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by

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Earthquake Risks and Mitigation in Oregon

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Abstract

This paper traces the changes in the understanding of Oregon's earthquake hazards and provides an overview of how Oregon addresses reducing earthquake risks. The threat of a great Cascadia subduction-zone earthquake identified during the last decade and the occurrence of two relatively minor yet damaging "wake-up calls" with the Scotts Mills (M 5.6) and Klamath Falls (M 5.9 and M 6.0) earthquakes of 1993 have underscored the reality of earthquake hazards in Oregon. While periodic earthquake shaking has been reported in Oregon for over the last century and a half, modern earthquake monitoring has been possible only for the past few decades. Most of the earthquake hazard assessment and mitigation efforts made to date have been accomplished within the last decade, and public awareness has risen remarkably during that same period. Major federal, state, and local government agencies and private organizations support earthquake risk reduction and have made significant contributions. Despite the progress, Oregon remains underprepared. Many structures and lifelines, such as buildings, bridges, and water systems, need to be strengthened, and land use planning needs to be improved. This paper reviews the nature of earthquakes in Oregon, important earthquake-related state legislation, site-specific seismic-hazard investigations, and active earthquake-involved organizations.

Introduction

Some people who used to live in Oregon believed so strongly that earthquakes posed a tremendous threat that they packed their belongings and moved out of the state. Others have sought refuge from earthquake hazards by moving to Oregon after the 1989 Loma Prieta earthquake in California. These extreme cases illustrate the range of problems that people are having in understanding and responding to earthquake hazards in Oregon.

Earth scientists now believe that all parts of Oregon can be shaken by earthquakes. Oregon lies where two tectonic plates, the North American plate and the Juan de Fuca plate, are colliding, and the Juan de Fuca plate is being forced to dive under the North American plate along a large active fault called the Cascadia subduction zone (Atwater et al., 1995). Earthquakes can occur within the Juan de Fuca plate (such earthquakes are called intraplate earthquakes), in the overriding North American plate (called crustal earthquakes), or along the Cascadia subduction zone, which is the interface between the two plates (called subduction zone earthquakes). All three possible earthquake types (intraplate, crustal, and subduction zone) (Figure 1) can severely impact the state. Active volcanoes in the Cascade Range present another earthquake source.

Although the number of earthquakes in Oregon's recorded history is limited compared to that of California or Washington, earthquakes have occurred in every Oregon county (Geomatrix Consultants, Inc., 1995). Surface expressions of faults capable of producing earthquakes are sparse, but young faults (defined here as active within the Quaternary Period, the last 1.6 million years) have been mapped in almost every county in Oregon (Figure 2). These facts show Oregon's earthquake potential despite its moderate level of seismicity and suggest the existence of a significant seismic threat to the inhabitants.

Earthquake Sources and Their Significance

The western part of the Pacific Northwest lies in an actively converging plate-tectonic setting. The scenic topography along the coast, throughout the Coast Range and the Willamette Valley, and in the Cascades, was essentially created by plate tectonic activity related to the Cascadia subduction zone, the active fault zone separating the Juan de Fuca and North American plates. The Juan de Fuca plate extends from northern California to British Columbia and lies just off Oregon's coastline. This plate is continually being "subducted" or forced under the North American plate (Figure 1). As a result, the highly publicized Cascadia subduction zone "megathrust" earthquake is expected to occur sometime in the future along the boundaries of these plates. Although no significant Cascadia subduction zone earthquake has occurred in historic times, several large-magnitude subduction zone earthquakes are thought to have occurred during the past few thousand years, with the last event about 300 years before the present (Atwater et al., 1995). The maximum magnitude of Cascadia subduction zone earthquakes, for both past and future events, is estimated to be about 8.5–9.0. Some studies have even suggested that the entire coast from northern California to central British Columbia could slip in a single earthquake of M 9 or greater (Weaver and Shedlock, 1996).

Intraplate earthquakes occur within the subducting Juan de Fuca plate at depths of 40–60 km. The maximum magnitude of an intraplate earthquake is estimated to be about 7.5. Although numerous microearthquakes have been identified as intraplate events in Oregon, none has been of significant magnitude. The Puget Sound region in Washington has experienced two significant intraplate events in modern times, in 1949 and 1965, with magnitudes of 7.1 and 6.5, respectively. Both events caused serious local damage and were felt in Portland and as far away as Montana.

Shallow crustal earthquakes typically occur within the overriding North American plate at depths of 10–25 km. The 1993 M 5.6 Scotts Mills earthquake (Figure 3) centered northeast of Salem was a crustal event, as were the 1993 Klamath Falls earthquakes (M 5.9 and M 6.0). The maximum estimated magnitude of a crustal earthquake ranges from 6.5 to over 7.0. In 1962, a M 5.5 event with a maximum intensity of Modified Mercalli Scale VII (Bott and Wong, 1993) that occurred in the Portland area was felt a distance of 150 mi away (Dehlinger and Berg, 1962; Dehlinger et al., 1963).

Volcanic earthquake sources, such as at the Mount St. Helens seismic zone in Washington and the less active Mount Hood area in Oregon, generally pose a lesser threat than the other types of earthquake sources. Seismic volcanologists limit the maximum magnitude of volcanic earthquakes to about 5.25. Two volcanic earthquakes of M 4.9 and M 5.1 occurred in May 1980 at the time

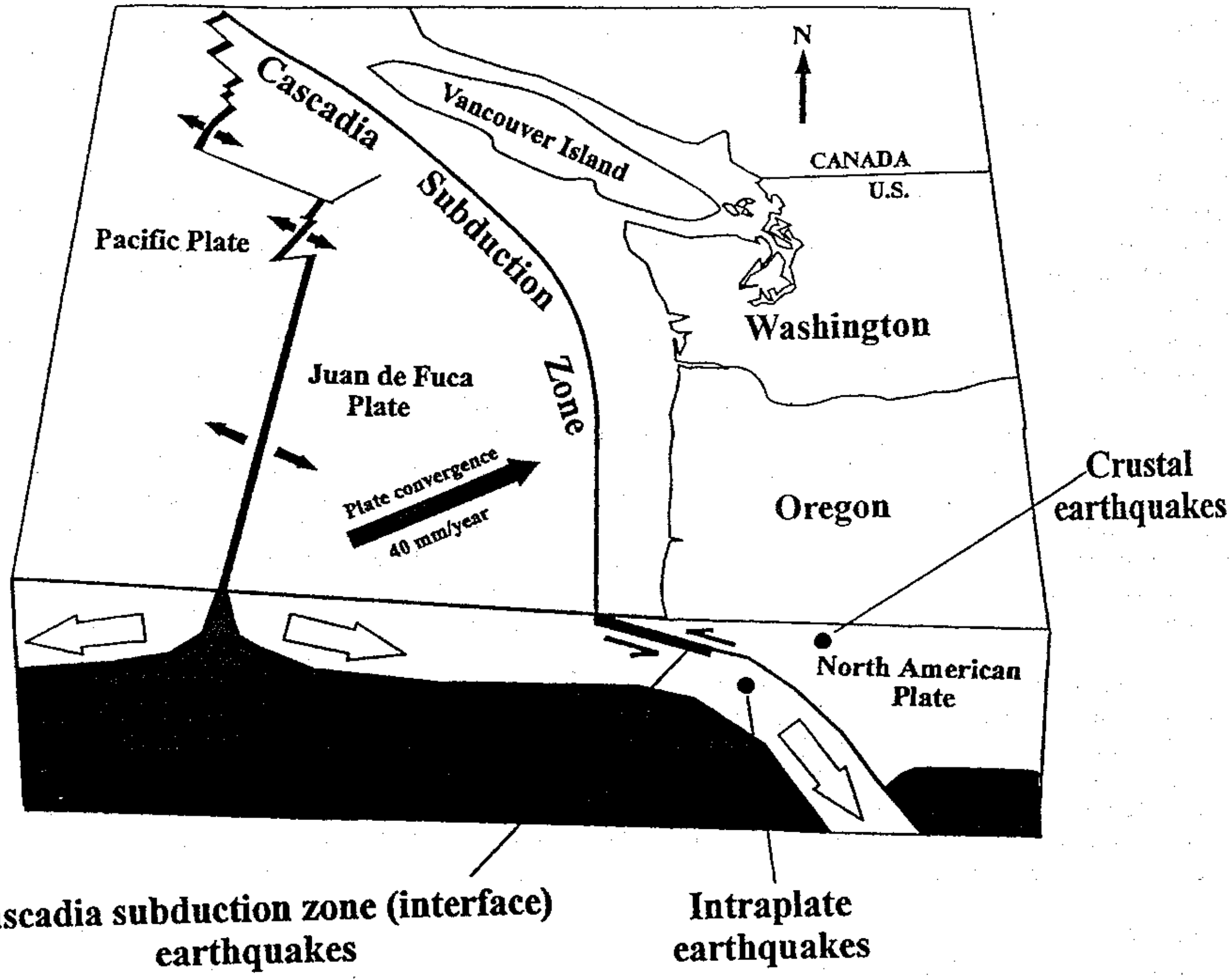

Figure 1
Map and cross section showing the North American plate, the Juan de Fuca plate, the Cascadia subduction zone, and typical locations for the three earthquake types discussed in the text.

of the Mount St. Helens volcanic eruption (Steve Malone, University of Washington, personal communication, 1996).

A recent statewide seismic study commissioned by the Oregon Department of Transportation (ODOT) includes a map onto which the locations of all known Quaternary-active faults and earthquake epicenters since 1827 were compiled. The report, which also includes probabilistic ground motion maps, provides the most current and comprehensive data available for the state (Geomatrix Consultants, Inc., 1995). This information is being used by ODOT to provide ground motion parameters necessary for design, construction, and earthquake mitigation of the state-owned road system.

A recent study of historic earthquakes in the greater Portland area indicates that several earthquakes larger than M 5 have occurred in the Willamette basin over the last 150 years and gives descriptive accounts of each earthquake (Bott and Wong, 1993).

The Growing Understanding

Earthquakes were felt in Oregon as early as 1877 (Algermissen, 1983). Human recollections of earthquakes tend to fade quickly, however, and the general sentiment has been that "Oregon is not earthquake country." As early as 1912, geologists recognized and documented the fact that Oregon was seismically active (Smith, 1919). Despite early scientific recognition, the public failed to understand and appreciate the seismic risk for many decades. During the past decade, however, there has been increasing acknowledgment that earthquakes pose a real threat to the state's inhabitants.

In reality, the seismic risk is getting more severe, not because the level of seismicity is increasing, but because the population is increasing. With more people, more buildings, more infrastructure, and more businesses and industries in the state, more is at stake. It is fortunate that the awareness of Oregon's seismic threat has grown from "almost nil by most" to "well recognized by many." Furthermore, awareness of Oregon's vulnerability to earthquakes has even reached the national level, and several significant

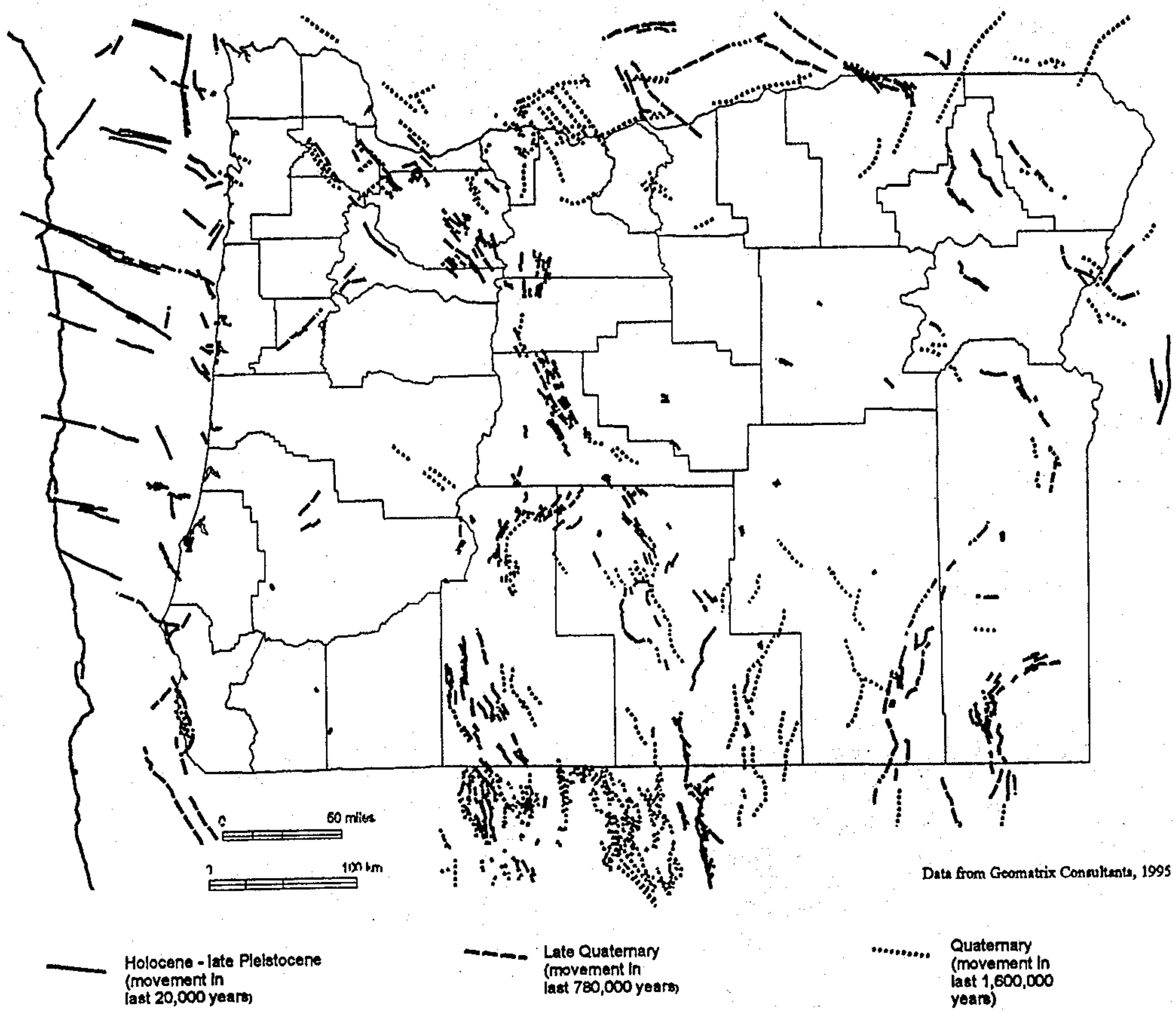

Figure 2
Map showing young faults in Oregon. Map from Geomatrix Consultants, Inc. (1995).

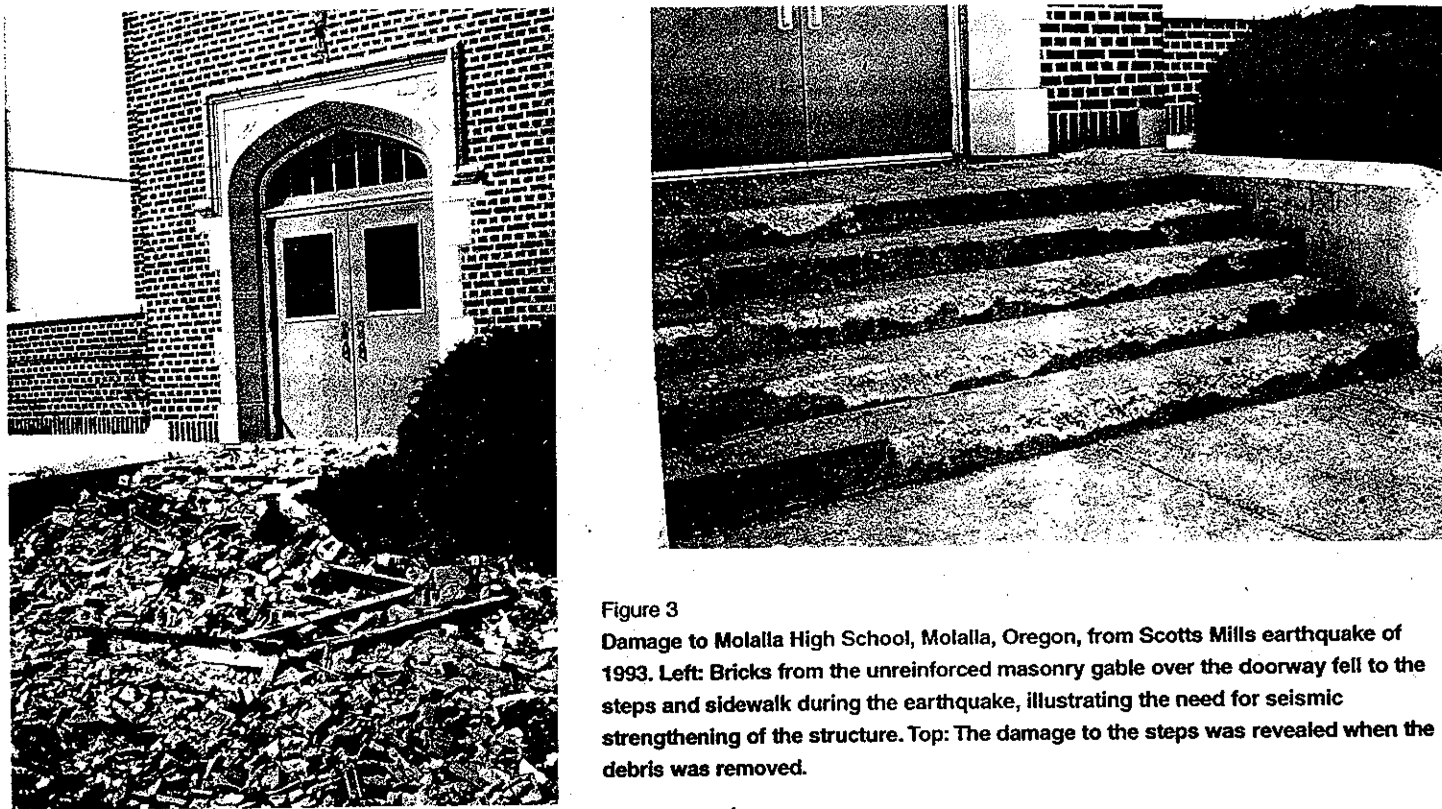

Figure 3
Damage to Molalla High School, Molalla, Oregon, from Scotts Mills earthquake of 1993. Left: Bricks from the unreinforced masonry gable over the doorway fell to the steps and sidewalk during the earthquake, illustrating the need for seismic strengthening of the structure. Top: The damage to the steps was revealed when the debris was removed.

Portland-based seismic projects that will be discussed later in this paper were federally supported.

The first major earthquake risk studies in the Pacific Northwest, however, were related to siting of nuclear power plants. In 1970, when the siting of the Trojan nuclear power plant near Rainier in Columbia County was under consideration, the realization of the need for considering earthquake risk for the siting of this facility led to an investigation of earthquake potential and risk within the state. The U.S. Geological Survey conducted a formal investigation of the geologic conditions, which included risks from earthquakes and earthquake sources. Their findings indicated that based on presently available information, the site was geologically adequate for safe plant operation and temporary storage of spent fuel. These conclusions were formally supported by the Oregon Department of Geology and Mineral Industries (DOGAMI) under then State Geologist Raymond E. Corcoran's direction (Oregon Department of Geology and Mineral Industries, 1978).

The question of seismic hazards at Trojan was later revisited. In 1978, DOGAMI conducted an independent geologic hazard review of the site, including earthquake hazards (Oregon Department of Geology and Mineral Industries, 1978). In 1981, following the May 1980 Mount St. Helens volcanic eruption, DOGAMI geologists conducted a seismic and volcanic hazard evaluation of the Trojan site (Beaulieu and Peterson, 1981). The 1981 study indicated that the maximum possible earthquake in the source region is in the range of M 5.2 to M 6.2. This report also described the plate tectonic setting off the coast of Oregon and presented the seismic potential associated with the Cascadia subduction zone as an unresolved question.

The first notable regional seismic study was performed in 1972. It was conducted to assess ground motion characteristics in the federal Bonneville Power Administration service area (Shannon and Wilson, Inc., 1972), which includes Oregon, Washington, Idaho, and western Montana. At that time, the still relatively new theory of plate tectonics, which helped to explain the nature of earthquakes, was gaining broad acceptance. The report's findings alluded to the existence of the Cascadia subduction zone and stated that "it is generally recognized . . . that the Pacific Northwest is not the site of major tectonic thrusting, nor is it as inactive as the central area of a tectonic plate." The study surveyed historic earthquakes and considered an earthquake of "magnitude mb = 6.5 as the likely maximum for Portland and vicinity" (Shannon and Wilson, Inc., 1972).

Among many important studies on the Cascadia subduction zone, the following three studies played key roles in leading toward the current mainstream understanding that the Cascadia subduction zone is an active subduction zone. First, in 1981, findings from a study on geodetic strain measurements in Washington indicated that, in the vicinity of the Olympic Peninsula, measurable horizontal strain parallel to the direction of plate-convergence had accumulated over a 10-year observation period (Savage et al., 1981). This manifestation of crustal shortening indicated that active convergence was taking place on the Cascadia subduction zone and supported a history of subduction zone earthquakes. Second, in 1984, a study that compared the Cascadia subduction zone with many other subduction zones around the world was published (Heaton and Kanamori, 1984). The authors noted the low level of seismicity associated with the Cascadia subduction zone and provided three possible explanations: "(1) The North American and

Juan de Fuca plates are no longer converging; (2) the plates are converging, but slip is accommodated aseismically; or (3) the northwestern United States is a major seismic gap that is locked and presently seismically quiescent but that will fail in great earthquakes in the future." The authors concluded that the plate convergence rate appeared to be 3–4 cm/yr and "that there was sufficient evidence to warrant further study of the possibility of a great subduction zone earthquake in the Pacific Northwest." Finally, a paper by B.F. Atwater (1987) presented paleoseismic evidence (buried peat soils) for great Holocene earthquakes along the outer coast of Washington. These three studies have fundamentally shaped the way earth scientists currently view the Cascadia subduction zone and its potential impact on Oregon.

In 1987, the Oregon State University Geology Department and DOGAMI hosted a landmark professional gathering at the Oregon Academy of Science in Monmouth, Oregon. For the first time, earth scientists gathered together to discuss the potential of a Cascadia subduction zone earthquake. Later that same year, DOGAMI hosted a "cluster" meeting of regional state surveys with U.S. Geological Survey (USGS) scientists to discuss earthquake hazards in the Pacific Northwest. With the added momentum generated by these scientific enthusiasts, the USGS was convinced that the Portland, Oregon, area was vulnerable to major earthquakes. This led to a cooperative agreement between the USGS and DOGAMI that involved collecting earthquake-related geologic data in the greater Portland area and educating the public on earthquake hazards. These initial meetings directed DOGAMI to assist in leading many of the present-day statewide earthquake efforts.

Current State of Understanding

Since 1987, voluminous research findings support the fact that the Cascadia subduction zone is active and is a threat. These research data are from three primary sources: (1) prehistoric earthquakes, (2) instrument-recorded earthquakes, and (3) geologic records from old earthquakes. More specifically, data on prehistoric earthquakes include Native American legends and Japanese historic documents. Instrument-recorded earthquake data include geophysical and seismicity analyses, geodetic (including global positioning system [GPS]) analyses, and heat-flow analyses. The geologic evidence of old earthquakes (paleoseismic data) comprises the most compelling evidence and includes earthquake-induced landslides (in Washington State), marsh soils buried and forests drowned by coseismic subsidence, tsunami sand deposits, liquefaction features, turbidites, and offshore submarine landslide features possibly related to past Cascadia subduction zone events.

By the early 1990s, the idea of the threat of a Cascadia subduction-zone earthquake in the Pacific Northwest was accepted by many in the scientific community; by the mid-1990s, the idea was much more widely accepted by scientists. In April 1996, at the Geological Society of American Cordilleran Section conference in Portland, a straw poll of some 150 earth scientists attending a session on Cascadia subduction zone earthquake issues indicated they all believed that the Cascadia subduction zone could experience a M 8 or larger earthquake.

The most pressing unresolved problem that remains for most scientists is not whether a Cascadia subduction zone event will occur but rather how big it can be and how often it will occur. Some scientists believe that M 8 is the upper-magnitude limit (McCaffrey and Goldfinger, 1995), while others believe that an event even greater than M 9 is possible (Weaver and Shedlock, 1996). One can assert, based on presumed rupture zone, paleoseismic evidence, and historic Japanese tsunami records, that it is possible for the Cascadia subduction zone to generate an earthquake greater than M 9. One counterargument is that major offshore strike-slip faults, such as the offshore Wecoma fault located west of Siletz Bay in Lincoln County (Goldfinger et. al., 1992), may divide the Cascadia subduction zone into "segments" and limit the size of the maximum possible earthquake to M 8 or so. Although the possible maximum magnitude question needs to be pursued, clearly, even an M 8 event would be ominously large and would impact a widespread region.

How often do these great subduction-zone earthquakes occur? Current thinking limits the range for the average recurrence interval (the time between earthquakes) to between 400 and 600 years (Atwater et. al., 1995). The recent Geomatrix Consultants, Inc. (1995) study narrows the estimate of the recurrence interval to 450 +/–150 years. Japanese historic documents describing a tsunami not preceded by a local earthquake suggest that the most recent Cascadia subduction-zone event occurred on January 26, 1700 (Satake et. al., 1996).

Although these questions of magnitude and frequency of a Cascadia subduction zone earthquake cannot be definitively answered at this time, our understanding of earthquake hazards is at the level where we can say, "There is consensus in the scientific community that in Oregon strong ground shaking from earthquakes is inevitable and poses a significant threat."

Need for Action

Giving society a better chance to function in personal and economic safety and with minimal disruption after an earthquake involves a concentrated effort among many people. It is no easy task to convey to the community at large the importance of being well prepared and the necessity of taking concrete steps to get prepared. For instance, many who purchase earthquake insurance do not realize that being insured does not equate with being adequately prepared. Having insurance does not prevent fatalities, strengthen facilities, or stave off damage in any way—being prepared does.

Therefore, the next fundamental steps are to define the "hazards" associated with ground shaking and to identify the "risks" associated with the hazards. "Hazards" are important only when there are "risks," and the level of risk depends not only on the hazards present but also the amount of exposure (population and buildings). Therefore, the higher the hazard and the greater the exposure (such as vulnerable populations or weak buildings), the higher the risk. Damage and losses include not only fatalities, injuries, and property damage, which are immediate impacts, but also lifeline interruption, business interruption, worker displacement, homelessness, and other effects that can have a serious long-term impact on recovery from an earthquake.

The next steps are to identify ways to reduce these risks, mitigate the unacceptable risks to acceptable levels, and develop policies to reduce risk. The following discussion reviews how reduction of earthquake risks has been addressed through state legislation, site-specific seismic-hazard investigations and organized efforts in Oregon.

State Legislation

A broad array of earthquake-related state legislation has been introduced over the last decade, and many laws have been passed to help improve earthquake preparedness in Oregon. Listed below are the more important items of legislation that have been passed and written into the Oregon Revised Statutes (ORS).

In mid-1989, the Oregon legislature expanded the scope of DOGAMI's responsibilities, thereby requiring the agency not only to develop an understanding of hazards, including earthquakes, landslides, tsunamis, and floods, but also to mitigate the loss of life and property these hazards can cause (ORS 516.030[3]).

Following the October 1989 Loma Prieta earthquake, then-Governor Goldschmidt created a task force to evaluate Oregon's seismic vulnerability. In response to the task force findings that indicated the general vulnerability of the state, the Governor issued an Executive Order (EO-90-02) to form an eight-member commission. In 1991, this commission was formally established as the Oregon Seismic Safety Policy Advisory Commission (OSSPAC) (ORS 401.337 to 401.353). OSSPAC's mission is to reduce exposure to earthquake hazards through education, research, mitigation, and response preparation. In 1995, four more members were added to OSSPAC.

Also in 1991, State Senate Bill 96 was introduced by Senator Cease and endorsed by DOGAMI. It involved several seismic issues and, after passing, became law. It required site-specific seismic-hazard investigations for essential facilities, major structures, hazardous facilities, and special-occupancy structures (e.g., schools and hospitals); the filing of the hazard investigation reports with DOGAMI; and a program for the installation of strong-motion accelerographs in or near selected major buildings (ORS 455.447). It also required "duck, cover, and hold" drills to be conducted for grades K–8 in public schools (ORS 336.071).

By 1992, there was substantial support of seismic mitigation by state legislators and executive leaders. The Oregon Legislative Emergency Board increased DOGAMI's base budget to cover the salary of an earthquake geologist (initially funded by the previously mentioned USGS Cooperative Agreement).

In 1993, Senate Bill 81 designated $4.3 million in lottery funds for reinforcing the poorly constructed State Capitol dome that had been damaged from low levels of shaking during the 1993 Scotts Mills earthquake. The Legislative Administrative Committee oversaw this retrofit work and is pursuing additional seismic strengthening of the remainder of the State Capitol Building.

That same year, the State Senate adopted Senate Joint Memorial (SJM) 12, which asked Congress to retain existing earthquake funding levels and encouraged federal agencies to assist Oregon, California, Alaska, and Washington in earthquake hazard mitigation efforts.

Also in 1993, the Building Codes Division (BCD) of the Oregon Department of Consumer and Business Services adopted a zone change from Seismic Zone 2B to Seismic Zone 3 for western Oregon in the Oregon Structural Specialty Code (OSSC) (Figure 4). This change meant that new buildings were required to meet a higher standard of seismic strength. The code change has often been mistakenly understood as a legislative action, which it is not. The 1996 Oregon Structural Specialty Code shows the new seismic zonation map of Oregon.

In 1995, the State Legislature saw the introduction of 14 earthquake-related bills. Passage of several of them led to changes in the Oregon Revised Statutes (ORS), including a requirement for tsunami drills and education in schools (ORS 336.071), a requirement that essential and special-occupancy structures be built outside the tsunami zone (ORS 455.446), the creation of a Seismic Rehabilitation Task Force to make recommendations to the legislature for the seismic rehabilitation of existing buildings (ORS 455.446[4]), provisions for entering and inspecting earthquake-damaged buildings (ORS 455.448), and provisions for the abatement of unsafe buildings.

The Seismic Rehabilitation Task force was appointed in 1995 by the Governor in consultation with the State Geologist. This 13-member Task Force convened to examine the safety of buildings that were built under prior building code criteria and to make recommendations to the 1997 Legislature for any seismic rehabilitation that should be required in those existing buildings to protect the public from seismic risk. The identification of existing buildings that require mitigation and the implementation of mitigation measures are highly complex and controversial issues. A report containing the recommendations of the Task Force was submitted to the legislature in September 1996 and developed into 1997 House Bill 2139 (Seismic Rehabilitation of Existing Buildings in Oregon, 1996).

House Bill 2139 proposes a survey over the next six years that will determine the type of construction and degree of safety of each building in the state, except for one- and two-family homes and other exempt structures. House Bill 2139 also proposes that seismic rehabilitation be performed in a three-stage time frame, dating from notification that results from the survey: (1) within 15 years, for unreinforced masonry (URM) buildings with parapets, signs, and other appendages, except for cornices and nonstructural cladding, that may constitute a falling hazard during an earthquake; (2) within 30 years, for the remainder of the URM buildings; and (3) within 70 years, for all other unsafe buildings. The upgrading may be stimulated by tax credits, property tax abatements, and public education.

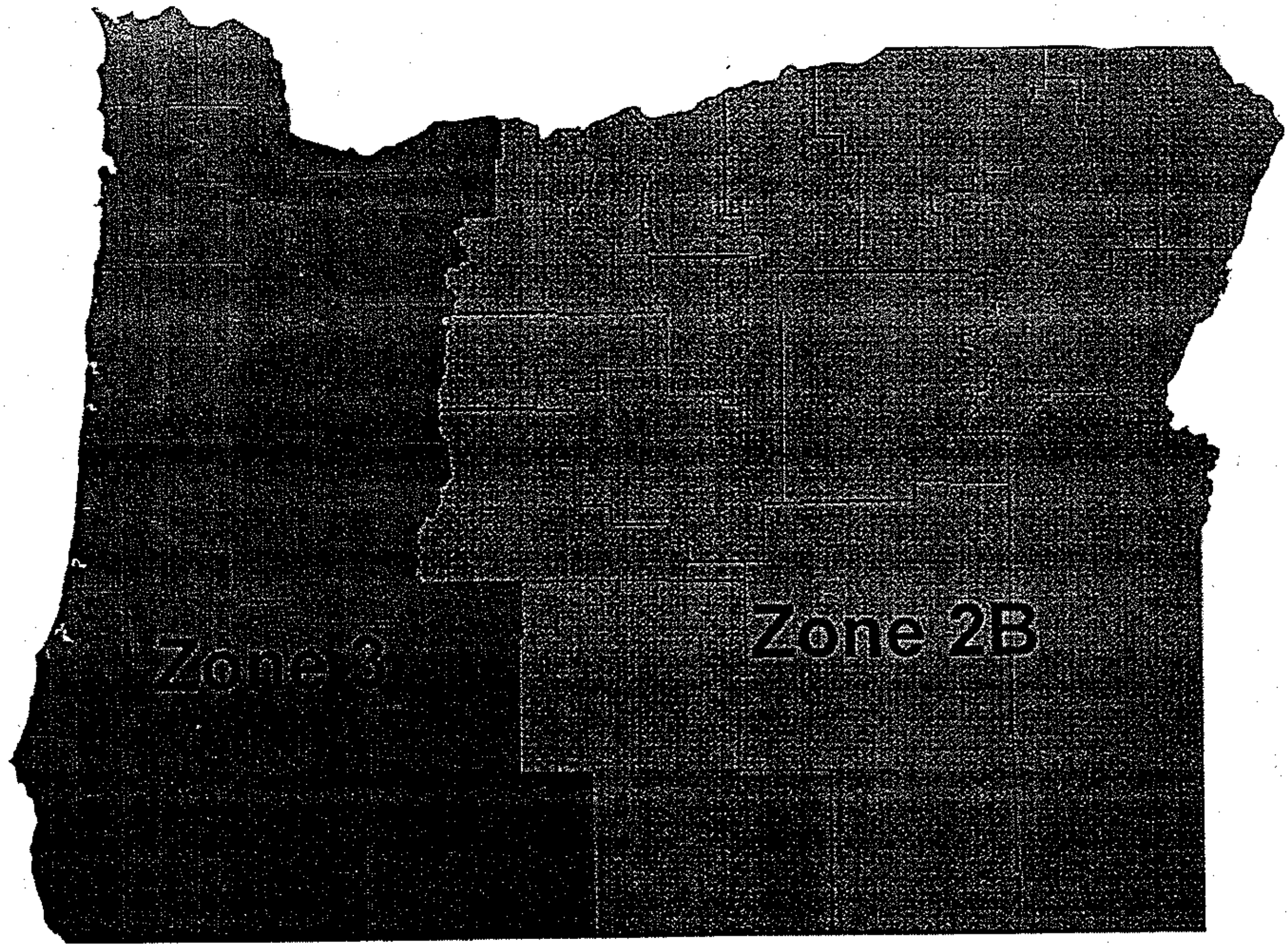

Figure 4
Seismic zone map of Oregon. Prior to the 1993 change of the Oregon Structural Specialty Code, all of Oregon was Seismic Zone 2B.

Results: Site-Specific Seismic-Hazard Investigations

In response to Senate Bill (SB) 96 of 1991, which amended ORS 455.447, a seismic-site-hazard task group was assembled in December 1992 to develop rules to implement SB 96. In September 1993, public hearings took place on the rules developed by the task group. The final rules were added to Oregon Administrative Rules (OAR) 918-460-015 and became effective in May 1994. Code amendment pages were issued in January 1995 and were incorporated in the Oregon Structural Specialty Code (OSSC), section 1804, in May 1995.

For most new construction, seismic hazards, such as earthquake-induced slope instability and liquefaction potential, should be investigated. The degree of detail of the investigation should be compatible with the type of development, the type of structure, and the geologic complexity. The investigations will range in scope from reconnaissance in nature to complex, detailed studies requiring rigorous technical analyses. The study area will range in size from smaller than a parcel to regional in scale, depending on the specific project.

Oregon law requires such investigations for some proposed developments with specific occupany types. The requirements are stated in the Oregon Revised Statutes (ORS) 455.446 and 455.447 and the 1996 Oregon Structural Specialty Code (OSSC), section 1804 (commonly referred to as the "yellow pages") (International Conference of Building Code Officials, 1996).

Part of OSSC section 1804.1.1 states, "Building sites for new structures and facilities defined by ORS 455.447 as essential facilities, hazardous facilities . . . , major structures and special occupancy structures shall be evaluated on a site-specific basis for vulnerability to seismic geologic hazards." Specified under section 1804.2.1, ". . . hazards which shall include but not be limited to source of earthquake, earthquake-induced ground-shaking, landslide, liquefaction, tsunami inundation, seiche, fault displacement and subsidence. The investigation shall include a literature review of the regional seismic or earthquake history (i.e., potential seismic sources, maximum credible earthquakes, recurrence intervals, etc.), investigation of the geologic conditions at the site and an evaluation of the ground response to the selected design earthquake. The geotechnical investigation may include geologic mapping, source of earthquake, study of aerial photographs, review of local groundwater data, exploratory borings, penetrometer results, geophysical surveys, trenching across faults or suspicious zones, laboratory soils and rock testing."

The code further stipulates the minimum design earthquakes as:

(1) A shallow crustal earthquake on real or assumed faults near the site subject to evaluation. The minimum design earthquake shall in no case be considered less than a Moment Magnitude 6.0 or a peak bedrock acceleration less than the Seismic Zone Factor Z on Table 16-I.

(2) A deep earthquake with a Moment Magnitude greater than 7 on the seismogenic part of the subducting plate of the Cascadia Subduction Zone.

(3) An earthquake on the seismogenic part of the interface between the Juan de Fuca Plate and the North American Plate on the Cascadia Subduction Zone with a minimum Moment Magnitude of 8.5.

The code specifies that, "This evaluation shall be done by an especially qualified engineer or engineering geologist registered by the state to practice as such. Such evaluation and report may require the services of persons especially qualified in fields of engineering seismology, earthquake geology and geotechnical earthquake engineering."

To further describe the specified occupancy structures, new essential facilities, major structures, hazardous facilities, and special-occupancy structures that require site-specific investigations,

"Essential facility" means:

(1) Hospitals and other medical facilities having surgery and emergency treatment areas;

(2) Fire and police stations;

(3) Tanks or other structures containing, housing or supporting water or fire-suppression materials or equipment required for the protection of essential or hazardous facilities or special occupancy structures;

(4) Emergency vehicle shelters and garages;

(5) Structures and equipment in emergency-preparedness centers;

(6) Standby power generating equipment for essential facilities; and

(7) Structures and equipment in government communication centers and other facilities required for emergency response.

"Major structure" means a building over six stories in height with an aggregate floor area of 60,000 square feet or more, every building over 10 stories in height and parking structures as determined by Department of Consumer and Business Services rule.

"Hazardous facility" means structures housing, supporting or containing sufficient quantifies of toxic or explosive substances to be of danger to the safety of the public if released.

"Special occupancy structure" means:

(1) Covered Structures whose primary occupancy is public assembly with a capacity greater than 300 persons;

(2) Buildings with a capacity greater than 250 individuals for every public, private or parochial school through secondary level or day care centers;

(3) Buildings for colleges or adult education schools with a capacity greater than 500 persons;

(4) Medical facilities with 50 or more residents, incapacitated patients not included in subparagraphs (1) to (3) of this paragraph;

(5) Jails and detention facilities; and

(6) All structures and occupancies with a capacity greater than 5,000 persons.

This checklist on the following page was developed by the State Building Codes Division as a tool to help building officials evaluate the completeness of site specific seismic hazard investigations mandated by the OSSC (Wang et. al., 1996).

Guidelines were prepared to assist with site-specific investigations titled "Guidelines for site-specific seismic hazard reports for essential and hazardous facilities and major and special-occupancy structures in Oregon." The guidelines describe the general content of these reports and provide a format that can be readily used by professional designers (such as engineers and architects). The guidelines were adopted by the State of Oregon Boards of Geologist Examiners and Examiners for Engineering and Land Surveying and have been reprinted in the January/February 1997 issue of *Oregon Geology*, vol 59, no 1.

A sketch outline for reports as provided in the guidelines includes:

(1) purpose and scope of the investigation;

(2) regional geologic and tectonic setting;

(3) site conditions;

(4) description of the investigation;

Seismic Site Hazard Investigation Checklist
(These must be provided per 1996 OSSC Sec. 1804)

Project Title: ____________________

Report Prepared by: ____________________

Today's Date: ____________________

Reviewer's Name: ____________________

Code Required Item	Complete or N/A	Not Complete	Remarks
1. Regional Geologic and Tectonic Setting			
2. Site Geologic Conditions Investigation			
2.1. Plot Map of Borings or Excavations			
2.2. Soil Classification and Description			
2.3. Water Table Elevation			
2.4. Geologic Profile to Bedrock			
3. Literature Review of Seismic History			
4. Earthquake Source Evaluation			
5. Earthquake Source Selection Criteria			
6. Recommended Design Earthquake			
6.1. Crustal (Mw=6.0min)(Specify)			
6.2. Intraslab (Mw=7.0min)(Specify)			
6.3. Interface (Mw=8.5min)(Specify)			
7. Ground Response Evaluation			
8. Ground Response Selection Criteria			
9. Recommended Ground Response			
10. Seismic Hazard Evaluation			
10.1. Ground Shaking Evaluation			
10.2. Landslide Evaluation			
10.3. Liquefaction Evaluation			
10.4. Tsunami Flooding Evaluation			
10.5. Seiche Evaluation			
10.6. Fault Displacement Evaluation			
10.7. Subsidence Evaluation			
10.8. Other (Specify)			
11. Expected Settlements (Total & Diff.)			
12. Recommended Soil Bearing Capacity			
13. Recommended Foundation Type			
14. Other Recommended Design Criteria			

(5) conclusions and recommendation;

(6) references and appendices; and

(7) illustrations.

Additional information, such as history of regional seismicity under (2) regional geologic and tectonic setting, and, geologic mapping, aerial photographic analysis, groundwater data review, subsurface exploration such as through drilling, cone penetrometer soundings, geophysical surveys, and trenching, in-situ and laboratory testing, and geotechnical analyses of ground response, under (4) description of the investigation may be included in the report.

Results: Tsunami Inundation Maps

In response to 1995 SB 379, which also amended the ORS 455.447

and 455.447, special attention is now required (effective in January 1996) for proposed construction of certain occupancy types (new essential facilities, major structures, hazardous facilities, and special-occupancy structures) within the tsunami inundation zone. It adds under OSSC section 1804.1.2 "Some new "essential facilities" and some new "special occupancy structures as defined in ORS 455.447 shall not be constructed in tsunami inundation zones established by the Department of Geology and Mineral Industries (DOGAMI). . . ." This law focuses on limiting construction of new important facilities in hazardous areas; it does not require site-specific seismic-hazard investigations to be conducted on proposed developments other than those already specified in the code.

After numerous public hearings, the tsunami inundation zone was established as the area depicted in DOGAMI Open-file reports (OFR) O-95-09 through O-95-38, O-95-43 through O-95-66, and O-97-31 and O-97-32 (Priest and Baptista, 1995; Priest and Baptista, 1997 [totaling 56 coastal quadrangle maps]). An explanation of the method used to determine the inundation zone is provided in DOGAMI OFR O-95-67 (Priest, 1995). DOGAMI's OAR chapter 632, Division 05, last amended in February 1997, discusses the agency's responsibility under ORS 455.446 and 455.447 relating to construction of specified facilities with the tsunami inundation zone.

The details of the specified occupancy structures that have no restriction, that are prohibited, or require consultation from DOGAMI are outlined in OSSC Table 18-I-E. For example, new standby power generators, emergency vehicle shelters, and tanks do not have any restrictions in regard to development in tsunami inundation zones. Specified structures that fall in the prohibited class can be exempted by local action or approved by DOGAMI's governing board.

Leading Organizations

Experience has shown that public expenditures for mitigation (e.g., risk reduction of loss of life and property) are dramatically less than the costs of reconstruction following a disaster. The potential billions of dollars that will be spent in Oregon on reconstruction and business interruption losses by governments, private insurers, and the public can be minimized by mitigation expenditures of an amount on the order of only millions. The benefit-to-cost ratio is generally estimated to be somewhere between 10:1 and 100:1. More important, many needless fatalities can be avoided.

Several organizations have led the effort on reducing earthquake risks. These organizations include DOGAMI, Metro (Metropolitan Portland area regional government), Oregon Seismic Safety Policy Advisory Commission, Building Codes Division, Seismic Rehabilitation Task Force, Oregon Department of Transportation, and Oregon Emergency Management. Their most significant contributions are described below.

Oregon Department of Geology and Mineral Industries

In addition to its other responsibilities, DOGAMI has the legislature's mandate to better understand and mitigate earthquake hazards. Part of the agency's mission is to "reduce the future loss of life and property due to potentially devastating earthquakes." Realizing that the state is currently underprepared to experience a destructive earthquake, the agency applies its earthquake efforts in three broad areas: (1) earthquake hazard identification, (2) mitigation of earthquake hazards, and (3) increasing earthquake hazard awareness. Although the agency provides technical information, it also encourages policy applications associated with its efforts.

Earthquake hazard identification

Since the year 1987, DOGAMI has incorporated earthquake hazard identification into the agency's scope of work. DOGAMI concluded that hazard identification was best approached by evaluating ground response from source-independent earthquakes, rather than by attempting to determine the locations of all active faults. The agency further concluded that the geology-related hazards that contribute to most of the damage are strong ground shaking (including amplification of peak ground accelerations), landsliding, and liquefaction. For coastal Oregon, there is an additional threat of tsunamis (seismic sea waves).

DOGAMI has focused on earthquake hazard identification by developing geology-based earthquake hazard maps that indicate susceptibility to ground shaking amplification of peak ground accelerations, landsliding, and liquefaction susceptibility. Also, a general hazard composite map was produced by combining these three hazards with geographic information system (GIS) tools. Information on expected ground response from these regional maps can be used for a variety of purposes and applications. For example, in the case of new buildings, consideration of the siting of facilities may be based on expected ground response, and the level of the geotechnical investigation, design, and construction may be scaled according to the expected hazards. For existing buildings, the maps can be used to conduct a systematic risk assessment, so that property owners have the information needed to prioritize retrofit of their structures. The maps can also help facilitate prudent regional land use planning and emergency response planning both before and during an earthquake disaster.

Hazard mapping is under way in many urban areas, including the outer reaches of the greater Portland area and the greater Eugene and Springfield area. Mapping has been completed for most of Portland, for Salem, and for the Siletz Bay area in coastal Lincoln County (Madin, 1990; Mabey et. al., 1993; Mabey et. al, 1995 [4]; Mabey et. al., 1996; Wang and Leonard, 1996; Wang and Priest, 1995). Continued similar mapping efforts are underway in Klamath Falls. Less detailed mapping efforts are underway in about 37 mid-sized communities in western Oregon, including McMinnville-Lafayette-Dayton, Roseburg, Grants Pass, Ashland, Woodburn-Hubbard, Pendleton, Warrenton-Astoria, La Grande-Island City, Monmouth-Independence, Lebanon, The Dalles, Dallas, Canby, Hermiston, Ontario, Baker City, St. Helens-Columbia City, Newport, Cottage Grove, Sublimity-Stayton, Sweet Home, Florence-Dunes City, Gearhart-Seaside, Sutherlin-Oakland, Sheridan-Willamina, Lincoln City, Silverton, Milton-Freewater, Brookings, Hood River, Reedsport, Sandy, Coquille, and

Tillamook. In addition, a ground-motion map of peak ground accelerations is available for the state (Madin and Mabey, 1996).

The Oregon coast is the focus of substantial risk from Cascadia subduction-zone earthquakes and accompanying tsunamis, which have estimated first-wave arrival times of about 5 to 30 minutes after the onset of ground shaking (Priest, 1995). Regional tsunami-inundation zone maps have been completed for the entire Oregon coast (Priest, 1995; Priest and Baptista, 1995). Also, detailed mapping has been completed for the greater Siletz Bay area (Priest et. al., 1995 [2]); mapping is being conducted in Seaside and Newport; and future mapping in other areas (including Gold Beach and Astoria-Warrenton) is in preparation. In addition, large historical markers describing tsunamis have been erected at Seaside, Newport, and Reedsport; tsunami hazard zone and evacuation route signs have been installed in several coastal towns and communities; and informational tsunami brochures and bookmarks have been distributed all along the coast.

Mitigation of earthquake hazards

In 1989, DOGAMI was charged with the additional duties of mitigating earthquake hazards, that is, reducing the loss of life and property from earthquakes. Four main areas are targeted: new buildings, existing buildings, uses of the DOGAMI hazard maps, and earthquake damage and loss studies.

Since 1993, the Building Codes Division has required construction of safer new buildings (discussed below under "Building Codes Division"). For existing buildings, efforts are under way to develop a prioritized strategy for reduction of future losses by identifying steps that can provide for greatly enhanced safety at reasonable and justifiable expense. The goal is to establish policies that will help identify and strengthen vulnerable existing buildings (discussed below in "Seismic Rehabilitation Task Force").

DOGAMI collaborates with Metro on the Portland earthquake hazard mapping project, with DOGAMI developing the maps and Metro focusing on the application of the maps in its jurisdiction over the greater Portland area (see discussion below under "Metro"). DOGAMI's and Metro's efforts can help guide the use of hazard maps in other areas of the state as well as other parts of the country.

Another element of mitigation is conducting damage and loss assessments to estimate the loss of life and property from expected future earthquakes. With this information, strategic retrofit programs can be developed. DOGAMI has been involved in several earthquake damage and loss assessments. In 1993, a hazard map of the Portland 7.5-minute quadrangle was accompanied by an earthquake damage and loss estimate for an area of 60 city blocks (Metro/Oregon Department of Geology and Mineral Industries, 1993). Initiated in 1995, a federally funded National Institute of Building Sciences (NIBS) damage-and-loss study of the greater Portland area is under way. Results are projected to be available to the public in early 1997 (discussed below in "National Institute of Building Sciences"). In 1996, DOGAMI completed an economic impact evaluation from a design earthquake for each county. The study led to the result that over the next 55 years, the estimated average annual loss in Oregon would total over $100 million (Whelan and Mabey, 1996).

The agency encourages local partnerships and cooperation with communities, so that a systematic evaluation of risk can be better understood and mitigation efforts can be prioritized. An additional element is cooperation with local officials, such as land use and emergency planners and building officials, to incorporate the understanding of the mapped hazards and risks into everyday practices, plans, and policies.

Increasing earthquake hazard awareness

Earthquake risk can be reduced by increasing hazard awareness in the public and professional communities. DOGAMI engages in technology transfer and public education by leading and participating in committees, conferences, workshops, and applied sessions with targeted audiences, including engineers and design professionals, geologists, planners and building officials, trades industries, and by developing and distributing fact sheets and brochures. Outreach includes disseminating information through media, schools, and universities and supporting continuing education and studies. Organizations include the American Society of Civil Engineers, Association of Engineering Geologists, Earthquake Engineering Research Institute, Geological Society of America, Oregon Building Officials Association, Oregon Planning Institute, American Society of Safety Engineers, Oregon Occupational Safety and Health Division of the Department of Consumer and Business Services, Construction Specification Institute, Oregon League of Women Voters, Northwest Power Pool (lifeline managers), and insurers. DOGAMI also assists with preparedness efforts of the American Red Cross.

Several earthquake-related articles published in DOGAMI's Oregon Geology by DOGAMI staff as well as other professional geoscientists on the following topics include: the 1993 Scotts Mills earthquake (Black, 1996; Madin et. al, 1993), 1993 Klamath Falls earthquakes (Lienau and Lund, 1994; Wiley et. al., 1993), Oregon seismicity, historic earthquakes, and ground shaking potential (Bott and Wong, 1993; Jacobson, 1986; Wong and Madin, 1993; Wong and Silva, 1990), and shear wave velocities and liquefaction susceptibilty of alluvium in the Willamette Valley (Mabey and Madin, 1992; Vessely and Reimer, 1996).

METRO

Metro is authorized through its charter to address natural-disaster planning and response coordination in the greater Portland area. The agency's focus to date is on collection and dissemination of seismic risk information and on interaction with federal, state, and local governments, businesses, utilities, and special-interest groups in developing a regional earthquake preparedness program.

Metro was a key player in the Regional Planning Group that created the Regional Emergency Management Workplan, with the stated goal "to determine the emergency management issues and needs of the region and propose methods of coordinating, improving, and maintaining the emergency services system in the region." A geographic information system (GIS) database with regional infrastructure and building inventory is about half completed and has been shared with those who are conducting the National Institute of Building Sciences (NIBS) damage and loss assessment of the greater Portland area.

In early 1994, Metro formed the Metro Advisory Committee for Mitigating Earthquake Damage (MACMED) to support cooperative efforts among community members and to address regional policy issues regarding uses of the DOGAMI earthquake hazard maps. In May 1996, MACMED completed its efforts to tie earthquake-hazard maps to land-use planning and building practices and issued a report titled "Using Earthquake Hazard Maps for Land Use Planning and Building Permit Application" (Metro, 1996). Metro plans to present the recommendations in the report to the Metro Policy Advisory Committee and Metro Council for future action.

Oregon Seismic Safety Policy Advisory Commission (OSSPAC)

OSSPAC serves to reduce earthquake exposure and advises the legislature and government agencies on earthquake policy issues. OSSPAC includes representatives from the Building Codes Division, DOGAMI, the Department of Human Resources, Department of Land Conservation and Development, Department of Transportation, Oregon Emergency Management, Department of Water Resources, legislature, school districts, structural engineers, city governments, and county governments.

While OSSPAC functions as a forum and is still in the developmental stage, it has identified the potential risk from existing buildings and bridges as the greatest earthquake-related risk the state now faces. OSSPAC played a vital role in presenting legislation that upgraded Oregon's building requirements from Zone 2B to Zone 3 for western Oregon. Currently, OSSPAC is evaluating the policy issues surrounding a possible change of seismic zone ratings along the Oregon coast for the Building Codes Division.

Department of Consumer and Business Services, Building Codes Division (BCD)

BCD sets state requirements of the minimum design and construction standards for new buildings. In 1993, BCD upgraded the Oregon Structural Specialty Code (OSSC) seismic zonation rating for western Oregon and Hood River and Klamath Counties from Zone 2B to Zone 3, which requires that new buildings be built to higher seismic standards.

Also since 1993, BCD requires that site-specific seismic hazard investigations be performed for new essential facilities, major structures, hazardous facilities, and special-occupancy structures such as hospitals, schools, and emergency response facilities. Based on technical advantages, BCD has recently (early 1997) recommended upgrading coastal Oregon to a more stringent Uniform Building Code Zone 4 rating. BCD is currently evaluating other issues for the coast, such as the political advantages and disadvantages of such a code change versus waiting to adopt the forthcoming new national code, which would generally require more stringent design along the coast. BCD is active on several earthquake committees and continuing-education programs.

Oregon Department of Transportation (ODOT)

ODOT has focused on reducing seismic risks by placing an emphasis on strengthening future construction and by developing a priority list for retrofitting existing structures. Starting in 1991, ODOT began seismic retrofit of high-priority bridges, a screening of all state-owned bridges for seismic retrofit prioritization, and installation of a statewide seismic strong-motion instrumentation network. By 1995, ODOT had concluded its seismic hazard mapping project for the state. The agency is continuing its aggressive search for funding alternatives for seismic strengthening of bridges and is moving forward as well on other mitigation efforts.

Department of State Police, Oregon Emergency Management (OEM)

OEM is charged with applying for and administering disaster and other grants related to emergency program management and emergency services for the state. OEM coordinates the activities of all public and private organizations providing emergency services within the state. Most of the coordination efforts are related to planning for and conducting emergency response. OEM coordinates the response to an earthquake, which includes providing inspectors to assess damage. OEM led its first biannual statewide emergency response exercise for a Cascadia subduction zone earthquake scenario (QuakEx) in 1994 and continues scheduling the exercise on a biannual basis, involving many public and private organizations and sponsoring conferences and education focused on mitigation.

Other Government Organizations

Other organized efforts by agencies on the federal, state, and local government levels, some of which are partnerships among various governmental agencies and private groups, are listed below. For the purposes of this paper, information about partnership efforts is generally provided under the section of the leading organization.

Federal Emergency Management Administration (FEMA)

FEMA is charged with mitigating the effects of natural disasters and responding to needs that develop after a disaster. FEMA provides disaster relief funds following an emergency and works most closely with OEM (for example, in response to the 1993 Scotts Mills and Klamath Falls earthquakes). FEMA has helped elevate the awareness of Oregon's seismic risk to the national level and has been a strong financial supporter of earthquake mitigation projects in the Portland area, including the Portland-area earthquake-hazard-mapping project.

U.S. Geological Survey (USGS)

The USGS actively engages in earthquake research and also strongly supports research by others by providing funds and professional involvement through a variety of means. Recent USGS research includes offshore turbidite studies (Adams, 1996); paleoseismic investigations along the Oregon coast and Columbia

River (Atwater et. al, 1995; Nelson, 1992; Nelson and Personius, 1996; Nelson et. al, 1995; Obermeier, in press), aeromagnetic surveys of the Portland area and the northern Willamette Valley (Blakely et. al., 1995; Blakely et. al, 1996), post-earthquake reconnaissance of the 1993 Scotts Mills and Klamath Falls earthquakes (Gordon, ed., 1994; Wiley et. al., 1993), studies involving recordings of the 1993 Scotts Mills and Klamath Falls earthquake aftershocks by deployment of temporary seismometers (Dewey et.al., 1994; Thomas et. al., 1996 [University of Washington and USGS]), evaluation of landslides induced by the 1993 Klamath Falls earthquake and of slopes in the greater Eugene and Springfield area that are prone to fail in earthquakes (Gordon, ed., 1994; Keefer and Wang, in press), evaluation of crustal strain related to the Juan de Fuca plate subduction zone through geodetic surveys and a global positioning system (GPS) network (Savage et. al., 1991), and paleomagnetic studies (Wells, 1990).

In addition, the USGS funds the Pacific Northwest Seismograph Network, with headquarters at the University of Washington (UW), which provides earthquake recording coverage of much of Oregon. Other parts of Oregon are covered by Boise State University. The USGS, UW, and DOGAMI are currently initiating a system that allows for real-time monitoring of earthquakes. The USGS participates in partnership efforts (FEMA, DOGAMI, and California Division of Mines and Geology) to develop standardized methods of making earthquake hazard maps.

National Earthquake Hazards Reduction Program (NEHRP)

NEHRP was established by act of Congress in 1977 and is charged with providing long-term, nationwide earthquake risk reduction. NEHRP consists of federal agencies FEMA, USGS, National Science Foundation (NSF), and National Institute of Standards and Technology (NIST) and awards grants on a competitive basis. NEHRP has funded such studies in Oregon as the evaluation of the 1993 Scotts Mills and 1993 Klamath Falls earthquakes, publication of liquefaction maps in the greater Portland area, Portland-area basin studies, Portland-area probabilistic ground motion studies, and Coos Bay area fault and geologic maps (Madin et. al., 1994; Madin et. al., 1995).

National Earthquake Loss Reduction Program (NEP)

NEP, which was formed in 1996 to focus on earthquake loss reduction by complementing NEHRP activities, is led by FEMA and involves many agencies in addition to those that make up NEHRP. The stated goals are to provide leadership and coordination for federal earthquake research, improve technology transfer and outreach, improve engineering of the built environment, improve data for construction standards and codes, continue the development of assessment tools for seismic hazards and risks, analyze seismic hazard mitigation incentives, develop understanding of societal impacts and responses to earthquake-hazard mitigation, and continue documentation of earthquakes and their effects.

National Institute of Building Sciences (NIBS)

FEMA has sponsored NIBS to develop for NEHRP a risk-assessment tool that estimates earthquake losses, which should be available in mid-1997. Ultimately, local officials responsible for planning and stimulating mitigation efforts can utilize this methodology to reduce losses and better prepare for emergency responses and recovery following an earthquake. With results obtained by a consistent method, NEHRP can better determine the level of resources needed on a nationwide basis and more accurately allocate those resources to appropriate regions.

At this time, two pilot studies to test the developmental software (HAZUS) produced by NIBS are being conducted. The greater Portland area was selected as the western U.S. site.

Cascadia Region Earthquake Workgroup (CREW)

CREW is a private-public coalition formed in 1995 that works to reduce the risk of Cascadia-region earthquake hazards by linking regional mitigation resources and encouraging regional mitigation projects. CREW consists of a broad spectrum of Northwest-based members, including representatives of government, corporate, medical, financial, manufacturing, utility, and transportation groups. CREW holds annual conferences to discuss regional issues and disseminate information and plans to develop earthquake scenarios of Cascadia subduction zone and Portland earthquakes to identify areas of high risk.

Western States Seismic Policy Council (WSSPC)

WSSPC is a policy consortium of 18 governmental bodies from 13 western states represented by their emergency managers and State Geologists, whose mission includes the sharing of information among the states for earthquake mitigation purposes.

Oregon Department of Land Conservation and Development (DLCD)

DLCD supports earthquake hazard planning relating to its Comprehensive Plan Goal 7 on natural hazards and encourages prudent land use planning according to the MACMED report recommendations (see "Metro," above). DLCD participates in earthquake efforts together with OSSPAC and MACMED.

Oregon State System of Higher Education

All three of the state's major public universities—University of Oregon, Oregon State University, and Portland State University—are involved with earthquakes and earthquake hazards in some capacity. At these institutions, the federally funded work tends to be oriented toward basic research, whereas the state-funded work typically has a more practical application.

Some of this work has included regional tectonic and ground-motion studies (Pezzopane, 1993; Pezzopane and Weldon, 1993 [2]; Weldon, 1991; Yeats et.al., 1996), the analysis of the Scotts Mills and Klamath Falls earthquakes and possibly related sequences (Braunmiller et. al., 1995; Nabelek and Xia, 1995; Werner et. al., 1992), studies of offshore faults and geology (Goldfinger et.al., 1996), studies of paleoseismic evidence along the coast and the Columbia River (Darienzo and Peterson, 1995; Dickenson et. al, 1994; Peterson and Priest, 1995; Peterson et. al., 1993; Peterson et.al., 1997), installation and operation of a limited seismic network in cooperation with the Pacific Northwest Regional Network, geodetic studies (Mitchell et. al., 1994), geologic modeling and geophysical studies for supporting DOGAMI earthquake hazard mapping (Beeson et. al., 1989; Beeson et.al., 1991; Burns et. al., 1992) general seismicity (Johnson et. al., 1994), and course offerings and seminar lectures on earthquake engineering issues.

Oregon Department of Education

The Department of Education is generally concerned with seismic safety in schools. It supports the required monthly earthquake drills mandated in the Oregon Revised Statutes (ORS 336.072). The Department does not have authorization to mandate seismic safety efforts in schools but can make recommendations to local school districts on such issues. For example, it encourages use of a curriculum produced by FEMA that focuses on mitigating nonstructural hazards in schools and assists schools in obtaining funds for these purposes.

Oregon Department of Administrative Services (DAS)

DAS is responsible for all state government buildings and has taken a leading role in applying the new earthquake awareness to the safety of structures. The new state office building in Portland was built to Zone 3 standards in 1991/1992—before Zone 3 was adopted by BCD. Existing structures, such as the Public Service building and the Public Utility Commission building in Salem, have been rehabilitated for increased seismic resistance.

Oregon Department of Water Resources (DWR)

DWR safeguards many of the existing dams in the state. The agency has recently begun to consider earthquake safety of dams, for instance, as part of the dam relicensing process and has recommended installing seismic instrumentation on dam sites.

Oregon Boards of Geologist Examiners and Engineering Examiners

In late 1996, the Boards jointly adopted guidelines for the preparation of reports on seismic hazard investigations required for new essential facilities, major structures, hazardous facilities, and special-occupancy structures.

Local governments

Implementation of earthquake preparedness policy often takes place at the local government level, in cities, counties, water districts, and on school boards. For example, many decisions regarding planning, building, strengthening of structures, and post-disaster response are made at the local level.

In August 1993, the City of Portland formed the Portland Seismic Task Force to address the City of Portland Dangerous Building Code, which was substantially affected by the 1993 state building-code changes. In order to determine which existing Portland buildings need to undergo seismic rehabilitation, the task force initiated a risk study to determine acceptable levels of risk within its jurisdiction. The ultimate goal of the task force is to develop public policies encompassing acceptable seismic practices involving the Portland Dangerous Building code and existing vulnerable structures. The history of the building codes for Portland can be found in Kennedy (1996).

Private Organizations

Various branches of the professional engineering, earthquake, and earth science communities have been actively involved in Oregon's earthquake issues. The Structural Engineers Association of Oregon (SEAO) has recommended requiring continuing education for structural engineers to better address the increasing level of competence needed to design seismically resistant structures. The Oregon Chapters of the American Society of Civil Engineers (ASCE) and the Association of Engineering Geologists (AEG) have provided input on various proposed earthquake-related items of legislation and have offered numerous lectures on seismic issues. National conferences of ASCE and AEG covering Pacific Northwest earthquake issues are planned in 1997. The Earthquake Engineering Research Institute (EERI) and the Geological Society of America (GSA) have sponsored conferences centered on earthquake issues in the Pacific Northwest.

The growing awareness of earthquakes and concern over earthquake preparedness and mitigation is reflected in the activities of many more organizations, institutions, media, and individuals. Coverage of earthquake-related issues has increased considerably in the region's public media. Educational facilities have developed instructional programs such as the FEMA-funded "Seismic Sleuths" and "Tremor Troops" teacher workshops presented throughout the Pacific Northwest by the Oregon Museum of Science and Industry. Nonprofit organizations have been active in earthquake-awareness activities. For example, the League of Women Voters of Oregon conducted a statewide earthquake hazard and awareness study partially funded by DOGAMI that also raised awareness of earthquake issues at the community level. The American Red Cross focuses on public education, preparedness, and emergency response aimed at families and businesses.

Conclusions

The understanding of Oregon's earthquake hazards and the way the state addresses earthquake risks have changed over the years. Periodic earthquake shaking has been felt in Oregon for over a century and a half. The great Cascadia subduction-zone earthquake threat was identified in the past decade. The 1993 Scotts Mills and 1993 Klamath Falls "wake-up call" earthquakes confirmed to most people that earthquake hazards are present in Oregon. These recent events have dispelled the notion that Oregon was not earthquake country.

Because earthquakes are low-probability catastrophic events, it is not easy to gain political support and the necessary resources to reduce earthquake risks. However, enough Oregonians have come to realize that the huge costs to society associated with damaging earthquakes can easily exceed the cost of reasonable efforts of preparedness, and attempts are being made to bring the state into a better position before the next big earthquake hits.

Progress in identifying hazards and risks, estimating the damage and loss potential, reducing risks, and planning for emergency response has been made mainly in the last decade. In view of the fact that no major earthquakes that would raise public awareness have occurred yet, Oregon has made great strides. Many, in fact, consider Oregon to have created an exemplary framework of proactive steps that may be applied elsewhere in the nation to regions that can benefit from guidance in earthquake preparedness. National and regional awards have been granted to the DOGAMI/Metro hazard-mapping project for the Portland area. The surprising thing about Oregon's remarkable progress is that the earthquake mitigation efforts have been performed in fragments by various organizations without comprehensive oversight, whereas addressing the region as a whole would probably have been more efficient. Perhaps the most noteworthy aspect of the accomplishments is that the professional disciplines, including those within government agencies, have managed to overcome the common communication barriers between each other to the advantage of society and have taken decisive initial steps in the right direction. Still, Oregon remains largely underprepared for a significant earthquake, and much more effort is needed to lower the earthquake risk.

History shows that every earthquake has been a "surprise." The exact timing of an earthquake always contains the element of surprise because true prediction is not possible at this time, nor does it seem likely to be possible for decades to come. Also, earthquakes are all different in respect to their type, the environment in which they occur, and the built environment they affect. In seismically active regions, the earthquake "surprises" and the associated damages and losses should not really be surprises. For that reason, inhabitants of seismically active regions have the opportunity to be prepared for the next "surprise" earthquake. It is possible to understand reasonable bounds of potential earthquakes and earthquake hazards, to approximate them through earthquake scenarios, and to reduce the risks to a reasonable level to the benefit of current populations and future generations.

Many earthquakes around the world have had disastrous consequences. Estimates from earthquake damage and loss studies of the densely populated greater Portland area indicate that many hundreds, if not thousands of lives could be lost and that property loss could be on the order of tens of billions of dollars in such an event. Quantifying potential losses is one step in getting closer to the difficult question: "How much can we invest prudently in safer living?"

Since 1993, a higher standard for the seismic safety of new buildings and seismic investigations of building sites for certain new structures, such as hospitals, schools, or emergency-response facilities, has been mandated in Oregon. To achieve safer conditions for the entire community, however, more than just the safety of its new buildings must be assured. All buildings and the vulnerability of lifelines such as roads and water, waste-water, electricity, gas, and communication systems need to be addressed. Many need seismic strengthening. Realistic measures to prioritize seismic strengthening must be taken quickly and prudent land-use measures established promptly. In addition, a higher degree of preparedness needs to be attained at many levels, from emergency response at the government level to disaster preparedness at the personal level.

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Although it is not the author's intention, this paper may be biased with general viewpoints of the Oregon Department of Geology and Mineral Industries due to the fact that much of the background was gathered from the agency's staff and files. Significant earthquake research and mitigation efforts by those not mentioned in this paper can be brought to the author's attention for future clarification. This paper is a modified version of a similar paper in Oregon Geology, v. 59, no. 2, pp. 27-38 (Wang, 1997). Some scientific and technical papers have been referenced in Oregon Geology, rather than the professional journals, so that local practitioners may more readily obtain the papers.

References

Adams, J., 1996, "Great earthquakes recorded by turbidites off the Oregon-Washington coast," in Rogers, Walsh, Kockelman, and Priest eds., Assessing earthquake hazards and reducing risk in the Pacific Northwest, *U.S. Geological Survey Professional Paper 1560*, Vol. 1, pp. 147–158.

Algermissen, S.T., 1983, An introduction to the seismicity of the United States: Berkeley, *Calif., Earthquake Engineering Research Institute Monograph*, 148 p.

Atwater, B.F., 1987, "Evidence for great Holocene earthquakes along the outer coast of Washington State," *Science*, v. 236, pp. 942–944.

Atwater, B.F., Nelson, A.R., Clague, J.J., Carver, G.A., Yamaguchi, D.K., Bobrowsky, P.T., Bourgeois, J., Darienzo, M.E., Grant, W.C., Hemphill-Haley, E., Kelsey, H.M., Jacoby, G.C., Nishenko, S.P., Palmer, S.P., Peterson, C.D., and Reinhart, M.A., 1995, "Summary of coastal geologic evidence for past great earthquakes at the Cascadia subduction zone," *Earthquake Spectra*, v. 11, no. 1, pp. 1–18.

Beaulieu, J.D., and Peterson, N.V., 1981, "Seismic and volcanic hazard evaluation of the Mount St. Helens area, Washington, relative to the Trojan nuclear site, Oregon," *Oregon Department of Geology and Mineral Industries Open-File Report O-81-9*, 80 pp.

Beeson, M.H., Tolan, T.L., and Madin, I. P., 1989, Geologic map of the Lake Oswego quadrangle, Clackamas, Multnomah, and Washington Counties, Oregon Department of Geology and Mineral Industries GMS-59.

Beeson, M.H., Tolan, T.L., and Madin, I.P., 1991, Geologic map of the Portland quadrangle, Multnomah & Washington Counties, Ore., and Clark County, Wash., Oregon Department of Geology and Mineral Industries GMS-75.

Black, G., March, 1996, "Earthquake intensity maps for the March 25, 1993 Scotts Mills earthquake," *Oregon Geology*, Vol. 58, No. 2, pp. 35–41.

Blakely, R. J., Wells, Ray E., Yelin, T.S., Madin, I.P., and Beeson, Marvin H., 1995, "Tectonic setting of the Portland-Vancouver area, Oregon and Washington: Constraints from low-altitude aeromagnetic data," *GSA Bulletin*, Vol. 107, No. 9, pp. 1051–1062.

Blakely, Richard J., Wells, Ray E., Yelin, Thomas S, Dougherty, M.E., and Trehu, A.M., "Faults and Earthquakes in the Willamette Valley and Portland Basin: A Regional Perspective from Newly Acquired Aeromagnetic Data," *1996 Program with abstracts for GSA92nd Annual Cordilleran Section Conference*, Vol. 28, No. 5.

Bott, J., and Wong, I., September, 1993, "Historical earthquakes in and around Portland," *Oregon Geology*, Vol. 55, No. 5, pp. 116–122.

Braunmiller, J., Nabele,, J., Leitner, B., Qamar, A., 1995, The 1993 Klamath Falls, Oregon, earthqauke sequence: source mechanisms from regional data, Geophysical Research Letters.

Burns, S.F., Caldwell, R.R., Mulder, R.A., Madin, I.P., and Mabey, M.A., 1992, "Mapping geological earthquake hazards, Salem, Oregon," *Association of Engineering Geologists annual meeting, 35th, Los Angeles, Calif., Preceedings*, pp. 291–296.

Darienzo, M., and Peterson, C., January, 1995, "Magnitude & Frequency of subduction zone earthquakes along the northern Oregon coast in the past 3,000 years," *Oregon Geology*, Vol. 57, No. 1, pp. 3–12.

Dehlinger, P., and Berg, J.W., Jr., 1962, "The Portland earthquake of November 5, 1962," Oregon Department of Geology and Mineral Industries, *Ore Bin*, v. 24, no. 11, pp. 185–188.

Dehlinger, P. Bowen, R.G., Chiburis, E.F., and Westphal, W.H., 1963, "Investigations of the earthquake of November 5, 1962, north of Portland," Oregon Department of Geology and Mineral Industries, *Ore Bin*, v. 25, no. 4, pp. 53–68.

Dewey, James W., Reagor, B. Glen, Johnson, Dennis, Choy, George L., and Baldwin, Frank, The Scotts Mills, Oregon, Earthquake of March 25, 1993: Intensities, Strong-Motion Data, and Teleseismic Data, *U.S. Dept. of the Interior U.S. Geological Survey*, O-94-163.

Dickenson, S.E., Obermeier, S.F., Roberts, T.H., and Martin, J.R. II, 1994, "Constraints on earthquake shaking in the lower Columbia River region of Washington and Oregon during late-Holocene time," *Fifth U.S. National Conference on Earthquake Engineering. Proceedings*, Vol. III, EERI, Oakland, California.

Geomatrix Consultants, Inc., 1995, Seismic design mapping, State of Oregon: Final report to Oregon Department of Transportation, Project no. 2442, var. pag.

Goldfinger, C., Kulm, LaV.D., Yeats, R.S., Applegate, B., MacKay, M.E., and Cochrane; G.R., 1996, "Active strike-slip faulting and folding of the Cascadia subduction-zone plate boundary and forearc in central and northern Oregon," in Rogers, Walsh, Kockelman, and Priest eds., Assessing earthquake hazards and reducing risk in the Pacific Northwest, *U.S. Geological Survey Professional Paper 1560*, Vol. 1, pp. 223–256.

Goldfinger, C., Kulm, L., Yeats, R., Mitchell, C., Weldon, R., Peterson, C., Darienzo, M., Grant, W., and Priest, G.R., 1992, Neotectonic map of the Oregon continental margin and adjacent abyssal plain; *Oregon Department of Geology and Mineral Industries Open-File Report O-92-4.*

Gordon, D.W., ed., Klamath Falls, "Oregon Earthquakes of September 30, 1993," *USGS Earthquakes and Volcanos Special Issue*, Vol. 24, No. 3.

Heaton, T.H., and Kanamori, H., 1984, "Seismic potential associated with subduction in the northwestern United States," *Seismological Society of America Bulletin*, v. 74, no. 3, pp. 933–941.

International Conference of Building Code Officials, State of Oregon 1996 edition structural specialty code, April 1 1996, based on 1994 Uniform Building Code, Section 1804-Site and Foundation Investigation.

Jacobson, R.S., 1986, Map of Oregon seismicity, 1841–1986, Oregon Department of Geology and Mineral Industries GMS-49.

Johnson, A.G., Scofield, D.H., and Madin, I.P., Earthquake database for Oregon, 1833 through October 25, 1993, *Oregon Department of Geology and Mineral Industries Open File Report O-94-04*.

Keefer, D.K., and Wang, Y., (in press), "Predicting Slope Instability for Earthquake Hazard Maps," Proceedings for 1997 Association of Engineering Geologists, Portland, Oregon.

Kennedy, R.E., 1996, "The development of the Portland, Oregon, Building Code_50 years of evolution, 1945-1995. A comparison of seismic events and structural aspects," *Oregon Geology*, v. 58, no. 1, pp. 10–14.

Lienau, P., Lund, J., January, 1994, "Ground-water anomolies associated with the Klamath Falls earthquakes of Sept. 20–24, 1993," *Oregon Geology*, Vol. 56, No. 1, pp. 7–9.

Mabey, M., and Madin, I. P., 1992, "Shear wave velocity measurements in the Willamette Valley and Portland Basin," Oregon, *Oregon Geology*, Vol. 54, No. 3.

Mabey, M., Madin, I., Black, G., and Meier, D., 1996, Linnton Quadrangle, Multnomah & Washington Counties. NW of Portland, Oregon, Oregon Department of Geology and Mineral Industries GMS-104.

Mabey, M., Madin, I., and Meier, D., 1995, Beaverton Quadrangle, Washington Co. Ore., SW of Portland, Oregon, Oregon Department of Geology and Mineral Industries GMS-90.

Mabey, M., Madin, I., and Meier, D., 1995, Gladstone Quadrangle, Clackamas & Multnomah Counties. SE of Portland,Oregon, Oregon Department of Geology and Mineral Industries GMS-92.

Mabey, M., Madin, I., and Meier, D., 1995, Lake Oswego Quadrangle, Clackamas, Multnomah & Washington Cos., Ore. South of Portland, Oregon, Oregon Department of Geology and Mineral Industries , GMS-91.

Mabey, M., Meier, D., and Palmer, S., 1995, Mount Tabor Quadrangle, Multnomah Co. Ore. & Clark Co. Wash., East of Portland, Oregon, Oregon Department of Geology and Mineral Industries GMS-89.

Mabey, M. Madin, I., Youd, T., Jones, C., 1993, Lateral Spread Displacement, Relative Ground Motion Amplification and Relative Dynamic Slope Instability maps of the Portland Quadrangle, Oregon, *Earthquake Hazard Maps of the Portland Quadrangle, GMS -79.*

Madin, I. P., Earthquake hazard geology maps of the Portland metropolitan area, *Oregon Department of Geology and Mineral Industries Open File Report O-90-02.*

Madin, I.P., Hemphill-Haley, M.A., and Roberts, T., 1994, "Late Quaternary faulting in the South Slough area, Coos County Oregon," *Oregon Geology*.

Madin, I., and Mabey, M., 1996, Earthquake Hazard Maps for Oregon, Oregon Department of Geology and Mineral Industries GMS-100.

Madin, I. P., McInelly, G. W., and Kelsey, H., 1995, Geologic Map of the Charleston Quadrangle, Coos County, Oregon, Oregon Department of Geology and Mineral Industries GMS-94.

Madin, I., Priest, G., Mabey, M., Malone, S., Yelin, T.S., Meier, D., May, 1993, "March, 25, 1993 Scotts Mills earthquake—Western Oregon's wake-up call," *Oregon Geology*, Vol. 55, No. 3, pp. 51–57.

McCaffrey, R., and Goldfinger, C., 1995, "Forearc deformation and great subduction earthquakes: implications for Cascadia offshore earthquake potential," *Science* v. 267, pp. 856–859.

Metro, 1996, Using Earthquake Hazard Maps for Land Use Planning and Building Permit Administration, Report of the Metro Advisory Committee for Mitigation Earthquake Damage (unpublished).

Metro/Oregon Department of Geology and Mineral Industries, 1993, Earthquake scenario pilot project: Assessment of damage and losses, *Oregon Department of Geology and Mineral Industries Open File Report O-93-06.*

Mitchell, C.E., Vincent, P., Weldon, R.J. III, and Richards, M.A., 1994, "Present-day vertical deformation of the Cascadia margin, Pacific Northwest," *Journal of Geophysical Research*, Vol. 9, pp. 12,257–12,277.

Nabelek, J., and Xia, G., 1995, Moment-tensor analysis using regional data: Application to the 25 March, 1993, Scotts Mills, Ore. earthquake, Geophysical Research Letters.

Nelson, A.R., 1992, "Discordant ^{14}C ages from buried tidal-marsh soils in the Cascadia Subduction Zone, southern Oregon coast," *Quaternary Research*, Vol. 38, pp. 74–90.

Nelson, A.R., Atwater, B.F., Bobrowsky, P.T., Bradley, L., Clague, J.J., Carver, G.A., Darienzo, M.E., Grant, W.C., Krueger, H.W., Sparkes, R., Stafford, T.W.Jr., and Stuiver, M., 1995, "Radiocarbon evidence for extensive plate-boundary rupture about 300 years ago at the Cascadia subduction zone," *Nature*, Vol. 378, No. 23, pp. 371–374..

Nelson, A.R., and Personius, S.F., 1996, "Great-earthquake potential in Oregon and Washington--An overview of recent coastal geologic studies and their bearing on segmentation of Holocene ruptures, central Cascadia subduction zone," in Rogers, Walsh, Kockelman, and Priest eds., Assessing earthquake hazards and reducing risk in the Pacific Northwest, *U.S. Geological Survey Professional Paper 1560*, Vol. 1, pp. 91–114.

Obermeier, S.F., in press, Preliminary limits for the strength of shaking for the Columbia River valley and the southern half of coastal Washington for the Cascadia subduction zone earthquake of about 300 years ago, *U.S. Geological Survey Open-File Report 94-589*.

Oregon Department of Geology and Mineral Industries, 1978, Geologic hazards review, Trojan nuclear power plant site, Columbia County, Oregon: *Oregon Department of Geology and Mineral Industries Open-File Report O-78-1*, 42 p.

Peterson, C.D., Barnett, E.T, Briggs, G.G., Carver, G.A., Clague, J.J., and Darienzo, M.E., 1997, Estimates of Coastal Subsidence from Great Earthquakes in the Cascadia Subduction Zone, Vancouver Island, B.C., and Washington, Oregon, & Northernmost California, *Oregon Department of Geology and Mineral Industries Open File Report O-97-05.*

Peterson, C., Darienzo, M., Burns, S., and Burris, W., September, 1993, "Field trip guide to Cascadia paleoseismic evidence along the northern Oregon coast, evidence of subduction zone seismicity in the central Cascadia margin," *Oregon Geology*, Vol. 55, No. 5, pp. 99–114.

Peterson, C., and Priest, G., March, 1995, "Preliminary reconnaissance survey of Cascadia paleotsunami deposits in Yaquina Bay, Oregon," *Oregon Geology*,Vol. 57, No. 2, pp. 33–40.

Pezzopane, S.K., 1993, Active faults and earthquake ground motions in Oregon: Eugene, Oregon, University of Oregon doctoral dissertation, 208p.

Pezzopane, S.K., and Weldon, R.J., II, 1993, "Tectonic role of active faulting in central Oregon," *Tectonics*, v. 12, no. 5, pp. 1140– 1169..

Pezzopane, S.K., and Weldon, R.J., II, 1993, Predictive ground acceleration maps for Oregon, unpublished report to Oregon Department of Geology and Mineral Industries.

Priest, G. R., 1995, Explanation of mapping methods and use of the tsunami hazard maps of the Oregon coast, *Oregon Department of Geology and Mineral Industries Open-File Report O-95-67*, 95 pp.

Priest, G. R., Baptista, A., Qi, M., Peterson,C.D., and Darienzo, M.E., 1995, Simplified explanation of the tsunami hazard map of the Siletz Bay area, Lincoln County, Oregon in Priest, G.R., ed., Explanation of mapping methods and sue of the tsunami hazard map of hte Siletz Bay area, Lincoln County, Oregon, *Oregon Dept. of Geology and Mineral Industries Open-File-Report O-95-5*.

Priest, G., and Baptista, A., 1995, Tsunami hazard maps of coastal quadrangles, 56 quadrangle maps for Oregon, *Oregon Department of Geology and Mineral Industries Open File Reports O-95-09 to O-95-38, O-95-43 to O-95-66, O-97-31 and O-97-32.*

Priest, G. R., Qi, M., Baptista, A., Peterson,C.D., and Darienzo, M.E., 1995, Tsunami hazard map of the Siletz Bay area, Lincoln County, Oregon, *Oregon Dept. of Geology and Mineral Industries GMS 99.*

Satake, K., Shemazaki, K., Yoshinobu, T., and Ueda, K., 1996, "Time and size of a giant earthquake in Cascadia inferred from Japanese tsunami records of January 1700, 1996," *Nature*, v. 379, no. 6562, pp. 246–249.

Savage, J.C., Lisowski, M., and Prescott, W.H., 1991, "Strain Accumulation in Western Washington," *Journal of Geophysical Research*, 96, pp. 14493–14507.

Seismic Rehabilitation of Existing Buildings in Oregon, September 1996, Report to the Sixty-Ninth Oregon Legislative Assembly, unpublished.

Shannon and Wilson, Inc., 1972, Seismic regionalization studies, Bonneville Power Administration service area, Washington, Oregon, Idaho, and western Montana: Portland, Oreg., Report to Agbabian Associates, El Segundo, Calif. (Job no. 0-653); R.W. Couch and R.J. Deacon, investigators, 43 pp. (unpublished).

Smith, W.D., 1919, "Earthquakes in Oregon," *Seimological Society of America Bulletin*, v. 9, no. 3, pp. 58–71 (Reprint: University of Oregon Publications, v. 1, no. 3).

Thomas, G.C., Crosson, R.S.,Carver, D.L., and Yelin, T.S., 1996, "The 25 March 1993 Scotts Mills, Oregon, Earthquake and Aftershock Sequence: Spatial Distribution, Focal Mechanisms, and the Mount Angel Fault," *Bulletin of the Seismological Society of America*, Vol. 86, No.4, pp. 925–935.

Vessely, A., and Riemer, M., November, 1996, "Liquefaction susceptibility of soft alluvial silts in the Willamette Valley," *Oregon Geology*, Vol. 58, No. 6 pp. 142–145.

Wang, Y., 1997, "Preparing for earthquakes in Oregon," *Oregon Geology*, Vol. 59, No. 2.

Wang, Y., Leonard, W.J., 1996, East & West Salem Quadrangles, Marion & Polk Counties, *Oregon Department of Geology and Mineral Industries GMS-105*.

Wang, Y., and Priest, G., 1995, Relative earthquake hazard maps of the Siletz Bay Area, Coastal Lincoln County, Oregon,*Oregon Department of Geology and Mineral Industries GMS-93.*

Wang, Y., Wilson, D., and Priem, S., 1996, Earthquake Alert! Course notes for Oregon Building Officials Assoc. Fall Education Institute, unpublished.

Weaver, C.S., and Shedlock, K.M., 1996, "Estimates of seismic source regions from considerations of the earthquake distribution and regional tectonics in the Pacific Northwest," in Rogers, A.M., Walsh, T.J., Kockelman, W.J., and Priest, G.R., eds., Assessing earthquake hazards and reducing risk in the Pacific Northwest, *U.S. Geological Survey Professional Paper 1560*, v. 1, pp. 285–306.

Weldon, R. J., 1991, "Active tectonic studies in the United States, 1987–1990," Reviews of Geophysics Supplement (U.S. National Report to International Union of Geodesy and Geophysics), pp. 890–906.

Wells, R.E., 1990, Paleomagnetic rotations and the Cenozoic tectonics of the Cascade Arc, Washington, Oregon, and California, *Journal of Geophysical Research*, Vol. 95, pp. 19409–19417.

Werner, K., Nabelek, J., Yeats, R., Malone, S., September, 1992, "The Mount Angel fault: Implications of seismis-reflection data and the Woodburn, Oregon earthquake sequence of August 1990," *Oregon Geology*, Vol. 54, No. 5, pp. 112–117.

Whelan, R., and Mabey, M., November, 1996, "Expected financial losses due to buildings damage caused by severe earthquakes in Oregon," *Oregon Geology*, Vol. 58, No. 6, pp. 146–149.

Wiley, T., Sherrod, D.R., Keefer, D.K., Qamar, A., Schuster, R.L., Dewey, J.W., Mabey, M.A., Black, G.L., and Wells, R.E., "November, 1993, Klamath Falls earthquakes, Sept. 20, 1993, including the strongest quake ever measured in Oregon," *Oregon Geology*, Vol. 55, No. 6, pp. 127–134.

Wong, I., Madin, I P., November, 1993, "Strong ground shaking in the Portland Oregon metropolitan area," *Oregon Geology*, Vol. 55, No. 6, pp. 137–143..

Wong, I.G., and Silva, W. J., November, 1990, "Preliminary assessment of potential strong earthquake ground shaking in the Portland, Oregon metropolitan area," *Oregon Geology*, Vol. 52, No. 6, pp. 131–134.

Yeats, R.S., Graven, E.P., Werner, K.S., Goldfinger, C., and Popowski, T.A., 1996, "Tectonics of the Willamette Valley, Oregon in Rogers, Walsh, Kockelman, and Priest eds., Assessing earthquake hazards and reducing risk in the Pacific Northwest," *U.S. Geological Survey Professional Paper 1560*, Vol. 1, pp. 183–222.

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