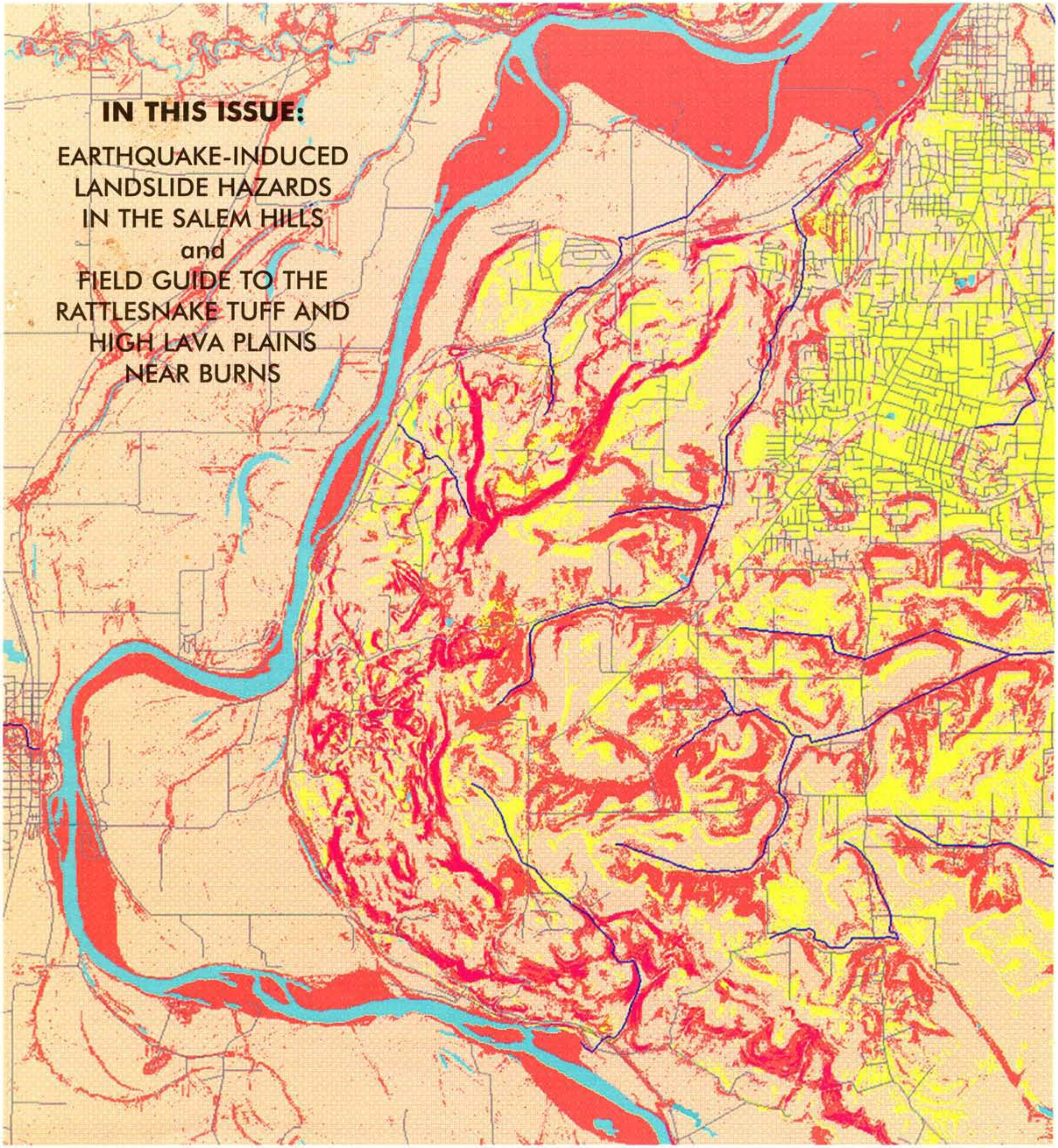
OREGON GEOLOGY

Oregon Department of Geology and Mineral Industries

Volume 61, Number 3, May/June 1999



IN THIS ISSUE:

EARTHQUAKE-INDUCED LANDSLIDE HAZARDS IN THE SALEM HILLS

and

FIELD GUIDE TO THE RATTLESNAKE TUFF AND HIGH LAVA PLAINS NEAR BURNS

OREGON GEOLOGY

(ISSN 0164-3304)

VOLUME 61, NUMBER 3 MAY/JUNE 1999

Published bimonthly in January, March, May, July, September, and November by the Oregon Department of Geology and Mineral Industries. (Volumes 1 through 40 were entitled *The Ore Bin*.)

Governing Board

Jacqueline G. Haggerty, Chair ..... Enterprise

Arleen N. Barnett ..... Portland

Donald W. Christensen ..... Depoe Bay

State Geologist ..... Donald A. Hull

Deputy State Geologist ..... John D. Beaulieu

Editor ..... Klaus K.E. Neuendorf

Production Assistants ..... Geneva Beck

..... Kate Halstead

Main Office: Suite 965, 800 NE Oregon Street # 28, Portland 97232, phone (503) 731-4100, FAX (503) 731-4066.

Internet: http://sarvis.dogami.state.or.us

Baker City Field Office: 1831 First Street, Baker City 97814, phone (541) 523-3133, FAX (541) 523-5992.

Mark L. Ferns, Regional Geologist.

Grants Pass Field Office: 5375 Monument Drive, Grants Pass 97526, phone (541) 476-2496, FAX (541) 474-3158.

Thomas J. Wiley, Regional Geologist.

Mined Land Reclamation Program: 1536 Queen Ave. SE, Albany 97321, phone (541) 967-2039, FAX (541) 967-2075.

Gary W. Lynch, Supervisor.

Internet: http://www.proaxis.com/~dogami/mlrweb.shtml

The Nature of the Northwest Information Center: Suite 177, 800 NE Oregon St. # 5, Portland, OR 97232-2162, phone (503) 872-2750, FAX (503) 731-4066, Donald J. Haines, Manager.

Internet: http://www.naturenw.org

Periodicals postage paid at Portland, Oregon. Subscription rates: 1 year, $10; 3 years, $22. Single issues, $3. Address subscription orders, renewals, and changes of address to Oregon Geology, Suite 965, 800 NE Oregon Street # 28, Portland 97232.

Oregon Geology is designed to reach a wide spectrum of readers interested in the geology and mineral industry of Oregon. Manuscript contributions are invited on both technical and general-interest subjects relating to Oregon geology. Two copies of the manuscript should be submitted. If manuscript was prepared on common word-processing equipment, a file copy on diskette should be submitted in place of one paper copy (from Macintosh systems, high-density diskette only). Graphics should be camera ready; photographs should be black-and-white glossies. All figures should be clearly marked; figure captions should be together at the end of the text.

Style is generally that of U.S. Geological Survey publications. (See USGS Suggestions to Authors, 7th ed., 1991, or recent issues of *Oregon Geology*.) Bibliography should be limited to references cited. Authors are responsible for the accuracy of the bibliographic references. Include names of reviewers in the acknowledgments.

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, letters, notices, and meeting announcements should be sent to Klaus Neuendorf, Editor, at the Portland office (address above).

Permission is granted to reprint information contained herein. Credit given to the Oregon Department of Geology and Mineral Industries for compiling this information will be appreciated. Conclusions and opinions presented in articles are those of the authors and are not necessarily endorsed by the Oregon Department of Geology and Mineral Industries.

POSTMASTER: Send address changes to Oregon Geology, Suite 965, 800 NE Oregon St. # 28, Portland, OR 97232-2162.

Cover illustration

New relative hazard map of earthquake-induced slope instability for the vicinity of the Salem Hills on the southwest edge of the city of Salem, Oregon (see also page 63). Developing this map is the subject of the article beginning on the next page.

Sign dedication at Beverly Beach remembers children drowned in 1964 tsunami

On March 27, 1964, four children died on Beverly Beach, after a magnitude-9.2 earthquake off the coast of Alaska spawned a tsunami that slammed the Oregon coast. A Tacoma family was asleep in a small driftwood shelter when the first tsunami wave struck the coast at approximately 11:30 p.m. The four McKenzie children were swept out to sea.

A new geologic information sign with life-saving information about tsunamis was unveiled and dedicated at the Beverly Beach State Park campground, 7 mi north of Newport, on March 27.

Invited speakers included State Representative Terry Thompson; Robert Meinen, Director, Oregon Parks and Recreation Department; June S. Spence, Commission member of the Oregon Parks and Recreation Department; Alberta Bryant, Retired Lincoln County Commissioner; and Donald Christensen, Governing Board of the Department of Geology and Mineral Industries (DOGAMI). Comments from Congresswoman Darlene Hooley were read. Donald A. Hull, DOGAMI Director and State Geologist, welcomed the attendants and introduced the speakers.

The sign warns people about the dangers of tsunamis (large waves caused by great undersea earthquakes), tells them what to do to save themselves if a tsunami should occur, and explains how and why tsunamis periodically strike the Oregon coast. The sign was funded by DOGAMI, the Federal Emergency Management Agency, Leading Edge Entertainment, Southpaw Productions, and the Oregon Parks and Recreation Department and designed by Sea Reach, Ltd.

A walking tour of the newly signed tsunami evacuation route designed for Beverly Beach State Park was led by John Allen, Area 1 Parks Manager; Mark Darienzo, Oregon Emergency Management; and Jim Hawley, Lincoln County Emergency Services.

The Oregon Parks and Recreation Department is an active partner in educating coastal visitors. "A goal of State Parks is more emphasis on partnerships, and we are delighted with the opportunity to work with DOGAMI on a number of tsunami public awareness programs. We are very pleased to be a part of this very important tsunami public awareness campaign," said Commission member June Spence.

To get information about how to protect yourself in an earthquake or to purchase tsunami inundation maps or a tsunami educational videotape, contact the **Nature of the Northwest Information Center**, or the DOGAMI field offices in Baker City and Grants Pass. See addresses, phone numbers, and internet access in the box on the left side of this page. □

Earthquake-induced slope instability: A relative hazard map for the vicinity of the Salem Hills, Oregon

by R. Jon Hofmeister, Oregon Department of Geology and Mineral Industries, Portland, Oregon 97232

INTRODUCTION

Public and private agencies that create regional hazard maps can benefit from the use of a standardized regional hazard mapping methodology. The methodology should be uniform yet flexible enough to remain appropriate for, and verifiable across, vast and geographically diverse regions. The ideal is to produce the most accurate maps possible (that is, the best predictors of high-risk versus low-risk areas) in the least amount of time and at the lowest cost.

A recently-developed methodology by David Keefer of the United States Geological Survey (USGS) and Yumei Wang of the Oregon Department of Geology and Mineral Industries (DOGAMI) is aimed at this ideal in evaluating slope stability hazards on a regional scale (Keefer and Wang, 1997). Their methodology is specifically intended for implementation using Geographic Information Systems (GIS) and utilizes common methods for scientific and engineering analysis of slope stability.

The Salem study presented here is the second project employing that methodology. The first was a study for the Eugene-Springfield metropolitan area in Lane County, Oregon (Wang and others, 1998; Black and others, 1999).

This project had two primary objectives:

1. To implement and evaluate the methodology for assessing regional earthquake-induced slope instability by Keefer and Wang (1997) and to refine the method, where applicable, for subsequent regional mapping efforts in Oregon and elsewhere.

2. To create the most accurate and representative hazard map feasible for earthquake-induced slope instability in the Salem Hills vicinity, given the existing time and economic constraints.

The resulting hazard map provides a rational basis for evaluating the spatial variability of landslide hazards within the Salem area. The calculations were performed with GIS tools and a 10×10 m grid spacing, and the final hazard map depicts zones of *Very Low, Low, Moderate, and High* potential for earthquake-induced slope instability.

The map is intended to help guide regional decisions by planners, emergency management officials, and others responsible for planning and implementing measures aimed at minimizing potential loss of life and property damage from future earthquake events.

BACKGROUND

Salem is the third largest city in Oregon. As population growth has expanded city boundaries, new development has spread into the marginal, steeper areas south of downtown Salem, including the Salem Hills area, and is expected to accelerate. Slope instability hazards are of particular concern in the area. Several rainfall-induced slides have recently caused damage to development in the study region. Extensive portions of the Salem Hills vicinity, particularly along the north and west flanks, are characterized by jumbled, "hummocky" terrain that resulted from major historical landslide events. These features are a noteworthy reminder that the area has been unstable in the past and that portions will inevitably move again in the future.

This project focuses on seismic slope stability hazards in the Salem study area. The Oregon Emergency Management Office has received funding from the Federal Emergency Management Agency (FEMA) for a complementary project to evaluate rainfall-induced landslide hazards in the Salem Hills. That funding is being used by DOGAMI, the City of Salem, and Marion County to study the hazards in the Salem area and develop mitigation measures to reduce future losses. The characterization of precipitation-induced landslide hazards was contracted to Squier Associates, a geotechnical engineering firm based in Lake Oswego, Oregon. Results have been released as DOGAMI Interpretive Map Series map IMS-6 (Harvey and Peterson, 1998), a generalized hazard map depicting relative hazard zones from 1 to 6 (low to high susceptibility) and associated text outlining development recommendations for each zone (Harvey and Peterson, 1998).

The study region used for this study of earthquake-induced slope instability includes the area analyzed for rainfall-induced landslide hazards, and the two maps should serve as useful complements for evaluating critical hazard areas in the Salem vicinity.

This project builds upon previous earthquake hazard mapping in the Salem area published by DOGAMI in 1996 (Wang and Leonard, 1996). The Wang and Leonard analysis included an evaluation of ground shaking amplification, landslide, and liquefaction hazards in the Salem East and Salem West 7½-minute quadrangles. Those quadrangles overlap the northern portion of the region evaluated in this new study. The landslide hazard categories in the Wang and Leonard project were purely a function of calculated slope angles. In addition to expanding the geographic area mapped, the current study bolsters the slope stability portion of the earlier analysis by augmenting topographic data with soil property and other physical data to further differentiate areas of relative hazard within the critical Salem Hills vicinity.

METHODOLOGY

The Salem Hills study area includes some challenging and complex geologic conditions that provide a unique opportunity to test the methodology introduced by Keefer and Wang (1997). Field evaluation by David Keefer of the USGS, Yumei Wang of DOGAMI, consulting geologist Robert Murray, and myself in March 1998 verified both the geologic complexity as well as the geographic importance of the study region.

Keefer and Wang methodology

The Keefer and Wang methodology uses three different methods to evaluate overall earthquake-induced slope stability hazard. The purpose in separating the analysis into three distinct facets is to account for the range of commonly observed modes of slope failure in earthquake events.

Steep slopes (generally rock) tend to fail as rock falls, rock slides, and debris slides (Keefer, 1984).

Moderate slopes (generally soil) most often fail as translational block slides and rotational slumps (Keefer, 1984).

For more gently sloping topography, the soil and rock slope hazards are usually lower, but in regions with saturated granular materials, liquefaction-induced lateral spread displacements can be significant.

The engineering and scientific methods differ depending on whether rock-slope, soil-slope, or lateral-spread hazards are evaluated. Since all three hazards may be present in a regional study, different methods are selected for modeling each of these hazards. The choice also takes into account technical merit and applicability for regional GIS analysis.

For steep rock slopes, an empirical decision tree developed by Keefer (1993) is used. The method is based on empirical correlations between recorded landslide concentrations (number of landslides per km^2) and material properties such as degree of weathering, cementation, fracture spacing and openness, and degree of saturation.

Moderate soil slopes are evaluated by means of a simplified Newmark sliding block analysis (Newmark, 1965) adapted for natural slopes by Jibson (1993).

For evaluating lateral spread hazard, an empirical relationship based on a regression analysis by Bartlett and Youd (1995) is used to establish relative hazard categories.

The results from these three methods of analysis are combined to create an overall relative slope instability hazard map.

Keefer and Wang proposed using slope groupings of <5°, 5°–25°, and >25° to differentiate between gentle, moderate, and steep slopes, respectively, and select the appropriate hazard analysis model. Table 1 summarizes the methods of analysis by slope group.

In the Keefer and Wang methodology, no analytical techniques are applied to mapped landslide areas, but these areas are assigned a "very high" hazard rating.

Application in the Salem Hills

The approach implemented in this study maintains the intent of the grouping into "gentle, moderate, and steep" slopes, but the methodology is slightly modified. Changes for the Salem study include the following:

1. A 6-percent (=3.4°) slope value is used to distinguish between "gentle" and "moderate" slope groups, rather than the 5° (=8.75 percent) break used by Keefer and Wang (1997). The 6-percent value corresponds to the maximum slope used in the regression analysis performed by Bartlett and Youd (1995).
2. The 6-percent slope value does not function as a strict cutoff between the Bartlett and Youd and simplified Newmark analyses. Lateral spread hazards may be significant on steeper slopes, particularly along cut banks in river and stream channels. Therefore, lateral spread hazard ratings are assigned to all susceptible sedimentary deposits, including those with calculated slopes of >6 percent.
3. The simplified Newmark analysis is used to evaluate all soil deposits, including some sites with slopes of <6 percent and some sites with slopes of >25°.
4. Steep-slope cutoff values are incorporated in the simplified Newmark analysis to ensure reasonably conservative hazard ratings in steep terrain.
5. Mapped preexisting landslide areas are assigned reduced residual strength values and are then analyzed with the simplified Newmark method. Large portions of the northern and western flanks of the Salem Hills have experienced movement in the past.

Table 1. Summary of hazard analysis methodology by slope group (adapted from Keefer and Wang (1997)

	Gentle Slopes	Moderate Slopes	Steep Slopes
Typical materials	Loosely-consolidated sediments	Semi-consolidated soils	Rock
Dominant hazard	Liquefaction-induced lateral spread	Soil slides	Rock falls, rock slides and debris slides
Analysis method based on:	Regression analysis by Bartlett and Youd (1995)	Simplified Newmark Sliding Block analysis adapted by Jibson (1993)	Decision tree analysis by Keefer (1993)

Grouping these regions into a uniform high-hazard category does not provide information on relative hazards within these extensive zones and would limit the usefulness of the final hazard map for planning and other uses. Incorporating a strength reduction factor and performing the simplified Newmark method allows the inclusion of other parameters, such as slope and material property variations, and the differentiation of the relative hazards within these important zones.

These modifications result in dual hazard analyses for some slopes, and as a result there is a less obvious differentiation between the three modes of slope failure being modeled. These changes, however, expand the applicability of the methodology and ensure that each area is analyzed for all potential hazards that may be relevant. Figure 1 presents a schematic flow chart of the Keefer and Wang methodology as modified for this study.

Four general steps are designated on the flow chart. The first step outlined is to select the applicable regions for each hazard type (lateral spread, soil slide, and rock slope). This step involves a consideration of the types of materials that are susceptible to each of the hazard groups. It also requires an evaluation of the best and most appropriate sources of information for each method of analysis.

After gathering the information available for the study area, the next general step is to assign the corresponding input parameters for each of the three analytical techniques and perform the analyses. This is the most time consuming and difficult portion of the method and depends greatly on the nature and resolution of the data available within a given study region. For this study, a lateral spread analysis using equations developed by Bartlett and Youd (1995) is performed for all Quaternary sedimentary deposits delineated on a surface geologic map. The soil slide analysis, based on a simplified Newmark analysis (Jibson, 1993), is performed for all soil units contained in databases obtained from the Natural Resource Conservation Service (NRCS). The rock slope analysis, based on a decision tree developed by Keefer (Keefer, 1993), is performed for all bedrock units on the geologic map with calculated slopes >25°.

The final steps outlined on the flow chart include translating the outputs from each analysis into relative hazard ratings, then combining the results to generate an overall hazard map. These steps require the application of good professional judgement and depend to some extent on the particulars of the region being analyzed. For this study, the three hazard types are first evaluated as separate data layers, then combined to create an overall map of earthquake-induced slope instability.

STUDY REGION

The size of the study region is approximately 13.5 km (8.4 mi) north/south by 12.3 km (7.6 mi) east/west. This region includes the southwest portion of the Salem urban growth boundary. Figure 2 is a map showing the location of the study area, and Figure 3 shows some of the local political boundaries. The Willamette River divides Polk County on the west from Marion County on the east. The

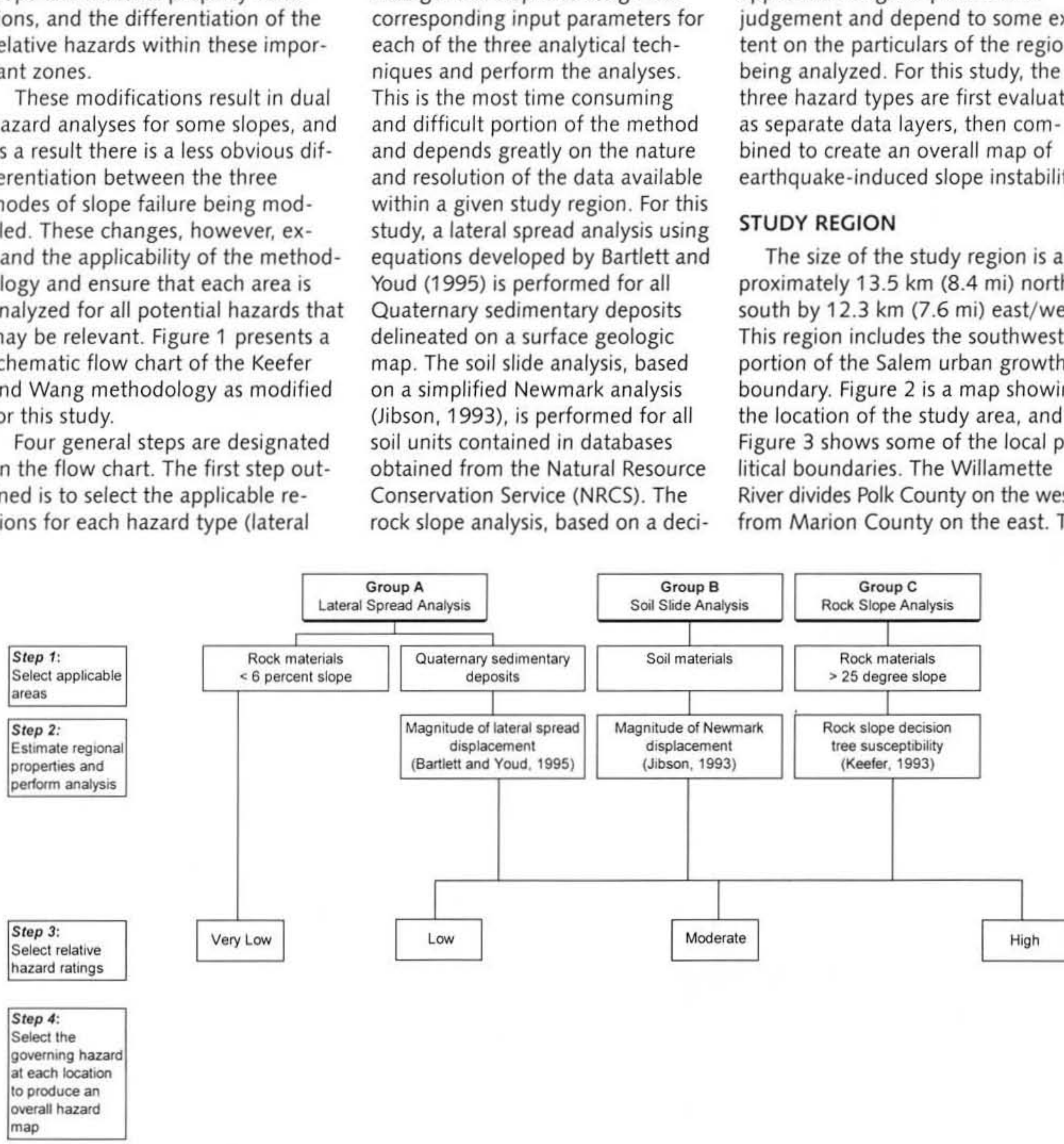


Figure 1. Flow chart showing method of hazard ratings as modified from Keefer and Wang (1997).

topography is predominately flat in the low-lying alluvial plains in the western portion of the study area, with moderate-to-steep slopes in the Salem Hills area to the east. Elevations range from approximately 38 m (125 ft) along the banks of the Willamette River to 345 m (1,130 ft) in the Salem Hills.

Figure 2. Vicinity map showing location of Salem Hills study area.

Extensive portions of the west and south sides of the Salem Hills are mapped as "landslide topography" by Bela (1981). The landslide terrain is distinguished by weathered headscarps, hummocky topography, mixed geologic materials, translated blocks of bedrock, interspersed sag ponds, and complex drainage patterns. The upslope topography of the eastern portion of the study area is marked by more regular topography and drainage patterns.

Active seismic setting

The Willamette Valley is located approximately 150 km inland from the Cascadia subduction zone, a convergent plate boundary where the Juan de Fuca plate is being subducted beneath the North American plate (Figure 4). Similar environments exist off the coasts of Japan, Mexico, Alaska, and Chile, where the largest earthquakes have occurred in recorded history. Three potential earthquake sources are associated with colliding tectonic plates: subduction zone, intraplate, and crustal events. Subduction zone earthquakes occur along the interface between the overriding North American plate and the subducting Juan de Fuca plate. Deep events that occur within the subducting Juan de Fuca slab are referred to as intraplate events. Intraplate events are associated with internal deformation and volume changes due to high temperature and pressure gradients within the earth's crust. The third potential source for earthquakes in the Pacific Northwest is associated with deformation within the overriding North American plate. These events, referred to as crustal earthquakes, occur at shallower depths (typically 10 to 20 km) and are usually associated with fault zones within the crust.

In the Pacific Northwest, as in other similar settings, a great deal of uncertainty limits estimating the size and location of future earthquakes, because the events are infrequent and the mechanisms are not fully understood. Using the best available methods, this study includes estimates of probable magnitude (M) and source-to-site distance (R) to evaluate subduction, intraplate, and crustal sources that could affect the study area.

SOURCE DATA AND ANALYSIS

The Salem Hills study area was selected, in part, because of the range of available and usable geologic, topographic, and geotechnical data. In preparation for and throughout the analysis, a number of data sources

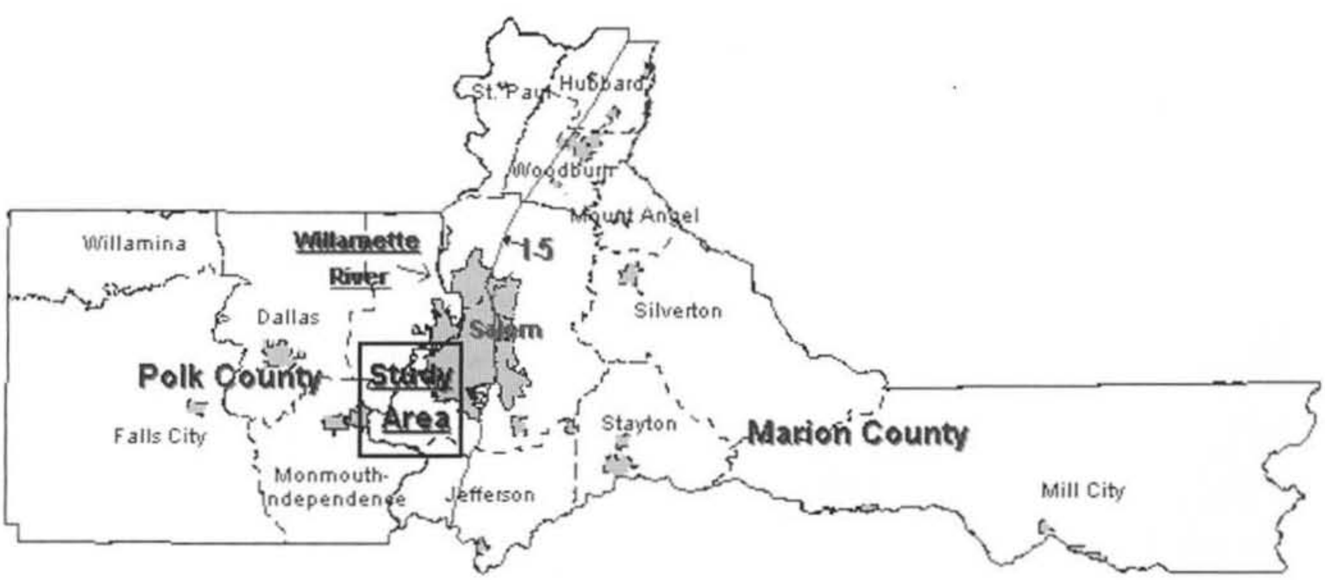


Figure 3. Outline of local political boundaries for the Salem Hills study area.

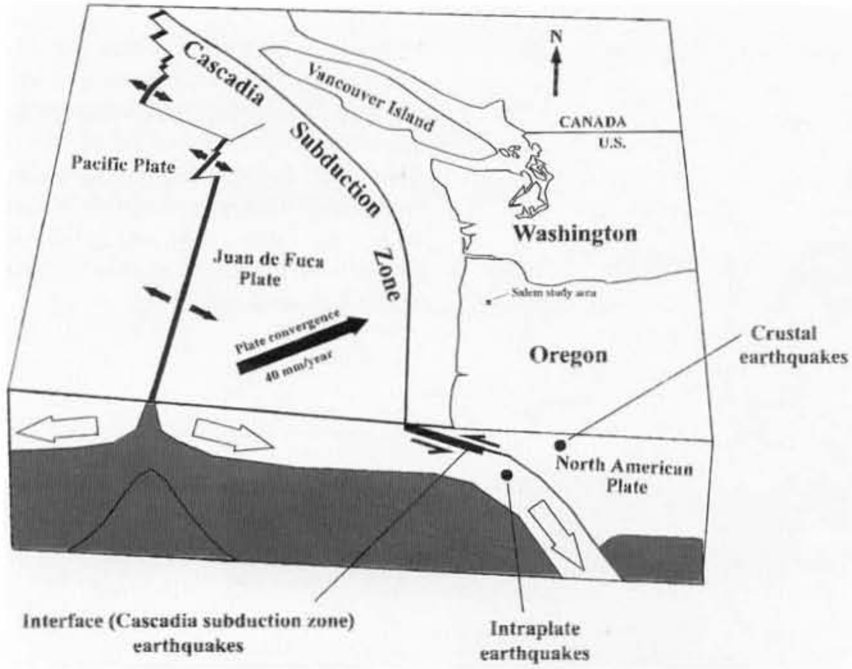


Figure 4: Schematic of the Cascadia subduction zone showing typical locations for the three types of earthquake sources in the Pacific Northwest.

was utilized. These are summarized below, organized by subject. Solid bullets (•) indicate that information from these sources was either available in digital form or was converted to digital form.

Topographic data

- ○ 1:24,000-scale USGS 7.5-minute topographic map series (10-ft contour interval)
- • DOGAMI 10-m Digital Elevation Model (DEM[1])
- • USGS 30-m DEMs

Geology/soils

- • 1:24,000-scale DOGAMI geologic map GMS–18
- ○ Geologic information in Burns and others (1992), McDowell (1991), Crenna and others (1994), and Wang and Leonard (1996)
- • USDA Soil Conservation Service [now Natural Resource Conservation Service] map of Polk County (Knezevich, 1982)
- • USDA Soil Conservation Service map of Marion County (Williams, 1972)
- • Oregon Water Resources Department water-well database
- ○ Borehole and laboratory data collected by DOGAMI

Other sources

- ○ U.S. Army Corps of Engineers Color Infrared (CIR) photographs, scale 1:30,000, taken September 11, 1979
- ○ Black-and-white aerial photographs, scale 1:48,000, taken April 6, 1986
- ○ Geotechnical consultant reports collected by DOGAMI

For this project, the Keefer and Wang (1997) methodology, modified as described above, was implemented mainly with the GIS application MapInfo. GIS applications are specifically designed for working with geographic databases and manipulating spatial data. With the GIS application, various layers of information can be overlaid, combined, and analyzed accurately and efficiently. The combination of spatial data, databases, and analytical tools allows for convenient updating and modifying of spatial databases within one environment.

Several other applications were used in conjunction with MapInfo, including Vertical Mapper, 3D Mapps, ArcView, and IDRISI (Eastman, 1990,1993).

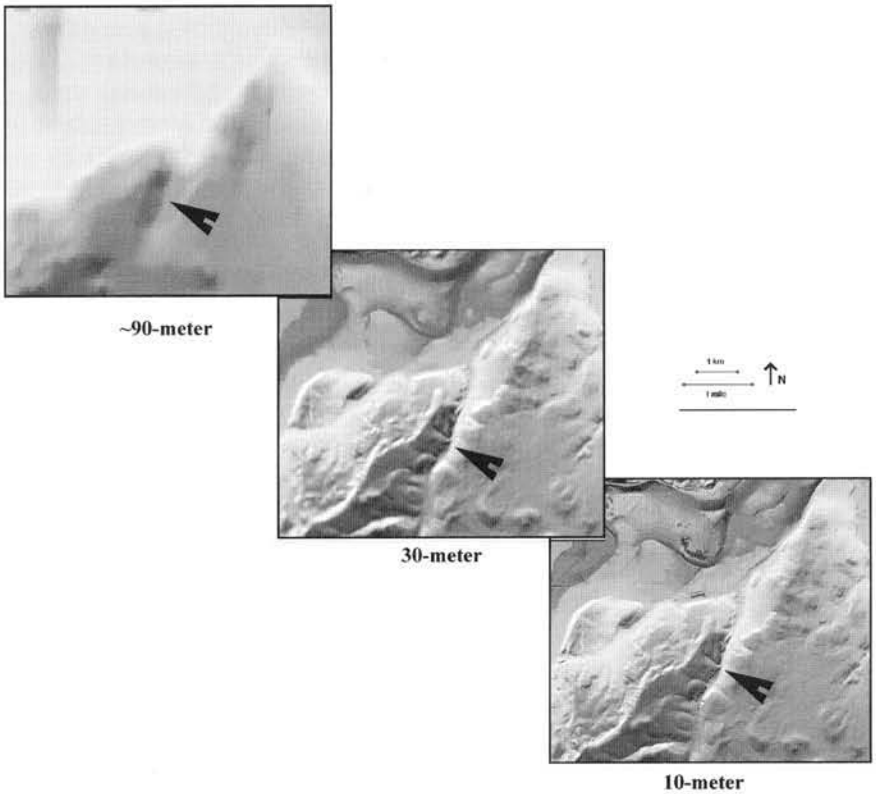
For working with digital spatial information within a GIS, resolution of the data is an important consideration. For the topographic data, DEM with a 10-m grid spacing was used. An illustration of the significance of resolution is shown in Figure 5, where 10-m, 30-m, and approximately 90-m DEMs of the same area are shown side by side. A superimposed arrow points out a southwest-northeast-trending drainage ditch that is visible in the 10-m DEM, but is difficult to distinguish in the 90-m elevation file due to the larger sample spacing.

While the 90-m and 30-m DEMs are USGS products that have been produced for most of the United States, 10-m DEMs are not as widely available. For the Salem study area, DOGAMI funded the creation of a 10-m DEM from the 10-ft contour interval topographic quadrangles of the USGS. A shaded-relief map derived from the DOGAMI DEM is shown in Figure 6.

With the 10-m DEM as basis, the GIS program Vertical Mapper was used for the generation of a slope map (Figure 7). The calculated slope values are stored at the same grid points as the original DEM. The slope map, then, served as the database used for reporting hazard values. It was overlaid on both the geology and soils map layers, and the properties associated with each were assigned to the slope map grid points. A schematic of the GIS overlay operation to create a single database with slope, geology, and soils data stored at grid points is shown in Figure 8. The subsequent hazard analyses outlined in the following sections were performed on this combined data file, with values stored at a 10-m grid spacing throughout the study area.

(Continued on page 62)

[1] A DEM is a regularly spaced series of points (a grid) with an elevation value and geographic coordinates (e.g., latitude, longitude) stored for each point. Grid spacing is the distance between the points.

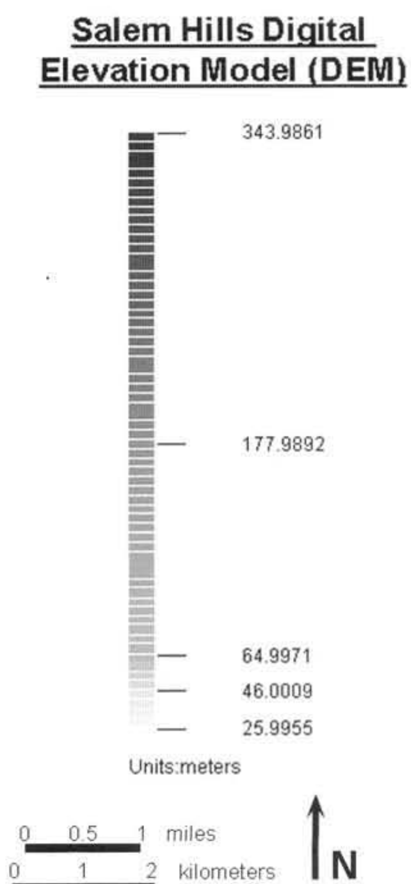


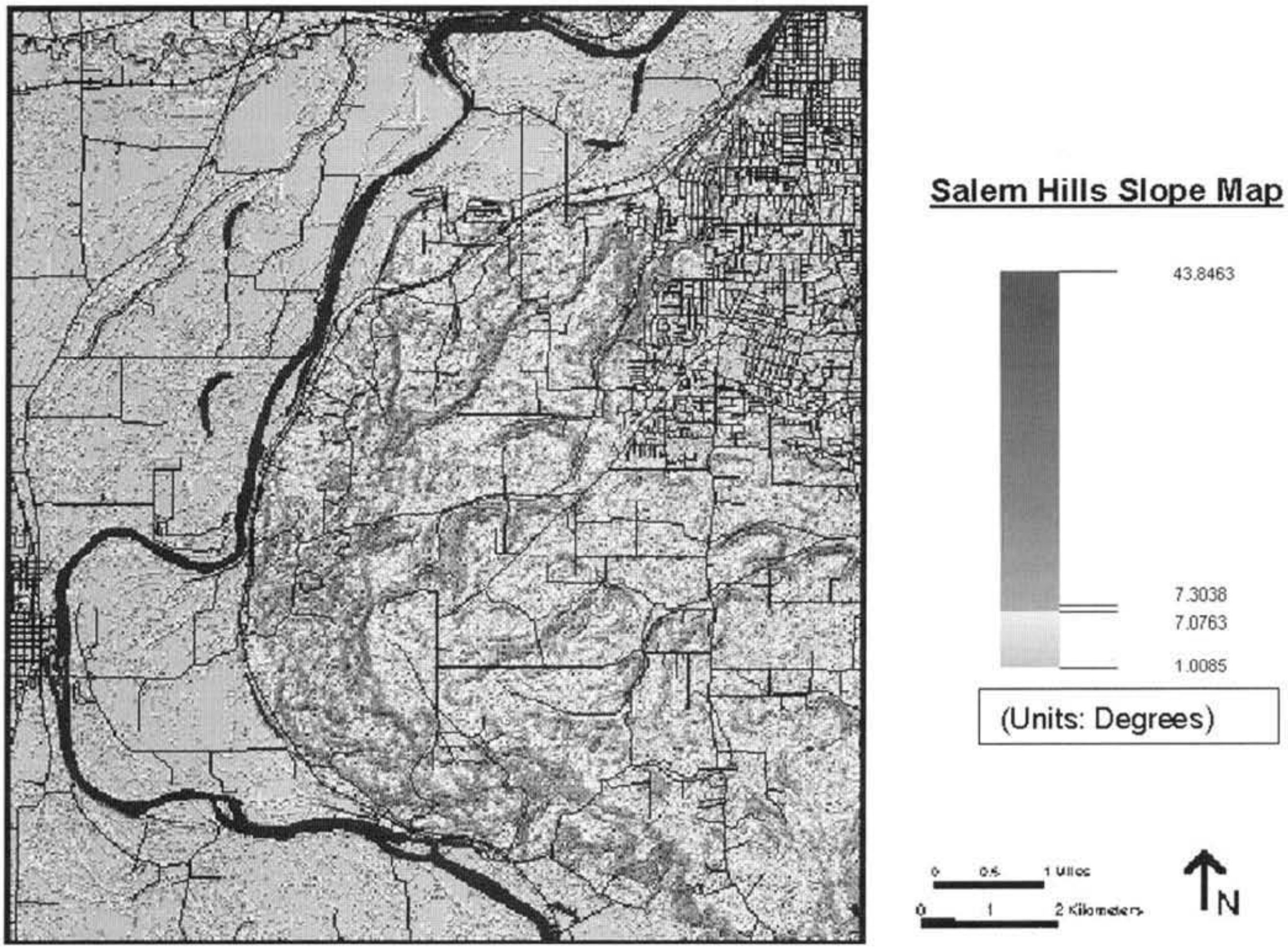
⇐ Left:

Figure 5: Resolution comparison between a USGS 1:250,000-scale (~90-meter grid spacing), USGS 1:24,000-scale (30-M=meter) and the 10-meter DEM used for the Salem Hills study. The arrows mark a drainage ditch that stands out in the 10- and 30-meter DEMS but is barely visible in the 1:250,000-scale USGS file.

⇓ Below:

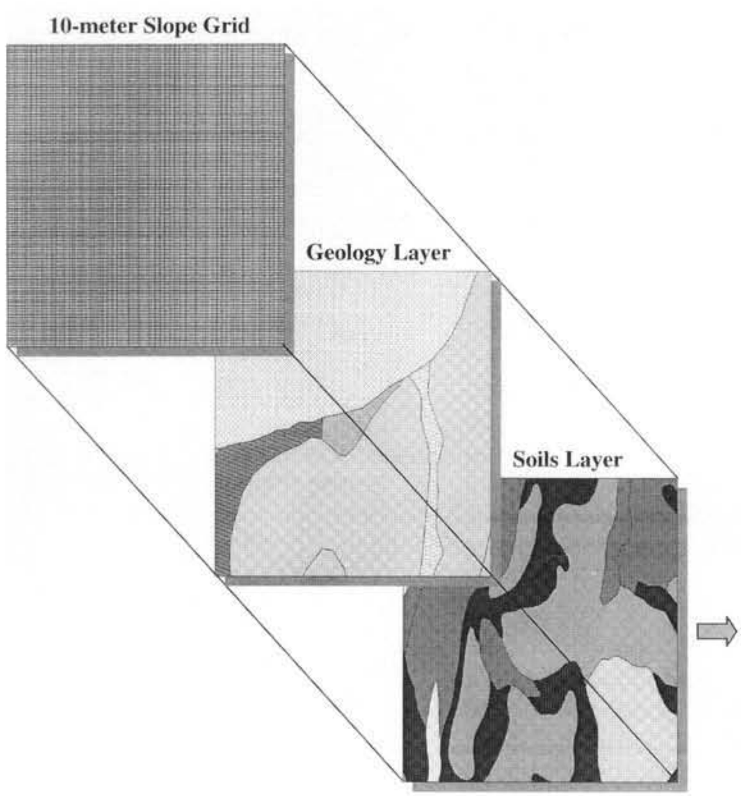
Figure 6: Shaded relief map from the 10-meter DEM used for the Salem Hills study area.





⇑ Above:

Figure 7: Slope map for the Salem Hills study area.



⇐ Left:

Figure 8: Schematic of the GIS overlay operation to create a single database with slope geology and soils data stored at grid points with 10-meter spacing.

Database with Slope and Material Properties

Global_ID	Slope_deg	Geo_Unit	Geo_Modifier	Soil_Unit	Total_Stress	Effective_Stress	Cohesion	Phi_Angle
1	2.5333	Qtm	LS_topo	21	46.3324	20.9167	22.5036	0
2	4.6442	Qtm		20	51.053	24.8897	28.728	0
3	2.2225	Qtm		25	48.0938	24.1731	22.5036	0
4	3.4444	Qtm		77A	48.19	28.7544	28.728	0
5	1.3342	Qtm		14	48.2498	48.2498	28.728	0
6	2.6528	Qtm	LS_topo	20	51.053	24.8897	28.728	0
7	3.6643	Qtm	LS_topo	33	48.8143	25.4412	22.5036	0
8	2.8736	Qtm		20	51.053	24.8897	28.728	0
9	1.6778	Qtm		77A	48.19	28.7544	28.728	0
10	1.9962	Qtm		45	47.5783	47.5783	28.728	0
11	2.0023	Qtm		20	51.053	24.8897	28.728	0
12	2.4567	Qtm	LS_topo	77A	48.19	28.7544	28.728	0
13	2.8892	Qtm		20	51.053	24.8897	28.728	0
14	3.0356	Qtm		20	51.053	24.8897	28.728	0
15	3.6723	Qtm		3	47.3416	23.4209	28.728	0
16	3.9818	Qtm		3	47.3416	23.4209	28.728	0
17	4.0561	Qtm		20	51.053	24.8897	28.728	0
18	3.8714	Qtm		3	47.3416	23.4209	28.728	0
19	3.5912	Qtm		20	51.053	24.8897	28.728	0

(Continued from page 59)

A more detailed discussion of analyses performed and equations used for the analyses of lateral spread, soil slide, and rock slope is found in the respective sections of DOGAMI Special Paper 30 (Hofmeister, 1999).

SUMMARY OF RESULTS

The relative hazard map of earthquake-induced slope instability of the Salem Hills vicinity (shown in Figure 9) is the combination of the lateral spread, soil slide, and steep slope analysis maps. The overall map delineates hazard zones, using a simple, relative scale from "Very Low" to "High." The hazard ratings in the Salem Hills portion of the study area are governed primarily by the soil slide and the rock slope susceptibility ratings. For the more gently sloping alluvial deposits in the low-lying areas, the hazard ratings primarily reflect the lateral spread hazard ratings.

The relative nature of the hazard ratings needs to be emphasized. Developing the scale of hazard zones includes using potential earthquake scenarios and includes a number of regional assumptions. The extent and severity of slope instability that occurs during an actual earthquake depends on the size and location of the event. A hazard rating of "high" does not necessarily mean that a slope will fail in any earthquake, and a rating of "very low" does not mean that there is no potential for movement. In a large earthquake event, there may, in fact, be instability in zones of moderate, low, and very low hazard as well as in a high hazard zone. In small earthquakes, only slight damage may occur even in zones of high hazard. In general, however, one would expect a higher percentage of earthquake-induced ground failures in "high" zones than in the "moderate," "low" and "very low" zones in any given earthquake event.

While a relative hazard map cannot serve as a replacement for site-specific studies in critical areas, it can, and should, serve as a useful tool for estimating the regional impact of future earthquake events. Creation of a regional hazard map is an initial step, which ideally is followed by hazard mitigation programs that focus efforts on the higher risk areas. Realistic evaluations of relative hazards are vital for planning and development, for emergency response management, as inputs for damage and loss estimations, and in making informed land use decisions. Potential users may include public policy makers, land use planners, civil engineers, developers, insurance adjusters, public safety officials, home owners, and home buyers, to name a few.

The Salem area is growing at a rapid rate; some predict it may soon surpass Eugene to become Oregon's second-most-populated urban area. In recent years, residential and commercial development has steadily expanded southward, and this study covers an area that is likely to experience increased development in the near future. This map is intended to be used in conjunction with other available resources to make informed decisions regarding regional development as well as retrofit or other mitigation measures to limit loss of life and property damage in future earthquake events.

The Keefer and Wang (1997) methodology, slightly modified for this study, proves to be one of the most promising approaches available for the accurate mapping of earthquake-induced slope instability hazards within reasonable time and cost limits. The successful completion of this study advances the ongoing efforts by DOGAMI to map hazards in major population areas statewide. A mapping project is now underway in Klamath Falls, and future studies are expected in Klamath and Tillamook Counties.

ACKNOWLEDGMENTS

I have benefited from the expertise, advice and encouragement of many people. I offer special thanks to the entire staff at DOGAMI for generously providing expertise and resources, particularly to Yumei Wang and Gerald Black, who made this project happen. I am grateful to Dale Carlson and the rest of the Valle Scholarship personnel for their generous financial support of the original study. I am also very grateful to University of Washington Professors Pedro Arduino, Robert Holtz, Steven Kramer, and Teresa Taylor for their valuable insight and mentorship throughout my graduate studies, and to Stanford Professors Ronaldo Borja, Anne Kiremidjian, Gordon Brown, and David Pollard for laying the groundwork in my undergraduate studies. I would also like to thank David Keefer of the USGS, Andrew Harvey of Squier Associates, George Freitag of Geotechnical Resources, Inc., and William Leonard of AGRA Earth & Environmental, each of whom provided valuable technical insight. I appreciate the critical data assistance I received from Brandi Baird of the USDA Natural Resource Conservation Service, Loren Mell of Group Health Cooperative, Tim Spear of the Oregon Department of Corrections, and Stephanie King of the Blume Earthquake Engineering Center. Finally, I wish to thank Robert Murray for his help with field outcrop mapping and David Keefer for reviewing this paper.

REFERENCES CITED

Bartlett, S.F., and Youd, T.L., 1995, Empirical prediction of liquefaction-induced lateral spread: Journal of Geotechnical Engineering, v. 121, no. 4, p. 316–329.

Bela, J.L., 1981, Geology of the Rickreall, Salem West, Monmouth, and Sidney 7½' quadrangles, Marion, Polk, and Linn Counties, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS–18, 1:24,000.

Black, G.L., Wang, Z., Wiley, T.J., Wang, Y., and Keefer, D.K., 1999, Relative earthquake hazard map of the Eugene-Springfield metropolitan area, Lane County, Oregon: Oregon Department of Geology and Mineral Industries Interpretive Map Series IMS–11, 1:24,000.

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 meet-

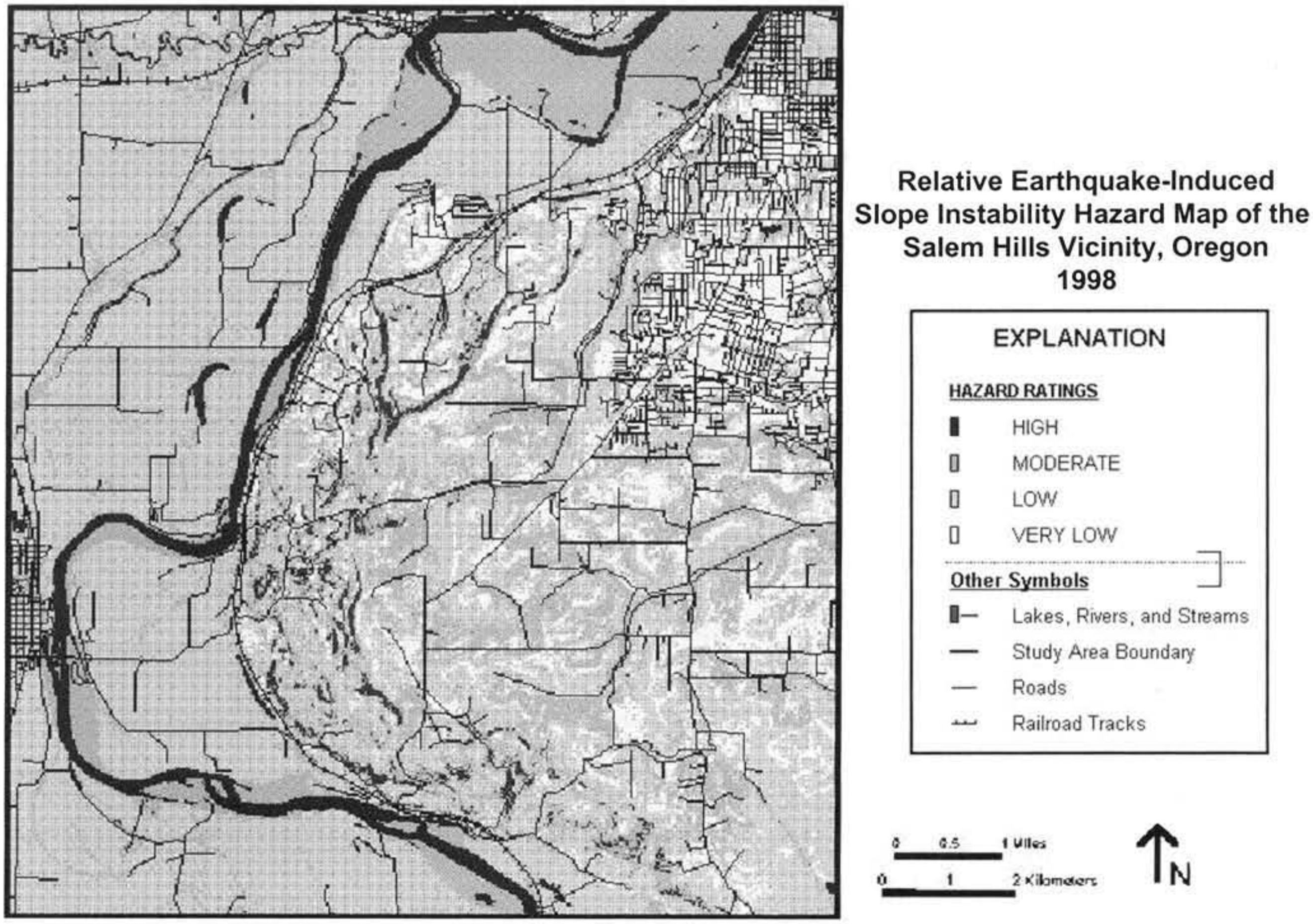


Figure 9: Overall hazard layer for the Salem Hills study area, with gray shades instead of color for ratings in original map.

ing, 35th, Los Angeles, Calif., Proceedings, p. 291–296.

Crenna, P.A., Yeats, R.S., and Levi, S., 1994, Late Cenozoic tectonics and paleogeography of the Salem metropolitan area, central Willamette Valley, Oregon: Oregon Geology, v. 56, no. 6, p. 129–136.

Eastmann, J.R., 1997, IDRISI for Windows Geographic Analysis System. User's guide, version 2.0, January 1997, revision 5, December 1997: Worcester, Mass., Clark University, Clark Labs for Cartographic Technology and Geographic Analysis, var. pag.

Harvey, A. F., and Peterson, G.L., 1998, Water-induced landslide hazards, western portion of the Salem Hills, Marion County, Oregon: Oregon Department of Geology and Mineral Industries Interpretive Map Series IMS–6.

Hofmeister, R.J., 1999, Earthquake-induced slope instability: A relative hazard map for the Salem Hills, Oregon: Oregon Department of Geology and Mineral Industries Special Paper 30.

Jibson, R.W., 1993, Predicting earthquake-induced landslide displacements using Newmark's sliding block analysis: Washington, D.C., National Research Council Transportation Research Record 1411, p. 9–17.

Keefer, D.K., 1984, Landslides caused by earthquakes: Geological Society of America Bulletin, v. 95, no. 4, p. 406–421.

———1993, The susceptibility of rock slopes to earthquake-induced failure: Association of Engineering Geologists Bulletin, v. 30, no. 3, p. 353–361.

Keefer, D.K., and Wang, Y., 1997, A method for predicting slope instability for earthquake hazard maps: Preliminary report, *in* Wang, Y., and Neuendorf, K.K.E., eds., Earthquakes—Converging at Cascadia. Symposium proceedings: Association of Engineering Geologists Special Publication 10/Oregon Department of Geology and Mineral Industries Special Paper 28, p. 39–52.

Knezevich, C.A., 1982, Soil survey of Polk County, Oregon: USDA Soil Conservation Service, in cooperation with Oregon Agricultural Experiment Station, 250 p.

McDowell, P.F., 1991, Quaternary stratigraphy and geomorphic surfaces of the Willamette Valley, Oregon, *in* Morrison, R.B., ed., Quaternary nonglacial geology: Conterminous U.S.: Boulder, Colo., Geological Society of America Decade of North American Geology, Geology of North America, v. K-2, p. 156–164.

Newmark, N.M., 1865, Effects of earthquakes on dams and embankments: Géotechnique, v. 15, no. 2, p. 139–159.

Wang, Y., Keefer, D.K., and Wang, Z., 1998, Seismic hazard mapping in Eugene-Springfield, Oregon: Oregon Geology, v. 60, no. 2, p. 31–41.

Wang, Y., and Leonard, W.J., 1996, Relative earthquake hazard maps of the Salem East and Salem West quadrangles, Marion and Polk Counties, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS–105, 10 p., 4 maps, scale 1:24,000.

Williams, L.H., 1972, Soil survey of the Marion County area, Oregon: USDA Soil Conservation Service, in cooperation with Oregon Agricultural Experiment Station, 132 p. □

Field guide to the Rattlesnake Tuff and High Lava Plains near Burns, Oregon

by *Martin J. Streck, Department of Geology, Portland State University, Jenda A. Johnson, Hawaii Volcano Observatory, Hawaii National Park, and Anita L. Grunder, Department of Geosciences, Oregon State University*[1]

This field trip guide was prepared for the 1996 meeting of the Geological Society of America, Cordilleran Section, in Portland, Oregon.—*Ed.*

INTRODUCTION TO THE HIGH LAVA PLAINS

The High Lava Plains Province of central and southeastern Oregon lies at the northwestern margin of the Basin and Range Province and extends from the Cascade Range to the east, to merge with the Owyhee Plateau and Snake River Plain (Figure 1). The High Lava Plains are mainly widespread flows of high-alumina olivine tholeiite (HAOT) (Hart and others, 1984), typically a few meters thick, some regionally extensive ash-flow sheets, and locally intercalated silicic tuffaceous sediments. The province is punctuated by rhyolitic and lesser dacitic dome complexes.

Volcanism of the High Lava Plains is strongly bimodal, composed mainly of basalt (48–51 weight percent SiO_2) and high-silica rhyolite (>75 weight percent SiO_2), although individual eruption centers commonly exhibit a range of compositions. Silicic volcanism less than 11 Ma in age is progressively younger to the northwest and mirrors an opposite age progression of silicic volcanism along the Snake River Plain, ending at Yellowstone (Figure 1B) (MacLeod and others, 1976). The average rates of progression along the two trends are similar: ~3–4 cm/year (Armstrong and others, 1975; MacLeod and others, 1976). The High Lava Plains temporal trend complicates a hot-spot interpretation of the Snake River Plain-Yellowstone plateau.

A relationship between the two provinces is reinforced by geomorphic and compositional continuity between the basalt plateaus, persistence of Quaternary basalts along the length of the two provinces, and a continuous, narrow, low-velocity zone in the upper mantle (Dueker and Humphreys, 1990; Hearn and Barazangi, 1991). An important difference between the two is that silicic vol-

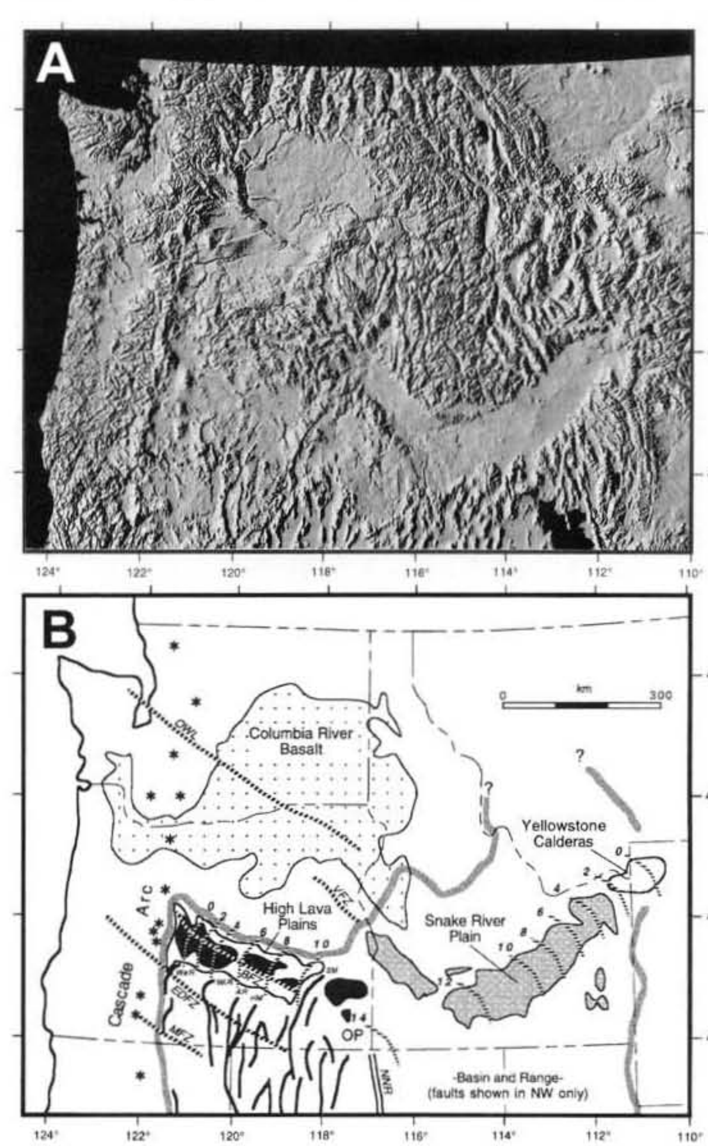


Figure 1. A. Digital topographic image from Pike (1991). B. Geologic features superimposed on area of A. High Lava Plains, Owyhee Plateau (OP), and Snake River Plain define a basalt plateau extending from the Cascades to Yellowstone. Isochrons (in Ma) of silicic age progression are modified from MacLeod and others (1976) and Smith and Braille (1994). Quaternary basalts of Snake River Plain shaded gray, of High Lava Plains and OP black. *=Cascade volcano; NNR=Northern Nevada Rift. Major horst escarpments of the Basin and Range: WaR=Walker Rim, WiR=Winter Rim, AR=Abert Rim, HM=Horse Mountain, SM=Steens Mountain. Fault zones: MFZ=McLaughlin; EDFZ=Eugene-Denio, BFZ= Brothers, VFZ=Vale. OWL=Olympic Wallowa lineament. Thick gray lines indicate limits of topographic expression of the Basin and Range Province.

[1] E-mail addresses:
Martin Streck: StreckM@pdx.edu;
Jenda Johnson: jenda@tako.wr.usgs.gov
Anita Grunder: grundera@geo.orst.edu

canism of the High Lava Plains is about one tenth the volume of that of the Snake River-Yellowstone trend according to the relative volume of ash-flow sheets.

The High Lava Plains are also an important structural boundary. North-northeast-striking Basin-and-Range-style block faults die out northward in southeastern Oregon and intersect steep, northwest-striking faults. The Brothers fault zone is a concentration of such northwest-striking faults. It transects the High Lava Plains obliquely to the trend of the silicic vents. Several parallel fault zones have been identified (Figure 1), but the Brothers fault zone is the only one to have Quaternary volcanic expression. The age of the Brothers fault zone is not known. Faults offset Pleistocene and some Quaternary basalt flows, but alignment of silcic vents suggests an older, subparallel, structural grain. Along the Snake River-Yellowstone trend, episodes of faulting migrate with the advance of volcanism. The regional work to demonstrate such a relationship for the High Lava Plains has not been done, but movement of the Steens Mountain range-front fault is in part synchronous with 11-Ma-old silicic volcanism in the eastern High Lava Plains (Johnson and Deino, 1994).

The Rattlesnake Tuff, defined as the Rattlesnake Ash-Flow Tuff by Walker (1979), is one of the several ash-flow sheets that crop out widely in southeastern Oregon and are part of the High Lava Plains silicic trend. The largest of these tuffs are the Devine Canyon, Prater Creek, and Rattlesnake Tuffs, 9.68 ± 0.03, 8.48 ± 0.05, and 7.05 ± 0.01 Ma, respectively, which have inferred sources in the Harney Basin (eastern High Lava Plains) (Walker, 1970; MacLeod and others, 1976; Streck and Grunder, 1995; Grunder and Deino, unpublished data). Other tuffs have been identified to the west. They appear to be fewer and smaller. No caldera structures have been identified.

REGIONAL TRENDS OF THE HIGH LAVA PLAINS

Age progression

Additional dating of silicic centers of the High Lava Plains bears out the age progression of MacLeod and others (1976) (Figure 2). New $^{40}Ar/^{39}Ar$ ages are typically at the old end of published ranges of ages. We have identified more dacite centers older than the age progression, and Iron Mountain is anomalously young. There is no compelling argument for a change in rate, mainly because the endpoint of the silicic volcanism can be identified at Newberry volcano or at the South Sister volcano in the Cascades. Trends in the age distribution of basalts is less clear. There are basalts both older and younger than the rhyolites all along the High Lava Plains.

Compilation of existing data suggests that mafic volcanism preceeded northwestward-younging silicic volcanism by as much as a million years and that it persisted afterwards. The youngest mafic volcanism may be a continuation or a rejuvenation of magmatism.

Compositional trends

Although most of the rhyolites have over 74 weight percent SiO_2, there is remarkable diversity in composition. Each center has its own characteristics and petrologic history. Strongly peralkaline rhyolites appear to be restricted to the area close to long 120° W. Interestingly, strongly peralkaline rhyolites (pantellerites) occur to the south at Hart Mountain; they are about 26 m.y. old (Mathis, 1993). Within individual centers, compositional variation of the rhyolites is best accounted for by crystal fractionation (MacLean, 1994; Johnson, 1995; Streck and Grunder, 1997). Rhyolites from eastern Harney Basin to Duck Creek Butte (about 11–8 Ma) typically have lower Zr/Nb and Y/Nb and higher Ce/Yb than do rhyolites of western Harney Basin (about 8–5 Ma), except for the highest silica rhyolites in which zircon fractionation has lowered Zr/Nb. Basalts have the same trend, but for the cases studied, rhyolites do not appear to be derived by crystal fractionation from basalt. Instead, it is possible that rhyolites are derived by partial melting of crust that has Zr/Nb imparted by basalt, which in turn varies regionally.

Sparse isotopic data for basalts indicate a westward decrease in $^{87}Sr/^{86}Sr$ across the Harney Basin from values around 0.704 to 0.703 (Carlson and Hart, 1987). Rhyolites have values close to basalts with the exception of the highest silica rhyolite at Duck Creek Butte and the Rattlesnake Tuff, which have slightly elevated values around 0.705, indicating some other crustal influence. Such rhyolites are low in Sr (a few to a few tens of ppm), and so they are sensitive to shifts in $^{87}Sr/^{86}Sr$.

Intermediate-composition rocks are few but ubiquitous. They are derived chiefly by mixing between silicic and mafic melts as in the case of Duck Creek Butte (Johnson, 1995), western Juniper Ridge (MacLean, 1994), the Rattlesnake Tuff (Streck, 1994; Streck and Grunder, 1999) and Newberry volcano (Linneman and Myers, 1990). At Duck Creek Butte, the rate of mixing and eruption exceeded the rate of production of silicic melt and was likely linked to concurrent fault activity along the north end of the Steens escarpment. At eastern Juniper Ridge, intermediates are derived by combined crystal fractionation of basalt and assimilation of silicic melts (MacLean, 1994). Several mafic andesites have, or trend toward, high Fe and P and have extreme trace element enrichments (best exemplified by Paiute Butte). These are most succesfully modeled as derived from mafic magma chambers that were repeatedly recharged and fractionated (Grunder and others, 1995; Streck and Grunder, 1999).

Working model

Our working model proposes that age-progressive silicic volcanism and related basaltic activity of the High Lava Plains represent the westward propagation of Basin and Range ex-

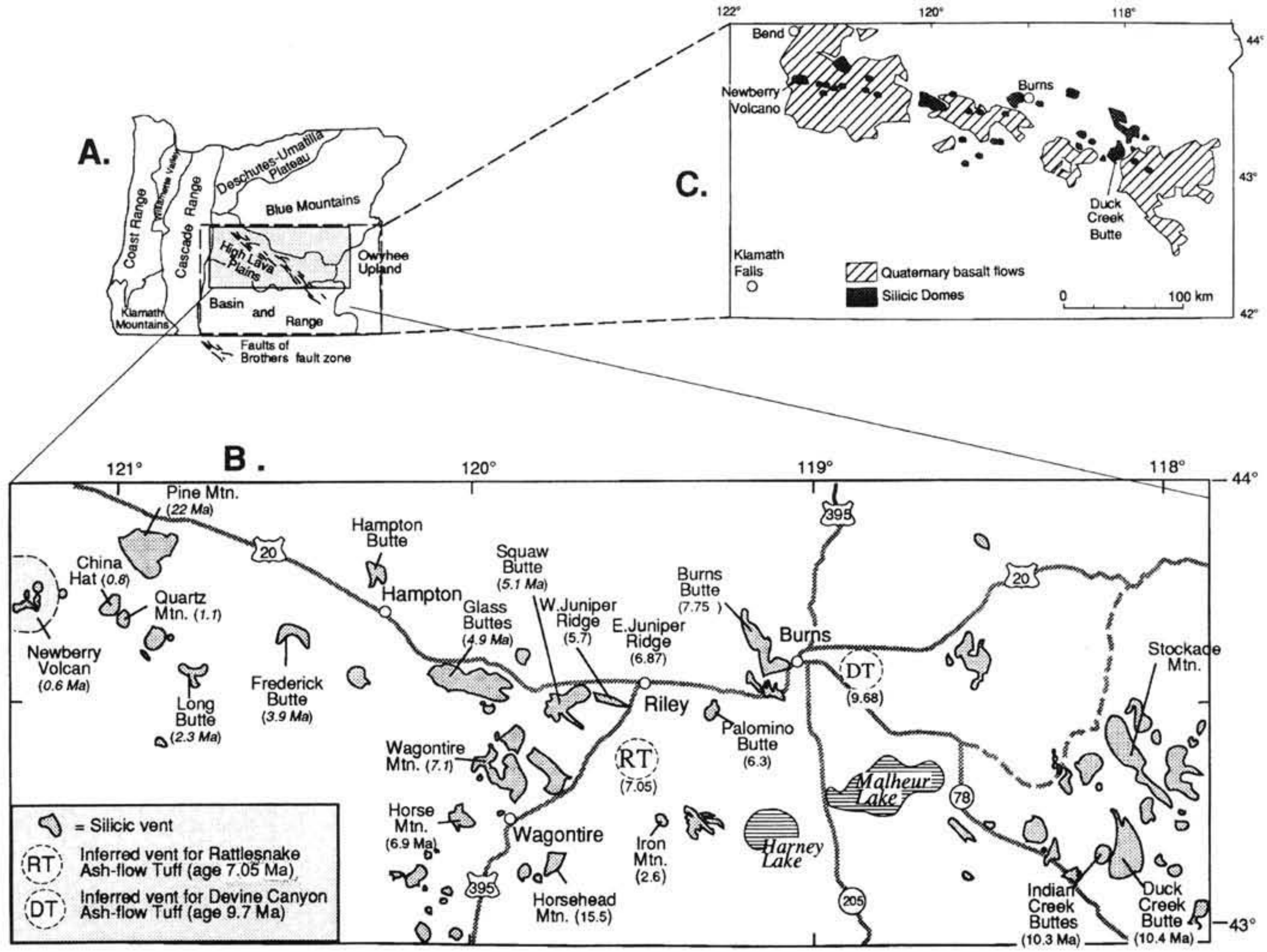


Figure 2. Oregon's High Lava Plains. (A) Physiographic provinces; (B) Age distribution of High Lava Plains silicic vents. Ages from MacLeod and others (1976), Streck and Grunder (1995), and Grunder and Deino, unpublished data. (C) Distribution of Pliocene-Pleistocene primitive olivine basalts.

tension from about 11 Ma to the present. The Quaternary expression of the High Lava Plains we view essentially as a leaky intracontinental transform boundary (Johnson, 1995). The compositional variation of rhyolites and of intermediates is linked to an interplay of mafic input and tectonic (fault) activity. By integrating regional temporal and geographic variations in composition and tying them to fault history where possible, we aim to understand the High Lava Plains Province.

RATTLESNAKE TUFF

The Rattlesnake Tuff is a single cooling unit that was deposited from multiple high-energy ash flows. The tuff covers about 9,000 km^2 (as indicated by isopach map shown in Figure 3) with an estimated tuff volume of 130 km^3. Original coverage was between 30,000 and 40,000 km^2 with reconstructed magma volume of the outflow about 280 km^3 DRE (dense rock equivalent) (Figure 3).[1] Pumice distribution and grading characteristics indicate that the transport medium consisted of highly expanded flows, and the deposition medium consisted of much less expanded flows near the ground.

The tuff was erupted from an area near the center of today's outcrop distribution, as can be inferred from a radial decrease in pumice clast size and general radial decrease of welding and crystallization (see discussion of source area at Stop 3). The size distribution of lithic fragments gives little insight into locating the vent area; the tuff picked up cobbles from the substrate as far as 66 km from the source (Streck and Grunder, 1995).

Vitric welding facies range from nonwelded to densely welded with three intermediate welding degrees: incipiently welded, partially welded with pumice, and partially welded with fiamme. Crystallization facies include the early pervasively devitrified and vapor phase zones, and the later spherulitic and lithophysal zones (Figure 4) (Streck and Grunder,

[1] Added in proof: Newly recognized outcrop of Rattlesnake Tuff~80 km east-northeast from Burns, near the town of Juntura (M.L. Cummings, Portland State University, oral communication, 1999), extends confirmed original coverage eastward (see Figure 7).

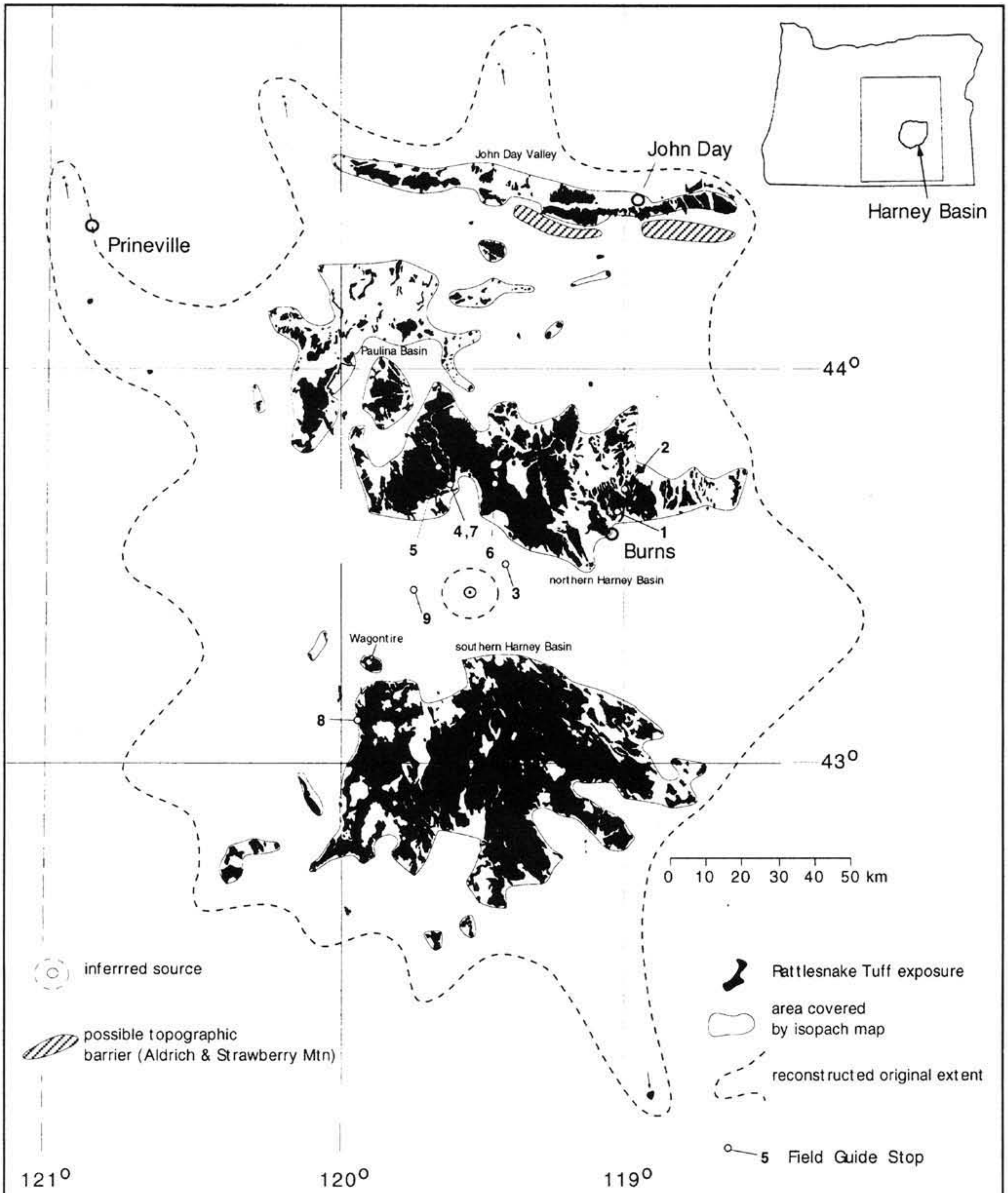


Figure 3. Field trip stops superimposed on outcrop map of Rattlesnake Tuff.

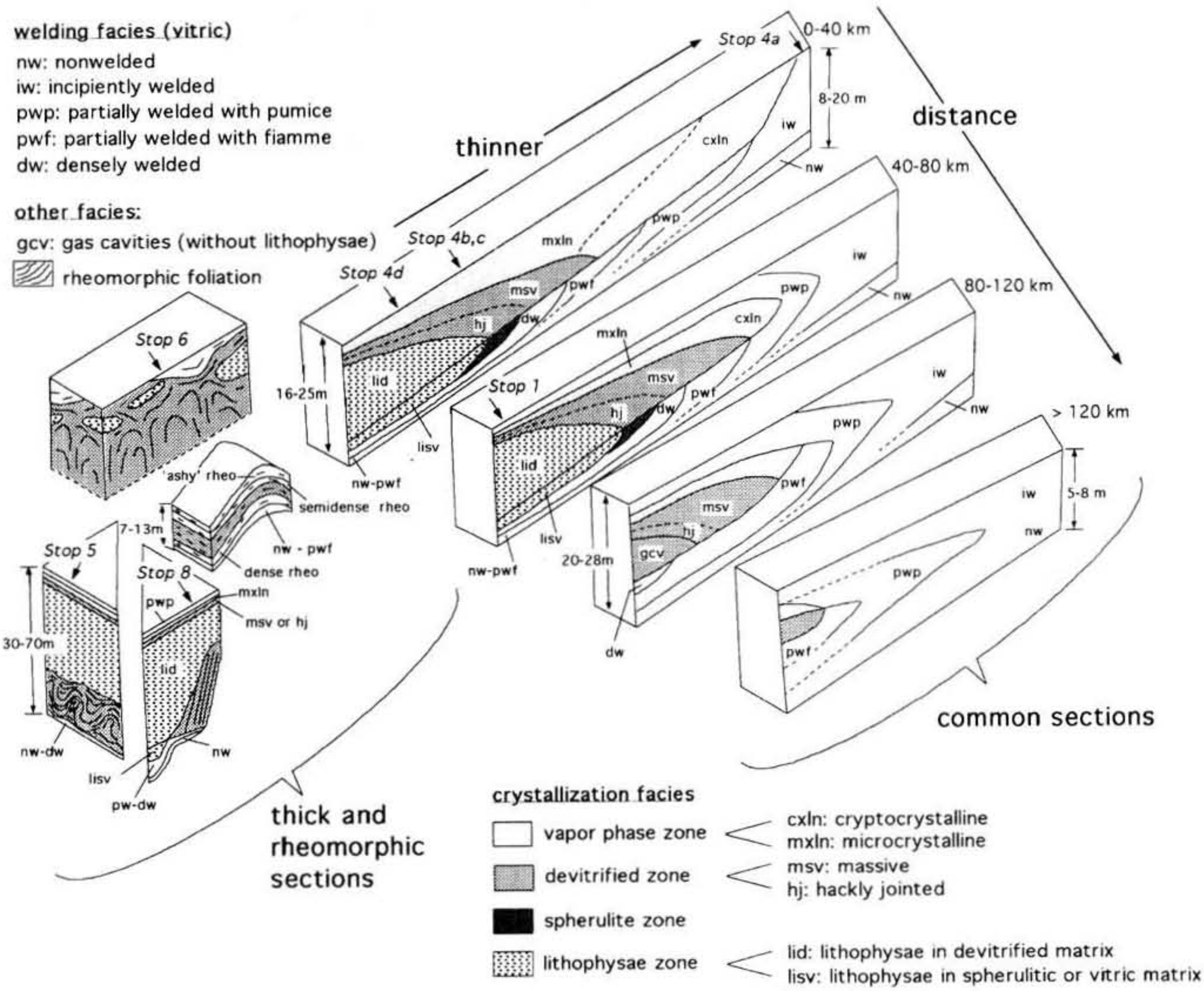


Figure 4. Three-dimensional model representing welding and crystallization facies distribution in the Rattlesnake Tuff showing sections seen at field trip stops (modified from Streck and Grunder, 1995).

1995). All overprint welding. The pervasively devitrified zone is restricted to partially welded with fiamme to densely welded tuff. The vapor phase zone occurs in partially welded tuff with pumice or less welded tuff and is divided into two subzones: (1) cryptocrystalline and (2) microcrystalline facies, distinguishable by the size of crystals. Spherulites occur in densely welded vitric tuff, and lithophysae overprint vitric and all other crystallization facies, except possibly vapor-phase tuff. Vitric to devitrified rheomorphic tuff occurs within 50 km of the source area and formed mainly during or after welding but before devitrification.

Strong local variations over 1–3 km include the complete spectrum of regional variations exhibited over tens to hundreds of kilometers. The drastic local changes suggest that facies variations result from subtle differences in emplacement, such as thickness or accumulation rate, which in turn lead to slightly different residence times above, at, or below threshold conditions (high temperature, volatiles) that are required for welding and crystallization.

The Rattlesnake Tuff contains white, gray, black, and mingled (banded) pumices and white and gray shards. White and gray pumices and shards are high-silica rhyolite and black pumices are slightly alkalic dacite (Streck and Grunder, 1997, 1999). The compositions of nonbanded rhyolite pumices define five compositional clusters called Groups *A, B, C, D,* and *E,* from most to least evolved. Outcrop proportions vary from subequal proportions of white, gray, and mingled pumice to almost exclusively white. In general, the proportion of white pumice and shards is greatest at the base and in distal outcrops, and the abundances of gray and black pumice and gray shards increase upward within the first 1–2 m. Pumice clasts range from 1 to 90 cm; the largest pumices at any given location are always of the white and gray type. Average sizes of the five largest pumice clasts at many localities show an exponential decrease in size away from the inferred source. No vertical grading of pumices was observed, except for lack of largest pumice sizes near the base.

Group ***A*** and ***B*** pumices are white and ***A*** is essentially aphyric. Pumices of the other groups range from beige to gray and are sparsely phyric. Phases observed in all phyric pumices are alkali feldspar, Fe-rich clinopyroxene, titanomagnetite, quartz and accessory zircon, and apatite. Additional minerals that occur in some pumices are fayalite, biotite, pyrrhotite, and chevkinite. Feldspars change from anorthoclase to sodic sanidine with differentiation, pyroxenes become more magnesian (from Fe-hedenbergite to Fe-augite) and titanomagnetites more Fe rich. Zircon saturation temperatures indicate a pre-eruptive thermal gradient from 880° to 795°C from ***E*** to ***A*** (Streck and Grunder, 1997).

SUMMMARY OF FIELD TRIP STOPS

The route of this field trip leads north from Burns to look at (1) gradation within the Rattlesnake Tuff (RST) as well as the contact with the underlying tuffaceous sedimentary rocks; and (2) the contact between the three major Harney Basin ash-flow tuffs exposed in the stream-cut canyon of Poison Creek. The trip then returns south through Burns and west to a panoramic overview of western Harney Basin. This is followed by several stops to see facies variations and rheomorphic structures within the RST in the Silver Creek area, north of Riley. Finally, the trip heads south from Riley to look at a thick cliff of rheomorphic RST overlying basalt and older tuff and ends with the crossing through Juniper Ridge, one of the silicic dome complexes that are so characteristic of the High Lava Plains. Also, near Juniper Ridge, one of the few but ubiquitous intermediate magma centers will be crossed. All travel is on paved roads or maintained dirt roads readily traversed by passenger cars. Mileages are not cumulative but begin from established map locales. All stops can be comfortably visited during a two-day trip with Burns as place of departure and overnight stay. Figure 3 shows the geographic locations of field trip stops in relation to all Rattlesnake outcrops, and Figure 4 shows the approximate lithologic position of field trips stops in relation to the facies model of the Rattlesnake Tuff.

Day 1

DIRECTIONS TO STOPS 1 AND 2

Begin from junction of Highways 395/20, and 78 in downtown Burns. Drive north on Hwy 395 about 6.5 mi for Stop 1. Road bends left as it enters mouth of Devine Canyon. Park in turn-out on right side of road across from rimrock cliffs seen directly on left side of road. For Stop 2, continue 2–3 mi north on Hwy 395 into Devine Canyon drainage and stop at turn-out on west (left) side of road at prominent confluence with Poison Creek, near milepost 61.

STOP 1. TYPE LOCALITY OF RATTLESNAKE TUFF

The Rattlesnake Ash-Flow Tuff (Walker, 1979) is here referred to as Rattlesnake Tuff (RST), named for the original type locality on Rattlesnake Creek (John Day valley), ~100 km north from here. Total thickness of the tuff at Stop 1 is 22 m. It is a highly zoned section (Figure 5).

The underlying pale-orange to buff-colored, fine-grained, poorly consolidated tuffaceous sedimentary sequence is a ubiquitous slope-forming unit in Harney Basin.

The lowermost, white, 1-m-thick, finely laminated fallout deposit consists almost entirely of clear glass shards and was likely a precursor to the eruption(s) that formed the RST.

This is conformably overlain by 0.5 m of nonwelded vitric RST with "mixed" shard matrix (clear and brown rhyolitic glass shards) and 7–10 percent white pumice to 2 cm in diameter. In some places, the transition from the lower laminated deposits, representing likely surge deposits, to the nonwelded tuff is gradational, and the transition may be overemphasized by the change from white to mixed shard matrix. Bubble wall shards can be seen in both nonwelded and surge deposits.

The nonwelded zone grades abruptly to 0.5 m of partially welded vitric tuff, overlain by 1 m of black vitrophyre.

The >19-m-thick, capping, cliff-forming unit is entirely lithophysal tuff. The lower 4 m of this section are divided into a perlitic black matrix base and an upper part with spherulitic matrix. The upper 15 m are entirely lithophysae in devitrified matrix and are capped by float of pervasively devitrified tuff. Just across the highway (east) from this location, float on top of cliff-forming RST includes upper vitric, partially welded tuff, indicating proximity to the inferred original top of the unit.

STOP 2. HARNEY BASIN TUFFS

This stop shows excellent exposures of Harney Basin tuff stratigraphy (Figures 6, 7). Lowermost cliff is Devine Canyon (Ash-flow) Tuff (DCT) separated from the overlying Prater Creek (Ash-flow) Tuff (PCT) by poorly exposed tuff and tuffaceous sedimentary rocks. The sequence is capped by the RST. The tuffs are high-silica rhyolites that range from the peralkaline DCT to the peralkaline/metaluminous RST and form important regional stratigraphic and structural markers. The tuffs dip slightly southward to the Harney Basin, and the thickness of intercalated tuffaceous sediments also increases basinward.

Devine Canyon Tuff

The Devine Canyon Tuff is crystal-rich and originally covered more than 18,600 km^2 of southeastern Oregon, with a total volume of approximately

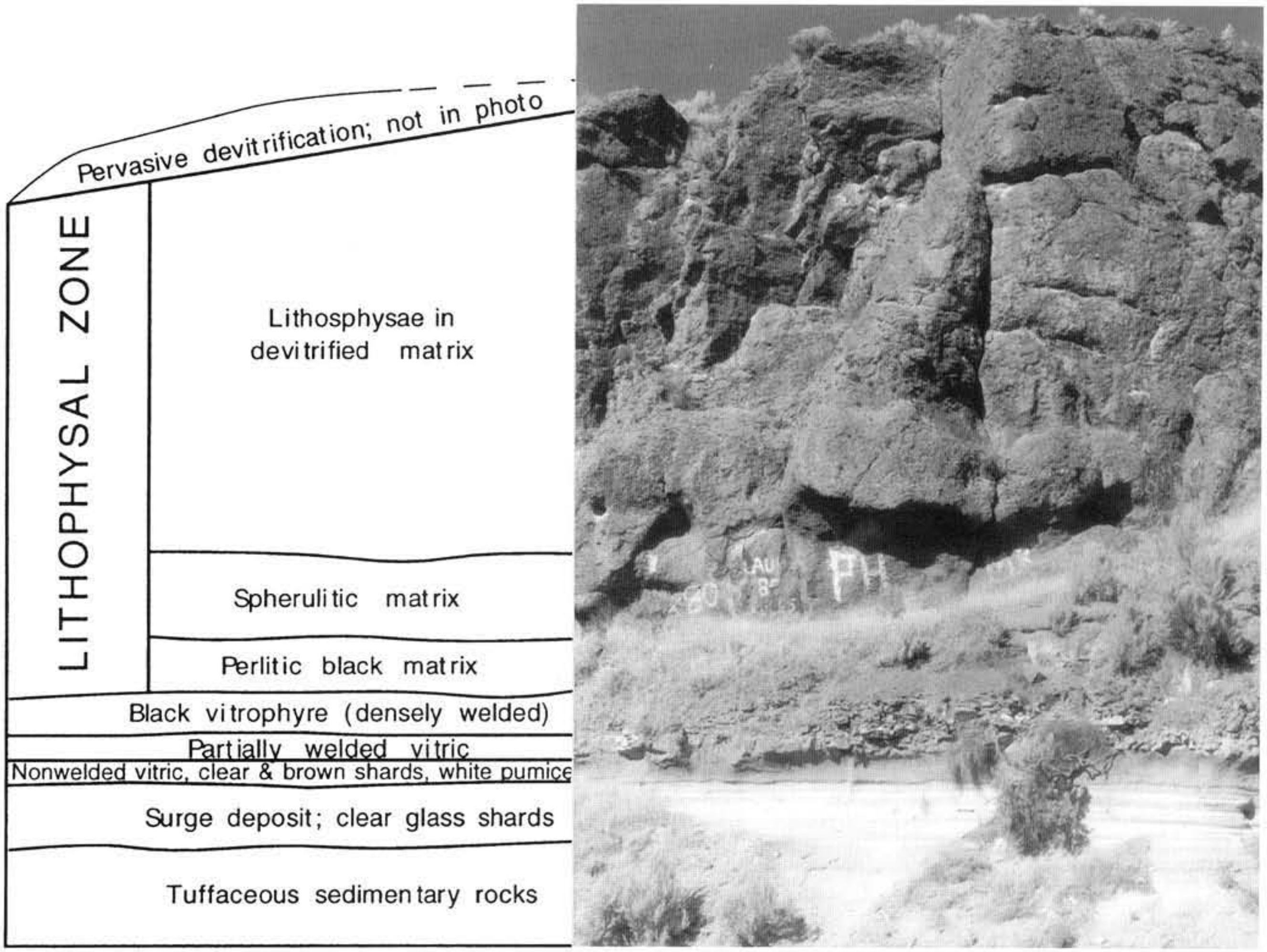


Figure 5. Outcrop photograph and line drawing of zonal variations in tuff at Stop1 on Hwy 395.

195 km^3 (Greene, 1973). It is characterized by 10–30 percent phenocrysts of alkali feldspar and quartz, with sparse clinopyroxene. It varies from nonwelded to densely welded; most commonly it occurs as greenish-gray glassy or stony devitrified tuff. Thickness is ~30 m near the type section about 0.5 km northeast of the confluence of the canyon with Poison Creek and corresponds to observed maximal thicknesses (Greene, 1973). $^{40}Ar/^{39}Ar$ age of 9.68±0.03 Ma was obtained from sanidine separates (Deino and Grunder, unpublished data). At this location, the tuff is partially welded and pumice rich, with pumices up to 30 cm in diameter.

Prater Creek Tuff

The Prater Creek Tuff is mainly a devitrified, crystal-poor ash-flow tuff. Exposures of the type section (designated by Walker, 1979) can be seen from Hwy 395 on the walls of Poison Creek, where the maximum thickness is 12 m. Lithologic variations can be seen in reference sections in Prater Creek, about 5 km east of Poison Creek. The type section consists chiefly of pale grayish-red, devitrified tuff with grayish-pink gas cavities to ~2 cm in diameter. Flattened, devitrified pumice fragments are present throughout but are not abundant. Alkali feldspar and quartz are sparse, and the tuff contains rare lithic fragments (Walker, 1979). Devitrified whole-rock tuff gave an age of 8.48±0.05 Ma (Deino and Grunder, unpublished data).

Rattlesnake Tuff

This is nonwelded to densely welded pumice-rich to ash-rich tuff with spherulitic, lithophysal, devitrified and vapor-phase crystallization zones. The phenocryst content is <1 percent throughout the bulk of the tuff. Where pumiceous, the tuff commonly has distinctive white, gray, black, and banded pumice clasts set in a salt-and-pepper matrix of white and gray glass shards. Typically, the tuff occurs as 10- to 20-m-thick, cliff-forming rimrock; maximum thickness is ~70 m. Analyses of 15 single-crystal $^{40}Ar/^{39}Ar$ samples of alkali feldspar yielded a weighted mean age of 7.05±0.01 Ma (Streck and Grunder, 1995).

SCENERY BACK TO BURNS

Return south on Hwy 395 toward Burns. View is across the central Harney Basin with snow-capped Steens Mountain to the south-southeast. Wrights Point is seen due south as a

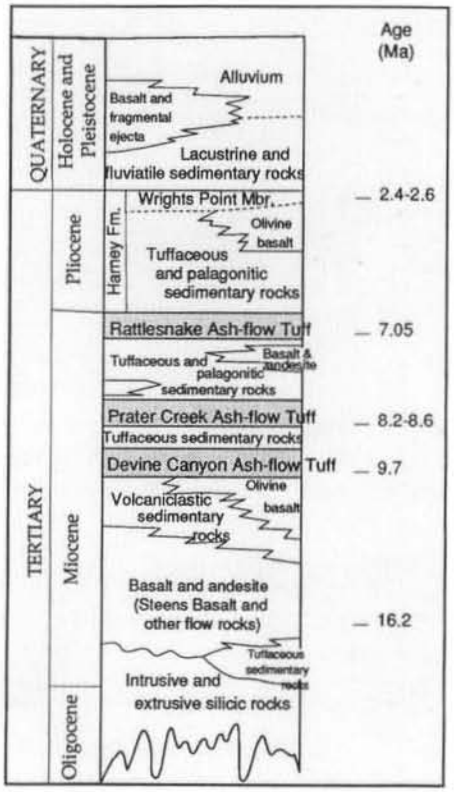


Figure 6. Lithologic units of Harney Basin (modified from Walker, 1979)

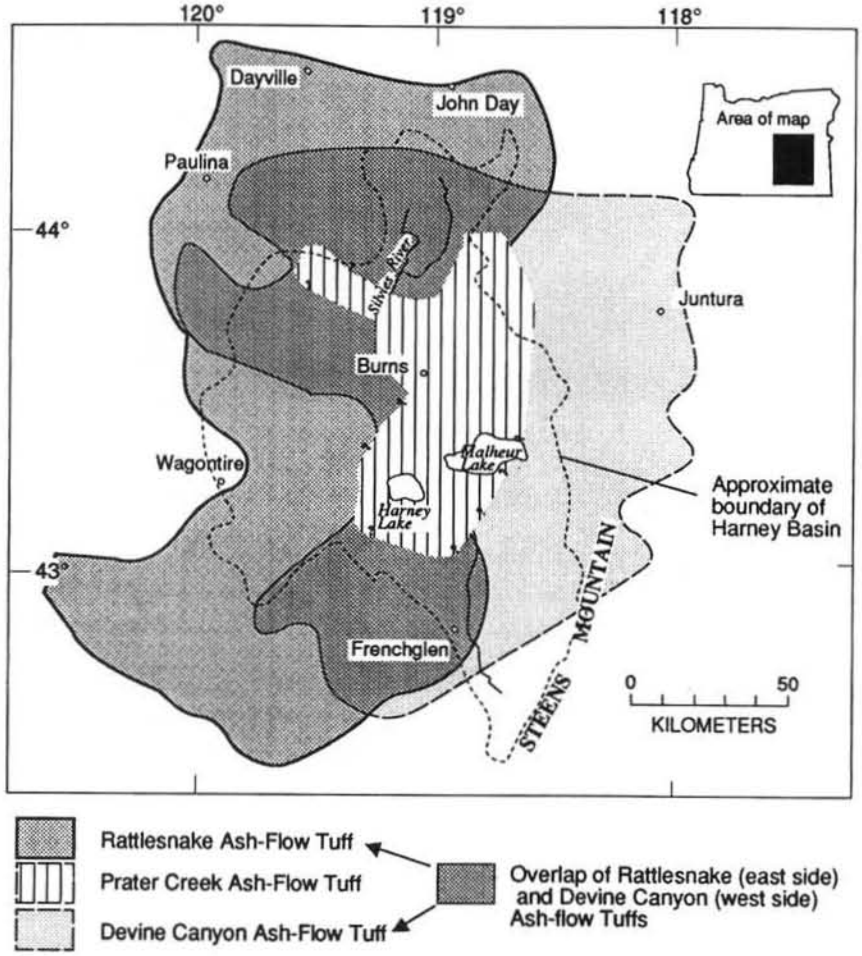


Figure 7. Regional distribution of Rattlesnake, Prater Creek and Devine Canyon Tuffs (from Walker, 1979)

flat-topped structure. It is a sinuous, 12-km-long erosional remnant of ~2.5-Ma olivine-basalt (HAOT) intracanyon lava flows overlying well-bedded tuffaceous sedimentary strata (Niem, 1974). The Malheur lowland, seen to the east of Wrights Point, and Harney lowland, hidden behind Wrights Point, host ephemeral lakes in Harney Basin, a closed depression.

DIRECTIONS TO STOP 3

Drive through Burns on Highway 395/20 and continue west. At ~24 mi (3.5 mi east of Riley) pull into gravel pit on north (right) side of road. Borrow pit of Pliocene basalt provides road metal for the State Highway Division.

STOP 3. PANORAMIC VIEW OF WESTERN HARNEY BASIN

Clockwise from southeast the following centers are visible (Figure 2): Palomino Butte, Iron Mountain (prominent sharp peak to the south), Horsehead Mountain, Little Juniper Mountain, Wagontire Mountain, Sheep Mountain, Paiute Butte (sharp peak to the west; called Squaw Butte prior to 1996), and Juniper Ridge. All are silicic domes except Paiute Butte, which is basaltic trachyandesite. Dry Mountain, the broad peak to the northwest, is an older andesite volcano.

The silicic centers form kipukas (areas sticking out of a lava flow) surrounded by Pliocene and Quaternary olivine basalt, and most conform to the westward younging trend. Iron Mountain is anomalously young, and Horsehead Mountain, Little Juniper Mountain, and parts of Wagontire Mountain are substantially older than the High Lava Plains volcanic trend. Abundant mafic cinder cones are scattered throughout the basalt field south of the highway.

The younger basalt is found throughout the High Lava Plains with no apparent age progression (Figure 2). These basalts are commonly tholeiitic with Al_2O_3>16 weight percent (wt.%), MgO>8 wt.%, P_2O_5~0.1 wt.%, TiO_2<1.0 wt.%, and Cr≥200 ppm. They have a flat REE (rare-earth-element) pattern characteristic of MORB (mid-oceanic ridge basalt)-like tholeiites, although some LIL (large-ion-lithophile-element) enrichment relative to MORB could indicate involvement of minor crustal material in their genesis (e.g., Bailey and Conrey, 1992).

Source area for Rattlesnake Tuff

No caldera structure related to the Rattlesnake Tuff is exposed. By analogy with pyroclastic deposits of similar volume, we might expect a caldera with an approximate diameter of 20 km (cf. Smith, 1979). Several source areas have been proposed, all lying within the Harney Basin. Walker (1969) and Parker (1974) proposed the Buzzard Creek area, based on rheomorphic features interpreted as venting features. Walker (1970, 1979) proposed a caldera under Harney Lake. MacLeod and others (1976) favored a site in the western Harney Basin based on the clustering of silicic domes of similar age.

The source area of the Rattlesnake Tuff (Figure 3) was chosen to be consistent with the areal distribution, distribution of facies within the tuff, increasing pumice size toward the vent, and flow direction indicators in the tuff (Streck and Grunder, 1995). The pumice-size data locations were compared for all proposed source areas, and the best mathematical fit for the source area is "Capehart Lake" located in the western Harney Basin (18 km south-southwest of the town of Riley, i.e., in the flat between the panoramic view point [Stop 3] and the town of Wagontire along Hwy 395). This area is almost identical with the source area proposed by MacLeod and others (1976), based on the regional age distribution pattern of silicic volcanism and suggested by magnetic anisotropy patterns within the tuff that are thought to be related to flow during deposition (Stimac, 1996).

DIRECTIONS TO STOP 4

Continue west on Hwy 20 to Silver Creek Road ~1.7 mi west of the Riley Post Office and turn right (north). At intersection with Oakerman Lane (~1.5 mi) turn left. Road wraps around ~15 Ma andesite volcano Dry Mountain. Drive ~15.5 mi to junction of Forest Service Roads 45 and 4130 at confluence of Silver and Wickiup Creeks. Turn left onto Road 45. Make stops along the route cautiously.

Prominent outcrop in the confluence is Stop 4a. Outcrop on west side of road, 0.6 mi from intersection is Stop 4b; ~1 mi further at junction of Roads 45 and 4535, rim rock at south wall is Stop 4c, north wall is Stop 4d (Figure 8).

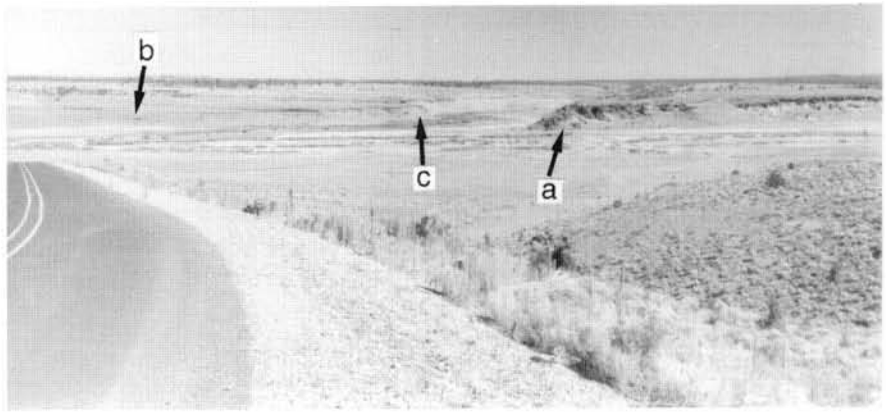


Figure 8. Overview of area around Stop 4 (4d not visible behind 4c). View is to the northwest from Forest Service Road 45, about 1 mi south of the intersection of Forest Service Roads 45 and 4130. All rim rocks in the picture are Rattlesnake Tuff.

Important: Part of this area is private land, with right of entry by permission of landowner only (Ranch to the north of Stop 4a)!

STOP 4. EXTREME LOCAL FACIES VARIATIONS

Strong local facies variations observable at Stop 4 are found at various places throughout the vast ignimbrite sheet but are strongest near the vent area. Stop 4 is an example for this (Figure 8).

Stop 4a consists of 16-m-thick, mainly incipiently welded RST with large pumices (average maximum pumice ~35 cm).

Outcrop at Stop 4b shows exposure of basal contact with underlying tuffaceous sedimentary rocks; there, RST grades from nonwelded to densely welded lower vitric zone overlain by pervasively devitrified zone. RST outcrop at Stop 4c includes lower partially welded zone with pumice (~1 m) overlain by zone that is partially welded with fiamme, in turn overlain by 7 m of black vitrophyre. The base is not exposed. Upper hackly jointed devitrified tuff is marked by sharp, commonly planar, transition. On north wall of road junction (Stop 4d), devitrified part of RST outcrop includes dominantly hackly jointed tuff intermixed with portions of lithophysal tuff (lithophysae in devitrified matrix).

DIRECTIONS TO STOP 5

Drive west on Forest Service Road 4535 for ~2.5 mi to first dirt road on left. Park and walk to outcrop north of intersection.

STOP 5. RHEOMORPHIC SANDWICH SECTION

The more than 30 m of RST visible here consist of ~20 m of rheomorphic tuff that is sandwiched between lower and upper normal (nonfolded) tuff (Figure 9). Lower half of outcrop is devitrified rheomorphic tuff. Folding in the middle part of this zone is steeply inclined with isoclinal fold hinges. The upper and lower parts of this zone exhibit more open fold hinges with less steep inclination. Pumice, best observed along base of outcrop, is flattened but not strongly stretched despite pronounced foliation.

Basal contact can be inferred from rare float of undeformed lower vitric tuff found along base of exposure and from lower open fold hinges. Upper half of outcrop is undeformed RST, with crystallization facies grading from a lithophysal zone with devitrified matrix to a pervasively devitrified zone and to a capping microcrystalline vapor-phase zone.

Note that macroscopic axiolitic structures are well-developed in

Figure 9. Outcrop photo of Stop 5 showing facies boundaries (dashes) and orientations of flow foliations (arrows). One isoclinal fold hinge is indicated (U-shape). Abbreviations of crystallization facies as in Figure 4.

some fiamme, particularly near the top of the section.

DIRECTIONS TO STOP 6

Return to intersection of Roads 45 and 4130. Go east on Road 4130 ~9.2 mi to Egypt Well. Turn right (south) on Road 4135 and drive 1.7 mi to fork in road; take left fork, Road 4120, for 2.8 mi to outcrop that is ~0.7 mi up Curly Canyon from intersection of Roads 4120 and 4126.

Editor's note: The name "Curly Canyon" appears only on the 1995 map of the Snow Mountain Ranger District, Ochoco National Forest. On the Forest Service 1993 "visitors' map" of the Ochoco National Forest and on the U.S. Geological Survey's 7½-minute map of the Egypt Canyon quadrangle (1992), the canyon is identified as the continuation of Dick Miller Canyon.

STOP 6. CURLY CANYON SECTION

Almost exclusively rheomorphic RST; locally overlain by undeformed lithophysal tuff, pervasively devitrified, and vapor phase zones. Rheomorphic tuff is either devitrified, with vapor phase minerals lining the elongate openings, or is vitric with flame-shaped lozenges of deformed pumice. Locally, lithophysal tuff is intercalated with devitrified rheomorphic tuff. The vitric part, which is partially to densely welded, occurs at the top of the section, indicating that it is near the original top. Although it has eutaxitic structure, it is not strictly vitroclastic, and we interpret the less welded, vitric tuff as the pumiceous carapace. In one location, float of the vitric tuff is weathering out of the central part of the devitrified tuff, which suggests that the vitric tuff was folded into the devitrified. Foliation and folds are gently inclined at base and top of tuff. In the central part, foliation is almost always nearly vertical. Although the base is not exposed, fold hinges at the base of the exposure indicate proximity to basal contact.

Optional addition: Return to Egypt Well (intersection of Roads 4130 and 4135), turn right (east), and continue for 1.1 mi to ~10-m-high outcrop of freshly exposed lithophsal tuff (lithophysae in devitrified matrix facies). Note range of lithophysae from completely filled to hollow varieties (cf. Figure 11 in Streck and Grunder, 1995). Return to Egypt Well.

DIRECTIONS TO STOP 7

From Egypt Well, drive back west for 9.2 mi on Road 4130 to junction with Road 45 and Silver Creek Road. Turn south (left) on Silver Creek Road toward Highway 20. Stop 7 is 0.6 mi down Silver Creek Road from the intersection. Park in turn-out on the east side of the road.

Important: Please leave lithic-enriched zone undisturbed for future visitors.

STOP 7. ASH-RICH SECTION

Nonwelded to partially welded ash-rich section. Basal contact of RST with lithic-enriched zone at contact

This is an unusual section in that it is pumice poor at this proximal locality. The color grades upsection from white to gray. Although part of the color change can be attributed to increased welding upsection, mostly it reflects upward increase in the proportion of brown to white shards.

Continue south to Hwy 20 and follow it for ~30 mi east back to Burns.

Day 2

ROUTE AND SCENERY TO STOP 8

From Burns, drive 27 mi west on Highway 20 to the junction with Highway 395 at Riley. Drive south on 395.

The small butte just southwest of Riley is Shields Butte, a strombolian basalt cone. Several such cones crop out near the highway on the way to Stop 8. The low ridge about a mile south of the junction is the eastern end of 6.87-Ma Juniper Ridge, a silicic flow and dome complex (MacLean, 1994). Note the turnoff to the Northern Great Basin Experimental Range (a few miles further). We will return via this road.

The prominent butte on your right side is Paiute Butte (formerly Squaw Butte), a basaltic trachyandesite with unusual trace-element enrichments. The next northwest-trending ridge to the south is Egli Ridge, composed of nearly aphyric rhyolite. The more massive buttes to the southwest are Sheep Mountain and Wagontire Mountain, mainly rhyolites, around 7 Ma. A rhyolite tuff (ash-flow tuff of Wagontire Mountain) with spectacular rheomorphic features is exposed at Wagontire Mountain (Walker and Swanson, 1968). Part of Wagontire Mountain has a reported age of 14.7 Ma (MacLeod and others, 1976). The alluvial cover is thin and underlain mainly by Rattlesnake Tuff or basalts, which make up the rimrocks.

The town of Wagontire—commonly for sale, population 2, coffee sold by the hour—is 28 mi south of Riley. The plain here is mainly Rattlesnake Tuff overlain by the 6.87-Ma tuff of Buckaroo Lake (first rimrock above the plain). The buttes to the south and southeast are 15-Ma dacites called Horsehead Mountain and Little Juniper Mountain.

Drive another 15 mi south toward the town of Alkali Lake. The hills seen to the west as you pass the junction to Christmas Valley are Horse Mountain, the most peralkaline of the rhyolite domes. The rimrock to the east is Rattlesnake Tuff, locally overlain by tuff of Buckaroo Lake. From the intersection of Hwy 395 with Christmas Valley Road, go ~4.8 mi south and take a gravel road east to the base of the cliff (toward Hotchkiss Cow Camp).

This is the northern end of the Abert Rim range-front fault escarpment. At the cow camp, turn south and go about 1 mi. This is Stop 8.

STOP 8. ALKALI RIM SECTION

The prominent rim is the Alkali Rim fault scarp. The fault scarp is mainly (~90 percent) rheomorphic and lithophysal Rattlesnake Tuff, reaching the maximum thicknesses observed throughout the tuff sheet (~70 m). Primitive tholeiitic basalts are exposed here underneath, in (dark layers in upper half of escarpment), and above (at northern termination of fault scarp) the Rattlesnake Tuff. The base of the thick, mainly rheomorphic and lithophysal RST section is exposed and can be observed as very thin white horizontal band. At the nearby cow camp, the base of Rattlesnake Tuff overlies basalt with a ropy surface that overlies another ash-flow tuff. Partially to densely welded vitric zone of Rattlesnake Tuff is extremely thin (~30 cm) and sandwiched between nonwelded and rheomorphic facies.

Three basalt sills (thin lower, thick middle, thin upper) intrude (or invade?) the Rattlesnake Tuff. Near the northern termination of the ~1-m-thick upper sill, pipe vesicles developed at the top and basal contact to the Rattlesnake Tuff. Intruding features, ripped off pieces of Rattlesnake Tuff, and well-developed vesicle sheets can be observed along upper contact of the thick middle and the upper sill.

DIRECTIONS TO STOP 9

Drive back north, past Wagontire to the sign pointing to the U.S. Agricultural Research Service's Northern Great Basin Experimental Range. Turn onto that road that leads northwest. Continue ~5 mi to Stop 9 to see some lavas of the Juniper Ridge center and Paiute Butte.

After this stop, continue north to Highway 20, crossing the entire silicic dome complex of Juniper Ridge.

Note: Before you reach Stop 9, be sure to TURN RIGHT when you get to the "dead-end" (T-) intersection in the road. It will lead you past the Experimental Station.

STOP 9. JUNIPER RIDGE-PAIUTE BUTTE

The small cliff is composed of a dacite lava with several percent phenocrysts, overlain by an aphyric rhyolite, both part of the Juniper Ridge volcanic center (MacLean, 1994).

Juniper Ridge (JR) is divided into two suites of rocks designated western and eastern JR based on their position relative to the northwest-striking Tin Mine fault (TMF in Figure 10). A diktytaxitic high-alumina olivine basalt laps onto the north side of the entire complex. Eastern JR is elongate, bounded to the northeast by a fault. Basal aphyric rhyolite (75 percent SiO_2) has a $^{40}Ar/^{39}Ar$ age of

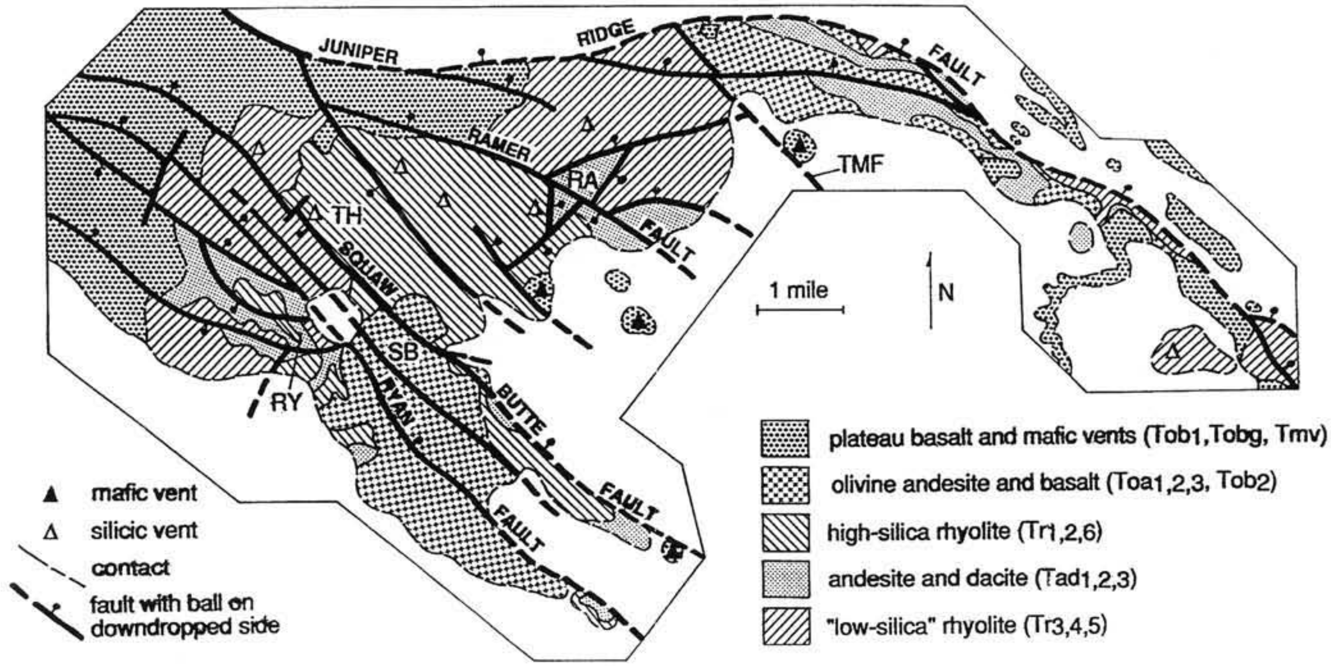


Figure 10. Geologic map of the Juniper Ridge silicic dome complex (from MacLean, 1994). RY = Ryan Peak; SB = Paiute (formerly Squaw) Butte; TH = Thomas Peak; RA = Ramer Peak; TMF = Tin Mine fault.

6.87±0.02 Ma. The basal rhyolite is overlain by porphyritic rhyolite (73 percent SiO_2), aphanitic olivine basalt, some andesites and dacites, and aphyric rhyolite (77 percent SiO_2). The oldest unit at the western JR is rhyolite (75 percent SiO_2), which is overlain by porphyritic andesite and dacite. The section is capped by high-silica (77 percent) rhyolite with a $^{40}Ar/^{39}Ar$ age of 5.7±0.02 Ma (Figure 10).

Paiute Butte is a prominent, partially eroded cone of basaltic trachyandesite in the center of the western JR. It is composed of alternating thin lava flows and scoria. Two dikes intersect at the summit. Paiute Butte has high concentrations of Fe and P, akin to FeTi basalts, and has extreme enrichments in REE and HFSE (high field strength elements), about twice that in Juniper Ridge high-silica rhyolites, and in Ba, Sc, Zn, and Ga. In contrast, Sr, Cs, Rb, U, Pb, and Th are similar to local, more calc-alkaline basaltic andesite. Trace element patterns like those of Paiute Butte are seen in basaltic andesite rocks issued from a few other mafic vents within the western Harney Basin (i.e., between Iron Mountain and Paiute Butte) and in inclusions of the Rattlesnake Tuff, although enrichments of the latter are less extreme (Streck and Grunder, 1996; Streck and Grunder, 1999).

End of trip at junction of Experimental Range road with Highway 20. Bend lies about 100 mi west and Burns about 30 mi east.

ACKNOWLEDGMENTS

The field trip based on this guide was held during the GSA Cordilleran Section meeting at Portland, Oregon, in 1996. We thank the participants for their enthusiasm and insights. We thank Scott Burns and Michael Cummings for their support in our endeavor. Thanks also to our colleague James MacLean, wherever he and Elmer might be. Funding for the research came from National Science Foundation grant EAR-9220500 to A.L.G., Geological Society of America Penrose grants to M.J.S. and Jim MacLean, and U.S. Geological Survey internship support awarded to J.A.J.

REFERENCES CITED

Armstrong, R.L., Leeman, W.P., and Malde, N.E., 1975, K-Ar dating, Quaternary and Neogene rocks of the Snake River Plain, Idaho: American Journal of Science, v. 275, p. 225–251.

Bailey, D.G., and Conrey, R.M., 1992, Common parent magma for Miocene to Holocene mafic volcanism in the northwestern United States: Geology, v. 20, no. 12, p. 1131–1134.

Carlson, R.W., and Hart, W.K, 1987, Crustal genesis on the Oregon Plateau: Journal of Geophysical Research, v. 92, p. 6,191–6,206.

Dueker, K., and Humphries, G., 1990, Upper mantle velocity structures of the Great Basin: Geophysical Research Letters, v. 17, p. 1327–1330.

Greene,. R.C., 1973, Petrology of the welded tuff of Devine Canyon, southeastern Oregon: U.S. Geological Survey Professional Paper 797, 26 p.

Grunder, A.L., Johnson, J.A., and Streck, M.J., 1995, Basalt-rhyolite volcanism of the High Lava Plains, mirror of the Snake River Plain [abs.]: IUGG XXI General Assembly, Denver Colo., Proceedings, p. A443.

Hart, W.K., Aronson, J.L., Mertzman, S.A., 1984, Areal distribution and age of low-K, high-alumina olivine tholeiite magmatism in the northwestern Great Basin, U.S.A.: Geological Society of America Bulletin, v. 95, p. 186-195.

Hearn, T., Beghoul, N., and Barazangi, M., 1991, Tomography of the western United States from regional arrival times: Journal of Geophysical Research, v. 96, p. 16,369–16,381.

Johnson, J.A., 1995, Geologic evolution

of the Duck Creek Butte eruptive center, High Lava Plains, southeastern Oregon: Corvallis, Oreg., Oregon State University master's thesis, 151 p.
Johnson, J.A., and Deino, A.L., 1994, Timing of volcanism and extension, Duck Creek Butte eruptive center, northern Basin and Range Province, southeastern Oregon [abs.]: Geological Society of America Abstracts with Programs, , v. 26, no. 7, p. 192.
Linneman, S.K., and Myers, J.D., 1990, Magmatic inclusions in the Holocene rhyolites of Newberry volcano, central Oregon: Journal of Geophysical Research, v. 95, p. 17,677–17,691.
MacLean, J.W., 1994, Geology and geochemistry of Juniper Ridge, Horsehead Mountain, and Burns Butte: Implications for the petrogenesis of silicic magma on the High Lava Plains, southeastern Oregon: Corvallis, Oreg., Oregon State University master's thesis, 141 p.
MacLeod, N.S., Walker, G.W., and McKee, E.H., 1976, Geothermal significance of eastward increase in age of upper Cenozoic rhyolitic domes in southeastern Oregon, *in* Second United Nations symposium on the development and use of geothermal resources, San Francisco, Calif., May 20–29, 1975: Lawrence Berkeley Laboratory, University of California, for U.S. Energy Research and Development Administration, U.S. National Science Foundation, and U.S. Geological Survey, p. 465–474 (also published as U.S. Geological Survey Open-File Report 75-348).
Mathis, A.C., 1993, Geology and petrology of a 26-Ma trachybasalt to peralkaline rhyolite suite exposed at Hart Mountain, southern Oregon: Corvallis, Oreg., Oregon State University master's thesis, 141 p.
Niem, A.R., 1974, Wright's Point, Harney County, Oregon: An example of inverted topography: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 36, no. 3, p. 33–49.
Parker, D.J., 1974, Petrology of selected volcanic rocks of the Harney Basin, Oregon: Corvallis, Oreg., Oregon State University doctoral dissertation, 119 p.
Pike, R.J., 1991, Surface features of central North America: A synoptic view from computer graphics: GSA Today, v. 1, p. 241 and 251–253.
Smith, R.L., 1979, Ash-flow magmatism, *in* Chapin, E.E., and Elston, W., eds., Ash-flow tuffs: Geological Society of America Special Paper180, p. 5–27.
Smith, R.B., and Braille, L.W., 1994, The Yellowstone hotspot: Journal of Volcanology and Geothermal Research, v. 61, p. 121–188.
Stimac, J.P., 1996, Rock magnetic and paleomagnetic characteristics of the late Miocene Rattlesnake and Devine Canyon Ash-Flow Tuffs, eastern Oregon: Eugene, Oreg., University of Oregon doctoral dissertation, 183 p.
Streck, M.J., 1994, Volcanology and petrology of the Rattlesnake Ashflow Tuff, eastern Oregon: Corvallis, Oreg., Oregon State University doctoral dissertation, 185 p.
Streck, M.J., and Grunder A.L., 1995, Crystallization and welding variations in a widespread ignimbrite sheet: The Rattlesnake Tuff, eastern Oregon: Bulletin of Volcanology, v. 57, p. 151–169.
———1996, Strong local trace element variability in a tholeiitic suite from Oregon: Dominance of intra-suite interactions vs. mantle or crustal processes [abs.]: Journal of Conference Abstracts, v. 1, p. 603.
———1997, Compositional gradients and gaps in high-silica rhyolites of the Rattlesnake Tuff, Oregon: Journal of Petrology, v. 38, p. 133–163.
———1999, Enrichment of basalt and mixing of dacite in the root zone of a large rhyolite chamber: Inclusions and pumices from the Rattlesnake Tuff, Oregon: Contributions to Mineralogy and Petrology, in press.
Walker, G.W., 1969, Geology of the High Lava Plains province, *in* Weissenborn, A.E., ed., Mineral and water resources of Oregon: Oregon Department of Geology and Mineral Industries Bulletin 64, p. 77–79.
———1970, Cenozoic ash-flow tuffs of Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 32, no. 6, p. 97–115.
———1979, Revisions to the Cenozoic stratigraphy of Harney Basin, southeastern Oregon: U.S. Geological Survey Bulletin 1475, 35 p.
Walker, G.W., and Swanson, D.A., 1968, Laminar flowage in a Pliocene soda rhyolite ash-flow tuff, Lake and Harney Counties, Oregon, *in* Geological Survey research 1968, Chapter B: U.S. Geological Survey Professional Paper 600-B, p. B37–B47. □

Search the Database of USGS Publications

The Publications of the U.S. Geological Survey, a subset of the GeoRef database established by the American Geological Institute, is now available online (http://usgs-georef.cos.com). Previously produced on a CD-ROM, this online version of the USGS publications database is provided by the Community of Science under a licensing agreement. The database provides access to the publications of the USGS and includes references to U.S. Geological Survey reports and maps published from 1880 to date, references to non-USGS publications with USGS authors published from 1983 to date, and 225 references to reports produced by the Hayden, King, Powell, and Wheeler surveys.

The text of documents is not included; however, the database includes complete bibliographic references and index terms drawn from the GeoRef Thesaurus. Reports with chapters by different authors have complete references for each chapter. The sheet size, scale, and latitude and longitude are given for maps. Each reference averages more than 13 index terms, and some references have abstracts. Publications that exist in electronic form at the time of announcement include a URL. Prices are included for USGS publications.

Using the "Search Publications of the U.S. Geological Survey" web site, you can select a search interface designed for your level of search experience; search for abstracts in specific journals; download search results in citation formats for use with most citation management software packages; track your queries so that you can repeat past searches against current data; and link directly from your web site to individual GeoRef records. An instructions button on the web site leads to a user's guide, and a help desk button offers the ability to request help on specific problems.

—From USGS news release
Contact Rea Mueller
703-648-5954, FAX: 703-648-5939
e-mail: rlmueller@usgs.gov

Study tip: Earthquake cycles

Background information

Earthquakes occur along faults. Faults are fractures in the rock below the Earth's surface, places where two masses of rock separate from each other, usually by sliding past each other. The Earth's crust is in motion (as explained by the theory of plate tectonics). This motion results in stresses within the Earth. Normally, a fault is locked or stuck and will not move. However, if the stresses build up high enough, the rocks along the fault will move suddenly. This makes the rocks "shiver,"—and that is an earthquake. Seismologists and geologists have a model for this. For some faults they believe that the stress must reach a certain level before it is high enough to overcome the frictional resistance to sliding in the fault rocks. If the stress buildup is continuous, the earthquakes occur at regular intervals and are part of an earthquake cycle.

Seismologists have learned that some faults are more likely to move at short intervals, and others are more likely to move at long intervals. Not all faults fit a cyclic or predictable pattern, and even very cyclical faults do not always fit a pattern. In general, however, studies of a fault's earthquake history help geologists determine how likely it is that an earthquake may occur in the future.

Parkfield background

This town in central California is located right on the San Andreas fault.

To attempt to answer the questions about when, where, how big, and how often an earthquake will happen along a fault, scientists look at the historical record of the fault. A good example of this is a segment of the San Andreas fault near Parkfield, the site of a moderate earthquake (about magnitude M6) about every 20 years. Based on the historical record and other evidence, the U.S. Geological Survey predicted in the 1980s that an earthquake near Parkfield would occur before the end of 1993. Although the expected earthquake has yet to occur, Parkfield remains the most likely site in California for a moderate earthquake. A list of the dates of recent earthquakes there is shown below. For more information, look on the web at http://quake.wr.usgs.gov/QUAKES/Parkfield/.

Earthquakes near Parkfield, California	
1.	1857
2.	1881
3.	1901
4.	1922
5.	1934
6.	1966

To understand the cycle of earthquakes at Parkfield, answer these questions:

1. What was the shortest time period between the earthquakes?
2. What was the longest time period between the earthquakes?
3. Plot these dates on graph paper and draw a straight line on the graph that best fits the data points.
4. Continue the line on your graph and use it to predict when the next big earthquake (no. 7) will hit Parkfield. What year did you get?
5. Calculate the **average** time between earthquakes. This is also known as the average recurrence interval.
6. (a). What is one of the least predictable earthquakes? (Falls farthest from the line or had a time interval farthest from average?)

   (b) In what year would you predict this earthquake should have occurred?
7. Looking at your answers to the above questions, do you think that this method of predicting earthquakes works in the Parkfield area? Why or Why not?

When it comes to determining the earthquake cycle of an area, Parkfield, is an unusual case. Most areas subject to earthquakes do not have them this often or this regularly. Oregon has not had any great earthquakes (greater than M 7.5) in historic time (since about 1800). Because of this, we used to think that Oregon did not have much risk of earthquakes.

Geologists are just beginning to learn about the Oregon earthquake cycle from the sedimentary deposits formed by great Northwest earthquakes. With this method, the dates of the earthquakes are difficult to determine, and some quakes may be missed. The table below shows the approximate dates of the last great earthquakes in Oregon.

Cascadia subduction zone earthquakes	
1.	1400 BCE
2.	1050 BCE
3.	600 BCE
4.	400
5.	750
6.	900
7.	1700

To understand the cycle of earthquakes on the Cascadia subduction zone, answer these questions:

1. What was the shortest time period between the earthquakes?
2. What was the longest time period between the earthquakes?
3. Plot these dates on graph paper and draw a straight line on the graph that best fits the data points.
4. Continue the line on your graph and use it to predict when the next big earthquake (no. 8) will hit Oregon. What year did you get?
5. Calculate the **average** time between earthquakes. This is also known as the average recurrence interval.
6. Looking at your answers to the above questions, do you think that this method of predicting earthquakes works for Cascadia subduction zone earthquakes? Is it more or less accurate than in Parkfield?
7. Based on this information, when do you think the next great earthquake will occur in Oregon? Do you think an accurate prediction can be made?

—From T. Atwill, Oregon earthquake and tsunami curriculum, grades 4–6, 1998.

BOOK REVIEW

Oregon Fossils, by Elizabeth L. and William N. Orr. Dubuque, Iowa, Kendall/Hunt, 1999. ISBN 0-7872-5454-1, 381 p., soft cover, $40.95.

In preparation for the coming field season, amateur and professional paleontologists alike will enjoy perusing Orr and Orr's "Oregon Fossils". Out this year by Kendall/Hunt Publishing as an adjunct to the authors' standby *Handbook of Oregon Plant and Animal Fossils*, the book provides far more than field-type information concerning where to look for fossils in Oregon. As in the previous book, there are sections detailing each of the major groups of fossils that occur in the state. But the table of contents gives no hint to the added wealth of information about Oregon paleontologists, their specialties in research, and their backgrounds. Much of this is transmitted in an anecdotal manner, giving a delightful dimension to the book, and revealing the human side of the science. This aspect of the book alone should provide inspiration to budding paleontologists and is one of the few sources of which I am aware that preserves some of the treasure of stories passed along in the "oral tradition" of professional paleontologists. Many photographs, some formal, but some blessedly not, greatly add to this feature. In addition to these photos, the book is packed with well-executed line drawings and photos of fossils (including restorations) and charts and maps detailing statigraphic and geographic settings of the fossils. Typography and layout are equally well done, and the text reads smoothly, pleasantly spiced with the aforementioned personal and historical anecdotes.

Each section begins with a general introduction, proceeds to a discussion of some of the peculiarities of the group or the main applications of research on the group, then reviews the floras or faunas in stratigraphic order. Woven into this is information on the general geology of parts of the state and prevailing interpretations of age, climate, paleogeography, and other aspects of applied paleontological knowledge. Because different kinds of fossils are used to determine different aspects of the past (age, climate, etc.), each section is somewhat different in format and emphasis. This definitely helps in avoiding a "catalog" style, as does the inclusion of several items that deal with problems of interpretation of age or paleoclimate or the occasional "lost locality."

For the reader's further research or reference, eighteen pages are devoted to an excellent bibliography, covering more technical, historical, and related geological subjects. In fact, one could hardly go wrong using the bibliography as a starting point for researching a number of Oregon-related paleontological or geological themes.

In summary, *Oregon Fossils* is a very well done, useful, and enjoyable book, and it should give those interested in the paleontology of our state a good deal of help and encouragement.

—Richard E. Thoms
Emeritus Professor of Geology
Portland State University

AVAILABLE PUBLICATIONS
OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

BULLETINS	Price
103 Bibliography (8th supplement, 1980-84). 1987	8.00
102 Bibliography (7th supplement, 1976-79). 1981	5.00
101 Geologic field trips, W. Oregon/SW Washington. 1980	10.00
99 Geologic hazards, NW Clackamas County. 1979	11.00
98 Geologic hazards, E. Benton County. 1979	10.00
97 Bibliography (6th supplement, 1971-75). 1978	4.00
96 Magma genesis. Chapman Conf. on Partial Melting. 1977	15.00
95 North American ophiolites (IGCPproject). 1977	8.00
94 Land use geology, central Jackson County. 1977	10.00
93 Geology, min. res., and rock material, Curry County. 1977	8.00
92 Fossils in Oregon. Reprints from the *Ore Bin*. 1977	5.00
91 Geol. hazards, Hood River, Wasco, Sherman Co. 1977	9.00
90 Land use geology of western Curry County. 1976	10.00
89 Geology and mineral resources, Deschutes County. 1976	8.00
88 Geology and min. res., upper Chetco R. drainage. 1975	5.00
87 Environmental geology, W. Coos/Douglas Counties. 1975	10.00
82 Geologic hazards, Bull Run watershed. 1974	8.00
78 Bibliography (5th supplement, 1961-70). 1973	4.00
71 Geology of lava tubes, Bend area, Deschutes County. 1971	6.00
67 Bibliography (4th supplement, 1956-60). 1970	4.00
65 Proceedings of the Andesite Conference. 1969	11.00
53 Bibliography (3rd supplement, 1951-55). 1962	4.00
46 Ferruginous bauxite, Salem Hills, Marion County. 1956	4.00
44 Bibliography (2nd supplement, 1946-50). 1953	4.00
36 Papers on Tertiary Foraminifera (v. 2 [parts VII-VIII]). 1949	4.00
33 Bibliography (1st supplement, 1936-45). 1947	4.00

MISCELLANEOUS PAPERS	Price
20 Investigations of nickel in Oregon. 1978	6.00
19 Geothermal exploration studies in Oregon, 1976. 1977	4.00
15 Quicksilver deposits in Oregon. 1971	4.00
11 Articles on meteorites (reprints from the *Ore Bin*). 1968	4.00
5 Oregon's gold placers. 1954	2.00
SHORT PAPERS	
27 Rock material resources of Benton County. 1978	5.00
25 Petrography of Rattlesnake Formation at type area. 1976	4.00
OIL AND GAS INVESTIGATIONS	
19 Oil and gas potential, S. Tyee Basin. 1996	20.00
18 Schematic fence diagram, S. Tyee Basin. 1993	9.00
17 Cross section, Mist Gas Field to continental shelf. 1990	10.00
16 Avail. well records and samples, onshore/offshore. 1987	6.00
15 Hydrocarbon exploration/occurrences in Oregon. 1989	8.00
14 Oil and gas investigation of the Astoria Basin. 1985	8.00
13 Biostratigraphy–explor. wells, S. Willamette Basin. 1985	7.00
12 Biostratigraphy–explor. wells, N. Willamette Basin. 1984	7.00
11 Biostratigraphy, explor. wells, Coos, Douglas, Lane Co. 1984	7.00
10 Mist Gas Field: Explor./development, 1979-1984. 1985	5.00
9 Subsurface biostratigraphy, E. Nehalem Basin. 1983	7.00
8 Subsurface stratigraphy, Ochoco Basin. 1984	8.00
7 Cenozoic stratigraphy, W. Oregon/Washington. 1983	9.00
6 Prospects f. oil and gas, Coos Basin. 1980	10.00
5 Prospects f. natural gas, upper Nehalem Basin. 1976	6.00
4 Foraminifera, E.M. Warren Coos County 1-7 well. 1973	4.00
3 Foraminifera, General Petroleum Long Bell #1 well. 1973	4.00

AVAILABLE PUBLICATIONS
OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES (continued)

GEOLOGICAL MAP SERIES

		Price
GMS-113	Fly Valley 7½' quad., Union County. 1998	10.00
GMS-110	Tucker Flat 7½' quad., Union/Baker C. 1997	6.00
GMS-108	Rio Canyon 7½' quad., Jackson C. 1998	6.00
GMS-106	Grizzly Peak 7½' quad., Jackson County. 1997	6.00
GMS-105	EQ hazards, Salem East/West 7½' quads. 1996	12.00
GMS-104	EQ hazards, Linnton 7½' quad. 1996	10.00
GMS-101	Steelhead Falls 7½' quad. 1996	7.00
GMS-100	EQ hazard maps for Oregon. 1996	8.00
GMS-99	Tsunami hazard map, Siletz Bay, Lincoln C. 1996	6.00
GMS-98	Dora and Sitkum 7½' quad.s, Coos County. 1995	6.00
GMS-97	Coos Bay 7½' quad., Coos County. 1995	6.00
GMS-95	Henkle Butte 7½' quad., Deschutes County. 1998	10.00
GMS-94	Charleston 7½' quad., Coos County. 1995	8.00
GMS-93	EQ hazards, Siletz Bay area, Lincoln County. 1995	20.00
GMS-92	EQ hazards, Gladstone 7½' quad. 1995	10.00
GMS-91	EQ hazards, Lake Oswego 7½' quad. 1995	10.00
GMS-90	EQ hazards, Beaverton 7½' quad. 1995	10.00
GMS-89	EQ hazards, Mt. Tabor 7½' quad. 1995	10.00
GMS-88	Lakecreek 7½' quad., Jackson County. 1995	8.00
GMS-87	Three Creek Butte 7½' quad., Deschutes C. 1996	6.00
GMS-86	Tenmile 7½' quad., Douglas County. 1994	6.00
GMS-85	Mount Gurney 7½' quad., Douglas/Coos C. 1994	6.00
GMS-84	Remote 7½' quad., Coos County. 1994	6.00
GMS-83	Kenyon Mountain 7½' quad., Douglas/Coos C. 1994	6.00
GMS-82	Limber Jim Creek 7½' quad., Union County. 1994	5.00
GMS-81	Tumalo Dam 7½' quad., Deschutes County. 1994	6.00
GMS-80	McLeod 7½' quad., Jackson County. 1993	5.00
GMS-79	EQ hazards, Portland 7½' quad. 1993	20.00
GMS-78	Mahogany Mountain 30×60' quad., Malheur C. 1993	10.00
GMS-77	Vale 30×60' quad., Malheur County. 1993	10.00
GMS-76	Camas Valley 7½' quad., Douglas/Coos C. 1993	6.00
GMS-75	Portland 7½' quad. 1991	7.00
GMS-74	Namorf 7½' quad., Malheur County. 1992	5.00
GMS-73	Cleveland Ridge 7½' quad., Jackson County. 1993	5.00
GMS-72	Little Valley 7½' quad., Malheur County. 1992	5.00
GMS-71	Westfall 7½' quad., Malheur County. 1992	5.00
GMS-70	Boswell Mountain 7½' quad., Jackson County. 1992	7.00
GMS-69	Harper 7½' quad., Malheur County. 1992	5.00
GMS-68	Reston 7½' quad., Douglas County. 1990	6.00
GMS-67	South Mountain 7½' quad., Malheur County. 1990	6.00
GMS-66	Jonesboro 7½' quad., Malheur County. 1992	6.00
GMS-65	Mahogany Gap 7½' quad., Malheur County. 1990	5.00
GMS-64	Sheaville 7½' quad., Malheur County. 1990	5.00
GMS-63	Vines Hill 7½' quad., Malheur County. 1991	5.00
GMS-62	The Elbow 7½' quad., Malheur County. 1993	8.00
GMS-61	Mitchell Butte 7½' quad., Malheur County. 1990	5.00
GMS-60	Damascus 7½' quad., Clackamas/Multnomah C. 1994	8.00
GMS-59	Lake Oswego 7½' quad. 1989	7.00
GMS-58	Double Mountain 7½' quad., Malheur County. 1989	5.00
GMS-57	Grassy Mountain 7½' quad., Malheur County. 1989	5.00
GMS-56	Adrian 7½' quad., Malheur County. 1989	5.00
GMS-55	Owyhee Dam 7½' quad., Malheur County. 1989	5.00
GMS-54	Graveyard Point 7½' quad., Malheur/Owyhee C. 1988	5.00
GMS-53	Owyhee Ridge 7½' quad., Malheur County. 1988	5.00
GMS-52	Shady Cove 7½' quad., Jackson County. 1992	6.00
GMS-51	Elk Prairie 7½' quad., Marion/Clackamas C. 1986	5.00
GMS-50	Drake Crossing 7½' quad., Marion County. 1986	5.00
GMS-49	Map of Oregon seismicity, 1841-1986. 1987	4.00
GMS-48	McKenzie Bridge 15' quad., Lane County. 1988	9.00
GMS-47	Crescent Mountain area, Linn County. 1987	7.00
GMS-46	Breitenbush River area, Linn and Marion Counties. 1987	7.00
GMS-45	Madras West/East 7½' quads., Jefferson County. 1987	5.00
	as set with GMS-43 and GMS-44	11.00
GMS-44	Seekseequa Junction/Metolius Bench 7½' quads. 1987	5.00
	as set with GMS-43 and GMS-45	11.00
GMS-43	Eagle Butte/Gateway 7½' quads. 1987	5.00
	as set with GMS-44 and GMS-45	11.00
GMS-42	Ocean floor off Oregon & adj. cont. margin. 1986	9.00
GMS-41	Elkhorn Peak 7½' quad., Baker County. 1987	7.00
GMS-40	Aeromagnetic anomaly maps, north Cascades. 1985	5.00
GMS-39	Bibliogr. & index: Ocean floor, cont. margin. 1986	6.00
GMS-38	NW¼ Cave Junction 15' quad., Josephine County. 1986	7.00
GMS-37	Mineral resources, offshore Oregon. 1985	7.00
GMS-36	Mineral resources of Oregon. 1984	9.00
GMS-35	SW¼ Bates 15' quad., Grant County. 1984	6.00
GMS-34	Stayton NE 7½' quad., Marion County. 1984	5.00
GMS-33	Scotts Mills 7½' quad., Clackamas/Marion C. 1984	5.00
GMS-32	Wilhoit 7½' quad., Clackamas/Marion Counties. 1984	5.00
GMS-31	NW¼ Bates 15' quad., Grant County. 1984	6.00
GMS-30	SE¼ Pearsoll Peak 15' qu., Curry/Josephine C. 1984	7.00
GMS-29	NE¼ Bates 15' quad., Baker/Grant Counties. 1983	6.00
GMS-28	Greenhorn 7½' quad., Baker/Grant Counties. 1983	6.00
GMS-27	The Dalles 1° × 2° quadrangle. 1982	7.00
GMS-26	Residual gravity, north/ctr./south Cascades. 1982	6.00
GMS-25	Granite 7½' quad., Grant County. 1982	6.00
GMS-24	Grand Ronde 7½' quad., Polk/Yamhill Counties. 1982	6.00
GMS-23	Sheridan 7½' quad., Polk and Yamhill Counties. 1982	6.00
GMS-22	Mount Ireland 7½' quad., Baker/Grant C. 1982	6.00
GMS-21	Vale East 7½' quad., Malheur County. 1982	6.00
GMS-20	S½ Burns 15' quad., Harney County. 1982	6.00
GMS-19	Bourne 7½' quad., Baker County. 1982	6.00
GMS-18	Rickreall, Salem W., Monmouth, Sidney 7½' quads. 1981	6.00
GMS-17	Aeromagnetic anomaly map, south Cascades. 1981	4.00
GMS-16	Gravity anomaly maps, south Cascades. 1981	4.00
GMS-15	Gravity anomaly maps, north Cascades. 1981	4.00
GMS-14	Index to published geol. mapping, 1898–1979. 1981	8.00
GMS-13	Huntington/Olds Ferry 15' quads., Baker/Malheur C. 1979	4.00
GMS-12	Oregon part, Mineral 15' quad., Baker County. 1978	4.00
GMS-10	Low- to intermediate-temp. thermal springs/wells. 1978	4.00
GMS-9	Aeromagnetic anomaly map, central Cascades. 1978	4.00
GMS-8	Bouguer gravity anom. map, central Cascades. 1978	4.00
GMS-6	Part of Snake River canyon. 1974	8.00
GMS-5	Powers 15' quadrangle, Coos and Curry C. 1971	4.00

INTERPRETIVE MAP SERIES

IMS-6	**Water-induced landslide hazards, Salem Hills. 1998**	**10.00**
IMS-4	Geology/faults/sedim. thickness, Oregon City quad. 1997	10.00
IMS-3	Tsunami hazard map, Seaside area. 1998	6.00
IMS-2	Tsunami hazard map, Yaquina Bay area. 1997	6.00
IMS-1	Relative EQ hazards, Portland metro area. 1997	12.00

MINED LAND RECLAMATION PROGRAM STATUS MAPS

MLR-03	Clackamas County. 1998	10.00
MLR-10	Douglas County. 1998	10.00
MLR-17	Josephine County. 1998	10.00
MLR-24	Marion County. 1998	10.00

U.S. GEOLOGICAL SURVEY MAPS PLOTTED ON DEMAND

OFR 97-513	Volcano hazards at Newberry volcano	10.00
OFR 97-089	Volcano hazards in the Mount Hood region	10.00
OFR 94-021	Geologic map, Tillamook highlands (2 sheets)	20.00

Allow two weeks for delivery on all maps plotted on demand.

OREGON GEOLOGY

Suite 965, 800 NE Oregon Street # 28,
Portland, OR 97232-2162

Periodicals postage paid at Portland, OR

AVAILABLE DEPARTMENT PUBLICATIONS (continued)

SPECIAL PAPERS	Price
29 Earthquake damage and loss estimates for Oregon. 1999	10.00
28 Earthquakes Symposium Proceedings, AEG Meeting. 1997	12.00
27 Construction aggregate markets and forecast. 1995	15.00
26 Cross section, N. Coast Range to continental slope. 1992	11.00
25 Pumice in Oregon. 1992	9.00
24 Index to Forums on Industrial Minerals, 1965-1989. 1990	7.00
23 Forum on Industrial Minerals, 1989, Proceedings. 1990	10.00
22 Silica in Oregon. 1990	8.00
21 Geology, NW¼ Broken Top 15' quad., Deschutes Co. 1987	6.00
20 Bentonite in Oregon. 1989	7.00
19 Limestone deposits in Oregon. 1989	9.00
18 Investigations of talc in Oregon. 1988	8.00
17 Bibliography of Oregon paleontology, 1792-1983. 1984	7.00
16 Index to *Ore Bin* and *Oregon Geology* (1939-82). 1983	5.00
15 Geology/geothermal resources, central Cascades. 1983	13.00
14 Geology/geothermal resources, Mount Hood area. 1982	8.00
13 Faults and lineaments of southern Cascades, Oregon. 1981	5.00
12 Geologic linears, N. part of Cascade Range, Oregon. 1980	4.00
11 Bibliography/index, theses/dissertations, 1899-1982. 1982	7.00
10 Tectonic rotation of the Oregon Western Cascades. 1980	4.00
9 Geology of the Breitenbush Hot Springs quadrangle. 1980	5.00
8 Geology and geochemistry, Mount Hood volcano. 1980	4.00
7 Pluvial Fort Rock Lake, Lake County. 1979	5.00
6 Geology of the La Grande area. 1980	6.00
5 Analysis and forecasts of demand for rock materials. 1979	4.00
4 Heat flow of Oregon. 1978	4.00
3 Rock material, Clackam./Columb./Multn./Wash. Co. 1978	8.00
2 Field geology, SW Broken Top quadrangle. 1978	5.00

MISCELLANEOUS PUBLICATIONS	Price*
Oregon earthquake and tsunami curriculum. 1998. 3 vols., ea.	**25.00**
*Oregon fossils.1999	40.95
*Living with earthquakes in the Pacific Northwest. 1998	21.95
*Islands & Rapids. Geologic story of Hells Canyon. 1998	25.00
*The Pacific Northwest coast: Living with shores. 1998	18.50
*Hiking Oregon's geology, E.M. Bishop and J.E. Allen, 1996	16.95
*Assessing EQ hazards in the PNW (USGS Prof. Paper 1560)	25.00
*Geology of Oregon, 4th ed. 1991	33.95
*Geologic map of Oregon. 1991	11.50
*Geol. of the Pacific Northwest. 1996	45.00
*Geologic highway map (AAPG), PNW region. 1973	8.00
*Landsat mosaic map (published by ERSAL, OSU). 1983	11.00
Mist Gas Field map. 1999 (OFR O-99-1)	8.00
Digital disk (CAD formats .DGN, .DWG, .DXF)	25.00
Mist Gas Field production 1979-1992 (OFR O-94-6)	5.00
Oregon rocks and minerals, a description. 1988 (OFR O-88-6)	6.00
Mineral information by county (OFR O-93-8), 2 diskettes	25.00
Directory of mineral producers. 1993 (OFR O-93-9)	8.00
Geothermal resources of Oregon (DOGAMI/NOAA map). 1982	4.00
Mining claims (State laws on quartz and placer claims)	Free
Back issues of *Oregon Geology*	3.00

*** Non-Departmental publications require additional $3 for mailing.**

Separate price lists for open-file reports, tour guides, recreational gold mining information, and non-Departmental maps and reports will be mailed upon request.

The Department also sells Oregon topographic maps published by the U.S. Geological Survey.

ORDER AND *OREGON GEOLOGY* RENEWAL FORM

Use publications in list to indicate desired publications and enter total amount below. Send order form to **The Nature of the Northwest Information Center, Suite 177, 800 NE Oregon Street, Portland, OR 97232-2162**, or to **FAX (503) 731-4066**. If you wish to order by phone, have your credit card ready and call **(503) 872-2750**. Payment must accompany orders of less than $50. Payment in U.S. dollars only. Publications are sent postpaid, except where noted. All sales are final. Subscription price for *Oregon Geology*: $10 for 1 year, $22 for 3 years.

Renewal __ / new subscription__ to *Oregon Geology*: 1 yr ($10) or 3 yrs ($22) $________

Total amount for publications marked in list of available publications: $________

Total payment enclosed—or to be charged to credit card as indicated below: $________

Name/Address/City/State/Zip________________________

____

Please charge to Visa__ / Mastercard__, account number: ________________

Expiration date:__________Cardholder's signature________________