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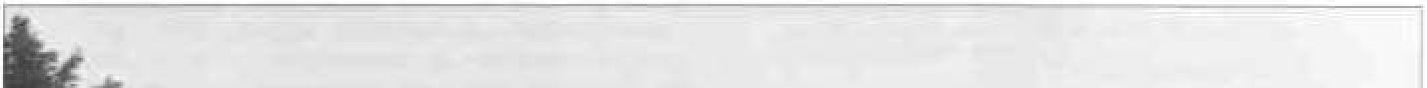
NATIONAL NATURAL LANDMARKS PROGRAM IN THE PACIFIC NORTHWEST

"REAL-TIME" EARTHQUAKE INFORMATION HAS COME TO DOGAMI



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

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Cover photos

Fort Rock in south-central Oregon (upper photo) and Newberry Crater (East Lake shown in lower photo) in the Newberry National Volcanic Monument are two examples of designated National Natural Landmarks in Oregon. See article describing the National Natural Landmarks Program on pages 123–124.

Portland light rail tunnel praised by Engineering Geologists

During its annual national meeting, September 30 to October 4, 1997, in Portland, Oregon, the Association of Engineering Geologists (AEG) will honor the city's Westside Light Rail Tunnel as an "Outstanding Environmental and Engineering Geologic Project." The Tri-County Metropolitan Transportation District (Tri-Met) is extending its light rail line to the west of the city center and is completing twin rail tunnels under the West Hills that border the city center on the west. The following is excerpted from the association's proclamation.

"One hundred years ago, rail trolleys ran from Portland's city center to the residential neighborhoods of the West Hills. This early rail system was severely damaged by a massive landslide now called the Washington Park landslide, and also severely affected construction of the city's water-supply reservoirs. Even then, residents of Portland began to appreciate the geologic hazards of the West Hills.

"The success of this project was achieved through the understanding and management of the many geologic hazards posed by the West Hills. Difficult and widely variable rock types were penetrated; faults were crossed and avoided; landslide forces were balanced—and the result provides a safe, convenient transportation route for all.

"Host rocks for the Washington Park station and the eastern two miles of the light rail tunnels originated as enormous eruptions of lava that flowed from fissures in northeastern Oregon and southeastern Washington. Numerous lava floods occurred, and some extended across the Pacific Northwest to the Pacific Ocean. They cooled forming a layered basalt sequence. A tunnel-boring machine named "Bore-Regard" carved a path for the Metropolitan Area Express (MAX) light rail cars through these basalt flows. The western mile of the twin tunnels was dug and blasted through younger lavas that are interlayered with windblown silt deposits. Two volcanoes are located within a mile of the alignment. The tunnel was drilled through one feeder dike where lava once welled up.

"This Westside Light Rail Tunnel Project has preserved for public enjoyment the unique cultural and environmental resources that lie above it." ☐

NWMA meeting set for December

The 103d annual meeting of the Northwest Mining Association (NWMA) is scheduled for December 1–5, 1997, at the Doubletree Hotel-Spokane City Center, Spokane, Wash. Former Idaho Governor and Interior Secretary Cecil D. Andrus will be the keynote speaker. For information, contact NWMA at 10 N. Post Street, Suite 414, Spokane, WA 99201, ph. (509) 624-7655. ☐

Zeolites in the Cascade Range of northern Oregon

by Keith E. Bargar and Robert L. Oscarson, U.S. Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025

ABSTRACT

Twenty-three zeolite minerals were identified during secondary mineralogy studies of late Tertiary volcanic rock outcrop samples and/or late Tertiary to Quaternary geothermal drill-hole specimens in three areas of the Oregon Cascade Range (near Mount Hood, the Breitenbush-Austin Hot Springs area, and Newberry volcano). The Neogene to Holocene volcanic rocks contain euhedral to subhedral zeolite crystals in open spaces of fractures and vesicles and between breccia fragments. The widespread occurrence of zeolite minerals indicates that a substantial portion of these volcanic rocks underwent low-temperature (<200°C), zeolite-facies, hydrothermal alteration at some time following their emplacement. A few of the zeolites (wairakite, faujasite, ferrierite, harmotome, and yugawaralite) encountered during these studies had not previously been reported from Oregon.

Zeolite minerals occur in most geothermal exploration holes drilled on the flanks of Newberry volcano and in the upper part of drill holes completed within the volcano's caldera. Temperatures measured during drilling of these holes are compatible with zeolite-facies metamorphism. A temperature of 265°C was measured near the bottom (932-m depth) of one hole drilled within the caldera of the volcano, and secondary minerals recovered from this part of the drill hole are indicative of subgreenschist- to greenschist-facies metamorphism (temperatures up to ~400°C).

The studied late Tertiary volcanic rocks from the Western Cascade Range of northern Oregon have primarily been subjected to low-temperature zeolite-facies metamorphism. Some low-temperature zeolite minerals are superimposed upon higher temperature alteration minerals that occur in narrow halos surrounding the intrusive remnants of late Miocene volcanoes in the Breitenbush-Austin Hot Springs area and near Mount Hood. These higher temperature secondary minerals are indicative of greenschist- to subgreenschist-facies metamorphism that locally preceded zeolite-facies metamorphism. Secondary mineral distribution in these areas appears to be consistent with localized rather than widespread high heat-flow conditions.

INTRODUCTION

Quaternary volcanic activity, several hot springs, and a few fumaroles present in the Cascade Range of northern Oregon suggested the possibility that exploitable geothermal energy sources might occur within these mountains. During the 1970s and 1980s, numerous test drill holes were completed in several areas of

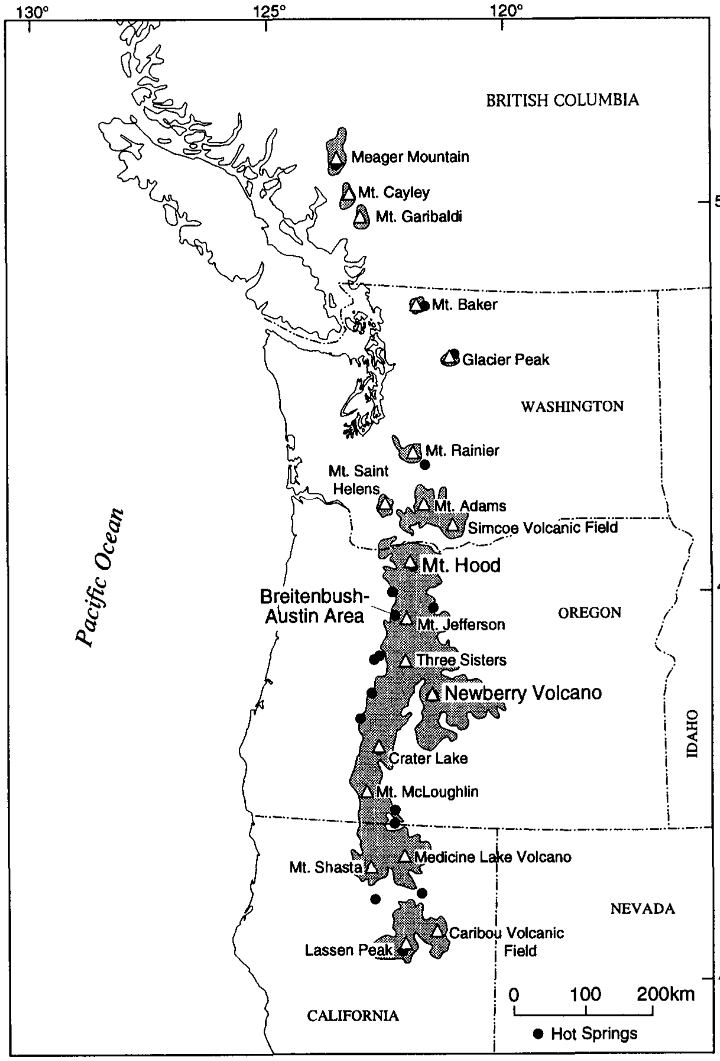

Figure 1. Map showing the location of the Pacific Northwest Cascade Range (shaded areas) The three areas included in this study are shown in larger type.

the Cascades to aid in the evaluation of some of the more favorable geothermal sites. Detailed studies of hydrothermal alteration mineralogy were made for core and cuttings from 24 of the drill holes at Newberry volcano (Bargar and Keith, 1984; Keith and Bargar, 1988; Bargar and Keith, in preparation), the Mount Hood area (Bargar and others, 1993), and the Breitenbush-Austin Hot Springs area (Keith, 1988; Bargar, 1990, 1994; Oscarson and Bargar, 1996) (Figure 1). During the investigations, twenty-three zeolite minerals were identified, along with many other hydrothermal minerals, in drill-hole specimens from these three areas or in nearby outcrops of late Tertiary volcanic rocks at Mount Hood and the Breitenbush-Austin Hot Springs area.

Zeolite minerals are a large group of hydrated aluminosilicates that contain one or more alkali or alkaline earth cations (Mumpton, 1977). Zeolites can function as catalysts to promote chemical reactions; they have the unique ability to gain or lose liquids (generally water) and gases (such as ammonia); and they can act as cation exchangers without significant alteration of their structures (Barrer, 1978). Consequently, there are numerous commercial uses for both natural and synthetic zeolites, ranging from additives for various types of pollution abatement, to agriculture and aquiculture, energy conservation, and metallurgy, and even to polishing agents in toothpaste (Mumpton, 1978). No ore-grade zeolite deposits occur in the Cascade Range. However, mining claims have been filed in several areas of eastern Oregon (Mumpton, 1983), and zeolite has been produced commercially from deposits near Adrian since 1983 (Leppert, 1990).

Zeolite minerals form in a variety of low-temperature (mostly <200°C), water-rich environments including alkaline lakes, deep-sea sediments, cooling lava flows, and hydrothermal systems (Tschernich, 1992). Drill-hole and rock-outcrop specimens of late Tertiary to Holocene volcanic rocks (intrusives, lava flows, pyroclastic flows, and volcaniclastic deposits) from the northern Oregon Cascade Range (including Newberry volcano) contain sparse to common, subhedral to euhedral zeolite crystals in open spaces of vesicles and fractures and between fragments of volcanic or tectonic breccias. Although zeolitization can occur with diagenetic or deuteric alteration, the large size of the numerous euhedral zeolite crystals is believed to be an indication that these minerals were precipitated from circulating hydrothermal fluids (Gottardi, 1989). Chemical composition of the zeolite minerals is somewhat variable and reflects the elements contained in the mineralizing solutions which in turn are influenced by the rocks through which the waters flow (Barrer, 1982).

Because of their unique properties, the large number of identified minerals, and their wide-spread abundance in the altered late Tertiary volcanic rocks, these zeolites constitute a significant mineral group in Oregon's Cascade Range. Unfortunately, they have been largely ignored by previous workers. Some studies list identified zeolite minerals (Hammond and others, 1980), but many investigators just report that "zeolites" were present in their studies. In part, the subordination of zeolite minerals has resulted from the difficulty in identifying individual members of this large mineral group, which includes more than 40 species. In this report, we present information on the occurrence, morphology, and chemistry of zeolite minerals encountered in studies of low-temperature hydrothermally altered volcanic rocks from three geothermal areas in the Oregon Cascade Range. A few of the zeolites (wairakite, faujasite, ferrierite, harmotome, and yugawaralite) discussed in this report do not appear to have been reported previously in Oregon.

ANALYTICAL METHODS

A few zeolite minerals have distinctive morphologies or optical properties, and individual mineral identifications can be made by routine binocular or petrographic microscope methods. However, most zeolites can best be identified by X-ray diffraction (XRD) for which in this study, a Norelco[1] X-ray unit and Cu-Kα radiation were used. Qualitative chemical analyses were obtained for several zeolites during scanning electron microscope (SEM) studies that used a Cambridge Stereoscan 250 scanning electron microscope equipped with an energy dispersive spectrometer (EDS). The SEM studies also provided much information on the paragenesis and morphology of the zeolites and associated secondary minerals. Quantitative chemical analyses for several zeolites and other minerals were obtained by use of either an ARL-SEMQ electron microprobe or JEOL JXA-8900L electron probe microanalyzer. The microprobe data for zeolites from the Mount Hood area, Breitenbush-Austin Hot Springs area, and Newberry volcano are reported in Bargar and others (1993), Oscarson and Bargar (1996), and Bargar and Keith (in preparation), respectively. Both natural and synthetic mineral standards were used. Instrument conditions employed for the carbon-coated, polished thin sections or mounts containing zeolite (and other) minerals were quite variable and included: a sample current of 7.5 or 15.0 nA, a beam diameter of 15–25 μ, count times of 10 or 20 seconds, and an accelerating voltage of 15 kV.

GEOTHERMAL AREAS

Breitenbush-Austin Hot Springs area

In the Breitenbush-Austin Hot Springs area, chemical geothermometers for three groups of hot springs, dis-

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[1] Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

charging dilute NaCl or Na-Ca-Cl (minor K and traces of Mg) water, indicate that reservoir temperatures may be as high as 186°C (Ingebritsen and others, 1989, 1994). These workers also indicate that high heat flow (>100 mW/m^2) throughout the area emanates from the Quaternary volcanic arc ~10–15 km to the east. Boden (1985) reported epistilbite, stilbite, laumontite, mesolite, analcime, mordenite, and clinoptilolite(?) from three shallow (150-m) drill holes (bottom temperatures 18°–55°C) in Miocene microdiorite and extrusive andesitic rocks near Austin Hot Springs. Two deep drill holes in the area, designated as CTGH–1 (1,463 m) and SUNEDCO 58–28 (2,457 m), encountered temperatures of only about 96°C and 141°C, respectively (A.F. Waibel, unpublished data, 1982; Blackwell and Steele, 1987). In drill hole CTGH–1, dominantly basaltic late Tertiary to Quaternary drill core samples yielded abundant heulandite, clinoptilolite, and mordenite below about 900-m depth. At depths of about 600–900 m, some chabazite, analcime, and thomsonite, and minor erionite, mesolite (misidentified as scolecite), phillipsite, and wellsite were recognized (Bargar, 1990). Seven zeolites were identified in late Tertiary, mostly basaltic to andesitic lava flows and tuffaceous drill cuttings from drill hole SUNEDCO 58–28. Many drill-hole specimens contain laumontite and heulandite. A few specimens contain stilbite/stellerite, or analcime, and traces of mordenite, epistilbite, and scolecite (Bargar, 1994). Several zeolite minerals (analcime, chabazite, heulandite, epistilbite, gismondine, laumontite, levyne, mesolite, mordenite, phillipsite, scolecite, stilbite/stellerite, thomsonite, and yugawaralite) were collected from scattered outcrops of late Tertiary volcanic rocks in the Breitenbush-Austin Hot Springs area.

Zeolites in late Tertiary rock outcrops must have formed sometime between extrusion of the volcanic rocks and their subsequent erosion to present-day levels. However, zeolite minerals in the CTGH–1 and SUNEDCO 58–28 drill holes might have formed from the present-day geothermal system, because their formation temperatures are compatible with measured temperatures in the drill holes (Kristmannsdóttir and Tómasson, 1978).

Mount Hood area

In the Mount Hood area, a few thermal springs occur near the southern base of the mountain. The dominant cation in the dilute, tepid Swim Warm Springs is Na, although substantial Mg, Ca, and K are present in the samples (Mariner and others, 1980). Most of the 30 geothermal test drill holes in the Mount Hood area encountered only low-temperature, marginally thermal fluids (<23°C). However, in four of the drill holes, bottom temperatures were between 60° and 113°C. Present-day zeolite-facies metamorphism could occur at these temperatures. However, all of the zeolite minerals (wairakite, chabazite, ferrierite, heulandite, laumontite, mordenite, scolecite, stilbite/stellerite, and harmotome) identified in fractures and vugs and between breccia fragments of late Tertiary basaltic to dacitic volcanic rocks and quartz diorite or quartz monzonite intrusives from outcrops and 13 geothermal drill holes are believed to have formed during earlier periods of hydrothermal metamorphism (Bargar and others, 1993).

Newberry volcano

At Newberry volcano, temperatures as high as 265°C were measured in one of two holes spudded in the Holocene caldera deposits. Temperatures as high as 170°C were recorded in drill holes on the western flank of the volcano (Arestad and others, 1988). Zeolite minerals (chabazite, dachiardite, heulandite, laumontite, mordenite, and phillipsite) are sparsely distributed in four of the seven flank drill holes studied (Bargar and Keith, in preparation). Within the caldera, analcime, chabazite, erionite, faujasite, clinoptilolite, dachiardite, and mordenite occur in fractures, vugs, and spaces between breccia fragments and as alteration products of glass in drill-hole specimens of Pleistocene to Holocene rhyolitic tuffaceous rocks and basaltic sediments (Keith and Bargar, 1988). Present-day temperatures (presumably the formation temperatures) at which the Newberry volcano zeolites occur are about 30°–160°C (Bargar and Keith, in preparation). Dilute hot springs within the caldera contain varying proportions of Na, Ca, Mg, and K (Mariner and others, 1980).

ZEOLITE MINERALS

Many of the zeolite minerals included in this study occur rarely and are not well known. Accordingly, chemical formulas from definitive zeolite references (Gottardi and Galli, 1985; Tschernich, 1992) are given for each of the zeolites identified in this investigation.

Analcime—$Na_{16}(Al_{16}Si_{32}O_{96})\cdot16H_2O$
Wairakite—$Ca_8(Al_{16}Si_{32}O_{96})\cdot16H_2O$

Analcime and wairakite in the Oregon Cascade Range usually occur as colorless, subhedral to euhedral, trapezohedral crystals that formed in open spaces of fractures and vugs or between breccia fragments (Figure 2). Analcime appears to be more common than wairakite, but this study suggests that neither mineral is especially plentiful in the northern Oregon Cascades. A continuous solid-solution series exists between the analcime and wairakite end members (Gottardi and Galli, 1985). In this report, the nomenclature of Tschernich (1992), which defines analcime as containing more than 50 percent Na and wairakite as containing more than 50 percent Ca, is used to distinguish between the two minerals. Distinction between the two end-member minerals also has been reported by Coombs (1955), based on minor differences in their XRD patterns. How-

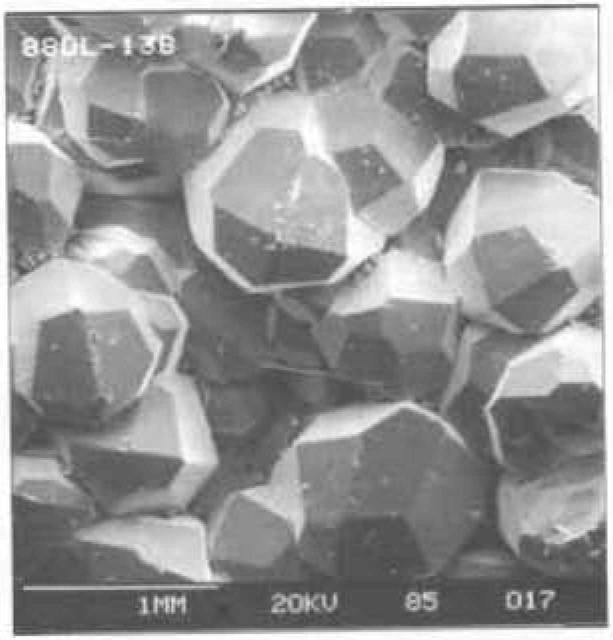

Figure 2. Scanning electron micrograph of colorless, euhedral, trapezohedral analcime crystals that cement early Miocene volcanic breccia fragments in the Breitenbush Hot Springs area. Tiny fibrous crystals are mordenite.

ever, Tschernich (1992) indicates that analcime and wairakite cannot be distinguished by XRD. In this report, we utilized both methods to distinguish between the two minerals. Microprobe analyses of two Mount Hood wairakites (Bargar and others, 1993) show that one specimen is very near the stoichiometric composition for the mineral (Figure 3A), whereas the second specimen contains substantially more potassium than previously has been reported for wairakite (Gottardi and Galli, 1985; Tschernich, 1992).

A "sodian" wairakite was identified by microprobe in core from the CTGH-1 drill hole near Breitenbush Hot Springs. The microprobe analyses also show the presence of significant potassium (Figure 3A). Analcime specimens collected from the SUNEDCO 58-28 drill hole and outcrops near Breitenbush Hot Springs mostly are a nearly pure analcime end member (Bargar, 1994). One analysis shows the presence of a "calcian" analcime (Figure 3A).

The intracaldera drill holes (USGS-N2 and RDO-1) at Newberry volcano both contain analcime (Keith and others, 1986; Keith and Bargar, 1988). Microprobe analyses for two specimens from depths of 314.6-315.1 m and 318.5 m in USGS-N2 show a pure end-member analcime and a "calcian" analcime containing significant potassium (Bargar and Keith, in preparation) (Figure 3A).

Analcime is a fairly common zeolite mineral that is found in many different environments; this includes

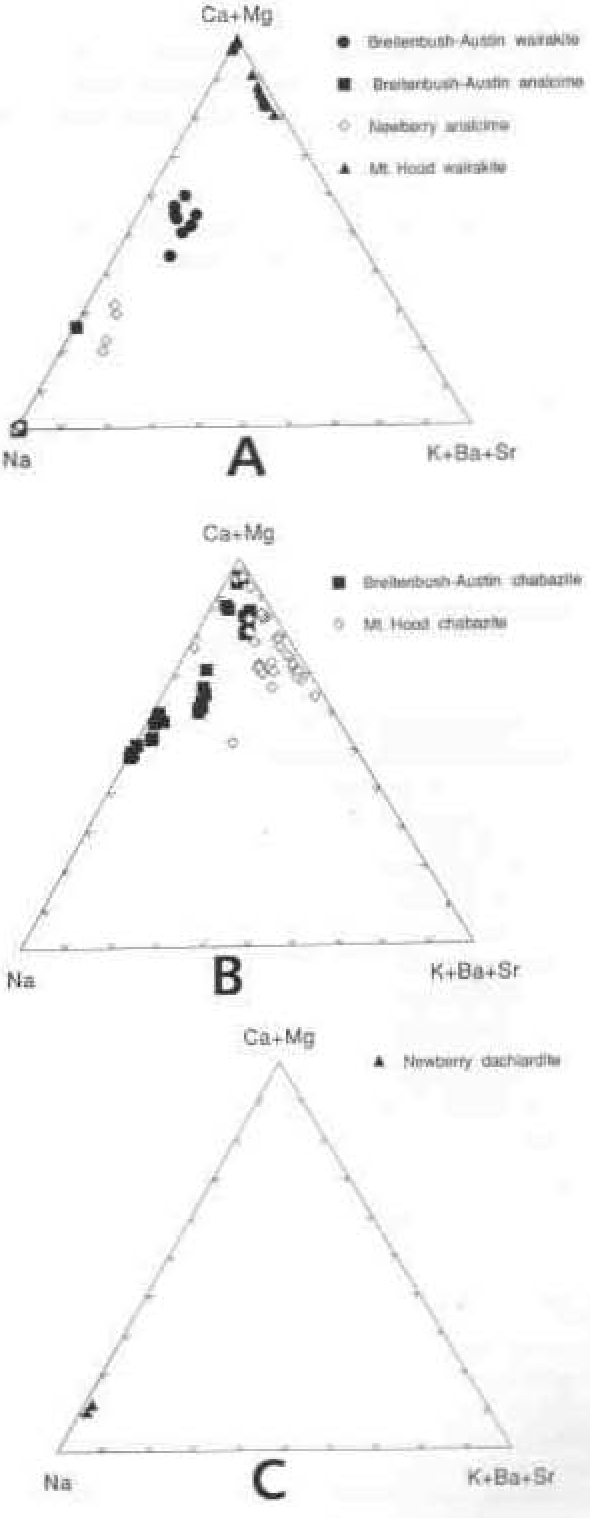

Figure 3. Ca+Mg-Na-K+Ba+Sr ternary diagrams for microprobe analyses of (A) analcime and wairakite, (B) chabazite, and (C) dachiardite from outcrops and geothermal drill holes in the Oregon Cascades.

geothermal areas throughout the world where it formed at temperatures ranging from about 60°–300°C (Kristmannsdóttir and Tómasson, 1978). Tschernich (1992) lists many localities in Oregon where analcime previously has been found. Wairakite also has been reported from geothermal areas in many parts of the world at about the same temperatures as analcime, but the mineral does not appear to have been located previously anywhere in Oregon (Tschernich, 1992).

Chabazite—$Ca_2(Al_4Si_8O_{24})\cdot 12H_2O$

Colorless to white, euhedral, pseudocubic rhombohedral, chabazite crystals (Figure 4A) were identified in open-space deposits of specimens from several drill holes and outcrops at Mount Hood and the Breitenbush-Austin Hot Springs area. Trace amounts of chabazite with the same morphology also coat fractures in core from one drill hole on the southern flank of Newberry volcano. The USGS–N2 drill hole, within the caldera of Newberry volcano, contains colorless, intergrown, twinned, hexagonal, lens-shaped, phacolitic chabazite crystals between depths of 308.9 and 318.5 m. This phacolitic habit (Figure 4B) apparently is uncommon in the Cascade Range; leastwise it was not observed elsewhere during this study.

The composition of chabazite is characteristically quite variable (Gottardi and Galli, 1985). Semiquantitative EDS analysis of chabazite from the Newberry volcano USGS–N2 drill hole shows the presence of (in order of abundance) Ca, K, and Na in addition to Si and Al (Bargar and Keith, in preparation). Numerous microprobe analyses of chabazite from near Mount Hood and the Breitenbush-Austin Hot-Springs area (Figure 3B) show that calcium is the dominant cation in both areas; however, the Mount Hood chabazite contains substantial potassium (Bargar and others, 1993) while, in some chabazite from the Breitenbush-Austin area, sodium comprises as much as 50 percent of the exchangeable cations (Oscarson and Bargar, 1996).

Chabazite is a characteristic hydrothermal mineral in low-temperature (<75°C) alteration zones of Icelandic geothermal areas (Kristmannsdóttir and Tómasson, 1978). Chabazite deposits in geothermal drill holes of the Cascade Range occur at similar low temperatures.

Dachiardite—$(Na,K,Ca_{0.5})_4(Al_4Si_{20}O_{48})\cdot 18H_2O$

Dachiardite is a fairly rare zeolite mineral, but previously it has been identified from two locations in Oregon (Tschernich, 1992). At Newberry volcano, clusters of fibrous, acicular, or lath-shaped dachiardite crystals were found in a single specimen of rhyolitic tuff from 443.2-m depth (temperature ~98°C) in drill hole USGS–N2, where the mineral, along with smectite, was formed by hydrothermal alteration of pumice fragments. A volcanic breccia specimen in drill hole GEO–N5 (southwest flank of Newberry volcano) contains tiny, colorless dachiardite crystals along with mordenite and smectite in open spaces between breccia fragments at 886.7-m depth (temperature ~65°C).

Electron microprobe analyses of dachiardite from USGS–N2 (Bargar and Keith, in preparation) show that the mineral is rich in sodium (Figure 3C) and probably

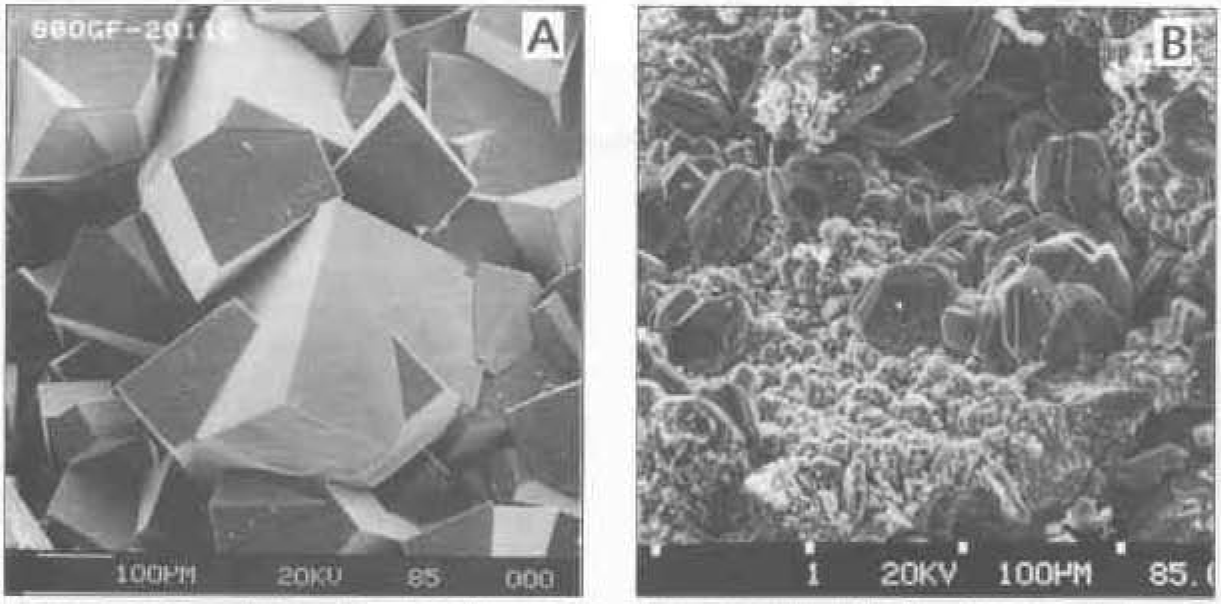

Figure 4. Scanning electron micrographs showing (A) colorless, euhedral, pseudocubic chabazite crystals, coating vesicles in Pliocene(?) andesite from an outcrop near Austin Hot Springs; (B) colorless, lens-shaped (phacolitic) chabazite crystals deposited on faujasite, coating a veinlet in basaltic sandstone from 308.9-m depth in USGS–N2 Newberry drill hole. Distance between white tick marks at bottom of micrograph is 100 μ.

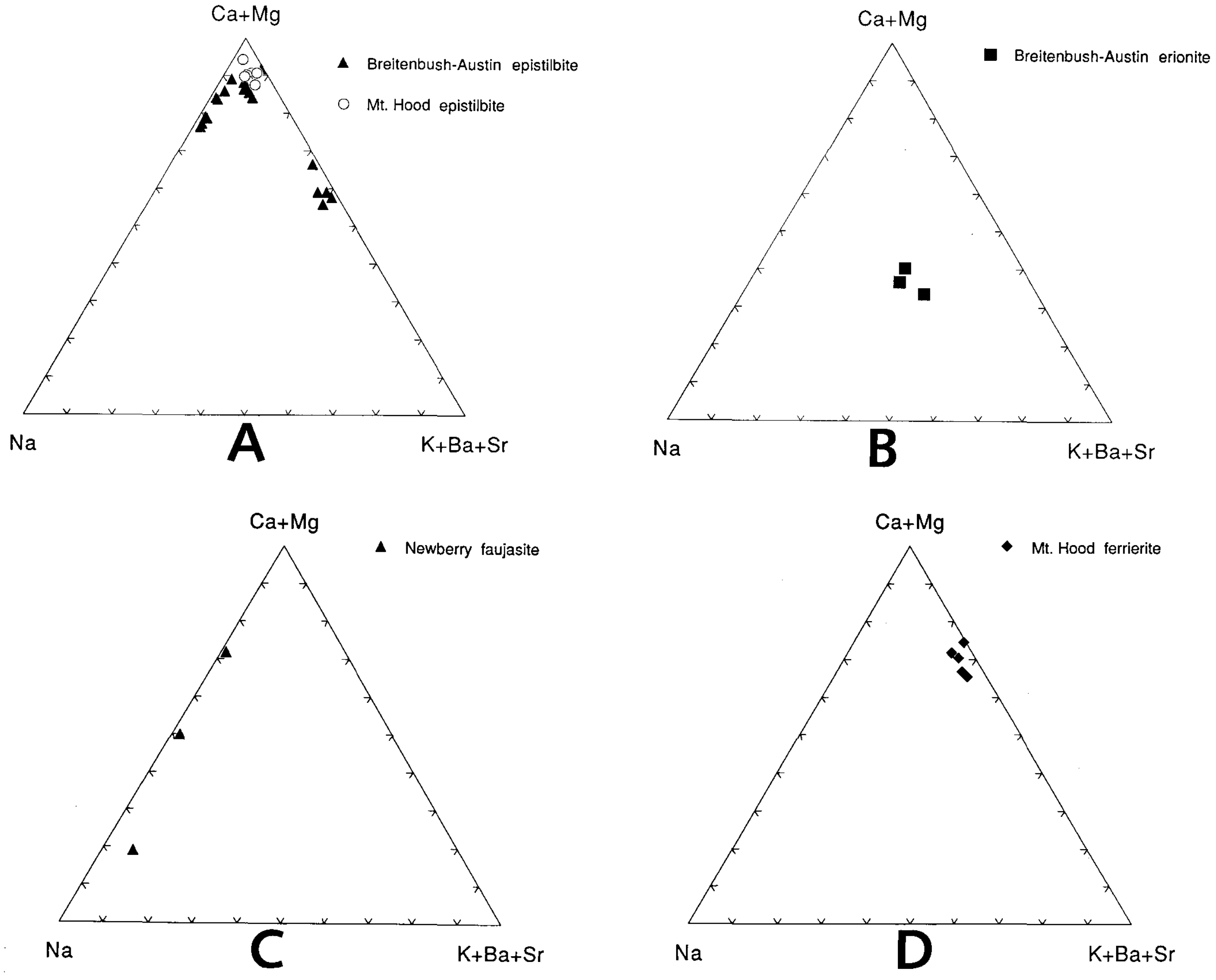

Figure 5. Ca+Mg–Na–K+Ba+Sr ternary diagrams for microprobe analyses of (A) epistilbite, (B) erionite, (C) faujasite, and (D) ferrierite from the Oregon Cascades.

should be referred to as "sodium dachiardite" rather than just "dachiardite" as recommended by Bargar and others (1987), who reported several optical, crystallographic, and chemical differences between dachiardite and sodium dachiardite.

Epistilbite—$Ca_3(Al_6Si_{18}O_{48})\cdot 16H_2O$

Epistilbite was identified in four geothermal drill holes and one late Tertiary volcanic rock outcrop in the Mount Hood area (Bargar and others, 1993). Epistilbite occurs in drill cuttings of a basaltic intrusive specimen from 1,411-m depth in the SUNEDCO 58–28 hole (Bargar, 1994). This study also located minor epistilbite in seven outcrops of late Tertiary volcanic rocks in the Breitenbush-Austin Hot Springs area. Epistilbite has only been reported from two other areas in Oregon (Tschernich, 1992).

Electron microprobe analyses of the Mount Hood Ca-rich epistilbite indicate that it is lower in Si and higher in Al and Ca than the stoichiometric formula (Bargar and others, 1993). Analyzed specimens from the Breitenbush-Austin Hot Springs area plot into two groups, with one group containing slightly more Na and the second group having substantially more K than the Mount Hood epistilbite (Oscarson and Bargar, 1996) (Figure 5A).

Erionite—$NaK_2MgCa_{1.5}(Al_8Si_{28}O_{72})\cdot 28H_2O$

Three specimens between 886- and 888-m depth in the CTGH–1 hole contain columnar bundles of acicular erionite crystals that formed later than smectite. SEM studies show that the erionite columns occasionally have hexagonal cross sections (Figure 6). Bundles of tiny prismatic erionite crystals occur in three basaltic sediment samples between depths of 315 and 318.5 m in the USGS–N2 hole. Temperatures at the depths where erionite occurs in the two geothermal holes were about 50°C. Electron microprobe analyses for erionite from the CTGH–1 hole show that the mineral contains nearly equal parts of Ca, Na, and K (Oscarson and Bargar, 1996) (Figure 5B).

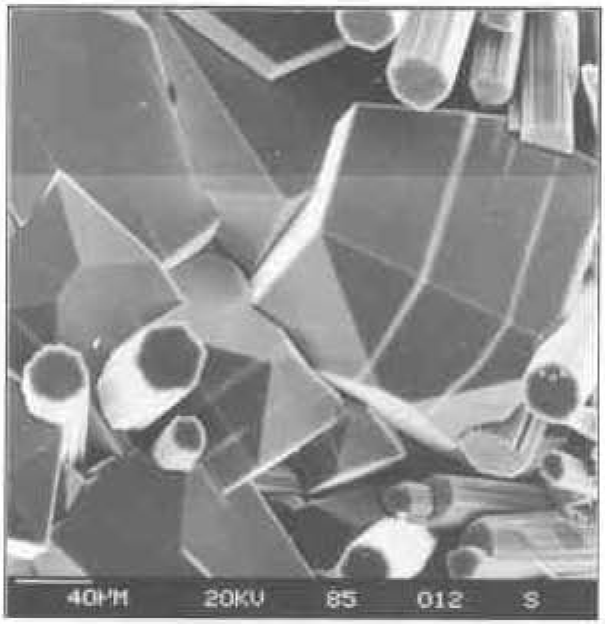

Figure 6. Scanning electron micrograph showing hexagonal bundles of fibrous erionite and later blocky heulandite crystals, filling vesicles in basaltic andesite breccia fragments from 887-m depth in the CTGH–1 drill hole.

Faujasite—$Na_{20}Ca_{12}Mg_8(Al_{60}Si_{132}O_{384})\cdot 235H_2O$

Faujasite is a rare zeolite mineral that was identified in colorless to white vein fillings and intergranular open-space fillings of eleven porous basalt sediment specimens between 308.9- and 320-m depth in the USGS–N2 geothermal hole (temperature about 40° to 50°C) (Bargar and Keith, in preparation). SEM studies of the faujasite show extensive deterioration with cracking and flaking of the crystal surfaces (Figure 7) that is perhaps caused by dehydration. Electron microprobe analyses of three faujasite crystals from 314.4-m depth show considerable variability in the Na and Ca contents (Figure 5C) (Bargar and Keith, in preparation), which is reported as typical for faujasite (Gottardi and Galli, 1985). To the best of our knowledge, this is the only faujasite ever found in Oregon.

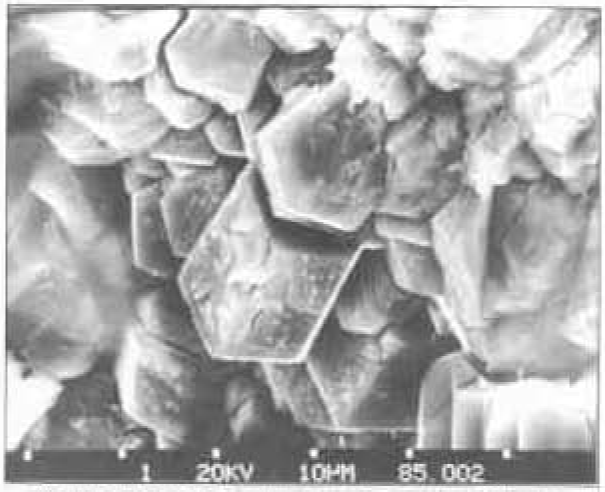

Figure 7. Scanning electron micrograph of fractured and flaking faujasite crystals filling a veinlet in basaltic sandstone from 308.9-m depth in the USGS–N2 drill hole at Newberry volcano. Distance between white tick marks at bottom of micrograph is 10 μ.

Ferrierite—$(Na,K)Mg_2Ca_{0.5}(Al_6Si_{30}O_{72})\cdot 20H_2O$

Another rare zeolite mineral that previously has not been reported from Oregon is ferrierite. One fault gouge sample from a late Miocene andesite flow at the southern base of Mount Hood contained colorless, acicular to lamellar crystals of ferrierite in association with smectite (Figure 8) (Bargar and others, 1993). Electron microprobe analyses (Oscarson and Bargar, 1996) show the presence of significant Mg (Figure 5D) (Mg:Ca ranges from 3:1 to 6:1). Ferrierite is one of the few zeolite minerals that may contain an appreciable amount of magnesium (Gottardi and Galli, 1985).

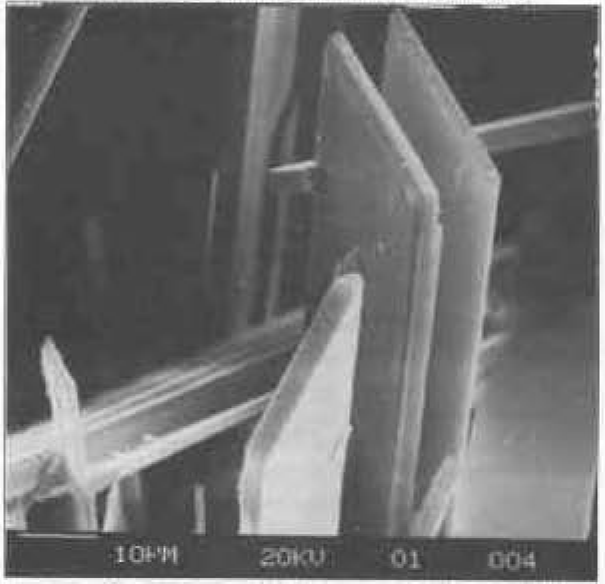

Figure 8. Scanning electron micrograph showing bladed ferrierite crystals from an outcrop near Mount Hood.

Gismondine—$Ca_4(Al_8Si_8O_{32})\cdot 16H_2O$

Tschernich and Howard (1988) described gismondine as filling vesicles, in association with chabazite, calcite, levyne, smectite, and thomsonite, in an outcrop of light-colored volcanic rocks along the Oak Grove Fork Clackamas River in the Breitenbush-Austin Hot Springs area. A vesicular basaltic lava flow specimen was collected from the same general area for the present study. Vesicles in this specimen are filled by pseudotetragonal gismondine crystals and later chabazite (Figure 9). A scanning electron microscope EDS analysis of the gismondine shows only Ca, Al, and Si (Oscarson and Bargar, 1996). According to Tschernich (1992), the Oak Grove Fork area is the only location in the Pacific Northwest where gismondine has been found.

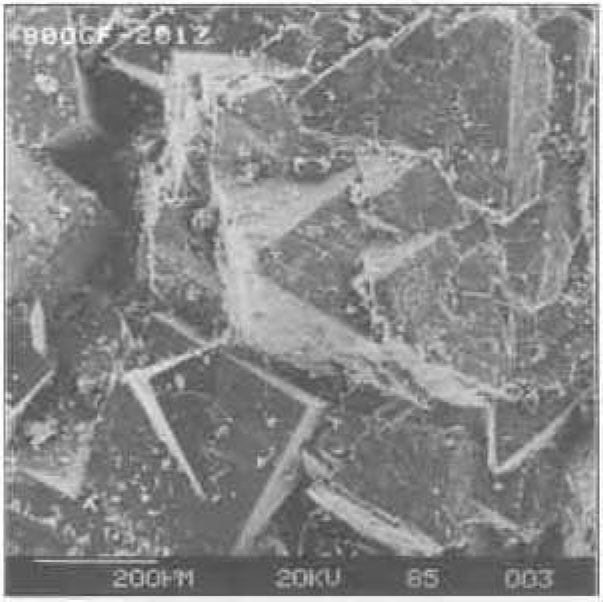

Figure 9. Scanning electron micrograph of pseudotetragonal gismondine crystals in association with penetration twinned chabazite crystals (lower left), filling vesicles in basaltic rock from the Oak Grove Fork Clackamas River.

Harmotome—$Ba_2(Ca_{0.5},Na)(Al_5Si_{11}O_{32})\cdot 12H_2O$
Phillipsite—$K_2(Ca_{0.5},Na)_4(Al_6Si_{10}O_{32})\cdot 12H_2O$
Wellsite—$(Ba,Ca,K_2)Al_2Si_6O_{16}\cdot 6H_2O$

The three zeolite minerals, harmotome, phillipsite, and wellsite, are generally classified as belonging to the phillipsite-harmotome group of zeolite minerals (Gottardi and Galli, 1985). A single specimen of harmotome was collected from a tailings pile in an old mining area southwest of Mount Hood (Bargar and others, 1993); the colorless, blocky, hydrothermal harmotome crystals (Figure 10A) formed in association with earlier stilbite/stellerite (chlorite, pyrite, and calcite also present) on the fracture surface of a late Tertiary andesite lava flow (Bargar and others, 1993). Electron micro-

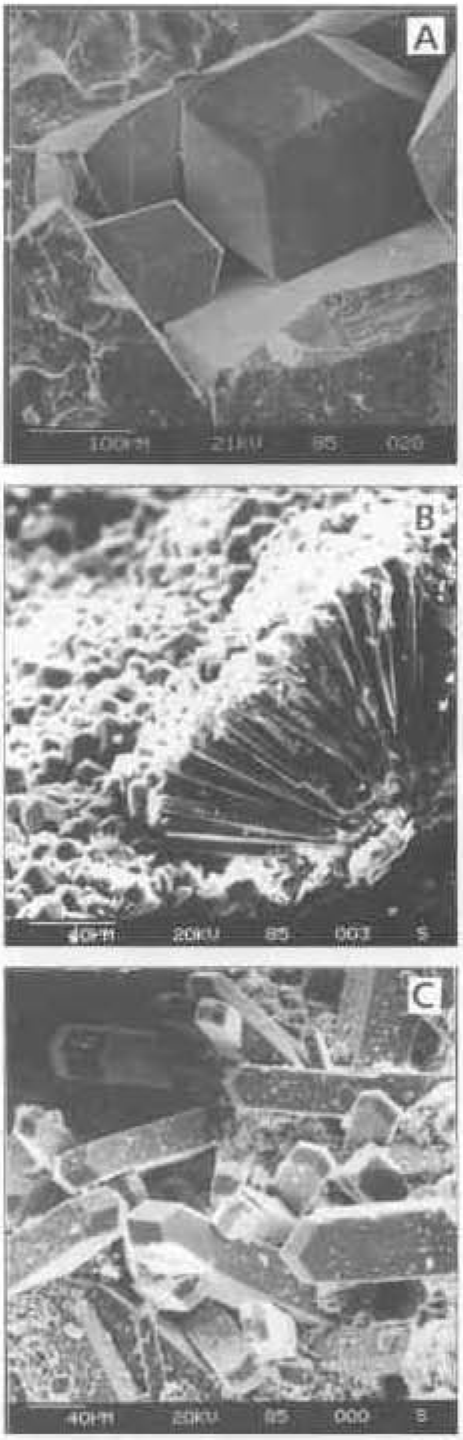

Figure 10. Scanning electron micrographs of (A) euhedral harmotome crystals from near Mount Hood, (B) radiating prisms of phillipsite crystals that fill open spaces between breccia fragments in core from 812-m depth in the CTGH-1 drill hole, and (C) prismatic wellsite crystals and later smectite that coat vesicles in basaltic andesite at 564-m depth in CTGH-1.

probe analyses (Bargar and others, 1993) show that the euhedral, pseudo-orthorhombic harmotome crystals have a very high Ba content (only minor Ca, Na, and K) (Figure 11A), which is characteristic of harmotome (Gottardi and Galli, 1985). Harmotome is a fairly uncommon mineral, and it does not appear to have been reported elsewhere in Oregon (Tschernich, 1992). Although harmotome has not been identified in modern geothermal areas, some harmotome is known to have a hydrothermal origin (Tschernich, 1992).

Phillipsite occurs at several localities in Oregon (Tschernich, 1992). However, in the present study, phillipsite was identified only in two Breitenbush-Austin Hot Springs area outcrop samples and three core specimens from the CTGH–1 hole (Bargar, 1990). Phillipsite, an early formed mineral in this drill core, occurs at depths of 811, 812, and 821 m (measured temperature ~40°C) as fillings in basalt vesicles or between fragments in volcanic breccia. Phillipsite from Icelandic geothermal areas occurs at temperatures between 60° and 85°C; however, Gottardi and Galli (1985), indicate that it can form at temperatures up to 200°C. The blocky to prismatic crystals occur in very closely spaced clusters (Figure 10B). At 812-m depth, the phillipsite crystals have a skeletal appearance and are partly dissolved. The dominant cation in one CTGH–1 specimen is K (Figure 11A); Na and Ca (uncombined) are less abundant and Ba is absent.

Wellsite was identified only in vesicles of basaltic core from 564-m depth in the CTGH–1 hole (measured temperature is ~32°C). The mineral formed as randomly oriented, elongate prismatic crystals (Figure 10C); clusters of radiating crystals; or closely spaced elongate crystals deposited as overlapping, radiating, hemispherical crystal clusters. The latter deposits produce a botryoidal-appearing vesicle coating similar to phillipsite in Figure 10B. Electron microprobe analyses of the CTGH–1 wellsite (Oscarson and Bargar, 1996) show that the mineral is composed of nearly equal amounts of Na and K+Ba, and contains relatively little Ca (Figure 11B). Tschernich (1992) indicates that "barian phillipsite (= wellsite)" occurs in at least two other locations in Oregon, both of which are only a few tens of kilometers from the CTGH–1 drill-hole site.

Heulandite—$(Na,K)Ca_4(Al_9Si_{27}O_{72})\cdot 24H_2O$
Clinoptilolite—$(Na,K)_6(Al_6Si_{30}O_{72})\cdot 20H_2O$

Heulandite group minerals—heulandite, clinoptilolite, and intermediate heulandite(?)—occur in drill holes and/or outcrops of all three areas studied. Past researchers have distinguished between heulandite and clinoptilolite by either XRD (Mumpton, 1960) or chemical differences (Mason and Sand, 1960). Later studies (Alietti, 1972; Boles, 1972) even indicated the presence of a third or intermediate heulandite mineral phase. Reliance upon the definitions presented in the above references indicates that all three phases of the heulandite group of minerals are present in the Oregon Cascade Range.

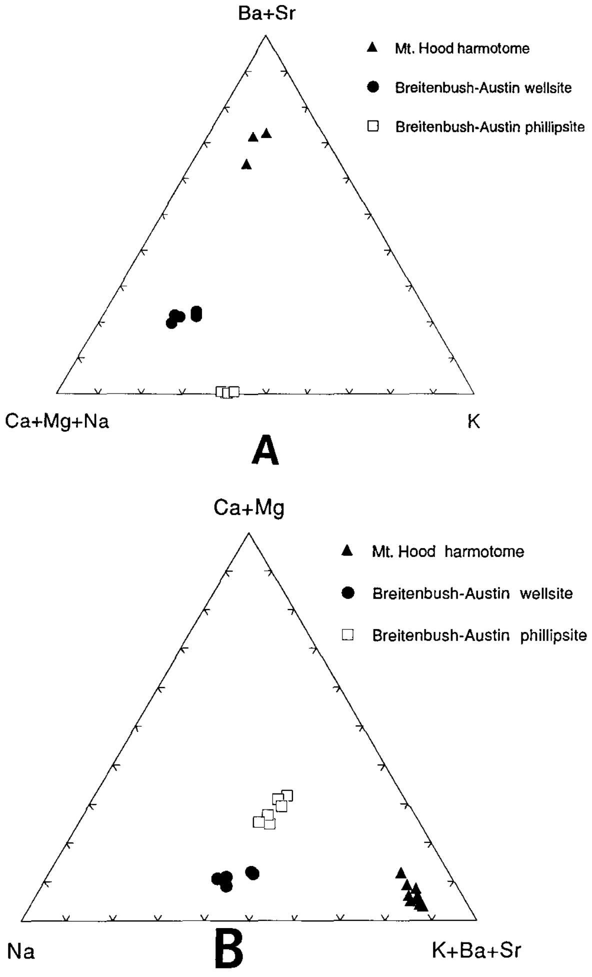

Figure 11. (A) Ba+Sr–Ca+Mg+Na–K and (B) Ca+Mg–Na–K+Ba+Sr ternary diagrams for electron microprobe analyses of harmotome, phillipsite, and wellsite from the Oregon Cascades.

Heulandite was identified from fractures and open spaces between rock fragments in a few outcrops of late Tertiary volcanogenic deposits near Mount Hood; also, late Tertiary to Quaternary volcanic drill chips from five nearby geothermal holes contain tiny, colorless, tabular or blocky, heulandite crystals (Bargar and others, 1993).

Both heulandite and clinoptilolite are present in the lower part of the CTGH–1 drill hole near Breitenbush Hot Springs (Bargar, 1990). These heulandite group minerals were deposited in vesicles and fractures and between breccia fragments of late Tertiary andesitic to basaltic lava flows, tuffs, and breccias. The tabular zeolite minerals formed later than hematite, most smectite, celadonite, and erionite but are earlier than cristobalite (Figure 12), mordenite, or minor late smectite.

Figure 12. Vesicle fillings in a very vesicular basaltic rock outcrop from the Oak Grove Fork Clackamas River that contain colorless, euhedral, tabular heulandite crystals and later hemispheric cristobalite.

Heulandite and intermediate heulandite are fairly common minerals in open spaces of late Tertiary volcanic rocks throughout the Breitenbush-Austin Hot Springs area. Drill cutting specimens from several depths in the SUNEDCO 58–28 geothermal hole near Breitenbush Hot Springs also contain heulandite (Bargar, 1994).

Minor clinoptilolite occurs in rhyolitic tuff breccia core from near the middle of the USGS–N2 geothermal hole within the crater of Newberry volcano (Keith and Bargar, 1988). The only other heulandite group mineral identified from this volcano is a small amount of heulandite which occurs in fractures and vesicles of basaltic to andesitic drill core recovered from near the bottom of the western flank GEO–N5 hole (Bargar and Keith, in preparation).

Heulandite group minerals typically are found in modern geothermal areas at low to moderate temperatures. Measured temperatures at the depths where heulandite occurs in the SUNEDCO 58–28 drill hole range from about 80° to 130°C. These temperatures are within the apparent temperature limits (about 70° to 170°C) for heulandite in Icelandic geothermal drill holes (Kristmansdóttir and Tómasson, 1978). However, some heulandite and clinoptilolite minerals occur at temperatures as low as 30°C (range is about 30° to 96°C) in the CTGH–1 hole (Bargar, 1990). A bottom-hole temperature of about 60°C was measured for the only Mount Hood geothermal hole containing substantial heulandite (Bargar and others, 1993). At Newberry volcano, clinoptilolite was located in the USGS–N2 drill hole at a depth where the measured temperature was about 99°C (Keith and Bargar, 1988). The present temperature at the core depth where heulandite was identified in the Newberry GEO-N5 hole is about 80°C (Bargar and Keith, in preparation).

Figure 13 shows a ternary diagram of the exchangeable cations commonly present in heulandite-group minerals of the northern Oregon Cascade Range. The Newberry and Breitenbush-Austin clinoptilolites are Na- or K-rich minerals that show no structural changes following heating at 450°C for 24 hours (Mumpton, 1960). One clinoptilolite specimen contains 8.34 weight percent K_2O (Bargar and Keith, in preparation). Clinoptilolites with such high K_2O contents usually are produced by sedimentary (Stonecipher, 1978) or diagenetic (Ogihara and Iijima, 1990) processes rather than hydrothermal alteration. However, Keith and others (1978) and Bargar and Beeson (1985) reported K_2O contents of 5.73 and 4.99 weight percent, respectively, for clinoptilolite in rhyolitic drill core specimens from thermal areas of Yellowstone National Park.

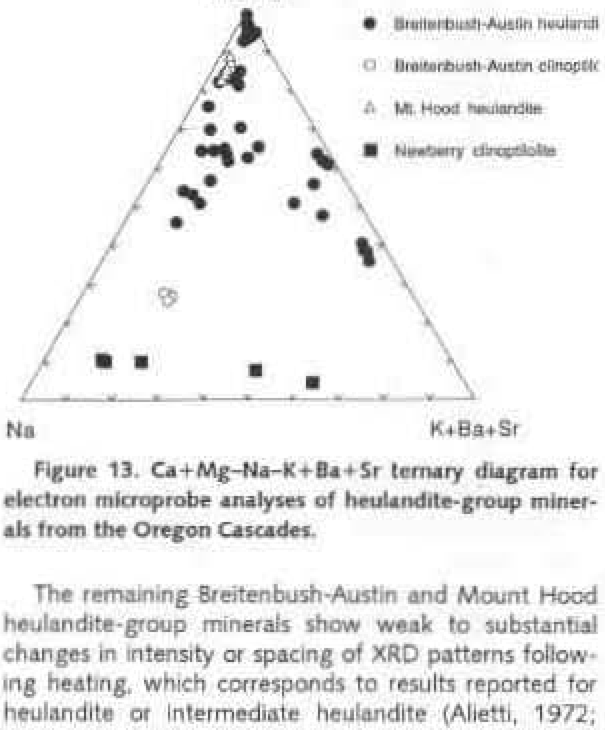

Figure 13. Ca+Mg–Na–K+Ba+Sr ternary diagram for electron microprobe analyses of heulandite-group minerals from the Oregon Cascades.

The remaining Breitenbush-Austin and Mount Hood heulandite-group minerals show weak to substantial changes in intensity or spacing of XRD patterns following heating, which corresponds to results reported for heulandite or intermediate heulandite (Alietti, 1972; Boles, 1972). The microprobe analyses of these mineral specimens (Oscarson and Bargar, 1996) are all Ca-rich, but many of the analyses exhibit considerable scatter (Figure 13), owing to the presence of substantial Na or K.

Laumontite—$Ca_4(Al_8Si_{16}O_{48})\cdot 16H_2O$

Laumontite is a common zeolite mineral in the Oregon Cascade Range. White, euhedral, prismatic laumontite crystals, up to about 3 cm in length, were found during this study, filling open spaces between volcanic breccia fragments and lining vugs and fractures. Frequently, laumontite can be readily identified from its distinctive habit in which the terminal sloping {201} crystal face is prominent (Figure 14).

Figure 14. Scanning electron micrograph showing euhedral laumontite crystals that coat a rock fragment in drill cuttings from 1,125-m depth in the Pucci geothermal drill hole located on the southern slopes of Mount Hood. Distance between white tick marks at bottom of micrograph is 30 μ.

In the Mount Hood and Breitenbush-Austin Hot Springs areas, laumontite occurs in several geothermal drill holes and numerous outcrops of late Tertiary volcanic rocks (Bargar and others, 1993; Bargar, 1994). The temperature range at which laumontite was identified in the SUNEDCO 58–28 hole is about 110°–130°C. Conversely, at Newberry volcano, traces of laumontite were identified in only two drill holes (temperatures about 150° and 160°C) (Bargar and Keith, in preparation). These temperatures fall within the wide temperature range (43° to 230°C) at which laumontite previously has been reported (Kristmannsdóttir and Tómasson, 1978; McCulloh and others, 1981).

Electron microprobe analyses of laumontite from both the Mount Hood and Breitenbush-Austin areas (Oscarson and Bargar, 1996) are Ca-rich with only minor amounts of other exchangeable cations (Figure 15A).

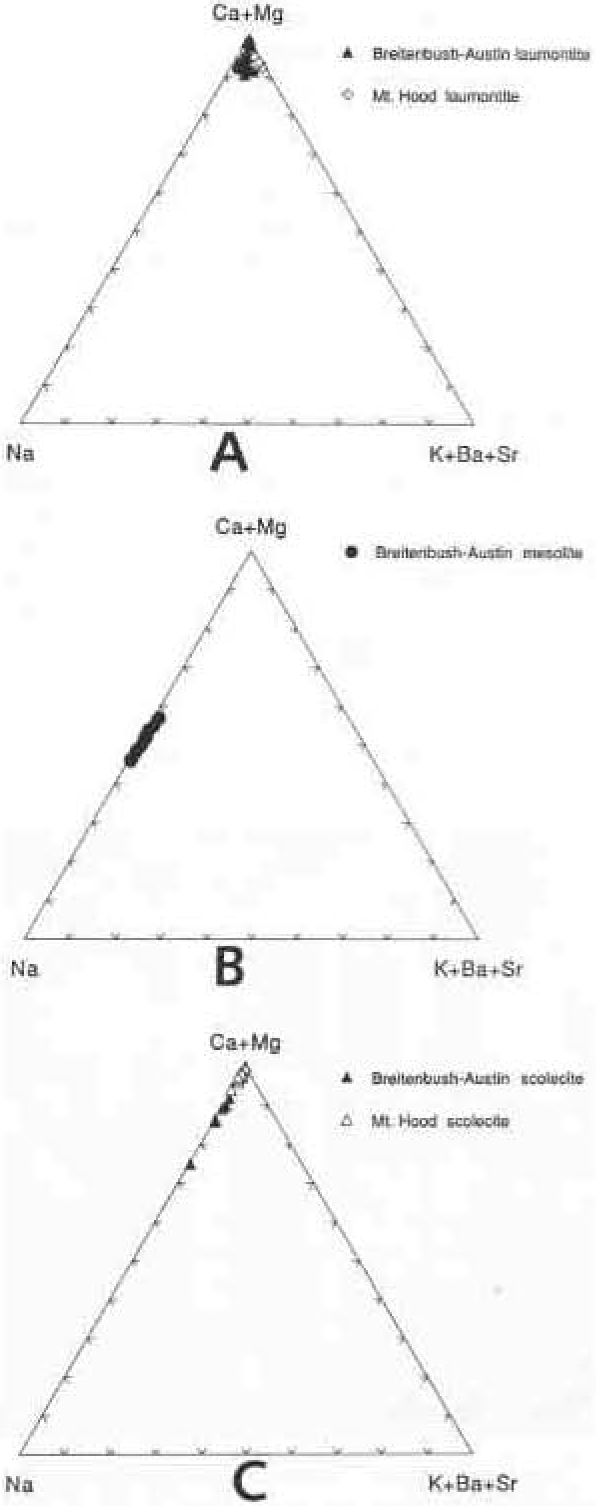

Figure 15. Ca+Mg–Na–K+Ba+Sr ternary diagrams for electron microprobe analyses of (A) laumontite, (B) mesolite, and (C) scolecite specimens collected from near Mount Hood and Breitenbush-Austin Hot Springs areas.

Levyne—$NaCa_{2.5}(Al_6Si_{12}O_{36})\cdot 18H_2O)$

Levyne was found in association with smectite, filling vesicles in a basalt outcrop located ~3–4 km southeast of Breitenbush Hot Springs. A fracture surface in the collected specimen was filled by thomsonite and chabazite. Levyne is not a rare mineral in Oregon, but it was not found elsewhere during the present study. According to studies of Kristmannsdóttir and Tómasson, 1978), levyne occurs in Icelandic geothermal areas at temperatures below 70°C; chabazite forms over the same temperature range; however, thomsonite occurs at temperatures as high as 110°C.

Mesolite—$Na_{16}Ca_{16}(Al_{48}Si_{72}O_{240})\cdot 64H_2O$
Scolecite—$Ca_8(Al_{16}Si_{24}O_{80})\cdot 24H_2O$

Mesolite and scolecite are classified in the same group of fibrous zeolites (Figure 16) (Gottardi and Galli, 1985). Morphologically, the two minerals are indistinguishable; however, they can be differentiated by optical characteristics, and they have different chemical compositions. Mesolite contains nearly equal proportions of Na and Ca, while Ca is the dominant cation in scolecite. Other cations mostly are absent in both minerals (Figures 15B,C) (Tschernich, 1992). Analysis of trace elements for one scolecite specimen from the Mount Hood area shows the presence of minor Ba, Cu, Mn, Zn, and some Sr (Bargar and others, 1993).

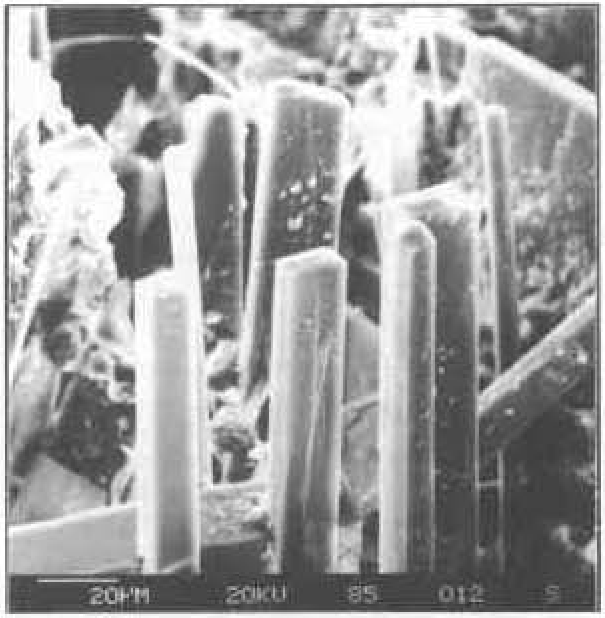

Figure 16. Scanning electron micrograph showing acicular mesolite crystals that coat fractures at 767-m depth in the CTGH-1 drill hole located near Breitenbush Hot Springs. Tabular mineral in the upper right and lower left corners of the figure is thomsonite. Both of these minerals are slightly coated by late smectite.

Mesolite has been reported from several locations in Oregon, including some areas within the Cascade Range. Scolecite, on the other hand, has been reported only from three areas in Oregon (Tschernich, 1992). Mesolite and scolecite occur in only a few specimens collected for this study.

Mordenite—$Na_3KCa_2(Al_8Si_{40}O_{96})\cdot 28H_2O$

Mordenite occurs in outcrop specimens and/or drill-hole samples in all three study areas, but it is not very abundant in any of them (Keith and Bargar, 1988; Bargar, 1990; Bargar and others, 1993; Bargar, 1994). Individual white, fibrous to acicular mordenite crystals or mats of fibrous crystals (Figure 17) have a qualitative EDS chemistry consisting of Ca, Al, and Si (Oscarson and Bargar, 1996) and, occasionally, trace amounts of Na or K. Mordenite usually formed later than associated hydrothermal minerals. In the Cascade Range, measured drill-hole temperatures at depths where mordenite was located range from about 50°C to more than 160°C. In Icelandic geothermal areas, mordenite occurs over a somewhat wider temperature range (~75° to 230°C) (Kristmannsdóttir and Tómasson, 1978).

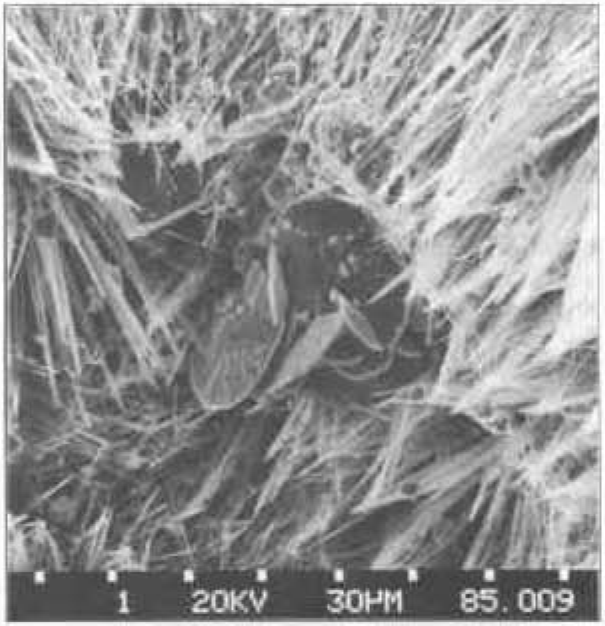

Figure 17. Scanning electron micrograph showing fibrous mordenite and earlier disk-shaped clusters of siderite, coating open spaces between breccia fragments in core from 496-m depth in the USGS-N2 drill hole. Distance between white tick marks at bottom of micrograp is 30 µ.

Stilbite/Stellerite
$NaCa_4(Al_9Si_{27}O_{72})\cdot 30H_2O$ / $Ca_4(Al_8Si_{28}O_{72})\cdot 28H_2O$

Next to laumontite, white to colorless, tabular (Figures 18A,B) stilbite and stellerite are the most common zeolite minerals found in the Mount Hood and Breitenbush-Austin Hot Springs areas. These minerals were not identified in the Newberry volcano drill holes. The two solid-solution series minerals are combined here because they are distinguishable with confidence only by single-crystal XRD analysis (R.C. Erd, written communication, 1992), which was not attempted for this report. Electron microprobe analyses of stilbite/stellerite from the two study areas (Oscarson and Bargar, 1996) may show a separation of the two minerals (Figure 19A), with Na-rich analyses corresponding to stilbite; however, the possibility was not investigated for this report. Trace element analyses for two stilbite/stellerite specimens from the Mount Hood area show the presence of significant Pb (Bargar and others, 1993, Table 5). Drill-hole temperatures at depths where stilbite/stellerite was identified in drill hole SUNEDCO 58–28 were between 100° and 120°C (Bargar, 1994). Stilbite from Icelandic geothermal drill holes occurs over a temperature range of 70° to about 170°C (Kristmannsdóttir and Tómasson, 1978). Tschernich (1992) lists several Oregon localities where stilbite previously has been reported.

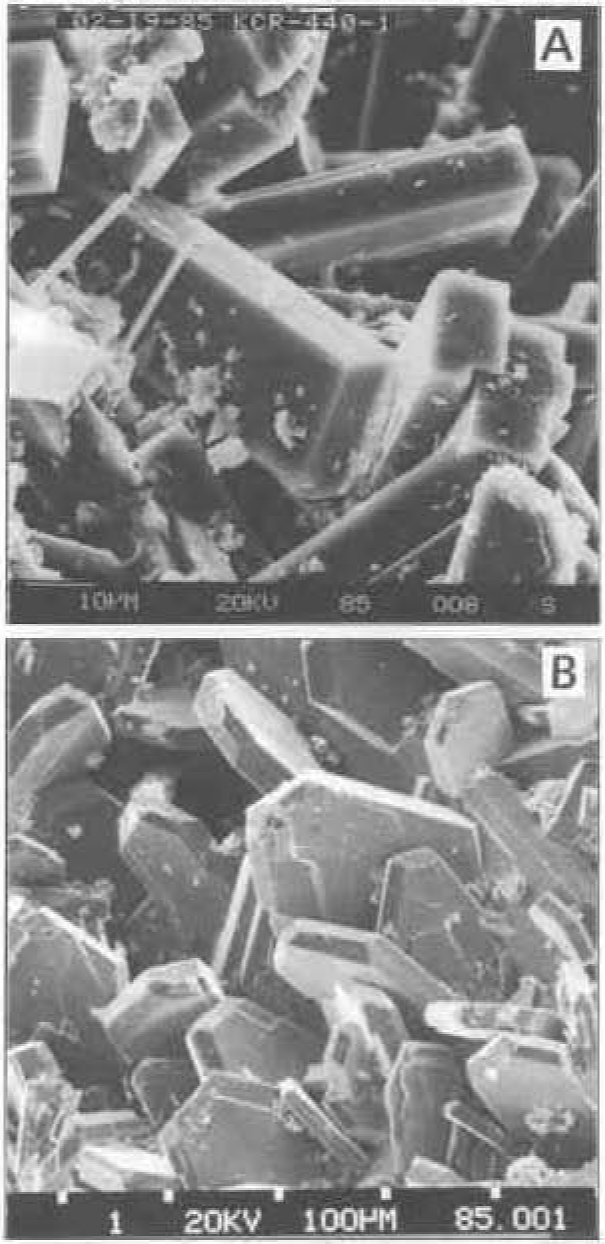

Figure 18. Scanning electron micrographs showing different morphologies for stilbite/stellerite that coats rock fragments in drill cuttings from (A) 134-m depth in the Zigzag River geothermal drill hole and (B) 1,161-m depth in the Pucci drill hole. Both drill holes are located near Mount Hood (Bargar and others, 1993). Distance between white tick marks at bottom of micrograph is 100 μ.

Thomsonite—$Na_4Ca_8(Al_{20}Si_{20}O_{80})\cdot 24H_2O$

Thomsonite was located in fracture and vesicle fillings between about 648- and 866-m depth in the CTGH–1 drill hole (temperatures between 30° and 50°C) (Bargar, 1990); bladed thomsonite (Figure 20) also was located, filling vesicles and fractures of three outcrops in the Breitenbush-Austin Hot Springs area. While thomsonite is fairly rare in the three study areas of this report, it is not uncommon elsewhere in Oregon (Tschernich, 1992). Electron microprobe analyses (Oscarson and Bargar, 1996) for three thomsonite specimens appear to be fairly typical for thomsonite (Gottardi and Galli, 1985) (Figure 19B).

Yugawaralite—$Ca_2Al_4Si_{12}O_{32}\cdot 8H_2O$

Rare specimens of yugawaralite are reported from a few geothermal areas where the temperatures range between 110° and 200°C (Gottardi and Galli, 1985; Tschernich, 1992). One sample, collected on the north shore of Detroit Reservoir, contains stacked, colorless, tabular yugawaralite crystals, along with laumontite, stilbite/stellerite, scolecite, and mixed-layer chlorite-smectite in an extremely altered outcrop of early Neogene (Hammond and others, 1982) volcanic rocks. This occurrence appears to be the only specimen of yugawaralite that has ever been found in Oregon (Tschernich, 1992). Electron microprobe analyses of the mineral are given in Oscarson and Bargar (1996); calcium is the dominant cation; only minor sodium and potassium was detected in these analyses (Figure 19C).

FINAL REMARKS

Twenty-three zeolite minerals were identified from rock-outcrop and geothermal drill-hole specimens ob-

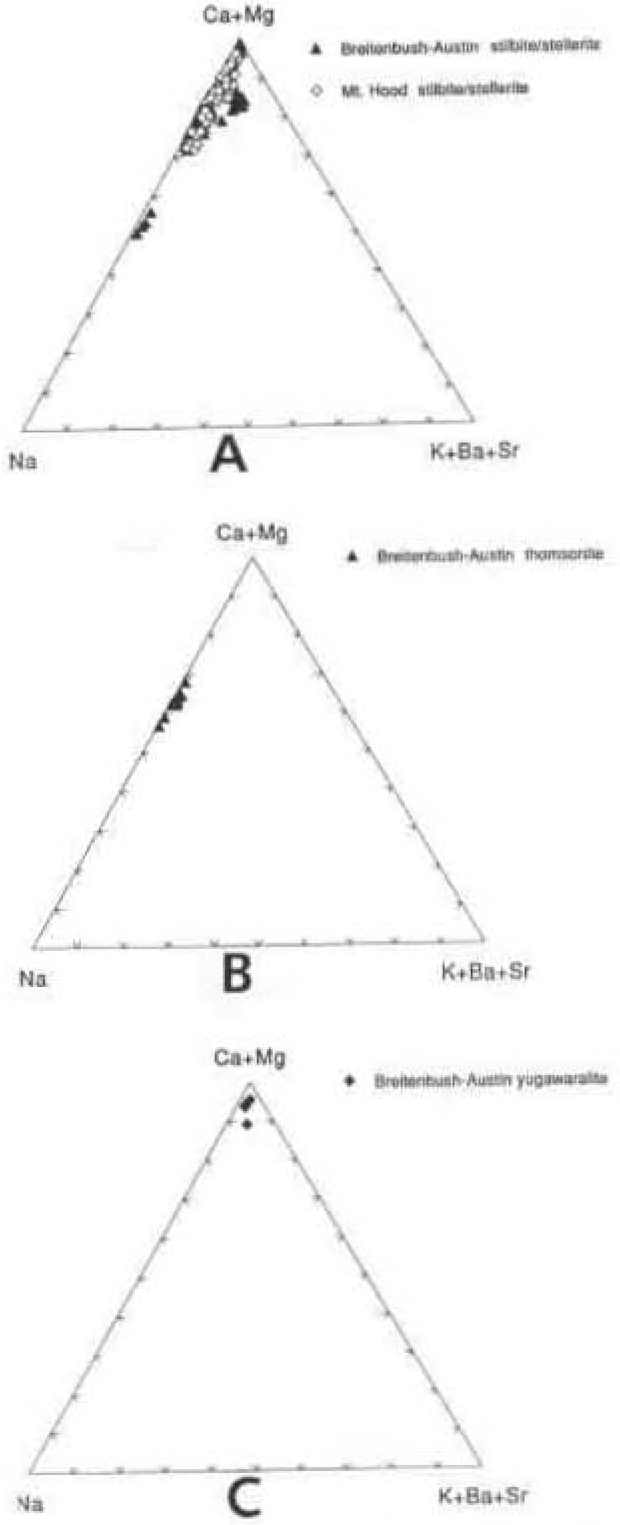

Figure 19. Ca+Mg–Na–K+Ba+Sr ternary diagrams for electron microprobe analyses of (A) stilbite/stellerite, (B) thomsonite, and (C) yugawaralite from the Breitenbush-Austin Hot Springs and Mount Hood areas.

Figure 20. Scanning electron micrograph showing bladed thomsonite and acicular scolecite that fill fractures in a basalt outcrop in the Breitenbush-Austin Hot Springs area.

tained from the three study areas (near Mount Hood, Newberry volcano, and the Breitenbush-Austin Hot Springs area). Of these zeolites, five (wairakite, faujasite, ferrierite, harmotome, and yugawaralite) are significant because they apparently have not been found elsewhere in Oregon. The widespread occurrence of zeolite minerals throughout the Western Cascade Range of northern Oregon (especially in the Breitenbush-Austin Hot Springs area) attests to the significance of zeolite metamorphism in altering the late Tertiary volcanic rocks.

The most intense (greenschist facies) hydrothermal alteration of volcanic rocks in the Mount Hood and Breitenbush-Austin Hot Springs areas was observed in surface-exposed or drill-hole-penetrated, small, scattered, late Tertiary intrusions. A few kilometers away from these intrusions, zeolites and other low-temperature minerals are the dominant hydrothermal alteration products. The low-temperature minerals frequently are superimposed upon the higher temperature minerals formed during late stages of hydrothermal alteration. Fluid inclusion data obtained for the two areas (Bargar, 1993, 1994; Bargar and others, 1993; Bargar and Oscarson, 1997) support and serve to quantify these conclusions.

Within the caldera of the active Newberry volcano, fluid inclusion and hydrothermal mineralogy studies of the Quaternary volcanic drill-hole specimens indicate that the rocks have been altered by thermal fluids compatible with zeolite (at shallower levels) to greenschist (at depth) metamorphism. Drill holes located a few kilometers outside the caldera on the north, east, and south flanks of the volcano contain evidence of only very low temperature alteration. On the west flank of Newberry, the available measured temperature and fluid-inclusion homogenization temperature data suggest that the fluids become hotter nearer the rim of the caldera.

Preliminary hydrothermal alteration and fluid inclusion studies of geothermal drill holes at Medicine Lake volcano in northern California (Bargar and Keith, 1993) also indicate that temperatures capable of producing greenschist-facies minerals appear to be confined to the area within the caldera. As at Newberry volcano, current available data for drill holes outside the caldera do not show evidence of high temperature alteration.

Two very different models have been proposed to explain the high heat flow observed throughout much of the Oregon Cascade Range. One model indicates that the source of the heat is widespread and that the geothermal energy potential of the area is very significant (Blackwell and others, 1990). The second model suggests that the heat source is more localized and the heat is spread by fluid movement, which results in a substantially smaller geothermal potential (Ingebritsen and others, 1994). The hydrothermal alteration studies conducted for this report appear to support the second model, inasmuch as hydrothermal mineralogical evidence of past or present high temperatures in the Cascade Range of northern Oregon (and at Medicine Lake volcano, northern California) was found only in close proximity to small, late Tertiary intrusions or within or very near the calderas of active volcanoes.

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AEG meeting in Portland has many features

The 40th annual meeting of the Association of Engineering Geologists will be held September 30 through October 4, 1997, at the Hilton Hotel in downtown Portland, Oregon, and is hosted by the organization's Oregon Section. In conjunction with the meeting theme, "Converging at Cascadia" (with its allusion to the Cascadia subduction zone), the technical program will focus on a variety of earthquake-related issues as well as classic topics of engineering geology, landslides, and environmental and groundwater concerns.

The meeting will offer 25 technical sessions with over 200 presentations. This includes six special symposia: "Building the Westside Light Rail Tunnel," "Earthquakes—Converging at Cascadia," "Probabilistic vs. Deterministic Seismic Hazard Analysis," "Characterization of Weak and Weathered Rock Masses," "Landslide Mechanisms and Failure Modes," and "Pros and Cons of ASTM Standard Guides."

Field trips before and after the meeting will lead to south and north Oregon coast landslides; the Columbia River Gorge; Ochoco and Bowman Dams in central Oregon; Mount St. Helens; and prehistoric earthquake evidence in Willapa Bay, Washington. Two "quick trips" of four hours during the meeting, on October 2 and 3, will offer a visit to the Westside Light Rail Transit tunnel.

Nine short courses, on September 29 and 30 and October 2, will offer a wide variety of educational opportunities. The courses are accredited for CEUs (Continuing Education Units).

A whole-day teachers' workshop, "Earth Science on the Edge," on October 1, offers sessions on volcanic, earthquake, and tsunami hazards; groundwater flow, wells, pollution, and cleanup; hydrothermal vents on the ocean floor at the Juan de Fuca Ridge; a plate tectonics curriculum for elementary schools; and the use of multimedia in the Earth Sciences. The workshop also includes a field trip to view bioengineering techniques for stream restoration and habitat improvement.

The 176-page book "Program with Abstracts" and further information are available from Julie Keaton, AEG '97, 130 Yucca Drive, Sedona, AZ 86336-3222, phone 520-204-1553, FAX 520-204-5597. ☐

National Natural Landmarks Program in the Pacific Northwest

by Stephen T. Gibbons, National Park Service, Columbia Cascades Support Office, 909 First Avenue, Seattle, WA 98104

The National Natural Landmarks Program was established in 1962 by Secretary of the Interior Stewart Udall under the authority of the Historic Sites, Buildings, and Antiquities Act of 1935. National Natural Landmarks (NNL) are nationally significant areas that have been so designated by the Secretary of the Interior. To be nationally significant, a site must be one of the best examples of a type of biotic community or geologic feature in its physiographic province. Examples include terrestrial and aquatic ecosystems, as well as features, exposures, and landforms that record active geologic processes and fossil evidence of biological evolution.

The goal of the NNL Program is to identify, recognize, and encourage the protection of sites containing outstanding examples of geological and ecological components of the nation's landscape. The landmarks have been designated on both public and private land; the program is designed to obtain concurrence of the owner or administrator for the landmark's status.

SELECTION CRITERIA

The determination that a site is one of the best examples of a particular feature in a natural region or physiographic province is based primarily on how well it illustrates the feature and the condition of the specific feature; secondary criteria are its rarity, diversity, and values for science and education.

Studies of the thirty-three physiographic provinces of the United States and its territories have produced an inventory of potential sites for further evaluation. These sites have a variety of ecological and geological themes. Sites can be added to this inventory through an initial recommendation by outside groups or private citizens. Recommendations quite often come from state natural heritage program inventories or other groups, including The Nature Conservancy.

DESIGNATION PROCESS

The National Park Service must receive prior approval from the landowner to conduct an on-site evaluation of areas that are highly ranked either in the theme studies or by outside recommendations. The National Park Service contracts with scientists to conduct on-site evaluations. The evaluations gather additional information and compare the site with other similar sites, guided by the national significance criteria.

Completed on-site evaluations are peer-reviewed by other scientists and then by the National Park Service. If a site is deemed to fulfill the requirements for NNL status, and if landowners have indicated their consent for designation, the Director of the National Park Service then nominates the site to the Secretary of the Interior for designation. During the designation process, the National Park Service solicits comments from landowners, from local, State, and Federal government officials, and from other interested groups and individuals. Once designated, the area is listed on the National Registry of Natural Landmarks.

The NNL Program recognizes and encourages voluntary, long-term commitment of public and private owners to protect an area's outstanding values. Owners who voluntarily agree to help protect their landmark property are eligible to receive a certificate and plaque for display at the site.

As of July 1997, 587 NNL sites have been designated. Thirty-four of these sites are in the Pacific Northwest Region: 6 in Oregon, 11 in Idaho and 17 in Washington. The general location of the Oregon sites is indicated in the map on the next page.

To date, 16 of the 587 sites originally designated as NNLs have become part of the National Park system. The three landmarks in the Pacific Northwest Region are Cassia Silent City of Rocks (City of Rocks National Reserve) and Hagerman Fauna Sites (Hagerman Fossil Beds National Monument) in Idaho and Point of Arches (Olympic National Park) in Washington.

NATIONAL NATURAL LANDMARK MORATORIUM

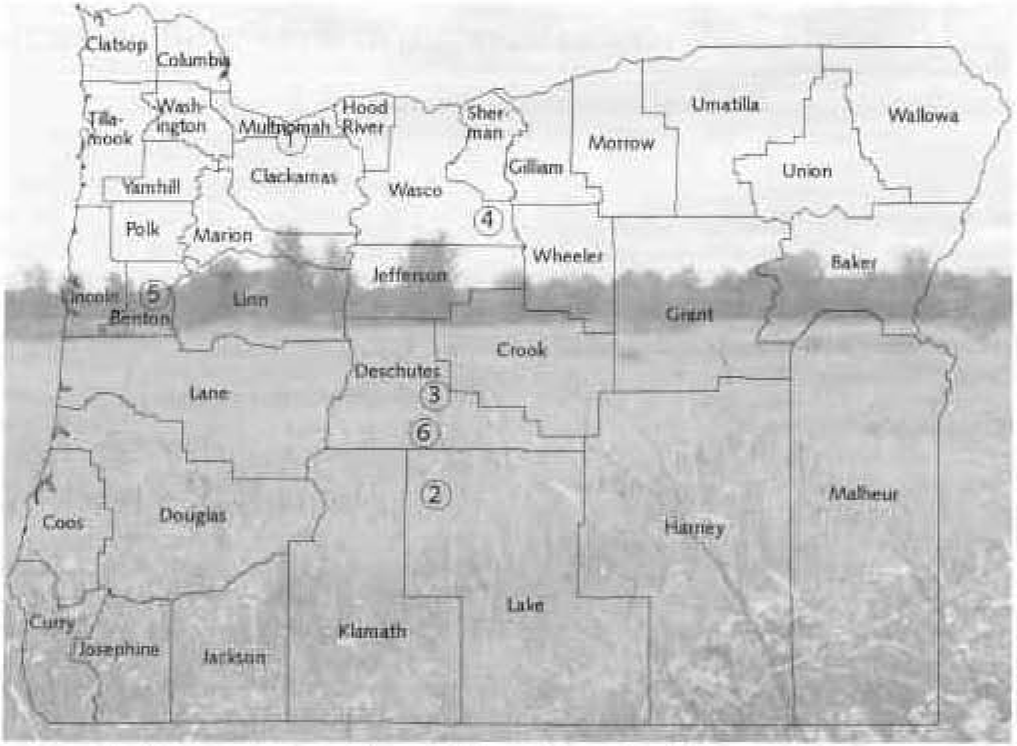
On November 28, 1989, the Director of the National Park Service placed a moratorium on the NNL Program, specifically postponing activities related to the evaluation, nomination, and designation of new sites for NNL status. The purpose of the moratorium was to allow sufficient time to conduct a thorough review of the program, including regulations and procedures. Attention was also focused on ensuring adequate provisions for landowner notification, rights, and consent. The moratorium is still in effect at this time.

STATUS OF THE NNL PROGRAM

The Washington, D.C., office of the NNL Program has promulgated five initiatives as a result of recent audits:

1. A proposed rule revising the regulations (36 CFR Part 62) for the NNL Program was published in November 1991. Provisions require landowner consent before conducting an evaluation of property as part of the landmark designation process. Publication of the final rule is pending.

2. A program handbook is being developed to ensure



Map showing approximate locations of National Natural Landmarks in Oregon. Numbers are keyed to text. Background shows Willamette Floodplain Landmark (no. 5) that is part of the William L. Finley National Wildlife Refuge in Benton County.

that applicable standards and quality-control procedures for all aspects of the landmark evaluation, nomination, designation, and monitoring process are complete.

3. A contract to identify and corroborate the names and addresses of all private NNL landowners has been completed.

4. A user needs analysis of the Natural Landmarks System database was completed, and an update of the database was completed in December 1993.

5. A management control system will be operational within six months after adoption of the NNL regulations.

OREGON LANDMARK SITES

Locations of sites described below are shown on the map above; numbers in the list are keyed to these locations on the map.

1. Crown Point—The Crown Point section of the Columbia Gorge illustrates more gradual stream valley formation as downcutting kept pace with the rise of the Cascade Range. The Columbia River Gorge at Crown Point passes from the steeper, more rugged terrain of the western slopes of the Cascade Range to rolling cultivated plains. The promontory provides a strategic vantage point for observing this classic illustration of riverine processes.

2. Fort Rock State Monument—The site is a striking example of a circular, fortlike outcrop. Although other volcanic outcrops may exhibit many of the same features, few are as well-shaped and distinct.

3. Horse Ridge Natural Area—The site is of national significance in providing a characteristic and high-quality example of Sandy Western Juniper (*Juniperus occidentalis*) Steppe. Its biota represent a distinctive climax community. It is an ecological community that typifies geographically the fringe of the Great Basin Desert and biologically the transitional area between the ponderosa pine (*Pinus ponderosa*) forest and the sagebrush (*Artemisia tridentata*) desert.

4. Lawrence Memorial Grassland Preserve—The site constitutes an excellent example of biscuit and scabland topography. Moreover, it is the patterned landscape superimposed upon the basaltic bedrock that is especially illustrative, as well as an associated matrix of minimally disturbed grassland and shrub-steppe ecosystems.

5. Willamette Floodplain—The site represents the largest remaining native and unplowed example of bottomland interior valley grasslands in the North Pacific Border natural region.

6. Newberry Crater—The crater is a young volcano formed within the last million years during the Pleistocene and is the largest Pleistocene volcano east of the Cascade Range. It stands isolated and conspicuous on a broad plateau of lava. ☐

"Real-time"earthquake information

DOGAMI has been chosen as test site for a new, quick earthquake alert system

by Shannon Priem, Oregon Department of Geology and Mineral Industries

When the Seattle and Bremerton-area earthquakes occurred on June 23 and 24 this year, geologists of the Oregon Department of Geology and Mineral Industries (DOGAMI) in Portland knew—almost instantly—the size, time, and location of the earthquakes and were able to relay this information without delay to the public and the news media.

They had just installed a prototype alert system that is linked to the Pacific Northwest Seismograph Network (PNSN) operated by the University of Washington Geophysics Department.

Within minutes of an earthquake, a computer alarm is triggered at DOGAMI, displaying a map with details of the event. The PNSN includes about 130 seismograph stations that record earthquake ground shaking from several thousand earthquakes a year in Oregon and Washington (of which one or two dozen are strong enough to be felt by local residents). PNSN's "nerve center" is the University of Washington's Seismology Lab.

DOGAMI's new system is one of only three pager-based earthquake alert systems in the United States. It is still considered a prototype, according to Mei Mei Wang, DOGAMI Earthquake Program Coordinator. It is part of a larger PNSN effort to provide more and better information about earthquakes and earthquake hazards to scientists, engineers, emergency managers, critical-facility operators, the media, and the general public. Improvements in pager technology now allow PNSN staff to broadcast basic earthquake information using a commercial paging system and personal computers as receivers. Eventually, any who choose to become subscribers to this system could benefit as well. PNSN chose DOGAMI to help develop the prototype because of the agency's increased efforts in earthquake hazard mapping, public education, and risk reduction.

The predecessor of the system was the Caltech/USGS Broadcast of Earthquakes (CUBE), developed in 1991 in southern California and operated by the U.S. Geological Survey and the California Institute of Technology. For a quick assessment of earthquake ground shaking levels and associated damage, knowing the location, size, and magnitude of an earthquake is essential. CUBE reports earthquakes recorded by the 350-station southern California seismograph network. A companion seismograph network and broadcast system reports earthquakes in northern California.

An example will show how CUBE helped in the 1994 Northridge, California, earthquake: Ten seconds of strong ground shaking on the north edge of Los Angeles left more than 40,000 people homeless. While police and fire departments and medical emergency teams rescued people and fought fires, emergency managers were faced with deciding what resources would be needed to shelter people and help them recover from the disaster. Scientists and engineers quickly prepared a shaking-intensity map for all parts of the greater Los Angeles area. This map showed estimated severity of shaking and the level of damage likely associated with such shaking. It was available long before a complete picture of the damage could be assembled and enabled emergency managers to promptly locate the hardest hit areas and to send appropriate help. Victims whose homes were destroyed or severely damaged could be directed to shelter before a predicted storm added to their misery. Teams of relief workers were sent where they were most needed, and the time for delivery of relief money to individuals was reduced from weeks to hours.

Preparation and use of the shaking-intensity map after the Northridge earthquake was the first instance in which this technology helped focus relief efforts during a disaster.

The new alert system in Oregon and Washington, although it is still in its development stage, will offer similar benefits as well as added advantages. For example, in the case of Cascadia tsunamis (giant damaging waves caused by offshore earthquakes), the ability to pinpoint the fact that an earthquake occurred offshore will help coastal communities to evacuate more quickly —or, in contrast, reduce the incidences of "false alarms." □

Rare tsunami photos on the Internet

An earthquake of magnitude 8 shook the Pacific coast of central Mexico on October 9, 1995, and produced a moderate tsunami along about 200 km (125 mi) of coastline with runup heights up to 5 m (16 ft). Because much of the affected area is sparsely populated, only one person was reported killed, while damage was considerable in some places.

Remarkably, some people were able to take photographs of the tsunami in action, specifically at Tenacatita Bay and the small town of La Manzanilla. These photos have been made available for viewing on the University of Southern California website at

http://www.usc.edu/dept/tsunamis/.

This information is taken from a report by Jose Borrero and others in EOS, v. 78, no. 8 of February 25, 1997, which also mentions a reference to J. Ramirez and R. Pugliesi in *EERI Earthquake Report* 29(12), 6, 1995, describing the tsunami event. □

THESIS ABSTRACTS

The Oregon Department of Geology and Mineral Industries 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.

The Olympic-Wallowa Lineament, Hite fault system, and Columbia River Basalt Group stratigraphy in northeast Umatilla County, Oregon, by Stephen Christopher Kuehn (M.S., Washington State University, 1995), 170 p.

The significance of strike-slip faulting on the Columbia Plateau, including displacement along the structural zone coincident with the Olympic-Wallowa Lineament (OWL zone) and along the Hite fault System (HFS), has long been controversial, in part because of difficulty in determining strike-slip displacements in horizontal flows of the Columbia River Basalt Group (CRBG). Even the significance of apparent strike-slip displacement of vertical feeder dikes has been questioned because of the possibility of en echelon dike emplacement. This investigation was undertaken to clarify the type and timing of displacements on faults of the OWL zone and HFS. The area immediately southeast of Walla Walla, Washington, and Milton-Freewater in northeast Oregon was chosen for study because it is located at the intersection of the OWL and HFS and contains many important exposures.

Numerous faults in this area, both those mapped by earlier workers and those observed for the first time in this study, were examined to determine striae, associated minor structures, and displacements. To determine displacements, which occur entirely within horizontal flows of the CRBG, it was necessary to distinguish the numerous basalt flows. This was done by building a local stratigraphic framework through the sampling of a series of sections on opposite sides of major faults and correlating the flows by their petrologic and paleomagnetic character and chemical composition. To accomplish this, 347 samples of basalts were analyzed for 27 major and trace elements by XRF.

The main conclusions are (1) that there is significant, albeit still somewhat circumstantial, evidence that the structures acted as right-lateral (OWL zone) and left-lateral (HFS) fault zones prior to the eruption of the Columbia River basalts, (2) that there has been 300 m of exposed syn- and post-CRBG vertical displacement of flows on the Hite fault, (3) that virtually all of the fault zones studied are dominated by horizontal striae, and (4) that the OWL zone and HFS probably represent conjugate fault systems with real, but limited, post-CRBG strike-slip displacements.

Rock magnetic and paleomagnetic characteristics of the late Miocene Rattlesnake and Devine Canyon Ashflow Tuffs, eastern Oregon, by John Paul Stimac (Ph.D., University of Oregon, 1996), 183 p.

Thirty-seven sites from the Rattlesnake Ash-Flow Tuff (7.05 Ma) and twenty-one sites from the Devine Canyon Ash-Flow Tuff (9.7 Ma) of eastern Oregon were analyzed to study the application of rock magnetic and paleomagnetic techniques for emplacement and deformation studies in ash-flow tuffs (AFT). Rock magnetic analysis of the tuffs reveals that the main carrier of magnetic remanence in both units is fine-grained (~10 µm), pseudo-single domain titanomagnetite. Although both alternating field (AF) and thermal (TT) demagentization reveal primary and secondary remanences, a comparison of the AF and TT techniques shows that TT demagnetization removes all overprints, whereas AF demagnetization does not; thus thermal demagnetization results in smaller site uncertainties. Emplacement temperatures for both tuffs are in excess of the Curie temperature of magnetite (~575°C), since ripup clasts of basalt and pumice clasts have had their directions reset to that of the encompassing tuff.

Vertical and horizontal traverses show that paleomagnetic variations are similar to site uncertainties for the tuff. These data indicate that natural variations within a tuff are such that sampling from any appropriate microfacies within a well-oriented structural block will produce reliable paleomagnetic results. Structural corrections based on eutaxitic foliation, defined by the fiamme, increased dispersion of the entire data set and therefore are not reliable indicators of paleohorizontal; underlying sedimentary units or a trend surface fit of the outcrop base are more reliable indicators of paleohorizontal, and these corrections greatly reduce dispersion.

The Devine Canyon AFT records systematic vertical axis rotations that average 5°, relative to the mean, and become more clockwise to the northeast. The younger Rattlesnake AFT shows no systematic rotation (average <1°). Both contain a few small blocks that record larger variable rotations or errors.

Anisotropy of magnetic susceptibility (AMS) measurements show an approximately radial outflow pattern from the postulated source caldera near Lake on the Trail in the U.S. Geological Survey 7.5-minute quadrangle by the same name. The AMS vectors due to individual sites show deviations from radial that are interpreted to be from paleotopography. The most striking paleotopographic feature is the John Day Valley. ☐

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