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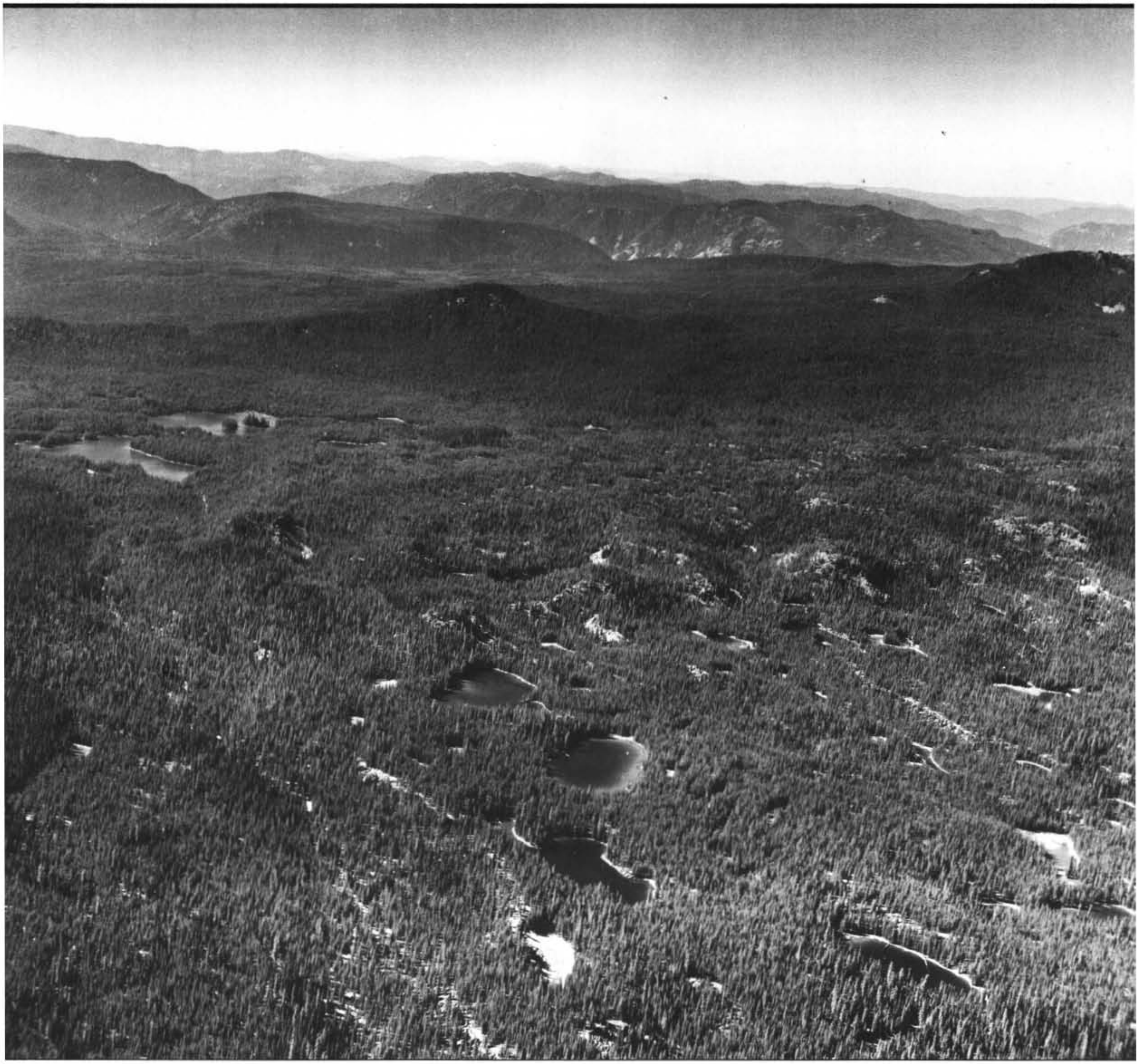

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Information for contributors

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

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

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, letters, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office (address above).

Cover photo contest

What do you see? Where is it? —How well do you know Oregon?—Send your answer by mail or FAX to editor Klaus Neuendorf (address above) before the next issue is released. If you are correct, your name will be entered in a drawing for a one-year free subscription to *Oregon Geology*, applicable to your current subscription. If you are a subscriber and use your win as a gift to a new subscriber, we'll double the winnings: a free subscription for two years.

The photo is one of the many masterful aerial photographs taken by the late Leonard Delano of Portland and (hint, hint) shows a view to the northwest. Copyright photo courtesy of Delano Horizons, Inc. □

Ian Madin honored by Metro

Ian Madin of the Oregon Department of Geology and Mineral Industries (DOGAMI) received one of seven Regional Hazard Mitigation Awards presented by Metro (the Portland area regional government) on June 17, 1994, at the Disaster Preparedness Conference held at the Monarch Hotel in Portland.

Madin received his award for the development of the Portland earthquake hazards map project that provides the key link between geologic earthquake information and practical mitigation opportunities. According to Metro, "Mr. Madin has been instrumental in interpreting the evolving scientific information concerning the earthquake threat in the metropolitan area to the needs of a general, nontechnical audience."

Other awards were given to (1) the City of Gresham, for construction of the emergency operations center (EOC), which can serve as a model for other jurisdictions; (2) Ms. Sherry Grandy, Emergency Manager for the City of Beaverton and Tualatin Valley Fire and Rescue, for her championing of coordination and cooperation among regional emergency managers; (3) Holliday Park Plaza in northeast Portland, for retrofitting the 15-story retirement community building for seismic protection; (4) Mr. Roger McGarrigle, volunteer Chair of the Oregon Seismic Safety Policy Advisory Commission, for advancing the cause of hazard mitigation in both his professional capacity as a structural engineer and in his many volunteer activities; (5) the Oregon Trail Chapter of the American Red Cross, for consistent excellence in its work on hazard mitigation training and neighborhood-organization programs, and in its booklet *Before Disaster Strikes*; and (6) U.S. Bancorp, for voluntarily upgrading its downtown Portland Plaza Building to Zone 4 earthquake standards, rather than the required Zone 3 standards, and for building a new data facility in Gresham to higher-than-required seismic safety standards. □

Culbertson to chair DOGAMI Board of Governors

The Governing Board of the Oregon Department of Geology and Mineral Industries has elected Board member Ronald K. Culbertson of Myrtle Creek as Chair for a term of one year beginning in July. He served as Chair once before, in 1991–1992, during his first term as a member of the Board.

Culbertson has been serving on the Board since 1988. His appointment as a Board member was renewed by Governor Roberts in 1992 and will extend until mid-1996. □

Subscription rates to increase October 1

Oregon Geology must raise its prices to stay alive in a world where almost nothing is cheap and certainly nothing is getting cheaper. In fact, as a subscriber to journals you may have gotten used to paying more every time you renew these days. We hope for your understanding and will do our best to continue offering what is of interest to you in Oregon's geology in the manner to which you have become accustomed.

We also want to give you a chance to renew at the old prices. Remember that your renewal will go into effect only after your current subscription expires—there is no overlap and no loss. So we are letting you know **now** that, **effective October 1, 1994**, the price for a single issue of *Oregon Geology* will be $3, the subscription price for six issues (one year) will be $10, and the subscription price for 18 issues (three years) will be $22.

The September issue of *Oregon Geology* will be the last one to show the current prices. Use the renewal form on the back cover **now** and let us have your renewal **by October 1** at the old price! □

Hydrothermal alteration in the SUNEDCO 58–28 geothermal drill hole near Breitenbush Hot Springs, Oregon

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

ABSTRACT

In 1981, a 2,457-m-deep geothermal exploration drill hole, designated SUNEDCO 58–28, was completed about 3 km southeast of Breitenbush Hot Springs near the High Cascade-Western Cascade boundary in northwestern Oregon. A non-equilibrium temperature of about 141°C was recorded at the bottom of the drill hole, but the actual bottom-hole temperature may be nearer 150°C. Cuttings from the drill hole consist mostly of tuffs and tuffaceous sedimentary rocks of the Oligocene and lower Miocene Breitenbush Tuff. Several lava flows and occasional intrusive intervals are interspersed within the volcaniclastic deposits. The late Tertiary volcanic and volcaniclastic drill cuttings contain at least 26 hydrothermal minerals. Of the seven zeolite minerals identified, laumontite and heulandite occur most frequently. Calcite was found throughout most of the drill hole, but siderite is rare. In the upper 2,000 m of the drill hole, smectite and celadonite are the predominant clay minerals with lesser amounts of sepiolite(?), mixed-layer chlorite-smectite, chlorite, and corrensite(?); below 2,000 m, illite and a serpentine-kaolinite mineral are the main clay minerals along with minor chlorite. Chalcedony and crystal fragments of quartz were found throughout the drill hole, whereas cristobalite was identified only in a single sample. Pyrite crystals and red iron-oxide staining occur in many of the examined samples, but chalcopyrite and magnetite were each found in a single drill-cutting specimen. Several samples contain traces of epidote, and a few specimens have colorless anhydrite crystal fragments. Garnet(?), which could not have formed under the present moderately low-temperature conditions, was tentatively identified in one specimen. Some of the pyrite, quartz and chalcedony and all of the epidote also appear to have formed in a previous geothermal system and were transported later to the site of the SUNEDCO 58–28 drill hole. Fluid inclusion studies suggest that the drill hole probably penetrated the same shallow aquifer that feeds the Breitenbush Hot Springs. A second aquifer with significantly higher salinity may occur near the bottom of the drill hole.

INTRODUCTION

The SUNEDCO 58–28 geothermal drill hole is located about 3 km southeast of Breitenbush Hot Springs (Figure 1) at an elevation of 899 m (Conrey and Sherrod, 1988), near the Western Cascade-High Cascade boundary in northwestern Oregon. Drilling of the 2,457-m-deep exploration hole by Sunoco Energy Development Company began on October 2, 1981, and was completed December 11, 1981 (A.F. Waibel, unpublished data, 1982). The maximum reported near-equilibrium temperature for the drill hole is 129.3°C at a depth of 1,715-m (Blackwell and others 1986; Blackwell and Baker, 1988). A Pruett Kuster Tool Survey non-equilibrium temperature of about 141°C was recorded at the drill-hole bottom (A.F. Waibel, unpublished data, 1982); however, Blackwell and Baker (1988) estimate that the actual bottom-hole temperature may have been 145°–150°C.

The upper ~100 m of the SUNEDCO 58–28 drill-hole cuttings consist of middle and upper Miocene basalt and basaltic andesite (Priest and others, 1987; Conrey and Sherrod, 1988). The remainder of the drill hole penetrated the volcanic and volcaniclastic deposits of the Breitenbush Tuff of Oligocene and early Miocene age (Priest and others, 1987; Sherrod and Conrey, 1988). In the SUNEDCO 58–28 drill hole, this formation consists predominantly of ash-flow tuffs (some welded), tuffaceous sedimentary rocks, and basaltic to andesitic lava flows. These units are intruded locally by minor basalt to diorite sills or dikes of the same age (Figure 2) (Priest and others, 1987; Conrey and Sherrod, 1988). Primary minerals (both phenocryst and groundmass) in most lava flows are plagioclase and magnetite crystals. Hornblende phenocrysts were observed in some of the lava flows, and A.F. Waibel (unpublished data, 1982) reports that accessory minerals in other flows consist of olivine or pyroxene crystals. The tuffs range from lithic- to crystal-rich; one crystal-rich tuff zone contains embayed subhedral to euhedral quartz crystals. Primary plagioclase was generally identified in these samples; magnetite occurs commonly, but other accessory mafic minerals either were not observed or were altered. One basaltic sill, included in the drill-cutting samples for this study, contains plagioclase, magnetite, and pyroxene (hypersthene?). Another dioritic intrusion contained primary plagioclase; no mafic minerals were identified, but reflections for chlorite in one X-ray diffraction (XRD) analysis suggest that they may be altered.

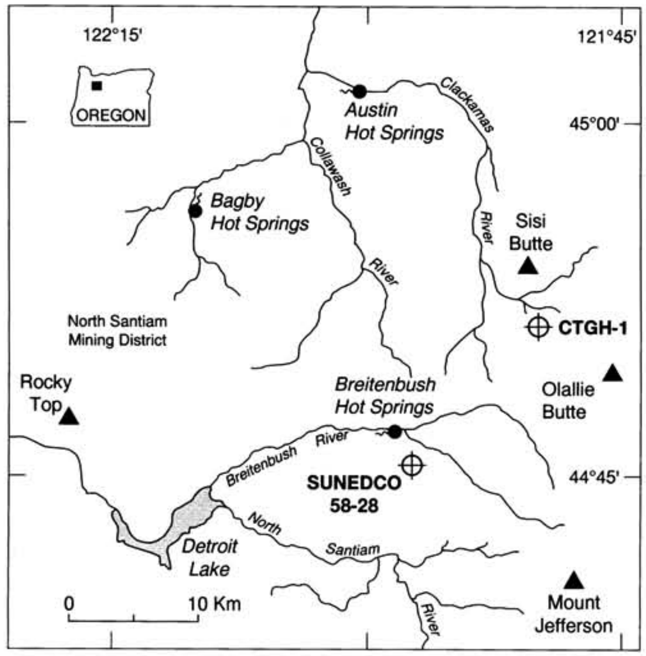


Figure 1. Map showing the location of geothermal drill hole SUNEDCO 58-28, as well as hot springs and the CTGH-1 geothermal exploration hole in the Breitenbush-Austin Hot Springs area of northern Oregon.

METHODS

The entire depth of the SUNEDCO 58–28 hole was rotary-drilled with drill-cutting samples collected for nearly all ~3-m intervals. Drill cuttings are useful in providing rock samples from deep within the earth that would not otherwise be available for examination; however, the samples frequently have been ground to a very small size (in many samples, the grains are <1 mm in diameter, although occasional samples contain fragments as large as ~1 cm), and details of crystal morphology, paragenesis, and lithological occurrence of the hydrothermal minerals often are obscured. Other problems that

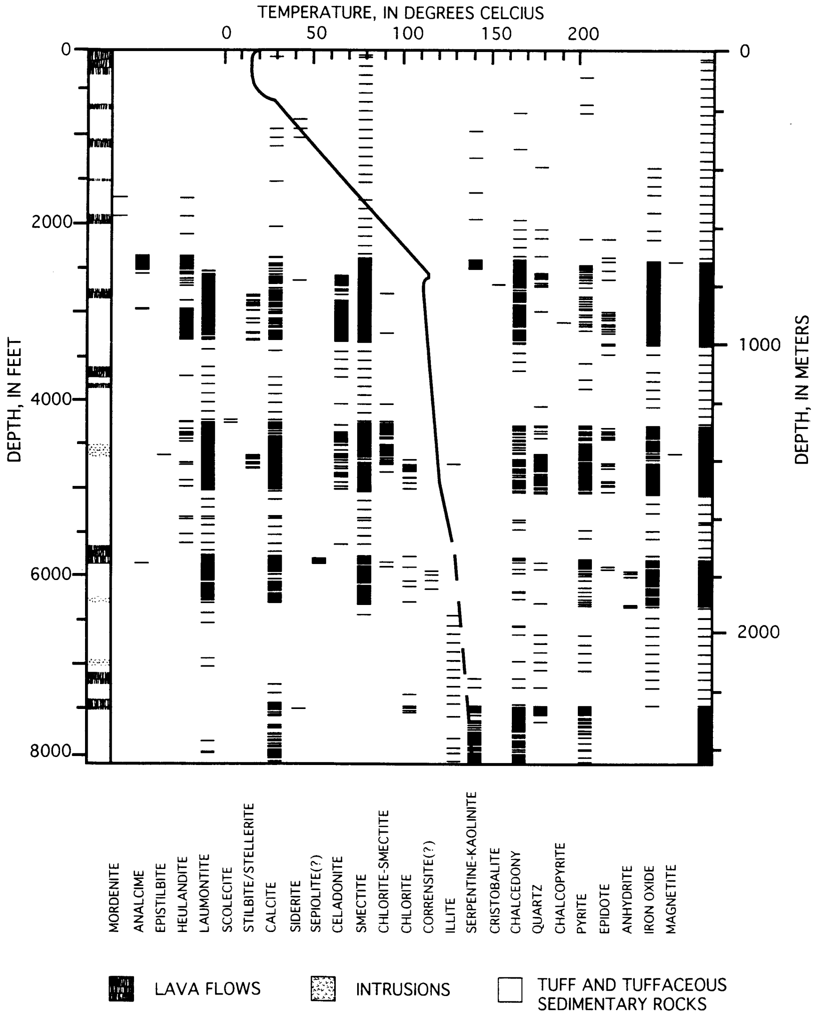


Figure 2. Distribution of hydrothermal minerals with depth in the SUNEDCO 58–28 drill hole. Left column shows a stratigraphic section of rock units penetrated by the drill hole (modified from Conrey and Sherrod, 1988). Right column shows the distribution of samples studied. Solid temperature curve is from Blackwell and others (1986); dashed part of the temperature curve connects the data from Blackwell and others with a bottom-temperature measurement of 141°C reported by A.F. Waibel (unpublished data, 1982).

hinder reliance upon drill cuttings for geologic information include contamination due to slumping of grains from higher in the well and mixing of drill chips from within each sample interval, so that precise delineation of lithologic boundaries is impossible.

Extensive lithologic descriptions of the drill-cutting samples and a comprehensive stratigraphic column for the drill hole were compiled by A.F. Waibel (unpublished data, 1982). Conrey and Sherrod (1988) published a generalized lithologic column for the SUNEDCO 58–28 hole based on the unpublished descriptions of A.F. Waibel. The stratigraphic column shown in Figure 2 is an abbreviated version of the Conrey and Sherrod (1988) compilation.

This study was undertaken primarily to obtain fluid inclusion homogenization temperature (T_h) data, using a Linkam[1] THM 600 heating/freezing stage and TMS 90 controller, from the lower half of the SUNEDCO 58–28 drill hole in order to determine how past temperatures compare with the present measured temperature profile shown in Figure 2. Some hydrothermal quartz was observed, but fluid-inclusion-bearing crystals were very sparse. Hydrothermal minerals most suitable for fluid-inclusion work were a few calcite and anhydrite crystal fragments. These broken crystals are very small, and the cleavage chips utilized in the study are either unpolished or polished only on one side. Only limited information on the salinity of the fluids trapped within the fluid inclusions was obtained from the unpolished samples. A few positive melting-point temperature measurements (T_m) (a clathrate or gas hydrate, which typically melts at positive temperatures, was not observed) for these low-salinity, low-temperature inclusions indicate that the fluids within some of them are metastable and do not provide reliable salinity estimates (Roedder, 1984). This was observed when the vapor bubble disappeared upon freezing and did not reappear by the time the last ice melted during warming of the fluid inclusion.

In order to locate appropriate minerals for fluid-inclusion study, it was necessary to examine many of the drill-cutting samples in great detail; accordingly, every ~3-m sample interval from four zones (Figure 2; extreme right column) was closely scrutinized and described. Throughout the remainder of the drill hole, cuttings from only ~30.5-m intervals were studied. Most mineral identifications were made by routine binocular and petrographic microscope methods. Using a Norelco X-ray unit and Cu-Kα radiation, 196 XRD analyses were obtained from selected samples that commonly contain clay or zeolite minerals. A few hydrothermal minerals were studied by a Cambridge Stereoscan 250 scanning electron microscope (SEM) equipped with an energy dispersive spectrometer (EDS) in order to discern mineral paragenesis and semiquantitative chemical compositions. Electron microprobe analyses of some of the zeolite minerals were obtained from a JEOL JXA-8800L electron probe microanalyzer using a 25-μm beam diameter and 7.5-nÅ beam current.

HYDROTHERMAL MINERALOGY

Hydrothermal minerals in the SUNEDCO 58–28 drill-hole samples were listed by A.F. Waibel (unpublished data, 1982), and brief, generalized descriptions of the hydrothermal alteration were given in Conrey and Sherrod (1988) and Keith (1988). In the present investigation, about 42 percent (335) of the drill-hole samples was examined, and only a few previously unidentified hydrothermal minerals were recognized, mostly from XRD analyses. In the drill cuttings studied, several hydrothermal zeolite minerals and clay minerals were identified; other hydrothermal minerals include calcite, siderite, cristobalite, chalcedony, quartz, chalcopyrite, pyrite, epidote, anhydrite, magnetite, and iron oxide (Figure 2).

In addition to showing previously formed crystals of primary minerals and fragments of volcanic rocks, many of the tuff samples contain small lithic grains composed of hydrothermal chalcedony (± epidote) or grains with tiny pyrite crystals. This chalcedony and pyrite is obviously from a fossil hydrothermal system, but it is included in Figure 2 because at least some of it undoubtedly formed from geothermal activity that postdates the lithic tuffs. The very small grain size of other drill cuttings precludes distinguishing between minerals from possible late Tertiary fossil hydrothermal systems and those from subsequent hydrothermal systems, including the present active one.

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

Zeolite minerals

Seven zeolite minerals (analcime, epistilbite, heulandite, laumontite, mordenite, scolecite, and stilbite/stellerite) have been identified in drill cuttings from the SUNEDCO 58–28 drill hole; laumontite and heulandite occur most frequently (Figure 2). Late Tertiary outcrops in the Breitenbush-Austin Hot Springs area contain many of these same hydrothermal zeolite minerals plus several additional zeolites. Formation temperatures for several hydrothermal zeolite minerals generally are thought to be about the same as the temperatures reported in studies of modern geothermal areas (summarized in Figure 2 of Keith, 1988). However, because of the Tertiary age of the rocks in the SUNEDCO 58–28 drill hole (Conrey and Sherrod, 1988), it is emphasized that favorable comparisons between measured temperatures at which zeolite minerals occur in this drill hole and the published formation temperatures is not unequivocal evidence that the minerals actually formed in the present thermal regime.

Analcime, $Na_{16}(Al_{16}Si_{32}O_{96}) \cdot 16H_2O$[2] — Analcime, in association with heulandite, laumontite, smectite(?), and halloysite, was identified in XRD analyses of several small greenish siliceous-appearing grains, light-gray lithic tuff fragments, and composite zeolite chips at 716–780 m. Analcime (plus laumontite, heulandite, and smectite) was found in two altered lithic tuff samples at 900 m. In addition, a single hornblende andesite sample from 1,787 m contains two isotropic, colorless crystal fragments with a refractive index of ~1.49 that probably are analcime; laumontite, calcite, chalcedony, pyrite, chlorite, and epidote(?) also are present in this sample.

Several outcrops of Oligocene and lower Miocene volcanic and volcaniclastic rocks in the Breitenbush-Austin Hot Springs area contain colorless, euhedral, trapezohedral analcime crystals lining vugs and fractures. An average electron microprobe analysis of one of these samples shows that the mineral is nearly a pure analcime containing essentially Na as the exchangeable cation (Table 1). Electron microprobe analyses of analcime from ~744-m depth in the SUNEDCO 58–28 drill hole also contain Na as the principal exchangeable cation. Some deviation from the stoichiometric formula given above is present in both outcrop and drill-hole analyses, but the balance errors for all analyses are within acceptable limits for zeolite minerals (Passaglia, 1970). These analyses indicate that the mineral is a nearly pure end member of the analcime-wairakite solid-solution series. Colorless, euhedral analcime crystals also line fractures and vesicles in drill core from geothermal drill hole CTGH–1, located about 14 km northeast of the SUNEDCO 58–28 drill hole (Figure 1); EDS semiquantitative chemical analyses of this analcime show that significant Ca is present in addition to Na, and the mineral is not a pure analcime end member (Bargar, 1990).

Analcime is a common mineral in geothermal areas, where, according to Kusakabe and others (1981), its formation appears to be favored by increasing the fluid pH and Na^+ concentration. In Iceland geothermal areas, analcime forms over a wide temperature range of about 70°C to near 300°C (Kristmannsdóttir and Tómasson, 1978). If analcime in the SUNEDCO 58–28 drill hole crystallized under present conditions, measured temperatures (~110°–130°C) indicate that the formation temperature was near the lower end of the Icelandic temperature range.

Epistilbite, $Ca_3(Al_6Si_{18}O_{48}) \cdot 16H_2O$ — An XRD analysis of white zeolite grains from the basaltic sill at 1,411 m contains reflections for epistilbite and quartz. Epistilbite is not a rare mineral, but it has not been frequently reported in the Oregon Cascade Range. Bargar and others (1993) identified epistilbite in a few geothermal test drill holes and one outcrop in Tertiary volcanic rocks of the Mount Hood area. Electron microprobe analyses of the Mount Hood epistilbite indicate that it is lower in Si and higher in Al and Ca than the stoichiometric formula. XRD analyses of samples from a few Tertiary outcrops in the Breitenbush-Austin Hot Springs area also contain reflections for epistilbite (Bargar, unpublished data).

Kristmansdóttir and Tómasson (1978) report that epistilbite in Iceland geothermal areas occurs at measured temperatures ranging from 80° to 170°C. The single occurrence of epistilbite in the SUNEDCO 58–28 drill hole was at a depth where the present-day temperature is near 120°C (Figure 2); thus it could be compatible with current thermal conditions.

Heulandite, $(Na,K)Ca_4(Al_9Si_{27}O_{72}) \cdot 24H_2O$ — Heulandite was identified by XRD from numerous samples throughout the middle portion of the drill hole (Figure 2). Many tuff grains contain heulandite that probably formed due to alteration of glass. Heulandite also occurs as open-space vesicle and microfracture fillings, where it frequently has a salmon to orange color. Other associated minerals identified in the XRD analyses are analcime, laumontite, smectite, mixed-layer chlorite-smectite, chlorite, celadonite, cristobalite, pyrite, chalcopyrite, and iron oxide. Only a few samples contained euhedral heulandite crystals as shown in Figure 3.

Electron microprobe analyses of one heulandite specimen from 939 m in the drill hole showed that it is Ca-rich heulandite (Table 1) rather than Na+K-rich clinoptilolite. This identification was confirmed by heating eight of the samples to 450°C for 24 h (Mumpton, 1960). After heating, the XRD 020 reflections for heulandite at ~9 Å disappeared. One sample appeared to have retained a very low XRD peak at ~8.6 Å, indicative of intermediate heulandite (Alietti, 1972). Both heulandite and intermediate heulandite have been identified from Tertiary outcrop samples in the Breitenbush-Austin Hot Springs area (Bargar, unpublished data). An average microprobe analysis for one late Tertiary heulandite specimen is given in Table 1; the analysis shows that the mineral consists almost entirely of Ca, Al, and Si, and is closer to the stoichiometric formula than are the analyses for heulandite from the SUNEDCO hole. Cation balance errors for all of the analyses fall within acceptable limits (Passaglia, 1970).

Figure 3. Scanning electron micrograph of randomly oriented, tabular to blocky, euhedral heulandite crystals from about 771 m.

[2]*Stoichiometric formulas after Gottardi and Galli (1985).*

Both heulandite and clinoptilolite were identified from vesicles, fractures, and between breccia fragments in late Tertiary basaltic drill-core samples from nearby geothermal well CTGH–1 (Bargar, 1988, 1990). The measured temperatures at the depths where heulandite in the SUNEDCO hole occurs range from 80°–130°C. These temperatures are within the range (<70° to ~170°C) for heulandite in Iceland geothermal areas (Kristmansdóttir and Tómasson, 1978). In contrast, clinoptilolite and heulandite occur at significantly lower temperatures (~30°–96°C) in the CTGH–1 drill hole (Bargar, 1990).

Laumontite, $Ca_4(Al_8Si_{16}O_{48}) \cdot 16H_2O$ — Soft, milky-white laumontite was seen in most samples studied between 768 m and 1,981 m in the SUNEDCO hole (Figure 2). Some samples from a depth below 2,000 m contain a few grains of laumontite that might have sloughed from higher in the drill hole. Laumontite is readily dehydrated to form the mineral leonhardite, which is designated as "only a variety" of laumontite (Gottardi and Galli, 1985). While leonhardite may occur in the drill-cutting samples from this drill hole, no attempt was made to distinguish between the two minerals, and only the name "laumontite" is used in this report. The presence of laumontite in whole-rock XRD analyses of several tuff samples suggests that some occurrences may have formed due to alteration of glass fragments or matrix. However, most laumontite occurs as euhedral crystals that formed in open spaces of fractures and vugs and between lithic fragments (Figure 4). Other hydrothermal minerals identified in association with laumontite in the drill hole samples are analcime, heulandite, calcite, siderite, quartz, pyrite,

Figure 4. Scanning electron micrograph of fractured to broken laumontite (L) crystals in association with earlier, euhedral quartz (Q) crystals from about 1,454 m. See also Figure 8.

Table 1. *Electron microprobe analyses of zeolite minerals from the SUNEDCO 58–28 drill hole and outcrops in the Breitenbush-Austin Hot Springs area. Reported outcrop analyses are averages of 5 analyses. — = not analyzed. Bal. error is determined by method of Passaglia (1970). (Continued on next page)*

Mineral	Analcime				Heulandite						Laumontite	
Sample no.	SUNEDCO 58–28 2440			80 COL-2040A	SUNEDCO58–28 3080					80 OGF-2076F	SUNEDCO 58–28 4230	
Analysis no.	1	2	3	1	1	2	3	4	5	1	1	2
	Weight percent oxides											
SiO_2	59.44	59.33	59.74	56.99	65.04	65.60	66.42	67.87	67.15	63.93	51.77	51.71
Al_2O_3	22.24	22.01	21.79	22.13	14.41	14.56	15.52	14.49	14.57	16.77	21.40	20.39
Fe_2O_3	0.10	0.02	0.07	0.01	0.11	0.07	0.00	0.14	0.03	0.00	0.00	0.00
MgO	0.00	0.03	0.00	0.01	0.02	0.03	0.02	0.02	0.02	0.00	0.00	0.03
MnO	0.03	0.02	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.01
CaO	0.17	0.15	0.13	0.00	6.81	6.83	7.35	6.89	7.19	8.77	11.79	10.98
SrO	0.11	0.15	0.12	—	0.28	0.24	0.33	0.21	0.27	—	0.19	0.23
BaO	0.07	0.01	0.00	—	0.25	0.15	0.18	0.15	0.19	—	0.00	0.01
Na_2O	14.32	13.59	13.99	13.24	0.52	0.41	0.55	0.55	0.55	0.08	0.02	0.14
K_2O	0.02	0.03	0.02	0.01	0.33	0.23	0.27	0.21	0.25	0.32	0.05	0.14
Total	96.50	95.34	95.87	92.39	87.78	88.13	90.64	90.53	90.22	89.87	85.23	83.64
	Number of atoms on the basis of											
	96 oxygens				72 oxygens						48 oxygens	
Si	33.09	33.29	33.37	32.96	28.56	28.60	28.27	28.78	28.65	27.53	16.12	16.37
Al	14.59	14.56	14.35	15.09	7.45	7.48	7.79	7.24	7.33	8.51	7.85	7.61
Fe	0.04	0.01	0.03	0.00	0.04	0.02	0.00	0.05	0.01	0.00	0.00	0.00
Mg	0.00	0.03	0.00	0.00	0.01	0.02	0.01	0.01	0.01	0.00	0.00	0.01
Mn	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca	0.10	0.09	0.08	0.00	3.20	3.19	3.35	3.13	3.29	4.04	3.93	3.72
Sr	0.00	0.05	0.04	—	0.07	0.06	0.08	0.05	0.07	0.00	0.03	0.04
Ba	0.02	0.00	0.00	—	0.04	0.03	0.03	0.03	0.03	0.00	0.00	0.00
Na	15.46	14.78	15.15	14.85	0.44	0.35	0.45	0.45	0.46	0.07	0.01	0.09
K	0.01	0.02	0.01	0.01	0.19	0.13	0.15	0.11	0.14	0.18	0.02	0.06
Si+Al	47.68	47.85	47.72	48.05	36.01	36.09	36.06	36.03	35.98	36.04	23.97	23.97
$Si/Al+Fe^{3+}$	2.26	2.28	2.32	2.18	3.81	3.81	3.10	3.95	3.90	3.23	2.05	2.13
$Si/Si+Al+Fe^{3+}$	—	—	—	—	—	—	—	—	—	—	—	—
Bal. error	-6.99	-4.02	-6.62	1.54	2.67	6.06	3.63	4.00	-0.70	4.51	-1.49	-1.32

chalcopyrite, hematite, smectite, celadonite, and mixed-layer chlorite-smectite. SEM studies indicate that laumontite formed later than quartz, mixed-layer chlorite-smectite, and siderite and was deposited earlier than smectite and heulandite.

Laumontite is a very common hydrothermal mineral and has been found over a wide temperature range (43°–230°C) (Kristmannsdóttir and Tómasson, 1978; McCulloh and others, 1981) in many geothermal areas. The present-day temperature range at which laumontite was identified in the SUNEDCO hole is very narrow (110°–130°C).

Electron microprobe analyses of laumontite from about 1,289 m in the SUNEDCO hole showed that the mineral contains only small amounts of elements other than Ca, Al, and Si (Table 1). During related field studies of the Breitenbush-Austin Hot Springs area, laumontite was collected from several late Tertiary outcrops. Electron microprobe analyses of laumontite from two of the widely separated outcrops in this area (Table 1) are very similar to the SUNEDCO 58–28 analyses. Both drill-hole and outcrop analyses of laumontite do not quite match the stoichiometric formula given above; however, cation balance errors for all of the analyses are within acceptable limits (Passaglia, 1970).

Mordenite, $Na_3KCa_2(Al_8Si_{40}O_{96}) \cdot 28H_2O$ — XRD analyses of a few milky-white siliceous fragments from depths of 518 m and 579 m contain reflections for mordenite. These two samples are the only ones in which mordenite was identified; however, mordenite occurs in several late Tertiary outcrops in the Breitenbush-Austin Hot Springs area and is common in drill core from the lower part of the nearby drill hole CTGH–1 (Bargar, 1988, 1990). In these occurrences, mordenite is a late hydrothermal mineral deposited in open spaces of fractures and vugs together with heulandite and chalcedony.

In SUNEDCO 58–28, mordenite was found where the measured temperature is ~80°C. In Icelandic geothermal areas, mordenite is found over a temperature range of 80°–230°C (Kristmansdóttir and Tómasson, 1978); however, in drill hole CTGH–1, mordenite was identified at depths where present-day temperatures are 60°–96°C.

Scolecite, $Ca_8(Al_{16}Si_{24}O_{80}) \cdot 24H_2O$ — Two samples at 1,280 m and 1,289 m contain a few grains of hard, white, fibrous scolecite; laumontite and smectite occur in the same samples. Scolecite also has been found in a few late Tertiary outcrops in the Breitenbush-Austin Hot Springs area. The mineral is identified as scolecite (Ca-rich) because it exhibits inclined optical extinction; structurally similar mesolite (Na+Ca) and natrolite (Na-rich) both have parallel extinction. Electron microprobe analyses of scolecite from the Mount Hood area (Bargar and others, 1993) are consistent with the stoichiometric formula given above.

Ca-rich scolecite was reported from drill hole CTGH–1 (temperature is ~30°–40°C) (Bargar, 1990); however, subsequent electron microprobe analyses (Bargar, unpublished data) show that the mineral contains significant Na and is mesolite. The measured temperature at the depth where scolecite was found in the SUNEDCO hole is about 120°C. From their studies of Icelandic geothermal areas, Kristmannsdóttir and Tómasson (1978) reported scolecite (and mesolite) only from drill holes in low-temperature areas at <70°–100°C.

Stilbite / Stellerite,
$NaCa_4(Al_9Si_{27}O_{72}) \cdot 30H_2O$ / $Ca_4(Al_8Si_{28}O_{72}) \cdot 28H_2O$ — Crystal fragments of a colorless (sometimes white or orange iron-oxide stained), tabular to lamellar, soft zeolite mineral were observed

Table 1. *Electron microprobe analyses of zeolite minerals–(continued from previous page)*

Mineral	Laumontite					Stilbite/Stellerite						
Sample no.	SUNEDCO 58–28 4230			80COL-2033E	81 BP-2102C	SUNEDCO 58–28 3300					80 COL-3031I	81 FC-2052E
Analysis no.	3	4	5	1	1	1	2	3	4	5	1	1
	Weight percent oxides											
SiO_2	52.18	53.11	53.09	52.42	53.62	64.61	62.79	62.05	61.78	64.02	56.44	59.12
Al_2O_3	20.63	21.21	21.75	21.70	22.17	16.12	16.64	15.74	16.23	16.25	15.04	18.01
Fe_2O_3	0.00	0.00	0.02	0.03	0.00	0.05	0.04	0.00	0.04	0.00	0.00	0.00
MgO	0.00	0.01	0.00	0.02	0.00	0.02	0.01	0.01	0.02	0.02	0.01	0.01
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.01
CaO	11.07	11.45	11.82	10.93	11.38	7.71	7.76	7.67	7.75	7.89	7.64	8.36
SrO	0.12	0.10	0.26	—	—	0.40	0.45	0.49	0.56	0.40	—	—
BaO	0.07	0.10	0.01	—	—	0.37	0.61	0.45	0.59	0.35	—	—
Na_2O	0.19	0.17	0.13	0.18	0.31	0.49	0.43	0.40	0.40	0.45	0.56	1.02
K_2O	0.13	0.12	0.09	0.52	0.13	0.23	0.32	0.24	0.28	0.24	0.05	0.01
Total	84.39	86.27	87.17	85.80	87.61	90.00	89.06	87.06	87.66	89.62	79.74	86.54
	Number of atoms on the basis of											
	48 oxygens					72 oxygens						
Si	16.36	16.31	16.16	16.18	16.19	27.85	27.48	27.72	27.40	27.73	27.41	26.60
Al	7.63	7.68	7.81	7.90	7.89	8.19	8.58	8.29	8.49	8.30	8.61	9.55
Fe	0.00	0.00	0.01	0.01	0.00	0.02	0.01	0.00	0.01	0.00	0.00	0.00
Mg	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.26	0.01	0.01	0.01
Mn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca	3.72	3.77	3.86	3.62	3.68	3.56	3.64	3.67	3.68	3.66	3.98	4.03
Sr	0.02	0.01	0.05	—	—	0.10	0.11	0.13	0.14	0.10	—	—
Ba	0.01	0.02	0.00	—	—	0.06	0.11	0.08	0.10	0.06	—	—
Na	0.12	0.10	0.08	0.11	0.18	0.41	0.37	0.35	0.34	0.38	0.53	0.89
K	0.05	0.05	0.04	0.20	0.05	0.06	0.18	0.14	0.16	0.13	0.03	0.01
Si+Al	23.99	23.98	23.97	24.08	24.07	36.03	36.07	36.01	35.89	36.03	36.02	36.15
$Si/Al+Fe^{3+}$	2.15	2.12	2.07	2.05	2.05	3.39	3.20	3.34	3.22	3.34	3.18	2.79
$Si/Si+Al+Fe^{3+}$	—	—	—	—	—	0.77	0.76	0.77	0.76	0.77	0.76	0.73
Bal. error	-0.57	-0.95	0.05	4.34	3.87	3.31	3.80	0.35	-4.50	1.44	0.97	6.46

in two zones: 844–1,009 m and 1,405–1,454 m (Figure 2). XRD analyses indicate that the mineral is either stilbite or structurally similar stellerite between which a complete solid-solution series exists (Passaglia and others, 1978). A few specimens are associated with hydrothermal quartz, laumontite, or dark-green clay (both smectite and mixed-layer chlorite-smectite). Occasional cuttings show thin veins filled with late, colorless, tabular, broken stilbite/stellerite crystals oriented perpendicular to earlier dark-green clay-lined margins.

Electron microprobe analyses of several stilbite/stellerite crystals from about 1,006 m are given in Table 1 along with stilbite/stellerite from late Tertiary outcrops in the Breitenbush-Austin Hot Springs area. The analyses listed in Table 1 show that Ca is the dominant cation, suggestive of stellerite rather than stilbite, but these two very similar minerals are distinguishable with confidence only by single-crystal XRD analysis (R.C. Erd, written communication, 1992), which was not attempted for any of these stilbite/stellerite specimens.

Stilbite/stellerite occurs in the SUNEDCO hole at present-day temperatures of about 110°C to 120°C. In Iceland, stilbite is found at 70°–170°C (Kristmannsdóttir and Tómasson, 1978).

Carbonate minerals

Calcite — Samples throughout the SUNEDCO hole contain soft, white, cloudy, or colorless calcite (Figure 2). It usually occurs as monomineralic crystal fragments; complete crystals or crystal clusters (Figure 5) are uncommon. Calcite is seldom associated with other hydrothermal minerals, only rarely with laumontite. Calcite commonly fills fractures, vesicles, and cavities between tuff breccia fragments in the Oligocene and lower Miocene rocks of the Breitenbush-Austin Hot Springs area, and presumably its occurrence is similar in the SUNEDCO hole. In contrast, drill hole CTGH–1 contains only traces of calcite, mainly in early Pliocene lava flows (Bargar, 1988, 1990).

Liquid-rich secondary(?) fluid inclusions (Figure 6) were observed in several colorless to cloudy calcite crystal fragments. These fragments were too small and fragile to polish, although it was possible to obtain some fluid inclusion data. No melting-point temperatures (T_m) were obtained because, when the fluid inclusions were frozen, the tiny vapor bubbles disappeared and reappeared at temperatures as high as +3.9°C, indicating that the fluid inclusions were metastable and did not yield reliable salinity data (Roedder, 1984). However, 42 fluid inclusions in calcite from four sample depths yielded homogenization temperatures (T_h) ranging from 114° to 173°C (Table 2). Comparison of the fluid-inclusion T_h values with the measured temperatures in the SUNEDCO hole (Blackwell and others, 1986) in Figure 7 shows that (1) maximum fluid-inclusion T_h values record past temperatures that were at least as high as 152°C (one measurement is 173°C) and (2) minimum T_h measurements plot very close to the present-day temperatures at several depths within the drill hole. Close correspondence between minimum fluid-inclusion T_h values and present measured temperatures within other geothermal drill holes led Taguchi and others (1984) to conclude that minimum fluid-inclusion T_h can be used to estimate present-day temperatures within drill holes. Thus, fluid inclusions in calcite from this drill hole indicate that at least some of the trapped fluids are related to the present geothermal system. It may also be concluded that the geothermal system has cooled by about 35°C.

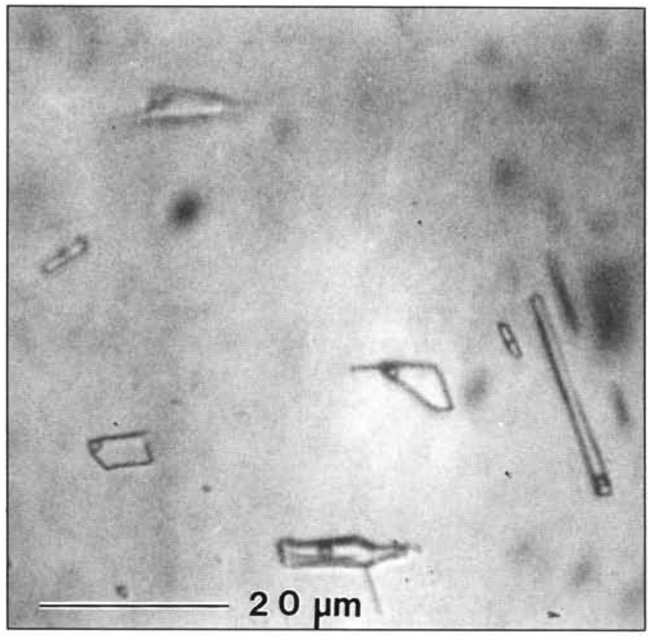


Figure 6. Photomicrograph of liquid-rich, secondary fluid inclusions in an unpolished calcite cleavage chip from about 1,470 m.

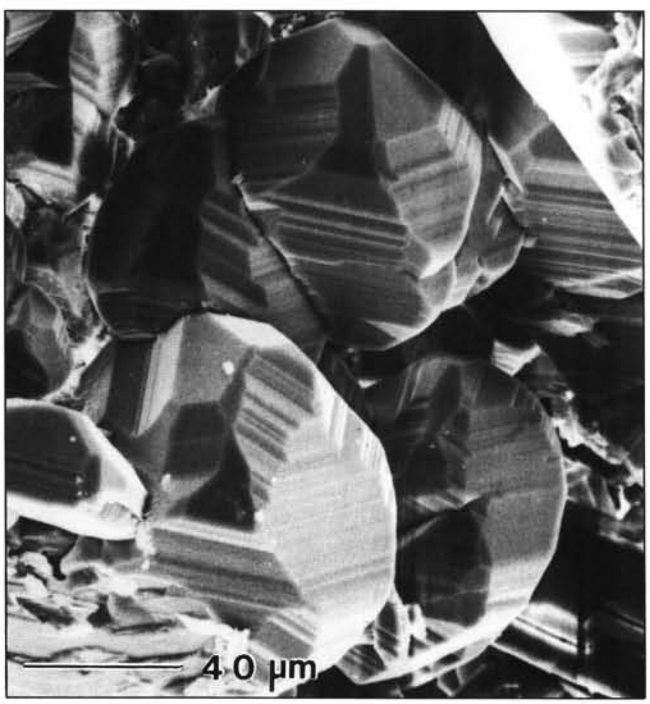


Figure 5. Scanning electron micrograph of twinned(?) calcite crystals from about 1,787 m.

Siderite — Orange siderite was identified in five samples from 244 to 305 m, 796 m, and 2,280 m. SEM analysis of an open-space (fracture?) filling at 796 m (Figure 8) shows that colloform clusters of rhombic siderite crystals formed earlier than laumontite and smectite; an EDS analysis of this deposit detected the presence of Fe, Ca, and Mn. Siderite has not been found in outcrops examined in this area, but it occurs in a few drill-hole and outcrop samples in the Mount Hood area (Bargar and others, 1993) and in several geothermal core holes at Newberry volcano (Bargar and Keith, unpublished data). In U.S. Geological Survey (USGS) drill hole Newberry 2, siderite is found at temperatures ranging from 60° to 130°C (Keith and Bargar, 1988). Siderite occurs at present-day temperatures of 40°–140°C in the SUNEDCO hole.

Clay minerals

Ten clay minerals were identified in the SUNEDCO samples. The distribution of clay minerals shown in Figure 2 is based on XRD analyses of 124 clay-bearing specimens.

Table 2. *Fluid inclusion heating and freezing data for SUNEDCO 58–28 drill-hole specimens*

Sample depth (m)	Host mineral	Number of melting-point temperature measurements	Melting-point temperature T_m (°C)*	Salinity (wt. % NaCl equivalent)	Number of homogenization temperature measurements	Range of homogenization temperatures T_h (°C)*	Median homogenization temperature T_h (°C)
398	Quartz	10	0.0	0.0	**11**	232–274	**258**
882	Calcite	0	—	—	**6**	128–152	**147**
931	Calcite	0	—	—	**4**	118–123	**120**
1360	Calcite	1	-0.1	0.2	**13**	114–145	**127**
1470	Calcite	12	+2.2, +3.9	**	**19**	116–173	**127**
1794	Anhydrite	0	—	—	**12**	125–191	**130**
1910	Anhydrite	5	0.0, -0.5, +1.5	**	**13**	123–133	**128**
2347	Primary quartz	5	-1.6, -1.7, -2.0	2.7–3.4***	**24**	138–209	**167**
2408	Primary quartz	4	-2.4	4.0***	**11**	202–216	**210**

* Multiple calibration measurements, using synthetic fluid inclusions (Bodnar and Sterner, 1984) and chemical compounds with known melting-point temperatures recommended by Roedder (1984), suggest that the T_h measurements should be accurate to better than ±2.0°C and that the T_m values should be accurate to within ±0.2°C.

** Positive T_m values indicate metastability, and the fluid inclusions cannot be used for salinity calculations (Roedder, 1984).

*** Salinity values are not corrected for CO_2.

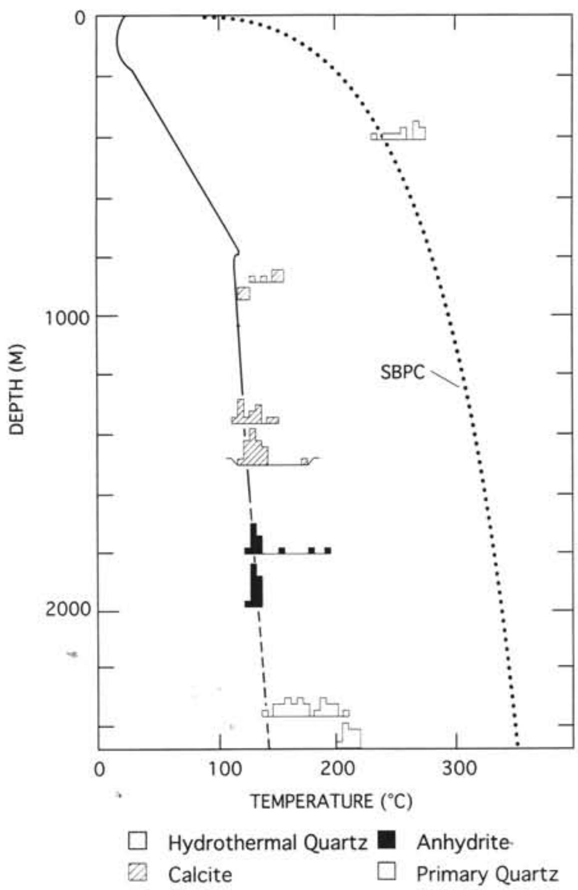


Figure 7. Depth versus homogenization temperatures for fluid inclusions in hydrothermal quartz, calcite, and anhydrite crystals, and primary quartz phenocrysts from drill hole SUNEDCO 58–28. Dotted curve labeled SBPC is a theoretical reference boiling point curve for pure water drawn to the ground surface. Solid curve shows a measured-temperature profile using data in Blackwell and others (1986); the continuing dashed line is an estimate of temperatures in the lower part of the drill hole based on a bottom-hole temperature of ~141°C given by A.F. Waibel (unpublished data, 1982). Individual T_h measurements, shown by different patterned boxes keyed to type of mineral analyzed, are plotted at 5°C intervals as histograms with sample depth as a baseline.

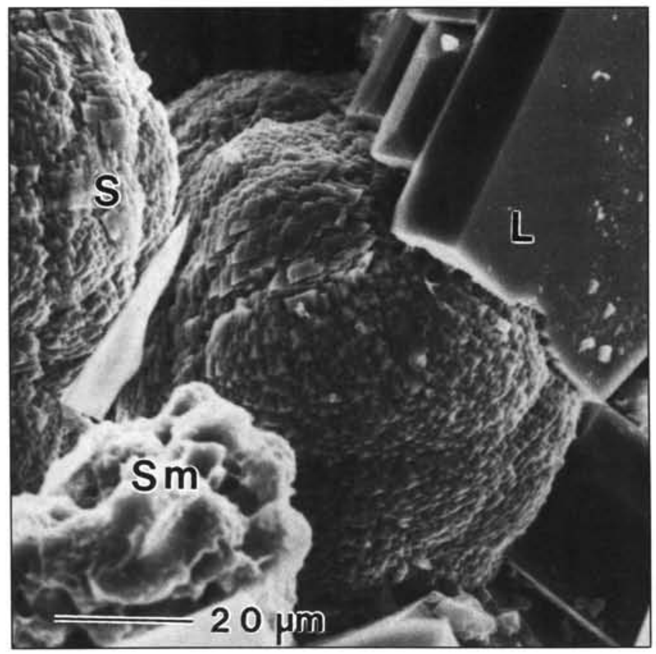
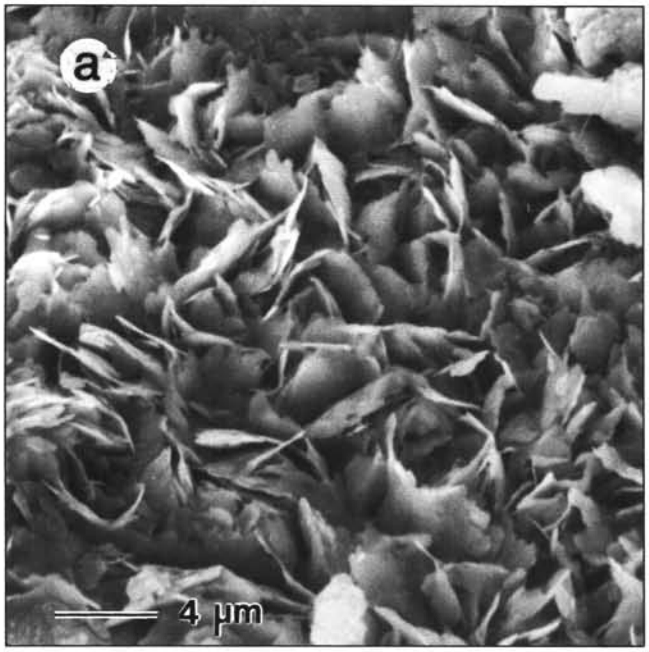
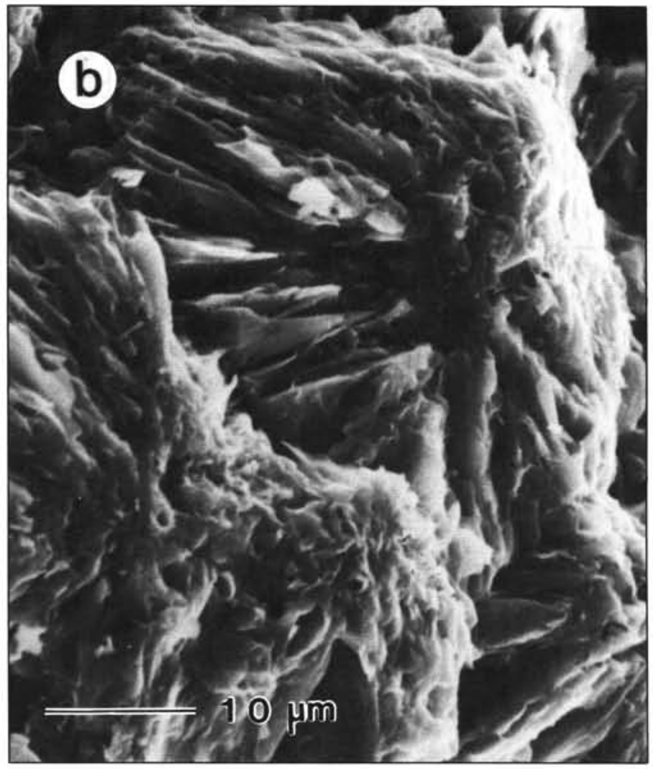
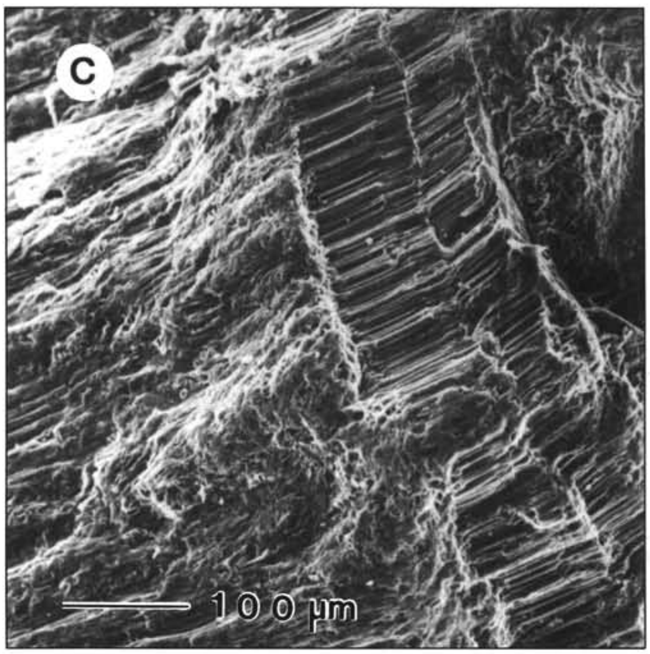


Figure 8. Scanning electron micrograph showing spherical clusters of rhombic siderite (S) crystals along with later euhedral laumontite (L) prismatic crystals and smectite (Sm) from about 796 m.

Sepiolite(?) — In a hornblende andesite lava flow at 1,762–1,780 m, a few soft, white, rounded chips of a clayey mineral that has a fibrous habit in SEM are present. The chips show a single XRD reflection at about 12.6 Å that remains unchanged following glycolation; however, no reflections are present after heating at 400°C for 1 h. These analyses suggest that the mineral is sepiolite (Starkey and others, 1984). Caramel-colored clay, also tentatively identified as sepiolite, occurs in cuttings from one geothermal drill hole in the Mount Hood area (Bargar and others, 1993). Hydrothermal sepiolite has been reported elsewhere in veins of mafic igneous rock, where it occurs as an alteration product of magnesium carbonates or silicates (Phillips and Griffen, 1981). Sepiolite formation by alteration of either of these two mineral groups would not appear compatible with conditions within either the Mount Hood or the SUNEDCO drill holes. Several of the Mount Hood drill holes contain abundant foreign materials, including drilling mud, added to facilitate drilling. Sepiolite is commonly used in drilling fluids for geothermal drill holes because







Left and above:

Figure 9. Scanning electron micrographs showing iron-rich platy smectite crystals that formed (a) in random orientation (~716 m), (b) as radiating clusters of crystals (~1,411 m), or (c) as fracture or vein fillings oriented perpendicular to the fracture surface (~1,411 m).

it does not flocculate at high temperatures (Greene and Goodman, 1982). Although the SUNEDCO cuttings studied were thoroughly washed, and foreign material was only occasionally observed, it seems likely that the sepiolite was introduced during drilling.

Celadonite — In field studies of hydrothermal alteration in the Breitenbush-Austin Hot Springs area, only one celadonite-bearing specimen was found in outcrops of late Tertiary rocks. However, chips of blue-green altered lithic tuff or clay were observed throughout much of the middle portion of the SUNEDCO hole at depths of 777–1,521 m. Celadonite, identified by XRD along with associated heulandite, smectite, laumontite, and mixed-layer chlorite-smectite, occurs at depths where present-day temperatures are 110°–130°C. In the lower part of the CTGH–1 drill hole, blue-green, clayey celadonite and tiny micaceous books of celadonite were found at measured temperatures of 65°–96°C (Bargar, 1988, 1990).

Smectite — Most samples above about 1,920 m contain varicolored (predominantly reddish and greenish) smectite that formed by precipitation from hydrothermal solutions in open spaces of fractures and cavities during alteration of glass or mafic minerals in lithic-crystal tuffs. Smectite shows a major XRD reflection at ~15 Å that shifts to ~17 Å following exposure to ethylene glycol vapors at 60°C for 1 h; heating to 550°C for 0.5 h results in collapse to ~10 Å. Many of these clays are poorly crystalline, which results in low, broad, asymmetrical XRD reflections. Associated hydrothermal minerals are pyrite, halloysite, chalcedony, kaolinite, heulandite, hematite, cristobalite, celadonite, laumontite, scolecite, calcite, and chlorite. The green color of many of the clays in this drill hole suggests that iron-rich nontronite probably is the prevalent smectite-group mineral; this is confirmed by semiquantitative EDS analyses indicating that Fe is the dominant cation present. The smectite commonly occurs as randomly oriented platy crystals (Figure 9a). However, it occasionally forms platy rosettes (Figure 9b) or vein fillings with plates oriented perpendicular to the vein margins (Figure 9c).

Mixed-layer chlorite-smectite — Mixed-layer chlorite-smectite was identified from the middle part of the SUNEDCO hole at 1,280–1,457 m. These medium- to dark-green clays have a strong (001) XRD reflection at ~14.5 Å and a weaker (002) peak at ~7.2 Å, which, following exposure to ethylene glycol vapors at 60°C for 1 h, show slight expansion to ~15.0 Å and ~7.3 Å, respectively. According to the identification guidelines for mixed-layer clay minerals (Hower, 1981), mixed-layer chlorite-smectite appears to be randomly interstratified and consists of ~80 percent chlorite. An

SEM study of one mixed-layer chlorite-smectite specimen from about 1,426 m shows random orientation of the platy crystals and the presence of Si, Al, Fe, Ca, Mg, Ti, and Mn in EDS. Several of the mixed-layer chlorite-smectite drill chips are shiny or striated and appear to have originated in fractures. The mineral sometimes is associated with later laumontite, heulandite, or stilbite/stellerite. Other associated hydrothermal minerals identified in the XRD analyses are calcite, quartz, and celadonite.

This mixed-layer chlorite-smectite in the SUNEDCO hole occurs where measured temperatures are 110°–130°C. Similar mixed-layer chlorite-smectite was found near the bottoms of several geothermal drill holes at Newberry volcano at temperatures of 110°–265°C (Keith and Bargar, 1988).

Chlorite — A few specimens from three zones in the drill hole, 1,417–1,472 m, 1,753–1,911 m, and 2,225–2,286 m (Figure 2), show broad, weak (001) XRD reflections at about 14.4 Å and slightly stronger (002) reflections at about 7.1 Å. For most specimens, the location of these reflections did not appear to change position significantly following glycolation, and the mineral is identified as chlorite. However, some slight apparent shifts in the (001) peaks noted for a few specimens suggest that a small smectite component is also present. The only other associated hydrothermal minerals identified by XRD analysis are laumontite, calcite, illite, and heulandite. Chlorite occurs over a wide range of temperatures in modern geothermal areas (Hulen and Nielson, 1986). In the SUNEDCO hole, the chlorite occurs at temperatures of 120°–140°C. In USGS Newberry 2 drill hole, the main chlorite zone occurs at temperatures between 120° and 265°C (Keith and Bargar, 1988).

Corrensite(?) — Five reddish lithic tuff samples from 1,800 to 1,950 m have a higher order reflection at about 25.3 Å and a subordinate reflection near 12.2 Å, which, after treatment with ethylene glycol vapors at 60°C for 1 h, shift to about 28.5 Å and 13.5 Å, respectively. Determination of the exact locations of these reflections is difficult because the peaks are mostly low, broad, and asymmetrical. Reflections for smectite and hematite are also present in some of the XRD analyses. For one of the samples containing smectite, heating to 400°C for 0.5 h resulted in destruction of all the reflections except for the ~10–Å smectite peak. Although these XRD data do not correspond to minerals with higher order reflections such as corrensite (a regular interstratification of chlorite and vermiculite), todusite, or rectorite (Starkey and others, 1984), somewhat similar XRD data, with glycolated reflections in the range of about 27 Å to 31 Å, were interpreted as an interstratification of corrensite and smectite by Inoue and others (1984). Tomita and others (1969) also report an interstratified mineral (chlorite-montmorillonite with another mixed-layer mineral?) having reflections at 26.8 Å and 12.6 Å that expand to 28.5 Å and 13.4 Å with ethylene glycol treatment; after heating at 500°C for 1 h only a 10-Å reflection remained. The mineral referred to in this report as corrensite(?) may be a complex interstratification of corrensite and smectite or possibly a mixture of other interstratified clay minerals.

Illite — Illite was identified by XRD analysis in samples from 1,426 m and in light-green clay chips and greenish clay-altered tuff fragments below 1,950 m. The majority of illite ~10.2-Å reflections are low, broad, asymmetrical peaks that shift to 10.0 Å following glycolation. Reflections slightly greater than 10 Å may indicate the presence of a very small amount of interlayered smectite, but no indication of smectite was observed on diffractograms of glycolated samples, and the mineral is referred to here as illite. Other hydrothermal minerals in the same XRD analyses are hematite, corrensite(?), chlorite, calcite, and a serpentine-kaolinite group mineral. Illite in the SUNEDCO hole occurs at temperatures of 120°–140°C. Hulen and Nielson (1986) indicate that illite in modern geothermal areas occurs at temperatures as low as about 120°C and as high as 330°C.

Serpentine-kaolinite group minerals — Scattered samples from the upper part of the drill hole, at depths of 274–747 m (Figure 2) contain clay-altered tuff fragments or chips of red, gray, or green clay that have XRD reflections for halloysite and kaolinite. Most of these specimens have low, broad, asymmetrical (001) reflections at ~7.2 Å, characteristic of halloysite (Brindley, 1980). However, a few specimens are less disordered and have (002) reflections near 3.57 Å in addition to the (001) reflections that are much sharper; the mineral probably is kaolinite. The XRD patterns show no change with glycolation, but the reflections are destroyed by heating to 550°C for 0.5 h. Other associated hydrothermal minerals identified on these X-ray diffractograms are smectite, hematite, analcime, and heulandite. Both kaolinite and halloysite were identified during studies of hydrothermal alteration near Mount Hood, where they probably formed by fumarolic alteration close to the summit of the mountain (Bargar and others, 1993). These kaolin minerals in the SUNEDCO hole are found at temperatures between about 40°C and 110°C, which according to Hulen and Nielson (1986) is the appropriate range for kaolinite.

Another serpentine-kaolinite group mineral identified in many samples near the bottom of the drill hole below 2,164 m (temperature ~140°C) is berthierine(?). Greenish metamorphosed tuff fragments in which this mineral occurs show fairly sharp (001) and (002) XRD reflections at about 7.1 Å and 3.54 Å, respectively, and semiqualitative chemical analysis by EDS on the SEM shows only Fe, Al, and Si. Other associated hydrothermal minerals identified in the same X-ray analyses are illite, siderite, calcite, and smectite. A mineral with similar characteristics was found in one specimen from a deserted mining area near Mount Hood (Bargar and others, 1993). An analogous serpentine-kaolinite group mineral referred to as septechlorite (no longer an accepted mineral name) was reported from USGS research drilling in the Mud Volcano area of Yellowstone National Park at temperatures of 110°–190°C (Bargar and Muffler, 1982).

Figure 10. Scanning electron micrograph of drusy subhedral quartz crystals that formed in a fracture or cavity filling at about 802 m.

Silica minerals

Cristobalite — A single specimen of red-orange silica from 802 m (temperature near 110°C) in the SUNEDCO hole has an XRD reflection at 4.07 Å, characteristic of cristobalite; reflections for smectite and heulandite are also present in the analysis. Cristobalite was identified in only two outcrop samples of late Tertiary volcanic rocks in the Breitenbush-Austin Hot Springs area, but it is fairly common in fractures and cavities of the Pliocene basaltic andesite lava flows in the lower part of CTGH–1 (Bargar, 1988, 1990). Sparse cristobalite occurs in late Tertiary volcanic rocks penetrated by geothermal drill holes near Mount Hood (Bargar and others, 1993), as well as in fractures and vugs in Pliocene and Pleistocene volcanic rocks from several geothermal drill holes at Newberry volcano (Keith and Bargar, 1988; Bargar and Keith, unpublished data). In all of these hydrothermal cristobalite occurrences, the measured temperatures were less than 150°C. Hydrothermal cristobalite commonly occurs as botryoidal masses (Bargar, 1990) and often forms as a disordered, poorly-crystalline phase during the transition from amorphous opal to microcrystalline chalcedony (Keith and others, 1978), with the botryoidal morphology being retained through the solid-state ordering process.

Chalcedony — Chalcedony is present in samples throughout much of the SUNEDCO hole (Figure 2). Microgranular or microfibrous, varicolored chalcedony occurs as lithic fragments in lithic-crystal tuffs, fills fractures and other cavities, and forms the matrix of silicified tuffs. Associated hydrothermal minerals identified by XRD or binocular microscope are pyrite, heulandite, chlorite, epidote, analcime, laumontite, calcite, smectite, and quartz. Some of the pyrite and all of the epidote are associated with chalcedonic lithic fragments and undoubtedly formed in an older hydrothermal system unrelated to the present geothermal system. The present measured temperatures (~90°–140°C) throughout the chalcedony section are within the lower range of temperatures for chalcedony in modern geothermal areas (Keith, 1988).

Quartz — Hydrothermal quartz was observed in several SUNEDCO samples (Figure 2). It usually occurs as one or more fragments of prismatic, colorless, euhedral crystals ~1 mm or less in length. Occasionally, quartz occurs as a druse of even smaller anhedral or subhedral crystals (Figure 10) that apparently formed on the walls of cavities or fractures. Some samples also contain irregularly shaped, colorless quartz fragments from larger broken crystals or massive vein fillings. Most of the quartzose fragments are monomineralic, but a few include quartz and earlier formed green smectite or pyrite. Quartz is also found in association with laumontite (Figure 4) and with mixed-layer chlorite-smectite.

Tiny, liquid-rich fluid inclusions, each with a very small vapor bubble, were observed in a few quartz fragments by use of refractive index oil. These fluid inclusions were not analyzed, but the tiny vapor bubbles suggest that the fluid-inclusion T_h values probably would be quite similar both to the measured temperatures and to the calcite T_h reported above. One frosted crystal fragment of quartz from 396 m contains liquid-rich secondary fluid inclusions (Figure 11) that homogenized at much higher temperatures than can be accounted for by the present-day measured temperatures of the hole (Figure 7) (Bargar, 1993). This crystal undoubtedly formed in a previous hydrothermal system of much higher temperature and was later incorporated within the tuff as a lithic fragment.

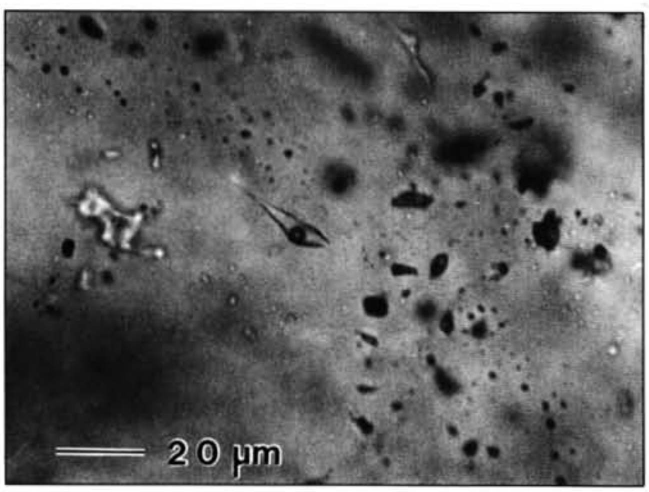


Figure 11. Photomicrograph of a liquid-rich secondary fluid inclusion in a hydrothermal quartz crystal lithic fragment from about 396 m.

Sulfide minerals

Chalcopyrite — A sample from 933 m contains a single chip of chalcopyrite with laumontite and heulandite. Chalcopyrite is a rare mineral in geothermal drill holes in the Cascade Range, but the copper-iron-sulfide mineral is found throughout the Western Cascades in occasional outcrops of old mining districts (Callaghan and Buddington, 1938). It also occurs in two geothermal drill holes near Mount Hood (Bargar and others, 1993).

Pyrite — Many samples throughout the SUNEDCO hole contain one to several pyrite-bearing chips. The pyrite most frequently occurs as individual tiny cubes or octahedra (Figure 12a) (usually <0.1 mm, but sometimes up to ~0.4 mm across) that fill fractures or are disseminated in the volcaniclastic grains. Massive or framboidal (Figure 12b) pyrite deposits are rare. In some tuffaceous drill chips, pyrite is found within lithic fragment components but not in the enclosing altered glassy matrix, suggesting that the pyrite formed in an older hydrothermal system. Cavity fillings of pyrite in association with hydrothermal minerals such as chalcedony, quartz, smectite, mixed-layer chlorite-smectite, heulandite, and laumontite may have been deposited from the present hydrothermal system.

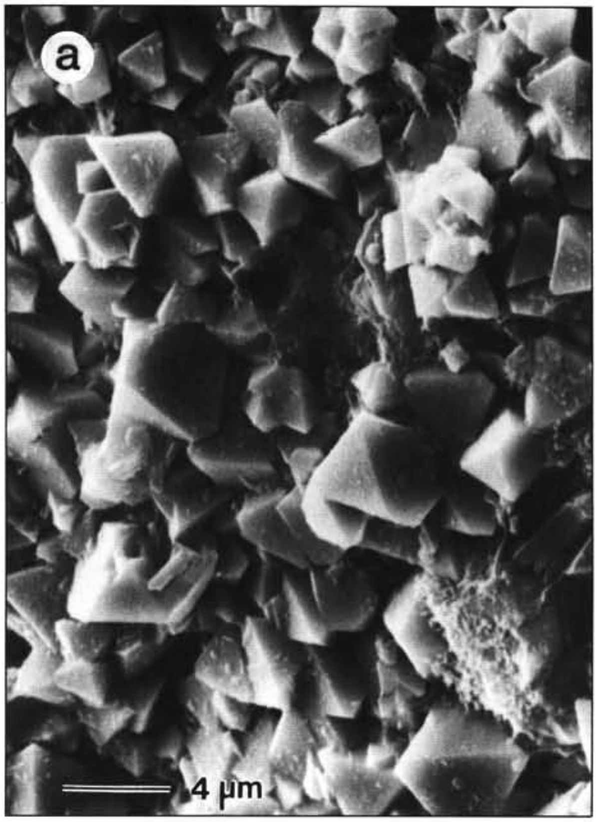
Iron oxides

Hematite — Hematite is present throughout much of the SUNEDCO hole. Hematite was identified in many XRD analyses of red, clay-altered, lithic tuffs, although occasional analyses suggest that some of these tuffs contain amorphous iron oxide. Hematite or amorphous iron oxide also are present in a few fractures and rubbly flow margins. Closely associated hydrothermal minerals in the XRD samples are heulandite, laumontite, smectite, halloysite, chlorite, and mixed-layer chlorite-smectite.

Magnetite — Traces of possible hydrothermal magnetite were located in only three drill-cutting chips from this drill hole. Two of the chips consist of magnetite veins from a basaltic sill at 1,381 m. A third chip, from 719 m, contains magnetite with associated epidote. The latter occurrence probably is from a previous geothermal system.

Other minerals

Epidote — Epidote was identified on the basis of its distinctive yellow-green color and high refractive index (>1.70) and occurs in numerous samples from 600 to 1,800 m. Although epidote appears to occur throughout this depth range, no more than a single chip containing epidote was found at any one sample depth. Epidote most frequently occurs with chalcedony; in one specimen it is associated with magnetite, and in another with smectite and earlier hydrothermal quartz. Much of the epidote appears to reside in lithic rock fragments within lithic tuffs, which are the predominant rocks in the drill hole. Epidote is commonly found in the alteration halos of the small plutons in the Western Cascade Range of Oregon. The epidote-bearing clasts in the SUNEDCO hole may have been derived from such hydrothermal halos and incorporated into later formed lithic tuffs.



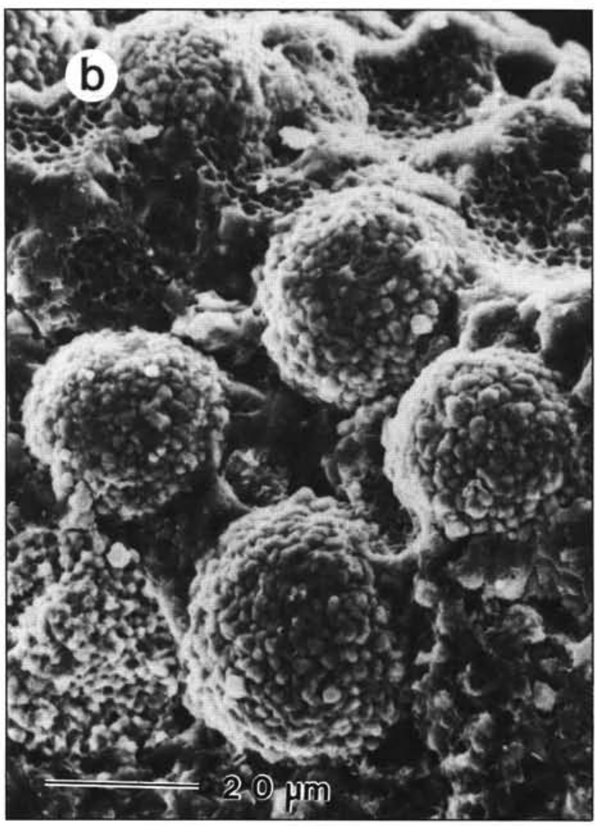


Figure 12. Scanning electron micrographs showing (a) octahedral pyrite crystals and later dusting of smectite from about 1,371 m, and (b) framboidal clusters of pyrite crystals and casts of the spherical crystal clusters of pyrite in later smectite from about 1,423 m.

Anhydrite — A few small, soft, tabular, colorless cleavage chips of anhydrite were identified from two narrow zones (1,792–1,817 m, and 1,908–1,920 m) in the lower part of the drill hole. Some of the unpolished anhydrite chips contain liquid-rich secondary(?) fluid inclusions with very small vapor bubbles (Figure 13). The T_h for 22 of these fluid inclusions in five sample chips (Table 2) range from 123° to 133°C, which is very close to the temperature-depth curve given in Blackwell and others (1986) (Figure 7). However, three primary(?) fluid inclusions from another sample chip have T_h of 152°C, 179°C, and 191°C, which indicates that this anhydrite crystal may have formed at significantly higher temperatures. Melting point temperatures for five of the anhydrite fluid inclusions are quite variable and are as high as +1.5°C. The fluid inclusions appear to be metastable (Roedder, 1984).

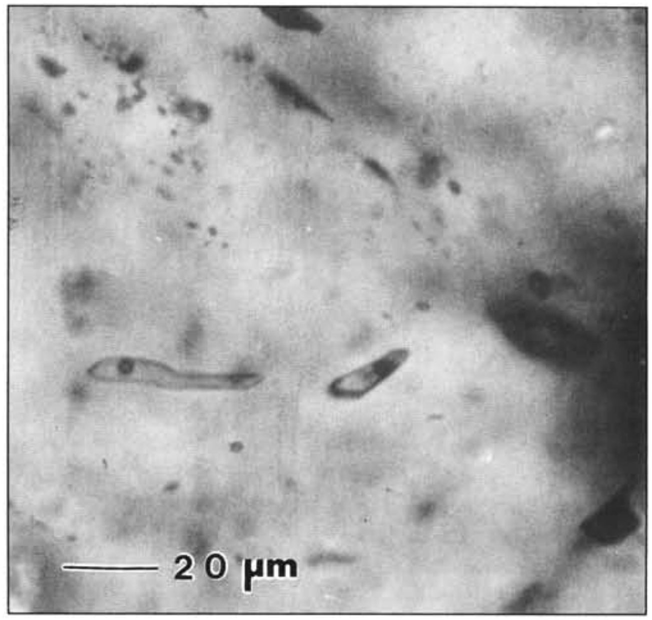


Figure 13. Photomicrograph of liquid-rich secondary fluid inclusions in an anhydrite cleavage chip from about 1,910 m.

Titanite(?) — A single grain from 1,759 m contains tiny wedge- or diamond-shaped crystals of titanite(?) (Figure 14) that consist of Ca, Ti, Si, and Al in EDS. Other hydrothermal minerals in the mixture of hornblende andesite and crystal-lithic tuff drill chips are laumontite, calcite, smectite and hematite. Authigenic titanite has been reported from New Zealand (Boles and Coombs, 1977) and the Cerro Prieto geothermal field of Mexico (Schiffman and others, 1985). Schiffman and others (1985) indicate that Al and Fe^{3+} substitute for Ti, and the titanite they described is very Al-rich. Aluminum- and iron-rich titanite was tentatively identified in drill cuttings from a geothermal drill hole near Mount Hood (Bargar and others, 1993). Schiffman and others (1985) indicated that the Cerro Prieto titanite probably formed at temperatures below 150°C, which is similar to the conditions for the occurrence of titanite(?) in the SUNEDCO hole.

Garnet(?) — Two drill chips from a lithic tuff unit at 1,369 m contain anhedral to subhedral crystals of a yellow-orange mineral containing Ca, Fe, ± Al, and Si in EDS. Crystal morphology (Figure 15) and the semiquantitative chemistry suggest that the mineral might be andradite garnet. Associated hydrothermal minerals in these chips are calcite, pyrite, and laumontite; celadonite and mixed-layer chlorite-smectite were also identified from this sample depth. Garnets are reported from several active geothermal systems where temperatures exceed 300°C (Bird and others, 1984). If the mineral is garnet, it most likely formed in an older, higher temperature hydrothermal system and was later incorporated into the lithic tuff unit.

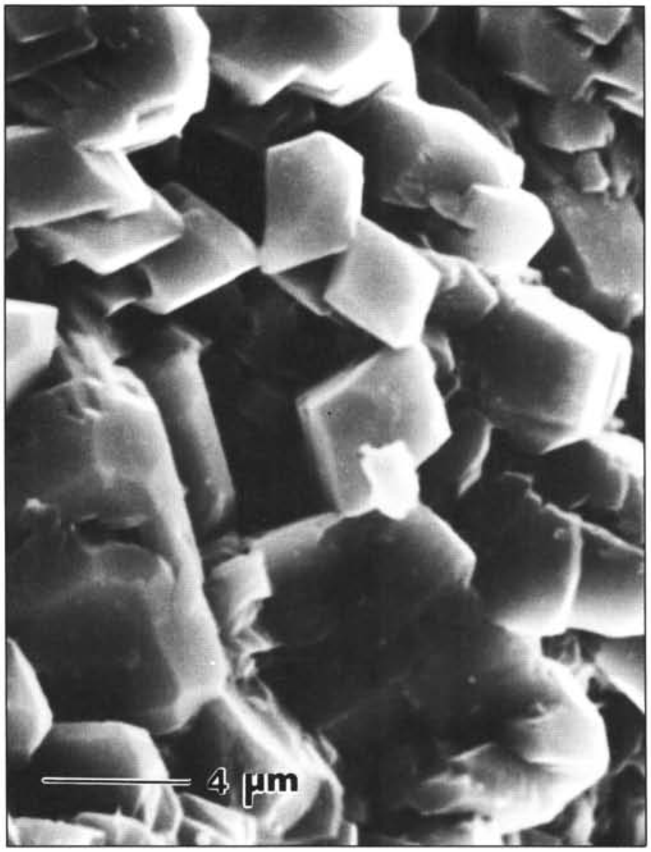


Figure 14. Scanning electron micrograph of subhedral titanite(?) crystals from about 1,759 m. Some of the titanite(?) crystals appear to be wedge shaped.

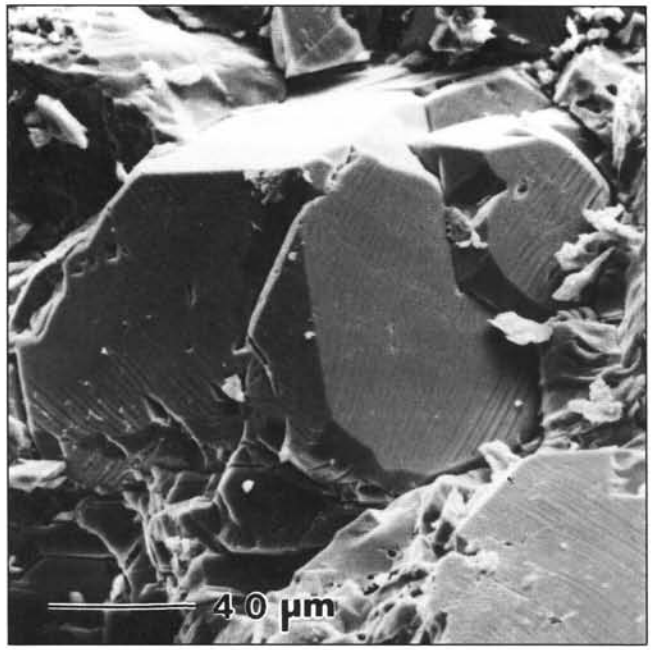


Figure 15. Scanning electron micrograph of subhedral garnet(?) crystals from about 1,369 m.

DISCUSSION

The 2,457-m-deep SUNEDCO 58–28 drill hole penetrated late Tertiary volcanic and volcaniclastic rocks, as well as a few minor intrusions. Drill cuttings from this geothermal exploration hole are altered to zeolites (analcime, epistilbite, heulandite, laumontite, mordenite, scolecite, and stilbite/stellerite), carbonates (calcite and siderite), clays (smectite, celadonite, mixed-layer chlorite-smectite, chlorite, serpentine-kaolinite group minerals, corrensite[?], and sepiolite[?]), silica minerals (cristobalite, chalcedony, and quartz), pyrite, iron oxide, and trace amounts of a few other hydrothermal minerals including epidote, chalcopyrite, anhydrite, magnetite, garnet(?), and titanite(?). Glassy material in the tuffs is altered to zeolites and clays; these minerals along with other hydrothermal minerals also appear to have formed in fractures and cavities throughout most of the drill hole. Hematite and amorphous iron oxide occur as open space deposits and alteration of mafic minerals.

A nonequilibrium temperature of ~141°C (A.F. Waibel, unpublished data, 1982) was measured at the bottom of the drill hole, although the actual bottom-hole temperature may have been near 150°C (Blackwell and Baker, 1988). Homogenization temperatures (T_h)for secondary liquid-rich fluid inclusions in calcite, and anhydrite suggest that these fluid inclusions may have formed in the present-day geothermal system, because the minimum T_h values are nearly coincident with the measured temperatures at the fluid-inclusion sample depths (Taguchi and others, 1984). The fluid inclusions in calcite and anhydrite have mostly (only a single exception) maximum T_h values of less than the 174°C geothermometer temperature that Ingebritsen and others (1989) reported for the aquifer supplying the nearby Breitenbush Hot Springs dilute Na-Cl waters (Mariner and others, 1993). The T_h measurements for fluid inclusions in primary quartz crystals from near the bottom of the drill hole range from near the estimated temperature at the sample depth to as much as 42°C higher than the geothermometer temperature for the Breitenbush Hot Springs water. This suggests that these fluid inclusions trapped water from a different aquifer than the one feeding the thermal springs. Also, limited T_m measurements for the near-bottom fluid inclusions indicate that the trapped water is from an aquifer that has a significantly greater salinity than Breitenbush Hot Springs.

Except for some mineral paragenesis observations in SEM, the sequence of mineral formation is difficult to determine from the drill-cutting samples. Although trace amounts of epidote are widespread in the cuttings, which might suggest temperatures of at least 230°C (Seki, 1972), petrographic observations indicate that the epidote, along with several other hydrothermal minerals including garnet(?), some pyrite, quartz, and chalcedony, is confined to lithic fragments in tuffs and tuffaceous sedimentary deposits and was incorporated by fragmentation of older geothermal halos. It has previously been pointed out that some of the hydrothermal alteration minerals (especially epidote) in the SUNEDCO 58–28 chips formed at higher temperatures than were measured in this drill hole (Keith, 1988). Other misleading pieces of evidence for higher temperatures in this drill hole are (1) the presence of garnet(?), which forms at temperatures above 300°C (Bird and others, 1984), and (2) fluid inclusion T_h values of 232°–274°C for a quartz fragment from the shallower part (396 m) of the drill hole.

CONCLUSIONS

Hydrothermal-mineralogy and fluid-inclusion studies of the SUNEDCO 58–28 drill hole samples indicate that most of the alteration minerals probably formed in the present-day geothermal system. The majority of hydrothermal minerals precipitated from Na-Cl water similar to that of nearby Breitenbush Hot Springs. However, some hydrothermal chalcedony, quartz, pyrite, and, especially, epidote and garnet(?) formed from one or more older, higher temperature geothermal systems. These minerals occur in lithic rock fragments that were either eroded or broken up by explosive volcanic activity and later were incorporated into the tuffaceous units penetrated in the SUNEDCO drill hole. A change in clay mineralogy from smectite/celadonite to illite/serpentine-kaolinite along with slightly higher fluid-inclusion T_h values and lower T_m values at about 2,000 m suggest that a second, more saline aquifer may be present near the bottom of the drill hole.

ACKNOWLEDGMENTS

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REFERENCES CITED

Alietti, A., 1972, Polymorphism and crystal-chemistry of heulandites and clinoptilolites: American Mineralogist, v. 57, p. 1448–1462.

Bargar, K.E., 1988, Secondary mineralogy of core from geothermal drill hole CTGH–1, Cascade Range, Oregon, *in* Sherrod, D.R., ed., Geology and geothermal resources of the Breitenbush-Austin Hot Springs area, Clackamas and Marion Counties, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O–88–5, p. 39–45.

———1990, Hydrothermal alteration in geothermal drill hole CTGH–1, High Cascade Range, Oregon: Oregon Geology, v. 52, no. 4, p. 75–81.

———1993, Fluid-inclusion evidence for previous higher temperatures in the SUNEDCO 58–28 drill hole near Breitenbush Hot Springs, Oregon: Geothermal Resources Council Transactions, v. 17, p. 83–89.

Bargar, K.E., Keith, T.E.C., and Beeson, M.H., 1993, Hydrothermal alteration in the Mount Hood area, Oregon: U.S. Geological Survey Bulletin 2054, 70 p.

Bargar, K.E., and Muffler, L.J.P., 1982, Hydrothermal alteration in research drill hole Y–11 from a vapor-dominated geothermal system at Mud Volcano, Yellowstone National Park, Wyoming: Wyoming Geological Association Annual Field Conference, 33rd, Mammoth Hot Springs, Wyoming, Guidebook, p. 139–152.

Bird, D.K., Schiffman, P., Elders, W.A., Williams, A.E., and McDowell, S.D., 1984, Calc-silicate mineralization in active geothermal systems: Economic Geology, v. 79, p. 671–695.

Blackwell, D.D., and Baker, S.L., 1988, Thermal analysis of the Austin and Breitenbush geothermal systems, Western Cascades, Oregon, *in* Sherrod, D.R., ed., Geology and geothermal resources of the Breitenbush-Austin Hot Springs area, Clackamas and Marion Counties, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O–88–5, p. 47–62.

Blackwell, D.D., Black, G.L., and Priest, G.R., 1986, Geothermal-gradient data for Oregon (1982–1984): Oregon Department of Geology and Mineral Industries Open-File Report O–86–2, 107 p.

Bodnar, R.J., and Sterner, S.M., 1984, Synthetic fluid inclusions in natural quartz I; compositional types synthesized and applications to experimental geochemistry: Geochimica et Cosmochimica Acta, v. 48, p. 2659–2668.

Boles, J.R., and Coombs, D.S., 1977, Zeolite facies alteration of sandstones in the Southland Syncline, New Zealand: American Journal of Science, v. 277, p. 982–1012.

Brindley, G.W., 1980, Order-disorder in clay mineral structures, *in* Brindley, G.W., and Brown, G., eds., Crystal structures of clay minerals and their X-ray identification: London, Mineralogical Society, Monograph 5, p. 125–195.

Callaghan, E., and Buddington, A.F., 1938, Metalliferous mineral deposits of the Cascade Range in Oregon: U.S. Geological Survey Bulletin 893, 141 p.

Conrey, R.M., and Sherrod, D.R., 1988, Stratigraphy of drill holes and geochemistry of surface rocks, Breitenbush Hot Springs 15-minute quadrangle, Cascade Range, Oregon, *in* Sherrod, D.R., ed., Geology and geothermal resources of the Breitenbush-Austin Hot Springs area, Clackamas and Marion Counties, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O–88–5, p. 15–29.

Gottardi, G., and Galli, E., 1985, Natural zeolites: Berlin, Springer-Verlag, 409 p.

Greene, K., and Goodman, L., 1982, Geothermal well drilling and completion, *in* Edwards, L.M., Chilingar, G.V., Rieke, H.H., III, and Fertl, W.H., eds., Handbook of geothermal energy: Houston, Tex., Gulf Publishing Company, chpt. 5, p. 243–263.

Hower, J., 1981, X-ray diffraction identification of mixed-layer clay minerals: Mineralogical Association of Canada Short Course, p. 39–59.

Hulen, J.B., and Nielson, D.L., 1986, Hydrothermal alteration in the Baca geothermal system, Redondo Dome, Valles Caldera, New Mexico: Journal of Geophysical Research, v. 91, no. B2, p. 1867–1886.

Ingebritsen, S.E., Sherrod, D.R., and Mariner, R.H., 1989, Heat flow and hydrothermal circulation in the Cascade Range, north-central Oregon: Science, v. 243, p. 1458–1462.

Inoue, A., Utada, M., Nagata, H., and Watanabe, T., 1984, Conversion of trioctahedral smectite to interstratified chlorite/smectite in Pliocene acidic pyroclastic sediments of the Ohyu District, Akita Prefecture, Japan: Clay Science, v. 6, p. 103–116.

Keith, T.E.C., 1988, Regional patterns of hydrothermal alteration, Breitenbush-Austin Hot Springs area, Cascade Range, Oregon, *in* Sherrod, D.R., ed., Geology and geothermal resources of the Breitenbush-Austin Hot Springs area, Clackamas and Marion Counties, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O–88–5, p. 31–37.

Keith, T.E.C., and Bargar, K.E., 1988, Petrology and hydrothermal mineralogy of U.S. Geological Survey Newberry 2 drill core from Newberry caldera, Oregon: Journal of Geophysical Research, v. 93, no. B9, p. 10,174–10,190.

Keith, T.E.C., White, D.E., and Beeson, M.H., 1978, Hydrothermal alteration and self-sealing in Y–7 and Y–8 drill holes in northern part of Upper Geyser Basin, Yellowstone National Park, Wyoming: U.S. Geological Survey Professional Paper 1054-A, 26 p.

Kristmannsdóttir, H., and Tómasson, J., 1978, Zeolite zones in geothermal areas in Iceland, *in* Sand, L. B., and Mumpton, F.A., eds., Natural zeolites: occurrence, properties, use: Elmsford, New York, Pergamon Press, p. 277–284.

Kusakabe, H., Minato, H., Utada, M., and Yamanaka, T., 1981, Phase relations of clinoptilolite, mordenite, analcime and albite with increasing pH, sodium ion concentration and temperature: Scientific papers of the College of General Education, University of Tokyo, v. 31, p. 39–59.

Mariner, R.H., Presser, T.S., and Evans, W.C., 1993, Geothermometry and water-rock interaction in selected thermal systems in the Cascade Range and Modoc Plateau, western United States: Geothermics, v. 22, no. 1, p. 12–15.

McCulloh, T.H., Frizzell, V.A., Jr., Stewart, R.J., and Barnes, I., 1981, Precipitation of laumontite with quartz, thenardite, and gypsum at Sespe Hot Springs, western Transverse Ranges, California: Clays and Clay Minerals, v. 29, no. 5, p. 353–364.

Mumpton, F.A., 1960, Clinoptilolite redefined: American Mineralogist, v. 45, p. 351–369.

Passaglia, E., 1970, The crystal chemistry of chabazites: American Mineralogist, v. 55, p. 1278–1301.

Passaglia, E., Galli, E., Leoni, L., and Rossi, G., 1978, The crystal chemistry of stilbites and stellerites: Bulletin de Minéralogie, v. 101, p. 368–375

Phillips, W.R., and Griffen, D.T., 1981, Optical mineralogy; the nonopaque minerals: San Francisco, W.H. Freeman and Company, 677 p.

Priest, G.R., Woller, N.M., and Ferns, M.L., 1987, Geologic map of the Breitenbush River area, Linn and Marion Counties, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS–46, scale 1:62,500.

Roedder, E., 1984, Fluid inclusions, *in* Ribbe, P.H., ed., Reviews in Mineralogy, v. 12: Washington, D.C., Mineralogical Society of America, 644 p.

Schiffman, P., Bird, D.K., and Elders, W.A., 1985, Hydrothermal mineralogy of calcareous sandstones from the Colorado River delta in the Cerro Prieto geothermal system, Baja California, Mexico: Mineralogical Magazine, v. 49, p. 435–449.

Seki, Y., 1972, Lower-grade stability limit of epidote in the light of natural occurrences: Journal of the Geological Society of Japan, v. 78, no. 8, p. 405–413.

Sherrod, D.R., and Conrey, R.M., 1988, Geologic setting of the Breitenbush-Austin Hot Springs area, Cascade Range, north-central Oregon, *in* Sherrod, D.R., ed., Geology and geothermal resources of the Breitenbush-Austin Hot Springs area, Clackamas and Marion Counties, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O–88–5, p. 1–14.

Starkey, H.C., Blackmon, P.D., and Hauff, P.L., 1984, The routine mineralogical analysis of clay-bearing samples: U.S. Geological Survey Bulletin 1563, 32 p.

Taguchi, S., Hayashi, M., Mimura, T., Kinoshita, Y., Gokou, K., and Abe, I., 1984, Fluid inclusion temperature of hydrothermal minerals from the Kirishima geothermal area, Kyushu, Japan [in Japanese with English abstract]: Japan Geothermal Energy Association Journal, v. 21, p. 55–65.

Tomita, K., Yamashita, H., and Oba, N., 1969, An interstratified mineral found in altered andesite: Journal of the Japanese Association of Mineralogists, Petrologists, and Economic Geologists, v. 61, no. 1, p.25–34. □

Geothermal exploration in Oregon, 1992–1993

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INTRODUCTION

After several years of declining activity, geothermal activity in Oregon increased in the past two years. There was no change in the low level of leasing, but drilling picked up substantially in two areas: Pueblo Valley and Vale.

LEASING

There were no geothermal lease sales during 1992 or 1993. Table 1 shows leasing trends for these years. In 1992, all new acreage was in the Newberry volcano area, Deschutes County. In 1993, leased acreage was in the Newberry area, elsewhere in Deschutes County, and in the Vale area, Malheur County.

DIRECT-USE PROJECTS

The Geo-Heat Center at the Oregon Institute of Technology (OIT), Klamath Falls, received in 1992 a contract from the U.S. Department of Energy to study increasing the use of geothermal energy. The study is concentrating on furthering the use of low- and moderate-temperature hydrothermal resources and of geothermal heat pumps. The objective of the Geo-Heat Center is to provide technical assistance to anyone who is interested or involved in the development of geothermal energy for direct-use applications.

The Geo-Heat Center has studied the effect of the fall 1993 earthquakes in the Klamath Falls area on the local geothermal resource (Lienau and Lund, 1993). Approximately 500 wells tap geothermal fluids from 50° to 110°C (122° to 230°F) at depths from 30 to 600 m (100–1,970 ft). Water levels in hot-water wells have increased since the earthquakes. At the same time, water levels in

Table 1. *Geothermal leases in Oregon, cumulative, 1992, and 1993*

Types of leases	Numbers	Acres
Cumulative–Leases issued since 1974:		
Noncompetitive, USFS	385	718,867
Noncompetitive, USBLM	274	415,778
KGRA, USFS	18	18,388
KGRA, USBLM	66	125,740
Cumulative–Leases relinquished since 1974:		
Noncompetitive, USGS	265	561,112
Noncompetitive, USBLM	264	405,215
KGRA, USFS	7	11,825
KGRA, USBLM	55	101,243
Federal leases issued during 1992, USFS	7	7,197
Federal leases issued during 1992, USBLM	5	8,072
Federal leases closed 1992, USFS and BLM	9	9,464
Federal leases issued during 1993, USFS	2	3,094
Federal leases issued during 1993, USBLM	7	8,981
Federal leases closed 1993, USFS and BLM	12	29,582
Federal leases in effect, 12/31/93:		
Noncompetitive, USFS	120	157,755
Noncompetitive, USBLM	10	10,563
KGRA, USFS	11	6,563
KGRA, USBLM	11	23,897
Federal income from geothermal leases, 1992		$153,634
Federal income from geothermal leases, 1993		$110,637

Figure 1. Anadarko Petroleum flow-test well 66-22A, located near Fields in southern Harney County.

five monitored cold-water wells decreased dramatically. Changes have been from 0.9 to 2 m (3–7 ft). The Klamath Medical Clinic well started an artesian flow of 115 L/min (30 gal/min) before the earthquakes and increased to 570 L/min (150 gal/min) afterwards with no change in temperature. Some wells did change in temperature, and one well developed a hydrogen sulfide odor.

In 1992, the Klamath Falls heating district discovered it would need additional buildings hooked up to the system to remain economically viable. The 82°C (180°F) water was used by a total of 14 public buildings in the downtown district. The Geo-Heat Center at OIT developed a marketing strategy to address rates, customer retrofit costs, financing, system reliability, and other factors. Since that time, eleven additional buildings have been or are about to be served by hot-water heat. Early last year, the city of Klamath Falls encouraged property owners to more quickly take advantage of the state's business energy tax credit to encourage investment in energy-saving technology, recycling, and conversion to renewable energy sources like geothermal for space heating. Through tax credits, the state will reimburse property owners 35 percent of investment for these purposes over five years, giving downtown businesses an incentive to use geothermal energy.

Liskey Farms Greenhouses, just south of Klamath Falls, has expanded from about 0.7 acres to approximately 1.5 acres. Tomatoes and jalapeno peppers are grown. Near Craine Prairie, east of Burns, Geo-Culture, Inc., is planning a 21.5-acre greenhouse operation to grow tomatoes. A test well has been drilled for installation of a downhole heat exchanger.

OREGON DEPARTMENT OF ENERGY (ODOE)

ODOE was active in several programs dealing with geothermal energy. The agency is contractor for the Geothermal Education Office, a nonprofit organization working to educate today's youth about geothermal energy and its place in the energy picture. Targeting grades four through nine, a self-contained educational unit is being designed to teach the following aspects of geothermal energy: geologic origin, how it is used, environmental impacts, and place in Pacific Northwest energy use.

ODOE continues to compile all available information and documentation on operations at geothermal power plants in the United States. Data for 64 power plants are collected and stored electronically. Field visits and interviews were conducted over the past two years at new geothermal plants at Brady and Steamboat in Nevada. The updated database is submitted to the Bonneville Power Administration (BPA) annually.

The agency regularly communicates with Northwest environmental organizations to support advocacy of technologies for renewable energy such as geothermal. It is also an ex-officio member of the Central Oregon Citizens Working Group, advising on Newberry volcano development issues.

ODOE performed a feasibility study to determine under what circumstances a ground-coupled heat pump program could meet BPA cost-effectiveness standards and other billing-credit criteria. Such a program was found not to be feasible, in spite of some utility support. Impediments, such as the high system capital cost, were identified and included in the findings.

OREGON WATER RESOURCES DEPARTMENT (WRD)

WRD has been working with the City of Klamath Falls and the Department of Environmental Quality to streamline the process for obtaining the necessary permits for reinjection wells. Users of the resource in Klamath Falls have, for the most part, switched to injection of spent geothermal effluent.

OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES (DOGAMI)

Agencies of 10 western states are compiling geothermal databases for wells and springs. DOGAMI is funded through a subcontract from the OIT Geo-Heat Center for its part of the project entitled "State Geothermal Energy Research, Development, and Database Compilation." Prime funding is from the U.S. Department of Energy, Geothermal Division. This project is phase 1 of the low-temperature geothermal resources and technology transfer program. The purposes of the project are to (1) update the inventory of the nation's low- and moderate-temperature geothermal resources, (2) study the location of the resources relative to potential users, and (3) collect and disseminate information necessary to expand the use of geothermal heat pumps. DOGAMI's involvement is primarily the first task listed; the agency shares responsibility with OIT for the second task.

DOGAMI has published an open-file report on the power-generation potential of Newberry volcano and on deep thermal data from the Cascades (Black, 1994; Blackwell, 1994). The "rain curtain" effect is also discussed in the report.

REGULATORY ACTIONS AND INDUSTRY DRILLING ACTIVITIES

Table 2 shows active state geothermal permits during 1992 and 1993, including wells permitted and drilling activity that occurred. In 1992, drilling activity included the deepening of a well by California Energy Company in the Bend Highlands area of Deschutes County (Permit 147D). The well has since been plugged and abandoned. In 1993, drilling included the deepening of a 1989 well

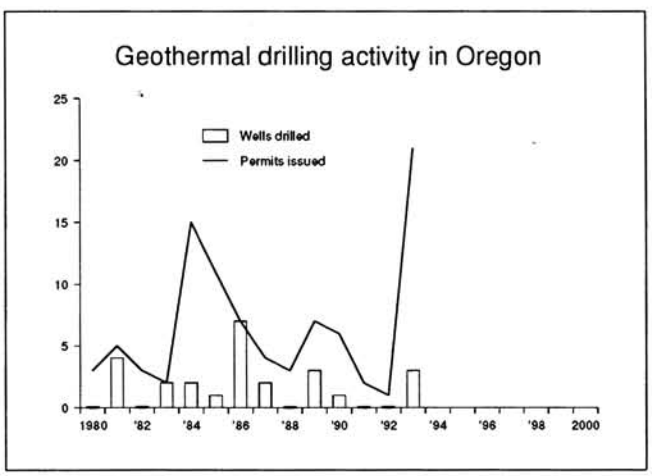

Figure 2. Geothermal well permits and drilling since 1980. Geothermal wells are deeper than 2,000 ft.

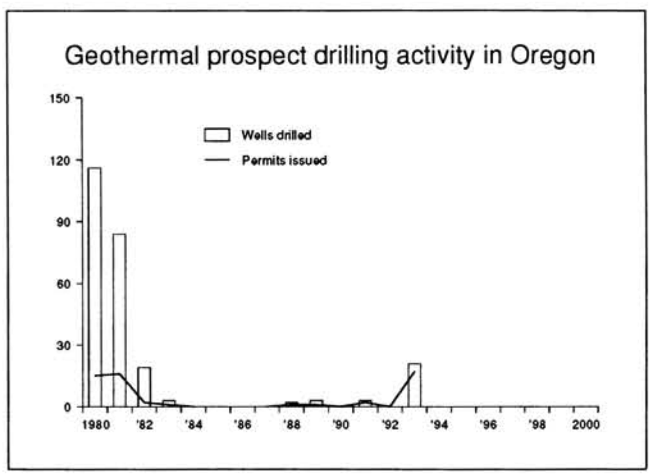

Figure 3. Geothermal prospect-well permits and drilling since 1980. Prospect wells are 2,000 ft or less in depth. One prospect permit may include several wells

and the drilling of two additional geothermal wells by Anadarko Petroleum Corporation in the Pueblo Valley of Harney County, in sec. 22, T. 27 S., R. 33 E. A press release by the company in November 1993 indicated that one of the wells reached a total depth of 724 m (2,376 ft) and was flow-tested at an average rate of 1,100 L/min (290 gal/min) with a wellhead temperature of 147°C (296°F). Temperatures in the wellbore exceeded 150°C (300°F). This well and the offset wells were completed for long-term observation of reservoir temperatures and pressures during possible development of the field for electric power generation. Anadarko holds 8,120 net lease acres at the Pueblo Valley discovery site.

Concurrently with drilling and testing, Anadarko monitored nearby Borax Lake water quality and quantity conditions, as required in the federal environmental assessment. Monitoring included air temperature, shallow water temperature, deep vent temperatures, water depth using a pressure transducer, and water temperature at a hot spring north of the lake.

In addition to the activity reflected in Table 2, DOGAMI and the

Table 2. *Geothermal permits and drilling activity in Oregon, 1992–1993*

Permit no.	Operator, well, API number	Location	Status, proposed or actual total depth
118	Geo Operator N-1 36-017-90013	SW¼ sec. 25 T. 22 S., R. 12 E. Deschutes County	Abandoned; 10-27-92.
125	Geo Operator N-2 36-017-90018	NE¼ sec. 29 T. 15 S., R. 12 E. Deschutes County	Abandoned; 11-02-92.
126	GEO Operator N-3 36-017-90019	NW¼ sec. 24 T. 20 S., R. 12 E. Deschutes County	Abandoned; 10-25-92.
131	GEO Operator N-4 36-017-90023	NE¼ sec. 35 T. 21 S., R. 13 E. Deschutes County	Abandoned; 10-28-92.
132	GEO Operator N-5 36-017-90024	NE¼ sec. 8 T. 22 S., R. 12 E. Deschutes County	Abandoned; 10-30-92.
147D	Calif. Energy Co. CE-BH-7 36-017-90032	NE¼ sec. 20 T. 17 S., R. 10 E. Deschutes County	Application to deepen; PTD 1,677 m (5,500 ft).
150	Anadarko Petroleum Pueblo Valley 52-22A 36-025-90007	NW¼ sec. 22 T. 37 S., R. 33 E. Harney County	Canceled; 8/13/93.
151	Anadarko Petroleum Pueblo Valley 66-22A 36-025-90008	SE¼ sec. 22 T. 37 S., R. 33 E. Harney County	Canceled; 8/13/93.
152	Vulcan Power Co. VP-83-29 36-017-90034	NE¼ sec. 29 T. 21 S., R. 12 E. Deschutes County	Application; PTD 3,050 m (10,000 ft).
153D	Anadarko Petroleum Pueblo Valley 25-22A 36-025-90009	NW¼ sec. 22 T. 37 S., R. 33 E. Harney County	Deepening; TD not released.
154	Anadarko Petroleum Pueblo Valley 52-22A 36-025-90010	NE¼ sec. 22 T. 37 S., R. 33 E. Harney County	Drilled and suspended; TD not released.
155	Anadarko Petroleum Pueblo Valley 66-22A 36-025-90011	SE¼ sec. 22 T. 37 S., R. 33 E. Harney County	Drilled and suspended; TD 724 m (2,376 ft).

Table 2. *Geothermal permits and drilling activity in Oregon, 1992–1993 (continued)*

Permit no.	Operator, well, API number	Location	Status, proposed or actual total depth
156	Trans Pacific Geothermal ESI-A-L Alt 36-045-90007	NE¼ sec. 33 T. 37 S., R. 45 E. Malheur County	Permitted; PTD 2,134 m (7,000 ft).
157	Trans Pacific Geothermal ESI-A-S Alt 36-045-90008	NE¼ sec. 33 T. 18 S., R. 45 E. Malheur County	Drilled and suspended; TD 1,755 m (5,757 ft).
158	Trans Pacific Geothermal ESI-B-L 36-045-90009	SE¼ sec. 33 T. 18 S., R. 45 E. Malheur County	Permitted; PTD 2,134 m (7,000 ft).
159	Trans Pacific Geothermal ESI-B-S 36-045-90010	SE¼ sec. 33 T. 18 S., R. 45 E. Malheur County	Permitted; PTD 1,524 m (5,000 ft).
160	Trans Pacific Geothermal ESI-C-L 36-045-90011	NE¼ sec. 34 T. 18 S., R. 45 E. Malheur County	Permitted; PTD 2,134 m (7,000 ft).
161	Trans Pacific Geothermal ESI-C-S 36-045-90012	NE¼ sec. 34 T. 18 S., R. 45 E. Malheur County	Permitted; PTD 1,524 m (5,000 ft).
162	Trans Pacific Geothermal ESI-D-L 36-045-90013	NW¼ sec. 33 T. 18 S., R. 45 E. Malheur County	Permitted; PTD 2,134 m (7,000 ft).
163	Trans Pacific Geothermal ESI-D-S 36-045-90014	NW¼ sec. 33 T. 18 S., R. 45 E. Malheur County	Permitted; PTD 1,524 m (5,000 ft).
164	Trans Pacific Geothermal ESI-D-L Alt 36-045-90015	NW¼ sec. 33 T. 18 S., R. 45 E. Malheur County	Permitted; PTD 2,134 m (7,000 ft).
165	Trans Pacific Geothermal ESI-D-S Alt 36-045-90016	NW¼ sec. 33 T. 18 S., R. 45 E. Malheur County	Permitted; PTD 1,524 m (5,000 ft).
166	Trans Pacific Geothermal ESI-E-L 36-045-90017	NE¼ sec. 4 T. 19 S., R. 45 E. Malheur County	Permitted; PTD 2,134 m (7,000 ft).
167	Trans Pacific Geothermal ESI-E-S 36-045-90018	NE¼ sec. 4 T. 19 S., R. 45 E. Malheur County	Permitted; PTD 1,524 m (5,000 ft).
168	Trans Pacific Geothermal ESI-F-L 36-045-90019	SE¼ sec. 3 T. 19 S., R. 45 E. Malheur County	Permitted; PTD 2,134 m (7,000 ft).
169	Trans Pacific Geothermal ESI-F-S 36-045-90020	SE¼ sec. 3 T. 19 S., R. 45 E. Malheur County	Permitted; PTD 1,524 m (5,000 ft).
170	Trans Pacific Geothermal ESI-G-L 36-045-90021	NW¼ sec. 11 T. 19 S., R. 45 E. Malheur County	Permitted; PTD 2,134 m (7,000 ft).
171	Trans Pacific Geothermal ESI-G-S 36-045-90022	NW¼ sec. 11 T. 19 S., R. 45 E. Malheur County	Permitted; PTD 1,524 m (5,000 ft).
172	Trans Pacific Geothermal ESI-H-L 36-045-90023	NE¼ sec. 11 T. 19 S., R. 45 E. Malheur County	Permitted; PTD 2,134 m (7,000 ft).
173	Trans Pacific Geothermal ESI-H-S 36-045-90024	NE¼ sec. 11 T. 19 S., R. 45 E. Malheur County	Permitted; PTD 1,524 m (5,000 ft).

U.S. Bureau of Land Management (BLM) issued permits to Trans-Pacific Geothermal Corporation for 21 temperature gradient wells in the Vale area in Tps. 18–19 S., R. 45 E., and 17 were drilled for temperature data to fine-tune the location for drilling a deep geothermal well. The deep test well, ESI-A-S Alt (Permit 157), was drilled in February 1994 and is suspended at this time. Figures 2 and 3 show the geothermal permitting and drilling statistics since 1980.

During 1992, DOGAMI and BLM abandoned five temperature gradient wells around Newberry volcano, using bonds posted by the operator, Geo-Operator. The company had left the wells deserted, and the DOGAMI Governing Board had declared the wells to be unlawfully abandoned.

U.S. GEOLOGICAL SURVEY (USGS)

Keith Bargar has been conducting studies of hydrothermal alteration of drill cores from Newberry volcano. The cores are from the USGS N-2 hole in the caldera as well as some industry wells on the flanks of the volcano. The results of the study will be presented in a USGS Bulletin, probably in 1995. Bargar conducted similar studies on drill-hole cuttings from the geothermal exploration well SUNEDCO 58-28 near the High Cascade-Western Cascade boundary at Breitenbush Hot Springs in Marion County. These are discussed in his report beginning on p. 75 of this issue.

Charlie Bacon is preparing a 1:24,000 geologic map of the Mazama caldera (Crater Lake area) on the basis of his field mapping over the past years. The map will include photographic panoramas as colored geologic sections. (See also Bacon, 1992; Bacon and others, 1992.)

USDA FOREST SERVICE (USFS)

In 1993, USFS released two draft environmental impact statements (DEIS) for the Newberry volcano area, the *Newberry National Volcanic Monument Comprehensive Management Plan* (12/93) and the *Newberry Geothermal Pilot Project* (1/94). Both have undergone comment periods and are being prepared in final form. Major concerns expressed in public comments have been air emissions, impacts to ground water and hot springs, staged vs. cumulative development, effect on the Monument, and decommissioning.

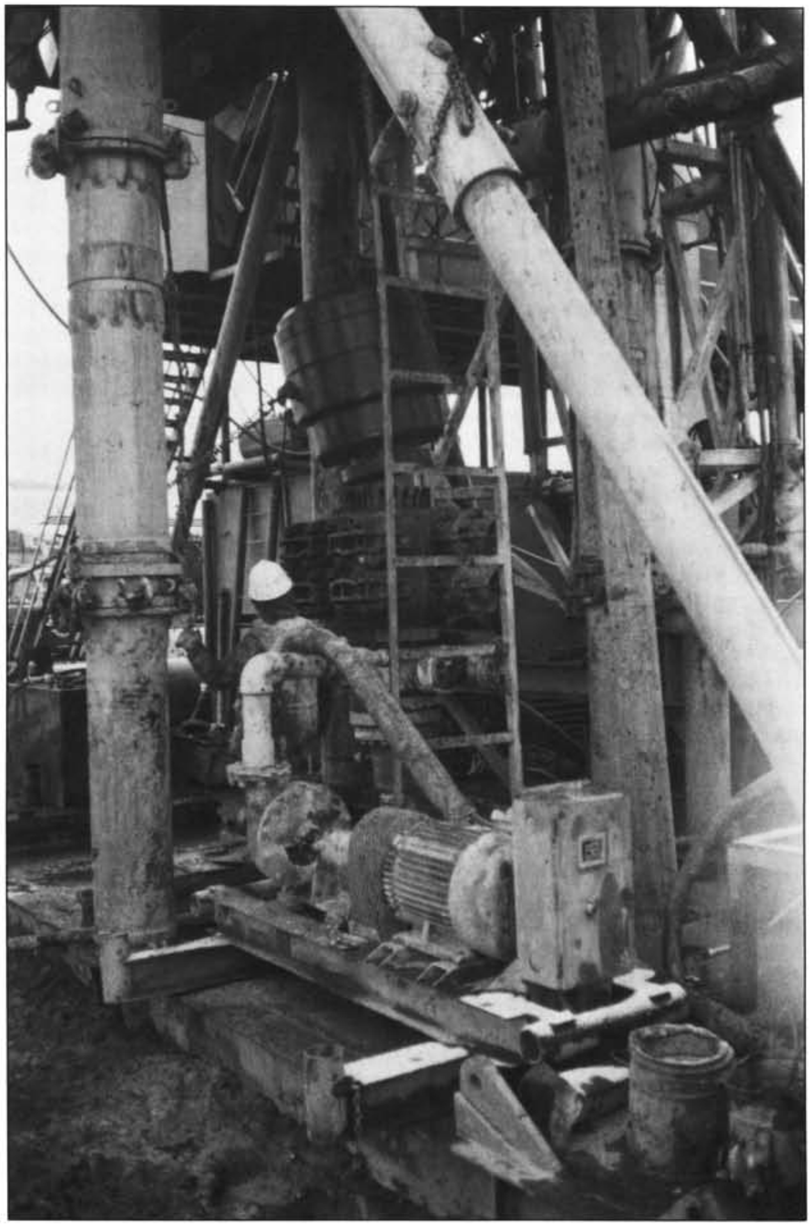

Figure 4. Installing blowout preventers on the Trans-Pacific Geothermal well ESI-A-S Alt near Vale, Malheur County, during February 1994.

The latter DEIS is in response to a proposal by CE Exploration Company of Portland to build and operate a geothermal pilot project and supporting facilities capable of generating 33 megawatts (MW) of electric power in the Deschutes National Forest. The facilities would include a power plant, access roads, exploration and production wells, a power transmission line, and a switchyard. The project would be located on the west flank of Newberry volcano on federal geothermal leases. In the DEIS, the USFS alternative identified 20 well-pad locations, 14 of which could be used, and three power plant locations. A single-pole transmission line design and a route away from the Forest Service road were proposed.

U.S. BUREAU OF LAND MANAGEMENT (BLM)

The above-mentioned drilling activity at Pueblo Valley was performed under an environmental assessment (EA) written by BLM in 1990. The EA had been appealed to the Interior Board of Land Appeals (IBLA) by seven interest groups, due to the proximity to Borax Lake and the Borax Lake chub. These interest groups felt that the proposed project warranted an environmental impact statement (EIS). In May 1993, the IBLA upheld the BLM decision, which consisted of a "finding of no significant impact," and stated that an EIS would not be needed until further geothermal development is contemplated.

BLM conducted its own baseline environmental data monitoring of Borax Lake before, during, and after the drilling of the Anadarko wells in 1993. The USGS assisted in the design of this monitoring. This work satisfied requirements of the environmental assessment and included a monitoring station at the lake to measure air temperatures and deep vent temperatures hourly. Additional measurements included shallow water temperatures and water depths, for which a pressure transducer was used. Recorded data were electronically available at BLM offices. Visual assessment of the lake and springs to the north was also conducted. Values measured at the monitoring station, including air temperature, shallow water temperature, deep vent temperature, and water depth, were recorded and, periodically, water temperatures at the hot springs. Samples were taken of the effluent of the lake during flow tests for general water chemistry determination. Analyses included carbonate, bicarbonate, hydroxide, total alkalinity, cation/anion balance, bromide, chloride, conductivity, fluoride, nitrate, pH, silica, sulfate, total dissolved solids, and turbidity. Trace element analysis was also conducted, including 15 elements.

BLM also conducted several additional studies in and around Borax Lake. These included census of the Borax Lake chub, alga and invertebrate studies in the lake, update of the 1987 chub recovery plan and the 1987 chub habitat management plan. In addition, the agency has contracted with the USGS and the U.S. Bureau of Mines to do a mineral assessment of parts of southeast Oregon in the Burns and Malheur districts.

In September 1993, BLM administratively enlarged the boundaries of the Newberry Known Geothermal Resources Area (KGRA) by 13,345 acres. Added acreage includes secs. 7, 8, and 9, T. 21 S., R. 13 E.; sec. 18, T. 22 S., R. 13 E.; secs. 9, 10, 12, 16, 17, 20, 30, 31, and 32, T. 21 S., R. 12 E.; and secs. 5, 6, 8, 13, 14, 15, and 16, T. 22 S., R. 12 E.

BLM is currently undertaking a mineral assessment of parts of the Burns and Malheur districts with the help of the Bureau of Mines and the USGS. No plans for publication of the results have been announced.

BONNEVILLE POWER ADMINISTRATION (BPA)

The main goal of BPA's geothermal program is to initiate geothermal development in the Pacific Northwest, to make sure it will be available to meet the region's energy needs. The program has focused on developing pilot power projects at sites with potential to support at least 100 MW of capacity. As an incentive to developers, BPA offered to buy the output from up to three projects. Two of the projects are in Oregon: the 30-MW project of CE Exploration Co. (CEE) at Newberry volcano and a 30-MW project by Trans-Pacific Geothermal Corp. at Vale. The Eugene Water and Electric Board (EWEB) is a partner in the Newberry project, and the Springfield Utility Board is a partner at Vale. Trans-Pacific's Vale leasehold is in the Vale Known Geothermal Resource Area, which extends from 1 to 5 mi southeast of Vale, near the Idaho border. A "plan of exploration" to drill and test up to 10 wells was approved by BLM at the latter project in October 1993. An exploration well was drilled in February 1994 (details elsewhere in this report). For the Newberry project, CEE and EWEB undertook an innovative public involvement program aimed at informing community leaders in the Bend-Sunriver-LaPine area about the project. The Central Oregon Geothermal Working Group (COGWG) represented a wide range of interests, from the Sierra Club to the Lodgepole Dodgers, a snowmobile club. The group met monthly. Each meeting centered around a topic or issue, such as environmental baselines or air emissions, usually featuring an outside speaker.The group also traveled to California's large geothermal producer, The Geysers, to view an operating field.

The pilot projects were supported by over 30 other activities aimed at increasing public knowledge and acceptance of geothermal technology. These activities included environmental studies, economic impact studies, public education projects, videos, technology development, outreach to environmental groups, and geothermal heat pump projects.

RELATED ACTIVITIES

The Newberry National Volcanic Monument Advisory Council has been meeting bimonthly to track the USFS process. The discussion is primarily driven by issues concerning threatened and endangered species and vegetation management. In its public-involvement program, CE Exploration has continued to hold informational meetings of its working group to educate key individuals and groups on what to expect of geothermal development.

The Nature Conservancy, an organization that buys land for conservation purposes, purchased 320 acres of property including Borax Lake and several hot springs to the north of the lake. The sale price was $320,000, and the sale was final in October 1993. The group has taken chub counts every fall since 1986.

Michael Cummings and Anna St. John, both of Portland State University, prepared a report for the Bonneville Power Administration on the hydrogeochemical characterization of the Borax Lake area. The report discussed the geologic and topographic evolution of the Alvord Desert, development of a sinter cap at the lake, lithology types at various hot-spring reservoirs based on strontium and radium isotopes, and the geochemistry of Alvord, Mickey, and Borax Hot Springs. It calculated reservoir temperatures for the three hot springs based on measurements by chemical and isotope geothermometers, the nature of the geothermal system, and water source and residence times.

ACKNOWLEDGMENTS

Numerous individuals and organizations have contributed to this report. Jackie Clark of BLM provided the federal leasing data. George Darr of BPA, Alex Sifford of ODOE, Gene Culver of OIT, and Jerry Black and George Priest of DOGAMI provided information on their agencies' activities. For other contributions we thank Keith Barger and Charlie Bacon of the USGS and Michael Zwart of the Oregon Water Resources Department.

SELECTED REFERENCES

Bacon, C.R., 1992, Partially melted granodiorite and related rocks ejected from Crater Lake caldera, Oregon: Transactions of the Royal Society of Edinburgh, Earth Sciences, v. 83 (also GSA Special Paper 272), p. 27–47.

Bacon, C.R., Newman, S., and Stolper, E.M., 1992, Water, CO_2, Cl, and F in melt inclusions in phenocrysts from three Holocene explosive eruptions, Crater Lake, Oregon: American Mineralogist, v. 77, p. 1021–1030.

Black, G.L., 1994, Geothermal electrical-power generation potential of Newberry volcano and the Oregon Cascade Range: Oregon Department of Geology and Mineral Industries Open-File Report O–94–07, p. 1–73.

Blackwell, D.D., 1994, A summary of deep thermal data from the Cascade Range and analysis of the "rain curtain" effect: Oregon Department of Geology and Mineral Industries Open-File Report O–94–07, p. 75–131.

Bruggman, P.E., Bacon, C.R., Mee, J.S., Pribble, S.T., and Siems, D.F., 1992, Chemical analyses of pre-Mazama silicic volcanic rocks, inclusions, and glass separates, Crater Lake, Oregon: U.S. Geological Survey Open-File Report 93–314, 20 p.

Cummings, M.L., and St. John, A.M., 1993, Hydrogeochemical characterization of the Alvord Valley Known Geothermal Resource Area, Harney County, Oregon: Bonneville Power Administration Report DOE/BP–19408–1, 272 p.

Kamata, H., Suzuki-Kamata, K., and Bacon, C.R., 1993, Deformation of the Wineglass Welded Tuff and the timing of caldera collapse at Crater Lake, Oregon: Journal of Volcanology and Geothermal Research, v. 56, p. 253–266.

Lienau, P.J., and Lund, J.W., 1993, Ground-water anomalies associated with the Klamath Basin earthquakes of September 20–24, 1993: Geo-Heat Center Quarterly Bulletin, v. 15, no. 2, p. 17–19. Revised reprint: Oregon Geology, v. 56, no. 1 (January 1994), p. 7–9.

Lienau, P.J., and Ross, H., 1993, Low-temperature resource assessment program update: Geo-Heat Center Quarterly Bulletin, v. 15, no. 1, p. 17–21.

Nakada, S., Bacon, C.R., and Gartner, A.E., 1994, Origin of phenocrysts and compositional diversity in pre-Mazama rhyodacite lavas, Crater Lake, Oregon: Journal of Petrology, v. 35, pt. 1, p. 127–162.

Suzuki-Kamata, K., Kamata, H., and Bacon, C.R., 1993, Evolution of the caldera-forming eruption at Crater Lake, Oregon, indicated by component analysis of lithic fragments: Journal of Geophysical Research, v. 98, no. B8, p. 14,059–14,074.

U.S. Department of Energy, 1993, Geothermal progress monitor: Report 15, DOE/EE–0014, 84 p. □

MLR recognizes outstanding reclamation

The Mined Land Reclamation Program (MLR) of the Oregon Department of Geology and Mineral Industries presented reclamation awards to six mine operators during the Oregon Concrete and Aggregate Producers Association annual convention in Sunriver, Oregon, on Saturday, May 21, 1994. The awards and the winners are listed and described below.

- Outstanding Operator Award:
  A tie between Karban Corporation, Washington County, and Eagle-Picher Minerals, Inc., Harney County
- Small Operator Award:
  O & S Quarry Products, Tillamook County
- Outstanding Reclamation Award:
  Bonnanza Mining, Inc., Baker County
- Exploration Award:
  Cambiex, Josephine County
- Good Neighbor Award:
  Clackamas Sand and Gravel, Clackamas County

Outstanding Operator Award (two winners): The outstanding operator award is given for excellence in mine development and operation on a daily basis, such as paying exceptional attention to detail, maintaining on-site controls to prevent or minimize degradation of water quality, going beyond reclamation requirements of Oregon laws and administrative rules, using innovative techniques that improve the quality of operation and enhance environmental protection, and operating in a manner that reduces reclamation liability by completing concurrent reclamation on sand and gravel or industrial mineral sites.

Joint winners of the Outstanding Operator Award for this year are Karban Corporation, for its aggregate operation near Timber in Washington County, and Eagle-Picher Minerals, Inc., for its diatomaceous earth mining complex located about 40 miles west of Burns in Harney County.

Karban received its award because of its proactive approach to solving problems. Karban developed a major regional quarry along Pennoyer Creek, which drains into Salmonberry River, considered by some fisheries biologists to be one of the most pristine and productive watersheds in Oregon. During the rainy winter season, Karban went to great efforts to stabilize a large stockpile, trap fine sediment above storm water ponds, and improve the water quality of the storm-water discharge. The operators monitored their own activities and did not wait for regulatory agencies to tell them they had a problem that needed attention. Consequently they were able to prevent problems before they developed.

Eagle-Picher received its award because the operators have been extremely successful in conducting concurrent reclamation at the Breede Desert site. Soil and overburden are stripped and hauled to an area undergoing reclamation, thereby reducing the amount of stockpiled material, keeping disturbed acreage to a minimum, increasing species diversity by keeping any seed in the soil viable, and reducing handling costs. The operator has established vegetation test plots to determine which seed mix works best in the relatively harsh environment and is attempting to establish squaw apples in order to develop deer browse.

Small Operator Award: This award is given for the same criteria as for the Outstanding Operator Award (listed above), except on a smaller scale.

Winner of this award is O & S Quarry Products, a family-owned quarry located on a 175-acre family farm in Tillamook County. Although the quarry was near the highway, it was hidden from view by a topographic barrier. After quarrying was completed, the owners backfilled the quarry wall into a slope and created a shallow wetland by hand-transplanting vegetation and introducing frogs from nearby ponds into the pond that filled the depression left in the pit floor. This outstanding reclamation was particularly noteworthy because it was done with limited resources.

Outstanding Reclamation Award: This award is given to an operator who goes beyond minimum requirements for reclamation or who uses an innovative or creative approach to reclamation. Examples are the establishment of wildlife habitat or riparian area, creation of wetland, voluntary reclamation on land that is not required to be reclaimed, development of public access and recreation opportunities on reclaimed land, and collection and use of native species of plants.

Winner of this award is Bonnanza Mining, Inc., located on USDA Forest Service land along Pine Creek near Halfway in northern Baker County. Mining to extract free gold from a glacial till deposit began on this property in 1986 and was completed in the fall of 1992. Reclamation began in 1988. Prior to mining, soil cover was stripped and stockpiled separately from the overburden. Because of earlier mining at the site, some of the area had no soil cover. To improve revegetation, new soil material was created by mixing sand and silt that had been separated from gravel during the mining with straw and manure obtained from nearby farms and ranches. During the reclamation, more than 5,000 conifers were planted along with numerous native plants including dogwood, black cottonwood, chokecherry, wild rose, snowberry, willows, cattails, and alder. Wetlands created at the site are now filled with thousands of frogs, and blue heron have been observed at the site. Bonnanza received this award because of its outstanding reclamation project and its willingness to address any problems identified by MLR inspectors.

Exploration Award: This award is given to an explorationist who reclaims exploration roads and drill pads to pre-mine topography, revegetates the exploration site to blend in with the surrounding vegetation, and follows established drill-hole abandonment procedures to protect ground water.

Cambiex received this award for a gold exploration site located about 5 miles east of the community of Wolf Creek in northern Josephine County. This site was in a Douglas fir forest on a steep hillside on Bureau of Land Management and Josephine County land. To reach the site, the company used bulldozers to clean out old roads and build one long road and several shorter ones. Upon completion of the exploration, the original contour of the land was restored along the long road by a backhoe. Roads built on county land were left for logging access. To minimize erosion, the surface was recontoured and left in a rough condition, and fallen branches and organic material were incorporated into the slope. Straw mulch was spread over the site. The area was not reseeded, because few grasses grow in the forest environment, and seeds already in the soil revegetated the area with native species. Cambiex was given this award for its successful reclamation on a difficult site.

Good Neighbor Award: This award is given to an operator who unselfishly works with neighbors and the community in a spirit of cooperation to reflect a positive image of the mining industry.

The award was given this year to Clackamas Sand and Gravel Company, who worked with 20 at-risk students from a local alternative high school, giving them hands-on experience in reclaiming eight acres in the Clackamas Industrial Center east of Milwaukie in Clackamas County. The students were taken to the site for four hours a day, two times a week, for six weeks. They learned about native plants, river ecology, and propagation techniques from experts and then used their newly acquired environmental education to create an artificial wetland in an abandoned gravel pit. Clackamas Sand and Gravel produced a video documenting the activities. The company's willingness to work with these students to reclaim an area earned it the Good Neighbor Award. □

Camp Carson Mine site to be reclaimed

Funding for a reclamation project located 20 miles south of La Grande, Union County, along Tanner Gulch Creek in the Wallowa Whitman National Forest was approved at the last meeting of the Strategic Water Management Group in Salem on June 14. Three agencies will work cooperatively to clean up the abandoned Camp Carson Mine site to protect critical salmon habitat in the upper Grande Ronde River. Cooperating agencies are the USDA Forest Service, which will contribute $45,000 to the project; the Bonneville Power Administration, which will contribute $20,000; and the State of Oregon Watershed Health Program, which will contribute $45,000. The Oregon Department of Geology and Mineral Industries and the USDA Forest Service will jointly do the actual reclamation work.

Design of the reclamation project is scheduled to begin immediately. The completion date is set for June 30, 1995. DOGAMI staff geologist Dan Wermiel said, "Steps must be taken immediately to protect the spawning habitat in the upper Grande Ronde River and downstream reaches from getting a heavy load of sediment from the Camp Carson area."

Gold mining at the Camp Carson Mine, one of the largest hydraulic placer gold mines in Union County, first began in 1872. Although the most intense mining took place in 1893 and 1894, mining occurred over a period of many years at the site. In the early 1980s, the operator who was mining at the site abandoned it, leaving silts, claystone, and gravels on the edge of a steep hillside. This material is being washed into Tanner Gulch Creek, which will eventually affect salmon spawning habitat. In addition, cracks that are appearing in the slope suggest that a massive landslide may be imminent. Plans to reduce the amount of sediment washed into Tanner Gulch, to stabilize the slide, and to reclaim the site include recontouring the land, revegetating the hillsides to stop runoff, dewatering the slide, and building structures to contain both the slide and sediments coming from it. □

GIS/AGI/AESE offer geowriting course

The Geoscience Information Society (GIS), the American Geological Institute (AGI), and the Association of Earth Science Editors (AESE) will cosponsor the short course "Geowriting: Guidelines for Writing and Referencing Technical Articles" at the 1994 Geological Society of America annual meeting in Seattle in October.

The morning session of the course will focus on technical report writing. As a resource and text it will use the newly revised book *Geowriting*, which was published by AGI and has gone through several editions since its first appearance in 1973. Discussion will cover organization, getting started, editing, common grammatical problems, graphic presentation of data, and a brief introduction to common software packages available for word processing and computer graphics.

The afternoon session will focus on library research and referencing: the use of library catalogs and bibliographic databases, the compilation of references, and the use of software for compiling references and bibliographies.

The short course will be given on Saturday, October 22, 1994, 8 a.m. to 5 p.m., at the Seattle Sheraton Hotel. The number of participants is limited to 35, and preregistration is required. The fee, which includes handouts and a copy of *Geowriting,* is $140 ($120 for early registration prior to August 1). For students, the fee is $99.

Contact for more information and registration is Julie Jackson, American Geological Institute, 4220 King Street, Alexandria, VA 22302; phone 703/379-2480; FAX 703/379-7563; internet email lar@aip.org. —*GIS news release*

DOGAMI PUBLICATIONS

Open-file report presents two geothermal studies

The Oregon Department of Geology and Mineral Industries (DOGAMI) has released two geothermal studies of the Cascade Range and of Newberry volcano just east of it in central Oregon. One report provides estimates for electrical generation potential; the other report helps in determining where and how deep future exploratory drill holes should be to provide useful thermal data.

The two studies have been released as one report, DOGAMI Open-File Report O–94–7. Gerald L. Black produced the report *Geothermal Electrical-Power Generation Potential of Newberry Volcano and the Oregon Cascade Range*; and David D. Blackwell produced *A Summary of Deep Thermal Data From the Cascade Range and Analysis of the "Rain Curtain" Effect.* Preparation of the reports was funded by the Bonneville Power Administration as part of a program to identify and characterize geothermal resources in Oregon.

Both reports are based on all relevant drilling data that have been produced so far. Black's report evaluates geothermal potential on a township-by-township or, for Newberry volcano, on a section-by-section basis. Blackwell's report summarizes and evaluates data of 17 deep geothermal exploration wells from Washington to northern California and of 12 deep wells from the Newberry volcano area. While temperature gradients cannot be determined except by drilling, the evaluation of previously collected data allows more systematic planning of future exploratory wells. The significance of the "rain curtain effect," which describes the influence of shallow ground-water flow on geothermal temperature data, appears to have been overestimated in the past.

Open-File Report O–94–7 sells for $9. The order form on the back cover of this issue has detailed ordering information.

New tsunami brochure available

The Oregon Department of Geology and Mineral Industries (DOGAMI) has prepared a brochure telling Oregonians and visitors to the state what to do in case of a tsunami. Entitled "Tsunami!" and printed by Portland General Electric Company, the brochure describes the causes of tsunamis, tells what to do ahead of time to prepare for such a disaster, and gives instructions on what to when a tsunami occurs. The brochure also presents facts about other tsunamis that have affected Oregon and other parts of the world, and lists names and addresses of emergency organizations and other sources of information about both earthquakes and tsunamis.

A tsunami caused by an offshore earthquake could strike the Oregon coast just minutes after the ground shaking stops and before there is time for an official warning. The earthquake may be the only warning that a tsunami is coming. So it is important that people know of the danger and what to do to protect themselves.

Although tsunamis are infrequent, they occur often enough around the world to warrant attention and preparation. Last year, for example, a tsunami generated by an offshore earthquake hit the Japanese island of Okushiri five minutes after the earthquake, generating waves from 10 to 100 ft high. Although the tsunami devastated a city on the island, only 200 people died, because the Japanese have been trained to go inland and uphill after an earthquake, even if there is no official warning, and most of the citizens saved their lives by doing so.

The tsunami brochure is available through coastal emergency offices and other locations on the coast. Single copies may be obtained by sending a self-addressed and stamped legal-size envelope to the Nature of Oregon Information Center, Suite 177, 800 NE Oregon Street #5, Portland, OR 97232. Organizations wanting larger numbers of copies should contact the Center, phone 731-4444. □

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