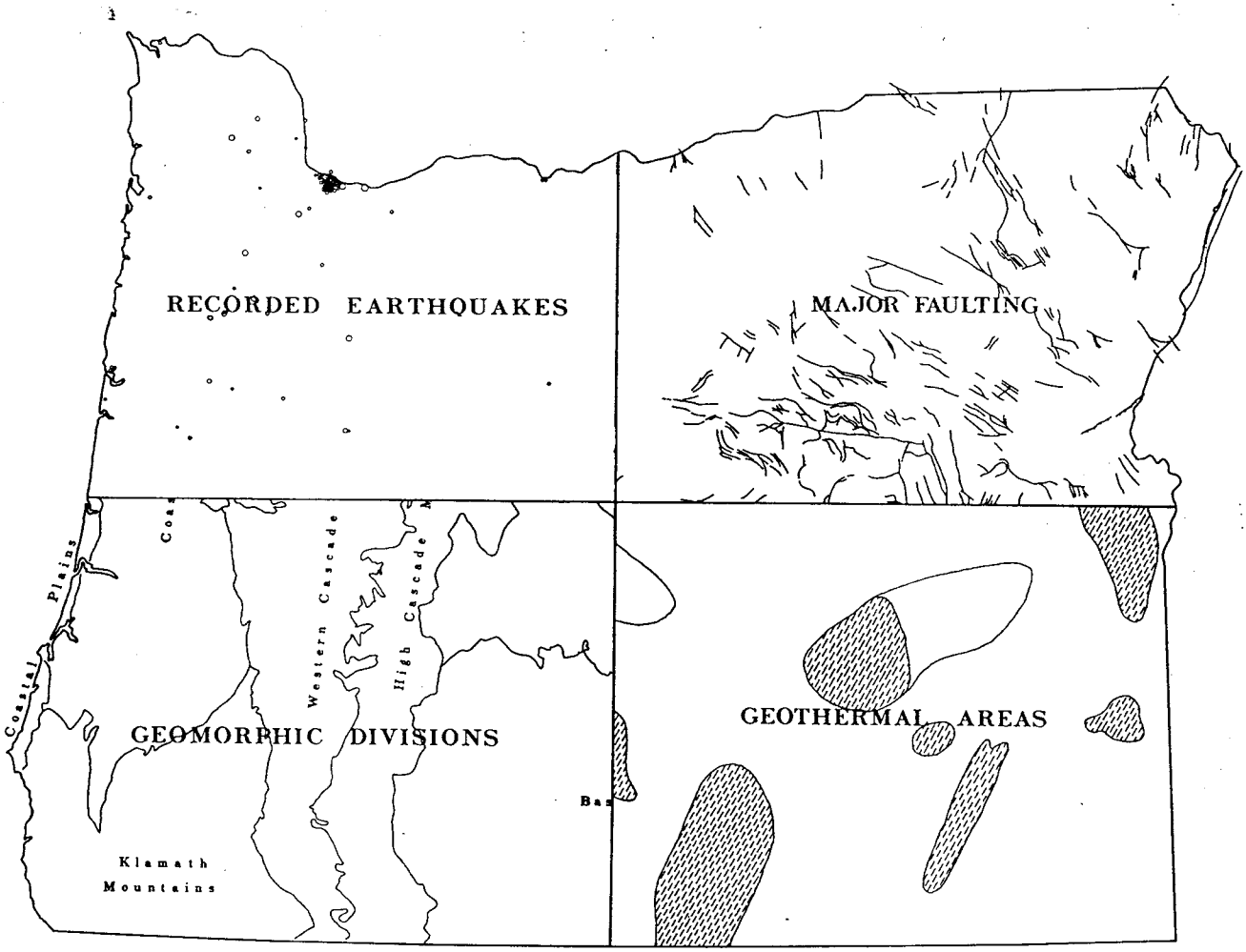
GEOLOGIC CRITERIA FOR SITING NUCLEAR POWER PLANTS IN OREGON



Prepared for the

STATE NUCLEAR AND THERMAL ENERGY COUNCIL

by

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

1973

GEOLOGIC CRITERIA FOR SITING NUCLEAR POWER PLANTS IN OREGON

Prepared for the

State Nuclear and Thermal Energy Council

by

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CONTENTS

	Page
Part I	
Introduction	1
Acknowledgments	1
Earthquakes in Oregon	3
Microearthquakes	8
Seiches	8
Tsunamis	8
Recent Volcanic Activity	11
Tectonic Features of Oregon	13
Unstable Foundation Rocks	16
Slope instability	17
Soil liquefaction	17
Subsidence	17
Siting characteristics by Geomorphic Province	19
Coastal Plain	19
Coast Range	19
Klamath Mountains	19
Willamette Valley	20
Western Cascades	20
High Cascades	20
Columbia Plateau	20

Page

High Lava Plains 20

Basin and Range 21

Owyhee Upland 21

Blue Mountains 21

Recommendations - Geology and Seismicity 21

Part II

General Geology of Oregon 23

Geologic History 25

Paleozoic Era 25

Mesozoic Era 25

Cenozoic Era 27

Evidence for Present Crustal Movements 28

Uplift and downwarp 29

Crustal slippage 30

Bibliography 31

Appendix

Oregon earthquakes, 1841-1970 36

Historic surface faulting - conclusions 43

Disaster protection and preparedness - volcanism 47

List of consultants 49

Correspondence 50

FIGURES

1. Seismicity of the earth 4
2. Scale of earthquake intensities 5
3. Earthquake characteristics of Oregon. 7
4. Seismic risk map of Oregon 9
5. Seismic risk map of the U.S. 10
6. Tsunami warning system 12
7. Tectonic features of the Pacific Northwest 14
8. Map showing major rift systems on the continent margin 15
9. Sea-floor spreading model 15
10. Map showing generalized geology of Oregon 24
11. Geologic time chart 26

MAP POCKET

Regional tectonic map

Statewide tectonic map

Statewide seismic map

Geomorphic province map

Map showing geothermal areas

State geologic map

Siting suitability map

PART I

Introduction

This report has been prepared for the State Nuclear and Thermal Energy Council to explain regional geologic criteria for siting nuclear power plants. It is accompanied by maps (in pocket) and tables (in appendix) compiled as guides to locating future power installations. Regional designations are based on siting suitability as determined by the siting task force. After several transitions, the task force decided upon two classifications: "suitable" and "less suitable". It was felt that more investigation would be needed before geological factors could be designated as "unsuitable" for construction of nuclear power plants. Therefore, it should be understood that within the areas shown on the siting map as "suitable" and "less suitable" are localities which are unsuitable for construction of power plants because of the potential for certain geologic hazards.

Geologic and seismic criteria for siting are taken mainly from Title 10, Chapter 1, Part 100, Appendix A of AEC Reactor Site Criteria. The two primary concerns related to location of power reactors are active faults and areas of high seismic potential. We have added a third primary criteria for Oregon: potential volcanism since there has been a vast amount of volcanism in Oregon up until the last few thousand years. A secondary factor which should be considered because it may affect site stability is bedrock that is subject to sliding, i. e. fine-grained tuffaceous marine sediments and clayey volcanic sediments. Rocks which have been highly altered and sheared (metamorphic rocks) are also considered potential unstable foundation material. For this reason, fairly large areas underlain by rocks that might contribute to instability of the proposed structure foundation are included in the regional criteria.

In making this regional approach to siting, the Department of Geology and Mineral Industries proceeded by fulfilling requirements of the AEC guidelines. Maps, charts, and finally this report were prepared for the Council.

It was decided early in the project to organize geologic siting categories by geomorphic province since each of these 10 divisions of Oregon is characterized by somewhat similar topography, geologic history, and geologic structure. This system appeared to be quite adaptable for regional siting also because steepness of slope is inherent to the geomorphic classification, and slope gradient is an important engineering factor.

AEC guidelines require that wherever possible earthquake epicenters be correlated with surface expressions of major tectonic features. A five-state tectonic and seismicity map was prepared to accompany the regional report for this purpose. The guidelines also call for detailed investigations of all major faults within 200 miles of the site and lesser faults up to within a few miles of the site. A tectonic map showing all significant, presently known faults in Oregon was compiled for this regional study. The compilation of the tectonic map was made from published and unpublished data by N. V. Peterson. A preliminary geologic map was also constructed for the present study. The U.S. Geological Survey is in the process of publishing a large-scale map of the state and is issuing a geologic map of the offshore geology sometime in 1973.

This regional geologic siting report contains discussions of forces affecting the earth's outer crustal rocks. The reason for such broad coverage is to apprise the Council of the mobility of crustal rocks and to put Oregon in perspective with global tectonics. Monitoring is suggested for sites constructed in regions known to be presently under crustal stress. Major structures are described briefly in terms of current plate tectonic theories. It appears that Oregon is contained in a fairly stable segment of crustal rock within the very active circum-Pacific region. Currently active major tectonic features are found to the north, east, and south of Oregon but apparently the bordering shelf is relatively inactive except for the southwestern portion near the Cape Blanco fracture.

This study of regional geologic characteristics is necessarily incomplete as there is much to be learned about the geology of the state. The geology of Oregon is very complex primarily because of the vast amount of past volcanism. Regional characteristics can be better understood as new data become available.

Broad regional evaluations must be followed by detailed studies for specific locations. Such work will involve a complete array of geologic, hydrologic, and seismologic investigations besides including data from other disciplines.

Acknowledgments

The authors are very grateful for extensive help and advice from many individuals while preparing this report. Discussions and written comments on the early drafts by George Walker and Parke Snavely of the U.S. Geological Survey and William Swiger of Stone and Webster Engineering, Boston, Mass. were very helpful in the organization of useful data. Richard Couch of Oregon State University gave considerable assistance on sections dealing with seismicity and tectonic structure of the Pacific Northwest. Many other persons contributed ideas and data for this report and they are listed with the correspondence in the appendix.

We are especially grateful to Margaret Steere and John Beaulieu of the department's staff for their assistance with organization and for general editing of the manuscript.

Earthquakes in Oregon

Oregon is situated in the mobile belt of rocks forming the western border of the North American continental plate. It is a part of the circum-Pacific earthquake belt, one of the most tectonically active regions in the world. According to available historic data, Oregon is contained within a fairly stable portion of crustal rock within this earthquake belt. Couch and Lowell, 1971, report "The sector of the circumpacific earthquake belt which extends along the west coast of North America bifurcates in southern California; the western focus of earthquake activity passes out to sea in the vicinity of northern California and is situated approximately 200 to 300 kilometers west of the coast of Oregon and Washington. The eastern focus of activity extends northward through Nevada, Utah, Idaho, Wyoming and Montana. The eastern activity appears either to terminate near the border between the United States and Canada or rejoin the earthquake activity in the vicinity of Puget Sound and Vancouver Island. Oregon appears as a relatively quiet island in this very active earthquake belt." (Figure 1)

Earthquakes in Oregon are believed to be mostly of shallow origin, 70 km or less in depth. Thus most of the expected future activity is likely to be within the crustal rocks. Calculated hypocenters are 5 to 15 km in depth in western Oregon and 20 to 25 km east of the Cascade Mountains (Couch and Lowell, 1971). These calculations conform well with gravity studies by Thiruvathukal (1970) which indicated that the crust is 20 km thick in western Oregon and 35 km thick in eastern Oregon.

Couch and Lowell (1971) state that none of the mapped fault traces in the state have been confirmed as being active in the sense that anyone has noted offset along the faults following an earthquake. This is not too surprising, since Bonilla (1967) notes that only 35 known historic ground ruptures along faults have been recorded in the United States. Vertical displacements in these instances ranged from 1 foot to more than 20 feet. Since Oregon was not heavily populated until the last 100 years, historic data on earthquakes is fairly limited. Ground rupture related to earthquakes was reported in the July 18, 1930, Perrydale earthquake, the July 1936 Milton-Freewater earthquake, and the October 1968 Warner Valley earthquake. Some cracks 200 feet long were observed in connection with the Milton-Freewater earthquake (Eppley, 1965). No instances of actual vertical or horizontal displacements of bedrock along known faults have been confirmed in Oregon; however, an elderly resident of Fields, Oregon described a fault rupture in Alvord Desert which had a $1\frac{1}{2}$-foot offset as a result of an earthquake in the 1920's (personnal communication, Walker, 1972).

Earthquakes result from shearing in crustal rocks. Since not all shears and fractures in the crust and mantle rocks extend to the earth's surface, they are not always visibly detected. Also, humid climates such as in western Oregon produce a deep zone of weathering which masks structural features. Fault scarps visible in the Basin and Range Province of eastern Oregon indicate vertical movements of several thousand feet since middle Pliocene time and some faults show displacement since the

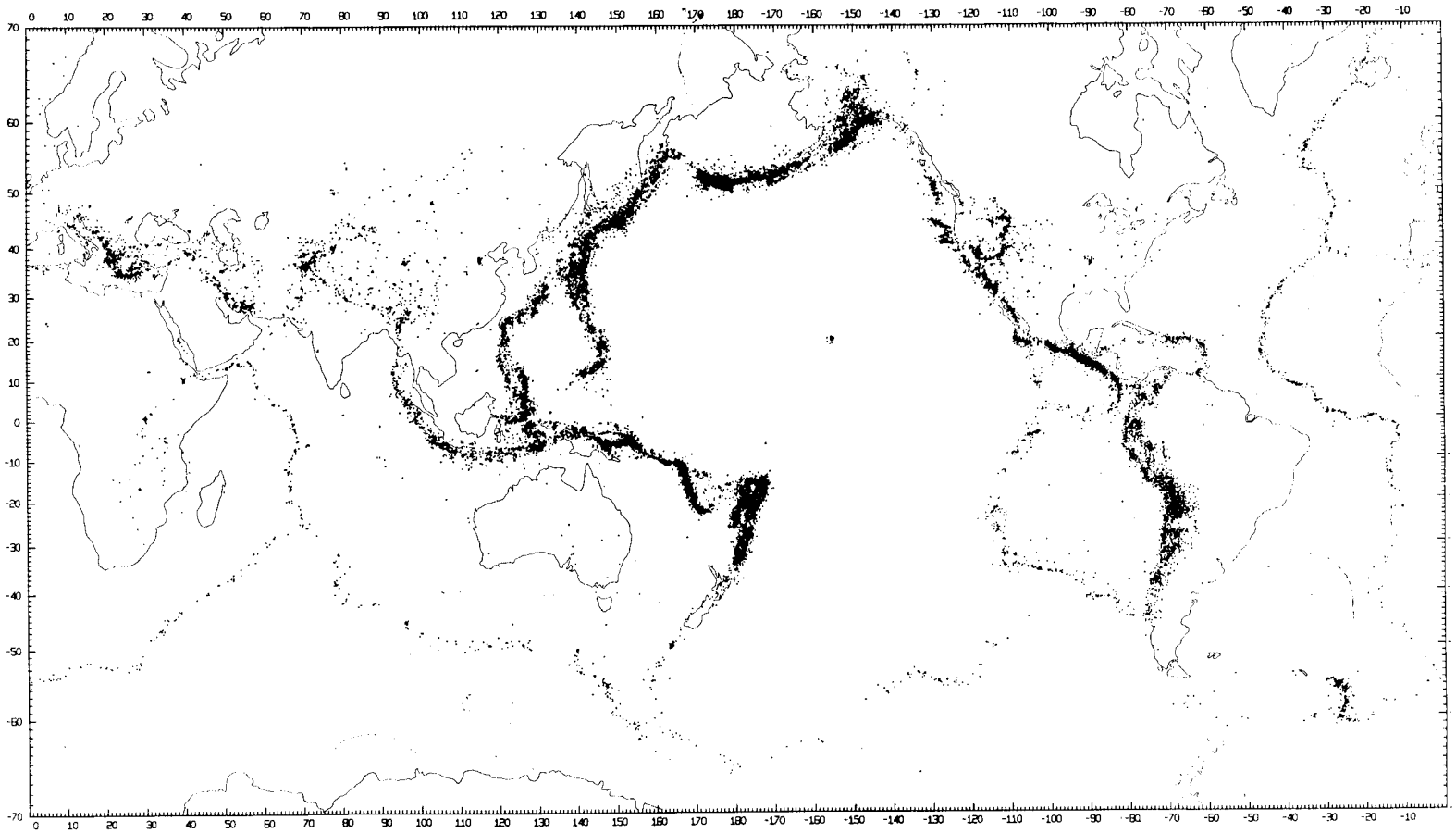


Figure 1. Seismicity of the earth, showing all ESSA, CGS epicenters from 1961 to 1967, depths 000–700 km (Barazangi and Dorman, 1969).

Mercalli Intensity	Description of Effects	Equivalent Richter Magn.
I	Instrumental: detected only by seismographs	
II	Feeble: noticed only by sensitive people.	3.5 to 4.2
III	Slight: like the vibrations from a passing truck; felt by people at rest, especially on upper floors.	
IV	Moderate: felt by people walking; swaying of loose objects, including standing vehicles.	4.3 to 4.8
V	Rather Strong: felt generally, most sleepers awakened and bells ring.	
VI	Strong: trees sway and all suspended objects swing; damage by overturning and falling of loose objects.	4.9 to 5.4
VII	Very Strong: general alarm; walls crack; plaster falls.	5.5 to 6.1
VIII	Destructive: car drivers seriously disturbed, masonry fissured, chimneys fall; poorly constructed buildings damaged.	6.2 to 6.9
IX	Ruinous: some houses collapse where ground begins to crack, and pipes break open.	
X	Disastrous: ground cracks badly; many buildings destroyed; and railroad lines bent; landslides on steep slopes.	7.0 to 7.3
XI	Very Disastrous: few buildings remain standing; bridges destroyed; all services disrupted; large landslides and floods.	7.4 to 8.1
XII	Catastrophic: total destruction objects thrown into the air; ground rises and falls in waves.	Max. recorded 8.9

Figure 2. Scale of earthquake intensities (after Holmes, 1964).

beginning of Pleistocene time (Peterson and McIntyre, 1970). Freshness of a few of the scarps indicate that some of the movement occurred late in Quaternary time.

Earthquake intensities described in Figure 2 are stated in terms of the Modified Mercalli Intensity Scale, 1931, with Richter magnitude equivalents shown.

Earthquake magnitude is ground motion measured at a given distance from an epicenter. This scale is related to the energy released by an earthquake and is generally reported in the unified scale developed by Gutenberg. Only a few earthquake magnitudes from Oregon are available prior to 1963. Couch and Lowell (1971) state "Observations indicate that intensities in Oregon are slightly greater than expected for a given magnitude earthquake. Enhanced ground motion in Oregon is due to relatively shallow foci, efficient energy transmission in crustal layers, and response of the surface layers. In areas of moderate seismicity in Oregon, the surface layers are composed of alluvial deposits. This type of material generally exhibits the greatest movement of any earth material during the passage of seismic waves." This is true for the Portland area and to a lesser extent for the Milton-Freewater area. Since calculations of energy release made thus far are based upon intensity data (felt seismic events) the greatest amount of information has been collected from populated areas of the state. Couch and Lowell (1971) prepared a table showing energy release and earthquake probabilities (Figure 3). For siting of nuclear power plants, the most severe earthquakes associated with tectonic structures are to be determined in a conservative manner because of limited historical data (Title 10-AEC, Chapter 1, Part 100). Calculations by Couch (personal communication, 1972) estimates the maximum magnitude for earthquakes in the Portland and Umatilla areas to be 6.5 Richter (Equivalent VIII Modified Mercalli intensity). He also estimated maximum 7.1 Richter magnitude for offshore northern California, the Puget Sound area, and for western Montana. The maximum expected for western Nevada is 7.5 Richter magnitude. Earthquakes centering in these areas could strongly affect adjacent communities in Oregon.

Although no confirmed incidents of fault displacement have been recorded in Oregon during historic times, the locations of epicenters of historical earthquakes and mapped faults appear to be related in some cases. Recorded earthquakes offshore from Oregon since 1963 delineate a major fracture which has been described as the Cape Blanco fracture. The fissuring is evidently active at present with a postulated movement of 5.8 cm per year (Atwater, 1970). Earthquakes appear to correlate fairly well with tectonic features in the west coast region (see regional tectonic map in pocket). As seen on this map, northwest-trending structures are dominant features and north-south tensional fractures are the second most prominent structural trend. Probably, the majority of earthquakes that could cause damage in Oregon will originate outside the state (Couch personal communication, 1972). For example, the Olympia-Tacoma earthquake in 1949, intensity VIII, registered an intensity of VII in Portland and several earthquakes in northwestern California and southeastern Washington have registered strong intensities in Oregon. It is also possible that earthquakes outside of the state may show greater intensities in certain locations in Oregon than at the epicenter (Couch and Lowell, 1971).

Physiographic Area	Maximum Intensity+	Maximum Acceleration (cm/sec^2)	Years of Maximum Intensity	Average E/yr(E=ERG) 1870-1970	Average $E/yr/km^2$ 1870-1970	Estimated Seismic Activity Level
Portland Area	VII	68.1	1962	2.6×10^{17}	8.7×10^{13}	One magnitude 4.8*(intensity V) quake per year; or One magnitude 5.3*(intensity VI) quake per ten years
Coast Range	VI	31.6	1957 1963	6.4×10^{16}	3.4×10^{12}	One magnitude 5.0*(intensity V) quake per ten years
Willamette Valley	VI	31.6	1896 1930 1961	1.3×10^{17}	9.6×10^{12}	One magnitude 5.3*(intensity VI) quake per thirty years
Klamath Mountains	VIII	147.0	1873	2.8×10^{18}	1.8×10^{14}	Insufficient Data
Cascade Range	VIII	147.0	1877	2.7×10^{17}	9.6×10^{12}	Insufficient Data
Deschutes-Umatilla Plateau	VII	68.1	1893 1936	8.4×10^{17}	4.4×10^{13}	One magnitude 5.7*(intensity VI-VII) quake per forty years
Basin and Range Province	VII	68.1	1968	8.8×10^{16}	3.3×10^{12}	One magnitude 5.2*(intensity V-VI) quake per twenty years
Blue Mountains	VI	31.6	1913 1969	6.6×10^{16}	1.1×10^{12}	One magnitude 5.1*(intensity V-VI) quake per fifteen years
High Lava Plains	III	3.2	1943	2.4×10^{13}	1.1×10^{9}	Insufficient Data
Owyhee Upland	IV	6.8	1944	2.0×10^{14}	6.9×10^{9}	Insufficient Data

+ Modified Mercalli Scale (1956 Edition)
* Unified Magnitude Scale

Figure 3. Earthquake characteristics of Oregon (Couch and Lowell, 1971).

According to Couch and Lowell, 1971, "Recent observations suggest that the Portland area, the Deschutes-Umtilla Plateau, and the Basin and Range area are the most active areas within the state." These conclusions are based upon energy release calculations by the two above cited authors. The assumption can generally be made that past earthquake activity is a fairly good indicator of future activity. (Figures 4 and 5)

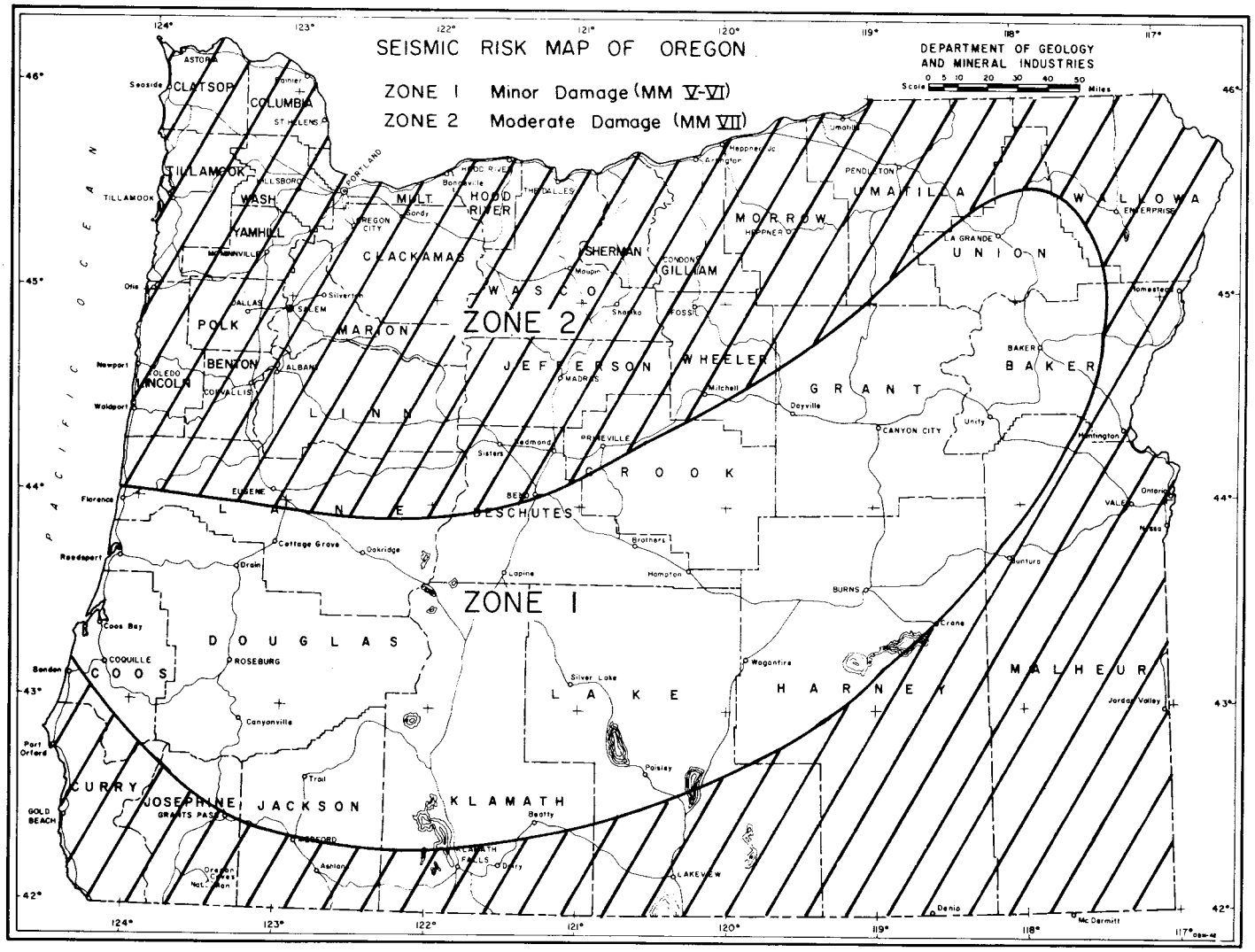
Microearthquakes: There are a multitude of tiny earth tremors occurring every month which go undetected by the network of seismograph stations located around the world because they are below the sensitivity of the instruments. New technology and ultra-sensitive instruments have been devised to record microearthquakes. These small seismic events tell of stress adjustments in the crustal rocks. Fault activity can be located where the epicenters of microearthquakes show linearity. Like their larger kin, the microearthquakes are singular seismic events having an abrupt beginning and diminishing to zero amplitude within a short time. They differ from the meteorologically caused microseisms by their singularity and noncontinuous nature as well as consisting of both surface waves and body waves. Meteorologically caused microseisms are made up of surface waves only (Couch, personal communication).

Well documented earthquake studies show that if a Richter magnitude 6.5 earthquake occurs along a fault once in a thousand years it will be followed by from 100 to 1,000 microearthquakes for a period of a few years (Raleigh, 1972). However, active faults may for a period of time exhibit no micro-activity so that a lack of microearthquakes is not conclusive evidence that a region is tectonically inactive. At some future time it may be possible using microearthquake recordings to predict major earth quakes.

Two other phenomena associated with tectonic events pose a hazard to nuclear plant sites in coastal areas.

Seiches: Seiches are oscillating waves in lakes and harbors caused by longitudinal earthquake waves. Large earthquakes originating within the crustal rocks produce longitudinal waves which travel great distances. These waves cause the earth's surface to oscillate horizontally and also cause the water in harbors and lakes to shake. Vertical displacement of these waves is usually less than a foot. Seiches may also be started by arrival of a tsunamis in an estuary (Couch and Lowell, 1971).

Tsunamis: Tsunamis are giant sea waves produced by submarine earthquakes or volcanic eruptions. Some of the greatest losses of life connected with earthquakes have been from these giant sea waves which inundate in habited shoreline areas. The collapse of the volcano Krakotoa in 1833 caused a sea wave that drowned more than 36,000 people. Nearly as many were lost in 1896 when a seismic sea wave hit the coast of Japan. The largest loss of life in the 1964 Alaskan earthquake was from seismic waves. Tsunamis or seismic sea waves are usually caused by vertical movements along undersea faults. This type of movement is not expected off the Oregon coast where fault movement is believed to be mainly in the horizontal direction. Tsunamis generated at other places in the Pacific Ocean can produce seismic waves which reach the Oregon coast. A tsunami hit the northern California and Oregon coasts 4 hours after the 1964 Alaskan earthquake. Four persons were drowned at Depoe Bay, Oregon, and 300 buildings were damaged at Crescent City, California.



(After Couch and Lowell, 1971)

Figure 4. Seismic risk map of Oregon.

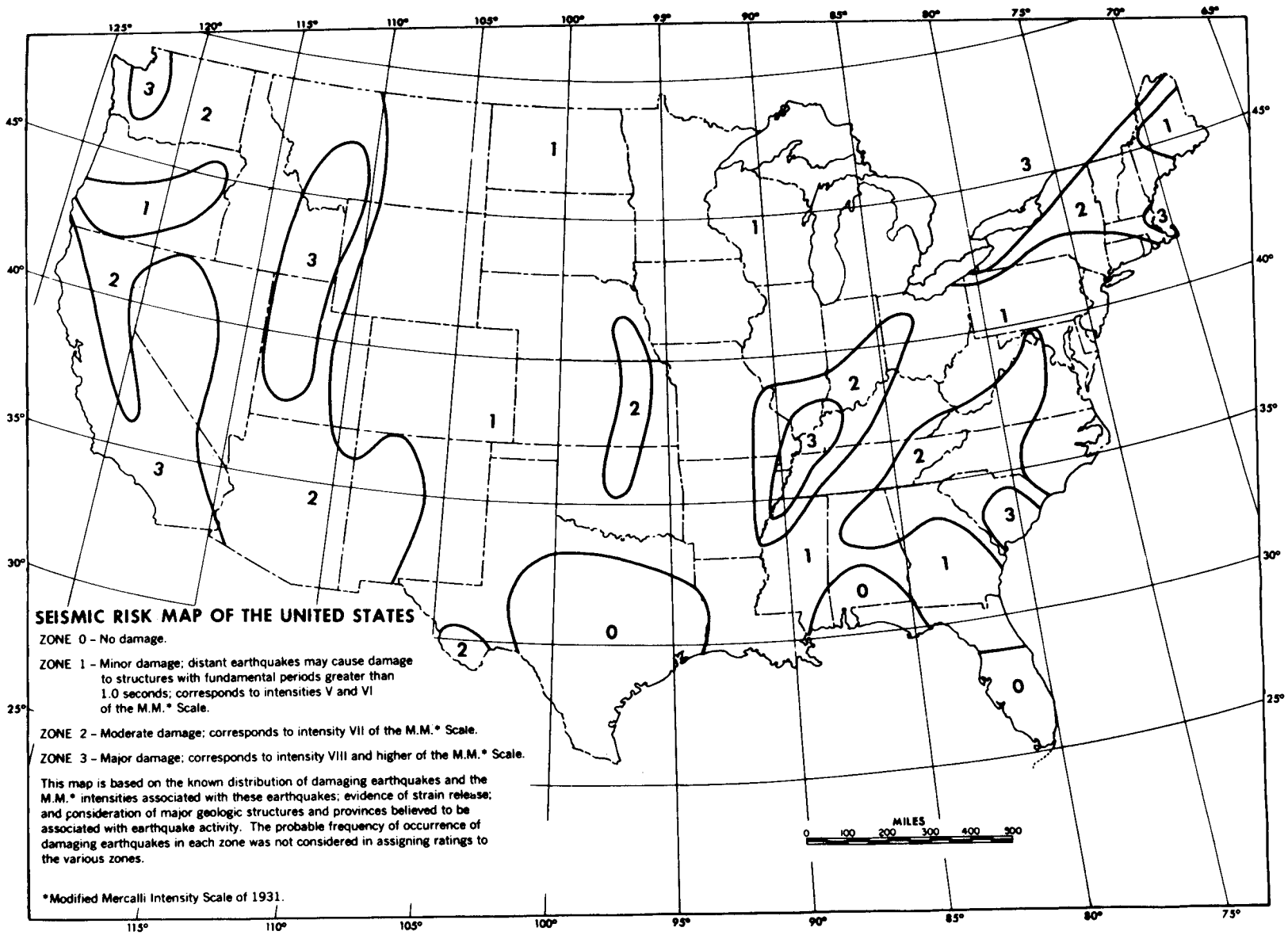


Figure 5. –Seismic Risk Map of the Conterminous United States–after S. T. Algermissen, "Seismic Risk Studies in the United States," *Proceedings of the Fourth World Conference on Earthquake Engineering* (Vol. 1, pp. 19-27), Santiago, Chile, 1969.

Tsunamis move at speeds of more than 400 mph. (Pattullo, and others, 1968) Wave heights of from 10 to 16 feet above high tide resulted along the Oregon Coast from the Alaska earthquake (Shatz and others, 1964). Although such waves are rapidly dissipated along the rugged coastline, the inlets and embayments are particularly sensitive to these seismic waves. Damage to the estuary environment and associated facilities depends upon the individual characteristics of each embayment and on the offshore topography. Power plant siting must take into consideration these, and similar hazards, generated by tectonic activity outside the state of Oregon.

A system of tsunami warning devices (Figure 6) has been installed at points on the Oregon Coast and approximately 4 to 15 hours of advance warning is provided to coastal residents (Couch and Lowell, 1971). Recently a series of seismic waves 0.5 feet in height generated by an earthquake near Japan were detected by instruments at Newport, Oregon. The instruments gave warning 10 hours before the waves reached the Oregon Coast (Pattullo and others, 1968).

Recent Volcanic Activity

Volcanism has been included as one of the main geologic criteria affecting the location of nuclear power plants in Oregon, particularly in regions where eruptions have occurred in the past few thousand years. The possibility of future volcanism was discussed in an article by Peterson and Groh (1963) and their conclusions were: "Oregon along with the other western states, is within the zone of volcanic activity which surrounds the Pacific Ocean. Several hundred volcanoes in various phases of activity occur in this circum-Pacific belt. This 'belt of fire' is also noted for its seismic (earthquake) activity, which signifies mobility of the earth's crust along this zone."

"Volcanic and seismic processes in different segments of this belt have varied greatly in intensity throughout past geologic time and also in historic time. For the present, Oregon is enjoying a stage when activity within its segment is probably at its least. Therefore, volcanism in Oregon should be considered only as dormant, not extinct."

Young volcanic areas in Oregon were outlined by the above authors in the same article. These eruptive rocks are typified by numerous mafic lava flows, silicic domes, and pumice and cinder cones. Much of the High Cascades consist of young volcanic rocks as does Newberry Crater in the vicinity of Bend, Diamond Crater, southeast of Burns, and Jordan Craters south of Vale. Ages of the youngest eruptions date from 10,000 years ago up to a few hundred years ago. Some fumarolic activity still exists near the top of Mount Hood. Mount St. Helens just north of the Oregon border last erupted steam and ash in 1838. Just south of the Oregon border in northern California the latest eruptions occurred at Mount Lassen between 1914 and 1917.

Large silicic volcanic centers are numerous in eastern Oregon and were apparently associated with major block faulting. The largest number of these explosive vents date back to the Miocene-Pliocene epochs but a few are younger. Most of the youngest volcanism was of the mafic lava-fissure type emanation (Greene and others, 1972).

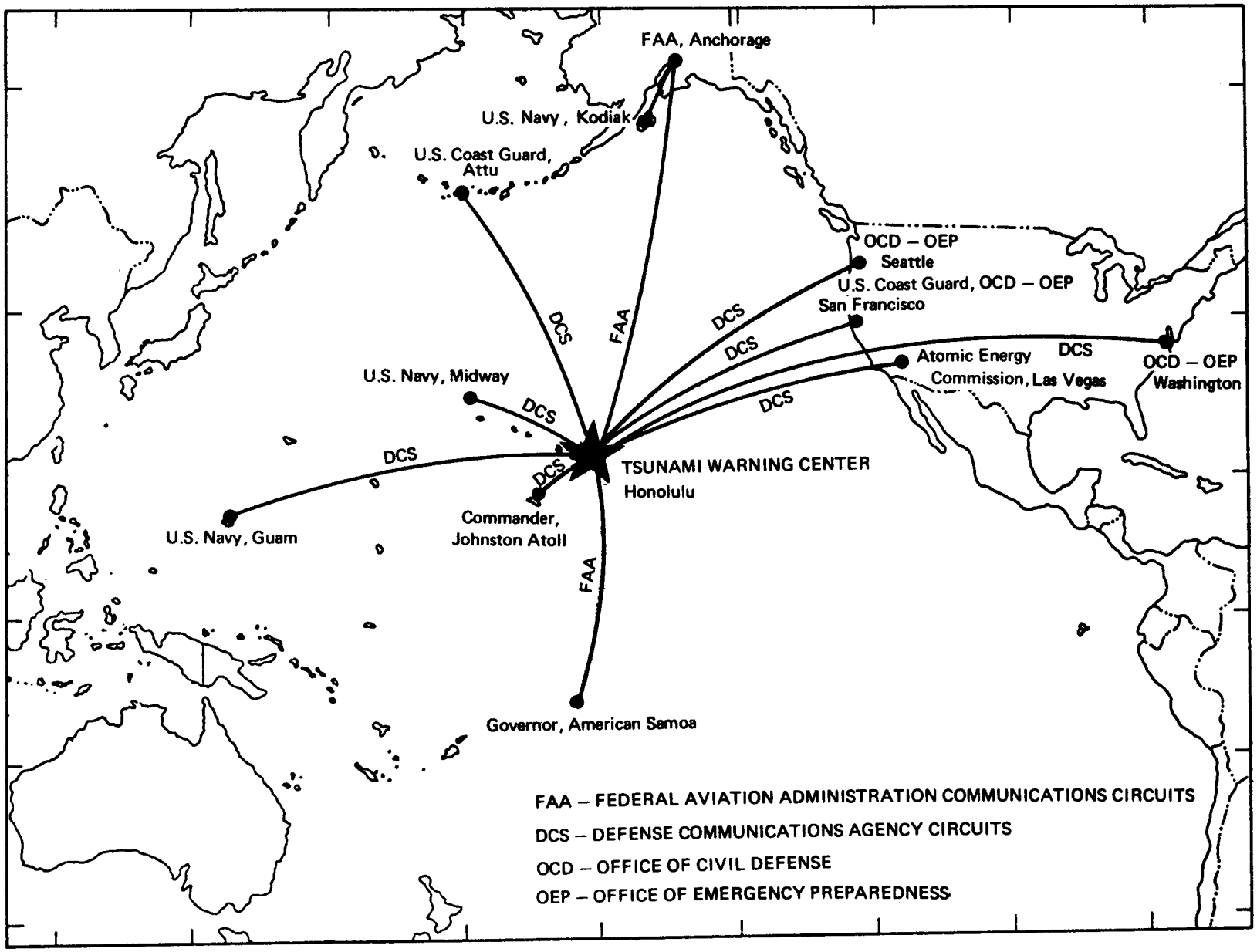


Figure 6. –Communications Circuits Serving United States Participants (excluding NOAA) in the Tsunami Warning System–NOAA.

Eruptions of volcanoes (silicic type) are often preceded by earth tremor and rumblings like thunder produced by material being violently blown from the vent. Fissures commonly form in the area surrounding the eruptions and hot springs appear at numerous places (Emmons and others, 1960). Because of the close association of hot springs and high geothermal gradients with late volcanic activity, known geothermal areas were outlined in this study.

Of the young lava flows investigated by Peterson and Groh (1963), individual flows were found to have inundated from 12 to 200 square miles of surface. Some of the Miocene-Pliocene flows covered considerably more area than this. Calculations on the latest ash fall from Mount Mazama (now Crater Lake) by Williams and Goles (1968) show that ash accumulated to a depth of 5 feet twenty miles from Mount Mazama and a few millimeters of this same ash was found deposited in British Columbia some 600 miles away.

Violent type eruptions such as occurred at Mount Mazama were common events in the last 10 million years in Oregon. The Mount Mazama eruptions are dated at approximately 7,000 years and some other silicic domes in eastern Oregon probably originated in the last few thousand years. Craters left by violent explosions can be seen at Hole-in-the Ground and Big Hole in northern Lake County. A total of 33 other explosion-type craters were located by Peterson and Groh in their 1963 study in Klamath and Lake Counties. Harney Basin may be a very large explosion volcanic feature of the caldera type and extensive Pliocene ash deposits in eastern Oregon may have originated from this source (Groh, 1966).

Tectonic Features of Oregon

In order to postulate what stress fields affected crustal rocks in past geologic time it is important to discuss the major tectonic features in Oregon. A synthesis of past activity provides a basis for making estimates for future movements of the crustal rocks.

In rocks older than mid-Tertiary (see Figure 5) the geologic structure in Oregon is characterized by north-to-northeast -trending folds and faults. The northeast alignment of folds suggests compressive forces were exerted in northwest and southeast directions. It is theorized that underthrusting (subduction) of the Pacific sea floor beneath Oregon produced these compressive structures (Figure 7). As the underthrusting subsided, crustal stresses changed to strike-slip motion along the San Andreas Fault and along offshore transform faults (Figure 8). Strike-slip movement of the crust is believed by some to have produced the extensional and normal faulting now represented by the north-trending Basin and Range topography in eastern Oregon.

Dott, 1971 describes two main periods of crustal deformation in Oregon which agree with the thesis on plate tectonics. The first prior to 20 million years ago and the second imposed from 20 million years ago to present. The isoclinal folds, thrust faults,

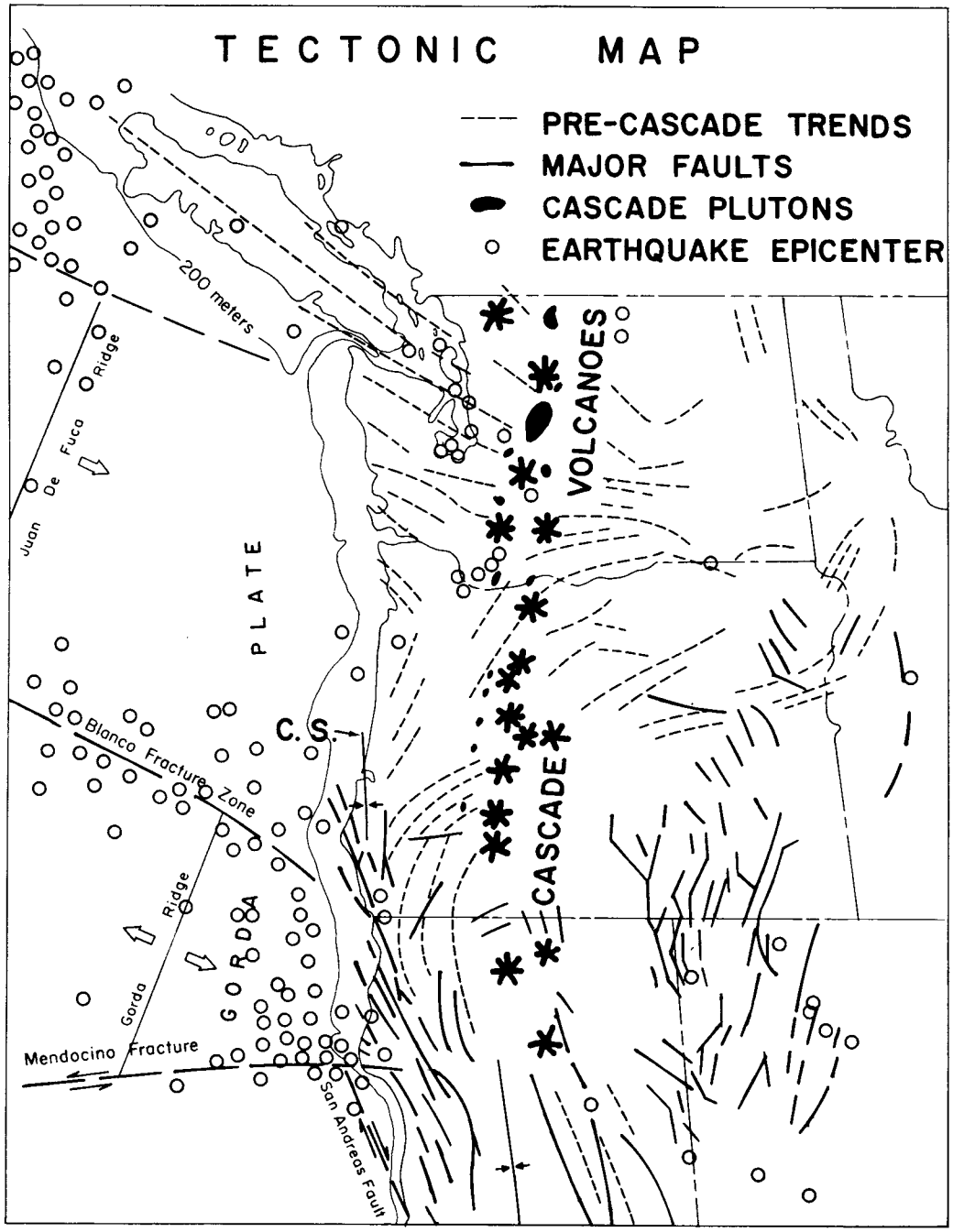


Figure 7.

Tectonic setting of the Pacific Northwest and adjacent oceanic crust. Note the discordance between the Mesozoic to early Cenozoic arcuate structural pattern (dashed lines) and the superimposed late Cenozoic Cascade volcanic arc and faulting (heavy lines). Lateral and block faulting are confined to the western edge of the American lithosphere plate, and do not extend to the Gorda oceanic plate, which appears to be continuing to spread from the Gorda-San Juan de Fuca ridge system and to be thrust beneath the continent. C.S. is the Coos Bay synclinorium. (Onshore: after Dott, 1965; offshore: after McManus, 1965; Morgan, 1968; Tobin and Sykes, 1968).

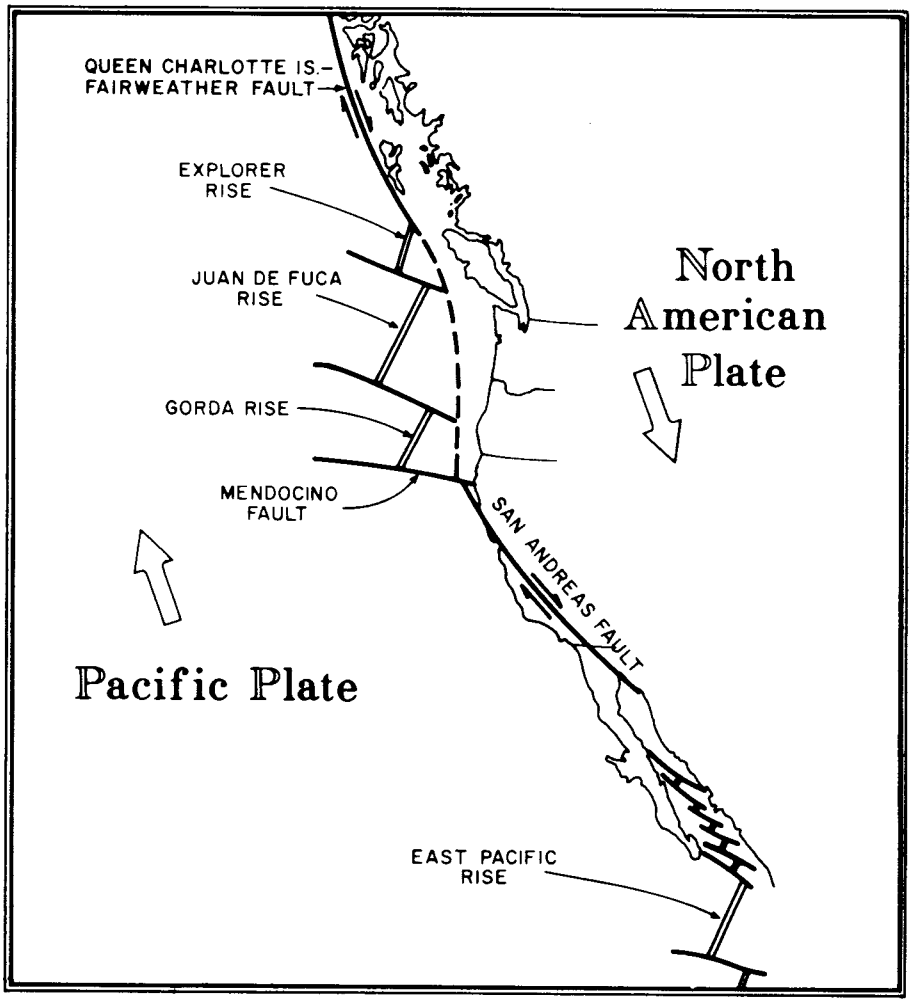


Figure 8. Faults and rift systems which make up the boundary between the North American Plate and the East Pacific Plate. Spreading ridges are shown as double lines.

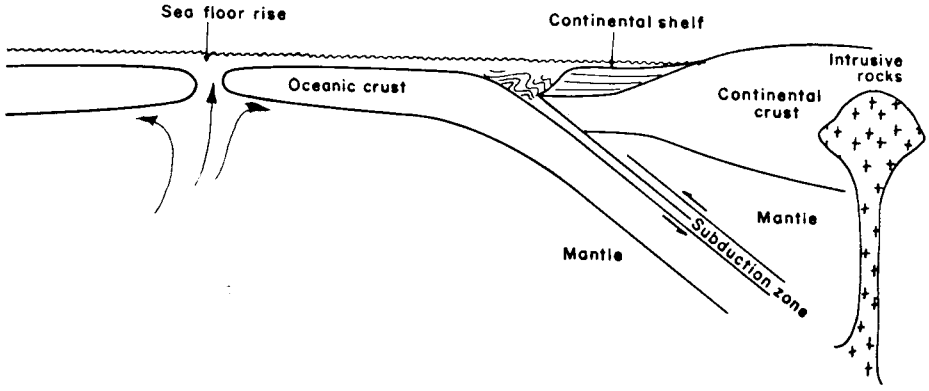


Figure 9. Sea-floor spreading model showing subduction of the ocean floor beneath the bordering continent.

intrusive rocks of intermediate composition and gross lithologies of sedimentary and volcanic rocks of the Mesozoic and early Tertiary in southwestern Oregon are characteristic of underthrusting or subduction (Beaulieu, 1972). In addition, large tectonic shear zones, or melanges were produced by underthrusting during Jurassic and early Cretaceous time (Dott, 1971). Eruption of andesitic volcanics during the Tertiary period also supports the theorized subduction along the northwest coast. (Figure 9)

In middle to late Miocene time a significant change in tectonic behavior occurred; basaltic lavas poured out of fissures in much of the state and continued to erupt during the ensuing 16 million years to the present. Underthrusting of the oceanic crust beneath Oregon apparently lessened approximately 20 million years ago and strike-slip movement was initiated along the San Andreas Fault system (Atwater, 1970; Silver, 1971). Northwest and north-south trending fractures were thus superimposed upon the older regional structures.

Two significant structural features in Oregon should be mentioned, although there is not wide agreement in their interpretation; these are the Olympic-Wallowa lineament and the Brothers fault zone. The latter feature comprises a multitude of northwesterly aligned faults extending from the north end of Steens Mountain to the Cascade Range and possibly connecting with faulting in northwest Oregon (see the regional tectonic map in appendix). Movements on this system of faults were produced by tensional stress. Since the Brothers fault zone cuts rocks of Quaternary age, the faults were active at least as late as the last half million years.

Skehan, 1965, describes the Olympic-Wallowa lineament as one of the most conspicuous surface features in the Northwest. It transects physiographic provinces and geologic units of varying development and age. The lineament extends from the Straits of Juan de Fuca southeastward to the edge of the Wallowa Mountains in northeastern Oregon. Faults in the Olympic-Wallowa trend also cut rocks of Quaternary age (Weissenborn, 1969). Skehan suggested this feature could be a reflection of a boundary in crustal blocks underlying the cover of Tertiary rocks. Trends of the Brothers fault zone and the Olympic-Wallowa lineament are sub-parallel and both features may be related to the same tectonic regime.

Unstable Foundation Rocks

Weathering of surface rocks partly by mechanical breaking and partly by chemical decay can cause a physical weakening that creates unstable conditions such as inadequate strength for foundations, slope instability, or landslides.

Metamorphic processes that result in completely changed rocks with a bright appearance and newly crystallized minerals also result in changed engineering properties. Metamorphic minerals such as mica, chlorite, talc, and graphite are usually flat and arranged in parallel layers that cause the rock to split easily in that plane. Also the softness of chlorite, talc, and graphite makes them act almost as lubricants when rocks in which they are contained are stressed. Locally metamorphic rocks may not have suitable engineering properties for foundations of large structures.

Slope instability: Landsliding is more common than generally realized. It is caused by a combination of factors: rock composition, rock texture, geologic structure, steepness of slope, and climate. When unstable material is loaded beyond its capacity to resist internal shear, sliding results. Sliding often occurs at the base of slopes when lateral support is removed by natural erosion or by man's activity. Some large massive earthslides have been caused by structural alignment in rock formations allowing the entire mass to move down dip on a zone of weakness.

Ground water is quite often a factor in slope failure and base failure. It produces a decrease in the shear strength of sedimentary rocks. Pore pressure is increased as the sedimentary rocks become saturated, increasing the tendency to shear.

Debris slides and rock falls occur after natural processes eventually erode away down hill support. Mass movements of this type sometimes occur rapidly and the rocks have great destructive force. At times the instability of soils and rock on slopes results in slow, continuous down-hill creep rather than sudden failure. Only detailed site studies can ascertain the existence of slope instability or the potential for mass movement. Much of western Oregon is underlain by fine-grained marine sedimentary rock which is deeply weathered and when moistened by rains forms unstable slopes. Volcanic ash and tuff also comprise a large percentage of the surface rocks in Oregon. Feldspar minerals and unstable glass in these rocks alter quickly to clays and they then become potential slide areas where slopes are moderate to steep.

Soil liquefaction: Many granular soils lose their resistance to shearing stress when subjected to earthquake or man-induced ground motion. Liquid saturation of such soils also reduces their resistance to shearing stress because of increased pore pressures. The effects of liquefaction can include lateral movement of soils up to distances of several hundred feet and vertical adjustments covering large areas (Couch, personal communication, 1972). Factors determining the tendency to liquefaction are: grain size and sorting, soil density, and confining pressure on the soil.

Frost heaving and expansion of sediments by the formation of ice crystals creates void spaces which fill with water upon thawing. Liquefaction of the sediments occurs and mass flowage results (Schlicker, 1956). The possibility of liquefaction during earthquakes is a serious concern for the design of containment structure foundations. Settlement of the soil beneath the structure may place large stresses on the massive, rigid containment building. Evaluation of oscillatory stresses and strains on saturated foundation material should be made to assist with the structural design (Housner, 1971).

Subsidence: In this section the term "subsidence" refers to settling, compaction, or collapse of rocks due to natural and man-made causes. It also refers to man-caused movements of rocks already under tectonic stress. One of the main man-made causes of subsidence is the withdrawal of fluids from rock formations. No areas of recent large-scale subsidence are known in Oregon but subsidence could become a problem as the State continues to develop.

Regional subsidence has taken place over a 2,500 square-mile-area of the San Joaquin Valley of California because of withdrawal of ground water for irrigation. The ground in this region is sinking as much as one foot a year and in some places subsidence has reached as much as 20 feet over the past four decades (Marsden, Sci. Amer.). Subsidence has occurred in connection with production of oil in several states. The most publicized occurrence is that connected with the Wilmington-Long Beach oil field in California. The ground has subsided a maximum of 26 feet in the center of an area of 22 square miles. In recent years subsidence related to pumping underground fluids has been mitigated by curtailing withdrawals and by pumping water back into the rock formation. Thousands of near-surface subsidence cracks were found while excavating for the San Joaquin Valley aqueduct. These tensional cracks formed as a result of prehistoric compaction brought about in alternate wetting and drying by streamflow in fan sediments. Subsidence of 5 - 10 feet occurred on some of the larger alluvial fans (Bull, 1972).

Large voids beneath the surface may become foundation problems when encountered. Karst topography (sink holes) develops in areas underlain by limestone. Circulating ground water dissolves the soluble carbonate and creates underground caverns which cave in as they enlarge. Although Karst caverns are not common in Oregon, other types of underground cavities have been encountered. Caves and irregular voids have formed at the terminus of many lava flows. Foundation construction of a large building in Portland was complicated a few years ago when excavation uncovered a cavern in the underlying lava rock. Since the cavity had not been detected in preliminary investigations, the foundation had to be redesigned (William Hill, personal communication, 1971). A lava tube cave was recently exposed in the excavation of the diversion tunnel of the Lost Creek Dam. Therefore,areas that are underlain at shallow depth by young lava flows are subject to loading collapse if lava tubes (caves) are present.

Many notable examples of seismicity related to man-made causes have been reported. Seismic recordings before and after the filling of certain reservoirs prove beyond any doubt that the small earthquakes were a result of loading stress and increased fluid pore pressures. Lake Meade, Nevada is a classic example of this type. Filling of the dam began in 1936 and was completed in 1941. The first earthquakes were felt in 1936 (Richter 5.0) and significant shocks recorded in 1945, 1948, and 1968. A similar occurrence was noted at Kariba Lake on the Rhodesian-Zambian border. Three years after completion of the dam at Kariba Lake nine shocks were felt ranging in magnitude from Richter 5.1 to 6.1. There is no indication thus far that man-made lakes in Oregon have caused earthquakes. Earthquakes were reported as far back as 1893 in the Milton-Freewater and Hermiston areas, years before the construction of McNary Dam on the Columbia.

The incident of the Denver earthquakes is a well-known example of man-caused seismicity in a region under tectonic stress. The U. S. Army began pumping waste-war chemicals into a 12,000 foot disposal well near Denver in 1962 because its surface disposal facility was found to be endangering water supplies. The well was drilled to

Precambrian gneiss and waste chemical pumped into fractures in the gneiss. Recordings of seismic activity correlated very closely with periods of the fluid injection between 1962 and 1967. Earthquakes of magnitudes up to 5.0 and 5.3 were felt in Denver. The seismic activity diminished after injection was halted (Hollister and Weimer, 1968).

Siting Characteristics by Geomorphic Province

The regional siting criteria discussed in this report are presented on the basis of the state's 10 physiographic divisions (see geomorphic province map in pocket). As mentioned earlier, each province has its characteristic topographic features and generally related geologic history.

The most critical geologic criteria relative to siting nuclear power plants in Oregon are; tectonism, seismicity, and volcanism. Secondary features which influence site foundation and slope stabilities are; rock type and alteration, including weathering.

Coastal Plain: The coastal lowlands are not known to be in a currently active tectonic zone except, perhaps, the southern coast which is at the north end of the San Andreas fault zone and known to be active. Earthquakes in historic times have been slight to moderate. Along the southern part of the coast, seismicity related to the San Andreas or the Cape Blanco fracture zone could have strong effects on adjacent areas in Oregon. The geology of the adjacent continental shelf and slope is largely unknown at present. Reactor sites located along the coast would require offshore studies to determine geologic structure and the location and attitudes of faults. There are some local areas of unconsolidated sediments in this province including sand dunes which contain fine-grained material of unstable characteristics. High rainfall in this region combined with fine-grained clayey rocks pose landslide problems, especially in northwestern Oregon. Suitable sites for nuclear plants should be available on the coastal plains north of Coos Bay.

Coast Range: Recorded seismicity in the Coast Range has been slight in the southern half and considerably more active in the northern half. Rocks of this province include large quantities of submarine basaltic lava mainly of Eocene age. No active faults are known in the province but detailed investigations should be made of faults within a few miles of any proposed site. Some large faults have been mapped and under close examination may prove to have been active in the past few thousand years. High rainfall and abundance of fine-grained sedimentary rocks result in unstable slopes where terrain is steep. Geothermal measurements indicate that heat flow in the Coast Range is normal or subnormal and there is no evidence of young magmatic activity. High-heat flow is an indication of fairly recent intrusion of magma. The Coast Range province is generally suitable for locating nuclear power plants, subject to slope stability problems.

Klamath Mountains: The overall region is fairly stable as far as seismic activity is concerned; no earthquake epicenters have been reported in the last 20 years. Large faults, including thrust faults, are mapped but none are known to be active. Topography is steep and rugged and will limit favorable sites. Zones of weakness resulting from shearing,

faulting, and metamorphism occur locally throughout the province. Parts of the area are suitable. The proximity of the southwest part of the area to the offshore San Andreas/Blanco tectonic systems may limit the suitability somewhat.

Willamette Valley: The central and northern portions of the Willamette Valley are moderately seismic. The Portland area has the greatest recorded seismicity of any part of the state. Thick alluvium in the northern end of the valley tends to increase response to earthquakes. There are local areas of unstable slopes because of high rainfall, clayey soils, and fine-grained unconsolidated silt. The area can be classified as less suitable for siting.

Western Cascades: The Cascade Range has been historically quiet as far as earthquake activity is concerned. This sub-province has been moderately folded and faulted but the extent of faulting is not well understood because of eradication of fault scarps by erosion and weathering. Zones of hydrothermal alteration are common in these rocks. Measured geothermal gradients indicate a slightly higher than normal heat flow for the Western Cascades (high heat flow is believed to be related to recent intrusion of molten rock from below the crust). The Western Cascades are tentatively classified as less suitable for siting but the geology of the region has been little studied up to this time.

High Cascades: The seismicity of this sub-province is generally fairly low as far as historic data describe it. A small amount of seismicity has been recorded north of Mount Hood and southeast of Crater Lake. Geothermal gradients are believed to be moderate to high for the High Cascades. Volcanism occurred in this sub-province no longer than a few thousand years ago. Fumaroles are still active near the top of Mount Hood. The north-south alignment of the contact between rocks of the High Cascades and the Western Cascades suggests a deep fracture zone by which ascending magmas were channeled. The fairly recent volcanic activity and the detection of high-heat flow make this region less suitable for siting of nuclear plants.

Columbia Plateau: The Umatilla and Milton-Freewater area is the second most seismic portion of the state. Several large faults have been mapped in the Columbia Plateau province but recent movement along these fractures has not been reported. Unconsolidated Quaternary fill occurs in the Umatilla-Boardman area which could accentuate earth movement. At other locations in this province, unstable slopes are likely to develop where clayey-tuffs are exposed. Very few geothermal measurements have been made in this region but it is believed to be an area of above-average heat flow (Blackwell, 1969). All but the eastern margin of this province is generally suitable for siting of nuclear plants.

High Lava Plains: There is no historical record of significant earthquakes in this region. Several large faults cut lavas of Quaternary age showing that displacement occurred along them within the last half million years. Some of the lowlands contain accumulations of young unconsolidated alluvium and intermixed pyroclastics which have unfavorable foundation characteristics. Exposures of clayey tuff are subject to sliding. Recent volcanic activity and associated high geothermal gradients suggest that future volcanism and seismicity are possible. This province is less suitable for siting of nuclear power plants.

Basin and Range: Much of the area has been tectonically active in Pleistocene time and some faulting may be Holocene (recent) age. Block faulting has occurred on a large scale in the past few million years. Earthquakes of moderate intensity may be associated with block faulting. Earthquakes along similar type faults in northwestern Nevada have registered magnitude of 7.1 to 7.6. Down-faulted valleys are covered with unconsolidated Quaternary sediments which may have accentuating characteristics to earth shocks. This province is less suitable for siting.

Owyhee Upland: Portions of the Owyhee Upland province have had Holocene volcanic activity, and measurements of geothermal gradients indicate much higher than normal heat flow. Some Quaternary fault movement may also have occurred in the province. The region is generally less suitable for siting.

Blue Mountains: The eastern margin of the Blue Mountain Province has been a moderately active earthquake area in the past. The region is cut by many northwest trending faults and subordinate northeast trending faults. Thrust faults occur in some areas. Upturned beds of Pliocene pyroclastic rocks and deep Quaternary erosion testify to warping and probable fault movement into Pleistocene time (Dickinson and Vigrass, 1965). Northwest striking faults in the Grand Ronde drainage probably belong to the latest period of crustal deformation, as fault scarps are relatively uneroded. Hampton and Brown (1964) state, "The fault system (in the Grand Ronde drainage) probably developed in about middle to late Pleistocene time." Rocks in this province have been complexly folded and faulted during several cycles of stress, and the shearing, faulting, and extreme deformation (metamorphism) have produced zones of weakness in portions of the province. The region is less suitable for siting.

Recommendations - Geology and Seismicity

Criteria established by AEC related to geologic and seismic conditions do not rule out any region of the state based upon the present knowledge of existing conditions. Consideration of mapped faults and records of earthquakes, however, does suggest that certain areas of the state are questionable for siting of nuclear plants. The location of Oregon within a mobile belt of rocks forming the western border of North America is sufficient reason to require that for every prospective site a study be made of known faults to establish their potential for movement in the next few hundred years and, where possible, to determine the potential magnitude of that movement. Seismicity of the site should be thoroughly investigated, as is now required by AEC guidelines, and micro-seismic measurements should be made where there is a history of earthquakes.

Design for seismicity should be based on dynamic considerations. At the present time the effects of earthquakes on structures is not well understood, and current methods of earthquake design do not closely reflect the actual performance under earthquake conditions. Safety factors now used for nuclear power plants are 3 to 5 times those used for fossil fueled plants. A sophisticated approach to earthquake design is the use of the response spectrum to estimate expected intensities of ground shaking (Housner, 1971).

It is desirable to have instrumentation installed at every containment building to record motion of the structure base during earthquakes. It is probably accurate to say, however, that present containment structure design is such that expectable earthquakes will not cause any damage.

Recent discussions of structural integrity of nuclear power plants have centered on the postulation that offset rupture occurs in the foundation rock beneath the containment structure. The structures are designed to withstand small displacements in the foundation materials but design for more than a small displacement would increase construction cost exponentially in relation to the amount of expected displacement (Housner,1971). Sites should avoid rocks where rupture and offset could occur.

Intensities of significant earthquakes should be projected to the site using standard formulas, and if such seismicity cannot be identified with known faulting then the extrapolation should be made to the site from the nearest boundary of the tectonic regime in which the significant earthquake occurred.

A seismic intensity map should be prepared for Oregon relating earthquake probabilities to siting of nuclear power plants. Procedures for measuring seismic response could also be outlined for power companies planning to build nuclear reactors in the state. We recommend that R. W. Couch, Oregon State University, be asked to prepare a state seismic intensity map and be consulted on matters of measuring seismic response.

Where reactor facilities are within a few tens of miles from a known active fault, or where the site lies within a fairly active seismic region, instrumentation should be installed to measure earth movements. Such instrumentation would include seismometers, tiltmeters, and microseismic recorders, geodetic strain and precise leveling equipment (Raleigh, 1972).

It is recommended that a strong-motion-triaxial accelograph be situated in the basement of the reactor containment structure and another placed at a higher elevation in the same structure (Swiger, personal communication, 1972). Where foundation rocks are known to be under tectonic stress, laterally or vertically, precision measurements should be made in order to measure the amount of movement. Regions of potential slope instability should be outlined by additional geologic study to alert planners of problem areas. Landslide conditions are not as well publicized as earthquakes and fault movements, but such conditions can be a serious problem to the stability of particular sites.

This study to determine regional geologic siting criteria is one of the first of its kind to be conducted in the United States. Possibly there are other geologic factors that should be considered, but their analysis would require additional time and further research.

PART II

General Geology of Oregon

Rocks exposed at the surface in Oregon are perhaps the most varied of any found in North America (see Figure 10 and geologic map in pocket). They include a complete suite of volcanic rocks, along with a wide variety of metamorphic, sedimentary, and intrusive rocks. The western margin of Oregon consists of marine-deposited sedimentary rocks thousands of feet thick containing interbedded flows of submarine lava. In the southwest, the Klamath Mountains represent uplifted and folded Mesozoic marine rocks considerably older than those to the north in the Coast Ranges.

The Cascade Range forms a broad north-south trending pile of volcanic rocks in western Oregon. The High Cascade volcanoes and Quaternary flows rest upon a broad base of older volcanic flows and ash and volcanically derived sedimentary rock. Lavas and volcanic ash have poured out upon the region now described as Oregon for the past 50 million years in voluminous quantity obscuring all but the highest areas of older rocks.

The high areas of older rocks constitute the peaks of the Blue Mountains and the Klamath Mountains. Rocks in the old exposures are composed of Mesozoic marine sedimentary and volcanic materials which have been squeezed into sharp folds, fractured, and faulted by movements of the earth's crust. Granitic plutons are exposed at high elevations in the northeastern Blue Mountains and in the Klamath Mountains. Although older rocks may be present elsewhere in Oregon at depth, exploratory drillings have never penetrated deep enough (deepest 12,000 feet below sea level) to reach them.

Lowland areas in the state are filled with stream and lake sediments deposited in the last million years or less. Two known areas of thick lake sediments are found in the Goose Lake Basin of south-central Oregon and the western Snake River Basin in the eastern portion of the state. The latter basin contains a thickness of 10,000 feet or more of young lacustrine sediments and interbedded volcanic flows (Newton and Corcoran, 1963). The Willamette lowland contains 100 to 200 feet of young river and lake sediment overlying marine rocks and basaltic lavas. In the Portland area several hundred feet of stream and lake sediments overlie Miocene lava.

The continental shelf off Oregon represents an extension of the geology seen in the Coast Range. As such, it consists of a thick accumulation of volcanic and

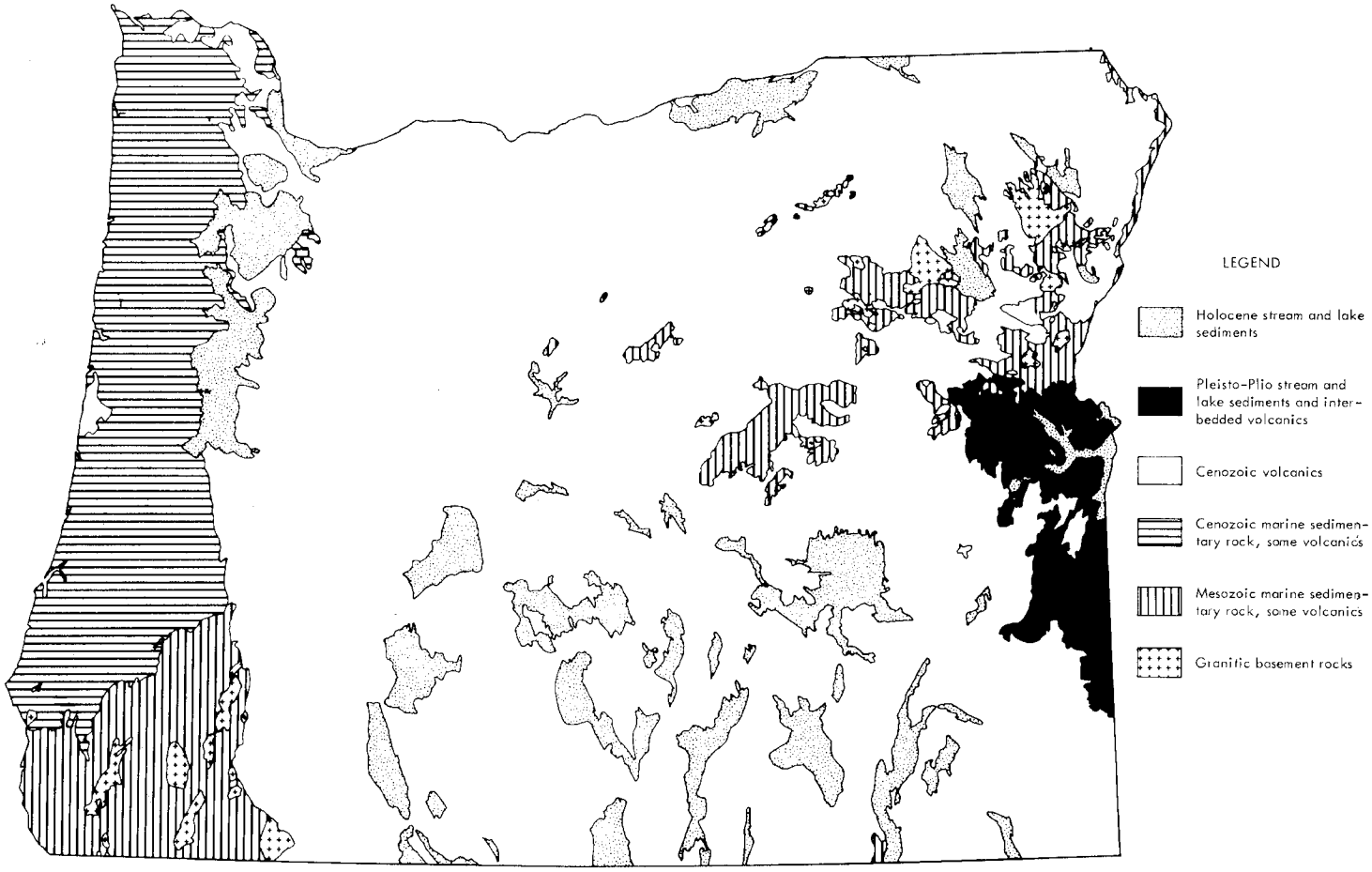


Figure 10. Map showing exposures of major rock types in Oregon.

sedimentary rocks which date as far back as the Eocene. In regions of crustal downwarp more than 20,000 feet of mud, sand and silt has accumulated. Ages of samples collected at various places on the sea floor and data obtained from deep drilling show that sediment has continued to accumulate on the shelf to the present time. Pliocene and Pleistocene beds offshore measure several hundred feet in thickness.

Geologic History

Oregon does not have a record of the very earliest geologic time (see Figure 11). No exposures of rocks older than Paleozoic have been found in the state. In terms of the new plate tectonic theory, it is conceivable that Oregon is underlain at depth by sea floor basalt rather than the more ancient rocks characteristic of the interior of the continent (Corcoran, 1969).

Mesozoic and Paleozoic rocks can be observed through two rather large "windows" where younger strata have either been uplifted and stripped off by erosion or perhaps were never deposited. These are: the Klamath Mountains of southwest Oregon and a sprawling, mountainous region in central and northeast Oregon generally referred to as the Blue Mountains. A third, much smaller window is in the Pueblo Mountains on the Oregon-Nevada border where metamorphosed sedimentary and volcanic rocks of probable Permian or Triassic age, together with some intrusive rocks, form the core of the mountains.

Paleozoic Era: Outcrops of Paleozoic age are very restricted in the state. Highly metamorphosed schists, probably derived from ancient sediments and volcanics, crop out along the Oregon-California border in southern Jackson County. According to Baldwin (1964) there is no direct geologic evidence in Oregon which could be used to date these schists. However, radiometric age determinations of the time of metamorphism of the rocks indicates that they were originally deposited before the Devonian Period.

Oregon's geologic past can be dated with certainty back more than 400 million years. In Crook County in central Oregon, and in the eastern part of the Blue Mountains, fossil remains date the formations from Devonian (middle Paleozoic) to Permian (late Paleozoic). The beds mark several periods of marine deposition during this long span of time throughout much of what is now the state of Oregon. Lime, mud, sand, and volcanic flows and breccias deposited in these seas were subsequently uplifted, folded, and faulted several times by mountain-building processes.

Mesozoic Era: Near the end of the Paleozoic Era and continuing into the early part of the Mesozoic, much of the western United States was above sea level and was undergoing complex mountain building, intrusion, and volcanism.

During the remainder of the Mesozoic (Late Triassic, Jurassic, and Cretaceous Periods) the sea extended across Oregon from the Klamath Mountains to the Wallowas.

GEOLOGIC TIME CHART

STRATIGRAPHIC DIVISIONS			TIME	DOMINANT LIFE	
ERA	SYSTEM OR PERIOD	SERIES OR EPOCH	Estimated ages of time boundaries in millions of years	ANIMALS	PLANTS
CENOZOIC	QUATERNARY	Holocene Pleistocene	2-3	Man	Flowering trees and shrubs
	TERTIARY	Pliocene	12	Mammals, birds, bony fish, mollusks, arthropods and insects	
		Miocene	26		
		Oligocene	37-38		
		Eocene	53-54		
		Paleocene	65		
MESOZOIC	CRETACEOUS	Upper (Late) Lower (Early)	136	Dinosaurs and Flying and swimming reptiles Ammonites	Conifers, Cycads, Ginkgos and Ferns
	JURASSIC	Upper (Late) Middle (Middle) Lower (Early)	190-195		
	TRIASSIC	Upper (Late) Middle (Middle) Lower (Early)	225		
PALEOZOIC	PERMIAN	Upper (Late) Lower (Early)	280	Giant insects, Primitive reptiles & Amphibians Crinoids and Blastoids Sharks & Lungfish Corals, Brachiopods, and Trilobites	Scale trees, Cordaites, Calamites, and Tree ferns Primitive scale trees and tree ferns Lycopods and Psilophytes Algae and Fungi
	Carboniferous: PENNSYLVANIAN	Upper (Late) Middle (Middle) Lower (Early)			
	Carboniferous: MISSISSIPPIAN	Upper (Late) Lower (Early)	345		
	DEVONIAN	Upper (Late) Middle (Middle) Lower (Early)	395		
	SILURIAN	Upper (Late) Middle (Middle) Lower (Early)	430-440		
	ORDOVICIAN	Upper (Late) Middle (Middle) Lower (Early)	500		
	CAMBRIAN	Upper (Late) Middle (Middle) Lower (Early)	570		
PRECAMBRIAN (More than 80% of earth's estimated 4.5 billion years falls within this era)		Informal subdivisions such as upper, middle, and lower; or upper and lower; or younger and older may be used locally.	3,600+	Beginning of primitive plant and animal life	

Oldest rocks known in Oregon: Limestones in central Oregon containing Middle Devonian fossils - about 370 million years old.
Oldest rocks known in North America: Granitic gneisses in Minnesota - 3550 million years old.
Oldest fossils known in the world: Algal stomatolites in southern Rhodesia - 2.7 billion years old.
Oldest rocks known in the world: Australia, Finland, South Africa, and North America have rocks about 3.5 billion years old.
Age of the earth: about 4.5 billion years old.

Adapted from U.S. Geological Survey and other sources.
Ages of oldest rocks and fossils from T. W. Stern,
U.S.G.S. Isotope Branch, March 1970.

State of Oregon
Department of Geology and Mineral Industries
1069 State Office Building, Portland, Oreg. 97201

April 1970

Figure 11.

Rocks now exposed at the surface indicate that many thousands of feet of marine sediments were laid down and tremendous volumes of volcanic ejecta (pyroclastics), lava flows, and breccias were incorporated into sediments which were deposited in the sea.

General uplift of the land toward the end of the Cretaceous Period caused the sea to retreat westward. Beginning in the early Tertiary, an accumulation of materials from numerous volcanic eruptions along the present axis of the Cascade Range formed a barrier to further encroachment by the sea into eastern Oregon.

Cenozoic Era: The Cenozoic Era is the most widely represented geologic age division in Oregon and is therefore of special interest. It is characterized by marine sedimentary and volcanic rocks in the western part of the state and continental sedimentary rocks and associated volcanic eruptives in the eastern part. Crustal deformation took place throughout the whole of this interval and has continued up to the present time.

During early Cenozoic time, 63 to 36 million years ago, western Oregon was part of the sea floor which probably extended from the Klamath Mountains northward about 400 miles through western Washington (Snavely and Wagner, 1963). The sea began an episodic northwesterly retreat in Oregon about 40 million years ago which continued until about 12 million years ago. This withdrawal resulted from crustal deformation which involved uplift of the entire western margin of the North American continent. A few minor embayments persisted along the southwestern coast into Pliocene time.

From 25 to 12 million years ago, during the Miocene Epoch, general uplift occurred in the Coast Range and most of western Oregon which resulted in an almost complete withdrawal of the sea. Accelerated volcanic activity during this period corresponds in age to increased tectonism throughout much of the Pacific Basin.

During the Miocene Epoch, volcanism continued to pile up lavas, tuffs, and other volcanic rocks in the Cascade region. Pyroclastic eruptions showered central Oregon with ash that aided in preservation of remarkable numbers of fossil plants and animals in the John Day country.

The major volcanic event in Miocene time occurred between 12 and 16 million years ago when flow upon flow of basaltic lavas poured out of fissures and covered extensive areas, particularly in northern Oregon and southeastern Washington, to form the famous Columbia River Basalt plateau. More than 35,000 cubic miles of lava poured out to cover 100,000 square miles in Oregon, Washington, and Idaho (Waters, 1955).

Great block faults developed in south-central and southeastern Oregon in Plio-Pleistocene time forming bold escarpments such as Abert Rim and the eastern front of Steens Mountain. Intermontane lakes that formed in basins between fault block mountains fluctuated greatly in size depending on seasonal variation in rain-

fall, and over a period of time they accumulated thick beds of sediments interspersed with volcanic ash. The Blue Mountains, as we see them now, were elevated by folding and faulting in early Pliocene time and sculptured by stream erosion and glacial scouring during the Pleistocene.

One of the outstanding events of the Pleistocene Epoch in the western United States was the building of a row of large composite volcanic cones, extending from Mount Baker in Washington to Mount Lassen in California. Volcanoes such as Mount Hood, Mount Jefferson, Mount Washington, Three Sisters, Broken Top, Mount McLoughlin, and Mount Mazama (Crater Lake) were superimposed on the older rocks of the Cascade Range.

The Pleistocene was also the time of the great Ice Age, and although continental ice sheets did not extend as far south as Oregon, alpine glaciers covered many of the peaks in the Cascade Range as well as the higher parts of the Blue and Klamath Mountains. Glacier-scoured, U-shaped valleys on the slopes of Steens Mountain show that ice once covered the crest of that upraised fault block.

Streams and rivers emptying into the Pacific Ocean carried large amounts of sediments from upland areas to the continental shelf before and after the melting of the continental glaciers and the accompanying 450 foot fall and rise of sea level (Byrne, 1963). Large fresh-water lakes developed in the lowland regions during the glacial advances and persisted for thousands of years. Summer Lake, Lake Abert, and Alkali Lake are remnants of much larger pluvial lakes of the Pleistocene Epoch.

About 7,000 years ago Mount Mazama erupted spreading approximately 3.5 cubic miles of ash over much of the northwest. The associated withdrawal of lava from the magma chamber to deeper parts of the crust caused the summit to collapse giving us the present-day Crater Lake caldera. At about the same time, another caldera formed on top of Newberry Volcano south of Bend, but on a slightly smaller scale. More recently, flows of basalt poured out on the surface at McKenzie Pass, Santiam Pass, and Lava Butte near Bend, Diamond Craters south of Burns, and Jordan Craters near Jordan Valley. Trees that were covered by these flows and preserved from decay have recently been dated by carbon-14 and show that some of the lavas are less than 1,500 years old. Other flows on which no absolute age dates are yet available appear to be less than 1,000 years old.

Evidence for Present Crustal Movements

The dynamic behavior of the earth's crust is reflected in the major structural features of Oregon (see tectonic overlay in appendix). It is believed that regional structural complexes are related to deep seated movements of immeasurably long duration and localized structures are a result of shorter term movements (Petrushevsky, 1969). The lithosphere has been involved for hundreds of millions of years in movements which have produced zones of major rifting in places and has compressed large blocks of crust to form high mountains in others.

Uplift and downwarp: Tectonic stability of portions of the earth's crust is thought to be dependent upon the composition of the rocks at depth and their position relative to plate tectonic boundaries. Very old rocks in central North America form a stable central core of the continent (Canadian Shield). Crustal rocks bordering the core become increasingly mobile away from the stable interior. Rocks of western United States have been subjected to continuous movements from at least 500 million years ago to the present time. Deep faults are believed to separate uplifted regions from depressions in mobile crustal belts. In the stable core area of North America, these deep faults commonly become inactive for millions of years but revive again when the stable platform is subjected to renewed tectonic stress (Khain and Muratov, 1969). This suggests that perhaps no major fault can be described as totally inactive within the framework of geologic time and earth processes. Inactivity must be described in a relative sense. To state that a particular fault is inactive is to say that the geologic region of the crust in which it occurs will continue to react to major stresses as it has done for at least the past few thousand years. Although there is unquestionably some speculation in such projection, it is also true that earth forces and associated movements in the crust occur continuously and more or less predictably at a slow rate.

Vertical movements in the earth's crust detected in the last 50 to 300 years have been studied in detail. Surveys of Scandinavia and Europe show that uplift and subsidence there have ranged from 2 to 10 mm per year. Measurements of isostatic movements show that these vertical adjustments in crustal rocks are still in progress today. Certain uplifts result from adjustment following the melting of continental glaciers at the close of the Ice Age. Rates of movement are calculated to have been as much as 10 cm per year soon after melting of the glaciers compared to the present rate of 1 cm per year. Isostatic movements are estimated to be taking place in the region of the Canadian Shield now at a rate of 3 to 5 mm per year. The Gulf Coast basin is presently subsiding while the Shield, Appalachian Mountains, and Ozark Mountains are being uplifted. Regions of highest isostatic adjustment rates are often associated with earthquake activity (Artyushkov and Mescherikov, 1969).

Vertical displacement of 1 cm per year is believed to be taking place in the Puget Sound area of Washington. Similar movement of 4 cm per year has been estimated at Glacier Bay, southwest Alaska. Coastal uplift in Oregon, based upon extrapolated paleontological data, indicates vertical movement of 1 cm per year (R.W. Couch, personal communication, 1972).

In Oregon, mountain ranges have risen, the sea has encroached and withdrawn many times and large areas of sea floor covered with sediments in the past 300 or 400 million years. Providing that the amount of subsidence can be roughly measured by thickness of accumulations of the sediments, at least 7 km (23,000 feet) of regional subsidence can be inferred in central Oregon since the beginning of Mesozoic time. In the western portion of the state where stratigraphic relations are more complex, subsidence has probably been on the order of 5 km (16,400 feet).

Crustal slippage: Early earth scientists explained tectonics solely by gravity adjustments in the mantle and crust. Outer mobile regions of continents were believed to be the sites of downwarp and unundation by the sea. Gravity balance in crustal rocks was thought to be the sole cause for building of mountains in these sediment-filled troughts. According to present-day theories, these processes may be only a minor contribution to tectonism. The broader concepts of continental drifting and plate tectonics may better explain observed tectonic features. The most plausible model currently being discussed includes isostacy, sea-floor spreading, and continental drifting. The linear character of main tectonic features such as sea-floor ridges (Mid-Atlantic Ridge, East Pacific Rises, etc.) are favorably explained by thermal convection in which upwellings in the mantle result in tensional stress where they diverge near the earth's surface. Conversely, deep sea trenches are formed in areas where the shifting lithosphere starts to descend back into the mantle.

Whatever the outcome of current scientific discussions, the important fact remains that crustal rocks are probably continually involved in stress-caused movements. Large segments of the earth's outer shell are believed to be moving at rates different from adjacent segments.

Rock units of Oregon are part of the mobile belt of rocks forming a perimeter on the stable interior of the continent. Figure 8 shows what is now believed to be the structural condition off the Oregon coast. Scientists (Silver, 1971) believe that strike-slip movement is taking place between plates along transform fractures west of the Oregon mainland. Displacement along the San Andreas Fault south of the Mendocino fracture off northern California is thought to occur at a rate of 4 to 6 cm per year.

BIBLIOGRAPHY

Artyushkov, E. V., and Mescherikov, Yu. A., 1969, Recent movements of the earth's crust and isostatic compensation, The Earth's Upper Crust and Mantle: Nat. Acad. Science Research Council, Publ. 1708, p. 379.

Atwater, Tanya, 1970, Implications of plate tectonics for the Cenozoic tectonic evolution of western North America: Geol. Soc. Amer. Bull., v. 81, n. 12 December 1970.

Baldwin, E. M., 1964, The geology of Oregon: University of Oregon Press, Second Edition, Eugene, Oregon, 165 pp.

Beaulieu, J. D., 1972, Plate tectonics in Oregon: State of Oregon DOGAMI, The Ore Bin, v. 34, n. 8, August 1972.

Berg, J. W., and Baker, C. D., 1963, Oregon Earthquakes, 1841 through 1958: Seismol. Soc. America Bull., v. 53, no. 1, January 1963.

Blackwell, D. D., 1969, Heat-flow determinations in the northwestern United States: Jour. Geophys Research, v. 74, no. 4, February 15, 1969.

Bonilla, M. G., 1967, Historic Surface faulting in continental United States and adjacent parts of Mexico: U.S. Geol. Survey TID -24124.

Bowen, R. G., and Peterson, N. V., 1970. Thermal Springs and Wells in Oregon: State of Oregon DOGAMI, Miscellaneous Paper no. 14.

Braislin, D. B., Hastings, D. D., and Snavely, P. D., Jr., 1971, Petroleum potential of western Oregon and Washington and adjacent continental margin: Am. Assoc. Petroleum Geol., Memoir 15.

Bull, W. B., 1972, Prehistoric near-surface subsidence cracks in western Fresno County, Cal.: Geol. Survey Professional Paper 437C.

Byrne, J. V., 1963, Geomorphology of the continental terrace off the northern coast of Oregon: State of Oregon Department of Geology and Mineral Indust. The Ore Bin v. 25, no. 12, December 1963, p. 201-213.

Corcoran, R. E., 1969, General geologic history of Oregon: State of Oregon Department of Geology and Mineral Industries, Bull. 64, p. 23-32.

Couch, R. W., Johnson, S., and Gallagher, J., 1968, The Portland earthquake of May 13, 1968 and earthquake energy release in the Portland area: State of Oregon Dept. of Geol. and Mineral Indust, The Ore Bin v. 30, no. 10, October 1968.

Couch, R. W., and Johnson, S., 1968, The Warner Valley earthquake sequence: May and June 1968: State of Oregon Dept. of Geol. and Mineral Indust., The Ore Bin, v. 3, no. 10 October 1968.

Couch, R. W., and Pietrafesco, L. J., 1968, Earthquakes off the Oregon coast January 1968 to September 1968: State of Oregon Dept. of Geol. and Mineral Indust., The Ore Bin, V. 30, no. 10, October 1968.

Couch, R. W., and Lowell, R. P., 1971, Earthquakes and Seismic Energy release in Oregon: State of Oregon Dept. of Geol. and Mineral Indust., The Ore Bin, April 1971.

Dickenson, W. R., and Vigrass, L. W., 1965, Geology of the Suplee-Izee area: State of Oregon Dept of Geol. and Mineral Indust., Bull. 58, 109 pp.

Dobrin, M. B., 1960, Introduction to geophysical prospecting: McGraw-Hill Book Company, Inc., New York, Toronto and London.

Dott, R. H., Jr., 1971, Geology of the southwestern Oregon coast west of the 124th meridian: State of Oregon Dept. of Geol. and Mineral Indust., Bull. 69.

Emmons, W. H., Allison, I. S., Stauffer, C. R., and Theil, G. A., 1960, Geology, Principles and Processes: McGraw-Hill Book Company, Inc., New York Fifth edition.

Eppley, R. A., 1965, Earthquake history of the United States, Part I: U.S. Dept. of Commerce Environmental Science Services Admin., Publ. 41-1, Washington, D.C.

Eppley, R. A., 1966, Earthquake history of the United States, Part II: U.S. Dept. of Commerce Environmental Science Services Admin., Publ. 41-1, Revised Edition through 1963, Washington, D.C., 1966.

Gilluly, James, 1971, Plate tectonics and magmatic evolution: Geol. Soc. Amer. Bull., v. 82, no. 9, September 1971.

Greene, R. C., Walker, G. W., and Corcoran, R. E., 1972, Geologic map of the Burns quadrangle, Oregon: U.S. Geological Survey Miscellaneous Geol. Invest. Map I-680.

Groh, E. A., 1966, Geothermal Energy potential in Oregon: State of Oregon Dept. of Geol. and Mineral Indust.,The Ore Bin, v. 28, no. 7, July 1966.

Hampton, E. R., and Brown, S. G., 1964, Geology and ground water resources of the upper Grande Rhonde River Basin: U.S. Geol. Survey, WSP 1597.

Heinricks, D. F., and Pietrafesco, L. J., 1968: The Portland earthquake, Jan. 27, 1968: State of Oregon Dept. of Geol. and Mineral Indust., The Ore Bin, v. 30, no. 2, February 1968.

Hollister, J. C., and Weimer, R. J., 1968, Geophysical and geological studies of the relationships between the Denver earthquakes and the Rocky Mountain Arsenal Well: Colorado School of Mines Quarterly, v. 63, no. 1, January 1968.

Holmes, Arthur, 1965, Principles of physical geology: The Ronald Press Co., New York, Second Edition, 1288 pp.

Housner, G. W., 1971, Earthquake research needs for nuclear power plants: Jour. of Power Div., Proceedings of the Am. Soc. of Civ. Engrs., January 1971.

Khain, V. E., and Muratov, M.V., 1969, Crustal movements and tectonic structure of continents, The Earth's Upper Crust and Mantle: Nat. Acad. Sci. Research Council, Publ. 1708, p. 523.

King, P. B., 1969, Tectonic map of North America: U.S. Geological Survey, Washington, D. C. - G67154.

Knopoff, Leon, 1969, Continental drift and convection, The Earth's Upper Crust and Mantle: Nat. Acad. Sci., Research Council, Publ. 1708, p. 683.

Krynine, D. P., and Judd, W. R., 1957, Principles of engineering geology and Geotechnics: McGraw-Hill Book Company, Inc., New York, Toronto and London.

Mackay, A. J., 1969, Continuous seismic profiling investigation of the southern Oregon continental shelf; U.S. Geological Survey Open-File Report.

Nelson, T. H., and Temple, P. G.,1972, Mainstream mantle convection: A geologic analysis of plate motion: Amer. Assoc. of Petrol. Geol. Bull., v. 56, no. 2, February 1972.

Newton, V. C., Jr., and Corcoran, R. E., 1963, Petroleum geology of the western Snake River Basin: Oregon Dept. of Geol. and Mineral Indust. Oil and Gas Invest. No. 1.

Pattulo, J. G., Burt, W. V., and Burdwell, C. D., 1968, Tsunami on the Oregon coast from an earthquake near Japan: State of Oregon Dept. of Geol. and Mineral Indust., The Ore Bin, v. 30, no. 9, September 1968.

Peterson, N. V., and Groh, E. A., 1963, Recent volcanic landforms in central Oregon: State of Oregon Dept. of Geol. and Mineral Indust., The OreBin v. 25, no. 3, March 1963.

Peterson, N. V., and McIntyre, J. R., 1970, Reconnaissance geology and mineral resources of eastern Klamath County and western Lake County, Oregon: State of Oregon Dept. of Geol. and Mineral Indust. Bull. 66.

Petrushevsky, B. A., 1969, Earthquakes and tectonics, The Earth's Upper Crust and Mantle: Nat. Acad. Sci. Research Council Publ. 1708, p. 279.

Raff, A. D., and Mason, R. G., 1961, Magnetic Survey off the west coast of North America, 40° N. Lat. to 52° N. Lat: Geol. Soc. Amer. Bull. v. 72, no. 8, August 1961.

Raleigh, C. B., 1972, Investigations of seismic activity related to reservoirs: Bull. of Assoc. Engr. Geol. v. IX, no. 3.

Ringwood, A. E., 1969, Composition and evolution of the upper mantle, The Earth's Crust and Upper Mantle: Nat. Acad. Sci. Research Council Publ. 1708, p. 1.

Schatz, C. E., Curl, H., Jr., and Burt, W. V., 1964, Tsunamis on the Oregon coast: State of Oregon Dept. of Geol. and Mineral Indust., The Ore Bin v. 26, no. 12, p. 231.

Schlicker, H. G., 1956, Landslides: State of Oregon Dept. of Geol. and Mineral Indust. The Ore Bin v. 18, no. 5, p. 39-43.

Silver, Eli, A., 1971, Tectonics of the Mendocino triple junction: Geol. Soc. Amer. Bull., v. 82, no. 11, November 1971.

Silver, Eli, A., 1971, Small plate tectonics in the northeastern Pacific: Geol. Soc. Amer., v. 82, no. 12, December 1971.

Simonen, Ahti, 1969, Batholiths and their orogenic setting, The Earth's Upper Crust and Mantle: Nat. Acad. Sci. Research Council Publ. 1708, p. 483.

Skehan, J. W., 1965, A continental-oceanic crustal boundary in the Pacific Northwest: U.S. Air Force Cambridge Research Laboratories, Bedford, Mass., Scientific Report No. 3, December 20, 1965.

Snavely, P. D., Jr., and Wagner, H. C., 1963, Tertiary geologic history of western Oregon and Washington: State of Washington Div. of Mines and Geology Rept. of Invest. 22, 25 pp.

Thiruvathukal, J. V., 1968, Regional gravity of Oregon: Oregon State University doctoral thesis.

Treasher, R. C., 1946, Earthquakes in Oregon 1846-1946: State of Oregon Dept. of Geol. and Mineral Indust. Report on File.

Waters, A. C., 1955, Volcanic rocks and the tectonic cycle, in Crust of the Earth, a symposium: Geol. Soc. of Am. Spec. Paper 62, p. 703-722.

Weissenborn, A. E., 1969, Geologic Map of Washington: U.S. Geological Survey, Geol. Invest. Map I-583, scale 1:2,000,000.

Williams, Howel, and Goles, Gordon, 1968, Volume of the Mazama ash fall and the origin of Crater Lake Caldera: State of Oregon Dept. of Geol. and Mineral Indust. Bull. 62.

Woollard, G. P., 1969, Tectonic activity in North America as indicated by earthquakes, The Earth's Crust and Upper Mantle: Nat. Acad. Sci. Research Council Publ. 1708, p. 125.

APPENDIX

OREGON EARTHQUAKES 1841 - 1970

Year	Date	Time	Locality	Intensity	Magnitude	N. Lat.	W. Long.	Remarks
1841	Dec. 2	16:00	Ft. Vancouver	III	--	--	--	
1866	Nov. 24	--	The Dalles	IV	--	--	--	
1866	Dec.	--	The Dalles	III*	--	--	--	
1873	Nov. 22	--	Port Orford	VIII	--	--	--	Epicenter at 42° lat. 124°
1877	Oct. 12	--	Cascade Mtns.	VII	--	--	--	
1877	Oct. 12	--	Portland	III	--	--	--	
1879		--	Portland	IV	--	--	--	
1882	Apr. 30	10:48	Portland	IV	--	--	--	R. C. Treasher, unpubl.
1882	May 1	--	Portland	III	--	--	--	
1883	Sept. 28	00:00	Portland	VI	--	--	--	
1884	Jan. 4	04:40	Portland	IV*	--	--	--	
1885	Oct. 10	09:-	Portland	II-III*	--	--	--	3 shocks
1891	Sept. 17	04:30	Salem	IV	--	--	--	
1891	Nov. 9	04:-	Ashland	IV	--	--	--	
1892	Feb. 3	20:30	Portland	VI	--	--	--	
1892	Feb. 29	10:45	The Dalles	IV	--	--	--	
1892	Apr. 17	2:50	Portland	IV*	--	--	--	R. C. Treasher, unpubl.
1893	Mar. 7	17:03	Umatilla	VII	--	--	--	
1895	Feb. 25	4:47	Portland	III	--	--	--	
1896	Apr. 2	03:17	McMinnville	VI	--	--	--	
1896	June 5	06:20	Cape Blanco	IV	--	--	--	
1897	Jan. 26	22:45	Newport	IV	--	--	--	
1897	Feb. 22	02:25	Portland	IV	--	--	--	
1898	Feb. 22	09:15	Portland	III	--	--	--	
1902	June 15	04:00	Newport	IV	--	--	--	
1902	June 15	09:00	Newport	IV	--	--	--	
1902	Dec. 2	10:00	Kerby	III	--	--	--	
1904	June 16	18:25	Portland	IV	--	--	--	
1906	Apr. 3	05:00	Ashland	IV	--	--	--	
1906	Apr. 19	90:30	Paisley	V	--	--	--	Followed by 3 aftershocks
1906	Apr. 23	09:12	Grants Pass	VI*	--	--	--	epicenter probably in N. Calif.

OREGON EARTHQUAKES 1841 - 1970

Year	Date	Time	Locality	Intensity	Magnitude	N. Lat.	W. Long.	Remarks
1906	Apr. 29	17:00	Paisley	V	--	--	--	
1906	Sept. 1	--	Baker	III	--	--	--	
1907	May 27	12:00	Portland	III	--	--	--	
1909	Dec. 31	00:23	Portland	IV	--	--	--	
1910	Feb. 15	24:00	Portland	IV	--	--	--	
1910	Aug. 5	01:31:36	At sea	VIII*	6.8	--	--	
1913	Mar. 15	20:40	Medford	III	--	--	--	3 distinct shocks
1913	Mar. 16	02:--	Roseburg	IV	--	--	--	
1913	Oct. 14	15:00	Seven Devils Region	VI	--	45.7	117.1	
1914	Mar. 22	14:30	Portland	IV	--	--	--	
1914	Sept. 5	10:00	Portland	III	--	--	--	Shock intensity V in Olympia, Wn. a few hours earlier
1914	Aug. 22	05:28:18	At sea	VIII*	6.75	44	129	
1915	Jan. 18	--	Summerville	III	--	--	--	
1915	May 18	19:00	Portland	V	--	45.5	122.7	
1915	Oct. 19	11:30	Fruita, Wallowa County	III	--	--	--	R. C. Treasher, unpubl.
1916	Jan. 4	18:40	Newport	IV	--	--	--	
1916	May 28	--	Baker area	III	--	--	--	
1917	June 10	04:32:24	At sea	VIII	6.5	44	129	
1918	Feb. 13	02:00	Portland	III	--	--	--	
1919	Dec. 26	06:00	Bullrun	IV	--	--	--	
1920	Apr. 14	15:45	Crater Lake	V	--	--	--	3 shocks felt
1920	Nov. 9	20:20	Portland	III	--	--	--	
1920	Dec. 15	18:50	Cascadia	III*	--	--	--	
1921	Feb. 25	12:00	Cascadia	V	--	--	--	
1921	Mar. 4	20:00	Portland	II-III*	--	--	--	Several shocks
1921	Sept. 22	19:20	Portland	IV*	--	--	--	
1922	Mar. 27	06:15	Portland	IV	--	--	--	
1922	May 15	17:30	Portland	IV	--	--	--	

OREGON EARTHQUAKES 1841 - 1970

Year	Date	Time	Locality	Intensity	Magnitude	N. Lat.	W. Long.	Remarks
1922	Oct. 16	04:20	Hermiston	III	--	--	--	3 shocks
1922	Dec. 12	--	Pendleton area	III	--	--	--	
1923	Jan. 10	20:30	Lakeview area	V	--	42.0	120.5	
1923	Jan. 11	--	Valley Falls	V	--	--	--	R. C. Treasher, unpubl.
1924	Jan. 5	3:15	Stanfield	IV-V	--	--	--	R. C. Treasher, unpubl.
1924	Jan. 6	23:10	Milton-Weston	V	--	--	--	
1924	Feb. 24	05:45:10	At sea	VII*	5.75	44.0	127.0	
1925	July 2	07:--	Lakeview	III	--	--	--	
1926	June 5	19:50:24	At sea	VII*	6.0	43.0	127.5	
1927	Apr. 8	21:00	Richland	V	--	44.8	117.2	
1927	Apr. 9	09:30	Richland	III-IV	--	--	--	
1927	Apr. 9	14:00	Richland	III-IV	--	--	--	
1928	Sept. 4	04:40	Newport & Eugene	IV	--	--	--	
1928	Sept. 11	12:36:19	At sea	VIII*	6.3	43.5	130.25	
1929	Aug. 14	19:03:30	At sea	VI*	5.25	43.0	130.0	
1930	July 8	20:30	Perrydale	III	--	--	--	
1930	July 18	18:38	Perrydale	V-VI	--	45.0	123.2	
1931	Aug. 17	19:20	Talent	V	--	42.3	122.8	
1931	Sept. 4	03:22	Central Point	II	--	--	--	
1932	Jan. 14	16:18	Portland	IV	--	--	--	
1932	June 20	09:26:27	At sea	VII*	5.5	43.0	127.5	
1933	Mar. 26	19:05:53	At sea	VII*	5.5	43.5	129.0	
1933	July 19	05:06:36	At sea	VI*	5.25	43.0	127.25	
1933	Nov. 23	14.25	Portland	III	--	--	--	
1934	July 6	22:50	North Bend	III	--	--	--	
1936	April 30	10:55:38	At sea	VII*	5.5	44.0	128.5	
1936	July 15	23:08	Northern Oregon	VIII	--	46.0	118.3	R. C. Treasher, unpubl.
1936	July 18	08:30	Umatilla area	V	--	46.0	118.3	(Milton Freewater; VII+, Berg)
1936	July 30	11:20	Freewater	IV	--	--	--	
1936	July 30	12:00	Freewater	IV	--	--	--	
1936	Aug. 4	01:19	Umatilla area	V	--	45.8	118.6	

OREGON EARTHQUAKES 1841 1970

Year	Date	Time	Locality	Intensity	Magnitude	N. Lat.	W. Long.	Remarks
1936	Aug. 27	20:39	Milton Freewater	V	--	--	--	
1936	Sept. 25	12:53:35	At sea	VIII*	6.2	42.5	128.0	
1937	Dec. 14	09:--	Dallas	IV	--	--	--	
1938	May 28	10:14:01	At sea	VII*	6.0	42.75	126.0	
1938	July 23	02:50	Astoria	IV	--	--	--	
1938	Aug. 3	13:32:30	At sea	VII*	5.3-5.9	43.0	127.5	
1938	Aug. 11	18:52	Milton	IV	--	--	--	
1938	Oct. 27	23:10	Milton	IV	--	--	--	
1939	Jan. 26	07:59	Mission	IV	--	--	--	
1939	Feb. 14	13:--	Tillamook area	IV	--	--	--	
1939	Apr. 13	19:45	Portland	III	--	--	--	
1939	Nov. 15	--	Portland	III	--	--	--	
1940	May 25	16:02	Waldport	IV	--	--	--	
1941	Feb. 16	--	Portland	II	--	--	--	R. C. Treasher, unpubl.
1941	June 9	06:17:26	At sea	VI*	5.25	42.75	126.0	
1941	June 9	08:43:45	At sea	VI*	5.0	42.75	126.0	
1941	July 7	03:30	Medford	II	--	--	--	
1941	July 26	20:00	Tigard	IV	--	--	--	
1941	Oct. 20	06:05	Seal Rock	III	--	--	--	
1941	Oct. 31	12:41:00	At sea	VII*	5.5	43.0	128.5	
1941	Dec. 23	17:48	Robinette	III-IV	--	--	--	
1941	Dec. 23	22:20	Robinette	III-IV	--	--	--	
1941	Dec. 29	18:37	Portland	VI	--	--	--	
1942	May 12	17:52	Corvallis	V	--	44.6	123.4	
1942	June 12	02:30	Halfway	V	--	--	--	
1942	June 12	09:35	Pine	III	--	--	--	
1942	June 14	06:--	Pine	III	--	--	--	
1942	Nov. 1	10:00	Portland	V	--	45.5	122.7	
1942	Nov. 1	19:30	Madras	IV	--	--	--	
1943	June 24	16:44	Bend	III	--	--	--	
1943	Aug. 4	--	Rockville, Malheur County	III	--	--	--	Tremors believed to be related to steam vent on Leake Ranch.

OREGON EARTHQUAKES 1841 - 1970

Year	Date	Time	Locality	Intensity	Magnitude	N. Lat.	W. Long.	Remarks
1944	Mar. 5	09:--	Dallas	III	--	--	--	
1944	Mar. 5	13:00	Dallas	V	--	--	--	
1944	Mar. 6	20:09:08	At sea	VII*	5.75	44.5	129.0	
1944	Mar. 6	23:16:30	At sea	VII*	5.75	44.5	129.0	
1944	Sept. 20	03:00	Rockville, Malheur County	IV	--	--	--	
1944	Dec. 30	22:03:02	At sea	VII*	5.75	43.75	126.75	
1945	Feb. 13	20:02	Homestead	IV	--	--	--	R. C. Treasher, unpubl.
1945	Sept. 28	22:24:10	At sea	VII*	6.0	42.0	126.0	
1947	Oct. 11	16:--	Fort Klamath	IV	--	--	--	
1947	Dec. 24	20.02	Klamath Falls	IV	--	--	--	
1948	Jan. 10	00:45:50	At sea	VI*	5.3	42.0	127.0	
1948	Mar. 1	06:30	Buxton	IV	--	--	--	
1948	Mar. 22	05:30	Hildebrand	V	--	--	--	
1948	May 25	15:32:02	At sea	VII*	5.5	43.5	127.0	
1948	Dec. 20	16:18	Fossil	IV	--	--	--	
1949	Mar. 24	20:58:06	At sea	VII*	5.9	42.0	126.5	Intensity III felt at Grants Pass
1949	Apr. 3	21:30	Grants Pass	III	--	--	--	
1949	Apr. 4	01:20	Klamath Falls	IV	--	--	--	
1949	Dec. 22	19:55	Klamath Falls	IV	--	--	--	
1950	Jan. 27	10:47	At sea	V*	4.7	42.2	125.45	
1950	June 19	18:30:15	At sea	IV*	4.2	44.0	127.0	
1950	Dec. 16	10:49:01	At sea	V*	4.5	43.5	127.0	
1951	Jan. 7	22:45	McNary	V	--	--	--	
1951	Jan. 29	05:43:47	At sea	VI*	5.0	43.0	128.0	
1951	Feb. 17	--	Surprise Valley	II	--	--	--	
1951	Mar. 25	17:00	Portland	II	--	--	--	
1951	Apr. 3	--	Klamath Falls	IV	--	--	--	
1951	June 16	23:46:58	At sea	VII*	5.5	44.5	130.0	
1951	June 17	09:40:15	At sea	VII*	6.0	44.5	130.0	

OREGON EARTHQUAKES 1841 - 1970

Year	Date	Time	Locality	Intensity	Magnitude	N. Lat.	W. Long.	Remarks
1951	Oct. 13	19:45:06	At sea	V*	4.5	43.5	127.0	
1951	Dec. 26	06:31:46	At sea	IV*	4.3	43.5	127.0	
1952	Aug. 20	15:24:50	At sea	VII*	6.0	43.0	127.0	
1953	Feb. 23	07:43:00	At sea	V*	4.7	42.0	124.5	
1953	Nov. 4	21:59	Corvallis	III	--	---	---	Epicenter at sea
1953	Dec. 16	20:32	Northwestern Oregon	VI	--	45.5	122.7	
1954	Apr. 23	19:19:26	Portland area	IV	--	45.1	122.9	
1954	Feb. 3	12:41:24	At sea	VI*	5.3	44.0	128.5	
1954	Aug. 23	15:32:40	At sea	VIII*	6-6.5	43.5	128.0	
1956	July 6	02:22	At sea	VI*	4.9	42.1	126.25	
1957	Mar. 22	24:00	Alsea	III	--	---	---	
1957	Nov. 17	22:00	N.W. of Salem	VI	--	45.3	123.8	
1957	Nov. 29	04:47	Portland	III	--	---	---	
1958	Mar. 13	01:27	Portland	II	--	---	---	
1959	Jan. 21	07:15	Milton-Freewater	V	--	---	---	
1959	Aug. 4	23:53	Portland	III	--	---	---	
1959	Nov. 9	21:10	Heppner	IV	--	---	---	
1960	Nov. 8	11:39	At sea	VII*	5.5	---	---	200 miles off Newport
1961	Jan. 4	07:26	15 mi. South of St. Helens	IV	--	---	---	
1961	Aug. 18	20:56	Northwestern Oregon	VI	--	44.7	122.5	
1961	Nov. 6	17:29	N.W. of Portland	VI	--	45.7	122.9	
1961	Nov. 7	13:30	Portland	V	--	---	---	
1961	Nov. 29	11:35	Portland	IV	--	---	---	
1961	Dec. 15	11:35	Scappoose	III	--	---	---	
1962	Sept. 5	05:37	Lebanon	IV	3.5	---	---	
1962	Oct. 17	08:33	West Linn	II	--	---	---	
1962	Nov. 5	19:36:43	East of Portland	VII	5.0	45.5	122.5	
1963	Mar. 7	15:53	NW Oregon	V	--	44.9	123.5	

OREGON EARTHQUAKES 1841 - 1970

Year	Date	Time	Locality	Intensity	Magnitude	N. Lat.	W. Long.	Remarks
1963	Dec. 26	18:36	N. W. Oregon	VI	--	45.7	123.4	
1963	Mar. 2	16:30	Portland	IV	--	---	---	
1963	Mar. 7	22:53	N.W. Oregon	V	4.6	44.9	123.5	
1963	Dec. 27	02:36	N.W. Oregon	V*	4.5	45.8	123.2	
1964	Oct. 1	12:31	N.W. Oregon	V	--	45.7	122.8	
1968	May 28	00:08	S.E. Oregon	IV*	4.4	42.25	199.6	
1968	May 28	12:55	S.E. Oregon	IV*	4.4	42.25	119.8	
1968	May 30	00:35	S.E. Oregon	VI*	5.1	42.3	119.9	
1968	June 3	13:27	S.E. Oregon	VI*	5.0	42.25	119.8	
1968	June 4	02:34	S.E. Oregon	V*	4.7	42.2	119.9	
1968	June 4	06:22	S.E. Oregon	IV	4.3	42.2	119.7	
1968	June 5	04:51	S.E. Oregon	V	4.7	42.2	119.9	
1968	June 5	05:12	S.E. Oregon	IV	4.4	42.3	119.7	
1968	June 12	01:46	S.E. Oregon	IV	4.3	42.1	119.8	
1968	June 21	20:33	S.E. Oregon	IV	4.3	42.2	119.6	
1968	June 22	09:39	S.E. Oregon	IV	4.3	42.2	119.7	
1969	Mar. 5	11:43	N.W. Oregon	III	3.5	45.6	122.8	
1969	Aug. 14	14:37	N.E. Baker	IV	3.6	44.9	117.75	
1970	Feb. 12	07:52	S.E. Salem	I	2.5	44.6	122.6	
1970	June 25	07:48	W. Portland	IV	3.6	---	---	

* Intensity estimated according to Chart, page 901, Arthur Holmes, 1964

References

Berg, J. W., Jr., and Baker, C. D., 1963, Oregon earthquakes, 1841 through 1958: Bull. Seismol. Soi. America, v. 53, no. 1.

Couch, R. W., and Lowell, R. P., 1971, Earthquakes and seismic energy release in Oregon:Ore Bin v. 33, no. 4

Eppley, R. A., 1965, Earthquake history of the U. S., Part I: U. S. Dept. Commerce, Environmental Science Services Administration, Coast & Geodetic Survey Publ. no. 41-1.

CONCLUSIONS

Several tentative conclusions, important in the siting of vital structures such as nuclear reactors, can be reached on the basis of this preliminary study of historic surface faulting:

1. Branch and secondary faulting commonly accompanies the main faulting. About half of the more than 30 main ruptures of undoubted tectonic origin had branch and secondary ruptures associated with them. The proportion is probably greater than half however, because in only one-sixth of the events are we reasonably certain that branch and secondary faulting did not occur.

2. The main fault zone and the zones of branch faults and of secondary faults are narrower for strike-slip faults than they are for normal faults, reverse faults, or dextral-normal faults. The maximum distances (for the particular events studied) from the center of the main fault zone to the outer edges of the three zones are A) for main zone, about 0.06 mile for strike-slip faults and 0.5 to 0.6 mile for the other types; B) for branch faults, 0.85 mile for strike-slip faults and 1.6 to 3 miles for the other types; C) for secondary faults 1.8 miles for strike-slip faults and 8 to 8.5 miles for the other types. Secondary faulting in the Yakutat Bay earthquake of 1899 may have been as much as 16 to 21 miles from the main fault.

3. A total of seven ruptures, associated with three earthquakes generated by normal, dextral-normal, and reverse faults, occurred 7.5 to 8.5 miles from the main faults. The displacements ranged from 0.3 feet to 4 feet and were equivalent to 3.5 percent to 17 percent of the maximum displacement on the main fault.

4. The displacements on individual branch and secondary faults were less than 30 percent as large as the displacement on the main fault, with three doubtful exceptions that ranged between 50 and 80 percent.

5. With one possible exception, the main faulting occurred along faults that were, or could have been identified beforehand by geologic means. The possible exception is the Sonora, Mexico faulting 1887, for which data are incomplete.

6. One-third of the branch and secondary faulting covered in this study is known to have occurred on preexisting faults that could have been identified by simple geologic investigations; whether the other two-thirds could have been also is not known.

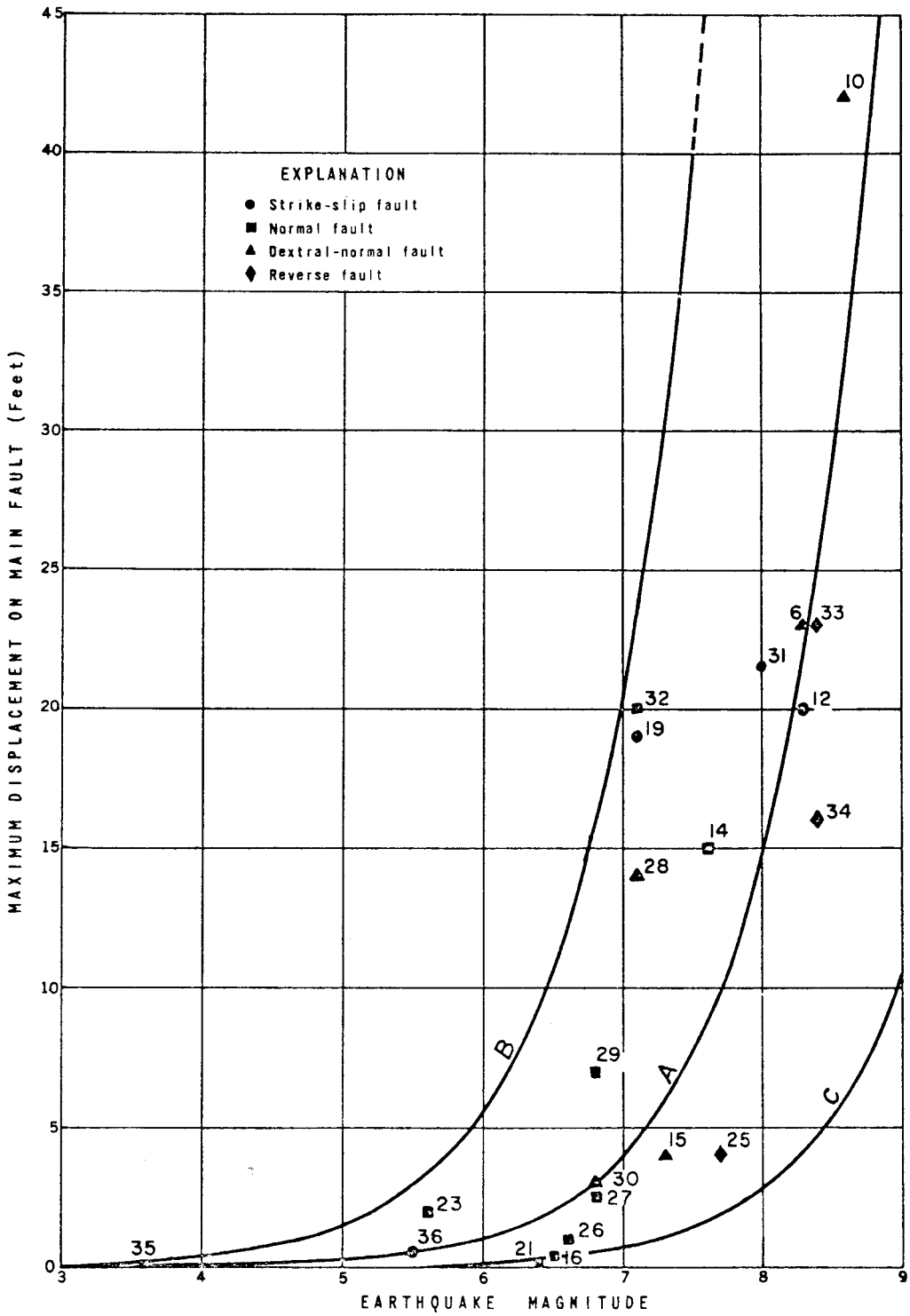


Figure 5.--Maximum displacement on main fault as related to earthquake magnitude (arithmetic plot).

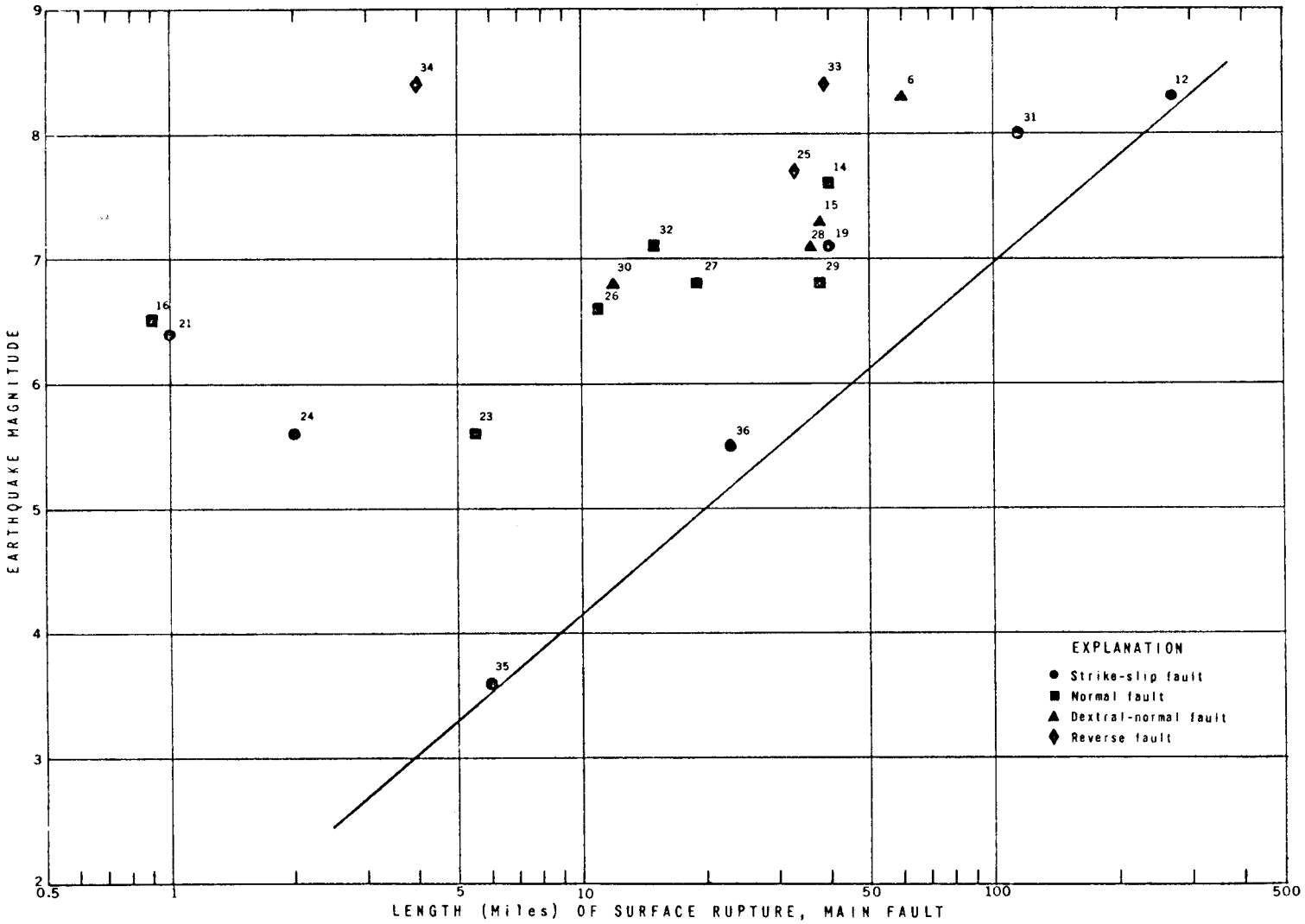


Figure 9.--Length of surface rupture on main fault as related to earthquake magnitude.

Bonilla, 1967
US Geol Survey TID-24124

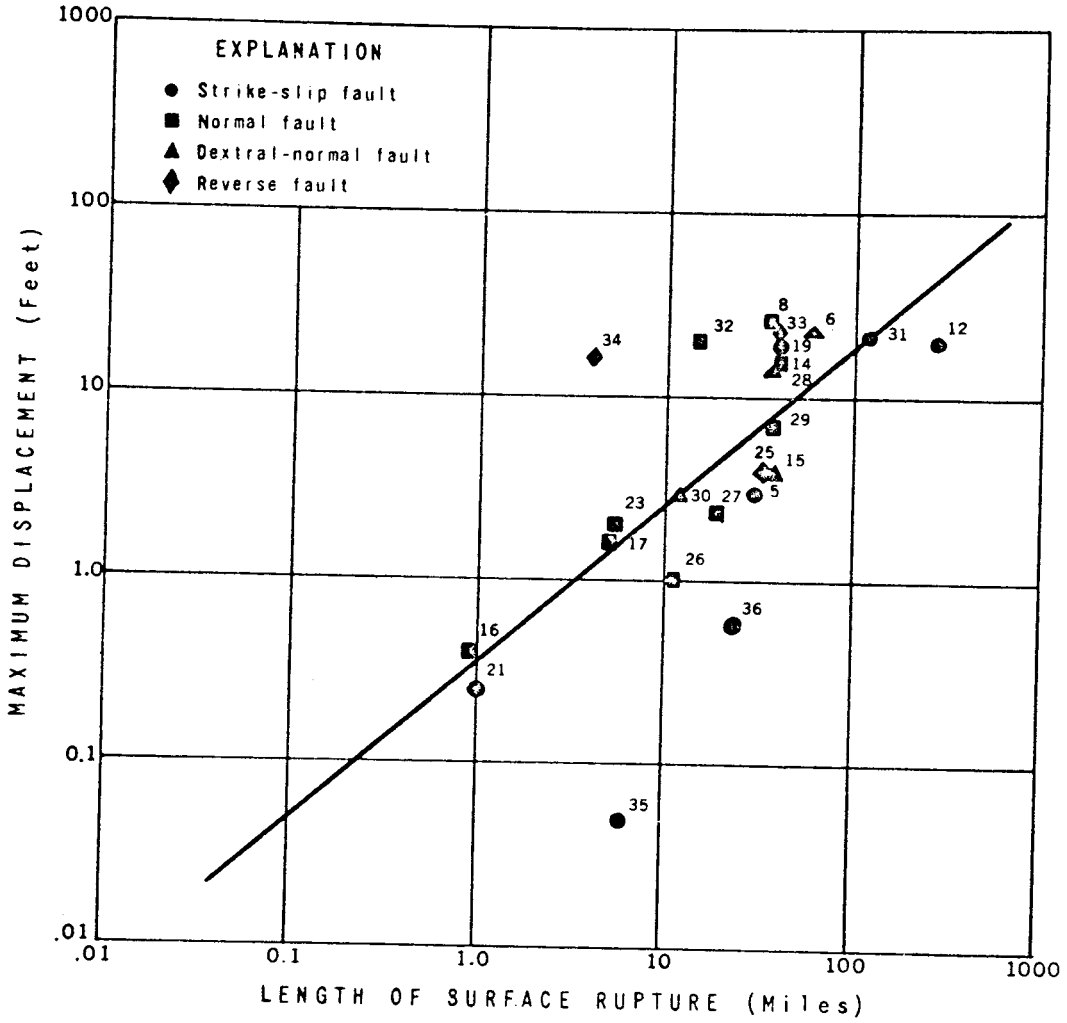


Figure 10.--Displacement as related to length of surface rupture on the main fault.

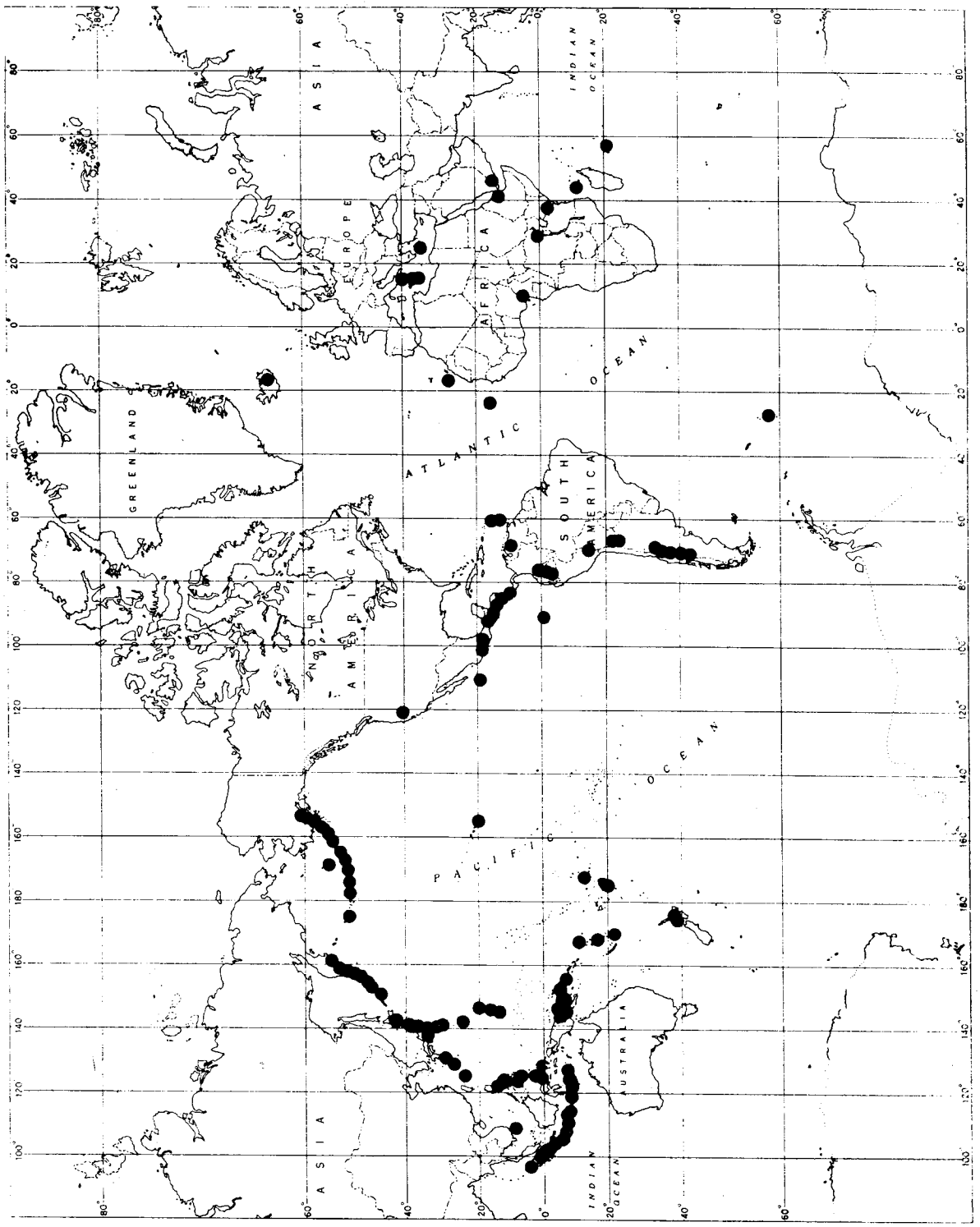


Figure 1.—Location of Volcanoes Which Have Erupted Since 1900.

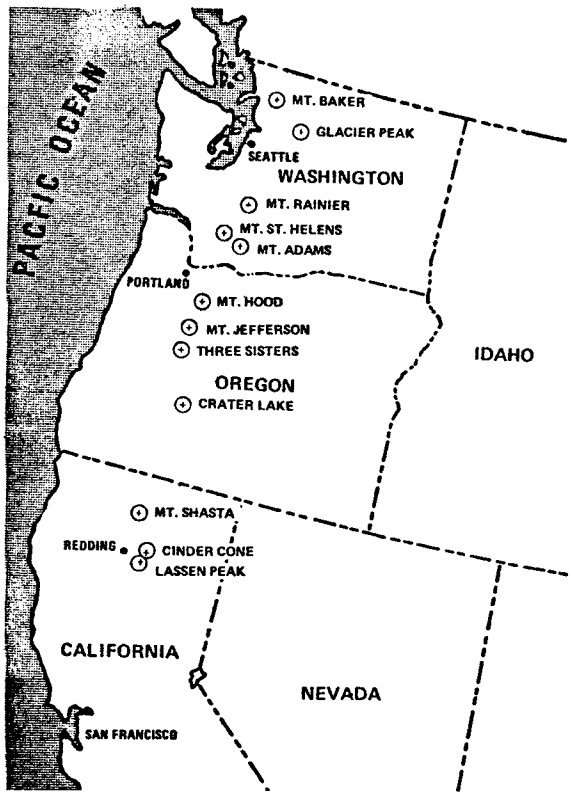


Figure 2.—Dormant Volcanoes of the Pacific Northwest—U.S. Geological Survey.

Lava Flows. These flows are completely destructive but confined to restricted areas in the immediate vicinity of the generating volcano. They may be effusive, represented by a slow outpouring from a crater or a fissure, or result from an explosive eruption which may generate a river of molten materials tens of yards wide, with rates of flow up to 30 miles per hour.

Volcanic soils are very productive, and the slopes of relatively quiescent volcanoes are often farmed extensively. Residences are sometimes situated on the slopes and in adjoining valleys in well-populated areas. This is prevalent in Mexico, Italy, Hawaii, and Japan. The property in the path of a lava flow cannot be saved, and any economic use of the slopes of a volcano involves a calculated risk.

Pyroclastic Ejecta. These are rock particles formed by the explosive fracture of liquid and solid material by rapidly expanding gases. When the particles are fine, they are combined with other debris and blown aloft in enormous quantities, where they remain suspended for long periods. Settling in a stifling blanket over wide areas, they cause respiratory problems, kill crops, and reduce the productivity of the land for many years until they assimilate into the soil.

Pyroclastic flows are the most dangerous and difficult volcanic phenomena to guard against. If people are not well clear of the danger area before the eruption, there is little hope of escape. These flows arise when airborne pyroclastic rocks are too heavy to remain aloft and flow downslope like a hot liquid. They attain speeds of more than 60 miles per hour, behaving much like an avalanche and causing plants and buildings to burst into flame.

Volcanic Mudflows. The threat posed by active volcanoes is not restricted to eruptions. The large amounts of loose ejecta scattered on slopes near active volcanoes, as well as parts of the volcanoes themselves, are highly susceptible to sudden downslope movement in the form of volcanic mudflows. The volcanoes of the Cascade Range are particularly susceptible to mudflow hazards because of the high rainfall along the crest of the Cascade Range and the large volume of water that is temporarily stored as snow and glacier ice at higher altitudes on the volcanoes.

During heavy rains, large volumes of unconsolidated debris can be stripped from steep volcanic slopes and carried quickly downslope by mudflows. A subtle increase in thermal emission can cause release of melt-water, saturating large quantities of debris and making it highly susceptible to mudflow transport. More than 55 mudflows have originated on the slopes of Mt. Rainier in the past 10,000 years. The largest of these, 4,800 years ago, traveled 45 miles down the valley of the White River before spreading out on the Puget Sound lowland as a lobe 20 miles long and 3 to 10 miles wide.

Capabilities and Limitations.

Mitigation. Because of the devastating force of volcanic eruptions, mitigation of damage has proved to be difficult. Some success has been attained in slowing or diverting lava flows by strategically locating stone barricades. Danger zones on slopes can be mapped and controlled to prohibit entry by humans and domestic animals. During periods of danger, animals and some items of property can be moved out of the paths of lava flows to safer locations.

Prediction and Warning. The capability to predict volcanic activity and give proper warning varies from acceptable to clearly inadequate, depending on the geographic areas involved.

Hawaii. HVO, through its seismic and deformation monitoring, has given accurate warning of eruptions of Kilauea, most notably in 1955 and 1960,[3] and again in August and September 1971. The extensive and accurate Kilauea data do not afford a basis for prediction of eruption of other volcanoes, although some techniques

List of Consultants

Bergstrom, R. E., Head Geologist, Groundwater Section, Illinois Geology Survey, Urbano, Illinois.

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Fogarty, David J., Vice-President, Southern California Edison Company, Rosemead, California.

Groh, Edward A., Geologist, Portland, Oregon.

Ivey, John B., Engineering Geologist, Amuedo and Ivey, Denver, Colorado.

Kulm, La Verne D., Professor of Geology, Oregon State University, Department of Oceanography.

Lightfoot, Joseph F., Executive Secretary, Washington Thermal Power Plant Site Evaluation Council, Olympia, Washington.

Palmer, Leonard, Professor of Geology, Portland State University.

Snavely, Parke D. Jr., Staff Geologist, U. S. Geological Survey, Menlo Park, California.

Swiger, W. F., Engineer and Geologist, Stone & Webster Engineering Corp., Boston, Massachusetts.

Von Hake, C. A., U. S. Department of Commerce, National Earthquake Center, Boulder, Colorado.

Walker, George W., Chief, Western Minerals Resources Branch, U. S. Geological Survey, Menlo Park, California.

Weaver, Kenneth N., Director, Maryland Geological Survey, Baltimore, Maryland.

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Mr. Vernon C. Newton, Jr.
Geologist and Petroleum Engineer
Department of Geology and Mineral
Industries
1069 State Office Building
Portland, Oregon 97201

December 18, 1972

Dear Vernon,

Please accept my apology for not writing sooner regarding your proposed draft on siting for the Oregon Nuclear and Thermal Energy Council. We are in the process of completing PSAR on several large nuclear power stations and the last several weeks have been extremely busy. You specifically requested guidance on two problems, storage of radioactive materials on site and liquefaction of granular soils.

It is against AEC rules to store radioactive material on site, other than fuel in the reactor or temporarily spent fuel in the spent fuel pit, from the time it is removed from the reactor during a refueling operation until it can be placed in a lead container and shipped to a fuel reprocessing plant. There it is broken down chemically and unspent fuel remanufactured for further use. All other nuclear waste must be disposed of promptly. At the termination of useful life of a power station, it is thoroughly cleaned up, all fuel removed, and the plant deactivated. This was done on the Carolina Virginia, tube type reactor at Parr Shoals, North Carolina, which was retired from service about four or five years ago. Just what would be done with the reactor vessel, that is, the steel vessel in which the reactor itself is actually located, which probably would have some residual activity after a long period of service, is not completely established. Presumably, it would be left in place and filled with concrete. The level of reactivity would be low and probably negligible at the outside wall of the containment structure.

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ILLINOIS STATE GEOLOGICAL SURVEY
NATURAL RESOURCES BUILDING, URBANA, ILLINOIS 61801 TELEPHONE 217 344-1481
JOHN C. FRYE, CHIEF

December 12, 1972

Mr. Vernon C. Newton, Jr.
Petroleum Engineer
Department of Geology and Mineral Industries
1069 State Office Building
Portland, OR 97201

Dear Vern:

I am sorry to hear that the DEQ did not grant Chem-Nuclear a license for radwaste disposal; I firmly believe Arlington is an excellent site and the Company really does need this facility. I was pleased that their application had the support of the Oregon Survey.

I am sorry that I don't have anything to offer with reference to your particular problem on the longevity of reactor facilities. Though we have two nuclear stations on the line in Illinois, we have never been involved with this particular aspect of the problem.

Give my regards to Andy, and Merry Christmas.

Sincerely,

Bob B.

Robert E. Bergstrom
Geologist and Head
Section of Ground-Water Geology
and Geophysical Exploration

United States Department of the Interior

GEOLOGICAL SURVEY

Branch of Western Mineral Resources
345 Middlefield Road
Menlo Park, California 94025

November 21, 1972

Mr. Vernon C. Newton, Jr.
Department of Geology & Mineral Industries
1069 State Office Building
Portland, Oregon 97201

Dear Vern:

I have just finished a critical review of your report and am faced with a number of major questions, perhaps the most important being that I am still in the dark as to the purpose and audience of this opus. The report touches briefly on a number of topics--tectonism, volcanism, subduction, gravity sliding, microseisms, fundamentals of seismicity, seiches, tsunamis, etc., etc.--without clearly defining the necessity for this very broad coverage. Perhaps what I am trying to say is that the report appears to lack direction (or purpose) and, hence, many of the data and speculations seem unwarranted or misdirected.

My recommendations are:

1. Include in the "Introduction" some of the objectives and reasons for writing the report. Several of these are covered in your transmittal letter to me, but are not adequately covered in your report.

2. Emphasize factual data--areas tectonically and volcanologically active, as demonstrated by seismic records and by systematic geologic mapping, areas of over-steepened slopes and active landslides, etc.--and curtail hypothetical parts--plate tectonics, spreading ridges, subduction, etc. Most, if not all, of the latter is highly speculative and certainly should not be a major part of a report prepared for a Council established to consider preliminary planning for nuclear plant sitings. Their opinions, decisions, and reports must necessarily deal with pretty hard facts, not with geologic speculations except as it bears on site stability. Speculation as to whether volcanic or tectonic activity can be expected in

areas recently active in Oregon is, of course, warranted and should be discussed. Furthermore, I would attempt to draw a more critical distinction between what is geologically old and of little seismic concern versus evidence of very young (late Pleistocene and Holocene) volcanism and tectonism, as well as historic and late prehistoric gravity sliding. Also I would attempt to develop the theme that broad, regional evaluation must be followed by detailed site evaluations involving a very complex array of geologic, hydrologic, and seismologic data, as well as data from other disciplines.

I've made a few minor comments on the manuscript pages and add a few here for your consideration.

p. 4--For what it's worth, an elderly resident of Fields, Oregon, told me that following an earthquake in the 1920's--felt by him and other residents of Alvord Valley--a distinct northeast rupture was found crossing the playa of Alvord Desert. The rupture offset surface layers about 1.5 feet in a vertical sense. Also on p. 4, I wonder whether the emphasis is wrong in terms of the age of major fault blocks in the Basin and Range. Certainly some of the faulting is late Pleistocene, but most is older, with some major increments in the period from middle Pliocene ($\approx$ 5-6 million years) through early Pleistocene ($\approx$ 1-2.5 m.y.).

Hope that these few comments will be of some value.

Sincerely,

George

George W. Walker, Chief
Branch of Western Mineral Resources

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
ENVIRONMENTAL DATA SERVICE
National Geophysical and Solar-Terrestrial
Data Center
Boulder, Colorado 80302

September 18, 1972

Mr. Vernon C. Newton, Jr.
Department of Geology and Mineral Industries
Administrative Office
1069 State Office Building
Portland, Oregon 97201

Dear Mr. Newton:

Your letter of August 11, 1972 has been referred by the National Weather Service office at Salt Lake City to this office for reply.

Enclosed is our Earthquake History of the United States, Parts I and II which lists the stronger shocks through the end of 1963. The summary on page 114 of Part I gives by date the earthquakes felt in Oregon. Dates not preceded by an asterisk indicate shocks located outside the state. Details on most of these earthquakes are covered in the Washington and Oregon chapter, pages 74-84. A few of the earthquakes (Oct. 10, 1915, May 12, 1916, Dec. 20, 1932, July 12, 1944, Feb. 13, 1945, Oct. 11, 1956, and Aug. 18, 1959) are listed in the Western Mountain Region chapter or with California and western Nevada in Part II.

One additional earthquake occurring outside Oregon caused intensity VI and lower effects in Oregon: April 29, 1965 - Epicenter 47.4° N, 122.3° W - Puget Sound, Washington area - Magnitude 6.5 - Maximum Intensity VIII in Seattle area.

If this office can supply further service please let us know.

Sincerely,

Carl A. von Hake

Carl A. von Hake
Earthquake Information

Enclosures

Southern California Edison Company

P. O. BOX 800

2244 WALNUT GROVE AVENUE

ROSEMEAD, CALIFORNIA 91770

DAVID J. FOGARTY
VICE PRESIDENT

TELEPHONE
213-572-2796

Mr. Vernon C. Newton, Jr.
Geologist-Petroleum Engineer
Department of Geology and
Mineral Industries
1069 State Office Building
Portland, Oregon 97201

Dear Mr. Newton:

As requested in your letter dated August 25, 1972, we have reviewed the geologic criteria for the Oregon Nuclear Siting Council and have the following comments:

1. Rule No. 40-005, Section 4, Geology (Revised 7/17/72) We have two suggestions which would make more specific the scope of the required geologic studies. We suggest that the third sentence of the section be reworded to read:

   "Submarine geologic and geophysical investigations will be required for coastal plant sites where offshore faulting is suspected."

   Such offshore geological and geophysical investigations would determine subsurface structural geology, fault trends and, where possible, the youngest formations which are cut by faulting.

   At the end of the paragraph, we suggest that the first three items listed be revised to read:

   "a. Areas where earthquakes have been recorded or areas with recorded macro-seismicity.

   b. Areas of recorded late Quaternary faulting and volcanism.

c. Areas where potentially unstable slopes could effect plant safety."

2. Draft Rule No. 25-005, Section 7, Geology and Seismology (a) Maps and Charts

We suggest the following revision to item 3:

"3. Geological map or maps which show geologic structures including faults and significant structural trends."

We also suggest the addition of an item 6, which would require maps showing historically recorded earthquakes within, say 50 to 100 miles of the site.

(b) Physiographic

We suggest that this section should be reworded to clarify the author's meaning.

(h) Seismic

We suggest that this section contain requirements for geophysical investigations and laboratory testing to determine site dynamic response during the maximum probable earthquake. In addition, description of earthquake intensity at the site during historical earthquakes should be required.

We also suggest that the last sentence of this section be modified to read:

"The possible effects of liquification shall be considered."

3. Draft Rule No. 25-010, Section 7, Geology and Seismology (Revised 8/24/72)

We do not have any comments on this section.

If you have any questions regarding our comments or wish to discuss the general subject further, please contact Mr. Phil West of our Environmental Engineering organization, who has been intimately involved with all our seismic investigations, at (213) 572-1887.

Yours very truly,

Burkland
and ASSOCIATES

CONSULTANTS IN ENGINEERING GEOLOGY • SLOPE STABILITY
ENVIRONMENTAL GEOLOGY • SOIL AND ROCK MECHANICS

17 July 1972

Mr. R. E. Corcoran, State Geologist
Department of Geology and Mineral Industries
1069 State Office Building
Portland, OR 97201

Dear Mr. Corcoran:

As indicated in our letter of 5 June, we have reviewed your draft of the Thermal Power Plant site certificate application information.

Dr. Jess Hayes of our staff and I have both reviewed the draft in detail. Our conclusions are that it is a very well written and thorough document. Section 7, dealing with Geology and Seismology, is particularly well done, and appears to cover all aspects of the subject.

Enclosed for your information is a memorandum with Dr. Hayes' comments.

We appreciated the opportunity for reviewing the draft, and trust that in its final form it will satisfactorily serve the State.

Sincerely yours,

BURKLAND AND ASSOCIATES

Philip V. Burkland, President

jg

Enclosure

RECEIVED
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Burkland and ASSOCIATES

CONSULTANTS IN ENGINEERING GEOLOGY · SLOPE STABILITY
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29 June 1972

M E M O R A N D U M

TO: P. V. Burkland

FROM: J. J. Hayes

SUBJECT: Oregon Geological Survey, Commentary on Application for a Site Certificate for a Thermal Power Plant

---

Reference preliminary manuscript prepared by the Geological Survey of Oregon has been reviewed. The following comments are for your information and consideration.

1. Location and Description

   Suggest small location map showing position of site within county or state borders with mileage scale to compare with nearby features of interest.

2. General Plant Description

   Perhaps special emphasis on foundation loads, depth of excavation, heigh and slopes of cut, proposed methods of rock stabilization (rock bolting, grouting, cribbing, etc.) should be indicated here. Perhaps already covered in Section 7 (?)

3. Approvals and Consultations

   No special comment.

4. Need for Power

   No special comment.

5. Population

   No special comment.

6. Nearby Facilities

   No special comment.

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7. Geology and Seismology

   Appears most complete. Possible reference needed to cover slope creep or landslide possibilities.

8. Meteorology

   No special comment.

9. Floods

   No special comment.

10. Land Use

    No special comment.

11. Water Use

    Possible use of pipelines from adjacent areas to supply project, or plant requirements may be indicated under certain circumstances.

12. Heat Dissipation

    No special comment.

13. Chemical Discharge

    Possible underground or surface temporary storage methods of undesirable chemicals or concentrates may require description of procedures and techniques.

14. Sanitary Wastes

    No special comment.

15. Radioactive Discharges

    Again temporary or permanent storage may be indicated.

16. Biological Impact

    No special comment.

17. Noise Control

    No special comment.

18. Aesthetics

    No special comment.

29 June 1972

19. Plant Economics

No special comment.

20. Applicants' Financial Ability

No special comment.

21. Operational Ability

No special comment.

22. Application Form

No special comment.

General Remarks:

The construction of the draft is excellent, and the wording clear. So far as the undersigned can discern, no essential or important factors have been omitted.

J. J. Hayes

jg

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Mr. Vernon C. Newton, Jr.
Geologist - Petroleum Engineer
Department of Geology and Mineral Industry
Administrative Office
1069 State Office Building
Portland, Oregon 97201

June 26, 1972

AIR MAIL

Dear Mr. Newton:

This is in answer to your letter of June 12 asking that I comment on the geologic sections of the proposed siting criteria which you are working on for the Oregon Nuclear and Thermal Energy Council. The geologic criteria seem appropriate for design of nuclear plants since there is a possible public safety problem with such plants in the event of a major accident. However, fossil fuel plants do not involve public safety problems. Accordingly, I feel the geologic studies and studies of seismicity required by the criteria are more stringent than could reasonably be justified. I suggest that a distinction be made in the criteria between the two. For nuclear plants, the criteria essentially as written could be required; I have made a few suggestions below. For fossil fuel plants, I would suggest you merely require a report by competent soils engineers and geologists, establishing the general site geology, foundation conditions, and basis of foundation design in accordance with good engineering practice.

For nuclear plants, the criteria which you are proposing conform very closely to the standard format presentation of the PSAR and FSAR as promulgated by the AEC. This, in my opinion, is a sound approach. The AEC requirements are quite broad and very thorough; patterning your requirements directly on theirs with essentially the same item sequence will greatly facilitate the work of the architect-engineer in that he will not have to write two reports to present the same data.

In line with this, I would suggest that you change the terminology for the Design Basis Earthquake to Safe Shutdown Earthquake again simply to correspond with AEC procedures in order that titles will not have to be changed on drawings.

As I have reflected upon the AEC requirements as they would apply in Oregon, it seems to me that certain geologic problems peculiar to Oregon might well be emphasized although they are covered in general terms. Among these are

the location of the plant relative to active or recently active volcanoes; consideration being given to the possibility of renewed volcanic activity which could result in lava flows, mud flows, or ash or pumice falls. There has been sufficient late Pleistocene activity of the Cascade volcanoes to indicate that this matter should be given consideration. Another item which should be carefully documented would be the possibility of lava tubes underlying the site, particularly for sites located on the Columbia River basalts. Consideration should also be given to metastable soils. This would include loess deposits in Eastern Oregon, playa deposits, alluvial fans, rock glaciers, and mud flows, since any of these can involve open, low density soil structures which can collapse upon wetting or under load. A similar problem which might be considered would be the situation where open work gravels are overlain by finer grained materials, such that internal erosion can occur with the finer overlying materials migrating downward into the coarse open work gravels.

Slide hazards are covered in the standard format but, again, you might find it desirable to emphasize this problem, especially slides in stiff fissured or highly consolidated clays or in weathered rock materials, and the effects on slides of eliminating forest cover. There is some indication that heavy forest cover results in sufficient water usage that such cover acts as a definite stabilizer in slide prone areas.

I am enclosing a copy of an interoffice memorandum by Mr. Allred, Assistant Chief Power Engineer, discussing in general the proposed criteria since these comments may be of interest to you.

My tentative plans call for me to be on the West Coast in the week beginning July 17 and, if it is convenient, I would indeed like to spend a day with you discussing geologic and foundation problems for nuclear power stations. In the meantime, I trust these comments will be of some assistance to you in your undertaking.

Please give my regards to Andy Corcoran.

Very truly yours,

W. F. Swiger
Senior Consulting Engineer

Enclosure

WFS:ER

INTEROFFICE MEMORANDUM

▲ 040.26

J.O. OR W.O. NO.

SUBJECT COMMENTS ON INFORMATION TO BE INCLUDED IN STATE OF OREGON APPLICATION FOR A THERMAL POWER PLANT SITE CERTIFICATE

DATE June 26, 1972

FROM WBAllred:RR

TO WFSwiger

CC General Files

I have reviewed the document which outlines information to be furnished with an application for a site certificate to the State of Oregon for a thermal power plant. The document includes a substantial amount of information on reactor safety, environmental effects, economic impact, and plant description which are currently required in the 10CFR50 for SAR documents, required by EPA in an environmental impact statement, or required by the Corps of Engineers in indicating thermal discharges to interstate waters. On face value it could be said that after preparation of these documents, the application and supporting information could be readily prepared for the State of Oregon.

However, the schedule for the site certificate application is such that this information probably would be required in advance of the other documents. This suggests, therefore, that project planning for thermal power plants must be started even earlier than is currently required; this tendency would be one to resist. I would also comment that the State of Oregon appears to be pre-empting some of the prerogatives of the AEC in regard to plant safety as well as the prerogatives of EPA and the Corps of Engineers in the area of environmental effects.

My comments are general with regard to the geology and seismicity of the site. I have not attempted to comment on this area since it is currently being handled by you.

W. B. Allred
Assistant Chief Power Engineer

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TELEPHONE: 235-0771
235-1792

MARYLAND GEOLOGICAL SURVEY

LATROBE HALL, THE JOHNS HOPKINS UNIVERSITY
BALTIMORE, MARYLAND 21218

May 17, 1972

Mr. Vernon C. Newton, Jr.
Geologist - Petroleum Engineer
Department of Geology and Mineral Industries
1069 State Office Building
Portland, Oregon 97201

Dear Mr. Newton:

Regarding your letter of May 2 we thus far have not developed any formal geologic siting criteria for nuclear reactor plants in Maryland.

Maryland's new power plant siting act with which you are familiar requires several levels of environmental investigations before a power plant site is approved by the State. Most of the research effort regarding general effects of power plants as well as specific site evaluations is being carried out through research contracts to Universities and private consulting firms. As a member agency of the Department of Natural Resources we have the opportunity to review and recommend on geologic problems which may be important at specific site. We may also become involved in some geologic investigations relating generally to power plant siting.

You may be familiar with the AEC Safety and Information Guide. In the event you do not have a copy of the geologic requirements in this guide I have attached a copy of some. Specific details about other aspects of the Power Plant Siting Program should be directed to:

Mr. Lee Zeni, Director
Power Plant Siting Program
State Office Building
Annapolis, Maryland 21401

Sincerely yours,

Kenneth N. Weaver
crb
Kenneth N. Weaver
Director

KNW:crb
CCE L. Zeni
Enc.

THERMAL POWER PLANT SITE EVALUATION COUNCIL
820 EAST FIFTH AVENUE, OLYMPIA, WASHINGTON 98501 PHONE: 753-7384

GOVERNOR DANIEL J. EVANS
Chairman: Oswald Greager

April 14, 1972

Mr. Vernon C. Newton, Jr.
Geologist - Petroleum Engineer
Dept. of Geology & Mineral Industries
1069 State Office Building
Portland, Oregon 97201

Dear Mr. Newton:

As you requested by letter of April 4, 1972, we are enclosing a booklet containing WAC 463-12, the "Guidelines to Applicants," which have been adopted by the Thermal Power Plant Site Evaluation Council. The only reference therein to geological information is in WAC 463-12-020(4). I question that these guidelines will be of particular assistance to you, however, if you have specific areas in which our recent experience in reviewing the Washington Public Power Supply System's application for certification of its proposed Hanford No. 2 plant might be helpful, we will be happy to attempt to share that experience.

You should know that Dr. Kelly Woods of your Nuclear and Thermal Energy Council is very familiar with our law and its application.

Do not hesitate to contact us again if you feel that we might be of help.

Very truly yours,

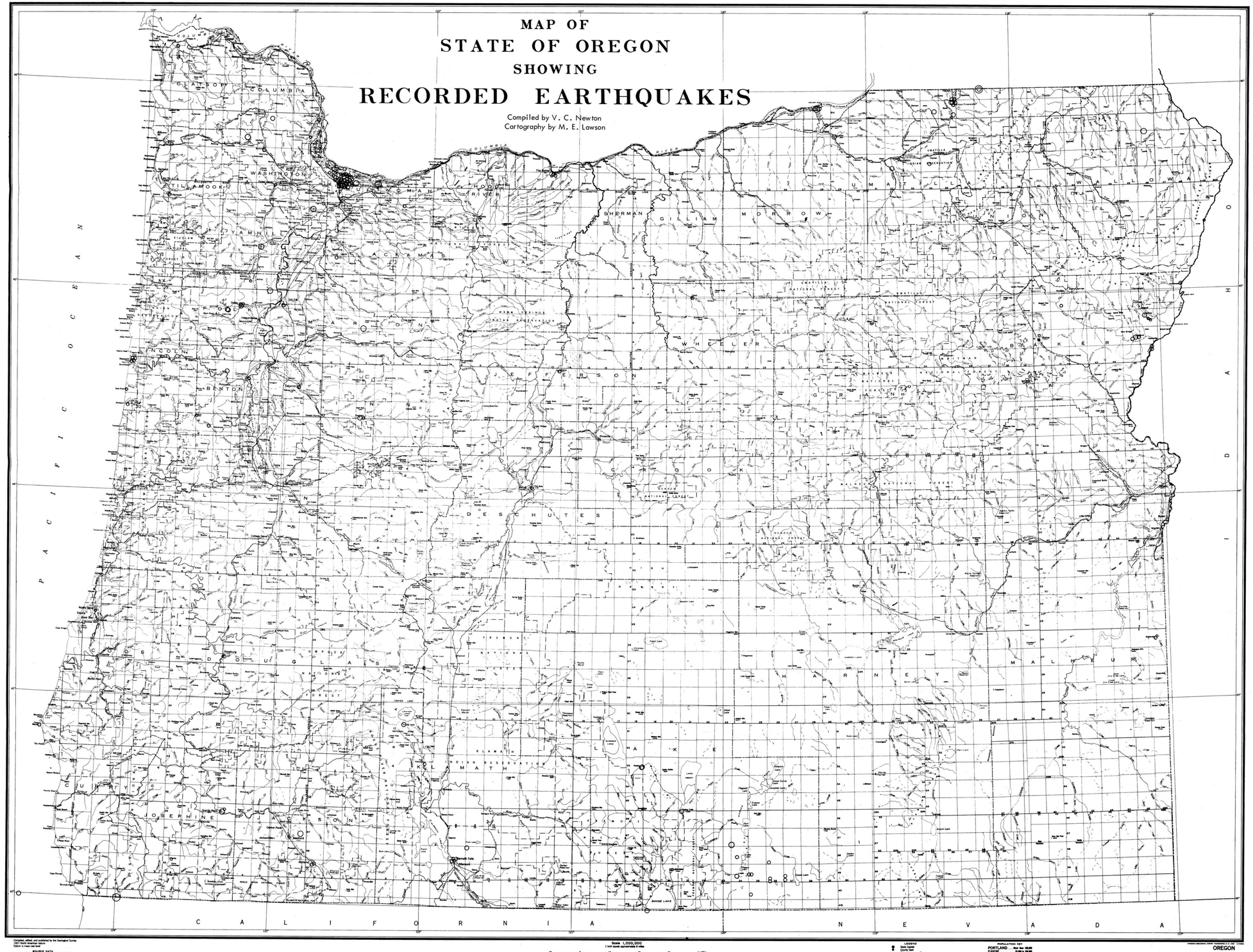
Joseph F. Lightfoot
Executive Secretary

JFL:els

Enclosure

Map prepared by
STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

O-73-01



SCALE OF EARTHQUAKE INTENSITIES

Intensity	Description of Effects	Max. Ground Accel. cm/sec^2	Richter Magnitude Equiv.
I	Instrumental: detected only by seismographs	1.0	
II	Feeble: noticed only by sensitive people	2.5	
III	Slight: like the vibrations due to a passing truck; felt by people at rest, especially on upper floors	5.0	3.5-4.2
IV	Moderate: felt by people walking; rocking of loose objects, including standing vehicles	10.0	4.3-4.8
V	Rather strong: felt generally, most sleepers awakened and bells ring	25.0	
VI	Strong: trees sway and all suspended objects swing; damage by overturning and falling loose objects	50.0	4.9-5.4
VII	Very strong: general alarm; walls crack; plaster falls	100.0	5.5-6.1
VIII	Destructive: car drivers seriously disturbed; masonry fissured, chimneys fall; poorly constructed buildings damaged	250.0	6.2-6.4

(after Arthur Holmes, 1965)

Compiled, edited, and published by the Geological Survey
1927 North American Datum
Datum is mean sea level

SOURCE DATA
U. S. Dept. of Commerce - Bureau of Census
U. S. Dept. of Commerce - Bureau of Public Roads Maps
U. S. Dept. of Agriculture - Forest Service Maps

Scale 1:500,000
1 inch equals approximately 8 miles
Miles
Kilometers
Lambert conformal conic projection
Standard parallels 37 and 45

LEGEND
State Capital
County Seat
Cities, towns, or villages
Concrete boundary shown for towns over 2500 population

POPULATION KEY
PORTLAND ..... More than 100,000
EUGENE ..... 25,000 to 100,000
Medford ..... 10,000 to 25,000
Hood River ..... 1,000 to 5,000
Canyon City ..... Less than 1,000
Populations indicated in area of dotted
COMPILED IN 1974 EDITION OF 1974

OREGON
BASE MAP

Map prepared by
STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

O-73-01

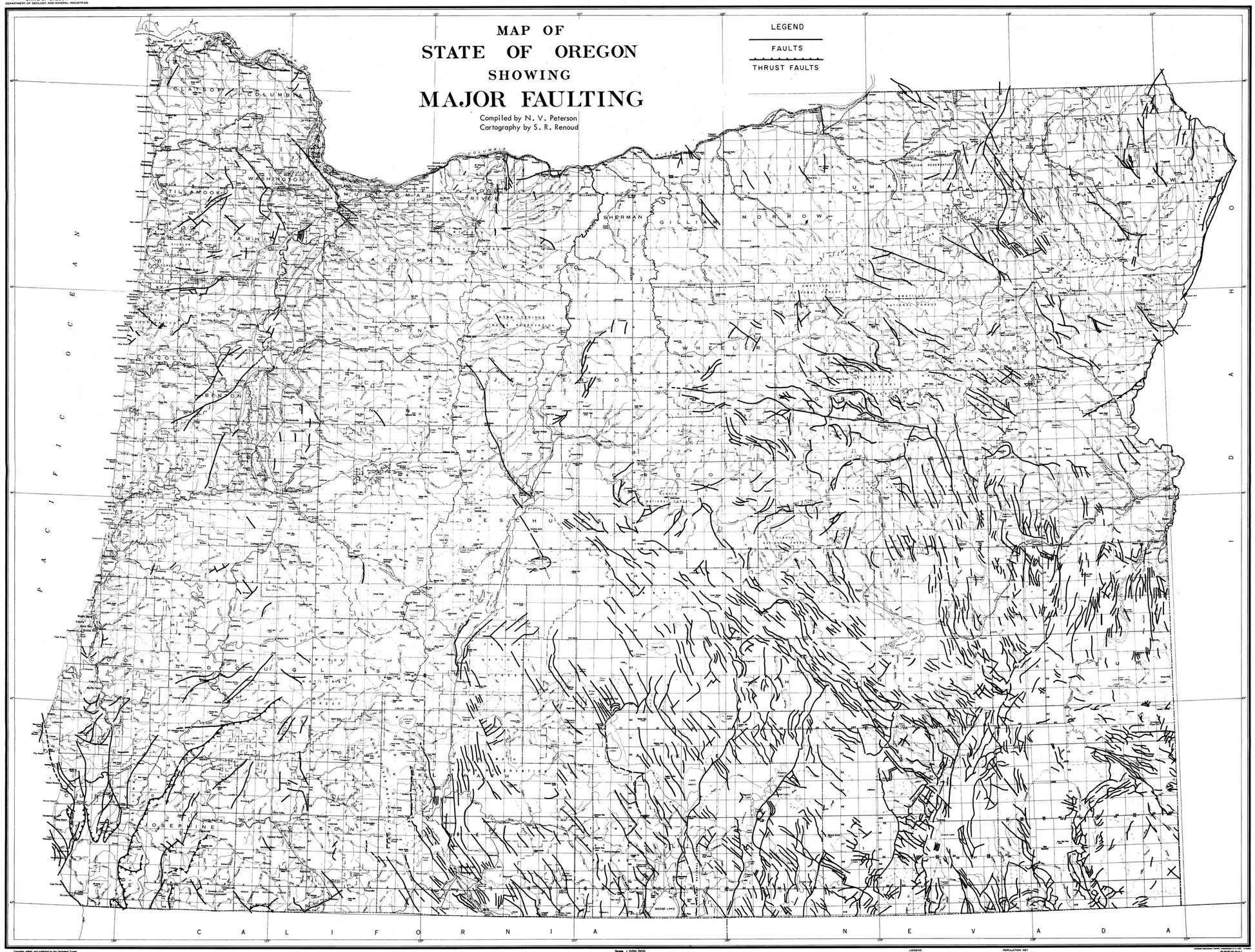
MAP OF STATE OF OREGON SHOWING MAJOR FAULTING

Compiled by N. V. Peterson
Cartography by S. R. Renoud

LEGEND

FAULTS

THRUST FAULTS



Compiled, edited, and published by the Geological Survey
Base map by Cartocraft
Datum is mean sea level

SOURCE DATA
U. S. Dept. of Commerce - Geological Survey, Topographic Maps
U. S. Dept. of Commerce - Coast and Geodetic Survey Maps
U. S. Dept. of Agriculture - Forest Service Maps

Scale 1:500,000
1 inch equals approximately 8 miles

Lambert conformal conic projection
Standard parallels 33° and 45°

LEGEND
State Capital
County Seat
Cities, towns, or villages
Corporate boundary known for towns over 2500 population

POPULATION KEY
PORTLAND ..... More than 100,000
EUGENE ..... 25,000 to 100,000
Pendleton ..... 1,000 to 25,000
Wood River ..... 250 to 1,000
Ukiah ..... Less than 1,000
Populations indicated by size of letters
1960 U.S. Census

OREGON
BASE MAP

REFERENCES

Baldwin, E. M., 1956, Geologic map of lower Siuslaw River area, Oregon: U.S. Geol. Survey Map OM-186.

_____, 1961, Geologic map of the lower Umpqua River area, Oregon: U.S. Geol. Survey Map OM-204.

_____, 1969, Geologic map of the Myrtle Point area, Coos County, Oregon: U.S. Geol. Survey Map MF-302.

_____, 1971, Geology of the Powers quadrangle, Oregon: Oregon Dept. Geol. and Mineral Indus. map GMS-5.

Baldwin, E. M., and Roberts, A. E., [undated] Geology of the Spirit Mountain quadrangle, northwestern Oregon: U.S. Geol. Survey Map OM-129.

Brown, C. E., and Thayer, T. P., 1966, Geologic map of the Canyon City quadrangle, northeastern Oregon: U.S. Geol. Survey Map I-447.

Corcoran, R. E., and others, 1962, Geology of the Mitchell Butte quadrangle, Oregon: Oregon Dept. Geol. and Mineral Indus., map GMS-2.

Dott, R. H., Jr., 1971, Geology of the southwestern Oregon coast west of the 124th meridian: Oregon Dept. Geol. and Mineral Indus. Bull. 69.

Greene, R. C., Walker, G. W., and Corcoran, R. E., 1972, Geologic map of the Burns quadrangle, Oregon: U.S. Geol. Survey Map I-680.

Hotz, P. E., 1971, Geology of lode gold districts in the Klamath Mountains, California and Oregon: U.S. Geol. Survey Bull. 1290.

Newcomb, R. C., 1970, Tectonic structure of the main part of the basalt of the Columbia River Group, Washington, Oregon, and Idaho: U.S. Geol. Survey Map I-587.

Oles, K. F., and Enlows, H. E., 1971, Bedrock geology of the Mitchell quadrangle, Wheeler County, Oregon: Oregon Dept. Geol. and Mineral Indus. Bull. 72.

Peterson, N. V., and McIntyre, S. R., 1970, The reconnaissance geology and mineral resources of eastern Klamath County and western Lake County, Oregon: Oregon Dept. Geol. and Mineral Indus. Bull. 66.

Ramp, L., 1972, Geologic map of the upper Chetco area: Oregon Dept. Geol. and Mineral Indus., unpublished.

Swanson, D. W., 1969, Reconnaissance geologic map of the east half of the Bend quadrangle, Crook, Wheeler, Jefferson, Wasco and Deschutes Counties, Oregon: U.S. Geol. Survey Map I-568.

Vokes, H. E., Myers, D. A., and Hoover, Linn, 1954, Geology of the west-central border area of the Willamette Valley: U.S. Geol. Survey Map OM-150.

Vokes, H. E., Norbisrath, Hans, and Snavely, P. D., Jr., 1949, Geology of the Newport-Waldport area, Lincoln and Lane Counties, Oregon: U.S. Geol. Survey Map OM-88.

Vokes, H. E., Snavely, P. D., Jr., and Myers, D. A., 1951, Geology of the southern and southwestern border area of the Willamette Valley, Oregon: U.S. Geol. Survey Map OM-110.

Walker, G. W., 1963, Reconnaissance geologic map of the eastern half of the Klamath quadrangle, Lake and Klamath Counties, Oregon: U.S. Geol. Survey Map MF-260.

_____, 1972, Structure of the east half of Oregon: unpublished.

Walker, G. W., Peterson, N. V., Greene, R. C., 1967, Reconnaissance geologic map of the east half of the Crescent quadrangle, Lake, Deschutes, and Crook Counties, Oregon: U.S. Geol. Survey Map I-493.

Walker, G. W., and Repenning, C. A., 1965, Reconnaissance geologic map of the Adel quadrangle, Lake Harney and Malheur Counties, Oregon: U.S. Geol. Survey Map I-446.

_____, and _____, 1966, Reconnaissance geologic map of the west half of the Jordan Valley quadrangle Malheur County, Oregon: U.S. Geol. Survey Map I-457.

Waters, A. C., 1968, Reconnaissance geologic map of the Dufur quadrangle, Hood River, Sherman and Wasco Counties, Oregon: U.S. Geol. Survey Map I-556.

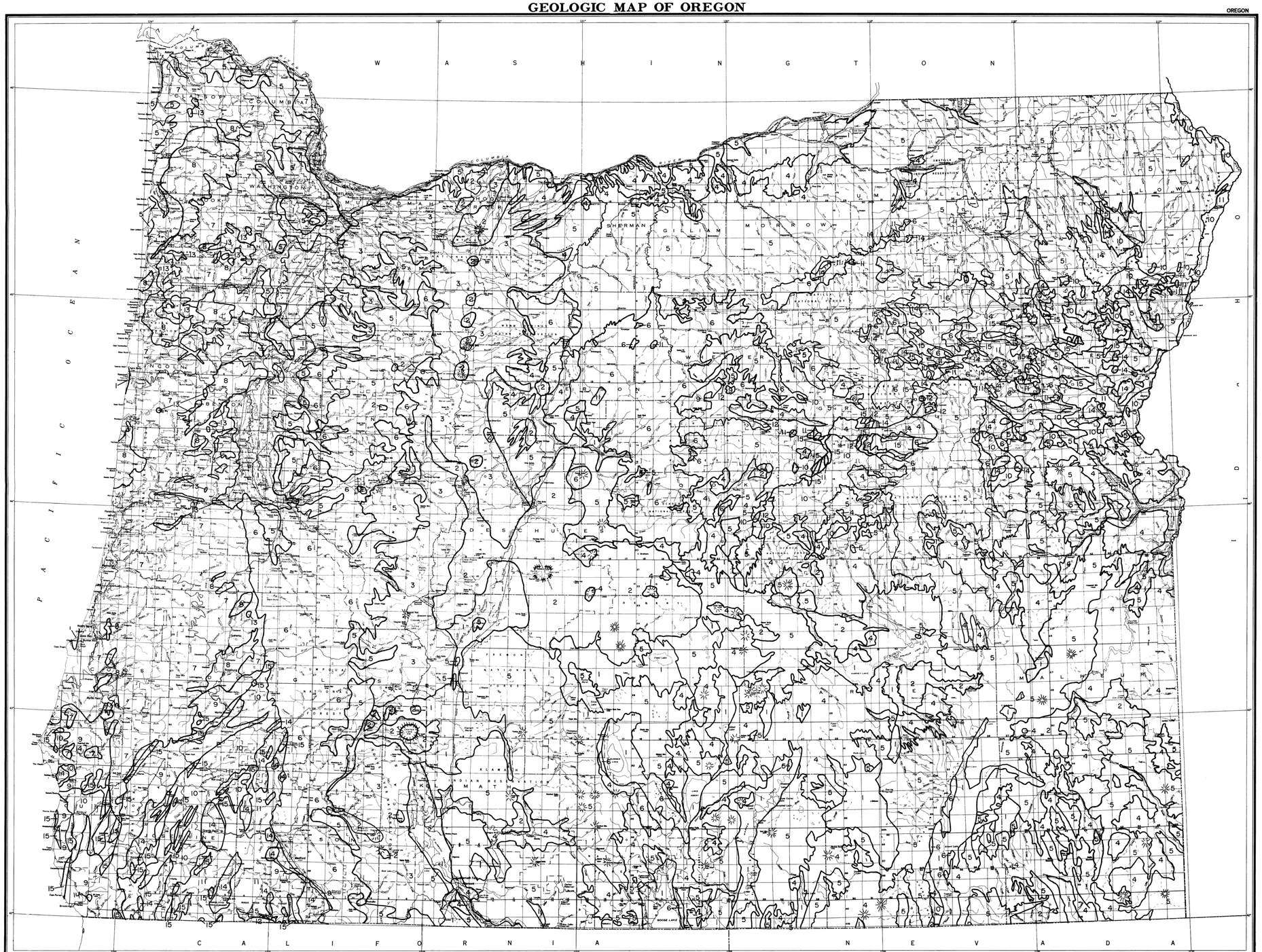
Wells, F. G., 1956, Medford, Oregon-California geology: U.S. Geol. Survey Map GQ-89.

Wells, F. G., and Peck, D. L., 1961, Geologic map of Oregon west of 121st meridian: U.S. Geol. Survey Map I-325.

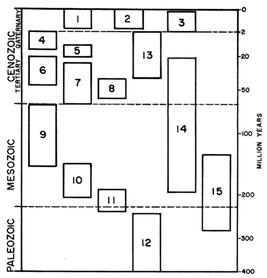
Wilkinson, W. D., and others, 1961, Reconnaissance geologic map of the Butte Falls quadrangle, Oregon: Oregon Dept. Geol. and Mineral Indus.

Williams, Howel, 1957, A geologic map of the Bend quadrangle and reconnaissance geologic map of the central portion of the High Cascades Mountains: Oregon Dept. Geol. and Mineral Indus., in coop. with U.S. Geol. Survey.

GEOLOGIC MAP OF OREGON



STRATIGRAPHIC TIME CHART



EXPLANATION

SEDIMENTARY AND VOLCANIC ROCKS

1 Alluvium, lake sediments and marine terraces

2 Basalt and andesite flows

3 Andesite and basalt of High Cascades

4 Plio-Miocene continental sedimentary rocks, ash-flow tuffs, some interbedded rhyolite flows and domes

5 Plio-Miocene basalt and andesite flows and minor continental sedimentary rocks

6 Mio-Oligocene and Eocene volcanic and continental sedimentary rocks

7 Mio-Oligocene and Eocene marine sedimentary rocks, some volcanics

8 Eocene submarine and continental basalt and andesite flows, tuffs, and some intrusives

9 Cretaceous-Late Jurassic marine sedimentary rocks and minor volcanic rocks

10 Jurassic-Triassic marine sedimentary and volcanic rocks older than Kimmeridgian age, in places strongly metamorphosed

11 Triassic and Permian marine sedimentary and volcanic rocks, in places strongly metamorphosed

12 Permian-Devonian undifferentiated, marine sedimentary rocks, in places strongly metamorphosed

INTRUSIVE IGNEOUS ROCKS

13 Gabbro and diabase

14 Granitic rocks

15 Ultramafic and gabbroic rocks

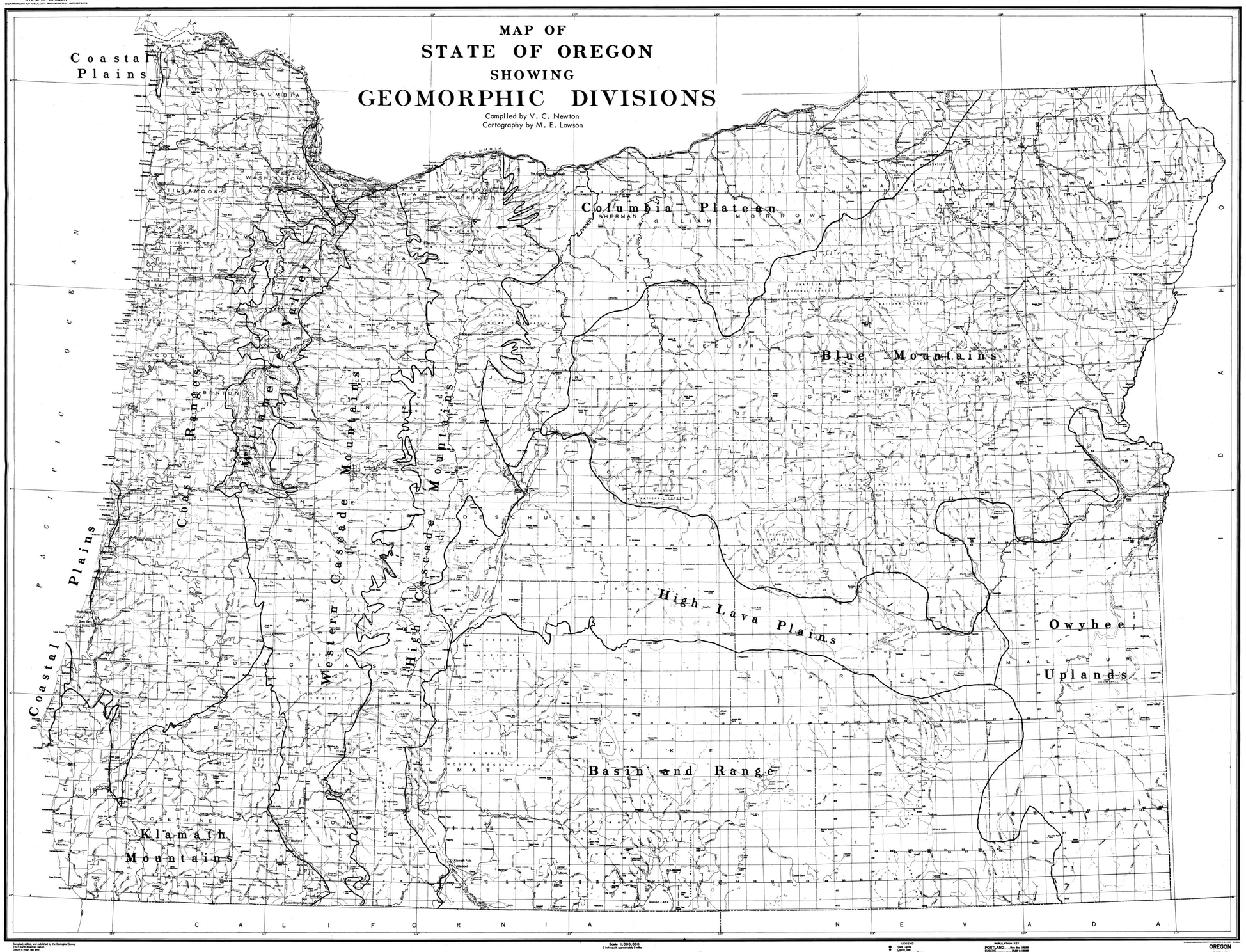
Major volcanic vents and domes

Large volcanic craters

Contact

Prepared by S. R. Renoud and V. C. Newton from compilations by D. L. Peck, 1961; G. W. Walker and P. B. King, 1963; and others.
December 1972

O-73-01



Compiled, edited, and published by the Geological Survey
Scale 1:500,000
Contour in meters; datum mean sea level

SOURCE DATA:
U. S. Dept. of Commerce - Bureau of Public Roads Topographic Maps
U. S. Dept. of Commerce - Bureau of Public Roads Maps
U. S. Dept. of Agriculture - Forest Service Maps

Scale 1:500,000
1 inch equals approximately 8 miles

Lambert conformal conic projection
Standard parallels 33° and 45°

LEGEND
State Capital
County Seat
Cities, towns, or villages
Corporate boundary shown for towns over 2500 population

POPULATION KEY
PORTLAND ..... More than 100,000
EUGENE ..... 25,000 to 100,000
Pendleton ..... 5,000 to 25,000
Hood River ..... 1,000 to 5,000
Condon ..... Less than 1,000
Population subject to change

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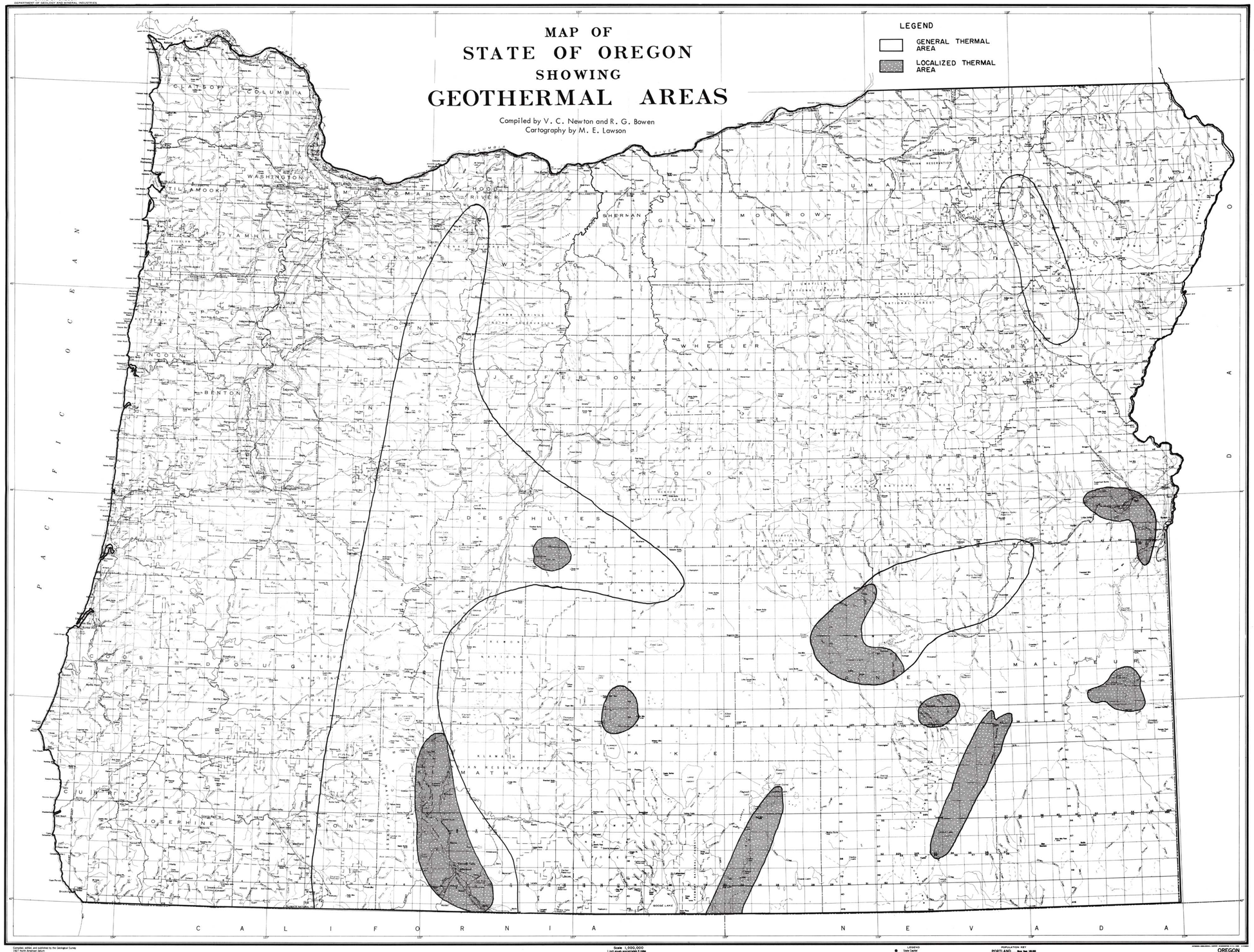
OREGON
BASE MAP

Map prepared by
STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

MAP OF STATE OF OREGON SHOWING GEOTHERMAL AREAS

Compiled by V. C. Newton and R. G. Bowen
Cartography by M. E. Lawson



Compiled, edited, and published by the Geological Survey
1927 North American datum
Datum is mean sea level

SOURCE DATA
U. S. Dept. of Interior - Bureau of Land Management Maps
U. S. Dept. of Commerce - Bureau of Public Roads Maps
U. S. Dept. of Agriculture - Forest Service Maps

Scale 1:500,000
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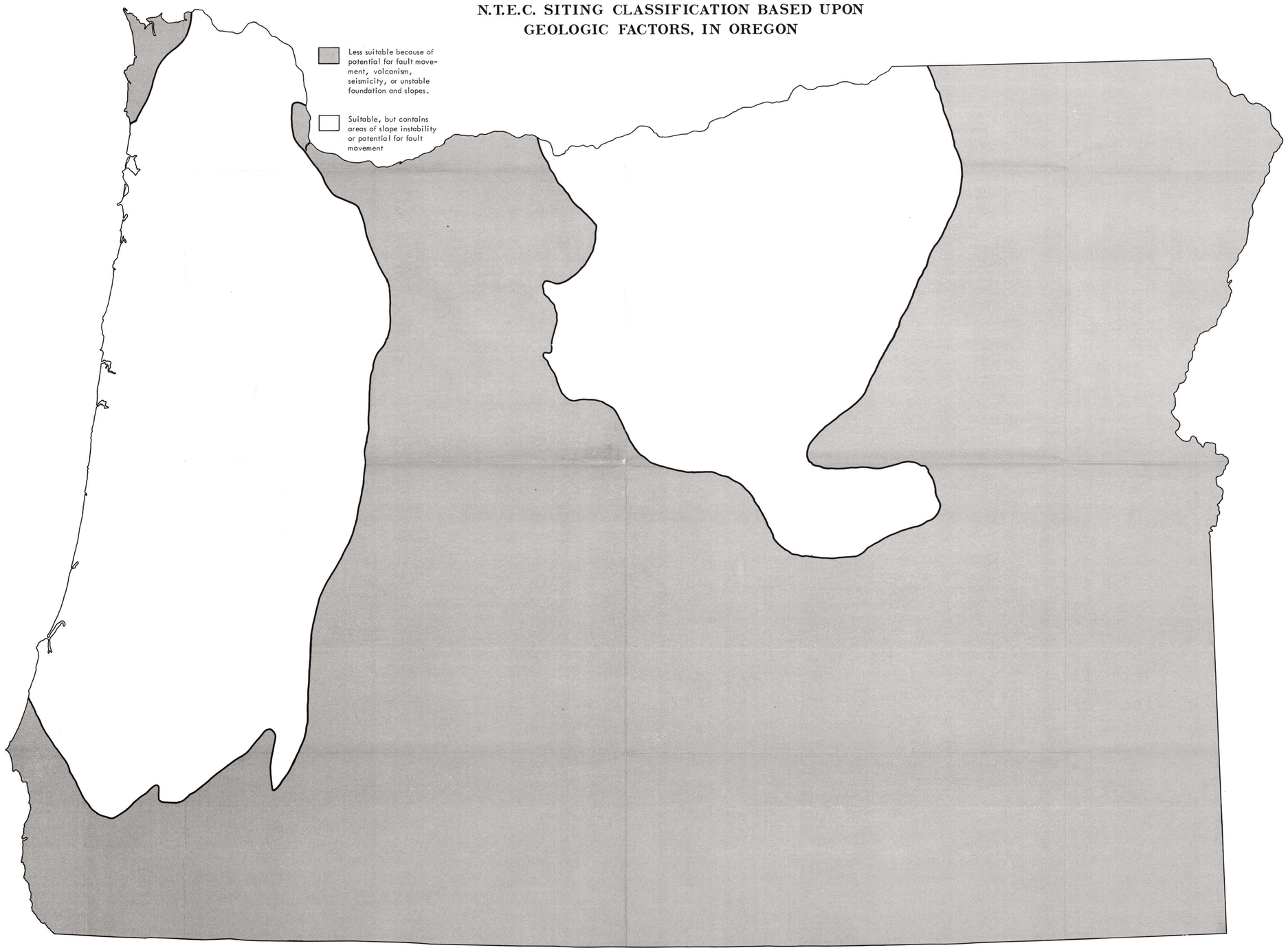
Lambert conformal conic projection
Standard parallels 33° and 45°

LEGEND
State Capital
County Seat
Cities, towns, or villages
Corporate boundary shown for towns over 2500 population

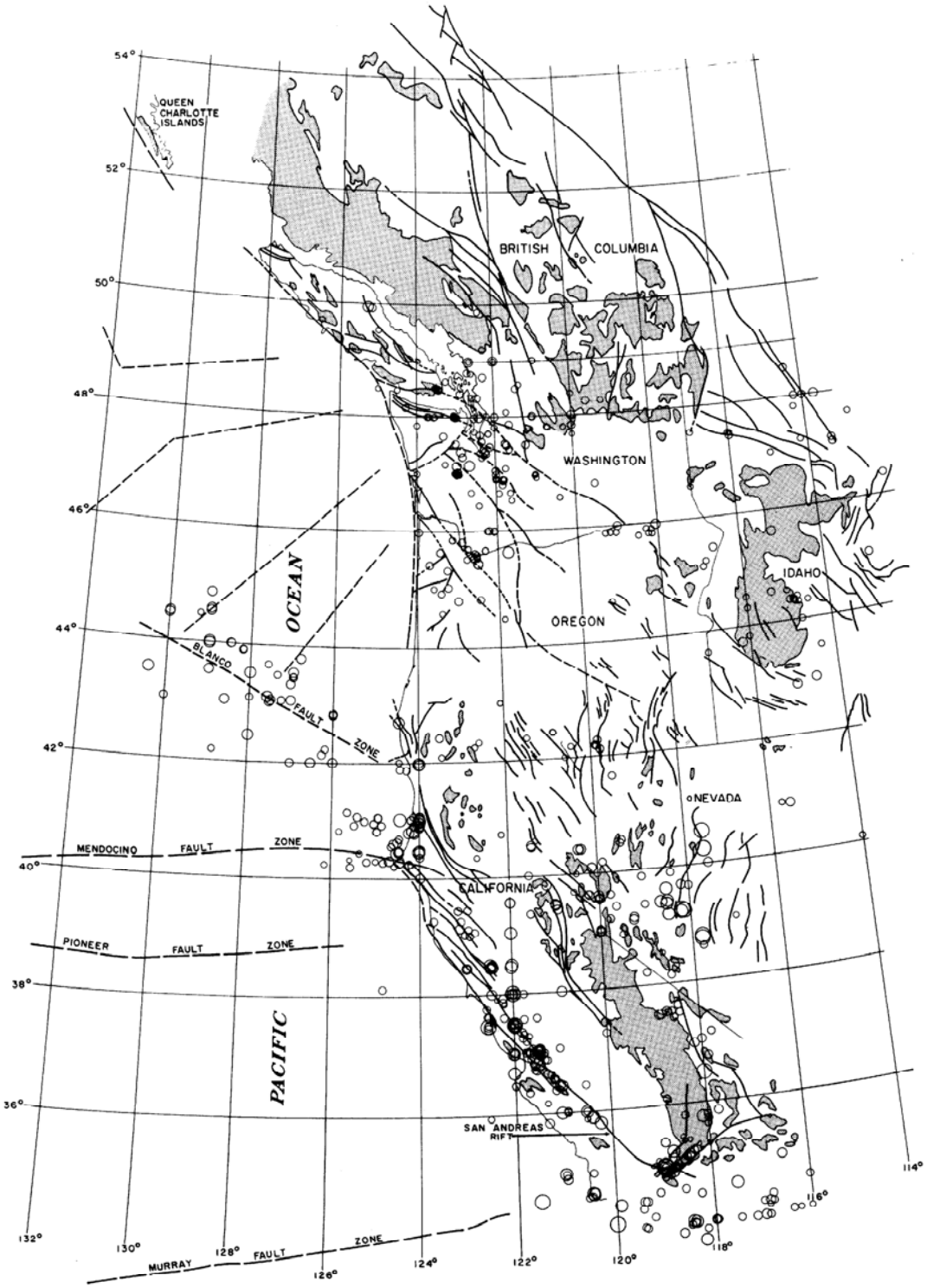
POPULATION KEY
PORTLAND ..... More than 100,000
EUGENE ..... 25,000 to 100,000
Pendleton ..... 1,000 to 25,000
Hood River ..... 500 to 1,000
Vernon Site ..... Less than 1,000
Populations indicated by size of letters
COMPILED in 1964 EDITION 12/1965

STATEWIDE GEOLOGICAL MAPS Prepared by R. G. Lowe & Associates
OREGON
BASE MAP

N.T.E.C. SITING CLASSIFICATION BASED UPON GEOLOGIC FACTORS, IN OREGON



Revised 2-1-73



Tectonic Map *of the* Pacific Northwest

Compiled by V. C. Newton
Cartography by S. R. Renoud and M. E. Lawson

LEGEND

- Major fault system
- Mapped fault
- Probable fault
- Granitic basement

EARTHQUAKE INTENSITY
(Modified Mercali)

- V
- VI
- VII
- VIII
- IX
- X
- XI

REFERENCES

Berg, J. W., Jr., and Baker, C. D., 1963, Oregon Earthquakes 1841 through 1958: Bull. Seismol. Soc. America, v. 53, no. 1, January 1963.

Couch, R. W., and Lowell, R. P., 1971, Earthquakes and seismic energy release in Oregon: Ore Bin, v. 33, no. 4, April 1971.

Dott, R. H., 1971, Geology of the southwestern Oregon Coast: Oregon Dept. Geology and Mineral Industries, Bull. 69.

Eppley, R. A., 1965, Earthquake history of the U.S., Part I: U.S. Dept. of Commerce, Publ. no. 41-1.

King, P. B., 1969, Tectonic map of North America: U. S. Geol. Survey.

MacKay, A. J., 1969, Continuous seismic profiling investigation of the southern Oregon continental shelf between Cape Blanco and Coos Bay: U.S. Geol. Survey open-file report.

Raff, A. D., and Mason, R. G., 1961, Magnetic survey off the West Coast of North America: Geol. Soc. America Bull., v. 72, no. 8, August 1961.

Silver, E. A., 1971, Small plate tectonics in the northeastern Pacific: Geol. Soc. America Bull., v. 82, no. 12, December 1971.

Map prepared by
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DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES