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Title: GEOLOGY OF THE WESTERN DETROIT RESERVOIR AREA, QUARTZVILLE AND DETROIT QUADRANGLES, LINN AND MARION COUNTIES, OREGON

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Cyrus W. Field

The Detroit Reservoir area is in the Western Cascade Range, as shown on U. S. Geological Survey maps of the Quartzville and Detroit quadrangles, in Linn and Marion Counties, Oregon.

Rocks exposed in the area mapped range from Middle to Late Miocene in age. They are mainly volcanic flows, pyroclastics and closely related fluviatile and lacustrine volcaniclastic sedimentary rocks of the Sardine Formation. They have been intruded by a stock of granodiorite, and smaller bodies of andesite, and mafic dikes.

The Sardine Formation within the area mapped has been subdivided informally into three members. The Lower Member consists mainly of tuffs, tuff-breccias, and intercalated andesite flows with minor volcanic sedimentary rocks. Outcrops of this member are extensive. As the base is not exposed, and with tuffs and tuff-breccias comprising the lowermost units observed, a minimum

thickness of 300 meters is inferred for the Lower Member. The Middle Member has a maximum thickness of about 370 meters and is composed of volcanic sedimentary rocks that are predominately breccias with minor interbedded conglomerates, sandstones, and mudstones. It normally overlies the Lower Member but it pinches out in some localities. The Upper Member consists of andesite flows which normally overlie the Middle Member. However, where the Middle Member has pinched out it directly overlies the Lower Member. Andesite flows of this member are fine-grained to aphanitic and many display a platy appearance. The minimum thickness ranges from 50 to 300 meters as the top of this member is not exposed in the area mapped.

Intrusive rocks include andesite as dikes and sills, granodiorite as stocks and dikes, and mafic dikes. The andesite and later granodiorite are tentatively assumed to be Middle to Late Miocene in age. The mafic dikes are Late Miocene or post-Miocene in age. Andesite and granodiorite intrude both Lower and Middle Members of the Sardine Formation. The mafic dikes intrude the Lower Member and granodiorite. Tuffaceous sedimentary rocks that border the granodiorite stocks have been subjected to weak contact metamorphism.

With respect to regional structure the thesis area is part of the eastern limb of the northeast-trending Sardine syncline. Folding probably took place in Late Miocene time after deposition of the Upper Member. This event was followed by faulting and intrusion of andesite, granodiorite, and the mafic dikes.

Pyrite of hydrothermal origin is the principal sulfide mineral found in the Detroit area. It is chiefly confined to the intrusive rocks where it occurs both as disseminations and as fracture fillings. All rocks in the area have been propylitically altered. Characteristic alteration minerals are chlorite, epidote, calcite, sericite, pyrite, quartz, and clay minerals.

Geology of the Western Detroit Reservoir Area, Quartzville and Detroit Quadrangles, Linn and Marion Counties, Oregon

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TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

LIST OF TABLES

LIST OF PLATES

GEOLOGY OF THE WESTERN DETROIT RESERVOIR AREA, QUARTZVILLE AND DETROIT QUADRANGLES, LINN AND MARION COUNTIES, OREGON

INTRODUCTION

Purpose of Investigation

The primary purpose of this research was to map the distribution of volcanic flows and pyroclastics, closely related sedimentary rocks, and plutonic units of this terrain to obtain a better understanding of stratigraphic and age relationships and geologic history of the area. A secondary effort was directed to the distribution, control, and mineralogy of sulfides and gangue minerals that were emplaced during a later phase of hydrothermal activity. With this general work as a basis, subsequent investigations may emphasize more detailed study of selected topics.

Methods of Study

Field work was conducted during August, September, and October of 1968. The geology was plotted on an enlarged portion (1:24,000) of the Quartzville and Detroit 15-minute topographic quadrangle maps, published by the U. S. Geological Survey in 1956 at the scale of 1:62,500.

Rock samples were collected from throughout the area mapped.

Laboratory work involved examination of 150 samples with the binocular microscope, and study of 48 thin sections with the petrographic microscope. Two samples of granodiorite were chemically analyzed for selected trace element constituents. Samples of granodiorite were stained to estimate the relative proportions of potassium and plagioclase feldspar. Modal analyses of 17 thin sections were made with a point counter and 1000 points were counted in each thin section.

Geographic Setting

Location and Accessibility

The thesis area is located in the Western Cascade Range of Oregon between latitudes 44° 39' 18" and 44° 44' 35" N., and between longitudes 122° 11' 32" and 122° 18' 00" W. (Plate 1). It is within Quartzville and Detroit quadrangles that cover the western part of the Detroit Reservoir area. The area is within both Marion and Linn Counties. Sardine Mountain lies immediately to the north. The area includes approximately 30 square miles which lie in sections 1-2, 11-14, 23-26, 35-36, T. 10 S., R. 4 E., and sections 4-9, 16-21, 28-32, T. 10 S., R. 5 E. It includes Detroit Dam power house (Figure 1) in the northern part and nearby topographic features such as Monument Peak, Slate Rock Mountain, and Blowout Cliff to the west, south and east of the area, respectively. Detroit and Gates are the

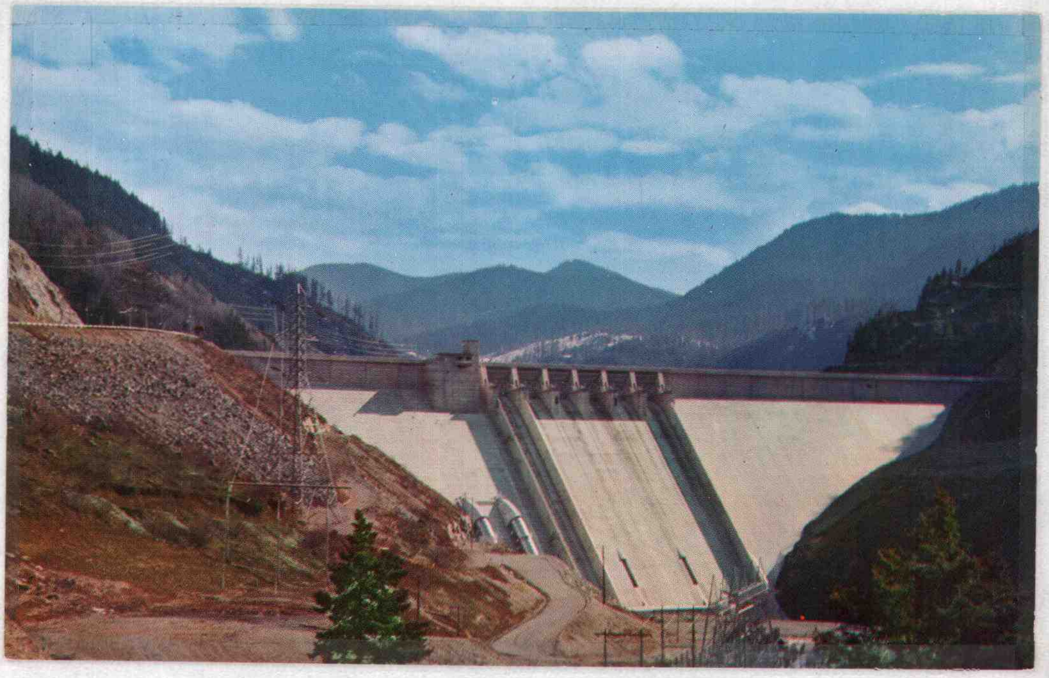

Figure 1. Detroit Dam looking east.

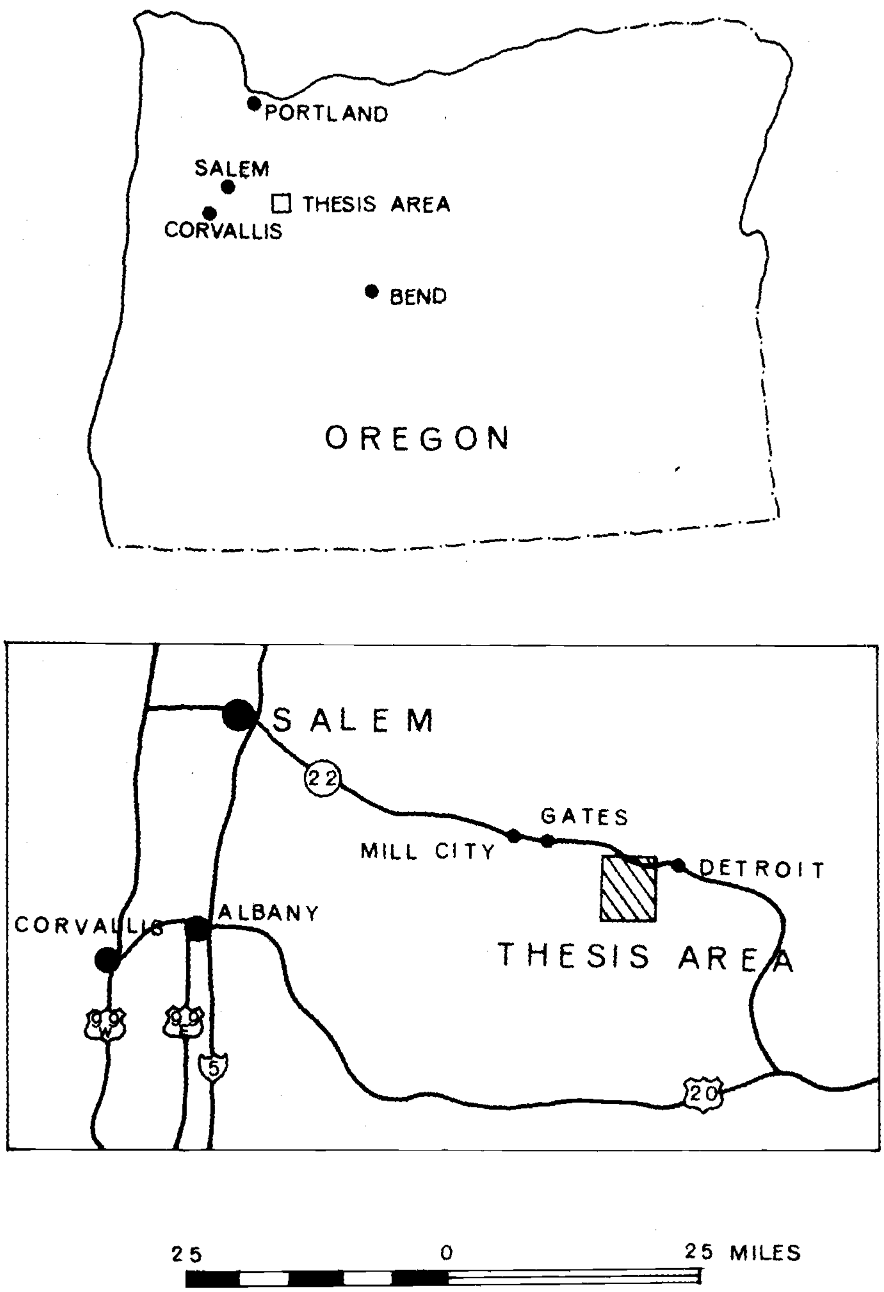

Figure 2. Index maps showing location of thesis area, nearby towns, and access.

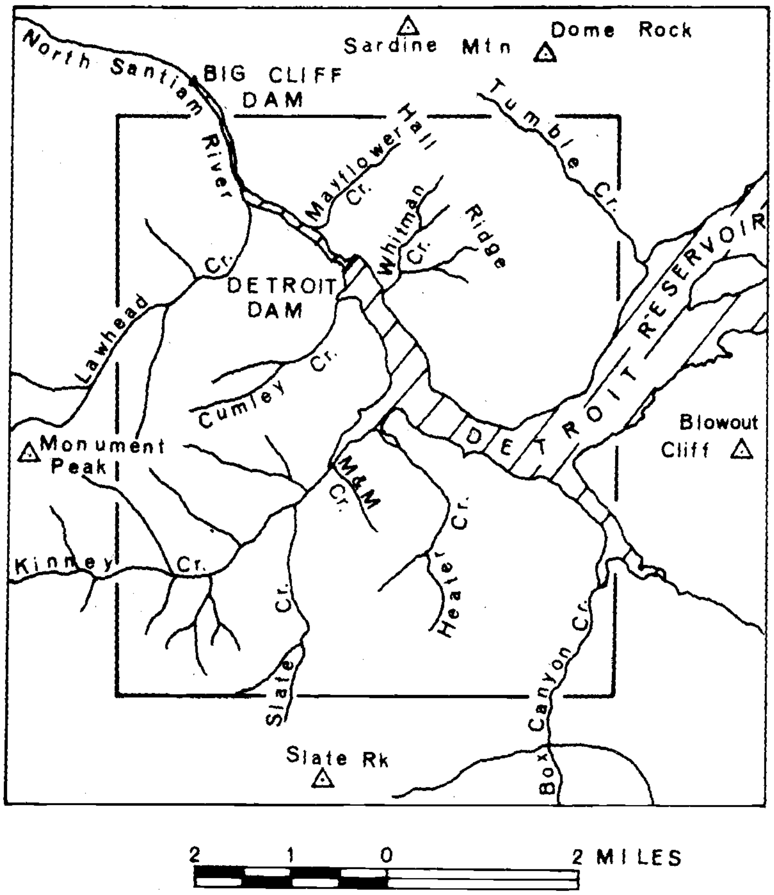

Figure 3. Generalized map showing the important geomorphic features in and around the thesis area.

two nearest towns; the former is about two miles to the east and the latter is about seven miles to the northwest (Figures 2 and 3).

State Highway 22 crosses the northern part of the area in an east-west direction. Timber roads and trails that are maintained by the Forest Service and private logging companies give access to some parts of the area.

Topography and Drainage

The area is characterized by deeply dissected topography with narrow steep-walled or V-shaped stream valleys. Maximum relief is about 4600 feet. The highest elevation is on the summit of Hall Ridge (Figure 4) near the northern boundary of the area. North Santiam River flows west and constitutes the principal through-going drainage for the area. Its valley floor is about 1200 feet above sea level (Figure 5).

The stream pattern is dendritic. The area north of North Santiam River is drained by way of Mayflower, Whitman, and Tumble Creeks. South of this river the drainage is by way of Lawhead (Figure 6), Cumley, Kinney, Slate, M & M, Heater, and Box Canyon Creeks. All of these creeks flow directly into the North Santiam River and Detroit Reservoir.

Figure 4. View to the northeast toward the southern part of Hall Ridge.

Figure 5. Oblique aerial of the North Santiam River showing meandering. View to the west. Map-area is on the northern half; Hall Ridges, middle.

Figure 6. View southwest up Lawhead Creek. The western boundary of the map-area crosses the photograph from the peak in the middle right to the northwest.

Climate

According to the climatological data reported at the Detroit Dam power house station the summer temperatures are moderately warm and range from 59° F to 68° F whereas winter temperatures are cooler and average between 37° F to 41° F. Average annual precipitation is about 70 inches; the months of highest precipitation are November, December, and January.

Vegetation

Most of the area is covered with dense forest and brush except for the steeper slopes, several peaks, and locally small areas that have been logged adjacent to roads. The vegetation cover hinders geologic field work and limits geologic observations chiefly to the road cuts, ridges, and stream valleys.

Douglas-fir and True fir are the most common trees in the area. Western hemlock and Mt. hemlock are subordinate. Vine maple, rhododendron, ceanothus, manzanita, huckelberry, bear-grass, fire weed, and salal are the associated ground species.

Previous Investigations

Previous geologic works in the Cascade Mountains of Oregon are principally regional studies of the flows, intrusive rocks, and structure. Russell (1837) was perhaps the first to suggest that part of the Cascade lavas had been folded, and that the younger volcanics lay unconformably on the older ones.

Hodge (1928) stated that there is an anticline in the valley of the South Santiam River. Steeply tilted beds of tuff in the vicinity of Detroit, on the North Santiam and Breitenbush Rivers, had been noted by Hodge and Piper (A.M., Water Resources of Willamette Valley and other unpublished reports on dam sites in files of U. S. Geol. Survey) and were mapped by Thayer (1934).

Callaghan (1933) briefly discussed the structure and stratigraphy of the Cascade Range, which he divided into the Western Cascades and High Cascades on the basis of a marked unconformity in the lava sequence. Thayer (1936) gave the name Sardine Formation to a sequence of lavas, tuffs, and breccias 4000 feet thick that are exposed on Sardine Mountain northwest of Detroit. In the North Santiam River region he subdivided the rocks into a number of formations, including the Sardine Formation, and described the regional structure. On the east limb of the Sardine syncline the formation is 10,000 feet thick. Thayer (1937) described the general petrography of the Sardine lavas. Buddington and Callaghan (1936 and 1938) described the various types of the volcanic and intrusive rocks of the Western Cascades. Thayer (1939) briefly described the geology and glaciation in the North Santiam River Basin area. Recently Peck and others

(1964) have described the stratigraphy, structure, and petrology of the volcanic rocks of the central and northern parts of the Western Cascade Range of Oregon.

GEOLOGY

Introduction

Volcanic rocks are widely exposed throughout the thesis area and range in age from Middle to Late Miocene as deduced by Thayer (1936) who named the Sardine Formation. The formation has been subdivided into Lower, Middle, and Upper Members. The Lower member consists of tuffs, tuff-breccias, andesite flows, and volcanic sedimentary rocks. It is the most widespread rock unit of the area. The Middle Member is composed of volcaniclastic sedimentary rocks that are predominately breccias with minor interbedded conglomerates, sandstones, siltstones, and mudstones. Andesite flows comprise the Upper Member.

Intrusive rocks of the area are andesites and granodiorites that occur as dikes, sills, and stocks and fine-grained mafic dikes. On the basis of geologic contacts and inferences the order of emplacement of these intrusions is believed to be andesite, granodiorite, and finally the fine-grained mafic dikes.

Sardine Formation

Lower Member

General Character, Stratigraphic Relations, and Thickness

The Lower Member consists of pyroclastics, andesite flows, and volcanic sedimentary rocks. It is extensive and covers approximately one-half of the thesis area. The minimum thickness of 300 meters is inferred. Exposures are reasonably good as they form foothills, slopes, ridges, and most of the major stream valleys.

This member constitutes the base of the local stratigraphic sequence. The Lower Member normally underlies the Middle Member of the Sardine Formation. However, where the Middle Member is absent, the Lower Member directly underlies the Upper Member.

Pyroclastic units of this member consist of tuff and tuff-breccia that are locally interbedded with andesite flows. Locally, related volcanic sedimentary rocks consist of breccias, sandstones, siltstones, and mudstones that are interbedded with the flows and tuffs. They represent minor rocks of this member.

The tuff-breccia occurs as beds, 3 to 30 cm thick, which are locally intercalated with thinner beds of fine-grained tuff, 2 to 10 cm thick, and which may grade laterally and vertically into fine tuff. Lateral extent of the thinner beds ranges from 3 to 400 meters. Disseminated pyrite is present in many outcrops.

Elsewhere the tuff, as in the NW 1/4 SW 1/4 sec. 25, T. 10 S., R. 4 E., displays nearly uniform layers 0.5 to 8.0 cm thick. This outcrop, in part, shows polygonal fractures 5 to 10 mm long on each side. The beds are deformed by a nearby andesite dike (Figure 7). In the southern part of NW 1/4 sec. 25, T. 10 S., R. 4 E., concretions that range from 1.0 to 10 cm in diameter lie parallel to tuff beds and locally show spheroidal fractures.

Attitudes of tuff beds are variable over relatively short distances. In general, the pyroclastic and sedimentary units strike northeast or northwest and have gentle dips that range from five to ten degrees. No attitudes were taken from the flows because of their irregularly jointed, and massive appearance.

Contacts between tuff and tuff-breccia are locally abrupt or they may grade laterally and vertically into one another. Contacts between the pyroclastic and sedimentary rock units and overlying andesite flows are sharp but irregular. However, the contacts are usually obscured by soil cover. Additionally, the contacts between individual flows are poorly exposed and are not discernible in the field.

Tuff and Tuff-Breccia

Distribution. The more prominent outcrops of these rocks are

Figure 7. Deformation features in Lower Member tuffs caused by intrusion of nearby andesitic dike in NW 1/4 SW 1/4 sec. 25, T. 10 S., R. 4 E.

located in the southwestern part of the area. Tuff and tuff-breccia occur at the base of the Lower Member as along the beach in the NW 1/4 sec. 19 and SE 1/4 sec. 24, T. 10 S., R. 4 E. Outcrops are found in the NW 1/4 sec. 20, T. 10 S., R. 5 E., and in secs. 25, 26, and 36, T. 10 S., R. 4 E. Good exposures are present along creek beds and road cuts.

Along Kinney Creek in sec. 26, T. 10 S., R. 4 E., tuff and tuff-breccia beds alternate with andesite flows. Sharp contacts between the tuffs and overlying andesite flows are exposed along road cuts in the NE 1/4 SE 1/4 (Figures 8 and 9) and SE 1/4 SW 1/4, sec. 24; NW 1/4 SW 1/4 sec. 25; NW 1/4 NE 1/4 sec. 36, T. 10 S., R. 4 E.; and in the NW 1/4 NW 1/4 sec. 20, T. 10 S., R. 5 E.

Lithology and Petrography. The Lower Member of the Sardine Formation contains tuffaceous units of three general types that are distinguished on the basis of grain size. They are fine and coarse-grained tuffs and a tuff-breccia.

The fine-grained tuff is generally moderately to well sorted. It is characterized by fair to high porosity, angular to subangular fragments, good induration, and non-calcareous cement. These rocks are mostly massive with the individual beds averaging about 20 cm in thickness, and display conchoidal fractures. Less commonly they are thinly bedded to laminated. The fine-grained tuff, in the SW 1/4 NW 1/4 sec. 25, T. 10 S., R. 4 E., shows liesegang

Figure 8. Lower Member andesite flows (cliff-former, about 15 meters high and 20 meters wide), overlying pyroclastics in NE 1/4 SE 1/4 sec. 24, T. 10 S., R. 4 E. Contact lies above road surface about three meters.

Figure 9. Outcrop of Lower Member andesite flows (dark color) overlying pyroclastics (light color) in NE 1/4 SE 1/4 sec. 24, T. 10 S., R. 4 E.

rings 0.25 to 2.0 mm wide that presumably formed by the diffusion of iron oxides during the supergene conditions of surficial oxidation.

The coarse-grained tuff is poorly sorted, well indurated, and is variably porous, with cavities up to 2 mm in diameter. Secondary calcite is present. Mafic rock fragments derived from andesitic lavas occur as minor constituents.

The tuff-breccia is poorly sorted and fairly well indurated. The coarser fraction consists of angular fragments of fine tuff and porphyritic andesite. The fragments range from 3.0 to 300 mm in diameter but the average size is nearer 5 mm. The matrix is fine tuff that comprises 25 to 90 percent of the rock.

On weathered surfaces the tuffaceous unit is moderate brown (5YR 4/2), light olive gray (5Y 6/2), pale red to grayish red (5R 6/2 to 5R 3/2), and dark yellowish orange (10YR 6/6) in color. On fresh surfaces the colors are grayish yellowish green (5GY 7/2), dusky yellow (5Y 6/4), dark gray (N 3) to brownish black (5YR 2/1), and grayish orange (10YR 7/4). The most common colors are grayish orange and yellowish green.

Petrographic study shows that most of the tuff is fine-grained to aphanitic and highly altered. Pyrite and limonite occur as irregular masses 0.1 to 1.0 mm in diameter and comprise 10 to 12 percent of the rock. They are associated with devitrified glass in the groundmass and commonly envelope finely crystalline grains of calcite. One sample revealed cusp-shaped glass shards under plane polarized light. The shards range from 0.1 to 1.5 mm in length and the average size is approximately 0.2 mm. They are partly devitrified and contain 50 to 65 percent glass. Phenocrysts of clinopyroxene, probably augite, 0.1 to 0.2 mm in diameter comprise up to 20 percent of the rock. They are partially replaced by epidote. Fine-grained andesite fragments that are slightly less than 1.0 mm in diameter and exhibit a pilotaxitic texture comprise less than 15 percent of the tuff. Thin-section analysis shows that the bedded tuff contains three to five percent quartz and feldspar fragments 0.1 to 0.2 mm in diameter. The matrix constitutes about 45 percent of the rock and contains devitrified glass, feldspar, limonite and hematite in decreasing order of abundance. Calcite is abnormally abundant and makes up about 40 to 50 percent of the matrix. Epidote is present up to several percent. The calcite and epidote are alteration products of feldspar and mafic minerals. Irregular stringers of limonite and hematite are present.

Thin-section analysis shows that the andesitic fragments of the coarse tuff range from 0.4 to 6.0 mm in diameter, average 3.0 mm in diameter, and make up 40 percent of the rock. The fragments contain feldspar and pyroxene that display a pilotaxitic texture. Also present are amygdules filled with chalcedony, chlorite, and inward projecting crystals of epidote. The rock contains up to 15 percent pumice fragments that are now almost completely replaced by chlorite, epidote, and calcite. The groundmass of the tuff is principally volcanic ash and contains about five percent microlites of plagioclase feldspar and crystals of pyroxene up to 0.4 mm in diameter. Numerous thin calcite veinlets were observed.

Andesite Flows

Distribution. Andesite flows that comprise the Lower Member of the Sardine Formation are exposed over 12 square miles in the northern part of the area. The flows are typically interbedded with tuffaceous units. They form ridges, stream valleys, and cliffs. Good exposures are found along valley walls, ridge crests and in the road cuts. They may occur as xenoliths of country rock, up to ten meters wide, that are engulfed by granodiorite. The andesite flows are normally confined to the upper part of the Lower Member. Evidence from several localities indicates the flows were derived from andesite sills that intrude older tuffaceous units at stratigraphically deeper levels.

Contacts between these flows and the overlying sedimentary rocks of the Middle Member are located in the SW 1/4 sec. 13; NW 1/4 SW 1/4 sec. 14; NE 1/4 NW 1/4 sec. 24; and NE 1/4 SE 1/4 sec. 36, T. 10 S., R. 4 E.; and in the SW 1/4 NW 1/4 sec. 31; SW 1/4 SW 1/4 sec. 20; and in the SE 1/4 SE 1/4 sec. 19, T. 10 S., R. 5 E.

Lithology and Petrography. The flows are porphyritic to fine-grained equigranular. On weathered surfaces the color is moderate olive brown (5Y 4/6), grayish brown (5YR 3/2), moderate brown (5YR 3/4), moderate yellowish brown (10YR 5/4), dark yellowish brown (10YR 4/2), and grayish red (5R 4/2). On fresh surfaces dark gray (N3) to medium gray (N5), dark bluish gray (5B 4/1) to light bluish gray (5B 7/1), and dark greenish gray (5GY 3/1) are the predominant colors. Platy jointing 1.0 to 3.0 cm thick is developed at several exposures.

Petrographic study reveals that the andesite flows are holocrystalline and display inequigranular, porphyritic, and pilotaxitic to subpilotaxitic textures. Amygdules up to 1.0 mm wide are common and are filled with chlorite, epidote, and smaller amounts of calcite and quartz, and minor zeolite.

The dominant phenocryst is plagioclase feldspar (An 38) which comprises 3 to 33 percent of the host rocks. The anorthite content of the plagioclase was determined chiefly by the Michel Lévy method and less commonly by the Carlsbad-Albite method. These phenocrysts occur as elongate euhedral to subhedral laths that range from 0.1 to 3.5 mm in length and average 0.5 mm in length. Many phenocrysts of plagioclase feldspar are intensely fractured. The crystals are commonly twinned according to the albite law. The plagioclase feldspar phenocrysts are partly to completely replaced by epidote, clay mineral, calcite, and chlorite as a consequence of hydrothermal alteration. Augite was found as phenocrysts in only one of six thin sections. In all other thin sections examined the augite had been completely altered to chlorite and epidote. The augite constitutes from one to slightly over three percent of the rock in which it occurs as euhedral to subhedral crystals 0.2 to 2.8 mm long. Many crystals are fractured but not to the extent displayed by phenocrysts of plagioclase feldspar.

The groundmass contains plagioclase, pyroxene, magnetite and hematite. Microlites of plagioclase average 0.1 mm in length and often show pilotaxitic texture. Apatite, the only accessory mineral recognized, is sparingly present in the groundmass. Magnetite occurs both as well-defined euhedra commonly enveloped by plagioclase feldspar and augite and also as a secondary alteration product of augite.

The andesite flows have been intensely altered by hydrothermal fluids. The principal alteration minerals are chlorite, epidote, and calcite. Additionally, numerous veinlets of quartz and chlorite 0.1 to 0.2 mm wide traverse the rock.

Table 1. Modal analysis of Lower Member andesite flow sample from NW 1/4 NE 1/4 sec. 25, T. 10 S., R. 4 E.

Mineral	Percent
Andesine	9.8
Augite	1.1
Magnetite crystal	1.2
Chlorite	1.3
Groundmass*	86.6
	100.0

*Plagioclase feldspar, pyroxene, magnetite, and hematite.

Volcanic Sedimentary Rocks

Distribution. Volcaniclastic sedimentary rocks constitute a minor constituent of the Lower Member. They occur interbedded with andesite flows and tuffs and are chiefly breccias, sandstones, siltstones, and mudstones. The best exposures are found in the southernmost part of the SE 1/4 sec. 17, T. 10 S., R. 5 E., and along the eastern slope of the north-trending ridge in sec. 25, T. 10 S., R. 4 E. These outcrops are as much as 100 meters long and up to 40 meters thick. An extensive exposure 250 meters long crops out in the SE 1/4 SW 1/4 sec. 24, and NE 1/4 NW 1/4 sec. 25, T. 10 S., R. 4 E. However, more commonly the volcanic sedimentary rocks are a slope-forming units.

Lithology and Petrography. The sedimentary rocks consist of breccias, fine-grained sandstones, siltstones, and mudstones. They are similar in general character to volcanic sedimentary rocks of the Middle Member. Breccia is the principal rock of this sedimentary unit. Locally it is intercalated with minor sandstones, siltstones, and mudstones. The rocks along the boundary of secs. 24 and 25 are laminated and exhibits various primary sedimentary structures such as load casts, shale-chips, flame structures, symmetrical ripple marks, and cut-and-fill structures (Figure 10). These features suggest both fluvial and lacustrine environments of deposition. No fossils were found in the Lower Member sedimentary rocks.

The physical appearances of the volcaniclastic sedimentary rocks are variable. The breccia is composed of angular fragments of tuff (pale blue 5B 6/2) and andesite (dark gray N3 to medium light gray N 6), that range from a few millimeters to 20 cm in diameter. They occur in a moderately to well sorted matrix of silt to coarse sand-sized grains. On fresh surfaces the sandstones are medium gray (N 5), whereas on weathered surfaces they are moderate yellowish brown (10YR 5/4) in color. Siltstones are greenish gray (5G 6/1) and the mudstones are grayish red purple (5RP 4/2), grayish red (5R 3/2), pale yellowish brown (10YR 6/2), and medium brownish gray (5YR 5/1) on fresh and weathered surfaces. The sandstones are usually fine-grained, angular to subangular, and poorly sorted.

Petrographic examination of the samples from one locality shows sharp contacts between siltstone and adjacent sandstone and mudstone. Laminations displayed by these rocks are of variable

Figure 10. Intercalated laminated tuffaceous siltstones and mudstones of Lower Member in NE 1/4 NW 1/4 sec. 25, T. 10 S., R. 4 E. showing symmetrical ripples. The white scale is 15 cm long.

thickness: 0.5 to 5.0 mm for sandstones; 0.4 mm for siltstones; and 0.2 mm for mudstones. Lithic fragments of volcanic rocks are present within the laminae.

The sandy siltstone contains about 78 percent clay and silt size matrix. The framework consists of ten percent feldspar fragments and seven percent andesite rock fragments. Limonite and carbonate act as cementing agents and compose approximately five percent of the rock. The fragments of feldspar and andesite range from 0.1 to 0.7 mm and 0.4 to 1.5 mm in diameter, respectively.

Middle Member

General Character, Stratigraphic Relations, and Thickness

The Middle Member volcanic sedimentary rocks which overlie andesite flows of the Lower Member consist predominately of breccias with subordinate conglomerates, sandstones, siltstones, and mudstones. A partial section of this volcaniclastic unit was measured (p. 31).

Sedimentary rocks of the Middle Member contain several features indicative of fluviatile-lacustrine deposition. These include (1) well preserved imprints of leaves in the fine-grained sediment of the SE 1/4 SW 1/4 Sec. 19, T. 10 S., R. 5 E. (Figure 11), (2) poorly- to well-sorted sediments, (3) cut-and-fill structures;

Figure 11. Leaf impressions in Middle Member volcanic sandstone from SW 1/4 SE 1/4 sec. 19, T. 10 S., R. 5 E.

(4) normal and reverse graded-bedding; and (5) local pinchouts of the unit in the NE 1/4 sec. 23 and S 1/2 NW 1/4 sec. 11, T. 10 S., R. 4E.

The source area for most of this sedimentary rock was a nearby volcanic terraine. Close proximity of the source area is indicated by the angular volcanic fragments in breccias, sandstones, siltstones, and mudstones. However, the presence of a smaller number of well-rounded pebbles, cobbles, and boulders of andesite, vein quartz, and quartzite suggests a more distant igneous and metamorphic source as well.

The variable attitudes of the rocks along with poor exposure make estimation of the thickness of the unit very difficult. The strike varies 160° from west-northwest to east-northeast and dips range from 2 to 24 degrees. The attitude of the rocks varies greatly over short distance. Despite these uncertainties it is possible to estimate an approximate maximum thickness of 370 meters for the Middle Member.

Although no paleontological determination have been made on the fossils, the age of the fossil leaves collected from correlative units in other localities in the Western Cascades is Middle to Late Miocene as reported by Peck and others (1964). A partial stratigraphic section of the Middle Member from which plant fossils were collected is given in Table 2.

Distribution

The poorly exposed Middle Member volcanic sedimentary rocks cover approximately five square miles of the mapped area. Exposures are in road cuts that pass through the NE 1/4 sec. 6; W 1/2 secs. 5 and 8; and NE 1/4 sec. 17, T. 10 S., R. 5 E.; in the area that lies south of Detroit Reservoir in the SW 1/4 SW 1/4 sec. 20; SE 1/4 SW 1/4 sec. 19 (Figure 12), and along the ridge in the same section; along the road cut to the south in W 1/2 secs. 30 and 31; and in the S 1/2 sec. 29; NW 1/4 sec. 32, T. 10 S., R. 5 E. Other outcrops are in the S 1/2 NW 1/4 sec. 11; NE 1/4 sec. 14; SW 1/4 sec. 13; NE 1/4 sec. 23; NW 1/4 sec. 36 and E 1/2 sec. 35, T. 10 S., R. 4 E.

Exposures of the contact between the Middle map-unit and the Upper andesite are in the SE 1/4 SW 1/4 sec. 13, T. 10 S., R. 4 E. (Figure 13); E 1/2 NW 1/4 sec. 36, T. 10 S., R. 4 E.; along the saddle in the SW 1/4 NW 1/4 sec. 36 and SE 1/4 sec. 35; NE 1/4 NE 1/4 sec. 23 and SW 1/4 sec. 14, T. 10 S., R. 4 E., and in the SE 1/4 SW 1/4 sec. 30, T. 10 S., R. 5 E. The nature of the contacts is usually masked by covering soil but a few exposures that were found show that the contacts are seldom sharp.

Figure 12. Outcrop of Middle Member volcanic sedimentary rocks in the southwest corner of SE 1/4 sec. 19, T. 10 S., R. 5 E.

Figure 13. Contact between Middle Member rocks (below) and overlying Upper Member andesite flows in SW 1/4 SE 1/4 sec. 13, T. 10 S., R. 4 E.

Lithology and Petrography

The breccias of the Middle Member of the Sardine Formation are composed of angular fragments which range from 0.6 to 15 cm in thickness and are set in a fine to coarse-grained sand matrix. The clasts of the breccia are mainly dark gray to brownish gray, fine-grained to porphyritic andesite, and light gray to greenish brown tuff. The matrix, which makes up as much as 70 percent of the rock, is composed of feldspar, pyroxene, limonite, hematite, and rock fragments. The color of matrix is grayish red (5R 4/2) to greenish gray (5G 6/1) on fresh surfaces. Weathered surfaces are moderate brown (10YR 4/2) to dark yellowish brown (5YR 3/4). The cementing material is feldspar and quartz. Outcrops are normally massive, but intercalated beds of sandstone and siltstone one to three meters thick are found locally. Several of the outcrops display spheroidal weathering (Figure 14).

The conglomerates of the Middle Member consist mainly of well rounded pebbles, cobbles, and boulders that are composed of andesite, minor tuff, and rare quartzite and quartz. They are set in a medium to coarse- sand sized matrix. The color and mineralogical composition of the matrix are similar to those of the breccia. The conglomerates are usually found associated with breccia and less commonly with sandstone, siltstone, and mudstone.

Figure 14. Spheroidal weathering of Middle Member volcanic sedimentary breccia in NE 1/4 NE 1/4 sec. 6, T. 10 S., R. 5 E. Granodiorite dike at the left.

The fine- to coarse-grained sandstones of this member commonly range from 5 to 7 cm in thickness (locally up to three meters) they are frequently intercalated with siltstone and mudstone and to a lesser extent with breccia. In the SW 1/4 NW 1/4 sec. 11, T. 10 S., R. 4 E. the contacts between beds sometimes display cut-and-fill structure. In addition to color the following features define variations in the general character of these sandstones: angular or less commonly subangular grains; poor to moderate sorting with occasional well sorted samples; quartz and feldspathic or locally slightly calcareous cement; good induration; low porosity; fossiliferous units of fine-grained sandstone that are intercalated with siltstone and mudstone; and local spheroidal weathering. On fresh surfaces, the sandstones are greenish gray (5G 6/1), grayish green (10GY 5/2), to grayish red (5R 3/2), but are weathered to yellowish brown (10YR 3/2) and moderate brown (5YR 3/4).

Megascopic and microscopic study of the sandstones show that they are composed of the following framework materials: 30 percent clinopyroxene and plagioclase; 10 to 15 percent andesite rock fragments and minor tuff fragments. About 15 percent calcite and limonite act as cementing agents. The very fine matrix is composed of silt and clay that comprises 40 percent of the rock. Feldspar fragments are altered to clay minerals, calcite, and epidote and the pyroxene is altered to chlorite and epidote. The fragments of the framework range from 0.1 to 1.0 mm in diameter.

The siltstones and mudstones are usually interbedded with or lense out into one another. On fresh and weathered surfaces the siltstone is yellowish brown (10 YR 5/4) and blackish red (5R 2/2) to medium brownish gray (5YR 5/1), while the mudstone is blackish red (5R 3/2). Both siltstones and mudstones are thinly laminated and the siltstones are somewhat thicker. The siltstones are moderately to poorly sorted whereas the mudstones are well sorted. Locally, concretions that range from 0.5 to 10 cm in size have been found in these rocks. Both rock types also contain fossil leaves that are preserved as thin films on bedding planes.

Upper Member

General Character, Stratigraphic Relations, and Thickness

The andesite flows of the Upper Member of the Sardine Formation cover approximately 3.5 square miles of the thesis area. Because of their resistant nature they form peaks and ridges (Figure 15). Most of these rocks are fine-grained to aphanitic and many exhibit a platy appearance (Figure 16). Weathering causes them to appear porphyritic. The upper surfaces of the flows are commonly vesicular. Platy jointing in which the rock breaks into thin slabs 0.2 to 2.0 cm wide is predominant. Vertical jointing that displays a crude columnar pattern is locally present. Joint sets trend from N. 87° W.

Figure 15. Upper Member andesite flows that forms ridge overlying Middle Member volcanic sedimentary breccia in SW 1/4 NW 1/4 sec. 36, T. 10 S., R. 4 E.

Figure 16. Upper Member andesite flows in NW 1/4 SE 1/4 sec. 14, T. 10 S., R. 4 E. showing platy jointing.

to N. 55° E. and the northwesterly strikes are more common. Dips range from 20° to 75° to the southwest although a few are to the northeast. Attitudes of flows could not be determined because of the irregular appearance and intricate jointing of most outcrops.

As the top of this member is not exposed in the area mapped the minimum thickness of the flows as deduced from their areal distribution varies from 50 to 300 meters if it is assumed that the flows are nearly horizontal or gently dipping. Dips obtained from outcrops of nearby sedimentary rocks suggest that this assumption is valid.

Distribution

The flows are completely limited to ridges in the thesis area. For example, they cap Hall Ridge in the northeastern part and peaks and ridges in the northwest, west, southwest, and south-central parts of the map-area.

Lithology and Petrography

The andesites have weathered to dusky brown (5YR 2/2), grayish brown (5YR 3/2), moderate brown (5YR 3/4), dark yellowish brown (10YR 4/2), or medium dark gray (N4) whereas on fresh surfaces they are greenish gray (5GY 6/1) to dark gray (N3) or black (N1) in color.

Petrographic examination reveals that the andesites of the Upper Member have a holocrystalline, microporphyritic, pilotaxitic to subpilotaxitic texture. Modal analyses for three andesite samples are given in Table 3. Phenocrysts of andesine (An 43) range from 0.2 to 1.0 mm in length and they are commonly zoned. Some crystals are almost completely replaced by quartz and iron oxides and only relicts of the original mineral remain. Pyroxene as augite or hypersthene occurs as phenocrysts ranging from 0.4 to 2.8 mm in diameter. The groundmass consists of plagioclase feldspar microlites, pyroxene, and magnetite, and is more altered than the phenocrysts. Magnetite occurs as primary euhedral crystals in the groundmass. They may be partly embedded in plagioclase and pyroxene crystals and yet they display no reaction rim borders. Magnetite is also present as an alteration product of the pyroxenes. Chlorite, epidote, calcite, and clay minerals constitute other secondary minerals in the andesites. Amygdules, up to 2 mm wide, are filled with quartz and magnetite.

Table 3. Modal analyses of three Upper andesites.

Mineral	1	2	3
Andesine	5.1	6.0	13.7
Augite	7.2	-	3.6
Hypersthene	0.6	1.1	-
Magnetite crystal	-	-	2.3
Groundmass*	87.1	92.9	80.4
	100.0	100.0	100.0

1. Andesite from NW 1/4 SE 1/4 sec. 14, T. 10 S., R. 4 E.
2. Andesite from NE 1/4 NW 1/4 sec. 36, T. 10 S., R. 4 E.
3. Andesite from NW 1/4 NE 1/4 sec. 6, T. 10 S., R. 5 E.

* Plagioclase feldspar, pyroxene, and magnetite

Intrusive Rocks

Intrusive rocks include andesite, granodiorite, and small mafic bodies that form stocks, sills and dikes. Because the sills and dikes are small (less than ten meters wide) their sizes as plotted on the map are exaggerated. The probable ages of the andesite and later granodiorite are tentatively assumed to be Middle to Late Miocene in age, whereas that of the mafic dikes are probably Late Miocene or post-Miocene in age.

Andesite Intrusives

General Character, Relative Age, and Distribution. Andesite intrusives that form dikes and sills have been emplaced into the Middle and Lower Members of the Sardine Formation. Field relationships indicate that the intrusives were emplaced contemporaneously or shortly after deposition of the Middle and Upper Members. Platy jointing that forms thin sheets approximately 5.0 mm thick is particularly common.

Andesite sills intrude the Middle Member of the Sardine Formation in three localities: along the boundary line of sec. 19, the

SE 1/4 NW 1/4 sec. 29 (Figure 17), and the SW 1/4 SW 1/4 sec. 30, T. 10 S., R. 5 E. They range from 30 to 300 meters in length and from 1.5 to 2.0 meters in thickness. Contacts with the country rocks are sharp and undulatory. The only thermal effect noted along contacts is the baking of underlying sediments to a brownish red color. These sills may change to dikes over short distances.

The dikes vary from 3 to 200 meters in length and are up to 20 meters or more in thickness. Soil cover makes it impossible to trace them great distances. The dikes are confined to the southern half of thesis area with the exception of one in NE 1/4 NE 1/4 sec. 6, T. 10 S., R. 5 E.

Lithology and Petrography. Weathered surfaces of andesite sills and dikes are dusky brown (5YR 2/2), grayish brown (5YR 3/4), pale brown (5YR 6/2), or dark yellowish brown (10YR 4/2) to pale yellowish brown (10YR 6/2) in color. Fresh surfaces are dark gray (N3), medium bluish gray (5B 6/1), greenish gray (5G 5/1), or olive gray (5Y 4/1) to brownish gray (5YR 3/1) in color.

The texture of most andesites is porphyritic with feldspar and pyroxene phenocrysts that range from 1 to 4 mm in diameter. The groundmass is fine-grained to aphanitic. A few intrusives

Figure 17. Andesite sill (light color) intruding volcanic sedimentary rocks of Middle Member in SE 1/4 NW 1/4 sec. 29, T. 10 S., R. 5 E.

are nonporphyritic. The andesites are holocrystalline and many display a subpilotaxitic texture. Plagioclase phenocrysts are andesine (An 48) and many are zoned and enclose magnetite. They are euhedral to subhedral in shape and range from 0.3 to 3.5 mm in length. The plagioclase feldspar is variably altered to epidote and clay minerals. Pyroxene phenocrysts of hypersthene and augite are euhedral to subhedral in shape, 0.2 to 3.0 mm in length, and are replaced by chlorite, epidote and magnetite. Augite commonly shows well defined basal sections and twinning is common. Hornblende was observed as subhedral phenocrysts in one thin section. It is almost completely altered to chlorite. Magnetite, ranging from microcrystalline to one mm in diameter, occurs as both primary crystals and as a secondary replacement of plagioclase and pyroxene. Amygdules, 0.5 to 1.5 mm wide, are not uncommon in the andesite and contain chlorite and quartz. The groundmass consists of plagioclase feldspar, occasionally as microlites, pyroxenes, magnetite and hematite. Modal analyses of five intrusive andesites are given in Table 4.

Table 4. Modal analyses of andesite intrusive samples.

Mineral	1	2	3	4	5
Andesine	30.8	32.0	32.9	33.6	21.9
Augite	0.2	6.2	1.5	4.3	-
Hypersthene	-	5.0	-	-	1.7
Hornblende	-	-	-	0.5	-
Magnetite	-	1.8	7.3	11.9	-
Chlorite	-	-	6.6	7.6	-
Epidote	-	-	-	1.8	0.5
Groundmass*	68.3	55.0	51.7	40.3	70.8
Cavities	0.7	-	-	-	1.4
	100.0	100.0	100.0	100.0	100.0

1. Andesite from NE 1/4 NW 1/4 sec. 24, T. 10 S., R. 4 E.
2. Andesite from NE 1/4 SE 1/4 sec. 31, T. 10 S., R. 5 E.
3. Andesite from SE 1/4 SW 1/4 sec. 24, T. 10 S., R. 4 E.
4. Andesite from SE 1/4 SW 1/4 sec. 19, T. 10 S., R. 5 E.
5. Andesite from SE 1/4 NE 1/4 sec. 24, T. 10 S., R. 4 E.

* Plagioclase feldspar, pyroxene, magnetite, and hematite

Granodiorite

The granodiorite intrusive was called the Halls Diorite Porphyry by Thayer (1939, p. 10) who described it as follows: ". . . . the rock of the main mass varies from a fine-grained almost white porphyry containing hornblende and plagioclase phenocrysts . . . ." Peck and others (1964, p. 4) described this stock as a granodiorite. The author of this thesis agrees with the latter classification.

Distribution and Topographic Expression. Exposures of granodiorite occur along the valley wall of the north bank of North Santiam River in the S 1/2 sec. 1, T. 10 S., R. 4 E., and secs. 6, 7, (Figure 18) 16 and 17, T. 10 S., R. 5 E. South of the main river the granodiorite crops out in the S 1/2 sec. 1, NE 1/4 sec. 12; W 1/2 sec. 7; sec. 18; and E 1/2 sec. 21, T. 10 S., R. 5 E. Along the lower course of Lawhead Creek in the NW 1/4 sec. 12, T. 10 S., R. 4 E. the granodiorite is barely exposed above the valley floor. In the E 1/2 sec. 13, east central-part of sec. 24, and SW 1/4 SE 1/4 sec. 25, T. 10 S., R 4 E.; in the NE 1/4 NE 1/4 sec. 6; W 1/2 sec. 19, N 1/2 sec. 20; N 1/2 sec. 30; E 1/2 SE 1/2 sec. 28 and NW 1/4 NW 1/4 sec. 32, T. 10 S., R. 5 E., the granodiorite is exposed as small outcrops, not greater than 30 meters in

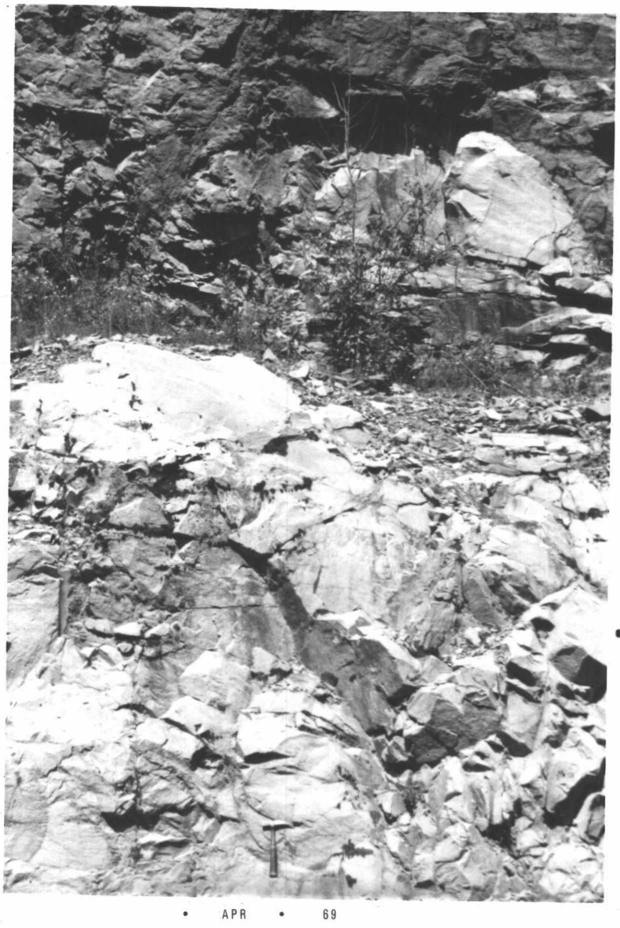

Figure 18. Granodiorite (below, light color) contact with Lower Member andesite flows (above, dark color) in NW 1/4 SW 1/4 sec. 7, T. 10 S., R. 5 E.

width, and as predominantly northwest-trending dikes that are traceable along the stream courses. Where dikes are found, and with the exception of the stock lying in the sec. 18, T. 10 S., R. 5 E., they are closely spaced (0.5 to 10 meters apart) with layers of andesite country rock separating them. This feature is particularly well displayed in the NW 1/4 NW 1/4 sec. 19 and the head of M & M Creek in the NW 1/4 sec. 30, T. 10 S., R. 5 E. Although no outcrops were found the presence of granodiorite float indicates that this rock lies immediately below the soil cover in two small areas near the southern boundary of sec. 12, T. 10 S., R. 4 E. A dike eight meters in width, in the NE 1/4 NE 1/4 sec. 6, T. 10 S., R. 5 E. (Figure 19), stands in bold positive relief about two meters above the intruded sedimentary rock. Dikes along the creeks form steep valley walls.

The stock that lies in sec. 18, T. 10 S., R. 5 E. (Figure 20), is elongate in form north-trending, and rises about 800 feet above reservoir level to an altitude of 2400 feet. Jointing developed in this granodiorite strikes predominantly west-northwest to north-northwest and dips about 70° SW. Another jointing direction that is less well developed trends east-northeast to north-northeast and dips 70°-80° to the northwest.

Lithology and Petrography. The granodiorite is fine to medium-grained and may be equigranular to porphyritic in texture. Locally it is brecciated. The fine-grained phase occurs locally

Figure 19. Granodiorite dike about eight meters wide cutting Middle Member breccia in NE 1/4 NE 1/4 sec. 6, T. 10 S., R. 5 E.

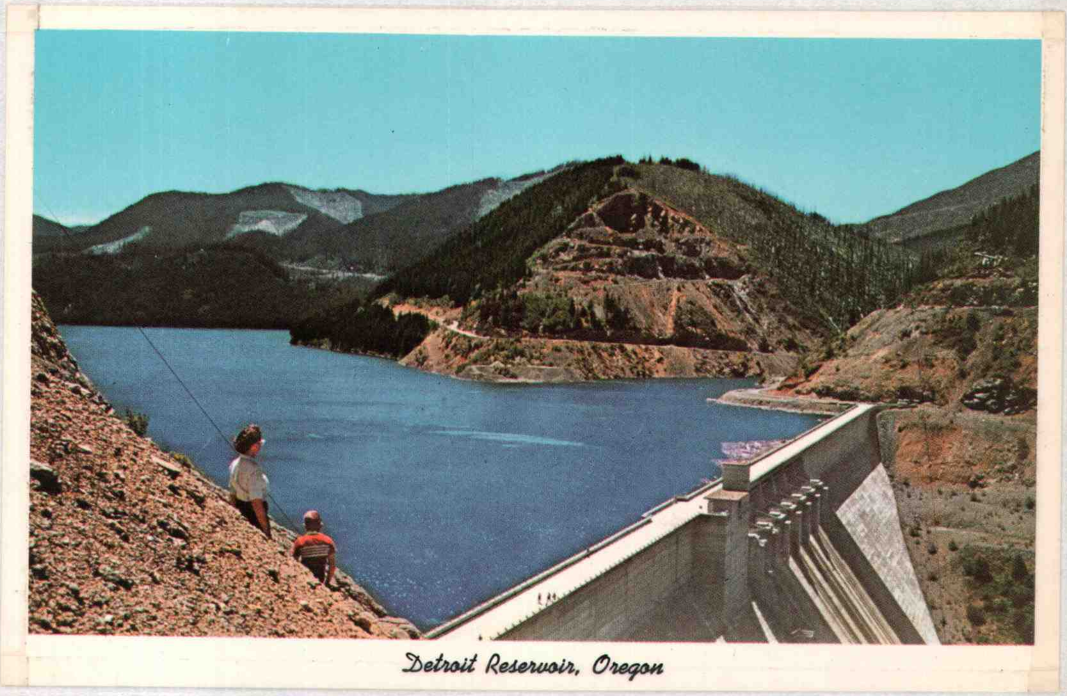

Figure 20. Looking south toward granodiorite stock of sec. 18, T. 10 S., R. 5 E. (center of figure).

in contact zones that are usually less than 1.0 meter wide. Here, andesite is the country rock and the fine-grained granodiorite probably represents a chilled margin or border facies of the main pluton.

An intrusion breccia is present along the contacts. It consists of angular fragments of dark fine-grained to porphyritic andesite. Fragments range from a few millimeters up to 15 millimeters in size and they are set in matrix of light-colored granodiorite. This breccia weathers to moderate brown (5YR 3/4) color but on fresh surfaces it is light bluish gray (5B 6/1).

Leucocratic to mesocratic, medium-grained granodiorites weather to grayish brown (5YR 4/2), moderate brown (5YR 4/4), and moderate yellowish brown (5Y 6/2) colors. The fine-grained granodiorites are dark yellowish brown (10YR 4/2) to grayish orange (10YR 7/4) in color on weathered surfaces whereas on fresh surfaces that are light medium bluish gray (5B 6/1), medium gray (N5), or light gray (N7).

The texture of the rock is largely porphyritic. However, equigranular varieties with crystals averaging two to three millimeters in diameter are also present. The porphyritic rocks contain phenocrysts, plagioclase and hornblende, 1.0 to 4.0 mm long, in a fine-grained groundmass. Chlorite and epidote may be seen in some hand specimens. Locally pyrite is found disseminated or as fillings on fractured surfaces.

Petrographic study indicates that granodiorite is holocrystalline, porphyritic, and highly altered. Plagioclase feldspar phenocrysts are 1.0 to 3.0 mm long. They are andesine (An 42) and a few phenocrysts are zoned. The plagioclase feldspar phenocrysts have been largely altered to clay minerals, epidote and calcite. Some replacement by potassium feldspar may have occurred. Hornblende is present as tabular crystals up to 2.0 mm in length. The crystals have been partly to completely replaced by epidote and pennine (chlorite). The fine-grained groundmass consists predominately of anhedral orthoclase and quartz crystals and rarely zircon as euhedral crystal is also present. The presence of abundant orthoclase feldspar was confirmed by using the staining method of Williams (1960). Euhedral apatite is occasionally found in the groundmass as an accessory mineral. Magnetite crystals occur as inclusions in both hornblende and andesine and as reaction rims that envelope the hornblende. This latter occurrence suggests a secondary or late magmatic origin.

All granodiorite dikes have the porphyritic texture described above. The dikes are 1.0 to 5.0 meters wide. Thin section examinations indicate that they have been intensely altered to chlorite and epidote and lesser amounts of calcite and sericite. Sphene, 1.8 mm long, was noted in one sample.

The equigranular granodiorites have hypidiomorphic-granular and myrmekitic textures. Andesine and hornblende crystals range up to 3.5 mm in length and average about 0.5 mm. The andesine is euhedral whereas the hornblende is subhedral. Quartz and orthoclase are found as interstitial masses 0.4 to 0.5 mm in diameter. Modal analyses of seven granodiorite samples are given in Table 5.

Contact Rocks. Country rocks within a zone 0.5 to 40.0 meters wide have locally undergone mild contact metamorphism during the emplacement and cooling of the granodiorite stock. They are fine-grained, bluish gray (5B 6/1) to dark gray (N3) on fresh surfaces and moderate brown (5YR 4/4) on weathered surfaces. Along fracture surfaces a coating of pyrite is ubiquitous. The rocks are composed of angular fragment of quartz, and untwinned plagioclase feldspar that range from 0.1 to 0.3 mm in diameter. These fragments are set in fine-grained matrix of quartz, hematite, and sericitized feldspar. No orientation of fragments can be seen. They possibly represent tuffaceous sediment that was originally deposited as lenses near the andesite flows. Locally, the contact zone displays horizontal columnar jointing and the rock disintegrates with weathering into small blocks of 5 to 15 cm in size.

Table 5. Modal analyses of granodiorite samples.

Mineral	1	2*	3	4	5	6*	7
Plagioclase	23.3	24.4	36.2	5.9	16.0	59.7	64.7
Hornblende	-	-	-	8.7	5.5	19.2	11.5
Quartz	2.0	-	1.6	0.4	-	5.1	7.1
Orthoclase	-	-	-	-	-	13.8	10.2
Magnetite	9.5	3.1	-	7.0	1.7	-	0.2
Pennine	8.1	12.3	-	-	-	-	-
Chlorite	-	-	6.9	6.0	2.3	2.2	4.3
Epidote	-	2.6	5.3	6.7	2.2	-	2.0
Groundmass**	57.1	57.6	50.0	65.3	72.3	-	-
	100.0	100.0	100.0	100.0	100.0	100.0	100.0

1. Dike from NE 1/4 NE 1/4 sec. 30, T. 10 S., R. 5 E.
2. Altered rock from SW 1/4 SW 1/4 sec. 18, T. 10 S., R. 5 E.
3. Dike from NW 1/4 SW 1/4 sec. 19, T. 10 S., R. 5 E.
4. Near contact from NE 1/4 sec. 7, T. 10 S., R. 5 E.
5. Stock from SE 1/4 sec. 7, T. 10 S., R. 5 E.
6. Stock from NW 1/4 NW 1/4 sec. 17, T. 10 S., R. 5 E.
7. Stock from NW 1/4 SW 1/4 sec. 7, T. 10 S., R. 5 E.

* with chemical analyses

** Orthoclase, quartz, and other accessory minerals

Relative Age and Correlation. As originally noted by Thayer (1936 and 1939), the granodiorite has intruded into the Sardine lavas and, thus, may be late Middle to Late Miocene in age. It is petrologically very similar to the Snoqualmie granodiorite in the Washington Cascades that is considered to be Late Miocene in age.

Howard Jaffe, of the U. S. Geological Survey, 1959, made a lead-alpha age determination of zircon from a sample of the granodiorite, collected from the SE 1/4 sec. 7, T. 10 S., R. 5 E. Jaffe reported an age of 23 million years or Late Miocene (post Sardine series or pre-Pliocene in age).

Professor M. Fuller (personal communication, 1968), Department of Earth and Planetary Sciences, University of Pittsburgh reported the following feature about the relict magnetism of the stock:

> . . . we did notice a systematic difference between the direction of magnetization on the two sides of the dam. We think that either there has been relative movement between these two sides or there are two intrusions. . .

On the basis of the study of this intrusive, there may be two different granodiorite intrusives in the area or possibly due to different time of consolidation of the same magma. In the SW 1/4 SW 1/4 sec. 7, T. 10 S., R. 5 E., leucocratic granodiorite cut across the mesocratic one is found in the road quarry. However, the field work conducted by the author did not disclose their presence.

The author accompanied Professor Edward M. Taylor and students on a field trip to this area in April 1969. Magnetic polarization studies of the granodiorite conducted at this time revealed what are believed to be significant variations within this pluton. The magnetic polarization was too weak to distinguish normal or reversal polarity for the dike in the NW 1/4 NW 1/4 sec, 19, T. 10 S., R. 5 E., weak and normal for the stock in the NW 1/4 SW 1/4 sec. 7, T. 10 S., R. 5 E., and strong and normal for the stock in the SE 1/4 sec. 7, T. 10 S., R. 5 E. This evidence suggests that the stock in the SE 1/4 sec. 7 cooled at a different time than both the dike and the stock at the other locations.

Mafic Dikes

The mafic dikes are later than granodiorite. They are 1.0 to 1.5 meters wide, strike N. 30° to 40° W., and dip vertically. What is probably the same dike cuts across both the tuff-breccia in the SW 1/4 NW 1/4 sec. 19 and a granodiorite dike in the NW 1/4 SW 1/4 sec. 19, T. 10 S., R. 5 E. Mafic dikes are also found in the NE 1/4 NW 1/4 sec. 30, T. 10 S., R. 5 E.

They are dark yellowish brown (10YR 4/4) to moderate yellowish brown (5YR 4/4) in color on weathered surfaces and light olive gray (5Y 4/2) on fresh surfaces (?). Megascopic study reveals that they are fine-grained and are composed of an abundant greenish gray mineral (possibly pyroxene or olivine), feldspar, and hematite as an accessory constituent. Vesicles ranging from 0.05 to 0.2 mm in diameter are common.

STRUCTURE

Principal Structural Features of the Region

Thayer (1936) described the structure of the North Santiam River section of the Cascade Mountains in Oregon as follows:

> . . . The Western Cascades consist of a thick mass of volcanic rocks of various types. These rocks have been compressed into a series of gentle folds trending northeast-southwest, the folding being more intense toward the southeast. The folds, in sequence from west to east, are the Willamette syncline, Mehama anticline, Sardine syncline, and Breitenbush anticline. All apparently plunge toward the northeast. The eastern limit of the Western Cascades is probably determined by the Cascade fault which cuts off the eastern limb of the Breitenbush anticline . . .. (Figure 21).

Peck and others (1964) noted that Sardine syncline is a north striking, doubly plunging syncline. The trace of the Sardine syncline axis passes through the eastern part of the mapped area.

Folding

Regional study of the Western Cascade range shows that folding in the area investigated probably took place in Late Miocene time. This deformation produced the Sardine syncline.

A complete description of the major folding within the thesis area is beyond the scope of the report because of poor exposures and lack of reliable attitudes because of appreciable variations over

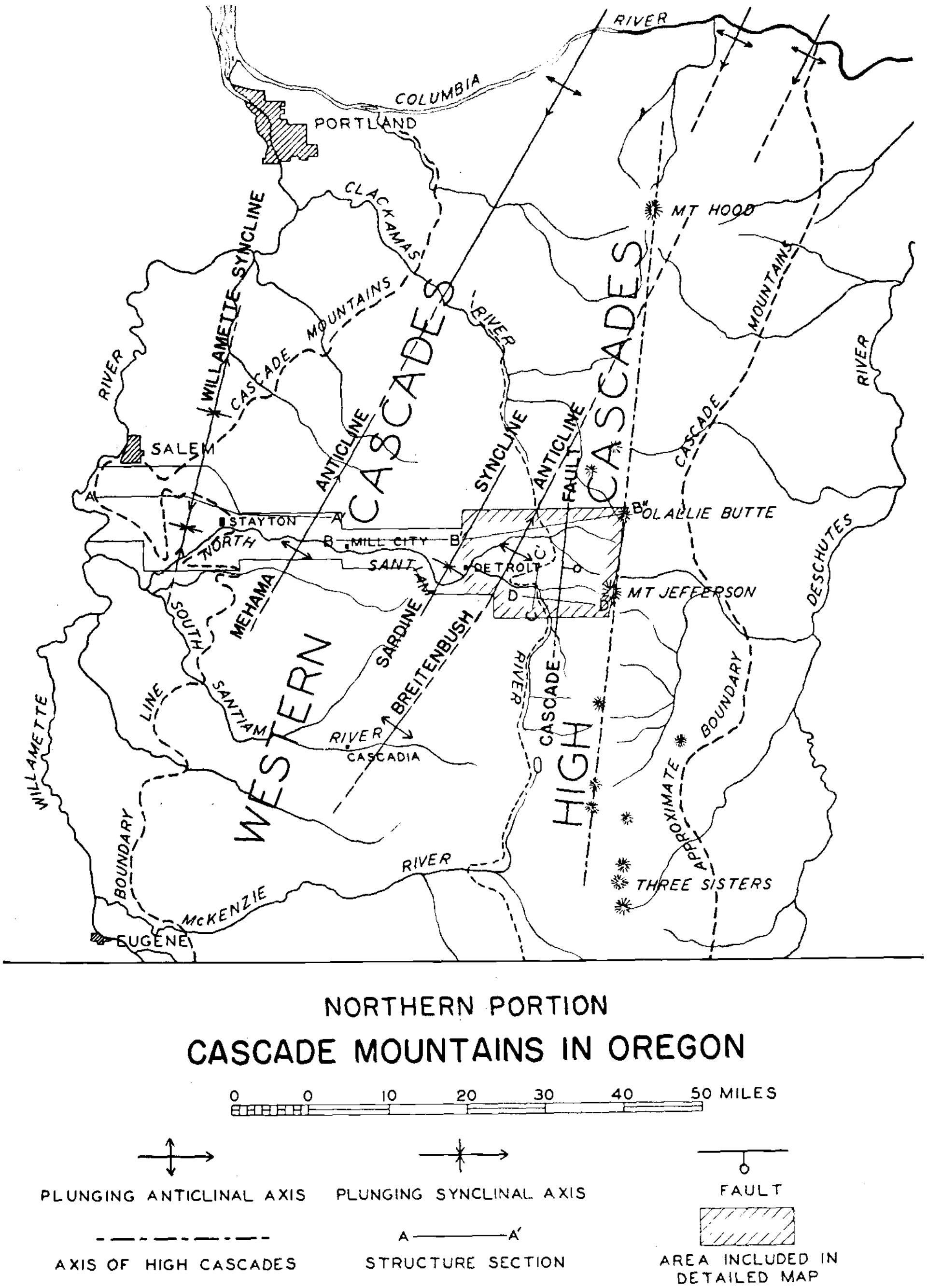

Figure 21. Major structural features of northern portion of the Cascade Mountains in Oregon. After Thayer (1936).

short distances. The variable attitudes may be attributed to the disruption of country rocks with emplacement of the numerous intrusive bodies found in the area. All of the above factors have contributed to the uncertainty of the structural relationships in the area.

According to data obtained from the Middle Member and the tuffs of the Lower Member, the most frequent attitude is a northeast strike and a dip to the southeast. A subordinate attitude is a northwest strike and northeast dip. Dips vary from 2 to 20 degrees and the most common is between 5 and 15 degrees.

Faulting

Displacement of rocks within the area is inferred to be minor since no major fault was recognized. The only faults observed with certainty are minor normal faults that occur in the volcanic sedimentary rocks. They trend northwest from N. 35 to 65° W. Vertical displacements range from 0.5 to 3.0 meters. The author suspects that a fault is present near the southern boundary of sec. 19, T. 10 S., R. 5 E. Its trace probably runs along the northwestward trending M & M Creek. The displacement could not be detected, however, because of the lack of marker horizons in the country rock. The age of the faulting is probably Late Miocene and may have been contemporaneous with or slightly later than the folding.

Structure Formed Around the Granodiorite Intrusion

Thayer (1936 and 1939) noticed that the granodiorite intrusion had disturbed the country rocks very little. He suggested that the lack of structural deformation in the surrounding country rocks indicated that the granodiorite had been intruded passively rather than forcibly.

In the field the author observed that the country rocks do not show the intensely folded structure probably because the intrusions are a continuous batholith at depth.

GEOMORPHOLOGY

The geomorphology of the mapped area is characterized by stream valleys, lava-forming ridges, and intrusion-supported ridges. The diversity of geomorphic features is a consequence of the interrelationships of lithology, stream erosion, and structure. Formation of the present land surface may have begun in Pliocene time or perhaps near the end of Miocene time with the advent of stream erosion.

Drainage Systems

The drainage pattern is dendritic. Streams are narrow, V-shaped, and have steep valley walls. Only the North Santiam River, the principal stream, is in the mature stage of the erosional cycle. The tributaries, however, are in the youthful stage and waterfalls are locally found along their courses.

In most of their lower courses, and in all of their middle courses, the streams flow in youthful deeply entrenched V-shaped valleys. In their upper courses, the stream valleys are generally straight, V-shaped, and have high gradients.

In general, the drainage systems of the area are lithologically controlled. Where the streams have cut down to the level of the andesite flows, or below them, they form step-like features with alternating cliffs and slopes. Where they have cut into the tuff and volcanic sedimentary units the streams have gentle gradients.

Erosional Forms

Major landform characteristic includes cliffs, ridges, and steep-walled valleys in the Lower andesite; gentle slopes and valleys in pyroclastic and sedimentary units; and ridges in the Upper andesite unit.

The Late Miocene granodiorite stock that intruded the Sardine Formation now forms a north-trending ridge in the W 1/2 sec. 18, T. 10 S., R. 5 E. (Figure 22). Elsewhere, this pluton occupies slopes and valleys.

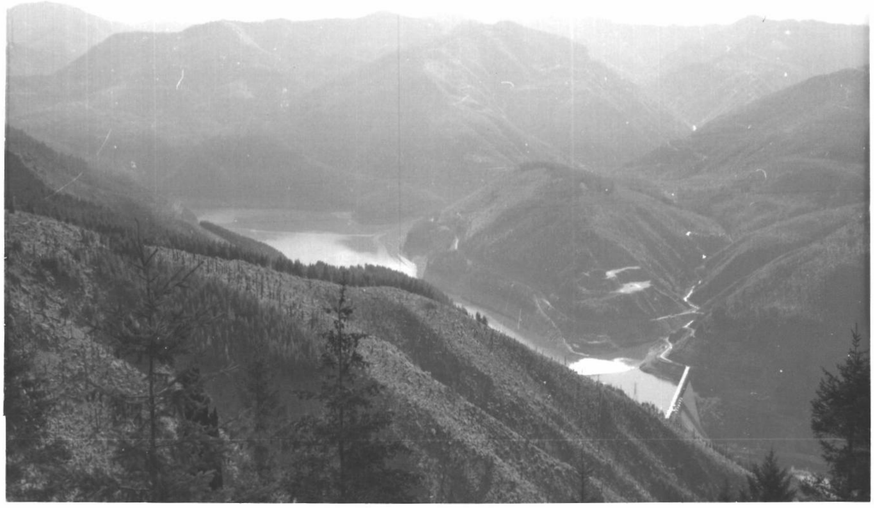

Figure 22. View south from Hall Ridge, Lower andesite flows in the foreground; granodiorite stock in sec. 18, T. 10 S., R. 5 E. in the middle right; south-central part of the area in the background; Detroit Dam is in the lower right.

MINERALIZATION AND ALTERATION

Pyrite is the principal sulfide mineral that was found in the mapped area. It is largely confined to the intrusive bodies; particularly the granodiorite stock and less commonly in dikes of granodiorite and andesite. It is sparse to absent in the adjacent country rocks. The pyrite occurs both disseminated and in fracture fillings. Most of the pyrite appears as irregular flakes, although in tuff it is found as cubic crystals, 0.25 to 1.0 mm in diameter, as well.

The widest zone of altered granodiorite is found in the S 1/2 SW 1/4 sec. 18, T. 10 S., R. 5 E. This zone and others smaller are found near the margins of the stock. The width of altered rock is generally ranges from 1.0 to 5.0 meters and rarely exceeds 15 meters. The highly altered granodiorite displays obvious physical changes such as bleaching and softening. The more leucocratic color is due mainly to the alteration of the mafic minerals to lighter colored products. Trace element analyses show that the altered granodiorite contains about three times as much copper (165 ppm) its unaltered equivalent (55 ppm).

All rocks in the area are propylitically altered. The intensity of alteration decreases from Lower Member to Upper Member. Characteristic alteration minerals are chlorite, epidote, calcite, clay minerals, sericite, pyrite, and quartz. Chlorite and epidote are the most abundant and these may be seen in some hand specimens. Pyroxene and hornblende are partly to completely altered to chlorite and/or epidote. In some thin sections chlorite appears to be pseudomorphic after hornblende. Magnetite replace the borders of plagioclase and pyroxene crystals in some thin-sections. Plagioclase is partly to completely altered to epidote, calcite, clay minerals, and orthoclase. The groundmass is rarely fresh yet in some flows it contains abundant magnetite. Chlorite and quartz appear to partially replace plagioclase and pyroxene. Clay minerals and sericite are also present in small amounts as replacements of plagioclase feldspar. Quartz and calcite veinlets are common in some sections. Also present are amygdules filled with chlorite, epidote, pyrite, and quartz.

Chemical analyses of fresh and altered granodiorite from the area are shown in Table 6. Although Sample 1, representing the fresh rock, appeared fresh, microscopic examination showed minor effects of alteration.

Table 6. Chemical analyses of trace elements in fresh and altered granodiorite samples. (Analyst: Rocky Mountain Geochemical Corporation)

ppm	1	2
Cu	55	165
Zn	70	60
Pb	10	20
Mo	1	-1
Ag	-0.2	-0.2

1. Stock from NW 1/4 NW 1/4 sec. 17, T. 10 S., R. 5 E.

2. Altered rock from SW 1/4 SW 1/4 sec. 18, T. 10 S., R. 5 E.

SUMMARY OF GEOLOGIC HISTORY

The oldest rocks exposed in the thesis area are Middle and Late Miocene in age. They comprise the tuffs and tuff-breccias of the Lower Member that were probably derived from some nearby explosive volcano in the Cascade Range. They are interbedded with andesite flows from local vents perhaps in the nearby Sardine Mountain and Dome Rock that lie just to the north of the area (Peck and others, 1964). Other flows may have come from fissures only a few meters wide. These dikes have been observed within the area mapped where they merge upward into horizontal sheets of lava or flows. Volcanic debris erupted during this time accumulated in small lakes and valleys and gave rise to the volcaniclastic rocks of the Lower Member. Their presence indicates at least minor topographic relief at the time deposition.

After deposition of the Lower Member a period of erosion prevailed here and in distant areas. Materials of volcanic origin were reworked by streams and deposited either along stream courses or in the lakes. Fossil leaves found in this Middle Member rock suggest a warm and temperate climate. These events were followed by deposition of andesite flows that comprise the Upper Member. Toward the end of Miocene time the volcanic activity subsided. The region was folded and the thick sequence of volcanic rocks was slightly warped to form a northeast-trending syncline. Minor faulting accompanied or followed this deformation. Intrusion of granodiorite as a stock and related dikes probably closely followed this episode of folding and faulting near the end of the Miocene time. The area was then subjected to a long period of erosion due to regional uplift that formed a mountainous terrain with relief similar to that of the present day. Probably near the end of Miocene time, or possibly in the beginning of the Pliocene time that is equivalent to the High Cascade Lavas, intrusion of mafic dikes took place. The erosional processes continued during Pliocene time and resulted in the development of the drainage pattern that was somewhat modified by Pleistocene glaciation.

At the present time the area is undergoing erosion. A few unconsolidated sediments are accumulating but there are restricted to the lower parts of stream courses that enter the Detroit Reservoir.

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