JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 93, NO. B9, PAGES 10,163–10,173, SEPTEMBER 10, 1988

GL01945

Core Hole Drilling and the "Rain Curtain" Phenomenon at Newberry Volcano, Oregon

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Two core holes have been completed on the flanks of Newberry Volcano, Oregon. Core hole GEO N-1 has a heat flow of 180 mW m^{-2}, reflecting subsurface temperatures, sufficient for commercial exploitation of geothermally generated electricity. GEO N-3, which has a heat flow of 86 mW m^{-2}, is less encouraging. We emphasize the "rain curtain" effect with the hope that a detailed discussion of this phenomenon at two distinct localities will lead to a better understanding of the physical processes in operation. Core hole GEO N-1 was cored to a depth of 1387 m at a site located 9.3 km south of the center of the volcano. Core hole GEO N-3 was cored to a depth of 1220 m at a site located 12.6 km north of the center of the volcano. Both core holes penetrated interbedded pyroclastic lava flows and lithic tuffs ranging in composition from basalt to rhyolite, basaltic andesite being the most common rock type. Potassium-argon age dates range up to 2 Ma. Caving and sloughing were encountered in both core holes at depths near the regional water table. Both core holes penetrate three distinct thermal regimes. The uppermost regime is isothermal at mean air temperature down to about 900–1000 m (the rain curtain). A thermally conductive regime exists near the bottom of each core hole. Separating these two thermal regimes is a transition zone exhibiting considerable hydrologic disturbance. The uppermost isothermal regime is characterized by (1) a low and fairly uniform response on the gamma ray log (N-1, N-3) and the electrical conductivity log (N-1), (2) temperatures below surface ambient measured downhole with a maximum recording thermometer (MRT) during periodic pauses in drilling operations (N-1, N-3), and (3) drilling fluids whose chemistry does not reflect an influx of geothermal fluids (N-3). In contrast, the thermally conductive regime is characterized by (1) a high and variable response on the gamma ray log (N-1, N-3) and on the electrical conductivity log (N-1), (2) temperatures (MRT) measured downhole during pauses in drilling which are above ambient and which track in situ conditions (N-1, N-3), and (3) drilling fluids whose chemistry clearly reveals a geothermal component (N-3). The transition zone is characterized by major washouts in the caliper log (N-1, N-3), a major anomaly in the mercury content of the rocks (N-1), an extremely strong response on the gamma ray log (N-1, N-3) and electrical conductivity log (N-1), and a major self-potential anomaly (N-1). Smectite alteration, which seems to control the results of surface geoelectrical studies, begins in the isothermal regime close to and perhaps associated with the regional water table.

INTRODUCTION

The Cascade Range, which consists of a series of Quaternary and late Tertiary andesitic volcanoes that extend from northern California to southern British Columbia, is a geologic province with immense potential for the generation of electricity from geothermal resources. The geothermal potential for the Cascades Province may well be thousands if not tens of thousands of megawatts [*Bloomquist et al.*, 1985]. Yet to date, there are no geothermal power plants operating in the Cascades Province, and none are planned. Furthermore, except for the obvious heat sources represented by the active volcanoes, very little is known about the potential geothermal resources in the Cascades.

The geothermal literature is particularly sparse on such key parameters as the chemistry of geothermal fluids, the deep thermal structure of the geothermal systems, and the nature of reservoir host rocks in the Cascades. The *Northwest Power Planning Council* [1986] has not even included geothermal energy in their long-range power forecasts, stating that "because the information regarding the character and extent of the regional geothermal resource areas used to prepare the estimates of cost and availability is very preliminary, this resource (geothermal) cannot be considered as available for the resource portfolio of this power plan."

The paucity of geothermal data in the Cascades Province and the consequent reluctance of the utility companies to plan for future geothermal development can all be traced to the single phenomenon known as the "rain curtain." This term refers to the zone of hydrologic disturbance where cool meteoric water percolates downward and spreads laterally, therefore masking the surface expression of geothermal activity. The rain curtain can severely complicate, if not render useless, the standard geophysical and geochemical techniques for locating and evaluating geothermal reservoirs. For example, hot springs are typically diluted or masked completely, temperature gradient holes may be isothermal to depths in excess of a kilometer, and surface geoelectrical studies must be designed

Paper number 7B1065.
0148-0227/88/007B-1065$05.00

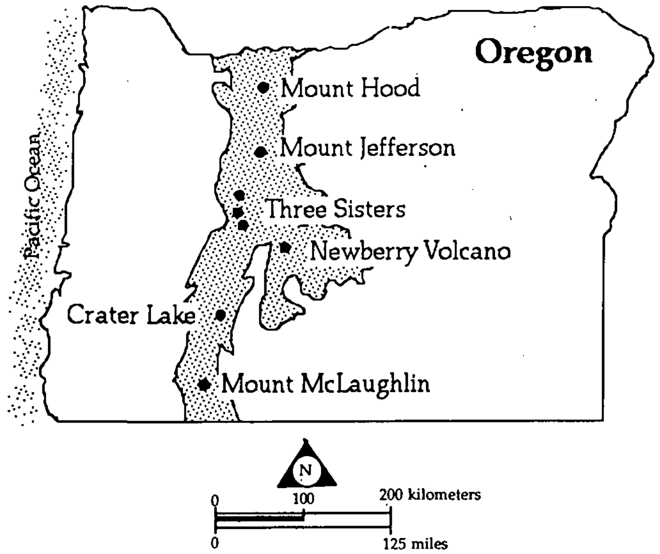

Fig. 1. Index map showing the location of Newberry Volcano in relation to the Oregon Cascades (stippled area).

to penetrate a kilometer or more of "noise" before geothermally useful data can be obtained. A case in point is Newberry Volcano, Oregon (Figure 1), where the rain curtain ranges in thickness from less than 300 m within the caldera [*Black et al.*, 1984] to about 1000 m on the southern flank [*Swanberg and Combs*, 1986]. The cool meteoric zone overlies a geothermal system that is at least 265°C at a depth of 900 m [*Sammel*, 1981], yet supresses the surface manifestations of this system to the extent that only two small warm springs exist over the entire volcano. Various geoelectric and geoelectromagnetic studies including magnetotellurics (D. Stanley, U.S. Geological Survey, Denver, Colorado, personal communication, 1986), Schlumberger soundings [*Bisdorf*, 1985], and transient geoelectromagnetic soundings [*Fitterman and Neev*, 1985] have shown the presence of electrically conductive zones both inside and outside the caldera, but the lack of drilling data has precluded a rigorous interpretation of these conductors [*Fitterman and Neev*, 1985, p. 409].

In recognition of this situation, the U.S. Department of Energy (DOE), Division of Geothermal and Hydropower Technologies (DGHT), initiated a Cascade Deep Thermal Gradient Drilling Program. The stated purpose of the program is to "support industry efforts in the Cascade Volcanic region," and the stated objectives are to "cost share with industry for the drilling of gradient holes which would penetrate the 'rain curtain' and obtain deep thermal, lithologic, and structural data." In exchange for the cost sharing, the industry participant would "release [the data] to the public for the benefit of the geothermal industry and the scientific community" [*Earth Science Laboratory*, 1986].

To date, GEO Operator Corporation (GEOOC) has cored and completed five core holes at Newbery Volcano, two of which were drilled under the DOE Cascades Drilling Program. The first cost-shared core hole, GEO N-1, was completed in the fall of 1985 to a depth of 1387 m on GEO leaseholds on the south flank of the volcano. Data and core from the upper 1219 m are in the public domain [*Earth Science Laboratory*, 1987]. The second cost-shared core hole, GEO N-3, was completed in the summer of 1986 to a depth of 1220 m. Data and core from all of this core hole are in the public domain [*Earth Science Laboratory*, 1987]. In the following sections, the basic data from these two core holes are presented with some preliminary observations which pertain to the understanding of the phenomenon of the rain curtain and its physical characteristics. We hope the data and observations will lead to an enhanced understanding of the rain curtain, to subsequent refinements in geothermal exploration techniques for use in the Cascade Province, and finally, to an increased understanding of Cascade geothermal systems and their potential for economic exploitation.

GEOLOGY OF NEWBERRY VOLCANO

Newberry Volcano, covering roughly 1300 km^2 in central Oregon, is one of the largest volcanoes in the conterminous United States and is one of a series of Quaternary bimodal volcanoes located to the east of the main Cascade Range trend (Figure 1). The volcano lies near the juncture of the Cascade Range with the Brothers fault zone, a northwest trending fracture system along which silicic volcanism and rhyolitic domes become progressively younger to the northwest [*MacLeod et al.*, 1975]. Considerable research has been conducted at Newberry during the past several years [*Sammel*, 1981; *MacLeod et al.*, 1981, 1982; *MacLeod and Sammel*, 1982; *Ciancanelli*, 1983; *Priest et al.*, 1983, 1987], which update the earlier work of *Williams* [1935] and *Higgins* [1973]. Holes drilled within the caldera by the U.S. Geological Survey (USGS) and Sandia National Laboratories attained 265°C at 932 m [*Sammel*, 1981] and greater than 160°C at 424 m [*Black et al.*, 1984], respectively. The geothermal potential of Newberry Volcano has been estimated at 740 MWe for 30 years by the USGS [*Muffler*, 1979] and 1551 MWe for 30 years by Bonneville Power Administration [*Bloomquist et al.*, 1985].

Newberry has a low, shieldlike profile with a central caldera measuring roughly 6 × 8 km, which contains two small lakes (Figure 2). Within the caldera, rhyolitic units predominate, the youngest of which is the Big Obsidian Flow that erupted about 1300–1400 years ago [*Pierson et al.*, 1966; *Friedman*, 1977]. The young silicic flows are generally younger than the ubiquitous Mazama Ash that blanketed the volcano 6845 years ago [*Bacon*, 1983]. The flanks of the volcano consist of basalt and basaltic andesite flows and andesite to rhyolite domes and flows which are typically less than a few million years old (Figure 2). Cinder cones and fissure vents are common throughout the volcano, particularly in the region surrounding core hole GEO N-1 [*MacLeod et al.*, 1982]. The youngest basalt flows are post-Mazama Ash and are therefore younger than 6845 years. A sample of charcoal, discovered while digging the mud pit for core hole GEO N-1, provided a ^{14}C age date of 5835 ± 195 years B.P. The sample was collected from a soil horizon beneath about a meter of basalt cinder and therefore establishes the age of the youngest rocks at the drill site.

CORE HOLE GEO N-1

Core hole GEO N-1 was drilled at a surface elevation of 1780 m on the south flank of the volcano at an intermediate distance (9.3 km) from the geometric center of the volcano (see Figure 2). Based on the GEOOC exploration plan, core holes have been drilled at different distances from the center of the volcano in order to determine whether there is radial symmetry of the heat source. Core hole GEO N-1 was drilled near the neck of a very young basalt flow, the Surveyors flow, whose age is probably comparable to the 5835 ± 195 years

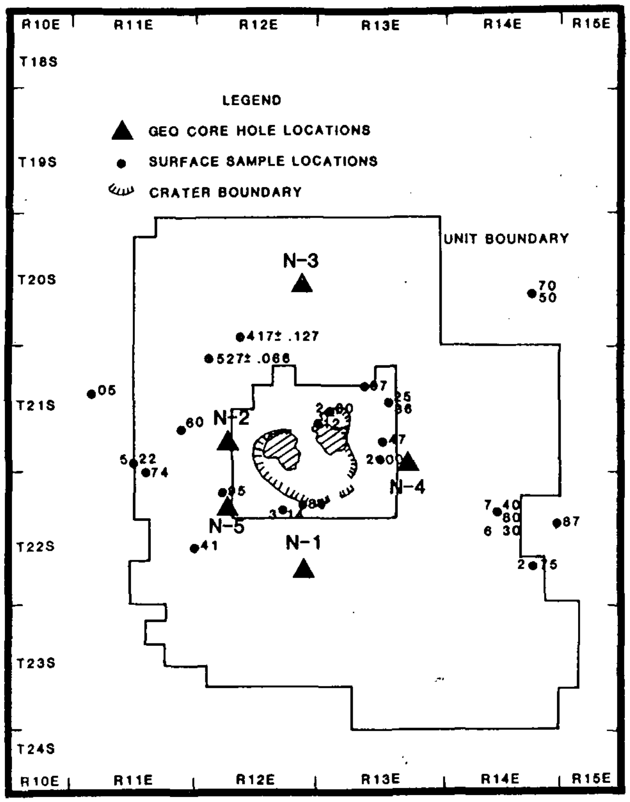

Fig. 2. Potassium-argon age dates (Ma) for surface samples at Newberry Volcano, Oregon. Data from *Fiebelkorn et al.* [1982] are plotted as age dates with the plot point representing the decimal point. Two GEO determinations are presented with errors indicated. The location of the Newberry Flank Federal Geothermal Unit (area between the two boundaries), the Newberry known geothermal resource area (KGRA) (inside the inner boundary), and the location of the two small lakes inside the crater are also shown.

B.P. date obtained for the near-surface cinders at the drill site [*Swanberg and Combs*, 1986]. The core hole is also located near the center of a major soil mercury anomaly [*Hadden et al.*, 1982].

The average heat flow from GEO N-1 is 180 mW m^{-2} based on a least squares fit to temperature-depth data over the thermally conductive regime between 1164 and 1219 m and 12 measurements of thermal conductivity representing the same interval (Table 1). Heat flow values of this magnitude imply temperatures in excess of 200°C at depths less than 3 km. Such temperatures are sufficiently high and accessible as to imply the possible commercial exploitation of geothermal resources for the generation of electricity utilizing either the single or double flash power conversion technologies, provided of course, that suitable production zones can be encountered in deep geothermal wells.

Geophysical Logging Program

The physical condition of core hole GEO N-1 caused deviation from a traditional geophysical logging program. Specifically, the interval 378–549 m was known to be associated with caving and sloughing. In order to minimize the risk of loosing a logging tool and possibly the entire core hole, it was decided to forego the geophysical logs over this interval. Therefore after drilling to total depth, the rods were pulled to a depth of about 550 m, leaving the upper 550 m of the core hole, including the incompetent section, behind pipe. The remainder of the hole was open. The hole was then conditioned, and a suite of logs was run from 550 m to total depth. After this first logging run, the rods were pulled out of the hole, and the geophysical logs were run from the base of the surface casing at 143 m to the top of the incompetent section 378 m. The logging program called for temperature, induction, gamma ray, caliper, sonic, bore hole compensated acoustic fraclog, and density logs; however, the density log was terminated because the tool would not freely penetrate the section.

Depth to Water Table

The depth/elevation of the water table is an important parameter in regional hydrologic studies of geothermal systems and is also useful in interpreting the results of experiments conducted at the surface or within the core hole. Unfortunately, the water table at GEO N-1 seems to be an elusive phenomenon. None of the geophysical logs indicate an obvious perturbation that might represent the water table. It is possible that the water table lies in the interval 378–550 m, which never was logged. The driller routinely estimates and records the standing water level in the core hole, and almost all such estimates fall within the unlogged interval, the most common estimate being about 490 m. This unlogged interval also represents the approximate depth at which smectite and other alteration products first occur within the subsurface section [*Bargar and Keith*, 1986]. These observations, coupled with the instability of the core hole (caving-sloughing), suggest a geologically plausible cause and effect relationship, i.e., geothermal fluids rising from depth spreading laterally near the water table and promoting hydrothermal alteration, which generally weakens the rocks. The closeness of the water table to physically incompetent rocks is noteworthy because it may allow difficult drilling conditions to be predicted, thus reducing the risks (drilling problems such as stuck rods and twist off) and costs.

The Temperature Log

The equilibrium temperature log is shown in Figure 3 and was taken 10 months after drilling. The data from all temperature logs over the interval 450–1219 m are illustrated in Figure 4. At least three distinct thermal regimes can easily be recognized on the logs (see Figure 3 or 4). The temperature log

TABLE 1. Heat Flow, Newberry Volcano, Oregon

	Depth Range, m	Gradient, °C/km	Thermal Conductivity, W m^{-1} K^{-1}	Number of Samples	Heat Flow, mW m^{-2}
GEO N-1	1164–1177	122.7	1.76 ± 0.40	5	216
	1180–1192	86.7	2.01	1	174
	1195–1219	74.9	2.00 ± 0.08	6	150
Average					180
GEO N-3	1172–1220	54.3	1.59 ± 0.14	9	86

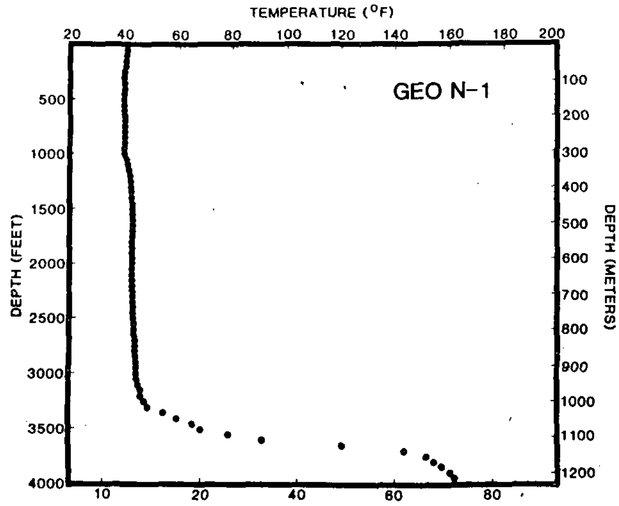

Fig. 3. Equilibrium temperature log for GEO N-1. Original data were collected (September 25, 1986) by Blackwell and Spafford and were measured at 2-m intervals with a precision of 0.01°C. Data plotted at 10-m intervals.

is isothermal at mean air temperature (6°C) down at least to the water table at about 490 m and probably beyond. The interval 1158 m to total depth is a thermally conductive regime. Between the isothermal and conductive regimes lies a third interval over which the temperatures increase very rapidly with depth (see Figures 3 and 4).

The nature and extent of the uppermost isothermal section (the rain curtain) have been the subject of debate among several workers who have examined the temperature logs. There is no doubt that the rain curtain extends at least to the water table (about 490 m), but there is a question as to whether the isothermal temperatures measured for several hundred meters below the water table indicate a rain curtain, or merely water percolating downward in the annulus between the completion tubing and the walls of the core hole.

One scenario has the rain curtain extending to an approximate depth of 1005 m, at which point the downward percolating groundwater exits the volcano along the highly permeable horizons depicted on the geophysical well logs (Figure 5). In this first model, the rain curtain is located in a suite of volcanics whose geological character (including porosity and permeability) is distinct from the suite of rocks lying below. This model is favored by the fact that the volcanic section does in fact change character at depths near the bottom of the isothermal section (Figure 5) and also by the fact that temperatures measured during pauses in drilling operations were never above ambient until depths of 500 m below the water table.

A second scenario [*Blackwell and Steele*, 1987] has the rain curtain extending to a depth of 350–400 m, while the remaining isothermal interval is a consequence of intrahole fluid flow. In this second model the rain curtain would coincide with the region above the water table. This model is favored by its simplicity and by the observation that an extrapolation upward of the deep temperatures intersects mean air temperature at a depth which is not incompatible with the water table.

A third (preferred) hybrid possibility would accommodate limited groundwater flow within the annulus over the interval 1005–1158 m. The first or third model is favored on the assumption that the temperatures measured during drilling are diagnostic, if not highly accurate, thus precluding the second model, which associates the rain curtain with the water table. Also, the first and third models are more compatible with the fluid geochemistry data from GEO N-3, which are dicussed below.

The Mercury Log

Core hole GEO N-1 was sited on one of the major soil mercury anomalies of *Hadden et al.* [1982], as was the USGS core hole NB-2, which was located near the center of the volcano, and which encountered temperatures of 265°C at 932 m [*Sammel*, 1981]. Because soil mercury surveys are routinely used as a surface manifestation of subsurface geothermal conditions, it was decided to attempt a detailed mercury survey of the rocks penetrated by core hole GEO N-1 in the hopes of learning more about the migration of mercury from a geothermal reservoir to the surface. The sampling procedure was to randomly select several core fragments from each 3-m interval, pulverize and sieve the aggregate to the same mesh as typically used in soil mercury surveys, and analyze the resulting powdered core sample for mercury content. The results of the survey are shown in Figures 5 and 6. The upper part of the core hole failed to yield detectable levels of mercury, so the sampling technique was modified to emphasize altered zones and fractures. This technique also failed to yield detectable mercury. However, once the hydrologically disturbed zone between 945 and 1000 m was entered, a major mercury anomaly was encountered. This anomaly has been verified by resampling and laboratory analysis by an independent laboratory. The mercury anomaly is shown in Figure 5 in relation to other core hole data sets, and the correlation among the mercury anomaly, the rapid temperature buildup, and the "washouts" in the caliper log is quite obvious. Clearly, geothermal fluids relatively enriched in mercury are migrating through this interval. But the relationship between this mercury anomaly within the core hole and the soil mercury anomaly at the surface remains unclear. None of the other fracture or rubble zones in the core hole are enriched in mercury, and the low

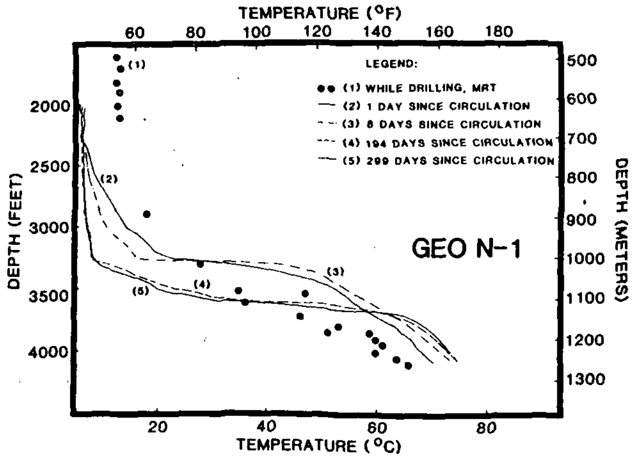

Fig. 4. Summary of all temperature data below 500 m for GEO N-1. Plotted points labeled "1" represent MRTs, which were allowed to sit on bottom for roughly 10 min without circulation. Logs 2–4 were obtained by Geotech Data and represent discrete measurements at 3-m intervals with a precision of 0.01°C. Log 5 is the same as that presented in Figure 3.

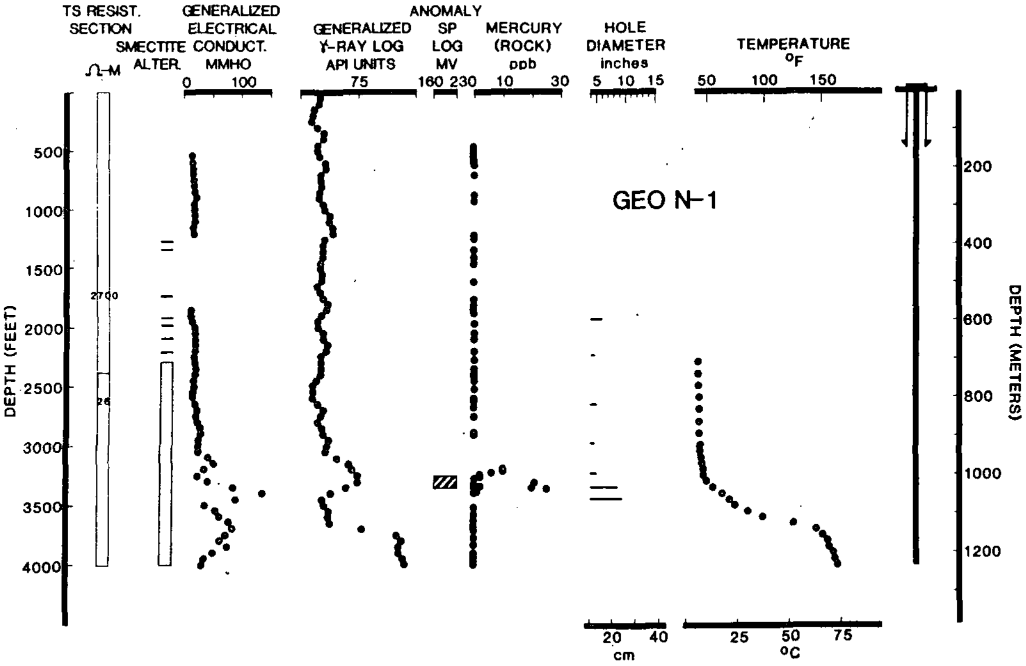

Fig. 5. Comparison of GEO N-1 logs, from left to right: (1) the one-dimensional geoelectric section determined from the surface measurements of *Fitterman and Neev* [1985] using transient geoelectromagnetic soundings (TS), (2) smectite alteration from *Bargar and Keith* [1986], (3) generalized electrical conductivity (see text for discussion), (4) generalized gamma ray log (see text for discussion), (5) the location of the self-potential anomaly, (6) mercury log (see Figure 6 for details), (7) location of washouts below 500 m as determined by the caliper log, (8) the bottom part of the temperature log shown in Figure 3, and (9) the core hole completion. Note the unlogged section (conductivity log) which reflects the depth interval of difficult drilling conditions and also the relationship between the zone of rapid temperature buildup and anomalies in the other geophysical logs.

background levels of mercury throughout the core hole would seem to preclude the volcanic pile itself as the source of the soil mercury anomaly. These data are consistent with the standard concept that soil mercury anomalies result from clay entrapment of mercury ascending along fractures from depth. However, it is not possible to prove that the mercury anomaly at depth is the origin of the soil mercury anomaly observed at the surface.

Geophysical Logs: Electrical Conductivity

A generalized electrical conductivity log derived from the induction log for core hole GEO N-1 is shown in Figure 5. It was prepared by averaging the log over 30-m intervals and plotting the resulting average at the midpoint of the 30-m section. Thus any anomalous point in this log may be reflecting changes up to 15 m on either side of the depth at which the point is plotted. The logic behind this type of presentation is the expectation that gross changes in the electrical properties of the volcanic pile might be detected from the ground surface using traditional geoelectric or geoelectromagnetic surveys. Examination of the generalized electrical conductivity log (Figure 5) shows the volcanic pile to be of generally constant conductivity down to a depth of 945 m. This interval of uniform conductivity coincides very well with the rain curtain, as defined by the five temperature data sets (Figure 4). The conductivity log shows no obvious perturbations at the water table (490 m), at the onset of smectite alteration (Figure 5, column 2), or at the depths at which smectite alteration becomes ubiquitous (Figure 5, column 2). Below 945 m, the volcanic pile becomes significantly more conductive and more variable in its electrical conductivity. The increased electrical conductivity may result as a direct consequence of higher temperature or from the effects of increasing rock alteration (Figure 5). In either case, the increased conductivity represents a marked change in the physical properties of the volcanic pile which is related to geothermal activity and which, at least in theory, should be detectable from the surface. *Fitterman and Neev* [1985] have published the results of a one-dimensional geoelectrical model based on a transient geoelectromagnetic sounding (TS) located at the GEO N-1 site. This model is reproduced in Figure 5, column 1, as "TS resist section Ω — M." Unfortunately, the model appears to reflect smectite alteration and not the geothermal system. A similar conclusion has been published by *Wright and Nielson* [1986], also based on analyses of data from core hole GEO N-1.

Geophysical Logs: Gamma Ray

A generalized gamma ray log for core hole GEO N-1 is presented in Figure 5. It was prepared in a manner analogous to the electrical conductivity log, i.e., averaged over 30-m sections and plotted at the midpoint. The generalized gamma ray log is fairly uniform from the surface to a depth of 945 m, below which the rocks become significantly more potassic (see stratigraphic column, Figure 6).

It is interesting to note that the gamma ray and electrical conductivity logs are inversely correlated throughout the nonisothermal section of the core hole (i.e., below 945 m) but not in the isothermal section (i.e., 0–945 m). A thermal origin for this inverse correlation is suggested and probably reflects the manner in which laterally migrating geothermal fluids promote rock alteration. Apparently, the more mafic glass-rich basalts are more prone to undergo alteration to highly con-

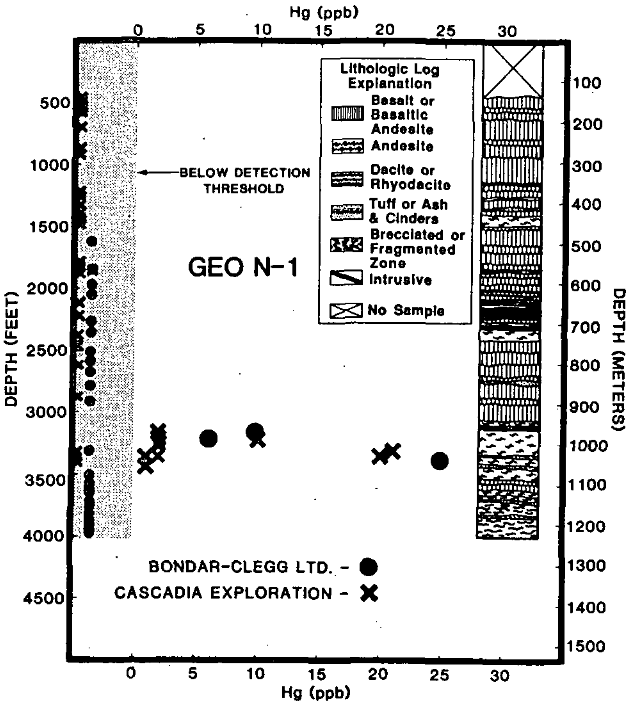

Fig. 6. Generalized lithologic log and detailed rock mercury analyses for GEO N-1. The detection thresholds for the Cascadia and Bondar-Clegg analyses are 1 and 5 ppb, respectively.

ductive clay minerals such as smectite than are the more potassic rocks which show the strong gamma ray signature (from ^{40}K). The lack of the inverse correlation throughout the isothermal section would therefore reflect a lack of migrating geothermal fluids (see Figures 3 and 4), a general lack of felsic volcanics (see Figure 6), or a combination of both.

Geophysical Logs: Caliper

The core hole diameter over the interval 550–1045 m as depicted by the caliper log is presented in Figure 5. The three lower washouts and their association with the rapid temperature increase and other anomalous features of the core hole have already been discussed. The four washouts further up the core hole do not appear to reflect migration of geothermal fluid (i.e., they are in the rain curtain).

Geophysical Logs: SP

The SP log (Figure 5) undergoes a drop of 70 mV over the interval from about 1000 to 1020 m. This feature probably reflects fluid movement and is the only such feature on the SP log.

Rock Alteration

Bargar and Keith [1986] have studied the alteration mineralogy of core hole GEO N-1. A generalized depiction of smectite alteration, taken directly from *Bargar and Keith* [1986], is shown in Figure 5. The relationships among alteration mineralogy, the electrical conductivity log, and surface geo-electromagnetic studies are discussed elsewhere in this report.

Potassium Argon (K-Ar) Age Dates

K-Ar age dates representing surface samples collected from around Newberry Volcano are presented in Figure 2 and typically are less than 2 Ma although ages as old as 5–7 Ma are reported for the outer flanks of the volcano. Age dates representing samples taken from core hole GEO N-1 increase systematically with increasing depth from values of 27,000 and 29,000 years B.P. at 481 and 491 m, respectively, to 1.63 Ma at 1081 m (Figure 7, Table 2). In addition, in an earlier work, *Swanberg and Combs* [1986], reported the results of a single ^{14}C age date based upon charcoal discovered while digging the mud sumps. This date of 5835 ± 195 years B.P. establishes the age of the basaltic cinders at the surface near the core hole.

Whenever age dates are determined in a geothermal environment, the possibility always exists of nonrepresentative ages due to argon diffusion and subsequent resetting of the K-Ar clock. Perhaps the best testament to the reliability of the age dates presented in Table 2 and Figure 7 is the fact that they are geologically reasonable. The dates are generally compatible with those determined from surface samples throughout the volcano. The dates increase systematically with depth throughout the core hole, and there is no radical departure from this trend upon encountering the zone of ubiquitous smectite alteration near 700 m (Figure 5) or encountering the zone of rapid temperature buildup near 1000 m.

Chemistry of Formation Fluids

During drilling operations, fluid samples were episodically selected for chemical analysis. Although such samples would be severely contaminated with drilling mud, it was felt that various geothermal constituents might be detectable above the background and, if so, would serve to indicate any environmental problems that might be encountered during eventual production. The results of silica analyses as a function of depth are presented in Figure 8. Representative samples of the drilling fluid are also shown. Analyses of other chemical constituents are even less revealing than silica and are not reported here.

The Rain Curtain as a Lithologic Discontinuity

The coincidence that the generalized gamma ray and electrical conductivity logs both change character at a depth (945 m, Figure 5) which is compatible with the rain curtain as defined by the five temperature data sets (Figure 4) suggests the possibility that the rain curtain may represent a lithologic

TABLE 2. K-Ar Age Dates, Newberry Volcano, Oregon

Depth, m	Age, Ma	Description
	GEO N-1	
370	0.306 ± 0.075	basaltic andesite
481	0.027 ± 0.009	basaltic andesite
491	0.029 ± 0.081	basaltic andesite
701	0.090 ± 0.026	basaltic intrusive
724	0.847 ± 0.110	basaltic andesite
892	0.768 ± 0.147	basalt
913	0.746 ± 0.110	basalt
987	0.943 ± 0.053	andesite
994	0.997 ± 0.050	andesite
1081	1.630 ± 0.13	basaltic andesite
	GEO N-3	
324	1.50 ± 0.63	phyric basalt
594	0.911 ± 0.188	phyric basaltic andesite
769	*0.109 ± 0.081*	*lithic tuff*
853	0.819 ± 0.113	basalt
1010	1.04 ± 0.03	rhyodacitic flow
1100	1.54 ± 0.05	rhyodacitic flow
1207	1.18 ± 0.30	basalt

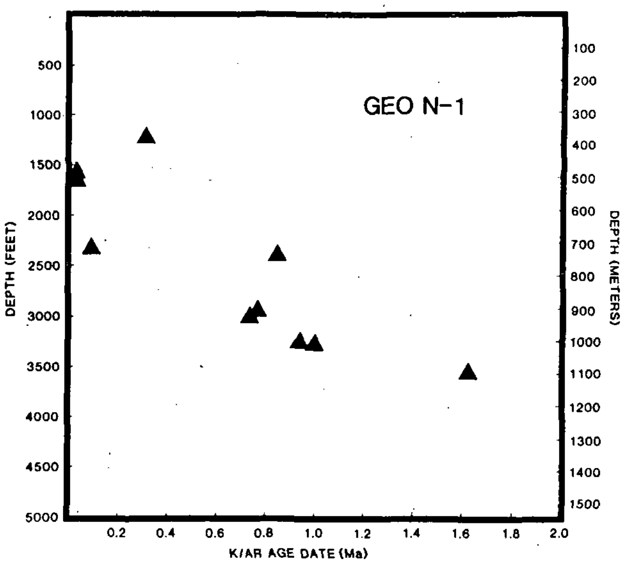

Fig. 7. Potassium-argon age dates from GEO N-1. Note the agreement with the surface data shown in Figure 2.

discontinuity. An intriguing (but speculative) extension of this logic is to associate such a discontinuity with the transition between pre- and post-Newberry strata. The pre-Newberry strata are generally more felsic than the Newberry pile (E. V. Ciancanelli personal communication, 1987), so that the pre/post-Newberry transition might well produce a generalized gamma ray signature similar to that shown in Figure 5. *MacLeod and Sherrod* [this issue] confine the Newberry section to those normally polarized strata younger than 0.73 Ma. The K-Ar age dates shown in Figure 7 are compatible with a pre/post-Newberry transition at 945 m. In fact, using selective license with the error bars on the K-Ar age dates (Table 2) indicates that all age dates shallower than 945 m are 0.737 Ma or less, while all age dates deeper than 945 m are older than 0.73 Ma. At present, however, the data do not totally support the postulation of a depth or even the existence of a pre/post-Newberry discontinuity. Any K-Ar age dates for extremely young potassium-poor rocks located in a geothermal regime are subject to question, and although the age dates presented in Table 2 and Figure 7 are considered reliable, this issue should be tabled until the paleomagnetic studies have been completed and the K-Ar age dates have been verified.

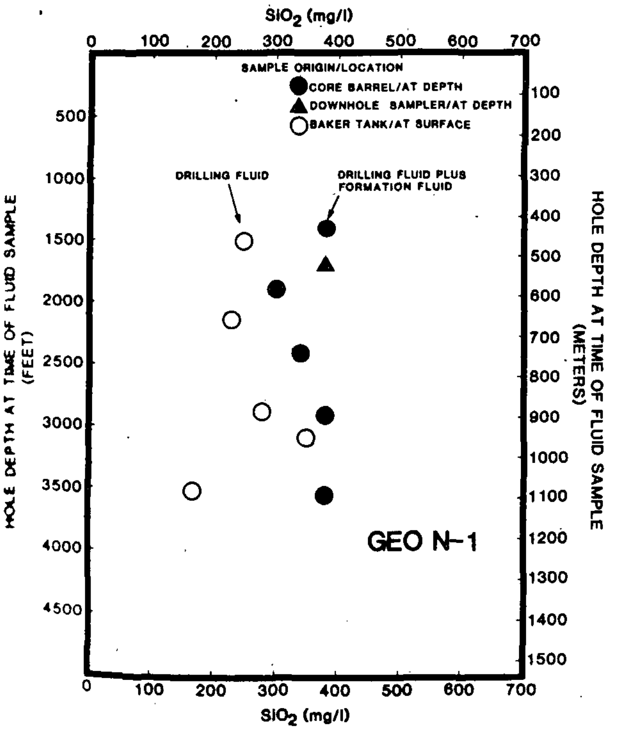

Fig. 8. Silica content of fluids recovered from GEO N-1. Surface samples are depicted as open symbols, while downhole samples are solid symbols. Note that all downhole samples are contaminated with drilling fluid.

Core Hole N-3

Core hole GEO N-3 was drilled at a surface elevation of 1753 m on the north flank of the volcano at a distance of 12.6 km from the center of the volcano (see Figure 2). Of all of the Newberry core holes, GEO N-3 is the most distant from the center of the volcano. Heat flow from GEO N-3 is 86 mW m^{-2} based on a least squares fit to the temperature-depth data over the thermally conductive region between 1170 and 1220 m and nine measurements of thermal conductivity representing the same interval (Table 1). This value is typical of heat flow values found throughout the nongeothermal areas of the Cascade Range [*Blackwell and Steele*, 1987] and therefore does not indicate the presence of an exploitable geothermal resource. This core hole, located 12.6 km from the center of the volcano, apparently constrains the radial extent of the major geothermal system associated with the core of Newberry Volcano. If geothermal resources are to be located at such large distances from the center of the volcano, they must be associated with heat sources which are separate from the main volcanic heat source.

Geophysical Logging Program

As in core hole GEO N-1, the integrity of core hole GEO N-3 forced modifications to the geophysical logging program. Specifically, at a depth of about 520 m the rods became stuck in the core hole and were cemented in place, causing a reduction in hole size. To compound the problem, the induction tools and gamma ray tools required to penetrate the smaller diameter hole all failed, The gamma ray log was recovered from the surface to total depth, since this log could be run through the completion tubing, but the induction log was lost. The temperature log and the neutron density log were also run from surface to total depth, but the caliper log and BHC acoustic fraclog could only be run from 520 m to total depth. The casing schematic for core hole GEO N-3 is shown in Figure 9.

Depth to Water Table

The depth to the regional water table is just as elusive as in GEO N-1. The standing water level in the core hole as estimated by the drillers ranges from about 455 to 565 m with a modal value of 525 m. Thus the water table may well lie close to, and perhaps exactly at, the depth at which the drilling problems were encountered which forced the cementing of the rods in place. Therefore the failure of the geophysical logs to clearly reveal the water table may well result from the complicating effects of the metal rods and the cement.

The Temperature Log

The final temperature log for core hole GEO N-3 is shown in Figure 10 and compared with other data sets in Figure 9. A

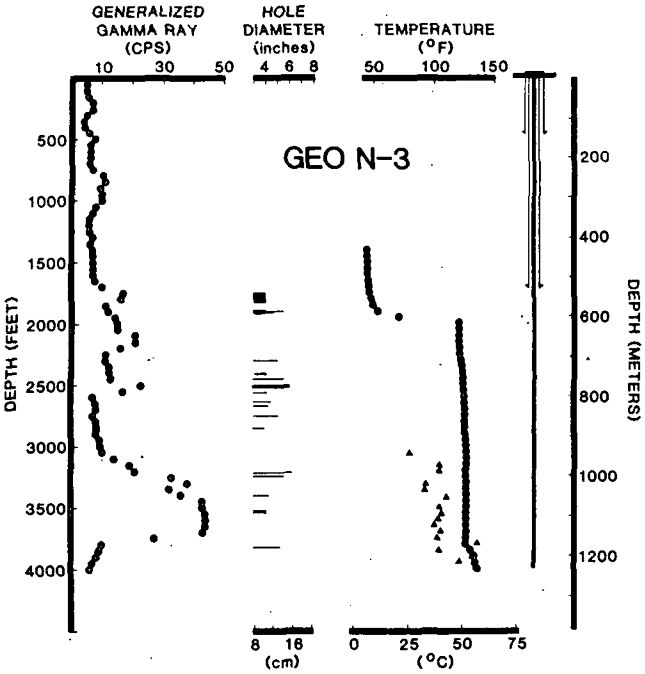

Fig. 9. Comparison of the temperature data from GEO N-3 with the generalized gamma ray log and the washouts as depicted by the caliper log. Note (1) the relation between the large washout in the caliper log and the intermediate drill string (drill rods cemented in place) reflecting the difficult drilling conditions, (2) the anomalous temperatures measured during drilling (triangles) and the washouts at depths below 915 m, and (3) the washouts which allow the artesian fluids to enter and exit the annulus of the core hole. The detailed temperature log is reproduced in Figure 10. Core hole completion is presented on the far right.

composite of all temperature logs measured in this core hole is presented in Figure 11. At first glance, the final temperature log appears to differ significantly from the corresponding log for core hole GEO N-1 (Figure 3). Closer examination, however, reveals that the two logs contain the same basic elements. Specifically, like GEO N-1, core hole GEO N-3 is isothermal to the water table and probably beyond, it has a thermally conductive zone near the bottom, and the isothermal and conductive zones are separated by a transition region exhibiting considerable hydrologic disturbance.

The interval between the upper isothermal and lower conductive sections of core hole GEO N-3 is a complicated region because it represents two separate and overlapping patterns of groundwater circulation, one of which was induced by drilling operations. Several obvious features of the temperature log are the rapid buildup of temperature at about 580–610 m, the smaller temperature buildup at about 1160 m, and the interval between them, which is very nearly isothermal at 52°C. These observations are the result of artesian water ascending the annulus of the core hole. Geothermal fluids under artesian pressure appear to enter the core hole at a depth of about 1160 m. This same depth is characterized by a significant washout as observed on the caliper log (Figure 9) and also by a thermal pulse as detected by the maximum recording thermometers (MRTs), which were run into the core hole during pauses in the drilling operations (Figure 11). The geothermal fluids appear to exit the core hole annulus at a depth of about 575–585 m. This zone is a major washout area as shown by the caliper log (Figure 9). It is significant that the ascending geothermal fluids seem to ignore the numerous washouts throughout the core hole interval 610–1100 m (Figure 9) and choose instead to exit the core hole annulus at a washout located at or near the regional water table estimated at about 455–564 m. If a man-induced vertical conduit such as a core hole will cause artesian fluids to rise and spread laterally near the water table, it might be expected that a natural conduit such as a vertical fracture might also cause the same phenomenon. If so, geothermal fluids migrating laterally near the water table are likely to promote hydrothermal alteration, reduce the mechanical strength of the rocks, and help explain why there seem to be difficult drilling conditions coincident with the water table.

The remaining unexplained feature of the GEO N-3 temperature log is the nature of the thermal regime which existed before the artesian breakthrough. The germane data are the temperatures taken during drilling by MRTs (Figures 9 and 11). As was the case for GEO N-1, these temperatures showed no tendency to increase near the water table, and in fact, readings did not exceed ambient temperatures until a depth of about 935 m. On this basis, it is suggested that the rain curtain extends to an approximate depth of 915–975 m, at which point the section becomes significantly more potassic as indicated by the gamma ray and lithologic logs (Figures 9 and 12). Having the rain curtain extend to a significant depth below the water table is supported by the close association between washouts as depicted by the caliper log and small temperature anomalies measured by the MRTs during drilling operations. Careful inspection of Figure 9 shows that below 915 m, the MRT readings taken at or near the washouts are slightly but consistently elevated relative to the remaining MRT values, as if thermal fluids were moving through these horizons. Above 915 m, no such correlation exists. If the washouts above 915 m represent horizons which permit lateral flow of groundwater, it is not thermal fluid that is migrating through these horizons but rather cold, descending groundwater, i.e., the rain curtain. As a final comment for those researchers who prefer to associ-

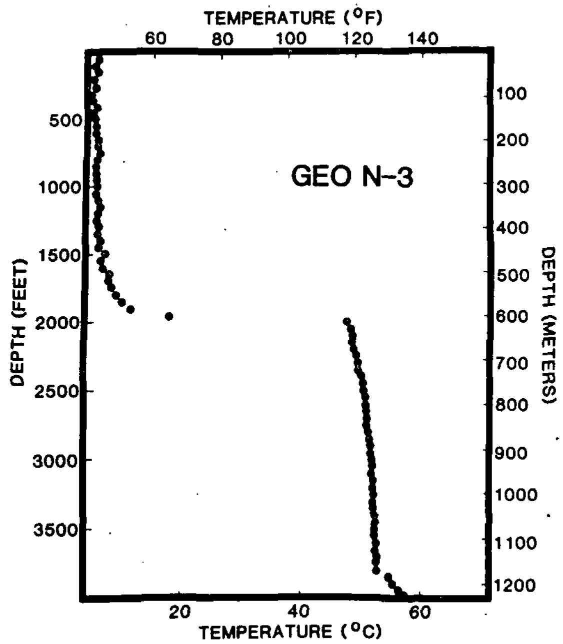

Fig. 10. Detailed equilibrium temperature log of GEO N-3. Measurements were taken every 6 m with a precision of 0.01°C by Geotech Data on August 18, 1986. Data plotted at 10-m intervals.

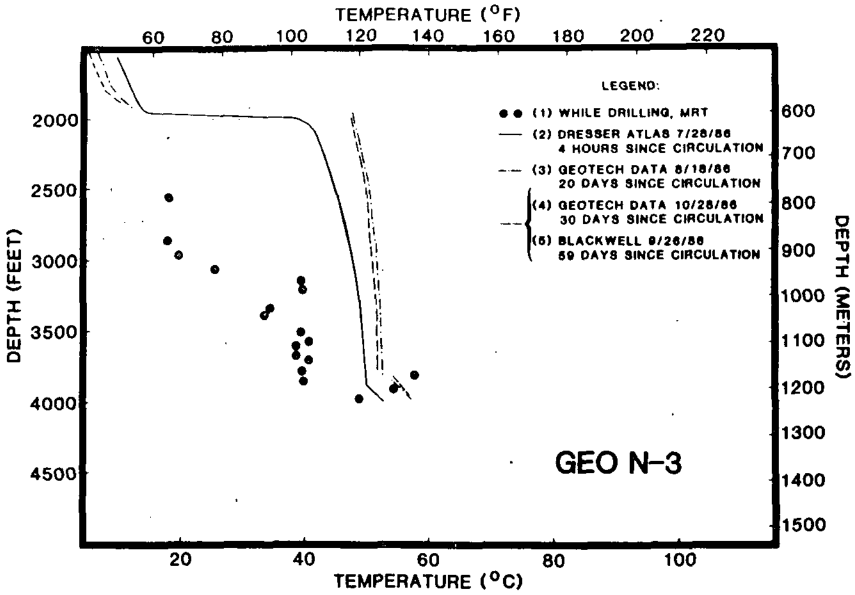

Fig. 11. Summary of all temperature data obtained below 500 m in GEO N-3. Note the highest MRT temperature reading coincides with the artesian aquifer (compare Figure 9).

ate the rain curtain with the region above the water table, it can be noted that an upward extrapolation of temperature from the thermally conductive region intersects the mean annual air temperature at a depth which is not incompatible with the water table.

Age Dates

The seven K-Ar age dates from core hole GEO N-3 range from 0.1 to 1.5 Ma and are presented in Figure 13 and Table 2. These dates are similar to those measured in core hole GEO N-1 (Figure 7) and throughout the volcano (Figure 2). There is also a tendency for the age dates to increase with depth, although the date of 1.5 Ma at 324 m is contrary to this trend.

Chemistry of Formation Fluids

During the drilling operations for core hole GEO N-3, fluid samples were systematically collected from the core hole for routine chemical analyses. As was the case for GEO N-1, these samples were not collected to provide reliable geochemical data of formation fluids, but rather to try to detect the presence of geothermal fluids and any associated chemical species that may require special treatment during eventual production. The results of silica concentration, a typical indicator of geothermal fluid, are shown as a function of depth in Figure 14. As shown in Figure 14, the bottom four samples, which were collected from depths below 1050 m, are greatly enriched in silica relative to samples taken at other depths, and this enrichment reflects the strong presence of geothermal fluids near the bottom of the core hole. Vertical zonation of the silica content of fluids sampled from GEO N-3 is an interesting feature of the core hole that may relate directly to the depth of the rain curtain. To examine the phenomenon further, a composite of all anomalous chemical constituents was prepared, and their distribution with depth was plotted in histogram form (Figure 15). Also shown in Figure 15 is a histogram of sample depth, and a comparison of the two histograms should reveal the depths at which the anomalous chemical constituents are located. As can be seen in Figure 15, the anomalous constituents are found primarily below the arbitrary depth of 915 m and reflect the presence of geothermal fluids below this depth. Above 915 m, nearly all samples collected are depleted in almost every chemical constituent analyzed, and these samples are thought to represent the cold descending groundwater of the rain curtain. A comparison of the data in Figure 15 with those in Figures 9 and 11 shows the anticipated result that the depths at which the chemically anomalous (geothermal) fluids were sampled are precisely the same depths at which the highest temperatures were recorded during drilling operations. This almost trivial observation would probably not be worth reporting were it not for the

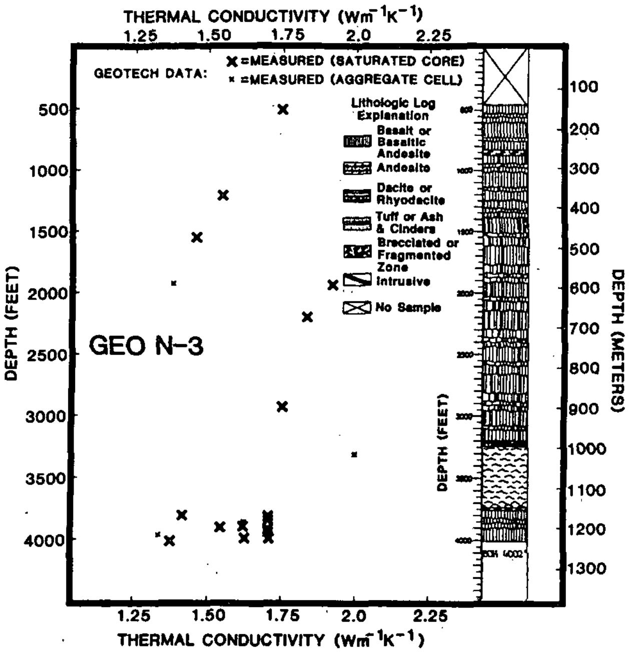

Fig. 12. Thermal conductivity from GEO N-3. Note the generalized lithologic log shows a rhyodacitic flow unit centered at 1100 m (compare Figure 9) and that the remainder of the core hole is essentially a series of basaltic andesite flows. Data from Geotech Data.

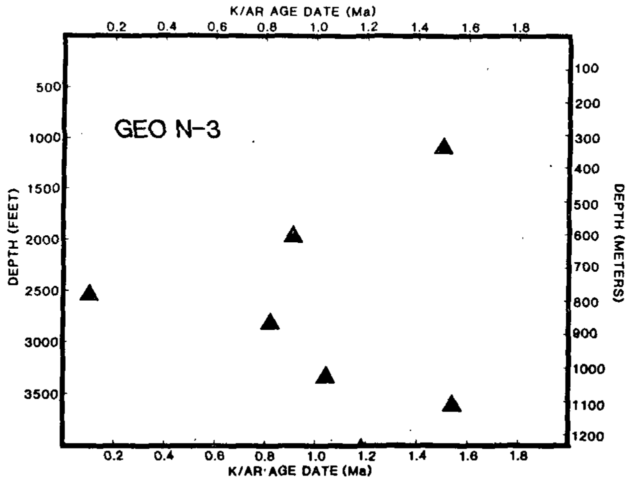

Fig. 13. Potassium-argon age dates from GEO N-3. Note the agreement among these dates and those from GEO N-1 (Figure 7) and the surface samples (Figure 2).

important role played by the rain curtain in the exploration for and evaluation of geothermal resources.

SUMMARY

In the preceding sections, the data and some observations for two core holes on the flanks of Newberry Volcano, Oregon, have been presented. Particular emphasis has been placed on the rain curtain with the intention that a detailed discussion of this phenomenon at two discrete localities will lead to a better understanding of the physical processes in operation. It is further expected that the data will spark scientific debate and additional research on the rain curtain phenomenon, with emphasis directed toward surface geophysical techniques that can "see through" the rain curtain and provide valuable exploration information on the underlying geothermal reservoirs. Unfortunately, most geoelectric and geoelectromagnetic surveys to date have been strongly affected by smectite alteration, which prevails at depths that are shallower than the geothermal reservoir (Figure 5) [e.g., *Fitterman and Neev*, 1985; *Wright and Nielson*, 1986]. *Wright and Nielson* [1986] have noted that "delineation of the high temperature (geothermal) system by electrical surveys may be difficult or impossible because of effects from altered rocks." While the problem is formidable, sufficient documentation has been provided that the rain curtain and the underlying geothermal systems are sufficiently different in their physical characteristics to justify continued search for a surface geophysical technique or a combination of techniques which will detect and provide information on geothermal systems in spite of the complicating effects of the rain curtain and smectite alteration. The goal is certainly worthwhile, since mile-deep core holes are rather expensive for reconnaissance exploration.

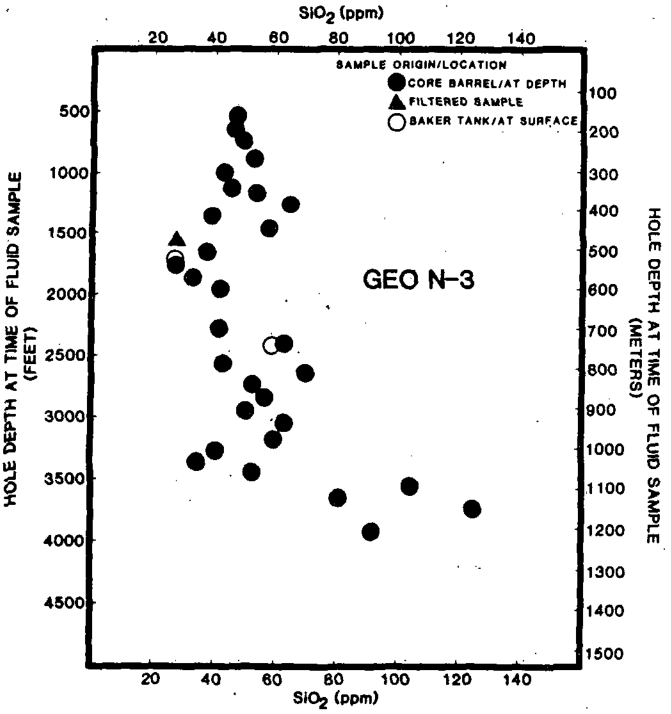

Fig. 14. Silica content of fluids taken from GEO N-3. Note the increase in silica below 1100 m and that all downhole samples are contaminated by drilling fluids.

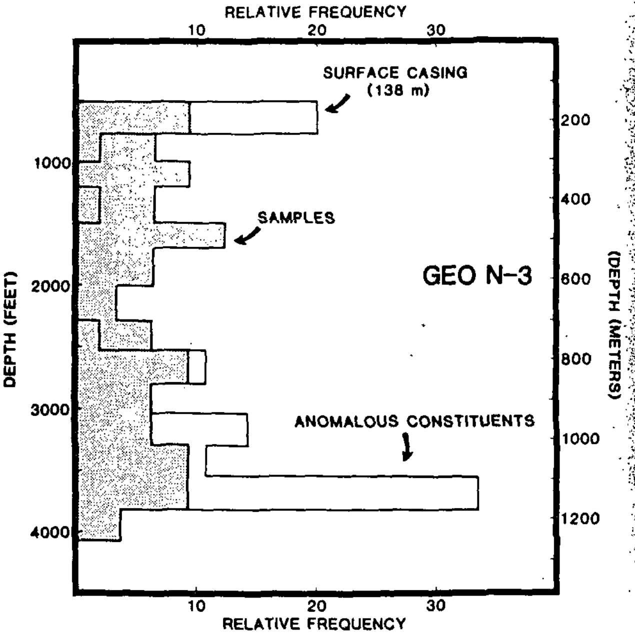

Fig. 15. Distribution of anomalous constituents of fluids taken at intervals of about 75 m from GEO N-3. Chemical species used in constructing this figure are Si, Hg, K, Al, Sr, B, and F. The highest 10% of each of the species are considered anomalous and their distribution plotted as a function of depth in histogram form. The shaded area reflects the depth distribution of sample depths. The difference between the two should qualitatively reflect drilling fluids mixing with formation fluids. Note that effects of geothermal fluids are basically lacking above 915 m (compare with Figure 9).

Acknowledgments. We thank the management of Geothermal Resources International, Inc. (GEO), and its wholly owned subsidiary, GEO Operator Corporation (GEOOC), for financial support of, and permission to publish, this work. We also thank Bruce Sibbett, University of Utah Research Institute, for his outstanding job as technical liaison between GEOOC and the U.S. DOE, and M. Johnson, W. J. Dansart, M. C. Hagood, and M. Woodruff, GEOOC, for providing the core descriptions. We acknowledge the professional services of Tonto Drilling Services, Vancouver, Canada (drilling), Dresser-Atlas, Houston, Texas (geophysical logging), and Geotech Data, Poway, California (temperature logging and thermal conductivity measurements). The figures were prepared by M. Maloney and the manuscript typed by Y. Stallings and S. Ballin of GEO. S. Prestwich and R. King acted as DOE technical and administrative monitors, respectively.

The project was funded by U.S. DOE cooperative agreements DE-FC07-85ID12612 and DE-FC07-85ID12613 (49%) and GEO corporate funds (51%).

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(Received August 17, 1987;
revised January 11, 1988;
accepted January 14, 1988.)

CASCADES DEEP GEOTHERMAL GRADIENT DRILLING PROGRAM

GEOPHYSICAL WELL LOGS

		GEO N-1	GEO AL-3	Thermal CTGH-1	CECI MZI-11A
①	Temperature	X	X	X	–
②	Caliper	X	X	4100-4800	–
③	Gamma Ray	X	X	X	–
⑥	Spontaneous Potential	X	–	4200-4798	–
⑦	Resistivity	X	–	4200-4799	–
⑩	Induction	X	–	–	–
⑪	Acoustic	X	X	4225-4425	–
⑫	Acoustic Fracolog	X	X	–	–
④	Neutron	–	–	X	–
⑤	Gamma-Gamma Density	–	–	775-900	–
⑧	Induced Polarization	–	–	4200-4799	–
⑨	Lateralog	–	–	4200-4798	–

X logged 0 - TD
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Minisub to Explore Crater Lake Depths In Effort to Halt Geothermal Testing

By Tom Towslee
United Press International

CRATER LAKE, Ore. — The National Park Service is bringing in a minisub as part of a high-tech search for scientific evidence to thwart development of geothermal wells near one of the world's natural wonders — the nearly 7,000-year-old Crater Lake.

Beginning Monday, a scientific expedition financed by the Park Service will use the one-man minisub Deep Rover to probe the bottom of the volcano-created lake — the deepest in North America — for "vents" they hope will end geothermal exploration just outside Crater Lake National Park.

The vents, the scientists believe, pump hot water into the bottom of the lake and are connected to surrounding underground reservoirs of hot water by an elaborate subterranean plumbing system that would be thrown out of kilter by extensive commercial development.

"I feel the existence of hot springs is the only hypothesis that answers all the questions," said Jack Dymond, a Oregon State University oceanography professor, who will take turns piloting the submersible on a series of 20 dives during August.

Last year, Dymond and fellow scientist Robert Collier used an unmanned, remote-control camera similar to the one used to explore the wreck of the Titanic to comb the lake bottom.

They found a vent emitting a milky-white substance, but were unable to measure the temperature of the water coming out of the vents or take samples.

If the minisub substantiates that the lake bottom and hot springs outside the park are connected, it will give the Park Service ammunition to have the Interior Department add Crater Lake to a list of national parks where geothermal development should be restricted.

"We don't know if what they [geothermal developers] have planned will affect the lake," said park superintendent Bob Benton, "but the law orders us to protect the park and we view with concern anything that might screw it up."

Crater Lake was created 6,850 years ago when Mount Mazama exploded in a fiery volcanic eruption that collapsed the top into a caldera that filled with water, forming a lake 1,932 feet deep that has the clarity of distilled water.

It was discovered by gold miners in the 1850s and designated a national park — the only one in Oregon — in 1902. Each year, 500,000 tourists visit the 160,000-acre park on the southern Cascade Range, 200 miles southeast of Portland.

The geothermal activity around the lake is the result of underground springs of water turned boiling hot by molten rock deep beneath the Earth's surface.

California Energy Co. of Santa Rosa, Calif., has leased more than 76,000 acres of state and federal land on three sides of the park, with plans to drill test holes to determine the extent of the area's geothermal resource.

The interest by California Energy prompted Congress to pass legislation to protect the lake from any ill effects of geothermal drilling. The measure is now in a House-Senate conference committee.

Also, Gov. Neil Goldschmidt has called on the Interior Department to halt geothermal leasing on federal forest land around Crater Lake.

"The evidence that we have in hand indicates that we are on a resource that is focused on that part of the forest and not tied to something that is part of the lake," said Joe LaFleur, chief geologist for California Energy Co.

He said the company's ultimate plan is to build production wells that feed a geothermal plant to produce electricity to ease an energy deficit predicted to hit the Pacific Northwest early in the next century.

The size of the wells and the extent of the development will depend on the results of nearly two dozen test wells. So far, they have drilled half of one test well.

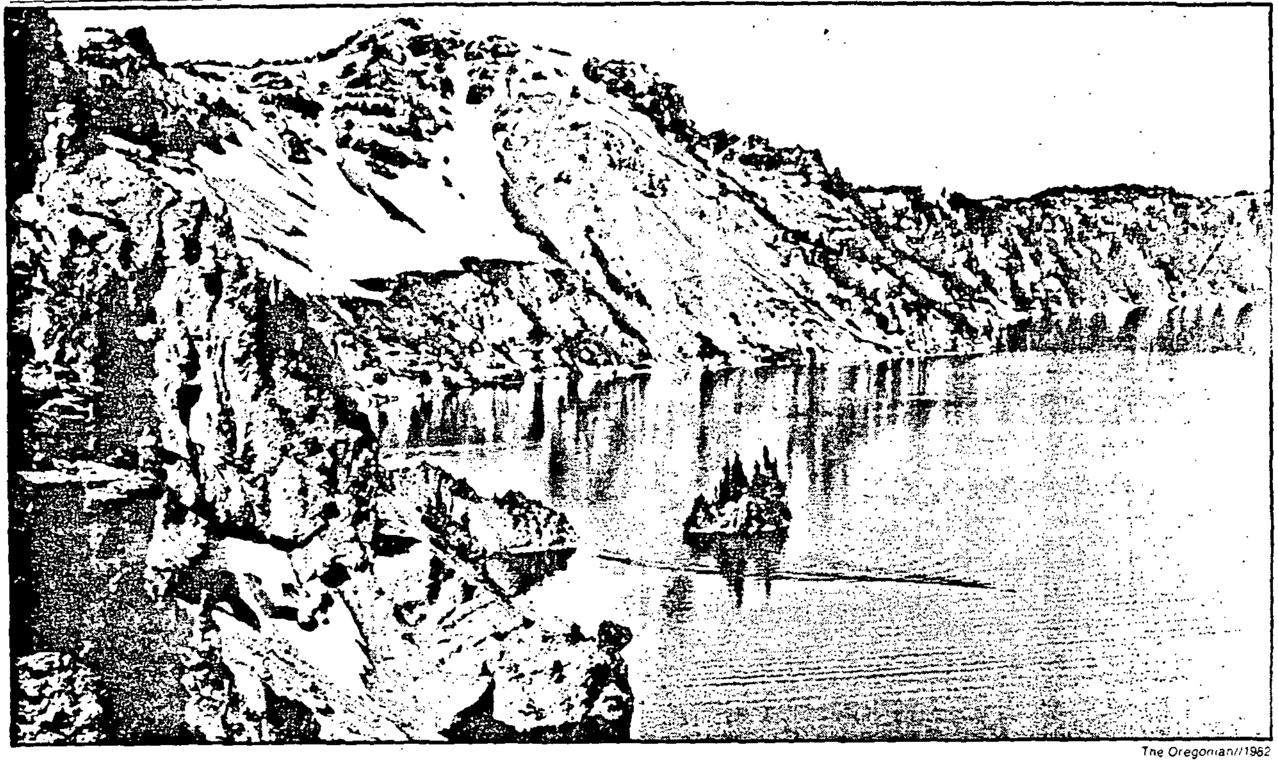
LaFleur discounts the "plumbing system" theory and claims differences in the ages of the rock and the elevation of the lake make it impossible for the proposed wells and the lake to be connected.

Nevertheless, he believes the Parks Service and the Oregon State University scientists already have made up their minds that the connection exists.

"I'm sure that if they can find the bottom of the lake, they will claim they have evidence of hot springs, but I don't think they could verify it to an objective third party," he said.

"The Park Service has stated to the press that they hope to use this evidence to shut down our projects," he said.

To present its side of the case, LaFleur's company will spend a week conducting demonstrations designed to coincide with the arrival of the minisub and show that geothermal wells are neither loud nor obtrusive.



The Oregonian//1962

Researchers say that Crater Lake's clarity and cobalt-blue color are definitely changing. They say they don't know why it's happening.

Reasons for Crater Lake changes unclear

By RICHARD L. HILL
of The Oregonian staff

CORVALLIS — Crater Lake's renowned clarity and cobalt-blue color are definitely changing, researchers say, but they don't know why.

"There's been an approximately 20 percent decrease in the clarity of the lake since the late 1960s," said Clifford Dahm, associate professor of biology at the University of New Mexico. "There's definitely been a change of clarity but as to the cause of the change, that's where we don't have an answer."

Dahm was one of several scientists taking part in a 10-year study of Crater Lake who participated in a symposium Tuesday at Oregon State University.

Several reasons have been proposed as to why the lake is not as clear as it once was, Dahm said, including possible airshed changes — such as particulates emitted from car engines; sewage input from Rim Village above the lake; and an accumulation of nitrates in the bottom of the lake that may be periodically mixed back into the surface water by hydrothermal vents.

"But none of these hypotheses has been tested fully," he said.

Stanley Gregory, an associate professor of fisheries and wildlife at Oregon State University, said that with "the change in clarity, you get a change in the color, so the deep cobalt-blue color would become more of a typical blue and — at the extreme — become a greenish blue."

Dahm said his research had shown that blue light wavelengths were not penetrating as far into the lake and "the green light is penetrating further, so you do have a shift to a light blue-green color."

Peter R. Fontana, professor of physics at OSU, said Crater Lake's blue color can be quantitatively measured. For the last three years, he has studied the lake's water, measuring the rate at which light scatters from molecules.

"There are so many factors involved that it's hard to draw any long-term conclusions," Fontana said. "If you take the mean, then Crater Lake is not as blue today as it was in 1935. But if you compare on a particular day, it might be more blue. If we continue the study for a few years, then we might be able to compare apples with apples."

He said the lake's quality varied significantly during any given year, with seasonal variations possibly resulting from dust, pollen, small avalanches or snowmelt.

Gary L. Larson, who is principal investigator of the study of Crater Lake, which ends in 1992, said the major impetus behind the project was to determine if the lake was losing its clarity.

"We simply don't have enough data at this point to reach any conclusions," said Larson, an aquatic ecologist with the National Park Service who is stationed at OSU. "Crater Lake is probably not as clear as it has been at times in the past, but it could be cyclical in nature."

1-man sub to explore Crater Lake

☐ OSU researchers hope to find hot springs at the bottom of the nation's deepest lake and settle a long debate

By RICHARD L. HILL
of The Oregonian staff

CORVALLIS — A probe of Crater Lake by a manned submersible this summer will settle the controversial question of whether hot springs exist at the bottom, both the chief detractor and the proponent of the theory said Tuesday.

Jack Dymond, professor of oceanography at Oregon State University who believes there is hydrothermal activity in the lake, and Joe LaFleur, senior geologist with the California Energy Co. and the theory's chief critic, agreed that the close look of the 1,932-foot-deep lake's bottom should settle the debate.


DYMOND

Dymond and LaFleur were part of a daylong symposium on Crater Lake at the 69th annual meeting of the Pacific Division of the American Association for the Advancement of Science at Oregon State University.

"I'm hoping the deployment of the submersible will answer the question once and for all," said LaFleur, whose company has a high stake in the findings because it is hoping to develop a geothermal power plant near Crater Lake National Park.

Sen. Mark O. Hatfield, R-Ore., has introduced legislation that would place Crater Lake on a list of national parks with significant geothermal features, which could block geothermal energy leases around the park. LaFleur's company is fighting to keep the lake off the list.

Dymond said he believes being able to see and maneuver on the bottom "will determine the issue of hydrothermal input."

"It could be that we won't find anything — we're testing our hypothesis," Dymond said in an interview. "Intellectually, I would realize that's the nature of science, but emotionally, I would be disappointed."

LaFleur said it's "very unlikely" that hydrothermal venting is occurring because "any kind of vents would have been clogged with silica long ago." He also said that the level of dissolved carbon dioxide in the water was very small, adding that its "absence is a very strong negative argument" against the existence of such vents.

Dymond and Robert Collier, assistant professor of oceanography at OSU, will alternate manning the one-person submersible, Deep Rover, in 20 dives to the lake floor beginning Aug. 2.

The two researchers found what they believed were small vents on the lake bottom last summer using an unmanned, remotely operated vehicle. Dymond said, however, that they weren't able to measure the water temperature at the vents because of the vehicle's maneuvering limitations.

Please turn to
CRATER LAKE, Page F6

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Crater Lake: Sub slated for 20 dives to lake's floor

■Continued from Page F1

"The submersible is more controllable," allowing such measurements to be easily made, he said. "We'll be able to navigate the sub within 2 meters (about 6½ feet) of the bottom.

"It also has incredible visibility, which allows the observer to see in all directions. With the remote vehicle we could only see in one direction."

Although Dymond said he was confident that "some sort of thermal input" would be found, he explained that the hot water could be coming into the lake either through individual springs or by a "diffuse flow of water through sediments."

"We just don't know yet, and that's the kind of thing we'll be looking for this summer."

Collier said they found at lower depths temperature increases of up to about 1 degree Fahrenheit, along with corresponding increases in the water's chemical components such as sodium, potassium, calcium, manganese and lithium — suggesting a hydrothermal emission at the bottom.

"Initially, what we will do with the Rover is to find the springs," Dymond said. "Then we'll carry down water bottles and collect samples. The Deep Rover's mechanical arms can be lowered right into the vents."

The researchers will lease the submersible from Can-Dive Services Ltd. in Vancouver, British Columbia, where they soon will begin training.

The battery-operated submersible can be used only four to six hours a day, so the oceanographers will use another remotely operated vehicle to conduct other research. The unmanned submersible also will serve as a rescue vehicle "in case the submersible gets stuck down there," Dymond said.

This summer's research is being funded by a grant of $225,000 from the National Park Service as one part of a 10-year study of the lake mandated by Congress five years ago.

NOTEBOOK

Low-down on the 'high'

The good feeling that comes from exercise is best described as "runner's calm" rather than "runner's high," according to a Canadian scientist who says too much running can be an emotional turn-off.

The chemicals produced by exercise actually slow down excess activity in the brain instead of producing excitable responses, says Dr. Murray Allen, a kinesiologist at Simon Fraser University in British Columbia. He argues that positive moods are "nature's way of rewarding us for staying fit."

His claim that too much exercise can be damaging draws support from a study at Georgia State University, which says the best benefits are likely to come from running no more than three miles about four times a week.

Wade Silverman, a psychologist, says in the same Psychology Today article that people who run 50 miles a week or more "are often drudges, masochists, running junkies. They don't really enjoy it."

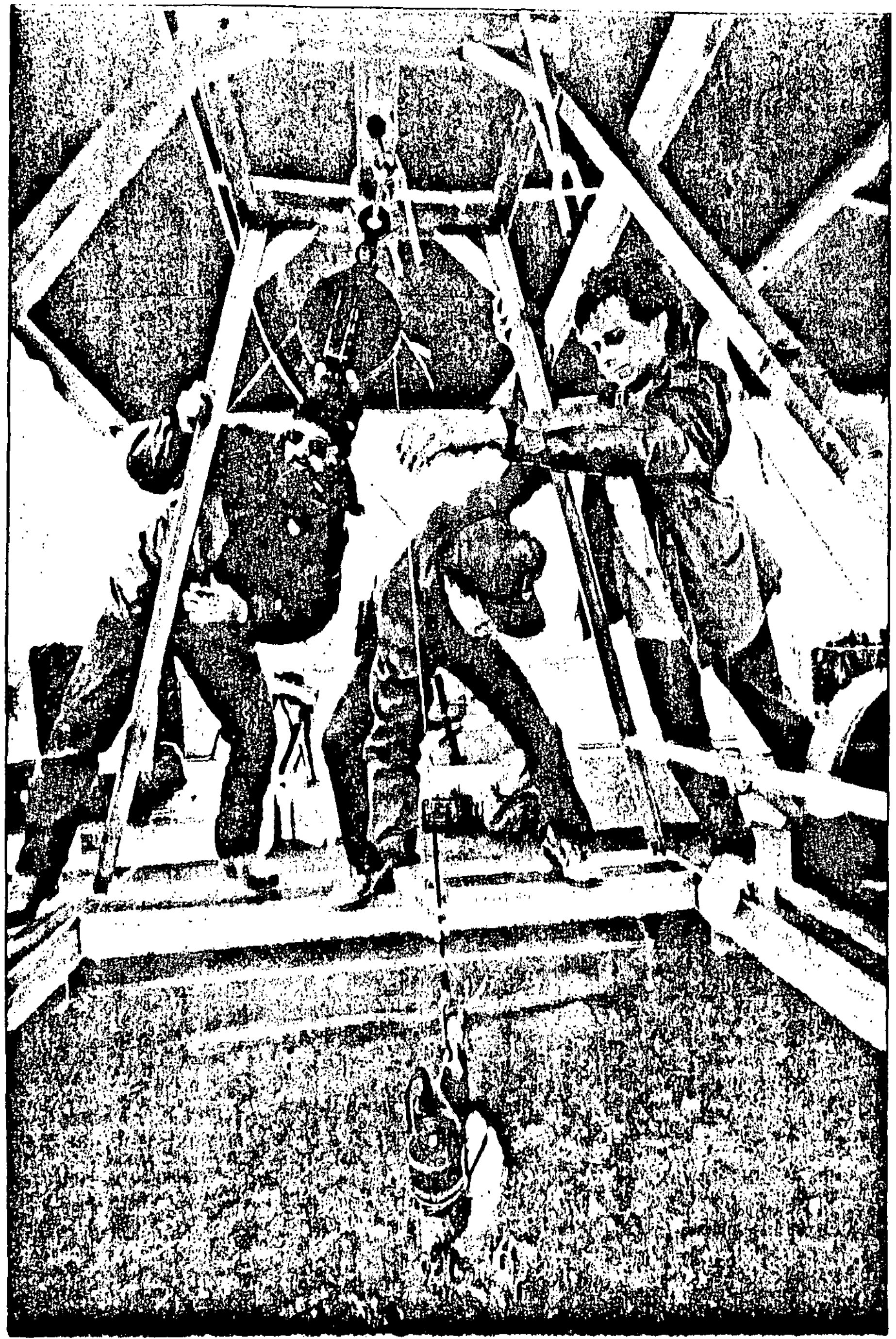
Scientist all abuzz

Government entomologist Lawrence Pickens says he has come up with an insecticide-free formula that flies can't resist: a concoction of sugar, baking powder, brewer's yeast, honey, dried blood or fish meal, and banana flavoring.

He puts it in a cylindrical trap, sets it out in the yard and waits for the flies to enter. They can get in easily enough, but they can't get out.

Pickens says one trap, measuring about 12 inches in diameter and 18 inches high with two quarts of water in a pan underneath, is easy to build and seems to work pretty well for a suburban home. A farmer with cows and a 3-acre barnyard might need 10 or more, because the traps only seem to attract flies that come within 20 to 30 feet of the bait.

The future for fly traps looks



The Oregonian/BRENT WOJAHN

Researchers (left to right) Robert W. Collier, Mark Buktenica and Scott Stonum lower a CTD transmissometer into Crater Lake earlier this month to measure conductivity, temperature, depth and clarity.

The Oregonian/BRENT WOJAHN

Crater Lake presents a picture-postcard scene for the thousands of visitors each year to Oregon's only national park. Scientists are midway through a decade-long study of the nation's deepest lake.

A QUESTION of CLARITY

By RICHARD L. HILL
of The Oregonian staff

For the half-million visitors who gaze upon its remarkable beauty each year, Crater Lake represents serenity and solitude.

But for the dozens of scientists who have been giving the nation's deepest lake a close look during the past five years, its placid exterior disguises a complex and active ecosystem.

A scientific investigation was launched because of concerns that the Southern Oregon lake's famed clarity was diminishing. If the lake is becoming less clear, the water's renowned color would be directly affected, changing from cobalt-blue to a more typical lake color of light blue or — in a worst-case scenario — blue-green.

"The lake is much more complicated than we thought it was," said Gary L. Larson, who is directing the National Park Service's 10-year study of the lake, mandated by Congress in 1982. "It's not just a sterile body of water resting comfortably on top of Mount Mazama. It's an extremely dynamic system.

"That makes it important that we study as many of the components that make up the lake as best we can in order to find out what makes the lake work."

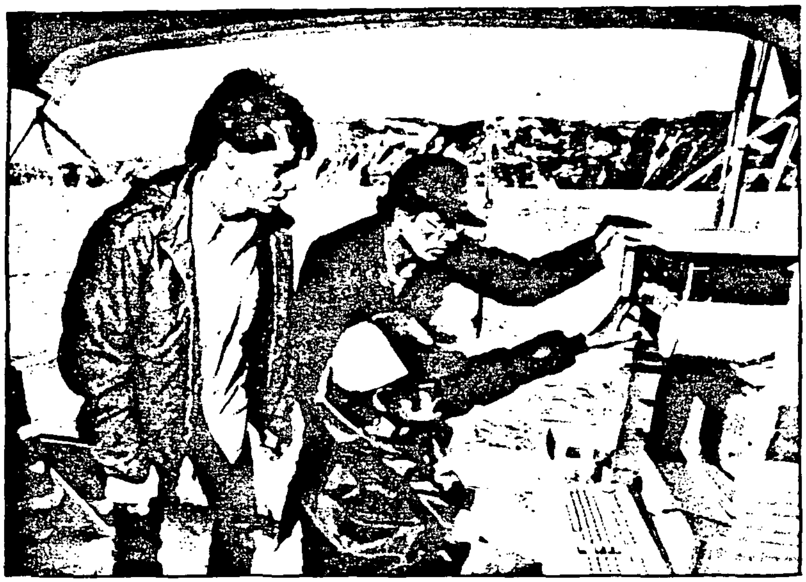
To examine the possible changes and their causes, researchers are taking a "holistic approach to the lake," said Larson, an aquatic ecologist who heads the Park Service's Cooperative Park Studies Unit based at Oregon State University, where he is associate professor of resource recreation.

Larson said the study's goals were to:

- Develop a data base for comparison with future conditions.
- Develop a better understanding of the biological, chemical and physical features of the lake.
- Establish a long-term monitoring program to provide a continuing examination of the lake's characteristics.

As the processes that are at work

Please turn to
CRATER, Page E3



The Oregonian/BRENT WOJAHN

Researchers (from left) Scott Stonum, Mark Buktenica and Jim McManus check monitoring equipment aboard a boat on Crater Lake after lowering a measuring device into the water.

Crater: Climatologist, physicist check lake's evaporation, color

■ Continued from Page E1

in, around and above one of the world's clearest lakes are complex and numerous, project researchers come from a variety of scientific disciplines, including oceanography, geology, physics, chemistry, biology, climatology, forestry and computer science.

"If we find changes that are man-made," Larson said, "then we're going to try and mitigate that action. On the other hand, if it's Mother Nature doing the work, then we'll leave the lake alone."

The most dramatic enterprise of the study will be launched next week when two OSU oceanographers, Jack Dymond and Robert W. Collier, begin a series of dives to the bottom of Crater Lake in a submersible to search for hydrothermal vents. It will be the first time anyone has been to the bottom of the 1,932-foot-deep caldera lake.

In addition to exploring the floor, scientists are looking beyond the water's edge to determine what effects might come outside the lake, especially Rim Village, the focal point for visitors to the only national park in Oregon.

The site's sewage system has been a prime suspect in the who-or-what-done-it mystery over the lake's clarity, but so far researchers have not come up with a definite link. Regardless, in the next few years the sewage system is going to be moved away from the lake as part of a park renovation project.

The streams and springs around Crater Lake also are being examined, as well as the area's geologic formations. Life in the lake itself, ranging from microscopic organisms to the non-native rainbow trout and kokanee salmon, also are under scrutiny.

As part of the study, Kelly Redmond, state climatologist and OSU research associate, has been keeping tabs on the lake's water level. He said the lake's unique ecology would help scientists understand complex lake processes during evaporation.

Redmond said that although all lakes vary in water level, Crater Lake is interesting in that there are few sources draining into the lake, and no major outlets from it. He compares the lake to a tin can with holes in it: "As long as the precipitation keeps up with the leaks, the lake will stay at the same height."

> ***"The lake is much more complicated than we thought it was. It's an extremely dynamic system."***
>
> — Gary L. Larson, National Park Service

The highest recorded water level of the lake was taken March 25, 1975, when it measured 6,179.3 feet above sea level, according to Redmond. The lowest level was at 6,163.2 feet, recorded Sept. 10, 1942.

In addition to yearly fluctuations, there are seasonal changes. Typically the lake reaches its lowest level in September and fills to a peak in March. "The yearly fluctuation is about a foot and a half on average," Redmond said.

Another researcher, Peter R. Fontana, has been examining the lake's color for the past three years. The OSU physics professor presented his findings at a recent symposium on the lake in Corvallis.

Fontana has been measuring the rate at which light scatters from molecules. "If you have really pure water, there is much more scattering at short wave lengths. If you have impurities — larger particles of dust and pollen — the light will scatter much more uniformly."

Light data is recorded as ratios of forward to backward scattering, Fontana explained. At 400 nanometers (a nanometer is one billionth of a meter), which he described as a benchmark indicating dark blue or violet, light scatters 4.1 times as much as it does at 600 nanometers. The ratio of 4.1 was recorded at Crater Lake in July 1935.

Few measurements were taken between that time and when Fontana began his research as part of the lake study, however. The physicist recorded ratios ranging from 3.29 to 3.99 in 1986 and from 3.37 to 4.25 in 1987, with the mean measurement in 1986 at 3.71 and in 1987 at 3.69.

As a reference point, Fontana said a measurement of 1.0 would indicate "very dirty water," while the ratio for dust-free, distilled water has been as high as 4.98."

Fontana said it is difficult to draw any long-term conclusions about whether the lake is changing color, however.

"If you take the mean, then Crater Lake is not as blue today as it was in 1935. But if you compare on a particular day, it might be more blue. If we continue the study for a few years, then we might be able to compare apples with apples."

Despite the wide variety of research, answers to the key study questions — is the lake losing its clarity and why? — remain elusive.

Clifford Dahm, associate professor of biology at the University of New Mexico, believes there's been about a 20 percent decrease in clarity in the lake since the late 1960s, but he emphasizes that data from the past used to make present-day comparisons are limited.

"In my mind, there's been a change of clarity, but as to the cause of that change, that's where we don't have an answer.

"It could be air-shed changes, it could be anthropogenic sewage input into the lake, it could be changes in the physical processes of the lake, it could be accumulation of long-term nitrate in the bottom of the lake that is periodically mixed back into the surface water . . . a number of hypotheses have been suggested, none of which has been tested fully."

Larson agrees, adding that project scientists "simply don't have enough data at this point to reach any conclusions."

"Crater Lake is probably not as clear as it has been at times in the past, but it could be cyclical in nature. It doesn't necessarily mean that the lake is losing its clarity. We really need several years of data."

Larson said the study is just the starting point in learning how the lake's system works. "Setting up a long-term monitoring program is a top priority for us," he said. "We don't want research to just end in 1992; the lake needs to be continually studied if we're going to gain a good understanding of what's going on."

Dive: Idea of springs stirs controversy

'Nobel Prize sperm ba
'superior' genes from

By SHARON L. JONES

The Associated Press

ESCONDIDO, Calif. — The walls of Dr. Robert K. Graham's relatively ordinary-looking office are lined with the pictures of dozens of babies he says are far from ordinary — the products of the so-called Nobel Prize sperm bank.

"This is our pride and joy and, by God, every one is a gem," said Graham of the children born to mothers inseminated with "superior" sperm provided by his Repository for Germinal Choice.

Graham, 81, a multimillionaire who developed the shatterproof eyeglass lens, is on a mission to save the human species. Superior genes are being lost, he says, because society's smartest don't have enough children while the masses proliferate with zeal.

Graham founded the bank in early 1980 and began collecting the sperm of a select few "outstanding intellects" and giving it to qualified couples, with the goal of bringing into the world potential leaders or great scientists.

The bank claims responsibility for 55 babies, and 18 women are pregnant.

Graham says his program is working, that most of the children develop at a much faster rate than their peers and are judged gifted. Geneticists, however, still find fault, saying the program minimizes women's role in reproduction and exaggerates the likelihood children will inherit all their parents' good genes.

Parents welcome bright kids

But the proud parents cheer Graham for bringing them bright children they deserved but couldn't have, usually because the father was infertile.

"I just wanted to have a child," said Adrienne Ramm, a dancer from New York City whose daughter Leandra turned 4 on Wednesday. "I believe that the donor sperm was from a man that seemed to be a great human being. We were increasing our chances of having a bright and healthy child."

"I can't imagine anyone would go there because they want a super baby," said a Riverside mother who asked that her name not be used. "It's just the best choice available for those who choose artificial insemination."

When Graham opened his repository, critics ranging from feminists to communists and the Roman Catholic church denounced it as a "master race" plan reminiscent of Adolf Hitler. The controversy was fueled by Nobel Prize winner William Shockley's revelation that he was a donor and by Graham's own views.

Shockley, a physicist who invented the junction transistor, believed that certain races — blacks for example — were genetically disposed to be intellectually inferior.

Man 'evolutionary derelict'

Graham, in his book "The Future of Man," called man "an evolutionary derelict" because "huge masses of those with ordinary minds have been allowed to come into being and then proliferate."

Over time, artificial insemination became common, and more radical techniques, like in vitro insemination and gene mapping, took the spotlight in the reproductive industry. To Graham's delight, protestors disappeared from outside his office about 30 miles north of downtown San Diego.

Alexander Capron, a scholar at the University of Southern California and former member of President Reagan's Commission on Bio-ethics, has concerns with the repository, but gratefully notes "it hasn't become a major force in reproduction."

Dr. Robert K. Graham displays phot
says were conceived with sperm from

amounts to a genetic accident.

"The idea that you're going to get an 'Olympian' could lead to parents' frustrations when expectations aren't fulfilled."

Capron also has ethical concerns. "What does it say about a mother's contribution in reproduction? In it is the potential for a more eugenic society with somebody deciding what genes get passed along."

Graham counters that he neither promises nor expects the children to reach their fathers' levels of success or intellect, but says:

"We can with considerable assurance say we are contributing to the next generation by bringing a number of capable, constructive individuals, including leaders who wouldn't otherwise have been born, or . . . wouldn't be as bright."

Donors' identities withheld

The identities of donors, described by Graham as "tops in their field" and "outstanding intellects," are withheld from the parents and the public. The list includes two Nobelists and an Olympian. All are of European descent or Jewish, and most are California scientists. Graham says he's invited blacks and Asians to donate, but that they've refused.

Donors are declared of good health and genetic ancestry, which means their families are free of such diseases as alcoholism and mental illness, and the donated sperm is screened for the acquired immune deficiency syndrome virus. Part of the AIDS screening includes a 180-day sperm quarantine.

The sperm, stored in tanks of liquid nitrogen that keep it frozen, has been sent around the country and as far away as Egypt.

Applicant parents must show they are married, intelligent, emotionally and financially stable, with a clean physical and mental health history. The mother must be under age 38. About half the applicants are rejected. Parents choose a donor from such information as intelligence test score, ancestry, hair and eye color, athletic ability, hobbies, and personality traits.

Graham still provides most of the operating costs and the repository does not charge its clients, although lab fees and other expenses have prompted it to start accepting donafeet of the bait.

The future for fly traps looks promising. The U.S. Department of Agriculture estimates that up to 1.5 million acres of farmland is being turned into housing developments each year, drawing nearby flies as well as people.

A little knowledge

Did cave-dwellers have to protect themselves from marauding dinosaurs? No, scientists say, since the two lived at least 65 million years apart.

However, the opposite answer was chosen by 40 percent of more than 2,100 college students surveyed nationwide by John Cronin, a molecular geneticist at the University of California-San Francisco. He cites that as one example of misconceptions held by students who at the same time say they generally agree with scientific explanations of how humans have developed.

Cronin, who presented the results of his survey in Current Anthropology, said students from rural areas agreed less often with scientific explanations than did those from urban areas and that "don't know" responses to some of the 72 questions about scientific assertions ranged as high as 50 percent.

Spectrum shuffled

Stanford researchers say the way that red and green pigment genes are arranged helps explain why red-green color blindness is so common, affecting one in 12 white males.

In an article in Science magazine, biochemist Douglas Vollrath says the genes lie next to each other on the X chromosome, giving them a tendency to exchange genetic material with other chromosomes. Color blindness occurs when the genes for red and green pigment move from one chromosome to another.

Vollrath says part of the red-green gene array sometimes breaks away from one chromosome and attaches to another, providing an extra amount of green. Males inheriting the chromosome missing its green gene will be color blind.

He also says the frequent occurrence of hybrid red-green pigment genes may indicate that a new pigment, sensitive to a different color, is evolving.

— From staff reports

Researchers (left to right) Robert W. Collier, Mark Buktenica and Scott Stonum lower a CTD transmissometer into Crater Lake earlier this month to measure conductivity, temperature, depth and clarity.

study of the lake, mandated by Congress in 1982. "It's not just a sterile body of water resting comfortably

Please turn to CRATER, Page E3

Lake's depths crowded

Intricate community of microscopic water inhabitants may be changing the appearance of Crater Lake

By WILLIAM BURTON
of The Oregonian staff

The water of Crater Lake is so blue, it looks as if you could scoop up a glass of it and the glassful would be blue.

It's an eerie blue. The lake looks as sterile as a swimming pool — nothing could live in water that color.

But in fact, lots of things do live in the 1,932-foot-deep lake. Far below the surface lies a strange, crowded world, where long-term residents and newcomers are forced to coexist in an uneasy relationship. Scientists are just beginning to understand the complex ecological community and how the inhabitants keep their watery neighborhood so clean.

The neighborhood may be changing.

Limnologists — scientists who study lakes — have been monitoring the clarity of Crater Lake since 1913 using a simple device called a Secchi disk. For the first 50 years, the 8-inch disk with black-and-white quadrants had often been visible more than 115 feet beneath the surface. So when readings of barely 85 feet became common in the 1970s, limnologists were worried. The lake ecology had shifted, and the water looked less blue. What was causing the change? And was man to blame?

In 1982 Congress ordered the National Park Service to begin a 10-year study of the lake. The researchers, now past the half-way point in their work, have already learned much about the give-and-take of the lake's inhabitants. But the causes of change remain elusive, the controversy has heightened, and in the meantime the lake seems to have mysteriously cleaned itself up.

Last week the Secchi disk was visible at 115 feet, and the 51-year-old record of 132 feet was almost equalled in late June when limnologists made a 128-foot reading.

"It was as clear as I've ever seen it," said Gary L. Larson, an aquatic ecologist at Oregon State University and head of the 10-year study. Scientists still don't know what causes the clarity fluctuations or what the overall trend in lake clarity is, he said.

At stake is the intense blue color that is the hallmark of Crater Lake.

A lake's color depends on the clarity of the water because water filters out light one hue at a time. First go the reds, then yellow and green. If the light can penetrate deep enough, only the blue gets reflected back out.

But microscopic algae, suspended in the water, can block and scatter the light. Called phytoplankton — literally "plants that float" — these single-cell plants can survive only far below the surface of Crater Lake because that's where the plant food is, according to C. David McIntire, professor of botany and plant pathology at OSU.

Please turn to LIFE, Page E2

CRATER LAKE

Crater Lake is renowned for its clarity and cobalt blue color. The lake is an enclosed basin, with no known outlets and no permanent streams entering it. Water is lost through seepage and evaporation, while about 78 percent of the water the lake receives is from precipitation falling directly on its surface, with the rest mostly coming from runoff.

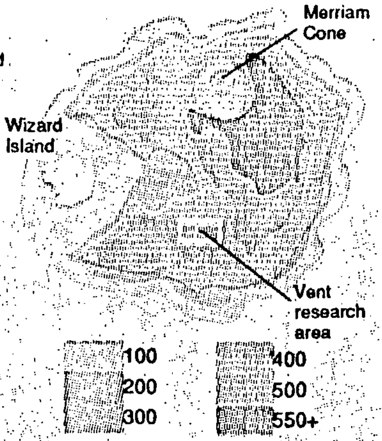
The lake occupies the caldera - a large volcanic depression produced by the catastrophic explosion and collapse of a volcano - rather than the crater of Mount Mazama, which erupted about 6,900 years ago, spreading ash over 350,000 square miles. The mountain ejected as much as 10 to 12 cubic miles of material, compared to Mount St. Helens, which ejected only about three-quarters of a cubic mile.

Rain and snowfall then began filling the caldera with water, forming the lake.

Later volcanic activity led to the formation of Wizard Island, which rises 763 feet above the lake's surface, and Merriam Cone, which rises from the lake floor to within 500 feet of the surface near the north rim.

The lake was discovered June 12, 1853, by John W. Hillman and a party of prospectors, who called it Deep Blue Lake. It was given its present name Aug. 4, 1869, by a party of visitors from Jacksonville, Ore., according to Oregon Geographic Names.

Crater Lake National Park, created by Congress in 1902, covers about 250 square miles.



- **Area:** 18 1/2 square miles
- **Depth:** 1,932 feet, the deepest lake in the United States and the seventh deepest in the world. In the Western Hemisphere, only 2,015-foot-deep Great Slave Lake in Canada is deeper.
- **Maximum width:** 6 miles
- **Elevation:** 6,176 feet above sea level
- **Temperature:** About 38 degrees Fahrenheit below 300 feet
- **Fish:** Rainbow trout and kokanee salmon (not native to the lake)

The Oregonian

Researchers will dive to Crater Lake bottom

By RICHARD L. HILL
of The Oregonian staff

Next week two oceanographers are planning to go where no one has gone before: the floor of the nation's deepest lake.

Using a manned submersible called "Deep Rover," Jack Dymond and Robert W. Collier will take turns piloting the craft on about 20 dives to the bottom of Crater Lake.

The two researchers from Oregon State University are out to test their hypothesis that thermal springs exist in the lake. It's a theory that not only is taking them to the caldera floor but has immersed them in a controversy over whether geothermal development should take place a few miles from the lake.

That hypothesis is based on a number of observations they have made since beginning work at the lake five summers ago:

- Temperature readings in the lake show minute increases below a depth of about 1,000 feet. The readings show stronger increases near the south-central area of the lake floor, where they believe hydrothermal vents may exist. The greatest temperature increase they have recorded was up to about 1 degree Fahrenheit.
- Water samples collected in the warmer bottom areas revealed unusually high concentrations of helium-3 and radon, chemical isotopes commonly associated with hot springs.
- Proportional to the temperature increases are higher concentrations of sodium, potassium, calcium, magnesium, lithium and silicate in the water.
- In sediments in the region where there are higher temperatures, increased amounts of elements associated with hydrothermal activity — zinc, copper, iron and barium — have been detected. Visual observations made with a remote-controlled diving vehicle last summer showed small red to dark-brown patches that appear to be iron- and manganese-rich deposits. Both are elements consistent with a hydrothermal source, the researchers say.

"Thermal springs is the only hypothesis that fits all the evidence," said Collier. "There has to be a process that brings all those elements into the system, and the best explanation is some sort of hydrothermal input."

Other hypotheses that have been suggested, such as conductive heating from a source under the lake and the pressure of lake water at great depths, might explain the temperature fluctuation but not necessarily the other factors, Dymond and Collier contend.

"Where the warmest water is, we found the most obvious chemical effects," Dymond said. "It would require a remarkable coincidence of events to justify any other hypothesis. The only theory that can logically explain all the factors is existence of hot or warm springs."

The two oceanographers have found themselves the focus of a controversy involving developers, who wish to tap the geothermal potential of the area just outside Crater Lake National Park, and environmentalists, who are concerned that such development could damage the park.

If the lake is found to have significant hydrothermal features, the U.S. secretary of the interior could block the issuance of leases for geothermal energy development around the park.

But Collier and Dymond aren't

Please turn to DIVE, Page E3

THE OREGONIAN THURSDAY JULY 28, 1988 PAGE E1 especially Rim Village, the local point for visitors to the only national park in Oregon.

The site's sewage system has been a prime suspect in the who-or-what-done-it mystery over the lake's clarity, but so far researchers have not come up with a definite link. Regardless, in the next few years the sewage system is going to be moved away from the lake as part of a park renovation project.

The streams and springs around Crater Lake also are being examined, as well as the area's geologic formations. Life in the lake itself, *ranging from microscopic organisms* to the non-native rainbow trout and kokanee salmon, also are under scrutiny.

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Few measurements were taken between that time and when Fontana began his research as part of the lake study, however. The physicist recorded ratios ranging from 3.29 to 3.99 in 1986 and from 3.37 to 4.25 in 1987, with the mean measurement in 1986 at 3.71 and in 1987 at

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Larson agrees, adding that project *scientists "simply don't have* enough data at this point to reach any conclusions."

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Larson said the study is just the starting point in learning how the lake's system works. "Setting up a long-term monitoring program is a top priority for us," he said. "We don't want research to just end in 1992; the lake needs to be continually studied if we're going to gain a good understanding of what's going on."

Dive: Idea of springs stirs controversy

■Continued from Page E1

focusing their attention on the controversy.

"We don't feel we have to find hot springs," Dymond said. "It's just as scientific if we don't find hot springs. We'll learn a lot about Crater Lake in the process. It's fundamental research which will contribute to our knowledge of how the lake functions. It's only incidental that it has a bearing on the controversy."

The oceanographers are not the first scientists to propose the theory that there is hydrothermal activity in the lake.

In February 1983, in a paper published in the Journal of Geophysical Research, David L. Williams of the U.S. Geological Survey in Denver and Richard P. Von Herzen of the Woods Hole Oceanographic Institution in Massachusetts said they had located two thermal springs on the lake floor.

"These springs discharge warm, dense water through faults or fractures that bring the water up from a sub-lake floor hydrothermal reservoir," they stated.

Five months later, Collier, who specializes in trace metals, and *Dymond, a sediment expert,* began work at Crater Lake as part of the National Park Service's 10-year study aimed at finding out whether the lake was losing its clarity and, if so, why.

> ***"So the research into possible hydrothermal activity is vital to our understanding of how the lake operates."***
>
> — Gary L. Larson, National Park Service

Hydrothermal vents may have an influence on lake clarity, according to Gary L. Larson, principal investigator for the study. "The warmer water at the bottom of the lake could cause the water to start moving, bringing nitrates and nutrients up into the light zone. If there was a wholesale shift in circulation of the lake, I think you would find the lake to be very different in its productivity.

"So the research into possible hydrothermal activity is vital to our understanding of how the lake operates."

The two oceanographers are no strangers to hydrothermal vents. In 1977 they were part of a research team that found the first hot vents on the ocean floor. The hot springs were found in an area known as the Galapagos Rift, an ocean crust-spreading center about 200 miles northeast of the Galapagos Islands, which are 500 miles west of Ecuador.

Collier said that in the Crater Lake research they first noticed "there was quite a high concentration of iron and manganese toward the bottom. Then, shortly thereafter, we did some other analyses for other components that normally indicated hydrothermal inputs."

Last summer, using the remote-controlled vehicle, Dymond and Collier spotted what they believed to be vents; but they were unable to take temperature readings, and the vehicle's lack of maneuverability proved frustrating.

"The submersible gives us far greater mobility," Dymond said, "so we can stick a probe in places we couldn't with the (remotely operated vehicle). Then we'll carry down water bottles and collect samples. The Deep Rover's mechanical arm can be lowered right into the vents."

Another remote-controlled vehicle will be used to carry out other aspects of the research and serve as a rescue vehicle "in case the submersible gets stuck down there," Dymond said.

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Man 'evolutionary derelict'

Graham, in his book "The Future of Man," called man "an evolutionary derelict" because "huge masses of those with ordinary minds have been allowed to come into being and then proliferate."

Over time, artificial insemination became common, and more radical techniques, like in vitro insemina*tion and gene mapping, took the* spotlight in the reproductive industry. To Graham's delight, protestors disappeared from outside his office about 30 miles north of downtown San Diego.

Alexander Capron, a scholar at the University of Southern California and former member of President Reagan's *Commission on Bio-ethics*, has concerns with the repository, but gratefully notes "it hasn't become a major force in reproduction."

"I continue to think of it as a rath*er silly, misguided effort,"* Capron said. "The whole notion of individuality and of uniqueness is what

their field" and "outstanding intellects," are withheld from the parents and the public. The list includes two Nobelists and an Olympian. All are of European descent or Jewish, and most are California scientists. Graham says he's invited blacks and Asians to donate, but that they've refused.

Donors are declared of good health and genetic ancestry, which means their families are free of such diseases as alcoholism and mental illness, and the donated sperm is screened for the acquired immune deficiency syndrome virus. Part of the AIDS screening includes a 180-day sperm quarantine.

The sperm, stored in tanks of liquid nitrogen that keep it frozen, has been sent around the country and as far away as Egypt.

Applicant parents must show *they are married, intelligent, emo*tionally and financially stable, with a clean physical and mental health history. The mother must be under age 38. About half the applicants are rejected. Parents choose a donor from such information as intelligence test score, ancestry, hair and eye color, athletic ability, hobbies, and personality traits.

Graham still provides most of the operating costs and the repository does not charge its clients, although lab fees and other expenses have prompted it to start accepting donations in the last year or so, said *spokeswoman Dora Vaux. Contribu*tions generally range from about $500 to $1,000, she said.

medical check and quality of donors that draw them, not a desire for super children.

Repository parents also acknowledge they promote their child's intellectual development and have high expectations, but say they are not unreasonable.

"I don't have flash cards around the crib since he was two weeks old, but I do expose Jeffrey to as much as I can," the Riverside mother said.

The 33-year-old woman and her 45-year-old second husband came to Graham because the husband had a vasectomy in an earlier marriage. Between them, they already had six other children from previous marriages.

Although her other children are bright — her two teen-age girls are honor students — she says 1½-year-old Jeffrey is different: He requires little sleep for his age, only seven hours, is extremely inquisitive and loves books.

Her stories echo those of other repository parents, several of whom have come back for a second child, Graham says. The children's "vocabulary is often twice that expected. They're standing early and walking young."

Graham requires annual reports from parents, but is frustrated that his experiment lacks rigid scientific standards because the donors and parents vary and the children are raised in different environments. But he added, "The *general consequences* of bright, happy kids is good enough for me."

Asthma's genetic link under scrutiny

By PAUL RAEBURN
The Associated Press

BAR HARBOR, Me. — Researchers have taken the first steps toward understanding the causes and the inheritance of asthma with the discovery of two asthma-related genes in laboratory mice.

Roy Levitt of the Johns Hopkins Medical Institutions in Baltimore said Wednesday that learning how these genes work could help doctors identify people at risk for asthma and also could speed the development of better drugs to treat it.

So far, Levitt and Wayne Mitzner, also of Johns Hopkins, have shown that at least two genes can produce a hypersensitivity in the bronchial tubes of mice.

The increased sensitivity of the airways to drugs or environmental agents, a phenomenon called increased bronchial reactivity, "is one of the hallmarks of asthma," Levitt and Mitzner wrote in the current issue of The FASEB Journal, published by the Federation of American Societies for Experimental Biology.

Asthma is estimated to afflict about 6 percent of the population, Levitt said.

Levitt, who presented his findings at a genetics course at the Jackson Laboratory in Bar Harbor, said increased bronchial reactivity can lead both to asthma and to a serious lung disorder called chronic obstructive lung disease, in which patients experience extreme difficulty breathing.

The causes of asthma and chronic obstructive lung disease are not known, but inherited genetic factors and exposure to agents in the environment play a role, Levitt said.

Studies of families in which asthma was inherited showed that even some family members without asthma had inherited an increased bronchial reactivity.

"This seemed to suggest there could be a simple genetic basis for airway hyper-reactivity, asthma and chronic obstructive lung disease," Levitt said.

He and Mitzner developed machines to monitor breathing in laboratory mice, and they have determined that at least two different genes in mice can lead to this bronchial sensitivity.

It is not yet known whether these genes have counterparts in humans, Levitt said.

One of the genes has been shown to be inherited in mice as a recessive genetic trait, meaning that an offspring would have to inherit the defective gene from both of its parents in order to have bronchial hyper-reactivity. Mice do not develop asthma, Levitt said.

The inheritance pattern of asthma in humans is not known, Levitt said.

Further studies of the asthma-related genes in mice should allow researchers to look for similar genes in humans, he said.

In order to demonstrate the bronchial hyper-reactivity in the mice, the researchers had to expose the mice to agents thought to be related to the development of asthma in humans.

There is no evidence of eruption from this growing volcano for the next 50,000 years. But during these 500 centuries of volcanic slumber, *alpine glaciers dissected the Phantom Cone and Danger Bay flows.*

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into Crater Lake below Cloudcap and north of the Phantom Ship. It is the relic of a dike that fed the next series of flows that built the foundations of Mount Mazama.

The volcano was quiet, without evidence of eruption for perhaps 70,000 years. And then it recycled, again erupting dark iron and magnesium-rich andesite flows, similar to those of the Phantom Cone. They are flat-lying, unlike the steep, cone-related flows from the Phantom Cloudcap Bay, and 2,000 years later, began a volcanic cone that makes up Hillman Peak. Hillman Peak, now cross-sectioned in the caldera's west wall, *completed erupting about* 67,000 years ago. More silica rich lavas, dacite and light-colored andesite, poured out of the center of Mazama 7,000 years later.

The geologic records researched by Mazama's biographers suggest that there were periodic eruptions of ash from the mountain between 00,000 year contest with the glaciers.

All was quiet for 15,000 years, then Llao awoke from his nap, fired up the stove and got ready for action once more.

In the few hundred years before Crater Lake was born, four areas of Mount Mazama erupted significant amounts of a viscous, silica-rich type of lava called rhyodacite. Redcloud Rock and Cloudcap oozed into place 7,015 years ago.

making explosive eruptions inevitable.

The climactic eruption of Mount *Mazama 6,845 years ago developed* in three stages from two different types of vents.

The first eruption probably resembled Mount St. Helens's paroxysm. It came from a central vent, probably located a little northeast of the center of Crater Lake, and probably was cataclysmic in its onslaught.

biography of Mount Mazama complete? Possibly not, although things have been quiet for the past 6,844 years. Wizard Island and Merriam Cone, a smaller volcano on the north floor of the caldera, as well as some silica-rich lavas, have been erupted since the collapse. They are insignificant in volume, but they do suggest *that the collapse of Mount Mazama* did not immediately turn off the burners. Llao may still be lurking, just below the surface.

Life: Researcher's 'spiked' water finds algae may be starving for nitrogen

■Continued from Page E1

Nitrogen, an important component of plant fertilizer, may be the key element missing from the upper water. Its absence there may be what keeps phytoplankton more *than 200 feet below the surface.*

Mary K. Debacon, a student of McIntire's, did some experiments in the laboratory that suggest the algae in the lake are starving for nitrogen. She "spiked" samples of lake water with each individual nutrient to see which one would cause more algae to grow.

Just like putting more gasoline in a car won't fix a flat tire, spiking the lake water with a nutrient the algae aren't starving for won't grow any more algae. If they already have enough of that nutrient, adding more won't help them if they need *something else.*

Debacon found that only by adding nitrogen could she grow more algae in the water. And nitrogen is known to be missing in the upper water of the lake.

Nitrogen stays down deep in Crater lake because of the unique shape of the lake basin.

A typical lake collects water from a large area, much like a storm sewer. As the water runs over the land on its way to the lake, it picks up nutrients that will become plant food for the lake's phytoplankton.

But Crater Lake, with its tremendous depth and steep basin sides, is like a giant rain barrel, collecting pure rainwater directly on its surface.

Deprived of fertilizer, phytoplankton can't grow in the clear upper water. The deeper water has plenty of nitrogen, but down there the plant cells don't get much light.

"They're caught between a rock and a hard place," said McIntire. *The phytoplankton don't have* enough nitrogen up top, but 260 feet down they get only 1 percent of the surface light, he said.

McIntire and Debacon have been cataloging the different kinds of algae in the lake as part of the 10-year study.

Debacon takes hundreds of different water samples from the depths of Crater Lake and lets the phytoplankton settle onto microscope slides. She then painstakingly counts every species of phytoplankton *on the slide. The mass of data* are then fed into a computer, which tells her how deep each species of algae lives in each season.

In winter the predominant species is a barrel-shaped algae called *Stephanodiscus*, which mingles with other phytoplankton in lake depths.

But in summer the different species tend to live in separate layers, and some scientists concerned about the clarity of Crater Lake have begun to focus on one species of phytoplankton, *Nitzschia gracilis*, that can grow as close as 60 feet to the surface during August, when Secchi disk *clarity readings* are usually worst.

Long and skinny, *Nitzschia*'s needle-like shape helps it to scavenge scarce nutrients in the upper water and, unfortunately, to block light, Debacon explained.

But it also is the preferred snack of the tiny water flea *Daphnia*, which grazes on algae hungrily, according to Elena Karnaugh, a biotechnician on the Park Service study. Down on the *Daphnia* ranch, the algae won't overgrow if the lake has a large enough herd of the voracious water fleas.

Daphnia are actually tiny crustaceans, more closely related to crabs and lobsters than to fleas and other insects. But, like fleas, they're smaller than the head of a pin.

Karnaugh catches and counts the water fleas of Crater Lake.

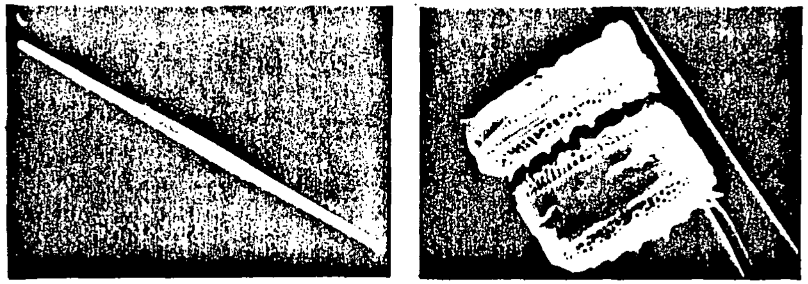
"It's tedious work," Karnaugh said. "That's how I got into it — nobody else wanted to do it."

When Karnaugh began her counting in 1985, she found far fewer *Daphnia* than had been seen in earlier studies of Crater Lake. What had happened to the water fleas? In most lakes, *Daphnia* are eaten main*ly by fish.*

Crater Lake, with no permanent inlet streams, is isolated from all other bodies of water. The only way for fish to get into the lake would be by bucket. And so they did.

It is a historical irony that the person who fought hardest for the protection of Crater Lake may have done the most to alter it.

William Gladstone Steel came to Crater Lake in 1885 and began a 17-year campaign to make the lake a national park.



AL SOELDNER, MARY K. DEBACON

The needle-like shape of one Crater Lake phytoplankton, *Nitzschia gracilis*, left, helps it scavenge scarce nutrients in the upper water. It is 75 micrometers long. A barrel-shaped algae, *Stephanodiscus*, right, is the predominant species of phytoplankton in winter at Crater Lake. It is 5 to 6 micrometers in diameter.

But in 1888, Steel brought a bucket of rainbow trout in from the Rogue River, thus beginning the practice of stocking Crater Lake with gamefish — a practice that continued until 1941.

During that time five species of fish were stocked: Rainbow, cutthroat and brown trout and steelhead and coho salmon, according to Mark Buktenica, a park ranger-biotechnician.

But at some point kokanee salmon slipped in, probably as the result of a mix-up at a fish hatchery, he said.

Now only the kokanee salmon and rainbow trout are left, according to Buktenica, who has made an extensive survey of the fish and of their stomach contents to find out what they eat.

What he found is that the rainbow live near the shore and mostly eat insects.

But the kokanee are living in the open water, down as deep as 300 feet, where they feed on water fleas.

The kokanee are gobbling up the natural lawnmowers of Crater Lake.

"The stocking of the lake with fish was one of the most profound ecosystem shifts in Crater Lake," says Stanley Gregory, associate professor of fisheries and wildlife at OSU.

The kokanee tend to all be born at the same time, in a cycle every few years. They grow up together, then spawn and die all at once, Buktenica said. A baby-boom generation of kokanee just spawned and died last winter.

"I think we have a low abundance of kokanee now; *Daphnia* apparently are on the increase. Coincidently — I don't know — we're getting the highest Secchi disk readings we've gotten in 20 years," Buktenica said.

The fish have become a permanent part of the lake ecosystem; trying to eradicate the fish would cause more damage, the limnologists agree. The Park Service would never poison the lake, and they have learned their lesson about introducing non-native predator species. Nets would fail to get the last of the fish. Buktenica estimates that 200,000 fish live in the lake and that sport fishermen take only 50 per year.

Scientists are still not sure *whether a decrease in the Daphnia* population leads to an increase in algae in Crater Lake. But even more controversial is whether an increase in algae growth could be due to an increase in the nitrogen level in the water.

Crater Lake gets nitrogen naturally from the caldera walls, and from rain and snow, Larson said. But these sources may now be putting unnatural amounts of the key nutrient into the lake.

Gregory measured the nitrogen in a number of gullies running into the lake from the caldera walls.

One gully, Spring 42, originates near a septic system at Rim Village, and Gregory found that it had much more nitrogen in its water than did gullies far from tourist facilities. But that does not pinpoint Spring 42 as a pollution source, he said.

"It could be sewage from the Rim Village area, or it could be some sort of natural process," Gregory said. He noted that some streams in the pristine Bull Run watershed, source of *Portland's drinking water*, had natural nitrogen levels just as high as what was measured at Spring 42.

Some later measurements at Spring 42 showed much lower levels of nitrogen, according to Jim Milestone, natural resource management specialist at Crater Lake, and this also would suggest that the stream's nitrogen level fluctuates naturally. But the Park Service plans to remove the septic system anyway.

"We're pulling it out of there," Milestone said, "and that will be the end of that controversy."

But there are other controversial sources of nitrogen in Crater Lake, including the rain and snow that fall directly on the surface.

"The acid rain that is affecting the North American continent right now we see every once in a while in our samples," Milestone said. "And we have the cleanest air in the United States here, in any national park."

Such man-made changes as sewage input and acid rain are what the Park Service wants to avoid at Crater Lake. But any natural process *occurring in the lake they want to* allow to continue, regardless of its effect on the lake.

Hydrothermal vents on the bottom of Crater Lake — if they exist — could be pumping heat and minerals into the water, and park management is adamant that this process, if occurring, be allowed to continue.

"We're trying to perpetuate the natural cycles here," Milestone said. *He and the park superintendent*, Robert E. Benton, are concerned that a proposed geothermal power plant could affect the same plumbing that feeds Crater Lake and diminish the hydrothermal input flowing into the lake.

Lessening the input of heat and minerals into the lake might actually make the water clearer. If hydrothermal vents are heating the bottom water of the lake, they could be moving nitrogen up from the fertile depths to the shallower water, where the algae need more nitrogen to grow.

"We have the possibility of this hydrothermal, this heat coming in, which can set up convection currents, and that starts internal movements of water. And that might bring some of the nitrogen up into the upper part of the system," Larson said.

"We don't understand how the lake circulates, or if it circulates," he said. Although the bottom water *has much more nitrogen and is* much colder than the upper water, suggesting that the two layers never mix, the bottom water is full of oxygen — hinting that it sometimes comes up for air.

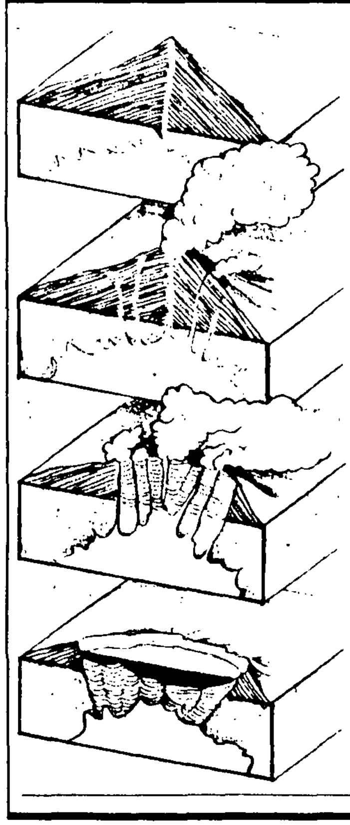
The hydrothermal issue is only one small piece of the puzzle, which might be resolved in the next few weeks when researchers examine the lake floor with a manned submersible. Other pieces of the ecological puzzle may take much longer to fall into place.

"That's the importance of doing long-term studies," said Karnaugh. "You just don't know until you have enough years behind you."

Mount Mazama's violent history created Crater Lake

By ELLEN MORRIS BISHOP

FORMING CRATER LAKE



1. Mount Mazama was born about 400,000 years ago as magma began to spew out of a chamber several miles underground, developing a volcanic cone.

2. During the next 300,000 years, other magma vents and cones developed on the mountain's mass. The mountain grew to a height of about 12,000 feet.

3. Nearly 6,900 years ago the mountain erupted, with some explosions about 42 times greater than those of Mount St. Helens in 1980. The mountain collapsed into the magma chamber.

4. The collapse left a hollow bowl, or caldera, which was enlarged by massive landslides. Water from springs, snow and rain began to fill the caldera as volcanic activity subsided, creating the world's seventh deepest lake.

The Oregonian/WERNER BITTNER

Carnegie Institution, Washington, D.C

A painting by Paul Rockwood shows how Mount Mazama may have looked after it erupted, collapsing the summit about 6,900 years ago.

In the days before the downfall of Llao, the Klamath Indians' god of the underworld, it was one of the Cascades' highest peaks. In the time of the glaciers and quick-flowing torrents its summit stood at perhaps 11,800 feet, higher than today's Mount Hood, and more massive than Jefferson.

But Mount Mazama is no more. What's left is Crater Lake, the seventh deepest lake in the world, 1,932 feet from the waterline to its deepest point.

TIME TRAVEL

The biography of most large stratovolcanoes is complex, the sum of quiescent growth, explosive activity, a variety of lava compositions, and erosion. Mount Mazama was no different in this respect. There was a long history of eruption and glaciation before 51 cubic kilometers — 12 cubic miles — of rock and debris was explosively removed 6,845 years ago, leaving the pit that would become Crater Lake.

Mount Mazama's most recent biographer, Charles R. Bacon of the U.S. Geological Survey in Menlo Park, Calif., as well as others, have painstakingly constructed the story from the evidence in the rocks.

Mount Mazama began about 400,000 years ago in the midst of the Pleistocene, the Ice Age. Before its destruction at least five sizeable stratovolcanoes would be clustered together in one massive mountain.

The oldest of these is called Phantom Cone. Its remnants are exposed low on Dutton Cliff along the south shore of Crater Lake. Potassium-argon radiometric dating indicates that the Phantom Cone was active about 400,000 years ago.

The Phantom Ship, a ragged vessel of rock at the southeast shore of Crater Lake, is a remnant of the central vent system and feeder dikes for this old part of Mount Mazama. The lavas of Mount Scott, just southeast of Crater Lake, may be the same age.

Fifty thousand years later, the next of Mazama's five cones began to build. At the base of cliffs at Danger Bay lie lavas lighter in color and higher in silica than those of the Phantom Cone. These are andesites and dacites, pasty flows that moved with the liveliness of Silly Putty and may have had a similar viscosity. They form an extensive and impressive stack that built nearly as high as the Phantom Cone.

There is no evidence of eruption from this growing volcano for the

Their telltale tracks — U-shaped valleys and stone-carved grooves — were filled by the next episode in Mazama's complex biography.

Dutton Cliff stands at the caldera rim's south side, rising to an elevation of 8,150 feet, an imposing presence above the Phantom Ship. The top one-third of this cliff is composed of light gray andesite and dacite, 190,000 years old. It is likely that these rocks represent a low-standing eruptive center near the Phantom Cone.

Not far away, Sentinel Rock juts into Crater Lake below Cloudcap and north of the Phantom Ship. It is

Cone, and probably represent a small shield volcano that erupted about 110,000 years ago, between major glacial advances of the Pleistocene, and centered slightly southwest of the caldera.

And so the foundation was built. Mount Mazama lay dormant for 35,000 years. Then, about 75,000 years ago, the underworld god Llao awoke again.

The construction of Mazama's present volcanic carapace began with andesites: Iron- and magnesium-rich andesites erupted at Cloudcap Bay, and 2,000 years later, began a volcanic cone that makes up

45,000 and 60,000 years ago.

At times it must have seemed as though there was a race between the forces of fire to build the mountain and those of ice to tear it down. Lava flows erupting from 20,000 to 50,000 years ago competed with glaciers for room on Mazama. The Watchman on Crater Lake's east rim represents a silica-rich andesite that erupted and then glaciated shortly thereafter.

From 22,000 to 30,000 years ago, silica-rich ash flows and debris flows were hurled out of Mazama from vents east of present-day Wizard Island. Domes such as Sharp Peak and cinder cones such as Forgotten Crater were built during this time.

By the end of the Pleistocene some 20,000 years ago, Mount Mazama must have stood as a cluster of "overlapping, eroded . . . volcanic cones that formed an irregular, asymmetric ridge from Hillman Peak to Mount Scott," according to Bacon. Mount Scott, Hillman Peak, and volcanoes centered at Cloudcap Bay and Sentinel Rocks were major peaks in this volcanic complex.

So Mazama, before its climactic eruption, was probably not a single, majestic cone with a profile like that of Jefferson or Hood. It was a sort of volcanic group, massive, multi-spired, and grizzled victor in its 400,000-year contest with the glaciers.

All was quiet for 15,000 years

The great cliffs at Llao Rock were formed from a single flow that filled its own volcanic crater with at least one-quarter cubic mile of hot, silica-rich paste, also about 7,015 years ago. Pumice erupted from this vent, falling over an area from western Nevada, across Steens Mountain, to northern and eastern Washington.

Similar material makes up Grouse Hill on the north side of the caldera. The last batch of this stuff made it to the surface probably just days before the climactic eruptions, and is called the "Cleetwood Flow." The top of this rhyodacite was still soft when the rock fragments from Crater Lake's explosive eruptions hit it.

Were it not for the oozing rhyodacites, Mount Mazama might have been a more sedate volcano. But the escape of more than 3 cubic miles of pasty lava, flowing ponderously outward and upward through cracks that encircled the large magma chamber below, decreased the pressure in the chamber, and allowed long-dissolved gases — mostly steam and carbon dioxide — to effervesce. The effect was similar to opening the top of a well-shaken soda bottle. Worse yet, the pasty rhyodacite plugged vents through which some gas might otherwise have escaped, making explosive eruptions inevitable.

It began as a high ash column rising tens of miles into the atmosphere, laden with rocks as wide as 3 feet wide or more in diameter. It left a deposit 70 feet thick on the slopes of Mazama, 20 inches thick at Newberry Volcano, and a half-inch thick where wind-drifting ash fell in southwestern Saskatchewan province.

This relatively cool, high-rising ash column was soon replaced by hotter stuff. Ash flows — the sort of thing that moves at 100 mph and has a temperature of 1,500 degrees Fahrenheit — swept out of the central vent, six miles northward toward Mount Theilson. Like the pasty flows a hundred years before, and the cooler, high-rise ash that immediately preceded them, these were rhyodacites. Their eruption removed the final support from beneath the complicated summits of Mount Mazama.

Take away the gas and the liquid supporting a volcano inflated by heat and churning magma in a shallow chamber, and the effect is much like removing the arch from beneath a railroad bridge. Collapse.

The magma below, with more and more pressure removed, continued to effervesce. And from the enlarging ring vents more ash flows erupted — at temperatures of 1,500 to 1,800 degrees Fahrenheit, probably moving at 100 to 150 mph. They carried volcanic fragments a foot in diameter more than three miles and left 10-inch diameter rocks stranded 270 feet above valley floors five miles south of the now-rapidly collapsing crater. As the eruption tapped the bottom of a once-bulging magma chamber, it encountered basaltic andesites again, now seen as the dark caps on the welded tuff columns at the Pinnacles.

In the end, Llao returned to the underworld. What had been the roof of the Cascades was either gone — carried aloft as debris or collapsed back into the magma chamber's abyss. Between 12 and 13 cubic miles of once-solid rock had vanished. And in its place was an awesome hole, a classical stratovolcano caldera nearly 4,000 feet deep, from the top of Llao Rock to the bottom of what once was a churning and dynamic magma chamber.

Klamath Indian legend suggests that Llao's battle with his rival, Skell, lasted seven days before Llao was defeated. It is a pretty good time estimate for the collapse of Mazama.

Will Llao return again? Is the biography of Mount Mazama complete? Possibly not, although things

Simulation of geothermal plant seeks to gain support of public

By RICHARD L. HILL
of The Oregonian staff

CRATER LAKE — A somewhat comical-looking scene being staged this week in a remote area of the Winema National Forest near here has a serious message to convey.

Two 100-watt stereo speakers are blasting noise toward 8,926-foot-high Mount Scott, about 2.5 miles away, as multicolored balloons sway about 200 feet overhead above the treetops.

What's going on amid the pines is a simulation of a 120-megawatt geothermal power plant. Its sponsor, California Energy Co. of Santa Rosa, Calif., wants the public to know that such a plant is environmentally safe and needed.

"They won't be able to see us, they won't be able to hear us, and they won't be able to smell us," James L. Moore, the company's vice president for exploration, said of the plant California Energy is seeking to build in the forest.

Indeed, a half-mile hike west from the proposed plant site to the boundary of Crater Lake National Park confirms to visitors that the noise — a recording of a plant in operation — is virtually inaudible, while the balloons, simulating the height of a plant steam plume, no longer are visible.

However, the major environmental fear isn't as easy to alleviate with a simulation.

The concern involves what might lie far below the surface in the geothermal plumbing, an area where no one can say with absolute certainty what is occurring.

The company has found itself embroiled in a dispute with the National Park Service and environmental groups over the plant's potential impact on Crater Lake and possible hydrothermal vents in the lake.

The vents are a hypothesis, but a determination whether it is correct may come as early as this week as oceanographers begin to explore the lake floor in a manned submersible.

Jack Dymond and Bob Collier, researchers from Oregon State University, are looking for the vents, which they believe may be bringing warm water, minerals and chemicals into the lake.

Even if such vents are found, however, the debate whether there could be a link between the lake and the nearby geothermal development will continue.

Dymond said it "would be very difficult to establish whether such a link existed, even if our research was focused on that — and it's not."

California Energy has timed its simulation to coincide with the media attention being given to the lake dives.

The Oregonian/STEVE NEHL

Wilson Goddard of California Energy Co. monitors the level of sound from nearby loudspeakers that simulate the noise from a power plant.

"We think we can meet all serious environmental considerations," Moore said, adding that he believes concerns over a plant affecting Crater Lake four miles away are not supported by any scientific evidence.

Even without the evidence, however, *the company finds its future in* the area threatened by legislation introduced in Congress by Sen. Mark O. Hatfield, R-Ore. His amendment, placed on a Senate bill involving geothermal resources, would place Crater Lake on a list with 13 other national parks that are found to have "significant thermal features."

Such a designation could block leases for geothermal energy exploration on the grounds that drilling could affect the thermal features in the park. If vents are located, the measure undoubtedly would gain considerable support.

Bob Benton, park superintendent and a leading detractor of the energy development project, applauds the move "as important in making sure we preserve what we have here. It gives the lake and park an extra measure of protection."

California Energy is leasing 76,000 acres in the Winema National Forest and had begun drilling a 4,000-foot test hole on the southeast flank of Mount Scott. The drilling was stopped after the Sierra Club appealed a drilling permit issued by the Bureau of Land Management over concerns that fluids used to lubricate the drill bit could affect the lake. A decision by the BLM is pending.

Moore says what largely has been overlooked in the controversy over environmental effects is that such power plants have been proven to be a "clean, safe and cost-effective" source of energy.

A hydrothermal power plant operates by piping hot water or steam out of the ground. When the pressure of being confined at great depths is released, the water or steam expands and can be used to power turbines for producing electricity.

The cooled hydrothermal fluids are then injected back into the ground.

Moore said one problem faced by California Energy is "a public perception that there's no need for additional power."

That is an erroneous view, Moore said, adding that the Bonneville Power Administration and the Northwest Power Planning Council have forecast electricity deficits in the Northwest in the early 1990s.

"So I feel there is a long educational process involved regarding both the environmental and energy issues involved with this project," Moore said. "I don't know how all this will come out, but I hope we're given a reasonable shot at showing we have a contribution to make here."

FRIDAY, AUGUST 5, 1988 PORTLAND, OREGON 35¢

AM
SUNRISE EDITION

The Oregonian

WEATHER: Mostly sunny; high 85, low 58 Page A2

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WHAT'S INSIDE

Swingin' saxophonist

Saxophonist Grover Washington Jr. headlines the Saturday lineup for the seventh annual Mt. Hood Festival of Jazz at the Mt. Hood Community College stadium in Gresham. He began playing at nightclubs in Buffalo, N.Y., at age 12. **Inside A&E**

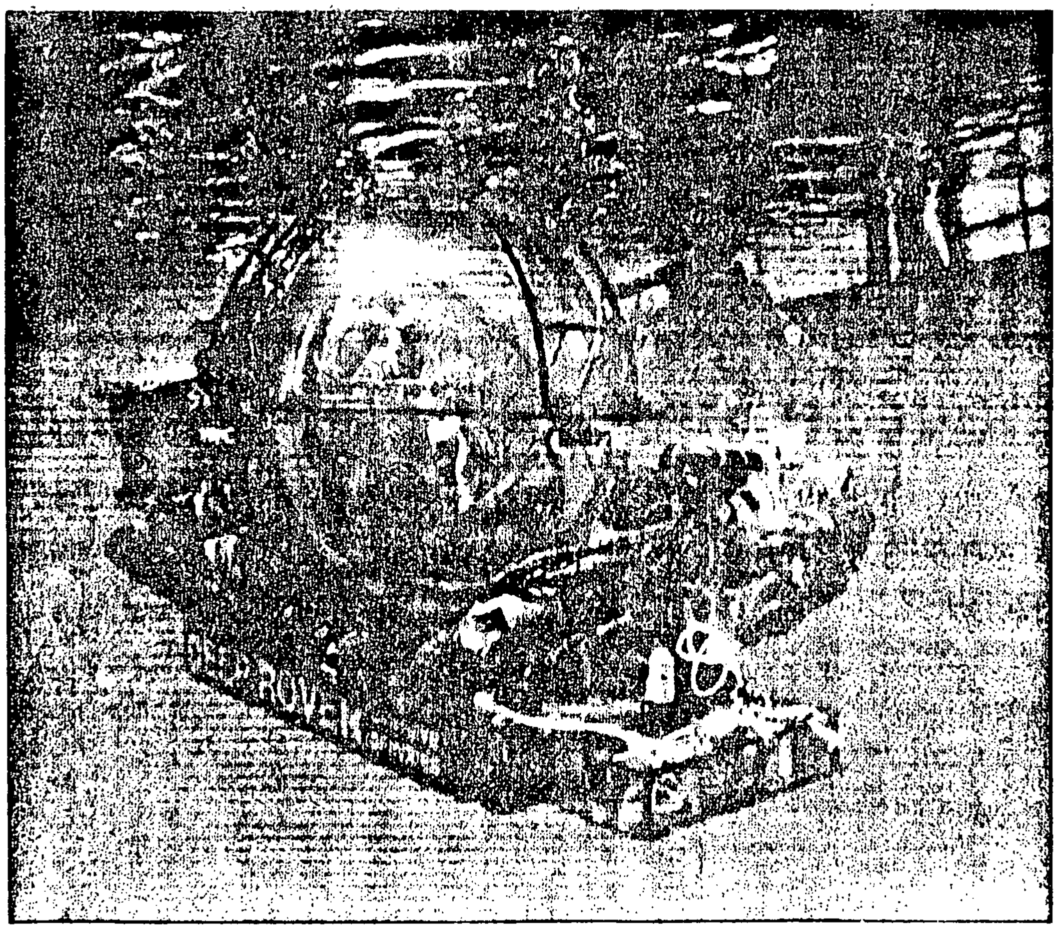
NEWS IN BRIEF

Lawmakers wary of fee boost

Legislators in Salem will not support a plan to triple vehicle registration fees to finance an anti-crime package, according to Gov. Neil Goldschmidt. The governor said there was still support for a special session of the Legislature if he found another funding mechanism for his anti-crime plan. He was backing away from the fee increase. **Page B1**

Fire hits Inn of 7th Mountain

Into the depths



The Oregonian/STEVE NEHL

The submersible Deep Rover, piloted by Jack Dymond, an Oregon State University oceanographer, descends Thursday into Crater Lake during a research dive to between 300 and 400 feet. Story on Page B2.

Burning in fields halted

☐ The DEQ moratorium is expected to last several days while the state investigates events leading to the fatal I-5 pileup

By MICHAEL ROLLINS
of The Oregonian staff

Field burning in Oregon came to an abrupt halt Thursday morning when the state's top environmental official called for a short-term moratorium after a massive accident Wednesday on Interstate 5 that killed seven people.

Fred Hansen, director of the Oregon Department of Environmental Quality, said the ban probably would last into next week while he sorted out the events that led to the deaths and to injuries to three dozen others after smoke obscured the vision of motorists.

Gov. Neil Goldschmidt also has requested that Hansen head a task force of state agency directors — who met Thursday afternoon — to re-examine field burning and safety. Members include officials of the Oregon State Police, the state fire marshal, a risk manager from the Executive Department and officials from the state departments of transportation and agriculture.

After that meeting Thursday, Hansen said it appeared the Wednesday tragedy was "truly an accident and you can't prevent all accidents." He added that the investigation was continuing.

Grass seed farmers in the Willamette

Scientists at Crater Lake begin bobbing for data

By RICHARD L. HILL
of The Oregonian staff

CRATER LAKE — "I'm speechless. It's exciting. I think it might be kind of fun, actually."

Speaking from 210 feet below the surface of Crater Lake, the usually soft-spoken Jack Dymond couldn't hide his enthusiasm for the watery world around him.

Sitting snugly in a one-person submersible called "Deep Rover," he took his first turn at piloting the craft in a series of about 20 dives that will explore the nation's deepest lake.

With scuba divers and a boatload of journalists watching nearby, Dymond plunged the 10-foot-long craft below the surface at 1:15 p.m., a few hundred yards east of Wizard Island. His goal Thursday, in addition to testing the scientific instruments on the craft, was to do research for the U.S. Geological Survey.

Dymond, an oceanography professor at Oregon State University, focused his attention on a dacite dome coming up from the floor of the lake.

"Visibility is only about 15 feet," he reported to clipboard-wielding workers in a research vessel above as he passed a depth of about 190 feet. "I've churned up some sediment. It's light-colored sediment with bits of talus and lava showing through."

The craft's pilots can communicate by means of an acoustic underwater telephone.

Bob Collier, assistant professor of oceanography at OSU, planned to make his first dive late Thursday. Also waiting to take his turn at the helm was Mark Buktenica, a biotechnician with the National Park Service.

On Saturday, Dymond and Collier hope to begin making deep dives to 1,500 feet with the primary goal of determining whether there are hydrothermal vents at the bottom of the lake.

Their research is part of a 10-year study of Crater Lake begun five years ago over concerns that the water was losing some of its famed clarity. Dymond and Collier hypothesize that hot springs are bringing warm water and chemicals into the lake, although no one is certain whether such vents would have any effect on the water's clarity.

They will be the first persons to actually see the bottom of the 1,932-foot-deep lake, although they viewed the caldera floor by means of a videotape camera mounted on a remote-controlled vehicle last summer.

Buktenica, meanwhile, will gather data about the lake's biology on his shallower dives.

Prior to Thursday's dive, Dymond went down a long checklist with engineers from Can-Dive Services Ltd. of Vancouver, British Columbia, which owns the craft. After the list was completed, the two-armed plastic bubble was towed out to the study area, where Dymond climbed aboard after a one-apple lunch.

The sub was gently hoisted into the water and released, with only about a foot of the vehicle showing above the water. Dymond drifted away from the tow vessel, then started the thrusters that propelled him within moments beneath the cobalt-blue water.

The researchers hope to define the chemical composition and temperature of fluids emitted from the suspected hydrothermal vents. They also hope to determine how those fluids are dispersed within the lake and learn more about the circulation patterns of the lake's waters and nutrients.

THE OREGONIAN FRIDAY, AUG. 5, 1988 PAGE B2

A gurgle, a happy glub, and sub hits lake bottom

☐ An oceanographer in Deep Rover is the first to see the floor of Crater Lake at a crushing 1,450 feet

By RICHARD L. HILL
of The Oregonian staff

CRATER LAKE — Oceanographer Jack Dymond on Friday became the first person to directly look at the floor of the nation's deepest lake.

In an eight-hour dive on the submersible Deep Rover, Dymond went in search of hydrothermal vents that he and fellow researcher Bob Collier think may exist on the lake's bottom. The researchers said they would not release information on the results of the dive until Sunday.

In the first deep dive, which occurred a day earlier than planned, Dymond went to about 1,450 feet in an area in the south-central area of Crater Lake where hot springs are thought to exist. The deepest point in the lake is 1,932 feet, making it the seventh-deepest lake in the world.

"It was very rough terrain down there," said Jim Milestone, natural resource management specialist for the National Park Service at Crater Lake. The roughness made it difficult for navigation equipment to keep tabs on the 10-foot-long craft.

He said that Dymond was following a rugged fault block, part of a fracture line that rings the caldera floor. The fracture is where Mount Mazama broke up while collapsing into its empty magma chamber after violently erupting nearly 6,900 years ago.

Dymond and Collier, oceanography professors at Oregon State University, theorize that hydrothermal vents occur along the fracture line, bringing hot water, chemicals and sediments from a source far below the lake.

Milestone said Dymond and Collier had decided to take the first deep dive Friday because "they felt comfortable" with the submersible after they both took shallow two-hour dives Thursday.


DYMOND

"Both were ready for it," Milestone said. The Friday dive began at 10 a.m. and ended at 6 p.m., according to Milestone.

Collier will get his turn to pilot the craft to the floor Saturday. Results of both dives will be released Sunday afternoon.

Cameras mounted on the submersible are recording the dives. The maneuverable, pincerlike arms on the craft also enable the scientists to use instruments to take temperature and other measurements.

Milestone said workers on the research vessel on the surface were "all working very hard" keeping track of the submersible. "It was a very intense scene."

Research team members were staying in constant communication with Dymond, he said. Every 15 minutes they run through a checklist with the pilot to make sure all the gauges and systems are functioning properly.

The team had some concerns about the weather Friday, as thunderstorms moved about the area. Rain and a rough surface could pose problems for the sophisticated electrical equipment on the research vessel. A pontoon boat that carries the submersible when it's on the surface also has a tall, metal hoist that could attract lightning.

Milestone said fire lookouts were making hourly checks with the research team to warn them of thunderstorms heading toward the dive area.

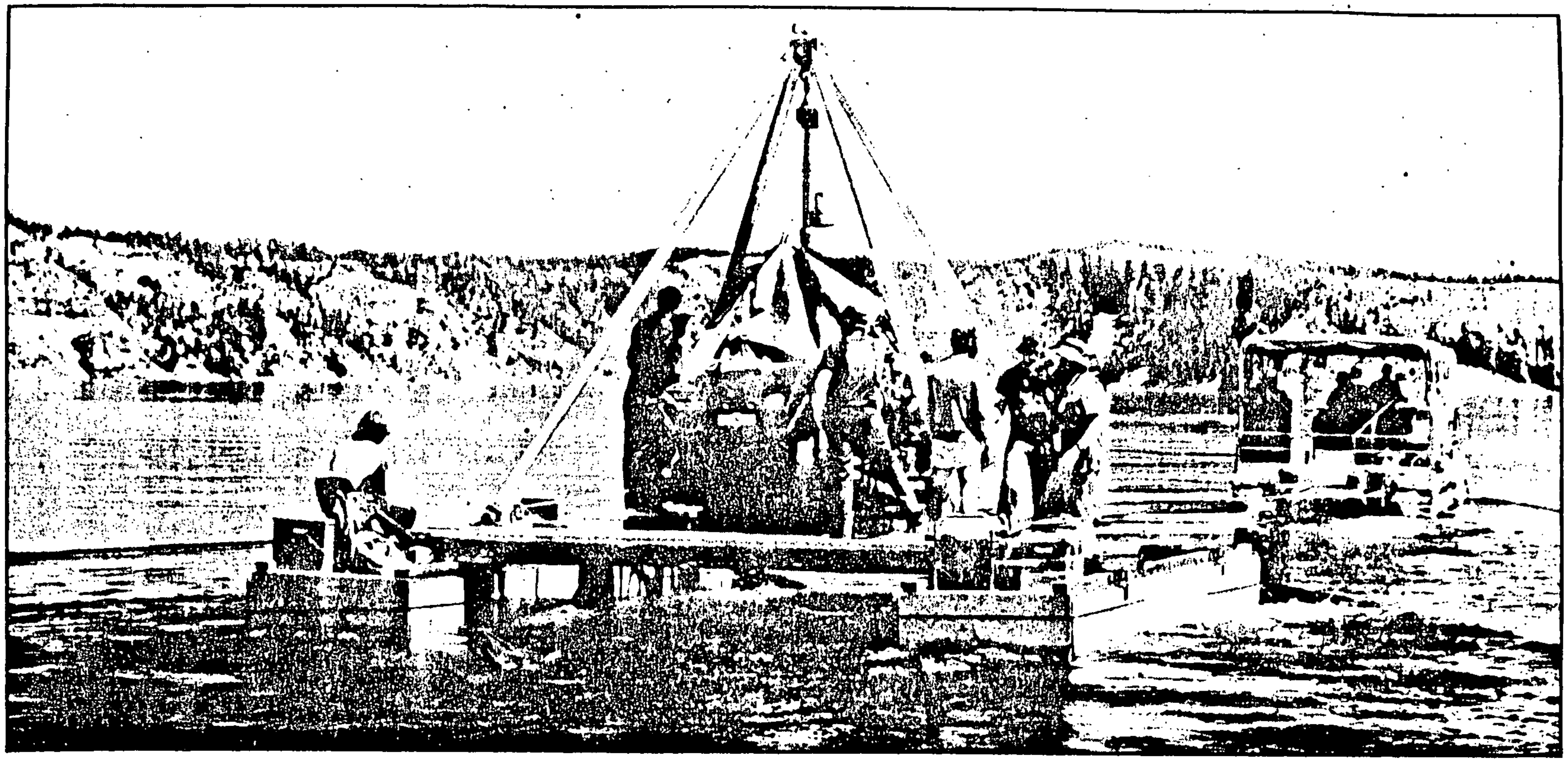
"We would have to bring him up fast" if there were a threat, Milestone said, adding that it would take the craft about 20 minutes to reach the surface from the depth Dymond was operating at Friday.

Collier will return to the same general area Saturday, Milestone said.

This summer's research is being funded by a $225,000 grant from the National Park Service.

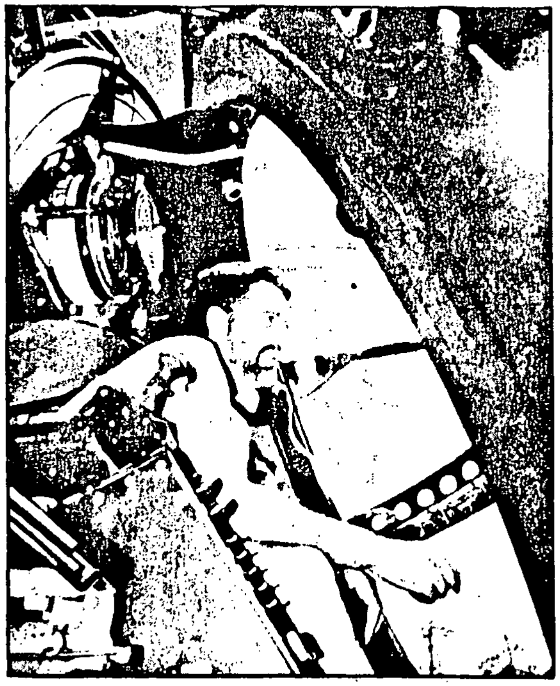
THE OREGONIAN SATURDAY AUGUST 6, 1988 PAGE A1

THE OREGONIAN SUNDAY AUGUST 7, 1988 PAGE E6



The Deep Rover and its tender, with a hoisting frame on it, is towed by a research vessel from its base on Wizard Island to a dive site in Crater Lake.

The Oregonian/STEVE NEHL



The Oregonian/RICHARD HILL

Oceanographer Jack Dymond prepares to plunge Deep Rover beneath the surface off Wizard Island.

Dives: Area of dark sediment seen

■Continued from Page E1

tion system used to position the submersible.

Dymond said reaching the bottom was especially exciting. "Just being there was very special."

The researcher said he initially had anxieties about diving in the deepest lake in the country, "but after I had checked the seals numerous times and assured myself that the sub was not leaking, I began to relax and enjoy myself."

He said that by 600 feet below the surface "it's pretty dark, and my eyes got used to it at the bottom. A few times I would come up to 1,100 feet, and I could see the glow of gray light from the surface."

Dymond said it was "remarkable how much light one can detect" from that depth. "It just goes to show how clear the water is."

Crater Lake is the seventh-deepest lake in the world — it is 1,932 feet at its deepest point — and it is one of the clearest.

Concerns about its possible diminishing clarity led to the National Park Service beginning a 10-year study of the lake in 1982. The oceanographers' research is one part of that study.

They theorize that thermal springs may bring hot water, chemicals and other material into the lake.

Dymond said he saw a large area of dark gray and black sediment underlying the normal buff-colored sediment at the bottom, which he thinks could be iron and manganese deposited by a thermal system. "I observed and photographed it," he said, and future dives will take other measurements.

> ***"It's pretty dark, and my eyes got used to it at the bottom. A few times I would come up to 1,100 feet, and I could see the glow of gray light from the surface."***
>
> — Jack Dymond,
> oceanographer

He also spotted tracks made by a remote-controlled vehicle the research team used last year to explore the floor.

In addition, he saw what he believes were holes made by worms, which have been found in the lake.

Shortly before completing his dive, Dymond spotted a large, sunken tree about 2 feet in diameter and about 30 feet long. All the bark was intact and it was hung up on a cliff face.

Dymond said he wanted to study it further but was told it was time to surface.

"The time went very fast," he said.

The oceanographer said he had made about 14 ocean dives on the three-person submersible Alvin. "The difference here is that you have all the control and responsibility, so I think it's kind of neat, but you're experiencing it alone," he said.

Collier's dive focused on the same area that Dymond explored, taking a temperature probe that could be placed in a suspected vent site by one of Deep Rover's mechanical arms.

He also took along a portable computer that can pick up information from a sensing probe mounted on the outside of the sub.

"It allows him to know what the probe is recording immediately," Dymond explained, so that an area could be examined further if there are temperature or other fluctutations.

Collier had to carry the computer on his lap because of the lack of space in the sub.

Dymond plans to make another deep dive Sunday morning, then the scientists plan to hold a news conference later in the day to report their findings.

Dymond said Saturday, "We hope to make one deep dive each day for the next 10 days, which will allow us to completely survey a portion of the lake with unusual chemical and thermal properties."

Also planning to make a dive Sunday is Mark Buktenica, a biotechnician with the National Park Service, who will make shallower dives to study the biological features in the lake.

Dymond said two kokanee salmon swam up to check out the craft at a depth of 126 feet on his first dive in the lake Thursday.

Crater Lake's floor 'quiet environment'; topography awesome

The Oregonian/STEVE NEHL

Bob Collier, Oregon State University oceanographer, tests the controls of the submersible Deep Rover in preparation for Saturday's dive to the depths of Crater Lake.

☐ The oceanographers' first deep dives have not confirmed theories about why the lake has lost some of its clarity

By RICHARD L. HILL
of The Oregonian staff

CRATER LAKE — Jack Dymond stood relaxed and smiling outside the open hatch of Deep Rover at its berth on Wizard Island early Saturday.

Less than 18 hours earlier, the oceanographer had become the first person to explore the floor of the nation's deepest lake, and he now was helping Bob Collier prepare for his trip to the bottom of Crater Lake.

"Sometimes I would just get in this groove and coast," Dymond told his colleague, who was sitting inside Deep Rover, checking switches, gauges, buttons and dials.

Now it was Collier's turn to dive to the lake floor, and Dymond was giving him tips on deep-lake travel as they waded through the 100 or so items on the checklist.

"By the way, I was cool down there, so I think long pants are more comfortable," the now-veteran lake traveler advised.

Soon, the lengthy checklist was complete, and shortly after noon Collier began his descent to the lake's bottom.

Dymond's dive Friday, which lasted 5½ hours and went to a depth of 1,456 feet, and Collier's similar dive Saturday, were the first in a series in which the Oregon State University oceanographers are searching for thermal vents.

Dymond said Saturday he didn't observe any hot springs, but he did report seeing deposits that may have been formed by thermal waters.

The primary purpose of the dive was to survey the area where the researchers think hot springs exist and "to deal with the technical problems involved in working in this unusual environment," Collier said.

Dymond said the lake floor was a "quiet environment," but he saw "awesome topography on the bottom, sheer underwater cliffs which no one knew existed. . . . It just shows how inadequate the nautical charts of the lake are."

During an interview, he said the most spectacular cliff, which was between 50 and 100 feet high, began as a gentle slope and then went straight up.

The rugged terrain poses the major problem for the research team, Dymond said, because it complicates the acoustic naviga-

Please turn to
DIVES, Page E6

THE OREGONIAN SUNDAY AUGUST 7, 1988 PAGE G1

First divers scan Crater bottom, but no hot springs uncovered

By RICHARD L. HILL
of The Oregonian staff

CRATER LAKE — Two scientists emerged from the nation's deepest lake Sunday to report they were amazed at the sights they'd seen.

Oceanographers Bob Collier and Jack Dymond said they haven't uncovered the hot springs they theorize exist, but they described as "spectacular" the geological and biological features in Crater Lake.

Dymond and Collier each made shallow dives in the mini-submarine Deep Rover on Thursday. Friday, Dymond took the submersible down to 1,456 feet, becoming the first person to ever see the floor of the lake. Collier dove to the bottom in the same area on Saturday. The lake's deepest point is 1,932 feet.

"The bottom around 200 feet (an area near Wizard Island) is completely covered with moss that is on the order of a foot or so in height," said Dymond, professor of oceanography at Oregon State University. "It's a spectacular scene. It looks like a grassy field."

Collier, assistant professor of oceanography at OSU, said his deep dive was "a very exhilarating experience. When they told me I had to come up (after about six hours) I was very disappointed," he said.

Both said they were surprised by the rough terrain, with outcrops of sharp, clifflike features.

The researchers dove in what they term the "hydrothermal basin," an area in the south-central part of the lake where they believe hot springs may exist.

Small temperature increases were recorded, they said, but the temperature variations weren't high enough to substantiate any thermal input.

"We haven't found any active thermal springs, but found some rock that was probably altered by a previous hydrothermal spring, but right now it's not active," Dymond said.

While the oceanographers spoke at a news conference on the northeast caldera rim high above the lake, a third pilot took his turn deep below the surface.

Mark Buktenica, a biotechnician with the National Park Service, was below the surface at about 900 feet examining biological features along the south wall.

Dymond and Collier will make several more deep dives over the next two weeks.

The three researchers' work is part of a 10-year National Park Service study of the cobalt-blue lake. The study began in 1982.

Dymond and Collier said most of the basin floor is covered with sediment that has built up since the lake began forming some 6,900 years ago when Mount Mazama erupted and collapsed.

"A lot of lake history is tied up in the sediment that is accumulating in the lake," Dymond said.

He reported Saturday that he had observed a "wide area" of black and dark-gray sediment made up of manganese and iron that might be an indication of hydrothermal deposits, and he said he would like to study the area more closely.

With the aid of Deep Rover's maneuverable arms, the research team is taking core and water samples from the basin floor to get a better idea of the lake's environment.

Collier said he had a "few moments of apprehension" before his deep dive Saturday, "but I realized it was just the first time down and the fears would pass, and I just went back to work and they did."

Dymond said he found the deep dive to be "an extraordinary experience."

"The bottom of the lake has a peacefulness I liked," he said. "Driving the sub also is challenging and thrilling."

Because of their hydrothermal-vent theory, the two researchers have found themselves involved in a controversy involving a proposed geothermal energy plant that would be built just outside the boundary of Crater Lake National Park and about 7½ miles from the lake area they're studying.

The Park Service and some environmental groups fear that such a development could have a negative impact on the lake. Officials of the California Energy Co., which wants to build the plant, say such fears are unjustified by any scientific evidence.

When asked about the dispute, Dymond said that he hopes "what we find will be definitive in one way or another in terms of whether there are thermal features in the lake."

He said the question of how that "will impact the geothermal development is pretty speculative," adding that the only way to find out if there is a link between the lake and the geothermal source the plant would use "would be to go ahead and do it (build the plant)."

"But then you might find out that it had an impact on the lake."

Collier said that there was no "scientific evidence to date that directly addresses the environmental impact of the drilling (on the lake). That's not what we're here studying, per se."

California Energy officials set up a simulation of a geothermal plant at the proposed site in the Winema National Forest this week to demonstrate that such a plant would not affect the aesthetics of Oregon's only national park.

Spokesmen for the company also were on hand nearby the news conference Sunday. "We can categorically state that in our opinion there can be no subterranean interconnection between that area that the Park Service is studying and our drill program," said David McClain, environmental manager for California Energy.

"It's 7½ miles from the area they're looking at and the nearest drill hole," he said, "and that a tremendous distance to say there is a hydrological interconnection."

The basic principles of physics, geology and hydrology indicate that "it's just not possible," he said.

SECONDARY MINERALOGY OF CORE FROM GEOTHERMAL DRILL HOLE CTGH-1, HIGH CASCADE RANGE, OREGON

By Keith E. Bargar

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ABSTRACT

Drill hole CTGH-1, a High Cascade core hole located about 7 km northeast of Breitenbush Hot Springs in northwest Oregon, was drilled to a depth of 1463 m and has a near-bottom temperature of a little less than 100°C. Minor vapor phase and devitrification mineralization is present in the drill core; however, vesicles, fractures, and open spaces between breccia fragments in the predominantly andesitic to basaltic drill core are partly to completely filled by secondary minerals that include hematite, smectite, celadonite, zeolite minerals (analcime, chabazite, clinoptilolite, erionite, heulandite, mordenite, phillipsite, scolecite, thomsonite, and wellsite), silica minerals (β-cristobalite, α-cristobalite, chalcedony, and quartz), native copper, apatite, calcite, and adularia. Paragenesis of the secondary minerals suggests a generalized depositional sequence involving first Fe-rich and Mg-rich minerals (hematite, smectite, and celadonite) followed by K-rich minerals (celadonite, wellsite, and phillipsite), minor Na-rich analcime, Ca-rich minerals (zeolites), silica minerals, and finally mordenite. Native copper, apatite, and wellsite precipitated in localized areas that contained sufficient Cu, P_2O_5, and Ba, respectively. The above minerals are compatible with present low-temperature diagenetic conditions.

INTRODUCTION

Geothermal drill hole CTGH-1 is located about 7 km northeast of Breitenbush Hot Springs and 6 km northwest of Olallie Butte, at an elevation of ~1170 m, near the Western Cascade - High Cascade boundary in northwestern Oregon. Drilling of the 1463-m deep core hole by Thermal Power Company and

Chevron Geothermal on a cost sharing basis with the U.S. Department of Energy began on June 7, 1986 and was completed September 7, 1986 (UURI, 1987). Open-filed drilling reports, available through the Earth Science Laboratory of the University of Utah Research Institute (UURI), indicate that the drill hole was rotary drilled to 161-m depth and then cored to the hole bottom with essentially 100 percent core recovery. The maximum reported temperature at the bottom of the drill hole was slightly less than 100°C and the temperature gradient below ~500-m depth was about 83°C/km (Priest and others, 1987).

Drill core from the CTGH-1 drill hole is stored in the UURI core library in Salt Lake City, Utah. A total of 307 core samples between the depths of 163 m and 1463 m, consisting of fracture fillings, vug fillings, or representative samples of stratigraphic intervals, were obtained from this facility in order to identify the alteration minerals in the drill core and to gain a preliminary understanding of the physical and chemical conditions responsible for secondary mineralization of the drill core. The drill core samples were studied using a binocular microscope and by X-ray diffraction, and scanning electron microscope (SEM) methods.

Preliminary lithologic descriptions of the CTGH-1 drill core are open-filed by UURI. Detailed stratigraphic and petrographic descriptions of Quaternary rocks recovered from the drill hole are discussed elsewhere (Priest, this volume). Except for one dacitic lava flow, drill core from the CTGH-1 drill hole consists predominantly of andesitic to basaltic lava flows, tuffs, and breccias. The more silicic rocks contain some vapor-phase tridymite in addition to primary minerals: quartz, plagioclase, magnetite, and pyroxene. Primary minerals of the mafic rocks are mostly plagioclase, pyroxene, magnetite, olivine, and hornblende (identified in only one sample); α-cristobalite from devitrification occurs in several samples.

Textures of the lava flows vary from massive to vesicular; fracturing ranges from moderate to very intense. Most fractures and vesicles contain at least traces of mineralization and the majority of open spaces are partly to completely filled by seondary minerals.

SECONDARY MINERALIZATION

Drill cuttings above 161-m depth in the drill hole were not sampled for this investigation. From 163- to 622-m depth the secondary mineralogy consists of smectite, hematite, and rare zeolites (chabazite, wellsite, and heulandite) (Figure 1). Between depths of 622 m and 885 m, smectite and chabazite are the predominant alteration minerals; although significant analcime and other zeolite minerals (clinoptilolite, heulandite, phillipsite, scolecite, and thomsonite) are present along with minor hematite, calcite, and apatite. Below 885-m depth, smectite remains the dominant secondary mineral and is found along with celadonite, zeolite minerals (clinoptilolite, erionite, heulandite, and mordenite), and silica minerals (β-cristobalite, α-cristobalite, chalcedony, and quartz); less abundant hematite and rare goethite, native copper, and adularia were also indentified.

Hematite

Red-orange-brown iron-oxide stains are scattered throughout the CTGH-1 drill core (Figure 1) in abundances that range from a pervasive brick-red coloring of an entire specimen to microscopic orange-staining. The iron oxide was usually identified as hematite by X-ray diffraction; however, a few samples appear to contain X-ray amorphous iron oxide. Much of the hematite occurs in association with volcanic breccias, highly vesicular basalts, or tuffaceous deposits where it probably formed by oxidation of primary magnetite during cooling of the volcanic rocks and is of deuteric origin. A few thin red hematite stains on fracture surfaces or vesicle walls in the lower part of the drill hole appear to be closely associated with later secondary mineral fillings. Similarly, soft orange-red goethite coats a fracture surface at 1456-m depth. The only other secondary iron oxide mineral identified in the drill core is ilmenite which occurs as black, metallic, hexagonal crystals that are closely associated with vapor-phase tridymite at 440-m depth.

Smectite

Core samples from depths of 163-480 m contain light-brown to orange (occassionally white or pink) clay that is frequently smeared along the exterior core surfaces and partly to completely fills open spaces in the drill core. Much of this clay is probably residual drilling mud which, according to daily progress well logs open-filed by UURI, was utilized in drilling the CTGH-1 drill hole. X-ray diffraction analyses of clays from this part of the drill core mostly show low, broad X-ray peaks that suggest poorly crystalline or even amorphous material. Several analysed samples contain a ~10Å peak that shows very slight expansion after being placed in an atmosphere of etheylene glycol at 60°C for 1 hour, and the mineral is probably a mixed-layer illite-smectite consisting predominatly of illite. In geothermal areas mixed-layer illite-smectite typically forms at temperatures much warmer than were measured in the upper part of the CTGH-1 drill hole (Aumento and Liguori, 1986). Mixed-layer illite-smectite was not found below 403-m depth in the drill core, and whenever the mineral was found in X-ray analyses of open-space fillings it was presumed to be drilling mud residue. Most of the X-ray diffraction analyses of clays from this interval also contained a ~15Å peak that expanded to ~17Å after exposure to ethylene glycol which is typical for smectite. Smectite was determined to be a component of several samples of drilling mud where it occurs alone or in association with the mixed-layer illite-smectite. In Figure 1, a few smectite samples between depths of 163 and 480 m are classified as secondary based on the mode of occurrance. It is possible that additional secondary smectite exists in samples from this zone; however, if present, such occurrences are masked by drilling mud contamination.

Below 480-m depth smectite (various colors but predominantly green) occurs in virtually every sampled interval as coatings on fracture surfaces, lining vesicle walls, between breccia fragments, or as groundmass alteration (particularly in tuffaceous rocks). Characteristically, secondary smectite from drill hole CTGH-1 has a basal spacing of ~14-15Å (although basal spacings as low as ~12Å were noted in a few samples) that expands to ~17Å with glycolation, and collapses to ~10Å after overnight heating at 450°C. Measurements of the 060 X-ray peak for 12 selected clay samples from the core ranged from 1.50Å (montmorillonite, commonly a Ca- or Na-rich smectite) to 1.52Å (nontronite, an Fe-rich smectite) and 1.53Å (saponite, a Mg-rich smectite) (Starkey and others, 1984) with apparent random distribution of dioctahedral (montmorillonite and nontronite) and trioctahedral (saponite) smectite species (Brindley and Brown, 1980). Semiquantitative chemical analyses of smectite were obtained using an X-ray energy dispersive spectrometer (EDS) on the scanning electron microscope (SEM). Samples from 564, 764, and 861 m have compositions including, in addition to Si and Al, Fe>Ca>Mg; the two shallower samples also contain minor amounts of K, and Ti. Using EDS, low concentrations of Na are difficult to detect with certainty, but it is possibly present in clay from 764-m depth. The 060 peaks for these clays are too indistinct for accurate measurement on routine X-ray diffractograms. However, because Fe is the predominant cation, it would appear that these three clays are dioctahedral nontronite; although trioctahedral saponite with high Fe content has been reported (Weaver and Pollard, 1973).

Celadonite

Celadonite, a micaceous mineral, occurs intermittently below 1130-m depth normally as a soft, blue-green clay-like material that is usually deposited as horizontal layers (later than green smectite) in cavities and fractures. In a few vesicles, the blue-green clayey layers are sandwiched between horizontal beds of medium- and dark-green smectite. Celadonite at 1133-m depth formed as a blue-green clay-like deposit (producing a low, broad, ~10Å X-ray peak) that formed earlier than a heulandite-group mineral (probably clinoptilolite) and β-cristobalite (Figure 2). Later emerald-green micaceous celadonite is sprinkled on top of the β-cristobalite, and is characterized by a high, sharp 10Å X-ray peak. A semiquantitative EDS analysis of soft blue-green celadonite from 1133-m depth shows, in addition to Si and Al, very abundant Fe and K, and very minor Mg, Ti, Ca, and possibly Na.

Zeolite Minerals

In the interval from 163 to 622 m, the only secondary minerals other than hematite and smectite are rare occurrences of chabazite, heulandite, and wellsite. The first two of these zeolite minerals will be discussed later. Wellsite, an intermediate zeolite mineral in the phillipsite-harmotome group was identified only in vesicles of basaltic rock from 564-m depth where the mineral formed as randomly-oriented, elongate, prismatic crystals, clusters of radiating crystals, (Figure 3) or closely spaced elongate crystals that are deposited as overlapping radiating hemispherical crystal clusters (Figure 4) to produce a botryoidal-appearing vesicle coating. In Figure 3, the wellsite crystals appear to be partly coated by later smectite; however, the majority of the light- to dark-green horizontal smectite layers fill the bottoms of the vesicles and are earlier deposits. Two semiquantitative EDS analyses of wellsite show significant Ba, and K, and a little Ca in addition to Si and Al. X-ray diffraction analyses of the wellsite are similar to phillipsite and harmotome, but the approximately equal proportions of Ba and K suggest that the mineral is wellsite rather than Ba-poor phillipsite or K-poor harmotome (Cerny and others, 1977).

The interval from 622- to 885-m depth is characterized by alteration of tuffaceous rocks or filling of vesicles, fractures, and open spaces between volcanic breccia fragments by orange to green smectite, occassional iron-oxide staining (mostly hematite but amorphous iron oxide may be present), and zeolite minerals. Phillipsite, an early zeolite mineral in this drill core, was identified only in three samples collected from depths of 811, 812, and 821 m. At 821-m depth, colorless phillipsite crystals (Figure 5) formed in basalt vesicles; whereas at 812-m depth open spaces in volcanic breccia are pervasively coated by clusters of closely spaced elongate phillipsite crystals that appear to be partly dissolved (Figure 6). Semiquantitative EDS analyses indicate that both samples have approximately the same chemical composition: Si, Al, and K>Ca.

At 812-m depth, phillipsite is associated with later clusters of colorless thomsonite crystals. SEM photographs show that the thomsonite crystal morphology is usually tabular or lamellar (Figures 7 and 8). In Figure 7, thomsonite crystals have formed irregularly oriented crystal clusters; whereas in Figure 8, the tapered thomsonite crystals form somewhat fan-shaped crystal groups. Thomsonite, identified in samples from several depths in this core interval, appears to be composed of only Ca, Si, and Al in three EDS analyses. Fractures and vesicles in very altered basaltic drill core at 663-m depth contain a soft, colorless, botryoidal-appearing coating that consists of closely spaced thomsonite crystals in hemispherical-shaped clusters.

The thomsonite crystals at 663-m depth are overlain by later deposits of colorless chabazite crystals. Pseudocubic rhombohedral chabazite crystals (frequently twinned) (Figure 9), deposited in association with earlier smectite in many open spaces, is the predominant zeolite mineral in this interval (Figure 1). Semiquantitative EDS analyses of chabazite from 634-m depth shows the presence of Ca, Al, Si, and very minor K.

Scattered open-space deposits of colorless, trapezohedral analcime crystals are closely associated with chabazite although the depositional sequence is undetermined; analcime also formed later than thomsonite (Figure 7), and phillipsite (Figure 10). EDS semiquantitative analyses for analcime show the presence of Si, Al, Na, K, and Ca. Sufficient Ca appears to be present in the analyses to indicate that the mineral is not a pure analcime end-member of the analcime-wairakite solid solution series and probably should be considered a "calcian" analcime (Gottardi and Galli, 1985).

Fracture fillings in drill core between 764- to 785-m depth contain radiating clusters of colorless, acicular scolecite crystals that were deposited later than thomsonite (Figure 11), chabazite, and analcime. Semiquantitative analyses by EDS indicate that the chemical constituents are Ca, Al, and Si and the mineral is identified as scolecite rather than structurally similar Na-rich natrolite or Na+Ca mesolite (Gottardi and Galli, 1985).

An abrupt change in secondary mineralogy occurs at 885-m depth in the CTGH-1 drill hole. Except for one occurrence of chabazite at 892-m depth, the zeolite minerals discussed above are completely absent and the interval is characterized by heulandite-group zeolites: heulandite and clinoptilolite. Abundant mordenite and minor erionite are also present in this part of the drill core. Early reddish hematite staining is sporadically distributed through the interval. Later smectite remains the dominant open-space filling, but below 1130-m depth blue-green clayey fracture and vesicle deposits, identified as celadonite in several X-ray diffraction analyses, formed either later than green smectite or are sandwiched between horizontal green smectite layers.

Three samples between the depths of 886 m and 888 m contain acicular or columnar appearing erionite crystals that were deposited later than green smectite. In the SEM, these columns were observed to consist of bundles of fibrous crystals; occassionally the erionite crystal clusters show hexagonal cross sections (Figure 12), and are seen to have formed earlier than associated blocky heulandite crystals at 887-m depth. An EDS analysis of erionite shows the presence of Ca, K, Al, and Si.

Heulandite and clinoptilolite, two heulandite group zeolite minerals, are both present in the lower part of the CTGH-1 drill core. The two minerals have virtually the same structure and are indistinguishable in X-ray diffraction analyses. Mumpton (1960) discriminated between clinoptilolite and heulandite on the basis of overnight heating at 450°C. If the (020) X-ray peak at ~9.0 Å is unchanged after heating, the mineral is identified as clinoptilolite, whereas heulandite is characterized by destruction of the

(020) peak. However, Gottardi and Galli (1985) favor nomenclature based on the chemical composition as suggested by earlier workers (Mason and Sand, 1960). In this classification, heulandite should contain more Ca+Sr+Ba than Na+K, and for clinoptilolite Na+K are dominant.

Fourteen samples containing a heulandite-group mineral, dispersed throughout the CTGH-1 drill core, were heated overnight at 450°C. Above 892-m depth only 1 sample showed no change in peak position or intensity after heating and the mineral is probably clinoptilolite; in the remaining samples above 892 m-depth, the (020) X-ray peak was destroyed and, according to Mumpton's (1960) classification, the mineral should be heulandite. Below 892-m depth, none of the heated samples showed a change in the (020) peak after heating and clinoptilolite would appear to be the only heulandite group zeolite present.

Semiquantitative EDS analyses are not completely supportive of the above distinction between heulandite and clinoptilolite in this drill hole. In heulandite from 887-m depth, Ca is undoubtedly more abundant than Na+K as would be suggested by the heating test. Below 892-m depth heating tests showed only the presence of clinoptilolite; however, Na+K is clearly dominant over Ca only at a depth of 983 m. In four other samples below this depth, Ca appears to be dominant over Na+K although the difficulty in detecting Na by EDS analyses makes the distinction between clinoptilolite and heulandite unreliable when significant Ca is present. In the distribution diagram of Figure 1, the heulandite-group minerals were combined and no attempt was made to resolve any possible ambiguity.

In drill hole CTGH-1, heulandite-group zeolite minerals, deposited in vesicles, fractures, and between breccia fragments, formed later than hematite, smectite, celadonite, and erionite, but are earlier than α-cristobalite, β-cristobalite or mordenite (Figures 13 and 14). Minor smectite appears to be deposited later than some open-space heulandite group minerals (Figure 15). The crystal morphology of the heulandite group minerals in drill core CTGH-1 varies from a tabular 'tombstone'-like habit shown in Figure 15 to a more blocky morphology as seen in Figures 12, 13, and 14.

White cotton-like mats of interwoven long thin fibrous crystals or small tufts of fibrous mordenite crystals (Figure 14) appear to be the latest mineral deposited in many open spaces below 1099-m depth in drill core from the CTGH-1 hole. At 1260-m depth, an EDS analysis of mordenite only showed the presence of Ca, Al, and Si.

Silica Minerals

Silica minerals (β-cristobalite, α-cristobalite, chalcedony, and quartz) from the CTGH-1 drill hole occur as open-space deposits that formed later than most other minerals except for mordenite (Figure 14) and minor smectite (Figure 16). Between depths of 956 and 1372 m colorless, frosted, or bluish botryoidal silica (Figures 2 and 13) was identified as β-cristobalite in several X-ray diffraction analyses. Deposits of β-cristobalite alternate with similar appearing botryoidal α-cristobalite between 1061-m and 1372-m depth. Below 1372-m depth, α-cristobalite is the predominant silica phase. In the SEM, β-cristobalite has a smooth, non-crystalline appearance, whereas α-cristobalite usually consists of spherical clusters of blocky crystals (Figure 14). However, the two minerals are best distinguished by X-ray diffraction analyses. β-cristobalite has a broad major peak between 4.07Å and 4.11Å and a single minor peak near 2.50Å; α-cristobalite has a sharp major peak between 4.04Å and 4.07Å and several other minor peaks. In Figure 1, α-cristobalite and β-cristobalite were combined because the presence of the two minerals was only spot checked by X-ray diffraction and no attempt was made to determine their precise distribution.

Tiny, colorless, euhedral quartz crystals occur in vesicles from 7 scattered drill core samples. Many other open-space white, colorless, yellow, or green massive silica deposits give an X-ray diffraction pattern indicative of quartz, but when viewed in refractive index liquids were observed to have a fibrous structure and are chalcedony. Chalcedony, a cryptocrystalline variety of quartz can be distinguished from quartz in thin-section or in immersion media; however, no attempt was made to distinguish between the massive quartz and chalcedony deposits for Figure 1. A further complication exists in that a few X-ray diffraction analyses of botryoidal silica showed the presence of chalcedony in addition to α- or β-cristobalite.

Other Minerals

The only other secondary minerals in this drill core are calcite, apatite, adularia, and native copper. The first three minerals were identified only in X-ray diffraction analyses from depths of 663 and 675 m (calcite), 665 m (apatite), and 1293 m (adularia); and the modes of occurrence for these three minerals were not observed. Native copper was identified in two samples from near 1015-m depth as an open-space deposit that appears to be earlier than botryoidal β-cristobalite and white smectite (Figure 16).

DISCUSSION

Drill core from the CTGH-1 drill hole is predominantly andesitic to basaltic in composition. Early vapor-phase tridymite and possibly ilmenite are present in a dacitic section from 260-m to 339-m depth. Minor scattered devitrification α-cristobalite was identified in a few pieces of drill core. Some mafic minerals and what was probably the glassy groundmass of several drill core samples are altered to iron oxide (mostly hematite but also minor X-ray amorphous iron oxide) and smectite. Vesicles, fractures, and open spaces between breccia fragments are partly to completely filled by secondary minerals that include iron oxide minerals, smectite, celadonite, zeolite minerals (analcime, chabazite, clinoptilolite, erionite, heulandite, mordenite, phillipsite, scolecite, thomsonite, and wellsite), silica minerals (β-cristobalite, α-cristobalite, chalcedony, and quartz), native copper, apatite, calcite, and adularia.

Iron oxide, primarily hematite, probably formed during cooling of the lava flows due to oxidation of magnetite and is the earliest significant secondary mineral in the CTGH-1 drill core. Iron- and magnesium-rich green smectite (nontronite and saponite) are sometimes found deposited later than reddish iron oxide on fractures or in vesicles. More than one generation of smectite was deposited in the drill hole and some vesicles were observed to contain multiple horizontal layers consisting of different shades of green smectite. Smectite color is quite variable in the CTGH-1 drill core and many colors (white, pink, brown, orange, or red) other than green were observed. Differences in X-ray basal spacing and position of 060 peaks suggests that some of the later smectite deposits may contain Ca, Na, or K as exchangeable cations rather than Fe and Mg. Blue-green clay identified as celadonite was deposited later than green smectite in many open spaces, and is sandwiched between horizontal green smectite in a few vesicles. Celadonite, containing abundant Fe and K, also occurs as an emerald-green micaceous deposit that is later than smectite, blue-green clayey celadonite, clinoptilolite, and β-cristobalite at 1133-m depth. Several zeolite minerals were deposited later than the above Fe, Mg, and K minerals. The first zeolite minerals to be deposited appear to be K-rich wellsite and phillipsite. Wellsite occurs in the upper zeolite zone along with the Ca-rich minerals heulandite and chabazite (exact order of deposition is uncertain). In the middle zeolite zone, Na-rich analcime and Ca-rich thomsonite, chabazite, and scolecite were deposited later than phillipsite. The lower zeolite zone contains Ca- and K-rich erionite along with later clinoptilolite, heulandite, and Ca-rich mordenite. Silica minerals apparently were deposited later than the zeolites (except for mordenite). β-cristobalite and α-cristobalite alternate in open-space fillings of the lower zeolite zone. Chalcedony and quartz crystals appear to be deposited later than either cristobalite mineral in several vesicles and fractures of this lower zone. The order of deposition for apatite, calcite, and adularia are unknown because they were only detected as minor components in X-ray diffraction analyses. Native copper was deposited in a few open spaces and is earlier than β-cristobalite and white smectite.

The paragenetic sequence of secondary minerals from this drill core suggests that rock/water interaction, initially through alteration of basaltic glass and mafic minerals, provided sufficient Fe and Mg to form the earlier deposited secondary minerals. During later mineralization, K, Na, Ca, and Si were more prevalent constituents of the fluids and the minerals that formed consisted mostly of zeolites, and silica minerals. Smectite and most of the zeolite minerals (Kristmannsdottir and Tomasson, 1977) are compatible with the present low temperatures. Apparently the silica minerals are not incompatible with temperatures below 100°C and have been reported at similar temperatures from several drill cores in Columbia River Basalt (CRB) of Pasco Basin, Washington (Benson and Teague, 1982). In fact, nearly all of the secondary mineral phases identified in drill hole CTGH-1 and their distribution within the drill core are remarkably similar to secondary mineral assemblages reported in the Pasco Basin drill holes by Benson and Teague (1982). The CRB alteration minerals are attributed to formation at temperatures less than 100°C and are characterized as diagenetic. A similar diagenetic origin for secondary mineralogy of the CTGH-1 drill core appears reasonable.

ACKNOWLEDGEMENTS

The author thanks P.M. Wright of UURI for making the drill core available for this study. R.O. Oscarson assisted in obtaining the scanning electron micrographs. R.C. Erd and L.C. Calk provided helpful reviews and constructive criticisms of the manuscript.

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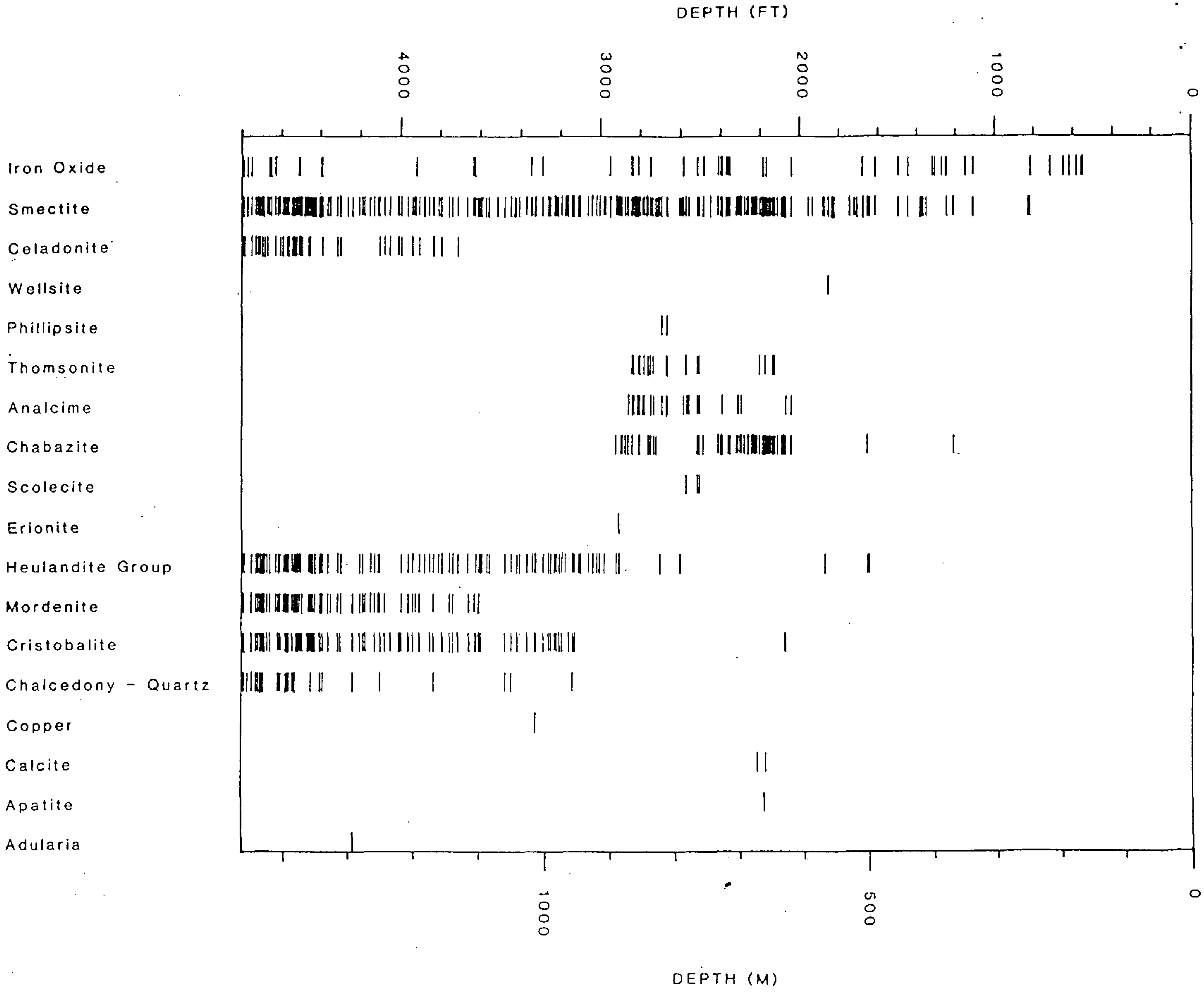

Figure 1. Distribution of secondary minerals with depth in drill hole CTGH-1.

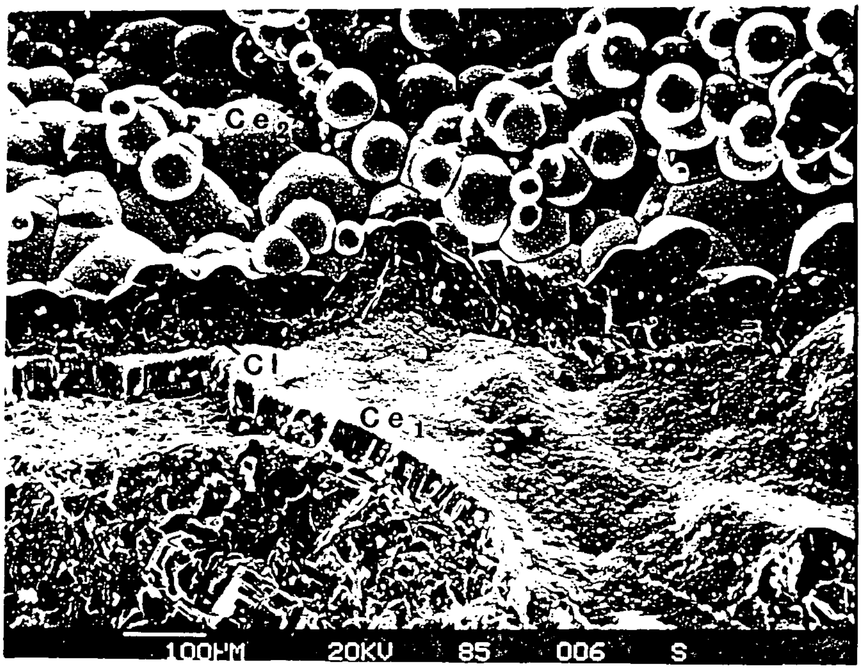

Figure 2. Scanning electron micrograph showing a fracture coating of clayey celadonite (Ce_1), blocky clinoptilolite (Cl), botryoidal β-cristobalite, and later micaceous celadonite (Ce_2) at 1138-m depth.

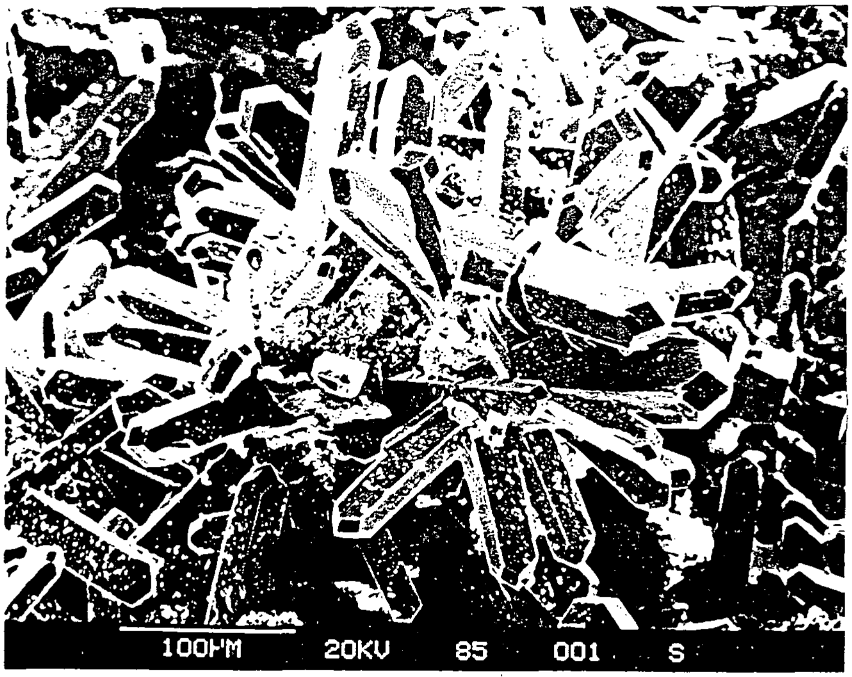

Figure 3. Scanning electron micrograph of a cluster of radiating wellsite prismatic crystals and later smectite deposits from 564-m depth.

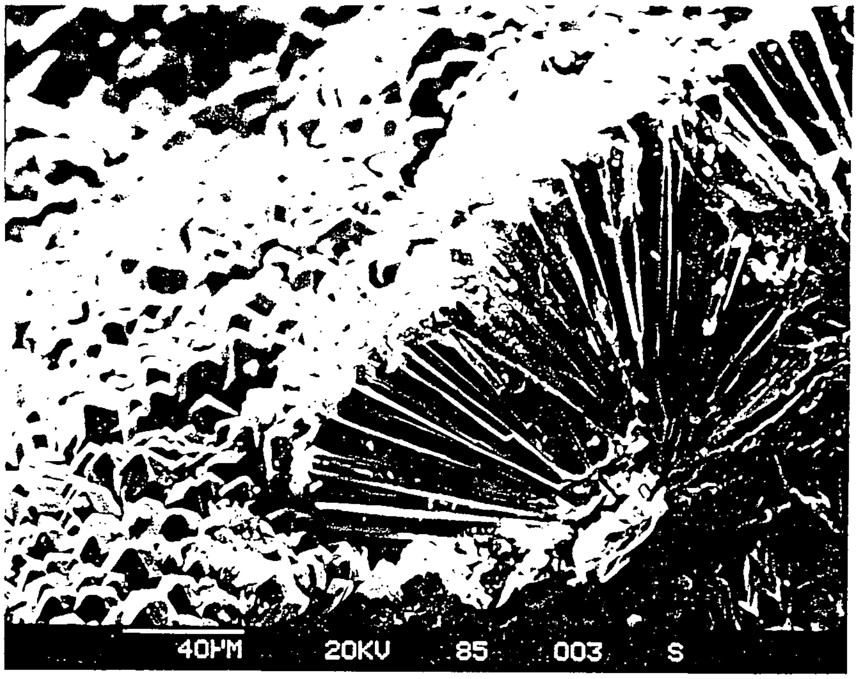

Figure 4. Scanning electron micrograph showing a cross-section through a hemispherical cluster of radiating wellsite crystals from 564-m depth.

Figure 5. Scanning electron micrograph of a vesicle filling from 821-m depth containing euhedral phillipsite and later analcime (upper left).

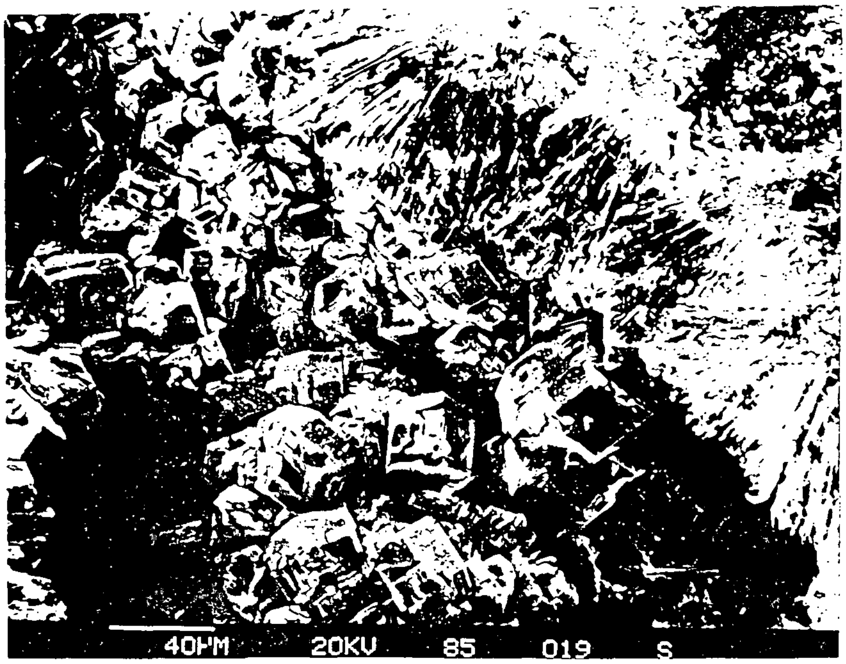

Figure 6. Scanning electron micrograph of a partly dissolved phillipsite filling between breccia fragments at 812-m depth.

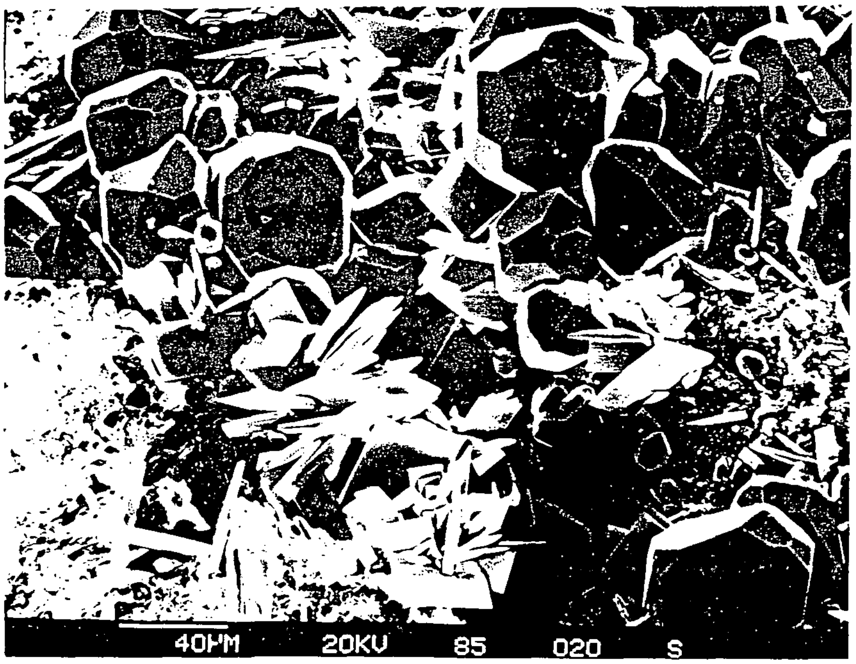

Figure 7. Scanning electron micrograph of a fracture filling from 764-m depth that is lined by smectite, later tabular thomsonite, and finally trapezohedral analcime crystals.

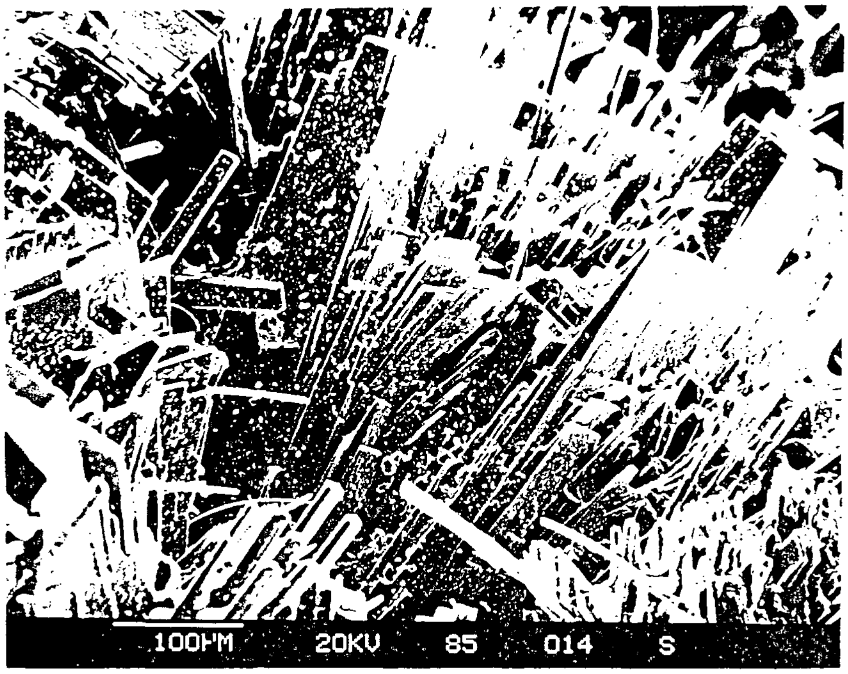

Figure 8. Scanning electron micrograph showing tabular thomsonite and acicular scolecite crystals from a fracture at 767-m depth.

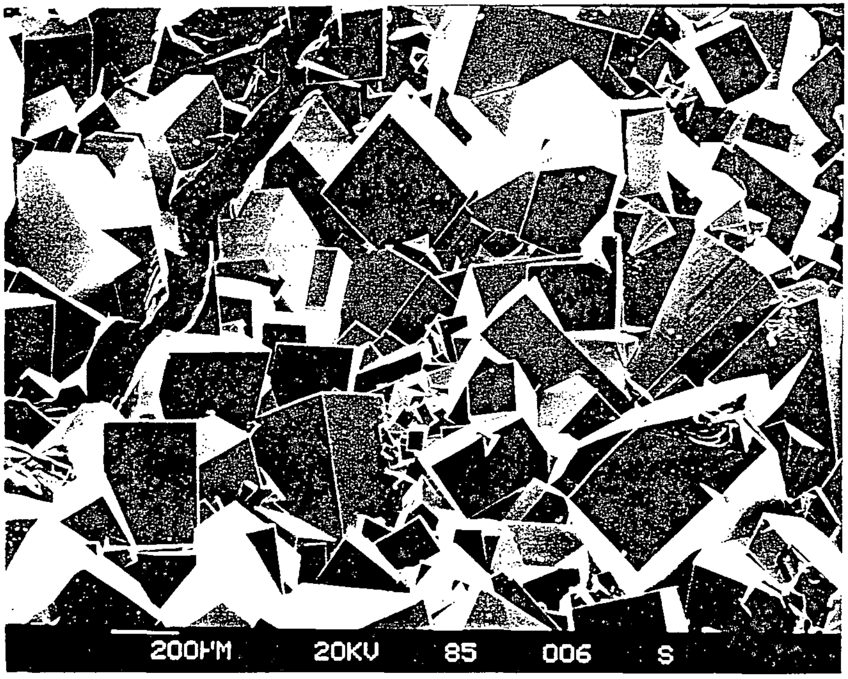

Figure 9. Scanning electron micrograph of euhedral pseudocubic chabazite crystals lining a fracture at 634-m depth.

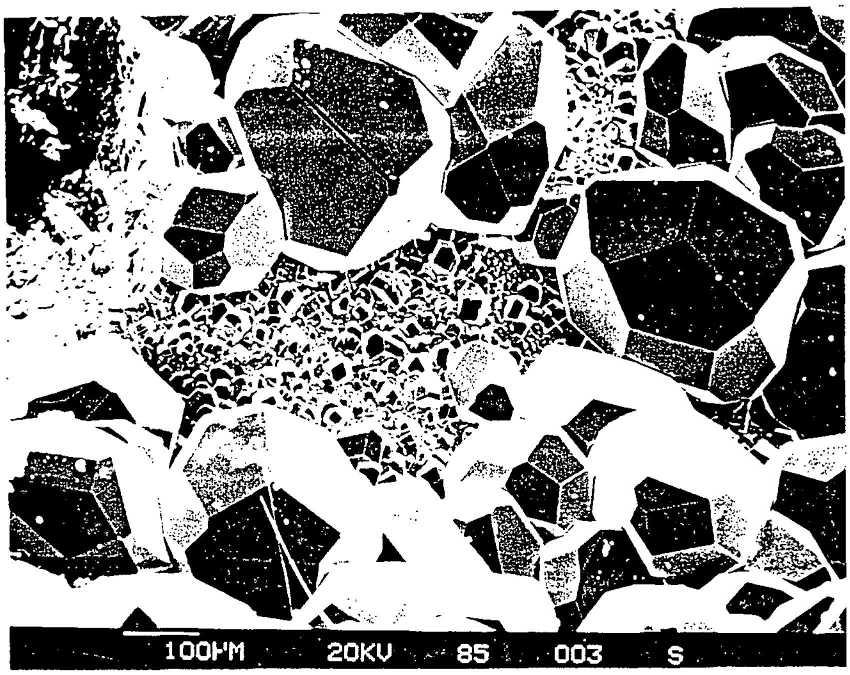

Figure 10. Scanning electron micrograph of a vesicle filling at 821-m depth lined by tiny phillipsite crystals and later large trapezohedral analcime crystals.

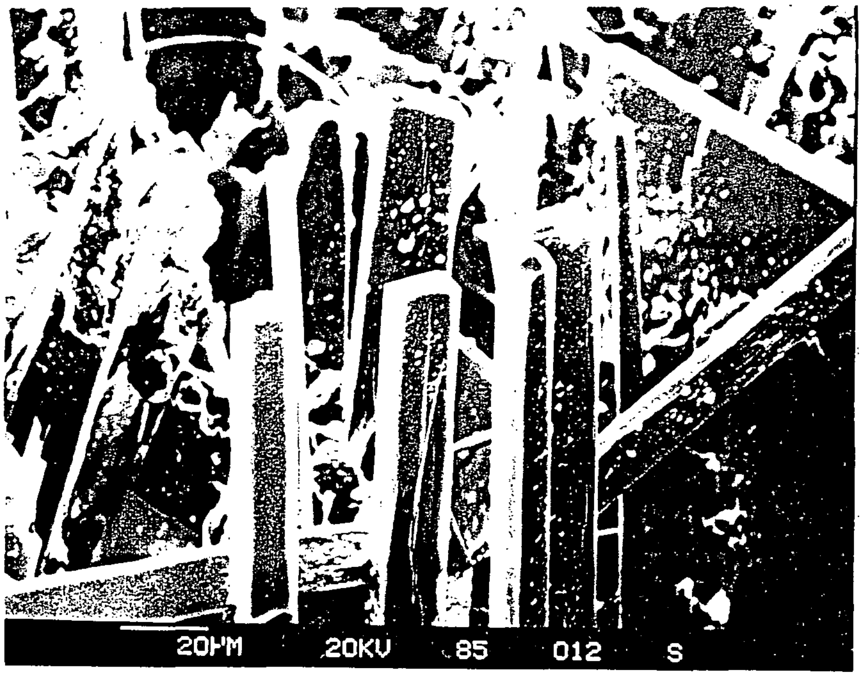

Figure 11. Scanning electron micrograph showing tabular thomsonite and later acicular scolecite crystals that coat fractures at 767-m depth.

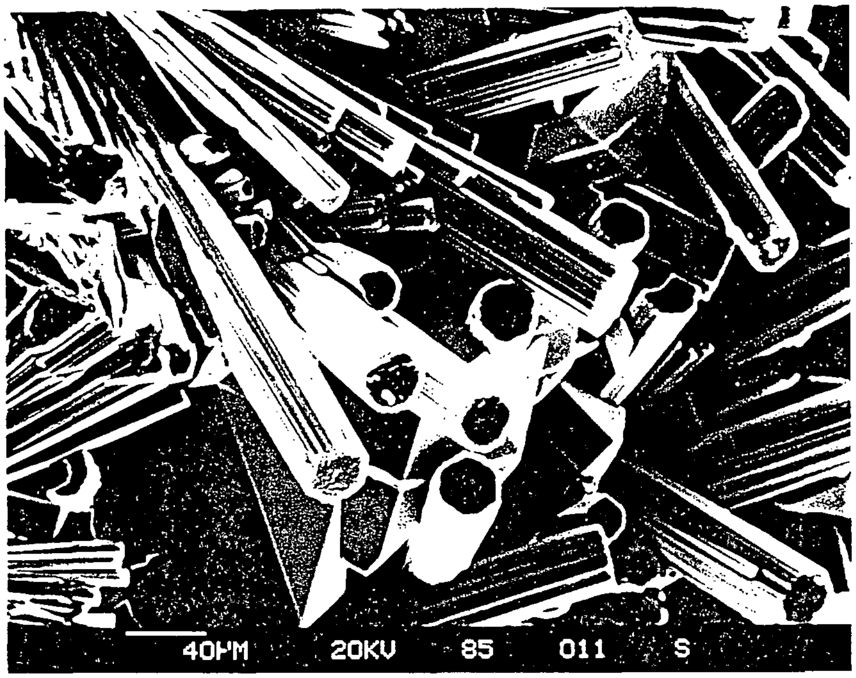

Figure 12. Scanning electron micrograph showing erionite columnar crystals and later blocky heulandite crystals from 887-m depth.

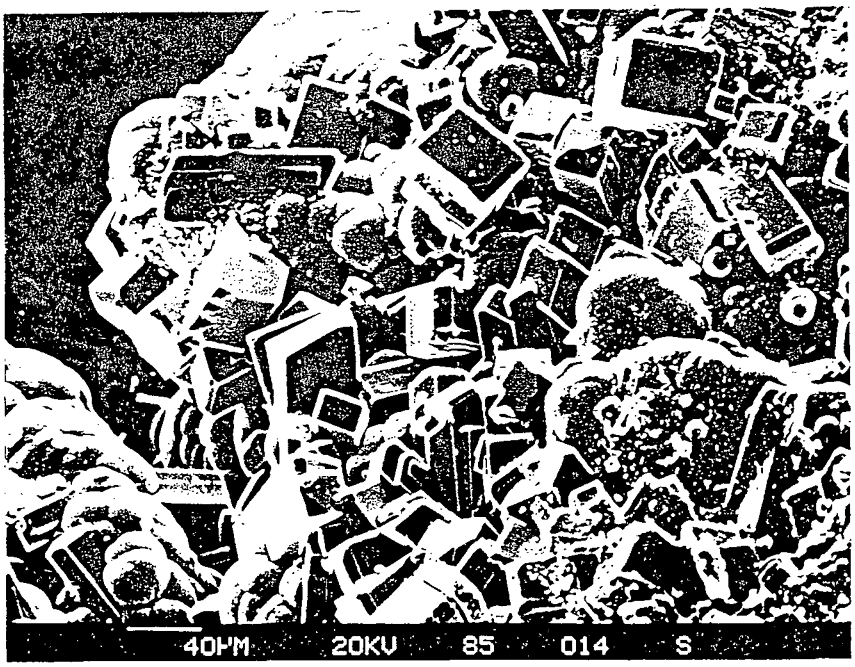

Figure 13. Scanning electron micrograph of a fracture filling at 983-m depth coated by blocky clinoptilolite crystals, later botryoidal β-cristobalite, and late smectite.

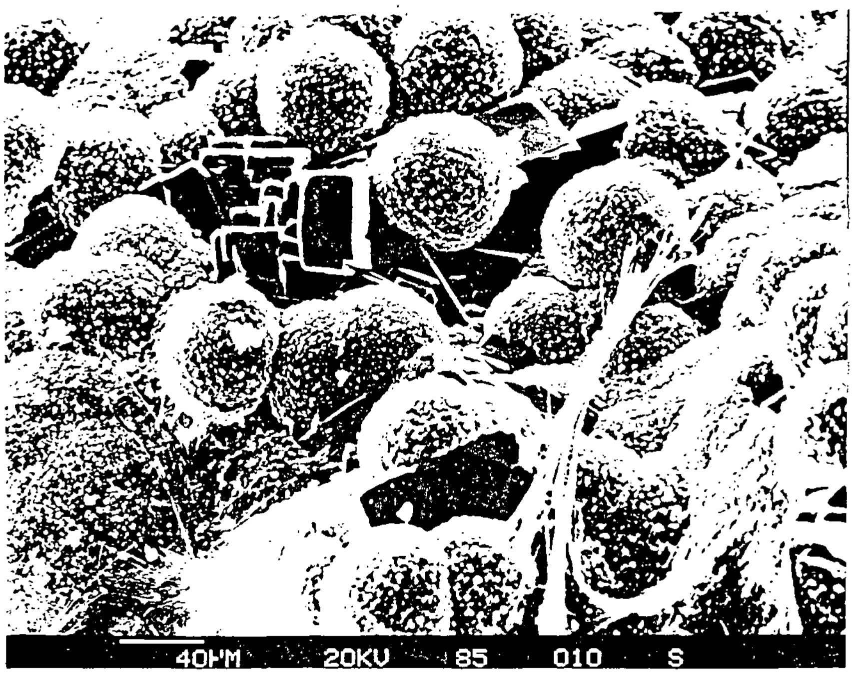

Figure 14. Scanning electron micrograph of a vesicle filling at 1394 m-depth consisting of blocky clinoptilolite, later botryoidal α-cristobalite crystal clusters, and still later fibrous mordenite.

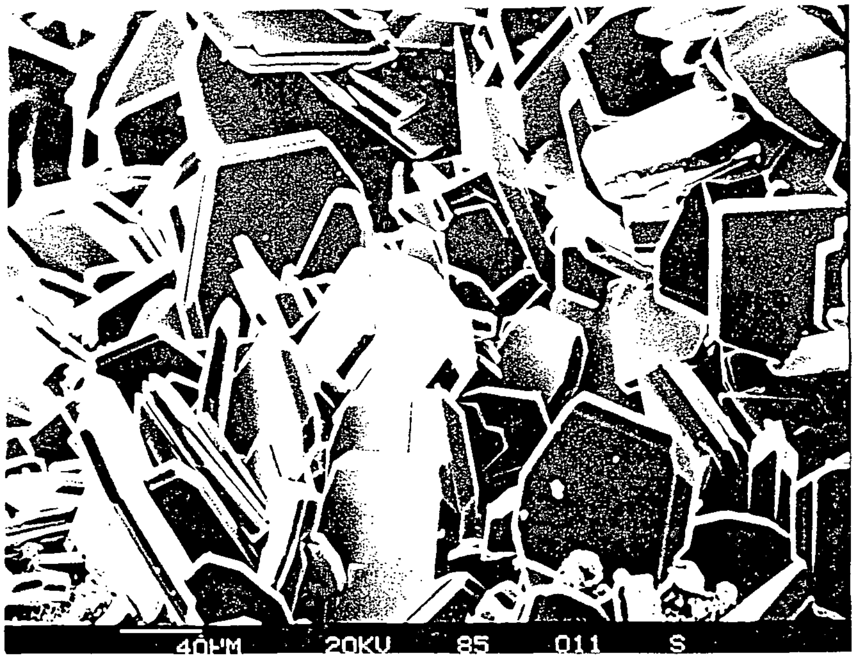

Figure 15. Scanning electron micrograph of tabular 'tombstone'-like clinoptilolite crystals and later smectite (bottom of photograph) lining a vesicle at 1341-m depth.

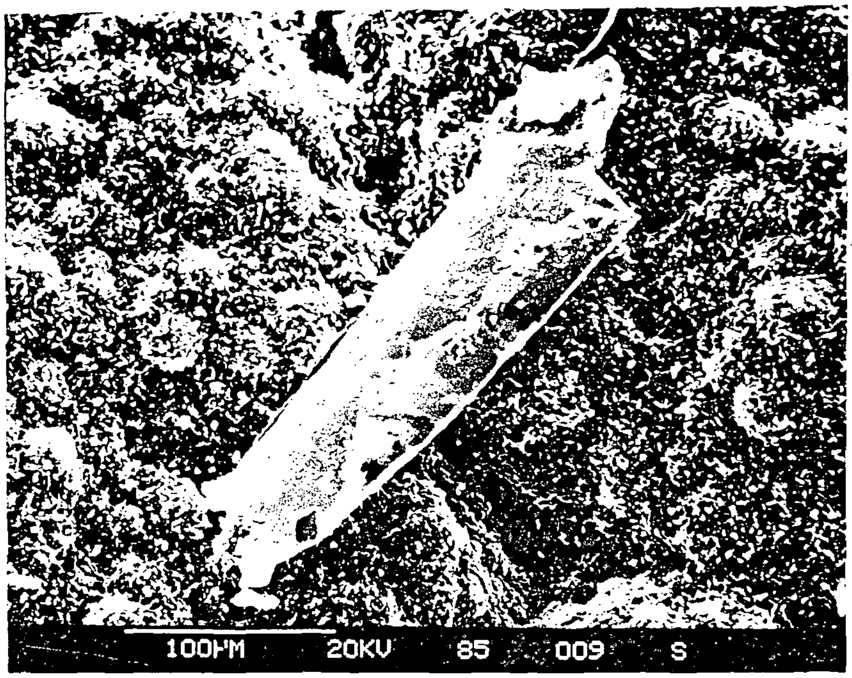

Figure 16. Scanning electron micrograph showing a deposit in an open space from 1015-m depth consisting of native copper, later botryoidal β-cristobalite and still later smectite.

Selected Mineralogical Analysis of Secondary Minerals in CTGH-1 by
M. Keith Bargar, USGS - Menlo Park.

SECONDARY MINERALS FROM CTGH-1 DRILL CORE
8/11/86

Samples from Al Waibel:

2508	smectite, chabazite, analcime-wairakite?, scolecite-mesolite?, thompsonite?
2813.3	smectite, chabazite, analcime-wairakite?, scolecite-mesolite?
2907	smectite, erionite
3291	smectite, ß-cristobalite?, stilbite-stellerite?
3329.5	smectite, ß-cristobalite, heulandite

Samples from Joe Iovenitti (analyses are from crumbs in bottom of sample sacks)

2071	smectite, chabazite (not-X-rayed - botryoidal silica? probably ß-cristobalite)
2574	smectite, analcime-wairakite?, scolecite-mesolite?, thompsonite?
3225	smectite, heulandite, ß-cristobalite
3329	not-Xrayed (no crumbs available but core appears to contain silica - ß-cristobalite? and clay - smectite)
3329.7	smectite

Notes:

1. Mineral identified as analcime-wairakite? lies somewhere within the analcime-wairakite solid solution series but need chemistry to pinpoint.
2. Scolecite-mesolite? are very similar structurally and have virtually identical X-ray patterns (along with natrolite - Na-rich). Scolecite contains Ca and mesolite has both Ca and Na.
3. Stilbite-stellerite? are also difficult to distinguish in X-ray. Stellerite is the Ca-rich mineral.
4. Thompsonite? is queried because it occurred with scolecite-mesolite? and all but 2 of the thompsonite peaks are masked by other minerals.

ESL-88012-JP

RESEARCH CORING IN THE CASCADES
A STATUS REPORT

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ABSTRACT

The High Cascades volcanic province has long been suspected to contain considerable geothermal potential. However, few deep wells have been drilled, and much of the data that have been accumulated are proprietary. In response to the need to obtain a better understanding of the Cascades region, the U.S. Department of Energy, Geothermal Technology Division, sponsored a cooperative research program with industry based around obtaining data from research coreholes. This paper is a progress report on the three coreholes completed to date, including a summary of drilling histories and a description of the scientific studies underway and of the open file data available.

INTRODUCTION

The Cascades is an area with high hydrothermal potential, but with few surface manifestations. The lack of widespread surface hydrothermal activity is generally believed to result from the masking of systems by downward and lateral movement of cold, meteoric water. In 1986, the U.S. Department of Energy, Geothermal Technology Division, initiated the Caldera Reservoir Investigation Program to evaluate the effects of the near-surface hydrologic regime and to obtain lithologic, hydrologic, and structural data on the Cascades.

The DOE program has four main elements: 1) cost sharing with industry in coring research holes; 2) acquisition of lithologic, geophysical, and hydrologic data within and below the shallow hydrologic regime; 3) data interpretation and integration; and, 4) open file release of data and core, as well as publication of technical reports and case histories.

Summaries of drilling histories and descriptions of the available data and scientific studies are presented in this paper for three holes drilled under the DOE program: Clackamas Thermal Gradient Hole #1 (CTGH-1), drilled by Thermal Power Co.; and GeoNewberry holes # 1 and # 3 (GEO N-1 and GEO N-3), drilled by GEO Operator Corporation. CTGH-1 is located approximately 10 miles north of Mt. Jefferson, while GEO N-1 and GEO N-3 are located on the southern and northern flanks, respectively, of the Newberry volcano. Figure 1 shows the locations of these holes.

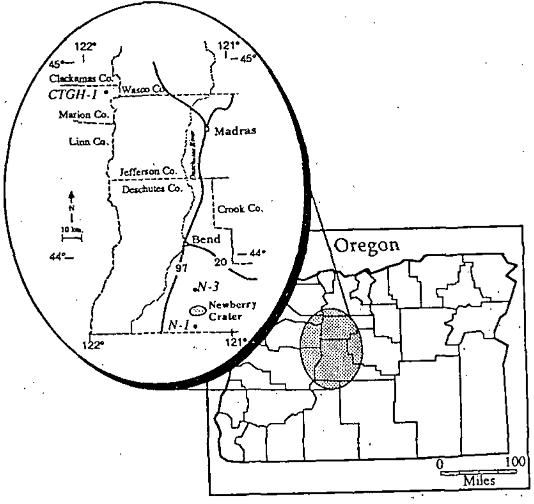

Figure 1. Location map of core holes.

CORING SUMMARY

CTGH-1

CTGH-1 was rotary drilled to a depth of 527 feet, and then diamond cored to a total depth of 4,800 feet. The hole required 93 days to complete; however, only 58 days were spent drilling. CTGH-1 has not been plugged and abandoned at this point. The hole condition is believed to be good so that deepening may be possible.

There were several unanticipated delays during the drilling of CTGH-1. First, the attempt to run a conductor into the top 40 feet of glacial boulders and till was not initially successful. Later, during the change-over from rotary drilling to wireline coring, there were problems setting the casing to the bottom of the hole. In addition, the initial test of the BOP detected a leak, requiring a new flange. Another significant delay occurred during coring at a depth of 4,203 feet, when the HX rods parted at 823 feet. After unsuccessful attempts at retrieval, coring was continued with NX rods, and the HX rods were left in the hole as casing. This precluded the collection of a full suite of geophysical logs, since some logs can not be run in a cased hole. Finally, at a depth of 4,800 feet, the U.S. Forest Service shut down rig operations because of a Class E fire risk. The results of a temperature survey run nine days after the shutdown, in which the bottom-hole temperature was found to be 99°C (210°F), led to a decision not to continue drilling.

GEO N-1

GEO N-1 was rotary drilled to a depth of 487 feet, and then diamond cored to a total depth of 4,550 feet (Swanberg and Combs, 1986). Data and core obtained to a depth of 4,000 feet are in the public domain. Drilling progressed smoothly; out of the 59 days required to reach a depth of 4,000 feet, 54 days were spent drilling. GEO N-1 has been scheduled to be plugged and permanently abandoned before September of 1988.

There were only a few minor problems in the drilling of GEO N-1. During rotary drilling, the rods parted, leaving the rods, sub and bit in the hole, and requiring removal with a tap. An additional delay occurred during the change-over from rotary drilling to wireline coring, when leaks were detected in the BOP.

GEO N-3

GEO N-3 was rotary drilled to a depth of 454 feet and then diamond cored to the total depth of 4,002 feet. Of the 60 days on site, 46 were spent drilling. GEO N-3 is scheduled to be plugged and abandoned before September, 1988.

There were several technical problems encountered in the drilling of GEO N-3. During the change-over from rotary drilling to wireline coring, the initial attempts at cementing the casing were not successful. In addition, the BOP tested negative due to faulty equipment. One significant problem the other two holes did not have was consistent caving in the cinder/ash units. This was particularly a problem when pulling out of the hole to change bits. In one instance, the caving caused the HQ rods to stick. After futile attempts at retrieval, as well as a loss of 138 feet of previously drilled hole, the HQ rods were cemented in place and the hole was reentered with NQ rods. Once again, this limited geophysical logging.

Comparison of Drilling Histories

Depth penetration profiles are shown in Figure 2 for the three holes. The overall daily penetration rate for CTGH-1 was 88 feet/day. For GEO N-1, the overall daily penetration rate to 4,000 feet was 69 feet/day. Finally, for GEO N-3, the overall penetration rate was 68 feet/day. According to Thermal Power Co. (1987), no systematic relationship between penetration rate, rock type and/or degree of fracturing was discerned. This seems to apply to the Newberry volcano holes as well.

Core recovery was excellent in CTGH-1 and GEO N-1, averaging nearly 100%. In GEO N-3, core recovery was equally good in the basaltic-andesite flows. However, GEO N-3 had several thick sections of cinders and ash where core recovery was significantly lower. During rotary drilling of the upper portions of the hole, cuttings were collected only in CTGH-1. There was continual loss of circulation during rotary drilling of the Newberry holes, with no returns.

A detailed itemization of project expenditures for CTGH-1 is given in Table 1a. Approximate expenditures for GEO N-1 and GEO N-3 are given in Table 1b. The overall unit cost for CTGH-1 was $95/foot; for GEO N-1 the overall cost was $72/foot (not including logging and demobilization); and for GEO N-3 the cost was $90/foot.

DATA ACQUISITION AND AVAILABILITY

A significant amount of data has been obtained on the lithologies, temperature gradients, and hydrologic regimes of the areas penetrated by the coreholes. Simplified lithologic columns for CTGH-1, GEO N-1 and GEO N-3 are given in Figure 3. For more detailed information, refer

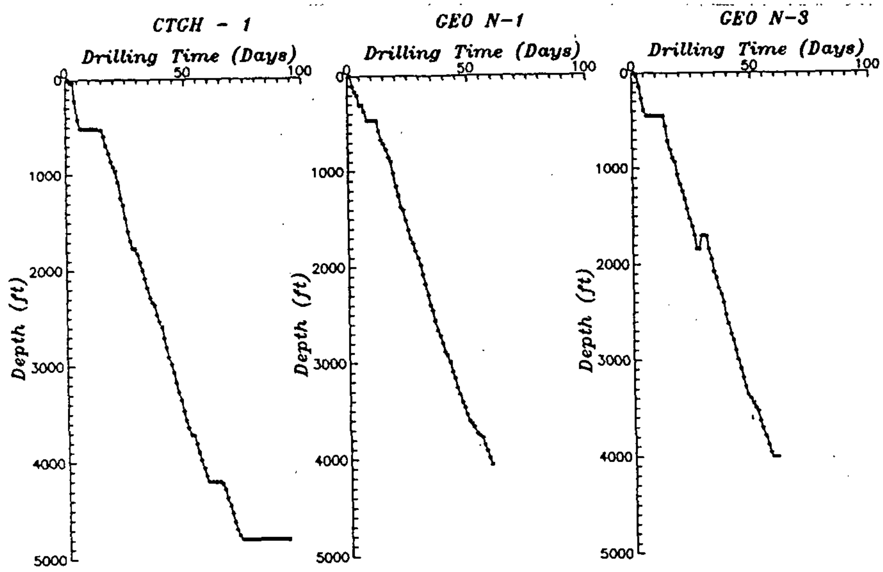

Figure 2. Depth penetration profile for CTGH-1, GEO N-1, and GEO N-3. Information based on daily drilling reports in open file data.

TABLE 1a.

Detailed Itemization of Expenditures for CTGH-1 (based on CTGH-1 Final Technical Report by Thermal Power Co., 1987).

ROAD, SITE AND LOCATION	$11,544.00
RIG MOB/DEMOB	$10,000.00
RIG	$296,807.00
TRUCKING & HAULING	$3,890.00
DRILL SITE GEOLOGISTS	$26,560.00
MUD & CHEMICALS	$24,618.00
CEMENT MATERIALS	$9,141.00
GEOPHYSICAL LOGGING	$10,032.00
DRILL BITS & TOOLS	$23,493.00
OUTSIDE LABOR	$1,424.00
OTHER EVALUTATION	$6,954.00
OTHER	$14,125.00
CONDUCTOR CASING	$419.00
SURFACE CASING	$10,589.00
WELLHEAD EQUIPMENT	$2,589.00
CAMP & CATERING	$4,271.00
TOTAL:	$456,456.00
OVERALL COST/FT =	$456,456/4,800 ft
=	$95/ft

TABLE 1b.

Estimate of Expenditure for GEO N-1 and GEO N-3 (based on daily drilling reports by GEO Operator Corp.)

	GEO N-1	GEO N-3
RIG MOBILIZATION	$3,000	$8,723
ROTARY DRILLING	$31,953	$24,957
CEMENTING CASING INSTALLING BOP	$17,830	$23,500
WIRELINE CORING	$233,776	$265,644
LOGGING AND DEMOBILIZATION	?	$37,619
TOTAL COST	~~$286,559~~ (to 4000') 429,455	~~$360,443~~ 429,455
OVERALL COST/FT	$72/FT 107/FT	$90/FT 107/FT

to the open file reports. In general, the lithologies are similar, consisting of basalt/basaltic-andesite flows. All of the holes have interbedded pyroclastic and volcaniclastic units. In GEO N-3, these units are thicker than in the other holes, and since they are poorly consolidated as well, caving occurred during

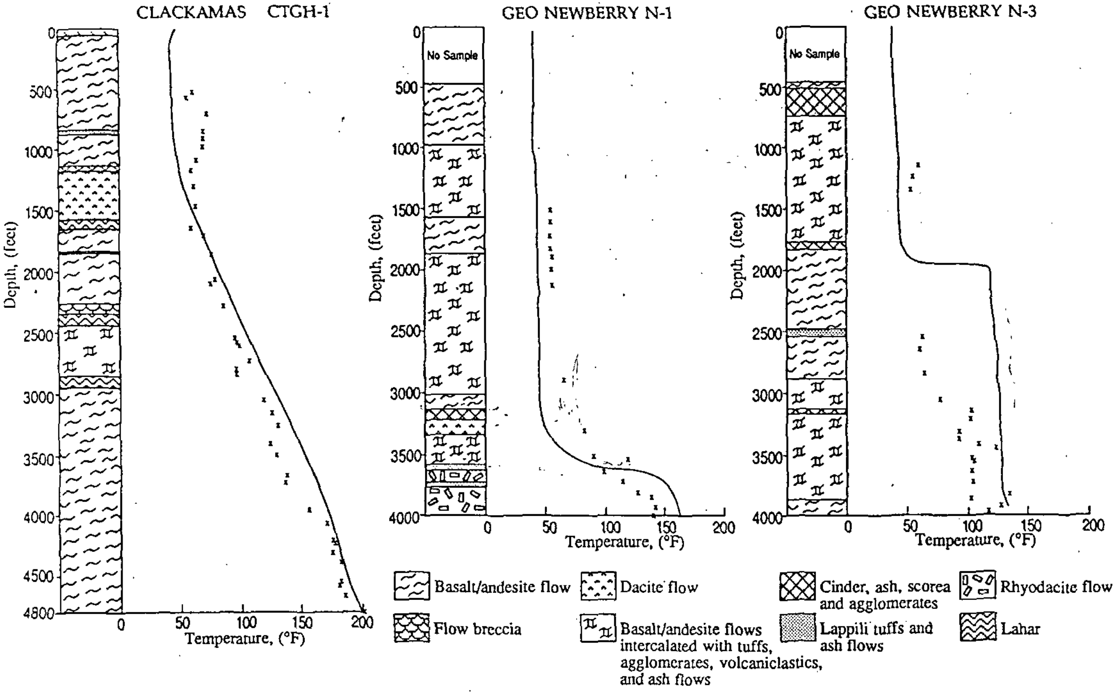

Figure 3. Generalized lithologic columns and temperature-depth profiles for CTGH-1, GEO N-1, and GEO N-3. Temperature-depth curves based on Blackwell and Steele (1987); MRT data, shown by "x"s, from open file reports. CTGH-1 and GEO N-1 lithologic columns modified from Sibbett, unpublished data.

the drilling of GEO N-3 that was not present in GEO N-1 and CTGH-1.

Figure 3 also compares the temperatures measured by Blackwell and Steele (1987) with those recorded using a maximum recording thermometer (MRT) during drilling. The temperature profiles for GEO N-1 and GEO N-3, after allowing the wells to stabilize, appear to reflect intra-hole fluid flow (Blackwell and Steele, 1987). In GEO N-3, they suggest that the temperature distribution results from upward movement of water in the wellbore. Similarly, the thermal profile of GEO N-1 could be produced by downward flow of water within the wellbore.

Since temperatures measured during drilling may be recorded before any significant intra-hole fluid flow has begun, MRT data should provide an indication of the depth to the base of the cold-water hydrologic regime. Figure 3 shows that the MRT temperatures are nearly constant with depth in the upper portions of all three holes. Below this zone, the gradients increase and higher temperature are recorded. We suggest, based on these measurements, that the lower boundary of the cold water regime is located at depths of about 3,600 feet in GEO N-1, 3,000 feet in GEO N-3, and about 1,600 feet in CTGH-1.

Comparison of the thermal profiles with the lithologic logs demonstrates that fluid movement may be influenced by rock type. For example, in GEO N-3, flow out of the wellbore occurs around 1,800 to 1,900 feet in an unconsolidated cinder and ash unit. The water appears to enter this well in interbedded pyroclastics and basalts. Additional information on GEO N-1 and GEO N-3 is given by Blackwell and Steele (1987). GEO N-1 has also been summarized by Swanberg and Combs (1986).

Geophysical well logs were run in all three holes shortly after hole completion. In both CTGH-1 and GEO N-3, it was not possible to obtain complete logs due to the casing. Table 2 lists the logs available, and the corresponding depth intervals.

TABLE 2.

Geophysical Well Logs Available. For copies contact: Rocky Mountain Well Log Service; P.O. Box 3150; Denver, Colorado 80201.

	CTGH-1	GEO N-1	GEO N - 3
TEMPERATURE	16 - 516.5 ft; 0 - 4785 ft	0 - 4000 ft ✓	50 - 4002 ft
CALIPER	10 - 514 ft; 4100 - 4800 ft	0 - 4000 ft	1690 - 3999 ft
GAMMA RAY	0 - 4800 ft	0 - 4000 ft	50 - 1692 ft
SPONTANEOUS POTENTIAL	35 - 516 ft; 4200 - 4798 ft	0 - 4000 ft	--
RESISTIVITY 16" - 64"	35 - 515.5 ft; 4200 - 4799 ft	0 ~~- 4000 ft~~	--
INDUCTION	--	0 - 4000 ft	--
ACOUSTIC	4225 - 4425 ft not available	0 - 4000 ft ✓	--
ACOUSTIC FRACLOG	--	0 - 4000 ft ✓	1700 - 4001 ft
NEUTRON	0 - 4800 ft	--	50 - 4000 ft
GAMMA - GAMMA DENSITY	0 - 510 ft; ~~775 - 900 ft~~ not available	--	--
INDUCED POLARIZATION	4200 - 4799 ft	--	--
LATERALOG	4200 - 4798 ft	--	--
DENSILOG, NEUTRON	--	--	50 - 1692 ft
GUARD RESISTIVITY	20 - 514 ft		--

Analysis of the well logs is presently being conducted. There are several other scientific studies underway on the three coreholes. Table 3 lists these studies as well as the entities that are conducting the studies. In addition, an attempt will be made to obtain a fluid sample from GEO N-3 before the hole is plugged and abandoned.

A summary of open-file data is given in Table 4. Core from the three holes is also available for inspection at the University of Utah Research Institute sample library by appointment.

An additional core hole has been drilled along the east side of Crater Lake National Park, Oregon by California Energy as part of the DOE/Industry cost-share program (located south of area shown in Figure 1). The hole has been drilled to approximately 1,400 feet, with a temperature at TD of 107°C (225°F) (Blackwell and Steele, 1987). However, drilling has been halted while possible effects of geothermal development on Crater Lake are evaluated. Some of the issues surrounding this evaluation are discussed by La Fleur (1987) and Sammel and Benson (1987). If continued drilling is approved studies and data, similar to that acquired on the other holes drilled under the DOE cost-share program, will become available for the Crater Lake hole.

SUMMARY

As part of a DOE-industry cooperative research program, three deep holes were cored in the Cascades to depths of 4,000 to 5,000 feet. The main objective of the program was to penetrate the near-surface hydrologic regime and obtain lithologic, hydrologic and structural data on the Cascades that would be available to the public. The near-surface hydrologic regime was penetrated by all three holes, and the appropriate data collected. At the present, studies on these three holes are still underway.

Table 3.

Scientific Studies Underway or Reported

	CTGH -1	GEO N-1	GEO N-3
HEAT FLOW.	SMU	SMU GEO	SMU GEO
DOWNHOLE Hg	--	GEO	GEO
ALTERATION	USGS	USGS GEO	USGS GEO
VOLCANIC STRATIGRAPHY	DOGAMI	Univ. of Wyo	Univ. of Wyo
CORRELATION OF ELECTRIC LOGS WITH ALTERATION/ANALYSIS OF WELL LOGS	UURI	UURI	UURI
GEOCHEMISTRY OF FLUIDS AND ROCKS	--	GEO	GEO
AGE DATA	--	GEO	GEO
PETROGRAPHIC ANALYSIS	--	GEO	GEO
SYNTHESIS OF DATA TO DEVELOP MODEL	DOGAMI	--	--
CORE STUDIES	UURI	UURI	UURI

SMU - Southern Methodist University

GEO - GEO Operator Corp.

USGS - United States Geological Survey

DOGAMI - Oregon Dept. of Geology and and Mineral Industries

Univ of WYO - University of Wyoming Dept. of Geology

UURI - University of Utah Research Institute - Earth Science Laboratory

Table 4.

Open File data available. For copies, contact the authors.

	CTGH -1	GEO N-1	GEO N-3
DAILY DRILLING REPORT	X ✓	X ✓	X ✓
DRILLING AND COMPLETION HISTORY	X ✓		
LITHOLOGIC LOG	X	X	X
CORE RECOVERY LOG	X✓	X✓	X✓
CORE PHOTOS		X	X
TEMPERATURE DURING DRILLING	X	X	X
STANDING FLUID LEVEL	X	X	X
TEMPERATURE LOG		X	X
GRAPHIC DRILLING LOG (lithology, temp. from MRT, penetration rate, water level, lost circulation zones)	X ✓		
SECONDARY MINERALOGY DESCRIPTION	X	X	X
HOLE COMPLETION SCHEMATIC	X	X	X
TABLE OF MEASURED THERMAL CONDUCTIVITY		X	
FINAL REPORTS	X	X	

ACKNOWLEDGEMENTS

This program has been supported by the U. S. Department of Energy, Geothermal Technology Division and Idaho Operations Office. Marshall Reed and Susan Prestwich of DOE have managed the program. UURI has been supported under Contract No. DE-AC07-85ID12489.

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Geothermal Resources Council, TRANSACTIONS, Vol. 11, October 1987

AN ANALYSIS OF THE HYDROLOGIC EFFECTS OF PROPOSED TEST DRILLING IN THE WINEMA NATIONAL FOREST NEAR CRATER LAKE, OREGON

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ABSTRACT

This paper describes the results of a preliminary study on the hydrologic regime underlying the Crater Lake Caldera, Oregon. The study was performed to provide a basis for evaluating the potential for polluting Crater Lake by drilling exploratory boreholes on the flanks of the mountain. A simple conceptual model of the hydrologic regime was developed by synthesizing the data from the region surrounding the Caldera. Based on the conceptual model, a series of numerical simulations aimed at establishing the basic groundwater flow patterns under and surrounding the lake were performed. In addition to the numerical simulations, we used simple volumetric techniques for estimating the distance that drilling mud would migrate away from the borehole if drilling proceeded without drilling fluid returns.

Based on our calculations that show the regional flow of groundwater will oppose the flow of drilling mud toward the lake, and based on our volumetric estimate of drilling mud migration, our study concludes that drilling without returns will not pollute Crater Lake, nor will it affect the hydrologic regime in the immediate vicinity of the Crater Lake Caldera.

INTRODUCTION

The investigation described in this report was undertaken at the request of the Oregon State Office of the Bureau of Land Management, the United States Department of the Interior, and the United States Department of Energy. The purpose of the study is to provide the hydrologic basis for an amended Environmental Assessment of the consequences of exploratory test drilling for geothermal resources within the Winema National Forest adjacent to Crater Lake National Park, Oregon. The specific objective is to analyze impacts due to drilling about 1700-m deep geothermal gradient holes *without maintaining circulation of drilling fluid*.

In addition to the published data on the geology and geophysics of Mount Mazama and the limnology of Crater Lake, useful background information was obtained from a two day conference on Crater Lake sponsored by the Geothermal Resources Council, held in Portland, Oregon on February 24 and 25, 1987. Many of the workers who have done pioneering studies of Mount Mazama and Crater Lake presented their findings. This conference provided a synthesis of old and new scientific data on the area, much of which has been incorporated in the conceptual and numerical models described below.

APPROACH AND METHODOLOGY

Crater Lake has been the object of geological, limnological, and hydrological studies over the years. However, in general, there is a lack of much of the data that is usually considered to be a prerequisite for the type of analysis that needs to be performed in order to predict migration of potential contaminants in a groundwater system. For instance:

1. The hydrologic system at Crater Lake is not well known, and there are few constraints on the boundary conditions of the flow system.
2. No data are available on the permeabilities of rocks beneath the Crater Lake Caldera.
3. The temperature distribution in the rocks beneath Crater Lake and elsewhere in the volcano is unknown. The history of volcanism at Mt. Mazama supports the belief that temperatures are higher than normal in the upper few kilometers of the crust beneath the volcano.

Our study utilizes the results of numerical simulation modeling as the primary basis for our conclusions. The numerical code used for the simulations was developed at the Lawrence Berkeley Laboratories by G. S. Bodvarsson (1981). The code, PT, employs an integral finite-difference method for solving coupled equations of mass and energy transport. PT has been extensively tested and used by numerous investigators to solve a variety of hydrothermal flow problems. In the light of the above deficiencies of data, our approach has been to perform a series of modeling computations that would establish the general characteristics of the flow system in and around the Crater National Park with reasonable certainty.

CONCEPTUAL FRAMEWORK

The conceptual basis for the numerical models relies heavily on geological studies of Mount Mazama by Howel Williams (1942) and Charles Bacon (1983) and the hydrologic study by Phillips and VanDenburgh (1968). Recent limnological and geophysical studies of Crater Lake have also contributed to the development of the conceptual model. Several fundamental assumptions underlie the model. Briefly, these are as follows:

1. The hydrologic flow system is assumed to be generally radially symmetrical in conformity with the overall radial symmetry of the volcano. Non-symmetric topography on the flanks of the volcano is recognized and differences between the east and south flanks are incorporated into the models.
2. The present shallow hydrologic regime was established at least 1000 years B.P. (Phillips and VanDenburgh, 1968). A further assumption is that long-term average precipitation and seepage loss from the lake are represented with accuracy sufficient for our purpose by the estimates of Phillips and VanDenburgh (1968).
3. A central magma body was present at shallow crustal depths approximately 7000 years B.P., and more recent eruptions give evidence of continued high heat supply to this body (Bacon, 1983).
4. The evolution of silicic magma and the ultimate collapse of the summit of Mount Mazama to form a large caldera are evidence for the location of the silicic magma chamber at shallow depths, possibly near the upper margin of a dense intrusive mass inferred from gravity data at a depth of about 2.5 km (Williams and Finn, 1985). It is expected, therefore, that temperatures may still be high in rocks of the collapsed block beneath the caldera.

Each of the foregoing assumptions applies equally well to Newberry, a large volcanic feature located about 95 km NE of Crater Lake, whose structure is similar in most important respects to Mount Mazama. At Newberry, extensive geological and geophysical studies, shallow test drilling, and recently completed numerical simulations offer insights that are useful in evaluating some less well documented aspects of Mount Mazama.

In the design of the numerical models, we make no assumptions regarding the location, size, or present condition of a magma chamber at Mt. Mazama. However, we accept the data presented by H. Nelson, R. Collier, and J. Dymond in three papers read at the GRC Technical Workshop on Crater Lake (Portland, Oregon, February 24 and 25, 1987) as evidence that high pressures and temperatures existed at shallow depths below the volcano as recently as 4000 years B.P.

Hydraulic heads at the surface of Crater Lake and in the adjacent rim rocks provide the principal driving force in the upper part of the hydrologic system at Mt. Mazama. We assume that the lake forms a recharge mound that forces a constant flux of water downward and radially outward. Thus, the amounts of precipitation and the subsurface leakage from the lake, both of which are known with reasonable accuracy, provide a known boundary condition at the upper surface of the model. For the boundary conditions at the outer edge of our model, we assume that temperatures and pressures are constant at a distance of about 30 km from the center of the caldera.

Many of the springs on the east and south flanks of Mt. Mazama emerge above lake levels at altitudes of more than 2100 m (7000 ft). Most of the remainder occur between altitudes of 1830 and 1890 m (6000 to 6200 ft). The presence of these springs indicates that vertical ground-water flow is impeded by low permeability rock units. We have assumed that the high apparent water tables east and south of the lake are, to a large extent, perched and that a true water table, related both to lake levels and to local base levels, lies at lower altitudes.

Below altitudes of about 1800 m on the east flank of Mt. Scott, the rocks are highly altered, dense, and poorly permeable. These rocks, which are predominantly rhyodacitic in composition, probably overlie hornblende andesites which may have similar hydrologic properties (Charles Bacon, oral commun., 1987). This rock assemblage appears to represent a barrier to downward percolation of meteoric water and is the probable cause of the large volumes of spring flow.

A rough estimate of the water budget for the east and south flanks of Mt. Mazama indicates that the water available from precipitation exceeds both the spring flows in this area and the total estimated seepage from Crater Lake. Average annual spring discharge to the east of Mt. Mazama may be about 1.1×10^8 m^3/yr and discharge to the south may be about 6.3×10^7 m^3/yr (from estimates provided by Garwin Carlsen, USFS, and published records of the USGS). If annual precipitation is assumed to average 45 in (1,143 mm) within a radius of 15 km from the lake center (above an altitude of about 1372 m), and if evapotranspiration is about 13 in (330 mm) (J. E. Vaughn, Deschutes National Forest, estimate for a lodgepole pine forest at Newberry Volcano, 1983), the net meteoric water available is about 810 mm, or 5.73×10^8 m^3/yr. Total spring flow is about 1.6×10^8 m^3/yr. Thus, there is no need to invoke seepage from the lake (approx. 8×10^7 m^3/yr; Phillip and van Denburgh, 1968) as a source of spring flow on the flanks of the mountain.

To the east of Mt. Scott, lake sediments of low permeability may underlie the lower slopes and extend beneath the Klamath Marsh. The sediments are assumed to be similar to those exposed in a road cut along Rte. 97 north of the Williamson River. Wells drilled through these sediments on the west margin of the Klamath Marsh penetrate permeable rocks and tap ground water under artesian pressure.

We have not attempted to model subsurface conditions related to the large domes and volcanic vents in the highlands east of the lake. The large volcanic features in this area, which include Pothole Butte, Mt. Scott, and Dry Butte, predate most of the construction of Mt. Mazama and show no evidence of recent volcanism or high heat flow. Mt. Scott, for example, is more than 400,000 years old and would not be expected to retain significant amounts of residual heat (Charles Bacon, oral commun., 1987). In the absence of reliable clues to the probable structure and rock properties at depth beneath these features, we model this region in the same way as the other areas surrounding the caldera.

Two cross-sections of the the hydrologic regime underneath and surrounding the caldera are modeled in this study, one trending approximately E-W (Model 1) and one trending approximately N-S (Model 2). In the following paragraphs, these models are described.

MODEL 1: E-W Cross Section

The first area modeled lies to the east of the la includes a wedge of terrain with its origin at midlake a outer boundary at a radial distance of 28 km. The mode intended to represent hydrologic conditions that apply to the cross section A-B, shown in Figure 1. A cross-sectional profile of the model lies along an azimuth of 105 degrees from the lake center, passing close to the top of Cloud Cap and crossing the north flank of Mt. Scott (Figure 2). Below the lake, the sunken caldera block is given a diameter of 6 km in accordance with seismic data from the lake bottom reported by Nelson (GRC meeting, Portland, Feb. 24, 25, 1987). The profile extends to the Klamath Marsh near the confluence of Big Spring Creek and the Williamson River.

From the eastern boundary of the model, the water table was projected inward with a slope of 0.0015 to a point near the bottom of drill hole I-11A. This hole, bottomed at an altitude of approximately 1431 m, reportedly did not penetrate the water table. From this point to the surface of Crater Lake, the height of the water table, and consequently, the elevation of the top boundary of the computational mesh, was adjusted as a function of observed pressures in the upper row of nodes.

Areas of the cross section shown in Figure 2 are labeled with Roman numerals designating the hydrologic units differentiated within the model. Values of material and fluid properties are shown in Table 1. Our knowledge of the subsurface conditions at Mt. Mazama is not sufficient to permit meaningful use of fine distinctions in rock density, porosity, heat capacity, thermal conductivity, and compressibility; hence, these properties were given constant values representative of volcanic rocks. Ranges of permeability were used in the models to represent probable differences in permeability among the units. The permeabilities chosen are based on field measurements in volcanic terrains reported in the literature, primarily those from Brace (1980, 1984), Hardee (1982), Henley and Ellis (1983), Sammel (1980), and Sammel and Craig (1981). For each of the models, numerous simulations were performed using a range of permeability (k) and anisotropy ($k_{vertical}/k_{horizontal}$ ranging from 0.01 to 1) values for each of the rock units. In this report, we discuss the results of the simulations with the horizontal permeabilities listed in Table 2.

The permeability in unit I is relatively high, in keeping with indications from eruptive centers such as Newberry Volcano and several centers in the vicinity of Klamath Falls. Unit VII is given a lower permeability on the basis of hydrologic indications (see above) and core from drill hole I-11A. Unit IV is given a low permeability on the basis of the presence of the lake perched above it and the likelihood that rock alteration and mineral deposition would have occurred at the low-temperature upper boundary of a former hydrothermal system. Permeabilities in the remaining units are intermediate to low on the assumption that the rocks are late Tertiary basalt flows overlying strata of unknown composition.

MODEL 2: N-S Cross Section

The cross section A-C shown in Figure 1 which is used for Model 2 (Figure 3) follows the high ground between Sun Creek Valley and Munson Valley, passes through Crater

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The rocks below an altitu d to
be basalt flows similar to t 0 m in
drill hole II-1. These rocks unknown
depths. In general, with the exc , the permeability values used for Model 2 are those in Model
1. Higher permeabilities are neede nit I to match the
water table distribution for Model 2. The values for the horizontal permeability of the various rock units used in the simulation runs for Model 2 that are reviewed in this report are listed in Table 2.

Heat Flow and Boundary Conditions

In the cases reported here, the lake surface is treated as a constant-flux boundary, with a seepage rate of 1250 kg/s. (Several simulations were performed using the full recharge rate of 2500 kg/s (about 8×10^7 m^3/yr), but, as discussed later, it is unlikely that the full recharge enters that regional groundwater flow system.) At the vertical outer boundary, water is free to flow in or out of the system but maintains a constant temperature and pressure profile. Along the bottom boundary of the system, we impose a constant heat flow of 105 mW/m^2, which is equal to the minimum value estimated by Blackwell and others (1982) for the main trend of the Cascade Range. No mass is allowed to enter or leave the system across the bottom boundary. The ground surface is treated as a constant temperature boundary, with a temperature of 3.9 ° C.

To simulate the influence of the magma body on the local heat flow, we assume that the temperature remains at 350 ° C at a depth of approximately 1.5 to 2.5 km below the lake surface (see hydrologic unit VI in Figures 2 and 3). In one of the Cases (Model 2, Case 2), hot water recharge is imposed at a rate of 125 kg/s of 350 ° C water at the bottom boundary in rock unit VI in order to simulate the effects of heated fluids upwelling from a great depth directly underneath the caldera.

Initial Conditions

The initial temperature distribution in our model (Figure 4) was obtained from a similar but much more detailed numerical modeling of the hydrothermal system at Newberry Volcano. Basically, the initial conditions were developed by considering the thermal regime surrounding a convectively cooling magma chamber (Sammel and others, 1987). In this transfer, we rely on similarities between Mt. Mazama and Newberry Volcano in size, construction, and the recency of silicic volcanism. We have assumed that the two volcanoes supported similar thermal regimes during the past few thousand years. At Newberry Volcano, maximum temperatures at a depth of 2.5 km below the caldera rim were estimated to be greater than 300 °C and perhaps as high as 400 °C after 4000 years of convective cooling.

RESULTS

The results from four numerical simulations, describing two cases each from Model 1 and Model 2 are discussed in the following paragraphs. In general, the results from Model 1 and Model 2 are similar, and inferences about the general flow directions and magnitudes, lake levels and seepage, and heat flow are transferable from one model to the other.

Lake levels and seepage

The simulated levels of Crater Lake are highly sensitive to the amount of seepage and the permeability of adjacent rocks. Early attempts to simulate the full recharge (2500 kg/s) estimated by Phillips and VanDenburgh (1968) showed that unexpectedly high permeabilities are required for the hydrologic units adjacent to the lake in order to keep it from rising to unacceptably high levels.

As an alternative to increasing the overall permeabilities in units I and II to unrealitically high values, we assume that much of the seepage from the lake is conveyed in a few highly permeable zones that are not part of the regional flow system. Evidence for one such permeable zone is found at the northeast margin of the lake (Charles Bacon, oral commun., 1987). To account for these channels, we assume that only one-half the recharge estimated by Phillips and VanDenburgh actually seeps into the bulk of the rock mass that is modeled.

With a recharge of 1250 kg/s, the lake level for Model 1 (Case 1) remained within a few meters of its present day elevation of 1882 m. In other cases, the lake declined to levels as low as 1728 m or rose as high as 2356 m from its initial level of 1882 m, depending primarily on changes in the permeability of units I, II and III. In all of the cases, small adjustments in the permeability distribution could have been used to achieve better agreement between the predicted and measured lake level. However, because the changes in lake level had little effect on the direction and rate of flow, we did not attempt to achieve an exact match in each case.

Vertical seepage through the lake bottom is directed both upward and downward in the various models, and, in most models, upward and downward seepage occur in adjacent nodes in response to small differences in pressure. The vertical seepage is never greater than 4 percent of the total outflow from the lake, and overall, it did not have a significant impact on the results of the models. Clearly, increased permeability in the unit directly underlying the lake could strongly affect seepage rates and temperatures beneath the lake, but the general flow pattern could not be significantly changed.

Flow Directions and Magnitudes

The modeling studies indicate the distribution of fluid velocities within the various sub-surface rock units. For example, the arrows in Figures 5, 6, 7 and 8 show the directions and magnitudes of ground-water flow for the cases listed in Table 2. In evaluating the patterns of flow shown in Figure 5 and succeeding diagrams, it should be kept in mind that the illustrations have a 4 to 1 vertical exaggeration. The result is to distort perceptions of the geometric relations, particularly the vertical components of the flow vectors and the depths of the drill holes relative to their distances from the lake. In true perspective, the model would be seen to consist of thin layers that extend to four times the length shown. In addition, the vectors are based on a linear scale of the logarithms of the magnitudes, which makes order of magnitude differences appear small.

The direction of flow is, as expected, generally downward and outward away from the lake. Vertical components of the flow vectors are directed strongly downward near the lake in spite of the low vertical permeability imposed by the anisotropy ratio (the ratio of the vertical to the horizontal permeability). In each case a large convection cell dominates flow in hydrologic units IV, V and VI beneath the lake. The magnitude of the upward flow is enhanced for the case where fluid recharge occurs under the caldera (Model 2, Case 2; see Figure 8).

In one case (see Figure 5), flow is radially inward in the lowest row of nodes at distances up to 8.5 km from the lake center. For Model 1, increasing the permeability of the rock units II and III from 5×10^{-14} and 1×10^{-15} m^2, respectively, to 1.3×10^{-14} m^2 (Case 2) eliminates the inward flow and creates a more uniform flow field. This results from the rapid outward flow in unit III and a consequent decrease in pressure, which prevents flow into the high-pressure region beneath the caldera. For Model 2, inward directed flow is small and confined to within a radius of 3 km from the center of the lake.

Many prior and subsequent trial runs showed that the flow patterns pictured in Figures 5 through 8 are well established in a few hundred years after the start from the initial hydrostatic equilibrium conditions. Models simulating times as long as 6000 years showed slow decreases in flow velocities but no significant changes in the flow pattern as time progressed.

Heat flow and lake temperatures

Although modeling heat flow was not the primary objective in this work, an analysis of the heat flow calculated from the models provides some reassurance that the temperature distribution and rock properties chosen for the caldera region in our models are reasonable estimates. Heat flow through the lake bottom at simulation times of 1000 years ranged from 930 to 1500 mW/m^2. The heat flow is almost entirely conductive. The lower of the two values is about 11 percent greater than the maximum value actually measured at lake bottom and the higher is about 10 percent less than the maximum estimate of total heat flow given by Williams and Von Herzen (1983).

The models presented here make no attempt to reproduce measured temperatures in Crater Lake. Nevertheless, the model results show reasonable approximations of lake temperatures and measured heat flows. In most of our simulations, lake temperature increased initially and then slowly decreased as cold recharge overcame high initial temperatures and convective upflow of warm water. From an initial temperature of 3.9 ° C, lake temperatures quickly rose to approximately 8 ° C and then slowly declined. We have not attempted to incorporate the effects of convective heat transfer between the lake and the atmosphere, which would tend to reduce the temperature of the lake.

Temperature data presented in this report are limited to the type of results described above. Unlike the fluid flow results, which after a period of several hundred years are not sensitive to initial conditions of pressures or temperature, temperature results are highly sensitive to initial temperatures and to the permeability distribution. In the absence of much additional data with which to constrain initial temperature distributions and boundary conditions, we have chosen to avoid presenting possibly misleading results.

Influence of Hot Water Recharge

The second case reported for Model 2 is designed to evaluate the influence of a significant amount of hot water recharge entering the system directly over the magma chamber. For this case, 350 ° C water is injected into the lower part of unit VI at a rate of 125 kg/s-(1/10 the rate of lake seepage) to simulate the upflow of hot water that might result from a hydrothermally driven convection cell. A previous trial with injection at 12.5 kg/s showed small effects of such injection by increased heat flows and vertical mass transport. Model 2; case 2 clearly demonstrates these effects.

Lake temperatures are slightly higher than in previous cases, and they continue to rise slowly through the 4000 year simulation period. Net mass flow into the lake is still dominantly conductive, but total heat flow has increased to 1500 mW/m^2 at 1000 years and is still rising at 4000 years. Clearly, hot water influx at depths of more than 2.5 km has a significant effect on the transport of both heat and mass beneath the caldera. However, as illustrated in Figure 8, the flow regime beyond the radius of the caldera is not greatly affected by the convective flows under the caldera.

DISCUSSION

The results from Model 1 and Model 2 lead to the conclusion that only major structural features such as faults or stratigraphic discontinuities could significantly alter the flow pattern on the flanks of Mt. Mazama as determined by the models. The following paragraphs review structural features that could potentially alter this conclusion.

A fault or dike that has a low permeability relative to the surrounding rock may or may not influence the flow pattern, depending on its orientation. If the structure lies in a vertical plane oriented along a radius to the lake, it would have little or no effect on the flow pattern. To the extent that such a structure cuts across the natural radial flow paths, and in the extreme case is perpendicular to the flow paths, it will act as a barrier to the flow. Nevertheless, on a regional scale, water will still flow from the high pressure area of the lake to the low pressure area of the local or regional base level. In such a case, there is virtually no possibility that fluid from beyond the barrier could be forced to flow toward the lake.

In the case of an impermeable sill or other horizontal structure or stratum of low permeability, water from the lake would flow above it, retaining much of its initial high hydraulic head. Fluids from outside the caldera area could neither move upward through the barrier against the overlying high hydraulic head nor flow on top of the barrier against the radially outward gradient that would exist there. As with the previous case, the large- scale flow field would be changed only locally by such a feature and could not be completely reversed.

Considering now cases in which structural features are more permeable than the surrounding rock, the consequences can be stated rather briefly. The flow in such features would in general simply be more rapid than in the surrounding rock, and the prevailing potential (head) differences between the lake area and the nearby base levels would govern the overall directions of flow in the same way as in the absence of permeable structures.

One special case deserves a separate description, however. This could be a permeable fault or fracture situated high on the flank of the mountain that would intercept ground-water recharge in the overlying perched water zone, shown in Figures 2 and 3. Water moving down this conduit could eventually mix with the underlying ground water, and if the hydraulic head in the fault or fracture were sufficiently high above lake level (greater than 1882 m), there would be a component of flow directed toward the lake. The concern here, of course, is whether or not such a flow component could carry any of the drilling fluid from proposed drill holes into the lake. In order for this to occur, two conditions must exist: (1) the drill hole must be located between the fault or fracture and the lake; and (2) the hydraulic head in the fault or fracture must be significantly higher than the lake level in order to produce a counter flow to the prevailing ground-water movement.

MIGRATION OF DRILLING FLUID

A typical drilling fluid that might be used in a core hole is a light bentonite mud with added caustic soda. For the purpose of these calculations, the maximum loss-of-circulation rate is estimated to be 10,000 gpd (38 m^3/d). We have compared this rate with the flow rates computed by the models by means of the following simple calculations. If the average hole diameter in the 1500 m of cored drill hole is 5 inches (0.127 m), the area available for discharge is 600 m^2 and the maximum specific loss rate is 7.33×10^{-7} m^3/s per square meter of drill hole surface. With respect to the rock mass and the formation adjacent to the hole, the injected fluid may be regarded as a finite-width line source having an area perpendicular to the stream lines equal to 190 m^2. The specific loss rate calculated in this approach is 2.26×10^{-6} m^3/s per square meter of formation rock perpendicular to the flow field. This rate is approximately 75 times the maximum ground-water flow rate in the vicinity of the proposed drill hole (I-11A). From these facts, we conclude that the the drilling fluid loss will control pressures and dominate the flow regime in the close vicinity of the drill hole.

Tracer studies have amply demonstrated the complexities of volcanic terraines. For example, recent tracer tests in the geothermal aquifer at Klamath Falls showed that fluid velocities can be as high as 4×10^{-3} m/s in an aquifer where overall mass flow velocity is probably in the range 1×10^{-7} to 1×10^{-9} m/s (Gudmundsson, 1984; Benson, and others, 1984). It is reasonable to assume that, at Crater Lake as elsewhere in volcanic aquifers, most ground-water flow occurs in fractures and permeable strata that represent only a small fraction of the total rock mass. Flow velocities in these features may be orders of magnitude greater than the velocities calculated by our models.

In spite of the lack of data on details of the permeability distribution within the fractured volcanic rocks, some simple calculations can lead to useful conclusions about the fate of drilling fluids in the rocks. Without regard to permeability, the volume of rock that could be invaded by injected fluid is commonly calculated as piston-flow displacement. For example, after 90 days of drilling, with loss-of-circulation at a rate of 10,000 gpd (4.38×10^{-4} m^3/s, the volume of injected fluid is 3400 m^3. Table 3 shows the maximum distance from the drill hole that would be occupied by drilling fluid injected into the specified thicknesses of permeable rocks. The porosity is assumed to be 10 percent. Two examples are shown: the first represents 360-degree radial flow and the second represents the result of injecting the entire amount of fluid into a 45-degree wedge of permeable rock. The assumption of piston flow is not unrealistic in cases where the injection pressure controls the flow regime in confined aquifers and where the injected fluid is cooler and more dense than the formation fluid. The calculations show that even in the extreme and highly unlikely case that the entire flow of drilling fluid entered a stratum 0.1 m thick and was confined to 1/8 of the surrounding volume, the fluid would spread to a radial distance of less than 1 km in the absence of regional groundwater flow.

In examining additional extreme cases, calculations like those above show, for example, that the assumed volume of drilling fluid could not reach the region of caldera fill beneath the lake if it were injected in a pipe-like lava tube 0.75 m in diameter, even if the drill rig pumps were capable of pumping it that far. Similarly, the drilling fluid would stop short of the caldera fill if all of it were injected into a single fissure 50 m high and 0.01 m wide (less than 1/2 inch).

The extreme cases outlined above are included primarily to demonstrate that even in the most unlikely circumstances, drilling fluids will not enter Crater Lake from the proposed drilling locations shown in Figure 1. When it is also considered that drilling mud is particulate matter, heavier than water, that will settle out at low velocities, it is concluded that, in all likelihood, the mud will not travel more than several hundred meters from the borehole.

Finally, the results of the modeling show that the regional ground-water flow field will transport fluids away from the lake and will oppose any travel toward the lake from the flanks of the mountain. This will be true regardless of the permeability of the rocks or the presence of high heat flows at depth.

Implicit in this study has been the assumption that the ground-water system in the vicinity of the lake is in hydraulic connection with ground water beneath the flanks of the mountain. Should this turn out not to be the case in any part of the area because of impermeable structural barriers, there could, of course, be no contamination of the lake by drilling fluids injected beyond these barriers. Parenthetically, the model results suggest that if high-temperature water is located at shallow depths beneath the flanks of the mountain, this finding would indicate that the hot water must be rising from a deeper hydrothermal system in faults and fractures that are, at least in part, isolated from the shallow ground-water body. Drill holes penetrating these features would also be isolated from the shallow ground-water body and, therefore, from the lake. In such cases, radially outward flow of hydrothermal fluids in the deep system would preclude the inward flow of drilling fluid in the same way as does the outward flow of seepage from the lake in the shallow groundwater system.

CONCLUSIONS

1. For the purpose of analyzing possible impacts of fluid injection from drill holes in the vicinity of Crater Lake, the ground-water flow system beneath Mt. Mazama can be represented by simple simulation models.

2. Two major driving forces are able to establish the fundamental nature of the ground-water flow. These forces are the hydraulic head imposed by the water level in Crater Lake and the high pressures generated at large depths beneath the lake by high-temperature rocks. Both of these forces tend to move ground-water radially outward under the flanks of the mountain. Each would operate in the way shown by this study independently of the other, although the vertical extent of mass flow from either is highly dependent on the vertical permeability.

3. Temperatures at depths of 2.5 km or more beneath the lake are probably high in view of the volcanic history of Mt. Mazama, which includes an eruption as recently as 4000 years B.P., and by analogy to Newberry Volcano, a Cascade Range volcano of similar size, characteristics, and eruptive history.

4. On the basis of temperatures measured in the lake and the hydrologic evidence provided by the models, the hydraulic head in the lake appears to be the dominant hydrologic force in the shallow (less than 1.5 km depth) ground-water regime. In the areas of concern for this report, the directions and magnitudes of ground-water flow are determined largely by the potential differences (hydraulic head differences) between the lake and the local base levels of the Klamath Marsh to the east and the upper Klamath Lake valley to the south of Crater Lake. Simply put, the uppermost ground water body is principally controlled by gravitational forces that cause it to flow from high elevations to lower elevations.

5. The general direction of ground-water movement under the flanks of the mountain is not sensitive to assumptions of permeability and anisotropy in the models, although the magnitudes of flow and the details of flow directions are sensitive to these factors. The principal flow directions could not be reversed by the presence of rocks that differed from those modeled or by the existence of major structural features that were not modeled. The reason is simply the dominating effect of high-altitude recharge of water from precipitation and snow melt and the consequent seepage from the lake.

6. The fundamental nature of the flow system appears to be well established by the models, and it is clear that natural hydraulic forces in the flow system will oppose the flow of drilling fluids toward the lake at any point in the proposed drilling areas. Nevertheless, the analysis of impacts from the injection of drilling fluid does not depend only on the presence of radial outward ground-water flow. Calculations of volume displacement show that drilling fluid could not reach Crater Lake from proposed drilling sites even in the most extreme and unlikely cases considered.
7. In view of the ground-water flow directions determined by the modeling, which would oppose the flow of drilling fluid toward the lake, and in view of calculations that show the volume of injected fluid to be too small to reach the lake by simple volume displacement, we conclude that the loss of circulation while drilling does not pose a threat to Crater Lake or in any way affect the hydrologic system in the immediate vicinity of the Crater Lake caldera.

ACKNOWLEDGEMENTS

We are grateful for the contributions of a number of colleagues. In particular, we thank Charles Bacon and Manuel Nathenson (USGS) for background information and discussions, Cindy Yates (LBL), who performed the data input and retrieval for much of the modeling, Garwin Carlson of Winema National Forest for a detailed description of streams and springs in the Crater Lake area, and personnel of the California Energy Company for making proprietary data available to us and sharing background information on the Crater Lake area.. We are also grateful to Marcelo Lippmann and Manuel Nathenson for reviewing this paper and providing valuable comments. This work was sponsored in part by the U. S. Department of Energy under contract number DE-AC03-76SF000098 by the Assistant Secretary for Conservation and Renewable Energy, Office of Renewable Technology, Division of Geothermal Technology.

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Table 1. Material and fluid properties used in all cases.

Rocks					Fluid
Density (kg m^{-3})	Specific Heat (J kg^{-1} K^{-1})	Thermal Conductivity (W m^{-1} K^{-1})	Compressibility (Pa^{-1})	Porosity (-)	Density is calculated as a function of temperature and pressure. Viscosity and expansivity are calculated as functions of temperature. Compressibility is calculated as a function of pressure.
2200	2000	2.0	5×10^{-10}	0.1	Specific Heat: 4200 Jkg^{-1} K^{-1}

Table 2. Permeability distribution used for reported results from Models 1 and 2.

Hydrologic	Model 1		Model 2	
Units	Case 1	Case 2	Case 1	Case 2[1]
I	6×10^{-14}	6×10^{-14}	1×10^{-13}	1×10^{-13}
II	5×10^{-14}	1.3×10^{-14}	5×10^{-14}	5×10^{-14}
III	1×10^{-15}	1.3×10^{-14}	1×10^{-15}	1×10^{-15}
IV	2×10^{-16}	2×10^{-16}	1×10^{-16}	1×10^{-16}
V	1×10^{-15}	1×10^{-15}	1×10^{-15}	1×10^{-15}
VI	1×10^{-16}	1×10^{-16}	1×10^{-15}	1×10^{-15}
VII	1×10^{-17}	1×10^{-14}	-	-

[1] Assuming a recharge of 125 kg/s of 350 ° C water from below the caldera

Table 3. Distance that drilling fluid would migrate in formations of various thicknesses.

Thickness of permeable formation	Maximum Distance from Drillhole	
	Radial (m)	45 °-Wedge (m)
1500	2.7	7.6
500	4.7	13
100	10.4	29
10	33	93
1	104	295
0.1	329	931

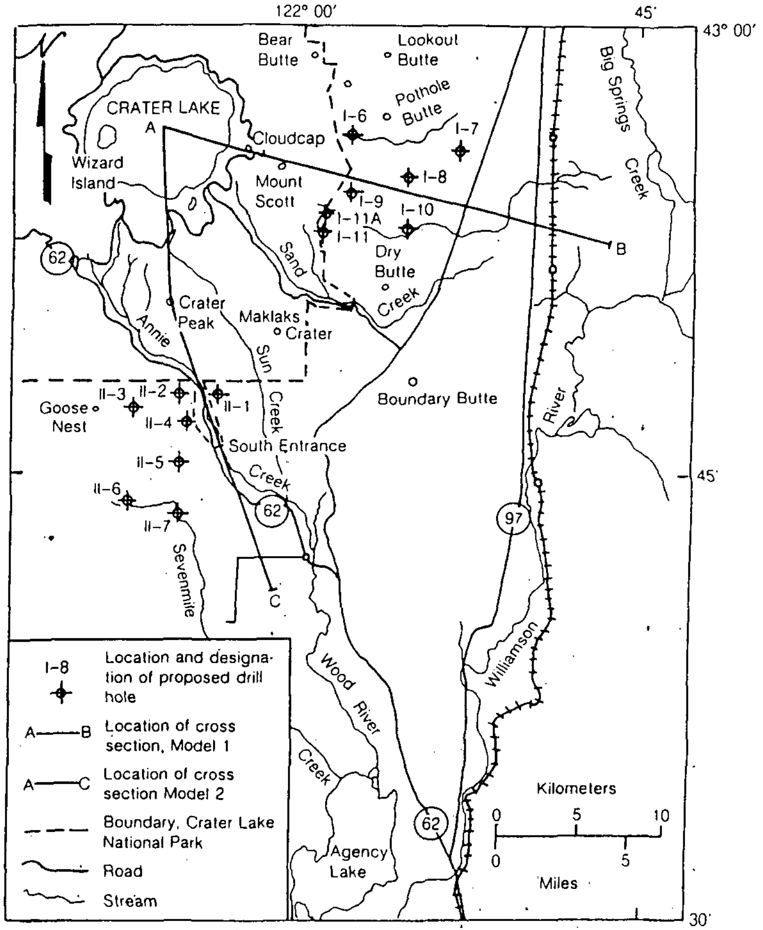
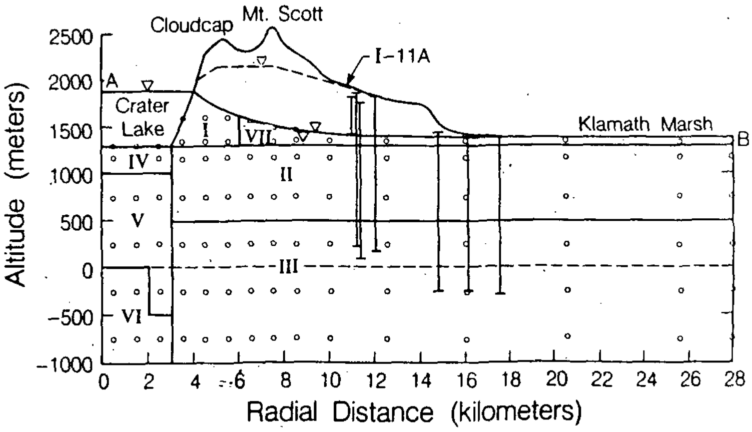


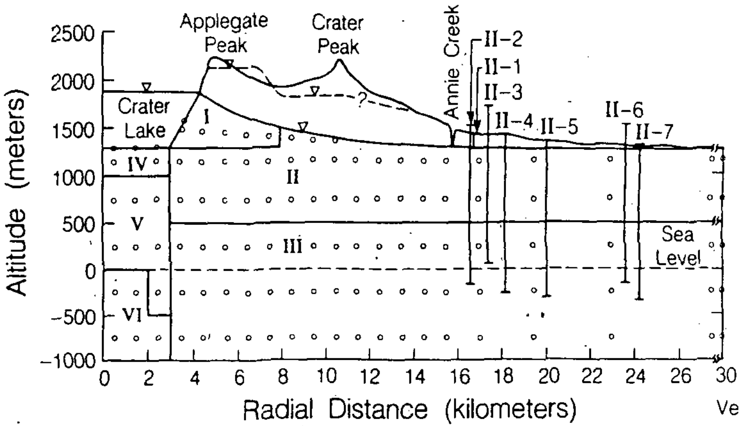
Figure 1. Map showing locations of model cross sections, proposed drilling sites, and selected geographic features.



Vertical Exaggeration 4:1

XBL 876-10216

Figure 2. Computational mesh for Model 1.



Vertical Exaggeration 4:1

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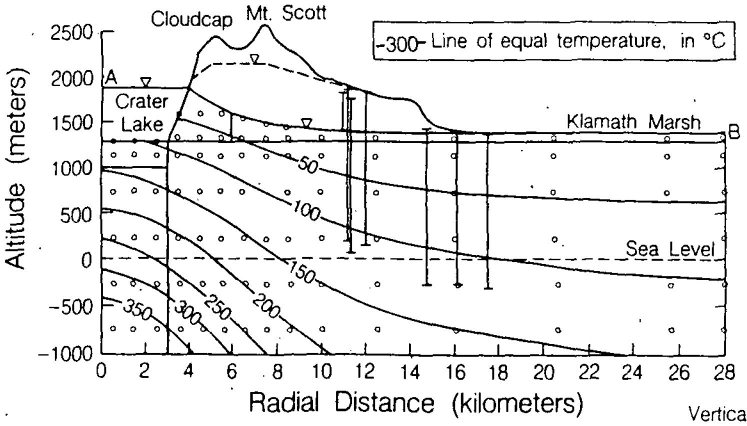
Figure 3. Model 2 boundaries are treated as in Model 1. Seven proposed drill holes in the Masama II area are projected on the cross section. Drill hole II-1 is shown to drilled depth.



Vertical Exaggeration 4:1

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Figure 4. Initial temperature distribution used in all models. The temperatures are taken from a simulation model of Newberry Volcano for a time 4000 years after cessation of volcanic activity (see text for explanation). The cross section represents Model 1, Case 1.

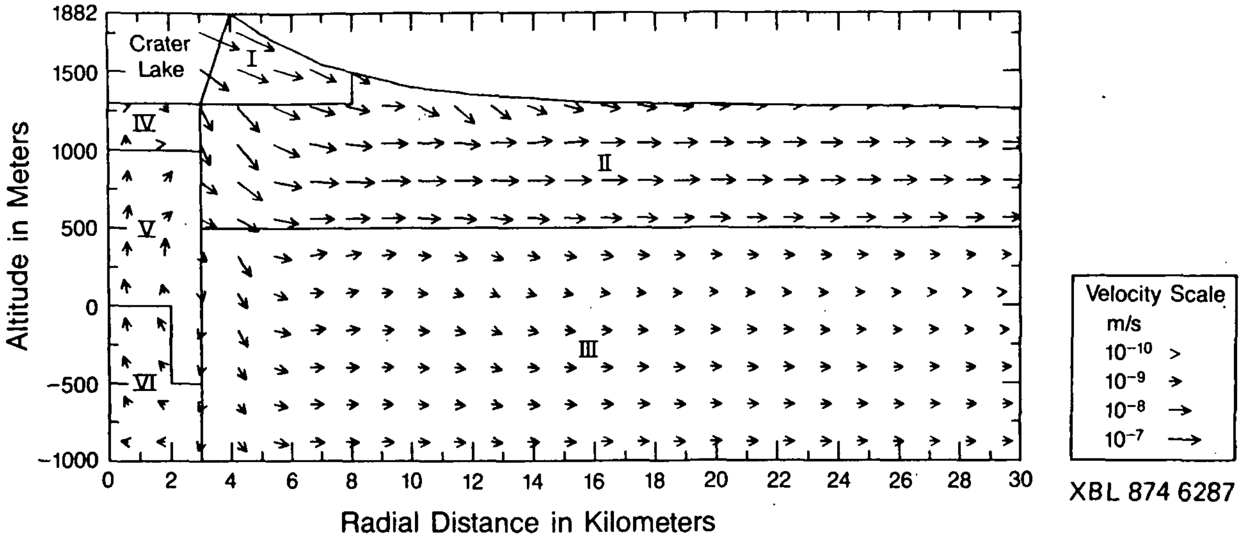

Figure 7. Directions and magnitudes of ground-water flow in Model 2, Case 1.

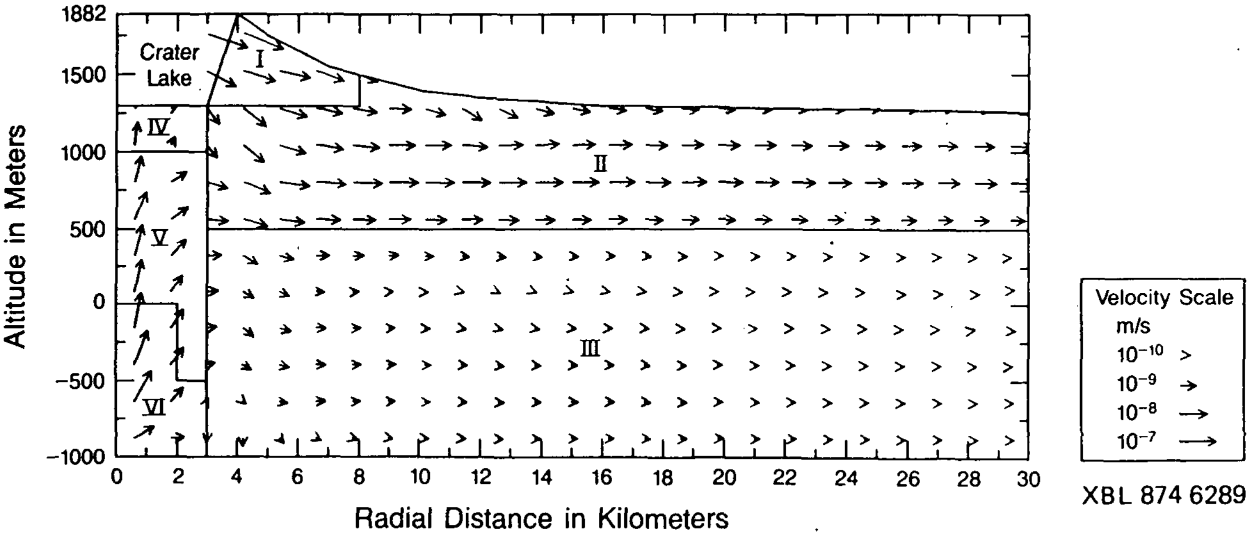

Figure 8. Directions and magnitudes of ground-water flow in Model 2, Case 2.

Geothermal Resources Council, TRANSACTIONS, Vol. 11, October 1987

GEOTHERMAL DATA FROM DEEP HOLES IN THE OREGON CASCADE RANGE

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INTRODUCTION

The Cascade Range in the Northwestern United States and Southwestern Canada is one of the major geothermal resource provinces of North America. It has the largest concentration of Pleistocene and Holocene-age volcanic rocks in the conterminous United States. Demonstrated temperatures in excess of 175°C in geothermal systems exist at Meager Mountain in Southwest British Columbia (Fairbank et al, 1981), Newberry Volcano in Central Oregon, and Lassen Peak Volcano in Northern California (Beall, 1981). High temperatures probably exist at Medicine Lake Volcano, but industry data there is proprietary. At Lassen Peak and Newberry Volcano, high temperatures are located in areas are not presently available for development. The only Cascade volcano with a significant number of deep drill holes and as yet no demonstrated high temperature system is the Mt. Hood Volcano (Steele et al., 1982). In addition to the emphasis on young volcanoes as possible sites of high temperature geothermal systems, there is significant evidence for high temperatures throughout much of the province, especially the northern half of the Oregon Cascade Range. Regional temperature gradients there have been demonstrated to be on the order of 65°C/km (Blackwell et al., 1978, 1982; Black et al., 1983). Data are sparse, but temperature gradients are probably similar in the Cascade Range in southern Oregon and northern California. Temperature gradients (40-50°C/km) are significantly lower, but still above average, in Washington and British Columbia (Blackwell and Steele, 1983; Lewis et al., 1985). Corresponding heat flow values are 100±10 mWm^{-2} and 75±5 mWm^{-2}.

The high gradients in Oregon have been interpreted to be related to a shallow heat source in the crust, probably a zone of very high temperatures with pockets of partial melt at a depth of 7-10 km (Blackwell et al., 1982). Interpretation of gravity, depth-to-Curie-point, and electrical resistivity measurements (Connard et al., 1983; Stanley, 1981) are consistent with high temperatures at shallow depths in the crust and suggest that the high temperature gradients and heat flow values observed in shallow (average 150 m) holes are in fact regional. At present the area of demonstrated high gradients is still a small part of the Cascade Range (the area demonstrated to have the high gradients is shown by the pattern on Figure 1). This area does not include much of the High Cascade Range because within the depth range of most of the shallow holes (150 m), temperature gradient and heat flow measurements cannot be made in the porous, young volcanic rocks in the High Cascade Range and in the High Lava Plains at their intersection with the Cascade Range (between the Newberry Volcano and the Three Sisters Volcano). Thus while high gradients have been demonstrated over part of the area, the total extent of these high gradients and the actual values of gradient along the axis of the Cascade Range (the locus of greatest volcanic activity during the last 0.5 Ma) remain as yet undetermined. Furthermore, the relationship of the hot springs, most of which are concentrated near the boundary between the high heat flow and the Western Cascade Range-Puget Sound-Willamette Valley normal heat flow province, to the regions of high heat flow and high gradient are as yet unexplored. Blackwell et al. (1982) suggested several models for the systems but these models are untested.

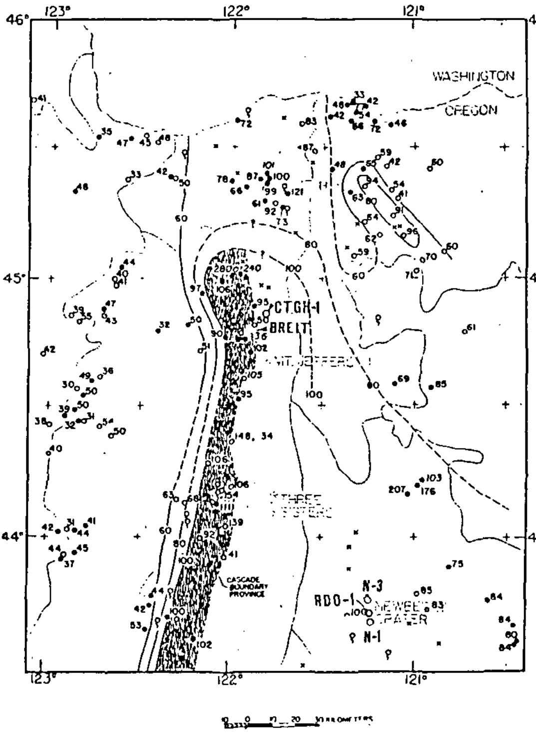

Figure 1. Location map of holes discussed in this paper. Heat flow values and locations of existing holes are given in mWm^{-2} (base after Blackwell et al., 1982).

The object of this paper is to present thermal data from several intermediate to deep drill holes in the Oregon Cascade Range, which are new or have recently become available. A total of 6 holes will be discussed in this paper and compared to existing data. These 5 holes include 3 holes at Newberry Volcano, 2 drilled by Geo-Operator Corporation, and 1 drilled by Sandia National Laboratories in 1983. In addition 2 holes drilled in the general vicinity of the Breitenbush Hot Spring area north of Mt. Jefferson will be discussed. These include a well drilled by Thermal Power near Olallie Butte close to the axis of the Cascade Range and a well drilled by Sunedco as a deep exploration test 11 km southwest at Breitenbush Hot Springs. In addition preliminary results from a drill hole along the east border of Crater Lake National Park will be mentioned.

The locations and preliminary thermal data for these holes are summarized in Table 1. None of the heat flow data in Table 1 are corrected for terrain effects. However, these holes are all deep enough that the terrain effects will be insignificant. The locations are shown on Figure 1. Three of the holes were drilled during 1985-86 with the co-sponsorship of the U.S. Department of Energy/Division of Geothermal and Hydrothermal Technology and industry on a cost-share program targeted toward intermediate-depth temperature gradient drilling in the Cascade Range. The primary objective of the program is to obtain data from test holes penetrating deeply enough to obtain valid temperature gradient measurements below the surficial cover of porous, young volcanic rocks. The holes drilled so far have succeeded in this objective.

NEWBERRY VOLCANO

Newberry Volcano is situated in central Oregon about 40 km east of the High Cascade Range axis and is the site of extensive Holocene volcanic activity (Macleod and Sammel, 1982) of bimodel type. It is a large shield volcano. The shield is capped by a shallow 4-5 km diameter caldera.

Temperature-depth plots from holes N-1 and N-3 are shown in Figure 2. N-1 has been summarized in some detail by Swanberg and Combs (1986). Hole N-3 (approximately 5 km north of the north rim of the caldera) shows an almost isothermal temperature-depth curve to 600 m, at which point the temperature increases abruptly to approximately to 50°C, is nearly isothermal at about 50°C to a depth of approximately 1150 m where temperatures increase rather uniformly to the bottom of the hole at 1220 m. This particular type of temperature-depth curve is generated by intra-hole fluid flow. Water is entering the hole at a depth of approximately 1150 m near the point shown by the arrow. It moves up the hole as artesian flow and exits at another aquifer at approximately 600 m. Because of this behavior it is difficult to determine the best geothermal gradient for the hole but a reasonable value lies somewhere between 53°C/km (the average gradient over the bottom 46 m of the hole) and approximately 71°C/km (the average gradient from the bottom of the hole to approximately 550 m as shown by the dashed line). The heat flow value for this hole ranges between 96 and 128 mWm^{-2}.

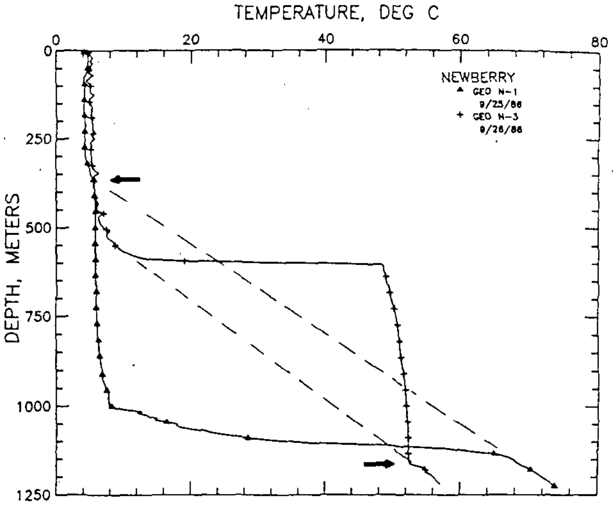

Figure 2. Temperature-depth curves for Geo-Operator Newberry holes. Every 5th point is shown.

In contrast, Hole N-1, approximately 2 km south of the south rim of the caldera, has a slightly higher temperature in the bottom of the hole, but a temperature-depth curve which may be due to intra-hole downflow. In this case, fluid might enter the hole at a depth of approximately 350-400 m (see arrows) and flow down the hole isothermaly to exit between 1000 and 1100 m. In fact, in the period of time between when the hole was completed and logged in late 1985 and when it was logged in 1986, the cold fluid had broken through into a deeper aquifer and 50 additional m of hole were isothermal as compared to the temperature-depth curve published by Swanberg and Combs (1986). The best average gradient for this hole is approximately 84°C/km and the resulting heat flow value is approximately 151 mWm^{-2}. Swanberg, (personel communication, 1987) suggests that the <u>in situ</u> curves for both holes are similar to the one measured for N-1 with very deep sections of isothermal conditions in the rock. This situation is also possible and would be comparable to the Timberline lodge hole at Mt. Hood (Steele et al., 1982, Figure 3).

Hole N-1, closer to the caldera, has a higher average geothermal gradient, heat flow, and bottom hole temperature. The average heat flow is approximately 50% higher than the regional background, suggesting the presence of a local geothermal anomaly associated with the geothermal system and/or with a magmatic heat source in the Newberry Volcano. On the other hand the heat flow in hole N-3 is equal to or only slightly higher than average regional values.

Two holes drilled within the caldera of Newberry Volcano are shown in Figure 3. The first of these holes was drilled by the U.S. Geological

Survey in 1981 (Sammel, 1981). The temperature-depth curve in this hole is rather spectacular, showing three areas of negative gradient and a bottom hole temperature of nearly 265°C. In the fall of 1983, a hole was drilled by Sandia National Laboratories to a depth of 424 m approximately 0.3 km south of the NB-2 hole. This hole encountered a non-equilibrium maximum temperature of 158°C at a depth of 350 m at the top of the same aquifer that is about 100°C in the NB-2 well (Black et al., 1984). The Sandia well is slightly closer to the caldera rim and to the 1300 Ya Big Obsidian rhyolite flow so the warm water maybe coming up somewhere south of RDO-1 and flowing northward, cooling off as it passes sequentially the RDO-1 well and the NB-2 well. The presence of very high temperatures at shallow depths and significant lateral flow of warm water within the caldera are clearly demonstrated by these results.

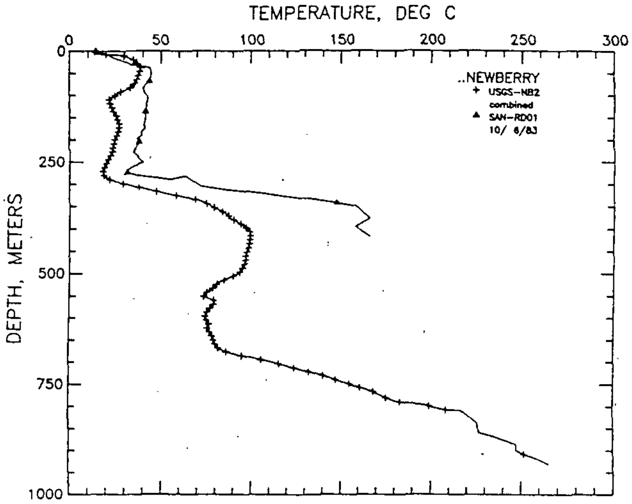

Figure 3. Temperature-depth curves for USGS-NB2 and Sandia RDO-2. Every 9th point is shown.

BREITENBUSH AREA

Based on the geochemistry of its fluids (Brook et al., 1979), Breitenbush may have the hottest geothermal fluid of any of the hot springs occuring along the boundary between the Western Cascade and the High Cascade Range. Sunedco completed a number of geophysical exploration studies in the area including the drilling of a number of shallow temperature-gradient test holes, one intermediate depth gradient test hole and one deep exploration well (Federal 58-28-1). The results from the shallow gradient test holes have been released in open file form (Blackwell et al., 1986). The deep well temperatures have been summarized recently as well (Priest, 1985). In addition, as part of the DOE/Industry program, a hole close to the axis of the High Cascade Range, approximately 11 km northeast of the Breitenbush hole, was drilled by Thermal Power in 1986. Temperature-depth curves from both of these holes are shown in Figure 4. Also shown in Figure 4 for comparison is the temperature-depth curve from the deepest hole previously available in the Cascade Range, the Old Maid Flat 7-A hole, approximately 5 km west of the Mt. Hood Volcano (Steele et al., 1982). The temperature gradient in the Thermal Power well (CTGH-1) increased systematically between 300-700 m to a value of approximately 80°C/km. The gradient is approximately constant from 700 m to the bottom of the hole at 1465 m. The gradient in the hole is higher than the average gradient along the High Cascade - Western Cascade boundary region (65°C/km, Blackwell et al., 1982; Black et al., 1983). However, in spite of the conductive-looking gradient, there were many fracture zones and evidence for secondary mineralization within this hole. Even on a small sample basis, porosity values were high, averaging over 10%. As a result, the average thermal conductivity for this hole is quite low and the calculated heat flow value is within 10% of the average heat flow for the Western Cascade - High Cascade boundary zone.

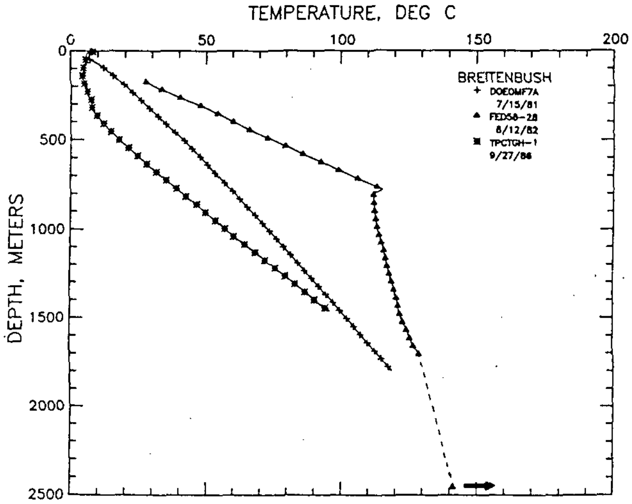

Figure 4. Temperature-depth curves for northern Oregon Cascade Range. Every 5th point is shown.

This hole appears to verify the hypothesis that the high gradients and heat flow observed to the west continue eastward to the axis of the High Cascade Range, although based on one hole such a conclusion must obviously be preliminary. The temperature gradient will probably decrease with depth as the rocks become less porous and higher in thermal conductivity. However, even so, the fact that temperatures at 3 km in the well site will exceed 200°C demonstrates that even along the crest of the Cascade Range with the strong hydrologically driven downflow of cold groundwater, temperatures of commercial interest exist within reasonable drilling depths. Such conditions in association with a geothermal system which can be produced have not yet been located, however.

In contrast to the CTGH-1 well, which is at an elevation of 1310 m, the Sunedco Federal 58-28-1 was collared at an elevation of only 823 m and drilled to a depth of 2457 m. Several months following completion of drilling, the hole was logged by SMU, although because of viscous mud in the hole, we were not able to penetrate below 1600 m. Thus the only temperature data at the bottom of the hole are a series of Kuster tool readings made 24 hours after circulation over a period of 50 min. A maximum temperature of 141°C was recorded (Al Waibel, personal communication, 1985). It is a difficult and uncertain proceedure to calculate equilibrium temperatures based on such a series of bottom hole measurements, but a plausible minimum equilibrium bottom hole temperature is well in excess of 150°C. The temperature-depth curve for this hole is quite complex, but taking a minimum equilibrium bottom hole temperature of 150°C, and a surface temperature of 10°C, the average gradient for the hole would be 56°C/km. On the other hand, the observed temperature gradient between the 250 and 800 m is 148°C/km.

The heat flow values corresponding to these two values of gradient are 106 and 222 mWm^{-2} respectively. The lower value is compatible with the average background temperature gradient and heat flow observed throughout this area of the Western Cascade/High Cascade boundary province. The higher value observed for the shallower section of the hole is compatible with results from shallow drilling (100-150 m) in the vicinity of Breitenbush Hot Springs. The interpretation for the shape of the temperature-depth curve is as follows. A geothermal aquifer filled with water at a temperature of approximately 110-120°C was cut by the drill hole at a depth of approximately 800 m. With increase in depth, the effect of this thermal aquifer decays and the regional background temperatures were approached below a depth of 2000-2500 m. The temperature difference at a particular depth between the OMF-7A and Federal 58-28-1 wells may represent the temperature effect of the 800 m aquifer. An interpretation for these types of temperature-depth curves has been described in general by Ziagos and Blackwell (1986) and by Blackwell (1985) for the Long Valley caldera.

The model that is suggested by these results for the geothermal system at Breitenbush is conceptual model 3 of Blackwell et al. (1982). In this model, water circulates downward to depths of several kilometers beneath the axis of the High Cascade Range, then returns toward the surface and flows westward along a stratigraphic or quasi-stratigraphic horizon to the site of the hot springs localized along the series of north-south trending structures marking the boundary between the High Cascade and Western Cascade provinces. On the other hand, models 2 and 3, which represent the hypothesis that thermal fluid circulation comes up from great depths beneath the site of the hot springs are not supported by the evidence from Breitenbush. These types of models may represent the situation at some of the other geothermal systems exposed along the Western Cascade/High Cascade boundary, however.

Temperatures in laterally flowing aquifers may change rapidly with distance, but without additional information on the rate of flow through the system, its size, its recharge area, etc., it is impossible to make lateral projections. Reentery of the Federal 58-28-1 well and sampling of the thermal aquifer and/or drilling to the aquifer east of the hole and closer to its presumed source area are needed to complete the evaluation of the geothermal potential of this area.

Whatever the significance of the results in terms of the local area, this hole presents documentation of high temperature gradients to depths of at least 2.5 km in the High Cascade/Western Cascade boundary zone. These results in combination with the data from intermediate depth holes such as CTGH-1 and OMF 7-A verify that the high gradients observed in the shallow holes (150 m or so) discussed by Blackwell et al. (1982) can be extrapolated to depths of at least 2-2.5 km. As was discussed earlier, geophysical data suggest such gradients can be extrapolated to depths on the order of 7-10 km.

CRATER LAKE

As part of the DOE/Industry cost-share Program, a hole was drilled by California Energy to a depth of 405 m along the east side of the Crater Lake National Park during the fall of 1986. This hole is south of the area shown in Figure 1, but its township-range location is given in Table 1. This hole is to be deepened during the summer of 1987. The results from the hole are quite encouraging in that a temperature of 107.1°C was encountered at total depth making the average gradient over the depth range of the hole at least 250°C/km with a resulting estimated heat flow of 375 mWm^{-2}. A non-equilibrium temperature-depth log for that hole is shown in Figure 5.

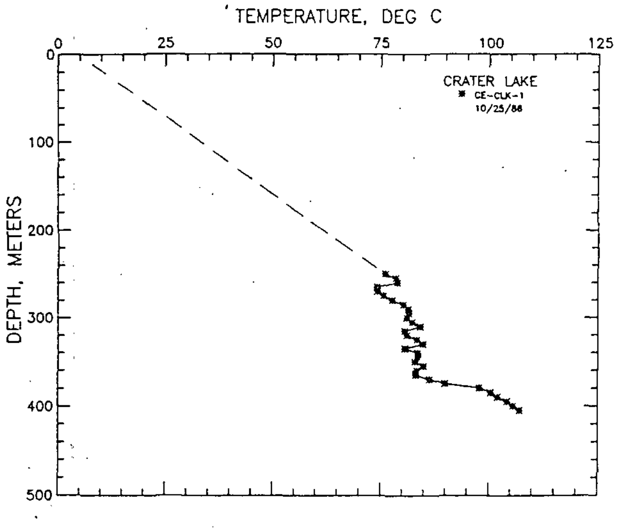

Figure 5. Temperature-depth curves for California Energy Crater Lake well.

DISCUSSION

The results from the drill holes discussed in this paper show that average temperature gradients at depth within the Cascade Range exceed 65°C/km at all locations so far investigated. The depth of the transparent or isothermal layer in holes drilled so far varies from a few meters to 500-700 m. The results demonstrate the presence of geothermal systems at several different locations within the Cascade Range and suggest that even given the limitations on access and development within the Cascade Range, exploitable geothermal systems may exist in the very large prospective area that remains to be explored. The regional significance of gradients and heat flow values measured in shallow exploration holes has been verified as well.

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Table 1. Location and thermal data for intermediate and deep holes in the Cascade Range.

Location	Hole Name	Hole Depth meters	Maximum Temperature °C	Depth Interval meters	Average Gradient °C/km	Thermal Conductivity $Wm^{-1}K^{-1}$	Heat Flow mWm^{-2}
8S/8E-28	CTGH-1	1465	96.4	500-1465	82	1.4	115
9S/7E-28NESESW	Federal 58-28-1	2457	141*	250-856	148	1.5	222
				0-2457	>56	1.9	>106
20S/12E-24NWSWNW	N-3	1220	57.1	1174-1220	53.2±11.0	1.8	96
					71	1.8	128
20S/13E-31NESWSW	RDO-1	424	158.3**		-	-	-
22s/12E-25SESENW	N-1	1226	73.9	1146-1226	83.7±4.4	1.8	151
31S/7 1/2E-10	CL-1	405	107.1	0-405	(250)	(1.5)	375

*Not equilibrium **Not equilibrium, measured at 350 m

Geothermal Resources Council, TRANSACTIONS, Vol. 11, October 1987

LEGEND OF THE CRATER LAKE HOT SPRINGS
A PRODUCT OF MODEL MANIA

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ABSTRACT

Lines of indirect evidence and, primarily, conclusions from hypothetical modeling have led some researchers to theorize that hot springs may occur on the bottom of Crater Lake, Oregon. It was the stated opinion of some National Park Service representatives that thermal vents actually exist and somehow contribute to the quality of the lake water. The Department of Interior is currently evaluating the topic. Although hot spring discharge would be deleterious to the clarity of the lake, the reported loss of clarity is more likely attributable to sewage contamination. The actual presence or absence of hot spring vents has become a serious point of consideration due to expressed concern that the hypothetical hot springs might theoretically be affected by possible geothermal development outside of the National Park. Although direct hydraulic communication between the lake and any possible commercial hydrothermal system on the flanks of Mount Mazama is highly unlikely due to the geohydrologic setting, expressed environmental concern has resulted in a temporary moratorium on the issuance of federal geothermal leases. This issue illuminates a growing problem within the geosciences; that the overextension of data through modeling procedures promotes inaccuracies and misunderstanding. This paper examines the hypothetical modeling and interpretations of Crater Lake data and addresses the validity of the resultant conclusions. Objective review of the applied modeling procedures and lines of evidence illustrates that there is no reliable evidence for the presence of thermal vents but there are impressive lines of negative evidence that argue strongly against the existence of the legendary Crater Lake Hot Springs.

INTRODUCTION

Crater Lake, Oregon partially fills the collapse caldera formed during the climactic eruption of Mount Mazama about 6,850 years ago (Bacon, 1983). The steep-sided caldera walls rise from 600 feet to almost 2,000 feet above current lake surface level which is at an elevation of 6,176 feet. Mass-wasting of the poorly vegetated caldera walls is commonplace. The lake is circular with a diameter of approximately 5 miles and an estimated volume of 4.56 trillion gallons (Phillips and Van Denburgh, 1968). Although Crater Lake is the deepest lake in the United States (maximum recorded depth 1932', mean depth 1066' [Simpson, 1970]) it is most accurately envisioned as a shallow plate of rain water held up to the sun and buffeted by strong winds. The lake water is quite pure containing about 80 ppm total dissolved solids (Phillips and Van Denburgh, 1968).

Exceptional optical clarity, facilitated by low nutrient levels is responsible for the lovely deep blue color observed from the rim (Smith, et al., 1973). The lake bottom temperatures are ubiquitously less than 4 °C (Williams and Von Herzen, 1983).

Over the last five years or so, various hypothetical models have been applied to some observed aspects of the lake. The impression, currently held by some of the National Park Service personnel, that significant thermal springs discharge on the bottom of the lake, stems from the conclusions of these hypothetical models. These hypothesized conclusions include: 1) Hydrothermal convection in the caldera floor to depths of 1.5 to 2.0 km (Williams and Von Herzen, 1983); 2) Thermal spring discharge rates of 30-150 L/sec (Sorey, 1985); 3) Thermal spring discharge temperatures of 23° - 200°C (Nathenson, PMT*, 1987); 4) Hydrothermal transport of helium and radon into the lake (Dymond, 1986); 5) Enrichment of common metallic cations on the lake floor by hydrothermal venting (Collier & Dymond, PMT, 1987).

If one is to objectively evaluate the validity of these conclusions it is necessary to first objectively evaluate the assumptions upon which the models were built. To date these models have been based on two principal assumptions: 1) That Crater Lake is analogous to an oceanic spreading center and; 2) That the chloride content of Crater Lake (about 10 ppm) is in theoretical steady state balance maintained by hypothetical thermal water discharge. Since there is no logical or factual support for either of these basic model assumptions, an objective scientist would have to view the conclusions as speculative at best. In instances where these conclusions result in what is seemingly physically impossible, they should be viewed with healthy skepticism. This paper examines the suggested lines of evidence for thermal venting and draws conclusions regarding alternative explanations. It is written to interest both scientific and non-scientific readers and is structured chronologically to illustrate how a legend grew into a problem.

*Note: PMT in a citation stands for Portland Meeting Tapes. These are transcript tapes of the February 24 & 25, 1987 GRC-sponsored Crater Lake Meeting held in Portland, Oregon.

BIRTH OF THE LEGEND

The Legend of the Crater Lake hot springs began in 1983 when David Williams, USGS Denver, and Richard Von Herzen, Woods Hole, published an article in J.G.R. claiming that "two thermal spring areas were discovered on the deep lake floor" (Williams & Von Herzen, 1983). This discovery claim was based on the modeled interpretation of two types of temperature data recordings. One data set was temperature gradients measured in the top 0.5 to 2.5 *meters of the lake floor sediments* (ibid., p. 1096). The other data set was vertical temperature profiles of the deep lake waters. The temperature gradient data showed two areas of elevated heat flow in the sediments (Fig. 1). Based on their experience with oceanic spreading centers, Williams and Von Herzen concluded that these areas of higher heat flow indicated convection of lake water within fault/fracture permeability. I have no disagreement with that *concept but it is not a unique interpretation* applicable to the data. The areas of elevated heat flow could just as easily reflect conductive heat transfer from a slower-cooling igneous rock in the lake subfloor. Also, a heat flow anomaly, be it from an underlying convection cell or from a near-surface cooling rock body, is not evidence of thermal spring discharge. High heat flow values are commonly recorded in areas where there are no hydrothermal vents.

Having theorized that convection cells produced the observed heat flow anomalies, Williams and Von Herzen turned to numerical modeling of oceanic *spreading* centers to calculate the depth of convection. The distance between the two heat flow anomalies was defined as a "wavelength" and concepts of convection within a homogeneously permeable medium were applied to conclude that the convection "cells" are equidimensional (Williams & Von Herzen, 1983, p. 1098). The modeling concepts applied came from Hartline & Lister, 1981, wherein they addressed the theoretical spacing of convection cells in uniformly permeable fault zones in oceanic *crust*. Application of this oceanic model to the Crater Lake heat flow anomalies assumes a hypothetical *through-going* NNE trending fault zone connecting the two thermal areas. The authors theorized that the southern anomaly was due to venting along a "north facing scarp" (ibid., p. 1098). The model applied does not fit the heterogeneity of a caldera floor nor the field observations of the authors nor the observations of Bacon that "No regional faults *have been recognized in the walls of* Crater Lake Caldera" (Bacon, 1963, p. 61). The conclusions of the modeling should therefore be viewed as speculation.

Williams and Von Herzen applied still more mathematical modeling to further describe the hypothesized convection cells and a theoretical horizontal hydrothermal aquifer connecting them.

> "Our heat *flow data* fit the theoretical curves best for fracture heights between 1 and 2 km and for fluids entering the

From: Williams and Von Herzen: Crater Lake Heat Flow, 1983

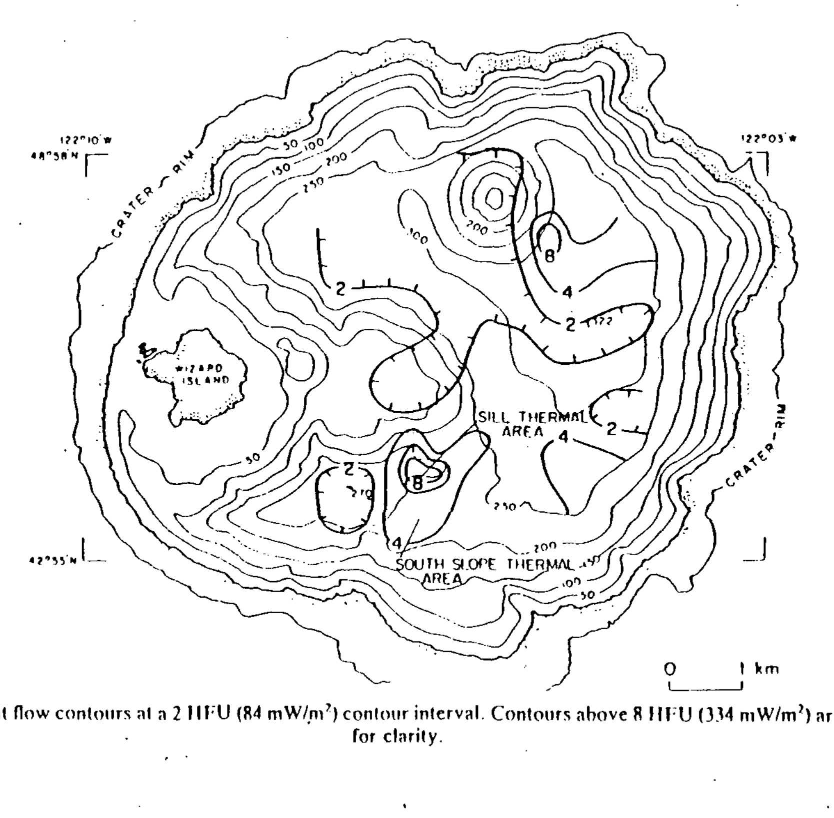


Fig. 1, Heat flow contours at a 2 HFU (84 mW/m²) contour interval. Contours above 8 HFU (334 mW/m²) are omitted for clarity.

> fissure at temperatures between 100° and 200 °C. This height would be the depth to the top of a hydrothermal aquifer. In these calculations we assumed a thermal conductivity for the sub-lake floor rocks of 1.26 W/m K (3 x 10^{-3} cal/cm s °C), a background heat flow of 125 mW/m^2 (3HFU), and a ratio of entering to exiting temperatures of 0.5.
>
> If we assume the aquifer that supplies fluids to the thermal area causes the 3- to 4-km variations in the heat flow fields, then we can roughly describe this aquifer. Its top lies at a depth of 1 to 2 km beneath the lake floor. It is 1° to 2 km thick and has a temperature between 100° and 200°C" (Williams & Von Herzen, 1983, p. 1098).

If translated literally, this modeling requires *the thermal fluid* to enter a vertical fracture at 100 ° to 200 °C, double in temperature while ascending, exit at 200° to 400°C, and then, to lie flat on the bottom of a 4 °C lake. "Dense thermal waters pond in the southwest basin" (ibid., p. 1094). Although this type of thermal modeling is obviously hypothetical, it was considered "far stronger than mere speculation" because it was "published in a definitive paper in a prestigious peer-reviewed scientific journal" (Muffler, 1986a). This statement by Muffler has been quoted by the local Park Service personnel to support the hot spring contention (Medford Mail Tribune, 1987). Even if the peer *reviewers had* recognized that the authors transposed "exiting" and "entering," the model would still require 50 ° to 100 °C to lie flat on the lake bottom. Also, if the "thermal fluid" is more dense than the lake water, why would it be ascending in the first place?

The concept that thermal spring discharge is actually occurring came largely from the interpretation of deep water temperature profile data (Williams and Von Herzen, 1983, p. 1098). These data showed one area where bottom water temperatures increased slightly (about 0.1 °C) with depth approaching the lake floor (bottom 285 meters) (ibid., p. 1100). These data were plotted on a greatly exaggerated vertical scale as shown in Fig. 2. This data plot was described as "convincing *evidence* that dense thermal waters are ponding in the southwest basin" (ibid., p. 1101).

Williams and Von Herzen described the deep water temperature profiles as a "thermal plume" despite the fact that the anomaly lies flat on the bottom of *a less than 4 °C lake.* One might consider that whatever was making the hypothetical thermal water "dense" would soon plug the hypothetical vent. The authors provided the following complicated explanation of how this phenomenon was supposed to work:

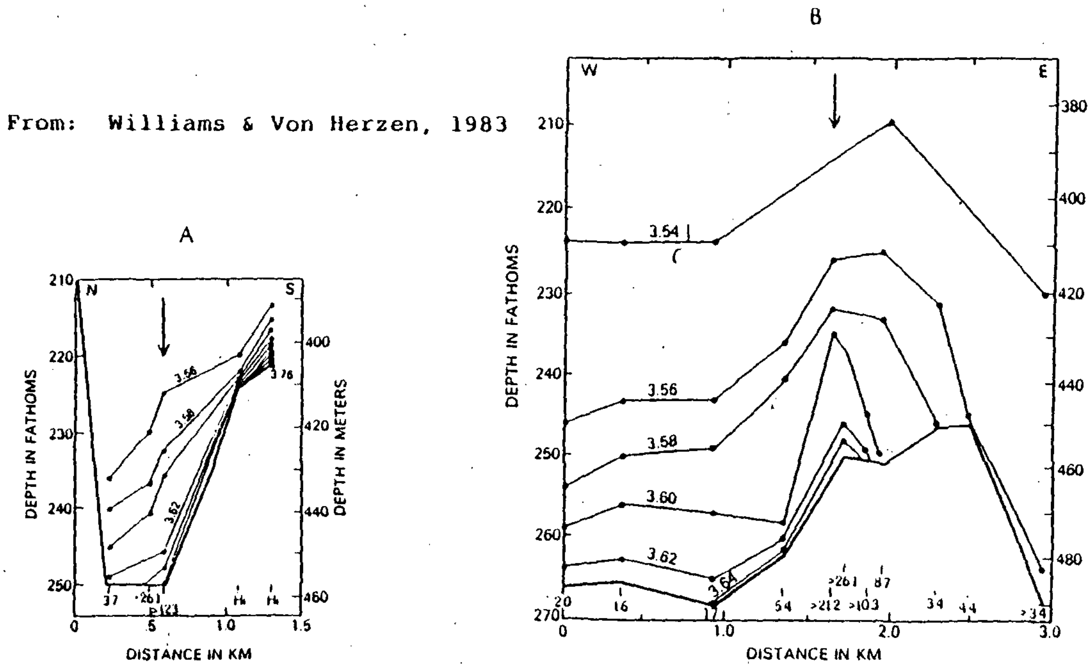

From: Williams & Von Herzen, 1983

Fig. 2. Cross sections of isotherms in the deep water of the lake. Locations are indicated in Figure 2. The vertical arrows indicate where the two profiles cross. Dots are actual data points. The *numbers on the isotherms* are the temperature in degrees Celsius. The lower heavy dark lines are generalized bathymetric profiles. The numbers below the line are the conductive heat flow values measured along the profiles. (*a*) A north-south profile through the water above south slope thermal area and the sill-thermal area. (*b*) A nearly east-west profile through the water above sill-thermal area. Not all the data are shown above the thermal areas. The data in the region were complicated with common small (0.01°C) temperature reversals. We were not able to unravel the data in detail because the station spacing was less than the accuracy of our positioning and there may have been temporal variation in temperatures during the 10-day period in which the data were gathered.

> "The thermal fluids that discharge from the springs behave in a complex manner. Some of the fluid rises in a plume and rapidly mixes the deep lake waters. The rest of the fluid is dense and flows down slope where some of it mixes turbulently with the overlying lake water and the rest ponds on the lake floor where the mixing process is considerably slower. The Red Sea brines area is a good example of this process at its extreme" (ibid., p. 1102).

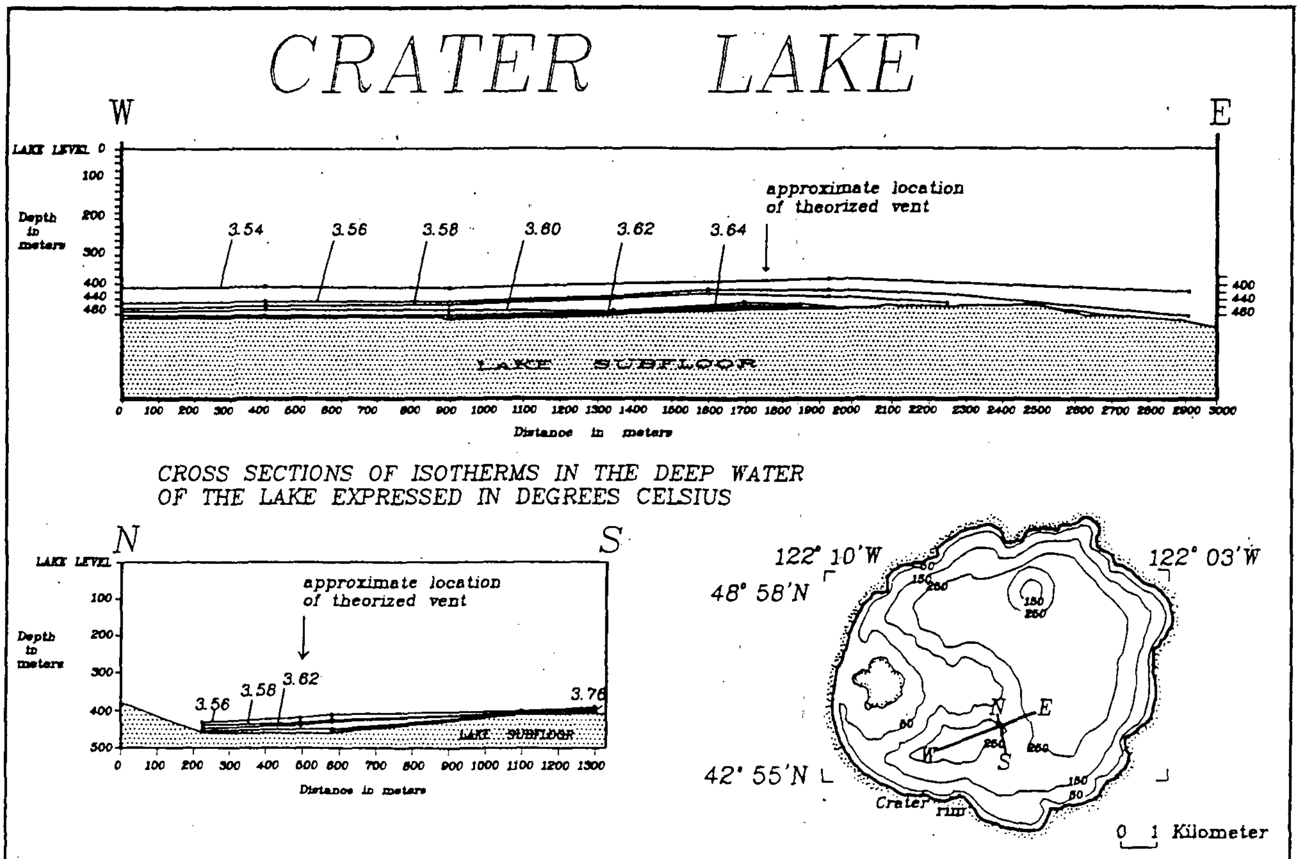
A replotting of the deep water temperature profile data on a non-exaggerated scale affords a realistic perspective (Fig. 3). These plots illustrate a fairly uniformly layered vertical section of isotherms that quasi-uniformly increase in temperature approaching the lake bottom. The reader is encouraged to compare these undistorted plots with the hypothesized "plume" description quoted above. Note that the authors' complicated interpretation demands the following: 1) That the hypothetical thermal fluid moves laterally away from the suspected source a distance of 1.7 km without any temperature loss (seemingly a physical impossibility); 2) That the thermal fluid remains uniformly thermally stratified over that distance with the warmest layer on bottom and; 3) That the thermal fluid flow runs uphill in one direction and downhill in the other while still lying flat on the bottom of the lake.

A much simpler and perhaps more logical interpretation of the deep water thermal anomaly is that it is produced by conductive heat transfer. Interpretation as a conductively heated layer would explain why it is warmest on bottom and displays lateral uniformity. In light of this simpler and seemingly more plausible alternative explanation, the deep water temperature profiles are not reliable evidence for thermal fluid venting.

THE LEGEND GROWS

One of the inherent pitfalls of model mania is that subsequent authors often build upon previous author's conclusions without adequate scrutiny of the original hypothesis. Once the Williams and Von Herzen hypothesis of thermal venting was published, other researchers soon began attributing all of the chemical idiosyncrasies of Crater Lake solely to currently active hot springs. Other plausible hypotheses were excluded in the rush to contribute to the new "discovery" despite the subjectivity of the interpretation of the less than 0.1 ° C observed temperature variation.

At the 1985 annual meeting of the AGU, three USGS scientists presented a poster with abstract



Modified from Williams,D. and Von Herzon,R.,1983 On the Terrestrial Heat Flow and Physical Limnology of Crater Lake, Oregon. J.G.R.,vol.88, no.B2,p.1094-1104 fig.7A

Fig. 3

entitled "Evidence for Thermal Water in Crater Lake, Oregon" (White, et al., 1985). The concentrations of Na, Cl, SO_4, Li and B in Crater Lake were decreed to be anomalously high in comparison to the cold springs on the flanks of Mount Mazama (ibid.). This is akin to comparison of an apple to an orange and declaration that the pips are anomalous. Snow melt coursing down through fractures and lava flow boundaries to rapidly exit as springs on the flanks, would have little in common (aside from meteoric origin) with ponded lake water subject to an entirely different geochemical environment. White et al., (1985) hypothesized that thermal water discharges into Crater Lake because "Crater Lake water contains significant quantities of many chemical species (e.g. Cl, SO_4, Li and B) commonly found in hot spring waters associated with volcanoes . . ." The actual concentrations of these chemical species in Crater Lake were given as: Cl 9.6 mg/L, SO_4 9 mg/L, Li 0.04 mg/L, and B 0.3 mg/L (ibid.). To describe these low level concentrations as "significant" appears to be a fairly subjective call. Had these authors not been predisposed to augment the Hot Springs theory, they might have considered that these chemical species are commonly observed in cold mineral springs and are also liberated by the alteration of silicic ash. Some portion of these chemical species could also have been derived from fumarolic deposits on the original caldera floor. These authors stated that "Phillips and Van Denburgh, 1968, suggested that Cl and SO_4 found in Crater Lake water originated from thermal water" (White, et al., 1985). The abstract of the Phillips and Van Denburgh paper reads as follows: "Much of the dissolved-solids content of Crater Lake-especially the sulfate and chloride-may be related to fumarole and thermal-spring activity that presumably followed the collapse of Mount Mazama" (Phillips and Van Denburgh, 1968, p. 1). White, et al. (1985), also mentioned that these chemical species where "anomalously high" in comparison to nearby Diamond Lake. Again, I find this an inappropriate comparison because Diamond Lake was never a caldera floor. Diamond Lake does not have the potential for noncondensible gas influx that Crater Lake has, nor the constant influx of silicic ash that Crater Lake has. Diamond Lake may also have a significantly lower evaporation rate because it is 1000 feet lower in elevation and situated in a sheltered, N-S trending depression which affords less sun exposure.

Since invalid background comparisons were used by White, et al., 1985, to subjectively declare the small concentrations of Na, Cl, SO_4, Li, and B to be "anomalously high", and since these constituents have other plausible sources, it is only an assumption that they indicate hot spring activity.

The main objection I have to the contention that these chemical data "support the hypothesis that thermal water discharges into Crater Lake" (White, et al., 1985) is that the present lake chemistry is not necessarily reflective of current processes. It is possible that some of these chemicals could have come from thermal water input at some time in the past, but that bears no evidence for the present. Hot springs have quite limited life expectancies, especially where they discharge into very cold, deep bodies of water. Even the large sea floor hydrothermal vents are estimated to have lifetimes on the order of tens of years (Macdonald, 1982, p. 175).

To circumvent this time problem consideration, the chemical modelers had to evoke the concept of a "chemical steady state lake" (Muffler, 1986a; Nathenson, PMT, 1987). Given the very brief pinch of time that the lake chemistry has actually been observed, this concept would have to be objectively viewed as a modeling convenience as opposed to logical assumption. Although the steady state lake concept was defended as being a "simpler and therefore better" perspective (Nathenson, PMT, 1987), it should be clarified that it only makes life simpler for the modelers but not Mother Nature. Undeniably, the lake has been progressively freshening with time. Initial inundations of caldera floors typically display total dissolved solids concentrations in the tens of thousands ppm, mainly from the dissolution of fumarolic deposits and influx of noncondensible gasses (Thompson, 1987). The "steady state lake" concept requires Mother Nature to obligingly halt this ongoing freshening process. This concept also burdens nature with the difficult task of carefully balancing the annual leakage loss of dissolved solids with an identical influx of identical chemical species. It is purely an assumption that this balance is actually taking place and only a guess that the assumed balance is provided by thermal water discharge.

The Legend gained in psuedo-credibiliity when Michael Sorey, USGS, Menlo Park, announced at a Cascades workshop in May 1985, that he had calculated flow rates of 30-150 L/sec for the "thermal-spring discharge" at Crater Lake (in Guffanti and Muffler, 1985). Although the bases for this calculation were not mentioned in the publication cited, they were essentially three: 1) That the chloride content of Crater Lake is in steady state; 2) That all the chloride lost through leakage is replaced solely by thermal water inflow, and; 3) That the hypothesized thermal springs, situated in the throat of a degassing 6,845 year old caldera, would have chloride concentrations similar to hot springs discharging from fault zones in the 5 to 40 million year old volcanic rocks of the Western Cascades (Muffler, 1986a). (Note: These assumptions were Sorey's not Muffler's, Muffler only provided them to me).

Based on these three assumptions, Sorey calculated the flow rates required to maintain the assumed balance. I doubt that Michael Sorey ever intended that his number pushing should be used as evidence for the Legend, but that is essentially what the Park Service has done. In the National Park Service (NPS) listing of "significant thermal features" published in the February 13, 1987 Federal Register, Sorey's entirely hypothetical mathematical ruminations were cited as Significant Criteria as follows:

> "Extent-Hydrothermal vents are located on the south central floor of the basin of Crater Lake at approximately 1500 feet depth. 30-150 liters per second inflow of thermal water is estimated to enter Crater Lake" (NPS, 1987).

This instance illustrates the most serious pitfall of model mania; the basic assumptions are seldom carried with the conclusions. The assumption that currently active hot springs provide all the chloride in the lake, was modeled to determine flow rates, that were then used as evidence for the basic assumption. This is circular reasoning.

OTHER POSSIBLE SOURCES OF CHLORIDE

It is possible that chloride has been concentrated in Crater Lake by evaporation. The estimate of evaporation loss by Ken Phillips (Phillips & Van Denburgh, 1968) was derived by subtracting the estimated seepage rate from the estimated recharge rate. The estimated seepage rate was made by observing the drop in lake level during a period when evaporation was assumed to be negligible (ibid.). This determination by subtraction resulted in an anomalously low evaporation rate attributed to Crater Lake. "The computed loss of 23 inches per year. . . is 10 inches less than the average annual lake evaporation in the area, not adjusted for altitude." (Phillips and Van Denburgh, 1968, p. E20). An estimate of 34 inches per year of evaporation loss for Crater Lake was obtained from regional evaporation maps (Simpson, 1970, p. 5196). This could also be viewed as a probable underestimate due to the unique caldera wind conditions and elevation of the lake. Since the average annual precipitation estimates are between 67 inches (Simpson, 1970) and 69 inches (Phillips and Van Denburgh, 1968) it is quite possible that the true evaporation loss of Crater Lake may actually exceed 50% of its annual recharge. Thus, it is quite possible that chloride is actually being concentrated by evaporation. This would be even more probable at times in the past when the lake was subjected to periods of warmer, drier climatic conditions (see Phillips and Van Denburgh, 1968, p. E9). Hydrogen isotope data suggests that "the lake water has been evaporated" (Salinas et al., 1984).

Another possible source of chloride could be salts that were originally deposited on the caldera floor by fumarolic and thermal spring activity following the collapse of Mount Mazama (Phillips & Van Denburgh, 1968, p. 1).

A significant input of chloride could come from the continual input of altered caldera wall rock into the lake (see Nelson, 1967, p. 843). Hydrothermal alteration of the older rocks exposed in the caldera walls and fumarolic alteration of the holocene tuffs and air-fall deposits are described by Bacon, 1983. These altered lithologies are repeatedly sloughed into the lake through mass-wasting processes and would undoubtedly contribute to the chloride content of the lake.

The hydrochemical breakdown of the Mazama ash and other volcanic particulate matter is another undeniable source of chloride input to the lake. The Mazama ash runs about 1,000 ppm Cl (Bruggman et al., 1987). "Nelson (1961, p. 30) concluded that deposits of colloidal clay derived from volcanic ash, reworked in places by submarine landsliding, have helped to seal the bed of the lake" (Phillips & Van Denburgh, 1968). Obviously Crater Lake is receiving chloride input every time the wind blows ash into the lake. "Wind transports materials such as pollen and pumice dust to the lake surface and moves these over the surface as a scum" (Nelson, 1961, p. 844). Montmorillonite, a clay mineral commonly formed from the alteration of volcanic ash (Berry and Mason, 1959, p. 509), is common in the clay-size fraction of Crater Lake sediments (Nelson, 1967, p. 839).

Cold mineral springs similar to those found throughout the Cascades could also be supplying chloride to the lake. A wide range of chloride concentrations is observed in these ambient temperature springs but Cl concentrations as high as 22,000 ppm have been recorded (Barnes, 1984).

Noncondensible gas influx could add chloride to Crater Lake, particularly since it resides in the throat of a volcanic vent. The significance of volcanic emanation of HCl gas has long been recognized (Zies, 1929). Stoiber and Williams (1984) reported 830 tons per day of HCl gas emanating from a non-erupting volcanic crater in Nicaragua. Any post-lake-filling gas eruptions and/or continuing seepage could have added to the chloride content of Crater Lake.

Another definite source of chloride input to Crater Lake is the leakage from the sewage facilities at Rim Village (Briggle, 1987). Since a tracer study has never been run on this leakage, no estimates of input volume are available; however, over a half million people visit Rim Village annually and urine is quite high in chloride.

Chemical Homogeneity of Lake Water

Although Sorey's flow rate calculations constitute only an assumption because they assume that thermal vents facilitate an assumed and unrealistic steady state lake, they can be used to assess another contended line of evidence put fourth to support the Hot Springs Legend. Vertical profiles of lake water chemical composition show a fairly uniform composition with depth throughout the lake (Williams and Von Herzen, 1983). This uniform chemical composition was attributed to physical mixing (as opposed to chemical diffusion) and the hypothesized thermal spring discharge was assigned the task of convecting and thoroughly mixing the lake (ibid.). Thus the chemical homogeneity of the lake has been attributed to convection and labeled as evidence for thermal water discharge (White, et al., 1985).

Since Sorey's flow rate calculations ignore all other sources of chloride, they can be viewed as an absolute maximum volume that the hypothetical springs might be putting out. By converting Sorey's rates of 30-150 L/sec to an annual inflow volume, one finds that a whole year's supply of this hypothetical fluid would amount to 0.0055 to 0.027 percent of the total lake volume (LaFleur, 1987). Compared to the total volume of the lake, the midpoint of the 30-150 L/sec is equivalent to putting 1.5 drops per day of thermal water into a 44 gallon bath tub of ice water (ibid.). These calculations suggest that even the hypothetical maximum thermal water discharge could not have a significant physical effect on the lake. The deep water profiles taken in the Southwest basin did indicate that local convections of the deep waters can occur (William and Von Herzen, 1983, p. 1100) but, this would have to be primarily, if not wholly, through conductive heat transfer. The two areas of elevated heat flow identified by Williams and Von Herzen (Fig. 1) would warm local bottom waters to the point where they would eventually diapirically convect upward in a manner similar to the old lava lamps that continue to transfix patrons of obscure bars throughout the west. Because of warmer surface water temperatures (Fig. 4) these local upward convections could only reach mid-depth range (ibid., p. 1102). Since these two areas of elevated heat flow are relatively small compared to the lake, it is questionable how instrumental they are in mixing the whole lake. The drop in the bathtub calculation indicates that it is highly unlikely that lake mixing results from thermal water discharge.

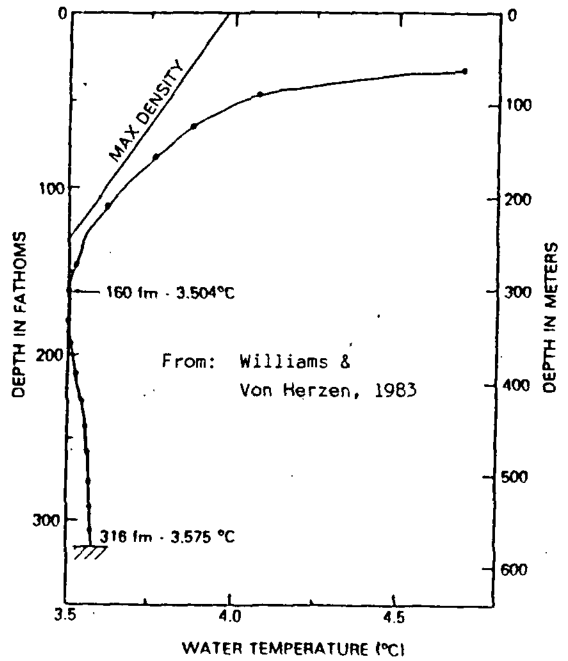


Fig. 4. Vertical water temperature profile from the east basin near Merriam Cone. The line labeled 'Max Density' is the curve of the maximum density from *Eklund* (1963).

FURTHER PERPETRATION OF THE LEGEND

More recent declarations of hot spring "evidence" have been put forth by members of the National Park Service Cooperative Park Studies Unit at Oregon State University. "The presence of hydrothermal inputs to the deep lake was conclusively documented based on the discovery of a helium isotope anomaly." (NPS-CPSU, 1986, p. 31). "These data show helium isotopic anomalies more than 200% greater than the atmospheric value . . . As such it is conclusive evidence of current hot spring input into the lake" (Dymond, 1986). When I mentioned this claim that helium isotope anomalies supposedly provide "conclusive evidence" to Patrick Muffler, erstwhile Branch Chief of Igneous and Geothermal Processes, USGS, Menlo Park, he immediately retorted; "That's bullshit, and you can quote me on that" (Muffler, 1986b). Albeit a bit blunt, one must appreciate the unbiased accuracy of Muffler's response. The isotopes of helium (^{3}He and ^{4}He) are extremely mobile noncondensible gasses that certainly do not require aqueous solution for vertical transport.

Professor Dymond also reported "We did measure ^{222}Ra anomalies that were 3-10 times background. Although not conclusive this is strong evidence of hot spring activity" (Dymond, 1986). Dr. Dymond actually meant ^{222}Rn (Radon). "A total of 24 radon samples were taken" (ibid.). Although not as mobile as helium, radon is a mobile noncondensible gas that most certainly does not require hydrothermal convection for transport. Radon detection "cups" are commonly used in soil gas sampling and in monitoring of radon seepage into homes and buildings. I suppose those unfortunate homeowners who have high radon determinations should look upon it as "strong evidence" of hot springs lurking in the carpets.

THE PORTLAND MEETING - THE LEGEND EXAMINED

Due to the legislative turmoil arising from the hot springs theory, a two day meeting was convened in Portland, Oregon to discuss whether the hypothesized Crater Lake thermal vents actually constitute a "significant thermal feature" that would be jeopardized by geothermal development. The meeting was sponsored by the Pacific Northwest Regional Section of the Geothermal Resources Council and was facilitated by cooperation of the BLM, USGS, and the National Park Service. The intent of this meeting was to examine existing data and evaluate current hypothetical models. Scrutiny of the modeling was seemingly a bit overwhelmed by lengthy presentation of data.

Charlie Bacon, USGS, Menlo Park, gave a run-down on the caldera geology. Hans Nelson also USGS, Menlo Park, gave us a look at sedimentary processes affecting the lake floor, emphasizing turbidites from mass-wasting of the caldera walls. I presented some discourse on the absence of data or logic to support the chemical steady state lake concept. I presented the volume calculations (discussed above) that demonstrate the minimal physical effects the hypothetical hot spring flow rates would have. I also presented the undistorted deep water temperature profiles (Fig. 3) and suggested that they were actually produced by conductive heat transfer. I pointed out that the elevated temperature gradients measured by Williams & Von Herzen (1983) did not really indicate actual thermal water discharge because areas of ascending fluids would have isothermal profiles as opposed to the steep gradients recorded. At the end of my spiel I called for any dissent or disagreement with my contentions but received none (LaFleur, PMT, 1987).

David Williams, USGS, Denver, provided some highly pertinent clarification of the "thermal vent" issue. Williams pointed out that to a geophysicist like himself, any temperature above ambient was a thermal anomaly. Williams explained that the "thermal venting" he and Von Herzen had actually identified was on the order of 0.1 °C above ambient and resulted from slow moving local convection of lake water; a phenomena that could not be affected by activities outside of the lake. (Williams, PMT, 1987)

The clarifications provided by Williams were somewhat offset by Manuel Nathenson, USGS, Menlo Park, who presented yet another model based on the assumption that an undocumented chloride balance in Crater Lake results solely from currently active hot springs and concluding that these hot spring vents would have temperatures from "23° to over 200°C" (Nathenson, PMT, 1987). In support of the basic assumption, Nathenson contended that "chloride cannot be leached from rock at low temperatures" (ibid.). One familiar with geochemical processes would realize that diagenetic alteration of the Mazama ash is undoubtedly taking place on the lake floor at less than 4 °C and chloride would be liberated in this process. Mazama ash runs about 1,000 ppm chloride (Bruggman et al., 1987). Thus, a significant addition of chloride is observable everytime the wind blows ash into the lake. To ignore the observable and place full credit on the hypothetical is hardly scientific. Nathenson received a round of applause for his modeling efforts, but I was unable to join in for want of one hand which was scratching my head in befuddlement wondering how "23° to over 200°C" was supposed to lie flat on the bottom of a 4°C lake.

An exhorbitant amount of time was spent on discussion of chloride values but it led to a consensus that, due to the error bars of analysis, no one could actually tell whether the chloride content of the lake was varying with time or not (PMT, 1987).

Nathenson also presented the data and conclusions from a 1983 AGU Poster by Michael Thompson and Douglas White, USGS, Menlo Park, entitled "Does Crater Lake Have a Discernible Outlet?" About 10 springs on the flanks of Mazama were analyzed for chloride, deuterium and oxygen 18. From my field work in the area, I would estimate there must be at least 500 springs on the flanks of Mazama, most of which are unmapped. Therefore it is about 2% correct to imply that the outlets of Crater Lake have been prudently sought. Quite apparently the USGS needs to proportion a higher percentage of its budget to field data acquisition.

Dave Blackwell, a heat flow authority from Southern Methodist University, presented a talk on data from Yellowstone Lake. Blackwell's talk illuminated the extreme differences between the very high heat flow values and elevated temperatures recorded in Yellowstone Lake contrasted to the tiny temperature variations recorded in Crater Lake.

Ivan Barnes, USGS, Portland, presented a talk largely focussed on the pneumatolytic transport of chloride as HCl gas. Barnes presented data and photographic evidence of this process, demonstrating that emanation of HCl gas is common to degassing volcanoes. This suggests that non-condensible gas influx could have provided chloride to the lake. Dr. Barnes also pointed out that any high temperature, high pressure discharge (as suggested by Nathenson's modeling) would be accompanied by discharge of CO_2 and a bicarbonate bloom in the lake water would be apparent. No such bloom has been reported.

On the second day of the Portland meeting, Dr. Douglas Larson, U.S. Army Corps of Engineers, Portland, presented data indicating a 25% loss of clarity in the lake and attributed this diminished clarity to the proliferation of a phytoplankton, probably facilitated by influx of nitrate nitrogen via sewage leakage from Rim Village. The National Park Service representatives in attendance were unable or unwilling to answer the question of why the repeatedly recommended sewage tracer study had not yet been initiated (PMT, 1987)

Bob Collier and Jack Dymond, two Oregon State oceanographers contracted by the Park Service to study the lake, presented chemical data and further comparison of Crater Lake to an oceanic spreading center. They contended that because ^{3}He and ^{222}Rn anomalies are found at sea floor hydrothermal vents, they evidence hot springs in Crater Lake. They also listed some common metallic cations observed in a few sediment cores and in the bottom lake water as hot spring evidence because they occur in anomalous concentrations at oceanic spreading centers. These cations included Al, Ba, Mn, V, P, Zn, and Fe. These cations and particularly iron were referred to as "hot spring tracers" (Collier and Dymond, PMT, 1987). Dr. Ivan Barnes objected to the reference to these cations as hydrothermal tracers because their mobilities are Eh/pH controlled as opposed to temperature controlled (Barnes, PMT, 1987). I would also add that these cations are not commonly employed in terrestrial geothermal exploration because they occur in a wide spectrum of geologic environments. Iron for instance, Dymond's most emphasized "tracer," is concentrated at ambient temperatures in such things as liesegang banding, red beds, hematitic ironstone, glauconitic sediments, and ordinary mineralized ground waters. Anyone who has observed iron stain build-up in their toilet bowl would question its validity as a "geothermal tracer". All of the elements cited by Dymond and Collier would be liberated by the diagenetic alteration of the Mazama ash and other volcanic particulates continually supplied to the lake (see Bruggman, et al., 1987).

Near the end of the meeting, there was some pertinent discussion on the geohydrologic setting. Ed Sammel, formerly USGS, Menlo Park, gave a short discourse that essentially identified Crater Lake as a perched water table in an area of regional recharge. There was some general discourse on the consideration that any thermal vents on the lake floor could not be in open communication with the regional water table (approximate elevation 4600 feet) because they would be repressed by the hydraulic head of the lake (elevation 6176 feet). For this reason, only local cells of convecting lake water, as theorized by Dave Williams, were considered realistically plausible. Therefore, there was a consensus that geothermal development on the flanks of Mazama outside of the park could not affect any thermal features on the lake floor (PMT, 1987).

A news release from the Associated Press on the meeting began, "Portland - Nearly 100 scientists agreed Wednesday that geothermal drilling near Crater Lake National Park would not harm the lake, but many believe evidence exists that America's deepest lake contains geothermal landmarks that should be protected" (Associated Press, 1987). Although seemingly paradoxical, this quote is accurate; however, without a score card the reporter was unable to distinguish the scientifically motivated from the politically motivated. The real paradox is that if there were actual hot spring vents in the lake, they most certainly would be deleterious to the clarity of the lake. When this assertion was emphatically made at the close of the Portland meeting and any dissent was called for, there was no disagreement, from anyone in attendance (PMT, 1987).

THE LEGEND LIVES ON

Despite the fact that the "measured temperature anomalies near the bottom of Crater Lake are approximately 0.05° - 0.1°C" (Muffler, 1987), and despite the fact that these anomalies could not be relocated the next year (Williams, PMT, 1987), the Park Service continues to promote the Hot Springs Legend and clamor for unnecessary legislative protection. I say unnecessary because the local convection cells as originally theorized by the Williams and Von Herzen (1983) were descending and reascending lake water in a closed system. Therefore, even if these cells exist, they cannot be affected by activity outside of the park, and that was the consensus of the Portland meeting (PMT, 1987). Furthermore, all the features within the National Parks are already protected by a number of existing laws. Incredibly, the legend surrounding an unthreatened, already-protected 0.1°C anomaly, is unjustifiably impacting possible utilization of a preferred alternative energy resource on multiple use National Forest ground 7 miles away. This irrational result of hyperextended conceptual modeling has become an issue of significant importance to those local citizenry who would like to experience the employment and tax revenue benefits of geothermal development. It is is also important to you and I the taxpayer and to anyone concerned with the clarity of the lake. The Park Service has recently announced that the search for the Crater Lake hot springs is their Northwest Regional Office's No. 1 funding priority (Associated Press, 1987b). They plan to spend $400,000 to put a submarine in the lake to hunt the elusive prey (ibid.). I'm not particularly against extravagant research spending but I do think the Park Service has questionable spending priorities. "A 25 percent decrease in the optical clarity of Crater Lake water occurred between 1968 and 1978" (Salinas, et al., 1984). More recent data indicates continuing degradation (Larson, et al., 1985). Park Service septic facilities at Rim Village are leaking sewage into the lake (Briggle, 1987). Several highly qualified researchers have concluded that the loss of lake water clarity is quite possibly caused by an increase in phytoplankton due to increased nutrients supplied by the sewage leakage (Hoffman, 1984; Larson et al., 1985). The Park Service was made aware of this possible cause-and-effect relationship nine years ago (Larson, 1978) yet the flow of sewage continues (Briggle, 1987). Public Law 97-250, September 1982, directs the Secretary of the Interior ". . . to immediately implement such actions as may be necessary to assure the retention of the lake's natural pristine water quality." For the $400,000 cost estimate of hunting hypothetical hot springs, the Park Service could pipe the sewage off the backside of the hill to a lower elevation so it couldn't leak into the lake. The Park Service and their OSU oceanographers have been comparing Crater Lake to a "primitive ocean" (NPS, Federal Register, 1987). "The similarity to ocean conditions has prompted park officials to liken Crater Lake to a miniature laboratory where scientists can compare conditions found in the world's oceans" (Medford Mail Tribune, April 19, 1987). There is little scientific validity to these contentions. Crater Lake undoubtedly initially had much higher salinity due to fumarolic activity at the time of caldera collapse and the lake has been freshening with time. The lake is now fresher than any primitive ocean could have been. The oceans have become saltier with time through evaporation and are now about 35,000 ppm total dissolved solids compared to the 80 ppm TDS of Crater Lake. Crater Lake is between 4,244' and 6,176' above sea level whereas oceans are notably below sea level. The only apparent similarity between Crater Lake and an ocean is that both contain water and oceanographers. Spending tax dollars to make curious oceanographic comparisons while the lake continues to receive sewage is totally contrary to the mandates of Congress.

Although I would enjoy seeing photographs of the lake bottom myself, I would rather see the optical clarity and beautiful blue color of the lake maintained. Before $400,000 is spent in pursuit of the Legend, it may be financially prudent to review the validity of the purported "lines of evidence."

EVALUATION OF "EVIDENCE"

Objectively, data cannot be viewed as valid evidence unless it is at least quasi-unique to the interpretation. If other interpretations are equally plausible, the data or observations cannot be considered as valid evidence.

Temperature gradients in the sediments: The steepened temperature gradients recorded illustrate conductive heat transfer as opposed to thermal fluid ascention. Areas where thermal fluids actually ascend demonstrate elevated, isothermal temperature gradient profiles. No elevated, isothermal profiles were reported (Williams and Von Herzen, 1983). Therefore, the heat flow anomalies provide no evidence for hot springs.

Deep water temperature profiles: The configuration and distribution of the deep water isotherms are more reasonably interpreted as local conductive heating of the bottom water as opposed to an actual hydrothermal vent "plume". Therefore, these profiles provide no reliable evidence of hot springs.

Helium and radon anomalies: Since these mobile noncondensible gasses emanate freely from the earth's crust without the assistance of aqueous transport, they provide no reliable evidence.

Chemical homogeneity of the lake: The maximum hypothetical thermal fluid discharge (annual flow rate of .0055 to .027 percent of the lake volume) would have negligible physical effect on the whole lake. Deep water convection is more logically attributable to conductive heat transfer. Therefore the observed chemical homogeneity of the lake provides no evidence of hot springs.

The 10 ppm chloride concentration of the lake: There are other potential and undeniable sources of chloride. It was only an assumption that the lake's chloride content is in a steady state balance and only an assumption that this balance is maintained solely by currently active hot springs. Therefore, the chloride content of the lake provides no reliable evidence for current hot spring activity.

The slightly elevated concentrations of common metallic cations on the lake floor: Since the mobility of these ions are Eh/pH controlled rather than temperature controlled, and since they very commonly occur in much higher concentrations in many mineralized non-thermal groundwaters and would also be liberated by diagenetic alteration of lake floor sediments, they provide no reliable evidence for hot springs.

The concentrations of Na, Cl, SO_4, and B in Crater Lake: The low levels of concentration of these chemical species cannot be decreed anomalous in comparison to local surface waters because that is an invalid background for comparison. Also, they could certainly come from sources other than hot springs (e.g. weathering of the ash, old fumarole deposits, cold mineral springs, etc.); therefore, they provide no reliable evidence for hot springs.

LINES OF NEGATIVE EVIDENCE

Objective researchers evaluate and give equal weight to lines of negative evidence. So far the Crater Lake hot springs modelers have ignored this consideration.

They haven't been found: Perhaps the strongest line of negative evidence against the existence of hot springs is that they have not been found. "The fact remains that no one has ever observed, identified, or sampled a thermal spring on the floor of Crater Lake" (Muffler, 1987). In looking for "hot" springs the most definitive evidence is heat. Bear in mind that Williams and Von Herzen placed their highly sensitive heat probe all around the lake floor and yet failed to report any significantly elevated temperatures in the sediments and only a less than 0.1°C above ambient in the bottom water layer (Williams and Von Herzen, 1983). This 0.1°C anomaly could not be relocated the next summer following its discovery (Williams, PMT, 1987).

A photographic survey of the "thermal area" was conducted but failed to locate any vents (ibid., p. 1098). If these techniques have successfully located hot spring vents in the vastness of the Pacific Ocean, why have they been unable to locate vents within the much more limited confines of Crater Lake? This consideration can objectively be viewed as circumstantial negative evidence.

Flat deep-water temperature profiles: If "hot springs" with temperatures of 23° to 200°C (as suggested by Nathenson, PMT, 1987) were actually entering the cold, still depths of Crater Lake, the "thermal plume" would stick up like a sore thumb instead of lying flat on the bottom of the 4°C lake (Fig. 3). Bear in mind that the depths of Crater Lake do not have strong oceanic-type bottom currents to facilitate rapid mixing. The absence of any significant vertical pluming is strong negative evidence against actual "hot spring" discharge.

Absence of anomalous CO_2/HCO_3: Hydrothermal systems of any significant magnitude ubiquitously exhibit large volumes of CO_2 (the reader is challenged to identify one that doesn't). Any "hot spring" discharge into the lake floor would have accompanying discharge of CO_2 and or HCO_3, and a bicarbonate bloom would be apparent (Barnes, PMT, 1987). Crater Lake water could be described as conspicuously low in HCO_3 with a concentration of only 34 ppm (Phillips and Van Denburgh, 1968). This is identical to the bicarbonate concentration of non-thermal Davis Lake, Oregon, but only a fraction of the bicarbonate concentration of Paulina Lake, Oregon (352 ppm HCO_3) and East Lake, Oregon (125 ppm HCO_3) (ibid.), both of which have near-shore hot springs. This absence of elevated bicarbonate in Crater Lake must be objectively viewed as very strong negative evidence against the existence of "hot springs."

Absence of anomalous dissolved silica: Another chemical constituent inherent to hot springs is dissolved silica. Crater Lake water runs between 10 and 18 ppm silica (Salinas, et al., 1984). Non-thermal Davis Lake has 19 ppm silica, whereas Paulina Lake has 46 ppm silica. (Phillips and Van Denburgh, 1968). I consider the absence of elevated silica in Crater Lake circumstantial negative evidence against the presence of hot springs.

No reports of secondary silica or carbonates in the sediments: The silica in any hot springs entering the cold lake floor waters would tend to rapidly precipitate out as secondary chalcedony. No secondary chalcedony or carbonate precipitates were reported in the sediment cores examined by the O.S.U. oceanographers and proclaimed to contain "chemical tracers" of hot spring activity (Dymond, PMT, 1987). Similarly, no secondary silica or carbonate precipitates were identified in the 130 sediment samples examined by Nelson (1967). The absence of these precipitates in the sediment samples is also considered circumstantial negative evidence against hot spring activity.

Low total dissolved solids: Another line of negative evidence against significant hot spring input that has been totally ignored by the chemical modelers is that Crater Lake is quite low (80 ppm) in total dissolved solids (Phillips & Van Denburgh, 1968). Although the chemical modelers insist that the chloride content of Crater Lake (approximately 10 ppm) is elevated greater than a full order of magnitude by hot spring input, they conveniently ignore the fact that Crater Lake shows no appreciably elevated level of total dissolved solids. Paulina Lake, Oregon, a caldera lake with observable hot springs, has an elevated chloride content of 2.8 ppm, but also an elevated total dissolved solids content of 366 ppm (ibid.). The ratio of Cl to TDS is 0.008 in Paulina Lake. If a similar ratio of chloride to TDS were reasonably anticipated, Crater Lake should have about 1250 ppm TDS. Therefore the considerably low TDS concentration of 80 ppm in Crater Lake constitutes strong negative evidence against significant hot spring input.

Isotope ratios: A significant line of negative evidence is that the isotopic composition of Crater Lake ($\sigma D = -78.3$ and $\sigma^{18}O = -9.5$ SMOW) suggests evaporation of the water but does not suggest thermal input (Thompson, 1984).

Low level of seismicity: A line of logic which further argues against the Hot Springs Legend is that Crater Lake Caldera is relatively tectonically quiescent (see Jacobson, 1986).

> "Commonly the vertical conduit needed for hydrothermal fluids to vent is provided by an active fault or fracture zone. The circulating fluids carry large quantities of dissolved solids that precipitate as the fluids approach the vent area where they undergo rapid cooling and chemical changes. These precipitated minerals will eventually clog the conduit" (Williams and Von Herzen, 1983).

Even on the highly tectonically active oceanic spreading centers, hot springs only persist for tens of years (Macdonald, 1982). In the absence of recurrent active faulting or rifting on the floor of Crater Lake, ascending convection limbs would soon seal off through mineral precipitation. Descending limbs would probably plug up with the fine grained sediments and clay depositing on the lake floor. Therefore, the still, cold depths of Crater Lake may be considered a less than optimum place to look for hot springs.

SUMMARY OF EVIDENCE FOR THE LEGEND

There is no reliable evidence that indicates the existence of thermal vents on the floor of Crater Lake. Objective review illustrates a far greater preponderance of negative evidence against the probability of hot springs than there is valid evidence for the Crater Lake Hot Springs Legend.

CONCLUSIONS

Modeling techniques, when properly utilized are an asset to the geosciences; however, the current fad of model mania with disregard to the inherent pitfalls of modeling has become a liability and a detriment to prudent geological interpretation. These pitfalls include:

1) Model conclusions become detached from the basic assumptions that created and defined the model and thereafter are assessed independent of these assumptions.

2) Detached model conclusions are often used to support the very assumptions from which they were derived, thereby, producing circular reasoning as opposed to lines of logic.

3) Modelers tend to build upon each other's detached model conclusions without adequate evaluation of the original basic assumptions. This often produces a house of cards or an inverted pyramid of speculation based upon speculation. Far too often ad hoc composite models aren't put back together to see if the pieces really fit or if the hypothetical model results actually describe the observed.

4) The principle of "multiple working hypotheses" is commonly discarded in the modeling process.

5) Lines of negative evidence are usually ignored to facilitate simplistic modeling of complex subjects.

The discourse in this article illustrates how submission to all of these modeling pitfalls resulted in the birth, growth and propagation of the Crater Lake Hot Springs Legend.

The ramifications of this form of psuedo-science have initiated a costly political turmoil and an apparent misdirection of public concern which is *now focused on the search for a legend as opposed* to a mitigation of sewage leakage into Crater Lake and diminishing water clarity. Will the elusive Legend ever be captured? Expedition leader, Jack Dymond, sounds confident; "I think the submarine part of it is going to grab people's imagination" (Dymond, in Associated Press, 1987b)

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