OREGON GEOLOGY

published by the
Oregon Department of Geology and Mineral Industries

VOLUME 59, NUMBER 1 JANUARY/FEBRUARY 1997

IN THIS ISSUE:

OREGON GEOLOGY

(ISSN 0164-3304)

VOLUME 59, NUMBER 1 JAN./FEB. 1997

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*.)

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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 Beverly F. Vogt, Publications Manager, at the Portland office (address above).

Cover photo

Slab of shale with fossil plant remains from the locality at Fossil, Oregon, at 85 percent of natural size. Impressions include leaves of *Juglans*, *Porrotia*, *Paracarpinus*, *Alnus*, and *Quercus*, fruit valves of *Craigia*, and an *Acer* samara. Specimen collected 1988 and housed at Florida Museum of Natural History, Gainesville, Florida. Article beginning on next page dates locality at about 32.6 million years.

In memoriam: John Eliot Allen

He was one of the "grand old men" of Oregon geology, well known as geologist, teacher, and author.

John Eliot Allen began his professional career in 1935 as a ranger-naturalist at Crater Lake National Park. In 1937, he became part of the beginnings of the Oregon Department of Geology and Mineral Industries, first as a "Field Geologist," finally as "Chief Geologist." He was one of three geologists with a doctoral degree (along with Wallace D. Lowry and Ewart M. Baldwin) whose simultaneous departure for better positions in industry or the academic world hit the agency hard in 1947.

John Eliot Allen, 1908–1996

Aside from his regular duties, field mapping continued to be a favorite occupation of his until 1954, and he conducted field studies in California, Washington, Nevada, New Mexico, Arizona, and Pennsylvania as well as in Oregon. His last geologic quadrangle map was produced on air-photo mosaics—"perhaps the first time they had been used that way," he wrote in his autobiography. (A brief summary appeared in *Oregon Geology* in the May 1994 issue.)

He guided the first steps of the Portland State University Geology Department, building its program and serving as its head for 18 years, from 1956 to 1974. For his outstanding and enthusiastic teaching, the National Association of Geology Teachers honored him with the Neil Miner Award in 1972. In his lectures, he was using a multimedia approach already in the 1960s. In 1995, he received a Presidential Citation from Portland State University for his "outstanding service and dedication."

When he retired from teaching in 1974, he concentrated on writing about geology for the lay reader. PSU commented on this start of his "third career" with the words, "And he has yet to slow down." The latest of his hundreds of articles and books is reviewed on page 21 of this issue.

John Eliot Allen died November 17, 1996, at age 88. He never slowed down. □

Age of the plant-bearing tuffs of the John Day Formation at Fossil, Oregon, based upon $^{40}Ar/^{39}Ar$ single-crystal dating

by William C. McIntosh, New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico 87801; Steven R. Manchester, Department of Natural Sciences, Florida Museum of Natural History, University of Florida, Gainesville, Florida 32611; and Herbert W. Meyer, Florissant Fossil Beds National Monument, Florissant, Colorado 80816.

ABSTRACT

The age of the fossil plant locality in the town of Fossil, Oregon, is estimated based upon $^{40}Ar/^{39}Ar$ analysis of sanidine crystals from the fossil-bearing tuffaceous shale. The resulting date of 32.58±0.13 Ma provides a more reliable date for the locality than previous whole-rock K-Ar dates of the underlying basalt (29.7±1.6 Ma and 33.8±1.7 Ma). The new date confirms an early Oligocene age for the flora, shows that the assemblage is approximately coeval with that of the Bridge Creek flora at the Painted Hills locality, and indicates that hardwood deciduous forest similar to that found today in eastern North America and eastern Asia was established less than 1.5 million years following the Eocene-Oligocene transition.

INTRODUCTION

A well-known locality for fossil plants occurs in the lower part of the John Day Formation in the town of Fossil, Oregon. A general overview of the plant assemblage from this locality, including brief descriptions and illustrations of the characteristic species, was presented by Manchester and Meyer (1987). Many additional taxa have been collected subsequently, and the assemblage is now known to contain more than 65 plant species (Meyer and Manchester, in press) as well as skeletal remains of bat (Brown, 1959), salamander (Naylor, 1979), and frog (T. Dillhoff, T. Fremd, oral communication, 1994). The fossil leaves, cones, flowers, and fruits represent a hardwood deciduous forest similar in composition to present-day forests of temperate eastern North America and eastern Asia. Based upon floral similarities with other fossil assemblages of the John Day Formation, the Fossil locality has been assigned to the Bridge Creek flora and has been considered to be Oligocene (Brown, 1959; Manchester and Meyer, 1987), but direct radioisotopic data have only recently become available.

The fossils occur in tuffaceous lake sediments. In the summer of 1995, we collected a sample of the fossil-bearing tuff from the Wheeler High School locality for radioisotopic age determination. Relatively large euhedral sanidine crystals were isolated from the sample and then dated using the single-crystal laser-fusion $^{40}Ar/^{39}Ar$ dating method. Such age determinations, obtained directly from fossil-bearing rocks, provide an important link between biostratigraphic and radioisotopic geologic time scales. The purpose of this report is to summarize the $^{40}Ar/^{39}Ar$ dating technique, present age results, compare the results with earlier K-Ar dates, and discuss the relevance of the date to the fossil plant assemblage at Fossil.

$^{40}AR/^{39}AR$ DATING TECHNIQUE

The argon-argon ($^{40}Ar/^{39}Ar$) dating technique offers several advantages over conventional potassium-argon (K-Ar) dating (Maluski, 1989). Both methods rely on the natural radioactive decay of ^{40}K to ^{40}Ar (the half-life of ^{40}K is 1.25 Ga [giga-annum=10^9 years]). Assuming that all ^{40}Ar gas escaped from the volcanic melt prior to formation of sanidine crystals, any measurable ^{40}Ar gas found in the sanidine crystals of a rock sample may be attributed to the decay of ^{40}K. Accordingly, the ratio of parent ^{40}K to daughter ^{40}Ar can be measured and used to calculate the age of the rock. In the conventional K-Ar dating technique, K and Ar are measured on separate aliquots of sample. In the $^{40}Ar/^{39}Ar$ technique, the sample is irradiated with neutrons in a nuclear reactor, converting some of the K into ^{39}Ar, which then serves as a proxy for the K. The ratio of parent to daughter isotopes is then measured as the ratio of ^{39}Ar to ^{40}Ar in a single aliquot of sample. This approach allows ages to be measured far more precisely than the conventional K-Ar technique and uses much smaller sample sizes. Laser-heating enables precise ages to be measured on individual, sand-sized mineral grains, permitting identification and rejection of contaminant or altered grains. This method is known as single-crystal laser-fusion $^{40}Ar/^{39}Ar$ dating. One constraint of the $^{40}Ar/^{39}Ar$ dating technique is that all samples must be irradiated with "monitor" minerals of known age in order to accurately determine the flux of neutrons received.

METHODS

A crystal-rich sample of tuffaceous sediment bearing fossil leaf impressions was collected from the Wheeler High School fossil locality (SW¼NW¼ sec. 33, T. 6 S., R. 21 E.). The sample was prepared by crushing and sieving to 120-500 μ (micron), followed by ultrasonic cleaning in dilute (7-percent) hydrofluoric acid. A sanidine separate was produced, using a Franz magnetic separator, density liquids (nontoxic lithium metatungstate), and hand-picking. A 20-mg aliquot of the sanidine separate was packaged with flux monitors of Fish Canyon Tuff sanidine (27.84 Ma, relative to Mmhb-1 hornblende at 520.4 Ma; Samson and Alexander, 1987) and irradiated at the Texas A&M Nuclear Research Center for 14 hours.

$^{40}Ar/^{39}Ar$ analyses were performed at the New Mexico Geochronology Research Laboratory of the New Mexico Institute of Mining and Technology. This facility includes an MAP 215-50 mass spectrometer attached to a fully automated all-metal argon extraction system equipped with a 10-watt CO_2 laser. A total of 31 sanidine crystals from the sample and four to six sanidine crystals from each monitor were individually analyzed. Sanidine crystals were fused by CO_2 laser for 15 seconds; then reactive gases were removed with an SAES GP-50 getter prior to expansion into the mass spectrometer. Extraction line blanks during these analyses ranged from 5×10^{-17} to 2×10^{-16} moles ^{40}Ar and 5×10^{-19} to 2×10^{-18} moles ^{36}Ar. The neutron flux values (J-values) within irradiation packages were determined to a precision of ±0.25 percent by averaging results from six sanidine crystals from each sanidine monitor.

RESULTS AND DISCUSSION

Single-crystal laser-fusion results are summarized in Table 1 and Figure 1. The 31 analyzed crystals range in age from 32.30 to 33.04 Ma, with analytical precisions (±1 standard deviation) generally between ±0.09 and ±0.15 Ma. The K-Ca ratios of individual sanidine crystals (calculated from $^{37}Ar/^{39}Ar$ measurements) range from 22.4 to 39.4, consistent with their derivation from a single eruptive source. The mean age of 30 crystals (excluding crystal 5887–23, which, at 33.04 Ma, is slightly but distinctly older than the other crystals) is 32.58±0.13 Ma. This mean was calculated by equally weighting the values from each crystal, and the error is a simple ±1 standard deviation.

The resulting age of 32.58±0.13 Ma for the leaf-bearing tuff at Fossil provides a refinement over previous unpublished ages obtained for the locality. Our age falls between two whole-rock K-Ar ages presented in a master's thesis by Riseley (1989) from an andesitic basalt immediately underlying the tuffaceous shales. These ages, from Geochron Laboratories, were 29.7±1.6 Ma and 33.8±1.7 Ma. A suite of ten crystals extracted from the same tuff as that treated in the present paper gave a slightly younger $^{40}Ar/^{39}Ar$ age of 32.24±0.18 Ma in an earlier un-

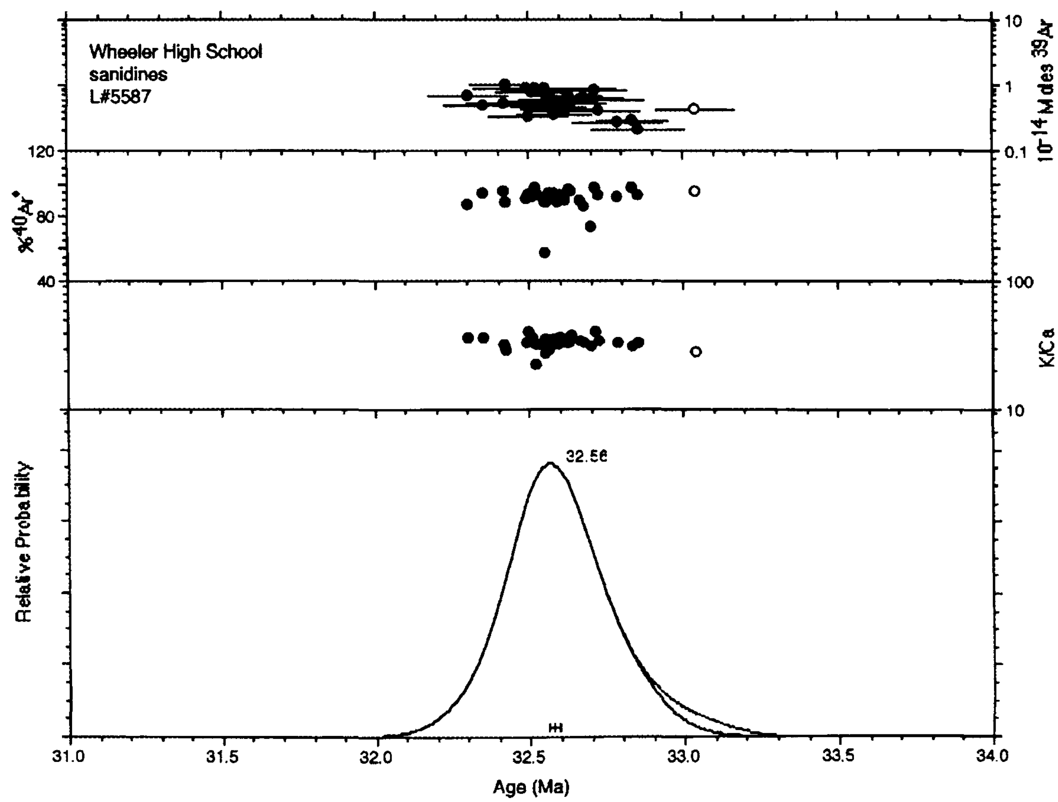


Figure 1. Single-crystal laser-fusion results from sanidines from Wheeler High School sample. Values plotted versus age are signal size in moles ^{39}Ar, radiogenic yield, K-Ca ratio, and relative probability. Analyses used in the mean age calculation are shown as solid circles, and the one analysis excluded from the mean is shown by an open circle. Age uncertainty of each analysis (±1 standard deviation) is shown as horizontal bars on age versus moles ^{39}Ar. The relative probability curve, or ideogram, is the sum of the gaussian probabilities of the individual age determinations.

Table 1. *Single-crystal laser-fusion $^{40}Ar/^{39}Ar$ results. All ages of single sanidine crystals. Errors expressed as ±1 σ. Results in italics excluded from mean values*

Run ID no.	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$	^{39}K moles	K/CA	%$^{40}Ar^*$	Age (Ma)	± Err
5587-20	14.41	1.43E-02	6.39E-03	6.9E-15	35.6	86.9	32.30	0.11
5587-32	13.38	1.41E-02	2.83E-03	4.9E-15	36.2	93.8	32.35	0.11
5587-25	13.26	1.63E-02	2.34E-03	5.2E-15	31.4	94.8	32.42	0.10
5587-40	14.33	1.77E-02	5.96E-03	9.8E-15	28.8	87.7	32.43	0.10
5587-37	13.96	1.55E-02	4.63E-03	8.8E-15	33.0	90.2	32.49	0.10
5587-39	13.56	1.29E-02	3.25E-03	3.3E-15	39.4	92.9	32.50	0.11
5587-28	13.52	1.40E-02	3.12E-03	4.9E-15	36.5	93.2	32.51	0.10
5587-10	13.86	1.49E-02	4.28E-03	7.5E-15	34.2	90.9	32.51	0.10
5587-33	12.92	1.59E-02	1.05E-03	8.6E-15	32.0	97.6	32.52	0.09
5587-36	13.19	2.29E-02	1.99E-03	8.6E-15	22.3	95.6	32.52	0.09
5587-04	13.66	1.64E-02	3.57E-03	8.0E-15	31.2	92.3	32.53	0.09
5587-07	22.16	1.44E-02	3.23E-02	8.8E-15	35.4	57.0	32.55	0.21
5587-30	14.30	1.89E-02	5.69E-03	8.1E-15	26.9	88.2	32.55	0.11
5587-03	14.28	1.56E-02	5.63E-03	5.7E-15	32.8	88.4	32.56	0.11
5587-22	13.51	1.79E-02	3.02E-03	4.5E-15	28.6	93.4	32.56	0.10
5587-02	13.43	1.47E-02	2.73E-03	6.1E-15	34.8	94.0	32.58	0.09
5587-27	13.41	1.47E-02	2.65E-03	3.4E-15	34.8	94.2	32.58	0.10
5587-35	14.45	1.63E-02	6.14E-03	5.6E-15	31.3	87.5	32.59	0.11
5587-31	13.72	1.39E-02	3.66E-03	4.2E-15	36.6	92.1	32.60	0.11
5587-34	14.19	1.56E-02	5.24E-03	3.9E-15	32.7	89.1	32.62	0.12
5587-38	13.21	1.55E-02	1.92E-03	6.9E-15	32.8	95.7	32.63	0.09
5587-06	13.33	1.39E-02	2.30E-03	5.3E-15	36.8	94.9	32.64	0.10
5587-09	14.27	1.52E-02	5.44E-03	6.0E-15	33.5	88.7	32.66	0.11
5587-01	14.72	1.57E-02	6.94E-03	6.3E-15	32.6	86.1	32.68	0.11
5587-08	17.40	1.65E-02	1.60E-02	5.8E-15	30.9	72.8	32.70	0.15
5587-21	13.01	1.29E-02	1.10E-03	8.0E-15	39.5	97.5	32.71	0.09
5587-26	13.74	1.50E-02	3.58E-03	4.1E-15	34.0	92.3	32.73	0.12
5587-05	13.96	1.56E-02	4.23E-03	2.8E-15	32.8	91.1	32.79	0.13
5587-29	13.05	1.64E-02	1.08E-03	2.8E-15	31.0	97.6	32.84	0.10
5587-24	13.73	1.56E-02	3.38E-03	2.0E-15	32.7	92.7	32.85	0.13
5587-23	*13.47*	*1.84E-02*	*2.26E-03*	*4.2E-15*	*27.7*	*95.1*	*33.04*	*0.11*

Mean values: n=30; K/Ca=33.0±3.5; age=32.58±0.13

Analytical parameters: Mass discrimination=1.005±0.002; $^{39}Ar_{Ca}/^{37}Ar_{Ca}$=0.0007±0.0005; $^{36}Ar_{Ca}/^{37}Ar/_{Ca}$=0.00026±0.00002; $^{38}Ar_K/^{39}Ar_K$=0.0119; $^{40}Ar_K/^{39}Ar_K$=0.0002±0.0003; J-value=0.001442918±0.000002. Decay constants from Steiger and Jager (1977).

published analysis (Brent Turrin, written communication to Manchester, 1989).

The new age of 32.58±0.13 Ma is consistent with those obtained for rocks associated with the classic locality of the Bridge Creek flora at the Painted Hills Unit of John Day Fossil Beds National Monument. Evernden and others (1964) published K-Ar ages of 31.8 and 32.3 Ma (corrected to decay constants of Steiger and Jager, 1977) based upon sanidine crystals from tuffs and whole-rock analysis of basalt, respectively. More recently, $^{40}Ar/^{39}Ar$ ages of 32.99±0.11 Ma and 32.66±0.03 Ma were obtained from a biotite tuff 3–5 m stratigraphically below the leaf-bearing tuffs at Painted Hills and from a tuff situated well above the leaf beds, respectively (C. Swisher *in* Bestland and Retallack, 1994); Bestland and others, 1994; Retallack and others, 1996).

The new radiometric data indicate that the Bridge Creek flora, represented by temperate forest assemblages at Fossil, Painted Hills, and various other sites in north-central Oregon (Meyer and Manchester, in press), are early Oligocene in age. Swisher has obtained a radiometric age of 33.62±0.19 for the "slanting leaf beds" on Iron Mountain (Retallack and others, 1996). With the Eocene/Oligocene boundary now placed at about 34.0 million years (Swisher and Prothero, 1990; Berggren and others, 1992), these ages show that the Bridge Creek flora, as known at Fossil, Painted Hills, and Iron Mountain, is representative of the forest that had developed within 0.3–1.5 million years following the Eocene-Oligocene transition.

ACKNOWLEDGMENTS

This research was funded in part by grant EAR 9506727 from the National Science Foundation to S.R. Manchester. Thanks are owed to the citizens of Fossil, Oregon, for keeping the Wheeler High School locality open for public fossil collecting. Critical comments on the original paper were kindly provided by Jeff A. Myers and Wesley Wehr.

(Continued on page 20)

Guidelines for site-specific seismic hazard reports for essential and hazardous facilities and major and special-occupancy structures in Oregon

by the Oregon Board of Geologist Examiners and the Oregon Board of Examiners for Engineering and Land Surveying. Printed with permission and assistance of these Boards. Adopted by the Oregon State Board of Geologist Examiners on September 6, 1996. Adopted by the Oregon State Board of Examiners for Engineering and Land Surveying on September 17, 1996, for distribution and comment.

For over a year, the Board of Geologist Examiners has fostered the development of this document. It was drafted by members of this Board, with input from the practice community through several professional societies. Local chapters of the Association of Engineering Geologists and the Geotechnical Engineering Technical Group of the American Society of Civil Engineers, Oregon Section, were major contributors. The Boards intend to keep the guidelines current and flexible through continuous input from the practice community. Comments and suggestions for improvement of the guidelines are welcomed and encouraged and should be directed to either Board. Both agencies are located at 750 Front Street NE, Salem, OR 97310.

I. INTRODUCTION

These guidelines were prepared by the State of Oregon Boards of Geologist Examiners and Examiners for Engineering and Land Surveying to assist those who prepare reports for site-specific seismic hazard reports for essential facilities, hazardous facilities, major structures and special occupancy structures as provided in Oregon Revised Statutes 455.447(2)(a) and Oregon Administrative Rules 918-460-015. The guidelines describe the general content of these reports and are not intended to be a complete listing of all the elements of a site-specific seismic hazard report as outlined in Section 2905 of the Oregon Structural Specialty code.

These guidelines are intended to be used as a checklist for projects of varying size and complexity including hospitals, schools, and emergency-response facilities. The preparer and the reviewer of site-specific seismic hazard reports are expected to tailor the scope of work and interpretations to the size, occupancy, and critical use of the proposed structure. It is recognized that the techniques used to evaluate a site for a larger and more critical facility will be more complete and detailed than for a smaller and less critical building or other structures. The site-specific investigations vary according to the local geologic conditions that may affect the performance of the proposed or existing structure and to the proximity to faults that are expected to be seismogenic. The investigator(s) is (are) expected to be knowledgeable about the current practice of seismic geology and earthquake engineering and should be aware of the need to provide designers of buildings and other structures with information that can be readily utilized in construction or remodeling projects to reduce seismic risk.

The professional who is performing, signing, and stamping the site-specific investigation is responsible for the adequacy of investigative procedures and reporting that will adequately characterize seismic risk for the proposed use of the subject site. The report should clearly state the techniques used in the investigation, the data acquired, and the findings and recommendations, so that peer reviewers and users of the resulting reports will have a basis for judging the adequacy of the investigation.

In Oregon, the complexity of local geology, limited geologic exposure, variety of earthquake types, and the potential for multiple seismic hazards, including ground shaking, fault rupture, amplification, landsliding, liquefaction, uplift and subsidence, seiche, and tsunami generation, necessitate a choice of investigative techniques that will vary from site to site and that must be chosen based on the geologic hazards and subsurface conditions and on the intended use of the structure.

The following guidelines are intended to be applicable for projects with a wide range in size, cost, and utility. Flexibility in the use of the guidelines is expected, and professional judgment is needed in the selection of work elements for the investigation and in the thoroughness of the resulting report. The preparer and the reviewer of site-specific seismic hazard reports are expected to be familiar with the use of such reports by engineers engaged in the geotechnical and structural design of buildings, so that the reports are designed to be routinely used by designers to maximize the reduction in seismic risk, as structures are constructed or retrofitted.

State law, related administrative rules, and state and local building codes are evolving in an effort to mitigate seismic risk. The preparers, supervisors, and reviewers of site-specific seismic hazard reports are expected to be knowledgeable about relevant laws, rules, and codes.

Some cities and counties in Oregon have ordinances requiring geologic hazard reports. The content of these reports may overlap with the guidelines for the site-specific seismic hazard reports. The geologic hazard reports typically are required for areas mapped by the Oregon Department of Geology and Mineral Industries as landslide or potential landslide areas or as tsunami inundation areas. The geologic hazard reports required by local government ordinance may cover a broader range of facility uses, sizes, and occupancy levels than the site-specific seismic hazard reports that are the focus of these guidelines. The geologic hazard reports range in scope from reconnaissance level investigations to more intensive site-specific seismic hazard studies.

These guidelines are intended to be informal and not regulations. The guidelines are expected to evolve, as the relevant seismic hazards are better defined and as building codes and engineering practices change.

II. CONTENT OF SITE-SPECIFIC SEISMIC HAZARD REPORTS

The following information should be considered in preparing site-specific seismic hazard reports in Oregon.

A. Purpose and scope of the investigation, including a brief description of the proposed site use, size of the proposed building or other structure, occupancy, and current seismic zonation (UBC).

B. Regional geologic and tectonic setting, including a complete list of all seismogenic faults that could impact the site and a description of the crustal, intraplate, and subduction-zone earthquake hazards.

C. Site conditions, including elevation, subsurface conditions, landforms, site grading, vegetation, existing structures, and other features that may influence the investigation.

D. Description of the investigation

1. *Regional seismic history and tectonic setting*
   - **a.** Significant historic earthquakes and tsunamis in the region and locations and magnitudes of seismic events in the vicinity of the site. Crustal earthquakes, intraplate, and interface subduction zone events should be included.
   - **b.** Evidence of prehistoric earthquakes and tsunamis that may have affected the site.
   - **c.** Map showing the location of seismic features relative to the proposed project and an estimate of the amount of disturbance relative to bedrock and surficial materials.
   - **d.** Selection for appropriate strong-motion attenuation relationships for the site.
   - **e.** Published probabilistic estimate of earthquake occurrence.
   - **f.** Geodetic and strain measurement, microseismicity monitoring, or other monitoring.
2. *Interpretation of aerial photography and other available remotely sensed images relative to the geology and earthquake history of the site*, including vegetation patterns, soil contrasts, and lineaments of possible fault origin.
3. *Site investigation*
   - **a.** Detailed field mapping of soils, geologic units and structures, and topographic features indicative of faulting, such as sag ponds, spring alignments, disrupted drainage systems, offset topographic and geologic features, faceted spurs, vegetation patterns, and deformation of buildings or other structures.
   - **b.** Review of local groundwater conditions including water depth and elevation.
   - **c.** Trenching and other excavating to permit the detailed and direct observation and logging of continuously exposed geologic units, including soils and features that are relevant to seismic hazards. Trenching should cross known or suspected active faults in order to determine the location, timing, and recurrence rate of past movements, the area disturbed, the physical condition of fault zone materials, and the geometry of faulting.
   - **d.** Exploratory drilling and/or test pits designed to permit the collection of data needed to evaluate the depth, thickness, and types of earth materials and groundwater conditions that may identify past seismicity or could contribute to damage potential at the site. Drill holes and/or pits should be located and spaced sufficiently to allow valid interpretations of the resulting data. Subsurface testing could include Standard Penetration Tests (SPT), Cone Penetrometer Tests (CPT), undisturbed tube samples, and collection of bulk samples for laboratory testing.
   - **e.** Surface and subsurface geophysical surveys as appropriate to determine the dynamic properties of the subsurface materials, including shear-wave velocity, shear modulus, and damping.
4. *Subsurface investigation*
   - **a.** Laboratory testing of samples for moisture content, grain size, density, dynamic properties, and other pertinent parameters.
   - **b.** Radiometric analysis of geologic units, study of fossils, mineralogy, soil-profile development, paleomagnetism, or other age-determinating techniques to characterize the age of geologic units.
   - **c.** Estimates of expected magnitude, acceleration, and duration of strong motion for the design earthquakes for crustal and intraplate and interface subduction-zone sources and for other defined earthquakes if required by statute or regulation of the proposed project. The rationale for earthquake-source selection for the relevant types of events should be provided. The design basis earthquakes and ground acceleration maps available from the State of Oregon should be consulted and described.
   - **d.** Determination of appropriate UBC site-specific soil-profile coefficients.
   - **e.** Analytic dynamic soil response analyses to evaluate potential amplification or attenuation of subsurface soil deposits to the underlying bedrock motions.
   - **f.** Evaluation of the liquefaction potential of the subsurface deposits at the site and, if applicable, estimation of liquefaction-induced settlement and liquefaction-induced lateral spreading.
   - **g.** Evaluation of other seismic hazards, including earthquake-induced landslides, generation of tsunamis or seiches, regional subsidence, and fault displacement.

E. Conclusions and recommendation

1. Summarize the results of the seismic study, including the review of regional seismicity, site investigations, selection of the design earthquakes, and office analysis, including the evaluation of ground response, liquefaction, landsliding, and tsunamis on the proposed structure and use of the site. The report should be stamped and signed by a certified engineering geologist or by a registered professional engineer experienced in seismic hazard design or by both, when the work of each can be clearly identified.
2. Recommendations for site development to mitigate seismic hazards. The recommendations could include: ground modification to reduce amplification of ground shaking or liquefaction-induced settlement and lateral spreading potential, remedial treatment options for slope stability, and foundation alternatives to minimize seismic impact to structure.

F. References and appendices

1. Literature and records reviewed.
2. Aerial photographs or other images used, including the type, scale, source, date, and index numbers.
3. Maps, photographs, plates, and compiled data utilized in the investigation.
4. Description of geophysical equipment and techniques used in the investigation.
5. Personal communications or other data sources.

G. Illustrations

1. Location map to identify the site locality, significant faults, geographic features, seismic epicenters, and other pertinent data.
2. Site development map at a scale appropriate to show the site boundaries, existing and proposed structures, graded and filled areas, streets, and proposed and completed exploratory trenches, geophysical traverses, drill holes, pits, and other relevant data.
3. Geologic map and sections showing the distribution of soils, geologic units, topographic features, faults and other geologic structures, landslides, lineaments, and springs.
4. Logs of exploratory trenches, borings, and pits to show the details of observed features and conditions. Groundwater data should be included.

III. ACKNOWLEDGMENTS

The Boards of Geologist and Engineering Examiners would like to thank the individuals who have reviewed and contributed to the preparation of these guidelines, including the local chapters of the Association of Engineering Geologists and the Geotechnical Engineering Technical Group of the American Society of Civil Engineering-Oregon Section. The Oregon guidelines represent a modification of guidelines that have been prepared by the Association of Engineering Geologists; the California Division of Mines and Geology, Department of Conservation; and the Utah Geological and Mineral Survey. □

DOGAMI PUBLICATIONS

Released November 27, 1996:

Relative Earthquake Hazard Map of the Linnton Quadrangle, Multnomah and Washington Counties, Oregon, by M.A. Mabey, I.P. Madin, G.L. Black, and D.B. Meier. Geological Map Series map GMS–104, 6 p. text., $10.

The new map covers portions of northwest Portland, Saint Johns, Linnton, Beaverton, Hillsboro, and West Slope.

The relative hazard map indicates areas that will be most severely affected by earthquakes. Included on the map sheet are smaller maps showing relative liquefaction, ground motion amplification, and slope instability hazards that depend on the way the ground responds to earthquake shaking. These were combined to develop the large relative hazard map. The scale of the relative hazard map is 1:24,000; the smaller maps are at a scale of 1:55,000.

The map is a continuation of a joint DOGAMI-Metro earthquake hazard mitigation study partly funded by the Federal Emergency Management Agency. Earlier released publications from this study include relative earthquake hazard maps of the Portland, Mount Tabor, Lake Oswego, Beaverton, and Gladstone quadrangles, as well as areas in Vancouver, Washington.

Released November 26, 1996:

Oil and Gas Potential of the Southern Tyee Basin, Southern Oregon Coast Range, by I.-C. Ryu, A.R. Niem, and W.A. Niem. Oil and Gas Investigation Series report OGI–19. 141 p., 9 plates, $20.

This report is the result of a five-year study funded by a consortium of corporations and agencies from private industry and federal, state, and county government. The study area is located in the southern Oregon Coast Range and is bounded by the northern margin of the Klamath Mountains.

The authors propose several revisions to the stratigraphy and have created several fence diagrams that correlate logs from numerous exploration wells and measured sections.

Although the authors believe that overall hydrocarbon potential of the area is relatively low, they suggest that the Spencer Formation and members of the White Tail Ridge Formation could serve as reservoir rock for hydrocarbons and that four structures have the potential for natural gas. They indicate that on the basis of their findings, further exploration drilling in the area is warranted.

These DOGAMI publications are now available over the counter, by mail, FAX, or phone from the Nature of the Northwest Information Center and the DOGAMI field offices in Baker City and Grants Pass. Addresses are on page 2 of this issue. Orders may be charged to Visa or Mastercard. Orders under $50 require prepayment. □

Field trip guide to the eastern margin of the Oregon-Idaho graben and the middle Miocene calderas of the Lake Owyhee volcanic field

by Mark L. Ferns, Oregon Department of Geology and Mineral Industries

INTRODUCTION

This field trip guide is for a one-day trip along the eastern flank of the Oregon-Idaho graben (Ferns and others, 1993a,b) in Malheur County, beginning in Jordan Valley and ending in Ontario. The focus is on the early volcanic evolution of the Oregon-Idaho graben, primarily the middle Miocene calderas formed during initial subsidence within the graben. En route commentary and specific stops have been compiled from guidebooks printed for the 1990 joint meeting of the Geological Society of Nevada and the U.S. Geological Survey (Rytuba and others, 1990) and for the 1994 Annual Meeting of the Geological Society of America (Cummings and others, 1994). Emphasis is on the more easily accessible portions of both field trips along segments of the Oregon Scenic Byway system that can be reached by ordinary motor vehicles under most weather conditions. A cautionary note: Although the route is generally suitable for passenger-car travel, wet road surfaces during the spring thaw and sudden summer rainstorms make travel along the unpaved Succor Creek Road between Highway 95 and Highway 201 hazardous. In the summer, the casual traveler is also advised to take along plenty of water. Private property should not be entered without previous permission from the owner. This pertains particularly to the Teague zeolite mine discussed at Stop 5.

The Oregon-Idaho graben is a 30-mi-wide, north-trending volcano-tectonic depression that lies midway between the McDermitt volcanic field (Rytuba and McKee, 1994) and the northeastern Oregon feeder dikes for the Columbia River basalt (Figure 1). Defined by recent geologic mapping of approximately 3,000 mi^2 of extreme eastern Oregon (Ferns and others, 1993a,b), the central part of the graben is filled by over 6,000 ft of middle Miocene volcanic and volcaniclastic rocks.

The Oregon-Idaho graben is one of a number of middle Miocene depressions that began developing during the later stages of Columbia River basalt volcanism, when significant volumes of silicic volcanic lavas were erupted from a north-south belt of vents extending from the south end of the Baker graben southward through the Lake Owhyee volcanic field (Rytuba and others, 1990) in the Oregon-Idaho graben to the McDermitt volcanic field (Rytuba and McKee, 1984) at the north terminus of the northern Nevada rift (Zoback and others, 1994). These features evolved as part of a north-northwest-trending, 560-mi-long middle Miocene synvolcanic rift system (Zoback and others, 1994) that links the northern Nevada rift with the Columbia River

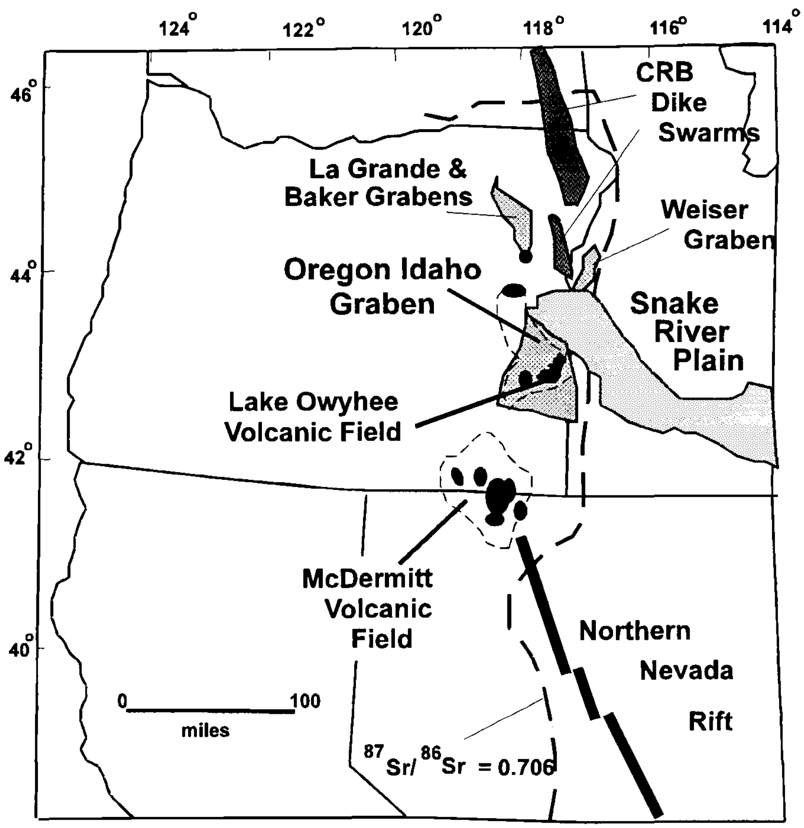


Figure 1. Tectonic setting of the Oregon-Idaho Graben, showing location between the northern Nevada rift, La Grande-Baker grabens, and the main feeder dike swarms of the Columbia River basalt (CRB). These features lie just to the west of the $^{87}Sr/^{86}Sr = 0.706$ line and define a major middle Miocene rift system. The western Snake River Plain is a younger structure that crosses the earlier middle Miocene structures. Current thinking (see Zoback and others, 1994) is that the extensional basins, dike swarms, and caldera fields are all related to emergence of the Yellowstone Hot Spot in this region at about 16 Ma.

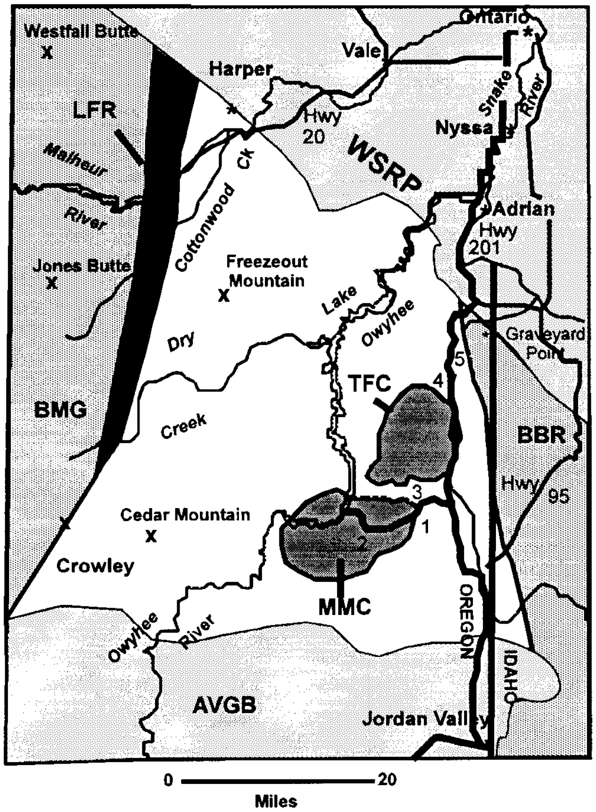


Figure 2. Sketch map of the Oregon-Idaho graben showing field trip route, stops, and major geologic features. AVGB=Antelope Valley graben, WSRP=western Snake River Plain; intragraben rhyolites include Littlefield Rhyolite (LFR), Mahogany Mountain caldera (MMC), and Three Fingers caldera (TFC). Margins of the graben are defined by middle Miocene tholeiitic basalts: the basalt of Bishop's Ranch (BBR) and the basalt of Malheur Gorge (BMG).

basalt dike swarms. Purpose of this field trip is to examine early calderas whose collapse coincided with initial subsidence within the graben.

Although the sedimentary, volcanic, and structural features that define the later stages of graben evolution are best developed in the central part of the Oregon-Idaho graben, which lies to the west of the field trip route, the reader should be aware of the overall structural, sedimentary, and volcanic history within the graben. Cummings and others (1994) noted three subsequent stages of structural evolution following caldera collapse:

Stage 1 was marked by incursion of fluviatile arkoses in a basin where topographic highs, rhyolite domes, and coalescing fields of silicic tuff cones were constructional features related to the caldera-forming eruptions. This was the period in which the lower units of the Sucker Creek Formation (Corcoran and others, 1962; Kittleman and others, 1965) were deposited.

Stage 2 was marked by the breakup of the graben floor into subsiding intragraben subbasins during initial eruption of the calc-alkaline lava flows that make up the Owyhee Basalt (Bryan, 1929). Topographic highs at this time were mainly constructional features formed by mafic volcanoes, such as Spring Mountain, and hydrovolcanic vents, all of which are situated along north-trending intragraben fault zones. Reducing rates of magmatism resulted in local erosion along fault scarps. Large geothermal systems active at this time fed hot springs that discharged into arkose-laden streams, forming epithermal gold systems such as the Katey and Mahogany prospects. The Deer Butte Formation (Corcoran and others, 1962; Kittleman and others, 1965) and upper units in the Sucker Creek Formation were deposited throughout Stage 2.

Fluviatile and lacustrine sediments of the Grassy Mountain Formation (Kittleman and others, 1965) were deposited in Stage 3 and mark a return to aggrading, basin-wide sedimentation accompanied by reduced rates of subsidence and waning volcanic and geothermal activity. Stage 3 units along the field trip route have been largely removed by erosion and are preserved only as arkose conglomerates in the uppermost part of the Sucker Creek Formation that crop out at the base of the Jump Creek Rhyolite (Kittleman and others, 1965).

The Oregon-Idaho graben ceased to be an important synvolcanic feature at about 11 Ma, when the Jump Creek and Star Mountain rhyolites were erupted on the east and west graben flanks, respectively. Renewed eruption of large-volume rhyolites coincided with cessation of calc-alkaline volcanism within the graben and marked the start of the westward-younging rhyolite track across central Oregon (MacLeod and others, 1976; Walker and MacLeod, 1991). Later subsidence, volcanism, and hydrothermal activity were related to regional forces accompanying development of the northwest-trending western Snake River Plain and the east-west trending Antelope Valley graben (Rytuba and others, 1990; Ferns and others, 1993a,b). Lavas erupted at this time are mainly olivine basalts, ranging in composition from high-alumina olivine tholeiites to alkalic basalts (Hart and Mertzman, 1983; Cummings and others, 1994). Much of the modern topographic relief now apparent within the graben formed as many of the north-trending faults were reactivated.

FIELD TRIP GUIDE

Mile point 0.0 Field trip begins at Jordan Valley (Figure 2), on the Oregon-Idaho state line at intersection of Yturri Road and U.S. Highway 95.

The town of Jordan Valley lies on the northeast edge of the Antelope Valley graben (Rytuba and others, 1990), a Pliocene to Holocene, east-west trending graben that truncates the south end of the Oregon-Idaho graben. Bold cliffs on the skyline to the south mark the major, down-to-the-north fault that defines the south margin of the Antelope

Valley graben (Rytuba and others, 1990). The northern margin of the Antelope Valley graben is not well expressed topographically and consists of a series of small-displacement, short-strike-length, down-to-the-south faults that have been largely buried by Pliocene to Holocene lava flows erupted from vents within and along the northern flank of the Antelope Valley graben.

En route to the Mahogany Mountain caldera

Mile point 1.0 Near hills to northeast and northwest are silicified siltstone and sandstone beds in the Sucker Creek Formation (Kittleman and others, 1965, 1967). The low hill immediately to the west is underlain by a basalt sill that is mined for road metal. Silicified mudstones mark the surface expression of a paleo-hot spring at the top of the hill. Ridge line 3 mi to the east is part of the eastern margin of the Oregon-Idaho graben and is underlain by 16-Ma rhyolite lava flows and tholeiitic basalts. The basalts were erupted at about the same time as the Imnaha and Grande Ronde Basalts of the Columbia River Basalt Group to the north and the Steens Basalt to the west and together make up an extensive middle Miocene flood-basalt province that extends from the northern Nevada rift northward through eastern Oregon to southeast Washington (Figure 1).

Workings of the DeLamar Mine are visible on the skyline to the southeast. The modern open-pit mine has been in operation since 1977. About 160,000 oz of silver and 26,000 oz of gold a year (Rytuba and others, 1990) are mined from mineralized fault zones in a rhyolite-dome complex here on the east flank of the Oregon-Idaho graben.

Mile point 6.0 Low hills on the right (east) of the highway and the low sinuous east-west trending ridge immediately to the left (west) are capped by unconsolidated gravels and are examples of inverted topography. Flat-topped mountain farther to the west is Table Mountain, capped by a Pliocene basalt flow. Even though unconsolidated, the gravels are more resistant to erosion than the adjacent soft tuffaceous lake sediments. Elevation of the channels suggest that they formed when the Pliocene basalt flows on Table Mountain were erupted. Opaline sinter exposed under the gravels on the low ridge to the west marks another ancient hot spring.

Mile point 9.0 The Table Mountain basalt is one of the older and northernmost flows erupted from vents within the Antelope Valley graben. Here, the northern margin of the Antelope Valley graben is not well expressed topographically. Road to the left leads to Jordan Craters, the youngest (2,000–4,000 yr B.P.) basalt flow in this region. The Jordan Crater flow blocked Cow Creek and formed Cow Lakes (Kittleman, 1973; Hart and Mertzman, 1983).

Mile point 10.0 The old town site of Sheaville was located just north of where Highway 95 crosses Cow Creek. The mountain that forms the skyline to the northwest is Spring Mountain, a large Stage 2 calc-alkaline shield volcano (MacLeod, 1990b). Silicified conglomerates exposed to the west overlie Spring Mountain basalt flows. Ridge to the east is made up of rhyolite lava flows similar to those at DeLamar that are overlain by the basalt flows. Bold cliff-formers on the ridges to the southeast are the tuff of Swisher Mountain (Ekren and others, 1982), an enormous ash flow that entered into the southern end of the Oregon-Idaho graben from the south at about 14.7 Ma (Minor and others, 1987; Evans and others, 1987; Rytuba and others, 1990). The stratigraphic position of the ash flow atop distal basalt flows from Spring Mountain indicates that the Spring Mountain volcano erupted between 15.5 and 14.7 Ma, at roughly the same time as the better studied Owyhee Basalt to the north. Eruption of these calc-alkaline flows heralded the Stage 2 breakup of the floor of the Oregon-Idaho graben into distinct subbasins.

The tuff of Swisher Mountain is one of the largest rhyolitic units identified in Oregon, covering an area of about 3,300 mi^2 with as much as 1,000 ft of rheomorphic ash-flow tuffs. It was emplaced at very high temperatures, hot enough to liquefy and flow for short distances following its initial emplacement as an ash flow. Volume of material emplaced in Oregon, Nevada, and Idaho during this eruption is estimated to be on the order of 300 mi^3 (Ekren and others, 1984).

Mile point 12.5 White beds exposed on both sides of the highway as it drops down to the valley of Succor Creek are zeolitized airfall tuffs that crop out in the lower part of the Sucker Creek Formation. At least five massive beds of clinoptilolite-rich zeolite are exposed. Holmes (1990) noted that zeolitization here is at least in part a hydrothermal process, as the most intensely altered rocks are associated with large breccia pipes. Although the rhyolite vents that produced these massive airfall deposits have not yet been identified, their stratigraphic position beneath the basalt flows at Spring Mountain suggests that the Mahogany Mountain and Three Fingers calderas might have been sources for the ashes.

Mile point 16.6 Disrupted rock layer to the east is part of a large landslide (MacLeod, 1990a). White ridges farther to the east are within Coal Mine Basin, a noted plant fossil locality within the Sucker Creek Formation (Walden, 1986).

The Sucker Creek and Deer Butte Formations are stratigraphic units well entrenched in the literature. The Sucker Creek Formation, as originally defined by Corcoran and others (1962), Kittleman and others (1965, 1967), and Kittleman (1973), includes all clastic rocks, including ash-flow and air-fall tuffs, hydrovolcanic deposits, and fluviatile and lacustrine sediments that lie either below the Jump Creek Rhyolite or the Owyhee Basalt, while the Deer Butte Formation (Corcoran and others, 1962; Kittleman and others, 1965, 1967) includes all middle Miocene units that lie above the Owyhee Basalt (Bryan, 1929). Thus, in the area encompassed by this field trip, the Sucker Creek Formation as originally defined includes all outflow and intracaldera tuffs and sedimentary units deposited between 15.5 and 10.6 Ma. Early workers (Corcoran and others, 1962; Kittleman and others, 1965, 1967; Kittleman, 1973), lacking radiometric dates, geochemical analyses, and high-resolution faunal dates, concluded that the Owyhee Basalt was a regionally extensive stratigraphic marker whose position determined whether a sedimentary unit was Sucker Creek Formation (stratigraphically below the Owyhee Basalt) or Deer Butte Formation (stratigraphically above the Owyhee Basalt). More recent workers, (Ferns and others, 1993a,b) have concluded that the Owyhee Basalt is confined to the central part of the Oregon-Idaho graben and, together with hydrovolcanic centers in both the Sucker Creek and Deer Butte Formations, was produced by an areally restricted pulse of early Stage 2 calc-alkaline volcanism (Cummings and others, 1994). Walden (1986) and Ferns (1988a,b) noted an angular unconformity within the Sucker Creek Formation that separates predominantly tuffaceous lacustrine units, such as the lowermost exposures in Coal Mine Basin, from overlying, predominantly fluviatile arkosic units.

Mile point 18.9 Turn left (west) off Highway 95 onto Succor Creek Road; marked by the Oregon Scenic Byway sign. Exposures at the intersection are distal hyaloclastite deposits erupted from a large mafic hydrovolcanic vent to the northeast. Picture rock (varicolored silicified tuff) and zeolite are being mined from parts of the large hydrothermal-alteration zone that encompasses the vent. A classic hydrothermal-eruption breccia within late Stage 2 arkose sandstones is exposed at the Mahogany gold prospect, located about 1.5 mi to the northeast (Rytuba and others, 1990).

Mile point 23.0 Succor Creek Road heads north along Deadman Gulch. The ridge to the east is made up of altered hydrovolcanic deposits. The large hydrovolcanic center lies to the east and forms Chrisman Hill.

CALDERAS OF THE LAKE OWYHEE VOLCANIC FIELD

Although Kittleman (1973) recognized the Leslie Gulch Ash-Flow Tuff as the product of a large volcanic eruption, Rytuba and others (1985) were the first to identify large rhyolite calderas in the Lake Owyhee region. Rytuba and others (1990) include all middle Miocene silicic vents that formed following eruption of the Steens Basalt in the Lake Owyhee volcanic field, the eastern margin of which coincides with the Oregon-Idaho state line. The western margin is roughly coincident with the course of the South Fork of the Malheur River, the southern margin is marked by the Antelope Valley graben, and the northern margin is marked by the pre-Tertiary exposures of the southern Blue Mountains province (Rytuba and others, 1990). Even though seven ash-flow sheets and five calderas are reported by Rytuba and others (1990) within the Lake Owyhee volcanic field, only two, the Mahogany Mountain and Three Fingers calderas (Figure 3), are recognizable middle Miocene silicic centers that predate Stage 1 subsidence of the Oregon-Idaho graben. Of the other calderas reported by Rytuba and others (1990), his "Castle Peak" lies west of the graben; his "Saddle Butte" is undefined; and his "Star Peak," presumably coincident with the 10- to 12-Ma Star Mountain center identified by Ferns and others (1993b), is a late Miocene center that formed after the Oregon-Idaho graben became quiescent. Another possible caldera, defined by a pronounced, arcuate gravity low to the southwest of the Mahogany Mountain caldera, has been suggested as the source for either the tuff of Birch Creek (Vander Meulen and others, 1990) or the tuff of Iron Point (Evans and others, 1990).

Of the two calderas—Mahogany Mountain and Three Fingers (Rytuba and others, 1990)—exposed well enough to show internal stratigraphy, only the Mahogany Mountain caldera has been studied in any detail (Vander Meulen, 1989). The Mahogany Mountain caldera is marked by thick sections of intracaldera pyroclastic surge, ash-flow tuff, and air-fall tuff deposits as well as ring-fracture and central-vent rhyolite domes, dikes, and autobreccias. Abrupt changes in ash-flow thickness over caldera margins mark the transition between outflow and intracaldera facies. Although the northern and western margins of the Mahogany Mountain caldera are poorly defined topographically and the eastern margin is truncated by the Devil's Gate fault zone, the near-coincident occurrence of an arcuate mass of thick ash-flow and air-fall deposits with a prominent, arcuate gravity low (Brown and others, 1980; Rytuba and others, 1990) provides evidence of a classic rhyolite caldera.

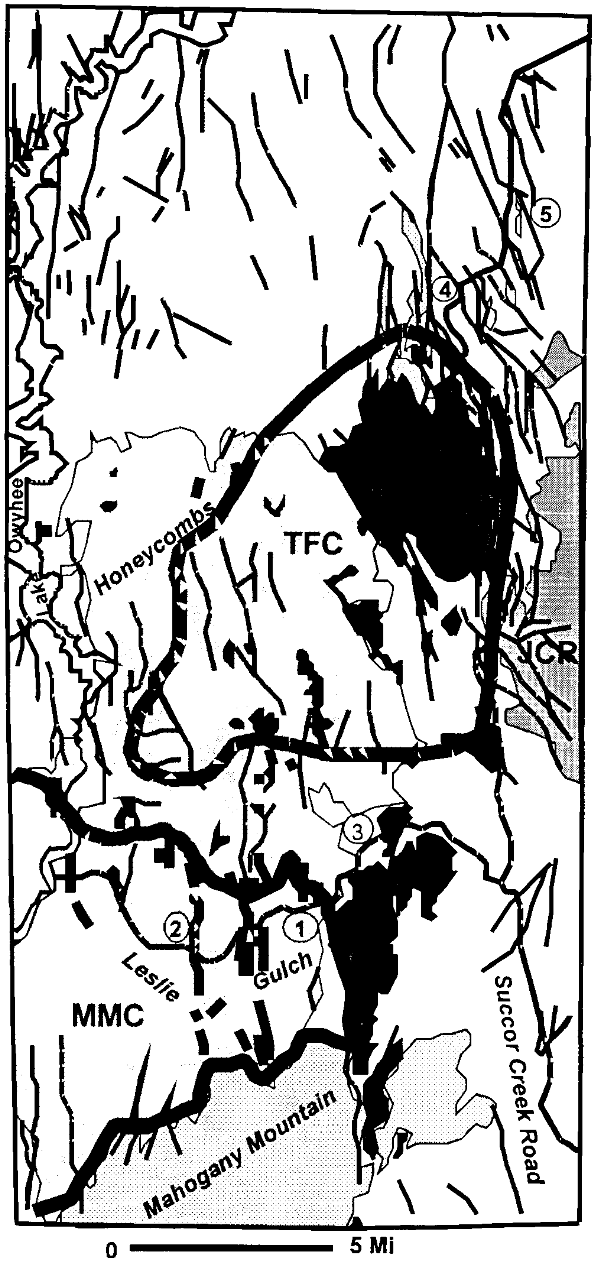
En route

Mile point 27.1 Turn west (left) at Rockville School; the road to the north leads back to Highway 95. Major cliff former to the northeast is the Jump Creek Rhyolite (Kittleman and others, 1965, 1967), a 10.6-Ma, large-volume rhyolite lava flow that was erupted near the east graben margin, near the end of synvolcanic subsidence within the graben. Prominent knob to northwest is Smith Butte, an older 15.5 Ma rhyolite dome that was emplaced along the southern ring fracture of the Three Fingers caldera.

Mile point 27.4 Cross small bridge and bear right, heading to north.

Mile point 27.9 The main massif formed by the Jump Creek Rhyolite lies to the north. Hummocky topography at the base of the cliffs is made up of landslide blocks of Jump Creek Rhyolite on underlying, less competent Sucker Creek Formation units. Brown and white units exposed just west of the are part of the younger Sucker Creek Formation units, here dominantly bentonite clays, that lie unconformably across older Sucker Creek tuffs.

Mile point 29.0 Turn left onto the well-maintained BLM gravel road leading to Leslie Gulch. Hills that form skyline



← *Figure 3. Geologic sketch map along the east side of the Oregon-Idaho graben showing locations of Stops 1–5. Margins for the Mahogany Mountain (MMC) and Three Fingers (TFC) calderas are from Vander Meulen (1989) and Rytuba and Vander Meulen (1991). Large, precaldera rhyolite lava flows on Mahogany Mountain (Stop 1) and at Devils Gate (Stop 4) mark caldera margins. Curvilinear faults on the southwest margin of the Three Fingers caldera suggest multiple stages of collapse (Vander Meulen and others, 1989). North-trending rhyolite dikes near the center of the Mahogany Mountain caldera (Stop 2) mark the central vent complex (Vander Meulen, 1989). Postcollapse domes at Bannock Ridge (Stop 3) that were erupted along the Devils Gate fault zone at about 12.8 Ma host hot-spring-type mineralization. Rheomorphic ash-flows at Stop 5 are outflow sheets that lie atop older middle Miocene tholeiitic basalt basement rocks (basalt of Bishop's Ranch). JCR = Jump Creek Rhyolite.*

in distance (west) are rhyolite flows and domes of Bannock Ridge, a rhyolite complex emplaced at 12.8 Ma (Rytuba and others, 1990; Zimmerman, 1991) along the north-trending Devils Gate fault zone (Ferns and others, 1993a). Major intragraben fault zones (shown on Figure 4) include the Wall Rock Ridge (WRZ), Dry Creek Buttes (DCZ) (Cummings, 1991; Cummings and others, 1993), and Devils Gate (DGZ) zones. The fault zones form prominent, north-striking structures that served as magmatic and hydrothermal conduits. Each fault zone typically consists of a 2- to 3-km-wide zone of closely spaced, short-strike-length, steeply dipping normal faults. During their early evolution, as the fault zones exerted control on volcanism, displacement on individual fault segments was small (<3 ft) with cumulate displacement in tens of feet across the fault zone. As an individual fault zone evolved, the greatest displacements (>150 ft) were localized along a few, longer strike-length faults. Displacements of this magnitude produced topographic scarps that deflected drainages along the sub-basin boundaries. Cumulative displacements of at least 500 ft typically occur along long strike-length master faults late in the evolution of the intragraben fault zones. Sense of movement along the Devils Gate zone is down to the east, with postcaldera units downdropped to the east.

Mile point 32.7 The southern topographic wall of the Mahogany Mountain caldera is visible on the skyline south of the road (Rytuba and others, 1985; Vander Meulen and others, 1987b). The Mahogany Mountain caldera was the vent from which the Leslie Gulch Ash-Flow Tuff (Kittleman and others, 1965, 1967) was erupted. The ash-flow is the lowest exposed unit of the Sucker Creek Formation and was first described by Kittleman and others (1965) as a sillar, an ash-flow indurated by escaping gases rather than by welding.

Prominent ridges to the north are made up of resistant rhyolite dikes and faulted rhyolite domes. Intervening areas of low relief are underlain by less resistant ash flows. The pale pink area to the northeast is part of the Bannock gold prospect. Alteration zones in the rhyolites are commonly marked by such bleached, lighter colored zones.

Mile point 35.7 Stop 1

Stop at view point for overlook of upper Leslie Gulch. Steep escarpment to the south marks where the south wall of the Mahogany Mountain caldera cuts a precaldera rhyolite-flow dome on Mahogany Mountain (Rytuba and others, 1985). Tall spires and pinnacles to the west are part of the intracaldera facies of the Leslie Gulch Ash-Flow Tuff, which was erupted at about 15.5 Ma (Rytuba and Vander Meulen, 1991). Section here dips to the west, toward

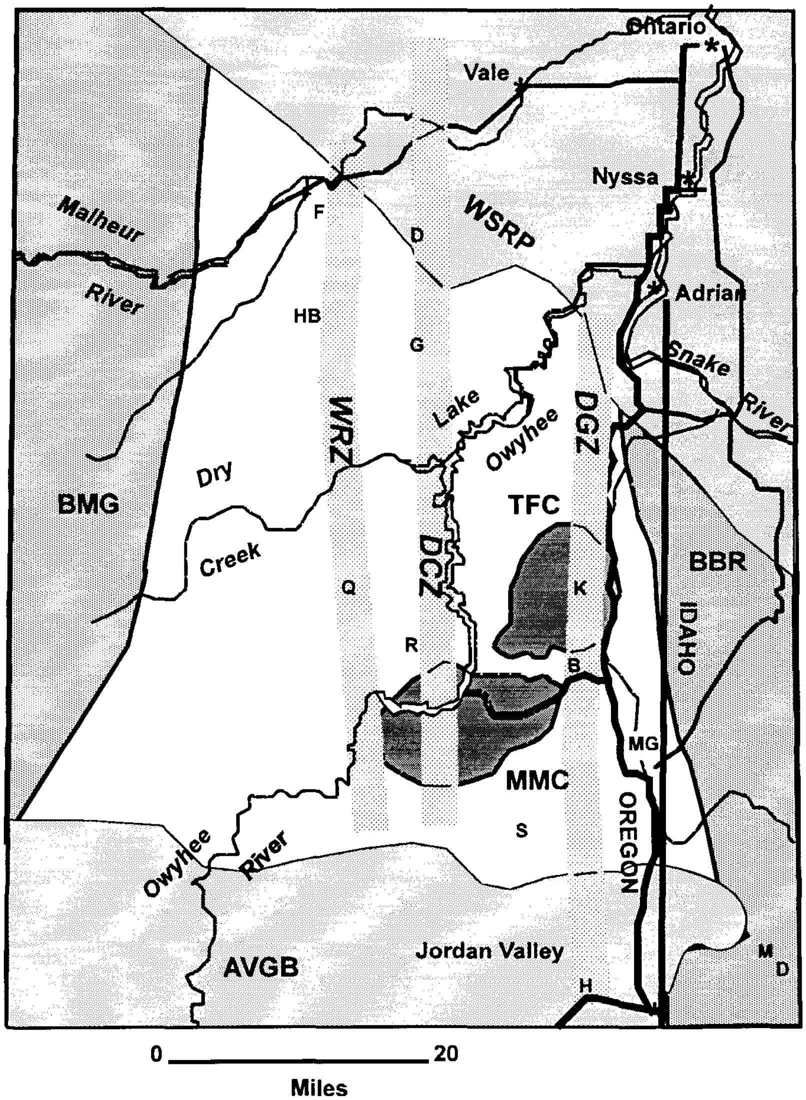


Figure 4. Sketch map showing major intragraben fault zones, major gold prospects, and the DeLamar Mine. DCZ=Dry Creek fault zone; WRZ=Wall Rock Ridge fault zone; DGZ=Devils Gate fault zone; D=DeLamar Mine, MI=Milestone; HI=Hillside; M=Mahogany; S=Storm; B=Bannock; K=Katey; R=Red Butte, Q=Quartz Mountain; G=Grassy Mountain, FZ=Freezeout, DM=Double Mountain; HB=Harper Basin; F=Fenceline. Other symbols are the same as in Figure 2.

the Oregon-Idaho graben axis. The interior of the caldera is well exposed along the road as it descends down Leslie Gulch.

En route

Mile point 37.2 Intracaldera-facies ash flows typically weather to form colorful cliffs and spires such as those to the left. During a climactic eruption, walls of the caldera commonly collapse inward, as multiple ash-flow sheets issue from ring-fracture and axial vents, surging across the subsiding cauldron. Calderas such as Mahogany Mountain evidently collapsed at such a rapid rate that most of the surge and ash-flow deposits are trapped within the caldera, producing relatively small outflow sheets.

Mile point 39.0 Prominent columnar-jointed rhyolite dikes are exposed on both sides of the road. Rhyolite dikes such as these generally trend north-south and can be traced for as much as 3 mi. The pronounced north-south trend of the dikes runs parallel to the graben axis.

Mile point 39.2 Please note that, although most of Leslie Gulch is managed by the U.S. Bureau of Land Management (BLM), the cabin here is on private property. Massive reddish-orange outcrops to the west are intracaldera surge and air-fall deposits of the Leslie Gulch Ash-Flow Tuff. More rounded, green exposures are interpreted by Vander Meulen and others (1987a) and Rytuba and others (1990) to be outflow sheets of the tuff of Spring Creek that entered into an axial graben formed during collapse and resurgence within the central core of the Mahogany Mountain caldera. Massive orange outcrops farther to the west make up part of the central vent complex, one of the main feeder vents for the Leslie Gulch Ash-Flow Tuff (Vander Meulen, 1989).

Details pertaining to the number of caldera eruptions as well as the magmatic and temporal evolution of the Lake Owyhee volcanic field are unclear. Rytuba and others (1990) favor a two-caldera model, initiated by eruptions of the Leslie Gulch Ash-Flow Tuff during collapse of the Mahogany Mountain caldera, followed by resurgence doming and block faulting at the center of the caldera along the eruptive axis, and later followed by eruption of the tuff of Spring Creek from the nearby Three Fingers caldera. Rhyolite dikes were then emplaced along north-trending fissures. This model is based in part on the outcrops straight ahead. The orange spires form the eastern margin of a feature interpreted by Rytuba and others (1990) as the central apical graben formed during resurgence doming following eruption of the Leslie Gulch Ash-Flow Tuff and preceding the eruption of the tuff of Spring Creek, the green-colored outcrops to the east.

Mile point 40.7 Stop 2

Contact between green and orange tuffs. Pull off into the parking area with restroom to the left of the road to examine outcrops on the north side of Leslie Gulch. Green outcrops to the north are considered by Rytuba and others (1990) to be younger Spring Creek outflow sheets that entered into central apical graben. Detailed examination of the outcrops to the north suggests that individual ash beds can be traced laterally from the green unit to the orange unit, which indicates that here the color contrast between rock units is an alteration front related to rhyolite dike intrusions into the central vent complex rather than two separate eruptions.

The orange pinnacles and spires form part of the central vent complex (Vander Meulen, 1989) for the Mahogany Mountain caldera. The complex consists of an irregularly shaped, matrix-supported autobreccia that is cut by dikes and irregularly shaped plugs of flow-foliated rhyolite.

En route

Mile point 43.0 The BLM road ends on the shores of the Owyhee Reservoir. Leslie Gulch ash flows exposed west of the reservoir are cut by the Rooster Comb, a rhyolite dike that has yielded a K-Ar age of 14.9±0.4 Ma (Rytuba and others, 1990). Green outcrops at the turnaround are interpreted as moat-filling Spring Creek units (Rytuba and others, 1990). Note iron staining of the tuff of Spring Creek where the tuff is intruded by dikes. Rounded hills to the west are made up of Stage 1 sediments that were deposited onto the caldera-fill. Turn around and retrace route to the east, back up Leslie Gulch

Mile point 53.3 Stop 3

Overview of the northern part of the Lake Owyhee volcanic field. The thick intracaldera facies of the Leslie Gulch Ash-Flow Tuff documents eruption, collapse, and fill of the Mahogany Mountain caldera. Although the exact margins of the caldera are in places unclear, the extraordinarily thick pyroclastic deposits visible along Leslie Gulch and a nearly coincident gravity low (Brown and others, 1980; Rytuba and others, 1990) are evidence of the Mahogany Mountain caldera. Pyroclastic eruptions to the north produced a second subsidence structure, the Three Fingers caldera (Rytuba and others, 1989, 1990), whose intracaldera facies, the tuff of Spring Creek, appears chemically distinct from the Leslie Gulch Ash-Flow Tuff (Rytuba and others, 1990). The northwest wall of the Three Fingers caldera is visible in the distance to the north as the rugged outcrops that comprise part of the Honeycombs volcanic center, a series of coalescing silicic tuff cones (Vander Meulen and others, 1987c). The east margin of the caldera is marked by ring-fracture domes such as Round Mountain to the northeast. Rugged topography just this side of the Honeycombs is made up of rhyolite intrusions that were emplaced along three arcuate intracaldera ring fractures (Vander Meulen and others, 1989) on the southwest edge of the Three Fingers caldera. While the Three Fingers caldera has not been studied in detail, it is certain that the caldera's geologic evolution was complex, involving multiple dome and pyroclastic eruptions, coincident with successive stages of collapse along the intracaldera ring fractures.

Rugged outcrops in the immediate foreground are part of the rhyolite of Bannock Ridge, a 12.8-Ma rhyolite (Zimmerman, 1991), which was erupted along the Devils Gate fault zone several million years after the Mahogany Mountain caldera collapsed. The Devils Gate, Dry Creek Butte, and Wall Rock Ridge fault zones have served as magmatic and hydrothermal conduits throughout the subsequent evolution of the Oregon-Idaho graben. While ancient hot springs along the faults occasionally deposited variable amounts of gold, the most important mineral resource mined in this area has been the renowned Owyhee picture rock, a silicified and variably colored fine-grained tuff. Most of the picture rock deposits occur just to the north.

En route to the northeast margin of the Three Fingers caldera

Mile point 53.7 Intersection of Leslie Gulch road with Succor Creek Road. Turn left (north) toward Succor Creek State Park.

Mile point 61.1 Smith Butte, the rhyolite dome exposed to the left (west) side of Succor Creek Road, is located near the southern margin of the Three Fingers caldera.

Mile point 66.6 Round Mountain to the north is another rhyolite dome. The domes are believed to have intruded along the southeast margin of the Three Fingers caldera following its collapse (Rytuba and others, 1990). Rhyolite flows and domes of McIntyre Ridge visible along the horizon farther to the north are also believed to have been emplaced along the caldera margin and overlie a thick section of caldera-fill ash-flow and air-fall tuffs (tuff of Spring Creek).

Mile point 69.1 Continue on main Succor Creek Road. The dirt road to the left leads to Three Fingers Rock and the Katey gold prospects. Gold mineralization at Katey is spatially associated with small high-silica rhyolite domes. Part of the prospect is hosted by late Stage 2 arkose sandstones.

Mile point 70.2 Negro Rock, immediately to the west of the road, is a small rhyolite porphyry dome. McIntyre Ridge to the north is made up of faulted segments of rhyolite domes and lava flows that extruded along the east margin of the Three Fingers caldera. K-Ar dates indicate that McIntyre Ridge flows are 15.8±0.6 Ma old (Rytuba and others, 1990).

Mile point 70.6 Here, Succor Creek Road crosses a landslide that can be tricky to negotiate during wet weather conditions. The landslide is formed on bentonitic clays in the upper part of the Sucker Creek Formation.

Mile point 72.2 The dirt road to the right leads to an overview of upper Sucker Creek Formation units. High cliffs in the background to the east are part of the Jump Creek Rhyolite.

Mile point 73.0 Cliffs to the west are formed of McIntyre

Ridge domes and flows, part of the 15.4-Ma Three Fingers caldera. Massive outcrops to the east are much younger (10.6 Ma) Jump Creek Rhyolite. A number of north- to northwest-trending, down-to-the-east faults cut diagonally across Succor Creek, dropping down the Jump Creek and underlying upper Sucker Creek units adjacent to the older caldera units.

Mile point 73.7 Campground at Succor Creek State Park. The road here follows Succor Creek as it cuts through faulted slices of McIntyre Ridge rhyolite lava flows. Note the steeply dipping vertical and complexly folded flow foliation in the rhyolite lava flows along the west side of the road.

Mile point 75.2 The Succor Creek area is renowned among rockhounds for thundereggs, silica-filled lithophysae, and large gas cavities commonly found in rhyolite. The talus slope to the west contains some thundereggs. While the role of mineralizing fluids in forming thundereggs is not well understood, it is certain that thundereggs here are located in alteration zones along mineralized faults.

Mile point 76.2 Green outcrops to the northwest below the McIntyre Ridge Rhyolite are a section at least 600 ft thick of multiple, caldera-fill ash-flow and air-fall units of the tuff of Spring Creek (Vander Meulen and others, 1987a). Darker outcrops include intermediate-composition dikes and sills that have intruded into these intracaldera tuffs and detached lenses of vitrophyre associated with individual ash flows. Old mine openings low on both sides of Succor Creek date back to an unsuccessful turn-of-the-century effort to mine nitrates. Nitrates were reportedly discovered in 1914, when the young sons of George Huntley started a fire in a cave and were surprised when the white material in rock crevices took fire and burnt vigorously (Mansfield, 1915).

Mile point 79.1 The road crosses Board Corral Creek and leaves Succor Creek canyon, which opens to the north into a broad valley. Dark exposures in the foreground to the northeast are vitrophyre lenses in an outflow sheet of the tuff of Spring Creek. Here, the buried caldera margin is marked by the dramatic thinning of tuff of Spring Creek, from >600 ft in Succor Creek canyon (base not exposed) to <100 ft north of Succor Creek, where the tuff of Spring Creek lies on older tholeiite basalt flows. Prominent cliffs to the northwest are made up of the Devils Gate rhyolite lava flow that issued from a vent along the northeast margin of the Three Fingers caldera. Dirt road to the left leads to an overview of the caldera margin. This is one of the few places where a pronounced lithologic break between caldera-fill tuffs and precaldera basalts can be identified along a caldera wall.

Mile point 80.0 Stop 4

Overview of the Three Fingers caldera margin. Stop at the turnout to the left at the summit of a small hill for an overview of the northeast margin of the Three Fingers caldera. The poorly consolidated arkose conglomerates at the top of the hill are one member of the late Stage 2 upper Sucker Creek Formation. Climb to top of hill to the right (east) for a panoramic view of lower Succor Creek. Granite and rhyolite clasts on the hill are typical of late Stage 2 arkoses in both the Deer Butte and Sucker Creek Formations. Highlands to the southeast are capped by the Jump Creek Rhyolite. High cliffs in foreground are silicified upper Sucker Creek conglomerates exposed below the rhyolite. Other upper Sucker Creek units include bentonitic claystones and siltstones, which are prone to produce landslides where overlain by the Jump Creek Rhyolite. It is instructive to note that here, on the east flank of the Oregon-Idaho graben, only about 200 ft of sediments separate the 10.6- and 15.5-Ma rhyolites, while in the central part of the graben, over 6,000 ft of sedimentary and volcanic rocks were deposited over the same time interval.

Highlands south and west of the Succor Creek canyon, are capped by the older McIntyre Ridge rhyolite flow, which overlies the intracaldera facies of the Spring Creek tuff. North-trending ridges are part of the Devils Gate fault zone (DGZ). Prominent knob in the foreground is a high-silica rhyolite dome that intruded along the caldera margin (Ferns, 1988a). Black, slope-forming outcrops on the north side of the knob are early Stage 2 high-alumina olivine tholeiite basalt (HAOT) flows (Table 1). The HAOT flows are in turn overlain by lower Sucker Creek units.

The Three Fingers caldera margin runs parallel to Board Corral Creek (Figure 4) and is defined by the southernmost exposures of tholeiitic lavas and overlying Devils Gate rhyolite. Eruption of the Devils Gate rhyolite coincided with early ash eruptions and the initial collapse of the caldera. The caldera margin is best exposed about 2 mi up Board Corral Creek.

The Devils Gate fault zone, like other major intragraben fault zones described by Cummings (1991, Cummings and others, 1993), was important in controlling the location of magmatic and hydrothermal conduits. Individual faults exposed here are typical of faults formed late in the evolution of the fault zones, where displacements (>150 ft) are localized along a few, longer strike-length faults that developed following the main pulse of calc-alkaline volcanism. Here, along the east flank of Owyhee Ridge, the Devils Gate fault zone formed a topographic barrier that prevented late Stage 2 members of the upper Sucker Creek Formation from being deposited to the west. Ridge-capping basalt flows to the northwest, west of the fault zone are 13- to 14-Ma Blackjack Basalt flows (Bryan, 1929; Corcoran and others, 1962; Ferns, 1988b) erupted from vents along the fault zone farther to the north. The Blackjack flows include hypersthene-phyric calc-alkaline flows erupted following the main pulse of Stage 2 calc-alkaline volcanism that produced the Owyhee Basalt to the west.

Late Stage 2 upper Sucker Creek Formation units are exposed in the low hills to the north, where arkose con-

Table 1. *Major- and trace-element analyses of tholeiitic and calc-alkaline mafic rocks along the east edge of the Oregon-Idaho graben. Blackjack, HAOT (high-alumina olivine tholeiite), and Spring Mountain samples are representative of post-caldera, calc-alkaline lavas. Hooker Creek and Graveyard samples are representative of the precaldera, tholeiitic basalt of Bishop's Ranch. The Hunter Creek sample is typical of precaldera tholeiites on the west flank of the graben. CRB-GR is a representative sample of the Grande Ronde Basalt, Columbia River Basalt Group, from Hooper and Swanson (1990). The alkali-olivine basalt flow (87-BO-54) lies immediately above outflow facies of the tuff of Spring Creek (Stop 5). Major- and selected trace-element analyses performed by XRAL Laboratories, who used X-ray fluorescence techniques. Major-element analyses were recalculated and normalized on a volatile-free basis. Trace elements marked by * were determined with wet chemical methods by the Oregon Department of Geology and Mineral Industries Analytical Laboratory. Major-element values in percent; trace-element values in ppm*

	Postcaldera calc-alkaline lavas					Columbia River basalt		Precaldera tholeiites			
Sample no.	**87-BO-121**	**87-BO-88a**	**87-BO-54**	**AXB-511**	**AZB-144**	**I-68**	**AXB-707**	**BAB-312**	**BAB-328**	**87-BO-26**	**TLB-1**
Unit	**Blackjack**	**HAOT**	**Alkali**	**Spring Mtn**	**Spring Mtn**	**CRB-GR**	**Hunter Cr**	**Hooker Cr**	**Graveyard**	**Graveyard**	**Graveyard**
SiO_2	52.98	48.67	50.85	56.11	48.52	54.86	54.31	52.40	53.13	56.22	52.48
Al_2O_3	16.70	18.05	15.12	16.49	16.65	13.71	13.25	13.78	16.15	15.41	14.50
TiO_2	1.36	1.15	1.94	1.08	1.43	2.02	2.33	1.73	1.48	1.91	2.60
FeO^t	10.20	11.61	14.71	8.42	12.34	13.11	14.26	13.38	11.99	10.82	12.95
MnO	0.17	0.15	0.24	0.16	0.24	0.23	0.22	0.22	0.26	0.24	0.19
CaO	8.70	10.43	7.35	7.10	10.59	7.51	6.90	9.26	7.18	6.37	7.92
MgO	5.14	7.19	3.87	4.50	6.79	4.02	3.17	5.08	3.62	2.36	4.10
K_2O	1.18	0.22	1.69	2.31	0.40	1.36	2.03	1.02	1.86	1.66	1.81
Na_2O	3.08	2.26	3.54	3.27	2.71	2.70	3.11	2.72	3.73	3.97	2.98
P_2O_5	0.49	0.26	0.68	0.56	0.33	0.30	0.42	0.42	0.60	1.05	0.47
	100.00	100.00	100.00	100.00	100.00	99.82	100.00	100.00	100.00	100.00	100.00
Cr	139	92	<10	87	57	16	25	58	29	<10	34
Co*	27	50	31	23	45	n.d.	25	n.d.	n.d.	19	33
Ni*	72	165	26	51	100	3	13	n.d.	n.d.	15	25
Cu*	44	138	61	46	90	33	18	n.d.	n.d.	17	34
Zn*	94	82	144	108	104	123	151	n.d.	n.d.	126	144
Rb	40	19	28	48	27	32	73	22	37	63	57
Sr	513	244	397	642	448	368	318	366	514	447	432
Y	14	29	46	35	38	36	27	30	31	34	18
Zr	128	39	149	203	101	185	229	159	137	201	275
Nb	20	10	23	26	<10	11	12	35	17	20	<10
Ba	553	89	696	720	222	620	690	528	846	978	668
Li*	11	33	13	7	8	n.d.	14	n.d.	n.d.	10	n.d.

glomerates and underlying bentonite claystone and tuffaceous siltstone were deposited onto a tilted surface of lower Sucker Creek tuffs and hyaloclastite deposits. The upper Sucker Creek is an important source of bentonite clay, which is mined by Teague Mineral Products of Adrian, Oregon, from shallow pits to the north. Drillhole data indicate that the clay resource was deposited in a shallow lake (Leppert, 1990), the western margin of which was marked by the Devils Gate fault zone.

En route to rheomorphic ash-flow tuffs, typical of outflow facies

Mile point 82.5 Turn off to right to proceed to Teague Mineral Products SC zeolite mine. Permission should be obtained from Teague (Adrian, Oregon) before entering the site.

Mile point 83.1 Stop 5

Succor Creek Zeolite Mine. Teague produces here a heulandite zeolite from a massive ash bed associated with a peralkaline ash-flow tuff considered by Ferns and others (1993a) to be an outflow sheet of Leslie Gulch Ash-Flow Tuff. The correlation is based on stratigraphic position and on petrographic and geochemical similarities to analyses reported by Vander Meulen (1989). The Leslie Gulch here is a prominently flow-banded rheomorphic ash-flow tuff that physically resembles a rhyolite lava flow. As is common with many rheomorphic tuffs, it is difficult to find clear field or petrographic evidence of an ash-flow origin. Flattened pumice lapilli and broken crystals are considered to be the best evidence for a rheomorphic ash-flow. Outcrop patterns are often the most diagnostic tool in determining origin: the ash-flows are generally planar sheets, commonly underlain by airfall pumice or tuff; whereas the rhyolite lava flows are considerably more irregular in thickness and possess basal flow breccias that lie on variably baked and deformed tuffaceous sediments (Bonnichsen, 1982). The Leslie Gulch Ash-Flow Tuff can be traced to the southwest, where it is overlain by an outflow sheet of the tuff of Spring Creek (Ferns, 1988b).

The zeolite deposit is a massive ash bed underlain by tholeiite lavas of the basalt of Bishop's Ranch (Kittleman and others, 1965, 1967; Lawrence, 1988). The basalts include ferroandesites and tholeiitic basalts (Ferns, 1988b) that are among the westernmost exposures of an extensive, >1,000-ft-thick section of interbedded middle Miocene mafic and intermediate flows that was erupted at about 17 Ma (Pansze, 1975) onto pre-Tertiary basement rocks to the east (Ekren and others, 1982). Although these flows were erupted at about the same time as Columbia River Basalt Group-type lavas in the Malheur Gorge area on the west side of the Oregon-Idaho graben (15.78±0.59 to 16.49±1.2 Ma, Lees and Hawkesworth, 1993), they typically have more alumina than the Malheur Gorge lavas.

An unusual alkali olivine basalt flow overlies the ash flow south of the mine pit. Well-developed pillows with hyaloclastite rinds are locally developed at the base of the flow, indicating flowage into water (Lawrence, 1988). Although correlation with Blackjack Basalt flows on the top of Owyhee Ridge may be warranted, based on a $^{39}Ar/^{40}Ar$ age of 13.08±0.56 Ma (Lees and Hawkesworth, 1993), no other Miocene alkalic olivine basalts have been identified within the Oregon-Idaho graben.

Faulted blocks of the basalt of Bishop's Ranch on the ridgeline and in the foreground to the east extend into Idaho, where they are unconformably overlain by the Jump Creek Rhyolite (Ferns, 1998a) along the eastern margin of the Oregon-Idaho graben. Ridges to the north include faulted segments of basalt of Bishop's Ranch and Leslie Gulch Ash-flow Tuff.

The prominent bluff in the foreground to the southeast is the Graveyard Point sill, a late Miocene (6.7±0.4-Ma) (Ferns, 1988b) thoeleiitic gabbro intrusion that was emplaced near the juncture of the east and south margins of the younger western Snake River Plain. The intrusion was emplaced during tholeiitic magmatism associated with early subsidence along the plain. The 360-ft-thick intrusion is capped by a cordierite-bearing, porcelanite hornfels and is a classic example of a fractionated mafic intrusion, ranging in composition from high-alumina olivine tholeiite along the chilled margins to ferrodiorite occurring as lenses 270 ft from the base (Long and White, 1992).

En route to Ontario, across the south margin of the western Snake River Plain

Mile point 83.7 Return along mine road west to Succor Creek Road, turn right, and proceed north. High ridge to the east is Owyhee Ridge, here capped by Blackjack Basalt flows. One of the vent areas for the Blackjack lies along the Devils Gate fault zone in the lower hills to the northeast. Note the pronounced northward tilt of Owyhee Ridge toward the western Snake River Plain, visible to the northeast. Much of the modern relief along Owyhee Ridge can be partially attributed to renewed, differential movement along older faults during downwarping of the western Snake River Plain.

Mile point 87.3 Here, the road crosses an unconformable contact between late Miocene sediments of the Idaho Group in the western Snake River Plain. Light-colored sediments are well exposed to the north along the truncated northern margin of the Oregon-Idaho graben. The contact follows and is, in places, marked by a series of northwest-trending, down-to-the-north faults that juxtapose western Snake River Plain and Oregon-Idaho graben units. Fault intersections have localized conduits for geothermal fluids that in places continue to vent to the surface as hot springs. These younger geothermal systems are characterized by high levels of arsenic and molybdenum (Ferns and others, 1993c). Varicolored chalcedonic quartz stringers are the source of the prized Graveyard Point plume agate, mined from small open pits to the southeast.

Mile point 87.5 Late Miocene lacustrine sediments are locally mantled by Pliocene-Pleistocene terrace and alluvial-fan gravels. The late Miocene lacustrine deposits are the lower part of the Chalk Butte Formation (Corcoran and others, 1962) and have been correlated with the late Miocene Chalk Hills Formation of Malde and Powers (1962) by Kimmel (1982). Most workers today agree that the lacustrine units were deposited in a single large lake system generally known as Lake Idaho that filled much of the plain from the late Miocene to the early Pliocene (Jenks and Bonnichsen, 1989). The terrace and alluvial fan gravels were deposited as tributary drainages incised through the lacustrine sediments following emptying of the lake to the north through Hells Canyon.

Mile point 90.3 Turn left (west) onto Highway 201.

Mile point 95.0 Late Miocene and Pliocene lacustrine units are exposed along the ridge line to the west. White layers include an air-fall tuff correlated by Swirydczuk and others (1982) with a Chalk Hills air-fall tuff. The ridge is capped by chert-pebble conglomerate that lies on a slight angular unconformity on the older tuffs. Smith and others (1982) and Kimmel (1982) reported fish fossils above the unconformity that indicate a correlation with the younger Glenns Ferry Formation (Malde and Powers, 1962) of western Idaho. The underlying angular unconformity marks a period of erosion and nondeposition coincident with lowering of the lake in the late Miocene (Smith and others, 1982; Kimmel, 1982). The chert-pebble conglomerate may mark incursion of fluviatile sediments from the north, as the lake began to refill in the Pliocene.

The north end of the ridge line is broken by small, down-to-the-north faults of the northwest-trending Adrian fault zone (Ferns, 1989; Ferns and others 1993a). Conglomerates near the fault zone have been silicified and contain elevated levels of trace metals such as arsenic and molybdenum.

Mile point 96.5 To the left is the Teague Mineral Products zeolite and montmorillonite clay processing plant. The Big Bend of the Snake River is to the right. Here, the Oregon-Idaho state line runs north-south, with part of Oregon lying to the east of the river. In the 1890s, very fine grained "flour" gold was mined from sand bars on the Snake River at Midas Bar along the inside curve of the Big Bend. The particles of gold mined were very small, each weighing less than $^1/_{2,000,000}$ of an ounce (Lindgren, 1901).

Mile point 99.0 Highway passes through Adrian, a small farming community. Browns Butte to the west is made up of silicified sandstones in Glenns Ferry Formation.

Mile point 103.0 Continue north on Highway 201 through crossroads community of Owyhee. Road to left leads up the Owyhee River to the Owyhee Dam. Fertile fields along the highway are in a thick flood deposit of overbank silt and mud left from the Bonneville flood (Malde, 1968) at about 14,000 yr B.P. (Scott and others, 1982). Low hills to the northwest are capped by terrace gravels deposited during the final draining of Lake Idaho between about 1.5 million and 2 million yr. B.P. The terrace gravels are locally displaced by faults.

Mile point 111.0 Nyssa city limits. Turn left (north) at stop light onto Highway 30.

Mile point 118.3 Cairo Junction, where U.S. 30 joins with U.S. 20. Highway 20 leads west to Vale and Burns. Continue north to Ontario.

Mile point 124.0 Ontario city limits. End of field trip.

ACKNOWLEDGMENTS

The author gratefully acknowledges the assistance of his fellow workers in the Owyhee region. Special thanks go Jim Evans, U.S. Geological Survey, Spokane, Washington, and Mike Cummings, Portland State University, Portland, Oregon, for providing a detailed review.

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BOOK REVIEWS

New book introduces hikers to Oregon's geology

Hiking Oregon's Geology, by Ellen Morris Bishop and John Eliot Allen. Seattle, Wash., The Mountaineers. Soft cover, 221 pages, 51 hikes, 80 black-and-white photos, 10 page-size maps. Price $16.95.

This new book, *Hiking Oregon's Geology*, was designed for the hiker who is interested in learning about geology. The authors are Ellen Morris Bishop, Lewis and Clark College Graduate School of Professional Development, and the late John Eliot Allen, Portland State University. Both authors are or were professional geologists, but they are also known to the general public for their numerous books, articles, and newspaper columns popularizing the geology of the state.

The book begins with a short nontechnical explanation of rocks and minerals, general geology, Oregon's geology, and general geologic terminology. The main part of the book is devoted to geologic information related to popular trails found in Oregon's various geologic provinces: the Klamath Mountains, the Coast Range, the Willamette Valley, the Columbia River Gorge, the Cascades, the Deschutes Basin, the High Lava Plains, the Basin and Range, the Owyhees, and the Blue Mountains. Some of the sections are further divided—the Blue Mountains sections, for example, is divided into the eastern, central, and western Blue Mountains, each of which covers geologically distinct areas. Trails are rated for difficulty, and information is included about the distance, elevation covered by the trail, relevant topographic and geologic maps, sources of information, geology of the general area, and geology of the trail.

The book contains a geologic time chart, a glossary of geologic terms, a list of recommended books, a list of geologic maps for geologic province, and the addresses of the Federal Forest Service and Bureau of Land Management offices. The book is also indexed.

The readers will be introduced to such interesting places as the seldom seen Coffeepot Crater at Jordan Craters near the Oregon-Idaho border, Spencers Butte near Eugene, the trail between Mariel and Illahee along the Rogue River, Latourell Falls in the Columbia River Gorge, and Sunset Bay to South Cove near Cape Arago on the southern coast. Not only will the readers learn about these places—they will also learn about the geology that makes each place unique and interesting.

This book does not present a mile-by-mile description of each trail. The serious hiker will still want the appropriate maps and trail guides for each trail. But this book complements the existing literature about trails. With this book serving as an introduction to the geology of the area, any hiker will have not only the pleasure of a good hike but also the fun of learning something new about the area. Now the hiker can find out why the trail is steep or slippery or beautiful, why it has rocks and cliffs that look the way they do, and what geologic forces shaped the area.

USGS Prof. Paper addresses earthquake hazards

Assessing Earthquake Hazards and Reducing Risk in The Pacific Northwest, volume 1, edited by A.M. Rogers, T.J. Walsh, W.J. Kockelman, and G.R. Priest. U.S. Geological Survey Professional Paper 1560, 306 pages, 5 map sheets. Price $25.

The book is a good technical compilation of knowledge about earthquake hazards through 1991, primarily for engineers, planners, decisionmakers, and land and building owners. The editors assure us that "Although many of the research reports address specialists having some familiarity with the geologic and geophysical sciences and earthquake-hazard mitigation, the overview chapter and reports on implementation of hazard-reduction techniques [to be published in volume 2] are intended to inform both technical and nontechnical readers." They hope to help policy makers promote the awareness of seismic hazards and reduce the risk of those hazards

The overview chapter of this volume takes up more than 60 pages and includes introductions to the various aspects of earthquake hazards as well as special advisory sections for different types of users, from government agencies to "private, corporate, and quasi-public users." It also includes an extensive bibliography and a 12-page glossary of technical terms.

The following 10 chapters discuss the tectonic setting of the Pacific Northwest with regard to past earthquakes, the potential for great earthquakes, and other aspects of paleoseismicity, tectonics and geophysics. ("Paleoseismic" and "tectonic" are explained in the glossary!)

The Willamette Valley appears to have received the most detailed attention. Of the five accompanying maps, one shows faults in the entire Pacific Northwest. The other four present the geologic units, cross sections, and the bedrock topography (below the sediments) of the Willamette Valley.

Both publications are now available from the Nature of the Northwest Information Center (see address in order form on back cover of this issue) or from the usual USGS publication outlets. Volume 2 is to be released in the near future. □

John Nielsen retires

John Nielsen, long-time institution with the Portland office of the Department of Geology and Mineral Industries (DOGAMI), has retired at the end of December 1996 from his position as fiscal manager of the agency.

Nielsen began to work for the State of Oregon in 1973 and served at Southern Oregon State College and the University of Oregon Health Sciences Center before he joined DOGAMI in 1978 as business manager.

He is succeeded by his former assistant Charles Kirby. □

This question will be debated in the 1997 Legislature:

Seismic rehabilitation—what price are we willing to pay?

by Donald A. Hull, Oregon State Geologist

Oregon is known for its natural resources—a heritage we are proud to help protect. Now that Oregon also is known as an "earthquake state," another heritage needs our protection: older buildings.

In the event of a large earthquake, unreinforced older structures pose a catastrophic threat to public safety. Those built before 1993, when western Oregon's seismic zone was upgraded, could be vulnerable. Oregon has about 97,000 nonresidential buildings, about 11 percent of which are unreinforced masonry buildings (URMs). They pose the biggest hazard. In the words of California's emergency manager Richard Eisner, "I'd rather be in L.A. when the big one hits than in Portland because, relatively speaking, they are not prepared at all."

sands if we do not reinforce URMs. Property loss would be in the billions of dollars.

The costs of reinforcing all URMs in Oregon is estimated at roughly $5 billion, according to the Task Force report. Who should pay these costs, how, and by when? These will be among HB2139's most debated issues. Recent quakes in Klamath Falls and Scotts Mills alone are strong evidence of the need for seismic rehabilitation. Further, much of the high cost of California's Northridge earthquake was caused by improper construction and inadequate inspection. The 1995 Kobe, Japan, earthquake took 5,400 lives, principally due to building damage.

Understanding this, the Task Force included a variety of tax incentives in HB2139 for building owners, along with a

Typical damage to a parapet made of unreinforced masonry (URM), caused by the Klamath Falls earthquakes of 1993.

House Bill 2139 will be introduced in the 1997 Legislature to address this need. The bill grew out of a balanced, comprehensive, year-long study by the Oregon Seismic Rehabilitation Task Force appointed by Governor Kitzhaber in 1995. Members represented views and expertise ranging from insurance, finance, and government to science, and engineering. Property owners and the general public were also represented. The Task Force findings balance public safety concerns against equity and economic reality.

According to studies performed for the City of Portland, the benefits of rehabilitating URMs could far outweigh the costs. For example, using values provided by FEMA, the firm of Goettel and Horner determined that URMs require only about one occupant per 1,000 square feet for life safety benefits to equal typical rehabilitation costs.

In his recent doctoral dissertation in civil engineering at Portland State University, Thomas McCormack developed a model to determine earthquake losses in terms of building damage and loss of life. He writes that deaths from an earthquake in the Portland area alone would be in the thou-

system of passive triggers to gradually and affordably help Oregon strengthen all public buildings over the next few decades. A critical first step in the bill is to conduct a statewide inventory.

The good news is that seismic rehabilitation is becoming a standard part of many renovation and remodeling projects. It has also become a national priority through FEMA and the President's orders to rehabilitate federal buildings. Examples of reinforcing projects include the Multnomah County Library, Portland City Hall, the Madeleine Parish School (completed), and the Multnomah Hotel, which is being renovated into an Embassy Suites Hotel. Several public schools are being strengthened throughout Oregon as money becomes available through local bonds and levies.

Regardless of HB2139's fate, the need for action is inescapable. Whether we see a major earthquake in our lifetime is uncertain—but it will happen. We do have a choice, however. We can begin to prepare now—or pay in catastrophic consequences later. □

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