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A Geochemical Study of the Rhododendron and Dalles Formations in the Area of Mount Hood, Oregon

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Title: A Geochemical Study of the Rhododendron and Dalles Formations
in the Area of Mount Hood, Oregon.

APPROVED BY MEMBERS OF THE THESIS COMMITTEE:

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The Miocene Rhododendron and Dalles Formations in the Mount Hood area are accumulations of chiefly pyroclastic andesitic material, largely confined to the Dalles-Mount Hood syncline. These very similar units are geographically separated by overlying andesites including the present Mount Hood cone, and past workers (Hodge 1938, Wise 1969) have suspected that they may share a common source. Prior to this study, few geochemical data were available for the Rhododendron and the Dalles Formations, compared to the well studied Columbia River basalts underlying them and the overlying Pliocene andesites. This geochemical study was designed to investigate certain aspects of the Rhododendron and Dalles Formations such as their possible common source, how they differ chemically from other andesites in the area, and how they fit into the chemical evolution of the

Cascade Mountains.

Sixty-one rocks collected from the Mount Hood area in the field or from drill cuttings were analyzed for trace elements by neutron activation analysis, and twenty-nine were analyzed for major elements by X-ray fluorescence. Several significant aspects of the chemistry of the Rhododendron and Dalles Formations were brought out by the data. The Rhododendron and Dalles Formations are chemically distinct from the overlying andesites and can be typified by rather narrow chemical parameters, and probably do share a common source. The ability to chemically define the top of the Rhododendron Formation is of use in structural modeling in the Mount Hood area. Data reveal definite chemical trends in volcanism in the Mount Hood area during the Neogene, toward a more mafic style of volcanism, and the Rhododendron-Dalles sequence and the Pliocene sequence represent two separate volcanic series along this trend. Trace element evidence suggests that the differences in their chemistry may be attributed to progressive changes in the mechanisms of magma generation in the mantle.

A Geochemical Study of the Rhododendron and Dalles Formations in the Area of Mount Hood, Oregon

by

Marshall W. Gannett

A thesis submitted in partial fulfillment of the

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TO THE OFFICE OF GRADUATE STUDIES AND RESEARCH:

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TABLE OF CONTENTS

Acknowledgments iii

List of Tables v

List of Figures vi

Introduction 1

Purpose and Scope 3

Previous Work 5

Geological Setting 7
    Timing of Volcanism 10

Field Work 11
    Zigzag Mountain 12
    Hunchback Mountain 17
    Lolo Pass 17
    Last Chance Mountain 18
    The Dalles Formation 20
    Sampling Strategy 21

Old Maid Flat No. 1 Drill Hole 24

Petrography of the Lavas 27
    Petrography of the Pyroclastic Matrix 28

Analytical Procedure 30

Geochemistry 34

Discussion 44

Summary and Conclusions 47

References 49

Appendix 52

LIST OF TABLES

Table **Page**

I. K-Ar Age Determinations 9

II. Major Element Data 31

LIST OF FIGURES

Figure **Page**

1. Sample Location Map . . . . in pocket
2. Schematic Geologic Section Southwest End Zigzag Mountain 14
3. Schematic Geologic Section Northwest End Hunchback Mountain 16
4. General Stratigraphy of the Rhododendron Formation in the Western Mount Hood Area 19
5. Generalized Lithology of the Old Maid Flat No. 1 Drill Hole 23
6. Co versus Sc 33
7. Chondrite Normalized Rare Earth Element Patterns 35
8. La/Sm Versus La 36
9. MgO Versus TiO_2 37
10. P_2O_5 Versus MgO 38
11. SiO_2 Versus FeO/MgO 40
12. K_2O, Na_2O, and FeO Versus SiO_2 41

INTRODUCTION

The Rhododendron and Dalles Formations are similar accumulations of chiefly pyroclastic material largely confined to structural lows on the surface of the Columbia River basalts, and are overlain by the Pliocene volcanics of the High Cascades. The Rhododendron Formation lies to the west of the High Cascades, and the Dalles Formation lies to the east. Workers in the past (Hodge 1938, Wise 1969) have suspected that these significant thicknesses of andesitic material may share a common source, and represent opposite ends of the epiclastic debris of a single volcanic center located in The Dalles-Mt. Hood area. The Rhododendron Formation is considered to be part of the Western Cascade Province, the wide belt of deeply dissected Tertiary volcanic rocks which lies to the west of the High Cascades in Oregon and Southern Washington. If the Dalles Formation is from the same source as the Rhododendron Formation, it is an excellent example of material similar to that of the Western Cascade Province lying to the east of the High Cascades.

The Rhododendron Formation has never been described in great detail, and was rather loosely defined originally as "a series of volcanic agglomerates and conglomerates" by Barns and Butler (1930), and the western end of Zigzag Mountain was designated the type section. Functionally the name "Rhododendron Formation" has been applied to all the volcanic material above the Columbia River basalt and below the lower Pliocene volcanics in the Mt. Hood area. The similarity of the Pliocene material to the Rhododendron and Dalles Formations has made placing the upper formational boundary an uncertain task, and the main criterion used has been the change from predominantly volcaniclastic material to predominantly volcanic flows. Both flows and volcanic breccias occur in the Rhododendron Formation and in the lower Pliocene material. Thicknesses of similar volcanic breccias and epiclastic material in the same stratigraphic position in basins other than The Dalles-Mt. Hood syncline, such as in the Bull Run syncline to the north and in the Clackamas River drainage to the southwest, have been placed in the Rhododendron Formation. The possibility exists that these are the products of different volcanic centers.

Recent geothermal exploration in the Cascades has stimulated interest in the detailed geology of the Mt. Hood area, and three moderately deep (in excess of 1200 meters) exploration test wells have been drilled. The lack of detailed stratigraphy and criteria for the recognition of formations has made geologic and structural interpretations difficult. Most of the structural modeling in the Mt. Hood area has been based on the stratigraphy of the Columbia River Basalt Group.

PURPOSE AND SCOPE

Detailed geochemical studies have been performed on rocks of the Columbia River basalt, which underlies the Rhododendron and Dalles Formations, and on the overlying Pliocene and Quaternary volcanics of the High Cascades. Trace element geochemistry has proven to be a powerful stratigraphic tool in the Columbia River Basalt Group, resolving a detailed stratigraphy which has been of unparalleled use in interpreting much of the post mid-Miocene structural history of the area (Beeson and Moran 1979, Beeson and others, in prep.). Geochemical studies of Pliocene and Quaternary volcanics of the High Cascades by Wise (1969) and White (1980) have made contributions to the stratigraphy, as well as the petrology and chemistry, striving for an understanding of the origin and chemical evolution of these andesites.

Prior to this study only a few geochemical analyses were available for the Rhododendron and Dalles Formations. Little has been done with this giant oblong lens of volcanic material roughly 125 km long, 30 km wide and over 600 meters thick which filled the Mt. Hood-The Dalles syncline; a northeast trending structural low, persistent throughout much of the Miocene (Beeson et al., in prep.). The Rhododendron and Dalles Formations represent the earliest phases of andesitic volcanism in the Mt. Hood area, during the time when there was major tectonic straining of western North America, interpreted to be the result of oblique subduction of the Farallon Plate (Atwater 1970, Davis 1981). This study addresses this lack of information, by chemical analysis of these Neogene rocks; the resulting geochemical data are interpreted, and the implications discussed. The term "Neogene" is used here for the Pliocene and Miocene epochs of the Tertiary Period.

Because of the fairly large geographical area covered by the Rhododendron and Dalles Formations, and the uncertainty of the lateral extent and relation to lateral facies, the Mt. Hood area was chosen as the focus for this study. The Mt. Hood area contains both the thickest section and the type section of the Rhododendron Formation (Barns and Butler 1930). Detailed sampling of the thicker and more continuous sections was augmented by additional sampling of isolated occurrences or patchy exposures. Samples included Rhododendron and post Rhododendron lava flows, and typical lava clasts from epiclastic units in the Rhododendron and Dalles Formations. Volcanic sandstones and mudflow matrices were sampled for petrographic study. Figure 1 (in pocket) is a map with the sample locations.

PREVIOUS WORK

The Rhododendron Formation was first described by Barns and Butler (1930) in their masters thesis as "a series of volcanic agglomerates and conglomerates." They noted that the matrix material varies from "tuff" to "fine material like glacial flour," and also that clasts range from a few millimeters to well over a meter in diameter. E.T. Hodge (1938) formalized the name "Rhododendron," and described the southwest flank of Zigzag Mountain as the type locality.

Hodge (1938) addressed many of the geologic problems of the Mt. Hood area. He recognized that folding of the Columbia River Basalts was synchronous with deposition of the Dalles and Rhododendron Formations, and stated that the tectonic activity responsible for the folding may have started in the Oligocene Epoch during deposition of the John Day Formation. He stated that there is evidence that many of the same structural trends seen in the basalts are present in the earlier rocks, in unconformable relationships between the basalts and older John Day material. All the post-Rhododendron Formation and post-Dalles Formation rocks, not part of the present Mt. Hood cone, were referred to by Hodge as the Cascan Formation. Hodge was first to speculate in print that the Rhododendron and Dalles Formations may have been derived from the same source, and described a thickness of volcanic material which also includes the Deschutes Formation. Other workers have since commented on Hodge's speculation, but none have chosen to test it.

William Wise (1969) in his study of the Mt. Hood area also dealt with the Rhododendron Formation. He described the section in the type locality as being composed of 91 meters of mudflow debris on the bottom, overlain by 275 meters of tuffs, lapillistones, and tuff-breccias; with the top 60 meters composed of interbedded olivine andesites and tuffs. Wise's work is by far the most comprehensive study of the Neogene and younger history of the Mt. Hood area, and he was the first to do any detailed geochemical studies on these rocks. While he did the most detailed work to date dealing with the Pliocene and younger rocks, he treated the Rhododendron and Dalles Formations in only a cursory way. Wise divided the Pliocene and Pleistocene rocks into various units based on stratigraphic position, petrography, and major element chemistry. Wise's stratigraphy provided the basis for the field work for this thesis, and is largely substantiated by the results.

Peck and others (1964) in their mapping of the Western Cascades combined the Rhododendron Formation with the Sardine Formation, a series of volcanic rocks to the south, for mapping purposes. They did not differentiate stratigraphy within the Rhododendron, and merely mapped exposures.

The most prolific worker to date dealing with the Dalles Formation near Mt. Hood has been R.C. Newcomb (1966; 1969). Newcomb's mapping was by far the most valuable to this study east of Mt. Hood. He described the Dalles Formation as "a thin to thick deposit of fragmental volcanic debris and sedimentary materials" and recognized two facies. In upper Mill Creek southwest of the city of The Dalles, 1800 feet of "fragmentary debris of volcanic origin" forms the thicker portion of a fan which thins to the northeast along the Dalles syncline. Newcomb states that this fan thins and shows a general decrease in size and proportion of clasts to the northeast. This fan grades into the other facies of the Dalles Formation which is best described as volcanic sedimentary deposits. These sediments are generally much finer than the massive volcaniclastic breccias to the southwest, show increasing proportions of pebble and cobble conglomerate, and decreasing proportions of angular lithic clasts, with distance from Mt. Hood.

The stratigraphy and structure of the Columbia River Plateau has received much attention lately in studies related to the possible storage of nuclear waste materials. Much of this work is unpublished and in the form of reports to companies by private consultants, and is not easily accessible. Davis (1981) provides a review of many of the important tectonic and structural points of these works.

Geochemical stratigraphic investigations of the Columbia River Basalt Group by Dr. Marvin Beeson and his graduate students at Portland State University (Beeson and Moran 1979, Beeson and others in prep., Timm 1979, Anderson 1978, Vogt 1981) have been unparalleled in leading to the understanding of Neogene geological history in the Mt. Hood area, and northwestern Oregon in general. This work has been of particular value in structural interpretations. Swanson et al. (1979) revised the stratigraphic nomenclature of the Columbia River basalts, and their terminology is used in this thesis.

GEOLOGICAL SETTING

The Rhododendron and Dalles Formations are accumulations of predominantly pyroclastic volcanic material in one of many large parallel synclines on the surface of the Columbia River Basalt Group. The mid-Miocene Columbia River basalts were in places subjected to north-south compressional stresses while in part still being extruded from dike swarms in eastern Washington and Oregon, starting around 16 my and lasting until at least 3 to 4 my (Beeson and Moran 1979; Davis 1981). The deformation caused by this stress resulted in a series of northeast-southwest trending anticlines and synclines tens of miles wide, with amplitudes of several hundreds of meters. These include the Mosier, Bull Run, and The Dalles-Mt. Hood synclines in the Mt. Hood area. Accompanying this folding are numerous normal faults parallel and oblique to the folds, and thrust faults parallel to the axes of the folds (Beeson and others, in prep., Beeson and Moran 1979). Davis (1981) sites numerous workers, and presents convincing lines of evidence that the folding is in part the result of right lateral shear stress caused by oblique subduction of the Juan de Fuca plate. This idea of oblique subduction in North America was first discussed in detail by Atwater (1970). A complete discussion of the tectonic setting of western North America is beyond the scope of this thesis, and Davis' work is highly recommended for an up to date review.

After the incursion of the Grande Ronde Basalt flows into the Mt. Hood area, approximately 16 million years ago (McKee et al. 1977), subsequent folding restricted later flows into the axis of The Dalles-Mt. Hood syncline. Evidence presented and discussed later in this thesis indicates fairly rapid subsidence of this trough, on the order of 120 meters per million years. Drill hole evidence (Beeson 1979; Gannett, this work) indicates the earliest andesitic volcanism occurred just after the Grande Ronde Basalts, dated at 16 my. A 150 meter thickness of andesitic material occurs between the Grande Ronde Basalt and the Frenchman Springs Member of the Wanapum Basalts. Another 120 meters of andesitic material occurs between the Frenchman Springs Member and the Priest Rapids Member. The occurrence of the Priest Rapids Member (tentatively identified by Marvin Beeson, personal communication) in the western Mt. Hood area is first reported in this thesis. At least 500 to 550 meters of Rhododendron Formation section lies between the Priest Rapids Basalt and lavas mapped as lower Pliocene volcanics by Wise (1969).

The "Pliocene" lavas are often visually similar to lavas of the Rhododendron and Dalles Formations, though they represent different styles of volcanism. These "Pliocene" lavas compose the next unit above the Rhododendron. Recent K-Ar age determinations obtained by the State of Oregon Department of Geology and Mineral Industries (DOGAMI) indicate the age of early Pliocene may be incorrect for some of these lavas (Priest, personal communication), so the term "Pliocene type" is be used for them in this work. Early Pliocene and older rocks are intruded by a dioritic intrusive body which crops out in the Still Creek area and Laurel Hill area. This has been dated at 8.2 ± 0.2 my by Bikerman (1970). A lithologically similar intrusive body was encountered approximately 100 meters below the western end of the town of Government Camp during drilling of a deep water well (Jack Meyer, 1980 personal communication), and it is probable that it is part of the same intrusion.

The Pliocene type lavas are directly overlain by the present cone and associated debris of the Mt. Hood volcano. Apparent lack of magnetically reversed lavas associated with Mt. Hood indicates that it is entirely less than 660,000 years old (White, 1980). Recent eruptive history and fumarolic activity near the summit indicates that Mt. Hood is still an active volcano (Crandell 1980).

Timing of Volcanism

The timing of much of the Neogene volcanism in the Mt. Hood area has been an issue confused by many questionable K-Ar age determinations and complex stratigraphy (Table I). The presence of alteration in much of the volcanic material in the area, and consequent loss of radiogenic argon makes one suspect that many of the dates may be too young. Wise (1969) obtained an age of 7.0 ± 2.0 my for hornblende from a lava clast from the "lower part" of the Rhododendron Formation, but presents an age for the Laurel Hill pluton, which intrudes the Rhododendron Formation, of 11.6 ± 1.2 my. East of Mt. Hood Wise obtained an age of 7.0 ± 0.8 my for a lava flow overlying the Dalles Formation.

Bikerman (1970) dates the Laurel Hill pluton at 8.2 ± 0.2 my and describes a scheme by which presence of non-radiogenic argon may have made Wise's age determinations too old. Either age seems reasonable in light of more recent stratigraphic information and K-Ar age determinations.

The State of Oregon Department of Geology and Mineral Industries has obtained 5 new

Table I. K-Ar Age Determinations

Investigator	Unit	Material	Location	Age
D.O.G.A.M.I (Priest, 1981 oral comm.)	qtz diorite	hornblende	OMF-7A	9.3 ± 0.9
	Rhododendron	altered whole rock	T2S, R8E, 15bdc	10.6 ± 0.5
"	Rhododendron	altered whole rock	T2S, R8E, 15dbb	9.5 ± 2.4
"	Rhododendron	altered whole rock	T2S, R8E, 15dbb	12.1 ± 1.7
"	Pliocene type andesite	whole rock	T2S, R8E, 16bdb	10.7 ± 0.5
"	Pliocene type andesite	whole rock	T2S, R8E, 16bdb	10.5 ± 0.5
Wise (1969)	Rhododendron	hornblende	"near Lost Cr."	7.0 ± 2.0
"	Still Creek intrusion	whole rock	T3S, R8E, 35b	11.6 ± 1.2
"	Lower Pliocene volcanics	whole rock	"near Lolo Pass"	5.8 ± 0.8
"	Lower Pliocene volcanics	whole rock	T2S, R8E, 5d	7.0 ± 0.8
Bikerman (1970)	Laurel Hill intrusion	hornblende	T3S, R8E	8.4 ± 0.6
"	Laurel Hill intrusion	hornblende	T3S, R8E	8.0 ± 0.6

internally consistent K-Ar age determinations considered reliable for material from Last Chance Mountain and the Old Maid Flat No. 7-A drill hole, which have been supplied to the author by George Priest of that department. They obtained an age of 10.6 ± 0.5 my for a coarsely plagioclase porphyritic andesite which is part of the lower Pliocene sequence of Wise (1969). This rock shows slight alteration of the hypersthene phenocrysts according to Priest. A hornblende separate from a micro-quartz-diorite intrusive in the Old Maid Flat No. 7-A drill hole yielded a date of 9.3 ± 0.87 my. This rock appears quite fresh, but has been affected by slight zeolitic alteration. In light of these recently obtained age determinations, it appears that much of this material is older than previously suspected. These older ages fit quite well with the known stratigraphy.

The K-Ar dates indicate a fairly short time span for deposition of the bulk of the Rhododendron Formation. The earliest pulse of Rhododendron type volcanism occurred after the Grande Ronde Basalt, dated at 16 my (McKee et al. 1977), and much of the Rhododendron material is younger than the Priest Rapids Member of the Wanapum Basalt which has an age of approximately 14 my. Taking as a younger limit the 10.6 ± 0.5 my age for overlaying Pliocene type andesites, this leaves as little as 3.5 million years for deposition of most of the Rhododendron Formation.

FIELD WORK

Twenty three days were spent observing and sampling the thicker and more continuous exposures of the Rhododendron and the Dalles Formations. More attention was paid to the Rhododendron Formation. After visual inspection and sampling of many outcrops particularly on Zigzag Mountain, Last Chance Mountain, Hunchback Mountain, and the Lolo Pass road; it became apparent that primary volcanic materials such as pyroclastic tuffs and lavas were quite subordinate to epiclastic material such as laharic breccias and volcanic sandstones. This is in slight disagreement with previous workers in the area who based interpretations on the poorly exposed and deeply weathered sections on Zigzag Mountain. Wise (1969) states that the middle 900 feet of the Zigzag Mountain section is largely pyroclastic and also states that one third of the total clastic material of the section is pyroclastic and includes "tuffs, lapillistones, and tuff breccias." Previous workers (Barns and Butler 1930, Wise 1969) provide no detailed descriptions of their outcrops, and their definitions and classifications are unclear.

Field recognition of primary volcanic breccias as opposed to laharic breccias is not always possible with a very high degree of confidence in the western Mt. Hood area for numerous reasons. Matrix material which is composed of ash-size lithic and crystal fragments in clay is generally weathered, and usually yields no textural clues as to origin. Exposures are almost invariably of limited extent so observation of the geometry of a particular unit is rare. Top or basal aspects which may yield lithological or morphological evidence as to origin (Fisher 1960a) are not usually exposed.

There are numerous lines of evidence which suggest that most of the Rhododendron breccias are laharic. Fluxgate magnetometer analyses of matrix material shows no remnant magnetism despite much magnetite, indicating emplacement below the Curie point temperature of about 575 degrees centigrade. There is a low initial dip of almost all of this material, even with large blocks. Fisher (1960a) states that "volcanian explosions rarely have sufficient energy to disperse large blocks and bombs far from the slopes of the parent volcano; therefore thick volcanian breccia deposits generally have high initial dips." There are variable states of alteration in the clasts in these units, and no fumarolic alteration was noted. The chemically similar and very well exposed and bedded material of the Dalles Formation to the east is known to be almost entirely epiclastic. Williams and McBirney (1949 p.178) state that virtually all lahars become finer grained, better sorted, and better stratified away from the source (as observed in the Dalles Formation), and that primary pyroclastic flows seldom show this. Macdonald (1972 p.171) makes a similar statement. Macdonald (1972 p.171) and Williams and McBirney (1979 p.178) suggest that the presence of non-charred wood fragments indicate laharic origin for a volcanic breccia. Petrified wood from the Rhododendron Formation in the Lolo Pass area shows no signs of being burnt. Macdonald (1972 p.171) states that "Successions of mudflow deposits also often contain interbeds of sandstone and conglomerate." Interbedded sandstones and finer sediments, locally fossiliferous, are present in the Rhododendron. No pumice was observed in the Rhododendron Formation in the Mt. Hood area, and no remnant glass shard textures were observed in thin section. While the above observations do not provide as conclusive evidence as quantitative petrologic studies such as pebble counts, and detailed accounts of rounding and composition of clasts, they are interpreted here to suggest a laharic origin for most Rhododendron and Dalles Formation breccias.

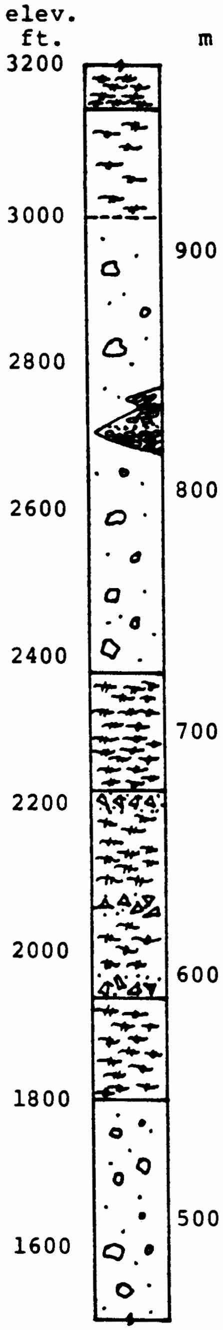
Classifications of fragmental volcanic rocks are discussed by Fisher (1958, 1960b) and Schmid (1981). In Schmids' classification, ratified by the International Union of Geological Sciences Subcommission on the Systematics of Igneous Rocks, lahars are considered "pyroclastic breccias." This term will be used in this thesis for the Rhododendron and Dalles Formation breccias.

Zigzag Mountain

Approximately 450 meters of Rhododendron Formation section is exposed on the southwestern flank of Zigzag Mountain. Two traverses were made, one along the West Zigzag Mt. trail, and another on the lower 300 meters of section 300 meters west of the trail. Exposures are generally poor, and occur mainly at trail switchbacks or on dangerously steep moss covered slopes. The general stratigraphy here is as follows (fig. 2). The lower 60 to 100 meters of section appears to be entirely pyroclastic breccias. Outcrops are massive faces of centimeter to meter size, angular to subrounded clasts, in varying proportions, generally unsorted, in a matrix of fine crystals, lithic fragments, and clay. The only hints of bedding present are occasional layers which show crude size sorting and concentration of a preferred size clast. Occasional areas of a concentration of larger (30-100 centimeter) clasts are present, not necessarily parallel to bedding, and form small promontories due to their resistant nature. Lithic clasts appear upon visual inspection to be predominantly one lava type at any given locality; some exceptions are noted.

The next 100 to 150 meters up-section is dominated by plagioclase porphyritic pyroxene andesite flows with interbedded volcanic breccias of various types including what are probably flow breccias. These flows typically have 25 to 30% mm size plagioclase phenocrysts. At least three flow units in excess of twenty meters in thickness are present, along with interbedded breccias. These lavas, along with correlative lavas to the south on Hunchback Mountain, make up most of the Rhododendron Formation lavas referred to in this report. Above these lavas, at an elevation of about 730 meters (2400 feet) and above, exposures of Rhododendron Formation are extremely rare on this part of Zigzag Mountain. This is interpreted to indicate a lack of lava flows, and a return to the less erosionally resistant pyroclastic material. Around 820 meters (2700 feet) elevation on the ridge there is an abundance of rounded to well rounded andesite cobbles as float, and while no outcrop is found, it appears this is a conglomerate. It is not known whether this is a conglomerate within the Rhododendron, or later material in unconformable contact. The next good outcrop is a 15 to 25 meter thick platy to blocky plagioclase porphyritic pyroxene andesite flow at around 945 meters (3100 feet) elevation. This flow is included in the "Lower Pliocene Volcanics" of Wise (1969).

On the eastern end of Zigzag Mountain, near the flanks of the present Mt. Hood cone, one of the most eastern exposures of the Rhododendron Formation occurs. This is an area mapped by Wise (1969) as lower Pliocene volcanics, but was recognized as Rhododendron Formation by Jack Meyer of Northwest Geothermal and Terry Keith of the U. S. Geological Survey (personal communication 1980). Here volcanic sandstone visually similar to that found in the upper parts of the Rhododendron Formation on other parts of Zigzag Mountain and in the Lolo Pass exposure is found at elevations of 1400 meters (4600 feet), higher than any other localities by 450 to 550 meters (1500-1800 feet). This is overlain by coarsely porphyritic andesite with plagioclase phenocrysts commonly in excess of one centimeter, which typically overlies the Rhododendron Formation throughout this area. These units are well exposed along the Cast Creek trail and connecting trail to east Zigzag Mountain lookout, and on down to Burnt Lake. The ridge above Burnt Lake is made up of the coarsely porphyritic andesite, and below this is interbedded lava flows and pyroclastic material typical of the Rhododendron Formation. Some of these flows have a resemblance to the lava flows of the Rhododendron Formation on the southwest flank of Zigzag Mountain.



Medium gray plagioclase porphyritic pyroxene andesite. 10 to 15%, 3 to 4mm subhedral plagioclase crystals. Local platey fracture. Exposures are poor, but lavas occur as float over much of the mountain above 900 meters.

Very poorly exposed volcaniclastic breccias, predominantly epiclastic.

High abundance of well rounded pyroxene and hornblende andesite cobbles and boulders indicate the presence of a comglomerate. This is not actually exposed, and it is not known if it is part of the Rhododendron Fm. or a later deposit in unconformable contact.

Medium gray to light gray fine grained plagioclase porphyritic pyroxene andesite. 25 to 30%, mm size clusters of plagioclase throughout. This is similar to the flow or series of flows to the south on Hunchback Mt.

Series of medium to light gray, locally weathered to a reddish gray plagioclase porphyritic andesite flows similar to the above lavas, but interbedded with autoclastic and apparent epiclastic volcanic breccias.

Fairly well exposed thick sections of epiclastic volcanic (laharic) breccias.

Figure 2. Schematic Geologic Section Southwest End Zigzag Mountain

Hunchback Mountain

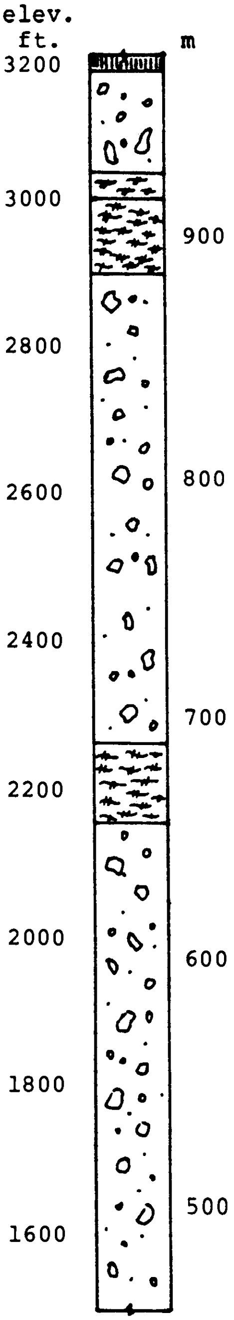
The northwest flank of Hunchback Mountain offers another thick section of Rhododendron Formation, capped by Pliocene andesites and olivine basalts. Exposures are very poor as on Zigzag Mountain, but a similar stratigraphy is apparent (fig. 3). Pyroclastic material predominates below about 670 meters (2200 feet). Exposures are very limited but trail cuts and uprooted trees reveal deeply weathered mudflow material. At around 670 meters (2200 feet) elevation, a 15 to 25 meter thick flow of plagioclase porphyritic pyroxene andesite occurs, which looks very similar to flows across the valley on Zigzag Mountain at about the same elevation, and chemical and petrographic evidence indicate that this is the case. Exposures are again poor above this flow but sparse evidence indicates clastic material dominates the section. One exposure to the east of the trail at an elevation of 780 meters (2560 feet) reveals a breccia with large clasts in excess of 1 meter. Above 850 meters (2800 feet) the steep slope breaks, and the narrow irregular ridge of Hunchback Mountain is composed of multiple lava flows ranging from pyroxene andesites to olivine basalts. At 850 meters (2800 feet) a medium-gray microporphyritic pyroxene andesite crops out in various spots all the way around the northern most peak of Hunchback Mountain. This peak is capped by a coarsely porphyritic diktytaxitic andesite. Higher in the section and to the southeast of these lavas, the flow are much more mafic, and olivine basalts are most common. Pyroclastic breccias were observed as high as 945 meters (3100 feet) on Hunchback Mountain.

An interesting aspect of the pyroclastic material on parts of Hunchback Mountain are the riblike, vertically oriented tabular features. These are erosionally resistant masses of the breccia which form prominences oriented perpendicular to the axis of the ridge. The cause of these is unknown, but may be selective cementation along vertically oriented permeable zones such as small faults or fractures.

Lolo Pass

The road cuts of the Lolo Pass Road (N-12) offer one of the best and most continuous exposures of the Rhododendron Formation in the Mt. Hood area. More or less continuous road cuts

SCHEMATIC GEOLOGIC SECTION NORTHWEST END HUNCHBACK MT.



Medium gray olivine basalt, locally diktytaxitic.

Epiclastic volcanic (laharic) breccia.

Medium gray to light gray highly porphyritic diktytaxitic pyroxene andesite, with 25 to 30% plagioclase crystals.

Medium gray micro-porphyritic pyroxene andesite.

Section is poorly exposed and composed chiefly of volcaniclastic breccias. These are probably mostly epiclastic, and some very large blocks (in excess of 2 of 3 meters) vere observed at about 780 meters elevation.

Medium gray to dark gray fine-grained porphyritic pyroxene andesite, with 25 to 30% mm size clusters of plagioclase. This flow or series of flows correlates with the series of flows at a similar elevation to the north on Zigzag Mt.

Lower part of section is poorly exposed, but scanty outcrops indicate that the section is dominated by volcanic breccias. Better exposures accross the valley to the north on Zigzag Mt. appear to be epiclastic.

Figure 3. Schematic Geologic Section Northwest End Hunchback Mountain

for approximately 5 km expose over 300 meters of section. The lowest exposure occurs on Old Maid Flat, on Road S-238 near McNeil Campground, where volcanic breccia crops out. Here also are slump blocks of a lava flow which occurs higher in the section at an elevation of about 640 meters (2100 feet). This flow is cut by road N-12 about 400 meters east of the intersection with road S-238. It is a narrow but thick (greater than 15 meters) flow of plagioclase porphyritic pyroxene andesite with 10% phenocrysts. Above the flow and to the east is a volcanic breccia which may be in part a flow breccia, as it apparently grades into solid lava, yet the lava is not continuous in any direction and is isolated by the breccia. This unit is around 15 meters thick. Above this, 700 to 850 meters (2300 to 2800 feet) elevation, the exposures are almost entirely laharic breccia. Mudflow deposits with centimeter to meter size clasts, very similar to material described in the Zigzag Mountain section, are most common. Also exposed are thin layered fine-grained volcanic sandstones. Bedding in the mudflows is absent except for occasional layers with increased lithic clast content, or layers with a preferred clast size. Clasts are angular to subrounded, and unsorted. Some units in the upper and eastern parts of the exposure here contain clasts several meters across. Lava flows are lacking, other than the ones mentioned low in the section. At 790 meters (2600 feet) there is an abundance of petrified wood included in an altered, crudely bedded volcanic sandstone; this wood does not appear to have been carbonized. Much of the material in this section shows low grade alteration. Smectite clays impart a greenish color to much of it; quartz veining and secondary zeolites are common.

At an elevation of about 850 meters (2800 feet), on line with the upper Sandy River-Last Chance Mountain lineament (Priest et al. 1982), is what appears to be a vent breccia of the coarsely porphyritic "lower Pliocene" andesite which directly overlies the Rhododendron Formation in this area. A dike of this, or similar material, occurs about 1 km to the southeast on Last Chance Mountain.

Last Chance Mountain

Last Chance Mountain, to the north of Old Maid Flat, offers good exposures of Rhododendron Formation, especially along logging roads. On the west end of the mountain, at least 200 meters of Rhododendron section is present below 950 meters (3100 feet) elevation. The material on this end is predominantly pyroclastic massive mudflow breccias and interbedded finer volcanic sandstones, including some layered sandstone units similar to those along the Lolo Pass road. At around 820 meters (2700 feet) elevation along Forest Service Road S-238 a mudflow breccia with very large inclusions in excess of several meters occurs. On the northwest side of Last Chance Mountain similar epiclastic material crops out along the road cut. One notable exposure is a fine tuffaceous sediment deposit (T.2 S., R.8 E., Sec. 9, CD) which contains the carbonized remains of much plant material including leaf and stem fragments, and bits of wood. None of this fossil material has been dated for this study, and no dates were found in the literature. A dike of a coarse-grained dark bluish-gray olivine andesite crops out just to the west of these sediments. In the valley of the major unnamed creek in the southeast quarter of section 9, one half mile to the northwest, a major northwest-trending lineament crosses Last Chance Mountain. Here stratigraphy is disrupted and multiple dike injections are visible. Chemical analysis of these dikes as well as the dike to the west indicates that they are post Rhododendron or "Pliocene type" material as discussed later.

Lava flows and minor epiclastic breccias mapped as "Lower Pliocene Volcanics" by Wise (1969) occur over most of Last Chance Mountain above around 950 meters (3100 feet) elevation. Pyroxene andesite dominates this section, and much of it is the coarsely plagioclase porphyritic lava that typifies the lavas which over lie the Rhododendron Formation. One of the dikes exposed on the northwest side of the mountain may be a feeder dike for the coarsely porphyritic flows. Vent breccia of this type of lava occurs 1 km northwest across the Clear Fork valley. Stratigraphic relations with sample points are presented schematically in figure 4.

The Dalles Formation

Sampling of the Dalles Formation was limited to upper Mill Creek southwest of the city of The Dalles, the Chenowith Hills area to the west of the city of The Dalles, and the east and middle forks of the Hood River near Mt. Hood. Samples were also taken in the Mosier syncline.[1] The area to the west of the townsite of Friend, on Tygh Ridge near Owl Hollow, mapped as the Dalles Formation by Waters (1968), was inspected. This, however, is an area of extensive silicic

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[1] The Dalles Formation in north-central Oregon has been elevated to group status as the result of recent work by Farooqui et al. (1981). This change of nomenclature was presented when this thesis was in the final stages of preparation, and the older terminology is used here. Under the new nomenclature, the material referred to as the Dalles Formation in this work would be included in the Chenowith formation of the Dalles Group.

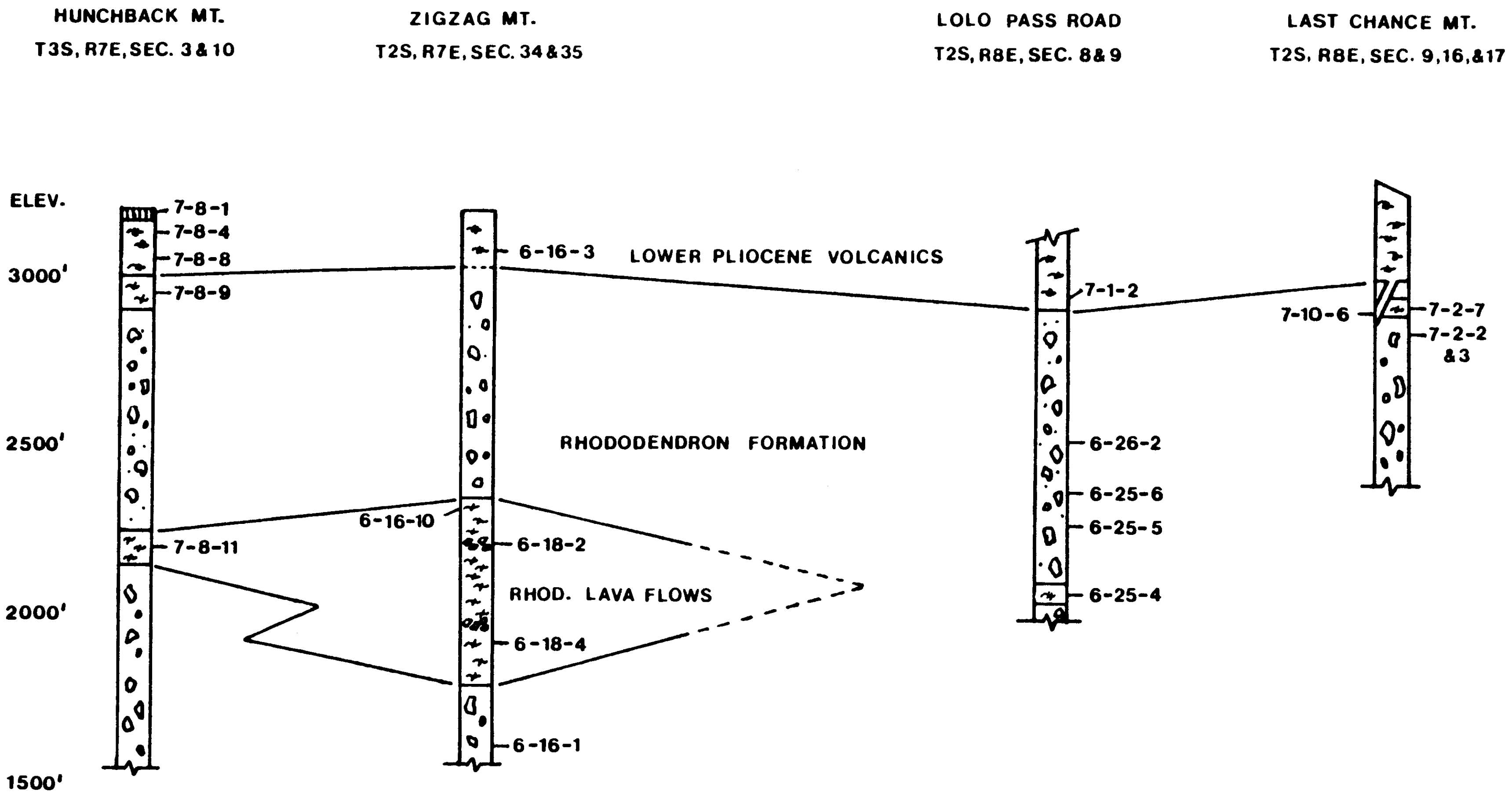


Figure 4. General Stratigraphy of the Rhododendron Formation in the Western Mount Hood Area

volcanism including pumice lapilli tuffs, and pumice-rich ash-flow tuffs totally unlike any rocks seen in the Dalles Formation near the city of The Dalles or Mt. Hood; and is considered by the writer to be dominated by an entirely different volcanic sequence. This material is not in The Dalles-Mt. Hood Syncline.

The best exposure of the Dalles Formation closest to Mt. Hood occurs along the east fork of the Hood River about 4 km north of Polallie Campground and the Cooper Spur road intersection. Here, a 120 meter section of bouldery mudflow is exposed on the east side of the river, capped by a flow which is thought to be part of The Dalles Formation. All of this is capped by Quaternary hornblende andesites (Wise, 1969). Most of the thickness exposed is massive bouldery mudflow material which lacks bedding or any indication that there are multiple flow units present.

In the upper reaches of Mill Creek, southwest of the city of The Dalles, one of the thickest sections of the Dalles Formation is exposed. Newcomb (1969) maps over 550 meters of section here, and at least 375 meters of section is exposed. This material is a redundant series of epiclastic volcanic breccias and associated finer detrital materials which are rhythmically bedded. Each layer is a few meters to tens of meters thick and includes a basal massive angular boulder-rich zone, that grades up into a finer deposit with more sand-size material and smaller clasts. It appears as if this material was emplaced as a series of individual pulses. This redundant layering is evident higher on the slopes where soil and vegetation cover the ground, in that shrubs and small trees prefer soil above the groundwater rich coarser breccias. Patterns in vegetation make layering visible from miles away. The breccias here appear to have more of a variety of clasts; any one unit may have both pyroxene and hornblende andesites.

The Chenowith Hills area, immediately to the northwest of the City of The Dalles, offers about 150 meters of excellent exposure. Here one finds 3 to 12 meter thick volcanic breccias interbedded with fine grained volcanic lithic wackes of fluvial origin, along with pumiceous water-lain tuffs. Some layers are rich in organic debris and some exhibit tree casts. Many primary sedimentary structures are present, including scour and fill structures, and cross-bedding. Many clasts are well rounded. This truly appears to be a finer grained aspect of the upper Mill Creek material and the other material closer to Mt. Hood.

Sampling Strategy

This section is presented to give the reader a feeling for what the sampling strategy was, what the samples represent, and how formational affinities were assigned; in order that they may view the data and interpretations objectively. Using the stratigraphy and mapping of Wise (1969), thickest and most accessible exposures or the Rhododendron and Dalles Formations were sampled in the Mt. Hood area. In The Dalles area, mapping by Newcomb (1969) was used.

Essentially two things were sampled in the Rhododendron and Dalles Formations; lava clasts from pyroclastic breccias, and lava flows. Typical lava clasts were sampled and analyzed from breccias. The clasts presented in the data plots here represent clasts from wide geographic areas, and are hopefully representative of most of the thickness and lateral extent of the formations. Lava flows are much less common than breccias in the Rhododendron and Dalles formations and were always sampled if encountered. Flows considered Rhododendron or Dalles in this study are those mapped as such by previous workers (Wise 1969, Peck et al. 1964). On Hunchback Mountain, where the scale of the mapping is very large and boundaries are indefinite one flow near the upper boundary was considered Rhododendron on the basis of the chemistry. Pliocene lavas refered to in this report are all mapped as such by Wise (1969) and Peck et al. (1964). Dikes on Last Chance Mountain are considered Pliocene type because of their discordant nature and lithologic similarity to Pliocene type flows.

The area above Burnt lake on eastern Zigzag Mountain was mapped as "Lower Pliocene Volcanics" by Wise (1969), yet was recognized as Rhododendron by Terry Keith (personal communication 1980) and Jack Meyer (personal communication 1980). The author considers it to be Rhododendron Formation due to the presence of volcanic sediments similar to those observed elsewhere mapped as Rhododendron. The chemistry of clasts and flows (discussed in later sections of this text) substantiates this.

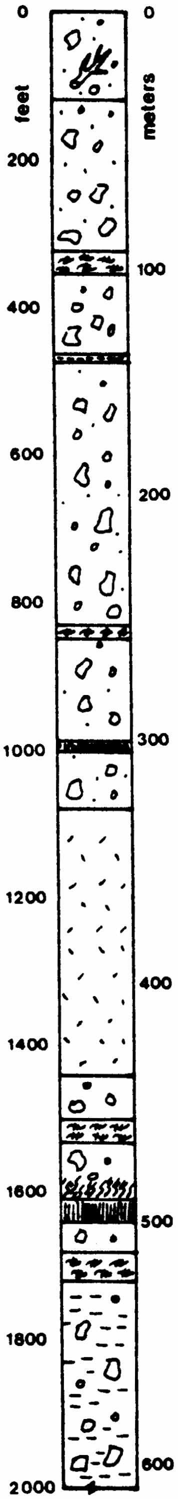
OLD MAID FLAT NO. 1 DRILL HOLE

Old Maid Flat No. 1 was drilled in 1977 and 1978 by Northwest Geothermal and the U. S. Department of Energy to a total depth of 1220 meters. The upper 915 meters of the hole encountered predominantly Rhododendron Formation; from 915 meters to 1220 meters, the section is dominated by Grande Ronde Basalt of the Columbia River Basalt Group. The lithology of the upper 915 meters of the hole was relogged for this study. Sample quality was poor, with much continual uphole contamination. Cuttings were stored wet, and the relatively large amounts of drill steel in many samples oxidized and made some of them difficult to interpret and unsuitable for chemical analysis. A 760 meter thickness of Rhododendron Formation section was encountered including about 185 meters of micro-quartz-dioritic intrusive material. The lithology of the drill hole is summarized as follows (fig. 5).

The first 30 meters are recent mudflow debris from Mt. Hood volcano; this material is in erosional contact with epiclastic breccias of the Rhododendron Formation. This Rhododendron Formation clastic material dominates, with only two positively identified interbedded lava flows, to a depth of 330 meters. The breccias consist primarily of angular to subrounded lithic clasts in a matrix of brownish-gray to greenish-gray clays, crystals and crystal fragments of feldspar and pyroxenes. Lithic clast size distribution determinations are impossible due to the inherent nature of drill cuttings, but most were drill broken indicating size greater than a centimeter. The breccias are hydrothermally altered to varying degrees; the common secondary minerals identified by binocular microscope were clay, chlorite, hematite, magnetite, pyrite, quartz and calcite.

From 330 to 440 meters a relatively fresh, fine-grained, plagioclase porphyritic micro-quartz-diorite occurs. This unit, which is probably a sill, is characterized by 2-3 mm, euhedral plagioclase crystals. This intrusion could be responsible for much of the observed hydrothermal alteration.

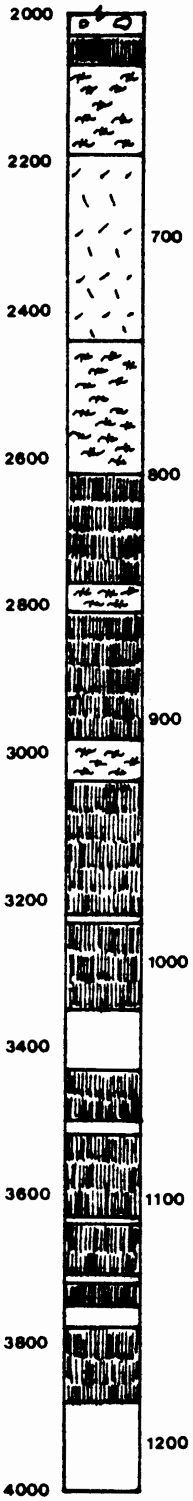
From 440 to 525 meters the section is very complex and cuttings and geophysical logs were difficult to interpret. The interval includes at least three flows, one of which is tentatively identified by Marvin Beeson (personal communication, 1981) as the Priest Rapids Member of the Columbia River basalt, interbeds of epiclastic or possible autoclastic material, and some very compacted clay-



0-100*	Recent mudflow debris.
100-320	Reddish-brown to greenish-gray lithic rich epiclastic volcanic breccia. Angular to subrounded andesitic clasts with variable alteration in a matrix of crystal fragments and brown to green clays.
320-350	Possible hornblende andesite flow.
350-830	Light reddish-gray to brownish-green-gray lithic rich epiclastic volcanic breccia as above. Secondary minerals include: clay, chlorite, magnetite, hematite, pyrite, quartz, and traces of calcite.
830-850	Purplish-gray plagioclase porphyritic pyroxene andesite, with clay alteration of the plagioclase, and pyroxenes altering to hematite, chlorite, clay.
850-990	Epiclasitc volcanic breccia, locally pyrite rich.
990-1000	Dark greenish-brown aphyric aphanitic basalt.
1000-1080	Epiclastic volcanic breccia with secondary calcite, drusey quartz, pyrite, and chalcopyrite.
1080-1440	Light to dark greenish-gray plagioclase porphyritic micro-quartz-diorite. Rather fresh, with well zoned plagioclase 2 to 3 mm in length.
1440-1500	Light greenish-gray epiclastic volcanic breccia.
1500-1530	Medium gray fine grained basalt/andesite.
1530-1610	Clay rich epiclastic volcanic material showing signs of faulting near base.
1610-1640	Priest Rapids Member, Wanapum Basalt (CRB).
1640-1680	Clay rich epiclastic debris.
1680-1720	Hydrothermally altered porphyritic basalt/andesite.
1720-2030	Hydrothermally altered clay rich epiclastic volcanic debris.

* Lithologic boundries presented in feet due to ten foot sampling interval.

Figure 5. Generalized Lithology of the Old Maid Flat No. 1 Drill Hole



2030-2070	Frenchman Springs Member, Wanapum Basalt (CRB).
2070-2190	Light greenish-gray hydrothermally altered andesite with secondary silica, zeolites, and traces of pyrite, in veins.
2190-2440	Plagioclase porphyritic micro-quartz-diorite as at 1081-1440. Slight clay alteration, and minor calcite as fracture fillings.
2440-2620	Hydrothermally altered aphyric basaltic andesites, multiple flow units, texture and alteration somewhat variable; secondary clay, silica, zeolites, calcite, and pyrite.
2620-2760	Frenchman Springs Member, Wanapum Basalt (CRB).
2760-2810	Altered aphyric basaltic andesites as above.
2810-2980	Low magnesium chemical type, Grande Ronde Basalt (CRB).
2980-3040	Medium gray fine grained andesite.
3040-3220	Prineville chemical type, Grande Ronde Basalt (CRB).
3220-4000	Section dominated by low magnesium chemical type Grande Ronde Basalt (CRB), with volcaniclastic (including autoclastic) interbeds. Interbeds were placed on the basis of geophysical logs, and the wellsite geologist lithologic logs.

Figure 5. (continued)

rich zones around 490 meters. Brick red compacted clays contaminated cuttings for the next hundred or so meters down.

The section from 525 to 620 meters consists of epiclastic material similar to that described above except for increased hydrothermal alteration, and zeolites including laumontite are much more common. The Frenchman Springs Member of the Columbia River basalts was encountered at 620 to 630 meters, and from 630 to 665 meters a highly altered andesitic flow rock occurs. From 665 to 743 meters the micro-quartz-diorite similar to that described above occurs in the section again.

Below the bottom of the diorite at 743 meters, hydrothermally altered aphyric andesites and basalts occur until 798 meters, where more of the Frenchman Springs basalt occurs. The possibility exisits that basalts, not recognized as such occur slightly higher than this. The altered condition of the lavas makes differentiation difficult; the basalt flow at 798 meters has been positively identified chemically.

Columbia River basalt dominates the section below 798 meters. The thicknesses of basalt are separated by epiclastic and autoclastic interbeds according to original lithologic information by wellsite geologists. All the basalt below 850 meters is the low Mg chemical type of the Grande Ronde Basalts.

Because of the apparent scarcity of lava flows in the Rhododendron section in the hole, and the obvious problems with sampling lithic clasts in epiclastic breccias from drill cuttings, sampling was biased toward the basalt flows and intrusive rock. The two Rhododendron Formation flows sampled, 254 meters and 301 meters, are somewhat enigmatic in their chemistry; both are hydrothermally altered. Other flows sampled thought to be aphyric basaltic andesites turned out to be Columbia River basalts when analyzed.

The lava flow at 254 meters, a purplish-gray, plagioclase-porphyritic, pyroxene andesite, shows chemistry similar to much of the Rhododendron Formation. The mafic rock at 301 meters is chemically different than other rocks in the area including any of the basalts; the chemistry of this unit may have been affected by alteration. The most valuable information from the stratigraphy in this hole is provided by the Columbia River basalts.

Beeson and Moran (1979) were first to analyze basalts from Old Maid Flat No. 1. They identified the basalts, and concluded that "considerable down faulting occurred about the Mt. Hood area in addition to earlier folding of Columbia River basalts." They also state that a local andesitic volcanic center was probably responsible for the thick interbed between the low Mg Grande Ronde

Basalt and the Frenchman Springs Basalt. The identification of the Priest Rapids Basalt Member at 493 meters depth further substantiates this conclusion. The Frenchman Springs Member and the Priest Rapids Member are both represented by relatively thin flows here. Where these flows occur together east of the Cascades they are usually in contact. The thinness of the flows and presence of the thick clastic interbed is easily explained by about 120 meters of subsidence of the syncline and contemporaneous deposition between incursion of these two basalt members, a span of time of approximately one million years.

Data from this work on Old Maid Flat No. 1 is combined with data from Old Maid Flat No. 7 A, drilled to 1828 meters in 1980, by Priest and others (in preparation). Lithologic correlation between holes indicates little or no structural offset below about 250 meters depth.

PETROGRAPHY OF THE LAVAS

Thirty-six petrographic thin sections were studied and twenty-seven of these were subjected to point counts of 500 points. No systematic petrographic criteria were recognized for distinguishing the stratigraphic groupings. Each group shows a certain diversity of mineralogy, texture, and alteration. The younger rocks are the freshest, notably the olivine basalts on east Zigzag and Hunchback mountains. The epiclastic material of the Rhododendron Formation shows the most alteration. There are, however, some general mineralogical features of each group.

The lava flows and clasts of the Rhododendron Formation are almost all plagioclase porphyritic two-pyroxene andesites. Plagioclase of An 48-50 composes 21-38% (usually 27-28%) of the rock. Plagioclase phenocrysts are usually 0.5 to 2 mm long, euhedral to subhedral, and glomerocrysts are not uncommon. Phenocrysts are commonly subparallel. Compositional zoning is ubiquitous in plagioclases phenocrysts, and crystals commonly show signs of alteration, usually kaolinization along cleavage planes. There is usually more than one generation of plagioclase present, two or three distinct sizes are common, and often the smaller size will be gradational to the groundmass size. A complete size gradation from the largest crystals to groundmass may occur. Hypersthene is usually 5-7% and clinopyroxene (augite) is generally 1-2% of the total rock. Crystals are euhedral to subhedral, and generally less than 1 mm in size. Opaque minerals are often associated with the pyroxenes, either as clusters, or as reaction rims. Alteration is usually present and affects the orthopyroxenes most, turning the hypersthene to clay, antigorite, and magnetite. Hornblende is not too common in the Rhododendron Formation and occurs in only three sections studied here. In all cases it shows greenish to brownish pleochroism and is badly corroded, showing hematite and/or magnetite reaction rims. Olivine is very rare and in only trace amounts when present.

The Pliocene type material includes plagioclase porphyritic two pyroxene andesites like the Rhododendron Formation but also includes olivine basalts. Olivine is generally more common, even in the andesites, in this group. In the andesites, plagioclase usually is 1-3 mm in size (5-10 mm in a few flows), euhedral to subhedral, and zonation of opaque inclusions is often present, as well as the usual compositional zonation. Two or more generations of plagioclase are commonly present in these andesites. Clay alteration and corrosion of the larger crystals is present, but not as common as in the older rocks. Hypersthene makes up generally 6-8% of these rocks, and augite composes around 2-4%. The ratio of clinopyroxene to orthopyroxene seems to be higher in these younger rocks. Hypersthene appears fresher, and in some cases augite shows more alteration. Hypersthene crystals with augite cores were observed.

The olivine basalts occur higher in the section than the andesites. Rockpile viewpoint on Hunchback Mountain, and the flow on East Zigzag Mountain lookout are good examples of these rocks. The basalts are dark gray and fine grained. In thin section they are holocrystalline with a groundmass of randomly oriented to sub-parallel, euhedral to subhedral plagioclase laths with anhedral to subhedral clinopyroxene in between, sometimes with a sub-ophitic texture. The amount of olivine is subordinate to clinopyroxene in the groundmass, and roughly equal to the opaque minerals. Crystals of olivine, 0.5-1 mm, are present as phenocrysts, making up to 5-7%. These are usually subhedral to anhedral, and typically show brown iddingsite rims. Clinopyroxenes are occasionally found as phenocrysts. The olivine basalt flow at East Zigzag Mountain lookout has 10% 0.5mm plagioclase phenocrysts.

Petrography of the Pyroclastic Matrix

The petrography of the matrix of the pyroclastic volcanic breccias in the Rhododendron Formation reflects a microscopic continuation of macroscopic observations. The greatest proportion of the mudflow matrix (60-75%) is composed of angular to subrounded, andesitic to basaltic andesitic lithic clasts from centimeter to sub millimeter size. The smaller clasts usually show a variation in texture and phenocryst mineralogy, though often the larger clasts, centimeter and up in size, will be of one petrographic type. Degrees of alteration are variable, and original differences in alteration are masked by post-deposition alteration or weathering. Ferromagnesian minerals show the greatest variation in alteration in any one section, from relatively fresh to totally replaced by clays and antigorite. The finer proportion of the matrix is composed of subhedral to anhedral crystals and broken fragments of plagioclase and ferromagnesian minerals. Plagioclase commonly shows some degree of smectite alteration, which may or may not be variable. Ferromagnesian minerals are usually moderatly to totally altered. The smallest fraction is composed of very fine crystal fragments and greenish-brown to brown smectite clays. Often relic textures in the clay matrix will reveal shapes interpreted to be very small lithic clasts which, due to their large surface area and unstable glassey groundmasses, have altered and blended in with the matrix. Opaque minerals (mostly magnetite) are common, and one with a reticulated texture was observed and interpreted to be MnO_2. Usually little or no hematite is present, and when observed it is usually specific to one lithic clast. Occasional clasts will show the blue-green clay celadonite as an alteration product. Zeolites occur mostly as fracture fillings and are not a common matrix mineral. Fibrous radial zeolites are noted rarely between clasts and in voids. No relic pumice or glass shard textures that would indicate a hot ash flow origin were noted in any of the thin sections studied.

ANALYTICAL PROCEDURE

Samples selected for chemical analysis were the freshest obtainable, and any weathered or oxidized surfaces were removed with a hydraulic rock splitter. Fresh cores were crushed to one centimeter size in a tool-steel, jaw-type crusher. Chips were hand selected for freshness and presence of any metal (none of which was found). Splits of these chips were sent to Dr. Peter Hooper at Washington State University for major element analysis by X-ray fluorescence. Other splits were powdered using a corundum disk-mill micro-pulverizer at the Oregon State University Radiation Center. All equipment was cleaned out between each sample with ethanol and compressed air, and precontaminated by running through and discarding some of each new rock before obtaining an actual sample. Approximately one gram of sample was put into an already labeled and cleaned 0.5 dram polyvial. Vials were cleaned with HNO_3, acetone, and distilled water as prescribed by Laul (1979), and weighed empty to 0.0001 g. Vials with sample were again weighed to the same precision to obtain net sample weight.

Samples were irradiated for one hour at 237 kilowatts in a rotating rack in the Triga Mark I reactor at Reed College, Portland, Oregon. Flux density was approximately 2×10^{12} n cm^{-2} sec^{-1}. Resultant gamma spectra were obtained at six days and thirty days after bombardment using a Princeton Gamma-Tech coaxial Ge(Li) detector, with a nominal active volume of 90 cm^3. Four thousand ninety six channel spectra, at 0.5 Kev per channel, were obtained with a Tracor Northern 4000 multi-channel analyzer. Full-width-half-maximums of peaks were less than two Kev at high energies. Peaks were integrated and statistical counting error calculated with Tracor Northern's Neutron Activation Analysis Program No. 1808. Element concentrations and errors were calculated by comparative methods against USGS standards W-1 and G-2 by computer, using the Instrumental Neutron Activation Analysis program written by Beeson and Keedy, and later modified by Moran and Johnson, on file at Portland State University. This program corrects for differences in decay time, decay while counting, and normalizes weights. Standard compositions used were those of Flanagan (1976). Quality of data is considered very good; precision is greater than the accuracy. Trace element data and error calculations are presented in appendix A. Major element data was generated by wavelength dispersive X-ray fluorescence at Washington State University, and is considered to be accurate within two or three percent of the amount shown in the results (table II).

Table II. Major Element Data

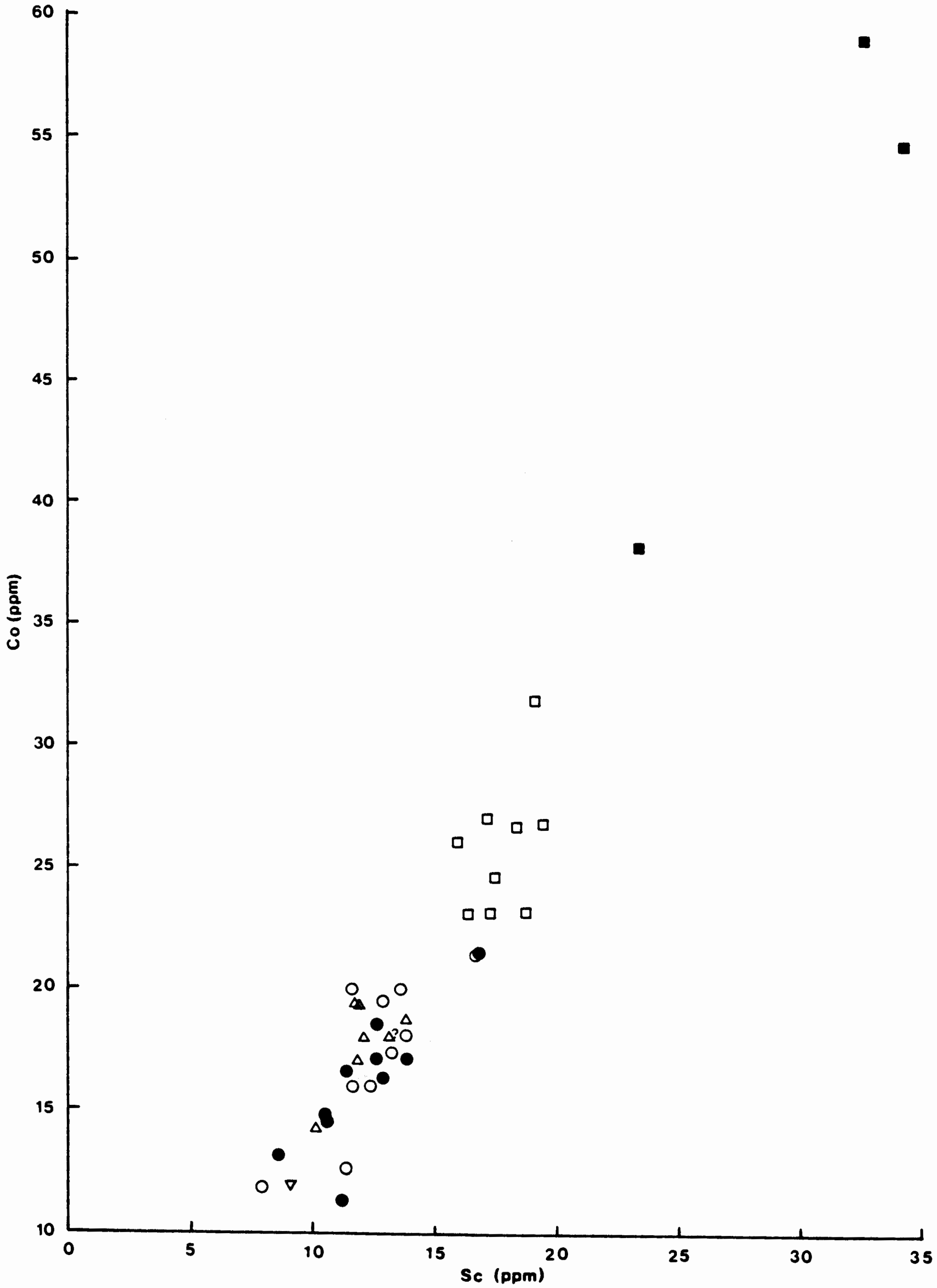
Sample	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	FeO	MnO	CaO	MgO	K_2O	P_2O_5
Rhododendron Formation breccia clasts										
6-16-1	62.01	17.37	0.74	2.84	3.26	0.11	6.00	2.80	1.22	0.17
6-18-6	64.27	17.90	0.64	2.36	2.70	0.07	5.53	2.13	1.32	0.12
6-25-5	62.64	18.47	0.73	2.22	2.55	0.05	6.61	2.07	1.31	0.16
7-2-3	64.22	18.27	0.58	2.19	2.51	0.07	5.38	1.96	1.20	0.16
7-8-4	60.95	18.13	0.82	3.33	3.82	0.09	6.11	2.16	1.03	0.16
Rhododendron Formation lava flows										
6-16-10	62.74	17.43	0.78	2.53	2.89	0.07	5.73	3.14	1.14	0.12
6-25-4	57.00	20.40	0.92	3.00	3.43	0.12	7.69	2.56	0.96	0.19
7-8-9	64.06	16.99	0.63	2.23	2.56	0.07	5.81	2.91	1.11	0.12
7-8-11	61.56	18.44	0.69	2.47	2.83	0.07	6.41	2.77	1.05	0.13
Dalles Formation breccia clasts										
8-24-3	61.10	17.97	0.80	2.91	3.33	0.08	6.31	3.16	1.06	0.14
8-24-5	62.21	18.77	0.72	2.15	2.46	0.05	6.63	2.10	1.33	0.15
9-10-2	64.13	17.23	0.74	2.45	2.81	0.09	5.46	2.09	1.20	0.15
9-13-4A	64.21	17.11	0.72	2.48	2.84	0.09	5.29	2.25	2.02	0.13
9-13-4D	60.92	18.19	0.96	3.02	3.45	0.08	6.26	2.56	1.09	0.17
Dalles Formation lava flows										
9-10-1	65.38	17.51	0.66	2.16	2.48	0.07	5.56	1.67	1.02	0.16
Pliocene type andesites										
6-16-3	60.29	17.85	0.79	2.98	3.41	0.10	6.69	3.48	1.00	0.14
7-1-2	59.59	16.72	0.99	3.29	3.77	0.12	6.97	3.97	1.29	0.18
7-1-4	58.22	17.99	1.02	3.48	3.98	0.10	7.22	3.46	1.01	0.22
7-2-9	58.03	18.35	0.91	3.44	3.95	0.12	7.15	3.69	0.77	0.16
7-10-5	57.50	19.34	1.12	3.45	3.95	0.10	6.55	2.95	1.45	0.24
7-10-6	61.31	16.83	1.03	3.09	3.54	0.08	5.85	3.21	1.59	0.20
8-5-3	54.35	17.58	1.49	3.90	4.47	0.13	8.26	5.17	1.14	0.35
Pliocene basalts										
7-8-1	50.97	17.27	1.33	5.26	6.02	0.18	9.23	6.39	0.59	0.20
7-18-5	51.98	18.58	1.48	4.36	4.99	0.14	8.61	5.71	0.77	0.22
Dike of unknown affinity										
7-2-8	57.32	18.04	0.94	3.52	4.03	0.12	7.76	4.45	0.64	0.16

GEOCHEMISTRY

Sixty samples were analyzed for trace elements for this study, and major element data was obtained for twenty five of these. Major element data is presented in table II, trace element data in appendix A. Rocks were placed into one of six categories based on field relations and mapping by previous workers (Wise 1969, Newcomb 1969, Peck et al. 1964) as follows. Rhododendron clasts include lava inclusions in Rhododendron Formation pyroclastic breccias from all areas sampled west of Mt. Hood. Rhododendron flows include lava flows interbedded with breccias on Zigzag and Hunchback Mountains and the Lolo Pass area. Dalles clasts include lava inclusions in pyroclastic breccias of the Dalles Formation east of Mt. Hood. One Dalles Formation lava flow was sampled along the east fork of the Hood River. Pliocene type andesites include the "Lower Pliocene Volcanics" of Wise (1969), and some lithologically similar dikes. Pliocene basalts include the olivine basalts mapped as "Upper Pliocene Volcanics" by Wise (1969). Essentially, stratigraphic designations in the discussion and on the data plots in this work are those of Wise (1969), Newcomb (1969), and Peck et al. (1964).

When the data are viewed in terms of those previously recognized stratigraphic groups, it becomes apparent that each of these units can be characterized by certain chemical parameters. Some of these recognized units show complete overlapping of chemistries with each other, some show partial overlap, and some do not overlap at all. The chemical relationships between the various recognized units are best typified by the plot of Sc versus Co (fig. 6). On this plot the Rhododendron and Dalles Formation material shows complete overlapping and fairly tight clustering, while the post Rhododendron andesites define a separate fairly tight cluster. The Pliocene basalts plot outside both these groupings. It should be noted that graphical presentations of major element data contain less points than those of trace elements. The chemical groupings can be typified as follows.

Two major groupings are recognized. The first includes almost all the andesite clasts from the pyroclastic breccias as well as lava flows from the Rhododendron and Dalles Formations. This group is characterized by having 11 to 20 ppm Co, 8 to 14 ppm Sc, less than 0.17% P_2O_5, and La/Sm ratios are 3.2 to 4.2. These rocks generally have 60 to 65% SiO_2.



Key to symbols: ○,Rhododendron Fm. clasts; ●, Dalles Fm. clasts; △ , Rhododendron Fm. flows; ▽, Dalles Fm. flows; □, Pliocene type andesites; ■, Pliocene basalts.

Figure 6. Co versus Sc

The second chemical grouping recognized includes the rocks mapped as "Lower Pliocene Volcanics" or "Lower Pliocene Shallow Intrusions" by Wise (1949), termed "Pliocene type andesites" in this thesis. These rocks differ from the older material of the first group by having higher Co (generally 21 to 29 ppm), higher Sc (15 to 20 ppm), higher P_2O_5 (above 0.18 wt%), and lower La/Sm ratios (usually 2.6 to 3.0). TiO_2 is generally higher than in other rocks in the area, usually 0.9 wt% or higher. Rocks of this group tend to be slightly more mafic than the older rocks. A plot of chondrite normalized rare earth element concentrations against atomic number (fig. 7) shows that these rocks are slightly more enriched in the heavy rare earths, and exhibit slight negative Eu anomalies. The difference in La/Sm ratios between these groups are shown in figure 8.

Three olivine basalts and olivine andesites analyzed in this report are from the "Upper Pliocene Volcanics" of Wise (1969). These, the youngest rocks sampled, are chemically different than rocks of the two groups discussed. These upper Pliocene rocks have the lowest concentrations of SiO_2, less than 55 wt%; higher Co, greater than 31 ppm; higher MgO, greater than 5 wt%; and higher TiO_2, greater than 1.3 wt%. These upper Pliocene rocks were not sampled extensively, and therefore are not represented by many points on most plots. Figures 9 and 10 show concentrations of TiO_2 and P_2O_5 in the rocks discussed.

The previously recognized Late Neogene stratigraphic units in the Mt. Hood area each have fairly narrow chemical parameters they seem to adhere to. Material from the Rhododendron and the Dalles Formations all has a very similar chemistry, and on most plots good over lap occurs; this material is considered to have a common source, or all be part of the same volcanic episode. Most of the Pliocene type andesites are similar chemically to each other, but distinct from the older Rhododendron-Dalles material, forming a grouping of their own on the Co versus Sc plot (fig. 6). The upper Pliocene material seems to represent a continuation of the departure from the Rhododendron type chemistry that the "Pliocene type" andesites exhibit. Each of the recognized Neogene volcanic sequences in the Mt. Hood area represents a "shift" in the chemistry of the volcanism. Successive shifts in the chemistry seem to follow the same chemical directions, for example increasing Co or Sc. This is not to imply, however, that the same temporal-chemical trends are observed within any of the recognized volcanic sequences. The systematic chemical variation exhibited by successive volcanic sequences does suggest some on going process was affecting the way magmas were generated or differentiated during the later Tertiary. An important point is that trace element data presented by White (1980) shows that Mt. Hood lavas are chemically more similar to the Rhododendron and

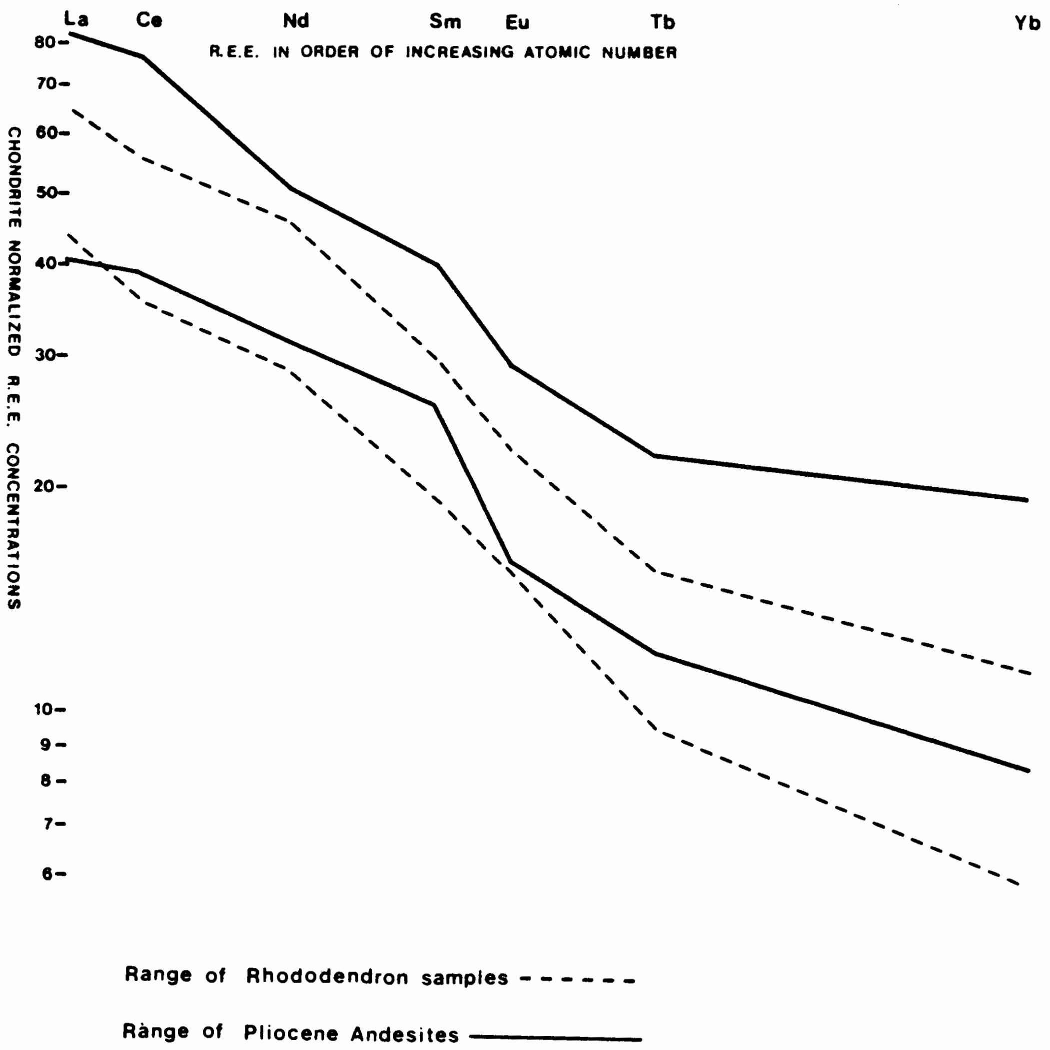


Figure 7. Chondrite Normalized Rare Earth Element Patterns

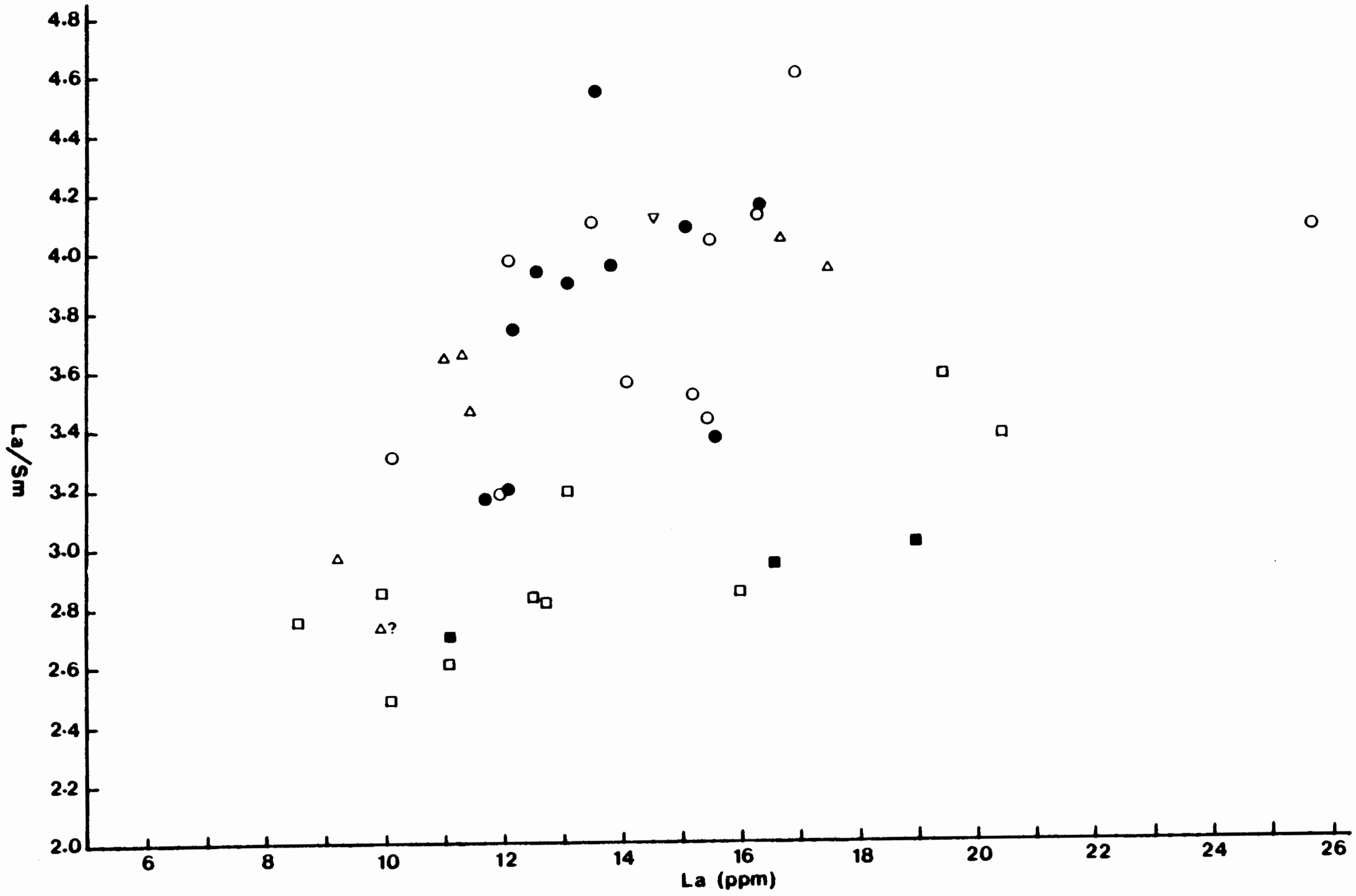
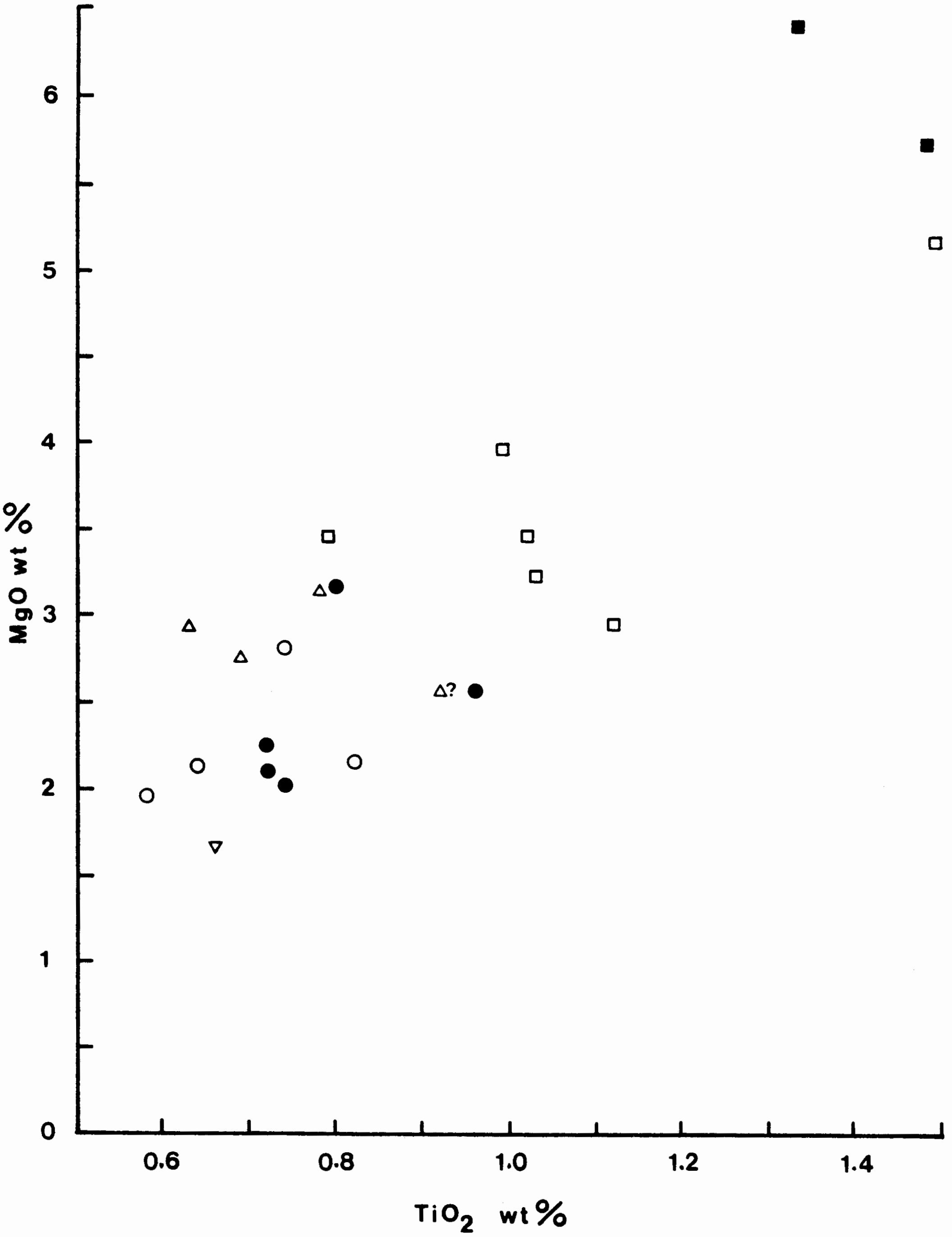
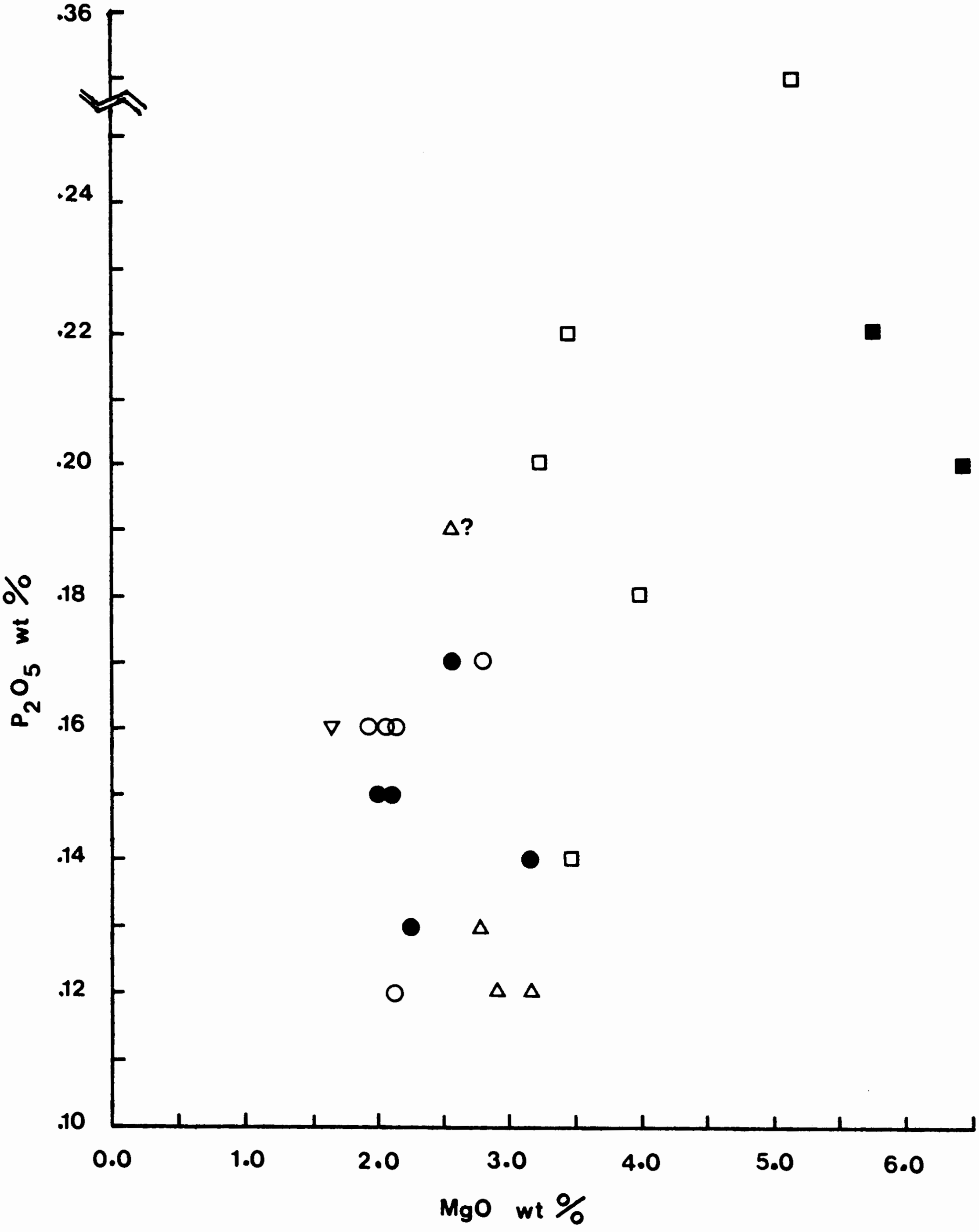


Figure 8. La/Sm versus La



Key to symbols: ○,Rhododendron Fm. clasts; ●, Dalles Fm. clasts; △ , Rhododendron Fm. flows; ▽, Dalles Fm. flows; □, Pliocene type andesites; ■, Pliocene basalts.

Figure 9. MgO versus TiO$_2$



Key to symbols: ○,Rhododendron Fm. clasts; ●, Dalles Fm. clasts; △ , Rhododendron Fm. flows; ▽, Dalles Fm. flows; □, Pliocene type andesites; ■, Pliocene basalts.

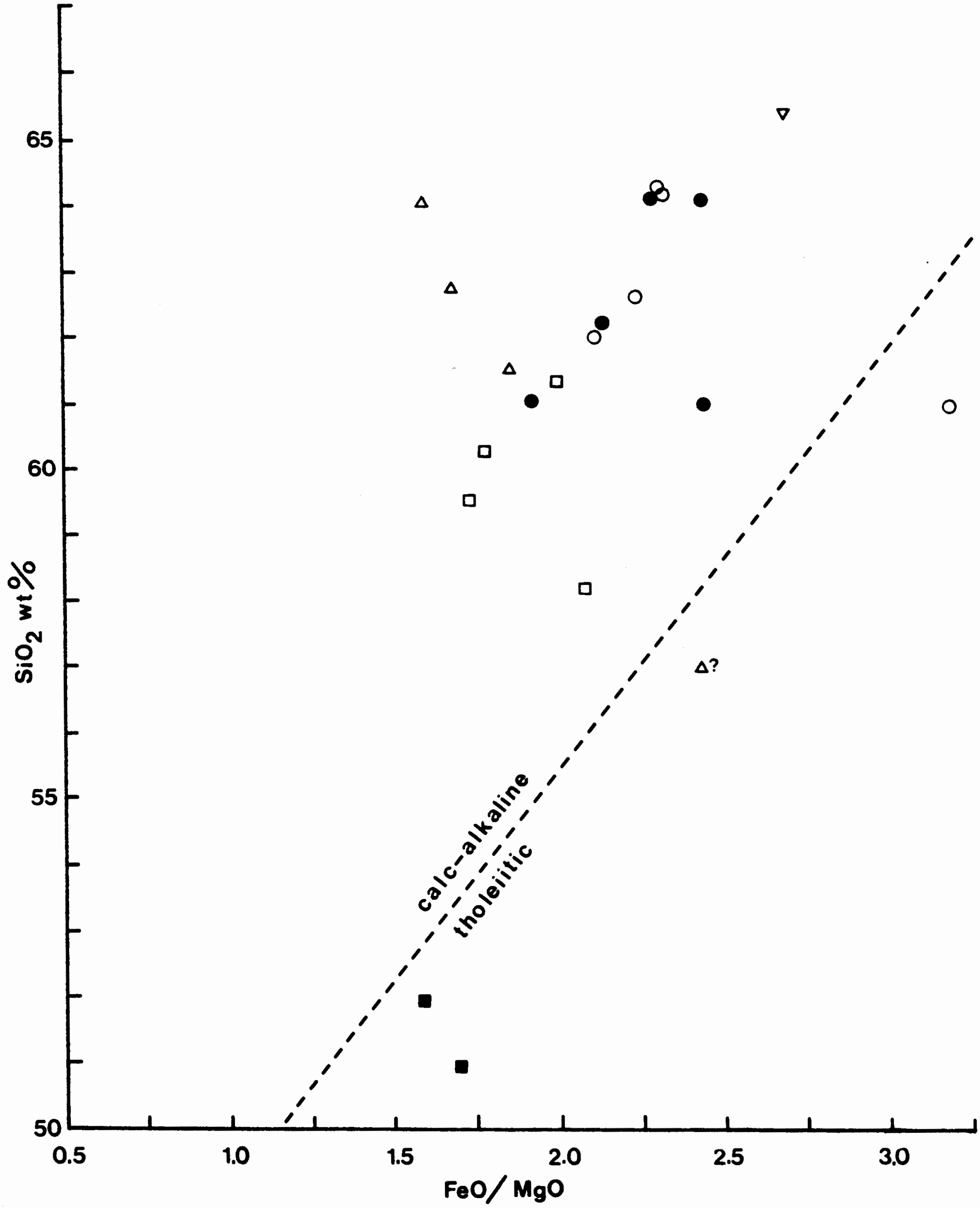
<u>Figure 10.</u> P_2O_5 versus MgO

Dalles Formation lavas than to the Pliocene lavas. Hence, the systematic chemical variation observed in the Neogene cannot be viewed as representing any evolutionary scheme applicable to the entire volcanic history of the Mt. Hood area. Following is a brief discussion on what the Neogene chemical variations may represent.

The chemical variation of the later Tertiary volcanics is basically dacites and andesites giving way to andesites and basalts. This decrease in SiO_2 is accompanied by general increases in Fe, Mg, Ca, Co, Sc, Ti, Cr, and P. Nearly all of the rocks analyzed are considered calc-alkaline by the criteria of Miyashiro (1974), though the late Pliocene olivine basalts exhibit slight tholeiitic affinities (fig. 11). The chemical variations observed do not seem atypical for a calc-alkaline suite of rocks. There are some features of the chemistry which do suggest more basic differences between two major groups of rocks in this study; the Rhododendron-Dalles series, and the Pliocene type andesites.

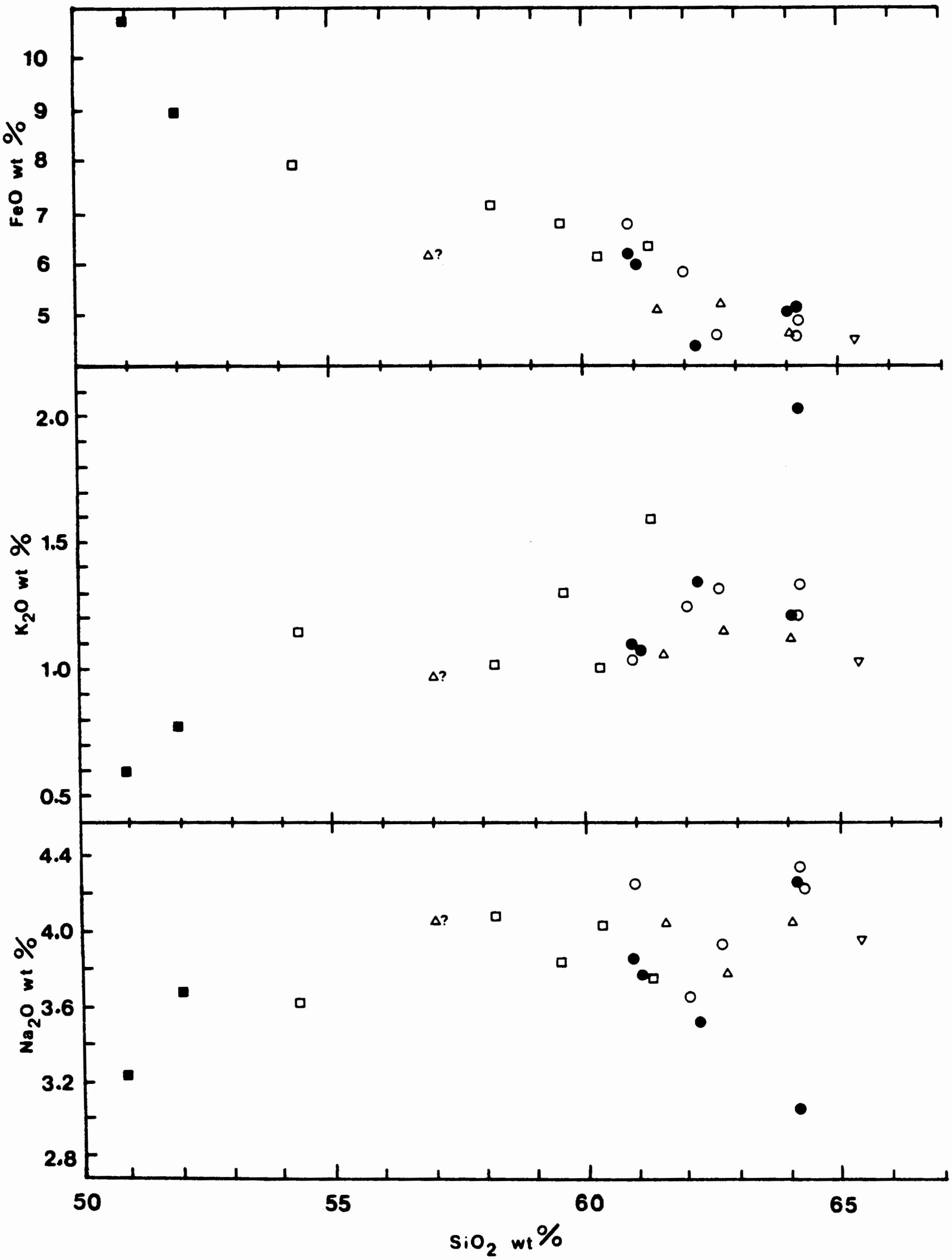
Variation diagrams of major cations against SiO_2 for the rocks analyzed (fig. 12) show FeO decreasing, and K_2O and Na_2O generally increasing, with increasing SiO_2. While a fairly linear relationship exists between SiO_2 and FeO, the plots of the alkalis are more spread out. The scanty K_2O data seems to indicate that the post Rhododendron lavas are more enriched in K_2O, relative to SiO_2, than the Rhododendron and Dalles Formation lavas. Unfortunately each group has a narrow range of SiO_2 values, so the variation of the alkalies within a group is not easily defined. However the K_2O plot seems to accomodate multiple sub-parallel lines, possibly indicating that the late Tertiary lavas were increasingly enriched in K_2O relative to SiO_2. Wise (1969) noticed and discussed variations in K_2O content between volcanic series in the Mt. Hood area. McBirney (1978) and White and McBirney (1979) discuss similar K_2O variations elsewhere in the Cascades. Hatherton and Dickinson (1969) document variations in the degree of K_2O enrichment in island arcs world wide, and demonstrate that it increases with increasing depth to the Benihoff zone. No such statement can be made in the Mt. Hood area.

The rare earth elements are sensitive indicators of petrological processes. The rare earth patterns of the Rhododendron and Dalles Formation lavas are very similar to the post-Rhododendron lavas, with some subtle yet important differences. Plots of the range of chondrite normalized concentrations of the rare earth elements for the two groups (fig. 7) clearly show that the post-Rhododendron lavas are slightly more enriched in the heavy rare earths, and exhibit a slight negative Eu anomalies, which are commonly thought to indicate removal of plagioclase from the melt by



Key to symbols: ○, Rhododendron Fm. clasts; ●, Dalles Fm. clasts; △, Rhododendron Fm. flows; ▽, Dalles Fm. flows; □, Pliocene type andesites; ■, Pliocene basalts.

Figure 11. SiO$_2$ versus FeO/MgO



Key to symbols: ○, Rhododendron Fm. clasts; ●, Dalles Fm. clasts; △ , Rhododendron Fm. flows; ▽, Dalles Fm. flows; □, Pliocene type andesites; ■, Pliocene basalts.

Figure 12. K_2O, Na_2O, and FeO versus SiO_2

fractional crystallization. The La/Sm ratio of these younger lavas is consistently lower than the older rocks (fig. 8). The La/Sm ratio is often used to measure the differences in behavior of the light rare earth elements relative to the heavy rare earth elements. Hanson (1980) provides an excellent review of the application of rare earth elements to the study of igneous systems.

Both major trace element data suggests that the post Rhododendron lavas are slightly more enriched in incompatible elements than the Rhododendron and Dalles Formation lavas. Incompatible elements are those that are partitioned into the liquid phase of a two phase (crystal/liquid) system, such as K, Na, and the rare earth elements. There are various degrees of incompatibility or compatibility. How a particular element is partitioned between a solid and liquid in equillibrium is a function of the compositions of the phases involved as well as temperature and pressure conditions. Trace element partition coefficients are discussed by Irving (1978), and applied to andesite genesis by Gill (1978).

Chemical variations in the cascades are discussed by Miyashiro (1974), McBirney (1978), and White and McBirney (1979). Miyashro (1974) proposes that chemical variations in active continental margins are due to variations in the amount of water in the mantle/melt system, progressive depletion of the upper mantle, and changes in the amount of partial melting. White and McBirney suggest a three stage model, with variations in chemistry the result of processes in the mantle source region, at the base of the lithosphere, and in shallow magma reservoirs beneath volcanoes. Hanson (1980) shows that rare earth element patterns can be affected by the degree and style of melting, partial pressure of H_2O and CO_2, as well as the mineral phases present during the processes of melting and differentiation, which will be a function of pressure and temperature conditions and composition of the system.

The progressive decrease in SiO_2 and relative enrichment of incompatible elements observed in the late Tertiary volcanics of the Mt. Hood area can be generally explained by Miyashiro's model of progressive depletion of the source causing decreased SiO_2 and increased Fe and Mg; with smaller degrees of partial melting causing relative enrichment of incompatible elements. By definition, an incompatible element will be most concentrated in smaller percent melts, and as percent melting increases the concentration of incompatible elements in the liquid decreases (Hanson 1980).

It is beyond the scope of this thesis, nor was it the intent, to chemically model the petrological history of the Mt. Hood area. The significant aspects of the chemistry pertinent to this study are that the Rhododendron and Dalles Formations in the Mt. Hood area can be defined by fairly narrow parameters, and appear to be part of the same volcanic series, and probably share a common source; and that they can be distinguished by trace element patterns from subsequent volcanics.

To this point the discussion has not addressed the affects of tectonism on the volcanism, and this is an important point. The way magmas ascend through the lithosphere and differentiate will no doubt be affected by the pattern and intensity of the stresses present. Davis (1980) points out that the late Tertiary was a time of major changes in the tectonic regime of western North America, and the style and chemistry of volcanism must reflect this.

DISCUSSION

Trace element variations in the Neogene volcanics in the Mt. Hood area have stratigraphic significance. The oldest andesitic and dacitic material sampled lowest in the section from drill holes on Old Maid Flat have Rhododendron-type chemistry. Almost all the andesitic and dacitic material up section to the top of the Rhododendron Formation has a similar chemistry. The appearance of flows of the Pliocene type chemistry is at a fairly sharp boundary higher in the section. This change in chemistry is accompanied by a change in the style of volcanism to a much more effusive and less fragmental type, which was recognized by earlier workers in the area (Wise 1969, Barns and Butler 1930).

With the chemical and stratigraphic evidence at hand, the Neogene volcanic history of the Mt. Hood area can be developed. In doing so, certain elements pertaining to the history must be addressed. First is the chemical similarity of the clastic material which makes up the bulk of the Rhododendron and Dalles Formations, and the appearance of Pliocene chemical types in the upper parts of the Dalles Formation. Second is the mode of emplacement of these deposits, and the apparent contemporaneous subsidence of the trough in which they reside. Thirdly, the occurrence of Pliocene type volcanism, its stratigraphic relationships, and structural implications must be addressed.

The first two points mentioned above may be discussed together. When one looks at what is known of the chemistry, petrology (both igneous and sedimentary) and geometry of the Dalles and the Rhododendron Formations, a clear picture evolves. These two deposits in part represent opposite ends of an oblong lens of pyroclastic material of very similar chemistry with the thickest portion in the area of the Mt. Hood. Source direction indicators are scarce and difficult to interpret, but seem to point toward a source in that area. The best indications are the general thinning of the deposits to the northeast and the southwest of Mt. Hood along the syncline, with a definite decrease in clast size in the same directions. The largest clasts observed by the author are in the upper Lolo Pass area near Mt. Hood, where clasts in excess of 2 or 3 m are not uncommon. Newcomb (1969), east of Mt. Hood, notices a similar decrease in clast size with distance to the northeast, as well as a general increase in roundness, and overall decrease in abundance of lithic clasts. Similar observations were made by this author, particularly when comparing the Chenowith Hills area, near the city of The Dalles, to the area south and west of there toward Mt. Hood. Another notable point is the lack of known vent areas for any of this material, and the general scarcity of lava flows in the Rhododendron and the Dalles Formations. The only flow which shows nearly identical chemistry to the breccia clasts occurs in the area of Burnt Lake very close to Mt. Hood. While the flows of Zigzag and Hunchback mountains must be considered Rhododendron, they have slightly different chemistry than the clasts in the epiclastic breccias. While in most chemical respects they are similar, the Zigzag Mt. and Hunchback Mt. flows consistently show slightly higher MgO, lower La and La/Sm ratios, and slightly higher Cr than most of the Rhododendron material. While most chemical evidence leaves little doubt that these flows are part of the Rhododendron sequence, the significance is that they cannot be viewed as a possible source for the epiclastic debris.

The thickness of andesitic material in the Old Maid Flat drill holes between the Frenchman Springs and Priest Rapids Members of the Wanapum Basalts of the Columbia River Group indicates around 120 meters of subsidence in roughly one million years. A basin which could entrap over 600 meters of clastic debris, was likely subsiding as material was coming in. Geochronologic evidence discussed earlier suggests a period of rapid deposition for most of the Rhododendron Formation, within three to four million years.

All this data taken together is interpreted to suggest the presence of a fairly large composite volcano somewhere in the vicinity of the present Mt. Hood during the middle to late Miocene epoch. A large rapidly growing steep sided cone erupting fairly silicic andesite would be unable to provide a stable resting place for effusive flows or domes extruded. Unstable accumulations would be quickly remobilized and redeposited as epiclastic volcanic breccias lower on the flanks and away from the cone. This redeposited material is what is now the bulk of the Rhododendron and the Dalles Formations in the Mt. Hood area. Other ongoing erosional agents continued to rework this material in a more normal sedimentary fashion as seen to the northeast as Newcomb's (1966) sedimentary facies of the Dalles Formation.

Eruptions of this nature had probably ceased when the first Pliocene type lavas erupted. These lavas are chemically dissimilar to the Rhododendron Formation, and apparently have multiple widely spaced vent areas (Wise 1969). The occasional appearance of lavas of this later chemical type included in pyroclastic breccias of the upper part of the Dalles Formation is interpreted to suggest that this cone was still rapidly eroding when the later lavas came out. Eruptions of Pliocene type lavas on or near the flanks of a large unstable eroding volcanic edifice would likely trigger mudflows, and undoubtedly would be incorporated into the resulting deposit. In order for the boundary represented by the change in volcanism from the Rhododendron type chemistry to the Pliocene type chemistry to be of stratigraphic use, certain considerations are necessary. Mainly what was the time span between the two volcanic episodes, and what was the geometry of the contact. There is evidence that suggests that there was no great expanse of time between these two volcanic episodes. There is generally no observable erosional horizon, and Wise (1969) states that the "early Pliocene lavas" are conformable on the Rhododendron Formation. As mentioned above, clasts of both chemical types occur together in epiclastic breccias in the upper parts of the Dalles Formation. It appears that post-Rhododendron lavas were extruded onto the Rhododendron-Dalles surface quickly enough to be intimately involved in the last parts of the pyroclastic deposition, at least to the east of Mt. Hood.

Much can be deduced about the geometry of the top of the Rhododendron Formation with what is known about the environment of deposition and the nature of the present contact. If a large volcano with the cone in a phase of erosion was present, but with the flanks and surrounding area accumulating clastic debris, the topography could perhaps be compared with much of today's High Cascade Province. This topography would be much gentler and not as deeply dissected as today's Western Cascades. In fact, the elevation of the top of the Rhododendron, where actually mapped in the Mt. Hood area, usually varies by only a few hundred feet. Any occurrences of the top of the Rhododendron Formation at drastically different elevations than 2800 to 3000 feet in the immediate area around Mt. Hood, such as above Burnt Lake near East Zigzag Mt. Lookout, must be considered anomalous, and should be viewed as having structural implications. Distal aspects of these deposits were undoubtedly once at lower elevations than proximal aspects by several hundred feet, and this must be included in structural interpretations based on this boundary.

SUMMARY AND CONCLUSIONS

Examination of the trace element chemistry of Neogene volcanic rocks of the Mt. Hood area has revealed a systematic chemical variation similar in many ways to that found elsewhere in the Cascade Range. A number of distinct volcanic series are recognised, and each has a rather narrow variation in chemistry with little or no overlap between chemical groupings. Previously recognised formational units parallel the trace element groupings quite well, as the different chemical types are reflected in different styles of volcanism. The earlier, more silicic Dalles-Rhododendron series was much more fragmental in its eruptive style, and was probably restricted to a single central vent or area of vents. The later, slightly more mafic Pliocene type volcanism had a much more effusive eruptive style, and issued from multiple separated vents (Wise 1969). It is probable that changes in the Neogene tectonic regime of Western North America influenced the observed variation. A detailed examination of the Neogene tectonic evolution of Western North America along with changes in the style and chemistry of volcanism would be most worthwhile.

The Rhododendron and Dalles Formations appear to be part of the same volcanic series, and evidence indicates that they represent the pyroclastic accumulations low on the flanks of a large composite volcano, which occupied the subsiding The Dalles-Mt. Hood syncline during the middle to late Miocene epoch. Sometime during the late Miocene a rather abrupt change in the style of volcanism and chemistry of the erupted products occurred. These more mafic, effusive type lavas were recognised as post Rhododendron Formation, and termed "Cascan Formation" by Hodge (1938), and "Lower Pliocene Volcanics" by Wise (1969). This series is overlain by a more mafic series of basaltic andesites and olivine basalts termed "Upper Pliocene Volcanics" by Wise. This last series shows slight iron enrichment and is considered tholeiitic by the criteria of Miyashiro (1974).

Trace element geochemical analysis can be used to place rocks of questionable affinity into either the Rhododendron-Dalles series, or the Pliocene type lava series, with a high degree of confidence. The ability to place the formational boundry, coupled with what is known about the geometry of the upper surface of the Rhododendron Formation, can be of use in structural modeling in the Mt. Hood area.

Field sampling for this project was restricted to The Dalles-Mt. Hood syncline. A suggestion for future work would be geochemical sampling of similar epiclastic thicknesses in nearby structural lows, such as the Bull Run syncline or the Clackamas River drainage, and comparison of the petrochemistry of those sections with the Rhododendron series. Extremely detailed sampling of two or three thick sections of the Rhododendron Formation (more detailed than was possible for this study) may reveal a petrological evolution within the Rhododendron-Dalles series. It is felt that a complete section is not present at any one location however, and such an effort may prove futile.

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APPENDIX A

TRACE ELEMENT DATA

SAMPLE	NA		SC		FE		CO		CR		TH	
6-16-1	2.71	0.01	12.92	0.06	4.40	0.04	19.50	0.30	24.30	1.50	3.70	0.40
6-16-3	2.99	0.01	18.73	0.07	5.01	0.04	23.20	0.40	96.00	3.00	3.10	0.30
6-16-10	2.80	0.01	13.94	0.06	3.56	0.03	18.70	0.30	68.20	2.00	1.80	0.20
6-18-2	2.59	0.01	12.64	0.06	3.85	0.03	20.00	0.30	53.20	1.80	2.90	0.30
6-18-4	2.87	0.02	12.07	0.05	3.80	0.03	18.00	0.30	49.00	1.70	2.70	0.30
6-18-6	3.14	0.02	11.70	0.05	3.76	0.03	16.00	0.30	17.10	1.30	4.40	0.40
6-25-4	3.01	0.02	13.13	0.06	4.36	0.04	18.00	0.30	15.10	1.40	1.70	0.20
6-25-5	2.92	0.01	12.42	0.06	3.25	0.03	16.00	0.30	58.00	1.90	3.00	0.30
6-25-6	3.36	0.02	11.04	0.05	3.77	0.03	12.60	0.30	44.80	1.60	4.30	0.40
6-26-2	2.88	0.02	13.25	0.06	3.79	0.03	17.40	0.30	42.80	1.70	4.40	0.40
7-1-2	2.85	0.01	17.51	0.06	4.76	0.04	24.60	0.40	128.00	3.00	3.30	0.30
7-1-4	3.03	0.02	19.45	0.07	5.14	0.04	26.80	0.40	72.31	2.85	4.10	0.40
7-1-6	3.16	0.03	14.50	0.06	6.83	0.05	27.80	0.40	0.	0.	1.60	0.20
7-2-2	3.60	0.02	9.52	0.04	1.94	0.02	4.95	0.16	26.26	1.33	4.90	0.50
7-2-3	3.22	0.02	7.98	0.04	3.24	0.03	11.90	0.30	24.74	1.30	3.30	0.30
7-2-7	2.76	0.01	10.11	0.05	3.44	0.03	14.30	0.30	31.93	1.49	4.40	0.40
7-2-8	2.87	0.02	22.77	0.08	5.74	0.04	28.90	0.40	117.00	3.00	2.40	0.30
7-2-9	2.87	0.01	17.45	0.06	5.14	0.04	23.30	0.40	72.00	2.00	2.30	0.30
7-3-2A	3.47	0.02	9.73	0.04	2.23	0.03	8.50	0.20	27.70	1.40	2.60	0.30
7-3-3	1.38	0.01	14.55	0.06	4.51	0.04	22.60	0.40	96.00	2.00	1.90	0.30
7-8-1	2.40	0.01	34.27	0.10	9.62	0.06	54.70	0.60	177.00	4.00	2.60	0.30
7-8-4	3.16	0.02	13.81	0.06	4.91	0.04	18.20	0.30	24.40	1.60	3.20	0.30
7-8-8	2.90	0.02	17.09	0.06	4.49	0.04	27.10	0.40	83.00	2.00	1.90	0.30
7-8-9	3.02	0.02	11.94	0.05	3.36	0.03	19.30	0.30	86.00	2.00	2.60	0.30
7-8-11	3.01	0.02	11.73	0.05	3.65	0.03	19.40	0.30	45.00	1.70	2.30	0.30
7-9-3A	2.77	0.01	16.69	0.06	4.37	0.04	21.40	0.30	135.00	3.00	4.50	0.40
7-10-5	2.49	0.01	11.03	0.05	4.77	0.04	22.30	0.30	5.40	1.30	3.10	0.30
7-10-6	2.79	0.01	17.37	0.06	4.70	0.04	23.20	0.40	125.00	3.00	5.00	0.50
7-18-2	2.66	0.02	18.41	0.07	5.04	0.04	26.70	0.40	155.00	3.00	3.80	0.40
7-18-5	2.74	0.02	23.44	0.08	6.69	0.05	38.20	0.50	134.00	3.00	1.50	0.30
7-28-5	3.14	0.02	11.78	0.05	3.85	0.03	17.10	0.30	25.20	1.50	4.20	0.40
7-28-7	2.47	0.01	15.46	0.06	4.43	0.04	19.80	0.30	38.60	1.80	3.10	0.30
9-10-1	2.94	0.02	9.11	0.05	3.23	0.03	12.00	0.20	31.80	1.50	3.40	0.30
9-10-2	3.16	0.02	8.55	0.05	3.35	0.03	13.20	0.30	30.10	1.40	3.30	0.30

All data are in ppm except Na and Fe which are in weight percent

SAMPLE	LA		CE		ND		SM		EU		TB		YB	
6-16-1	14.10	0.40	31.70	1.30	0.	0.	3.56	0.05	1.03	0.03	0.58	0.07	1.40	0.20
6-16-3	13.10	0.40	29.70	1.30	15.62	4.46	4.07	0.05	1.19	0.03	0.56	0.08	1.70	0.30
6-16-10	9.20	0.30	17.40	0.90	12.67	4.31	3.09	0.04	0.95	0.02	0.38	0.06	0.98	0.18
6-18-2	11.90	0.40	23.80	1.10	0.	0.	3.19	0.05	1.02	0.03	0.48	0.06	1.30	0.20
6-18-4	11.30	0.30	23.60	1.10	0.	0.	3.08	0.04	0.97	0.02	0.40	0.06	1.10	0.19
6-18-6	16.30	0.40	33.90	1.40	15.12	4.05	3.94	0.05	1.00	0.02	0.59	0.07	1.70	0.20
6-25-4	9.90	0.30	24.30	1.10	14.58	4.03	3.62	0.05	1.13	0.03	0.56	0.07	1.60	0.30
6-25-5	12.20	0.40	27.00	1.20	12.96	3.78	3.11	0.04	1.00	0.02	0.45	0.06	1.28	0.20
6-25-6	16.90	0.50	35.50	1.50	15.40	4.80	3.67	0.05	0.97	0.02	0.49	0.06	1.50	0.20
6-26-2	15.50	0.40	35.70	1.50	14.55	4.80	3.84	0.05	1.06	0.03	0.55	0.07	1.60	0.20
7-1-2	12.50	0.40	32.10	1.40	16.95	4.71	4.41	0.06	1.12	0.03	0.67	0.08	1.90	0.30
7-1-4	20.40	0.50	39.30	1.60	24.57	5.94	6.03	0.07	1.58	0.03	0.79	0.09	2.30	0.30
7-1-6	12.90	0.40	31.30	1.40	20.22	5.85	4.73	0.06	1.65	0.04	0.58	0.08	2.20	0.30
7-2-2	13.50	0.40	30.20	1.30	14.05	3.81	3.29	0.05	0.99	0.02	0.40	0.06	1.40	0.20
7-2-3	25.70	0.60	40.10	1.60	27.04	5.99	6.31	0.07	1.45	0.03	0.85	0.09	2.00	0.30
7-2-7	16.50	0.40	39.90	1.60	15.68	4.23	4.18	0.05	1.24	0.03	0.50	0.06	1.40	0.20
7-2-8	10.40	0.30	25.20	1.30	15.00	5.00	3.73	0.05	1.15	0.03	0.56	0.08	2.00	0.40
7-2-9	9.90	0.30	23.50	1.20	14.00	4.00	3.47	0.05	1.10	0.03	0.49	0.07	2.20	0.30
7-3-2A	10.20	0.40	22.10	1.00	12.00	3.00	2.59	0.04	0.82	0.02	0.38	0.05	1.28	0.20
7-3-3	3.59	0.14	21.40	1.10	0.	0.	1.18	0.02	0.70	0.02	0.36	0.06	1.30	0.20
7-8-1	16.60	0.50	43.90	1.90	30.50	7.49	5.64	0.06	1.72	0.04	0.86	0.11	3.30	0.40
7-8-4	15.40	0.40	35.20	1.50	16.21	4.56	4.48	0.06	1.17	0.03	0.56	0.07	2.30	0.30
7-8-8	11.10	0.40	25.10	1.20	15.13	5.30	4.25	0.05	1.18	0.03	0.60	0.08	2.20	0.30
7-8-9	11.40	0.40	25.60	1.20	14.19	4.84	3.28	0.05	0.95	0.02	0.41	0.06	1.10	0.20
7-8-11	11.00	0.40	23.50	1.10	0.	0.	3.02	0.05	0.96	0.02	0.44	0.06	1.40	0.20
7-9-3A	15.20	0.40	28.80	1.30	13.56	4.32	4.33	0.06	1.13	0.03	0.65	0.08	2.30	0.30
7-10-5	18.40	0.50	38.40	1.60	16.49	4.49	5.23	0.06	1.47	0.03	0.64	0.07	2.00	0.30
7-10-6	15.90	0.40	40.90	1.70	16.98	5.89	5.57	0.07	1.21	0.03	0.80	0.09	2.80	0.40
7-18-2	12.70	0.40	32.00	1.40	0.	0.	4.49	0.06	1.12	0.03	0.58	0.08	2.20	0.30
7-18-5	11.10	0.40	26.10	1.30	16.52	5.05	4.10	0.06	1.40	0.03	0.62	0.09	2.00	0.30
7-28-5	16.70	0.50	34.50	1.40	20.09	5.00	4.13	0.05	1.18	0.03	0.54	0.07	1.60	0.30
7-28-7	12.60	0.40	28.30	1.30	14.91	4.40	3.67	0.05	1.10	0.03	0.58	0.07	1.80	0.30
9-10-1	14.60	0.40	31.90	1.30	17.14	4.42	3.54	0.05	1.09	0.03	0.39	0.06	1.30	0.20
9-10-2	15.10	0.40	34.70	1.40	14.08	4.02	3.70	0.05	1.17	0.03	0.38	0.06	1.20	0.20

SAMPLE	LU		HF	
6-16-1	0.22	0.06	4.00	0.30
6-16-3	0.26	0.07	4.00	0.30
6-16-10	0.	0.	3.20	0.20
6-18-2	0.25	0.06	3.60	0.30
6-18-4	0.	0.	3.30	0.30
6-18-6	0.33	0.06	4.00	0.30
6-25-4	0.37	0.07	3.30	0.30
6-25-5	0.18	0.06	3.60	0.30
6-25-6	0.26	0.06	4.10	0.30
6-26-2	0.23	0.06	4.40	0.30
7-1-2	0.35	0.06	5.20	0.40
7-1-4	0.38	0.07	3.90	0.30
7-1-6	0.33	0.06	3.40	0.30
7-2-2	0.	0.	3.80	0.30
7-2-3	0.29	0.06	4.00	0.30
7-2-7	0.17	0.05	4.20	0.30
7-2-8	0.34	0.06	3.10	0.30
7-2-9	0.31	0.06	3.60	0.30
7-3-2A	0.20	0.05	3.10	0.20
7-3-3	0.12	0.03	3.00	0.20
7-8-1	0.43	0.07	3.30	0.30
7-8-4	0.26	0.06	4.20	0.30
7-8-8	0.23	0.06	3.30	0.30
7-8-9	0.20	0.05	3.30	0.20
7-8-11	0.19	0.05	3.30	0.20
7-9-3A	0.31	0.06	4.10	0.30
7-10-5	0.27	0.05	4.10	0.30
7-10-6	0.42	0.07	6.90	0.50
7-18-2	0.25	0.05	5.00	0.30
7-18-5	0.33	0.06	4.10	0.30
7-28-5	0.25	0.05	4.30	0.30
7-28-7	0.26	0.05	3.70	0.30
9-10-1	0.18	0.05	3.70	0.30
9-10-2	0.	0.	4.30	0.30

SAMPLE	NA		SC		FE		CO		CR		TH	
7-29-1	2.58	0.01	16.33	0.05	6.12	0.04	23.20	0.30	82.20	1.70	1.15	0.14
7-29-7	2.49	0.01	15.96	0.05	6.03	0.04	26.10	0.30	182.00	3.00	0.96	0.12
7-29-13	2.84	0.01	13.63	0.04	5.22	0.04	20.00	0.30	36.30	1.20	1.94	0.14
8-5-1	2.80	0.01	12.59	0.04	5.48	0.04	18.50	0.30	20.70	1.10	1.98	0.17
8-5-3	2.69	0.01	19.05	0.06	7.53	0.04	31.80	0.40	114.00	2.00	2.17	0.17
8-5-5A	1.85	0.01	32.70	0.07	10.75	0.05	59.00	0.50	312.00	4.00	2.50	0.20
8-19-1	2.63	0.01	12.85	0.04	5.12	0.03	16.40	0.20	39.70	1.50	3.70	0.20
8-24-3	2.80	0.01	16.62	0.05	5.91	0.04	21.50	0.30	54.40	1.50	3.40	0.20
8-24-5	2.62	0.01	10.62	0.04	4.82	0.03	14.60	0.20	38.10	1.20	3.20	0.20
9-5-4	2.85	0.01	7.06	0.03	4.02	0.03	5.34	0.15	9.00	1.40	10.50	0.60
9-5-6	2.79	0.01	14.39	0.05	6.59	0.04	20.70	0.30	28.80	1.30	5.70	0.30
9-13-1	2.87	0.01	11.43	0.04	4.90	0.04	16.60	0.30	21.40	1.10	2.74	0.18
9-13-2	2.65	0.01	12.63	0.04	4.79	0.04	17.20	0.30	35.90	1.20	2.80	0.20
9-13-3	2.84	0.01	11.19	0.04	4.59	0.04	11.30	0.20	24.50	1.10	4.30	0.30
9-13-4A	2.27	0.01	10.50	0.04	4.33	0.03	14.60	0.20	34.40	1.20	4.80	0.30
9-13-4D	2.86	0.01	13.96	0.04	5.50	0.04	17.20	0.30	19.80	1.20	2.59	0.19
OMF-835	3.86	0.02	10.24	0.04	4.40	0.03	14.70	0.20	18.40	1.00	3.60	0.20
OMF-990	1.91	0.01	26.09	0.06	6.80	0.05	30.30	0.40	130.00	2.00	1.30	0.15
OMF-1060	2.95	0.01	7.55	0.03	3.84	0.03	11.05	0.19	20.60	1.00	4.50	0.30
OMF-1190	2.99	0.01	7.53	0.03	3.87	0.03	11.40	0.20	20.70	1.00	4.20	0.30
OMF-1290	2.76	0.01	7.29	0.03	3.54	0.03	10.30	0.20	20.10	1.00	4.00	0.20
OMF-1320	2.86	0.01	7.60	0.03	3.86	0.03	11.20	0.20	22.10	1.00	4.40	0.30
OMF-1620	2.41	0.01	38.39	0.11	11.56	0.07	47.30	0.50	90.00	2.00	4.10	0.30
OMF-2380	3.11	0.02	8.32	0.05	4.20	0.05	11.80	0.30	25.20	1.40	5.20	0.30
OMF-2640	2.70	0.02	36.76	0.10	13.26	0.08	42.00	0.60	0.	0.	8.50	0.60
OMF-2680	2.73	0.02	35.75	0.11	12.50	0.07	39.90	0.50	12.00	2.00	7.50	0.50
OMF-2820	2.96	0.02	33.37	0.09	12.32	0.08	39.50	0.50	7.29	1.78	7.20	0.50

SAMPLE	LA		CE		ND		SM		EU		TB		YB	
7-29-1	8.50	0.30	17.70	0.80	15.00	5.00	3.07	0.04	0.96	0.02	0.41	0.06	1.23	0.17
7-29-7	10.10	0.30	16.90	0.80	19.00	7.00	4.07	0.05	1.07	0.02	0.47	0.06	1.43	0.18
7-29-13	10.10	0.30	21.20	0.80	16.00	5.00	3.05	0.04	0.93	0.02	0.41	0.05	1.13	0.16
8-5-1	15.60	0.50	27.70	1.00	28.00	9.00	4.62	0.06	1.34	0.03	0.52	0.06	1.32	0.17
8-5-3	19.40	0.50	49.00	1.60	38.00	12.00	5.41	0.06	1.64	0.03	0.62	0.07	1.45	0.19
8-5-5A	18.90	0.50	48.50	1.50	38.00	10.00	6.24	0.05	1.74	0.04	0.74	0.09	2.60	0.30
8-19-1	13.60	0.40	28.90	1.00	17.00	5.00	2.99	0.04	0.94	0.02	0.42	0.05	1.27	0.17
8-24-3	12.10	0.40	28.20	1.00	21.00	6.00	3.82	0.04	1.05	0.02	0.53	0.06	1.80	0.20
8-24-5	13.80	0.40	31.90	1.10	15.00	6.00	3.49	0.05	1.00	0.02	0.49	0.06	1.08	0.15
9-5-4	29.60	0.80	72.00	2.00	47.00	15.00	7.84	0.09	1.43	0.03	1.30	0.11	3.20	0.30
9-5-6	22.10	0.60	50.40	1.50	33.00	9.00	6.12	0.06	1.55	0.03	0.95	0.08	2.60	0.30
9-13-1	12.60	0.40	27.50	0.90	18.00	6.00	3.20	0.04	0.99	0.02	0.46	0.05	1.17	0.16
9-13-2	12.20	0.40	24.40	0.90	22.00	7.00	3.26	0.04	0.95	0.02	0.44	0.05	1.20	0.16
9-13-3	16.30	0.50	31.00	1.00	24.00	7.00	3.91	0.05	1.07	0.02	0.61	0.06	1.90	0.20
9-13-4A	13.10	0.40	28.90	1.00	22.00	7.00	3.36	0.06	0.87	0.02	0.44	0.05	1.20	0.16
9-13-4D	11.70	0.40	23.30	0.90	22.00	6.00	3.69	0.05	1.18	0.03	0.52	0.06	1.51	0.20
OMF-835	13.30	0.40	28.90	1.00	16.00	5.00	3.11	0.04	0.93	0.02	0.42	0.05	1.43	0.18
OMF-990	7.30	0.30	16.90	0.90	0.	0.	3.09	0.04	1.01	0.03	0.50	0.07	1.80	0.20
OMF-1060	16.70	0.50	37.00	1.20	22.00	6.00	3.65	0.05	1.03	0.02	0.50	0.05	1.00	0.13
OMF-1190	16.30	0.40	36.30	1.20	22.00	6.00	3.59	0.05	1.05	0.02	0.47	0.05	0.88	0.13
OMF-1290	15.30	0.40	33.90	1.10	24.37	7.94	3.48	0.05	0.98	0.02	0.36	0.04	1.14	0.15
OMF-1320	16.70	0.50	37.40	1.20	23.00	6.00	3.89	0.06	1.04	0.02	0.45	0.05	0.91	0.13
OMF-1620	23.90	0.60	60.00	2.00	36.00	11.00	9.84	0.08	2.94	0.06	0.	0.	3.90	0.40
OMF-2380	18.10	0.60	42.20	1.50	27.00	8.00	4.18	0.07	1.16	0.04	0.54	0.07	1.22	0.19
OMF-2640	27.60	0.70	71.00	2.00	49.00	14.00	9.14	0.10	2.48	0.07	1.48	0.15	3.70	0.40
OMF-2680	24.00	0.70	60.00	2.00	46.76	16.04	8.05	0.10	2.09	0.05	1.45	0.14	3.80	0.50
OMF-2820	24.00	0.60	58.50	2.00	35.00	10.00	7.72	0.09	2.09	0.04	1.34	0.14	3.60	0.40

SAMPLE	LU		HF	
7-29-1	0.23	0.05	2.37	0.18
7-29-7	0.22	0.05	2.27	0.17
7-29-13	0.24	0.05	3.00	0.20
8-5-1	0.24	0.05	3.40	0.20
8-5-3	0.21	0.05	3.70	0.20
8-5-5	0.40	0.08	4.10	0.30
8-19-1	0.26	0.05	3.90	0.20
8-24-3	0.20	0.05	4.40	0.30
8-24-5	0.14	0.04	3.90	0.20
9-5-4	0.47	0.08	10.80	0.60
9-5-6	0.45	0.08	6.40	0.40
9-13-1	0.20	0.05	3.60	0.20
9-13-2	0.18	0.04	3.20	0.20
9-13-3	0.30	0.06	4.00	0.20
9-13-4A	0.18	0.04	3.30	0.20
9-13-4D	0.16	0.05	3.30	0.20
OMF-835	0.21	0.05	3.60	0.20
OMF-990	0.26	0.06	2.50	0.20
OMF-1060	0.11	0.03	3.80	0.30
OMF-1190	0.10	0.03	3.70	0.30
OMF-1290	0.12	0.03	3.60	0.20
OMF-1320	0.	0.	3.80	0.30
OMF-1620	0.56	0.09	5.00	0.40
OMF-2380	0.20	0.05	4.50	0.30
OMF-2640	0.50	0.10	5.40	0.50
OMF-2680	0.52	0.11	5.80	0.40
OMF-2820	0.40	0.08	5.30	0.40

APPENDIX B

SAMPLE DESCRIPTIONS

6-16-1	Dark gray, plagioclase porphyritic pyroxene andesite; 20% 3-4mm euhedral to subhedral plagioclase, 3% clinopyroxene, 3% orthopyroxene, 1.5% hornblende.
6-16-3	Dark gray, plagioclase porphyritic pyroxene andesite; 16% 1-2mm euhedral to subhedral plagioclase, 5% orthopyroxene, 2% clinopyroxene, trace olivine, clinopyroxenes altering to a yellowish mineral.
6-16-10	Medium gray, very plagioclase porphyritic pyroxene dacite; 30% 1mm sub-parallel plagioclase, 10% pyroxene, hypersthene, and lesser augite, most showing dark iron oxide rinds.
6-18-2	Dark gray, very plagioclase porphyritic pyroxene andesite; 30% 1-3mm sub-parallel plagioclase, often in clusters, 8% 0.25mm pyroxenes, orthopyroxene>clinopyroxene.
6-18-4	Medium gray, plagioclase porphritic pyroxene-andesite; 32% 1mm plagioclase, often in clusters, 10% pyroxenes, orthopyroxene>clinopyroxene.
6-18-6	Medium gray, plagioclase porphyritic hornblende pyroxene dacite; 23% 2-8mm variable size euhedral to subhedral plagioclase, 4% pyroxene, orthopyroxene>clinopyroxene, 1.5% hornblende, very glassy groundmass.
6-25-4	Dark gray, highly plagioclase porphyritic pyroxene andesite; 38% 2-4mm euhedral to subhedral often broken plagioclase, with light clay alteration common, 3% 0.5mm hypersthene, traces of clinopyroxene and hornblende.
6-25-5	Medium gray, plagioclase porphritic pyroxene dacite; 27% 1mm euhedral to subhedral plagioclase, often in clusters, 8% altered pyroxenes, orthopyroxene>clinopyroxene. Ground-

	mass is altering to clay.
6-25-6	Light gray, plagioclase porphyritic pyroxene andesite; 27% 0.5-1mm euhedral to subhedral clay altered plagioclase, 7% pyroxenes totally replaced by clays and magnetite.
6-26-2	Very dark greenish-gray, plagioclase porphyritic pyroxene andesite; 15% 1-5mm euhedral to subhedral plagioclase, occasionally with red iron stain, 5% 1-2mm pyroxenes.
7-1-2	Very dark gray, coarsely plagioclase porphyritic pyroxene andesite; 27% 2-10mm euhedral to subhedral sub-parallel plagioclase, 11% 2-5mm pyroxene, orthopyroxene>clinopyroxene, hypersthene with augite cores observed.
7-1-4	Medium gray, plagioclase porphyritic hornblende-pyroxene andesite; 20% 1-4mm subhedral plagioclase, 5% pyroxenes altered to yellow-brown clay, 3% 2-3mm hornblende.
7-1-6	Medium gray, fine grained, aphyric basalt; <1% 1-2mm euhedral plagioclase phenocrysts.
7-2-7	Light brownish-gray, plagioclase porphyritic hornblende andesite /dacite; 10-15% 4-10mm euhedral plagioclase; 5-7% 1-4mm subhedral to anhedral greenish hornblende, usually with reaction rims, often quite corroded, trace very corroded clinopyroxene associated with plagioclase.
7-2-8	Dark gray, fine grained, plagioclase porphyritic pyroxene andesite; 28% 1-3mm euhedral plagioclase, 11% 0.25-1mm anhedral to subhedral pyroxene, orthopyroxene=clinopyroxene, 1-2% opaque minerals.
7-2-9	Dark brownish gray, fine grained, plagioclase porphyritic, pyroxene andesite (intrusive); 15-20% 1mm subhedral to euhedral locally altered plagioclase; 5% 0.5mm pyroxenes, occasionally corroded, clinopyroxene>orthopyroxene.
7-3-2A	Light blue-gray plagioclase and hornblende porphyritic dacite; 10% 2-5mm subhedral to euhedral plagioclase, often clay altered; 10% 2-10mm greenish black fresh hornblende, often in clusters.
7-3-3	Grayish green, clay altered, cemented lapilli tuff.

7-8-1	Medium gray, fine grained, olivine basalt; 3-5% 1mm anhedral to subhedral olivine in a uniform randomly oriented groundmass of plagioclase, clinopyroxene, olivine, and magnetite, with virtually no glass.
7-8-4	Medium gray, plagioclase porphyritic, hornblende-pyroxene andesite; 15% 2-5mm subhedral plagioclase, 5% 1-4mm pyroxene and hornblende; minor clay alteration.
7-8-8	Medium brown-gray, coarse grained, diktytaxitic, plagioclase porphyritic pyroxene andesite; 28% 1mm subhedral to euhedral uniform size plagioclase; 6% sub-mm orthopyroxene, 4% sub-mm clinopyroxene; very glassy groundmass.
7-8-9	Medium gray, fine grained, plagioclase porphyritic, pyroxene dacite; 20% 0.5-1mm subhedral to euhedral plagioclase, 5-7% sub-mm pyroxene; glassy groundmass.
7-8-11	Dark gray fine grained plagioclase porphyritic pyroxene andesite; 29% 1mm uniform plagioclase, usually as clusters; 4.5% hypersthene, 0.5% clinopyroxene.
7-9-3A	Dark blue-gray, coarsely plagioclase porphyritic, pyroxene andesite; 21% 2-8mm euhedral to subhedral plagioclase, commonly with corroded margins; 5% 1-2mm orthopyroxene, 2% 1-2mm clinopyroxene, trace olivine.
7-10-5	Medium gray, fine grained, plagioclase porphyritic, hornblende andesite; 10-15% 0.1-0.5mm euhedral to subhedral plagioclase; 3% 2-5mm euhedral to subhedral brown-green hornblende, often in clusters with plagioclase; glassy groundmass.
7-10-6	Very dark gray, coarsely plagioclase porphyritic, pyroxene andesite; 27% 2-10mm euhedral to subhedral sub-parallel plagioclase, 11% 2-5mm pyroxene, orthopyroxene>clinopyroxene, glassy groundmass.
7-18-2	Very dark gray, plagioclase porphyritic pyroxene andesite; 15% 2-8mm variable size subhedral to euhedral plagioclase, 7-10% 1-4mm pyroxenes, glassy groundmass.
7-18-5	Light gray, medium grained, holocrystalline olivine basalt; 5% 0.5mm euhedral plagioclase, 5% 0.5mm olivine, in a groundmass of plagioclase, clinopyroxene, olivine, and opaque minerals.

7-28-5	Medium gray, plagioclase porphyritic pyroxene andesite; 20% 2-6mm euhedral to subhedral plagioclase, 3-5% hornblende, 1-2% pyroxene, altered glassy groundmass.
7-28-7	Light greenish gray, very clay altered pyroxene andesite.
7-29-1	Dark reddish gray, fine grained basalt; 3-5% sub-mm pyroxenes in a uniform fine glassy groundmass. Possible remnant olivine.
7-29-7	Dark green-gray, fine grained, porphyritic olivine basalt; 15% sub-mm yellow-green anhedral olivine phenocrysts, 2-3% 1mm pyroxenes often in clusters, fine dark crystalline groundmass.
7-29-13	Dark gray, plagioclase porphyritic pyroxene andesite; 15% 1-3mm euhedral to subhedral plagioclase, 5% sub-mm pyroxene; glassy groundmass.
8-5-1	Light gray, highly plagioclase porphyritic pyroxene andesite; 31% .25-4.0mm plagioclase, 6% .25-1mm pyroxenes, orthopyroxene>clinopyroxene, trace olivine, very glassy groundmass.
8-5-3	Medium brown-gray, fine grained olivine basalt; 7% 0.5-1mm anhedral to subhedral olivine with iddingsite rims, 1% fractured sub-mm clinopyroxene, holocrystalline groundmass.
8-5-5	Medium brown-gray, medium grained, olivine basalt; 7-10% .25-1.0mm fractured iddingsitized olivine phenocrysts in a holocrystalline groundmass.
8-19-1	Light gray, plagioclase porphyritic hornblende-pyroxene andesite; 25% 1-2mm euhedral to subhedral plagioclase of 2 generations, 3% orthopyroxene, 0.5% corroded hornblende, glassy groundmass.
8-24-3	Medium gray highly plagioclase porphyritic pyroxene andesite, 38% .5 and 1.5mm euhedral to subhedral plagioclase of two distinct generations, 9% sub-mm orthopyroxene, 4% sub-mm clinopyroxene, minor glass in groundmass.
8-24-5	Light gray, slightly diktytaxitic, plagioclase porphyritic pyroxene dacite; 25% 1-5mm euhedral to subhedral plagioclase often in clusters, often corroded; 5% pyroxene, 1% hornblende with reaction rims.

9-5-4	Black plagioclase porphyritic pumice; inclusion in ash flow tuff.
9-5-6	Gray-black, slightly vesicular plagioclase porphyritic hypocrystalline andesite; 35% 3-4mm clear sub-parallel plagioclase. Inclusion in ash flow tuff.
9-10-1	Light gray, fine grained, hornblende-pyroxene dacite; 1-2% 1mm altered pyroxene, 1% 1-2mm altered hornblende.
9-10-2	Medium blue-gray plagioclase porphyritic dacite; 3-5% 3-9mm euhedral plagioclase phenocrysts, <1% sub-mm altered pyroxenes, clay altered glassy groundmass.
9-13-1	Brownish gray, slightly vesicular, hypocrystalline, pyroxene andesite; 10% plagioclase, size varying from <1mm to 5mm; 1% sub-mm pyroxene and hornblende.
9-13-2	Dark gray, micro porphyritic, hypocrystalline pyroxene andesite, 10% sub-mm clear plagioclase phenocrysts, sparse sub-mm pyroxenes.
9-13-3	Light brown-gray, plagioclase porphyritic, hornblende dacite; 5% 3mm clear euhedral plagioclase, <1% variable size subhedral hornblende.
9-13-4A	Light gray, diktytaxitic, plagioclase porphyritic, hornblende dacite; 15% 2-4mm subhedral plagioclase, 2% 3mm hornblende.
9-13-4D	Dark gray, hypocrystalline, plagioclase porphyritic, pyroxene andesite; 20% 0.5-1mm euhedral to subhedral plagioclase, 5-7% .5-1mm pyroxene, orthopyroxene>clinopyroxene.

APPENDIX C

SAMPLE LOCATIONS

Sample No.	Township/Range	Section	Elevation (ft)	Stratigraphic Designation
6-16-1	3S/7E	3abc	1620	Rhod. clast
6-16-3	2S/7E	35cba	3150	Plv
6-16-10	2S/7E	34dca	2270	Rhod. flow
6-18-2	2S/7E	34dbd	2230	Rhod. clast
6-18-4	2S/7E	34dcb	1900	Rhod. flow
6-18-6	2S/7E	34dcc	1750	Rhod. clast
6-25-4	2S/8E	19bdd	2100	Prob. Plv
6-25-5	2S/8E	19abb	2280	Rhod. clast
6-25-6	2S/8E	18ddb	2360	Rhod. clast
6-26-2	2S/8E	17bcc	2510	Rhod. clast
7-1-2	2S/8E	9bbc	2750	Plv
7-1-4	2S/8E	4daa	3150	Plv
7-1-6	2S/8E	16cba	3040	Quaternary Basalt
7-2-2	2S/8E	17dad	2780	Rhod. clast
7-2-3	2S/8E	17dad	2780	Rhod. clast
7-2-7	2S/8E	9cac	2900	Rhod. flow
7-2-8	2S/8E	9ccc	2840	unknown
7-2-9	2S/8E	17cbc	2120	unknown
7-3-2A	2S/8E	20cad	2200	Rhod. tuff?
7-3-3	2S/8E	20ccc	2480	Rhod. tuff?
7-8-1	3S/7E	10caa	3520	Puv
7-8-4	3S/7E	10bca	3080	Plv?
7-8-8	3S/7E	10bbb	3000	Plv
7-8-9	3S/7E	10bbb	2900	Rhod. flow
7-8-11	3S/7E	3cbb	2200	Rhod. flow
7-9-3A	2S/7E	34dac	2700	unknown, Quat.?
7-10-5	2S/8E	9dac	2900	unknown, Quat.?
7-10-6	2S/8E	9dac	2900	Plv
7-18-2	2S/8E	33bad	4553	Plv
7-18-5	2S/8E	34cac	4971	Puv
7-28-5	2S/8E	34dca	4280	Rhod. flow
7-29-1	2S/6E	34bd	2700	Plv?
8-5-1	1S/9E	15aac	2750	Dls. clast
8-5-3	1S/9E	16cbd	3400	Plv
8-5-5A	1S/9E	10daa	2600	Plv?
8-19-1	2N/11E	21dad	1520	Dls. clast

Sample No.	Township/Range	Section	Elevation (ft)	Stratigraphic Designation
8-24-3	2N/13E	31daa	760	Dls. clast
8-24-5	2N/13E	31dad	480	Dls. clast
9-5-4	2S/12E	32cca	2600	Pliocene welded tuff
9-5-6	2S/12E	32cca	2600	Pliocene welded tuff
9-10-1	1S/10E	29dbc	2800	Dls. flow
9-10-2	1S/10E	29cad	2400	Dls. clast
9-13-1	1N/13E	9bdd	520	Dls. clast
9-13-2	1N/12E	30cdb	1960	Dls. clast
9-13-3	1N/12E	30cdb	1840	Dls. clast
9-13-4A	1N/12E	30dcd	1600	Dls. clast
9-13-4D	1N/12E	30dcd	1600	Dls. clast