# OREGON GEOLOGY

Oregon Department of Geology and Mineral Industries

Volume 63, Number 3, Summer 2001


**IN THIS ISSUE:**

# TO OUR READERS — A new publishing format for *Oregon Geology*

This is the last issue of *Oregon Geology* you receive in the traditional fashion — the magazine will continue, but on our website.

As a public agency, we must balance the need to distribute information with limited resources at hand. To a large extent, that's why we publish *Oregon Geology*. It is an avenue to disseminate information about our area to the people who are most likely to need it.

The content and format of the magazine has changed dramatically through the years. Our editor is now a desktop publisher on top of the traditional editing responsibilities of review, correction, and improvement of text.

As the price of postage, ink, and paper continues to rise, we are at a point where we must make major changes to *Oregon Geology* to allow it to survive.

We've already made one change. We have redirected the content to technical papers, not information for the general public. Although that limits the potential audience, it reinforces one of the department's core values: providing scientific information of use to our state.

We are now getting ready to take another step. Subscription prices no longer cover the expense of publishing the magazine. There are no easy choices to fix that. One option is to raise prices several-fold. Another is to publish an electronic version on our web page.

A web version offers some advantages. For example, there would be no restriction on using color photos or charts. In addition, having issues on the web site would allow researchers complete access to issues. (We are working on getting back issues scanned for the website, but that project will not be done until at least next year.)

If you are a contributor, the good news is that readership of magazines goes up when they go online. More people will read the articles. We will continue to request peer review, so the quality of articles will not decline.

It is now commonplace to have documents on the Internet that can be opened with Adobe Acrobat Reader, a free software program easily found on the web. This is the file format we will use, making it possible to open and print articles from any computer. We believe that moving *Oregon Geology* to our web page will

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# OREGON GEOLOGY

(ISSN 0164-3304)

**VOLUME 63, NUMBER 3 SUMMER 2001**

Published quarterly in Winter, Spring, Summer, and Fall by the Oregon Department of Geology and Mineral Industries. (Volumes 1 through 40 were entitled *The Ore Bin*.)





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Periodicals postage paid at Portland, Oregon. Subscription rates: 1 year, $10; 3 years, $22. Single issues, $3.

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## Cover photo

Air photo of former gravel pit (McNutt site) of Morse Brothers, Inc., winners of this year's Oregon Plan Award for their reclamation work here. The location is adjacent to the Willamette River, just upstream of Harrisburg. This pit was inundated during the 1996 flood event and was found to have salmon stranded when the water receded; so the pond was connected to the river for fish passage (barely visible in northwest corner of pond). This one and similar ponds now offer important off-channel habitat for endangered fish. Digitally modified MLR photo by David Shear. Report on 2001 Mined Land Reclamation Awards begins on page 97.

# Partial melting of tonalite at the margins of a Columbia River Basalt Group dike, Wallowa Mountains, northeastern Oregon

*by Heather L. Petcovic and Anita L. Grunder, Department of Geosciences, and Roger L. Nielsen, College of Oceanic and Atmospheric Sciences, Oregon State University,Corvallis, OR 97331*

**ABSTRACT**

Columbia River Basalt Group feeder dikes cut the tonalite-granodiorite Wallowa batholith in northeastern Oregon, providing a unique setting in which to examine the process of partial melting. This paper summarizes the progressive partial melting reactions in biotite- and hornblende-bearing tonalite at the margin of a near-vertical Grande Ronde basalt dike. Samples collected from the dike margin represent five progressive stages of melt reaction from unmolten wall rock to about 40 volume quenched melt. This melt is now represented by devitrified glass plus plagioclase, pyroxene, and magnetite quench crystals.

With progressive melting, hornblende, biotite, and orthoclase are entirely consumed, but plagioclase, quartz, and magnetite persist in the restite. Hornblende dehydration produces a dusty intergrowth of augite, pigeonite, lesser enstatite, and sparse magnetite. Biotite dehydration produces magnetite and lesser ilmenite aligned in bands in an intergrowth of enstatite and plagioclase. Residual plagioclase develops a spongy texture, as the albite component is lost to the melt. In the initial stages of melting, the reaction of hornblende, quartz, and feldspars produces silicic melt localized around decomposed mafic sites and as seams on quartz-feldspar grain boundaries. The melt composition was modified during cooling by the formation of quench crystals and later by devitrification of the glass. At higher temperatures, the reaction of orthoclase, clinopyroxene, and plagioclase produces additional silicic melt.

**INTRODUCTION**

Although there is general consensus that basalt input is fundamental to crustal melting, there are few places where this interaction can be directly sampled. The Wallowa Mountains of northeastern Oregon provide a rare natural setting in which to examine shallow crustal melting. Here, hundreds of Columbia River Basalt Group (CRBG) feeder dikes cut granitoids of the Wallowa batholith. Dikes have interacted with wall rock in a variety of ways, including some contact melting in the wall rock. We have examined the 5-m-wide partially melted zone in tonalite at the margin of a near-vertical Grande Ronde Basalt dike in the vicinity of Maxwell Lake (Figure 1). Samples collected from the western margin of this dike represent five progressive stages of melt reaction, from unmelted tonalite (Stage 1) to about 40 volume percent quenched melt (Stage 5). This melt is represented by devitrified silicic glass containing plagioclase, pyroxene, and magnetite quench crystals.

This paper summarizes the natural partial melting reactions fully characterized by Petcovic (2000).

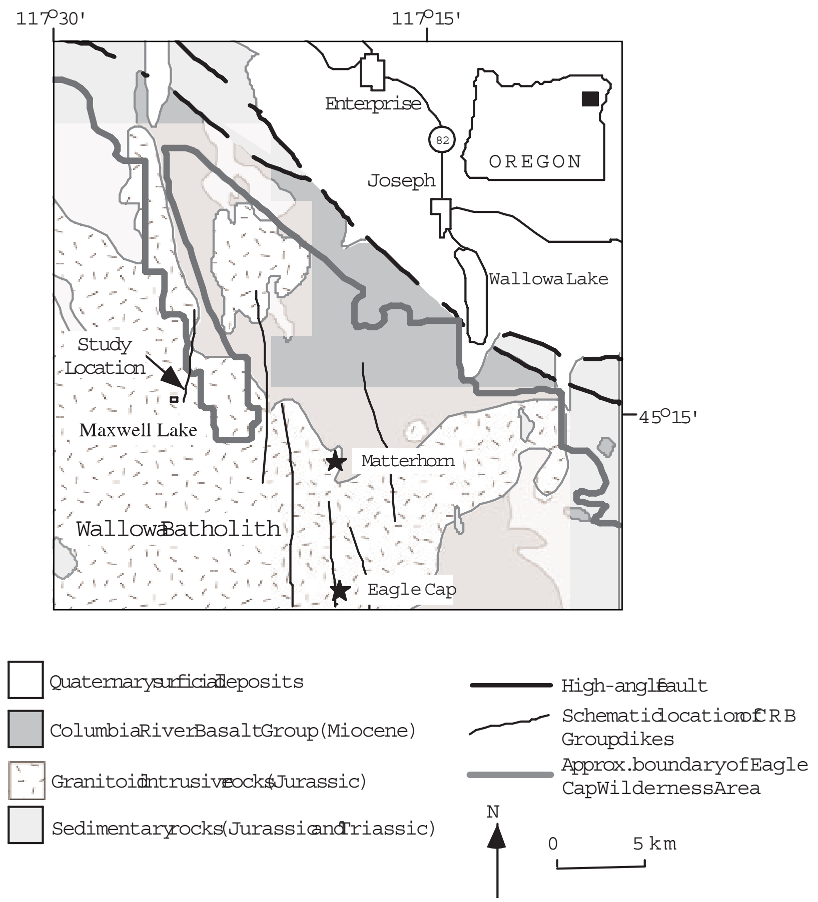


**Figure 1. Generalized location and geologic map of the study area and vicinity in the Wallowa Mountains. Modified after Taubeneck (1995).**

## THE WALLOWA BATHOLITH AND CRBG DIKES

The Wallowa Mountains are largely composed of the Wallowa batholith, a series of Late Jurassic intrusions (140–160 Ma; Armstrong and others, 1977) related to the accretion of island-arc terranes onto the former margin of North America. The batholith is composed of biotite- and hornblende-bearing tonalite to granodiorite. During the Miocene, CRBG flood basalt was erupted from vents primarily in northeastern Oregon, with the Wallowa Mountains hosting over 90 percent of the CRBG dikes in Oregon (Grunder and Taubeneck, 1997). Feeder dikes of both the Imnaha Basalt (16.8–17.3 Ma; Hooper and Hawkesworth, 1993) and the Grande Ronde Basalt (15.6–16.8 Ma; Hooper and Hawkesworth, 1993) lace the batholith (Figure 1). Uplift and Pleistocene glaciation have resulted in exposure of both the Wallowa batholith and the CRBG dikes to a paleodepth of 1–2 km (Grunder and Taubeneck, 1997).

Individual basalt dikes within the Wallowa batholith extend up to several kilometers along strike, are a few centimeters to 50 m wide, are steeply dipping (average 70°), and strike generally northwest-southeast (Taubeneck, 1987). Dikes have one or more of the following morphologies (Grunder and Taubeneck, 1997):

- Dikes with quenched margins and no interaction with the wall rock,
- Dikes with partially melted wall rock at their margins,
- Dikes that have eroded their wall rock, and
- Dikes containing whole to disaggregated crustal xenoliths.

The presence of a melted zone in the wall rock correlates with a thin or absent quenched edge of the dike and larger grain size in the CRBG dike (Taubeneck, 1987). In general, melted margins are typically one quarter of the width of the dike, and in cases where dikes are not vertical, the hanging wall has a thicker melted zone (Grunder and Taubeneck, 1997).

## THE MAXWELL LAKE DIKE

This study focuses on a single, well-exposed Grande Ronde Basalt dike with partially melted wall rock at its margins. Located within the Eagle Cap Wilderness Area, the dike is exposed on the western side of the Lostine River Valley in the vicinity of Maxwell Lake (Figure 1). The dike strikes about N. 20° E., dips steeply to the west (about 75°), and is from 2.7 to 8.1 m wide. It extends for at least 1 km along strike. Paleodepth at the time of dike emplacement was at most 2 km, as reconstructed from regional geology.

The partial-melt margin along the hanging wall (western margin) of the dike is generally 2–2.5 m wide but reaches a width of 5 m at the southern end of the outcrop, whereas the partial melt margin along the footwall (eastern margin) is about 1.5 m wide. The dike margins are divided into four zones based on field characteristics: the unmelted wall-rock zone, the mafics-out zone, the mottled zone, and the mush zone (Figure 2). Individual zones are 10 cm to 2 m wide with gradational transitions from one zone to the next. Partial melt zones parallel the dike along strike, vary in thickness with dike thickness, and are wider along the western margin (hanging wall) than the eastern margin.

Five stages of melt reaction can be distinguished within the wall-rock partial melt zones at the dike margin. Unmelted wall rock (Stage 1) is found 2–5 m from the dike margin. The mafics-out zone (Stages 2 and 3) is 1–2 m wide and characterized by the breakdown of biotite and hornblende, which yields fine-grained reaction products (predominantly pyroxene and iron-titanium oxides) that form pseudomorphs after the original minerals. Quartz and feldspar are unaltered, and glass may be present as thin seams around felsic grains. The mottled zone (Stages 4 and 5) is characterized by a blue-gray mottled texture in outcrop and is generally 1–2 m wide. Biotite and hornblende are entirely decomposed; both mafic reaction sites and residual quartz and feldspar lack distinct margins; and seams of brown glass commonly surround grains. The mush zone is a discontinuous, 10- to 50-cm-wide zone paralleling the dike margin. This zone contains sparse amorphous blebs of quartz and feldspar in a fine-grained blue-gray groundmass. The presence of the mush zone appears to correlate with thicker areas of the dike. A dense network of blue-gray veins cut through the partially melted tonalite at the southern end of the outcrop, giving this end of the outcrop a cataclastic texture. Samples representing Stages 2 and 4 were collected from this end of the outcrop. Within the range of samples we have examined, there appears to be no exchange of mass between the CRBG dike and partially melted wall rock.

## TEXTURAL AND COMPOSITIONAL CHANGES DURING EACH STAGE OF MELTING

Unmelted (Stage 1) tonalite is medium to coarse grained and composed of, in decreasing abundance, plagioclase, quartz, hornblende, biotite, orthoclase, magnetite, and traces of fluorapatite, titanite, and zircon (Figure 3). Biotite is commonly altered to chlorite at crystal margins and is found in clumps with hornblende, apatite, and magnetite.

In Stage 2, biotite, hornblende, orthoclase, and plagioclase show incipient reaction, but modal proportions of these phases remain more or less unchanged (Figure 3). The sample representing Stage 2 has a cataclastic texture as expressed in extensively fractured quartz and plagioclase. Hornblende is dusted with submicroscopic reaction products and has lost $K_2O$, Cl, and F relative to Stage 1 hornblende. Magnetite occupies cleavages and rims of bi-

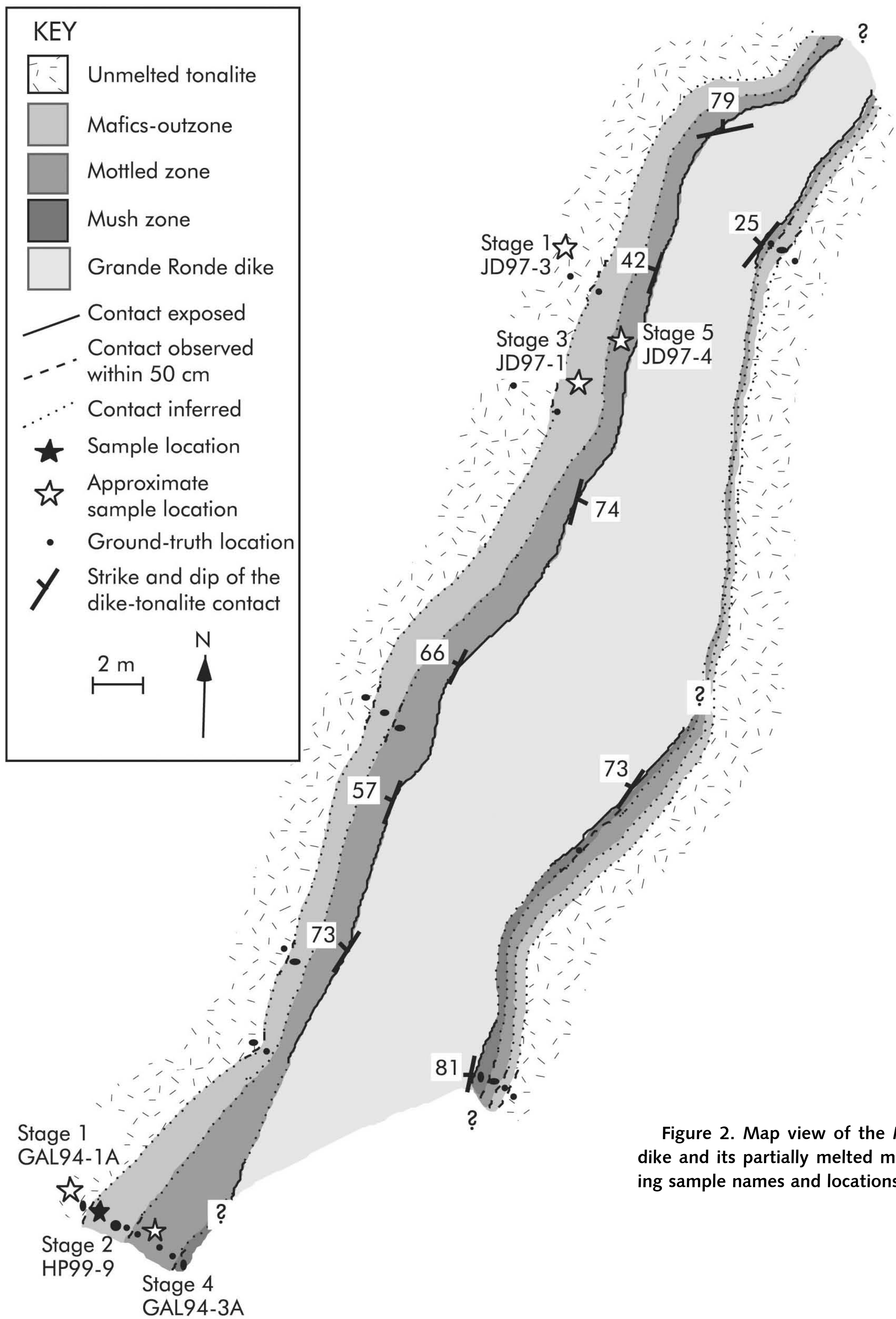


**Figure 2. Map view of the Maxwell Lake dike and its partially melted margins, showing sample names and locations.**

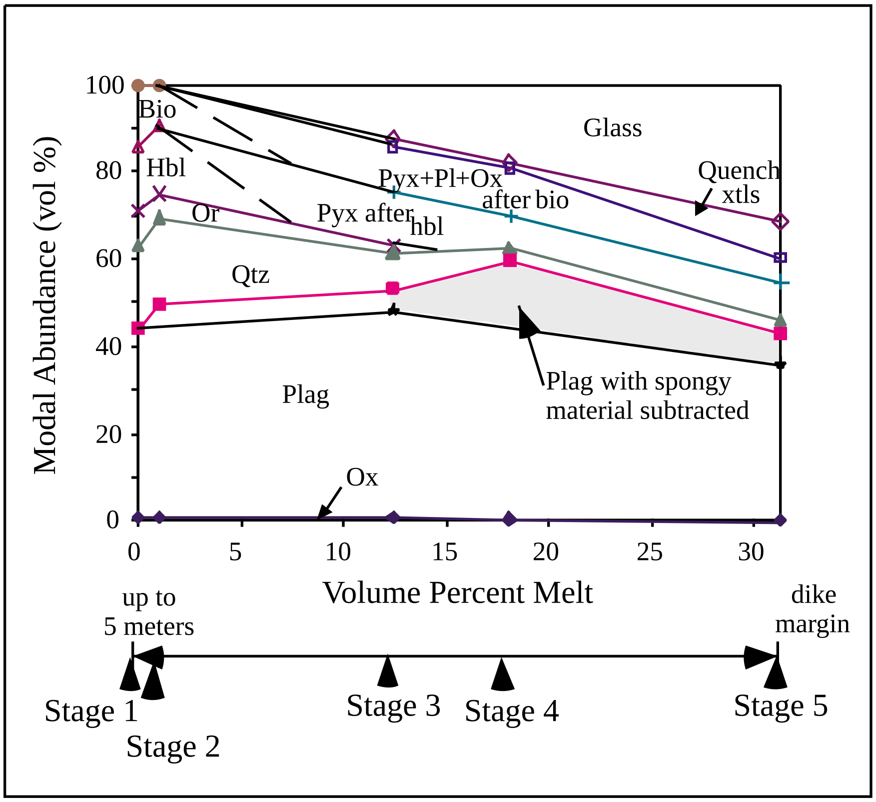


**Figure 3. Modal abundance (in volume percent) of phases in unmelted and partially melted tonalite plotted against melt fraction (also in volume percent). Abbreviations are as follows: Ox = iron-titanium oxide (magnetite and ilmenite), Plag or Pl = plagioclase feldspar, Qtz = quartz, Or = orthoclase feldspar, Hbl = hornblende, Bio = biotite, Pyx = pyroxene, xtls = crystals. Modal abundances were determined by point counting on multiple thin sections except for the shaded region, which was determined by visual estimates.**

otite, which is depleted in $K_2O$ and Cl but enriched in $TiO_2$ and F relative to Stage 1 biotite. Dehydration melting of biotite has produced at least one thin (<50 µ wide) glass seam on a biotite-quartz contact.

In Stage 3, widespread mineral breakdown reactions have produced about 15 volume percent glass found around mafic sites that have undergone reaction and as up to 1-mm-wide seams on feldspar-quartz contacts. Modal proportions of orthoclase and quartz have decreased significantly, and the spongy texture of plagioclase indicates that a minor amount of this phase has also been consumed (Figure 3). Spongy-textured plagioclase may contain up to 4 volume percent glass. Plagioclase composition is more calcic than in Stage 1, which indicates that the albite component is lost to the melt.

Hornblende dehydration has yielded micron-sized, $Al_2O_3$- and $Na_2O$-rich augite and pigeonite, lesser enstatite, and sparse magnetite. Biotite dehydration produces magnetite and ilmenite aligned along former biotite cleavage planes in an intergrowth of enstatite and plagioclase. The glass is complexly devitrified into several domains (Table 1): a dominant, high-K brown glass domain; a high-Ca domain of dark brown glass; and a minor domain of clear, high-Si glass. About 2 volume percent quench crystals of plagioclase, pyroxene, and magnetite are associated with the devitrified brown glass domains (Figure 3).

Stage 4 is characterized by the absence of orthoclase and the creation of an additional 6–7 volume percent glass (Figure 3). The sample representing Stage 4 has a cataclastic texture, including finely fractured quartz and plagioclase crystals. The abundance of augite in decomposed hornblende sites has decreased, and enstatite is enriched in MgO. Concentrations of $TiO_2$, $Al_2O_3$, and MgO in magnetite and ilmenite replacing biotite have also increased. The three devitrified glass domains are present in Stage 4, as are about 1.5 volume percent quench crystals.

By Stage 5, a total of about 30 volume percent glass is produced by the breakdown of clinopyroxene and the consumption of plagioclase (Figure 3). Stage 5 residual plagioclase is slightly higher in $K_2O$ and CaO than Stage 1 plagioclase. When in contact with glass, residual plagioclase has developed a spongy texture, fritted margins, and 25-µ-wide rims high in CaO, FeO, and MgO. As much as 7 volume percent glass may be trapped in spongy feldspar (Figure 3). Optically aligned enstatite is the lone pyroxene in decomposed hornblende sites. Pyroxene microlites are aligned with their c-axes parallel to the c-axis of the parent hornblende. Decomposed biotite sites remain occupied by aligned magnetite and lesser ilmenite in a slightly coarser matrix of plagioclase and enstatite. Devitrified brown glass containing quench crystals of plagioclase, augite, enstatite, and magnetite is localized on quartz-plagioclase contacts and around former biotite and hornblende sites; a minor amount of clear glass is also present.

## DEHYDRATION MELTING REACTIONS

Recent studies point to the importance of hydrous minerals in crustal melting (e.g., Beard and Lofgren, 1991; Skjerlie and Johnston, 1993; Vielzeuf and Montel, 1994; Patiño Douce and Beard, 1995; Singh and Johannes, 1996a & 1996b). Dehydration melting is the breakdown of a hydrous mineral (such as biotite or amphibole) to form melt plus anhydrous minerals. The Wallowa tonalite contains both biotite and hornblende, important sources of melt in dehy-

**Table 1. Compositional data for bulk rock, glass domains, and bulk melt (glass + quench crystals), in weight percent**

(* = all Fe reported as FeO; — = concentrations below detection limits)

| | Unmelted wallrock[1] | High-Ca glass domain[2] | | High-K glass domain[2] | | High-Si glass domain[2] | Bulk melt[3] | |
|---|---|---|---|---|---|---|---|---|
| Oxide | Stage 1 | Stage 3 | Stage 5 | Stage 3 | Stage 5 | Stage 3 | Stage 3 | Stage 5 |
| $SiO_2$ | 59.32 | 74.18 | 78.90 | 75.99 | 76.26 | 90.48 | 68.37 | 68.43 |
| $TiO_2$ | 0.70 | 0.21 | 0.58 | 0.49 | 0.87 | — | 0.50 | 0.78 |
| $Al_2O_3$ | 17.97 | 11.49 | 11.46 | 11.62 | 11.02 | 1.76 | 10.73 | 13.20 |
| FeO* | 5.35 | 0.49 | 0.56 | 0.44 | 0.95 | — | 6.00 | 3.85 |
| MgO | 3.84 | — | — | — | 0.05 | — | 2.45 | 1.83 |
| CaO | 6.45 | 3.51 | 3.36 | 0.53 | 0.73 | 0.61 | 1.68 | 2.91 |
| $Na_2O$ | 4.12 | 3.15 | 3.51 | 2.17 | 2.81 | 0.32 | 2.22 | 2.92 |
| $K_2O$ | 1.35 | 0.31 | 0.33 | 6.21 | 5.35 | 0.21 | 3.86 | 3.97 |
| $P_2O_5$ | 0.18 | 0.07 | 0.19 | 0.08 | 0.27 | — | 0.07 | 0.18 |
| Total | 99.37 | 93.57 | 99.03 | 98.45 | 98.45 | 93.69 | 96.10 | 98.27 |

1 Bulk rock analyzed by x-ray fluorescence at Washington State University.

2 Glass analyzed by electron microprobe at Oregon State University using a 20 micron beam diameter, a beam current of 30 nA, and an accelerating voltage of 15 kV. Data reported are the average of between 4 and 50 spot analyses on glass domains.

3 Data reported are calculated melt compositions by mass balance (see text for explanation). High concentrations of FeO, MgO, and $TiO_2$ in Stage 3 bulk melt is likely due to overcounting fine-grained magnetite quench crystals in the modal analysis.

dration reactions. Between Stage 1 and Stage 3, biotite and hornblende are consumed, and the abundances of quartz and orthoclase decrease. Pyroxene, magnetite, and glass occupy sites where hornblende has undergone reaction, whereas pyroxene, plagioclase, magnetite, ilmenite, and glass occupy corresponding biotite sites. According to these textural and compositional considerations, the initial melt-producing reactions are

hornblende + quartz + orthoclase = orthopyroxene + clinopyroxene + minor magnetite + melt (glass + quench crystals)

and

biotite + quartz + orthoclase = orthopyroxene + plagioclase + magnetite + ilmenite + melt (glass + quench crystals).

These reactions are terminal for biotite and hornblende.

Since its formation, the melt was modified both by the growth of quench crystals during cooling and by devitrification. The original melt composition at the time of basalt cooling, therefore, is equivalent to the present devitrified glass domains plus quench crystals. We have been able to reconstruct the original melt composition by mass-balance calculations, using the modal abundance and compositions of the devitrified glass domains and plagioclase, pyroxene, and magnetite quench crystals (Table 1). In Stage 3, the bulk reconstructed melt is granitic; however, the high concentrations of MgO, FeO, and $TiO_2$ may be due to overestimation of magnetite in point counts during modal analysis.

Between Stages 3 and 5, orthoclase is entirely consumed as well as the clinopyroxene produced during initial hornblende dehydration, and the modal proportions of quartz and plagioclase decrease. No new phases are created, although breakdown reactions produce nearly an additional 20 volume percent glass. Plagioclase has developed a spongy texture, and the albite component is lost to the melt. This textural and compositional information suggests that the higher temperature melt-producing reactions are

plagioclase + quartz + orthoclase + clinopyroxene = melt (glass + quench crystals)

and

andesine plagioclase = labradorite plagioclase + albitic melt trapped in spongy plagioclase.

These reactions are terminal for orthoclase and clinopyroxene, leaving a restite of plagioclase, quartz, orthopyroxene, and iron-titanium oxides coexisting with melt (now represented by glass and quench crystals). A bulk melt composition was calculated by mass balance for Stage 5 (Table 1); the Stage 5 calculated melt is higher in concentrations of CaO and $Al_2O_3$ than the Stage 3 melt.

## SUMMARY

Partial melting of the Wallowa tonalite took place over a distance of 4–6 m from the western margin of a Grande Ronde basalt dike. During partial melting, hornblende, biotite, and orthoclase were entirely consumed. The absolute modal abundance of plagioclase, quartz, and magnetite decreased, which indicates that these phases were also consumed; however, these phases persisted in the restite with as much as 40 volume percent quenched melt (31 volume percent glass and 9 volume percent quench crystals). Orthopyroxene, clinopyroxene, sparse magnetite, and glass occupy decomposed hornblende sites, with pyroxene microlites aligned along the original amphibole c-axis. Decomposed biotite sites are occupied by aligned magnetite and ilmenite in an intergrowth of orthopyroxene,

plagioclase, and glass. Glass seams are localized around decomposed mafic sites and also as seams up to 2 mm wide between relict quartz and plagioclase. The original melt composition was modified during quenching by the formation of plagioclase, pyroxene, and magnetite quench crystals and by devitrification. However, bulk compositional data indicate that melting and quenching took place in a chemically closed system. The microcosm of partial melting that we have examined in the Wallowas provides an excellent starting point for understanding the complex problems of crustal magmatism.

### ACKNOWLEDGMENTS

We would like to thank Bill Taubeneck for his assistance with the petrographic analysis and his advice on the field component of this research. This research was supported in part by a grant from the Geological Society of America awarded to H. Petcovic, grant number 6514–99.

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## BOOK REVIEW

**Geology of the Pacific Northwest**, 2d ed., by William N. Orr and Elizabeth L. Orr, 2001. New York, McGraw-Hill, 409 pages, $67.75.

Geology of the Pacific Northwest, second edition edition, is geared to provide, for the casual reader as well as for those with geologic training, an overview of the geologic processes that shaped the Pacific Northwest through time.

After an introductory chapter including "cornerstones" of Pacific Northwest geology, the main body of the book is made up of ten chapters treating successively various physiographic provinces from the Coast Range Province of British Columbia and Alaska south to the Klamath Mountains and west to Central Idaho. The book therefore covers an immense, widespread geographic area while attempting to reach at the same time an audience with wide-ranging backgrounds. The result is therefore a strong compromise between simple explanations of geologic concepts, complex stratigraphic columns, brief regional summaries, and extra points of interest such as histories of regional mineral exploration. What is welcome by one audience may be overwhelming or too simple to another audience.

The book would have benefitted from a narrowing of its target audience, especially after the first edition had already revealed such concerns. I find many illustrations excellent (a trademark of Orr and Orr), although many could have been better reproduced. For the casual reader, the reference basis is substantial, but professionals will miss recent publications in areas of their expertise.

In summary, this book is a welcome addition to my shelf despite some reservations. It will serve me well whether I need an overview of a physiographic province of the Pacific Northwest that is less familiar to me or where my memories demand a quick brush up.

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# The mid-Pliocene Imbler fish fossils, Grande Ronde Valley, Union County, Oregon, and the connection between Lake Idaho and the Columbia River

*by Jay Van Tassell, Science Department, Eastern Oregon University, La Grande, Oregon 97850; Mark Ferns and Vicki McConnell, Oregon Department of Geology and Mineral Industries, Baker City, Oregon 97814; and Gerald R. Smith, Museum of Paleontology, The University of Michigan, Ann Arbor, Michigan 48109-1079*

**ABSTRACT**

The Grande Ronde Valley began to form ~9 m.y. ago. Diatoms, sponge spicules, and peat in the lower Grande Ronde Valley sedimentary sequence indicate that alluvial and fluvial sedimentation in the valley was interrupted by deposition of marshes and shallow lakes from ~9 to 7.5 Ma and by bogs and marshes at ~6 Ma during the late Miocene. Alluvial and fluvial sedimentation was broken by a later period of deep to shallow lake and marsh sedimentation which occurred from ~4 to 2 Ma.

During the spring of 2000, fossilized Pliocene fish bones were recovered from a water well located near Imbler, Oregon, at a depth of 138-141 m, just above andesitic bedrock. The fish species include a pikeminnow (*Ptychocheilus* sp.), catfish (*Ameiurus* cf. *reticulatus*), a sunfish (*Archoplites* sp.), and a whitefish (*Prosopium* sp.). Rough estimates based on the stratigraphic position of the fish fossils relative to ~7.5 Ma and ~3 Ma tephras in the valley-fill sedimentary sequence suggest that the fish fossils are ~3.7-3.8 m.y. old. The Imbler fish fossils are warm-water species with the exception of the cool-water whitefish. The sizes of the catfish and sunfish were limited by cool summer temperatures and a reduced growing season. Individual bones of the Imbler fish fossils are most similar to the late Pliocene Taunton Fauna of the Ringold Formation of eastern Washington, although there are some similarities to fish in the Pliocene Glenns Ferry Formation of the Lake Idaho Group. Several characteristics of the pectoral spine bony base and muscle attachment area indicate that the Grande Ronde Valley catfish, *Ameiurus* cf. *reticulatus*, is most like that of the Pliocene Ringold Formation and less like *Ameiurus vespertinus* of the Glenns Ferry Formation of Idaho. On the basis of the proportion of shared species, the Imbler fish fossils are most similar to the Blufftop Fauna of the Ringold Formation because of the absence of three species of minnows found in both the Lake Idaho sequence and the Taunton Fauna. This suggests a drainage connection to the Columbia River at ~3.7-3.8 Ma. A whitefish is known from the Glenns Ferry Formation of the Snake River Plain, but not known from Taunton or the White Bluffs Faunas of the Columbia River drainage basin. The presence of the whitefish vertebra in the Imbler fish fossil suite is a possible indicator of a connection between Lake Idaho and the Grande Ronde Valley.

Two rare diatoms, *Tetracyclus stellare* v. *eximia* and *Aulacoseira* (*Alveolodiscus*) *jouseana*, found in the sediments just above the fish fossils, appear to have been reworked from earlier sediments. They may have been washed into the Grande Ronde Valley area from the Snake River Plain, although it is possible that they were dispersed by anticyclonic winds. Abundant *Stephanodiscus* sp. and *Aulacoseira* sp. aff. *A. solida*, which were deposited just after the fish fossils, are probable equivalents to diatoms in the Pliocene Glenns Ferry Formation of the Lake Idaho sequence. This is evidence of a connection between the Grande Ronde Valley and Lake Idaho shortly after the Imbler fish fossils were deposited during the mid-Pliocene.

**INTRODUCTION**

Earthquake hazards and water supply are becoming ever bigger issues in the interior valleys of eastern Oregon. In order to understand the geology relevant to these problems, it is also becoming ever more critical to improve the knowledge of geologic correlations within and between sedimentary basins. Increasing demand for water resources in the Grande Ronde Valley has prompted the Oregon Department of Geology and Mineral Industries to begin detailed studies of the bedrock geology and sediments in the basin. Techniques used in these investigations include geologic mapping, seismic profiling and magnetic and gravity measurements. The discovery of ash layers, diatoms, sponges, and fish bones in cuttings from four recently drilled water wells (from north to south, Bing '00, Bing '98, Terry, and La Grande) (Figure 1), provide new insights into the early geologic history of the Grande Ronde Valley.

The modern Grande Ronde Valley (Figure 1) is a large structural basin situated along the east flank of the Blue Mountain uplift. The valley is bounded on the east and west by active or potentially active faults (White, 1981; Bishop and others, 1992; Liberty and Barrash, 1998; Personius,1998; Ferns and others, in press; Ferns and others, in preparation), and the present-day valley floor is at an elevation of ~1,000 m. It may have originated as a graben formed along en echelon tension fractures related to right-lateral strike-slip motion along the Olympic-Wallowa lineament (Hooper and Conrey, 1989) and evolved into a northwest-trend-

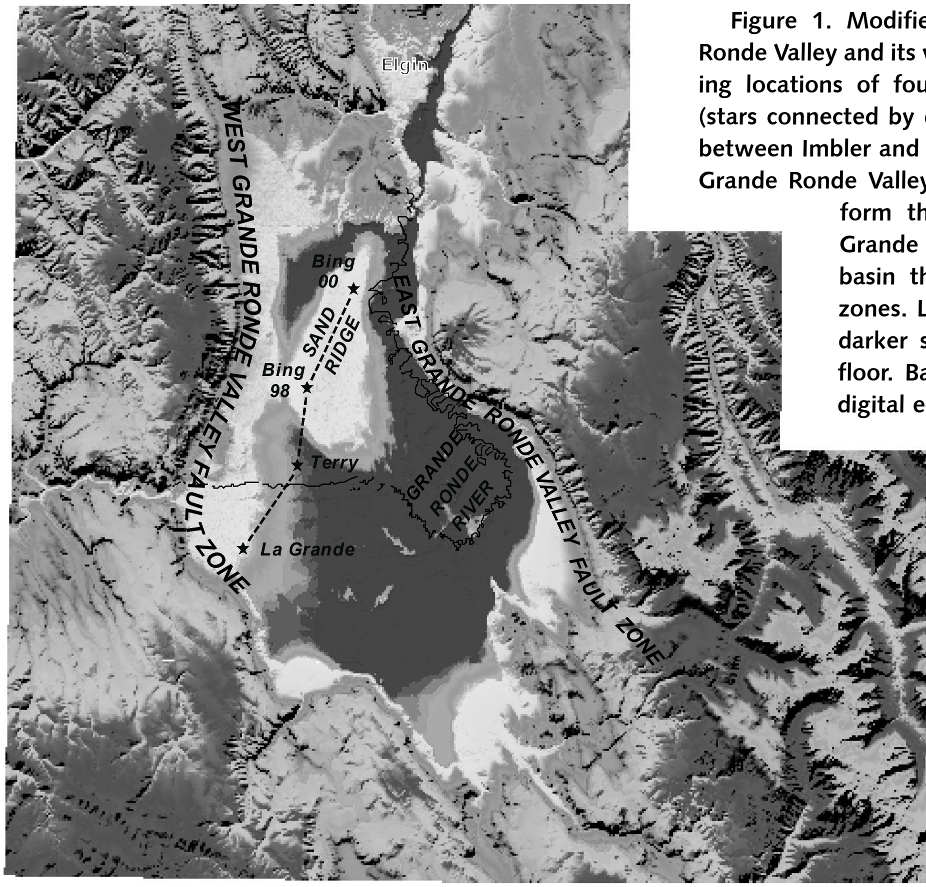


**Figure 1. Modified shaded-relief map of the Grande Ronde Valley and its vicinity in northeastern Oregon, showing locations of four recently drilled, deep water wells (stars connected by dashed line). These wells are situated between Imbler and La Grande in the northern part of the Grande Ronde Valley and provided the drill cuttings that form the basis for the present paper. The Grande Ronde Valley is a deep, sediment-filled basin that is now bordered by major fault zones. Lighter shades of gray indicate higher, darker shades lower elevation of the basin floor. Based on U.S. Geological Survey 30-m digital elevation model (DEM) data.**

ing, tectonically active pull-apart (strike-slip) basin (Davis, 1980; Gehrels and others, 1980; Gehrels, 1981; White, 1981; Simpson and others, 1989). Barrash and others (1983) suggested that the Grande Ronde Valley was downfaulted during the late Tertiary, between 10±2 and 4 Ma, with faulting continuing on into the Quaternary. The shape of the valley is controlled by northwest- and northeast-trending fractures and an older set of north- and east-trending fractures (Barrash and others, 1980).

The modern-day floor of the Grande Ronde Valley is a broad, flat alluvial plain, ringed by terrace, alluvial-fan, debris-flow, landslide and debris-avalanche deposits and youthful faults. Large alluvial fans have formed where major streams enter the valley. These fans have coalesced along the bounding escarpments and merged to form broad bajada surfaces. The valley's modern alluvial plain is traversed by tortuously meandering streams and is marked by marshes and shallow lakes in the south. Fromwiller and Van Tassell (1999) noted that the sediments of the marshes and lakes of the Grande Ronde Valley contain sponge spicules and abundant diatoms, including *Aulacoseira*, *Cymbella*, *Epithemia*, *Gomphonema*, *Navicula*, *Nitzschia*, *Rhoicosphenia*, and *Synedra*. Diatoms are present also in the channel and floodplain sediments of the Grande Ronde River but are less abundant there. Low-relief, windswept ridges of aeolian sand and silt occur in the north. As much as 600 m of late Miocene to Pleistocene sediment underlies the alluvial plain (Hampton and Brown, 1964; Walker, 1990; Ferns and others, in press). Faults in the valley subsurface offset Holocene alluvium (White, 1981; Bishop and others, 1992; Liberty and Barrash, 1998; Personius, 1998).

As the Grande Ronde Valley began to form during the late Miocene, the existing drainage was deranged by faulting. Hampton and Brown (1964) suggested that the basin fill consisted mainly of lacustrine deposits. Sequences of laterally discontinuous gravels, sandy gravels, and sandy muds on the order of meters thick suggest codeposition of stream sediments as the basin was forming. The valley margins are marked by interfingering, poorly sorted bouldery fanglomerate and well-sorted alluvial-fan gravel deposits. Bishop and others (1992) suggested that the basin fill was largely alluvial and fluvial and that the presence of several widespread muds and sands suggested damming of the outflow: Possibly by uplifting of fault blocks in the area of the basin's outlet, short-lived lacustrine environments may have been created. Seismic profiling by Boise State University showed clearly that the sediments in the southern part of the basin have been tilted to the west (Liberty and Barrash, 1998). During the Holocene, the outlet of the basin has been eroded down to bedrock, and more than 30 m of the valley fill has been removed (Hampton and Brown, 1964).

## METHODS

A total of 776 cutting samples were collected for analysis from the four wells at intervals of 0.3–3.0 m. The cuttings were air-dried and examined under the binocular microscope for color, sediment type, and other characteristics as well as wood, ash, and fish fossils. A 20-g subsample of each cutting interval was wet-sieved through a 63-μ sieve with 1 liter of distilled water. The mud that washed through the sieve was stirred, and a 10-ml subsample of the solution was pipetted onto a glass slide, dried, and mounted in mineral oil. Each slide was examined under a petrographic microscope, and the number of individuals of each of the different genera of diatoms, sponge spicules, and pollen in a 1-$cm^2$ area was determined (Figure 2). The presence of volcanic ash was also noted. Four samples were sent to J. Platt Bradbury (U.S. Geological Survey, retired) for identification of selected diatom species.

The >63-μ-size fraction of each subsample was sieved and the type of sediment determined, based on the percentages of gravel, sand, and mud, according to the classification of Folk (1974). A representative subsample of the gravel was placed on a gridded petri dish, and the percentages of different types of rock fragments and minerals in the sample were counted. The sand fraction was examined under the binocular microscope for ash, wood, fish bones, and the types of lithic fragments and minerals present. Three ash samples, one from the Terry well (Terry 356) and two from the Bing '98 well (Bing 1502, Bing 1553), were analyzed for whole-rock and trace-element composition at the Washington State University GeoAnalytical Laboratory with XRF techniques. Glass separates from the Terry 356 and Bing 1553 tephra were radiometrically dated by $^{40}Ar/^{39}Ar$ at the University of Alaska, Fairbanks, Geochronology Laboratory. The Bing 1502 ash is chemically distinct but has not yet been dated.

The fish bones were separated from the sediment and identified. Representative examples are illustrated in Figures 3–6. Repositories for the fossils are Eastern Oregon University and the University of Michigan Museum of Paleontology. Accordingly, fossil numbers include the institutional abbreviations EOU and UMMP.

## BASIN STRATIGRAPHY

The thick sedimentary sequence in the Grande Ronde Valley unconformably overlies lavas from the Powder River Volcanic Field. This 14.5- to 9-Ma sequence of olivine basalt, andesite, and dacite lava flows postdates flows of Columbia River Basalt Group lavas (Hooper and Conrey, 1989; Hooper and Swanson, 1990; Reidel and others, 1996; Ferns and others, in press). The most detailed information on the sediments in the valley comes from cuttings from the four water wells mentioned above (Figures 1 and 2). In the deepest well (Bing '98), the lower section coarsens upward from an 8-m-thick section dominated by organic-rich clays and silts into a 280-m-thick section of sandy silt interbedded with thin seams of gravel and sand. Judging by well cuttings, individual gravel-bearing zones are no more than 3 m thick and make up less than 18 percent of the section. The upper 200 m of section in the Bing '98 well is composed primarily of sandy silt with thin (<3 m) seams of sand and gravel.

Correlations between individual wells (Figure 2) are based on the lithology and the relative abundance and types of diatoms in the sequence. The stratigraphy of the Pleistocene terrace sediments just south of the city of La Grande, based on the observations of Pilling (1998), is also shown in Figure 2, along with the depth to bedrock in the City of La Grande well at 12th Street. A mammoth tooth *(Mammuthus washingtonii)* from the silt loam sediments on top of the terrace was radiocarbon-dated ($^{14}C$) by Geochron Laboratories at 15,280±180 yr B.P. (see Table 1).

Several tephra layers of high-silica ash were discovered in the cuttings from the Grande Ronde Valley wells. Glass shards from tephras from the wells Terry and Bing '98 were dated with $^{40}Ar/^{39}Ar$ techniques and yielded ages of 3.1±0.3 Ma and 7.5±0.11 Ma, respectively. F.F. Foit, Jr. (Department of Geology, Washington State University, written communication, 1999) reported a similarity coefficient of 0.93 between the ~3.1-Ma ash from the Terry well and ash from Lake Bonneville, Utah. Williams (1994) suggested a possible age of 2.9 Ma for a tephra sample from the Bonneville Basin (his sample BUR-871.11) and compares it with an ash of similar composition from an upper Lake Idaho section near Grandview, Idaho.

Average sediment accumulation rates were calculated from the ages of ~9 Ma for the andesitic bedrock (Ferns and Madin, 1999) and ~7.5 Ma and ~3 Ma for the ash layers mentioned above. These data suggest that the basin has filled with alluvial, fluvial and lacustrine sediments at rates ranging from ~0.03-0.06 mm/yr since it began forming ~9 m.y. ago. The southwest side of the basin has subsided at a rate ~0.03 mm/yr faster than the northeast side of the basin over the past 9 m.y. (Van Tassell and others, 2000).

## IMBLER FISH SPECIES ACCOUNTS

Drilling of the Bing '00 well, located just west of the city of Imbler, Union County, Oregon, at lat 45°27'24" N., long 117°57'11" W., recovered fish bones from depths of 452–462 ft (138–141 m). The Bing '00 well is located ~2.15 km east of the H.L. Wagner well, where fish fossils are reputed to have been recovered in 1949. The fish fossils in the Imbler well (Figures 3–6) belong to four species, a pikeminnow (*Ptychocheilus* sp.), a catfish (*Ameiurus* cf. *reticulatus*), a sunfish (*Archoplites* sp.), and a whitefish (*Prosopium* sp.).

### Family CYPRINIDAE
### Genus *Ptychocheilus* sp.

Pikeminnow

Figure 3a,b

The family Cyprinidae is represented in the Bing '00 well samples by two distinctive bones of the predaceous minnow *Ptychocheilus*. One, a canine pharyngeal tooth (UMMP 35046), 4 mm long, is elliptical in cross section, robust, enlarged near its midpoint, and hooked posteriorly at its point. It is not distinguishable from teeth of similar

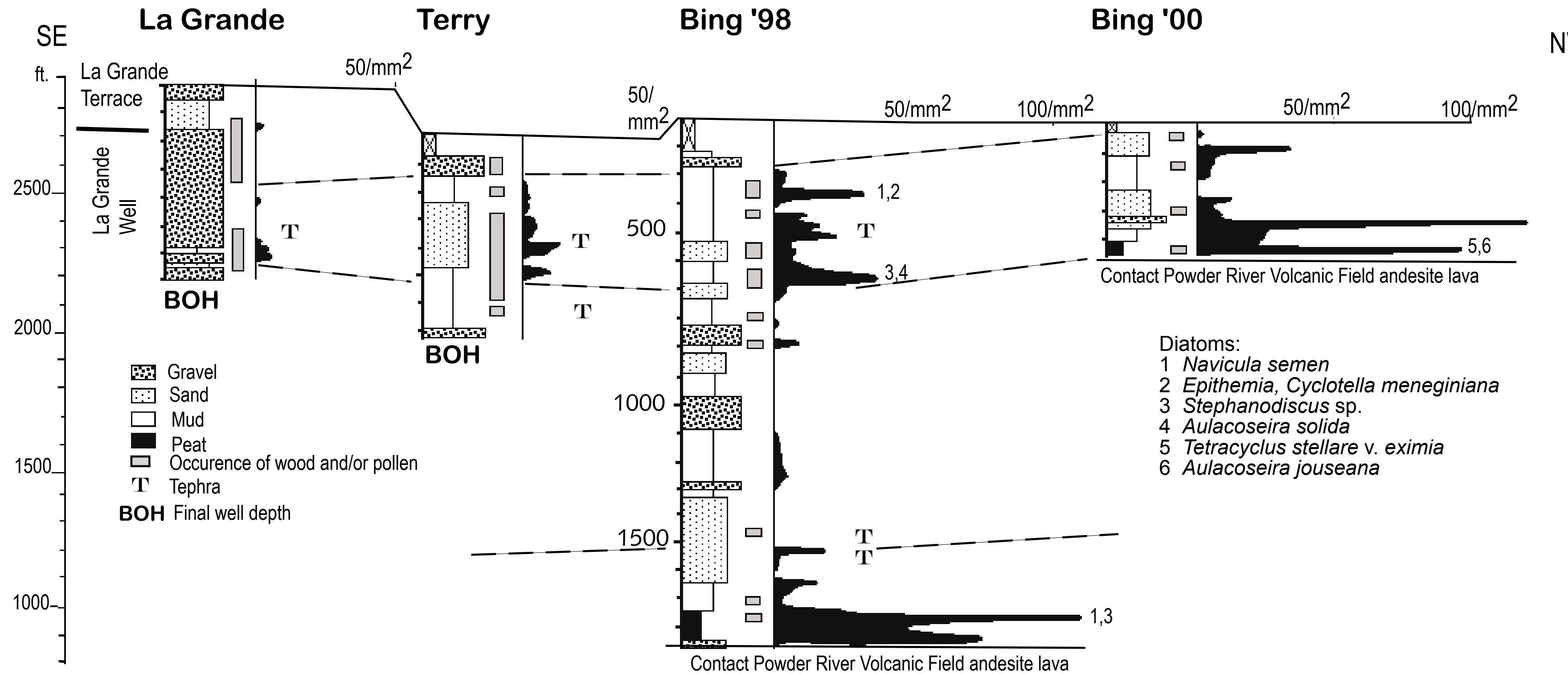


**Figure 2. Stratigraphy of the Grande Ronde Valley and frequency counts of diatoms, based on analysis of the recovered sediments from the four water wells identified in Figure 1. Stratigraphy of the La Grande terrace gravel deposits is stacked upon the La Grande well stratigraphy in order to simplify the diagram. Bars on extreme left and right show elevation in feet and meters, respectively; tick marks on left side of well diagrams show depth in 100-ft increments. Sediments in the wells range from gravel-rich beds indicative of stream-channel, alluvial-fan, and fan-delta deposits to mud and peat layers that were deposited in floodplains, shallow lakes, and marshes. Dashed lines show borders of two periods when the valley floor was relatively wet, as shown by the abundances of benthic and planktic diatoms in the valley sediments. Wells Bing '98 and Bing '00 bottomed in volcanic rock; wells Terry and La Grande did not reach bedrock. The fish fossils were recovered from the Bing '00 well at a depth of 452–642 ft (138–141m). The mammoth tooth mentioned in the text (see Table 1) was found in silty loam atop the La Grande terrace gravels.**

**Table 1. Radiometric age determinations for selected samples discussed in this paper**

| Sample ID | Material | Well | Depth (ft.) | Age | Dating Technique |
|---|---|---|---|---|---|
| EO-613 | Mammoth tooth | N/A | surface | 15.3±0.18 ka | Carbon 14 |
| Terry 356 | Volcanic ash | Terry | 356 | 3.1±0.3 Ma | $^{40}Ar/^{39}Ar$ |
| Bing 1553 | Volcanic ash | Bing '98 | 1553 | 7.5±0.4 Ma | $^{40}Ar/^{39}Ar$ |

position (anterior #1 or 2, main row) from *P. arciferus* Cope from the Miocene and Pliocene of the Snake River Plain and the Ringold Formation in south-central Washington, or from *P. oregonensis* from the Holocene fish fauna of the Columbia River drainage. The fish from which the fossil tooth was derived was about 25–30 cm in length. The second *Ptychocheilus* bone (UMMP 35046), an anterodorsal fragment of an opercle, 7 x 7 mm, is diagnosed by the angle of the hymandibular socket, its broad, robust reinforcing bar, and the shape and curvature of the levator arm and its dorsal flange. It is from a fish about 14 cm long.

Pikeminnows (formerly known as squawfish) are piscivores. Their distribution is western, ranging from the Colorado and Sacramento River basins, north to the Nass River, British Columbia. They are the largest North American minnows, although the Imbler fossils are not large. The *Ptychocheilus* fossil record extends from 15 Ma to the Holocene in the Columbia River drainage (Smith and others, 2000).

The Imbler collection also contains one small fragment of an unidentified cleithrum. This fragment is probably a cyprinid, but it is not possible to tell whether it is a pikeminnow.

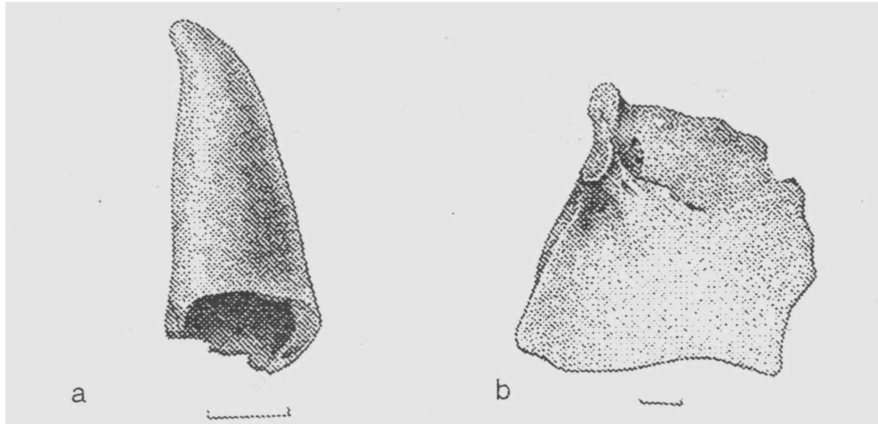


**Figure 3. *Ptychocheilus* sp., pikeminnow from the well Bing '00: (a) Pharyngeal tooth (UMMP 35046); (b) right opercle (UMMP 35046), mesial view, (scale bars = 1 mm). Drawings by Emily Damstra.**

### Family ICTALURIDAE
### Genus *Ameiurus* cf. *reticulatus*

Bullhead Catfish

Figure 4b,d,e

Bullhead catfishes are represented in the Bing '00 well samples by 14 pectoral spines (10 items EOU 634, 4 items UMMP 35041); 1 supraoccipital (UMMP 35043), 12 mm long; 1 partial premaxilla (UMMP 35042), 10 x 7 mm; 1 dorsal spine (EOU 634); 1 pterygiophore (UMMP 35041), 12 mm long; 6 vertebrae (EOU 634); 1 Weberian vertebra (EOU 634); and several skull fragments (EOU 634).

The supraoccipital bone is reticulated on its dorsal surfaces, like those of *Ameiurus reticulatus* of the Ringold Formation (see also Smith and others, 2000, Figure 9g). The supraoccipital has a deeper median-

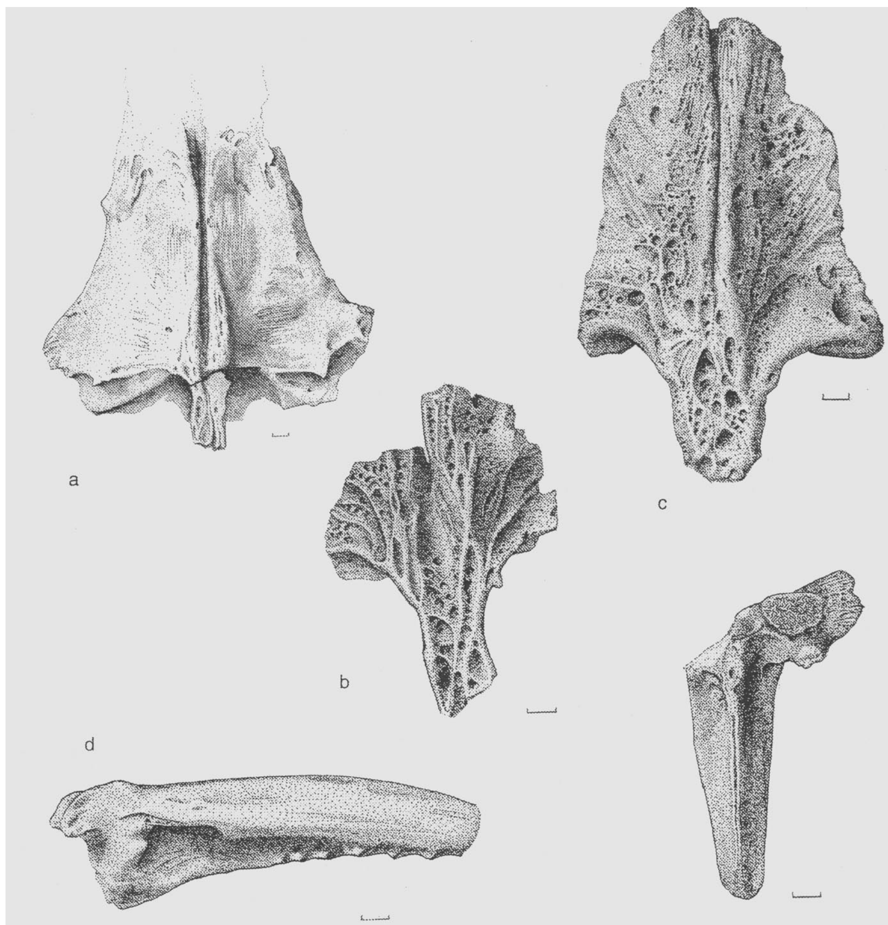


**Figure 4. *Ameiurus*, bullhead catfish from Bing '00 well, with comparison specimens (a and c): (a) *Ameiurus vespertinus* from Glenns Ferry Formation, dorsal view of posterior part of skull, showing supraoccipital with its smooth surface and open fontanelle (UMMP 62443); (b) *Ameiurus* cf. *reticulatus* (UMMP 35043), dorsal view of posterior part of skull, showing supraoccipital with its reticulate surface and closed fontanelle; (c) *Ameiurus reticulatus* from Ringold Formation, Washington, dorsal view of posterior part of skull, showing supraoccipital with its reticulate surface (UMMP 104031); (d) *Ameiurus* cf. *reticulatus*, first dorsal pterygiophore, anterior view (UMMP 35041); (e) *Ameiurus* cf. *reticulatus,* basal part of left pectoral spine, ventral view (EOU 634); (scale bars = 1 mm). Drawings by Emily Damstra.**

dorsal longitudinal groove or fontanelle, somewhat like those of *A. vespertinus* from the Glenns Ferry Formation of Owyhee County, Idaho, described by Smith (1975). The longest of the pectoral spines is a fragment, 20 mm long (apparently 26 mm long in life). They are striated like *A. reticulatus* and *vespertinus*. The dorsal pterygiophore has characteristics of each of those species. The bones indicate fishes about 20 cm long.

Bullhead catfishes are lowland, warm-water fishes whose present-day range is mainly in eastern North America. These catfishes are found in low-gradient streams and lakes generally below 1,000 m in elevation, in warm-temperate climatic zones that experience at least 230 frost-free growing days and at least 40 cm of rainfall. *Ameiurus* lived in western North America from the Eocene through the Pliocene, but became extinct west of the Rocky Mountains during the late Pliocene; they have been successfully reintroduced in the western U.S. over the past 120 years. The large sample of relatively small bones suggests slow growth. The small size of the *Ameiurus* in the Imbler assemblage suggests that the catfish were limited by cool summer temperatures and a reduced growing season.

**Family CENTRARCHIDAE**
**Genus *Archoplites* sp.**
Western Sunfish
Figure 5a,b

Sunfishes are represented in the Bing '00 well samples by 131 dorsal and anal spines (126 items EOU 635, 9–14 mm long; 5 items UMMP 35044); an incomplete right cleithrum (UMMP 35045); and several small fragments. The cleithrum is similar to Pliocene preopercles of *Archoplites taylori* from the Glenns Ferry Formation described by Smith (1975) and *A. molarus* from the Ringold Formation described by Smith and others (2000). The large sample of bones from small sunfish suggests slow growth.

Modern sunfish, *Archoplites interruptus*, are found today in low-gradient streams, lakes, and reservoirs generally below 1,000 m in elevation. They are native to the Central Valley of California in areas where they experience a yearlong growing season and at least 40 cm of annual rainfall. They have been successfully reintroduced into western waters in areas with eight months of frost-free temperatures.

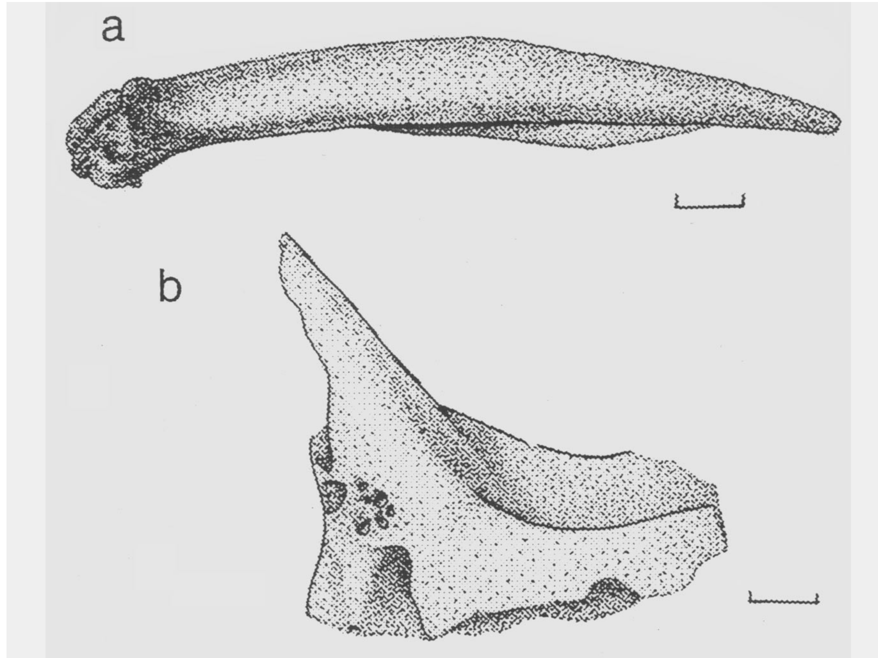


**Figure 5. (a) *Archoplites* sp., western sunfish: median spine (UMMP 35044), lateral view; (b) partial right cleithrum (UMMP 35045), lateral view; Scale bars = 1 mm. Drawings by Emily Damstra.**

**Family SALMONIDAE**
**Subfamily COREGONINAE**
**Genus *Prosopium* sp.**
Mountain Whitefish
Figure 6a-d

The whitefish identification is based on one complete, well-preserved mid-thoracic vertebra (and one partial vertebra). The specimen (UMMP V35064) is 5 mm wide, 4.5 mm high, and 2.8 mm long. It is identified as a salmonid by the pitted, lacework texture of the lateral surfaces between the neural arch and rib fossae (Figure 6a); however, the texture is much coarser than in the Salmonidae. There are large ventro-lateral fossae for rib attachments and moderately large dorso-lateral fossae for the neural arch attachments (Figure 6b). The mid-dorsal pair of fossae (Figure 6a) is asymmetrical and elongate; the ventral fossae are symmetrical, elongate, and separated by an long, narrow longitudinal ridge that is characteristic for the thoracic vertebrae of the family and the genus (Figure 6c). The vertebra is distinguished from vertebrae of Catostomidae, Cyprinidae, Ictaluridae, and Centrarchidae, because those families lack the paired longitudinal ventral fossae separated by a narrow ridge.

Whitefish of the genus *Prosopium* were common in Pliocene Lake Idaho. There, the appearance of the genus, according to Smith and others (1982), indicates immigration from the north facilitated by a cooling climate. *Prosopium* is now found in cool waters from the Great Lakes and streams in western North America, northwest to Siberia. The fish are now common in Oregon streams, but have not been recorded from the Taunton or White Bluffs Faunas (Ringold Formation) of the Columbia River drainage basin.

*Prosopium* is indicative of cooler waters than suggested by the other families represented in the Imbler

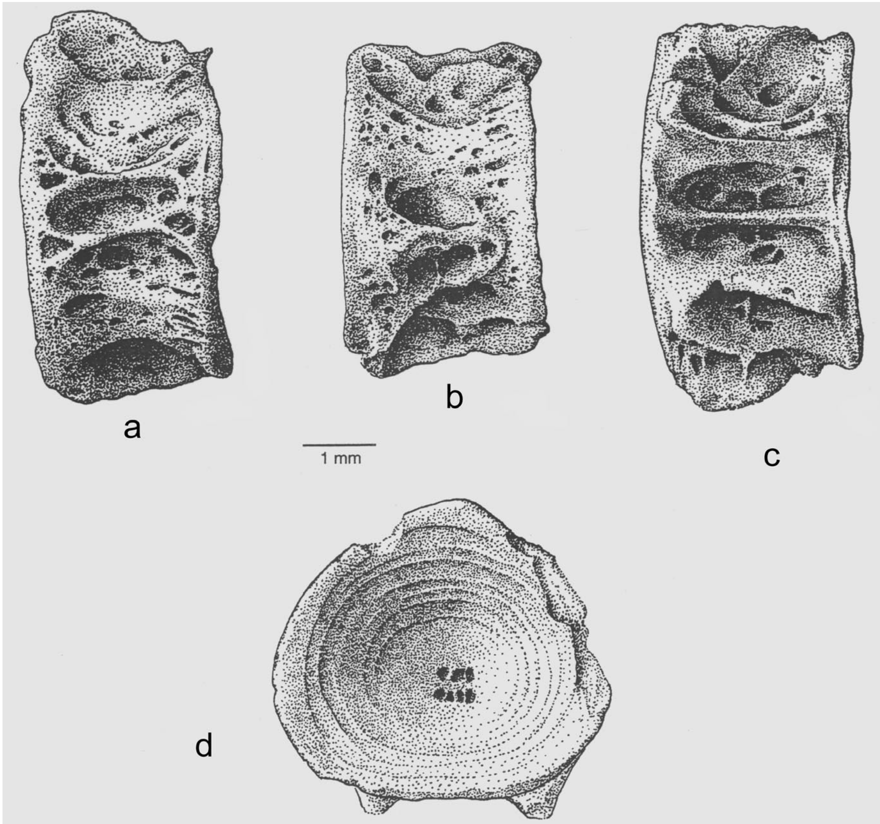


**Figure 6. *Prosopium* sp., mountain whitefish, vertebra (UMMP V35064) from Bing '00 well; (a) dorsal view; (b) lateral view; (c) ventral view; (d) anterior view showing growth rings. The growth rings indicate that the whitefish was 8 years old. Scale bar = 1 mm. Drawings by Emily Damstra.**

fauna. Whitefish would not ordinarily live with catfish and sunfish. Either the summers were cool enough for the *Prosopium* to coexist with *Ameiurus* and *Archoplites*, or the whitefish specimens were washed into the warmer lowland and its ponded environment from upstream. The number of growth rings on the vertebra shows that the specimen was eight years old (Figure 6d), which indicates that the diameter of the whitefish vertebra grew at an average rate of ~0.6 mm/yr. This growth rate is similar to those of whitefish that live today in the cold waters of the Laurentian Great Lakes.

## DIATOMS AND SPONGES

Diatom genera in the Grande Ronde Valley well cuttings include *Aulacoseira*, *Cyclotella*, *Cymbella*, *Epithemia*, *Fragilaria*, *Navicula*, *Nitzschia*, *Stephanodiscus* (large and small), *Synedra*, *Tetracyclus*, and rare *Amphipleura*, *Anomoeoneis*, *Asterionella*, *Diatoma*, *Eunotia*, *Gyrosigma*, *Meridion*, *Pinnularia*, *Reimeria*, *Rhoicosphenia*, *Rhopalodia*, *Surirella*, and *Tabellaria*. The lower diatom-rich zone (see Figure 2), deposited after emplacement of the andesitic bedrock and until slightly after the Bing 1553 ash (~9-7.5 Ma), is characterized by abundant benthic diatoms and the planktic diatom *Aulacoseira* sp. From interpolation between dated horizons, the upper diatom zone is estimated to have been deposited between ~4 and 2 Ma. It is characterized by an abundance of the planktic diatoms *Aulacoseira*. sp. and *Stephanodiscus* sp. but also contains abundant benthic diatoms.

J.P. Bradbury identified the diatoms *Navicula semen*, *Epithemia*, and *Cyclotella meneghiniana*? in a sample from the upper diatom zone at a depth of 253 ft (77.1 m) in the Bing '98 well (Bradbury, written communication, 2001). Abundant *Stephanodiscus* sp. and another centric diatom, *Aulacoseira* sp. aff. *Aulacoseira solida*, were identified in the upper diatom zone at a depth of 550 ft (167.7 m) in the same well. An organic-rich sample from a level of 1,769 ft (539.6 m) in the lower diatom zone in the Bing '98 well contained abundant *Navicula* semen and pollen. A sample from the upper diatom zone at a depth of 452 ft (137.8 m) in the Bing '00 well contained the relatively rare diatom *Tetracyclus stellare* v. *eximia* and an even rarer species, *Aulacoseira jouseana* (Figure 2).

Sponge spicules in the Grande Ronde Valley well cuttings include *Ephydatia lacustris*, *E. mulleri* and *Spongilla lacustris*. Sponge spicules are most common in cuttings containing abundant benthic diatoms.

The Bing '00 well cuttings that contain the fish fossils consist of peat, quartz- and feldspar-rich sand, andesite fragments, and fragments of diatomite which may have been mixed in from an overlying layer as a result of the drilling process. The diatomite includes the planktic genera *Aulacoseira*, *Stephanodiscus*, and *Synedra*, plus the benthic and epiphytic genera Nitzschia, *Tetracyclus*, *Cymbella*, *Epithemia*, *Fragilaria*, and *Gomphonema*. The diatomite also contains sponge spicules which are dominantly *Ephydatia fluviatilis*, plus *E. mulleri* and *Spongilla lacustris*.

## AGE OF THE IMBLER FISH FOSSILS

The age of lava flows that floor the Grande Ronde Valley area without ponding suggests that the valley began to subside ~9 m.y. ago. A similar date for the initiation of sedimentation can be derived by (1) dividing the thickness of sediment between bedrock and the ~7.5-Ma ash layer in the Bing '98 well by the average sediment accumulation rate between the ~3.1-Ma and 7.5-Ma layers, and (2) adding this time to the age of the ~7.5-Ma ash.

The relatively rare diatom, *Tetracyclus stellare* v. *eximia*, present in the Bing '00 well sediments at a depth of ~138 m, just above the fossil fish bones, was identified by VanLandingham (1985) in the lower Idaho Group in Mann Creek, Washington County, Idaho. The even rarer diatom *Aulacoseira jouseana* in the Bing '00 sediments was found abundantly in another lower Lake Idaho Group outcrop on Sagebrush Hill, Washington County, Idaho (Bradbury and Krebs, 1982; Bradbury, written communication, 2001). The age of these sediments is poorly constrained, however (Bradbury and Krebs, 1982). According to VanLandingham (1985), *A. jouseana* is not restricted and extends to the Blancan and possibly into the Pleistocene. On the other hand, *T. stellare* v. *eximia* is known only from sediments of 14 Ma and older. It was found in the Mann Creek district with other middle Miocene diatoms that are also found in the middle Miocene Truckee Formation of Nevada. Since it occurs in the Bing '00 well just above the fish fossils, it is possible evidence that the Imbler fish fossils are middle Miocene in age; however, the occurrence of the diatoms above ~9-Ma bedrock argues against this. The scarcity of these diatoms in the samples suggests redeposition, and it seems likely that the *A. jouseana* and *T. stellare* v. *eximia* diatoms in the Grande Ronde Valley sediments have been reworked from older sediments (Bradbury, written communication, 2001). The presence of *Stephanodiscus* sp. and *Aulacoseira* sp. aff. *A. solida*, which are probable equivalents of similar diatoms in the Pliocene Glenns Ferry Formation of the Lake Idaho sequence, in the sediments just above the fish bones suggests that the fish bones are Pliocene in age.

The types and sizes of the Imbler fish fossils provide important clues to their age. The pikeminnow is not helpful in assigning age—northern pikeminnows span a period from 15 Ma to Holocene in the Columbia River drainage (Smith and others, 2000). The large sample of bones from unusually small sunfish and catfish suggests slow growth as expected in cooling Pliocene climates. Miocene sunfishes in Oregon and Idaho reached sizes three to four times larger, and Miocene catfishes in the western United States were several times larger than the Imbler catfish. Miocene fish faunas from Oregon, Washington, and Idaho include several species of large salmon and trout, not seen in the Bing '00 samples. Earlier Pliocene faunas from Washington, Oregon, and Idaho include not only many more species than the Imbler fauna, but larger specimens of the comparable species. The whitefish *Prosopium* is known from Pliocene and Holocene on the Snake River Plain and Pleistocene to Holocene in the Bonneville Basin. Catfish became extinct in the western United States during the late Pliocene, establishing an upper limit of 1.6 Ma for the age of the Imbler fish fossils. This evidence suggests a mid- to late Pliocene age for the Imbler fish fossils.

Of all of the Neogene fish faunas in western North America, the individual bones in the Imbler fauna are most like the late Pliocene Taunton Local Fauna of the Ringold Formation, 13 km (8 mi) west-southwest of Othello, Washington, 180 km (112 mi) to the north-northwest of the Grande Ronde Valley. Three Imbler species—-bullhead catfish (*Ameiurus* cf. *reticulatus*), western sunfish (*Archoplites* sp.), and northern pikeminnow (*Ptychocheilus* sp.)—are similar taxonomically and ecologically to their counterparts among the Taunton fishes.

On the basis of the proportion of shared species, the Imbler fish fauna is most similar to the early Pliocene Blufftop Fauna of the Ringold Formation (described by Smith and others, 2000). Three Imbler fish fossil species are also present in the Blufftop Formation. The Taunton and other Pliocene Ringold faunas include several additional suckers and minnows as well as muskellunge and sturgeon. For these reasons, the Imbler (Bing '00) fishes are interpreted to have an age somewhere between the age of the Blufftop Fauna (3.9 Ma) and the age of the Taunton Fauna (~2.8–3 Ma), namely ~2.8–3.9 Ma.

Vertical variations in the abundance of *Stephanodiscus* sp. (a deep-water species) in the Bing '98 well match with vertical variations in the abundance of *Aulacoseira* sp. (a shallow-water species), benthic diatoms, and sponge spicules in nearby wells (Figure 7). These correlations suggest that the position of the Imbler fish fossils in the Bing '00 well is stratigraphically below the Terry 356 ash. Since the Terry 356 ash matches geochemically with the 2.9-Ma Bonneville Basin ash of Williams (1994) mentioned above, the age of the Terry 356 ash may also be ~2.9 Ma. Based on its stratigraphic position between the Terry 356 and Bing 1553 ashes (Table 1), the estimated age of the Imbler fishes, is ~3.7–3.8 Ma. (Figure 7). This age should be regarded as only a rough estimate, since average sedimentation rates are often not representative of the real sedimentation rates, which tend to be more episodic, particularly in alluvial and fluvial sediments.

**PALEOENVIRONMENTS**

The diatoms and sponges in the Grande Ronde Valley sequence indicate that, in addition to alluvial environments, a wide range of marsh and lacustrine environments have been present in the Grande Ronde Valley over the past 9 Ma (Figure 8). These include (1) marsh, bog, and shallow-water environments dominated by sponge spicules and benthic diatoms; (2) shallow, open-water environments dominated by benthic diatoms and *Aulacoseira* sp.; and (3) deep-water environments dominated by *A.* sp. and *Stephanodiscus* sp. Rainy, wet periods during the history of the basin occurred at ~9–7.5 Ma, 6.5 Ma, 4–2 Ma, and 1.2 Ma (ages based on average sedimentation rates interpolated between dated horizons).

Diatoms present in the ~9–7.5 Ma sequence suggest that the Grande Ronde Valley was dominated by marsh and bog environments with scattered areas of open water during that pe-

*(Continued on page 89*

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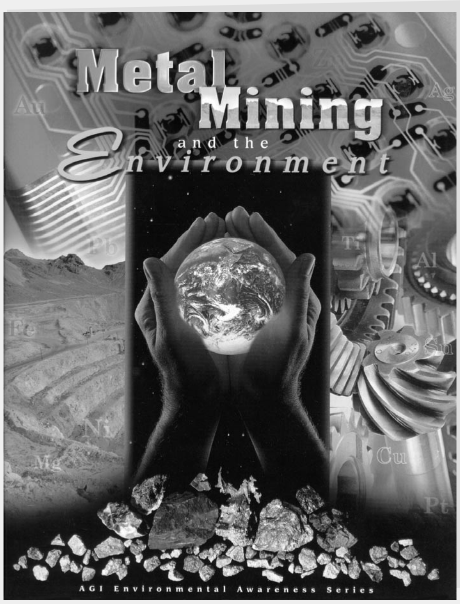
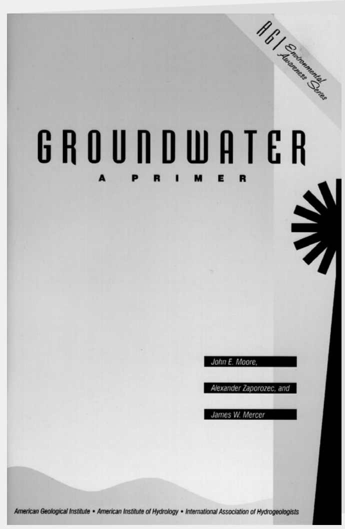
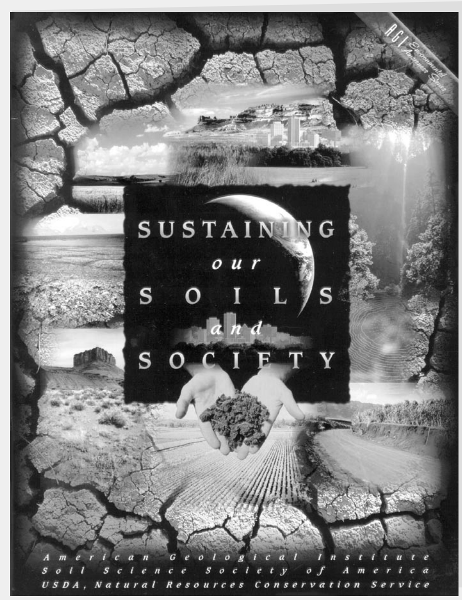



Each of the books is about 65 pages long, is lavishly illustrated, and provided with a list of references, a glossary, and an index. Books 2 and 3, on soils and metal mining, respectively, are in full color throughout and come with an equally colorful poster. Prices at the Nature of the Northwest Information Center are $6.50 for Book 1 (Groundwater), and 15.95 each for Books 2 (Sustaining our Soils) and 3 (Metal Mining and the Environment).

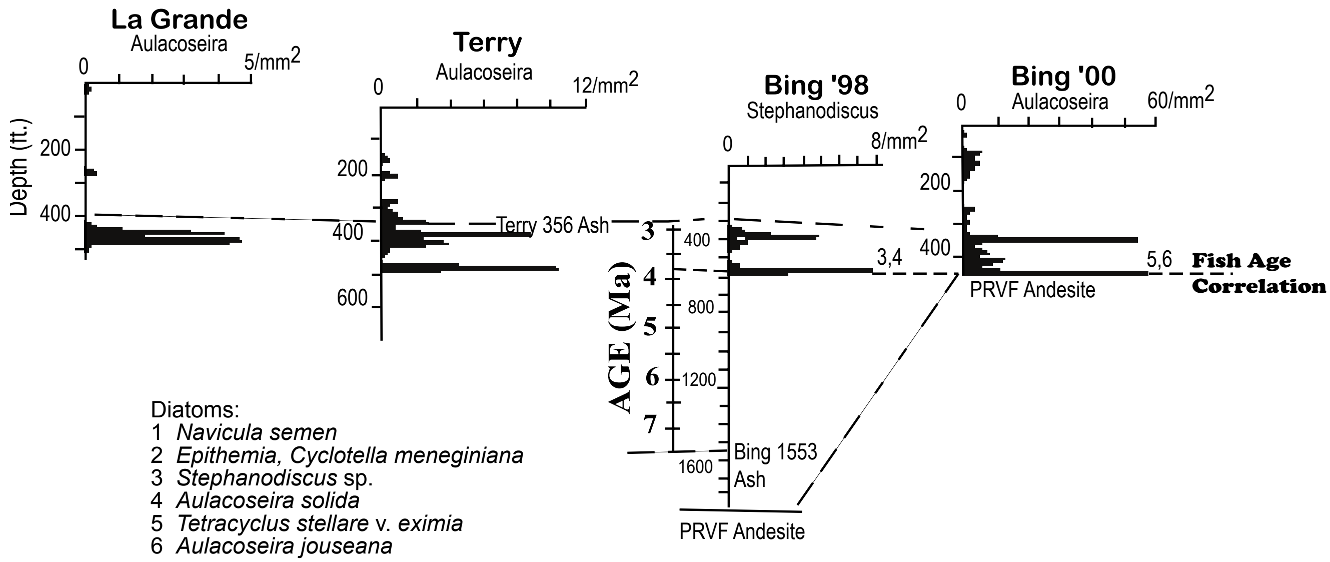



**Figure 7. Age correlation diagram illustrating how the ~3.7- to 3.8-Ma age of the Bing '00 fish fossil horizon was determined. The peaks in diatom abundance (upper dashed line) were used as a guide to determine which layers in the Bing '98 well match those that contain the Imbler fish fossils in the Bing '00 well and those that contain the Terry 356 ash in the Terry well. The stratigraphic position of the fish fossil horizon between the Bing 1553 and Terry 356 ash horizons was then used to estimate the age of the fish fossils (lower dashed line). The age of the Terry ash was adjusted to be ~2.9 Ma to match the age of geochemically similar ashes from the Bonneville basin. Note that the peak abundances of the shallow-water diatom genus, *Aulacoseira*, in the La Grande, Terry, and Bing '00 wells correlate with peaks in the abundance of *Stephanodiscus*, a deep-water diatom genus, in the well Bing '98. This suggests that between ~2.9 and 3.7 Ma water depth was greater in the area of the Bing '98 well than it was at the other well sites.**

*(Continued from page 89)*

riod, while mainly marsh and bog environments were present at ~6.5 Ma. The diatoms in the ~2- to 4-Ma sediments suggest that deepwater lakes were present during this period in addition to marshes and bogs. According to J. Platt Bradbury (written communication, 2001), the presence of *Navicula semen* at a depth of 253 ft (77.1 m) in the Bing '98 well suggests a shallow, oligotrophic marsh or bog environment. However, *Epithemia* and *Cyclotella meneghiniana?* in the same sample imply greater alkalinity and nutrient status. This may be the result of mixing during transport. Abundant *Stephanodiscus* sp. and another centric diatom, *Aulacoseira* sp. aff. *Aulacoseira solida*, in the upper diatom-rich zone in the same well suggest a nutrient-rich lake. The brief period of marsh and bog sedimentation at ~1.2 Ma interrupted a period of alluvial and fluvial sedimentation that has dominated the area over the past two million years.

The sedimentary sequence just above bedrock in the Bing '00 well records a change from alluvial to shallow, open-water lacustrine environments. The Imbler sunfish and catfish fossils are shallow-water and warm-water species and appear to indicate a small pond or oxbow-lake habitat. Their presence suggests an elevation below 1,000 m, at least 230 frost-free growing days, and at least 40 cm of annual rainfall. Cool summer temperatures and a reduced growing season are indicated by the small size of the *Ameiurus* in the Imbler assemblage. The occurrence of a large pikeminnow suggests that the size of the habitat was not a factor limiting the size of the Imbler sunfish and catfish. Nearby mountain streams may have been a source of cool water, limiting the size of the Imbler catfish and sunfish, perhaps from the nearby Wallowa and Elkhorn Mountains, as indicated by the presence of the mountain whitefish vertebra. The Imbler fish fauna includes fewer species and smaller specimens of comparable species than the earlier Pliocene fish faunas from Washington, Oregon, and Idaho; this indicates shorter growing seasons and/or smaller aquatic habitats. The Imbler fishes indicate that the mid-Pliocene Grande Ronde Valley was higher in elevation and had smaller habitats and slightly lower fish diversity than the late Pliocene Taunton locality.

The organic-rich, peaty sediments in the Bing '00 well, just above the layer containing the most abundant fish fossils, are rich in benthic and epiphytic diatoms. Some fish bones were found in these peaty sediments but fewer than in the mixture of rock fragments, quartz sand, and diatomite in the layer just above andesite bedrock. The diatoms in this layer resemble diatoms in the upper detrital peats of the Pleistocene American Falls Lake beds of southeastern Idaho (noted by Bright, 1982, and Scott and others, 1982) and in certain facies of the uppermost Glenns Ferry Formation (described by Bradbury and Krebs, 1982).

The Bing '00 samples that contain fish bones also contain abundant sponge spicules. The sponge spicules resemble specimens in some peats of the American Falls Lake beds, which, in turn, are similar to those found in modern freshwater (very low chloride) ponds and lakes in southeastern Idaho and western Wyoming. These sponge spicules indicate water temperatures of 12°–4°C and water depths less than 1.5 m (Bright, 1982).

The sediments above the peaty layers in the Bing '00 well are rich in *Aulacoseira* and benthic diatoms (although the percentages of benthic diatoms are less than in the peaty sediments). This suggests a change to shallow, open-water, lake environments at the Bing '00 well site after the deposition of the peats. The abundance of the diatom *Stephanodiscus* deposited in the Bing '98 well at the same time (Figure 7) suggests that the water depth was greater at the site of the Bing '98 well than at the site of the Bing '00 well during the same period (~3.6–2.9 Ma).

## DISCUSSION: THE LAKE IDAHO-COLUMBIA RIVER CONNECTION

"The Blue Mountains abound in physiographic problems caused by many changes in river courses . . . many of them, and the most important ones, among which is the origin of the Snake River Canyon, are still unsolved and a rich field here remains for future work." (Lindgren, 1901, p. 598).

The hypothesis that a large lake occupied the western and central parts of the Snake River Plain during the Tertiary was proposed by Cope (1870, 1883a,b) after he examined fish bones collected from the area by the Hayden expedition (Hayden, 1872) and the King survey (King, 1878). Cope named this great lake "Lake Idaho." This conclusion was supported in later work by Russell (1902). Lindgren and Drake (1904) divided the depositional sequence into two distinct basin-filling episodes, the Payette and Idaho Formations, separated by an unconformity. Malde and Powers (1962) revised this terminology by calling the sequence the Idaho Group and subdividing it into the late Miocene Chalk Hills Formation, the Pliocene Glenns Ferry Formation, and several other volcanic and sedimentary units. Workers have studied fossil fish (Miller and Smith, 1967; Smith, 1975; Smith and others, 1982; Drummond and others, 1993; Patterson and others, 1993; Smith and Patterson, 1994; Coburn and others, 1996), lavas and volcanic ash layers (Swirydczuk and others, 1982; Jenks and Bonnichsen, 1989), and sediments (Malde, 1972; Kimmel, 1982; Middleton and others, 1985, Wood, 1994) of the central and western Snake River Plain and have documented a complex lake system and accompanying floodplains, in which lake-basin sedimentation alternated between lacustrine, fluvial, and fluvial-deltaic environments. Lake Idaho was drained when the Salmon River eroded headward and captured a tributary of the Snake River, creating a

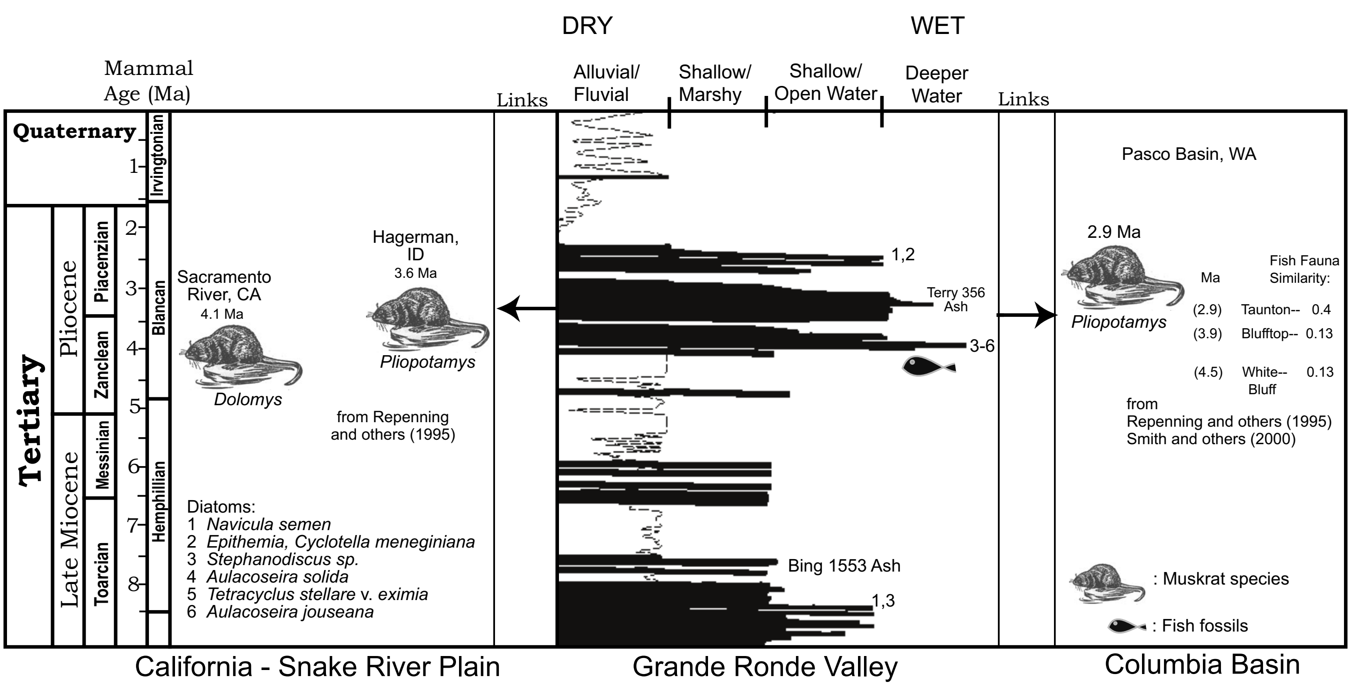



**Figure 8. Composite diagram of the stratigraphy and diatom species identified in the four water wells, indicating environmental/climatic changes over time in the Grande Ronde Valley. The dashed peaks plot times of predominantly gravel deposition indicating alluvial and fluvial environments and the black peaks indicate times of abundant shallow- to deep-water diatom species deposition.**

drainageway through Hells Canyon (Livingston, 1928; Wheeler and Cook, 1954; Cook and Larrison, 1954; Othberg, 1988, 1994; Malde, 1991; Othberg and others, 1995). This caused canyon-cutting and deposition of gravels in the river valleys, as the lake levels dropped (Lindgren, 1901). As the lake receded, braided streams and stream deltas spread across the basin, capping the Lake Idaho sequence with gravels (Othberg, 1988; Jenks and Bonnichsen, 1989).

Livingston (1928) proposed that the original outlet for Lake Idaho was through northeast Oregon via the Burnt, Powder, and Grande Ronde Rivers to the Columbia River. He based his opinion on the geomorphology of the area and, in particular, the presence of barbed stream tributaries. Wheeler and Cook (1954; see Figure 9) suggested that Livingston's proposed drainage course was improbable for several reasons: (1) there are no barbed tributaries in the Burnt River area; (2) the pass through which the diversion to the Powder River system supposedly occurred is at a higher elevation than the Oxbow in Hells Canyon, which both Livingston (1928) and Wheeler and Cook (1954) proposed as the point where a tributary of the Salmon River captured the Snake River at the start of the Quaternary; (3) there are no known lacustrine sediments in the Powder River (Baker) Valley that can be related to the Snake River's history; and (4) there is no evidence that the Grande Ronde River accommodated a stream of the Snake River's magnitude.

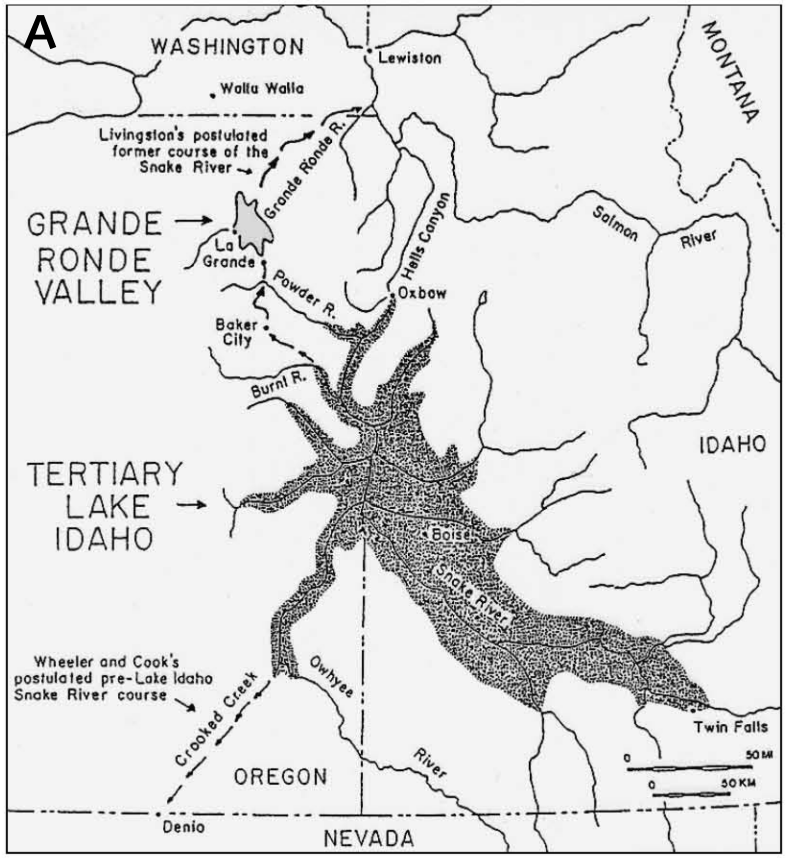
Wheeler and Cook (1954) were careful to note that the timing of the Snake River capture with respect to the stratigraphy and history of the Snake River Plain was still incompletely understood, but suggested that capture took place at ~2 Ma. This date is supported by stratigraphic evidence that suggests a drop of ~120 m in the level of Lake Idaho at Glenns Ferry Formation age (~2 Ma), and by biostratigraphic evidence that indicates the time when the Snake River became part of the Columbia River drainage: through the distribution record of the snail *Fisherola nuttali* (Taylor, 1985; Othberg, 1988; Malde, 1991).

Othberg (1994) pointed out that evidence from the Snake River Plain cannot prove that the capture of the Snake River by the Salmon occurred as the Pleistocene ice ages began and that it is possible that the drainage diversion may have occurred during the late Pliocene. Recent paleontologic studies support the possibility that the Snake River-Hells Canyon-Columbia River connection may have been established even earlier during the Pliocene. Repenning and others (1995) noted fossil assemblages that suggest an expansion of the range of muskrats during the Pliocene from the Sacramento River drainage (4.1 Ma) to Lake Idaho (Glenns Ferry Formation, 3.6 Ma) and then to the Columbia River drainage (Ringold Formation, 3-4 Ma). The study by Smith and others (2000) of fishes in the Ringold Formation at Pasco, Washington, supports the late Pliocene date suggested by Repenning and others (1995) for the advent of the Lake Idaho-Columbia River connection through Hells Canyon. Faunal similarity and the absence of Glenns Ferry fishes in the Taunton fauna of the Ringold Formation at Pasco, Washington, suggest that the connection was prior to 3 Ma or that a substantial ecological barrier was established (Figure 8). Wood (2000) has suggested that the spillover of Lake Idaho into Hells Canyon may have occurred even earlier, at ~4.5 Ma, although the timing is poorly constrained.

Recent estimates of the maximum elevation of Lake Idaho during the Pliocene, ~2–3 m.y. ago, range from 1,070 to 1,160 m (Smith and others, 1982; Jenks and Bonnichsen, 1989). Smith and others (2000) pointed out that these estimates negate the dismissal by Wheeler and Cook (1954) of the Lake Idaho drainage route proposed by Livingston (1928). They pointed out further that (1) lack of barbed tributaries on the Burnt River was not relevant, because the Burnt River was submerged by the Powder River embayment of Lake Idaho (Figure 9b); (2) the upper Powder River flows at an acute angle and in reversed direction to the trunk stream, which indicates a reversal of drainage as noted by Livingston (1928); (3) the Wheeler and Cook argument against Livingston that was based on elevation differences is also negated, because those elevations depend on the relative rates of uplift of the Blue Mountains-Wallowa Mountains-Seven Devils Mountains area. Smith and others (2000) concluded that, if Livingston's hypothetical connection occurred, it was after the Blufftop Fauna at Ringold (3.9 Ma) and before the late Pliocene capture of Lake Idaho through Hells Canyon, which probably occurred no later than 2 Ma.

Fish fossils and diatoms in the Grande Ronde Valley sequence provide new evidence of possible Lake Idaho-Columbia River drainage connections, but larger sample sizes are necessary before firm conclusions can be drawn. The similarity of *Ameiurus* cf. *reticulatus* fossils in the Imbler and Taunton suites and the estimated age of the Imbler fish fossils suggest a connection between the Grande Ronde Valley and the Columbia River at ~3.7–3.8 Ma. (Figure 8).

The Imbler fish fossils share some characteristics with mid-Pliocene Lake Idaho fishes but not enough to establish a link between the Grande Ronde Valley and Lake Idaho. Three species of minnows (*Lavinia*, *Acrocheilus,* and *Klamathella*) that were present in the Snake River Plain prior to 3 Ma are absent from the 3.9-Ma Blufftop Fauna of the Ringold Formation and from the ~3.7- to 3.8-Ma Imbler fish fossil suite (although additional Imbler fish specimens are needed to confirm this). These same minnows are found in the 2.8- to 3.0-Ma Taunton Fauna of the Ringold Formation, which indicates the initiation of a connection between the lower Columbia River drainage and the Snake River Plain between ~3.9 and 3 Ma. This evidence suggests that the Imbler fish fossils probably rep-



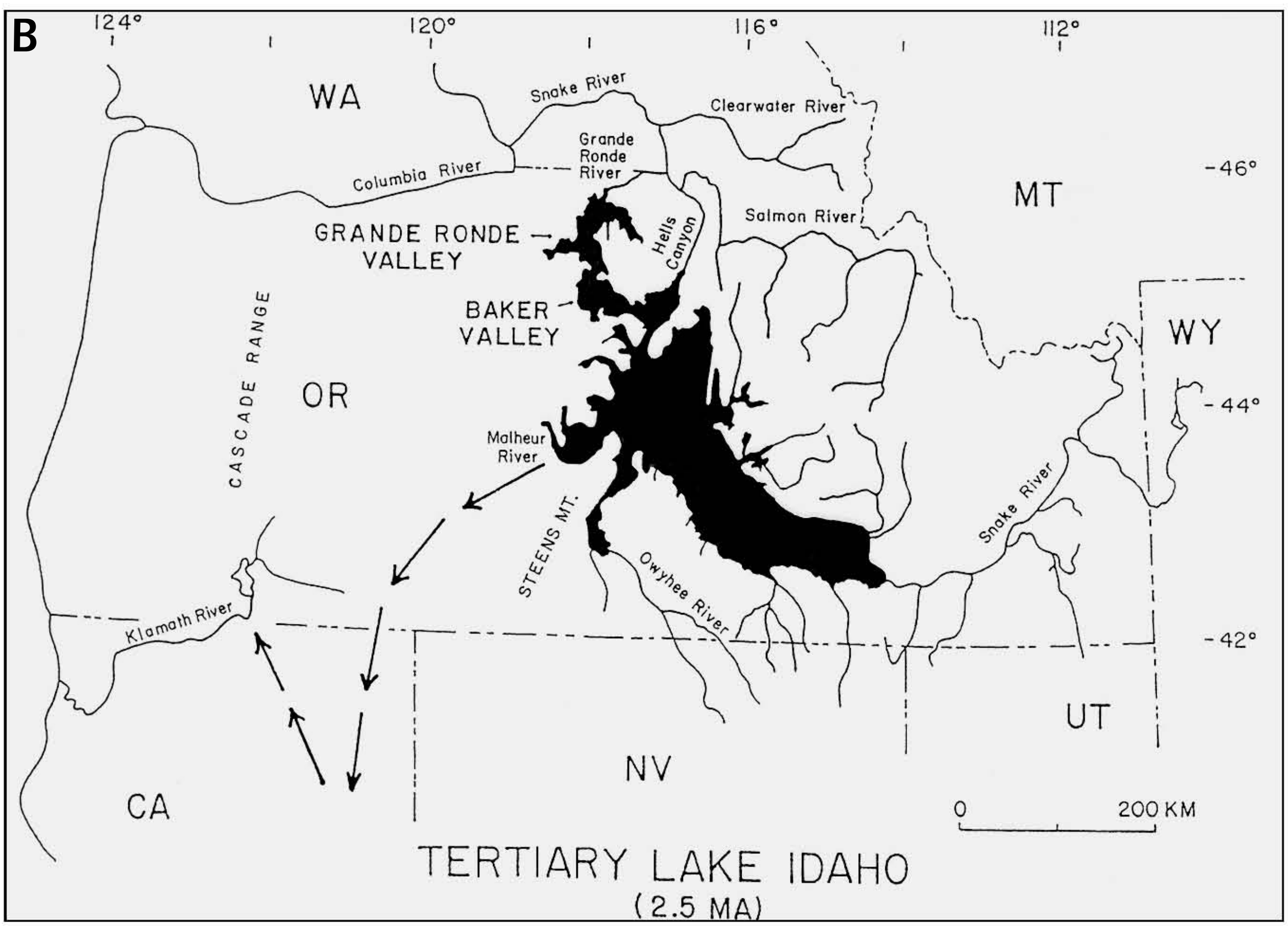




**Figure 9. Lake Idaho and its possible drainages: (A) based on Wheeler and Cook (1954). The boundaries of Lake Idaho are based the distribution of Lake Idaho sediments, and (B) The maximum extent of Lake Idaho at ~ 2.5 Ma, assuming a lake level of 1160 m, based on Jenks and Bonnichsen (1989). Note that the lake may have flooded the Baker, Grande Ronde and Wallowa Valleys. Arrows indicate routes of Pliocene drainage from Lake Idaho inferred by Taylor (1985) from biogeographic evidence.**

resent a time prior to the drainage of the Snake River to the Columbia. The presence of the whitefish vertebra in the Imbler fish fossil suite is a possible indicator of a connection between Lake Idaho and the Grande Ronde Valley.

The relatively rare diatom *Tetracyclus* v. *eximia* and the even rarer *Aulacoseira jouseana* in the Bing '00 well, just above the horizon containing the Imbler fish fossils, also occur in the Idaho Group. These reworked diatoms may have been blown into the Grande Ronde Valley from the western Snake River Plain by anticyclonic winds (J.P. Bradbury, written communication, 2001). It is also possible that they were washed in.

The zone of possibly reworked Lake Idaho diatoms just above the Imbler fish fossils in the Bing '00 well correlates with the occurrence of abundant *Stephanodiscus* sp. and the centric diatom *Aulacoseira*. sp. aff. *A. solida* at the 550-ft (167.7-m) level in the Bing '98 well in the Grande Ronde Valley (Figure 7). These two species probably relate to Glenns Ferry units in Idaho (J.P. Bradbury, written communication, 2001). The presence of these diatoms and the abrupt change to deep-water lake environments in the Grande Ronde Valley after the Imbler fish fossils were deposited suggest that a water connection between Lake Idaho and the Grande Ronde Valley was established at ~3.7 Ma. This conclusion provides support for the Jenks and Bonnichsen (1989) hypothesis that Lake Idaho flooded the Grande Ronde Valley area during the Pliocene (Figure 9b).

Another possible point of evidence for a connection between the Grande Ronde Valley and Lake Idaho is the presence of the 3.1±0.3-Ma Terry 356 ash which, geochemically, matches ashes of the same age from the Bonneville Basin and from the late Pliocene Glenns Ferry Formation of the Lake Idaho Group. One possible explanation for the presence of this ash in the sedimentary fill of the Grande Ronde Valley is that it was washed in from the Snake River Plain. But the ash is very pristine, good enough to determine an eruption age by radiometric dating. This suggests that the ash must have been rapidly transported and buried, so it is also possible that it was deposited by airfall.

Although this evidence does not prove the Livingston (1928) hypothesis that the Snake River drained from Lake Idaho through the Grande Ronde Valley to the Columbia, it does indicate that the Grande Ronde Valley was linked to both areas during the mid-Pliocene. This suggests the possibility that, starting at ~3.7–3.8 Ma, Lake Idaho may have flooded the Grande Ronde Valley and drained down the Grande Ronde River to the Snake and Columbia Rivers. This connection may have been open episodically until ~2 Ma, the time when the deep-water diatom, *Stephanodiscus* sp., largely disappears from the Grande Ronde Valley well sediments.

One possibile scenario is that the Lake Idaho drainageway during the mid-Pliocene was through the Grande Ronde Valley as proposed by Livingston (1928). This hypothesis provides an alternate route, other than Hells Canyon, for the migration of fish (Smith and others, 2000) and muskrats (Repenning and others, 1995) from Lake Idaho to the lower Columbia River during the Pliocene. The route could have existed until Lake Idaho was drained at ~2 Ma, the time when the Snake River was captured by a tributary of the Salmon River. A second possibility is that the main connection between Lake Idaho and the lower Columbia (Taunton Fauna) was established during the mid-Pliocene through Hells Canyon, with the drainage from the Grande Ronde Valley flowing, as it does today, as a tributary into the Snake River. This would explain the similarity between the Imbler fish fossils and the Taunton fauna. Perhaps both drainageways were active at various times, depending on the relative rates of uplift in the Blue Mountains-Wallowas-Seven Devils area (as proposed by Smith and others, 2000).

## CONCLUSION

The Grande Ronde Valley began to form ~9 m.y. ago and is filled with a complex mixture of alluvial, fluvial, and lacustrine sediments. It experienced two distinct wet periods when diatom-rich sediments were deposited. The first wet period occurred during the late Miocene (~9-7.5 Ma), when the valley was occupied by marshes and shallow lakes. Deeper water lakes were present in the Grande Ronde Valley during the second wet period that occurred during the Pliocene (~4-2 Ma).

The Imbler fish fossils (pikeminnow, catfish, sunfish, and whitefish) suggest that the Grande Ronde Valley area during the mid-Pliocene (~3.7-3.8 Ma) was at an elevation below 1,000 m but higher than the Taunton locality near Othello, Washington. The sizes of the catfishes and sunfishes were limited by cool summer temperatures and a reduced growing season. The individual bones of the Imbler fish fossils are most similar to the 2.8- to 3.0-Ma Taunton fauna of the Ringold Formation of eastern Washington, although there are some similarities to fishes in the late Pliocene Glenns Ferry Formation of the Lake Idaho Group. On the basis of shared species, the Imbler fish fauna is most similar to the 3.9-Ma Blufftop fauna of the Ringold Formation. The presence of the whitefish vertebra in the Imbler fish fossil suite is a possible indicator of a connection between Lake Idaho and the Grande Ronde Valley.

Two rare diatoms, *Aulacoseira jouseana* and *Tetracyclus stellare* v. *eximia*, were reworked from Lake Idaho deposits and may have been blown into the Grande Ronde Valley area, although river transport is also a possibility. Abundant *Stephanodiscus* sp. and the centric diatom *Aulacoseira*. sp. aff. *A. solida* , which probably also relate to the Lake Idaho Glenns Ferry units (J.P. Bradbury, written communication, 2001), suggest a water connection between the two basins. The presence in the Grande

Ronde Valley of a 3.1±0.3-Ma ash that is geochemically similar to an ash in the Lake Idaho sequence and a 2.9-Ma ash in the Bonneville Basin, is also a possible indicator of a connection between the Grande Ronde Valley area and Lake Idaho at ~3 Ma, although this ash could also have been deposited by airfall.

This evidence suggests links between the Grande Ronde Valley and both Lake Idaho and the lower Columbia River drainage during the mid-Pliocene. The diatoms in the sequence suggest that the link between the Grande Ronde Valley and Lake Idaho started at ~3.7 Ma, after the deposition of the Imbler fish fossils. This link may have recurred episodically until ~2 Ma. The evidence suggests that Lake Idaho spilled over into the Grande Ronde Valley (as proposed by Jenks and Bonnichsen, 1989), but it is not clear whether the Snake River flowed through the Grande Ronde Valley (as proposed by Livingston, 1928). If a connection between Lake Idaho and the Columbia River through the Grande Ronde Valley did exist during the Pliocene, it would provide an alternate route in addition to Hells Canyon for the migration of fish and muskrats from the Snake River Plain to the Columbia Basin after the deposition of the ~3.7- to 3.8-Ma Imbler fish fossils and prior to the draining of Lake Idaho at ~2 Ma.

Further work is needed to determine whether the Grande Ronde Valley area was connected to Lake Idaho earlier in its history, during the late Miocene. More seismic profiling would add greatly to our knowledge of the stratigraphy of the Grande Ronde Valley sediments and pave the way for better modeling of the groundwater flow through the sequence. More drilling and analysis of the microfossils in the sediment samples down to the species level would provide the samples necessary to unravel the link between climate variations, tectonics, and sedimentation in the basin and possibly produce additional fossils that would help us better understand the migration of fish and other animals between Lake Idaho and the lower Columbia River drainage during the Pliocene.

## ACKNOWLEDGMENTS

Special thanks go to Waldo Lowe and his assistants, the well drillers who found the fish fossils in the well cuttings and put in an incredible effort collecting many of the well cuttings analyzed in this study. We also thank Ross Bingaman, owner of the Imbler fish fossil well, for his genuine interest in the scientific aspects of a water well. We are grateful to J. Platt Bradbury, U.S. Geological Survey, retired, for identifying the diatoms in samples from the Bing '98 and Bing '00 wells and for reviewing an early draft of this paper. Emily Damstra created the illustrations of the fish bones. The manuscript was greatly improved by a thorough, detailed, and insightful review by Tom Wiley of the Oregon Department of Geology and Mineral Industries.

Thanks go to John Rinehart and Denny Swanger of the Eastern Oregon University Biology Department, who helped in the preliminary identification of the fish and diatoms. Ted Fremd, paleontologist at the John Day Fossil Beds National Monument, identified a limb cast from the Terry well. The City of La Grande provided cuttings from the La Grande well. The students of the Eastern Oregon University Historical Geology class of Spring 2000 helped pick the fish bones out of the Bing '00 well cuttings. Early studies of sediment samples from Grande Ronde Valley wells by Curt Peterson and his students at Portland State University helped provide insights that made this study possible.

This research was funded in part by a grant from the Grande Ronde Model Watershed Program and the U.S. Geological Survey National Cooperative Geologic Mapping Program under assistance award #99HQAG0036. Jay Van Tassell was funded in the early stages of this project by an Eastern Oregon University summer research stipend.

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***(Continued from page 70)***

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**U.S. POSTAL SERVICE STATEMENT OF OWNERSHIP, MANAGEMENT, AND CIRCULATION**

Publication title: OREGON GEOLOGY, no. 600040; filing date 9-13-01. Published quarterly, 4 issues per year, annual subscription price $10. Address of publication office, publisher's business office, editor, and owner: State Office Building, 800 NE Oregon St., #28, Portland, OR 97232-2162. Publisher and owner: Oregon Department of Geology and Mineral Industries; editor: Klaus K.E. Neuendorf. No bondholders. Circulation during last 12 months/of single issue, respectively: Net press run 2,625/2,500; paid outside-county mail 1,091/1,069; paid in-county mail 0/0, total paid circulation 1,266/1,119; free distribution outside county 123/79; free distribution inside county 0/0, other classes mailed 0/0; free distribution outside the mail 146/165; total free distribution 268/244; total distribution 1,534/1,363; not distributed 1,091/1,137; total 2,625/2,500; percent paid and/or requested circulation 82/82. I certify that the statements made by me above are correct and complete.

Klaus K. Neuendorf, Editor

# Statewide Mined Land Reclamation annual awards announced

Helping endangered salmon during flood events, reclaiming historically mined-out areas and controlling waste water at mine sites are some of the highlights of this year's Reclamation Awards presented by the Mined Land Reclamation (MLR) Program of the Oregon Department of Geology and Mineral Industries (DOGAMI) in July.

Winners were chosen by a panel of regulatory, industry, and environmental experts, and the awards were presented at the annual conference of the Oregon Concrete and Aggregate Producers Association. The MLR awards recognize mining companies and individuals that lead by example, surpassing the basic requirements of planning, operation, and reclamation at Oregon mine sites.

This year's MLR Award winners, judged on performance in the past year include the following:

**Outstanding Operator:**
**Pendleton Ready-Mix, Inc.,**
**Pendleton, Oregon**

Contact: Terry & Jayne Clarke, (541) 276-6951, prminc@oregontrail.net

The Pendleton Ready-Mix, Inc. (PRM), operation is located 4 mi east of Pendleton, south of and adjacent to the Umatilla River. Up until 1989, Umatilla County administered a mined land reclamation program for all aggregate sites in the county. In 1989, DOGAMI assumed administration of mined land reclamation from the county.

PRM operates a plant site where aggregate is processed into the raw product, concrete, and asphalt. No mining occurs at the plant site. Aggregate is mined at five permitted sites in Umatilla County. The two areas where PRM has concentrated its efforts are the reclamation of sites and the wise use and protection of water.

In the late 1980s, discharge of wastewater became a very important issue for aggregate producers and ready-mix operations, and an engineered hydrologic plan was developed for the PRM plant site. Lined ponds with leak-detection equipment were constructed for process water. A 750,000-gal, welded-seam, lined pond was constructed along with a pump/piping system that controls water to all aspects of the plant operation. Water is conveyed from the storage pond to the crusher and asphalt plants for reuse. Even with a valid water right on the Umatilla River, PRM went to the water storage system, so that negative impacts to the river during low flows could be minimized or eliminated. Storm water is collected in several sumps around the plant site and pumped to the storage pond for operations use and thus turned into a beneficial commodity.

Another phase of water recovery at the plant site involves the water used to wash rock at the crusher: it is cleaned through a series of ponds. Water from the outlet of these ponds is then piped to the storage pond for reuse. To protect against an accidental release, all ponds are monitored by an alarm system, which may be disarmed only at the point of alarm.

People at PRM have worked hard to establish a positive role in the community and to insure that their operation does not create adverse off-site impacts. Their commitment to improving the plant site over the past several years as well as stabilizing extraction areas puts PRM in the category of Outstanding Operator.

**Oregon Plan Award:**
**Morse Brothers, Inc., McNutt Site**

(see front cover)
Morse Brothers, Inc.,
Tangent, Oregon
Contact: Jeff Steyaert, 541-928-6491

Morse Brothers, Inc. (MBI), began mining the McNutt site in Linn County in 1974. This site is located one mile upstream from Harrisburg, adjacent to the Willamette River. It is within the active floodway and typically floods during high-water events. There is a steep channel gradient through this reach, and the river is also continually changing channels. During floods in 1996, the river breached an extraction pond, and a subsequent fish survey indicated that listed salmonids were in the pond. Working with Peter Bailey of Oregon State University, the Oregon Department of Fish and Wildlife, and the National Marine Fisheries Service, MBI constructed a habitat restoration project involving three mine ponds now connected to the Willamette River.

MBI is being recognized for its proactive approach to creating beneficial uses of existing ponds (by restoring them as off-channel fish habitat. The operators' goal is to show state and local agencies and individuals working on the Oregon Plan that floodplain mining can work, and they succeeded impressively by restoring fish and wildlife habitat along the Willamette River system in areas that make sense.

**Outstanding Reclamation:**
**Cascade Pumice Company,**
**Bend, Oregon**

Contact: Richard Pearsall,
(541) 382-2051

Cascade Pumice Company has been mining pumice, fill gravels, and cinders west of Tumalo in Deschutes County since the 1940s. The company is recognized for two decades of exemplary approaches to concurrent reclamation, reclamation of exempt areas, and innovative techniques that have allowed this operation to exceed state requirements. A significant portion of the company's mined areas has been exempt from the DOGAMI reclamation rules, because the land was disturbed prior to 1972.

DOGAMI inspection reports from 1984 and 1986 show that exempt mine areas were being reclaimed and revegetated and that disturbed areas were being reclaimed faster than new mining areas were being opened up. A 1994 report noted mined-out areas being regraded, topsoiled, and reseeded with cereal rye and native grasses.

Cascade Pumice Company has shown a great willingness to look beyond operating requirements by reclaiming lands outside of the permitting and reclamation process.

**Outstanding Reclamation: Paul Mathews, Baker City, Oregon**

Contact: Paul Mathews, (541) 523-2460

Paul Mathews is recognized for restoring a historically mined area to a beneficial use of higher value than before his mine operation began.

Mathews operated a small gold placer mine on U.S. Bureau of Land Management (BLM) claims in Baker County, along Clarks Creek, 3 mi east of Bridgeport and 30 mi south of Baker City. Historic mining in the Clarks Creek area extends back to the late 1800s, with evidence of hydraulic mining still apparent. The landowner is the BLM.

Beginning in 1989, as mine excavation expanded, mined-out areas were concurrently backfilled and then covered with soil and reseeded. These mined and reclaimed areas produced better grazing ground than the land in its pre-mining condition. By salvaging all available soil materials and supplementing with process fines, a good growing medium was placed over graded areas and then seeded in native-species bunchgrasses. Careful placement and construction of process water ponds assured that there were no discharges to the creek. By 1994, when operations ceased, 10–12 acres had been disturbed by mining. Mr. Mathews oversaw the final reclamation and took care that the revegetation of the land was a success.

**Outstanding Operator – Government Agency: Clackamas County, Fernwood Quarry Clackamas County, Oregon City, Oregon**

Contact: Darrel Burnum, (503) 650-3210, Darrelb@co.clackamas.or.us

Clackamas County is being recognized for extra effort in planning and development to protect adjacent natural resources at its Fernwood quarry.

The Clackamas County Road Department has operated this upland quarry located 4 mi southeast of Molalla since 1955. DOGAMI assumed administration of this site in 1991, when Clackamas County returned the responsibility of reclamation oversight to the state. An initial inspection report of February 1992 confirmed that at least 5 acres were eligible for exemption from the reclamation rules, but Clackamas County has committed to reclaim all areas of the quarry.

In 1999, a new Operating and Reclamation Plan was submitted, which accomplished three main goals: minimize the area of mine disturbance, stabilize disturbed areas, and treat and/or reduce storm water on the site.

Mining is done in 50-ft-wide strips, and mined-out areas are reclaimed concurrently. All overburden stockpiles are seeded annually. Internal haul roads have been graveled to reduce dust from truck traffic. Brow ditches have been excavated above the quarry to intercept storm water before it can enter the mine site.

The storm water control system consists of a sediment retention pond to collect large debris and suspended particles and an engineered overflow to take water from the pond to a treatment bioswale. The bioswale is a half-acre vegetated structure below the quarry that acts as a fine filter. During an inspection in October 2000, the off-site discharge from a rain event was significantly less turbid than the receiving stream.

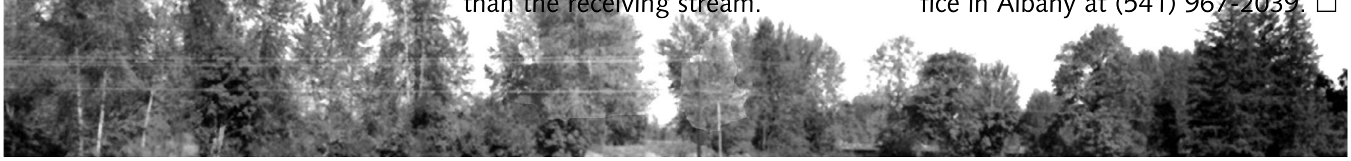
The sod used to stabilize the bioswale was laid down in one day. People who drive by this site every day saw a rock quarry in the morning and half an acre of green grass on the drive home. This prompted several calls by people who were wondering whether the County was building a golf course. Calls continued until the County erected a sign that explained the goals of the project.

**Reclamationist of the Year: Bill Murphy, Garrett Construction, Drain, Oregon**

Contact: Bill Murphy, (541) 836-2166

Bill Murphy of Garrett Construction is responsible for the day-to-day operation of the Parker Creek and Bear Creek quarry sites. Both of these properties have had storm water problems in the past, and both are located adjacent to streams. Bill has taken an active role in designing storm water control systems that have become a model for MLR Best Management Practices. He promotes the attitude that all employees should become involved, not only attending to problems as they see them, but also helping to improve the overall design of the storm water control systems. An oil residue problem at the Bear Creek site has also been eliminated, and many of the ditches and ponds are now supporting wetland vegetation, which acts to improve sediment filtration. Through the use of ditches, check dams, French drains, and sumps, nearly all storm water discharge from both sites has been eliminated. There is a pride evident for environmental considerations in these operations that goes beyond basic regulations.

For more information on the Mined land Reclamation (MLR) Program at DOGAMI, please visit the DOGAMI website at www.OregonGeology.com or call the MLR office in Albany at (541) 967-2039. ☐



*For those who do not have the time or opportunity . . .*

## Geologic notes — Gleanings from recent publications that may be of interest

*by Lou Clark, Oregon Department of Geology and Mineral Industries*

***Nature***, *June 14*
*"Seismic Sleuths," by Larry Hanlon*

There is no degree in forensic seismology, but the increasing sensitivity of instruments meant to measure earthquakes sometimes makes seismologists into detectives.

Seismographic identification of underground nuclear explosions is now routine. But the small amount of movement on the earth's surface that can now set off seismometers means that a great deal of noise must be filtered out. Other people have found uses for some of that information.

For example, microseisms from ocean waves can suggest changes in long-term weather patterns. One researcher used 40 years of seismic data to show that the northeast Atlantic Ocean has had more storms in the past 20 years.

Since some stations are so sensitive they can track kangaroos jumping, one alternative to an oversupply of data is a new network of satellite-based seismometers.

***Nature***, July 12
***Science***, *August 24*
*A review of a biography of William Smith, "The Father of English Geology"*

Few scientists, even fewer geologists, have biographies written about them. In 1815, William Smith published a geologic map of England, at a scale of five miles to the inch. His dedication and perseverance at the young science of geology makes him an ideal figure for later generations to remember.

Smith's map was plagiarized, he went to a debtor's prison, but he was eventually recognized for his achievements. He received the very first Wollaston Medal from the Geological Society of London and was given a lifetime pension by the King.

His maps were innovative and artistic, an important step in the ability to communicate geologic information.

***Nature***, *August 16*
*Direct observation of a submarine volcanic eruption from a sea-floor instrument caught in a lava flow (Letter to the editor by Fox, Chadwick and Embley)*

The Juan de Fuca Ridge is an active rift zone. In 1997, two monitoring instruments were placed at Axial volcano. When Axial erupted in 1998, serendipity provided researchers a wealth of information about deep-sea eruptions. One of the instruments placed to monitor the area was overrun with lava but survived.

Researchers were able to recover it and get a detailed record of a two-hour eruption and several days of post-eruption subsidence.

***Geotimes***, *June*
*"Silent earthquakes," by M. Rudolph*

From August 18 to September 22, 1999, Washington experienced a cumulative magnitude 6.7 earthquake along the Cascadia subduction zone—but the quake produced no seismic shock. The total slip over the month was roughly equivalent to six months of typical plate movement.

Although similar silent quakes have been known to precede large earthquakes, the importance of this particular movement is not currently known. The stress field of the Cascadia subduction zone is not well understood, and it is unknown how this unusual type of event affected it.

*"Listening to undersea quakes" ("Geophenomena," compiled by Christina Reed)*

Equipment that was once used by the U.S. Navy to track submarines is now being used to hear undersea eruptions. On April 3, hydrophones picked up the sound of an eruption off the Oregon coast. To hear the rumbling online, go to www.pmel/noaa.gov/vents/acoustics/seismicity/nepac./gordaridge01.html

***Geotimes***, *July*

Short summaries of the year's major research efforts are included in this issue. Topics reviewed include seismology, volcanoes, geothermal energy, hydrology, and other disciplines.

***Geotimes,*** *August*
*"Hunting Mount Rainier's danger zones," by Carol Finn and Thomas Sisson*

Because of Mount Rainier's proximity to urban areas, evaluating future hazards is essential. U.S. Geological Survey staff used high-resolution, helicopter-borne magnetic and electromagnetic surveys to see if they can help identify landslide-prone areas. These tools are safe and cost-effective alternatives to field work in rugged, dangerous terrain.

The results of the experiment were encouraging. A three-dimensional view of altered rock was developed. The most likely future landslide site is on the upper west side, although all sides are at risk during volcanic eruptions.

***Science***, *August 17*
*"Researchers target deadly tsunamis," by Robert Koenig*

A tsunami devastated villages in Papua, New Guinea, in 1998, and researchers are intensely studying the event to help make other areas safer. The size and destructive force of the waves was out of proportion to the moderate earthquake that preceded them.

Costas Synolakis (USC) believes that many local tsunamis, those generated just offshore, are caused not directly by earthquakes, but by the underwater landslides they may induce.

Besides detailing the New Guinea event, this article describes some of the monitoring, modelling, and mapping that is rapidly increasing our understanding of these hazards. □

## THESIS ABSTRACTS

*The Department maintains a collection of theses and dissertations on Oregon geology. From time to time, we print abstracts of new acquisitions that in our opinion are of general interest to our readers.*

**A methodology for regional seismic damage assessment and retrofit planning for existing buildings**, by Thomas McCormack (Ph.D., Portland State University, 1996), 285 p.

Recent geologic research has shown that earthquakes more destructive than formerly expected are likely to occur in the Pacific Northwest. To mitigate catastrophic loss, planners are gathering information to make decisions on implementing regional seismic retrofit programs.

This research develops a model to estimate regional earthquake losses for existing buildings and determine optimal retrofit priorities and budgets.

Fragility curves are developed to provide earthquake damage estimates for a range of seismic intensities. The published earthquake damage estimates of a large group of prominent earthquake-engineering experts are extended to include the combined effect of structure type, earthquake-sensitive variations in building design, site-specific soil conditions, and local seismic design practice.

Building inventory data from a rapid visual screening survey of individual buildings form the basis for modeling structural variations. Earthquake hazard maps are the basis of modeling the effect on building damage of ground motion amplification, soil liquefaction, and slope instability.

Published retrofit effectiveness estimates and retrofit cost data are used to estimate post-retrofit damage avoided, lives saved, and retrofit cost. A Building Classification System is formulated to aggregate buildings with similar retrofit benefit magnitudes.

A cost-benefit analysis is used as the basis for a retrofit prioritization and efficiency analysis, to establish the cutoff point for an optimal retrofit program. Results from an Expected Value and a Scenario Earthquake Event are compared.

Regional EArthquake Loss and Retrofit Analysis Program (REALRAP) software was developed and used to make a loss estimate for more than 7,500 buildings inventoried in the 1993 Portland Seismic Hazards Survey. One hundred percent of the loss of life is attributed to only 10 percent of the buildings.

A retrofit analysis is made for a Design Basis Earthquake. Twelve percent of the building inventory was identified for the optimal retrofit program, wherein 98 percent of the loss of life is avoided at less than one-quarter the cost of retrofitting all the buildings.

An alternate optimal retrofit program was determined, using an Expected Value Analysis. Most of the buildings in the Design Basis Earthquake optimal retrofit program are also contained in the alternate program.

**Analysis of tephra components from Rock Mesa, South Sister volcano, Oregon: Implications for evolution of the explosive phase**, by James P. Rogers (M.S., University of Oregon, 1996), 85 p.

The Rock Mesa obsidian flow and associated airfall deposits lie on the southwest flank of South Sister volcano in central Oregon. This thesis examines the tephra sequence generated during the 2,300-year-old eruption. Grain-size distributions, component distributions, density distributions, and groundmass textures (microlites) were determined for juvenile clasts from the deposits at three sites. Eruptions of larger magnitude (bed thickness) and/or intensity (clast size) produced primarily microlite-free white pumice and dense juvenile obsidian. In contrast, tephra beds from eruptions of smaller magnitude and/or intensity contained microlite-bearing gray pumice. I interpret these deposits to reflect a series of small, pulsatory eruptions preceding the major phase of dome growth at Rock Mesa. High-density, high-crystallinity clasts that were erupted during the explosive phase may reflect early phases of dome growth.

**Changes in the distribution of selected conifer taxa in the Pacific Northwest during the last 20,000 years**, by Ann Margaret Tattersall (M.S., University of Oregon, 1999), 111 p.

Regional patterns of vegetation change since the last glacial maximum are portrayed by pollen maps for four conifer taxa plus *Artemisia* and Poaceae at 72 sites in western North America west of long 110° W. and between lat 42° N. and 51° N. These maps are records of vegetation change against which paleoclimate modelling predictions of past climate may be tested. The maps suggest variations in precipitation trends across the region, with maximum Holocene dry periods ranging from 9,000 to 6,000 $^{14}$C years B.P. Temperature trends were similar throughout the region, with maximum warmth around 9,000 $^{14}$C years B.P. These maps contribute to understanding the responses of individual tree taxa to past climate change in western North America. This study addresses the question of glacial refugia of *Pseudotsuga*. Coastal *Pseudotsuga* was located in the Pacific Northwest of the U.S. during the last glacial maximum, although the locations of the refugia are uncertain.

**Alpine glacier and pluvial lake records of late Pleistocene climate variability in the western United States**, by Joseph M. Licciardi (Ph.D., Oregon State University, 2000), 155 p.

This investigation focuses on the development of Quaternary dating techniques to construct high-resolution numerical chronologies of late

Pleistocene climate variability in the western United States. Cosmogenic $^3$He concentrations were measured in radiocarbon-dated, olivine-bearing Holocene lava flows in Oregon, yielding a mean production rate of 116±3 $^3$He atoms per gram per year. This value is consistent with previous estimates at mid-latitudes and helps refine the accuracy of the cosmogenic $^3$He dating technique. Cosmogenic $^3$He and $^{10}$Be chronologies were developed for well-preserved moraine sequences in the northern Yellowstone region, Montana, and in the Wallowa Mountains, Oregon. Cosmogenic data indicate that the northern outlet glacier of the Yellowstone ice cap reached its terminal moraine at 16.7 $^3$He ka / 16.2 $^{10}$Be ka, and retreated to ~50 percent of its maximum extent by ~13.8 ka. In the Wallowa Mountains, two major late Pleistocene alpine glacier advances occurred at ~21 ka and ~17 ka, and a minor advance occurred at ~11 ka. The ~21-ka advance in the Wallowa Mountains coincides with the last glacial maximum and is correlative with the last Pinedale maximum advance in the Wind River Mountains. The ~17-ka advance in the Wallowa Mountains is probably correlative with the advance of the northern Yellowstone outlet glacier. The youngest event in the Wallowa Mountains, at ~11 ka, may be correlative to an advance that deposited the Titcomb Lakes moraines in the Wind River Mountains during the Younger Dryas. New accelerator mass spectrometry radiocarbon ages from gastropods in shore deposits within the pluvial Lake Chewaucan basin, Oregon, identify a significant lake-level high at ~12 $^{14}$C ka. The Chewaucan lake-level high is coeval with lake-level lows in the Bonneville and Lahontan basins, and with a period of relatively wet conditions in the more southerly Owens Lake basin. This spatial pattern of pluvial lake levels in the western U.S. at ~12 $^{14}$C ka indicates a variable synoptic response to climate forcing at this time. These new data contribute critically needed geographic coverage to existing glacial and pluvial lake records for examining spatial and temporal late Pleistocene climate variability in western North America.

**The distribution of naturally occurring soil radionuclides and radon potential of southwest Oregon**, by W.H. Douglas (M.S., Portland State University, 1999), 124 p.

Naturally occurring uranium and thorium in rocks and soil, through a series of radioactive decays, produce radon gas, the second leading cause of pulmonary cancer. Soil samples from 143 B-horizons from the main geologic units in southwest Oregon were analyzed using gamma spectroscopy to quantify the activities of five soil radionuclides. The mean and range values in Bq/kg for $Ac^{228}$, $Cs^{137}$, $K^{40}$, $Th^{232}$, and $Bi^{214}$ (a decay product of radon) are 17.4 (4.0 to 48.3), 5.1 (0.7 to 37.3), 303.7 (18.0 to 719.7), 14.2 (1.7 to 41.6), and 19.8 (2.9 to 51.3), respectively.

$Bi^{214}$ activity of B-horizon soil samples is used to define three radon potential zones, Low 1 (less than 25 Bq/kg), Low 2 (25 to 45 Bq/kg), and Moderate (greater than 45 Bq/kg). 73 percent of the $Bi^{214}$ values fall within Low 1 zone, 24 percent fall within Low 2 zone, and 3 percent fall within the Moderate zone. Based on soil radionuclide concentrations, southwest Oregon is not considered to be a high-potential area for radon.

The percent map areas for Low 1, Low 2, and Moderate radon potentials for the study area are 62, 32, and 6 percent, respectively. The highest radon potential is found in the Coast Range, where most sites are Low 2 and Moderate potential. The Coastal Plain region has the lowest potential and is mapped mostly as Low I radon potential. The Cascade Range, Basin and Range, and High Lava Plains regions contain Low 1 and Low 2 radon potentials. The Klamath Mountains region contains a mix of all three radon potential areas. The formations with Moderate radon potentials are units Ty (Yamhill Formation) and Jss (Jurassic black to gray shale, mudstone, and sandstone) and are found mainly in the Coast Range.

The $Th^{232}/K^{40}$ ratio and the Buntley-Westin color index of the soils both generally increase with soil development. Soils developed on sedimentary formations generally have a higher range in naturally occurring radionuclide values than those developed on igneous formations. Soils developed on felsic rocks tend to have higher $Bi^{214}$ values than those derived from mafic rocks. The Basin and Range region has the lowest range in soil radionuclide activities.

**Middle Cretaceous sedimentation and tectonics of the Mitchell inlier, Wheeler County, central Oregon**, by Robert J. Lenegan (M.S., University of Oregon, 2001), 125 p.

Cretaceous (Albian) sedimentary rocks of the Ochoco basin are exposed on the limbs of the Mitchell anticline in central Oregon. The Basal Member of the Hudspeth Formation contains sandstone and conglomerate that rest unconformably on metamorphic basement rocks and grade laterally into mudstone. The Main Mudstone Member of the Hudspeth shows an increase in thickness from ~200 m on the northwest to ~900 m on the southeast limb of the Mitchell anticline and records southeastward tilting during mudstone deposition. Tight folds are found in the Basal Member and lower Main Mudstone Member, but not in the overlying Gable Creek Formation (submarine conglomerate and sandstone). This, combined with stereonet fold analysis, indicates that tight folds formed during Main Mudstone time and were later refolded by the Tertiary Mitchell anticline. A growth normal fault is recognized in the lower Gable Creek Formation, providing further evidence for tectonic activity during Albian basin development. ☐

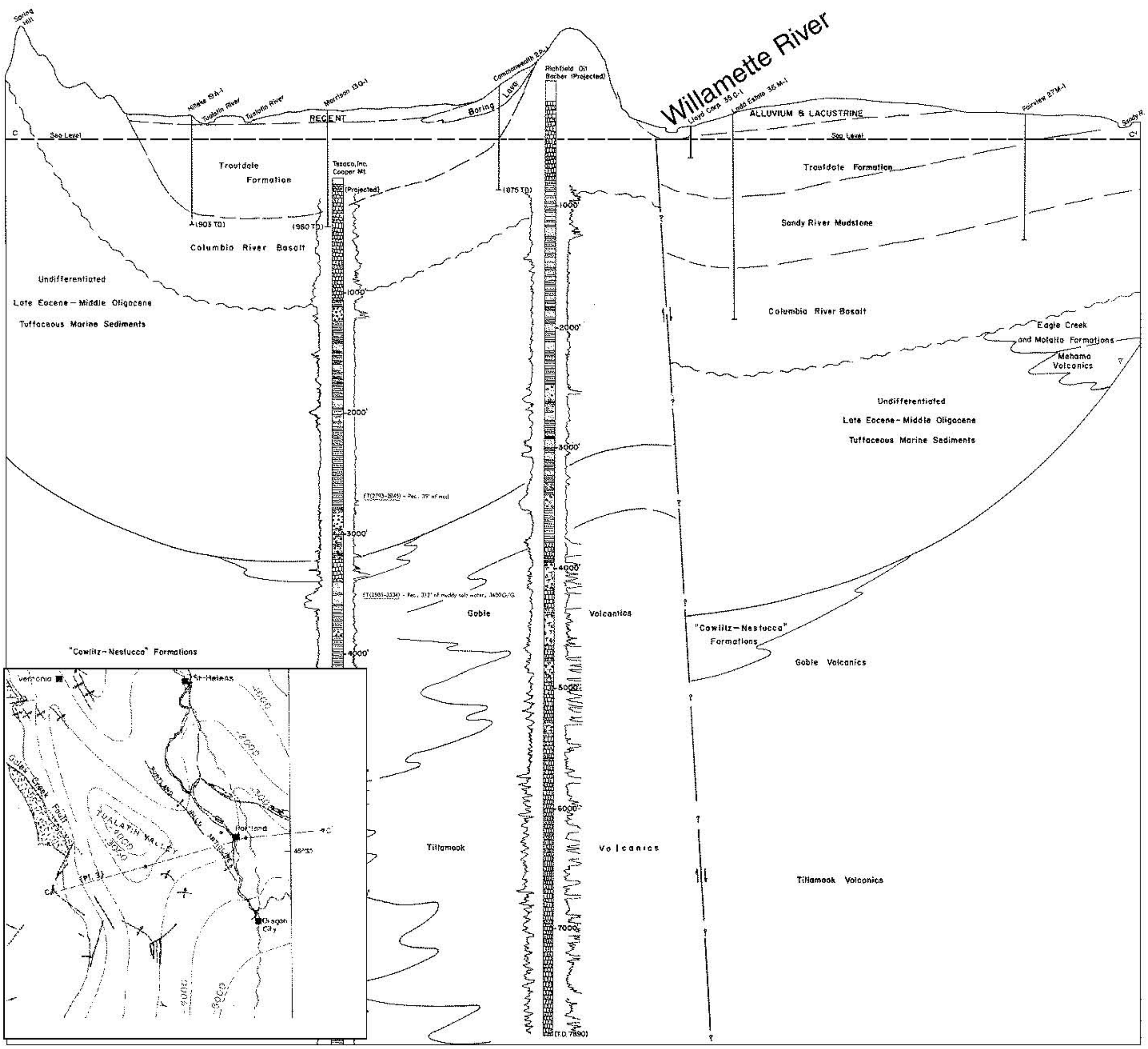
# LETTER TO THE EDITOR

I was very interested in the article on the Portland Hills fault in the last issue of *Oregon Geology*. I was the author of [DOGAMI] Oil and Gas Investigation 2, 1969. I made several cross sections for this publication, using deep oil and gas test holes and deep water wells. On Plate III of this report, I show a cross section through the Tualatin Valley eastward to the front of the Cascade Range. In making stratigraphic correlations, it was necessary to put a large fault at the east front of the Portland Hills. What is disturbing in constructing this cross section is that most of the high buildings in west Portland are situated on silts and gravels adjacent to the Portland Hills fault. A large earthquake on this fault could result in very serious damage and probable loss of life.

Vertical offset indicated on my cross section must be several hundred feet. This movement has occurred since late Miocene time. The recent article indicates that there has been movement on faults in the area in late Pleistocene time. More study is needed of faulting in the Portland area to learn how to mitigate seismic damage from large earthquakes.

*—Vernon C. Newton, Jr.*
*Beaverton, Oregon*
[First DOGAMI petroleum engineer, 1957–1980]

**Below: Portions from DOGAMI Oil and Gas Investigation 2 published in 1969. They show the cross section mentioned in Vern Newton's letter above and, in the inset, the location of this cross section (C–C') from Plate VII of that publication. *—ed.***



## DOGAMI PUBLICATIONS

Publications are available from: Nature of the Northwest, 800 NE Oregon St. #5, Portland, OR 97232, info@naturenw.org or www.naturenw.org, (503) 872-2750; or from the DOGAMI field offices in Baker City, 1510 Campbell Street, (541) 523-3133, and Grants Pass, 5375 Monument Drive, (541) 476-2496. See also the gray pages at the center of this issue.

Released August 21, 2001:

**Tsunami hazard maps for coastal communities, reissued on CD-ROM**. One disk, $25.

The Oregon Department of Geology and Mineral Industries (DOGAMI) has released a digital reissue of tsunami hazard maps of the entire coast of Oregon on one CD-ROM. The maps were originally produced in 1995 to help implement Senate Bill 379 (SB 379), which was passed that same year by the Oregon Legislature. SB 379, implemented as Oregon Revised Statutes (ORS) 455.446 and 455.447, limits construction of new essential facilities and special-occupancy structures in tsunami flooding zones. The focus of the maps is therefore on implementation of this public safety bill and not on land use or emergency planning. (Learn more about Senate Bill 379 at: http://arcweb.sos.state.or.us/rules/OARS_600/OAR_632/632_005.html)

The CD-ROM was released as DOGAMI Open-File Report O-00-05. It contains maps in .pdf and GIS formats and a separate explanatory text. The maps cover one 7½-minute quadrangle each (scale 1:24,000) and were released as Open-File Reports O-95-09 through O-95-66, while the explanatory text is Open-File Report O-95-67. Because of changes adopted in 1997, the maps O-95-39 and O-95-42 were withdrawn and O-95-40 and O-95-41 were replaced by new maps O-97-31 and O-97-32. The maps and report were produced by George R. Priest of DOGAMI, (541) 574-6642, george.priest@state.or.us.

Tsunamis are generally caused by earthquakes, landslides, or volcanic eruptions on the sea floor. The mapping project addressed only the most common cause: simultaneous uplift and subsidence of the sea floor accompanying undersea earthquakes on the Cascadia subduction zones.

The CD-ROM is available for $25 from the Nature of the Northwest Information Center and DOGAMI Field Offices in Grants Pass and Baker City. See the addresses on the first inside page (p. 70) or the instructions on the gray pages in the middle of this issue. ☐

## EDITOR'S CORNER

### In memoriam

**Archie Kelly Strong** was mentioned in this place just two issues ago–on the occasion of his 91st birthday. Now we mourn his death.

The "Supervolunteer" in the Nature of the Northwest Information Center came within six months of completing an entire decade of volunteer work. Between 1992 and this summer, Archie donated 2,488 hours of work, mainly in managing the stock of USGS topographic maps.

Archie had a Master of Science degree from Oregon State University, had been a biology instructor and coach in Oregon high schools, and had worked for the USDA Forest Service before he retired in 1975. He also was an avid and much honored flower and vegetable gardener.

He was born February 20, 1910, in Marcola, Oregon, died September 24, 2001, in West Columbia, South Carolina, and found his final resting place in Portland, Oregon, in Skyline Memorial Gardens.

We miss him.

### At home

The **DOGAMI library** has added to its shelves paper copies of some recent maps published by the **U.S. Geological Survey (USGS) as Open-File Reports**: OFRs 01-226, geologic map of the Dixonville quadrangle, and 01-294, color shaded relief map of the Willamette Valley.

The USGS offers them on its web sites. For our "Western Region," these maps and other USGS publications are most easily accessible under the (Menlo Park, CA) address: **http://geopubs.wr.usgs.gov/**.

### In the neighborhood

The **Western States Seismic Policy Council** has announced that it **has moved**. The new address is

WSSPC
Palo Alto Central Building
125 California Avenue
Suite D201, #1
Palo Alto, CA 94306.
Phone (650) 330-1101
Fax (650) 326-1769

E-mail addresses and website have not changed. You can still find WSSPC under www.wsspc.org.

Do you need **geologic information about Washington**? You can **search** now on the Washington Division of Geology and Earth Resources website

**http://www.wa.gov/dnr/htdocs/ger/washbib.htm**

in the agency's "Digital Bibliography of the Geology and Mineral Resources of Washington." ☐

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## Places to see—Recommended by the Oregon Department of Geology and Mineral Industries:

**North Umpqua River in the southern Cascade Range.**

The North Umpqua River drains the southern Cascades to the west and to the Pacific Ocean, joining its "South" counterpart near Roseburg in Douglas County. The picture shows Old Man Rock, rising well over 1,000 feet above the river, on the edge of the Boulder Creek Wilderness Area in the Umpqua National Forest. Typically heavy rainfall on the western slopes of the Cascade Range has brought about deep weathering and created spectacular stream valleys.

Access: From Roseburg to the east, Oregon Highway 138 follows the North Umpqua River for much of the distance, crosses the Cascades, and connects with U.S. Highway 97 near Crater Lake National Park.