AN ABSTRACT OF THE THESIS OF

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Title: GEOLOGY OF THE BACHELOR MOUNTAIN AREA, LINN AND MARION COUNTIES, OREGON

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The thesis area is located along the boundary between the central Western Cascade and High Cascade physiographic provinces in Oregon. The volcanic and volcaniclastic rocks range in composition from olivine basalt to dacite and in age from Middle Miocene to Pleistocene. The most common rock type is a columnar-jointed olivine basalt and basaltic andesite. Platy jointed andesite and dacite are relatively uncommon. Ash-flow tuffs of dacitic composition are abundantly represented in the lower part of the section and also occur in stratigraphically higher units. Pyroclastic and epiclastic volcanic rocks represent about 20 percent of the total section. The volcanic rocks of the area are calc-alkaline, though very near the calc-alkaline-calic boundary, and all plot within the high alumina basalt field of Kuno (1965).

The older Miocene and Pliocene units dip, with small

variation, about 10 degrees to the southeast. An angular unconformity separates these older units from Pleistocene (?) intracanyon and sheet lavas which occur in the eastern part of the thesis area. The Pleistocene (?) flow sequences are horizontal or may have a slight westerly primary dip. Faults and basaltic andesite dikes show a strong north-south alignment. The faults are all normal and, with minor exceptions, have their western sides displaced relatively downward.

T. P. Thayer mapped the northern part of the thesis area in 1933. The rock-stratigraphic units established by him have been further subdivided in this work and certain contacts have been relocated. The intracanyon lava flows found in the study area were previously grouped (Thayer, 1939) with flow sequences which cap several of the eastern ridges and were collectively called the Minto Basalts. The intracanyon flows which occur in the northwest part of the study area were named Santiam Basalts (Thayer). Detailed study indicates that the intracanyon flows, including the Santiam Basalt, comprise a continuous sequence of intracanyon lavas. These intracanyon lavas are distinctly younger than the flows which cap the eastern ridges and are therefore grouped seqarately.

The geologic boundary between the Western Cascade and High Cascade boundary has been interpreted to be a large-scale normal faulting, with the High Cascade side down, is excellent on the eastern side of the High Cascades, it is reasonable to suspect a similar relationship on the western side of the High Cascades. This study revealed that a large-scale fault is not present and that the boundary is an angular unconformity which separates Miocene and Pliocene rock units from Pleistocene(?) rock units.

Geology of the Bachelor Mountain Area, Linn and Marion Counties, Oregon

by

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To my wife, Becki, I wish to extend my heart-felt thanks for her understanding and sacrifice, which allowed the completion of this thesis project.

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INTRODUCTION

Location

The thesis area is located in southeastern Marion and northeastern Linn Counties, roughly 11 km east of Detroit, Oregon (Fig. 1). The size of the thesis area is just over 95 square km, and the relief of the thesis area is in excess of 1,000 m.

Accessibility and Exposure

Oregon Highway 22 passes through the center of the thesis area, linking the towns of Detroit to the northwest with Sisters to the southeast. This major highway provides easy, year-round access to the central part of the area. Several U. S. Forest Service roads provide access into the western part of the area, as do similar roads into most of the eastern part during the summer months.

Exposure is limited because precipitation is so heavy during the winter months that weathering, vegetation and slope instability combine to obscure the outcrops. These conditions prevail strongly in the westernmost Cascades, particularly at lower elevations. These effects are reduced at elevations above 1,500 m, resulting in a greater number of useful outcrops. Also, the last period of glaciation (Frazier) created large, spectacular erosional

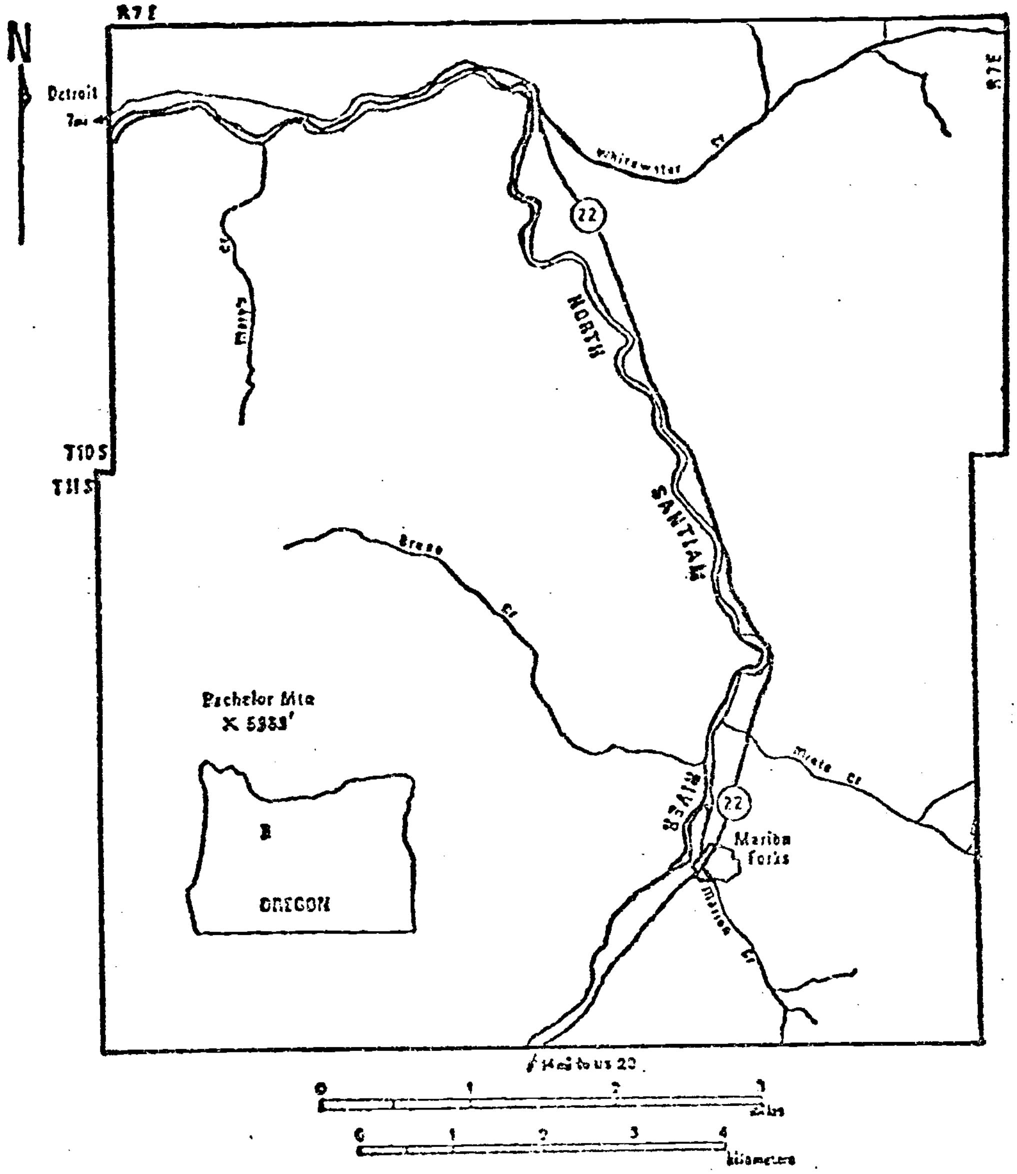

Figure 1: Location of thesis area, Linn and Marion counties, Oregon.

escarpments, which provide limited areas of excellent exposure.

Methods of Investigation

Field work was done during the 1974 summer season. The base map used was a composite of the eastern half of the Detroit 15-minute quadrangle (enlarged to 1:24,000 scale), and the NW1/4 and SW 1/4 advanced sheets of the Mount Jefferson 15-minute quadrangle (1:24,000). High altitude (1:63,000) aerial photographs and Earth Resources Technology Satellite (ERTS) imagery, made available by Dr. R. A. Lawrence, provided an overview of the area and gave an insight into the geologic structure. Low altitude U. S. Forest Service photographs, provided by the Oregon State Department of Geology and Mineral Industries, were used in the field for outcrop location and recording of contact and attitude data.

More than 100 rock samples were collected for laboratory studies, which were completed during the winter of 1974-75. Laboratory investigation included petrographic examination of thin sections and study of hand samples with the aid of a binocular microscope. The Michel-Levy method was used to determine plagioclase composition. Whole-rock chemical analyses were performed using X-ray fluorescence spectrometry for FeO, CaO, K_2O, TiO_2 and Al_2O_3;

atomic absorption spectrometry for MgO and Na_2O; and a colorimetric method utilizing visible light spectrophotometry for SiO_2. The methods used in the analyses did not allow for the determination of H_2O and all iron is expressed as FeO.

Geologic Setting

The thesis area is located along the north-central part of the Western Cascade-High Cascade boundary in Oregon. The Western Cascades are a complex volcanic province of moderate relief directly adjacent to the High Cascades of central Oregon. Eruptive centers as old as Oligocene can be found in the Western Cascade province (Peck and others, 1964) and hot springs are active in the region today. In the High Cascade province Pleistocene and Recent composite volcanoes, lava flows and ash deposits are found. The chain of High Cascade volcanoes, including Mount Jefferson immediately adjacent to the thesis area, comprise a narrow north-south region of Recent and Pleistocene volcanism (Walker and others, 1968).

To the east of the High Cascade platform lies the Deschutes Basin, which has received 250-300 m of volcanic ash and fluvial volcanic sedimentary rocks during the Pliocene (Taylor, 1973). To the west is the Willamette Valley, which is underlain by nearly 1,000 m of Eocene and Oligocene marine tuffaceous sandstones and mudstones (Newton, 1969). The marine sequence is overlain by more than 100 m of Miocene plateau basalt (Thayer, 1939).

Previous Work

T. P. Thayer investigated the geology of the North Santiam River drainage in the 1930's and published several articles on the structure and petrology of the exposed units. Thayer (1933) discussed the general features of the cascades of Oregon, and he proposed that the western margin of the Western Cascades is an erosional feature and is not fault-controlled. In 1936 Thayer introduced a structural interpretation of the Western Cascade-High Cascade boundary. Thayer proposed that rhyolite flows found on the eastern side of the North Santiam River were correlative with Miocene rhyolite found to the west. As the eastern occurrence is lower in elevation than the western by some 500 m, he suggested that the eastern part had been faulted downward 500 to 750 m sometime in the late Miocene. Thayer called this fault the "Cascade Fault", and described it as the "....western most of a series of buried fractures of the Basin and Range type." (Thayer, 1936, p. 1611). After the faulting had ceased, volcanic rocks of the High Cascades were erupted over the scarp, burying it. In 1937, Thayer published a discussion of the petrology, petrography and chemistry of the rocks exposed in the North Santiam River drainage. Apparently, Thayer had developed more conservative thoughts concerning the fault hypothesis because it is not mentioned in the section entitled "Structure". The final article, published in 1939, was a synopsis of his Ph.D. thesis work, extending from Mount Jefferson to Salem.

Peck and others (1964) produced a reconnaissance geologic map covering the northern part of the Western Cascade and High Cascade provinces in Oregon. Concerning the reliability of the map, Peck wrote: "....artificial rock exposures in road cuts were used far more than natural exposures. As a result, the geologic map is much less reliable in those areas where access was limited by lack of roads." (Peck and others, 1964, p. 4). Further, Peck and associates published small-scale geologic maps, and therefore, were unable to include detail.

In 1966 G. W. Walker, R. C. Greene and E. C. Pattee published an evaluation of the mineral resources of the Jefferson Primative Area, the western part of which is in the study area. The position of the Western Cascade-High Cascade boundary as located by Walker and others differed sharply from Peck's interpretation, although less so with Thayer's interpretation.

R. C. Greene (1968) published petrographic descriptions and chemical data for volcanic rocks of the Mount

Jefferson Primative Area. Some of these rocks can be traced into the eastern part of the thesis area.

STRATIGRAPHY

The stratigraphic units described below, in order of oldest to youngest, are informal rock-stratigraphic units defined on the basis of field criteria recognized in the thesis area.

Breitenbush Tuff

General

The name Breitenbush Tuff was first used by T. P. Thayer (1939) to refer to a sequence of tuffs exposed in the upper North Santiam River drainage and the Breitenbush River drainage. The name is retained here and used to refer to the same sequence of ash-flow and ash-fall tuffs, the upper 150 m of which are exposed in the western part of the thesis area. The Breitenbush Tuff is the oldest unit found in the thesis area. Exposure of Breitenbush Tuff is limited because landsliding and vegetative cover prevent the cropping out of less resistant units. Lakes and poorly developed drainage patterns are common on Breitenbush terrain; an excellent example is the Bruno Lakes area north of Mount Bruno.

The Breitenbush Tuff has been dated as Early Miocene on the basis of plant fossils identified by J. Wolfe (in Peck and others, 1964, p. 8).

Unit Description

The Breitenbush Tuff consists of welded ash-flow tuffs, nonwelded ash-flow tuffs, ash-fall deposits and reworked pyroclastic deposits. The ash-flow units are often more than 25 m thick and may reach 75 m thick. Individual ash-flow units are highly variable in thickness along their length, reflecting variations in depositional thickness and variations in thickness imposed by erosion. Individual ash-flow tuff units can be recognized in isolated outcrops on the basis of pumice color and crystal content because those characteristics are distinctive and remain constant within a given unit.

Welded ash-flow tuffs comprise about 75 percent of the Breitenbush Tuff. The welded ash-flow tuffs are composed predominately of ash-sized glass fragments and crystals, lapilli-sized pumice fragments and are crystal-vitric lapilli-tuffs. Some of the welded ash-flow units with a high proportion of rock fragments approach a fragment-rich lapilli-tuff. However, fragment-rich units are rare in the Breitenbush Tuff.

The welded ash-flow tuffs display a vertical zonation in degree of welding. Three layers or zones are particularly well developed in the thicker ash-flow units.

Pumice fragments range in size from 16 cm to 0.5 mm and are usually found in matrix support. In the more pumice-rich units, the pumice fragments are found in framework support and the rock fragments and ash occupy the interstices. A size-grading of the pumice fragments is present in some of the ash flows. The pumice becomes smaller upward through the unit and also somewhat less abundant.

The pumice varies from white to deeper shades of brown and green. Commonly, white or brown pumice is surrounded by a green halo of alteration which begins at the fragment-matrix interface and extends a few meters into the matrix.

In the upper and lower poorly welded zones, the pumice is highly vesicular, often as much as 40 percent of void space. In the central densely welded zone the pumice may be completely fused into black or dark gray glass totally free of vesicles. In one of the welded ash flows, two varieties of pumice can be recognized. One type apparently welded to a greater extent than the other, resulting in a rock which contains totally fused, elongate, black glass lenses and partially collapsed, light tan pumice fragments.

Breitenbush welded ash-flow tuffs contain as much as 25 volume percent plagioclase crystals. The plagioclase crystals occur as subhedral grains and broken fragments in the matrix, and as subhedral phenocrysts in the pumice fragments. The crystals display a clear and unaltered appearance in hand specimen with albite and carlsbad twinning visible under the binocular microscope.

Volcanic rock fragments are found throughout the welded ash flows. Generally, the fragments are of basalt and andesite and are less than one cm in size; nonporphyritic fragments predominate over porphyritic fragments. The rock fragments occur in the greatest amount at or near the base of a welded ash-flow unit and decrease steadily upward.

Nonwelded ash-flow tuffs and ash-fall deposits are found in the Breitenbush section although they are less commonly observed because they lack densely welded, erosionally resistant horizons. These pyroclastic deposits comprise about 25 percent of the total Breitenbush section.

The nonwelded ash-flow units closely resemble the nonwelded parts of the welded ash flows, particularly the upper pumice-rich parts of the latter. Rock fragments occur in greater amount at the base and become less abundant upward, but never reach the abundance typical of the welded ash-flow tuffs. Pumice is generally better sorted and does not reach the large sizes encountered in the welded ash flows. Pumice color variations are similar to the welded ash flows and probably result from the same causes. Plagioclase crystals are slightly less abundant, although of the same mode of occurrence and compositional range.

Ash-fall units are rare and discontinuously exposed in the Breitenbush Tuff. The ash-fall deposits are thin, 2 to 5 m, and are difficult to trace along strike. The pumice fragments are less than 1 cm in size, light buff to bleached white, and fairly well sorted. Ash-fall deposits appear to have accumulated between major ash-flow eruptions. It is probable that the original ash-fall deposits were much more extensive and because of their low resistance to erosion, have been reworked by streams and are preserved only in the lense-shaped deposits of local extent, probably stream channels. The ash-fall deposits are finely bedded with parallel laminations and crossbedding. Bedding is visible due to variations in the lithic fragment component.

Rock fragments are present in the ash-fall deposits, amounting to about 25 volume percent. Basalt fragments, 1 to .025 mm in size, are the most abundant and are well rounded. Light-colored, silic volcanic rock fragments occur also, but are rare.

The pumice fragments often contain phenocrysts of plagioclase which are clear and visibly twinned. The pumice is well rounded and may have the vesicles filled with finer material.

Overall, the ash-fall deposits are notable for their uniformity. No variation in type of sorting, type of sedimentary structures or in lithic fragments was recognized.

Many of the units in the Breitenbush Tuff have had their uppermost part reworked by streams. Current structures, including festoom crossbedding and scour and fill, can be recognized. In the reworked deposits, the volcanic rock fragments are rounded and the samd and silt-sized fraction is well bedded, often with fine-scale, parallel laminations.

Petrography

The Breitenbush ash-flow tuffs have a well-developed eutaxitic texture with the glass shards aligned and draped over the crystals and rock fragments. This texture is developed fully in the densely welded central rocks of the welded ash flows, less so in the nonwelded ash flows. Figure 3 is a series of photomicrographs of the densely welded part of an ash flow exposed along Oregon Highway 22 near Whispering Falls Campground.

The plagioclase crystals contained in the ash flows range in composition from An_{28} to An_{54}. The plagioclase crystals are usually subhedral with well developed side pinacoids and irregular terminations. The crystals are twinned according to the albite and carlsbad twin laws and show fine-scale zoning. The plagioclase crystals are embayed, suggesting that they were unstable in the melt.

Some of the ash-flow tuffs contain a percent or less of mafic crystals. Those crystals which have been observed in thin section include fresh and heavily altered pyroxene and magnetite. Pyroxene is found in trace amounts in the welded ash-flow tuffs, and is rarely unaltered. The crystals of pyroxene are anhedral, suspended in the shard matrix and usually less than 0.5 mm in size. Fresh pyroxene has been determined to be a clinopyroxene with a 2V of 55-60^{o}, and is length-fast. It is most probably an augite. In many units the mafic silicate has been completely altered to radial masses of yellow-green celadonite. The celadonite replacement has preserved the eight-sided prismatic habit of the pyroxene crystals. Magnetite occurs as rounded granular masses and as fine disseminations in the shard matrix. In many of the ash-flow tuffs magnetite is altered to clear-red hematite. Hematite occurs as disseminations through the matrix, as rims around the magnetite and as stains along fractures in the plagioclase crystals.

Grizzly Creek Lavas

General

The Grizzly Creek Lavas are exposed near the bottom of the Cheat Creek, Whitewater Creek, Pamelia Creek and North Santiam River canyons. Resting atop the Breitenbush Tuff, the Grizzly Creek Lavas consist of 300 m of olivine basalt and very minor olivine-bearing basaltic andesite lava flows with intervening breccias, which are uniform in color, lithology and alteration. Locally, the Grizzly Creek Lavas occupy topographic lows eroded into the Breitenbush Tuff; however, the relief along the irregular basal contact rarely exceeds 15 m. The base of the Grizzly Creek Lavas is very poorly exposed in a landslide area north of Mount Bruno. The age of the Grizzly Creek Lavas is unknown. Isotopic age determinations were not available to the author and none are published.

Unit Description

The Grizzly Creek Lavas are olivine basalts and are amydgaloidal with vesicle fillings of several types. The weathered rinds, which rapidly form on exposed rock surfaces, are dark reddish-brown, having been stained by hematite. The red-brown color together with the amydgaloidal texture is very useful in identification of Grizzly Creek Lavas as none of the other flow sequences display those characteristics. The individual flows are columnar jointed although there is a tendency for the upper parts to grade into a platy joint pattern.

The bases of the flows are sharply defined with pipe vesicles occasionally present. Pipe vesicle inclinations are extremely variable. The limited data available suggest a source to the northwest of the thesis area. Vesicularity increases upward reaching a maximum just below the autobrecciated upper part of the flow. Open or secondarily-filled void space rarely exceeds 10 volume percent and is commonly much less.

The autoclastic breccias which occur discontinuously between the flows are reddened and deeply altered. The clasts are cemented by calcite, zeolites of several types and rarely by chalcedony. X-ray diffraction analyses confirm the presence of heulandite, chabazite and natrolite in the interstices of the breccias.

Petrography

The Grizzly Creek Lavas are porphyritic olivine basalts. The phenocrysts are either olivine exclusively or olivine with sparse plagioclase or clinopyroxene. The olivine phenocrysts are, in most cases, altered to hematite and magnetite and rarely exceed 5 volume percent of the rock. Clinopyroxene and plagioclase occur as phenocrysts less commonly than does olivine. In detail the olivine is highly altered to celadonite or hematite and magnetite, and in some cases, identifiable only by inference from crystal habit. Those flows which have plagioclase and clinopyroxene phenocrysts may be glomeroporphyritic with radial masses of plagioclase and minor clinopyroxene evenly distributed throughout the groundmass. Grain size is generally between 1.0 and 0.5 mm for the phenocrysts and less than 0.025 mm for the groundmass.

The groundmass is universally intergranular, composed of microlites of plagioclase, mafic silicates and disseminated magnetite.

Plagioclase occurs as phenocrysts and as microlites in the groundmass. The phenocrysts are slightly variable in composition between individual flows, ranging from about An_{54} to about An_{58}. The phenocrysts are roughly equidimensional, anhedral and embayed by the groundmass. The groundmass grains are subhedral, elongate crystals composed of simple albite twins.

Clinopyroxene occurs as rare phenocrysts of small size, .125 mm or less, and as extremely fine, anhedral grains distributed evenly throughout the groundmass.

Magnetite is found either included within, or as rims around, the olivine phenocrysts and is finely disseminated grains through the groundmass. Magnetite is usually altered to hematite, which pervades the groundmass and stains the phenocrysts.

Apatite is a common accessory found within the plagioclase phenocrysts.

Chemically the Grizzly Creek Lavas are true high alumina basalts with SiO_2 values between 50.2 and 55.0 weight percent and Al_2O_3 values of 18.0 weight percent. Chemical analyses of Grizzly Creek Lavas can be found in Appendix A.

Nan Creek Volcanics

General

The Nan Creek Volcanics are composed of lava flows and volcanic sedimentary rocks approximately 600 m thick. The Nan Creek Volcanics are variable in lithology, both vertically and laterally, with no systematic variation suited to further rock-stratigraphic subdivision. The flow sequences vary in composition from extremely rare dacite to olivine basalt. Welded ash-flow tuffs can be found within the sequence, as can mudflows and palagonitic breccias, but these, along with the sediments, comprise less than 25 percent of the total section. Nan Creek flows are not greatly altered and secondary mineralization is minimal, allowing the Nan Creek Volcanics to be easily distinguished from the Grizzly Creek Lavas.

The Nan Creek Volcanics rest atop the Grizzly Creek Lavas with slight angular unconformity. The lower contact of the Nan Creek Volcanics has a maximum relief in excess of 75 m. In the Mary's Creek area, Grizzly Creek Lavas are missing and the Nan Creek Volcanics rest directly on the Breitenbush Tuff.

Unit Description

The flow sequences comprise the largest part of the Nan Creek section. The lithology of the flows is highly variable, including porphyritic olivine basalts, basaltic andesites, hornblende bearing andesites and two-pyroxene andesites. The flows vary considerably in thickness also, but are usually between 5 and 25 m thick. Jointing patterns are variable, ranging from small-scale columnar jointing in the basalts to thin, platy jointing in the andesites. Vesicularity is low, on the order of 2 volume percent, and is nonmineralized. Autoclastic breccias are restricted in occurrence to the tops of the thicker basalt flows.

Four mineralogically and chemically distinct lava types have been recognized in the Nan Creek Volcanics. They are 1) porphyritic olivine basalt, analyzed sample No. TR-58, 2) porphyritic basaltic andesite, analyzed sample No. TR-37, 3) porphyritic hornblende bearing andesite, analyzed sample No.'s TR-97, TR-90 and TR-98, and 4) porphyritic two-pyroxene andesite, analyzed sample No.'s TR-20 and TR-34. Chemical analyses of Nan Creek Lavas are listed in Appendix B.

The porphyritic olivine basalt flows represent approximately 50 percent of the total flow section. The basalts contain about 1 percent olivine phenocrysts and abundant plagioclase phenocrysts, in part glomeroporphyritic. The phenocrysts are suspended in a pilotaxitic, subophitic groundmass. The olivine is a magnesian variety with a 2V of approximately 90°. The olivine crystals are anhedral with numerous fractures, rims of hematite and inclusions of opaque oxide. The plagioclase phenocrysts have a composition of An_{52} to An_{54}. The groundmass microlites range in composition between An_{32} and An_{38}. The plagioclase phenocrysts are zoned and roughly equidimensional crystals. The microlites are elongate and are usually made of two or three albite twins. The groundmass contains, in addition to plagioclase, a clinopyroxene with a 2V in excess of 50° and a positive optic sign. It is probably an augite. Magnetite is present as fine disseminations throughout the groundmass.

Chemical analyses of the olivine basalts yield SiO_2 values of 52.0 weight percent and Al_2O_3 values in the range of 17-18 weight percent.

Porphyritic basaltic andesite flows comprise about 40 percent of the Nan Creek Volcanics flow section. The basaltic andesites contain olivine phenocrysts, about 1 percent or less, and abundant plagioclase phenocrysts, commonly more than 40 percent of the rock. The groundmass is extremely fine-grained and of intergranular texture. Many of the basaltic andesites are strongly pilotaxitic and the glomeroporphyritic texture, typical of the basalts, is absent. The olivine, as before, is a magnesian variety with a 2V of nearly 90° and occurs in anhedral crystals about 0.5 mm in diameter. In some thin sections the olivine is almost completely altered to hematite, however, the olivine is commonly fresh. The plagioclase phenocrysts are labradorite An_{55} to An_{60} and are elongate, subhedral crystals with normal zoning.

The groundmass is composed of plagioclase and mafic microlites as well as magnetite. The two silicate species are in roughly equal proportions and account for about 75 percent of the total groundmass. The remainder is finely disseminated magnetite.

The basaltic andesite have SiO_2 contents of about 54 weight percent. These basaltic andesites are also of high alumina content, between 17 and 19 weight percent.

The porphyritic hornblende andesites represent about 5 percent of the total Nan Creek flow section. The hornblende bearing andesites contain a percent or less of hornblende phenocrysts as well as three to five percent of plagioclase phenocrysts. The hornblende occurs as anhedral crystals surrounded by reaction rims of plagioclase and magnetite. Hornblende was apparently unstable in the magma and was in the process of being resorbed at the time of eruption. The hornblende is pleochroic yellow-green and of moderate relief. Plagioclase phenocrysts are roughly equidimensional, subhedral crystals which range in composition between An_{40} and An_{44}. The groundmass is extremely fine grained, pliotaxitic and of intergranular texture. The groundmass is composed of plagioclase microlites, a mafic silicate and magnetite. The silicate phases account for about 70 percent of the groundmass with fine-grained magnetite making up the remainder.

Chemical analysis of the hornblende andesites reveals their SiO_2 contents to vary between 59.9 and 67.2 weight percent. Al_2O_3 ranges between 17 and 18 weight percent.

The porphyritic two-pyroxene andesites comprise about 5 percent or less of the Nan Creek flow sequence and are evenly distributed throughout. The two-pyroxene andesites contain about 2 percent of orthopyroxene phenocrysts and another percent of clinopyroxene phenocrysts. Plagioclase phenocrysts are generally in greater abundance in the two-pyroxene andesites than in the hornblende andesites. The groundmass texture is holocrystalline, intergranular and with no alignment of the microlites.

The mineralogy of the two-pyroxene andesites is more complex than is normal for the volcanic rocks of the thesis area. They commonly contain about 1 percent of olivine, 15 percent of orthopyroxene, 5 percent of clinopyroxene, 75 percent of plagioclase and 5 percent of magnetite. Olivine is rare, but where it does occur, it is deeply altered to celadonite with rims of hematite. The original composition of the olivine grains is unknown because they are too altered. Olivine grain size is variable, but generally

0.5 mm. Orthopyroxene occurs as phenocrysts, which are generally elongate, subhedral grains with good prismatic cleavage and a well-developed parting perpendicular to their prismatic elongation. The orthopyroxene is a hypersthene with a 2V of 55-60^{o} and a negative optic sign. Pleochroism is distinctive from pale green to pale pink. Grain size ranges from 1.0 to 0.25 mm. Clinopyroxene is less abundant than orthopyroxene. However, many crystals are of larger diameter, about 1.5 mm. The clinopyroxene has a low 2V of 25^{o}, a lower relief than the orthopyroxene, a very pale green color and no pleochroism. The clinopyroxene is probably a pigeonite because the crystals are length-slow, eliminating members of the augite-ferroaugite series which are length-fast. Plagioclase occurs as phenocrysts and as groundmass microlites. The phenocrysts are oscillatory zoned with cores of An_{46-48} and rims of An_{38-40}. The plagioclase phenocrysts are subhedral, about 1 mm in length and are only rarely embayed by the groundmass. Many of the phenocrysts contain inclusions of hypersthene in a band, just inside the last rim of andesine added to the crystals. Magnetite occurs as granular masses and disseminations throughout the groundmass. Commonly the magnetite will be partially altered to hematite, which also stains the phenocrysts.

The two-pyroxene andesites have SiO_2 contents between 61.3 and 64.0 weight percent with Al_2O_3 at 17 weight percent.

There are two types of sedimentary rocks in the Nan Creek sequence. Volcanic lithic sandstones and conglomerates composed of volcanic rock pebbles are more abundant than fine-grained, tuffaceous, leaf-bearing sediments.

The tuffaceous, fine-grained sediments which occur on the eastern flanks of Mount Bruno are finely bedded and contain many recognizable leaf fossils. The sediments are fine sand-to-silt sized with a characteristic buff color (10 YR 6/4) and reach a maximum of 15 m thick.

The pebble conglomerates and lithic sandstones are poorly sorted volcanic lithic wackies containing up to 30 percent nonporphyritic basalt and andesite fragments. The conglomerates and sandstones contain a high proportion of tuffaceous material and lithic fragments in the matrix along with andesine and labradorite plagioclase feldspar and rare quartz. Grain size is variable, between 4 and 0.125 mm for the rock fragments, and fairly uniform 0.125 mm for the feldspar and quartz.

Sedimentary structures include crossbedding, parallel laminations and scour and fill in channel lenses. There is abundant evidence of penicontemporainous deformation. Convolute bedding is often present as is the breakup of semiconsolidated beds into clasts suspended in a uniform matrix of sand. Such textures are suggestive of oversteepening of sediment accumulations during deposition.

Mudflows and poorly welded ash-flow tuffs are present in the Nan Creek section. The mudflows occur on the lower part of the east flank of Bachelor Mountain and are usually 18 m or less in thickness. The mudflows contain blocks about 0.5 to 10 cm in size, of both nonporphyritic and porphyritic basalt and andesite. The blocks are subangular to well rounded, the latter being restricted to the upper parts of mudflows which display bedding, strongly suggestive of stream reworking.

Palagonitic breccias have been recognized in the Nan Creek section and can be found in the lower Cheat Creek drainage and the Nan Creek drainage. The breccias are distinctive in that they contain several different fragment types. Porphyritic basalt fragments are most common, but of two types. One type is a deep red color suggestive of complete alteration of the magnetite to hematite. The plagioclase phenocrysts in the red clasts are altered to an opaque white and twinning is indistinguishable in hand specimen. The other type is fresh in appearance, medium gray and contains clear plagioclase phenocrysts.

A densely welded ash-flow tuff has been recognized in the Nan Creek drainage. The unit is composed of black glass lenses, rock fragments and pumice lumps and is roughly 5 m thick. The ash-flow tuff was recognized on the basis of a well developed eutaxitic texture, by the presence of included volcanic rock fragments and fully collapsed and fused pumice. In thin section the eutaxitic texture is clearly seen with the shards draped over the rock fragments and crystals of plagioclase feldspar. The plagioclase composition is An_{28} and the crystals are subhedral with some embayment evident. Bulk chemical analysis of the glass (Sample No. TR-11) yielded SiO_2 values of 68.9 weight percent and Al_2O_3 content of 15.5 percent.

Coffin Mountain Flows

The tops of Coffin Mountain, Bachelor Mountain and Cub Point northwest of Coffin Mountain, are underlain by a series of basalt and basaltic andesite lava flows, which reach a maximum thickness of 175 m. The stratigraphic position of these flows remains uncertain because they are in contact with only the Nan Creek Volcanics which underlie them. For that reason they are included in the Nan Creek section. The bottom contact is irregular and gently concave upward, suggesting that the Coffin Mountain flows occupied a topographic depression in the Nan Creek Volcanics. Small lenses of lithic sandstone, usually less than 1 m thick, occur intermittently along the bottom contact. The sandstones are well bedded and contain festoon crossbedding, scour and fill and parallel laminations.

Individual flows reach a maximum thickness of more than 45 m, but pinch out rapidly to either side. The flow series thins to the north of Coffin Mountain and to the east on Bachelor Mountain.

The flows show columnar jointing on a large scale, the columns reaching a maximum diameter of 1 m. The columns begin at the sharply defined base of the flows with a small diameter (2 to 3 cm) and highly undualtory vertical walls. The columns become larger in diameter and fewer in number vertically by confluence of the small columns in several steps. Five to ten meters above the bottom contact the columns reach 0.5 to 1 m in diameter and the vertical walls become planar with only a large-scale rhythmic "pinch and swell" undulation. Toward the top, the columns combine into a joint pattern which creates rock masses, roughly cubic in shape, 1 to 2 m on an edge. In this upper part vesicularity slowly increases upward and reaches a maximum of 3 to 5 volume percent in the fine blocky jointed part just below the overlying autoclastic breccia.

Pipe vesicles are common along the base of the flows and, where they show an inclination, suggest that the flows originated from the southeast. Columnar concentrations of vesicles are rare in the Coffin Mountain Flows. However, those which were observed were longer vertically than those few encountered in the thinner flow units.

Autoclastic breccias are present intermittently between each of the flows. The breccias are dark colored, angular, monolithologic breccias which have a fine matrix of altered clay-rich material. They are poorly consolidated and often the upper parts contain small (6 m long) lenses of crossbedded volcanic sandstone. The breccias are eroded preferentially on a cliff-face exposure, creating an undulatory "notch" between flows.

Coffin Mountain Flows are fine-grained porphyritic olivine basalts and basaltic andesites with sparse phenocrysts of olivine. The Coffin Mountain Flows are uniform in mineralogy and show only small textural variation. The groundmass texture varies between holocrystalline intergranular and holocrystalline subophitic with the former most common. Plagioclase commonly shows pilotaxtic texture as well as numerous radial growth centers or "glomerocrysts" throughout the rock.

The mineralogy of the basalts includes about 1 percent of olivine, 65 percent of plagioclase, 20 percent of clinopyroxene and 15 percent of magnetite-hematite. Apatite is a minor accessory found in the plagioclase.

Olivine occurs as anhedral phenocrysts usually altered to either hematite or celadonite with hematite rims. The olivine, which is relatively fresh, is a magnesian variety with a 2V of nearly 90°. Olivine is a rare constituant amounting to a percent or less of the total rock. Grain size is variable, but always between 0.5 and 0.25 mm.

The plagioclase has a composition of An_{66} to An_{68} and occurs exclusively as microlites in the groundmass. The labradorite is subhedral with albite and carlsbad twinning visible.

Clinopyroxene is present in the groundmass and occurs as rounded, anhedral crystals varying in size between 0.25 and 0.01 mm.

Magnetite is found as granular, rounded masses and as disseminations throughout the groundmass. Magnetite is commonly altered to hematite, and in some thin sections, magnetite is very rare, most having been altered to hematite. Magnetite is distinctive in the Coffin Mountain Flows because it occurs in relatively large masses, up to 0.25 mm in diameter.

Analyses of Coffin Mountain Flows yield SiO_2 values of 52-53 weight percent, across the commonly used 52 weight percent division between basalt and basaltic andesites (Williams, and others, 1955). The Al_2O_3 values of 18-19 weight percent place the Coffin Mountain Flows in the high alumina basalt category. Chemical analyses of the Coffin Mountain Flows are listed in Appendix B, sample numbers TR-92, TR-93 and TR-94.

Cheat Creek Beds

General

The Cheat Creek Beds are pyroclastic breccias and volcanic sandstones about 245 m thick, which are found on the southern flanks of Triangulation Peak, near the top of Woodpecker Ridge and near the top of Mount Bruno. The Cheat Creek Beds overlie the Nan Creek Volcanics and are themselves overlain by the Triangulation Peak Lavas. The overall shape of the bottom contact suggests that the Cheat Creek Beds filled a topographic low which existed between Triangulation Peak, Woodpecker Ridge and Mount Bruno. The relief along the contact is low, less than 10 m. The sediments consist principally of bedded palagonitic breccias with angular to subrounded fragments of basalt varying in size from large lapilli (3 cm) to coarse ash (0.250 mm). Basaltic fragments generally comprise less than 15 percent of the rock, except in the parts of the unit where the fragments are rounded. There, basalt fragments reach a maximum of 30 percent of the rock.

The origin of the Cheat Creek Beds is most probably a combination of Maar-type eruptive activity with low to moderate energy current reworking of parts of the unit. The bedding features described for Maar volcanoes (Fisher and Waters, 1970) are present in large part in the Cheat Creek Beds. However, a significant part of the section displays sedimentary structures commonly observed in fluvial sediments.

Unit Description

Palagonitic breccias comprise most of the Cheat Creek

Beds. The volcanic clasts are lapilli size to medium ash (5 cm to 1/2 mm) with a fine ash (0.25 to 0.125 mm) matrix of palagonitized glass. Palagonitization of the glass fragments is, in most cases, complete. However, in rare cases, some sideromelane can be seen in thin section. The rock fragments are nonporphyritic and sparsely porphyritic basalt. The clasts are angular to subangular with little evidence of rounding in the majority of the section.

Bedding varies between massive beds which are as much as 0.5 m thick and contain no apparent internal stratification, and thin beds which contain a variety of bedding structures. The massive beds occur infrequently throughout the section. Generally, massive beds are less than 25 cm thick and discontinuous compared to finer bedded parts. The finely bedded units comprise the larger part of the section and display fine parallel laminations and cross bedding. A given laminae is composed of a deposit of angular basaltic fragments, from several grains to several dozen grains thick, suspended in a very fine matrix of palagonite. Beds that are single grain thick are not found in the angular brecciated parts of the Cheat Creek section. The bedding rarely displays small scale wave form bedding, with wave lengths of 2 to 4 m and amplitudes of about 10 cm. Graded beds are very commonly observed, particularly in the fragment-rich parts of the section. Cross bedding is predominately of the festoon forset variety, particularly in the graded beds and in the beds which contain a large proportion of rounded basaltic fragments.

The beds exposed on the southern flank of Triangulation Peak in the Cheat Creek drainage display primary dips. The beds dip away from the red cinder deposits in the upper part of the unit and dip uniformly to the southeast in the lower part. Attitude data from the flow sequence above the Cheat Creek Beds suggest that the Cheat Creek Beds have been tilted tectonically about 10° to the southeast. Accordingly, the dips on the eastern flank of the cinder deposits and associated palagonite deposits are much steeper (25°) than the dips in similar beds on the western flank (5°). The lower part of the section dips 7° to the southeast and the successive truncations of individual beds to the west suggest that the source area was to the east. The primary dip was probably small, 5° or less, down to the west.

The red cinder breccias grade laterally and downward into yellow palagonite breccias suggesting that a subaqueos vent built up out of water, erupting subaerial cinder and ash. The cinder deposits are found in the middle and upper parts of the Cheat Creek Beds. They grade downward and laterally into the palagonitic breccias described previously, but do not display the same textural or depositional features. The cinder deposits are reddened, oxidized bomb- and lapilli-size nonporphyritic and sparsely porphyritic basalt fragments embedded in ash-sized matrix of similar material. X-ray diffraction studies reveal the presence of chabazite in the matrix, which probably acts, in part, as a cementing agent. The deposits are now compacted and firmly cemented; for this reason the rock breaks across the constituent clasts. The cinder deposits exhibit a pronounced primary dip, often in excess of 15°. As the entire Cheat Creek section is tilted 5 to 10° downward to the southeast, the dips in the cinder deposits vary from 30° to the southeast on the eastern side, to 10° to the northwest on the western side. No source intrusions are exposed in the cinder deposits or in the palagonite breccias adjacent to them. Dikes cut the Cheat Creek Beds immediately to the west, but these dikes extend into the overlying flow sequence, eliminating them as possible feeder systems.

An ash-flow unit occurs in the upper part of the Cheat Creek Beds in the Outerson Mountain-Triangulation Peak area. The ash-flow tuff is a crystal-poor vitric lapilli tuff which is moderately welded with some collapse of the larger pumice fragments. Some volcanic rock fragments are present, but in this deposit they represent less than 10 volume percent of the rock. The pumice fragments and ash are pinkish buff to white throughout the deposit. Pumice varies from coarse ash to medium lapilli size. The deposit shows a moderately well developed eutaxitic texture. The ash flow is approximately 15 m thick and zonation is not apparent although some suggestion of a decrease upward of included lithic fragments was noted.

Triangulation Peak Lavas

General

The Triangulation Peak Lavas occur on the top of Woodpecker Ridge, Mount Bruno and Triangulation Peak. They are a series of porphyritic basaltic andesite and fine-grained porphyritic hypersthene-bearing dacite lava flows. The unit is composed exclusively of lava flows with thin, discontinuous autoclastic breccias between them. The Triangulation Peak Lavas lie unconformably atop the Cheat Creek Beds and reach a maximum thickness of approximately 150 m on the top of Mount Bruno. No age data are available for this unit.

Unit Description

In hand specimen the unit is distinctive in that the flows are universally fresh and light colored with no visible alteration. The finer-grained basaltic andesites show a well developed fine-scale flow banding.

Individual flows vary in thickness between 5 and 15 m. The lower-central parts of the flows are platy or columnar jointed and the upper parts are platy jointed. Vesicles are less common in the nonporphyritic flows, usually less than 2 volume percent of the rock. In the porphyritic flows vesicles can amount to between 5 and 10 volume percent of the rock, particularly near the top of the flow. Pipe vesicles are rarely exposed. However, those observed suggest that the source was to the north of the thesis area.

Autoclastic breccias are rare in the Triangulation Peak flow series. Those which were recognized could be traced for only a few meters and were less than a meter in thickness.

Two lava types are found in the Triangulation Peak Lavas. Porphyritic basaltic andesites comprise 95 percent of the section. Rare porphyritic hypersthene-bearing dacite flows are found on the flanks of Mount Bruno.

The porphyritic basaltic andesites are hypocrystalline with an intergranular groundmass texture. Plagioclase usually amounts to more than 70 volume percent of the rock with pyroxene about 16 percent, magnetite 5 percent and interstitial glass about 5 percent. They contain olivine phenocrysts in amounts between 1 and 5 volume percent. The olivine is a forsteritic variety with a 90° 2V. Refractive index of the olivine is 1.700, indicating a chrysolite with a composition near Fa_{17}. The olivine is altered to hematite around the rims and along internal fractures. Plagioclase is also a common phenocryst, usually decreasing in abundance as olivine increases. The plagioclase phenocrysts vary in composition from An_{48} to

An_{54}. The phenocrysts are elongate, subhedral grains which were apparently in equilibrium with the groundmass. The phenocrysts are about 0.75 mm in size, but may reach 1.5 mm in the coarser-grained flows.

The groundmass is composed of microlites of plagioclase, pyroxene, magnetite and glass. The plagioclase microlites are elongate, subhedral grains composed of two or three albite twins. The pyroxene is a clinopyroxene of length-fast orientation, suggesting that it may be a part of the augite-ferroaugite series. Magnetite occurs as fine disseminations throughout the groundmass and may be concentrated in the interstitial glass. The glass varies slightly in abundance, but is always present in small amounts.

The basaltic andesites vary in SiO_2 content between 52.1 and 55.0 weight percent, alumina values are slightly below the average of the other flow units at 16 weight percent. Chemical analyses are listed in Appendix C.

The porphyritic hypersthene-bearing dacite flows are thick, 15 to 20 m, and of limited extent. The dacites are blocky to platy jointed, the latter being most common.

The hypersthene phenocrysts are of low abundance, usually 2 volume percent or less. The hypersthene phenocrysts are elongate, subhedral crystals which show strong green to pinkish-red pleochroism. The hypersthene is fresh and unaltered. Plagioclase is a common phenocryst occurring in equidimensional crystals in apparent equilibrium with the groundmass. The plagioclase phenocrysts have a composition of An_{24} to An_{26} and are zoned, equidimensional grains. As phenocrysts, plagioclase comprises about 15 volume percent of the rock. The groundmass is intergranular and consists of extremely fine-grained plagioclase and magnetite with a small amount of interstitial glass. The plagioclase of the groundmass is too fine grained for composition determination. The microlites are elongate and consist of two or three albite twins. Magnetite occurs as disseminations throughout the groundmass associated with the minor interstitial glass. The glass is found in the small intersticies between the plagioclase microlites and is light brown.

The hypersthene-bearing dacites have SiO_2 contents of 68.0 weight percent and Al_2O_3 contents of about 16.0 weight percent. A chemical analysis is listed in Appendix C.

Minto Mountain Lavas

General

The Minto Mountain Lavas are restricted in occurrence to the upper most one-third of Minto Mountain, the top of Bingham Ridge and a small remnant which supports Bruno Meadows. The Minto Mountain Lavas are the oldest unit in the thesis area that is demonstratably part of the High

Cascade Platform. The Minto Mountain Lavas lie with angular unconformity atop the Nan Creek Volcanics. The contact between the Minto Mountain Lavas and the Nan Creek Volcanics is well exposed in Nan Creek Canyon on the southern flank of Minto Mountain. The Minto Mountain Lavas begin with approximately 10 m of well-bedded, fine-grained tuffaceous sandstone, which provides accurate structural control of the unit. The Minto Mountain Lavas are part of the High Cascade Platform and their upper surface reflects this as it gently slopes downward to the west.

Unit Description

The Minto Mountain Lavas reach a maximum thickness of 400 m on Minto Mountain. Of this, approximately 30 percent is porphyritic diktytaxitic basalt and 70 percent is basaltic andesite.

The diktytaxitic flows are abundant in the lower part of the section. There, the diktytaxitic flows are thick, usually 15 m or more, and in their lower part may become medium to coarsely crystalline. The diktytaxitic flows of the Minto Mountain Lavas are more variable in thickness than diktytaxitic flows in other units, varying from 5 to 25 m. The individual flows are also highly variable in thickness along their length. Joint patterns vary from imperfect columnar to blocky.

Vesicularity does not vary greatly between the diktytaxitic flows. The total void space approaches 25 volume percent on the average. The vesicles are concentrated in layers 0.5 to 2 cm in thickness parallel to the flow banding. In these layers the total void space may approach 65 volume percent. Vertically oriented, imperfect cylindrical zones of high vesicularity occur here and there throughout the mass of the flow. They rarely continue vertically for more than a meter or two.

The mineralogy of the diktytaxitic basalts consist of olivine, plagioclase, clinopyroxene and magnetite. Plagioclase is the most abundant, about 65 percent of the rock. Clinopyroxene amounts to 20 percent, magnetite 10 percent and olivine is fairly constant at about 2 percent. Olivine is found as anhedral phenocrysts, approximately 0.50 to 0.25 mm in size. The olivine is a magnesian variety with a 2V of 90° and high relief. The olivine is usually rimmed by hematite as well as having hematite disseminated along the fractures within the crystals. Plagioclase occurs as phenocrysts and as microlites in the groundmass. The phenocrysts have a composition of An_{56} to An_{58}. The groundmass crystals are andesine, variable in composition between An_{48} and An_{52}. The phenocrysts rarely exceed 2 mm in length and are usually about 1 mm long. Groundmass plagioclase is extremely fine-grained in most cases, although it may reach .5 mm in size. Clinopyroxene occurs as small anhedral crystals in the groundmass either in a subophitic or intergranular texture. The clinopyroxene has a 2V of 50 to 55° and is probably an augite. Magnetite is present as disseminated crystals or as rounded crystal masses. In the groundmass the crystals are extremely fine-grained, often difficult to distinguish except under high magnification. Apatite is a common accessory as is pyrite in trace amounts.

Chemical analysis of Minto Mountain diktytaxitic basalts discloses that they are high alumina basalts with SiO_2 at 50 weight percent and Al_2O_3 at about 17.5 weight percent. A chemical analysis is listed in Appendix D.

The basaltic andesite flows are found both interbedded with and stratigraphically above the diktytaxitic basalts. They are uniformly 5 to 10 m in thickness. Joint patterns include poorly columnar in the central and lower parts of the flows, and blocky to platy in the upper parts. Autoclastic breccias are common in the section and many reach 2 m in thickness. The breccias are composed of reddened, highly altered fragments of flow crusts, which vary between 2 cm and 0.5 mm in size. The matrix of the breccias is composed of very fine ash-sized fragments of the underlying flow which tightly bind the breccia so that it fractures across the constituent clasts.

The basaltic andesites are porphyritic with olivine and plagioclase phenocrysts which amount to approximately 5 and 10 volume percent, respectively. The olivine phenocrysts are a forsteritic variety of olivine with a 90° 2V. The crystals are anhedral with some embayment by the groundmass. The olivine is altered in all cases to hematite which rims the crystals and is disseminated along internal fractures. The plagioclase phenocrysts vary in composition from An_{56} to An_{60} between individual flows and are subhedral, elongate laths.

Groundmass textures are not significantly variable, and are holocrystalline, intergranular and often pilotaxitic. The groundmass consists of very fine-grained plagioclase, a mafic silicate and magnetite. The groundmass is composed of 70 percent plagioclase microlites, 25 percent mafic silicate and 5 percent magnetite. The plagioclase crystals are elongate and composed of two or three pairs of albite twins. The mafic silicate occurs as rounded, anhedral grains of high relief, high birefringence and a greenish color. Magnetite is disseminated evenly throughout the groundmass and apatite is a common accessory found in very small amounts in the plagioclase.

The basaltic andesites range between 54.2 and 55.8 weight percent SiO_2. The more silic varieties have fewer phenocrysts of olivine and a greater amount of plagioclase phenocrysts. Al_2O_3 is slightly below that expected of a high alumina basaltic andesite at 16.9 weight percent. Chemical analyses for the Minto Mountain basaltic andesites are listed in Appendix D.

Pigeon Prairie Lavas

General

The Pigeon Prairie Lavas are a series of intracanyon lava flows which nearly filled Whitewater Creek, Pamelia Creek and North Santiam River Canyons. The unit reaches a maximum thickness of 500 m in the North Santiam River Canyon, north of Mount Bruno. The flows which reached the western part of the thesis area, in the North Santiam River Canyon, are largely intact, although their southern extensions have been removed by the North Santiam River. The lavas have been extensively glaciated and large, high-standing erosional remnants, which are excellent examples of reversed topography, are found in the upper Whitewater Creek and Pamelia Creek Canyons. The presence of older, possibly Salmon Springs, glacial deposits on top of the Pigeon Prairie Lavas in the North Santiam River Canyon indicates that the lavas were erupted at least before the Salmon Springs glaciation.

The distribution of the Pigeon Prairie flows, along with their morphology, suggests that they originated from vents in the High Cascades and flowed westward, down the ancestral Whitewater Creek and Pamelia Creek Canyons, into the North Santiam River Canyon and out to the west about 15 km. Some of the lava flowed to the south, back-filling into the Minto and Marion Creek Canyons. Independence Rock and the quarry rock at the western base of Minto Mountain are remnants of those flows.

Unit Description

The lava flows of the Pigeon Prairie are typically 5 to 25 m thick with autoclastic breccia 1 or 2 m thick at the tops. Joint patterns include blocky to platy in the thinner flows and well-developed columnar in the thicker flows. In the Minto quarry a porphyritic andesite flow is excellently exposed and the columnar jointing is well developed, displaying rosette, fan and inverted fan geometry.

The Pigeon Prairie Lavas are of three types: 1) porphyritic olivine basalt, 2) porphyritic andesite and 3) diktytaxitic olivine basalt.

The porphyritic olivine basalts comprise more than 50 percent of the Pigeon Prairie section. The basalt flows vary individually in thickness between 5 and 20 m, but are of generally constant thickness along their length. The contacts between flows are of low relief with little erosional effects apparent. Columnar jointing is extremely well developed in the thicker flows, particularly in the lower part of the section. The thinner flows, 5 to 10 m, display a blocky jointing, which creates roughly cubic blocks 0.5 to 1 m on an edge. Individual flows can be traced for 1 km or more along their length, particularly in the upper Whitewater Creek Canyon where exposures are best.

The porphyritic olivine basalts are fine-grained and are of several textural types. Olivine is variable in amount although always present as phenocrysts. The olivine is usually between 1.0 and 0.125 mm in size. Plagioclase is often a more abundant phenocryst than olivine, but is commonly restricted to the groundmass, particularly in the very fine-grained flows. Groundmass textures include holocrystalline intergranular, holocrystalline subophitic and hypocrystalline intergranular. Pilotaxitic texture is present in some of the finer-grained flows. Vesicularity of the basalts is generally below 5 volume percent.

The mineralogy of the olivine basalts is simple, involving only four major phases; olivine, about 2 percent of the rock, plagioclase 70 percent, pyroxene 15 percent and magnetite 12 percent. The olivine is a forsteritic variety with a 90° 2V. The olivine commonly contains magnetite grains and may be partially altered to hematite around its rim and along internal fractures. The crystals of olivine are anhedral and extremely irregular in shape because they have been embayed by the groundmass. Between individual flows, plagioclase varies only slightly in composition from An_{52} to An_{56} in the phenocrysts, and from An_{34} to An_{38} in the microlites of the groundmass. The plagioclase is in elongate, subhedral grains which are about 0.750 mm in size as phenocrysts and about 0.250 mm in size as groundmass microlites. The plagioclase displays albite and carlsbad twinning. The pyroxene is restricted to the groundmass of the basalts where it occurs as small, anhedral crystals. In the intergranular-textured basalts the pyroxene occurs as nearly spherical anhedral grains about 0.0125 mm in diameter. In the subophitic basalts the pyroxene is more irregular in shape and about 0.125 mm. The pyroxene is a clinopyroxene of moderate relief.

Magnetite occurs as disseminated grains in the groundmass, as inclusions in, or as rims around, the olivine phenocrysts. The magnetite occurs as anhedral grains or aggregates of grains and is often altered to hematite. In some of the porphyritic olivine basalts, magnetite completely surrounds the olivine phenocrysts.

The olivine basalts have SiO_2 contents between 49 and 51.2 weight percent and Al_2O_3 contents of about 16.5 weight percent. The Al_2O_3 content is slightly below that of high alumina basalt according to the classification of basalts by Kuno (Kuno, 1966). See Appendix E for chemical analyses of the Pigeon Prairie Lavas.

Porphyritic andesite flows amount to about 35 percent of the total Pigeon Prairie section. The andesite flows are thicker than the basalts, reaching 30 m in thickness. The basal contacts of the andesites are semi-planar with little relief. Platy jointing predominates, creating plates with a thickness of about 3 cm.

The andesites vary little in texture, being universally porphyritic with phenocrysts of plagioclase. The groundmass textures vary between intergranular to subophitic and are commonly pilotaxitic. The flows are holocrystalline with finer-grained, less than 0.025 mm, microlites of plagioclase, clinopyroxene and disseminated magnetite.

The andesites are composed of 70 percent plagioclase, 20 percent clinopyroxene and 10 percent magnetite. Plagioclase occurs both as phenocrysts and microlites in the groundmass. The plagioclase phenocrysts have a composition of An_{38} to An_{42}, are subhedral, elongate and show albite and carlsbad twinning. The microlites are subhedral, elongate and are composed of two or three albite twins. Clinopyroxene phenocrysts are identifiable as pigeonite. The pigeonite is anhedral, occasionally twinned and embayed.

The clinopyroxene of the groundmass occurs as disseminated, fine-grained, anhedral crystals located in the intersticies between the plagioclase microlites. Minor apatite is frequently found in the plagioclase phenocrysts. Magnetite occurs as disseminated grains in the groundmass and rarely as individual grains in the phenocrystic clinopyroxene.

Because the SiO_2 content varies between 57 and 59 weight percent, the porphyritic andesites actually lie astride the chemical boundary between basaltic andesites and andesites. The term andesite is preferred for these rocks because olivine is absent and the plagioclase phenocrysts are of andesine composition. Alumina content is generally about 18 weight percent, although one very porphyritic sample contains 21.6 weight percent. Chemical analyses of Pigeon Prairie porphyritic andesites are listed in Appendix E.

Diktytaxitic olivine basalt flows are present in the Pigeon Prairie Lavas although they represent only a small part of the total section. The diktytaxitic flows occur near the top of the section in the North Santiam River Canyon and in the upper Whitewater Creek Canyon. The individual flows are thin, 5 to 10 m, and uniform in thickness along their length. Vesicularity is uniform, around 20 volume percent, with pipe vesicles and vesicle cylinders present. Pipe vesicle inclinations suggest that the flows moved westward from an easterly source, consistant with the data obtained in the other flow types. The diktytaxitic flows display very poorly developed columnar jointing in the lower and central parts of the flow, giving way to a blocky jointing toward the top. Individual flows can be traced for several kilometers along their length because their texture is distinctive and easily traced across areas of poor exposure.

The diktytaxitic olivine basalts do not vary greatly in texture or mineralogy other than in the abundance of olivine and plagioclase phenocrysts. Coarse-grained flows with abundant plagioclase phenocrysts display the best developed diktytaxitic texture. Some flow alignment is evident in the elongate plagioclase phenocrysts and rarely in the microlites. The diktytaxitic basalts are holocrystalline.

The mineralogy of the diktytaxitic olivine basalts consists of olivine, plagioclase, clinopyroxene and magnetite. Plagioclase is the most abundant amounting to about 65 percent of the rock. Clinopyroxene comprises about 20 percent, magnetite 10 percent and olivine 5 percent. Olivine occurs exclusively as phenocrysts in anhedral, fractured crystals. The olivine is a forsteritic variety with a 2V of nearly 90°. The olivine usually has rims of hematite as well as hematite disseminated along internal fractures.

Olivine is between 1.0 and 0.5 mm in size, most often about 0.5 mm. Plagioclase occurs as phenocrysts and as microlites in the groundmass. The phenocrysts have a composition of An_{54} to An_{56} and the microlites a composition of An_{44} to An_{46}. The plagioclase is intergrown in an open latticework in which part of the intersticies are filled with gas and are part filled with very finely crystalline plagioclase, clinopyroxene and magnetite. Clinopyroxene is restricted to the groundmass, where it occurs as anhedral crystals intergrown with, and commonly partly surrounding, plagioclase. The 2V of about 55^{o} suggests that the pyroxene is probably an augite. Magnetite occurs as disseminations in the groundmass, usually so fine as to be difficult to distinguish as individual crystals. The magnetite may be altered to hematite imparting a reddish color to the rock. Apatite is a universally present accessory found in varying amounts in the plagioclase feldspar.

Chemically the diktytaxitic basalts are high alumina basalts with SiO_2 values of 49.7 weight percent and Al_2O_3 values of 17.9 weight percent. Chemical analyses of Pigeon Prairie Lavas are listed in Appendix E.

In the upper Marion Creek drainage, just east of Marion Forks, a series of intracanyon diktytaxitic basalt flows are exposed. The stratigraphic relationship between these basalts and the Pigeon Prairie Lavas is uncertain because the two units are not in direct contact. The Marion Creek basalts have been heavily glaciated, indicating that the flows were erupted at least before the last glacial advance. Because the Marion Creek flows occupy the same structural position, and because both the Pigeon Prairie and Marion Creek flows have been glaciated, the Marion Creek flows are included with the Pigeon Prairie Lavas.

The Marion Creek unit consists of about 100 m of diktytaxitic basalt flows which individually may reach 20 m thick. All remain uniform in thickness for most of their length. Thin, 5 to 25 cm, discontinuous autoclastic breccias occur between many of the flows. However, an equal number have no breccia associated with them. These breccias are composed of reddened, highly-altered fragments of the underlying flow which range in size from 0.5 mm to 8 cm.

The thicker, coarser-grained flows display the most readily recognized diktytaxitic texture, and have abundant plagioclase phenocrysts. Vesicularity is generally less than 20 volume percent, although concentrations of vesicles of several types do occur. Horizontal concentrations of vesicles occur in the central parts of the flows and may continue, parallel to the fabric of the flow, for several meters before lensing out rapidly. Vesicle cylinders occur in the lower parts of the flows and commonly extend a meter or more vertically.

The diktytaxitic basalts are porphyritic with phenocrysts of olivine and plagioclase. Olivine amounts to about 1 percent of the rock, plagioclase 40 percent and the groundmass 60 percent. The olivine is a magnesian variety with a 2V of nearly 90°. Refractive index studies reveal the olivine to be a chrysolite with a composition near Fa_{15}. Rarely, olivine is partly altered to hematite around the rim. Plagioclase occurs as phenocrysts and as microlites in the aphanitic groundmass. The phenocrysts have a composition of An_{52} to An_{54} and occur as subhedral crystals in apparent equilibrium with the groundmass.

The groundmass contains microlites of plagioclase of uncertain composition, a mafic silicate and magnetite. The mafic silicate occurs in extremely small, anhedral, highly birefringent crystals. Magnetite occurs as finely disseminated grains throughout the groundmass. Apatite is a common accessory foune in the plagioclase phenocrysts.

The diktytaxitic basalts range in SiO_2 content from 48.2 to 49.8 weight percent. Al_2O_3 contents are fairly constant at about 16.8 weight percent. Chemical analyses of Marion Creek flows are included in the Pigeon Prairie Lavas listed in Appendix E, sample numbers TR-77 and TR-50.

Intrusive Rocks

The intrusive bodies of the thesis area occur in the form of dikes and small plugs.

Volumetrically more important, dikes are common in the stratigraphically lower units. The most common type is of basaltic andesite composition with sparse phenocrysts of plagioclase and olivine. The basaltic andesite dikes are about 10 m wide, but vary greatly along their length. Groundmass textures vary between holocrystalline intergranular and holocrystalline subophitic, the former being more common.

Their mineralogy includes phenocrysts of plagioclase and olivine and a groundmass composed of plagioclase, clinopyroxene and magnetite. The olivine is a forsteritic variety with a high 2V very near 90°. Anhedral olivine crystals amount to about 5 percent of the rock. Alteration of the olivine is common, usually in the form of hematite around the rims and along internal fractures. Alteration of the entire crystal, to either celadonite or hematite and magnetite, has been observed in some cases. The plagioclase phenocrysts have a composition of approximately An_{54} with some slight variation between individual dikes. The phenocrysts are subhedral, equidimensional and normally zoned crystals in apparent equilibrium with the groundmass. The phenocrysts are approximately 0.75 mm in size with little variation.

The groundmass consists of plagioclase, clinopyroxene and magnetite. The plagioclase is most abundant, about 75 volume percent of the groundmass. The plagioclase is elongate, subhedral and composed of simple albite twins. The clinopyroxene occurs as rounded, anhedral grains disseminated evenly throughout the groundmass, amounting to roughly 20 percent of the groundmass. Magnetite is disseminated also as very fine grains and accounts for about 5 percent of the groundmass.

The basaltic andesite dikes range in SiO_2 content from 53 to 57 weight percent. The dikes are certainly members of the high alumina basalt series as Al_2O_3 is quite high, between 17.7 and 19.7 weight percent. Chemical analyses are listed in Appendix F.

Basalt dikes occur, but are much less common. Those that the author has found, were located in the western part of the thesis area, intruding the Brietenbush Tuff. Basalt dikes are thin, 1 to 3 m, and in most cases, cannot be traced for more than 50 m along their length. The basalt dikes are sparsely porphyritic with phenocrysts of olivine and plagioclase. The groundmass is holocrystalline intergranular with some pilotaxitic alignment of the plagioclase microlites. The olivine is a forsteritic variety with a 2V of 90°. The olivine is commonly altered to hematite, celadonite or iddingsite. Olivine amounts to about 5 volume percent of the rock. The plagioclase phenocrysts have a composition of An_{56} and are elongate, subhedral crystals in apparent equilibrium with the groundmass. The groundmass consists of plagioclase microlites, clinopyroxene and magnetite in nearly equal proportions.

Several intrusive plugs of dacitic composition occur in the Outerson Mountain-Triangulation Peak area. The intrusions are roughly oval shaped, varying from about 50 to 125 m^2 in outcrop area. The smaller plugs stand 10 to 15 m above the general topography and the largest, Spire Rock, stands 25 m high, in a shape worthy of its name. In all, there are five separate intrusive outcrops, all of identical mineralogy. It is possible that the five separate exposures of the dacite are actually interconnected at depth.

The dacite is porphyritic with phenocrysts of hypersthene and plagioclase which comprise approximately 2 and 5 volume percent of the rock, respectively. The dacite is glomeroporphyritic with a tendency for the hypersthene phenocrysts to be very closely associated with groups of plagioclase phenocrysts. The hypersthene is subhedral, elongate and unaltered. Apparently, the hypersthene was in equilibrium with the enclosing liquid as no embayment has occurred. The plagioclase phenocrysts have a composition of An_{26} and show oscillatory zoning. The phenocrysts are subhedral and equidimensional in shape. The plagioclase phenocrysts are extensively embayed and were probably not in equilibrium with the enclosing liquid. Magnetite occurs as large, granular masses which occur in association with the hypersthene phenocrysts. The groundmass consists of extremely fine subhedral crystals of plagioclase and disseminated magnetite.

Quaternary Deposits

General

The thesis area is located in a region which has been greatly affected by alpine glaciation. The result has been to modify the topography and to cover a large part of the thesis area with a considerable volume of glacial debris. Streams have reworked most of the glacial deposits, particularly in the North Santiam River Canyon.

Unit Description

The Quaternary Deposits are of two types: Those formed by glacial processes, and those formed by fluvial processes. Further, two sets of glacial deposits have been recognized in the thesis area. A single occurance of weathered glacial debris is referred to as "older" moraine, so as to distinguish it from fresher appearing, presumably younger, glacial deposits.

The glacial deposits include lateral and terminal or recessional moraines. Lateral moraines are found in the upper Whitewater Creek and Pamelia Creek drainages, and "older" lateral moraine deposits occur on the Pigeon Prairie in the western part of the thesis area. The deposits are composed of large, angular cobbles and boulders in a sand and silt-sized matrix. The clasts consist of many types of volcanic rock, though predominately of nonporphyritic basalt. The deposits are in matrix support with the larger clasts rarely amounting to more than 30 percent. The lateral moraines occur against the canyon walls and stand about 6 m above the canyon floor. The largest of these extends for about 1 km along the northern wall of Whitewater Canyon just downstream from the confluence of Cheat and Whitewater Creeks. These moraines contain clasts which are fresh and unaltered. The deposit is a dark gray, reflecting its unaltered character. "Older" lateral moraines are recognized on the basis of weathered rinds on the larger clasts and a pervasive limeonite stain throughout the matrix of the deposit. The occurrence of "Older" lateral moraines is restricted to a single deposit located adjacent to the Pigeon Prairie in the northwestern part of the thesis area.

Recessional or terminal moraines are present in the lower part of the Whitewater Creek Canyon and in the middle of the Pamelia Creek Canyon. Exposed in the river bank, adjacent to the Whitewater U. S. Forest Service Campground, is approximately 7 m of terminal or recessional moraine deposits. The deposits are very poorly sorted with clasts ranging in grain size fron boulders nearly 1 m across to fine sand. The larger clasts are in matrix support and are angular. The clasts consist of many types of extrusive lava including several varieties of fine-grained basalt, andesite and rhyolite. Bedding is absent from the deposit. The moraine has been breached by Whitewater Creek and a large part has been removed by the stream. Whether or not this deposit is a recessional or terminal moraine is difficult to determine. If the deposit is actually recessional, the proof can be obtained only in the North Santiam River Canyon farther west. Glacial deposits have been extensively reworked by the North Santiam River and apparently no moraine deposits remain. The evidence of recent glaciation extending at least as far as the ends of the east-west oriented canyons in the eastern part of the thesis area is abundantly preserved. It is possible that the latest glacial advance did not extend into the North Santiam River Canyon. It is equally possible that it did and that the evidence is sufficently obscure so as to require detailed study beyond the scope of this thesis.

The moraine deposits which are located in the middle of the Pamelia Creek Canyon are much smaller and are most probably a recessional deposit. The moraines occur as two separate arc-shaped ridges about 5 m in relief. The two ridges are separated by Pamelia Creek. As before, the deposits are composed of very poorly sorted angular fragments of volcanic rock and appear fresh and unaltered.

Alluvial deposits occur in the bottom of all the canyons and reach a maximum thickness of about 15 m in the main North Santiam River Canyon. The alluvial deposits consist of moderately sorted cobbles and pebbles with a matrix of coarse to medium sand. The larger clasts are in framework support and imbarcation is commonly present. The cobble- and pebble-sized clasts are well rounded and the sands are subrounded to subangular. All the clasts are volcanic rock fragments of many types and textures, though porphyritic and nonporphyritic basalt is in greatest abundance.

A thin layer of light-colored ash is present in the soil in some parts of the thesis area. This ash is presumably Mazama Ash as it is reportedly present all around the thesis area (Lidstrom, 1972). The ash is most commonly observed in soil horizons which have been dissected by small streams.

COMPARISON OF STRATIGRAPHIC UNITS ADOPTED IN THIS WORK TO THOSE PREVIOUSLY ESTABLISHED BY THAYER

T. P. Thayer (1933, 1936, 1936, 1939) mapped the northern part of the thesis area and stratigraphic units he defined and described have been further subdivided and described in this thesis. In places contacts have been relocated and specific rock sequences have been reassigned to new rock-stratigraphic units as a result of this investigation.

The name "Breitenbush Tuff" introduced by Thayer (1939), as a modification of "Breitenbush Series" (Thayer, 1936) is retained and used in this thesis to refer to the same sequence of ash-flow tuffs. The contacts displayed for the Breitenbush Tuff are modified, particularly on the eastern slope of Mount Bruno. There, a new logging road cut reveals that Breitenbush Tuff does not extend around to the eastern flank of Mount Bruno. Instead, the Breitenbush Tuff dips under the Grizzly Creek Lavas at about the point where the North Santiam River turns west.

The Pliocene flow sequence (Outerson Formation of Thayer, 1939) has been subdivided in the Grizzly Creek Lavas, Nan Creek Volcanics, Cheat Creek Beds and Triangulation Peak Lavas. The Grizzly Creek Lavas, and Nan Creek Volcanics are subdivided on the basis of differing degrees of alteration. The Grizzly Creek Lavas are amygdaloidal with vesicle fillings of quartz, calcite and zeolites. The olivine phenocrysts in the basalts and basaltic andesites of the Grizzly Creek Lavas are altered to celadonite, hematite and magnetite. Accordingly, Grizzly Creek Lavas are stained by hematite, imparting to them a deep red-brown color. The Nan Creek Volcanics lie on top of the Grizzly Creek Lavas and are recognized on the basis of a general lack of alteration. The vesicles in Nan Creek flows are not secondarily mineralized. Overall, the rocks are fresh and unaltered. The Cheat Creek Beds are distinctive and rest with angular unconformity atop the Nan Creek Volcanics separating them from the Triangulation Peak Lavas. The Triangulation Peak Lavas have attitudes which diverge from the bulk of the rest of the Pliocene units, and for this reason are distinctive structurally. Also, the Triangulation Peak Lavas consist of distinctive basaltic andesites and hypersthene-bearing dacite; the latter is not found in the lower flow units.

The flow units which are stratigraphically above the inclined Pliocene flow units were believed to be Quaternary by Thayer and were subdivided by him into "Undifferentiated Young Lavas", "Minto Basalts", "Battle Ax Basalts" and "Santiam Basalts". The name "Minto" is retained and used to refer to the flow sequence which occurs on the upper one third of Minto Mountain and Bingham Ridge. The flow sequence of Minto Mountain and Bingham Ridge was grouped with the younger intracanyon flow sequences which stand in relief in the upper Whitewater Creek and Pamelia Creek Canyons. Thayer recognized the intracanyon relationship of the flows underlying the Pigeon Prairie and also the isolated occurrences of intracanyon lava up the North Santiam River Canyon. These flows he grouped together and called Santiam Basalts. In this thesis the large high-standing flow sequences have been grouped together with the intracanyon flows of the Pigeon Prairie and with the North Santiam intracanyon flows. Additional geochemical data and careful field correlation of the diktytaxitic flows, particularly between the Whitewater Creek flows and the flows of the Pigeon Prairie support the conclusion that they are parts of the same flow sequences. Flow correlation was not possible between the Pamelia Creek flows and the rest of the intracanyon lava, but their topographic expression, lithology, chemical variation and structural position are very similar and are strong evidence that they are part of the same sequence. The name Pigeon Prairie Lavas was adopted for these intracanyon flows.

STRUCTURE

General Statement

The rock units which are stratigraphically below the Minto Mountain Lavas dip with some variation to the southeast approximately 10°. The structural variation is found principally in the Nan Creek Volcanics and in the Triangulation Peak Lavas. The former has been thoroughly fractured and effected by minor normal offsets, which are most likely responsible for the attitude variations. The latter probably had considerable primary dip, as part of a volcanic complex, and as the tectonic dip is small, the primary dips have had a significant effect on their present attitude. The Minto Mountain Lavas and the rock units stratigraphically above them are horizontal or may actually have a slight westerly dip. This angular unconformity marks the geologic boundary between the Western Cascade and High Cascade physiographic provinces.

Dikes and faults in the thesis area have a preferred orientation, roughly N10°W, with the dikes showing the strongest parallelism.

Folds

The thesis area is on the eastern limb of the Idana anticline (Thayer, 1939) whose axis trends northeastsouthwest. The anticline is part of a regional fold series which extends across the northern part of the Western Cascade province in Oregon (Peck and others, 1964). The folding is confined to the Miocene and Pliocene rock units and folding on a smaller scale is not evident in the thesis area.

Faults

The faults found in the thesis area are steeply dipping normal faults, which cross-cut all the stratigraphic units below the Minto Mountain Lavas. Faults in the Minto Mountain Lavas and stratigraphically higher units are very rare and of very small, 1 m or less, displacement. These cross-cutting relationships suggest that faulting occured in the late Pliocene or early Pleistocene, but since the dating of the rock units is generally poor, more accurate estimates of the timing of faults is impractical.

The faults which could be traced for any distance trend very close to ten degrees west of north, roughly parallel to the dikes found in the thesis area.

The displacement along the faults in the thesis area is quite variable. Usually displacement is less than 5 or 10 m although faults of larger displacement have been found. Of interest is the direction of displacement along a large number of the tracable faults. The largest fault, both in displacement and in length is located on Woodpecker Ridge and is offset such that the western block is down relative to the eastern by some 25 m. This is significant considering that much discussion in the literature (Allen, 1966) is devoted to a major fault, which is suggested to have displaced the eastern half of the thesis area downward 1,000 m or more. In actuality, the normal faults which have displacements large enough to warrant mapping have the west side down thrown relative to the east.

Faults of an east-west orientation are rare in the thesis area and none can be traced for more than a few m. The east-west faults are of small displacement, rarely more than 1 m and are all of normal displacement.

The Western Cascade-High Cascade Boundary

The High Cascades of Oregon are a chain of high-standing composite volcanoes which rest atop a sequence of volcanic rocks which comprise the High Cascade platform. The Western Cascades of Oregon lie immediately west of the High Cascades and are composed of older volcanic rocks. The structural evidence for large-scale normal faulting of the basin and range type is persuasive for the High Cascade-Deschutes Basin boundary which is the eastern margin of the Cascade range in Oregon. Because the Western Cascades are of sufficiently high relief directly adjacent to the High Cascades, and because some of the High Cascade rock units are actually at lower elevations than many of the Western Cascade rock units, Thayer (1937) suggested that the western boundary was also a normal fault. Allen (1965) proposed that the High Cascades were actually the central part of a large volcano-tectonic depression whose width corresponds to the distance from the thesis area east to Green Ridge.

One of the principal objectives of the thesis project was the accurate location of the geologic boundary between the Western Cascade and the High Cascade provinces. Along with accurate positioning, the exact nature of the boundary was also to be determined. The High Cascade-Western Cascade boundary is an angular unconformity which separates the older, Miocene and Pliocene flow units, Breitenbush Tuff, Grizzly Creek Lavas, Cheat Creek Beds, Nan Creek Volcanics and Triangulation Peak Lavas from the flat-lying Minto Mountain Lavas and Pigeon Prairie Lavas. The latter series apparently had their source vents somewhere in the present High Cascade province. As far as can be determined from stratigraphic relations and field exposure, no large-scale normal fault, with the eastern side displaced downward relative to the western exists. The course of the North Santiam River is not fault controlled and the stratigraphy continues without interruption across it.

VARIATION OF CHEMICAL COMPOSITION OF VOLCANIC ROCKS

The volcanic and intrusive rocks of the thesis area range in composition from olivine basalt to dacite. The predominant rock type is columnar-jointed porphyritic olivine basalt having SiO_2 contents between 48 and 52 weight percent. Columnar-jointed porphyritic basaltic andesite, whose SiO_2 content ranges from 53 to 58 weight percent, is the next most common and usually contains phenocrysts of olivine and labradorite. Platy jointed andesite, whose SiO_2 content ranges from 59 to 64 weight percent, makes up most of the rest of the flow sequence. Dacite lava and intrusive plugs, whose SiO_2 content is 68 weight percent, are also present, but comprise less than 5 percent of the total. The ash-flow tuffs range from dacite, whose SiO_2 content is 68 weight percent, to rhyodacite, whose SiO_2 content is 70 weight percent, and represent about 10 percent of the total section. Volcanic sedimentary rocks of undetermined chemical composition comprise about 20 percent of the rocks in the thesis area.

Overall, the volcanic and intrusive rocks of the thesis area are calc-alkaline with a Peacock (1931) alkali-lime index of about 60, very near to the calc-alkaline-calcic boundary of 61 (Fig. 11). Many of the basalts and basaltic andesites have Al_2O_3 contents in excess of 17 weight percent and when plotted on the basalt classification

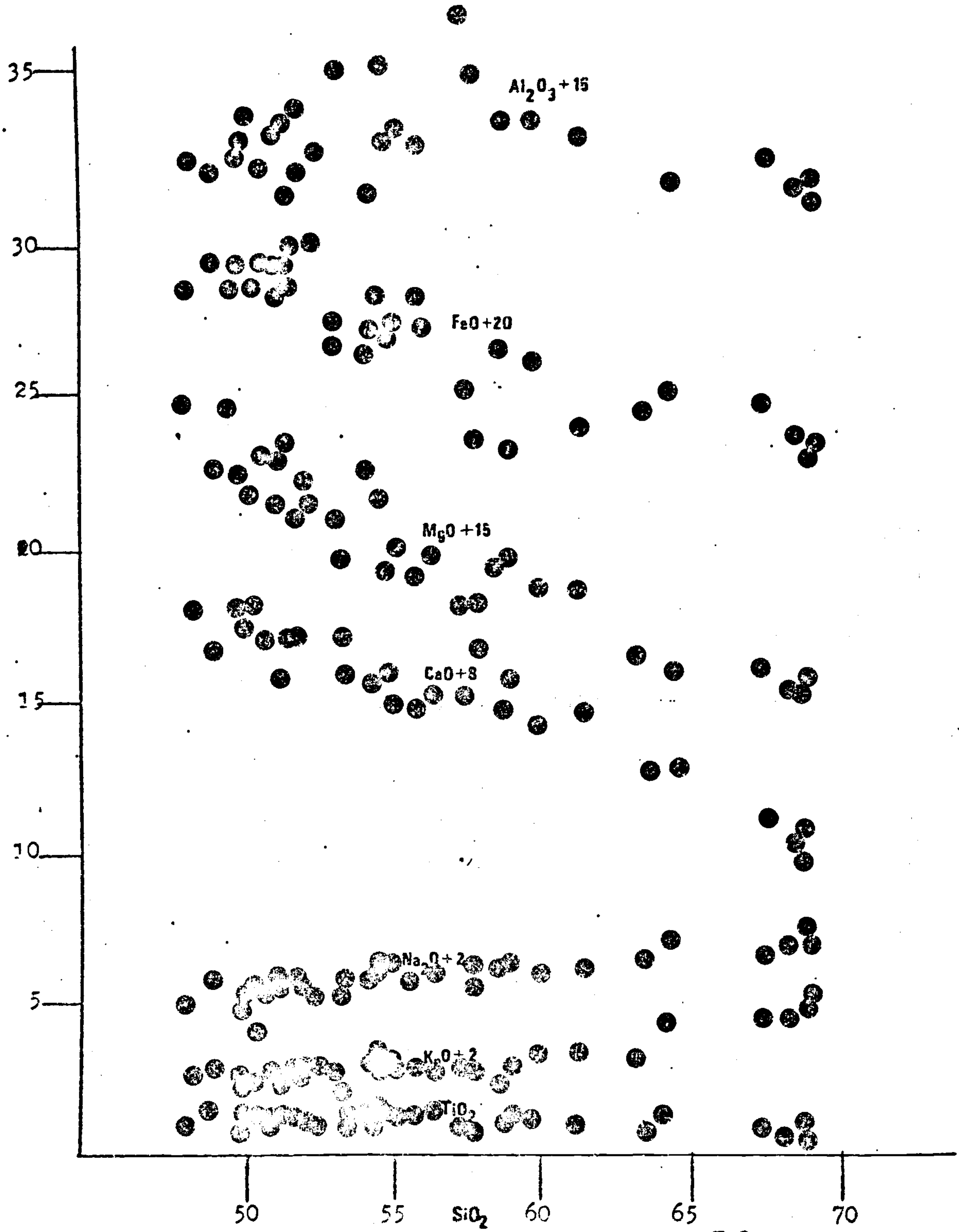

Figure 2 Silica variation diagram, all iron as FeO

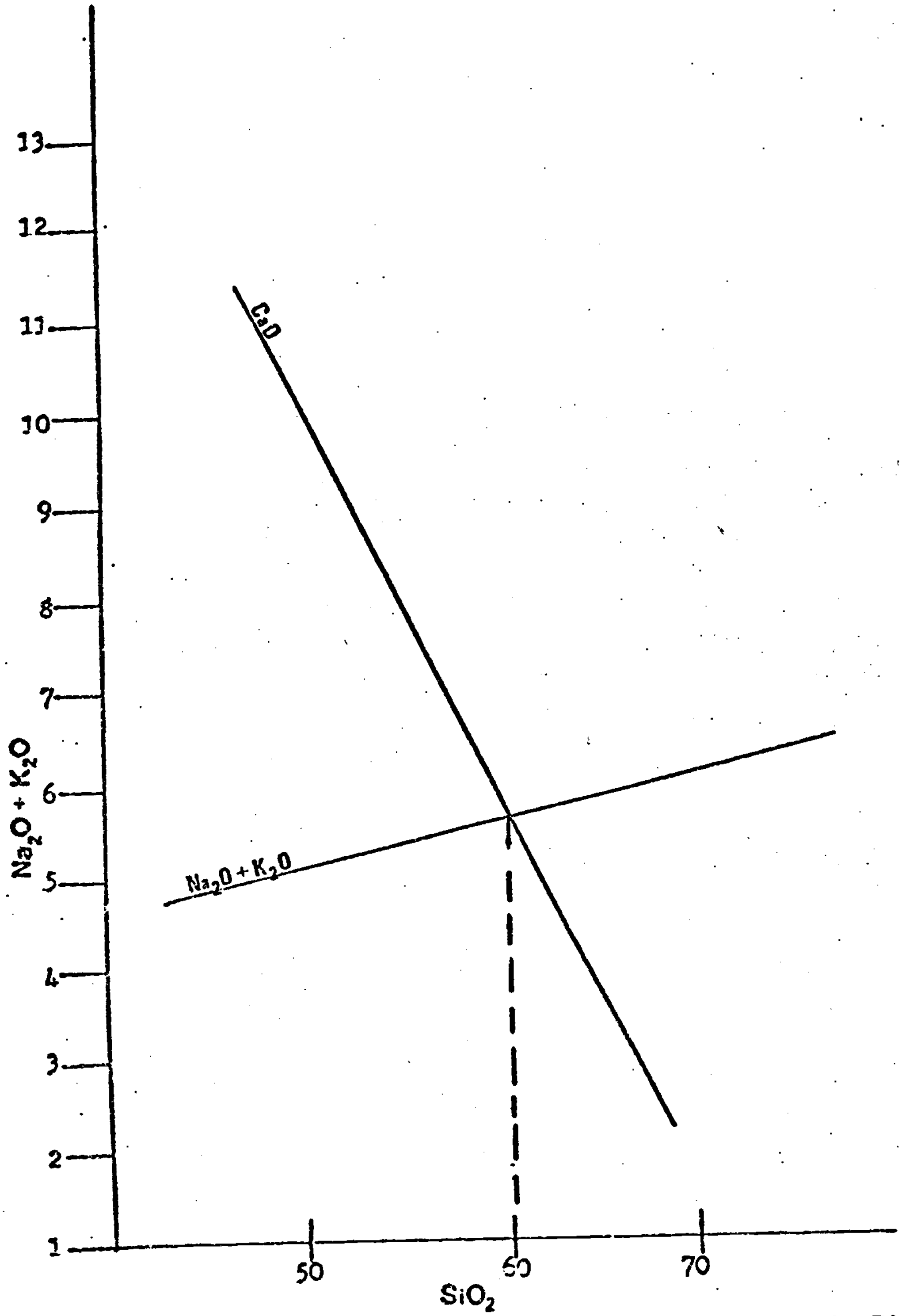

Figure 3 Peacock diagram constructed from data in Fig. 2.

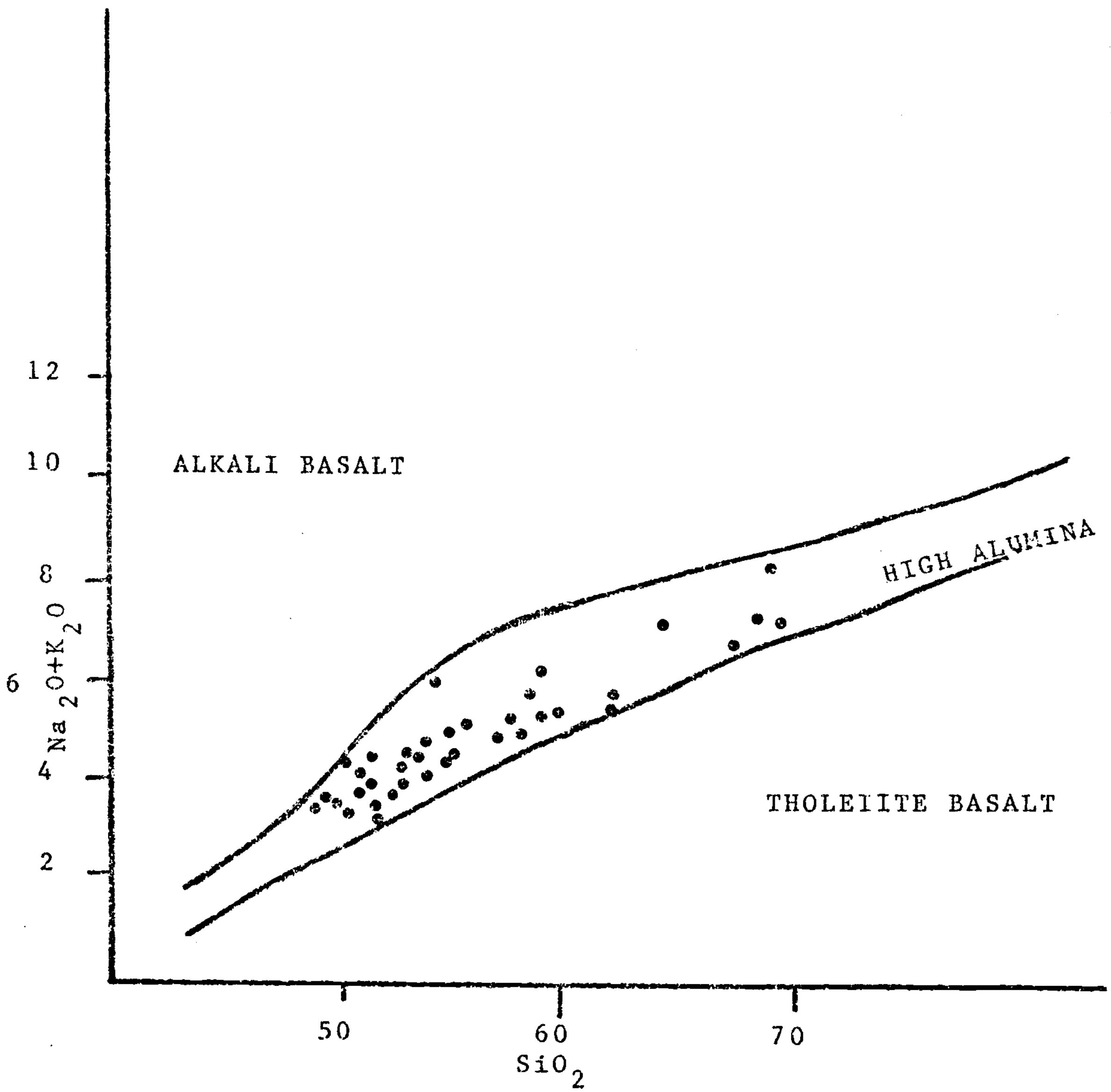

Figure 4 Basalt classification diagram, after Kuno 1966.

diagram of Kuno (1966) all analyses fall within the high alumina basalt field (Fig. 12). The variation of the metal oxides with SiO_2 for the rocks of the thesis area are displayed in Figure 13.

There is an apparent hiatus in SiO_2 values between 64 and 67 weight percent. Chemical analyses of Western Cascade rocks compiled by Peck and others (1964) show a similar hiatus in the extrusive suite between 63 and 68 weight percent. The SiO_2 values for the volcanic rocks of the High Cascades (Peck, 1964) also show this break, but it occurs at 62 to 66 weight percent.

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APPENDICES

Appendix A. Chemical analyses of Grizzly Creek Lavas.*

Sample	TR-63	TR-44	TR-17
SiO_2	51.8	50.1	55.0
Al_2O_3	16.5	18.2	17.9
FeO	10.2	8.9	7.5
CaO	9.3	10.1	8.1
MgO	7.1	6.9	5.1
K_2O	0.47	0.23	0.54
Na_2O	2.5	3.2	3.8
TiO_2	1.17	1.60	1.30
Total	99.04	99.13	99.24

TR-63 Olivine basalt: elevation 3,500 ft, N.W. 1/4 Sec. 26, T. 10 S., R. 7 E.

TR-44 Olivine basalt: elevation 2,480 ft, C. Sec. 29, T. 10 S., R. 7 E.

TR-17 Olivine bearing basaltic andesite: elevation 2,480 ft, S.E. 1/4 Sec, 33, T. 10 S., R. 7 E.

*H_2O-Free, All Iron as FeO.

Appendix B. Chemical analyses of Nan Creek Volcanics.

Sample	TR-97	TR-98	TR-90	TR-34	TR-58	TR-20
SiO_2	59.9	67.2	63.1	64.0	52.0	61.3
Al_2O_3	18.1	16.8	18.7	16.1	17.0	17.6
FeO	6.3	4.7	4.8	5.6	9.4	4.2
CaO	6.1	3.2	5.0	4.7	7.7	6.5
MgO	3.8	1.0	1.6	1.0	7.1	3.7
K_2O	1.05	2.20	0.81	2.17	0.70	1.05
Na_2O	4.0	4.5	4.5	5.0	3.7	4.2
TiO_2	0.77	0.79	0.56	1.07	1.32	0.88
Total	100.02	100.39	99.07	99.64	98.72	99.41

TR-97 Porphyritic hornblende bearing andesite: elevation 3,280 ft., C.E. 1/2 Sec. 4, T. 11 S., R. 7 E.

TR-98 Porphyritic hornblende bearing andesite: elevation 3,200 ft., C.N. 1/2 Sec. 4, T. 11 S., R. 7 E.

TR-90 Porphyritic hornblende bearing andesite: elevation 3,320 ft., N.E. 1/4 Sec. 30, T. 11 S., R. 7 E.

TR-34 Porphyritic two pyroxene andesite: elevation 3,100 ft., S.E. 1/4 Sec. 36, T. 11 S., R. 7 E.

TR-58 Porphyritic olivine basalt: elevation 4,400 ft., S.E. 1/4 Sec. 9, T. 10 S., R. 7 E.

TR-20 Porphyritic two pyroxene andesite: elevation 3,840 ft., C.N. 1/2 Sec. 32, T. 10 S., R. 7 E.

Appendix B. (continued)

Sample	TR-92	TR-93	TR-94	TR-11	TR-37
SiO_2	50.9	57.0	52.9	68.9	54.6
Al_2O_3	19.1	17.0	18.3	15.5	19.1
FeO	10.2	8.5	8.3	3.2	8.6
CaO	8.3	6.9	8.8	2.8	8.1
MgO	6.0	5.0	5.2	0.9	3.7
K_2O	0.59	1.10	0.56	2.85	0.80
Na_2O	3.5	3.6	3.70	4.7	3.7
TiO_2	1.50	1.19	1.50	1.60	1.37
Total	100.9	100.29	99.26	100.45	99.97

TR-92 Olivine Basalt: elevation 5,200 ft., N.W. 1/2 Sec. 23, T. 11 S., R. 7 E.

TR-93 Basaltic andesite: elevation 5,625 ft., C. Sec. 14, T. 11 S., R. 7 E.

TR-94 Basaltic andesite: elevation 5,400 ft., N.E. 1/4 Sec. 13, T. 11 S., R. 7 E.

TR-11 Dark glassy groundmass, dacite welded ash-flow tuff: elevation 3,380 ft., N.E. 1/4 Sec. 14, T. 11 S., R. 7 E.

TR-37 Basaltic andesite: elevation 3.920 ft., S.E. 1/4 Sec. 23, T. 10 S., R. 7 E.

Appendix C. Chemical analyses of Triangulation Peak Lavas

Sample	TR-88	TR-38	TR-46	TR-65
SiO_2	56.1	54.4	52.7	52.1
Al_2O_3	17.5	16.1	18.5	17.0
FeO	7.4	7.4	8.6	10.1
CaO	7.2	7.9	8.4	7.6
MgO	4.9	6.7	6.0	6.3
K_2O	0.90	1.36	0.55	0.75
Na_2O	4.0	4.4	3.6	3.4
TiO_2	1.02	1.17	1.38	1.08
Total	99.02	99.43	99.73	98.33

TR-88 Basaltic andesite: elevation 5,200 ft., S.E. 1/4 Sec. 10, T. 10 S., R. 7 E.

TR-38 Basaltic andesite: elevation 4, 880 ft., S.E. 1/4 Sec. 23, T. 10 S., R. 7 E.

TR-46 Basaltic andesite: elevation 4,840 ft., N.W. 1/4 Sec. 25, T. 10 S., R. 7 E.

TR-65 Basaltic andesite: elevation 5, 301 ft., Mount Bruno Summit.

Appendix C. (continued)

Sample	TR-67
SiO_2	68.2
Al_2O_3	15.9
FeO	3.6
CaO	2.4
MgO	0.7
K_2O	2.45
Na_2O	4.8
TiO_2	0.54
Total	98.59

TR-67 Porphyritic hypersthene dacite: elevation 4,800 ft., S.E. 1/4 Sec. 31, T. 10 S., R. 7 E.

Appendix D. Chemical analyses of Minto Mountain Lavas.

Sample	TR-78	TR-59	TR-62	TR-76
SiO_2	50.0	54.2	54.8	55.8
Al_2O_3	17.7	15.8	17.5	17.4
FeO	9.7	6.2	7.9	8.7
CaO	9.8	7.9	7.2	7.0
MgO	7.5	7.8	4.9	4.7
K_2O	0.17	1.38	1.15	0.90
Na_2O	3.1	3.6	4.3	3.7
TiO_2	1.32	1.10	1.18	1.34
Total	99.29	98.48	98.63	99.74

TR-78 Diktytaxitic basalt: elevation 3,760 ft., N.E. 1/4 Sec. 14, T. 11 S., R. 7 E.

TR-59 Basaltic andesite: elevation 4,080 ft., off grid system, 1/2 km east of center east boundary Sec. 13, T. 11 S., R. 7 E.

TR-62 Basaltic andesite: elevation 3,640 ft., C.S. 1/2 Sec. 14, T. 11 S., R. 7 E.

TR-76 Basaltic andesite: elevation 4,240 ft., S.E. 1/4 Sec. 11, T. 11 S., R. 7 E.

Appendix E. Chemical analyses of Pigeon Prairie Lavas.

Sample	TR-31	TR-29	TR-30	TR-23	TR-39
SiO_2	50.8	49.0	51.2	57.3	51.1
Al_2O_3	16.5	16.3	15.9	21.6	17.9
FeO	9.2	9.7	9.5	5.4	8.5
CaO	9.1	8.4	9.4	7.1	7.7
MgO	8.3	7.8	8.6	3.3	6.5
K_2O	0.54	0.80	0.70	1.00	0.70
Na_2O	3.4	3.6	3.6	4.3	3.7
TiO_2	1.59	1.43	1.70	0.96	1.04
Total	99.43	97.03	100.60	100.96	97.14

TR-31 Olivine basalt: elevation 3,040 ft., N.W. 1/4 Sec. 20, T. 10 S., R. 7 E.

TR-29 Olivine basalt: elevation 3,120 ft., N.E. 1/4 Sec. 20, T. 10 S., R. 7 E.

TR-30 Olivine basalt: elevation 2,800 ft., N.W. 1/4 Sec. 20, T. 10 S., R. 7 E.

TR-23 Porphyritic andesite: elevation 3,480 ft., S.E. 1/4 Sec. 14, T. 10 S., R. 7 E.

TR-39 Olivine basalt: elevation 2,840 ft., S.E. 1/4 Sec. 15, T. 11 S., R. 7 E.

Appendix E. (continued)

Sample	TR-40	TR-18	TR-50	TR-77
SiO_2	49.7	58.9	48.2	49.8
Al_2O_3	17.9	18.3	16.9	16.7
FeO	9.5	3.4	8.8	8.7
CaO	9.3	7.8	10.0	10.1
MgO	8.0	4.7	9.8	9.8
K_2O	0.13	0.80	0.60	0.64
Na_2O	3.3	4.2	2.8	2.7
TiO_2	1.34	1.12	0.80	0.80
Total	99.17	99.22	97.90	99.24

TR-40 Diktytaxitic basalt: elevation 3,600 ft., S.W. 1/4 Sec. 17, T. 10 S., R. 7 E.

TR-18 Porphyritic andesite: elevation 2,600 ft., S.E. 1/4 Sec. 10, T. 11 S., R. 7 E.

TR-50 Diktytaxitic basalt: elevation 3,160 ft., N.W. 1/4 Sec. 35, T. 11 S., R. 7 E.

TR-77 Diktytaxitic basalt: elevation 3,200 ft., S.W. 1/4 Sec. 25, T. 11 S., R. 7 E.

Appendix F. Chemical analyses of Intrusive Rocks.

Sample	TR-22	TR-13	TR-55	TR-84
SiO_2	53.3	57.8	53.3	68.8
Al_2O_3	19.7	19.7	17.7	16.1
FeO	6.8	3.9	7.6	3.5
CaO	9.4	8.8	8.0	1.9
MgO	4.9	3.7	6.3	0.5
K_2O	0.35	0.82	0.67	2.76
Na_2O	3.7	3.5	3.8	5.2
TiO_2	1.16	0.96	0.94	0.49
Total	99.31	99.18	98.31	99.25

TR-22 Basaltic andesite dike: elevation 3,000 ft., S.W. 1/4 Sec. 14, T. 10 S., R. 7 E.

TR-13 Basaltic andesite dike: elevation 3,160 ft., S.W. 1/4 Sec. 14, T. 10 S. R. 7 E.

TR-55 Basaltic andesite dike: elevation 3,280 ft., S.W. 1/4 Sec. 30, T. 10 S., R. 7 E.

TR-84 Hypersthene dacite plug: Spire Rock, N.W. 1/4 Sec. 11, T. 10 S., R. 7 E.