

# Lithology and hydrothermal alteration of drill hole RDO-1, Newberry caldera, Oregon

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## ABSTRACT

Lithologies penetrated by Sandia National Laboratories drill hole RDO-1 are correlative with those encountered by U.S. Geological Survey (USGS) Newberry 2 drill hole located 0.5 kilometers (km) to the northwest of RDO-1. Minerals produced by hydrothermal alteration are similar in both holes, but distribution with depth shows that higher temperatures were reached at a shallower level in RDO-1 as compared to Newberry 2. An aquifer penetrated by RDO-1 between 379.5 and 397 meters (m) induced artesian flow of water with temperatures in excess of 158° Celsius (C). This hot-water aquifer in RDO-1 correlates with the 100° C temperature maximum at 415 m in the upper part of Newberry 2. Hot water may flow upward from the ring fracture southeast of RDO-1 and spread laterally into permeable layers within the caldera; however, RDO-1 appears to be more directly in the path of the hot-water aquifer than Newberry 2.

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## INTRODUCTION

RDO-1 was drilled to a depth of 424 m by Sandia National Laboratories, using mud rotary drilling methods. Drilling began on September 16 and ended on October 20, 1983. The hole was sited at an elevation of 1,969.0 m, approximately 0.5 km south-east of the USGS drill hole Newberry 2 (N2) (Figure 1).

Cuttings were collected from either 3- or 6.1- m intervals as drilling progressed and were logged at the drill site using a binocular microscope. A split of the cuttings was further studied in the laboratory by binocular microscope examination and petrographic and X-ray diffraction techniques. Detailed mineralogical studies were conducted on selected samples using a scanning electron microscope equipped with an X-ray energy dispersive analyzer.

Temperature data and some of the drilling history have been reported by Black and others (1984) and are summarized here. Maximum measured temperature in the well was 158° C at the 350.5-m depth two days after circulating mud; temperatures were not measured below 350.5 m at this time because the temperature probe failed. Between 379.5- and 397-m depth, the well penetrated an aquifer with a temperature in excess of 158° C and sufficient hydrostatic pressure to cause the well to dis-

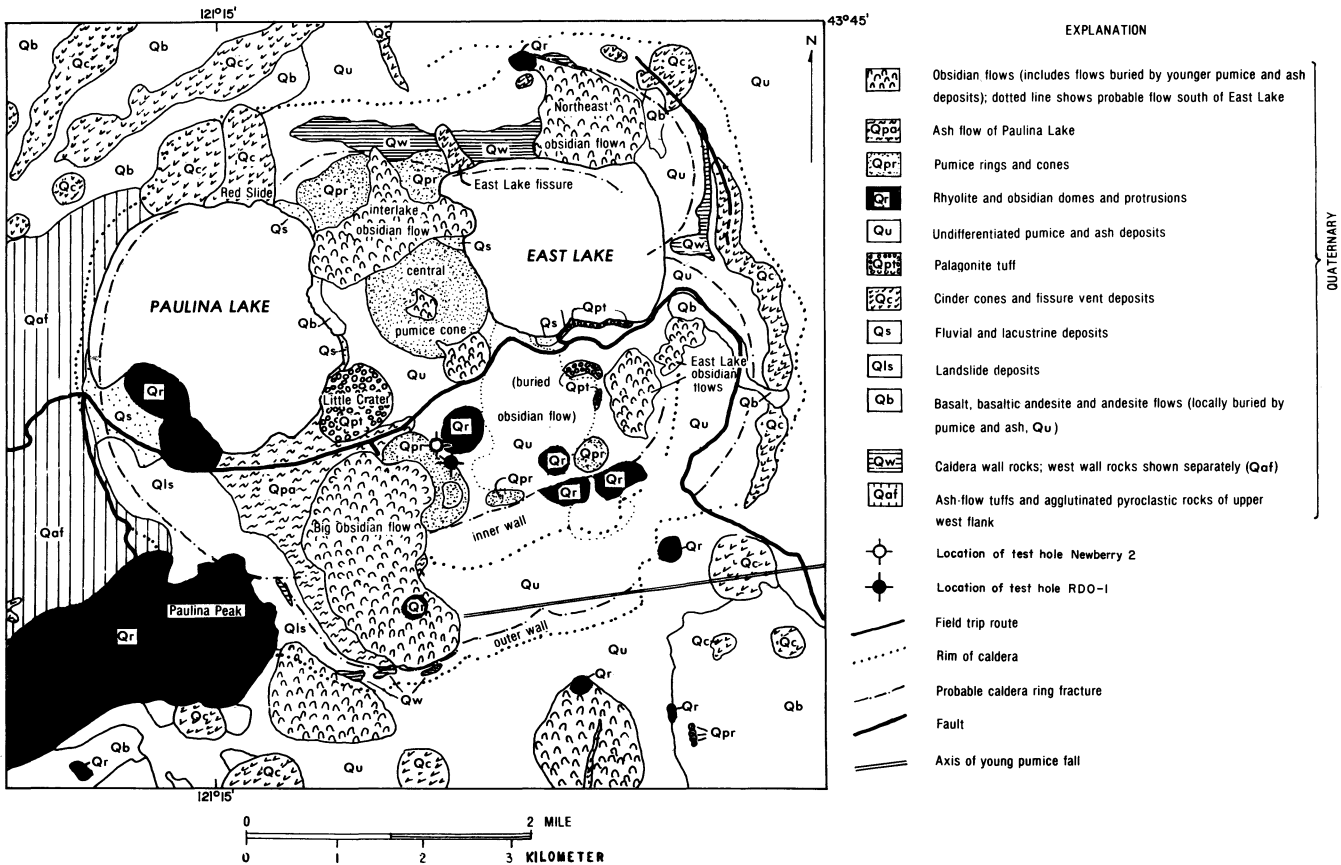


Figure 1. Geologic map (modified by Black and others, 1984, from MacLeod and Sammel, 1982), showing locations of the RDO-1 and N2 drill holes at Newberry caldera, central Oregon.

charge at the surface at a rate of approximately 340 liters per minute. Black and others (1984) suggest that the temperature of the main fluid entry of the aquifer may be in excess of 170° C.

### LITHOLOGIC DESCRIPTIONS

Lithologic descriptions for RDO-1, except for the lowest unit, are given in Figure 2 and are not repeated here.

The lowest unit, a pumice and lithic tuff breccia extending from 328.6 to 424 m, appears to be the same as the pumiceous sand and gravel unit and the pumice lapilli tuff and lithic breccia unit of N2 (MacLeod and Sammel, 1982) (Figure 3). The core samples of N2 show similar textures and relative amounts of pumice fragments, pumiceous tuff matrix, and lithic fragments including mostly aphanitic to porphyritic mafic volcanic rocks. Clast sizes in N2 cores range from less than 1 millimeter (mm) to much larger than the core diameter of 6 centimeters (cm) (probably boulders). In RDO-1, six stratigraphic subdivisions have been recorded for the pumice and lithic tuff breccia unit on the basis of binocular examination of cuttings (Gannett and

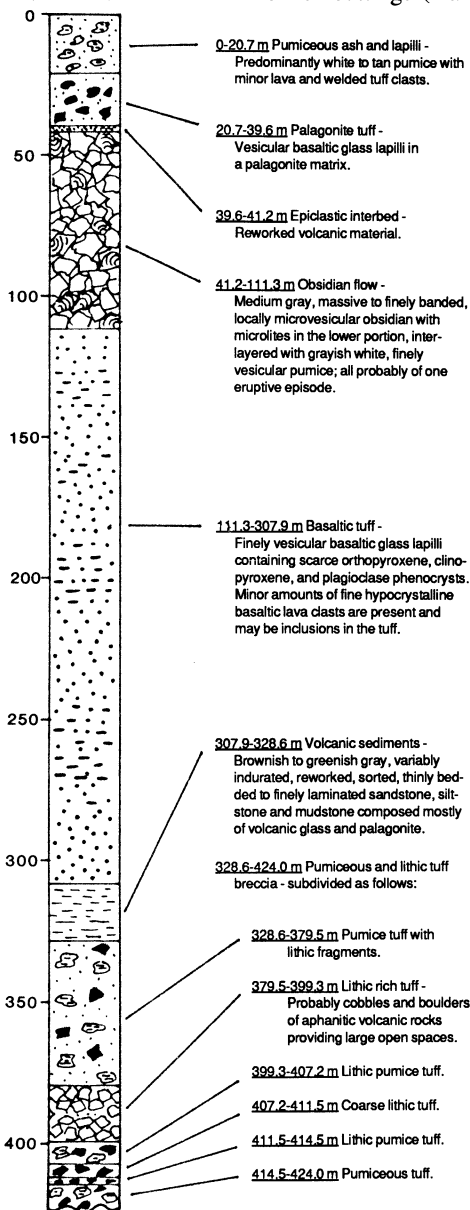


Figure 2. Lithologic log for drill hole RDO-1 (after Gannett and Waibel, 1983).

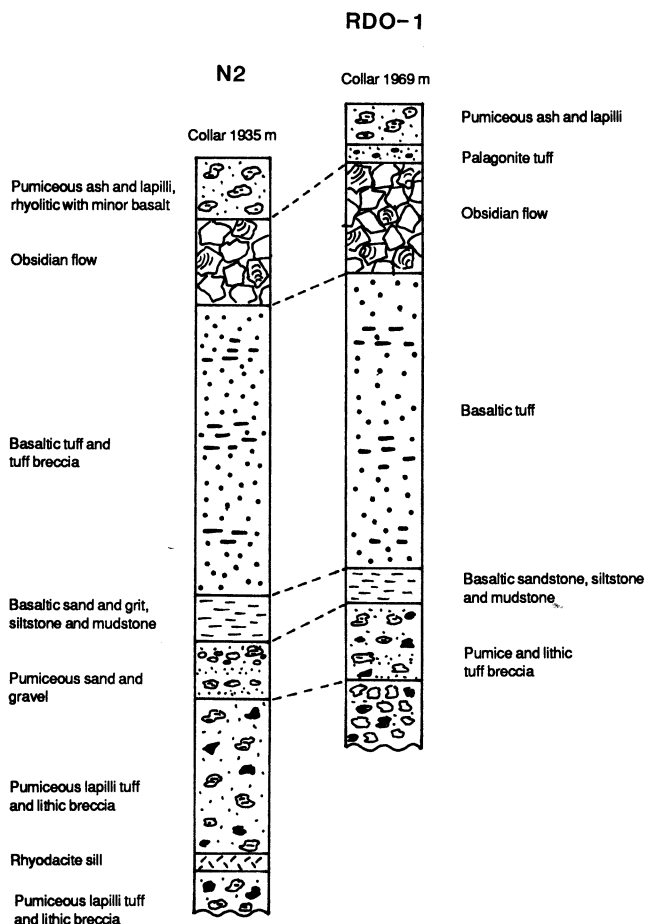


Figure 3. Lithologic correlation between drill holes RDO-1 and N2, with data for N2 from MacLeod and Sammel (1982). Collar elevations are approximately 1,935 m for N2 and 1,969 m for RDO-1.

Waibel, 1983); these subdivisions are made on the basis of relative abundance of pumiceous and lithic material.

Of particular significance is the subdivision between 379.5 and 399.3 m, which contains the 158+° C water that induced artesian flow. Hydrothermally deposited minerals in this interval are as long as 4 mm in the largest dimension, and textures of intergrown minerals show abundant open spaces. The fact that these minerals had space to grow suggests (1) that this interval contains a large proportion of cobbles and boulders and/or (2) that the interval may have large, open fractures resulting in high secondary permeability.

### HYDROTHERMAL ALTERATION

In RDO-1, there is virtually no hydrothermal alteration to a depth of 285 m. Local traces of deuteric minerals above 285 m consist of clear to white amorphous silica and thin greenish coatings of incipient clay minerals in vesicles. Present temperatures vary between 14.4° and 44.7° C from the surface to a depth of 285 m (Figure 4).

Hydrothermal alteration begins at 285 m and increases rapidly with depth; corresponding temperatures increase rapidly from 31° C at 275 m to 158° C at 350.5 m. Hydrothermal mineral distribution with depth is shown in Figure 4. The greatest proportion of the hydrothermal minerals (quartz, calcite, mordenite, chlorite, smectite, pyrite, and pyrrhotite) occur in open spaces such as vesicles, fractures, and pore spaces. Replacement of pumice matrix and mafic phenocrysts by smectite, chlorite,

mordenite, quartz, and pyrite is locally pervasive.

The base of the basaltic tuff unit from 285 to 307.9 m contains trace amounts of smectite and pyrite as replacement minerals that may have formed from diagenetic processes and trace amounts of hydrothermally deposited siderite in small vesicles. Minor alteration in the basaltic sandstone, siltstone, and mudstone unit from 307.9 to 328.6 m consists of incipient replacement of basalt glass by smectite and local thin veinlets filled with calcite, aragonite, and rhodochrosite.

Alteration in the pumice and lithic tuff breccia unit from

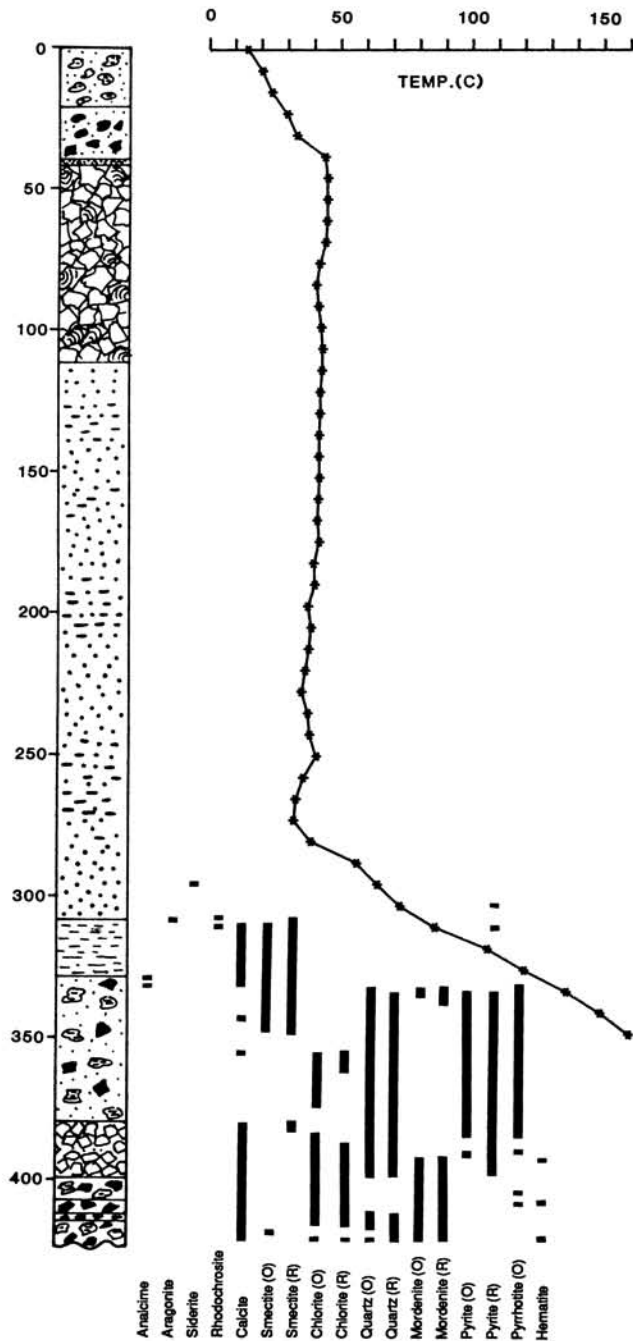


Figure 4. Lithology, hydrothermal mineral distribution, and measured temperatures plotted against depth for RDO-1. Lithologic symbols are as for Figures 2 and 3. No indications of relative abundances of minerals are shown. O = open-space deposit; R = replacement. Temperature data are from Black and others (1984).

328.6 to 424 m has resulted in replacement of glass in the pumiceous tuff groundmass and pumice fragments, and hydrothermal minerals have precipitated in open spaces. Volcanic lithic fragments were not permeable to hydrothermal fluids and, therefore, have only local alteration rims. Minor amounts of analcime fill pore spaces in the upper part of the unit. Pyrite, pyrrhotite, quartz, and either smectite or chlorite are concentrated from 328.6 to 379.5 m. The most intense hydrothermal alteration is in and adjacent to the interval from 379.5 to 397 m which contains the present hot-water ( $158^{\circ}\text{C}$ ) aquifer. At approximately 386 m and extending down to approximately 414 m, large (4-mm) calcite blades have been deposited with quartz, mordenite, and chlorite in open spaces (Figures 5 and 6).

In general, through the more highly altered part of RDO-1, the iron sulfides were deposited early, along with smectite. Pyrrhotite crystals are structurally hexagonal, as determined by X-ray diffraction techniques, and have not been altered or etched (Figure 7). The main sequence of deposition of the later minerals from first to last is pyrrhotite, mordenite, calcite, quartz, and chlorite; however, there is significant overlap of these phases, suggesting codeposition.

Most of the units of RDO-1 are quite permeable because of their primary lithologies; however, hydrothermal minerals have locally reduced permeability. The basaltic sandstone, siltstone, and mudstone unit would be expected to have lower primary permeability because of the fine-grained layers composing the unit. Reduction in permeability is caused principally by partial alteration of the glass particles to smectite, and this reaction, along with further reduction in permeability, can be expected to continue. Permeability of the pumiceous and lithic tuff breccia unit is greater where the proportion of lithic fragments to pumice fragments is greater and where the size of the fragments is larger. Pumice is more susceptible to hydrothermal alteration than are the volcanic lithic fragments. The present alteration is still in an early stage, and permeability is high through most of the unit. From 414.5 to 424 m, permeability has decreased because a high proportion of small pumice and tuff fragments have been extensively replaced, and vesicles have been filled by mordenite and chlorite. Quartz and calcite usually occur as euhedral crystals rather than massive vein or pore filling and, therefore, have less effect on overall rock permeability.

The effects of present temperatures on hydrothermal mineralogy can best be seen in the distribution of smectite and chlorite (Figure 4). Smectite occurs from 308 to 350 m at temperatures from approximately  $80^{\circ}$  to  $150^{\circ}\text{C}$ . Chlorite first appears at 355 m, where present temperatures are greater than  $158^{\circ}\text{C}$ . Isolated occurrences of smectite are present at 380 and 417 m, where temperatures are probably higher than  $158^{\circ}\text{C}$ . There are no mixed-layer clays in RDO-1. Chlorite appears to be the clay mineral in equilibrium with the present waters below 355 m, and smectites either have not had time to react or have been shielded from the hydrothermal fluids by their location in small vesicles and in groundmass pore spaces.

Trace amounts of hematite that occur with chlorite below 393 m are more dependent upon local increases in oxygen fugacity than temperature.

#### COMPARISON OF RDO-1 AND N2

RDO-1 and N2 correlate well lithologically, as would be expected from their close proximity (Figure 3). The cores from N2 served as a guide for interpreting the cuttings from RDO-1. Intervals from the lower part of RDO-1 that could have been interpreted as lava flows were correlated with cores from N2 containing large volcanic lithic fragments.

Measured temperatures are consistently hotter in RDO-1 than at equivalent depths in N2 (Figures 4 and 8). The occurrence of hexagonal pyrrhotite in RDO-1 is suggestive of higher temper-

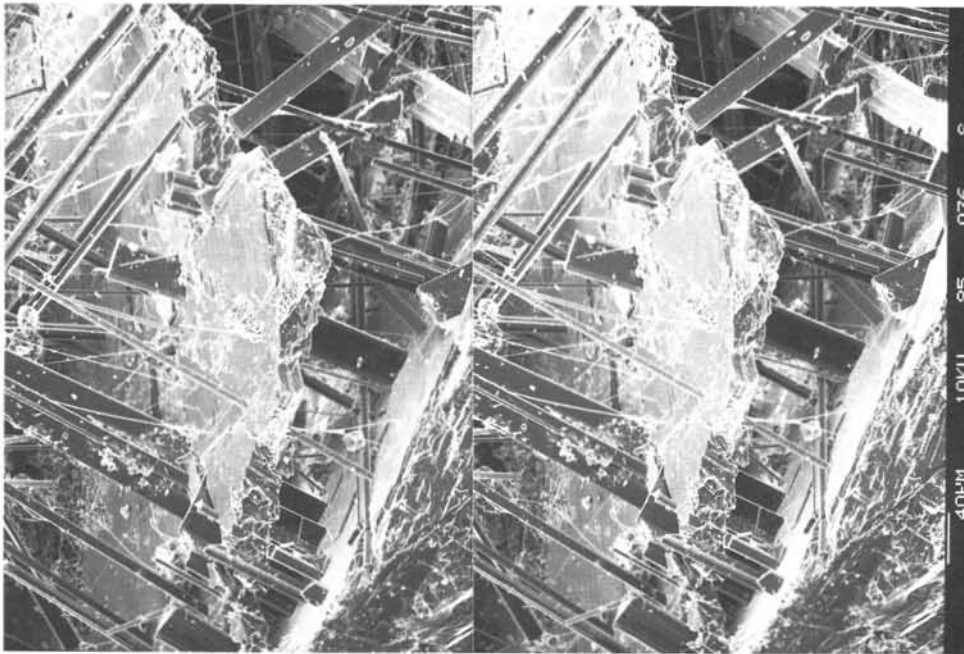


Figure 5. Scanning electron photomicrographs (stereo pair) showing bladed calcite and fibrous mordenite from a depth of 393 m.

atures than are found in the upper 500 m of N2, where pyrrhotite is monoclinic (Bargar and Keith, 1984). One bladed calcite sample from 390 m in RDO-1 was studied for oxygen and carbon isotopes for comparison with N2 carbonates. Assuming the same water occurs at this depth in both drill holes, calculated temperature of deposition of the bladed calcite is 220° C (Carothers and others, in preparation), which is higher than any measured temperature in RDO-1 but which corresponds to the temperature extrapolated by projecting the measured gradient to the aquifer depth by Black and others (1984) (Figure 4).

Rocks in both drill holes are virtually unaltered to approximately the 300-m depth; present temperatures between the surface and 300 m reach a maximum of about 40° C in N2 and 45° C in RDO-1. Incipient alteration in the basaltic sandstone, siltstone, and mudstone unit is similar in both holes where calcite and aragonite occur. Analcime in RDO-1 occurs very close to the same depth where analcime and other zeolites occur in N2 (Bargar and Keith, 1984). Only a trace of siderite is found in RDO-1, whereas it is abundant in N2; in both, it is a late mineral. The one occurrence of rhodochrosite in RDO-1 appears to be codepositional with siderite; microprobe analyses of siderite crystals in N2 consistently show a large manganese component (Bargar and Keith, 1984). Calcite is the prominent carbonate in RDO-1, whereas siderite is prominent in the corresponding interval of N2.

In N2, a rhyodacite sill between 460 and 470 m interrupts the alteration mineralogy through a long interval of pumice and lithic tuff extending from 320 to 500 m (Figure 8). A higher temperature assemblage of quartz, calcite, chlorite, mordenite, pyrrhotite, and pyrite is superimposed upon a lower temperature assemblage of hydrated pumice glass and smectite assemblage between approximately 435 and 490 m. The intrusion of the rhyodacite sill could have caused the higher temperature mineral crystallization, or the fractures in the sill may have been sufficient to allow flow of thermal waters similar to that in RDO-1 at some time in the past. Later siderite, pyrite, and marcasite with locally developed native sulfur and iron hydroxide from oxidizing pyrrhotite occur in fractures in the massive rhyodacite sill, indicating that temperatures have decreased. Isotope data from N2 show that siderite was deposited at present measured temperatures, which range from 76° to 100° C (Carothers and others, in preparation). Present temperatures in the rhyodacite sill reach a

maximum of 95° C, and the temperature maximum for the 320-to 500-m interval is 100° C at 415 m in the pumice and lithic tuff just above the sill. The rhyodacite sill is not penetrated in RDO-1, although stratigraphic correlation suggests that it might be present below total depth.

Alteration mineralogy in the pumice and lithic tuff breccia of RDO-1 samples below 328.6 m consists mainly of large, well-developed crystals of calcite, chlorite, quartz, and mordenite; in

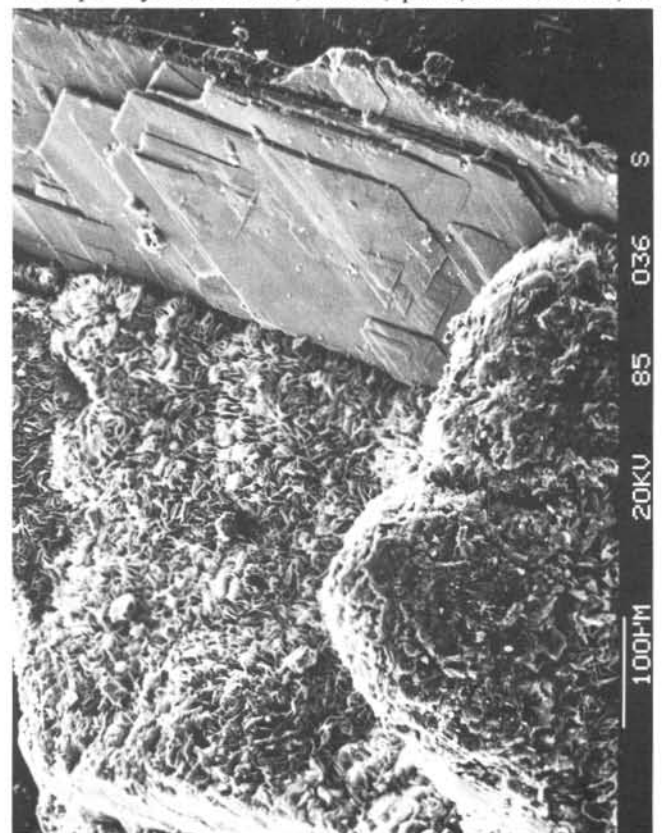


Figure 6. Scanning electron photomicrograph showing bladed calcite with chlorite from a depth of 390 m. 1 cm = 67 μm.





Figure 7. Scanning electron photomicrograph of twinned hexagonal pyrrhotite crystals from a depth of 335 m. 1 cm = 50 μm.

N2 adjacent to the rhyodacite sill, the same minerals occur, but they are fine grained. Large, hydrothermally deposited crystals in RDO-1 indicate open fractures or spaces between large lithic fragments, as opposed to small fractures and pore filling in N2.

The hot-water aquifer of RDO-1 is within the highly fractured or open-textured interval of the pumice and lithic tuff breccia between 379.5 and 397 m; in N2, the temperature bulge occurs in the same lithologic interval. The aquifer of RDO-1 projects parallel to stratigraphy to the temperature maximum of 100° C at 415 m in N2. Since the hydrothermal mineralogy at this level in N2 is incipient smectite replacement of pumice glass along with late siderite deposition in open spaces, temperatures at this level in N2 have not been higher than 100° C and probably have not been as hot as 100° C for a very long time (otherwise smectite alteration would be more extensive). A problem of cooling from at least 158° C in RDO-1 to 100° C in N2 over only 0.5 km horizontal distance suggests the path of the fluids may have been diverted from N2. Since the zone of the rhyodacite sill in N2 was once hotter than at present, either part of the N2 system may have been self sealed so that hot fluids no longer have access, or the total amount of hot fluids in the system has decreased so they are no longer reaching N2. The rhyodacite sill itself might now be a low-permeability layer providing a base for an aquifer in both drill holes. In any case, RDO-1 appears to be closer to a major upflow zone for thermal waters upflowing from a caldera ring fracture to the southeast (Figure 1) as suggested by Black and others (1984).

### CONCLUSIONS

Lithologies can be correlated between RDO-1 and N2, and comparison of measured temperatures and hydrothermal alteration mineralogy show that RDO-1 is consistently hotter for given

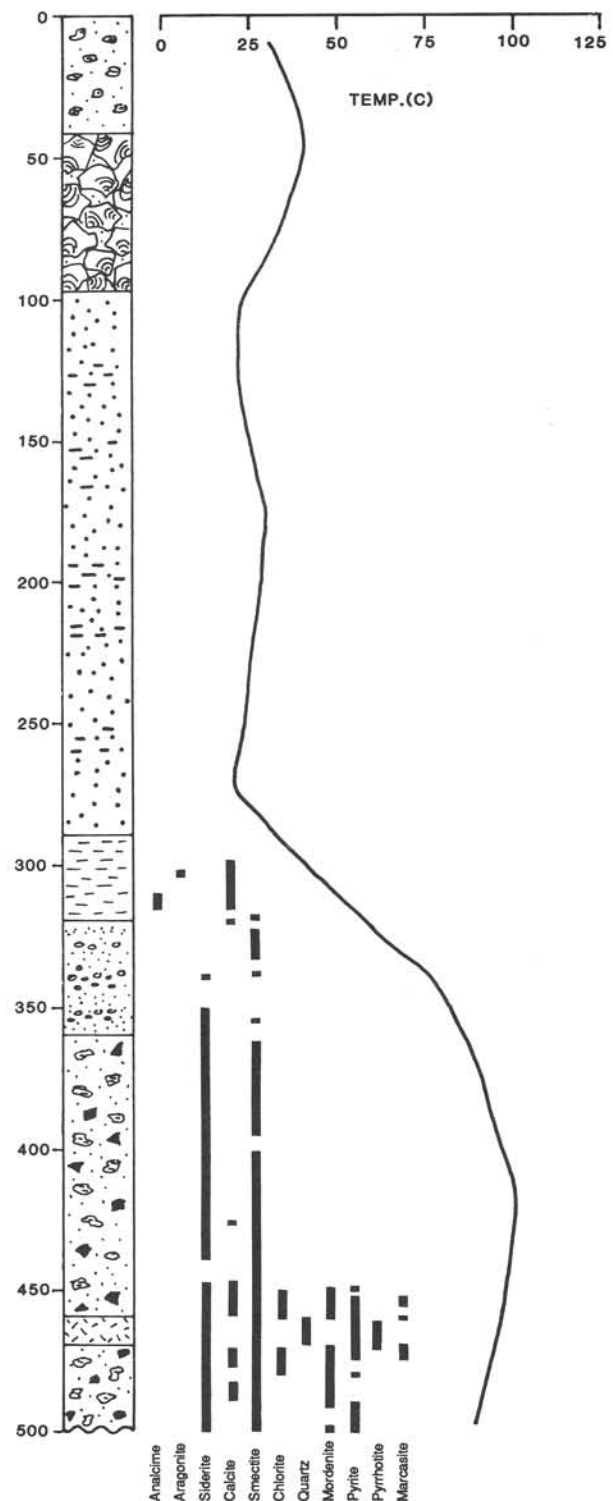


Figure 8. Lithology, hydrothermal mineral distribution, and temperatures measured during drilling plotted against depth for the upper 500 m of N2 (after Keith and others, 1984). Temperature data are from Sammel (1981). Lithologic symbols are as for Figure 3.

depths than N2. In RDO-1, the chlorite, calcite, quartz, and mordenite assemblage below approximately 355 m crystallized at temperatures at least as hot as the highest measured temperature of 158° C at 350.5 m. The minerals were probably deposited  
(Continued on page 110, Newberry)

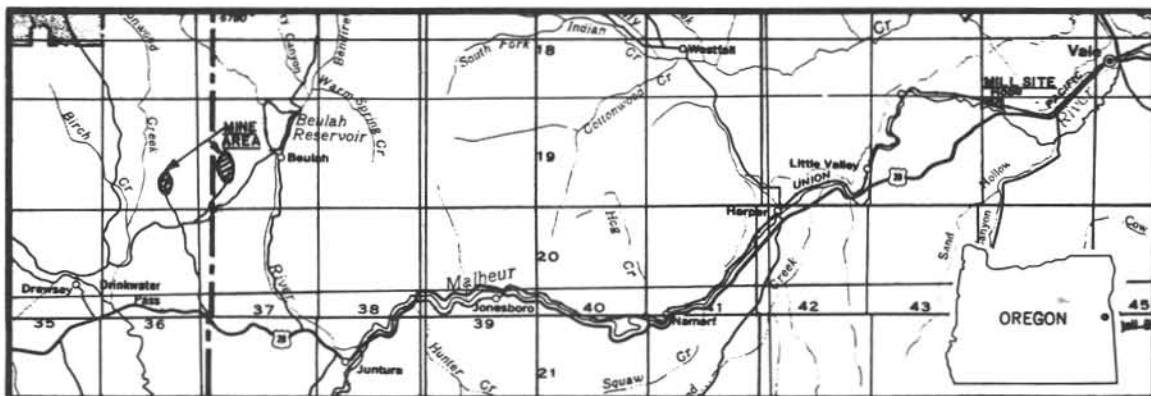
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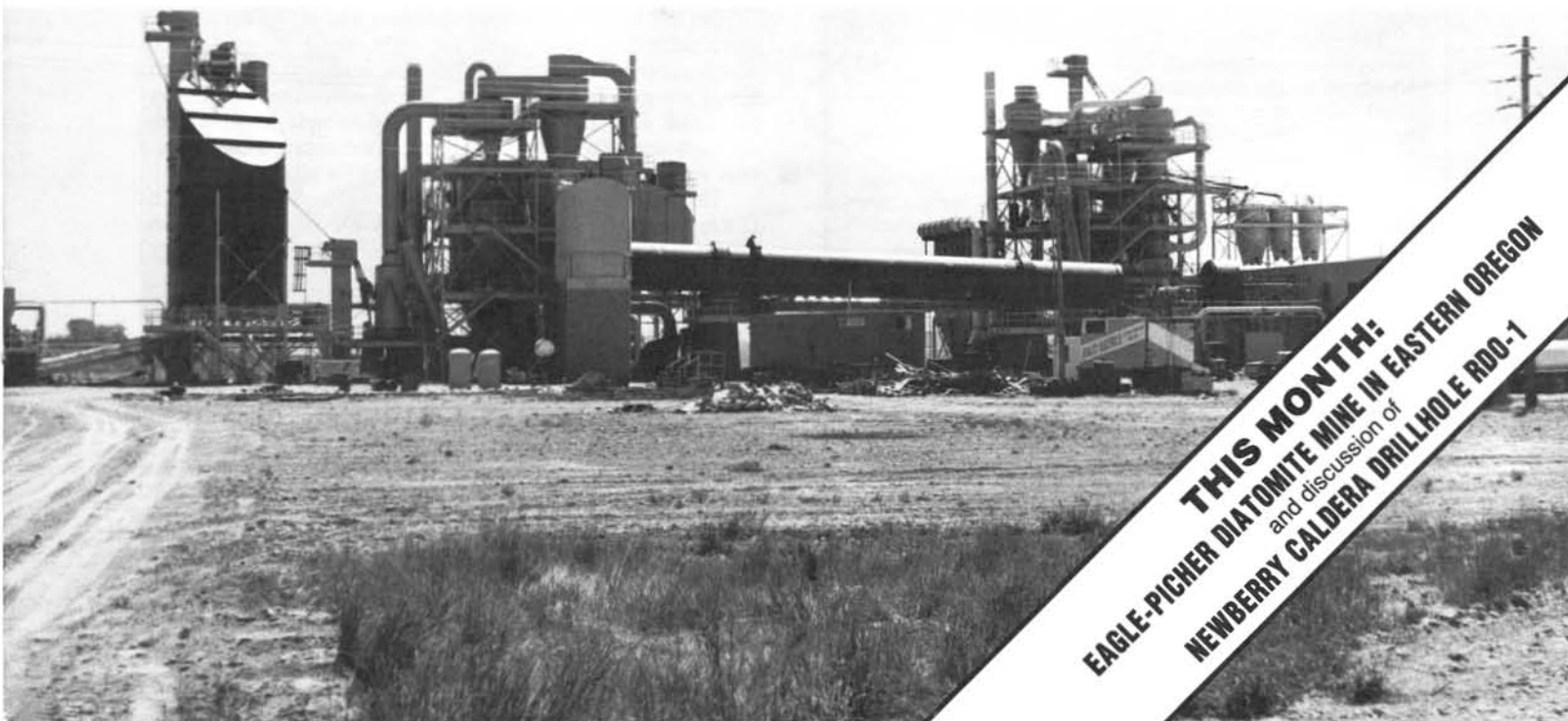
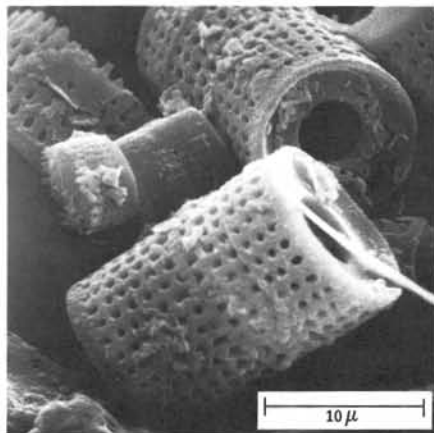
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LOCATION MAP

SCALE in Miles



**THIS MONTH:**  
EAGLE-PICHER DIATOMITE MINE IN EASTERN OREGON  
and discussion of  
NEWBERRY CALDERA DRILLHOLE RDD-1