VOLCANIC STRATIGRAPHY AND SECONDARY MINERALIZATION OF U.S.G.S. PUCCI GEOTHERMAL TEST WELL, MOUNT HOOD, OREGON

by

Marshall W. Gannett [1]

and

Keith E. Bargar [2]

Open-file Report

81-1330

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards. Any use of trade names is for descriptive purposes only and does not imply endoresment by the U.S.G.S.

[1] Department of Earth Sciences, Portland State University, Portland, Oregon 97207

[2] U.S. Geological Survey, Menlo Park, California 94025

INTRODUCTION

In 1979 and 1980, seven geothermal test wells were completed near Mount Hood, Oregon by the U.S. Geological Survey (USGS) as part of a joint study involving the U.S. Department of Energy (USDOE) the Oregon Department of Geology and Mineral Industries (DOGAMI), and the U.S. Forest Service (USFS). The drill holes were part of a concentrated effort to evaluate the geothermal potential of Mount Hood, a 3424 m Oregon Cascade volcano that has had minor eruptive activity as recently as the mid-1800's (Crandell, 1980). One 1220 m well, called the Pucci drill hole, was drilled on the south slope of the mountain at an elevation of 1628 m, about 1 km SSW of Timberline Lodge near the base of the Pucci ski chairlift (3S/9E-7dbb) (Lat. 45° 19' 18", Long. 121° 42' 46") (Fig. 1). Drilling methods and specifications, drillers log, temperature data, and generalized lithology of the hole are

Figure 1 near here

given in Robison, Forcella, and Gannett (1981). Results of several geophysical surveys of the drill hole are on file with the Oregon Department of Geology and Mineral Industries, Portland, Oregon.

Ninety-one sample splits of drill cuttings from ~ 6.1 m intervals in the 610 m hole that was completed in 1979 were provided for this study. An additional 225 sample splits (3.05 m intervals) from 536 m to the bottom of the drill hole at 1220 m were added to the study following the 1980 deepening of the drill hole. A portion of the hole (from 536 to 610 m) was redrilled in 1980 due to caving at the bottom of the 1979 drill hole.

Stratigraphic and petrologic observations of the cuttings were made by the first author at the drill site using a binocular microscope. In the lab, the drill cuttings were wet sieved through a 200 mesh (0.074 mm) screen and both fractions were air dried and saved. Cuttings retained on the screen were systematically examined by binocular microscope. Nearly 200 slurry slides of finely-ground, hand-picked alteration material and representative rock types were X-rayed at 1°/min. from 3° to 38° 2θ using unfiltered Cu Kα radiation on a Norelco X-ray diffractometer equipped with a focusing monochrometer. Scanning electron microscope (SEM) examinations were made of several samples of alteration minerals using a Cambridge Stereoscan 180 that is capable of providing qualitative chemical data by energy-dispersive X-ray analysis (EDAX).

Many of the samples studied contained rounded, soft, buff-colored grains (frequently coated by a white calcite crust) of cement that was introduced during drilling. X-ray diffractograms of the exotic grains show calcite, portlandite, brownmillerite, vaterite, and thaumasite: a mineral association that is very suggestive of portland cement (Taylor, 1964). Other introduced drilling contaminants (comprising as much as 50 percent of some samples) include metal filings from drill steel and casing, often oxidized to orange iron-oxide staining and cementing material, and plastic and plant fragments from lost circulation material.

LITHOLOGIC LOG OF PUCCI DRILL CUTTINGS

The Pucci drill hole is sited near the headwaters of the west fork of the Salmon River in an area Crandell (1980) shows as a possible pathway for future pyroclastic flows, mudflows and floods and in a unit mapped by Wise

(1968, 1969) as Quaternary clastic debris that consists of reworked detritus and pyroclastic material. The drilled interval is composed of approximately 5 to 158.5 m thick units of this volcaniclastic material that are interbedded with 28 grayish pyroxene andesite flows that vary in thickness from 3 to 97.5 m (Fig. 2). Most samples of drill cuttings contain at least

Figure 2 near here

some contamination rock chips from higher in the drill hole. The volcaniclastic and andesitic flow intervals identified in Figures 2 and 3 are based upon the predominant character of the grains studied from each sample; unit thicknesses and boundaries are corrected to match geophysical logs. It is possible, however, that some of the thicker units, in particular, may have thin volcaniclastic debris or lava flow units that were not adequately represented by the recovered samples, or did not have a distinct signature on the electric logs and thus were not identified. The lithologic log of Figure 2 is divided into 2 intervals, 0 to 731.5 m and 731.5 to 1220 m, on the basis of different alteration mineral assemblages and degree of alteration.

0-731.5 m

Nineteen lava flows were identified in the upper 731.5 m of the Pucci drill hole. All but one of the flows, a black to brownish-black microvesicular olivine(?) basalt, consist of grayish pyroxene andesite with about 5-10 percent clear plagioclase (~0.5-3 mm) and 1-3 percent clear brown orthopyroxene (hypersthene) (0.1-3 mm) phenocrysts. Most X-rayed samples also contained abundant vapor-phase(?) α-cristobalite and magnetite and minor vapor-phase tridymite and clinopyroxene; a few samples have traces of quartz, K-feldspar(?) and an amphibole (probably hornblende). Nearly every flow has some degree of iron-oxide (hematite) alteration, but only flows 9, 14, 16, 18, and 19 contain minor amounts of one or more of the alteration minerals: montmorillonite, calcite, pyrite, chalcedony or α-cristobalite. The andesite flows are interbedded with volcaniclastic debris intervals. These debris units are probably of variable origin and may include colluvium, mudflow, landslide, or fluvial material. The angular to rounded varicolored pyroxene andesite rock chips contain clear plagioclase and brown hypersthene phenocrysts. Accessory minerals include abundant magnetite and vapor-phase(?) α-cristobalite and minor clinopyroxene, amphibole, K-feldspar(?), and vapor-phase tridymite. Nearly all of the debris units contain secondary alteration minerals that may include hematite, opal, gypsum(?), chalcedony, kaolinite, montmorillonite, pyrite, 10 A° mica, calcite, α-cristobalite, β-cristobalite, natroalunite, and quartz.

731.5-1220 m

From 731.5 m to the bottom of the drill hole at 1220 m, flows 20 to 28 consist of various shades of red, green, or gray pyroxene andesite. Phenocrysts are cloudy to clear plagioclase and pyroxene. Clinopyroxene appears to be dominant over orthopyroxene, although most mafic crystals are altered to green to blue-green montmorillonite. One X-ray trace contained minor vapor-phase(?) α-cristobalite (most α-cristobalite appears to have been altered to quartz or chalcedony?); no other accessory minerals were identified. Fracture or vein(?) and vug fillings consist of calcite, chalcedony, stilbite, laumontite, hematite, montmorillonite, magnetite, quartz, mordenite, chlorite, pyrite, and vermiculite(?).

The lava flows are interbedded with varicolored, subangular to rounded, hydrothermally altered, pyroxene andesite, volcaniclastic debris material. Secondary minerals identified from the debris units include calcite, chalcedony, hematite, montmorillonite, laumontite, stilbite, heulandite, chlorite, mordenite, pyrite, and epistilbite.

SECONDARY MINERALIZATION

The distribution of alteration minerals in the Pucci drill hole is shown in Figure 3. Iron oxide, identified as hematite on numerous X-ray traces, occurs in the majority of samples studied and was not included

Figure 3 near here

in the figure. The alteration minerals opal, α-cristobalite, β-cristobalite, 10 A° mica (illite or celadonite?), kaolinite, natroalunite, and gypsum were only identified in X-ray traces from volcaniclastic debris units above 731.5 m; some hydrothermal montmorillonite, chalcedony, calcite, quartz and pyrite also occur in these debris units (and in a few lava flows near the base of the interval). With the exception of quartz, all of the minerals listed could have formed due to near vent fumarolic alteration (Naboko, 1959; Crandell, 1971) and many representatives from this group of minerals have been found both near the summit and in debris deposits flanking Mount Hood (Bargar, 1980; Beeson, Keith and Bargar, 1980). The single quartz crystal fragment occured near the base of the interval and probably originated from erosion of older volcanic rocks. A few flows near the base of the interval contain traces of hydrothermal minerals that could be contamination from the interbedded debris units.

Below 731.5 m, the drill cuttings contain an almost completely different set of hydrothermal minerals that include: chalcedony, quartz, montmorillonite, vermiculite(?), chlorite, calcite, pyrite, and several zeolite minerals: epistilbite, heulandite, laumontite (Fig. 4), mordenite (Fig. 5), and stilbite (Fig. 6).

Figures 4, 5, and 6 near here

The maximum temperature measured in the Pucci drill hole was 80°C at the hole bottom (J. H. Robison, U. S. Geological Survey, personal communication, 1981). Kristmannsdottir (1978) summarizes temperature data for hydrothermal alteration minerals found in basaltic rocks from Iceland geothermal areas. Pyrite and calcite occur over a wide temperature range. The zeolite minerals epistilbite, heulandite, mordenite, and stillbite generally are found below 100°C, whereas laumonitite begins to form by replacement of other zeolites at temperatures above 100° to 120°C and is stable up to 230°C (Krismannsdottir and Tomasson, 1978). Chalcedony has been found at temperatures lower than 100°C while quartz forms at higher temperatures. montmorillonite occurs at low temperature, below 200°C, and chlorite begins to form above 200°C.

Kristmannsdottir's (1978) data would suggest that all of the hydrothermal minerals found below 731.5 m in the Pucci drill hole, except for laumontite, quartz and chlorite, could have formed at the temperature of the present geothermal regime. Even laumontite could conceivable have formed at the temperature measured in the Pucci drill hole because warm spring water (40°-65°C) in New Zealand has been shown to be supersaturated with respect to laumontite (Barnes, Downes, and Hulston, 1978). However, the presence of quartz (although possibly of detrital origin?) and especially chlorite suggest that the temperature conditions may have been warmer in the past. Similar arguments have been used by Tomasson and Kristmannsdottir (1974) to suggest retrograde metamorphism in some low temperature geothermal areas of Iceland.

CONCLUSIONS

A geologic cross-section, drawn by Wise (1969), is reproduced here as Figure 7. The Pucci drill hole is projected about 2 km northwestward to

Figure 7 near here

intersect with the trace of the cross-section (see dashed line of Figure 1 for approximate cross-section trend). Wise's cross-section suggests that if a 1200 m drill hole were put down at the projected Pucci location it would penetrate ~500 m of the main shield-building deposits of Mount Hood, ~350 m of upper Miocene[1] volcanic material and ~350 m of Late Miocene Rhododendron Formation. No rock cuttings of the Rhododendron Formation were identified in the Pucci drill hole; however, the upper 731.5 m consists of interbedded pyroxene andesite flows and volcaniclastic debris units of the Mount Hood main shield-building material and the bottom 488.5 m are highly altered andesite lava flows and interbedded volcaniclastic debris units that are interpreted here as being upper Miocene.

Wise (1969) describes the upper Miocene (see footnote 1) pyroxene andesite lavas south of Mount Hood as fractured and extensively altered. His appendix indicates that montmorillonite, chalcedony, and opal were identified as alteration minerals. On Zigzag Mountain to the west of Mount Hood, Wise found that the upper Miocene (see footnote 1) lava flows are

[1] On the basis of K-Ar ages of 4-7 m.y., Wise (1969) indicates that these rocks are lower Pliocene; however, recent revision of the geologic time scale (Sohl, and Wright, 1980) suggests that they are Late Miocene.

about 1500 feet (457 m) thick and that they contain some flows with large (up to 10 mm) hypersthene phenocrysts.

Figures 2 and 3 show a major break between comparatively fresh lava flows and debris units above 731.5 m and the extensively altered units in the bottom 488.5 m of the drill hole. Geophysical logging data of Robison and others (1981) suggest fracturing in a large section of the drill hole from 942 to 1039 m. Rock chips containing slickensided(?) montmorillonite and chalcedony and zeolite mineralization in veins(?) or fractures are abundant throughout the lower third of the drill hole. The groundmass and mafic(?) phenocrysts in this section show considerable alteration with some flows containing large pyroxene(?) phenocrysts altered to blue-green montmorillonite.

Alteration minerals in drill cuttings from interbedded lava flows and volcaniclastic debris units penetrated by the Pucci drill hole appear to have originated from two different sources. From 0 to 731.5 m the alteration mineral assemblage, primarily concentrated in the debris units, suggests near vent fumarloic alteration of material subsequently transported by sedimentary processes. The majority of lava flows in this drill hole interval are mostly fresh with some hematite alteration. Below 731.5 m both the lava flows and volcaniclastic debris units are very altered and the hydrothermal mineral assemblage is quite similar to that described in older rocks related to Western Cascade volcanism (Peck and others, 1964; Beeson, Keith and Bargar, 1980).

A reconstruction of the sequence of geologic events suggested by the drill cuttings recovered from the Pucci drill hole includes: (1) deposition of a thick section of interbedded pyroxene andesite flows and volcaniclastic debris units of Late Miocene (see footnote 1) age; (2) hydrothermal alteration of the entire stratigraphic section; possibly due to the onset of a newer Pliocene or later eruptive period related to construction of the present Mount Hood edifice about 660,000 years ago (White, 1979, 1980); (3) deposition of numerous pyroxene andesite lava flows (and one olivine basalt flow) along with interbedded volcaniclastic debris units that brought fumarolic alteration minerals down from vent areas at the top of the mountain; and (4) secondary minerals found in the lower part of the Pucci drill hole suggest that low grade hydrothermal alteration may still be continuing at the present time, although the data are ambiguous.

1504c

ACKNOWLEDGMENTS

This study benefitted from the laboratory assistance of J. R. Boden and scanning electron microscope work of R. L. Oscarson. M. C. Guffanti and M. H. Beeson critically reviewed the manuscript.

REFERENCES

Bargar, K. E., 1980, Lithologic log of drill cuttings for Northwest Geothermal Corp. drill hole at Lost Creek near Mount Hood, Oregon: U.S. Geological Survey Open-file Report 80-1166, 17p.

Barnes, I., Downes, C. J., and Hulston, J. R., 1978, Warm springs, South Island, New Zealand, and their potentials to yield laumontite: American Journal of Science, v. 278, p. 1412-1427.

Beeson, M. H., Keith, T. E. C., and Bargar, K. E., 1980, Secondary mineralization in the Mt. Hood area, Oregon: Geological Society of America, Abstracts with Programs, 12, p. 96.

Crandell, D. R., 1971, Postglacial lahars from Mount Rainier Volcano, Washington: U.S. Geological Survey Professional Paper 677, 75 p.

Crandell, D. R., 1980, Recent eruptive history of Mount Hood, Oregon, and potential hazards from future eruptions: U.S Geological Survey Bulletin 1492, 81 p.

Kristmannsdottir, H., 1978, Alteration of basaltic rocks by hydrothermal activity at 100° to 300°C: <u>in</u> M. M. Mortland and V. C. Farmer, (eds.) Proceedings of the Sixth International Clay Conference, p. 359-367, Elsevier, The Netherlands.

Kristmannsdottir, H., and Tomasson, J., 1978, Zeolite zones in geothermal areas in Iceland: <u>in</u> L. B. Sand, and F. A., Mumpton, (eds.) Natural Zeolites: Occurrence. Properties, Use. p. 277-284, Pergamon, New York.

Naboko, S. I., 1959, Volcanic exhalations and products of their reactions as exemplified by Kamchatka-Kuriles volcanoes: Bulletin Volcanologique, 20, p. 121-136.

Peck, D. L., Griggs, A. B., Schlicker, H. G., Wells, F. G., and Dole, H. M., 1964, Geology of the Central and Northern parts of the Western Cascade Range in Oregon: U.S. Geological Survey Professional Paper 449, 56 p.

Robison, J. H., Forcella, L. S., and Gannett, M. W., 1981, Data from geothermal test wells near Mount Hood, Oregon: U.S. Geological Survey Open-file Report 81-

Sohl, N. F., and Wright, W. B., 1980, Changes in stratigraphic nomenclature by the U.S. Geological Survey: U.S. Geological Survey Bulletin 1502-A, 138 p.

Taylor, H. F. W., (ed.), 1964, The chemistry of cements: v. 1, Academic Press, New York, 460 p.

Tomasson, J., and Kristmannsdottir, H., 1974, Investigation of three low-temperature geothermal areas in Reykjavik and its neighborhood: Proceedings International Symposium on Water Rock Interaction. Prague, Czechoslovakia, p. 243-249.

White, C. M., 1979, Geology and geochemistry of Mt. Hood volcano: in Hull, D. A., and Riccio, J. F., (eds.) Geothermal Resource Assessment of Mount Hood: U.S. Department of Energy, contract no. EG-77-C-06-1041, U.S. Government Printing Office, Washington D.C., 330 p.

White, C. M., 1980, Geology and geochemistry of Mt. Hood volcano: State of Oregon Department of Geology and Mineral Industries Special Paper 8, 26p.

Wise, W. S., 1968, Geology of the Mt. Hood volcano: Andesite Conference guidebook: International Upper Mantle Project, Science Report 16-S and Oregon Department of Geology and Mineral Industries Bulletin 62 p. 81-98.

Wise, W. S., 1969, Geology and petrology of the Mt. Hood area: A study of Cascade volcanism: Geological Society of America Bulletin, 80, p. 969-1006.

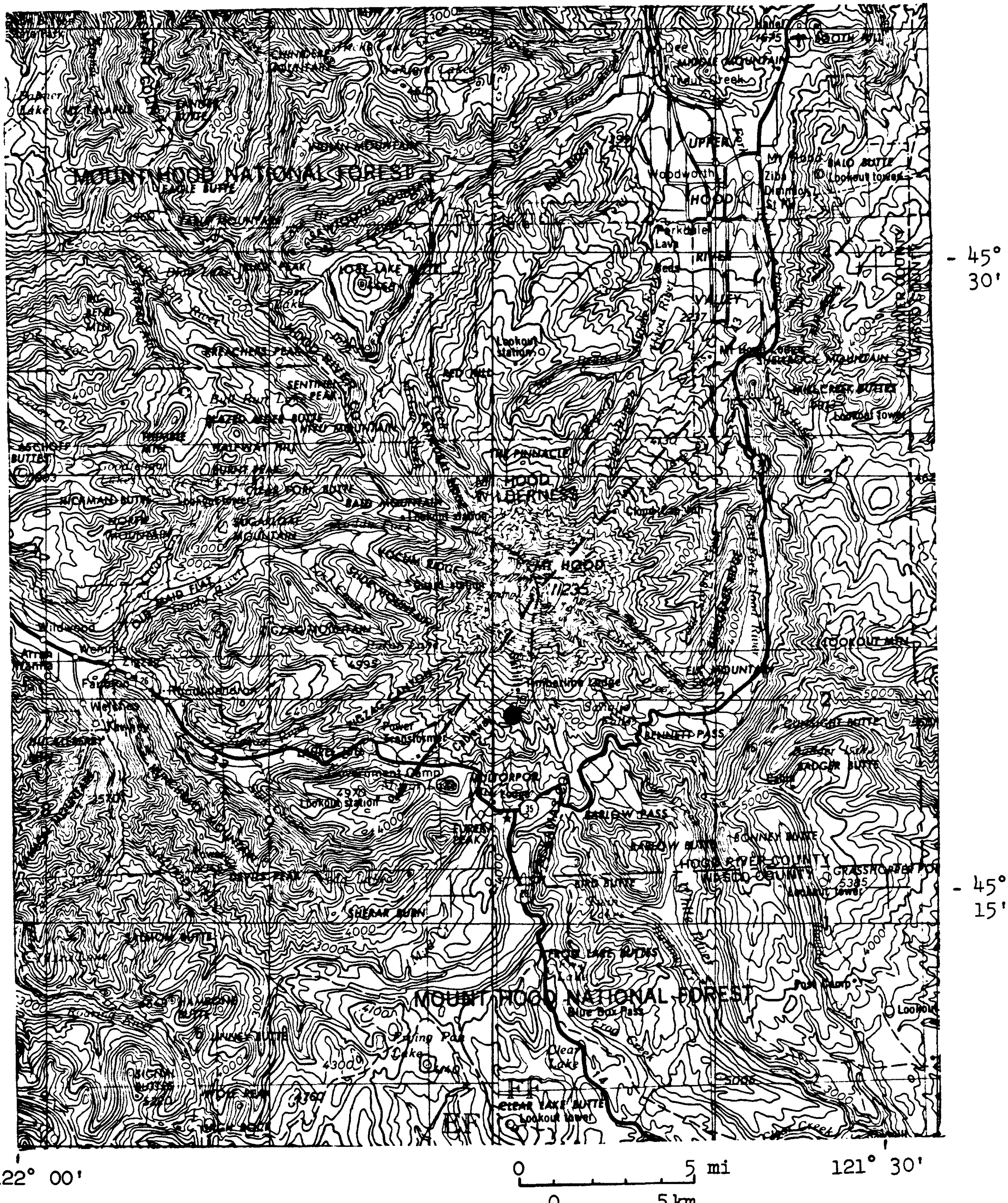
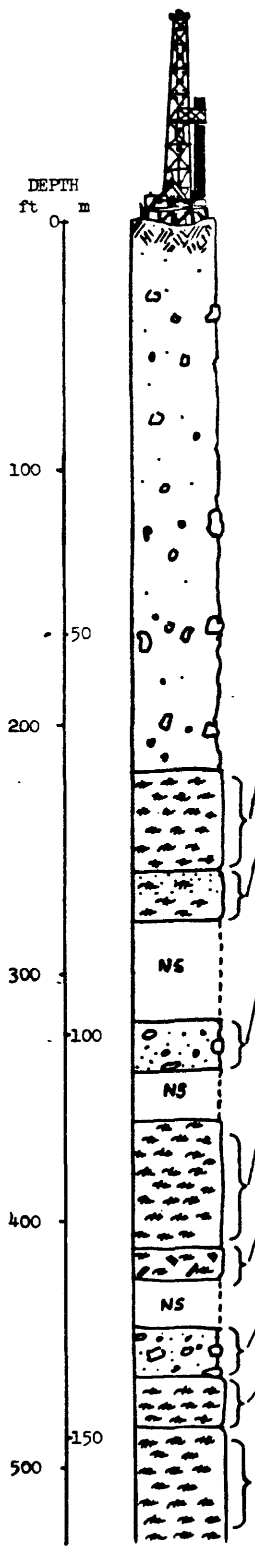


Figure 1. Location map of Pucci drill hole. From the Dalles 2° sheet. Dashed line shows trend of Figure 7 cross-section.

Figure 2. Lithologic log of the Pucci geothermal test well. [NS--no sample available]



0-67.1 m — Colluvium and other volcanic debris. Mixture of subangular to rounded, chiefly medium gray and reddish brown pyroxene andesite. Phenocrysts are clear plagioclase and brown orthopyroxene. Whole rock X-ray diffractograms show considerable magnetite and α-cristobalite and traces of clinopyroxene and amphibole; vesicular oxidized clasts also contain hematite. X-ray traces of a few orange-stained and white-bleached pyroxene andesite grains show tridymite, K-feldspar(?) and opal. Gypsum was identified by SEM.

67.1-79.2 m — Flow #1. Medium gray pyroxene andesite. Phenocrysts consist of 5% clear plagioclase (1-2mm) and 1-2% clear brown orthopyroxene (up to 3 mm). X-ray study also shows α-cristobalite, tridymite(?), quartz, magnetite and K-feldspar(?).

79.2-85.3 m — Flow #2. Very light gray, slightly vesicular pyroxene andesite. Contains up to 10% clear plagioclase (3 mm) and 2-3% honey-brown orthopyroxene (1 mm). α-cristobalite, magnetite, K-feldspar(?), hematite and tridymite were identified by X-ray diffraction.

97.5-103.6 m — Volcaniclastic debris. Mixture of subrounded to subangular andesitic lavas; mostly light gray pyroxene andesite which has 5-10% clear plagioclase and slightly altered pyroxene phenocrysts. X-ray diffraction show plagioclase, orthopyroxene, clinopyroxene, amphibole(?), tridymite, α-cristobalite(?), magnetite and hematite.

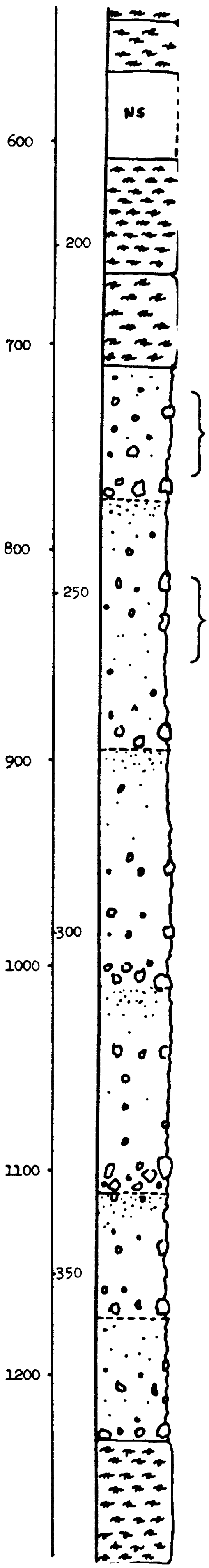
109.7-125.0 m — Flow #3. Light gray microvesicular pyroxene andesite. Has 8-10% clear plagioclase (3 mm) and 3% dark pyroxene (3-4 mm) (clinopyroxene and orthopyroxene in X-ray) phenocrysts. The groundmass contains disseminated magmetite; K-feldspar(?), α-cristobalite and tridymite were identified by X-ray.

125.0-128.6 m — Flow #4. Medium gray highly porphyritic pyroxene andesite. Phenocrysts are 15-20% clear, often anhedral, plagioclase and 3-5% pyroxene (both clinopyroxene and orthopyroxene in X-ray) (1-2 mm). Hematite, magnetite, tridymite, α-cristobalite and K-feldspar(?) were also identified in X-ray.

134.7-140.8 m — Volcaniclastic debris. Mostly subrounded pyroxene andesites. An X-ray trace of one light gray andesite grain showed plagioclase, α-cristobalite, magnetite, amphibole, clinopyroxene and orthopyroxene.

140.8-146.9 m — Flow #5. Very dark reddish gray to red black glassy, vesicular, pyroxene andesite. Phenocrysts are 5% clear plagioclase (1-2 mm) and brown orthopyroxene. Magnetite, hematite, amphibole, clinopyroxene and α-cristobalite were also identified by X-ray.

146.9-165.2 m — Flow #6. Reddish gray (oxidized) vesicular hypersthene andesite. Phenocrysts consist of 3-5% clear plagioclase (4 mm) and 1-2% brown hypersthene (1 mm). X-ray pattern also shows α-cristobalite, magnetite, hematite, and clinopyroxene(?).



165.2-172.8 m — Flow #7. Medium gray fine-grained pyroxene andesite. Phenocrysts are 5% clear plagioclase (2-3 mm) and <1% pyroxene (1 mm). An X-ray trace showed plagioclase, orthopyroxene, α-cristobalite, magnetite, and K-felospar(?).

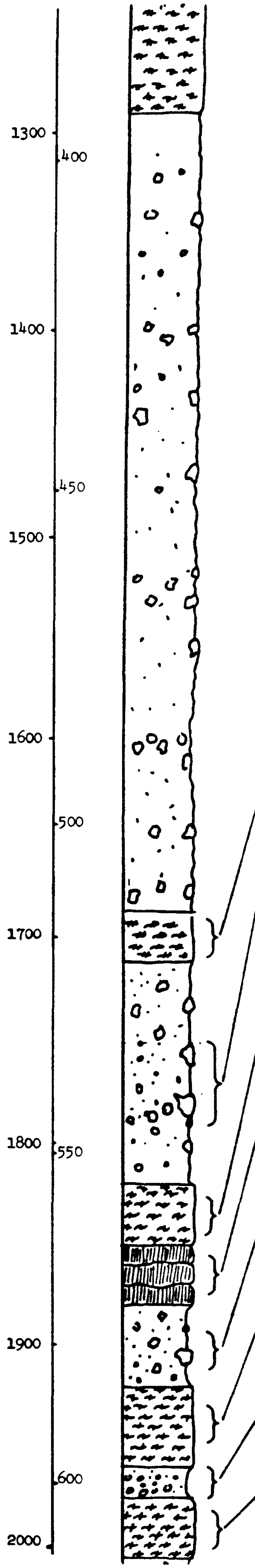
184.4-202.7 m — Flow #8. Medium to light gray pyroxene anaesite. Has two sizes of clear plagioclase phenocrysts (1x1 mm and 1x0.1 mm) comprising 3-5% of sample; another 1% of phenocrysts are clear brown orthopyroxene (1 mm). X-ray diffractogram also shows α-cristobalite, clinopyroxene, magnetite, ana K-felospar.

202.7-216.4 m — Flow #9. Medium gray pyroxene andesite. Phenocrysts are composed of 10% clear plagioclase (1-2 mm) and 1-2% brown orthopyroxene (0.5-1 mm). Magnetite, triaymite, ana α-cristobalite were iaentified by X-ray. One sample from 215.5 m contained a trace of montmorillonite.

216.4-374.9 m — Volcaniclastic volcanic debris: colluvium and mudsliae material typical of large stratovolcanoes. A mixture of angular to subangular pyroxene andesite grains that vary in color from light-medium-dark gray, black, brown and rea with a few orange-stained and white-bleached grains sprinkled throughout. X-ray diffraction and binocular microscope studies show that most of the grains consist of clear plagioclase and brown orthopyroxene phenocrysts, magnetite, and α-cristobalite; minor constituents may include hematite, clinopyroxene, amphibole, triaymite, and K-feldspar(?). The thickness was subaiviaed on the basis of the presence or absence of several alteration minerals.

216.4-236.2 m	chalcedony, kaolinite, montmorillonite, pyrite, 10 A° mica.
236.2-272.8 m	mostly fresh, some iron staining.
272.8-338.3 m	calcite, chalceaony, α-cristobalite, kaolinite, β-cristobalite, montmorillonite, natroalunite, opal, pyrite, 10 A° mica.
338.3-356.6 m	fresh.
356.6-374.9 m	chalcedony, pyrite.

374.9-393.2 m — Flow #10. Light gray, slightly vesicular pyroxene andesite. Phenocrysts are clear plagioclase, brownish orthopyroxene, and rare hornblende; the grounamass contains finely disseminated magnetite. Clinopyroxene, hematite, and α-cristobalite were identified from X-ray traces.



393.2-513.6 m Volcaniclastic volcanic debris: Colluvium and landslide material; possibly minor fluvial material. Mixture of angular to subangular mostly medium gray pryoxene andesite and subordinant light gray, dark gray, black, reddish and brown pyroxene andesite grains. Phenocrysts are clear plagioclase, brown orthopyroxene, and green clinopyroxene. X-ray diffraction studies also show magnetite, tridymite, amphibole(?), and K-feldspar(?). Most samples have a few orange-stained or white-bleached grains that contain one or more of the alteration minerals: calcite, chalcedony, or pyrite.

513.6-522.7 m Flow #11. Medium-dark gray pyroxene andesite. Phenocrysts consist of <5% clear plagioclase (1 mm) and rare small (<0.5 mm) brown orthopyroxene crystals. X-ray patterns also show α-cristobalite and tridymite.

522.7-554.7 m Volcaniclastic debris. Mixture of subangular to subrounded grains of light, medium and dark gray, brownish, reddish vesicular, and black glassy andesite. X-ray studies show plagioclase, orthopyroxene, α-cristobalite, hornblende, tridymite, magnetite, and K-feldspar(?). A few frosted calcite and white or pink silica grains were observed. X-ray traces of iron stained and siliceous grains also showed α-cristobalite, montmorillonite, kaolinite, 10 A° mica (illite) and hematite.

554.7-563.9 m Flow #12. Reddish gray to medium gray, porphyritic pyroxene andesite. Phenocrysts consist of 15% clear plagioclase (1 mm), often occuring as glomerocrysts, and 3-5% brown hypersthene (0.5 mm). Also α-cristobalite, tridymite, clinopyroxene and hematite in X-ray.

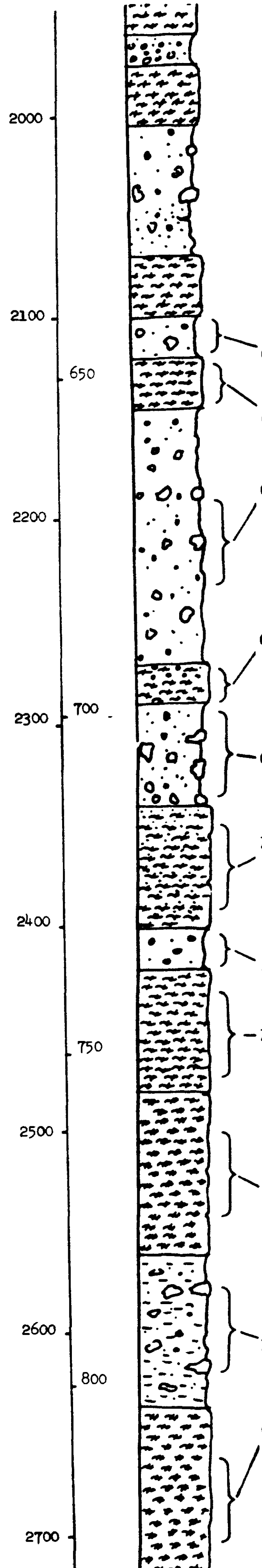
563.9-573.0 m Flow #13. Black-brownish black, diktytaxitic, olivine(?), basalt. Many grains are microvesicular and are frequently quite oxidized. Phenocrysts are 1-2% clear plagioclase (0.5 mm) and very minor yellow-green olivine(?). α-cristobalite and orthopyroxene are present in X-ray traces.

573.0-585.2 m Volcaniclastic debris. Mixture of subangular to rounded light and medium gray andesite that contain plagioclase, α-cristobalite, orthopyroxene, clinopyroxene, tridymite(?), and hornblende in X-ray. Calcite grains are also found in most samples.

585.2-597.4 m Flow #14. Medium to medium dark gray porphyritic pyroxene andesite with 7-12% clear plagioclase (0.5 mm) phenocrysts. α-cristobalite, clinopyroxene, hematite, tridymite, chalcedony, calcite, pyrite, and montmorillonite were identified by X-ray diffraction.

597.4-602.0 m Volcaniclastic material consisting of a mixture of subangular to rounded, varicolored andesite; some of which is quite altered. X-ray traces show plagioclase, α-cristobalite, tridymite, montmorillonite, calcite and opal(?).

602.0-611.1 m Flow #15. Dark medium gray hypersthene andesite. Phenocrysts consist of 10% clear plagioclase (1-1.5 mm), and 2-3% clear brown hypersthene (<0.5 mm). The groundmass is crystalline and contains plagioclase, orthopyroxene, α-cristobalite, tridymite and hematite alteration by X-ray.



611.1-630.9 m — Volcaniclastic material. A mixture of angular to rounded, varicolored andesite grains. Alteration mineralogy by X-ray diffraction is calcite, chalcedony, montmorillonite, hematite, α-cristobalite, natroalunite, and kaolinite(?).

630.9-640.1 m — Flow #16. Medium dark gray pyroxene andesite. Phenocrysts consist of 10% clear plagioclase (1.0 mm) and 2% hypersthene (0.5 mm). α-cristobalite, clinopyroxene and montmorillonite also detected in X-ray. Has some oxidized clasts and calcite.

640.1-646.2 m — Volcaniclastic debris consisting of subangular to subrounded varicolored andesite grains. Alteration minerals by X-ray are calcite, hematite, chalcedony, α-cristobalite, and natroalunite.

646.2-653.8 m — Flow #17. Brownish-gray pyroxene andesite. Phenocrysts are ~7% clear plagioclase (0.5 mm) and <1% very small (0.1 mm) pyroxene crystals. α-cristobalite and tridymite in X-ray.

653.8-691.9 m — Volcaniclastic debris. Mixture of subangular to subrounded, rarely rounded, varicolored andesite grains. Hematite is very abundant. Other alteration minerals include calcite, chalcedony, natroalunite, kaolinite, montmorillonite, α-cristobalite, quartz, and 10 A° mica.

691.9-698.0 m — Flow #18. Dark gray, slightly vesicular hypersthene andesite. 10-15% clear plagioclase (1 mm), brown hypersthene (0.2-0.5 mm), often as glomerocrysts, and rare larger augite phenocrysts. Groundmass(?) α-cristobalite in X-ray. Hematite coats ~20% of chips. Traces of calcite, green clay--montmorillonite(?) and chalcedony.

698.0-713.2 m — Volcaniclastic debris. A mixture of subangular to subrounded, varicolored andesite grains. X-ray shows presence of montmorillonite, chalcedony, and α-cristobalite. Also contains calcite, hematite, and green clay-montmorillonite(?).

713.2-731.5 m — Flow #19. Dark gray to orange-red, very oxidized, vesicular pyroxene andesite. Most chips are 75% oxidized (hematite?). Phenocrysts are 25-30% clear plagioclase (1.0 mm) and 3-5% clear brown orthopyroxene (0.1-0.5 mm), often as glomerocrysts. Groundmass is glassy. Alteration minerals identified by X-ray include: chalcedony, hematite, calcite, montmorillonite, and α-cristobalite.

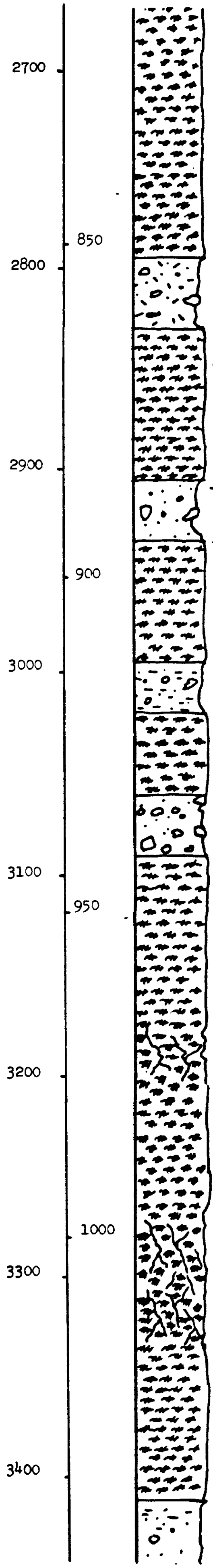
731.5-737.6 m — Volcaniclastic debris. Mixture of subangular to rounded, varicolored andesite grains. Few grains contain calcite, chalcedony(?), and white and green clay (montmorillonite?).

737.6-755.9 m — Flow #20. Brick orange pyroxene andesite. Has some autoclastic aspects. Phenocrysts are white plagioclase. Clinopyroxene mostly altered to green montmorillonite in X-ray. X-ray traces also suggest that α-cristobalite has altered to quartz or chalcedony. Groundmass is soft and altered to iron oxide and clay. Alteration material and open space deposits consist of calcite, chalcedony (in part colliform), stilbite, laumontite, hematite, and montmorillonite in X-ray.

755.9-780.3 m — Flow #21. Dark brownish-gray (rarely greenish-gray) pyroxene andesite. Phenocrysts are 2-3% clear, red or green stained plagioclase (1-2 mm). X-ray diffractograms also show clinopyroxene, orthopyroxene(?), montmorillonite, hematite and quartz or chalcedony. Mafics appear to be mostly altered to blue-green montmorillonite. Several X-ray traces of fracture fillings show green montmorillonite, stilbite, laumontite, chalcedony, and calcite. One grain had a crust of magnetite crystals.

780.3-803.2 m — Volcaniclastic debris. Mixture of subangular to subrounded hematite altered pyroxene andesites. Fracture fillings of laumontite, stilbite, chalcedony, green montmorillonite, calcite, and heulandite in X-ray.

803.2-851.9 m — Flow #22. Very dark green to dark greenish-brown, hydrothermally altered pyroxene andesites. Plagioclase phenocrysts are cloudy to white. Whole rock X-ray traces show plagioclase, clinopyroxene, quartz or chalcedony(?), montmorillonite and hematite. Fracture filling minerals consist of stilbite, laumontite, calcite, chalcedony and montmorillonite. One sample also had clear crystalline quartz cavity(?) filling.



851.9-862.6 m — Volcaniclastic material consisting of a mixture of subangular to subrounded pyroxene andesite grains. Secondary minerals found in altered andesite grains and fractures or vein fillings are calcite, chalcedony, hematite, heulandite, montmorillonite, laumontite, and chlorite.

862.6-885.4 m — Flow #23. Moderate brownish-red to grayish-green fine-grained pyroxene andesite. Plagioclase phenocrysts are clear to cloudy; pyroxene is altered to bluish-green montmorillonite. Alteration minerals are: chalcedony, hematite, quartz, calcite, stilbite, laumontite, and montmorillonite.

885.4-894.6 m — Volcaniclastic material. Mixture of subangular to subrounded hydrothermally altered andesitic lavas. Secondary minerals include hematite, stilbite, chalcedony, montmorillonite, calcite, and laumontite.

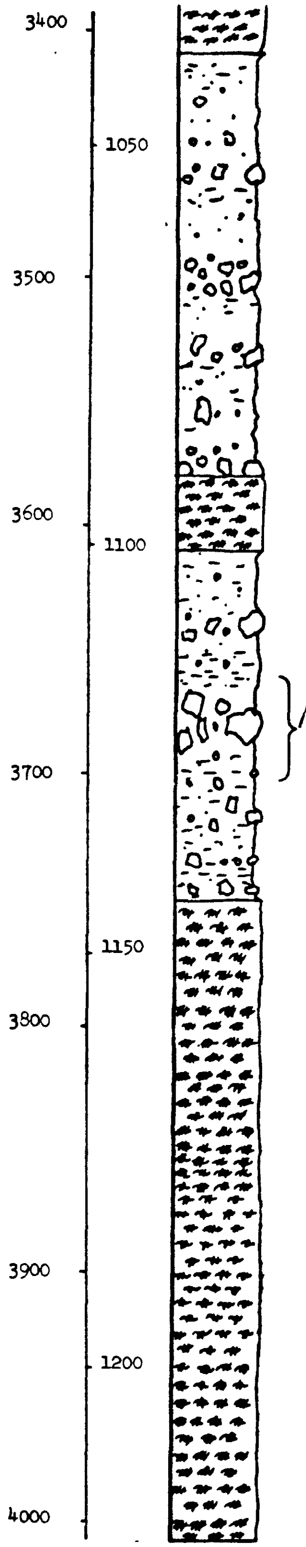
894.6-912.9 m — Flow #24. Dark greenish-gray to dark brownish-gray hydrothermally altered pyroxene andesite. Groundmass is soft and has altered to montmorillonite. Rare 1 mm cloudy plagioclase phenocrysts; α-cristobalite identified on 1 X-ray trace. Cuttings contain green montmorillonite fracture filling and stilbite, chalcedony, quartz, hematite, calcite and mordenite were identified in X-ray.

912.9-920.5 m — Volcaniclastic debris consisting of subangular to subrounded hydrothermally altered andesites. Alteration minerals are chalcedony, stilbite, mordenite, montmorillonite, hematite, and epistilbite.

920.5-932.7 m — Flow #25. Moderate reddish-brown intensely altered andesite. Original texture is obscured but was fairly porphyritic. Has much secondary stilbite, calcite, chalcedony, mordenite, hematite, laumontite, and montmorillonite.

932.7-941.8 m — Epiclastic material. A mixture of subangular to subrounded andesite grains. Secondary minerals identified in interval include stilbite, laumontite, mordenite, hematite, montmorillonite, and chalcedony.

941.8-1039.4 m — Flow #26. Thick series of altered, dark greenish-gray to grayish-olive green, porphyritic, pyroxene andesites. Phenocrysts are 5-10% plagioclase (2-5 mm), rarely up to 8 mm; pyroxenes (orthopyroxene? in X-ray) are seldom present and are mostly altered to green montmorillonite. α-cristobalite is altered to quartz or chalcedony(?). Alteration varies from minor hematite and montmorillonite altered groundmass to extremely intense and apparently fracture controlled alteration. Intensely altered clasts, which may account for ~50% of some sample intervals, consist predominantly of orange-pink-purple-green-white mottled montmorillonite with evidence of shearing and microbrecciation. Fracture zones shown on the lithologic column are based upon cuttings and geophysical logging data (Robison and others, 1981). Other secondary fracture or vug secondary minerals include mordenite, stilbite, chalcedony, calcite and laumontite.



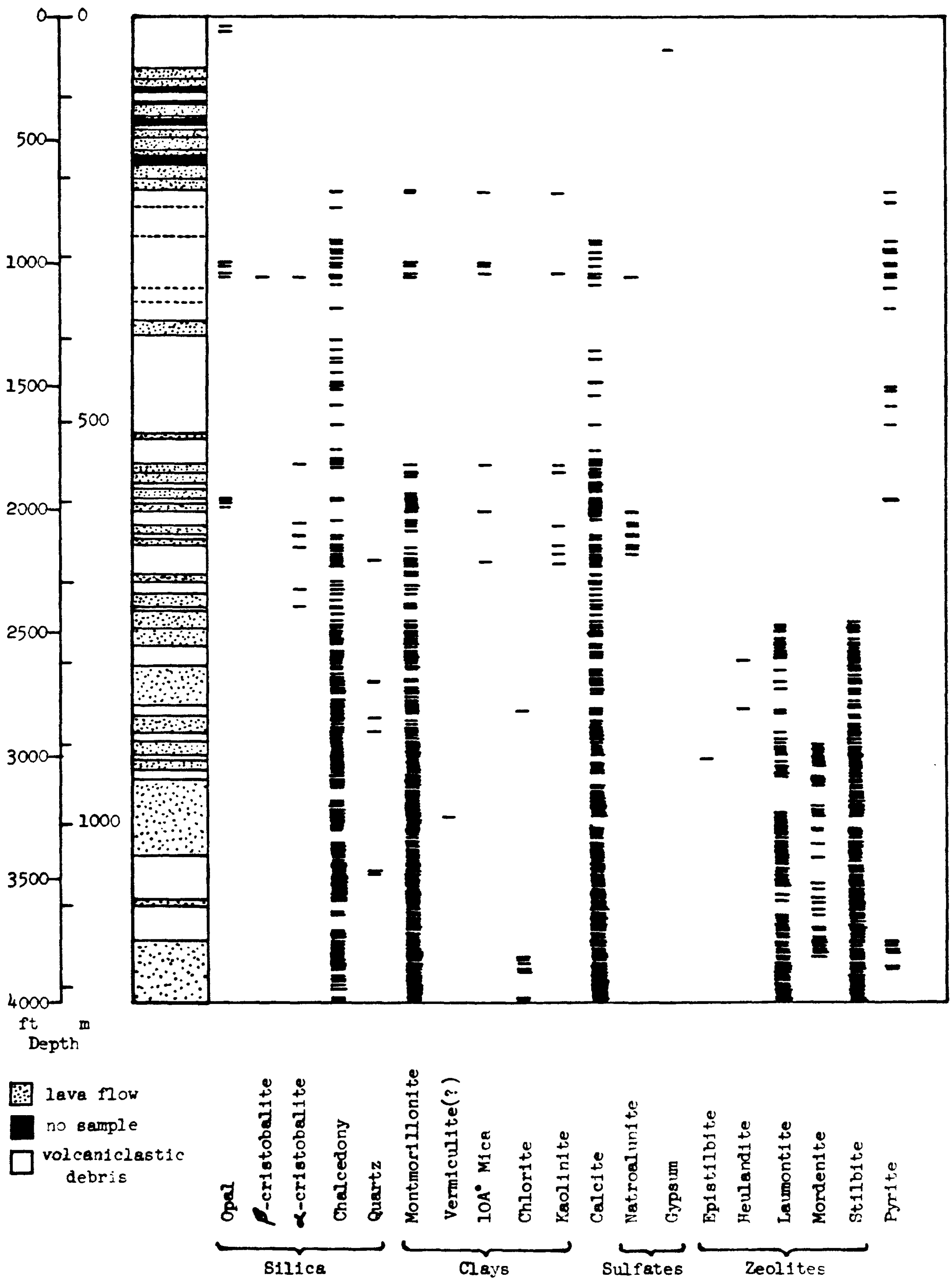
1039.4-1091.2 m Thick section of subangular to subrounded epiclastic andesitic material; probably a series of mudflows and/or colluvial debris. Most samples are a mixture of various colored andesite grains although some sample intervals are dominated by one color of grains. Secondary minerals are montmorillonite, mordenite, chalcedony, stilbite, calcite, laumontite, hematite, and quartz.

1091.0-1100.3 m Flow #27. Dark greenish-gray to grayish-black altered pyroxene andesite. Phenocrysts are 10%, often red stained, plagioclase (up to 1 cm but generally smaller) and 5-7% pyroxene (~1 mm). Apparently α-cristobalite altered to quartz or chalcedony(?). Other secondary minerals identified are montmorillonite, calcite, stilbite, and mordenite. (Similar to lavas from 941.8 to 1039.4 m).

1100.3-1143.0 m Volcaniclastic material similar to 1039.4 to 1091.2 m. A mixture of subangular to subrounded varicolored andesitic grains. Contains some of the most intensely altered lavas encountered in the drill hole. Secondary minerals are calcite, stilbite, chalcedony, montmorillonite, mordenite, laumontite, and pyrite.

1143.0-1221.1 m Flow #28. Thick dark grayish-green to grayish-brown pyroxene andesite section. Contains 15-20% cloudy or clear to slightly green or red stained plagioclase phenocrysts (~1 mm; some up to 2 mm) and 3-5% mostly altered pyroxene (hypersthene and augite) (0.5 mm). Groundmass is fairly coarse. Secondary minerals are montmorillonite, stilbite, laumontite, calcite, chalcedony, pyrite, mordenite, and traces of chlorite.

Figure 3. Distribution of secondary minerals in the Pucci drill hole.



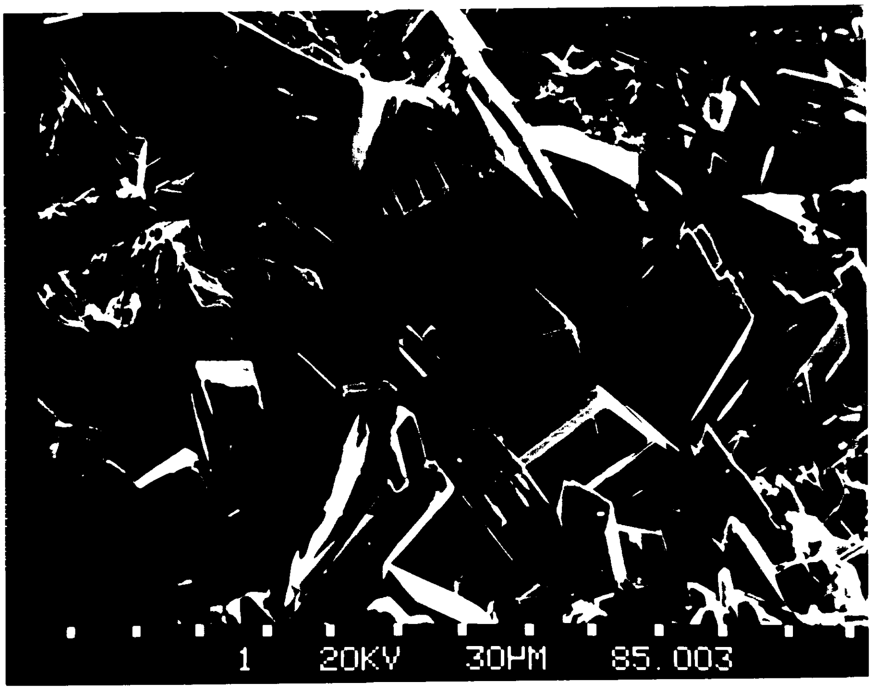


Figure 4. Scanning electron micrograph of intergrown laumontite crystals from vein filling at 1125-1128 m. Distance between white tick marks at bottom is 30 microns.

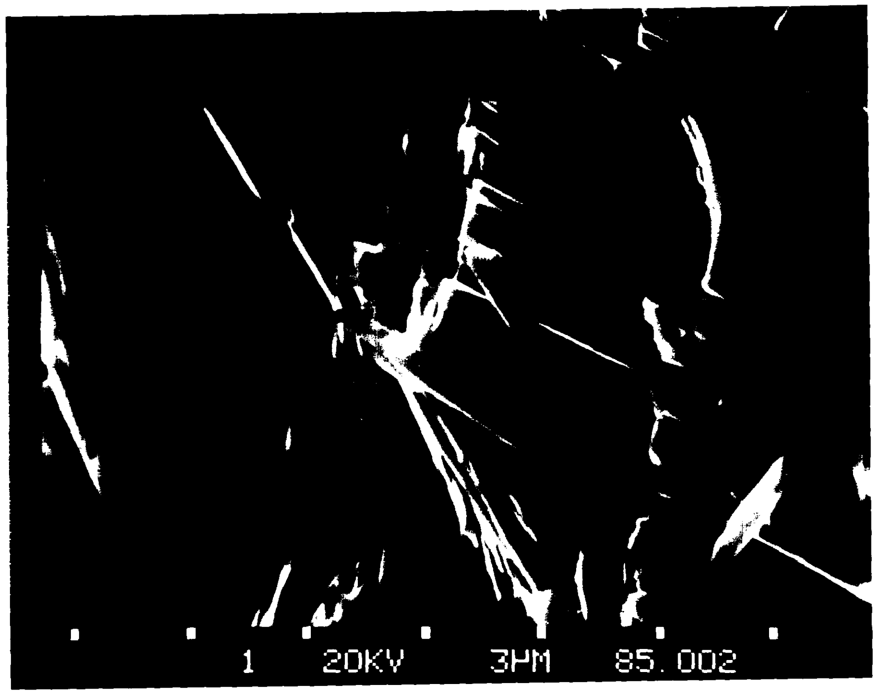


Figure 5. Scanning electron micrograph of fibrous mordenite crystals from 1161-1164 m. Distance between white tick marks at bottom is 3 microns.

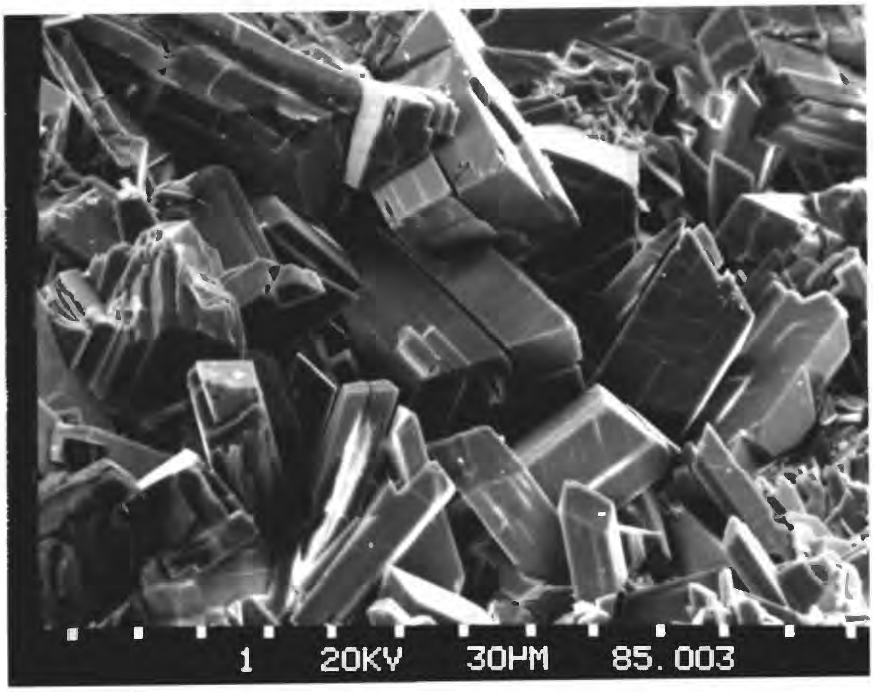


Figure 4. Scanning electron micrograph of intergrown laumontite crystals from vein filling at 1125-1128 m. Distance between white tick marks at bottom is 30 microns.

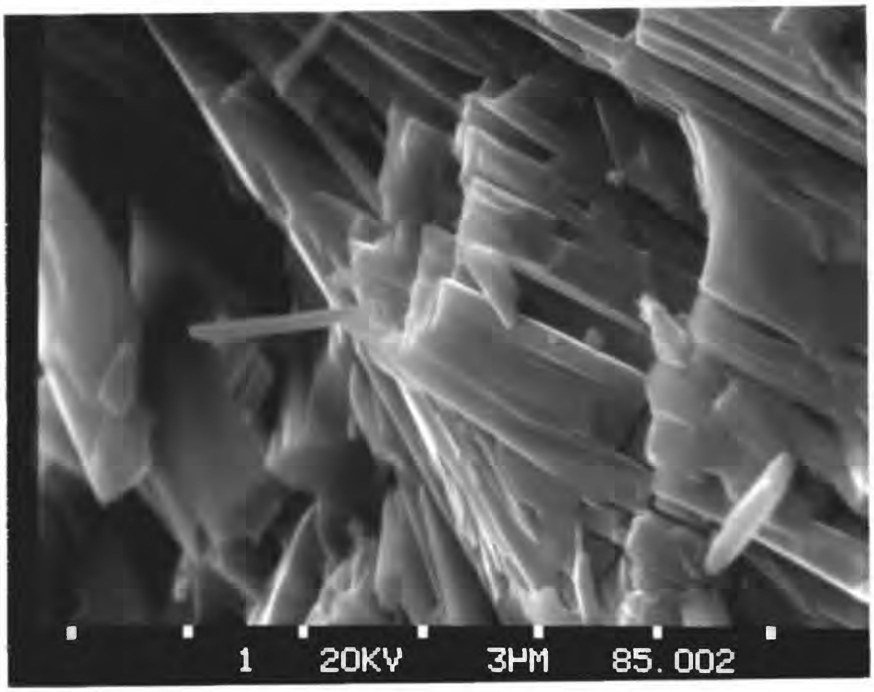


Figure 5. Scanning electron micrograph of fibrous mordenite crystals from 1161-1164 m. Distance between white tick marks at bottom is 3 microns.

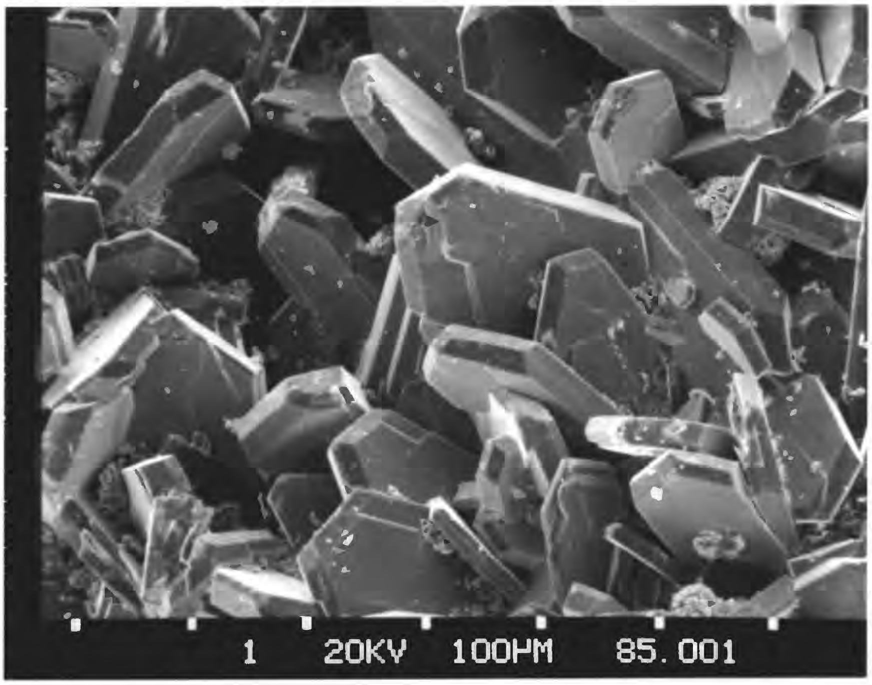


Figure 6. Scanning electron micrograph of intergrown tabular crystals of stilbite with later coatings of montmorillonite crystals from 966-969 m. Distance between white tick marks at bottom is 100 microns.

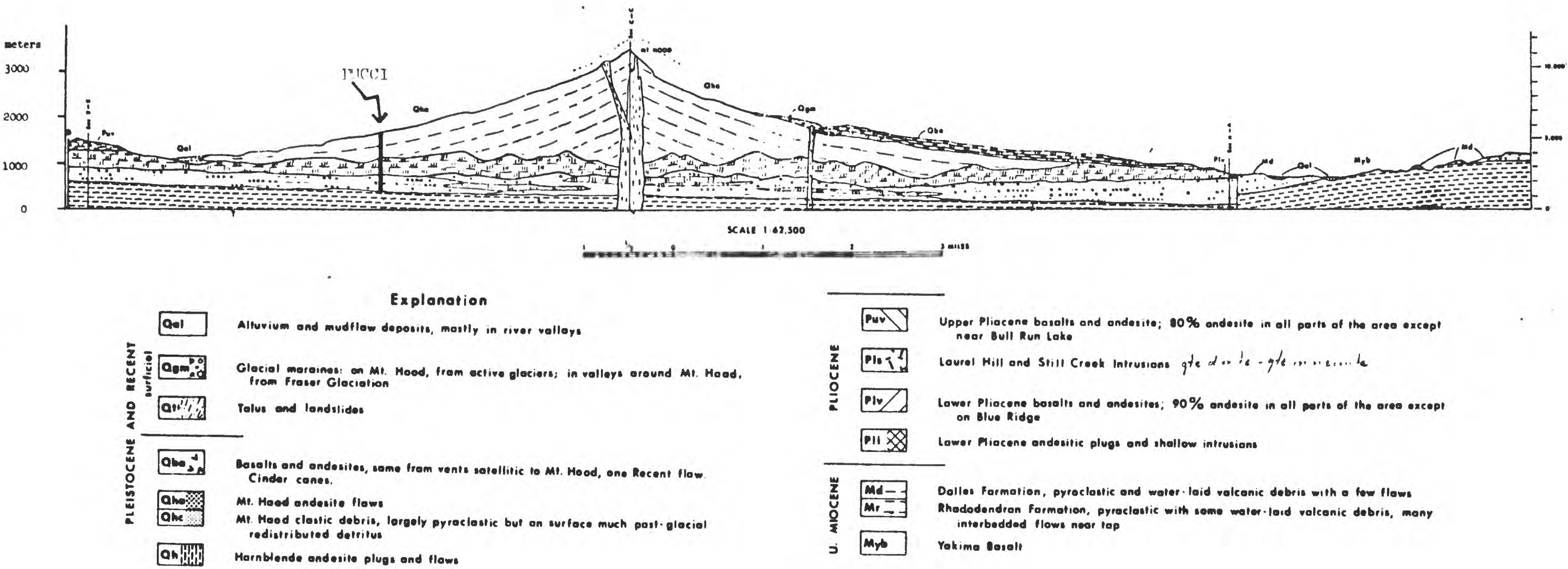


Figure 7. Geologic cross-section drawn through Mount Hood near the Pucci drill hole (after Wise, 1969) (Wise's lower Pliocene unit (Plv) is probably Late Miocene; see footnote 1).