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Hydrothermal Mineralization in GEO N-1 Drill Hole,  
Newberry Volcano, Oregon

by

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## ABSTRACT

GEO N-1 was drilled in November, 1985 by GEO-Newberry Crater, Inc., under a cost-sharing agreement with DOE, at a surface altitude of 1783 m on the south flank of Newberry Volcano, Oregon. Drill core, drilling data, and geophysical data from the upper 1219 m of GEO N-1 are available to the public; maximum measured temperature for the released interval is 71°C at 1219 m. The drill core intercepted mostly andesitic to basaltic lava flows with interlayers of ash-flow tuffs, lithic tuffs, cinders, and flow breccias; core recovery was about 95 percent. Twelve basalt dikes intrude the flows between 622 and 719 m but there is little alteration at the contacts. Intense fracturing and vesiculation are common in the basal and upper portions of most flows whereas the flow interiors are generally very dense with few fractures.

Very little evidence for hydrothermal alteration was found in the upper 500 m of drill core; however, pre-hydrothermal, low temperature, amorphous clay-like material and amorphous silica occur as fracture or vug fillings. Below 500 m, most ash-flow tuffs contain smectite, and, although the lavas generally show little alteration, many fractures and vesicles are lined with secondary minerals: hematite, smectite, and carbonates (siderite, kutnohorite, dolomite, rhodochrosite, calcite, and aragonite). Locally, small amounts of  $\beta$ -cristobalite, chalcedony(?), chabazite, phillipsite, okenite, illite(?), and pyrite were identified. The hydrothermal minerals were probably deposited at the <71°C temperatures measured following drilling of GEO N-1.

## INTRODUCTION

Geothermal drill hole GEO N-1, located on the southern flank of Newberry Volcano about 4.5 km outside the caldera rim at an elevation of about 1783 m, was completed by GEO-Newberry Crater, Inc. (subsidiary of GEO Operator Corporation) in November, 1985. This 1219+ m drill hole is the first Cascade geothermal drill hole to be finished under a new program of the U. S. Department of Energy (DOE). In this program, the U.S. government shares geothermal exploration drilling costs with industry at approved drill sites.

A brief summary of data from the GEO N-1 drill hole by the University of Utah Research Institute (UURI) Earth Science Laboratory, including abbreviated descriptions of temperature and selected geophysical logs, is given in a newsletter (UURI, 1986). GEO N-1 was rotary drilled to about 148 m, and then was cored to 1219 m with about 95 percent core recovery. Below 1219 m, information from this drill hole is proprietary, and has not been released by GEO-Newberry Crater, Inc. Swanberg and Combs (1986) present preliminary lithologic and temperature logs for the GEO N-1 drill hole; they also discuss the results of several geophysical tests conducted in GEO N-1 and indicate that such geophysical data may be of great importance to future geothermal exploration in the Cascades.

The drill core was logged and photographed upon recovery by GEO-Newberry

Crater, Inc. and a split of the core was sent to UURI. A selection of the UURI core (222 samples) including vein fillings, vug fillings, or representative samples of stratigraphic intervals was studied by us for hydrothermal alteration mineralogy. In addition, GEO-Newberry Crater, Inc., provided 49 hydrothermal mineral samples, geophysical logs, and a color photo log of the entire drill core. Altogether, 271 samples of the GEO N-1 drill core were studied by binocular microscope, petrographic microscope (15 thin sections), and X-ray diffraction methods (more than 300 X-ray diffractograms).

## LITHOLOGY

A lithologic log of the GEO N-1 drill core was compiled by GEO-Newberry Crater, Inc., and made available through UURI. The log contains detailed lithology notes and tentative rock identifications (pending receipt of thin sections and chemical analyses). The GEO-Newberry terminology will be followed in this report, modified only slightly on the basis of our observations of the entire split of UURI core. Age data are not available for any of the rocks recovered from the drill hole. The majority of core samples consist of basaltic to andesitic lava flows and associated flow breccia, pyroclastic, and ash-flow material (Fig. 1). Primary minerals in the lavas vary with the chemical composition of the lava but are predominantly plagioclase with varying amounts of olivine, clinopyroxene, orthopyroxene, magnetite, and  $\alpha$ -cristobalite; minerals such as hornblende or biotite are notably absent. Several lava flows contain vapor-phase tridymite, alkali-feldspar(?), and magnetite that has altered to hematite. The deepest lava flow available for study (1170.4-1219.2 m depth) is probably dacitic and contains trace amounts of primary quartz. Textures of the lava flows may be perlitic, massive, flow-banded, diktytaxitic, vesicular, or scoriaceous. Between 622 and 719 m depth, 12 moderate to steeply dipping basaltic dikes (up to about 12 m apparent core thickness) intrude the lava flows.

The lava flows are commonly vesicular at the top and bottom, dense in the interior and have intervening fractured intervals consisting of steeply dipping tight fractures. Ash and cinder layers and lithic tuffs appear to have good permeability where unaltered; one layer (567-572 m) retained significant water in the pore spaces several months after recovery of the drill core. At deeper intervals, below 830 m, ash-flow tuffs are pervasively altered to smectite and the present permeability is presumably quite low.

## PRE-HYDROTHERMAL ALTERATION

Many secondary minerals, not hydrothermal in origin, were deposited along narrow fractures and in vesicles throughout the upper 610 m of the drill core, especially above about 520 m. The deposits consist of thin coatings of reddish iron oxide (mostly amorphous iron hydroxide but some hematite), yellow, green, and pale blue soft amorphous material (which may be, in part, a precursor to smectite), and scattered small amounts of amorphous silica. Hematite was deposited at high temperatures during cooling of the lava flows and ejecta; amorphous silica, amorphous iron hydroxide, and at least some of the amorphous clay-like deposits are probably deuteric and formed at low

temperatures. Below 520 m depth some of these pre-hydrothermal minerals, especially hematite, persist intermingled with hydrothermal deposits. Amorphous clay-like material coating fractures and vesicles is similar in appearance to hydrothermal clay coatings but lacks the smectite structure. The abundant iron oxides, including some hematite in ash-flow tuffs, may have formed by oxidation of primary magnetite during deuteritic alteration.

#### HYDROTHERMAL ALTERATION

The lava flows are mostly very little altered. Below about 670 m depth, thin fracture fillings or vesicles contain hydrothermal deposits, dominantly carbonates (aragonite, calcite, dolomite, kutnohorite, rhodochrosite, and siderite), smectite, and hematite with local minor amounts of silica minerals ( $\beta$ -cristobalite and chalcedony?), zeolites (chabazite, and phillipsite), okenite (one occurrence of the calcium silicate hydrate mineral), illite(?), and pyrite (Fig. 2).

Fractures frequently have a smectite coating and may also contain one or more of the several carbonate minerals. Most vesicles do not contain any secondary minerals, but thin clay coatings and clusters of carbonate crystals are sporadically abundant.

Hydrothermal alteration of the pyroclastic layers and flow breccias is somewhat irregular. The flow breccias, ash-flow tuffs, and other pyroclastic layers are not altered above 567 m (but do contain deuteritic minerals). From 567 to 820 m minor clay alteration is present in three layers of ash and cinders but one ash-flow tuff (659 to 664 m) and two layers of ash and cinders (797 to 800 m and 816 to 820 m) are unaltered. Below 830 m, the pyroclastic deposits are extensively altered to smectite; however, layers of ash and cinders at 860 to 869 m, 897 to 901 m, 949 to 979 m, and 1125 to 1132 m have only minor smectite alteration. Iron oxide is abundant in many of the pyroclastic layers and usually stains the layers an earthy brick-red color. Some of the iron oxides are amorphous but most were identified as hematite by X-ray diffraction.

#### Silica Minerals

Several cavities in samples from 1124 and 1172 m are partly coated by bluish botryoidal  $\beta$ -cristobalite along with smectite, calcite, and siderite. X-ray diffraction analysis of a massive green fracture filling deposit at 1178 m shows the presence of  $\beta$ -cristobalite and minor smectite, siderite, hematite, and kutnohorite.  $\beta$ -cristobalite, smectite, and siderite were also identified on an X-ray trace of a clayey fracture filling at 1185 m. The only other hydrothermal(?) silica mineral in drill core GEO N-1 is yellowish botryoidal chalcedony which coats flow breccia fragments at 555 m. Several samples of white to clear amorphous silica deposits in the upper half of the drill core may be of deuteritic origin.

## Carbonate Minerals

Several carbonate minerals (aragonite, calcite, dolomite, kutnohorite, rhodochrosite, and siderite) occur as vesicle or fracture fillings in the lower half of the drill core; and calcite appears to replace plagioclase at about 1200 m depth. Aragonite can generally be distinguished from the other carbonates by its typical clear acicular crystals (as much as 1 cm long). However, white powdery, clear massive, or white cauliflower-like aragonite deposits were also verified by X-ray diffraction analyses.

Siderite, a fairly abundant carbonate mineral in the drill core, usually occurs as distinctive light to dark caramel-colored or rarely greenish discoidal, hemispherical, or spherical aggregates of rhombic crystals. 'Towery' stacked rhombic crystal clusters occur at 1090 and 1121 m. The color of GEO N-1 siderite probably reflects its composition. Lighter caramel or pale yellow siderite crystals have their most intense X-ray diffraction peak at about 2.82 Å corresponding to a manganese siderite (X-ray diffraction identification of carbonate minerals is based on data of the Joint Committee on Powder Diffraction Standards. No internal standard was used in any of the X-ray diffraction measurements; however, accuracy of the measurements is within about  $\pm 0.02\text{\AA}$ ). In darker caramel-colored siderite crystals (Fe-rich), the most intense X-ray peak occurs between 2.78 - 2.80 Å.

The remaining four carbonate minerals (calcite, dolomite, kutnohorite, and rhodochrosite) have no distinctive color or crystal habit. These open-space deposits may be clear, white, pink, or yellowish in color; and they may consist of powdery or massive deposits, blocky or acicular crystals, or spherical to hemispherical crystalline aggregates. Most carbonate mineral identifications in this study (including siderite) are based on the position of the most intense X-ray diffraction peak as follows: siderite (2.78 - 2.80 Å), Mn-siderite (2.82 Å), rhodochrosite (2.84 - 2.86 Å), dolomite (or possibly ankerite) (2.88 - 2.90 Å), kutnohorite (2.91 - 2.98 Å), and calcite (3.02 - 3.05 Å). Only a few samples of rhodochrosite or dolomite (ankerite?) were identified in the GEO N-1 drill core (Fig. 2). Characteristic X-ray peaks for these two minerals are fairly distinctive. However some difficulty was found in distinguishing between calcite and kutnohorite because the presence of manganese in the calcite structure expands the range of positions of the most intense X-ray peak from typical calcite (3.02 - 3.05 Å) to at least the upper border of the kutnohorite range (2.94 - 2.98 Å) (Krieger, 1930). A further complication is that although kutnohorite has a dolomitic structure, the X-ray peaks which are characteristic of dolomitic structure may be too weak to detect, at least in Ca-kutnohorite (Gabrielson and Sundius, 1965). In this study, the mineral was identified as kutnohorite if the highest X-ray peak ranged between 2.94 and 2.98 Å and calcite if the peak occurred at 2.99 to 3.05 Å; even though data in Krieger (1930) indicate that the most intense X-ray peak in calcite with high manganese content may extend to 2.95 Å.

In the GEO N-1 drill core, kutnohorite and calcite were not deposited in distinctive zones; instead they overlap in their distribution throughout the

lower half of the drill hole (Fig. 2). In some fractures or vugs, the two minerals are found together or are closely associated with up to three other carbonate minerals. This suggests that the fluids that deposited the carbonate minerals may have varied somewhat in cation composition with time.

### Zeolite and Related Minerals

Chabazite and phillipsite are the only zeolite minerals found in the GEO N-1 drill core. Flow rock between 801 and 802 m depth contain trace amounts of clear to white, twinned, pseudorhombic chabazite crystals. Tiny, clear, prismatic crystals from a lava flow at 756 m and three samples of open-space fillings in a lava flow between 801 and 804 m were identified as phillipsite by X-ray diffraction. The two zeolite minerals occur together in two of the samples; calcite and smectite are the only other associated hydrothermal minerals.

Okenite, a hydrous calcium silicate mineral, occurs as a soft white vug filling in a lava flow at 857 m. Okenite typically is found in basalt cavities in association with zeolite minerals (Heller and Taylor, 1956).

### Clay Minerals

Smectite is the most abundant hydrothermal mineral found in the GEO N-1 drill core (Fig. 1). This white, yellow, green, brown, blue, or black clay mineral ranges from poorly crystalline (low, broad X-ray peaks) to well-crystallized with sharp (001) X-ray diffraction peaks that generally fall within the range from about 15.2 - 16.7 Å and expand to between about 17.0 and 18.3 Å with glycolation (average values for 91 samples are 15.7 Å untreated and 17.6 Å glycollated). No correlation was found between poor or well-developed crystallinity, or position of the (001) X-ray peak, with depth of smectite formation in the GEO N-1 drill core. In the GEO N-1 drill core, smectite occurs as whole rock (glass) alteration in pyroclastic samples and as open-space (fracture and vug fillings) in the lava flows and flow breccias. Smectite was deposited at several different times, occurring both earlier than (beneath) and later than (above) some carbonate cavity and vein fillings.

Illite is provisionally identified (based on a low, usually broad, approximately 10 Å X-ray diffraction peak that showed no significant change with glycolation) in a few X-ray diffraction analyses of whole-rock, vesicle, and fracture filling samples from lava flows and pyroclastic deposits at 310-362 m, 568 m, 789 m, and 1217 m depth. The 10 Å illite(?) mineral formed later than calcite in one vesicle filling and is associated with calcite, dolomite, and smectite in other samples.

### Iron Oxide and Sulfide Minerals

Small patches of disseminated, very minute ( $\approx 0.02$  mm), yellow,

metallic, cubic pyrite crystals were identified only at 943, 945, and 1068 m in the GEO N-1 drill core. At 1068 m a pyrite veinlet crosscuts iron oxide deposits, and pyrite crystals formed later than smectite in vesicles. Associated minerals are smectite, calcite, siderite, and hematite.

Red deuteric amorphous iron oxide stains flow breccias, ash, and tuffaceous layers and coats fractures in lava flows in the upper part of the drill core. In contrast, crystalline hematite (identification based on X-ray diffraction analyses) occurs below about 300 m in red-stained tuffs, altered vapor-phase magnetite grains, and fracture coatings.

#### PARAGENETIC SEQUENCE

Deposition of the major secondary minerals began with vapor-phase hematite, which formed during cooling of the lava flows and pyroclastic intervals. During late-stage cooling and pre-hydrothermal circulation of meteoric waters, amorphous iron hydroxides, and amorphous clay-like deposits were precipitated. Hydrothermal smectite and carbonate minerals were deposited later than vapor-phase minerals. Smectite alteration of the pyroclastic layers occurred prior to carbonate deposition. Most open-space smectite formed earlier than the carbonates; however, smectite is also found locally deposited later than carbonate minerals. The several carbonate minerals appear to have been deposited from fluids that varied greatly in cation content with respect to time. Aragonite, however, formed later than the other carbonates. Silica minerals, zeolite minerals, and okenite all formed later than most smectite but their sequence relative to carbonates and to each other are unknown. Pyrite formed later than hydrothermal hematite in the single vein occurrence, and it formed later than smectite but earlier than carbonate in the disseminated occurrences.

#### DISCUSSION

A maximum temperature of about 71°C was reported following drilling of the GEO N-1 drill hole at 1219 m depth (UURI, 1986). Hydrothermal alteration minerals identified from the drill core are consistent with these low temperatures. The minerals form a nearly identical hydrothermal mineral suite to that found at temperatures of less than 100°C in the upper 650 m of the U.S.G.S. Newberry 2 drill core (Bargar and Keith, 1984; Keith and others, 1984) from a site about 7.5 km NNE of the GEO N-1 drill site. In both drill holes hydrothermal silica, zeolite, carbonate, and clay minerals were deposited from migrating fluids, mostly in open-spaces of vugs, fractures, and voids in flow breccias. Permeable ash-flow tuff and lithic tuff locally display more intense alteration of glass to smectite. Some replacement of plagioclase by calcite appears to have occurred in the vicinity of 1200 m in the drill core from GEO N-1.

In drill core GEO N-1, the numerous carbonate phases are not confined to discrete zones. Instead, the minerals may vary from fracture to fracture. Such abrupt changes are especially true for calcite and kutnohorite; a

sequence of three fractures can have fracture #1 coated by calcite, fracture #2 by kutnohorite, and fracture #3 by calcite. The fluids from which the minerals were deposited must have varied somewhat in chemical composition between at least two of the three adjacent fractures, and, consequently, the fracture fillings probably resulted from at least two separate fluid pulses. In fact, it is likely that fluctuations in fluid cation (Mg, Ca, Mn, and Fe) composition occur over a period of time because as many as four different carbonate minerals (aragonite, siderite, calcite, and dolomite) were identified in a single open-space filling. Aragonite is always the last carbonate phase to be deposited, but, locally, it appears to have been partly reordered to the more stable calcite phase.

The presence of 12 basaltic dikes between 622 and 719 m show that a transient heat source was introduced near the area when the dikes intruded the volcanic pile. Some of the dikes have chilled margins preserved, but there is no evidence of significant alteration directly adjacent to the contacts. The dikes occur near the upper limit of the occurrence of hydrothermal alteration minerals in the drill core.

Although the temperature gradient begins to increase at about 1000 m, there are no changes in hydrothermal mineralogy at that depth. The existence of smectite and amorphous clay-like material rather than mixed-layer clays indicates that temperatures probably were never hotter than the present measured temperature of about 71°C at 1219 m.

#### ACKNOWLEDGMENTS

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#### REFERENCES CITED

- Bargar, K. E., and Keith, T. E. C., 1984, Hydrothermal alteration mineralogy in Newberry 2 drill core, Newberry Volcano, Oregon: U. S. Geological Survey Open-File Report 84-92, 50 p.
- Gabrielson, O., and Sundius, N., 1965, Ca-rich kutnohorite from Langban, Sweden: *Arkiv For Mineralogi Och Geologi*, v. 4, p. 287-289.
- Heller, L., and Taylor, H. F. W., 1956, Crystallographic data for the calcium silicates: London, Her Majesty's Stationery Office, 79 p.
- Keith, T. E. C., Mariner, R. H., Bargar, K. E., Evans, W. C., and Presser, T. S., 1984, Hydrothermal alteration in Oregon's Newberry Volcano No. 2: Fluid chemistry and secondary-mineral distribution: *Geothermal Resources Council Bulletin*, v. 13, p. 9-17.
- Krieger, P., 1930, Notes on an X-ray diffraction study of the series calcite-rhodochrosite: *American Mineralogist*, v. 15, p. 23-29.
- Swanberg, C. A., and Combs, J., 1986, Geothermal drilling in the Cascade Range: Preliminary results from a 1387-m core hole, Newberry Volcano, Oregon: *EOS, Transactions, American Geophysical Union*, v. 67, p. 578-580.
- UURI, 1986, Announcement of open file data release: *Cascades Newsletter*, no. 2, 2 p.

## FIGURE CAPTIONS

Figure 1. Preliminary lithologic log of core from drill hole GEO N-1, based on stratigraphic data made available by GEO-Newberry Crater, Inc.

Figure 2. Distribution of selected secondary minerals with depth in geothermal drill hole GEO N-1. Left column shows a generalized stratigraphic section of rock units encountered in the drill hole including: basaltic or andesitic lava flows (star pattern), tuffaceous or pyroclastic material (solid), basaltic dikes (diagonal lines), and dacitic lava flow (horizontal lines). The column is blank above 148 m where no core was recovered. Filled circles are temperatures measured during drilling from the log provided by GEO-Newberry Crater, Inc. The temperature curve is dashed where measurements were imprecise. The maximum measured temperature was 61.1°C at 1208.2 m; however, maximum temperatures of 68.3°C and 71.1°C were recorded at 1219.2 m on subsequent temperature logs (Swanberg and Combs, 1986; UURI, 1986).

GEO N1 Annotated Lithologic Log

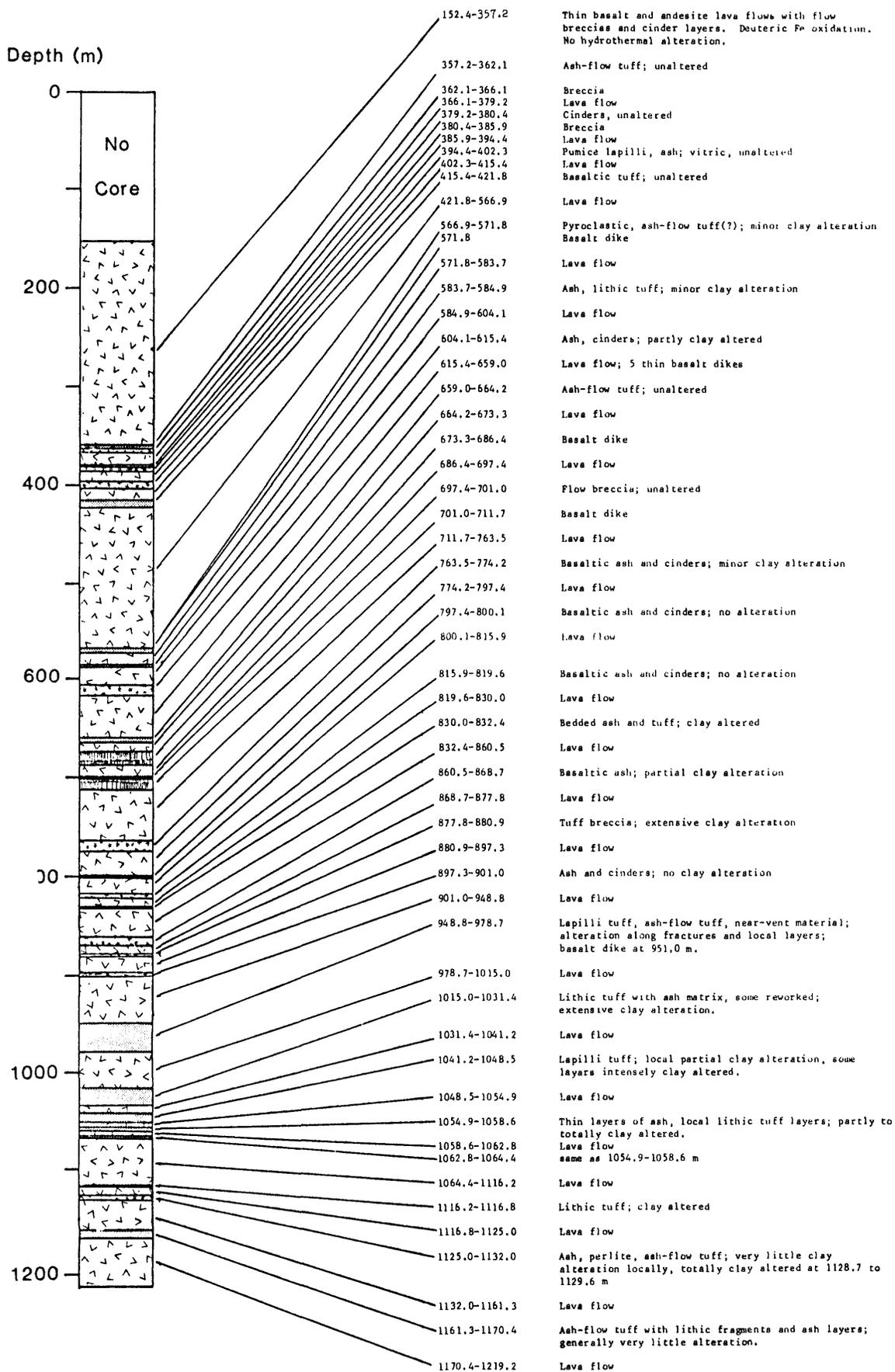


Fig. 2

