oregon at Port Orford in 1873, at Portland in 1877 and in 1880, and at Milton-Freewater in 1936. Earthquakes with intensities of VII were reported at Umatilla in 1923 and at Portland in 1962; and intensity quakes of VI occurred in Portland in 1953 and at Salem in 1957. Portland alone has been the epicenter for at least 46 earthquakes ranging from II to VII in intensities. Nine of these were V and above (Berg and Baker, 1962).

Future earthquake probability

Oregon lies within the circum-Pacific belt of crustal instability along with California and Washington, both of which have recorded violent shocks in recent years. Since Oregon is a tectonically active state, consideration of the effects of earthquakes is necessary in all design and construction, particularly for schools, churches, and public buildings.

Prediction of earthquakes is a subject of great interest to many investigators; however, the difficulties to be overcome in this worthy pursuit are staggering. Such predictions may very well prove to be beyond the capability of man. Records indicate that where earthquakes have occurred in the past they will probably recur, and that the intensity of the recurrence can be much greater than that of previous quakes. The probability that an earthquake will recur increases proportionally as time elapses.

Measuring earthquakes

The earth's crust is never still. Many of its small, continual vibrations can be detected only by delicate instruments. These trivial motions, called microseisms, are caused by heavy traffic, railroad trains, wind, tide, changes in barometric pressures, storms, large explosions, and similar phenomena. Earthquake waves differ from microseisms in that they have definite beginnings and endings, and they have a definite point of origin (epicenter). They are caused primarily by movement along faults resulting from tectonic adjustments in the earth's crust or, in some cases, by vulcanism.

Earthquake waves are vibrations which travel through the earth as elastic waves. Three types of undulations originate from this source. The primary or "P" wave has a vibration parallel to the direction of propagation and is longitudinal and compressional in motion. It is the fastest wave and the one which arrives first. It travels at a velocity that equals the speed of sound through rock and varies with the density of the media. The secondary or "S" wave is a transverse one which vibrates at right angles to the direction of propagation and arrives at its destination after the "P" wave. The "L" or longest wave is a surface surge which travels along the upper surface of the disturbed rock and arrives last. These waves travel greater distances than the faster ones and tend to affect materials having larger masses. The distance from the earthquake center, or epicenter, is measured by the difference in arrival time of the "P" and "S" waves.

Several scales have been devised to describe the magnitude and intensities of earthquakes. Magnitude refers to the instrumentally measured amplitude of the recorded trace corrected for the distance from the epicenter. Magnitude, measured by seismographs, is independent of the location of the recording station. The most commonly used magnitude rating is the Richter scale. The magnitude of an earthquake is related in a general way to the amount of energy released; however, the magnitude is not a quantitative measure of energy.

Intensity refers to the observed qualitative effects of earthquake forces (that is, shaking, principally in a lateral direction). These differ from area to area, depending upon the local geology and distance from the epicenter. It is to be noted that the intensity rating is not intended to be a damage report; consequently, secondary damages such as those caused by fire, flood, or landslide should be excluded when assigning an intensity rating. Frequent reference in earthquake literature is made to the Rossi-Forel, Mercalli, and modified Mercalli scales of intensity. The modified Mercalli scale is most commonly used today (see chart on page 212).

The Alaska Good Friday Earthquake

The following paragraphs describe the reported circumstances of the great Alaska earthquake, the types of damage it caused, and the geology of the Anchorage area. This information is presented for the purpose of allowing a correlation between the Anchorage earthquake and the possible effects of a similar earthquake in or near Portland.

Instrumented data

In spite of the great amount of instrumented information gathered throughout the world during and following the Good Friday earthquake, little if any of this will be of use to engineers or geologists concerned with the effects of earthquakes on man and his works. Instrumented records, to be of use in the design of structures, must include figures on amplitude, duration, maximum acceleration, and period of vibration within the immediate area by strong-motion seismograph. Recording instruments had not been placed within the Anchorage area prior to the March 27 earthquake. Summarized briefly are the general conclusions concerning the Good Friday earthquake:

Location of epicenter: Northern Prince William Sound, near the east shore of Anakuik Island, approximately 80 miles southeast of Anchorage, Alaska.

Time of beginning of earthquake: 5:36 p.m. (local time), March 27, 1964.

Magnitude: 8.4 to 8.6 on the Richter scale.

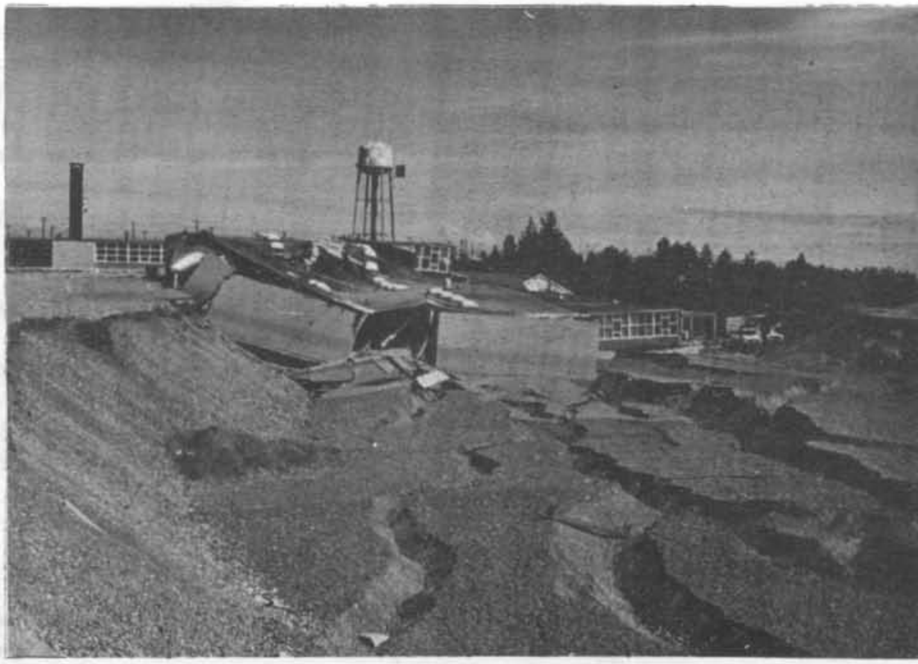
Loss of life: Approximately 114 persons dead or missing.

Property damage: Approximately $750,000,000.

THE MODIFIED MERCALLI INTENSITY SCALE OF 1931*
(Simplified for this report)

Scale degree	Effects on persons	Effects on structures	Other effects	Rossi-Forel equivalent	Equivalent shallow magnitude
I	Not felt except by few under favorable circumstances.			I	
II	Felt by few at rest.		Delicately suspended objects swing.	I-II	2.5
III	Felt noticeably indoors.		Duration estimated.	III	
IV	Felt generally indoors.		Cars rocked, windows rattled.	IV-V	3.5
V	Felt generally.	Some plaster falls.	Dishes, windows broken, pendulum clocks stop.	V-VI	
VI	Felt by all, many frightened.	Chimneys, plaster damaged.	Furniture moved, objects upset.	VI-VII	
VII	Everyone runs outdoors, felt in moving cars.	Moderate damage.		VIII	5.5
VIII	General alarm.	Very destructive and general damage to weak structures. Little damage to well-built structures.	Monuments, walls down, furniture overturned. Sand and mud ejected. Changes in well-water levels.	VIII-IX	6
IX	Panic.	Total destruction weak structures, considerable damage well-built structures.	Foundations damaged, under-ground pipes broken.	IX	
X	Panic.	Masonry and frame structures commonly destroyed. Only best buildings survive.	Ground badly cracked, rails bent. Water slopped over banks.		
XI	Panic.	Few buildings survive.	Broad fissures, fault scarps. Underground pipes out of service.	X	8.0
XII	Panic.	Total destruction.	Acceleration exceeds gravity. Waves seen in ground. Lines of sight and level distorted, objects thrown in air.		8.5

* Howell 1959



Government Hill School and adjacent gravel lot broken by landslide, Anchorage, Alaska. Photograph by Donald R. Herrick.

West Anchorage High School with once-level playground destroyed by landslide, Anchorage, Alaska. Photograph by Donald R. Herrick.

Seismic sea waves: Heavy damage in Kodiak, Seward, Valdez, and other portions of Alaska; loss of life inflicted as far away as Crescent City, California.

Duration: Not officially recorded. (The most common estimates of eyewitnesses ranged from two to four minutes. Several persons in the Anchorage area, however, timed the duration of perceptible motion and reported it to be of the order of seven minutes.)

Period of vibrations: Unknown. (Most estimates range between one and two cycles per second.)

Maximum amplitude of vibrations: Unknown.

Intensity at Anchorage: Not officially assigned. Unofficial estimates of the intensity in the Anchorage area place it at modified Mercalli VIII.

Maximum acceleration: Unknown. This information can be obtained only by means of strong-motion seismographs which must be installed and maintained in a locality on which information on earthquake motion is to be obtained. As recently as 1963, approximately 60 of the U.S. Coast and Geodetic Survey strong-motion seismographs were in use in the western United States.

Earthquake damage in Anchorage

Even a cursory examination of the Anchorage area following the earthquake of March 27 would have suggested immediately that the loss of life in Anchorage was remarkably small in comparison to the magnitude and dollar volume of the physical damage. This can be attributed in part to the fact that schools were closed, that many people had already left the downtown district where heavy damage occurred, and, in part, to simple good fortune. Similar mitigating effects attended the seismic sea-wave disasters in other parts of Alaska (Valdez, Seward, Kodiak); these waves arrived at the time of low tide. Nevertheless, the greatest loss of life was caused by seismic sea waves.

Damage inflicted in the Anchorage area by the Good Friday earthquake may be divided into two principal categories: (1) "normal" earthquake damage to structures induced by lateral forces, and (2) loss of foundation support caused by landslides set in motion by the earthquake.

Structural damage: Structural damage caused by lateral acceleration was, in general, confined to: (1) large buildings, (2) buildings which were poorly designed to resist lateral forces, and (3) buildings in which faulty construction practices or materials had been used (Steinbrugge, 1964). Many of the large, old, heavily constructed, reinforced concrete buildings survived without appreciable damage, as did a number of the one-story concrete block structures. On the other hand, several of the most recently constructed major buildings were totally demolished. Two nearly identical high-rise apartment structures suffered heavy damage to spandrel walls, and one major bearing wall in each building failed in a lower story. Nevertheless, the other main structural elements remained intact (National Board of Fire Underwriters and Pacific Fire Rating Bureau, 1964).

Building construction in the Anchorage area is governed by applicable provisions of the Uniform Building Code of the Pacific Coast Building Officials Conference. The large amount of structural damage which occurred as a result of the earthquake inevitably focuses attention on the adequacy of the building code. There is no evidence to indicate, however, that lateral acceleration caused irreparable damage where good design and construction principles were followed in accordance with the code.

Landslides: Landslides accounted for most of the major damages suffered by buildings in the Anchorage area. Four major slides and two minor ones occurred during the earthquake. The largest slide in terms of geographical area happened in the Turnagain housing district between the International Airport and downtown Anchorage. This slide involved a catastrophic flow of weak layers of the subsoil, accompanied by breaking of the upper layers into large blocks of earth. The entire mass moved as much as 500 to 600 feet in a northerly direction toward Cook Inlet. Approximately 75 houses were totally destroyed by this slide.

A large area in the apartment house district was involved in a landslide in which a single large block of the soil formation moved from 5 to 12 feet in a westerly direction toward Cook Inlet. Most of the damage done to structures in this slide occurred in a trough or graben which formed along the easterly margin of the slide block and along the pressure ridge which developed at the toe of the block. A similar slide took place in the downtown business district, where a large block of the soil formation moved approximately 17 feet in a northerly direction. A graben was formed along the south margin of this block and a pressure ridge developed at the toe of the block. Buildings located entirely on the block suffered no more damage than buildings located elsewhere at Anchorage; buildings within the graben area, however, were either severely damaged or completely destroyed.

The fourth of the major slides was in the Government Hill area. This resulted in severe damage to a new school building and destroyed a number of houses.

Geologic units in Anchorage affected by the earthquake

The City of Anchorage is built on a relatively low, flat plain of outwash sand and gravel which is underlain by a layer of soft clay and, at considerable depth, by compact glacial till (Miller and Dobrovolny, 1959). Mesozoic and Tertiary rocks underlie the Anchorage area at depths of hundreds of feet. The Mesozoic rocks rise to the east to form the Chugach Range, the highest elevation of which is 4,300 feet.

The geologic formations of greatest significance in the recent earthquake consist of: (1) the upper layer of outlying sand and gravel known as the Naptowne outwash, and (2) the underlying Bootlegger Cove Clay. The Naptowne outwash ranges from 20 to 40 feet in thickness and consists of well-graded, compact sands and gravels. This formation provides the foundation for most of the major buildings in the Anchorage area, the only exceptions being those structures which are located near the lower edges of the bluffs which border Cook Inlet.

The Bootlegger Cove Clay formation consists of three principal clay units, the uppermost of which is a fairly stiff layer ranging from 10 to 20 feet in thickness. It is underlain by a 20- to 30-foot layer of extremely soft, sensitive clay, which is in turn underlain by a stiff layer. Sand layers and lenses occur in somewhat erratic manner throughout the formation. Many of these are water bearing, although they do not provide domestic or commercial water supplies. The strength profile of the Bootlegger Cove Clay is such that shear strengths of the order of 0.5 to 1 ton per square foot occur within the upper stiff layer, decreasing to 0.3 ton per square foot in the zone of high sensitivity, and then increasing again to 0.8 to 1 ton per square foot in the lower stiff layer. The very soft, sensitive layer occurs generally between sea level and 20 feet above sea level.

The landslides which occurred in the Anchorage area developed primarily within the highly sensitive layer of clay, although it is not certain whether the primary cause of sliding was the sensitivity of the clay itself or the loss of strength of cohesionless sand or silt units under repeated shock-load applications. In any event, the slides may be considered to be the result of repeated dynamic stress application to weak, saturated materials. Complete loss of strength of both the sensitive clay and the cohesionless sand has been shown to occur in laboratory tests in which pulsating loads were applied to triaxially loaded samples. These tests were performed at the University of California in Berkeley and are reported by Shannon and Wilson (1964).

Although the Turnagain slide differed drastically in form from any of the other slides in the Anchorage area, the basic causes of all were essentially the same. The probable cause of the difference in form of the Turnagain slide is believed to be the presence of a greater thickness of the highly sensitive member of the Bootlegger Cove Clay.

Seismology of Anchorage area

Anchorage is located within a well-known earthquake region, one of many seismic belts which adjoin the Pacific Ocean. Seismic records for this area show that during the past 50 years only one earthquake of magnitude 8 or greater has occurred in Alaska. However, those of magnitude 7.0 or 7.5 have recurred nearly every five years during that time, and those of magnitude 6.0 to 6.9 are recorded at intervals of about three years (U.S. Coast and Geodetic Survey, 1964).

Earthquake damage in other Alaskan towns

In Seward the most extensive damage was caused by submarine landslides and by seismic sea waves. The Seward waterfront was completely destroyed as a result of a liquefaction slide of submerged gravels with deltaic structure. A strip of waterfront approximately 400 to 500 feet wide and nearly 7,000 feet long subsided into Resurrection Bay. Severe secondary damage was caused by fire from petroleum storage facilities.

Damage and loss of life were recorded at the Alaska Railroad terminal of Whittier; this was principally the result of seismic sea-wave inundation and fire.

Valdez, in addition to receiving severe damage from the ground motion during the earthquake, also suffered heavily from submarine landslides caused by liquefaction of submerged granular materials and was inundated by the seismic sea waves which followed the earthquake.

Geology of the Portland Area

Topography

The topography of the Portland area is controlled by the structure of the older bedrock and is modified by younger erosional and depositional features formed by the

Columbia and Willamette Rivers and smaller streams. The folded and faulted Columbia River Basalt forms the prominent northwest-trending Tualatin Mountains in the Portland area. The rather gentle slope along the west side of the mountains is controlled by the basalt dip slope, and younger lavas of Plio-Pleistocene age have tended to modify this topography. Mt. Sylvania, a relatively uneroded shield cone composed of these younger lavas, forms a prominent landmark near the south end of the Tualatin Mountains. The rather steep east flank of the Tualatin Mountains has been dissected by steep canyons of small streams flowing into the Willamette River. The silt overlying much of this basalt has been subject to landsliding due to oversteepening. In some cases the weathered basalt has been involved in landslides.

The business district and Guild Lake area on the west side of the city and the major part of northeast Portland are composed of terraced sands and gravels and interbedded silts of varied fluvio-lacustrine depositional histories and some man-made land.

Paralleling the Columbia River is a band of recent alluvium, including man-made fill. The area ranges from 1 to 2 miles in width and is low enough to be flooded annually by high waters except where it is protected by dikes. It is cut by numerous erosional scars; many are water filled. In the Willamette River channel area, made land is situated at Mocks Bottom, Guild Lake, Swan Island, and a strip several blocks wide along the east bank from the Broadway Bridge south to the Ross Island Bridge.

The Columbia River flood plain is bounded on the south by a strip of older terrace materials half a mile wide, with a slope of about 200 feet per mile. In west Portland these older terraces also slope about 200 feet per mile toward the Willamette River. In east-central Portland, these terrace deposits range from about 75 feet elevation near the Willamette River to 275 feet elevation near Mt. Tabor.

An older, gently sloping to nearly flat-lying terrace crops out in a strip about $1\frac{1}{2}$ miles wide trending southeast from the St. Johns area to S.E. 82nd Avenue, where it widens considerably and extends south to Mt. Scott.

Several prominent hills, generally round in outline with diameters ranging from half a mile to several miles, dot the terraces. These hills are resistant volcanic vents topped by either cinders or lavas and flanked by Troutdale gravels. They range from several hundred to about 1,100 feet in elevation.

Stratigraphy

Consolidated rock units cropping out in the Portland area consist of both volcanic and sedimentary rocks and include Columbia River Basalt, Boring Lava, Sandy River Mudstone, and the Troutdale Formation. Unconsolidated rock units include wide-spread lacustrine deposits, loessal clay and silt, recent alluvial material deposited by the Columbia and Willamette Rivers, and artificial fill. The distribution of these units throughout the Portland area is shown on the geologic map, page 222.

Columbia River Basalt: Columbia River Basalt of mid-Miocene age crops out in a nearly continuous band occupying most of the Tualatin Mountains (West Portland Hills). It is best exposed in road cuts and in stream and creek canyons and ravines along the east slope of the mountains facing the Willamette River. The formation consists of a variable sequence of weathered to unweathered basaltic lava flows. The total thickness of the Columbia River Basalt in the Portland area ranges from 800 to 1,000 feet as determined by deep oil tests drilled by Richfield and Texaco Oil

Companies. The basalt overlies the Oligocene marine sedimentary beds assigned to the Scappoose Formation and in turn is overlain by younger sedimentary and volcanic rocks.

The unweathered basalt flows are commonly vesicular and scoriaceous in their upper and lower parts and are dark gray and fine grained. Weathering of the basalt surface has been extensive and deep. Basalt exposures are generally light gray with variable brownish tones. The rock has been weathered locally to a depth of 170 feet (Allen, V. T., 1948, p. 61) and commonly to depths of 20 to 30 feet.

Sandy River Mudstone: Sandy River Mudstone of Pliocene age is locally present in the Portland area and is made up of claystone, siltstone, and sandstone beds. It is exposed in a small area on the west side of the Tualatin Mountains in secs. 26 and 27, T. 1 N., R. 1 W., and has been penetrated by deep-water wells in the downtown business district area in west Portland. It attains its greatest areal extent in the drainage systems of the lower Clackamas and Sandy Rivers (Trimble, 1963). It has a maximum thickness of 200 feet in the west Portland business district and is probably much thicker in the east Portland area where the Columbia River Basalt is structurally low.

Troutdale Formation: The Troutdale Formation of Pleistocene age is exposed along the flanks of local prominences. In east Portland it crops out at Rocky Butte, Kelly Butte, Mt. Tabor, and Mt. Scott. In west Portland it is exposed in a few small areas along the flanks of the Tualatin Mountains. It is extensive in the subsurface of the east Portland area and to the west in the Tualatin Valley. The formation consists of moderate- to well-indurated conglomerate and sandstone. It is believed to be more than 800 feet thick in east Portland, and in west Portland water-well logs indicate it ranges in thickness from 20 to 300 feet.

Boring Lavas: Boring Lavas of Plio-Pleistocene age locally overlie the Columbia River Basalt, the Sandy River Mudstone, and the Troutdale Formation. The distribution of the Boring Lava is controlled by the location of its eruptive vents and the topography over which the lavas flowed. These lavas are exposed in a nearly continuous belt flanking the west side of the Tualatin Mountains in the Portland area and extend from the Oregon City area northwest into Columbia County. Boring Lavas are present at Rocky Butte, Mt. Tabor, Mt. Scott, Mt. Sylvania, and generally widespread in the foothills of the Cascade Range east and south of Portland. It is likely that other parts of east Portland may be underlain by Boring Lava.

These lavas are composed mainly of flows of olivine basalt, but locally around the vents are pyroclastic rocks composed of volcanic ash, breccia, and cinders. The lavas are light gray in color and are commonly expanded in texture, containing small irregular holes. Weathering is usually much less than that of the Columbia River lavas.

Portland Hills Silt: Portland Hills Silt (loessal sandy silt) of Pleistocene age occurs as a mantle of yellowish-gray-brown, sandy, clayey silt which caps the Tualatin Mountains. It occurs mainly along the flatter areas and caps the spurs and the ridges as well. The eastern flank of the Tualatin Mountains is generally too steep for the retention of much silt, but where it is present it is relatively unstable and any overloading or oversteepening can cause slope failure. The west flank of the mountains is less steep and the silt is much thicker and more widespread. The silt generally conforms to the surface of the underlying rocks. The greatest known thickness is 55 feet but generally is less than 25 feet.

Lacustrine deposits: The Portland lowlands are covered almost entirely by Pleistocene to Recent gravel, sand, silt, and clay of lacustrine origin. These deposits lie between elevations of 50 and 350 feet, and their original surface has been dissected and terraced. Three units having significant distribution to be identified and mapped (Trimble, 1963) are a gravelly, a sandy, and a silty phase.

The gravelly deposits of this unit are exposed entirely in east Portland. In most places the gravels consist of slight to moderately compacted pebble, boulder, and cobble gravels having a sandy matrix. The gravels grade to pebbly sand near the western and northwestern limits of its distribution. Deltaic foreset bedding is common in exposures made as the result of gravel pit operations.

The sandy phase is present in an outcrop belt paralleling the Willamette River, generally extending eastward from the foot of the Tualatin Mountains. The sand is fine to very fine grained, gray to gray-brown in color, and firm to moderately dense. In north Portland it becomes medium to coarse grained and occasionally pebbly with well-developed stratification. The sand reaches a maximum thickness of about 50 feet. In west Portland it occurs between elevations of 50 to 150 feet, and much of the west-side business district is located on this unit.

The silty and clayey phase is found only in the Tualatin Valley area west of Portland and in the lowlands south of Oregon City.

Recent alluvium: Recent alluvium deposited by the Willamette and Columbia Rivers is the youngest geological unit in the Portland area. The Willamette River deposits consist mainly of uncompacted sand and silt and locally of gravel. The sand and silt deposits occur up to elevations of 50 feet. The gravels occur as prominent river bars from Ross Island upstream to the mouth of the Clackamas River.

Alluvium deposited by the Columbia River in northeast Portland is entirely fine sand and silt occurring on the flood plain up to an elevation of about 50 feet.

Artificial fill: Artificial fill areas are located in the Guild Lake area of northwest Portland, at Swan Island in the Willamette River of north Portland, and local areas along the Portland waterfront, one of the largest of which is that adjacent to the east end of the Ross Island Bridge.

Guild Lake was filled primarily by material sluiced down from the west hills Westover Terrace area. Fill material for the Swan Island and Ross Island Bridge areas was dredged from the Willamette River.

Ground water

The ground-water table is consistently near the ground surface in all of the flood plain areas adjacent to the Columbia and Willamette Rivers. In addition, many of the higher gravel terraces contain perched water tables. Many of these higher areas have a semi-perched water table which fluctuates with the seasonal rainfall. Ground water also is found at depth in confined and unconfined aquifers in the

Troutdale Formation and Columbia River Basalt.

Geologic structure

The Columbia River Basalt has been folded into a moderately gentle asymmetrical anticline with its axis roughly parallel to the northwest-trending Tualatin Mountains. The steep limb of the anticline is on its northeast flank. The eastern scarp of the Tualatin Mountains forms a nearly straight line from Oswego northwest to Scappoose Creek, where a major fault has been indicated by geologic mapping. To the southeast, the Clackamas River channel appears to have been controlled by this same fault, since this part of the Clackamas River is in direct line with the east scarp of the Tualatin Mountains. Additional evidence that the east edge of the Tualatin Mountains is faulted came from a study of the aftershocks of the November 1962 earthquake (Dehlinger and others, 1963), which indicated the disturbances emanated from about 6 miles east of the escarpment in north Portland at a depth of 15 to 20 km. The trace of an east-dipping normal fault at depth would be in agreement with this location.

A second major fault has been mapped in the Chehalem Mountains east of Newberg (Hart and Newcomb, 1956). This fault is aligned with the gash through the Tualatin Mountains now occupied by Lake Oswego and may have provided the zone of weakness which allowed erosion to cut this feature. Additional prominent faults west of the Portland area are shown on the tectonic map, page 225. Release of energy from tectonic forces along these lines of weakness could greatly affect the Portland area.

The San Andreas rift zone, which passes through San Francisco and extends northwestward off the coast of Oregon, lies 270 miles west of Astoria. Seismic waves originating from this fault zone have been felt as far inland as Portland.

Reaction of Geologic Units to Earthquake Shocks

General observations

The relationship between earthquake damage and geology is obscured by imperfect observations of the effects of the interaction of myriad variables. A few simple conclusions may be stated; however, many writers on this subject are tempted to over-simplify. For example, it is generally recognized that areas of thick alluvium or unconsolidated sediments are subject to the greatest damage during a severe earthquake. Consequently, an amplification of acceleration is commonly assumed for such geologic units, as compared to accelerations which occur in competent bedrock. Without question, a tendency toward amplification of vibrations does exist in thick deposits of alluvium, particularly under shocks of light or moderate intensity; however, the use of observed damages to substantiate the amplification of vibration leads to the inclusion of extraneous information, for example, foundation failures induced by differential settlement of loose alluvial deposits and not recognized as such.

Attempts to establish a relationship between damage and geology usually lead to a distinction between "good ground" and "bad ground." The implication is that "bad ground" should be avoided by persons or agencies contemplating building construction. Unfortunately, the environment of modern urban areas does not allow the luxury of avoiding "bad ground" which, aside from a susceptibility to damage from earthquakes, may have every other conceivable advantage of location. It therefore appears that more attention should be given to the various types of damage which may befall structures on thick alluvium, and the susceptibility of the structure to each type of damage.

Geologic formations may react to earthquake vibrations in a number of different ways. Five of the most important types of reaction are as follows: (1) elastic, (2) fluid, (3) brittle, (4) viscous or visco-elastic, and (5) granular.

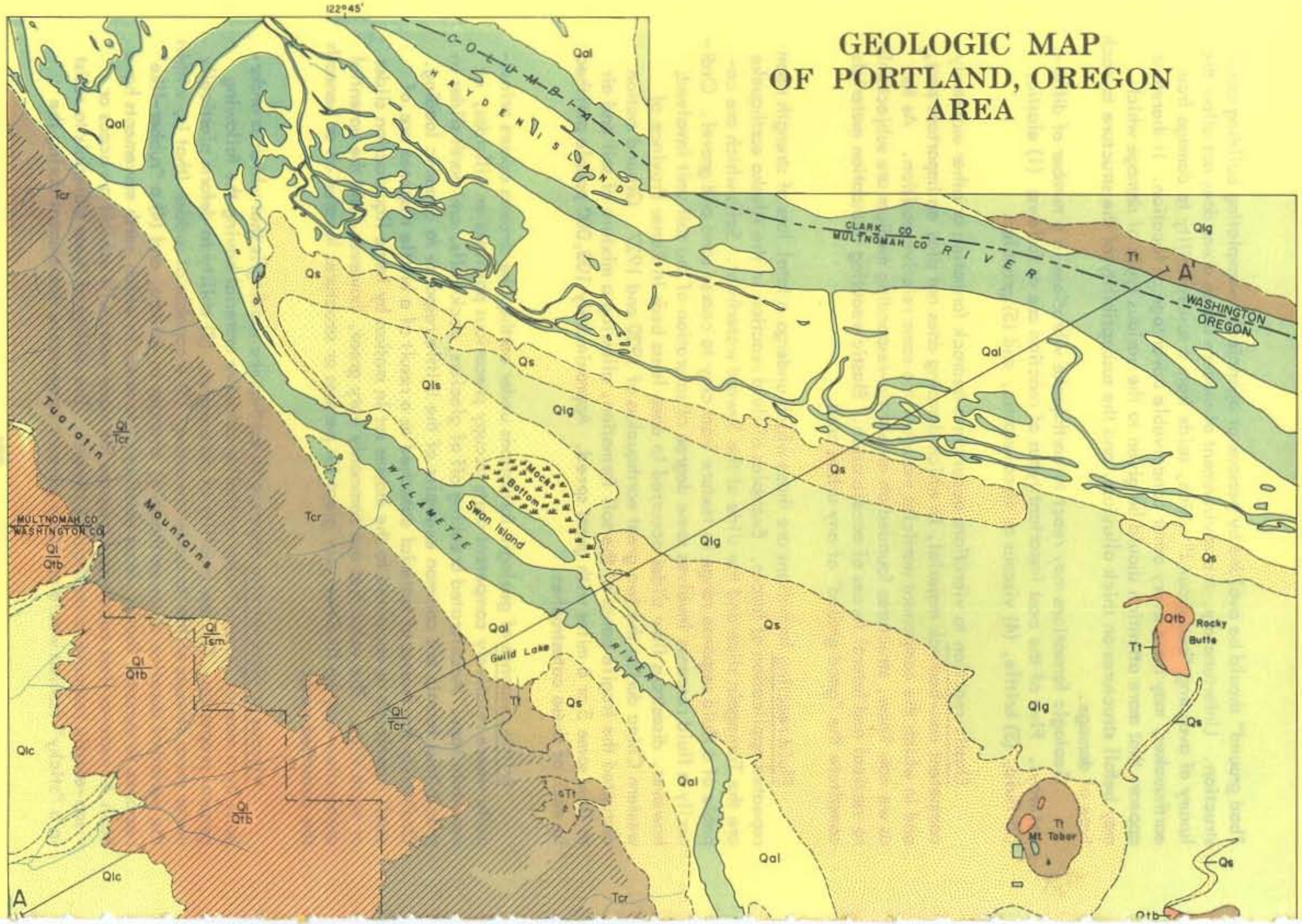
Elastic reaction to vibrations occurs in a bedrock formation or other extremely competent non-bedrock material, in which damping does not play an important part, and in which the component particles maintain the same relative position. As far as we now know, structures founded on an elastic-responding medium are subject only to vertical and lateral forces of acceleration. Elastic-reacting foundation materials constitute the "good ground" of any urban area.

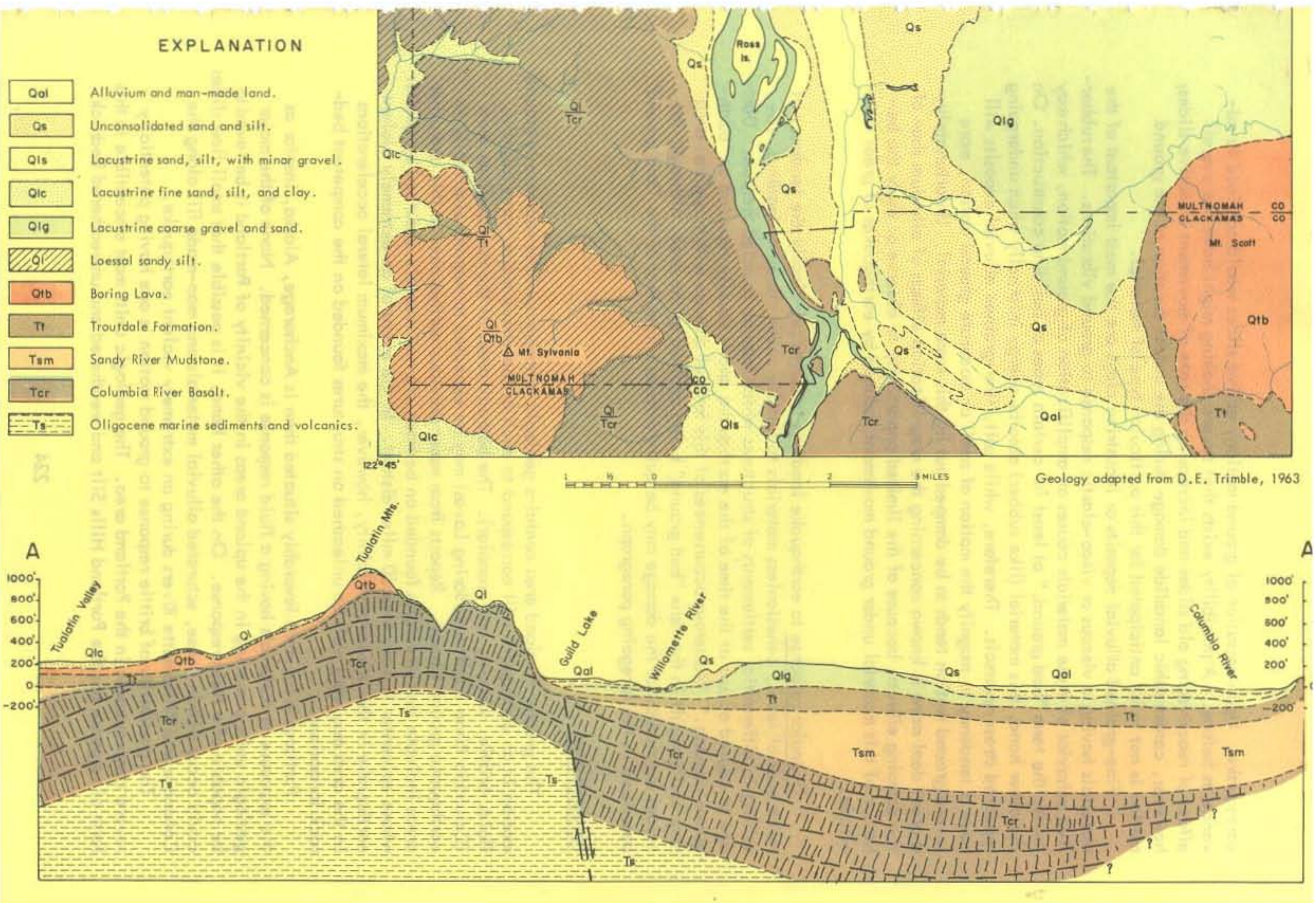
Fluid reacting formations are those which undergo a total loss of strength upon repeated application of forces. Examples of fluid reaction in the Alaska earthquake are the Turnagain slide and the slide of the Seward waterfront. Soils which are capable of a fluid response range in texture from clay to coarse sand and gravel. Ordinarily a fluid response involves some degree of saturation of the soil unit involved; however, disastrous flow slides occurred in deep loess beds in Kansu Province of western China during the two great earthquakes of 1920 and 1927. Ground motion disrupted the fragile bonds of the soil formation, allowing a mixture of soil and air to flow some 5 or 6 miles with great speed. Approximately 100,000 people perished in each of these catastrophes.

Brittle response of geologic formations under earthquake stresses occurs principally where relatively competent units occupy precarious positions on hillsides, or mountain tops. Accelerated breaking off of glaciers, rock-falls, and earth slides in precipitous terrain are common examples of the brittle response to dynamic loading. Ordinarily the masses of material detached as a result of a brittle response are of small magnitude as compared to the masses set in motion by large liquefaction slides or earth slips. The velocities are commonly very great, however, and the potential destruction may be likewise very great for persons or structures located on or beneath the detached mass.

Viscous or visco-elastic response to earthquake loading is that which is undergone by a mass of "plastic" clay or similar cohesive material having the following general properties: (1) low mobility of pore water, (2) ability to deform plastically under shear stresses of low to moderate order, (3) incapable of sudden (that is, within the period of duration of an earthquake) changes in volume, and (4) a "rubber-like" response to dynamic loads. Most existing slide areas in which earth movements have been in more-or-less continuous progress for many years will exhibit a viscous or visco-elastic response to earthquake stresses. The ability of these materials to resist in a "sticky" fashion would probably prevent large-scale detachment during the

GEOLOGIC MAP OF PORTLAND, OREGON AREA





Geology adapted from D.E. Trimble, 1963

earthquake. Upon cessation of ground motion, active slides would continue to advance as before. A possibility exists that severe shaking might have the overall effect of reactivating old slides and increasing the rate of movement of active slides; however, catastrophic landslide damage during the actual duration of the ground motion is not to be anticipated for this particular type of material.

Fine-grained alluvial deposits or lacustrine clays are the most important of the materials having a viscous or visco-elastic response to ground vibrations. The rubber-like behavior of these materials causes an amplification of ground motion, which may justify the term "bad ground," at least for certain types of building construction. On the other hand, this material (like rubber) absorbs energy internally when undergoing repeated stress reversals. Therefore, while soft, fine-grained alluvial deposits will have a tendency to magnify the motion of small or moderate ground motion, more severe ground motion tends to be damped out by this same material. Unfortunately, a great deal more is known concerning the magnification effects of alluvium than of the damping effects, because of the limited opportunity to observe or study the behavior of this material under ground movement induced by earthquakes of great magnitude.

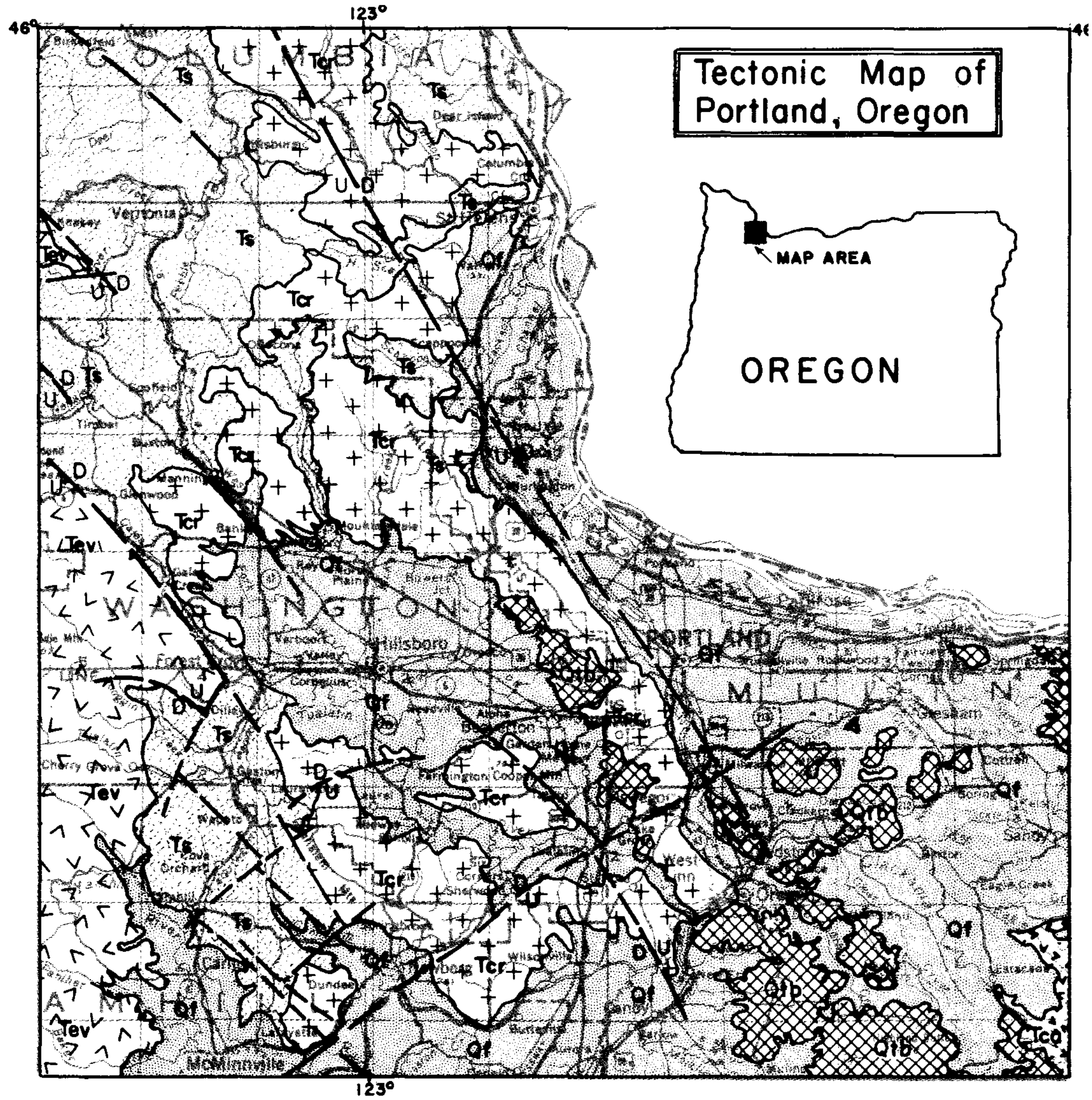
Granular response to earthquake loadings involves principally the tendency of thick beds of loose, cohesionless materials to densify under vibratory loadings, resulting in differential settlements of structures which may be founded thereon. Damage so caused occurs at the time of the earthquake and is usually reported as "earthquake damage." Numerous occurrences of this form of damage within a given area may easily result in the term "bad ground" being applied to the area, although the actual mechanism of the damage may be quite different from that of the "bad ground" described in the foregoing paragraph.

Portland area

The greater Portland area contains geologic formations whose response to ground motion in an earthquake will correspond to each of the above major types (elastic, fluid, brittle, viscous, and granular). The bedrock areas of the metropolitan area (Columbia River Basalt and Boring Lavas) may be expected to respond elastically to earthquake ground motion. Reports from many previous earthquakes in this and other areas indicate that structures founded on bedrock are not severely disturbed by quakes whose epicenter is more than 50 miles distant. In the event of an extremely violent earthquake in the immediate vicinity, however, the maximum lateral accelerations in the area may very well be unleashed on structures founded on the competent bedrock formations.

Portland is far more favorably situated than is Anchorage, Alaska, insofar as the exposure to materials having a fluid response is concerned. None of the major geologic units occurring in the upland areas in the vicinity of Portland is believed to be capable of a fluid response. On the other hand, it is possible that small flow slides could occur within loose, saturated alluvial materials and man-made fill along the Columbia and Willamette Rivers during an extremely violent earthquake.

The possibility of brittle response to ground motion is one having potentially severe consequences in the Portland area. The geologic units most susceptible to this form of response are the Portland Hills Silt and weathered and unweathered bedrock



EXPLANATION

Qf Valley fill

Qtb Boring Lavas

Tcq Cascade Andesite

Tcr Columbia River Basalt

Ts Eocene and Oligocene marine sediments

Tev Mid-Eocene volcanics, rocks, and sediments

0 10 20 Miles

Base map from U.S.G.S.

formations. In all instances the danger is the greatest where permanently high shear stresses are present because of steep high slopes, or in the case of bedrock, high vertical cliffs. Existing planes of weakness, such as jointing systems, interflow zones, and bedding planes, will be of great importance in individual localities.

Geologic units which will react to earthquake shocks in a viscous, visco-elastic, or granular fashion are confined primarily to the made-land and flood plain areas of the Willamette and Columbia Rivers. The possibilities of damage to structures in these areas appear to be somewhat greater than elsewhere for the following reasons: (1) differential settlement of loose granular deposits, (2) amplification of ground motion in light or moderate shocks, and (3) susceptibility to ground motion from distant earthquakes.

In the event of a nearby quake of extremely severe magnitude, the effect of ground motion of structures founded on these materials would tend to be mitigated by damping within the softer formations. In general, it is probable that the more severe the earthquake, the more serious would be damage resulting from differential settlement of structures founded on loose granular materials, regardless of what damping might take place within these materials.

Resonance

Vibrations from earthquakes at great distance tend to be of longer periods than nearby earthquakes as a result of damping out of the shorter period vibrations. Tall buildings may have natural periods of the same order as the ground vibrations induced from distant earthquakes; consequently, the phenomenon of resonance can be introduced in which the buildings are thrown into violent motion. Although the general nature of the phenomenon is easily understood, an inquiry into the exact mechanics of the process is complicated by the intricate interaction between the various components of the structure and the interaction between the structure and its foundation. Moreover, virtually no information is available concerning the type of ground vibrations and accelerations which a given building may be called upon to withstand.

Earthquake-Resistant Construction

The task of the engineering profession is not to restrict the construction of tall buildings to competent bedrock foundations, but to work toward the gathering of the necessary data and analytical tools to provide engineering solutions to the problems.

It is obvious that requirements of earthquake-resistant construction will not be the same for all types of geologic formations. Construction on an elastic-responding formation would require only consideration of pure "shaking forces," in the manner now prescribed in the building codes. This is not meant to imply, however, that only a pseudostatic lateral load is all that is needed in the design of a major structure on an elastic foundation.

Design of structures on the remaining types of formations involve problems in which mere attention to the horizontal forces may not be all that is required to effect a satisfactory degree of earthquake resistance. For example, construction on a formation having a granular response must reckon with the possibility of differential settlement and its damaging effects during an earthquake. A number of foundation treatments may be employed to this end, details of which are, of course, beyond the scope of the present paper.

Foundations on viscous or visco-elastic media offer particularly vexing design problems, inasmuch as the problems of amplification of acceleration, and resonance enter the picture. Although some authorities on seismology have taken the position that fine-grained alluvial deposits are "bad ground" for tall buildings, the fact nevertheless remains that these formations have been used and will continue to be used for this purpose where economic advantage dictates.

Somewhat more justification may be found for declaring formations (or locations) to be "bad ground" where a brittle or a fluid response is indicated. Even in these situations, however, attempts to provide constructive solutions are often warranted. For example, the serious liquefaction hazard of the Bootlegger Cove Clay at Anchorage has been found to be capable of containment, at least in certain areas, by the construction of a stabilizing (buttress) fill and possibly by several forms of in-situ stabilization. High, vertical cliffs can often be strengthened by rock bolting or by consolidation grouting to minimize or eliminate the danger of brittle response.

Since the primary purpose of earthquake provisions in building codes is to establish minimum standards for the safeguard of human life in the event of a major earthquake, extensive property damage can occur even though building codes are strictly enforced. To go beyond the "earthquake safe" provisions of the building code in order to make a structure "earthquake proof" may not be economically or physically possible. The better built structures at Anchorage apparently fulfilled the requirements for "safe" construction even though cost of repair may be uneconomical. Earthquake design reflects the present state of knowledge of the effect of earthquakes upon buildings.

The National Board of Fire Underwriters (1964) agrees that the code adopted at Anchorage is satisfactory from the standpoint of earthquake "resistance." They report, however, that performance of large structures was not as satisfactory as might have been expected. The following factors were listed as responsible for individual building failures:

1. Lack of professional plan checking by a structural engineer qualified in the field of earthquake engineering.

2. Inadequate field inspection by a governmental representative. Examples of insufficient grout around reinforcing steel in concrete block construction were cited as part of the evidence.

3. Faulty construction techniques as determined by improperly bonded joints in concrete, caused by foreign material between pours in "monolithic" construction.

4. Inadequate soils analysis. Soils and geologic information are needed to establish conditions in general areas. Major structures should have additional reports on the geology and soils.

Whether more detailed design procedures should be included in building codes if they were available is a subject on which the profession is sharply divided, some engineers holding that a code is an infringement on professional latitude and responsibility, while others maintain that codes should be strengthened and "loop-holes" plugged. For purposes of the discussion this is a moot point, in view of the current lack of information. It would appear that the information and analytical methods necessary to design earthquake-resistant structures on various types of geologic formations should first be developed and made available to the profession. It is entirely possible that as more knowledge is gained in this field the building code provisions will be revised and refined.

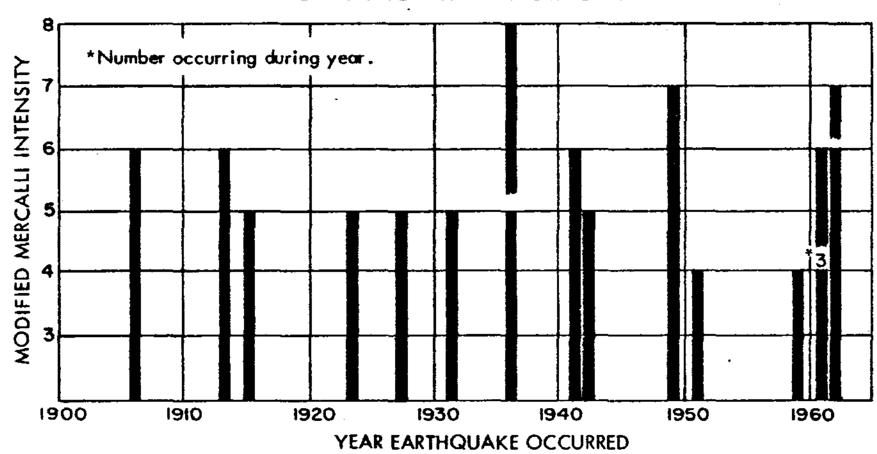
Conclusions

Although important scientific advances have been made in the field of seismology in recent years, the application of seismographs to engineering has lagged far behind. In spite of all of the studies made of the damage caused by the Alaska earthquake, no clear-cut conclusions have been reached as to whether the acceleration at Anchorage should be regarded as extremely severe, moderately severe, severe, or merely ordinary. Similarly, if a strong earthquake were to occur tomorrow in the Portland area, engineers and seismologists here would be in almost the same degree of confusion. The single strong-motion instrument in the Portland area is located in a downtown district on deep alluvium; this would be useful in correlating damages to buildings in the downtown area with recorded accelerations and ground displacements. No information would be obtained, however, for the bedrock areas, the flood plains, or for alluvium at more distant points.

This serious shortcoming can be met only by the installation of at least one strong-motion seismograph for each geologically unique ground condition. Such seismographs should be capable of recording maximum amplitude and acceleration, duration, period of vibration, and total intensity. They should require a minimum of attention other than routine inspection and maintenance.

The establishment of a system of strong-motion seismographs could best be undertaken by a joint effort of private and governmental organizations morally responsible for the safety of lives and property. Once such a system is operating, future quakes will then give information which can be applied to the design of earthquake-resistant structures for each type of geologic foundation. Since modern seismographs have now been developed for this purpose, the installation of such instruments in the Portland area should not be delayed.

EARTHQUAKES IN OREGON



Adapted from Oregon Section, A.S.C.E. Earthquake Committee, 1949.

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TSUNAMIS ON THE OREGON COAST

By Clifford E. Schatz, Herbert Curl, Jr., and Wayne V. Burt
Department of Oceanography, Oregon State University
Corvallis, Oregon

During the early hours of the morning of March 28, 1964 a tsunami struck the Oregon coast. This phenomenon, commonly called a "tidal wave," was generated by the earthquake that had shaken Alaska the evening before. The seismic waves forming the tsunami originated in the vicinity of the earthquake's epicenter and traveled in all directions to ocean shorelines where they were eventually dissipated; in some areas there was substantial loss of life and property.

Residents along the Oregon coast can be thankful that this tsunami caused relatively little loss along our shores. A tsunami of comparable magnitude struck the Hawaiian Islands in 1946 resulting in the loss of 159 lives and a $25 million property damage. Hawaii was 2,300 miles away from the epicenter in the Aleutians of that devastating earthquake, whereas our coast is only about 1,500 miles from Alaska. Oregon was fortunate this time for several reasons: the initial direction of impetus imparted to the seismic waves was away from our coast; the intervening continental shelf topography aided in refracting and dissipating the waves; and, finally, the generally high and rugged coast line of Oregon resulted in ultimate dissipation of the waves on unpopulated shorelines.

The Department of Oceanography, Oregon State University, in keeping with the national goal of oceanography to further man's knowledge of the oceans for the public's interest and welfare, dispatched survey teams up and down the Oregon coast to study the effects of this tsunami [1/]. A preliminary study of the data collected by these teams very pointedly emphasizes the perhaps obvious fact that major waves will be rapidly dissipated on our rugged open coast, but that our estuaries are especially vulnerable. Since the areas surrounding the latter are generally densely populated and will become more so within the next few years, it is apparent that a study should be conducted to determine to what extent a larger tsunami may affect the estuaries and the action which can be taken to reduce loss of life and property.

Each estuary has its own peculiarities. The location of jetties and sea walls, the existence of tidal flats and sloughs, the shape and length of the channel and the depth and width of the basin enter into the effects abnormal waves can produce. For example, referring to the accompanying chart: (1) At Coos Bay, the initial wave of about 10 feet above mean high water was dissipated in its travel up the channel by the wide tidal flats and was of negligible height by the time it reached Pony Point about 7 miles up the channel. (2) At Florence, on the Siuslaw River, the initial wave was about 8 feet above mean high water at the Coast Guard Station near the entrance, but due to a fairly narrow channel the wave was apparently only slightly dissipated by the time it reached Florence in the South Slough and surrounding tidal

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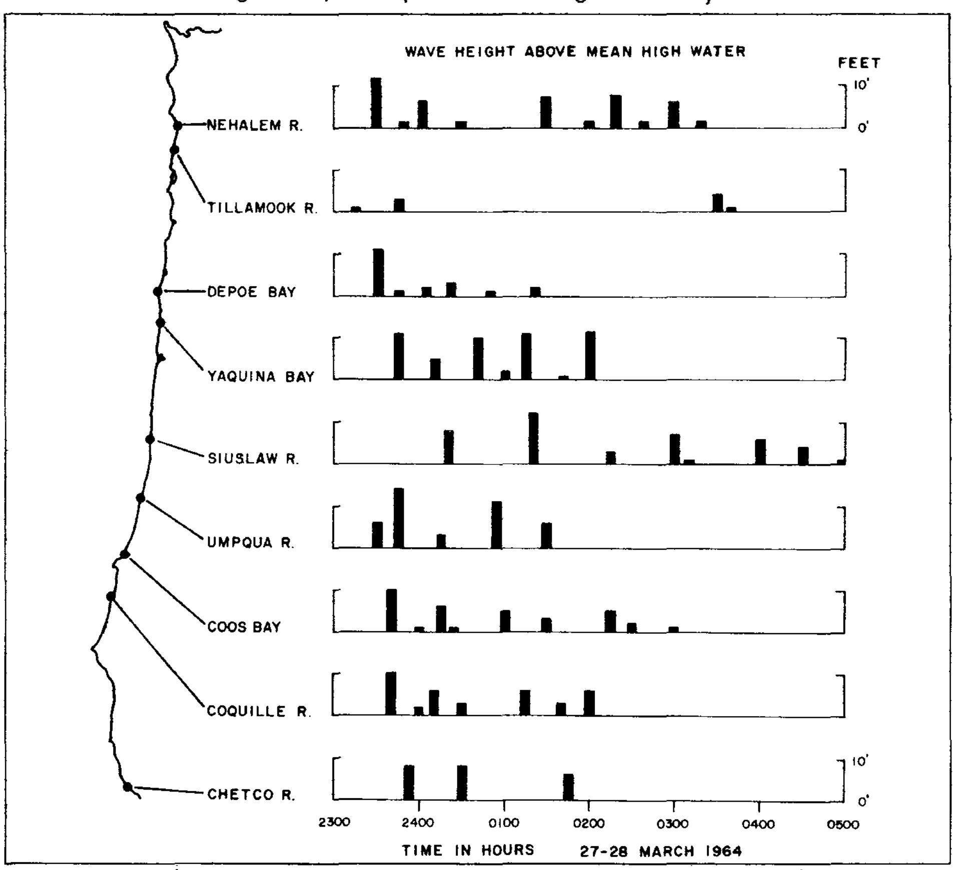
1/ Although it is not possible to acknowledge their efforts individually here, more than 20 members of the faculty and student body of the Department of Oceanography took part in this survey. Their efforts are greatly appreciated.

flats. (3) At Reedsport, about 10 miles up the Umpqua River only negligible indications existed of the 14-foot wave that was measured at the entrance. The meandering river with its wide tidal flats quickly dissipated the wave's energy. (4) In Yaquina Bay, four large waves of almost equal height were observed; whereas, in the other estuaries the subsequent waves generally decreased in magnitude following the second wave. This effect at Yaquina Bay could possibly be attributed to a seiche characteristic which is similar to the rocking motion of water from side to side in an open basin.

Since the Oregon coast is faced across the Pacific Ocean by many areas of strong earthquake activity, it is highly probable that many tsunamis have struck, and will continue to strike, our coast. It is possible that the next tsunami may be of considerably greater magnitude than this most recent one, which could increase the loss of life and property logarithmically. The Department of Oceanography at Oregon State University, therefore, proposes to initiate further studies of the major estuaries as personnel and funds permit to determine probable effects of direct seismic waves, tidal bores, and seiches of more powerful tsunamis. In line with this, survey teams made up of graduate students and staff members will be organized and briefed at the beginning of each term, and will be sent to the coast whenever reliable information predicts the approach of a tsunami. It is hoped that the results of these studies, along with those of other agencies, will prove rewarding and timely.



(Based on observations of U.S. Coast Guard personnel at the above locations.)

OREGON LEASES TWO OFFSHORE TRACTS

The State Land Board leased two of 18 submerged tracts offered at a lease-sale held in Salem December 3, 1964. Total bonuses paid amounted to $28,996. Added to this sum was $13,600 to cover rental for the first year on the two tracts.

The two leases are located along the Pacific shore three miles south of the mouth of the Umpqua River (see The Ore Bin for May, 1964, page 92). The only firms to bid on the state offshore tracts were Standard Oil Co. of California and Shell Oil Co.

Tract No.	Company	Bonus Bid	Per Acre Value
37	Shell Oil Co.	$15,663*	$2.27
37	Standard Oil Co. of California	13,662	1.98
38	Standard Oil Co. of California	13,333*	1.98
38	Shell Oil Co.	8,911	1.33

*Winning bid.

* * * * *

GROUND WATER AVAILABLE IN FORT ROCK BASIN

A professional paper recently issued by the U.S. Geological Survey reveals that an ample supply of ground water exists in volcanic rocks beneath the semiarid Fort Rock Basin, where a short growing season requires irrigation for successful farming. The report, entitled "Geologic factors that control the occurrence and availability of ground water in the Fort Rock Basin, Lake County, Oregon," is by E. R. Hampton and was prepared in cooperation with the Oregon State Engineer. The 1,500 square-mile basin is underlain by Pliocene to Recent rock units consisting largely of volcanic and pyroclastic materials. Depth and areal distribution of the water-bearing rock units are influenced by a system of northward-trending broad folds and normal faults.

The 29-page report (Professional Paper 383-B) includes illustrations, well logs, and a detailed geologic map with cross sections. The publication may be obtained from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402. The price is $1.50.

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BRISTOL NAMED CHAIRMAN OF ADVISORY COUNCIL

Fayette I. Bristol, president of Bristol Silica Co., Rogue River, Oregon, was elected chairman of the Western Governors' Mining Advisory Council for the coming year. The council will present its recommendations to the Western Governors' Conference when that group, under the chairmanship of Governor Mark O. Hatfield, meets at Portland, Oregon, in June 1965.

* * * * *

UPPER JURASSIC FOSSILS STUDIED

Recently issued by the U.S. Geological Survey is Professional Paper 483-D, "Upper Jurassic Mollusks from Eastern Oregon and Western Idaho," by R. W. Imlay. Dr. Imlay describes the Upper Jurassic formations in the three regions of northeastern Oregon and adjacent parts of Idaho where the mollusks have been found: Izee area near Burns, Oregon; Snake River Canyon near the northeast corner of Oregon; along Dennett Creek near Mineral, Idaho. The fact that more than 13,000 feet of strata were deposited in eastern Oregon during only a part of the Upper Jurassic should be of interest to geologists concerned with sedimentation and tectonics. The close affinities of the Oregon-Idaho ammonites with those of the same age in western British Columbia and Alaska increases our knowledge of the paleogeography of this part of the globe during Upper Jurassic time.

The 21-page report also includes a systematic description of the ammonite faunas. It may be obtained from the Superintendent of Documents, U.S. Government Printing Office, Washington, D. C. The price is 30 cents.

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WESTERN CASCADE RANGE DESCRIBED

"Geology of the central and northern parts of the Western Cascade Range in Oregon," by D. L. Peck, A. B. Griggs, H. G. Schlicker, F. G. Wells, and H. M. Dole, has been published as Professional Paper 449 by the U.S. Geological Survey in cooperation with the Oregon Department of Geology and Mineral Industries. The report describes the geology of the mountainous region lying between the High Cascades and the Willamette Valley and north of lat. 43° N. This belt of volcanic rocks consists of deformed and partially altered flows and pyroclastic rocks, the age of which ranges from late Eocene to late Miocene, as determined chiefly from fossil plants from more than 50 localities. These volcanic rocks overlie or interfinger westward with marine sedimentary rocks, and in the southwestern part of the area overlie pre-Tertiary plutonic and metamorphic rocks of the Klamath Mountains. The report is accompanied by a geologic map.

Professional Paper 449 may be obtained from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. Price has not yet been announced. A limited number of copies will be for sale by the Department as soon as they are received from the Geological Survey.

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CALAPOOYA RIVER GETS NEW SPELLING

The Calapooya River, which flows generally northwestward out of the Western Cascades in Linn County and joins the Willamette River at Albany, is now to be known as <u>Calapooia</u> River. This is in accordance with the most recent (January through April, 1964) list of Decisions on Geographic Names in the United States, by the U. S. Board on Geographic Names.

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