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Geology and Mineral Deposits of the North Half of the VAN ZANDT QUADRANGLE, Whatcom County, Washington

By
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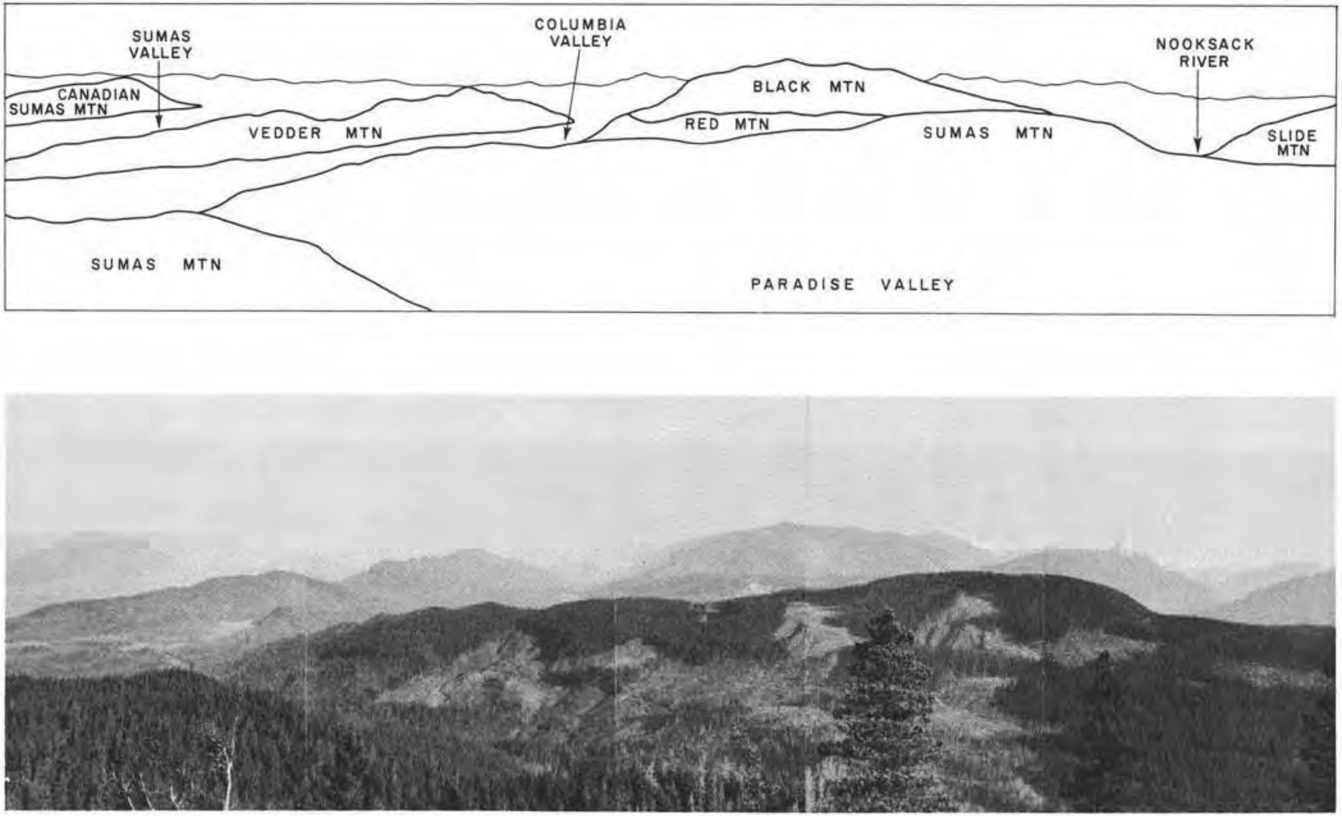

PANORAMA OF MAP AREA

Looking east from the north end of Sumas Mountain. Above the photo is sketch of the main physiographic features of the area.

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GEOLOGY AND MINERAL DEPOSITS OF THE NORTH HALF OF THE VAN ZANDT QUADRANGLE, WHATCOM COUNTY, WASHINGTON

By Wayne S. Moen

ABSTRACT

The north half of the Van Zandt 15-minute quadrangle contains deposits of limestone, quartz, and refractory clays in both quantity and quality to meet the requirements of certain mineral industries. Although gold, copper, chromite, and iron are present, the quantity and (or) quality of the metals are not favorable for profitable mining operations under present economic conditions. At present (1961), the mining operations in the area are confined to the limestone deposits.

The mapped area is underlain by rocks as old as Devonian and as young as Recent. The rocks that range in age from Devonian through lower Permian include argillite, graywacke, siltstone, grit, chert, tuff, limestone, and basic volcanic rocks. Rocks of Mesozoic age are chiefly grit, graywacke, argillite, and serpentinite. An Upper Cretaceous-lower Tertiary sequence consists of great thicknesses of nonmarine arkosic conglomerate, sandstone, and siltstone. Glacial deposits of till and outwash gravels of Pleistocene age overlie the Paleozoic, Mesozoic, and Tertiary rocks. The Recent materials consist of alluvium, landslide debris, and terrace and lacustrine deposits.

From late Paleozoic time to as recently as the Pliocene epoch, the area has been subjected to orogenic deformation. The major folds of the area trend north 5° to 20° east and north 40° to 70° east. High-angle faults that trend north 40° to 70° east are the predominant faults. The initial deformation probably was related to the Cretaceous Laramide orogeny, whereas the latest deformation occurred during the uparching of the Cascade Mountains in the Pliocene epoch.

INTRODUCTION

SCOPE OF THE REPORT

The geologic investigation of the north half of the Van Zandt quadrangle was undertaken primarily as a study of the refractory clay deposits of the area. The known clay deposits were evaluated, and geologic mapping was carried out in an attempt to extend the limits of the known deposits as well as to discover new ones. The study of the refractory clays of the area is only one phase of a program designed to evaluate the quality, quantity, and location of clay deposits in the State.

Although concerned primarily with the availability of clay, geologic investigations were extended to include any minerals that might become a significant part of the industrial and economic development of the State. In the course of examining the north half of the Van Zandt quadrangle for mineral occurrences, geologic data were gathered that were used in the compilation of the geologic map that accompanies this report.

FIELD WORK AND ACKNOWLEDGMENTS

The field work for this report was begun in July 1959 and terminated in November 1959. Field mapping was done on contact prints of vertical aerial photographs at a scale of about 2½ inches to the mile. The information on the photos was transferred to an enlargement of the Van Zandt quadrangle having a scale of 1½ inches to the mile.

An attempt was made to examine all known mineral deposits. Many of the reported mineral occurrences could not be found because of the extreme weathering and dense vegetation of the area that obscure the old mine workings. All accessible mine workings were examined. The underground workings of the clay mines were mostly inaccessible because of caving.

The author wishes to acknowledge the generous cooperation of the land owners of the area. Particular thanks are due to the logging operators, whose land holdings cover a large area, and to the limestone quarry operators who allowed their properties to be examined. The author is grateful to Gladding, McBean & Company for information on the Sumas clay mine, to Professor W. R. Danner for much of the information on the limestone deposits of the area, and to the U.S. Bureau of Mines Northwest Experiment Station, Seattle, for analyses of the clay samples. Thanks are also due to Professor Peter Misch and Jerry Miller for discussions on the geology of the area. The helpful criticism by the staff of the Washington State Division of Mines and Geology was of great value in the preparation of the report, and thanks are due particularly to Marshall T. Huntting, Supervisor, for helpful suggestions and for critical reading of the manuscript, and to W. A. G. Bennett, geologist, for help with the petrography.

PREVIOUS INVESTIGATIONS

The area has been examined at different times in the past, but no reports have been published that deal specifically with the geology and mineral deposits of the area.

Between 1901 and 1906 R. A. Daly (1912), of the Geological Survey of Canada, made a reconnaissance survey of the North American Cordillera along the 49th parallel. A small part of his survey extended into the United States; however, most of his work was on the Canadian side of the International Boundary.

In 1930, C. H. Crickmay (1930) published a paper on the structural connection between the Coast Range of British Columbia and the Cascade Range of Washington. In this paper he briefly discusses some of the geology of the area.

Peter Misch (1952), in an article on the geology of the northern Cascades of Washington, describes some of the rocks of the eastern part of the Van Zandt quadrangle.

W. R. Danner (1957), Neil D. Hillhouse (1956), and Clyde L. Smith (1961) discuss a small part of the area in their student theses. However, most of their work is concerned with the fossiliferous limestones.

Several reports have also been written about the various mineral occurrences of the area. Glover (1941) and Wilson (1923) have reported on the clays and shales of the area. Shedd and others (1922), in their report on the iron ores, fuels, and fluxes of Washington, mention briefly the Sumas iron deposit. Shedd (1914), in his report on the cement materials of the State, also briefly discusses the limestone and shale deposits of the area. Hodge (1938b), in his report on the clays of the Northwest, describes the Sumas clay mine operations.

One of the most intense mineral-resource investigations was conducted by the U.S. Works Progress Administration (1936). Four square miles of land, on the west slope of Sumas Mountain, was examined in detail for chromite and other valuable minerals. However, no significant mineral deposits were discovered.

Several other mineral investigations have been made in the area, but they were by consulting mining engineers and geologists who were examining specific properties.

HISTORY AND MINERAL PRODUCTION

The economy of the area is based primarily on logging and farming. However, some mining has been carried on since the region was first settled in the 1850's.

In 1858 gold was discovered to the north, in Canada. Because of the proximity of the discovery, the mountains of northwestern Whatcom County were prospected, and in the years that followed, occurrences of gold, copper, chromite, iron, clay, limestone, and coal were discovered.

Numerous attempts were made to mine the metallic mineral deposits of the area, but none proved successful. Perhaps the most extensive attempt to recover gold was undertaken at the Old Nooksack mine on the west slope of Sumas Mountain. At this property a stamp mill was erected and several tunnels were driven, but little, if any, gold was recovered. In the 1930's a small amount of gold was recovered by placer mining operations near the headwaters of Bells Creek on the southeast end of Sumas Mountain.

Although the metallic minerals had little effect on the economy of the area, the nonmetallic minerals have contributed significantly. Clay deposits were discovered a few miles southeast of Sumas and were mined between 1910 and 1949. Several limestone deposits were found on Sumas, Red, and Black Mountains. A few of these deposits have been worked since the early 1900's and supply the limestone needs of the pulp and cement industries of Whatcom County.

Quartz was discovered between Sumas and Kendall in 1897, but not until 1943 was the deposit utilized for its silica content. Coal seams were uncovered in many parts of the area, but most of them proved to be small and impure. Today, only caved workings exist where mining was once attempted.

Although there never has been an actual mining boom within the area, available figures show that between the years 1919 and 1959 production has been $5,583,639, all from the production of nonmetallic minerals.

LOCATION AND ACCESS

The area described in this report is in the north half of the Van Zandt 15-minute quadrangle, which is in western Whatcom County and the northwestern corner of Washington. (See fig. 1.)

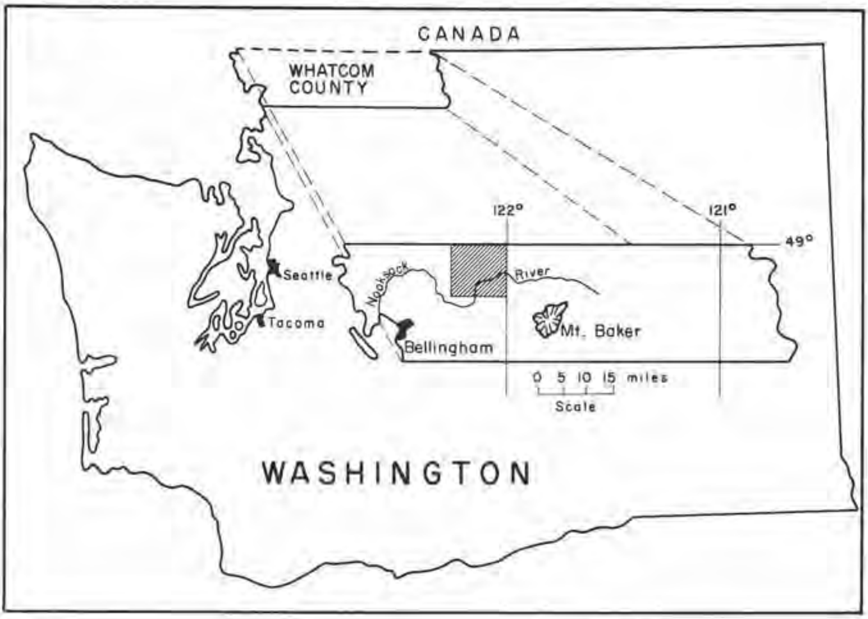

FIGURE 1. Index map showing location of the north half of the Van Zandt quadrangle.

This area is bounded by longitude 122°15′ on the west and by longitude 122°00′ on the east. The 49th parallel, which forms the United States-Canada border, is the northern boundary. The southern boundary falls along the center of Township 39 North, Willamette meridian.

Bellingham, the county seat, is about 15 miles to the southwest. The farming community of Sumas is 1 mile west of the northwest corner of the area. The unincorporated towns of Kendall and Maple Falls are within the area.

Access to the area is by way of State Highway 1 and several county roads. Many logging roads extend into the more remote parts of the mountains. The Chicago, Milwaukee, St. Paul and Pacific Railroad serves the area and extends as far east as Maple Falls.

LAND OWNERSHIP

The area investigated consists of approximately 100 square miles of land, of which roughly 68 percent is private land, 27 percent is State land, and 5 percent is Federal land. The distribution of these lands is shown on plate 2 (in pocket). Those lands designated as private lands are, for the most part, owned by individuals and lumber companies, but some county lands are included.

As land ownership is subject to changes, it is best to consult the county assessor as to the present legal owner of any parcel of land.

TOPOGRAPHY

The Van Zandt quadrangle is within the western foothills of the Cascade Mountains province. The area is characterized by a series of heavily wooded mountains, the summits of which have been subdued by glacial erosion. (See frontispiece.) A few steep rocky cliffs form prominent landmarks in the area.

The mountainous area is dissected by deep valleys and many ravines of the Nooksack River and its innumerable tributaries, as well as those of rivers and streams related to Pleistocene glaciers. The major valleys are Columbia Valley and the one through which the Nooksack River flows. Only a small part of Sumas Valley falls within the area covered by this report. A dendritic drainage pattern is formed by permanent and intermittent streams. Silver Lake, which is the largest lake in the area, is about 1½ miles long.

The mountains, which rise to a maximum elevation of almost 5,000 feet, are covered by Douglas fir, western hemlock, and western red cedar. Throughout the area there is a dense undergrowth that consists mainly of alder, willow, salmonberry, blackberry, ferns, and devil's club.

A modified oceanic climate prevails in the area as a result of westerly to southwesterly prevailing winds from the Pacific

Ocean. The mean annual temperature is near 50°. In the summer the temperature rarely reaches 90° and in the winter it seldom falls below 0°. The summers are generally cool and the winters comparatively mild.

Precipitation is heavy in the area, the average being about 60 inches per year. Most of it falls in the form of rain; however, snow may be expected from November through April, especially at elevations above 2,500 feet. About 75 percent of the precipitation falls between September and May.

Within the north half of the Van Zandt quadrangle there are five distinct mountains, each of which is separated from the others by well-defined valleys. (See frontispiece.) These mountains are named Sumas, Black, Red, Vedder, and Slide.

Sumas Mountain

Sumas Mountain, which is roughly 10 miles long and 5 miles wide, is the westernmost of the five mountains. It rises to a maximum elevation of about 3,400 feet. To the west is Whatcom Basin (Newcomb and others, 1949, p. 4), at an elevation of about 100 feet, and to the east is Columbia Valley, 500 feet in elevation. All sides of the mountain have been dissected by streams into many steep-sided ravines. Continental glaciation has produced a glaciated valley on the north end of the mountain and steep rocky cliffs on the northwestern corner. The valley is known as Paradise Valley.

Black Mountain

Black Mountain, on the eastern edge of the area, rises 4,290 feet above the valley floor and has a maximum elevation above sea level of 4,990 feet, which is the highest point within the area. The mountain is about 6 miles long and 3 miles wide, and extends 1½ miles into Canada. A thick mantle of glacial drift covers much of the south end of this mountain, and many steep rocky cliffs are on the north end.

Red Mountain

Red Mountain, the smallest of the five mountains, lies between Sumas Mountain and Black Mountain. It is 5 miles long and 2½ miles wide, and its highest point is 2,300 feet above sea level. It is not as rugged as the other mountains, and much of it is covered by a veneer of glacial drift.

Vedder Mountain

Vedder Mountain is the northernmost as well as the longest mountain in the area. It is roughly 12 miles long and from 1 to 2 miles wide. Most of it is in Canada, and only about 4 miles of the southwestern end of it is in the United States. The maximum elevation of the part in the map area is about 2,100 feet, whereas in Canada the mountain reaches an elevation of 3,029 feet. Sumas Valley, on the north, has an elevation of about 30 feet, and Columbia Valley, on the south, is at an elevation of 600 feet. A steep, rocky, scarplike front forms the northern flank of the mountain, and its southern flank resembles a dip slope.

Slide Mountain

Slide Mountain is the largest of the mountains, but less than half of it is within the area covered by this report. The mountain rises abruptly, from the valley of the Nooksack River, to an elevation of 4,850 feet above sea level. As the name implies, Slide Mountain contains many landslides, some of which are over 1 square mile in area. All sides of the mountain have been dissected by streams, the largest of which is Racehorse Creek.

GENERAL GEOLOGY

The north half of the Van Zandt quadrangle is underlain mainly by upper Paleozoic rocks of the Chilliwack Group and the Chuckanut Formation of Late Cretaceous-early to middle Eocene age. The Chilliwack Group crops out over much of Vedder, Black, and Red Mountains, as well as on the north half of Sumas Mountain, whereas the Chuckanut Formation is confined chiefly to Slide Mountain and the southern end of Sumas Mountain. The distribution of the rocks is shown on plate 1, and their stratigraphic sequence is summarized in table 1.

The Chilliwack Group is characterized by graywacke, argillite, siltstone, chert, limestone, basic volcanic rocks, and breccia that were deposited in eugeosynclinal environments. Since their deposition the rocks have been weakly metamorphosed by regional metamorphism. The complicated structures of the rocks make it impossible to accurately determine the total thickness of the section. However, at least 6,000 feet of upper Paleozoic rocks are believed to be present in the map area.

The Chuckanut Formation consists of continental arkosic sandstone, conglomerate, siltstone, and shale. Much of the shale contains coalified plant remains and coal seams as much as 2 feet thick. The complete section of the Chuckanut Formation is not represented, but it is estimated that at least 10,000 feet is present.

Graywacke, conglomerate, grit, and argillite possibly of early Mesozoic age crop out on Black and Sumas Mountains. On Sumas Mountain the sedimentary rocks are at least 900 feet thick. On Black Mountain they appear to be much thicker, but complicated structures make it impossible to determine their total thickness.

At least 3,000 feet of post-Chuckanut continental arkosic sandstone, conglomerate, siltstone, and shale crop out along the western slope of Sumas Mountain. Other small erosional remnants of these sedimentary rocks are exposed on the west end of Vedder Mountain and in the north end of Paradise Valley on Sumas Mountain. The shale near the base of the section contains the only known fire clay deposits of the area.

The central part of Sumas Mountain is underlain by serpentinite of Mesozoic age. Sill-like bodies of serpentinite are also found on other parts of the mountain, as well as on Vedder Mountain. Much of the serpentinite contains enstatite and approaches saxonite in composition.

Several small bodies of metadiorite, meta-quartz diorite, and amphibolite of uncertain age are poorly exposed in the north half of the map area. For the most part, they are believed to be fault blocks of the basement complex.

Pleistocene glacial drift covers much of the area, even to the summits of the highest peaks. Thick deposits of glacial outwash sand, gravel, and clay fill the bottoms of several of the largest valleys. Parts of these deposits are being reworked by the Nooksack River and its tributaries. The floor of Sumas Valley, the largest and lowest valley of the map area, is covered by silts and clays of lacustrine origin.

The larger landslides of the area are confined to Slide and Sumas Mountains. Parts of the steeper slopes of Slide Mountain as well as parts of the western slope of Sumas Mountain are still in the process of sliding.

ROCK UNITS

SEDIMENTARY ROCKS

Chilliwack Group

Almost 50 percent of the north half of the Van Zandt quadrangle is underlain by a thick sequence of sedimentary and basic volcanic rocks of Devonian through early Permian age. The sedimentary rocks are chiefly conglomerate, graywacke, siltstone, argillite, ribbon chert, and limestone.

The lack of fossils except in a few limestone beds, the similarity of the lithology, complicated structures, and lack of good exposures make it impossible to establish a definite stratigraphic section. These Devonian through early Permian rocks of the map area are herein referred to as the Chilliwack Group. Fossiliferous units such as the limestones, the ones for which the age has been determined, are differentiated in table 1 and on plate 1.

TABLE 1.—*Stratigraphic sequence of the north half of the Van Zandt quadrangle*

Age	Formation	Map symbol	Character	Thickness (feet)
Recent and Pleistocene	Alluvium	Qa	Flood-plain deposits of silt, sand, and gravel. Confined to present-day streams	50+
	Landslide debris	Qls	Heterogeneous mixture of detached masses of bedrock and overburden	
	Terrace deposits	Qt	Ancient flood-plain deposits of gravel, sand, and silt. Borders present-day streams	
	Lacustrine deposits	Ql	Silt, clayey silt, and silty clay. Some sand and gravel	50+
	Glacial outwash	Qgo	Stratified gravels. Includes some sand, silt, and clay	150+
	Glacial drift, undivided	Qg	Till, outwash, and glaciofluvial deposits of gravel, sand, silt, and clay	100+
		Unconformable contact		
Late Eocene(?)	Tertiary continental rocks	Tc	Arkosic conglomerate, sandstone, and shale. Includes refractory clay, ferruginous shale, and some thin coal seams	3,000+
		Unconformable contact		
Late Cretaceous-early to middle Eocene(?)	Chuckanut Formation	TKc	Arkosic conglomerate, sandstone, siltstone, and shale. Includes carbonaceous matter and coal seams	10,000+
		Unconformable contact		
Jurassic-Cretaceous (?)	Sumas Mountain Serpentinite	pTbi	Serpentinite and saxonite. Contains chromite stringers	
		Intrusive contact		
Early Mesozoic(?)	Lower Mesozoic sedimentary rocks	Mz	Conglomerate, grit, graywacke, and carbonaceous shale and argillite	1,000±
		Unconformable contact		
Early Permian through Devonian	Chilliwack Group	Pc	Mainly argillite, graywacke, siltstone, grit, conglomerate, chert, limestone, and basic volcanic rocks Where differentiated: Pcv—Chiefly augite and hornblende andesite, basalt, lithic tuff, and volcanic breccia Pls—Lower Permian fusilinid limestone Pls—Lower Pennsylvanian crinoidal limestone Dls—Devonian coral-bearing limestone Pd—Dioritic rocks	6,000±
Pre-Devonian (?)	Crystalline Complex	cc	Metadiorite, meta-quartz diorite, and amphibolite	

The rocks that have been mapped as the Chilliwack Group are, for the most part, similar to the Chilliwack Series as mapped by Daly (1912, p. 508-516) to the northeast in Canada. Daly's Chilliwack Series consists of argillite, quartzitic sandstone, grit, conglomerate, and limestone that are Carboniferous and older (?) in age. In the upper part of the Chilliwack Series, Daly (1912, p. 521-522) includes the Chilliwack Volcanic Formation of late Carboniferous age. The volcanic rocks consist chiefly of augite and hornblende andesite flows and interbedded ash beds.

Although the upper Paleozoic rocks of the map area are similar to the Chilliwack Series, the writer has not used the term "series," as it implies a time-stratigraphic unit. Also, the rocks within the map area are in part younger than Carboniferous. A recent geologic map by the Geological Survey of Canada (Rice, 1959) shows that the Chilliwack Series is now designated as the Chilliwack Group. However, this change apparently has not been formally made in any publication.

Rocks similar to the upper Paleozoic rocks of the map area are found also to the west, in the San Juan Islands. McLellan (1927, p. 100-101) mapped Devonian through Permian rocks of the Islands as the Leech River and Orcas Groups.

Distribution

Rocks of the Chilliwack Group underlie most of the north half of the map area. Almost all of Vedder Mountain, except for some Tertiary continental sedimentary rocks on the southwestern end and metadiorite and serpentinite near the International Boundary, is underlain by these rocks. Both Black and Red Mountains are made up largely of upper Paleozoic rocks. On Sumas Mountain the Chilliwack Group crops out mainly on the northeastern quarter of the mountain; however, smaller outcrops are scattered on the southwestern end of the mountain along the upper drainages of Smith Creek. No outcrops of the Chilliwack Group have been noted on Slide Mountain, within the area investigated for this report.

Argillaceous Rocks

Much of the Chilliwack Group consists of argillaceous sedimentary rocks that for the most part have been weakly metamorphosed to form argillite. Associated with the argillite is unmetamorphosed carbonaceous or calcareous shale. Slate and phyllite are also present but are not as abundant as the argillite and shale.

The argillaceous rocks are generally dark gray to grayish black, but shades of brown, green, and red have been noted in several thin beds. Interbeds of medium-gray quartzose siltstone occur throughout the argillite. The beds are usually from 1 to 6 inches thick, although in some thinly bedded argillites as many as 20 laminae to the inch have been noted. The more massive rocks that are interbedded with the argillite are quartzose siltstone, chert, graywacke,[1] conglomerate, and basic volcanic flow rocks.

Hand specimens of the argillite are uniformly dark gray in color, in part with and in part without bedding fissility. In some specimens, grains of quartz, feldspar, and pyrite are visible in the finely divided clay minerals. Thin white quartz stringers are present in much of the argillite, and on Vedder Mountain near the International Boundary the argillite has a definite lineation in which the quartz and feldspar parallel the schistosity. Parallel orientation of the constituents is more distinct in thin sections. Sericite, chlorite, carbonaceous material, and unidentified clay-size particles are oriented parallel to the fissility of the rock. Fine-grained fragments of quartz, feldspar, and pyrite are randomly oriented throughout much of the groundmass, but some fragments appear to have been rotated into a common orientation.

Some argillites and shales are definitely calcareous, and a few of them grade into argillaceous limestone. However, they are not common and appear to be restricted to the part of the section that contains the limestone beds.

The degree of deformation of the argillite varies throughout the area. The argillite on the north ends of Black and Red Mountains does not appear to have been deformed as much as that in other areas. On both Sumas and Vedder Mountains the strata are tightly folded and in places contorted and sheared. Argillite and shale adjacent to fault zones are extremely sheared and contorted. Argillite that has been subjected to greater deformation than normal argillite has quartz that is crystallized into small aggregates having a mosaic texture. Much of the quartz occurs in thin lenslike masses that parallel the shear planes of the rock and give it a definite flaser structure.

The thickest sequence of argillite and shale is about 3,000 feet thick and underlies the Lower Pennsylvanian limestone on Red Mountain. On the north end of Black Mountain the argillite and interbedded graywacke appear to be about 2,000 feet thick.

Chert

Chert that is interbedded with the argillite occurs throughout the section and ranges in thickness from several inches to as much

[1]In this report the terms "graywacke" and "arkose" are used as defined by Travis (1955, p. 20-24). Graywacke contains quartz, feldspar, and rock chips in a rock paste matrix. The grains are distinctly angular, and the sandstone is normally greenish gray and tough. Many of the graywackes could also be called lithic sandstones. The use of the term "arkose" is restricted to sandstone that contains quartz and more than 25 percent feldspar.

as 20 feet. The deposits of chert that are not bedded occur as nodules and lenses in the thinly bedded argillite and shale.

Although some of the chert is massive, most of it is less than 1 foot thick and alternates with argillite to form ribbon structure. In areas where the interbedded argillite beds are thin, the ribbon chert in places grades into massive bedded chert. Some of the more massive white chert forms distinct outcrops, which from a distance resemble those of limestone.

Many of the cherts show various degrees of contortion. One of the best examples of contorted ribbon chert in the map area is exposed in a road-material pit in the NW¼ sec. 22, T. 40 N., R. 6 E. The chert appears to be much more contorted than the interbedded argillite.

The typical chert is dense and brittle and has a dull to vitreous luster. Predominant colors are white, gray, and green. Under the microscope the chert is colorless and consists of a fine-grained micromosaic of quartz. No silicified fossil remains are present.

The chert commonly contains numerous closely spaced joints, many of which are filled by secondary quartz. Much of the highly fractured chert grades into a chert breccia that is composed of sharp angular fragments of chert as well as some argillite fragments.

The bedded chert of the area is believed to have been formed by direct precipitation of silica on the sea floor. The association of chert with the volcanic rocks of the area suggests that a silica-rich environment, caused by underwater volcanism, existed in the basins of deposition.

Siltstone, Graywacke, and Conglomerate

The coarser grained sediments are represented mainly by siltstone, graywacke, and conglomerate. They crop out in all parts of the map area and vary considerably in thickness. Common variations in lithology, even within a particular bed, make it impossible to correlate any unit throughout the area.

Siltstone.—Most of the siltstones occur interbedded with argillites and shales. Individual beds range in thickness from about 1 inch to as much as 100 feet. Bedding is not generally recognizable in the thicker beds, but in the thinly bedded siltstones the beds can be recognized by the differences in color of the individual beds. Many of the dark-gray siltstones are siliceous and some are cherty. The siliceous siltstones are grayish green and are composed of grains of quartz, feldspar, and muscovite having an average grain size of about 0.05 millimeter. Fine-grained disseminated iron pyrite and what appears to be outlines of radiolarians are present in some parts of the siltstone.

One of the better exposed siliceous siltstone units of the Chilliwack Group crops out on the northern ends of Red and Black Mountains, where it forms high, bold cliffs. The siltstone is massive to well bedded, with beds ranging from 6 inches to 1 foot in thickness. Fine-grained medium-gray quartzite and dark-gray argillite are interbedded with the siliceous siltstone but make up only a small part of the section. The position of this siliceous siltstone sequence within the Chilliwack Group is not definitely known. It may be of Mississippian age, as it has not been noted in the Pennsylvanian and Permian parts of the section. Exposures on the north ends of Red and Black Mountains suggest a thickness of at least 1,000 feet for it.

The greenish-gray siltstones are distinctly different and appear to be more tuffaceous than the siliceous siltstones. They are generally interbedded with and grade into tuffaceous sandstone. Microscopically, the groundmass is seen to be composed of chloritized and sericitized feldspar. Calcite, quartz, augite, hornblende, and very fine grained carbonaceous material are usually present but do not exceed 15 percent of the total minerals.

Graywacke.—Many of the greenish-gray tuffaceous siltstones grade both laterally and vertically into graywacke. These graywackes are usually massive, and, except where they are interbedded with finer grained sedimentary rocks, it is difficult to measure the attitudes of the beds. They are dark greenish gray, resemble igneous rocks in toughness, and many of them are difficult to distinguish from the basic volcanic rocks of the area. Many of the graywackes contain thin white quartz stringers. When exposed to weathering, the surface of the rock becomes yellowish gray.

The graywackes are composed of angular rock and mineral fragments in a matrix of chlorite, sericite, and clay. The matrix makes up 20 to 75 percent of the rock. The coarse fragments consist of feldspar, quartz, chert, argillite, basalt, and andesite. Argillite fragments are present in all samples and comprise as much as 75 percent of the coarse fraction of the rock. Many of the fine-grained graywackes are difficult to distinguish from igneous rocks, though some of them contain a few angular fragments of black argillite or slate that make it easier to distinguish one from the other. The fragments occur as thin splinters as much as 2 inches long. Crystals of hornblende and augite can be seen in thin sections but are seldom visible in hand specimens. Fine-grained iron pyrite is present in all the graywacke.

Most of the coarse fragments range in size from 0.5 to 10 millimeters. Every gradation exists, from a rock with only a few fragments to the coarser varieties that consist almost wholly of rock fragments and little, if any, matrix (fig. 2). Because of the coarseness and angularity of some of the fragments, much of the graywacke might be called "grit." However, the term "grit" as used in this report is restricted to graywacke that contains at least 25 percent angular rock and mineral fragments that are 2 millimeters or larger in diameter.

FIGURE 2. Photomicrograph of graywacke of the Chilliwack Group. Angular to subangular fragments of chert, quartz, plagioclase, and rock chips. Practically no matrix present. (× 15—plain light.)

With a decrease in rock fragments and detrital chert, some of the graywacke grades into subgraywacke and arkose. The arkose is generally light gray, medium grained, and contains quartz and feldspar as the dominant minerals. The matrix consists of silt, which makes up about 10 to 20 percent of the rock. The subgraywacke contains as much as 50 percent matrix, consisting of sericite, chlorite, and clay minerals, which give the rock a greenish-gray color. Quartz usually is more common than feldspar, and makes up as much as 75 percent of the rock. Some of the quartz-rich subgraywacke has been metamorphosed into metaquartzite.

Conglomerate.—Those rocks containing more rounded fragments than angular fragments, and in which the fragments are larger than 2 millimeters in diameter, are considered conglomerates. Graywacke conglomerate occurs throughout the Chilliwack Group, but is not as common as the grit. Most of the conglomerate is composed of granules and pebbles of chert, quartz, siliceous siltstone, argillite, and basic volcanic rocks in a graywacke matrix. It is interbedded in the graywacke and in many places grades into it. Several of the conglomerate beds appear to be more than 100 feet thick.

One of the best exposures of a cobble conglomerate is near the center of sec. 4, T. 40 N., R. 6 E., on Black Mountain, where it consists of cobbles of dark-green andesite and basalt, white chert, and limestone. Some boulders, as much as 1 foot in diameter, are also present. The cobbles and boulders are well rounded and are enclosed in a graywacke matrix. The conglomerate bed appears to be at least 150 feet thick and conformably overlies Lower Pennsylvanian limestone (fig. 3).

Limestone

Limestones of Devonian, Early Pennsylvanian, and early Permian age crop out on Sumas, Red, and Black Mountains. Within the map area no limestone is exposed south of the North Nooksack fault or on Vedder Mountain (figs. 28, 31, and 33, on p. 88, 92, and 95, respectively, and pl. 1).

Devonian limestone.—The Devonian limestone crops out on Sumas, Red, and Black Mountains. The best exposures of the limestone are at the site of the old Balfour quarry (NE¼ sec. 28, T. 40 N., R. 5 E.) and at the Doaks Creek quarry (center sec. 19, T. 40 N., R. 6 E.). Most of the other outcrops of the limestone (see pl. 1) are poorly exposed, and inaccessible by conventional vehicles.

The Devonian limestone is medium gray, dense to finely crystalline, and weathers bluish gray to buff. In some outcrops the bedding is distinct, but in many it has been obscured by folding and shearing. At the Doaks Creek quarry, beds of coral that are more resistant to weathering than the nonfossiliferous limestone give the limestone a definite bedded appearance. Most of the Devonian limestone is fairly uniform in composition, but it also contains interbeds of shaly and siliceous limestone.

The fossils of the limestone include *Thamnopora*-like coral, ostracods, crinoids, bryozoa, and small brachiopods. From the Balfour quarry W. R. Danner (written communication, 1961) has identified the Devonian stromatoporoid *Stromatoporella* (*laminata?*). The Doaks Creek quarry contains many beds of coral from which Danner collected specimens of *Coenites* and *Thamnopora*. Samples from the quarry were submitted by Danner to Dr. M. Lecompte of the Institut Royal des Science Naturelles de Belgique in Bruxelles, whose conclusions were as follows:

> I found the material Devonian without any doubt as your letter informed me. The organisms are *Scoliopora* (*Plagiopora*) sp. It is an unknown species for me, not very different indeed of the species found in our Devonian; the nearest one, considering general structure and skeletal elements, is *Scoliopora mailliensi* Lecompte of the Middle Frasnien (Upper Devonian) but the growth form is different.

The Devonian limestone is generally interbedded with argillite and graywacke, but at several of the smaller outcrops, igneous rocks occur in fault contact with the limestone. In the NW¼ sec. 9, T. 40 N., R. 5 E., and in the SW¼NE¼ sec. 23, T. 40 N., R. 5 E., rocks of the crystalline complex occur adjacent to the limestone. The crystalline rocks are metadiorite and meta-quartz diorite, and are believed to be upfaulted blocks of the basement complex.

Several sinks and at least one cave are known in the limestone. Although the sinks on Sumas Mountain are small and poorly exposed, W. R. Danner (written communication, 1961) reports that a cave near the center of sec. 21, T. 40 N., R. 5 E., is at least 100 feet long and contains several branches.

Lower Pennsylvanian limestone.—Limestone of Early Pennsylvanian age crops out as eastward- and northeastward-trending lenses across the center of Red Mountain and as northward- to northeastward-trending beds near the summit of Black Mountain (figs. 28 and 31, on p. 88 and 92, and pl. 1). The best exposures of the limestone are at the Kendall and Silver Lake quarries on Red Mountain.

The limestone is light to dark gray, dense to crystalline, and much of it has a clastic texture. Parts of it are highly fractured, and many of the fractures are filled with secondary calcite. Chert nodules are abundant in the upper part of the limestone. Both horizontal and vertical joints are present, and in some outcrops the closely spaced horizontal joints give the limestone a banded appearance. The banding is well displayed in a 200-foot cliff of limestone near the center of sec. 4, T. 40 N., R. 6 E. (fig 3). The jointed layers are usually darker than the rest of the limestone. Parts of the limestone contain generally thin, carbonaceous argillite seams, and some shale beds. One such shale bed, which is about 50 feet thick and greenish gray in color, is exposed in the Kendall quarry (fig. 30, on p. 90).

Much of the limestone is fossiliferous and is characterized by crinoid stem fragments. Some beds are made up almost entirely of crinoid columnals. Corals, bryozoa, pelecypods, endothyroids, brachiopods, fusulinids, and other foraminifera are also present. According to Danner (1957), the following fossils have been identi-

FIGURE 3. Lower Pennsylvanian limestone near summit of Black Mountain. Banding caused by closely spaced horizontal fractures. Overlying conglomerate forms cliff in upper right-hand corner of photo.

fied from the Lower Pennsylvanian limestone on Black and Red Mountains:

Coelenterata	Protozoa	Brachiopoda
Iranophyllum aff.	*Paranillerella*	*Gigantoproductus*
Spongifolium Smith	*Ozawainella*	
Pseudoromingeria	*Plectogyra*	
Lophophyllidium	*Texrataxia*	
Carruthersella sp.		
Heritschioides		
Cyathaxonia		

The limestone is underlain by argillite, shale, graywacke, and black chert. On Red Mountain it is overlain by argillite and basic volcanic rocks. On Black Mountain the limestone is overlain by a thick basalt-andesite cobble conglomerate. Exposures in the Kendall quarry and in the NW¼ sec. 13, T. 40 N., R. 5 E., suggest that the limestone is nearly 400 feet thick. On Black Mountain its maximum thickness is 300 feet.

Lower Permian limestone.—The only known limestone of early Permian age in the map area crops out near the summit of Black Mountain. It is well exposed in the SE¼ sec. 4, T. 40 N., R. 6 E., where it forms several cliffs. The limestone is medium to dark gray, dense to finely crystalline, and contains interbedded argillaceous and cherty limestone beds as well as thin beds and lenses of dark-gray chert.

Fusulinids occur through this limestone and represent the dominant fauna. Fusulinid-rich beds of the limestone are made up of fusulinid coquina. Danner (1957) reports the following fossils in the lower Permian limestone of Black Mountain:

Protozoa	Bryozoa
Schwagerina	*Fenestella*
Pseudofusulinella	*Polypora*
Textularia	*Rhomboporella*
	Stenophora

The limestone is at least 400 feet thick and appears to be conformable with the underlying Lower Pennsylvanian limestone. Several hundred feet of argillite and a basalt-andesite conglomerate separate the two limestones. The lower Permian limestone is overlain by siliceous argillite and thinly bedded quartzite that grade upward into graywacke. A bed of limestone of unknown thickness and devoid of fossils occurs in the argillite. It resembles the lower Permian limestone, but its relationship to the main limestone bed is not known, as it is poorly exposed. The limestone contains several large sinks, one of which appears to be at least 50 feet deep.

Lower Mesozoic (?) Rocks

Distribution.—A thick sequence of graywacke conglomerate, grit, graywacke, siltstone, argillite, and shale crops out on the northeastern end of Sumas Mountain and on the eastern slope of Black Mountain at the headwaters of Boulder Creek (pl. 1).

Lithology.—On Sumas Mountain the predominant rocks are conglomerate, grit, and graywacke, whereas on Black Mountain siltstone and shale predominate. The conglomerate, grit, and graywacke are medium bluish gray to dark greenish gray, very well indurated, and many of them resemble igneous rocks in toughness. On Sumas Mountain they are massive and form bold cliffs several hundred feet high. From a distance the outcrops of the rocks look like igneous rocks.

The graywacke consists of unsorted fragments of quartz, chert, plagioclase, argillite, and basic volcanic rocks in an abundant argillaceous matrix. Most of the fragments are angular to subangular. The matrix consists of a paste of chlorite, sericite, and clay- and silt-size particles that in some rocks is barely distinguishable from the fine-grained rock fragments. Scattered throughout the matrix is opaque carbonaceous material, some of which forms thin stringers that surround the rock fragments. Thin section studies show the graywacke to have approximately the following composition:

	Percent
Rock fragments	30
Feldspar	25
Quartz	15
Chert	5
Mica, pyroxene, and amphibole	5
Matrix (chlorite, sericite, clay minerals, and carbonaceous matter)	20

Where the graywacke becomes finer grained, the percentage of quartz and feldspar increases and of rock fragments decreases. The folia of chlorite and sericite are somewhat aligned, which gives some of the rock a crude schistosity. In most of the very fine grained graywacke, and especially in the siltstone, the minerals are completely altered to sericite, chlorite, and clay minerals.

The very coarse grained graywacke grades into grit that contains abundant argillite and chert fragments. The argillite fragments are mostly angular to subangular and platy; many of them are as much as 1 inch across. The chert fragments are subangular to subrounded and average about 5 millimeters across. Although the fragments of the grit consist chiefly of argillite and chert, fragments of other rock types may be present.

On Sumas Mountain the grit makes up the largest part of the lower Mesozoic section. On the northwestern slope of the mountain the uppermost part of the section contains a mixed pebble graywacke conglomerate (fig. 4). The pebbles consist of quartz, chert, argillite, basic volcanic rocks, diorite, and gneiss. A few granite pebbles are present, but they usually appear more gneissic or dioritic than the average granite. The matrix of the conglomerate is of the same general composition as graywacke. Numerous thin white veinlets of secondary quartz occur in the otherwise massive conglomerate.

On Sumas Mountain, shale and siltstone underlie the conglomerate and graywacke, but on Black Mountain their relative position in the section is uncertain. On Black Mountain the shale is black, and in places it is so highly carbonaceous that it appears sooty. Much of the shale is sufficiently indurated to be called argillite and contains numerous white quartz and calcite stringers. It is difficult to observe any bedding planes, as most of the shale is highly contorted and sheared.

On Sumas Mountain the only exposures of shale and siltstone are on upper Breckenridge Creek, where they are medium to dark gray and thin bedded. Some of the shale exhibits slaty cleavage, and in the NE¼ sec. 25, T. 40 N., R. 4 E., it is phyllitic. The outcrops are scarce, and where exposed the shale is highly fractured. Many of the fractures are filled with stringers of calcite and quartz. No fossils were found on either Sumas or Black Mountain.

FIGURE 4. Graywacke conglomerate boulder of early Mesozoic age. Cobbles and boulders of argillite, chert, andesite, and dacite in a graywacke matrix.

Age.—Because of the lack of fossils, the age of the lower Mesozoic sedimentary rocks cannot be accurately determined. The assigned early Mesozoic age is based on data indicating that the rocks were deposited unconformably upon the upper Paleozoic rocks and are overlain by Eocene sedimentary rocks. The lack of granite detritus in these sedimentary rocks suggests that deposition occurred prior to the erosion of the granitic masses that are both east and north of the map area. Studies by the Geological Survey of Canada indicate that most of the granitic rocks of southwestern Canada were emplaced from Early Jurassic to Tertiary time (Geological Discussion Club, 1960, p. 9). The relationship of the lower Mesozoic rocks of the map area to the Cultus Formation (Late Triassic-Early Jurassic) (Frebold, 1953, p. 1232) of southwestern Canada is not known; however, they may be of equivalent age.

Upper Cretaceous-Lower Tertiary Rocks

About 40 percent of the north half of the Van Zandt quadrangle is underlain by Upper Cretaceous and lower Tertiary sedimentary rocks. They are confined chiefly to Slide and Sumas Mountains, in the south half of the map area. The rocks consist of great thicknesses of conglomerate, sandstone, siltstone, and shale of continental origin. They are predominantly arkosic, but minor graywacke beds are also present. Coalified plant fragments occur in many of the shale beds, and in several beds form thin coal seams.

On lithological and structural differences, these sedimentary rocks have been mapped as two units. The older unit, which is of Late Cretaceous-early to middle Eocene age, is referred to as the Chuckanut Formation. The younger, which is of probable late Eocene age, is referred to as Tertiary continental sedimentary rocks.

Chuckanut Formation

Distribution.—Within the map area, all of Slide Mountain and most of the southern end of Sumas Mountain are underlain by the Chuckanut Formation. On the north end of Sumas Mountain an erosional remnant of this formation is exposed in secs. 17 and 20, T. 40 N., R. 5 E. (pl. 1). Rocks of the Chuckanut Formation are not present on Red Mountain, and they underlie only about 2 square miles of the southeastern slope of Black Mountain.

Lithology.—The Chuckanut Formation consists of thick beds of conglomerate, sandstone, siltstone, and shale. The relative percentages of the major rock types vary greatly throughout the formation; however, within the map area the distribution is about 70 percent sandstone, 20 percent conglomerate, and 10 percent shale and siltstone. Individual beds are as much as 200 feet thick, but are limited in areal extent and cannot be used for correlation purposes.

Conglomerate.—Conglomerate beds occur throughout the section and range in thickness from thin seams to massive beds about 200 feet thick. The conglomerate is composed of pebbles and cobbles ranging from 1 to 3 inches in diameter and minor amounts of granules and boulders. The fragments are generally well rounded, and consist chiefly of granitic and volcanic rocks, quartz, chert, quartzite, and argillite. Pebble counts of three massive conglomerates indicate the following percentages:

	Percent
Volcanic rocks	20–25
Granitic and gneissic rocks	15–25
Chert and quartzite	35–50
Quartz	5–10
Argillite and slate	5–15
Graywacke	3

The conglomerate in general is moderately to well indurated, poorly sorted, and unstratified. However, interbeds of sandstone and siltstone usually show some stratification. The matrix consists of a heterogeneous mixture of sand, silt, and clay. Subangular to subrounded fragments of quartz, feldspar, rock, and mica predominate. The cement consists of calcium carbonate, iron oxide, or secondary silica. Where unweathered the matrix is medium gray to greenish gray, but where weathered it is yellowish brown or buff.

As many of the conglomerate beds are more resistant to weathering and tend to form more conspicuous outcrops than the associated sandstone, siltstone, and shale, they usually form cliffs and ridges.

The thick conglomerate beds and their related poorly sorted sandstones and siltstones are indicative of rapid deposition. Probably they are in part fanglomerates that were deposited as a series of merging alluvial fans upon piedmont alluvial plains. A universal basal conglomerate is not present in the map area. Conglomerate, sandstone, and siltstone were deposited directly upon the basement rocks.

Sandstone.—Sandstone forms the major part of the Chuckanut Formation and is mainly arkose. It is medium to coarse grained and is composed of subangular to subrounded grains of quartz, feldspar, rock fragments, chert, and flakes of mica. Claylike particles of kaolinite, chlorite, and sericite occur interstitial to the larger grains, and secondary silica, calcium carbonate, and iron oxide form the cement. Most of the sandstone is moderately to well indurated, but some beds are so poorly indurated that they tend to disintegrate upon exposure to weathering. Both porosity and permeability of most of the sandstone appear to be low.

The composition of the sandstone varies throughout the formation, and it would be impossible to give an average composition for the whole. However, the composition of five samples from different parts of the formation is as follows:

	Percent
Quartz	20–30
Feldspar	30–60
Rock fragments	5–40
Mica	2– 5
Clay minerals	3– 5
Accessory minerals	< 5
Iron oxide	< 5
Calcite	< 3

Individual sandstone beds range from several inches to 100 feet or more in thickness. Although some units are distinctly bedded, much of the sandstone is so massive that it is difficult to recognize any bedding. Crossbedding is present in some beds. Unweathered surfaces of the sandstone are medium to greenish gray, whereas weathered surfaces are generally buff to light brown. Differential weathering has produced solution cavities in certain strata. The cavities, some of which are as much as 6 feet in diameter, are usually confined to the walls of the cliff-forming strata.

About 80 percent of the sandstone is arkose, and 20 percent is graywacke and subgraywacke. In the graywacke, fragments of basic volcanic rocks, chert, and argillite are more common than fragments of quartz and feldspar, and therefore the graywacke is darker in color than the arkose. Also, the rock fragments and mineral grains of the graywacke tend to be more angular than the grains in the arkose. Although graywacke and subgraywacke usually occur as minor beds in different parts of the Chuckanut Formation, a thick sequence of them is well exposed along Boulder Creek in sec. 22, T. 40 N., R. 6 E. The similarity between the rock fragments of the graywacke and the neighboring basement rocks suggests that the graywacke may be a basal unit of the Chuckanut Formation.

Siltstone and shale.—Siltstone and shale beds occur throughout the Chuckanut Formation and range from thin seams only a few inches thick to massive beds as much as 75 feet thick. They show all gradations from shale without any grit to sandy shales that approach very fine grained sandstones. Most of the shale, however, is within the siltstone class and is almost always gray or dark gray in color. Where abundant carbonaceous material is present they are black, and where rich in iron oxide they are dark reddish brown to grayish red. The siltstone is soft and easily weathered, whereas some of the purer shales are dense and so well indurated that they resemble argillite.

Many of the carbonaceous shales contain abundant imprints of plant fragments, usually of leaves and stems. Leaf imprints that are found in many of the shale beds are mostly of the broadleaf types; however, occasional imprints of conifer branches and palm fronds can be found. The palm frond imprints appear to be more common to the lower part of the Chuckanut Formation. In places, roots, trunks, and branches of trees have been preserved. Although outside of the map area, an excellent example of a buried tree trunk may be seen at a quarry in the SE¼ sec. 31, T. 39 N., R. 5 E. (fig. 5). It is evident that the exposed tree trunk was buried while still in an upright position, because the roots can be seen spreading out into a carbonaceous shale that represents the old soil profile. The thickness of the massive arkosic sandstone that buried the tree substantiates the theory of the rapid rate of the erosion and deposition that took place during Eocene time. Another fossil tree trunk is well exposed in a road cut near the SE¼NW¼ sec. 36, T. 40 N., R. 6 E. (fig. 5).

In parts of the Chuckanut Formation many of the carbonaceous shale beds grade into lignite and subbituminous coal beds of commercial value. However, in the north half of the Van Zandt quadrangle the coal beds are too thin to be of commercial value.

Conditions of deposition.—The Chuckanut Formation was deposited during Late Cretaceous and early Tertiary time, upon a coastal plain of low relief. The strata of the formation are entirely of continental origin and appear to have been deposited in broad alluvial valleys. Streams with steep gradients furnished abundant material that spread out into the valleys as alluvial fans, many of which were so closely spaced that they merged into continuous plains. Differential uplift in the area undergoing erosion, as well as differential subsidence of basins in the valleys, caused frequent shifts in the areas of deposition. Temporary ponding of water in basins allowed deposits of clay to accumulate. At different intervals during the deposition of the Chuckanut Formation, the area was stable enough to allow semitropical vegetation to grow. Many of these nondepositional intervals correspond to the numerous coal seams of the formation.

The prodigious amounts of arkosic sediments indicate that they were derived from the erosion of land masses composed of granitic bodies and associated metamorphic rocks such as gneisses. Many such pre-Tertiary rocks existed to the east and north of the area of deposition. However, not all the sediments were derived from granitic masses. The beds of graywacke indicate that land masses composed of argillite, chert, serpentine, siltstone, and basic volcanic rocks were also undergoing erosion. This is especially true of the lower part of the Chuckanut Formation. The basement rocks in the area of this report consist mainly of argillite, graywacke, chert, and basic volcanic rocks, which indicates that the area underwent erosion when the lowermost part of the Chuckanut Formation was being deposited. As the erosion proceeded eastward, the granitic bodies were eroded and the sediments became predominantly arkosic.

Thickness.—The lack of key beds, combined with much folding and faulting within the Chuckanut strata, makes it difficult to determine the thickness of the formation in the map area. Its maximum thickness appears to be about 10,000 feet. This represents the thickness of a sequence of steeply dipping conglomerate, sandstone, and siltstone that forms the southern end of Sumas Mountain. The total thickness appears to be much greater to the south, where homoclinal strata on Slide Mountain and the Van Zandt Dike suggest thicknesses in excess of 15,000 feet. This is in general agreement with Glover (1935, p. 24), who suggests a probable total thickness in excess of 16,000 feet, near Bellingham.

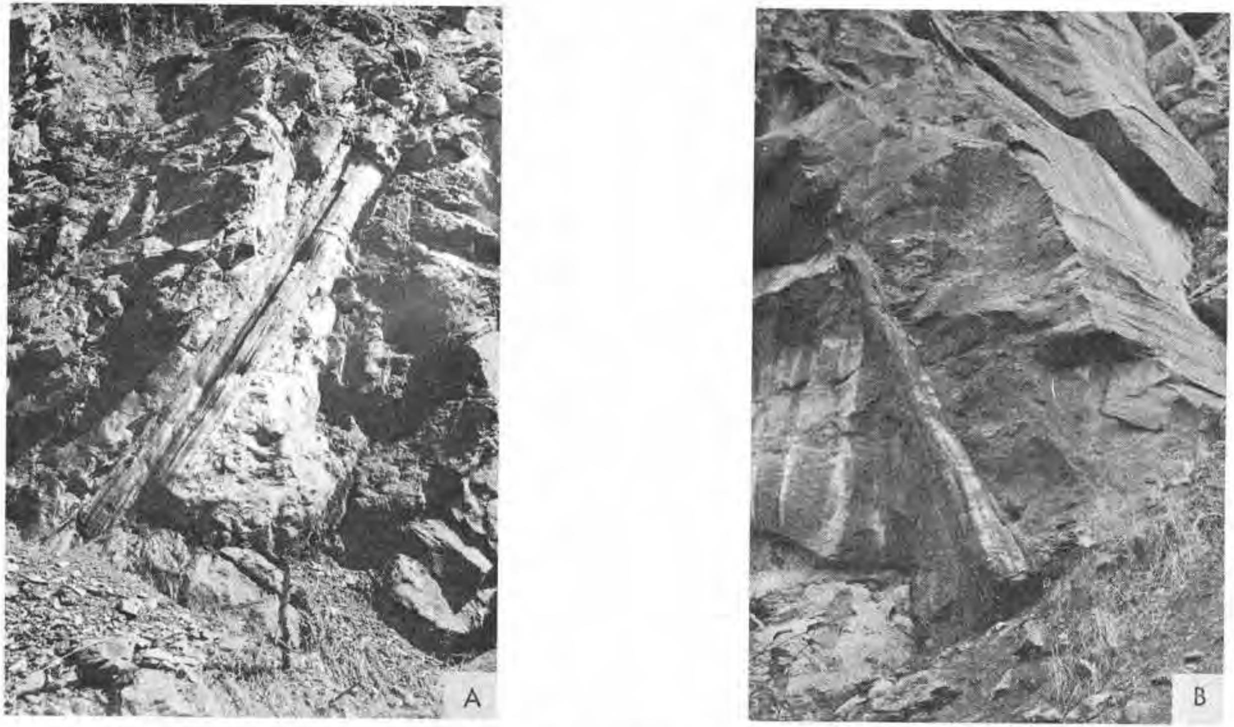

FIGURE 5. Fossil trees in Chuckanut sandstone.

A. Tree trunk is parallel to sandstone beds. Road cut near SE¼-NW¼ sec. 36, T. 40 N., R. 6 E.

B. Tree trunk is perpendicular to sandstone beds. Roots extend into lignite bed, which represents old soil profile. Quarry near SW¼SE¼ sec. 31, T. 39 N., R. 5 E.

Age.—The Chuckanut Formation for the most part appears to be of early Eocene age. This age is based on studies of plant remains collected from the formation at its type locality along Chuckanut Drive south of Bellingham. McLellan (1927, p. 136-138) states that work by Dr. F. H. Knowlton places the formation in the early Eocene. McLellan also points out that work by J. S. Newberry indicates that Late Cretaceous fossil plants are present. Recent studies by Marie Pabst (oral communication, 1960) of the Chuckanut flora from many localities in western Washington indicate that the Chuckanut Formation ranges in age from Late Cretaceous through early Oligocene. However, the sedimentary rocks of Oligocene age might possibly represent post-Chuckanut deposition.

Definite correlation with other formations has not yet been firmly established. However, the Chuckanut Formation was probably deposited at the same time as the Swauk Formation of eastern Washington. The Swauk Formation is considered to be of Late Cretaceous to Eocene age. The Chuckanut Formation may correlate, in part at least, with the marine sedimentary rocks of the San Juan Islands mapped by McLellan (1927, p. 118) as the Nanaimo Series.

Tertiary Continental Rocks

Distribution.—Those rocks mapped as Tertiary continental sedimentary rocks are confined mainly to the western slope of Sumas Mountain. The outcrops extend in a northerly direction for about 8 miles and average about 1 mile in width. Several small outcrops, all of which are less than half a square mile in area, crop out on other parts of Sumas Mountain as well as on the southwestern end of Vedder Mountain (pl. 1).

Conglomerate.—Conglomerate, which is composed of mixed pebbles and cobbles from 1 to 3 inches in diameter, makes up about 30 percent of the section. A few boulders as much as 15 inches in diameter are present in the lower beds. The pebbles and cobbles consist mainly of volcanic rocks, granitic and gneissic rocks, chert, quartz, and argillite that are well rounded and covered by a thin coating of iron oxide. The matrix is generally arkosic but approaches a graywacke in some beds. The conglomerate is poorly to moderately indurated and is cemented by a calcareous and ferruginous cement. Where only slightly cemented, the conglomerate resembles the stratified gravels of the Pleistocene glacial outwash deposits.

Conglomerate is distributed throughout the section of the Tertiary continental sedimentary rocks. In the canyon of Saar Creek (SW¼SE¼ sec. 12, T. 40 N., R. 4 E.) it appears as a basal conglomerate that unconformably overlies contorted argillite and quartzite of the Chilliwack Group. (See p. 72.)

A massive, poorly indurated pebble conglomerate crops out on upper Saar Creek in the SW¼ sec. 17, T. 40 N., R. 5 E. Though it is poorly exposed, the conglomerate appears to have been deposited unconformably upon rocks of the Chuckanut Formation and the Chilliwack Group. The conglomerate matrix is more silty than that of the other conglomerates of the area and contains abundant iron oxide, which gives a rusty color to the outcrops.

A small outcrop of Tertiary continental conglomerate is well exposed near the NE¼SE¼ sec. 19, T. 40 N., R. 5 E. It is slightly more indurated than the other conglomerates of the section and forms a cliff about 30 feet high. The conglomerate contains large angular blocks of serpentinite as much as 10 feet long and mixed pebbles in a sandstone of graywacke composition. The conglomerate appears to have been deposited near the base of a serpentinite cliff, for the angularity of the serpentinite blocks indicates little, if any, transportation after deposition.

What appear to be other basal conglomerates crop out in secs. 12 and 14, T. 39 N., R. 4 E. Although the actual contacts are not exposed, basic volcanic rocks of the Chilliwack Group crop out within 100 feet of the conglomerates. These conglomerates resemble Pleistocene outwash gravels, and because of abundant iron oxide-coated pebbles, the outcrops have a rusty color. Some of the conglomerate contains many interbeds of arkosic sandstone that range from 2 to 8 inches in thickness (fig. 6).

FIGURE 6. Tertiary continental conglomerate on south end of Sumas Mountain. Conglomerate contains interbedded arkosic sandstone. Pebbles are well rounded and coated with iron oxide.

At least four conglomerate beds are exposed on the western slope of Sumas Mountain. They are 50 to 75 feet thick and are separated by sandstone and siltstone beds that average about 150 feet in thickness. The conglomerate consists chiefly of pebbles and cobbles, but in some of the lower beds there are abundant boulders (fig. 7). The rocks that make up the conglomerate are mainly granite, gneiss, dacite, chert, argillite, and basic volcanic rocks that are enclosed in an arkosic sand matrix. Ferruginous cementation imparts a yellowish-brown color to the weathered outcrops. Being more resistant to weathering than the interbedded sandstone and siltstone, the conglomerate beds form prominent cliffs, especially where they have been incised by streams.

FIGURE 7. Tertiary continental conglomerate on north end of Sumas Mountain. Conglomerate exposed in slide area overlies Sumas Mountain Serpentinite.

Sandstone and siltstone.—The sandstone, which is best exposed on the western slope of Sumas Mountain, in secs. 10 and 11, T. 39 N., R. 4 E., is for the most part arkosic, massive, medium to coarse grained, and buff to light brown on weathered surfaces. Unweathered surfaces are most commonly greenish gray in color. The sandstone is poorly to moderately indurated and consists of angular to subrounded grains of quartz, feldspar, rock fragments, and mica. Mineral grain counts on what is believed to be a representative sandstone gave the following percentages:

	Percent
Quartz	20
Feldspar	50
Rock fragments	5
Mica	10
Clay minerals	10
Iron oxide	<5
Calcite	<5
Accessory minerals	<1

Most of the sandstone is poorly cemented by calcium carbonate or iron oxide and weathers readily. Both the porosity and permeability of the sandstone appear to be low.

Crossbedding is very pronounced in several beds, and changes from sandstone to siltstone along the strike of beds are not unusual. Some thinly bedded siltstone contains carbonaceous partings of unidentified plant remains.

Shale.—The shale of the Tertiary continental sedimentary rocks ranges from high-grade fire clay to silty clay that approaches siltstone. A stratigraphic section as measured by Glover (1941, p. 310-311) on Saar Creek is given on page 72 of this report. Of 525 feet of section that was described, 65 percent is shale, 20 percent is conglomerate, and 15 percent is sandstone. Individual shale beds are as much as 50 feet thick; however, the average thickness of the beds is about 10 feet. The shale varies in color through different shades of blue, red, and yellow, whereas the higher grades of fire clay are generally blue or light blue. Some of the shale beds contain thin layers of coalified plant material. In the now abandoned mine workings of the Sumas clay mine, 2 feet of carbonaceous shale and 2 inches of coal were encountered during earlier mining operations. (See p. 81.) Although the shale beds are carbonaceous, they do not appear to be as carbonaceous as the shale beds of the Chuckanut Formation.

The shales that possess refractory properties are more dense and better indurated than others in this unit. Some of the refractory shales have flintlike structure and conchoidal fracture. Although shale beds occur in different parts of the Tertiary continental section, only some of those shales in the lower 500 feet of the section are known to be of refractory quality. These shales are confined to secs. 7, 17, and 18, T. 40 N., R. 5 E., and sec. 12, T. 40 N., R. 4 E. (fig. 25, p. 68).

Shales, which represent the lowermost part of the Tertiary continental sediments, are exposed in the NE¼ sec. 2, T. 39 N., R. 4 E., on the western slope of Sumas Mountain. They are ferruginous, containing as much as 48 percent iron. The shales were developed from laterites that formed upon a pre-Tertiary peridotite erosion surface. They range from 30 to 50 feet in thickness and are known as the Sumas Mountain iron deposit. (See p. 107.)

Conditions of deposition.—These strata are entirely of continental origin and were deposited unconformably upon an old erosion surface of moderate relief. The basement complex varies in lithology from one locality to another; however, argillite and graywacke predominate.

The massive conglomerates and the rapid changes in lithology from one locality to another suggest that the Tertiary continental sedimentary rocks were deposited under unstable conditions similar to those of the Chuckanut Formation. Much of the sedimentary material was probably derived from the erosion and reworking of the older Chuckanut Formation. During the deposition of the sediments there appear to have been no long intervals of stability. A few thin coal seams indicate nondepositional periods, not, however, as frequent nor as long as those during Chuckanut time.

The total thickness of the Tertiary continental sedimentary rocks is not known, but on the northern end of the outcrop belt there are about 3,000 feet of strata. These represent the lower part of the section, the upper part of which is concealed by the surficial deposits of the Whatcom Basin. The western extension of this unit is not known; however, it probably underlies parts of the basin.

Age.—In the SW¼ sec. 17, T. 40 N., R. 5 E., conglomerate of the Tertiary continental sedimentary rocks was deposited unconformably upon tightly folded Chuckanut conglomerate and sandstone. In the NE¼ sec. 11, T. 39 N., R. 4 E., it was deposited over a post-Chuckanut fault that separates steeply dipping Chuckanut beds on the south from pre-Tertiary rocks on the north. Inasmuch as the Chuckanut Formation is of early Eocene age, the structural relationship between the two units indicates a post-early Eocene age for the Tertiary continental rocks.

In Canada, on the southwestern end of the Canadian Sumas Mountain, a similar sequence of conglomerate, sandstone, and shale crops out. Daly (1912, p. 520) assigned a questionable Eocene age to these rocks. Danner (1957, p. 5) places them in the late Eocene. Two other formations of southwestern British Columbia, the Kitsilano and Burrard (Johnston, 1923, p. 13-30) are also lithologically similar to the Tertiary continental sedimentary rocks of the American Sumas Mountain. Johnston considers the Kitsilano Formation as late Eocene and possibly early Oligocene, and the Burrard Formation as middle Eocene in age. Like the Tertiary conglomerate of the map area, the Kitsilano and Burrard Formations contain thick, poorly sorted and poorly consolidated conglomerate units that in part resemble Pleistocene outwash gravels.

Although a definite age cannot yet be assigned to the post-Chuckanut continental sedimentary rocks of the map area, they are probably of late Eocene age and are correlative with the Huntingdon Formation of southwestern British Columbia.

Quaternary Sediments

Pleistocene Deposits

Glacial outwash.—Deposits of recessional glacial outwash are found in the major valleys of the map area. In the valley of the Nooksack River the outwash, in most places, has been reworked by the river.

Outwash deposits consist of gravel, sand, and clay, upon which a thin soil profile has developed. The gravel is composed of unsorted pebbles and cobbles, of which as much as 50 percent is granitic rocks and the remainder volcanic and sedimentary rocks. Chert and argillite are present in most of the gravel, and interbedded with the gravel are numerous beds of medium- to coarse-grained sand. In many roadcuts, foreset bedding of the sand and gravel is well exposed. In Columbia Valley the deepest water well has penetrated about 138 feet of sand and gravel without reaching bedrock (Dee Molenaar, oral communication). The clay beds, some of which are as much as 50 feet thick in the vicinity of Kendall, are dark to light bluish gray in color. Most of the clay is sandy or silty and contains occasional pebbles.

The deposits of outwash are pitted, and in several areas kettles are present. Silver Lake, the largest lake in the map area, occupies one of these kettles. A smaller kettle is several hundred feet west of the north end of Silver Lake, but is filled with water only during the wettest parts of the year. Several smaller kettles, some of which contain water, are in sec. 10, T. 40 N., R. 5 E.

The outwash deposits of Columbia Valley and the valley that is occupied by Silver Lake are probably of Vashon age. They represent recessional outwash that has been reworked by streams that were diverted southward during the last advance of valley ice that occupied the Sumas Valley, about 11,000 years ago.

Glacial drift undivided.—The material mapped as glacial drift includes ground moraine and glaciofluvial deposits. Inasmuch as the area was completely covered by the continental ice sheet, the drift is present over the entire area. It ranges in thickness from a thin veneer of scattered stones to compact deposits of till as much as 50 feet thick. The areas mapped as glacial drift are those in which the drift is believed to be more than 25 feet thick and in which very little bedrock is exposed.

The ground-moraine till is generally a bluish-gray, massive, compact mixture of pebble gravel, sand, silt, and clay. Cobbles and boulders, some of which exceed 8 feet in diameter, are present in the till in many places. The till is generally unstratified and unsorted; however, in places it is somewhat sorted and exhibits crude stratification. Some thin sand and gravel lenses are also present.

When exposed to weathering, the till changes to a yellowish orange color.

Associated with the ground moraine are glaciofluvial deposits of pebble gravel, sand, silt, and clay. These sediments are distinctly bedded and well sorted. The beds are usually horizontal, and many of the sands exhibit crossbedding. The glaciofluvial deposits are poorly indurated and are readily eroded. They are best exposed in road cuts and gravel pits or where they have been incised by streams. The glaciofluvial sediments are usually 25 to 50 feet thick but in places attain thicknesses of more than 100 feet.

The deposits mapped as glacial drift (Qg) are products of the Vashon glaciation and were deposited during the last advance of a continental ice sheet. At higher elevations, such as on Black Mountain, deposits of later alpine glaciers are included but are not differentiated.

Recent Deposits

Lacustrine deposits.—Those sediments mapped as lacustrine are confined to the northwestern corner of the Van Zandt quadrangle and occupy a large part of Sumas Valley. At the surface the sediments consist chiefly of silt, clayey silt, and silty clay. The silt averages about 10 feet in thickness, but in some places it is as much as 50 feet thick. Sand and gravel beds, which have been penetrated by many water wells, lie beneath the lacustrine deposits. The depth to bedrock is not known, but a few miles to the north in Canada, Armstrong (1960, p. 9) reports that one well, drilled to a depth of 864 feet, did not reach bedrock. In its last stages, the basin into which the lake sediments were deposited was occupied by Sumas Lake. This lake, which was drained in 1926 to provide more farmland, was 6 miles northeast of Sumas, in Canada.

Terrace deposits.—The surficial materials that have been mapped as terrace deposits border the present-day flood plain of the Nooksack River and represent old flood plains. The deposits, which occur in terraces from 3 to 8 feet above the river level, are composed mainly of gravel, sand, and silt of fluvial origin. They are unconsolidated, and a covering of silt is generally present over the sand and gravel. When cleared of vegetation, the terraces provide excellent farmland. Although mapped as Recent deposits, they may be Pleistocene in part.

Landslides.—Deposits mapped as landslides are overburden and bedrock that have moved downward and outward from their original site. Normal surficial creep is excluded. Although there is evidence for many landslides in the area, only the largest slides were mapped.

Slide Mountain, as the name implies, contains numerous slides, most of which are of the block glide type (Eckel, 1958, p. 21). The largest slide is chiefly in sec. 33, T. 40 N., R. 6 E., and is more than 1 square mile in area (fig. 8). This slide developed on northward-dipping sedimentary rocks, sliding down dip on shale beds that became saturated with water. The toe of the slide appears to have crossed the Nooksack River, as numerous large blocks of sandstone may be found across and down river from the slide. Although most of the slide is covered by dense brush, new slides are still being formed near the head of the old slide. The scarps of these slides are plainly visible from State Highway 1 opposite the slide area.

FIGURE 8. Old landslide on north end of Slide Mountain. Area covered by slide is outlined by dashed line. Nooksack River skirts toe of slide.

Another slide of the block glide type is in sec. 10, T. 39 N., R. 5 E., and covers about half a square mile. The main scarp of this slide may be seen from the general area of Kendall, and is at about the 1,400-foot elevation on the northwest corner of Slide Mountain. The toe is 1½ miles from the scarp and almost reaches the Nooksack River. A small pond has developed upon the hummocky surface of the slide near its toe.

An active slide area is on the western slope of Sumas Mountain between 1,000 and 2,000 feet in elevation. It is chiefly in the SE¼ sec. 35 and the SW¼ sec. 36, T. 40 N., R. 4 E., and is visible from many places in the valley below, as it stands out as a prominent scar on the otherwise wooded slopes of Sumas Mountain. The stream that carries the drainage from the area of the slide is almost always milky white due to suspended clay particles. The rock materials involved in the slide are mixed cobble and boulder conglomerates of early Tertiary age that have been deposited upon a pre-Tertiary serpentinite basement. A deposit of clay that has developed upon the serpentinite acts as a lubricant between the two units. The westward-dipping conglomerates slide into the valley when the clay becomes so saturated with water that the friction holding them in place is overcome. Although the ground above the slide has not yet slid, it exhibits features found in areas of unstable ground. Much soil creep is evident, and trees are tipping in many directions. Many minor slides are developing within areas of steep slope. Throughout the area numerous transverse and longitudinal cracks have developed, some of which are as much as 5 feet wide and 25 feet deep. The area in general is susceptible to slides, and there is no reason to doubt that new slides will develop, especially during times of heavy rainfall, when the underlying clay becomes saturated with water.

A well-defined ancient slide is present half a mile west of Kendall, mainly in secs. 33 and 34, T. 40 N., R. 5 E. There is no evidence of recent movement of this slide, as it is covered by a good growth of brush and timber. The slide debris extends about a third of a mile into Columbia Valley and consists chiefly of large blocks of serpentinite, chert, and basic volcanic rocks. The matrix consists of partly disintegrated rock and soil. This slide is expressed topographically as extending fanlike onto the flat floor of Columbia Valley. (See pl. 1.)

Alluvium.—The material referred to as alluvium is the accumulation of present-day flood-plain debris of the Nooksack River and its tributaries. These deposits are confined to areas of active stream erosion and deposition, and consist of pebble- and cobble-size gravel derived chiefly from the reworking of glacial deposits. Beds of sand and silt are included with the gravel but comprise only a small part of the deposits. All rock types are present in the gravel, which in places is as much as 50 feet thick, and is suitable for gravel-pit operations.

IGNEOUS ROCKS

Chilliwack Group Volcanic Rocks

Distribution.—The distribution of the volcanic rocks of the Chilliwack Group is shown on plate 1. They crop out on all mountains of the map area except Slide Mountain. On Red Mountain the volcanics are confined mainly to the southern half of the mountain, and on Black Mountain they occur chiefly on the southeastern part.

On the southern end of Red Mountain the volcanic rocks are mainly andesitic lithic tuffs. Grit, graywacke, and siltstone are associated with the volcanics, but the contacts between the different rocks are not exposed. The most extensive exposures of the volcanic rocks are on the southeastern part of Black Mountain. They, too, are mainly andesitic lithic tuffs, and they include interbedded tuffaceous and siliceous siltstones. Augite andesite (some of which is porphyritic), spilite, and dioritic rocks are also present. The sequence is best exposed on the northwestern slope of a ridge that extends diagonally across secs. 9 and 17, T. 40 N., R 6 E., and along a logging road in secs. 21 and 22 of the same township and range.

On Sumas Mountain the volcanics are not as extensive. They are best exposed on the southwestern quarter of the mountain near the headwaters of Smith Creek and near the central part of its eastern slope. A few small bodies of the volcanic rocks crop out on the western end and the central part of Vedder Mountain, as well as on several small hills between Sumas and Vedder Mountains.

Extrusives and related intrusives.—Most of the volcanic rocks of the map area are dark greenish gray to greenish black. Hand specimens consist of a dense, compact aggregate of unidentifiable minerals. However, in some rocks lathlike outlines of plagioclase and subhedral crystals of augite or hornblende can be recognized. Chlorite occurs throughout the groundmass of most of the rocks.

Under the microscope, in thin sections, almost all the volcanics are seen to be composed of sodic plagioclase, chlorite, amphibole, pyroxene, epidote, and volcanic glass in various combinations and amounts. They are either holocrystalline or hypocrystalline, and some rocks exhibit diabasic or subophitic textures. Trachitic texture was noted in some of the rocks, but is not common.

Plagioclase is present in all the rocks as euhedral to subhedral laths and microlites. They are generally less than 0.3 millimeter in length, but in some of the porphyritic rocks they are as much as 3 millimeters long (fig. 9). Most of the plagioclase has been altered by saussuritization, which makes it difficult to determine its original composition. Measurements of the extinction angles on unaltered laths of plagioclase give a composition of An_{25} to An_{35}, or intermediate between oligoclase and andesine. Many of the altered plagioclase laths give low extinction angles suggestive of albite and oligoclase.

From 10 to 20 percent augite is present in most of the volcanic rocks. One sample from the SE¼ sec. 14, T. 39 N., R. 4 E., contained almost 50 percent augite. It is usually interstitial to the plagioclase; however, in the rocks that have subophitic texture the augite partly encloses the plagioclase. Most of the augite occurs as subhedral to anhedral granules and short prisms that are less than 0.3 millimeter long. Some prisms are twinned and zoned. In many of the rocks the augite is completely replaced by chlorite and (or) fibrous hornblende.

Chlorite is present in all the volcanic rocks, some of them containing as much as 5 percent of it. Chlorite is usually interstitial to the primary minerals but also occurs as thin stringers or amygdules (fig. 12). Penninite, with its anomalous "Berlin blue" interference color, is present in almost all of the samples. Iron-rich prochlorite in fan-shaped crystal aggregates was noted in some volcanics, but it is not as common as the other chlorites. A mineral that is believed to be pumpellyite is associated with some of the chlorite. It is usually surrounded by chlorite, but in one specimen it occurs as needlelike crystals in radiating groups (fig. 10).

Primary amphiboles are present in the volcanic rocks but are generally not as abundant as the pyroxenes. Hornblende appears as the main amphibole, whereas actinolite and tremolite are generally minor in quantity. Much of the amphibole is fibrous hornblende, which is an alteration product of pyroxene. Hornblende and chlorite pseudomorphs after pyroxene were noted in some specimens. Hornblende is also present as euhedral phenocrysts as much as 6 millimeters long in some of the porphyritic andesites. Although most of the volcanic rocks contain less than 10 percent of amphibole, those on the southwestern end of Sumas Mountain contain as much as 30 percent of it, much of which occurs as microlites of actinolite and tremolite.

The alteration of the volcanic rocks makes it difficult to identify the fine-grained minerals. What appears to be devitrified volcanic glass, as well as sericite, calcite, fine-grained epidote, serpentine, magnetite, sphene, leucoxene, and pyrite are present in most of the rocks. Combined, they usually make up less than 10 percent of the rock.

The predominant extrusive volcanic rocks of the Chilliwack Group are augite andesites. However, the chlorite-epidote-albite mineral assemblages of some of the basic volcanic rocks place them in the greenstone class.

Basic volcanic rocks that appear to be spilites crop out along the Boulder Creek logging road in secs. 21 and 22, T. 40 N., R. 6 E. The spilite is dark green, aphanitic, and contains many vesicles and amygdules. In thin section, the spilite consists of divergent laths of sodic plagioclase (albite-oligoclase) (fig. 11). The laths average 0.3 to 0.5 millimeter in length, and some are bent. The plagioclase is commonly cloudy and contains specks of chlorite and calcite. Chlorite, calcite, devitrified glass, sphene, and leucoxene fill the spaces between the plagioclase laths. What appears to have been the original pyroxene has been replaced by chlorite. Penninite and prochlorite appear to be the predominant chlorites. The prochlorite occurs as fan-shaped crystal aggregates, which fill the vesicles of the spilite.

One of the few volcanic rocks that is distinctly different from the andesitic and basaltic rocks is a pale-green porphyritic dacite.

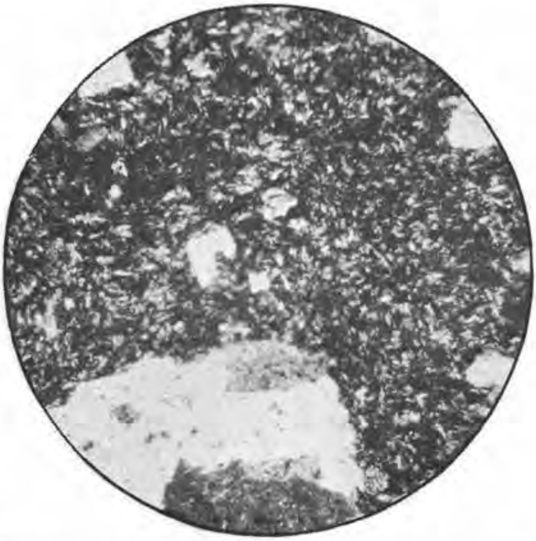

FIGURE 9. Photomicrograph of porphyritic andesite. Plagioclase (An_{30}) phenocrysts surrounded by chlorite, augite, and saussuritized plagioclase. (× 60—crossed nicols.)

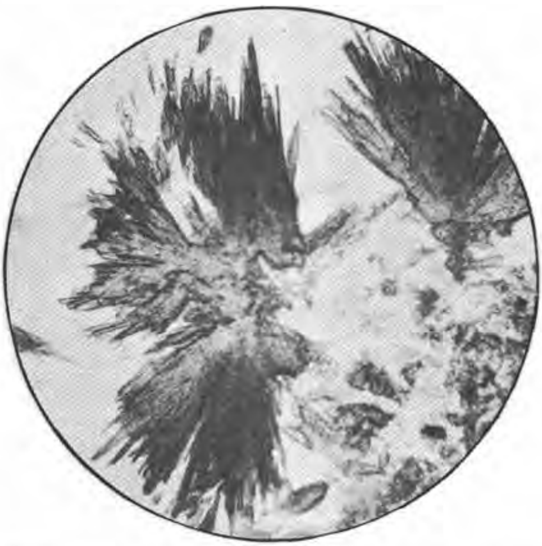

FIGURE 10. Photomicrograph of pumpellyite in greenstone. Pumpellyite (dark-gray radiating needles) in albite (white). (× 90—crossed nicols.)

The dacite crops out on the southwestern end of Vedder Mountain in the SE¼NW¼ sec. 7, T. 40 N., R. 5 E. In outcrop form it resembles a small plug that has been intruded into rocks of the Chilliwack Group, but in no place is the contact visible.

In hand specimen, the dacite is a pale-green aphanitic rock that contains some phenocrysts of quartz. Thin white stringers of quartz traverse much of the dacite. In thin section, the groundmass is seen to be composed of a fine-grained mosaic of quartz and feldspar that resembles chert. Fine-grained epidote and also sphene and leucoxene occur throughout the groundmass.

The quartz phenocrysts are angular to well rounded, average about 0.35 millimeter across, and make up about 5 percent of the rock. Many of the phenocrysts are embayed and have corroded borders (fig. 12). A few anhedral phenocrysts of plagioclase (An_{30}) are present also, but are generally highly corroded and altered. Hornblende, calcite, and chlorite are present in minor amounts.

The proximity of the fire clay deposits of the area to the dacite suggests that the dacite may have been the original source from which the clays were derived. Weathering of similar feldspathic rocks is believed to have formed the fire clay deposits that occur 5 miles to the north in Canada (Cummings and McCannon, 1952, p. 19).

Pyroclastic rocks.—In the upper part of the Chilliwack Group a thick sequence of pyroclastic rocks is associated with the augite andesites. The main outcrops of these rocks are on the southern end of Red Mountain and on the southeastern part of Black Mountain.

The pyroclastics are greenish gray, usually fine grained, and in hand specimens resemble andesitic rocks (fig. 13). Only where they are coarser grained does the fragmental nature of the rock become apparent. The individual beds are usually massive, but some fine-grained pyroclastics are interbedded with tuffaceous siltstones and graywackes.

Thin-section studies of the pyroclastics show that andesitic lithic tuffs predominate. Fragments of andesite, plagioclase, pyroxene, and glass are enclosed in a fine-grained matrix of essentially the same minerals and rock fragments (fig. 14). From 30 to 50 percent of the tuff is plagioclase, which occurs as laths of andesine and oligoclase, very few of which exceed 1.0 millimeter in length. Most of the plagioclase is altered, and many of the laths are corroded and filled with inclusions of glass and chlorite. Some laths are completely surrounded by fibrous chlorite and volcanic glass. Sericite and fine-grained epidote or clinozoisite are common alteration products of the feldspar. Much of the feldspar has been so highly altered that little remains of the original crystal.

Rock fragments amount to as much as 30 percent of some lithic tuffs, but are not present in all the tuffs. They are usually angular

FIGURE 11. Photomicrograph of spilite. Altered laths of albite in glassy groundmass surround amygdules of chlorite (medium gray) and calcite (light gray). (× 15—plain light.)

FIGURE 12. Photomicrograph of porphyritic dacite. Chert-like groundmass of quartz and feldspar surrounds rounded phenocrysts of quartz. (× 60—crossed nicols.)

fragments as large as 3 millimeters in maximum dimension and consist of a glassy groundmass occupied by microlites. The microlites fall within the oligoclase-andesine range, which suggests an andesitic composition for the rock fragments.

Volcanic glass is usually present and forms as much as 20 percent of the tuffs. It occurs as dust in the matrix and as fragments as large as 3 millimeters in diameter along with plagioclase and rock fragments. Much of the glass has been devitrified and altered to a light-brown mineral that resembles palagonite. Many of the glass fragments contain microvesicles filled with chlorite.

Between the coarse fragments of the tuff is a fine-grained matrix. This matrix consists of chlorite (commonly penninite), calcite, augite, quartz, serpentine, pumpellyite, and in places fibrous hornblende, which is the alteration product of the pyroxene. However, some tuffs are composed predominantly of coarse fragments and very little matrix.

In some tuffs the matrix is finely granulated, which gives the tuff a cataclastic texture (fig. 14). In these rocks, grains of feldspar and rock fragments are strewn through a fine-grained matrix of granulated feldspar, chlorite, glass, calcite, quartz, pumpellyite, and sphene.

In the field, the similarity of the andesite tuffs and the andesite flows makes it difficult to distinguish one rock from the other. This is especially true of the fine-grained varieties. Also, some of the rocks appearing to be andesitic lithic tuffs may actually be andesites that have been subjected to cataclastic deformation.

Dioritic rocks.—Although andesitic volcanic rocks are the predominant igneous rocks of the Chilliwack Group, some dioritic rocks are also present. Most of them are poorly exposed but probably occur mainly as dikes or sills. In hand specimens, it can be seen that the diorite contains about equal amounts of light and dark minerals, which give the rock a grayish color, as compared with the associated andesites that are always greenish in color. Most of the diorite is medium grained, and a hypidiomorphic texture can be seen in thin section.

The diorite is composed of 50 to 60 percent plagioclase, 20 to 30 percent hornblende, 5 to 15 percent augite, and as much as 5 percent biotite. Andesine and oligocene are the predominant plagioclases; however, low extinction angles on much of the highly altered plagioclase suggest the presence of albite. The alteration of some of the feldspar has been so complete that its composition is impossible to determine. All that remains of the original feldspar is an aggregate of fine-grained calcite, sericite, and epidote, the products of saussuritization.

Hornblende is present in all the diorite, either as a primary mineral or as the secondary fibrous variety formed by uralitization.

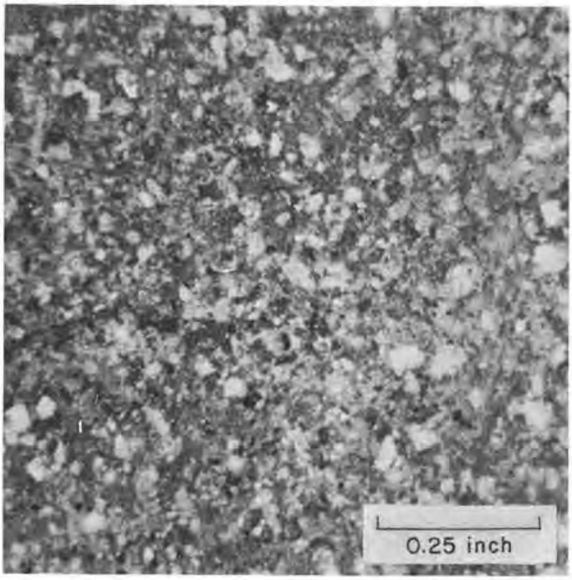

FIGURE 13. Andesite tuff. Crystals of plagioclase (white) in a matrix of chlorite, andesite fragments, and volcanic glass.

FIGURE 14. Photomicrograph of andesite tuff. Twinned plagioclase crystals surrounded by fragments of andesite, plagioclase, and volcanic glass. (× 15—crossed nicols.)

Much of the hornblende has been altered to chlorite. As much as 10 percent biotite is present in the diorite that contains primary hornblende. In the altered diorite, most of the biotite has been replaced by chlorite. Augite was noted in many samples, but much of it has been partially or completely altered to fibrous hornblende and chlorite. The minor constituents of the diorite are magnetite, sphene, skeletal ilmenite, and leucoxene. The distribution of the larger dioritic bodies is shown on plate 1. The smaller bodies, for the most part, occur within the areas designated as Paleozoic volcanic rocks; however, these bodies are too small to be shown on the geologic map.

Thickness and age.—Many of the volcanic rocks of the Chilliwack Group are highly deformed and poorly exposed, thus it is impossible to determine their thickness. The volcanic rocks in sec. 14, T. 39 N., R. 4 E., on the southern end of Sumas Mountain, and those on the southwestern slope of Black Mountain offer the best exposures in the map area. On Sumas Mountain the volcanics appear to be at least 1,000 feet thick, and on Black Mountain volcanic rocks and associated tuffaceous sedimentary rocks are almost 2,000 feet thick. Many of the volcanic rocks of the map area appear as dikes or sills, some of which are as much as 100 feet thick.

The thick volcanic sequence of the map area probably is equivalent to the Chilliwack Volcanic Formation of Daly (1912, p. 521). Daly mapped the volcanic rocks to the northeast along the International Boundary and assigned a late Carboniferous age to them. The Carboniferous age is based on fossiliferous limestones that overlie and underlie the volcanic rocks.

Within the map area, fossiliferous rocks that could be used for dating the volcanics are not present. However, near the summit of Black Mountain in the SE¼ sec. 4, T. 40 N., R. 6 E., a thick pebble conglomerate, composed of the same type of rocks as those that make up the volcanic sequence, overlies Lower Pennsylvanian limestone. The pebble conglomerate is overlain by lower Permian argillite and limestone. Should this conglomerate have been derived from the volcanic sequence of the Chilliwack Group, the volcanics would be of post-Early Pennsylvanian and pre-early Permian age.

Sumas Mountain Serpentinite

Distribution.—The main mass of the serpentinite underlies an area of about 4 square miles on the northwestern part of Sumas Mountain (pl. 1). It is about 3 miles wide on the south end and ½ mile wide on the north end. Smaller bodies, which appear to be related sills, crop out about 2 miles northeast of the main mass. In the central part of Sumas Mountain, most of the serpentinite is covered by glacial drift; however, it is exposed along the upper part of Coal Creek, in the NE¼ sec. 5, T. 39 N., R. 5 E. On the western flank of Sumas Mountain the serpentinite is confined chiefly to secs. 1 and 2, T. 39 N., R. 4 E.; and in a ravine in sec. 2 it extends to within half a mile of the valley floor.

FIGURE 15. Saxonite from the Sumas Mountain Serpentinite. Unaltered enstatite crystals (dark gray) surrounded by serpentinized olivine (light gray).

General character and petrography.—The weathered outcrops of serpentinite exhibit several distinct textures. Most surfaces tend to be smooth and even grained, like a fine-grained sandstone, but where the serpentinite contains enstatite crystals the surfaces are rough because of differential weathering. The enstatite protrudes from the serpentinite, and at times sparkles like rhinestones (fig. 15). Well-developed jointing is conspicuous, especially on cliffs (fig. 16). Two joint sets predominate throughout much of the serpentinite. In the SW¼ sec. 30, T. 40 N., R. 5 E., the joint system consists of a horizontal set and a N. 20° W.-trending vertical set. The vertical joints parallel the strike of the latest folds in the area. The folding has produced low-angle dips in the horizontal set. Many of the vertical joints have developed into faults of small displacement. Spheroidal weathering, which might be mistaken for pillow structure, is present in areas where two sets of closely spaced joints occur at right angles. This is especially noticeable in creek beds, where the weathering has been intense. Faulting in several areas has produced gouge zones of clay minerals, which impart a bluish-gray color to the soil. Where the slope is steep, numerous landslides have developed in the clay. The serpentinite that has been subjected to shearing contains many polished, slick, or slippery surfaces, and because of the shiny surfaces it is much more conspicuous than the normal weathered serpentinite. Weathered surfaces of the serpentinite tend to be yellowish gray or moderate yellowish brown. Many weathered or fresh surfaces show disseminated grains of magnetite and (or) chromite. Surfaces that were subjected to laterization are commonly moderate red to grayish red.

FIGURE 16. Sumas Mountain Serpentinite showing well-developed jointing.

The freshly broken serpentinite is dusky green or greenish black and has a sugary texture. It consists mainly of olivine and serpentine minerals. However, parts of the serpentinite contain as much as 20 percent enstatite, the crystals of which are distinctly visible. The original rock from which the serpentinite was derived appears to have been chiefly dunite, parts of which approached saxonite in composition (fig. 15).

Thin-section studies of the serpentinite from several localities show the following percentages:

	Percent
Olivine	20 to 50
Antigorite	20 to 30
Serpophite	20 to 40
Chrysotile	5 to 15
Enstatite	0 to 20
Diopside, chromite, magnetite, iddingsite, and picotite	<5

Olivine (forsterite), antigorite, serpophite, and chrysotile are the most prominent minerals. The olivine occurs as residual grains that range from 0.15 to 0.20 millimeter across. It is surrounded by the serpentine minerals, serpophite and antigorite. The serpophite appears structureless and is usually surrounded by anhedral crystals of antigorite. Thin veinlets of cross-fiber chrysotile traverse the serpophite and antigorite and also fill fractures in the olivine (fig. 17). The enstatite occurs as subhedral to anhedral crystals from 3 to 10 millimeters across. Some enstatite exhibits schiller structure and contains inclusions of olivine. Many of the enstatite crystals contain well-developed exsolution structures in which needlelike crystals of clinopyroxene (diopside?) occur parallel to the 100 cleavage. The enstatite shows little, if any, alteration as compared to the olivine, which is at least 50 percent altered. The magnetite is mostly secondary and occurs as finely divided dustlike particles.

FIGURE 17. Photomicrograph of Sumas Mountain Serpentinite. Olivine (light gray) surrounded by antigorite and serpophite (medium gray). Hairlike stringers of magnetite (black) traverse serpentinite. Note large phenocryst of enstatite in lower part of photo. (× 15—plain light.)

Many of the particles form hairlike stringers that fill fractures extending across the mineral grains of the serpentinite (fig. 17). Euhedral to anhedral grains of magnetite, chromite, and picotite (chromium spinel) are sparsely disseminated throughout most of the serpentinite. The grains average 1 millimeter across. Although the chromite for the most part occurs disseminated in the serpentinite, some chromite has been concentrated into small ore bodies. The chromite occurs as thin veins or as small irregular masses, most of which do not exceed 5 tons. (See Chromite, p. 112.)

The distribution of the enstatite-bearing serpentinite and the enstatite-free serpentinite within the Sumas Mountain mass was not established. However, from observations made on almost every exposure, it appears that the enstatite-bearing serpentinite predominates.

Although the serpentinite appears to be free of inclusions, several dikes cut the rock. The best exposed dikes are in the SW¼ sec. 36, T. 40 N., R. 4 E., and in the SE¼ sec. 17, T. 40 N., R. 5 E. These dikes are medium gray and fine grained, and because of differential weathering they are easily distinguished from the serpentinite. On the exposed surfaces of the dikes, weathering has produced what probably are solution cavities (fig 18). The dikes trend N. 10° E., are steeply dipping, and are from 10 to 20 feet wide, but because of overburden they cannot be traced for more than 50 feet. Usually, the serpentinite wall rock of the dikes is sheared and slickensided. The dike rock is composed mainly of chlorite, xonotlite, hornblende, and highly altered pyroxene. Although the crystals are chiefly anhedral, some of the partly altered grains of amphibole and pyroxene are subhedral. Most of the rock has been highly chloritized, but a few relic grains of hornblende and pyroxene still remain. Some of the hornblende, however, appears to be secondary. Sphene is disseminated throughout the rock and ranges in size from small anhedral crystals less than 0.1 millimeter across to euhedral wedge-shaped crystals as large as 0.24 to 0.64 millimeter. Much of the sphene shows well-developed cleavage, and some crystals exhibit twinning. Accessory magnetite is present in all samples.

The dikes are traversed by stringers and veins of xonotlite. Being more resistant to weathering than the rest of the dike material, these stringers tend to form distinct ribs on the surfaces of the dikes (fig. 18). The xonotlite veins average about half an inch in width and consist of chalk-white, compact, extremely tough fibrous crystals. Many of the veins are "two-fiber" veins, indicating that the xonotlite grew from both walls. A middle seam of a light-gray mineral is present in most veins. Although the veins are mainly xonotlite, small amounts of prehnite and pectolite are usually present. A sample of the vein material was submitted to R. K.

Sorem, of Washington State University, for an X-ray diffraction investigation. Dr. Sorem's report is as follows:

> The major component of the dikelet is xonotlite, judging from comparison with published X-ray pattern. A sample of the xonotlite and the middle seam, however, tested positive for P, As, or V. The central seam is not xonotlite, but perhaps is something related to the hydrogarnets.

FIGURE 18. Xonotlite-bearing dike intruding sepentinite. Xonotlite forms white veinlets in dike. Note weathering of dike.

The presence of prehnite boulders in the bed of a creek in secs. 35 and 36, T. 40 N., R. 4 E., indicates that massive prehnite is also present. Hornblende and biotite accompany the prehnite. Several of the boulders are as much as 6 feet in diameter and contain hornblende crystals as large as 1 foot in length and 2 inches across (fig. 19). Euhedral crystals of biotite up to 1 inch across were noted in several boulders, but they are not associated with the hornblende. The source of this material was not located; however, the float may be traced to the vicinity of the xonotlite-bearing dikes in sec. 36.

Boulders of enstatite as much as 18 inches in diameter also occur along the upper tributaries of the same creek and in the vicinity of the prehnite boulders. The average enstatite crystal is about 7 millimeters in length; however, several crystals about 50 millimeters in length were collected. As in the case of the prehnite-hornblende boulders, the source of the enstatite is not known. Perhaps it originally occurred as inclusions in the serpentinite.

FIGURE 19. Hornblende-prehnite boulder. From slide area on west slope of Sumas Mountain. Some hornblende crystals are as much as 1 foot long.

The contacts of the serpentinite are instrusive, depositional, and faulted, but are poorly exposed. In secs. 9, 16, 17, and 20, T. 40 N., R. 5 E., the serpentinite appears as sill-like bodies that have been intruded into argillites and siltstones of the Chilliwack Group. These bodies probably represent apophyses from the main Sumas Mountain mass. Subsequent folding has produced dips of from 60° to 80°. A high-angle N. 70° W.-trending fault forms the southern boundary of the main mass. Rocks of the Chilliwack Group and the Chuckanut Formation form the southern downdropped block of this fault. The western contact is both depositional and faulted. Along the southern half of the contact, post-Chuckanut, lower Tertiary continental sediments have been deposited upon the serpentinite. Northward, the contact is faulted, for Mesozoic grits and graywackes appear to have been thrust eastward over the serpentinite in sec. 36, T. 40 N., R. 4 E. A thick zone of bluish-gray gouge clay occurs between the two units. The eastern contact is nowhere exposed. However, near the SE¼SE¼ sec. 30, T. 40 N.,

R. 5 E., the serpentinite appears to be in contact with a hornblende diorite that crops out in Paradise Valley.

Age.—A tentative Jurassic-Cretaceous age has been assigned to the Sumas Mountain Serpentinite. It was intruded into rocks of the Chilliwack Group (upper Paleozoic), and in Late Cretaceous time was subjected to erosion, as is indicated by the presence of serpentinite pebbles in basal conglomerates of the Chuckanut Formation (Late Cretaceous-early Tertiary). The absence of serpentinite pebbles in lower Mesozoic conglomerates suggests that the serpentinite was intruded some time between the Middle Jurassic and Late Cretaceous.

Several other bodies of serpentinite, which do not appear to be part of the Sumas Mountain Serpentinite, crop out in the map area. In the NW¼ sec. 25, T. 40 N., R. 5 E., highly sheared and contorted serpentinite underlies massive amphibolite. At this locality the serpentinite appears to have been injected along the plane of a thrust fault, in which rocks of the crystalline complex (pre-Devonian?) were thrust over rocks of the Chilliwack Group (upper Paleozoic).

Along the International Boundary in the NW¼ sec. 34, T. 41 N., R. 5 E., serpentinite that resembles the Sumas Mountain Serpentinite underlies metadiorite of the crystalline complex. The relationship between the serpentinite and the metadiorite is not known, for nowhere was the contact observed. The main mass of this serpentinite crops out in Canada, along the base of Vedder Mountain. Very little of the serpentinite occurs in the map area, as a short distance south of the border it terminates against a high-angle N. 30° W.-trending fault.

Other bodies of serpentinite, which are too small to be shown on the geologic map, crop out in other parts of the map area (pl. 1). Almost all of the serpentinite is highly sheared and contorted, and occurs in areas where basic volcanic rocks have been subjected to extreme stress. One such deposit is well exposed along the North Nooksack fault in the NE¼NW¼ sec. 22, T. 40 N., R. 6 E. The serpentinite occurs between sandstone of the Chuckanut Formation and limestone and basalt of the Chilliwack Group.

Crystalline Complex

Bodies of exotic igneous and metamorphic rocks crop out in the north half of the map area (pl. 1). Compared with the other rocks of the area, their outcrops are small, and generally they are so poorly exposed that it is difficult, if not impossible, to determine their relationship to the other rocks of the area. The rocks of the crystalline complex are mainly meta-hornblende diorite, meta-quartz diorite, and amphibolite, in addition to one small body of diopsidite. Some of the rocks are cataclastic and (or) gneissic. All the rocks of the crystalline complex are believed to be up-thrown fault blocks of the basement rocks, or fault slices along fault zones.

Distribution.—The largest exposures of the crystalline complex crop out on Vedder Mountain, mainly in Canada. They extend for about 10 miles along the northwestern flank of the mountain and terminate less than half a mile south of the International Boundary. A high-angle northwestward-trending fault forms their southwestern boundary.

At least three bodies of the crystalline complex crop out in the valley between Sumas and Vedder Mountains (pl. 1). They are poorly exposed and not over 1,000 feet long. All of them occur on small drumlin-shaped hills. A massive quartz deposit in the NE¼NW¼ sec. 17, T. 40 N., R. 5 E., forms a large part of one of these outcrops.

Rocks of the crystalline complex crop out at two places on the south end of Red Mountain. In the SW¼NE¼ sec. 23, T. 40 N., R. 5 E., they may be seen along an abandoned logging road, and in the N½NW¼ sec. 25, T. 40 N., R. 5 E., they are poorly exposed along abandoned logging roads and in the bed of a small creek.

On Sumas Mountain the crystalline complex crops out near the headwaters of Breckenridge Creek in the SW¼SW¼ sec. 30, T. 40 N., R. 5 E. Because of much overburden, little is known on the extent of the crystalline complex rocks at this locality.

Only the largest outcrops of the crystalline complex are shown on the geologic map that accompanies this report (pl. 1). Those outcrops that are too small to be shown on the geologic map occur adjacent to faults in areas underlain by the Chilliwack Group.

Meta-hornblende diorite.—The dioritic rock of Vedder Mountain is light to dark greenish gray and medium to coarse grained. In every specimen that was examined, some degree of alteration was noted. In the slightly altered diorite the plagioclase and the interstitial mafic minerals are distinct, but in the more highly altered diorite the minerals are so obscured that identification is difficult, if not impossible.

Slightly altered samples of the diorite are composed of 50 to 60 percent plagioclase that ranges from albite (An_5) to andesine (An_{35}). Much of the plagioclase is altered to sericite and saussurite. Hornblende is always present and makes up from 20 to 30 percent of the diorite. Much of the hornblende has been altered to chlorite, which is a common alteration product of all rocks of the area. Zoisite and epidote are generally present; one sample contained almost 25 percent zoisite. The minor constituents are quartz, prehnite, pyrite, magnetite, sphene, and leucoxene. The texture of the diorite is generally hypidiomorphic-granular. However, near its contact with the argillite and serpentinite much of the diorite exhibits a cataclastic texture.

Although most of the crystalline complex on Vedder Mountain within the map area is a meta-hornblende diorite, some of it resembles a hornblende diorite gneiss. In Canada, parts of the crystalline complex grade into schists, some of which are garnetiferous.

Structurally, the crystalline complex of Vedder Mountain resembles a northeastward-trending sill. Within the map area it dips 40° to 60° SE., but less than 3 miles to the northeast, in Canada, it is nearly vertical. Along the International Boundary the diorite is underlain by serpentinite and overlain by argillite and graywacke of the Chilliwack group. The schistosity of the argillite adjacent to the contact of the diorite, as well as the cataclastic deformation of the argillite and diorite, indicates that the contact has been subjected to shearing stresses. Minor overturned folds in the argillite show that it was thrust northwestward over the diorite. It is possible that, during the faulting, the serpentinite was intruded along a similar thrust plane at the base of the diorite. To the northeast, in Canada, the Geological Survey of Canada has mapped the contacts of the diorite as high-angle faults (Roddick, J. A. and Armstrong, J. E., 1956).

Meta-quartz diorite.—Rocks of the crystalline complex in the valley between Sumas and Vedder Mountains have the composition of quartz diorite. Almost all of them show some degree of alteration, but not to the extent shown by the dioritic rocks on Vedder Mountain. The amount of mafic minerals ranges from 10 to 25 percent. Dark-gray to black inclusions are present as round to irregularly shaped clots, generally less than 2 inches in maximum dimension. The inclusions differ from the enclosing rock only in that they are finer grained and contain a higher percentage of mafic minerals.

The quartz diorite varies in texture and composition even within a single outcrop. It is fine to coarse grained and hypidiomorphic-granular (fig. 20). Most of the quartz diorite is structureless. However, in the NE¼NW¼ sec. 9, T. 40 N., R. 5 E., it exhibits a cataclastic texture in which the quartz and feldspar show a crude alignment. Other outcrops of the quartz diorite have weak gneissose structures in which the hornblende shows some alignment.

Thin-section studies of the quartz diorite showed plagioclase occurring as euhedral and subhedral grains and comprising 40 to 60 percent of the rock. The composition of the plagioclase (An_{13}-An_{18}), determined optically, generally falls within the oligoclase range. Much of the plagioclase is altered to saussurite and sericite. Differential alteration shows that zoning of the plagioclase is common.

Quartz and potash feldspar occur interstitial to the plagioclase; the grains are mostly anhedral, and as much as 30 percent of either mineral may be present. Although the potash feldspar usually occurs as small patches, some of it encloses plagioclase laths. The larger quartz grains show numerous minute inclusions, which could not be identified. Some of the quartz exhibits granulation and recementation by fine-grained quartz.

Either green hornblende or brown biotite is generally present. Some of the rock contains as much as 20 percent hornblende, which occurs as euhedral and subhedral grains up to 5 millimeters in length. The biotite usually does not exceed 3 percent and occurs as bent plates between the quartz and feldspar grains. In some places the biotite and hornblende have been altered to chlorite and fine-grained epidote.

Chlorite, sericite, epidote, and prehnite are the common alteration minerals of the quartz diorite. Chlorite, which makes up as much as 15 percent of some of the rocks, occurs interstitial to the quartz and feldspar and has replaced many of the ferromagnesian minerals. The chlorite is commonly penninite, which has a distinct anomalous blue interference color. The sericite and epidote are usually fine grained and are the alteration products of feldspar, hornblende, and biotite. Prehnite is present in most of the rock; as much as 15 percent was noted in one sample. Clear sheaflike groups of prehnite occur interstitial to the other minerals of the rock and also fill thin fractures (fig. 21). In the NE¼NW¼ sec. 17, T. 40 N., R. 5 E., abundant prehnite occurs in the quartz diorite of this area. A massive quartz deposit underlies the quartz diorite, which suggests that the plagioclase was metasomatically transformed by hydrothermal solution during emplacement of the quartz.

The accessory minerals of the quartz diorite are diopside, apatite, sphene, leucoxene, magnetite, pyrite, hematite, and ilmenite. They occur interstitial to the other grains of the rock as euhedral to anhedral grains. Some leucoxene appears as opaque dustlike particles throughout the groundmass of the rock.

In the SW¼NE¼ sec. 23, T. 40 N., R. 5 E., parts of the crystalline complex are monzonitic. Hand specimens of the rock are light colored and medium grained. Hornblende, which is common to the rocks of the crystalline complex, is not present in this monzonite rock. From 50 to 60 percent of the rock is orthoclase and microcline. The plagioclase is sodic andesine and makes up about 20 percent of the rock. The potash feldspars are perthitic and contain irregular blebs and threadlike veinlets of sodic plagioclase. The texture is hypidiomorphic-granular.

As much as 10 percent bioite and 5 percent chlorite are present. The biotite and chlorite grains are subhedral to anhedral and occur interstitial to the feldspar. Some of the biotite is partially altered to chlorite, and what appears to have been the original amphibole is completely replaced by chlorite. Leucoxene, the alteration product of ilmenite, occurs throughout the rock. It forms euhedral to subhedral inclusions in the biotite and also occurs interstitial to

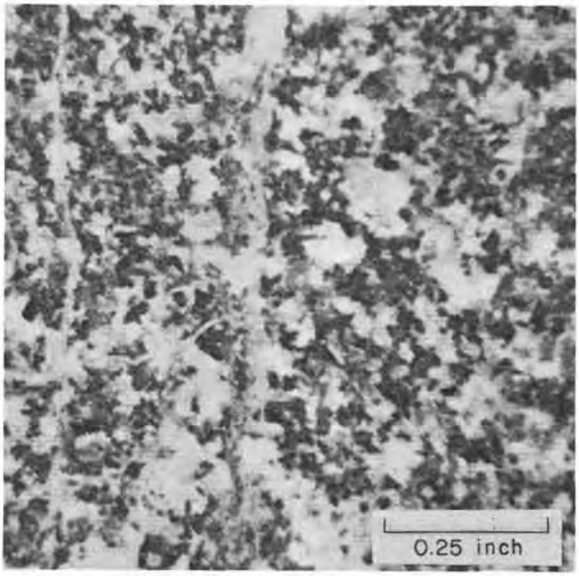

FIGURE 20. Quartz diorite of the crystalline complex. Prehnitized plagioclase (light gray), hornblende and chlorite (dark gray). Prehnite forms veinlets in the rock.

FIGURE 21. Photomicrograph of quartz diorite of the crystalline complex. Quartz, plagioclase, and orthoclase with interstitial prehnite. Prehnite forms divergent crystals. (× 60—crossed nicols.)

the feldspars. Calcite, quartz, and apatite are the common accessory minerals.

Amphibolite.—Rocks of the crystalline complex that contain as much as 75 percent hornblende are best exposed on the southeastern end of Red Mountain. They are distinctly different from the other rocks of the complex and have not been discovered elsewhere within the map area. The amphibolite appears to be confined to the eastern end of a body of metadiorite that resembles the dioritic rocks of Vedder Mountain. Much of the amphibolite should properly be called a massive nonschistose amphibolite, as it lacks the schistosity of the typical amphibolite.

When examined megascopically, the rock appears to consist of hornblende and altered plagioclase (fig. 22). Some of the amphibolite is distinctly porphyroblastic; it contains feldspar porphyroblasts as much as 15 millimeters across. In parts of the outcrop there is a definite alignment of the hornblende and feldspar, which gives the rock a gneissose structure. However, most of the amphibolite exhibits a granular texture. Because of the abundant hornblende, it is generally dark in color.

Microscopic examination of several specimens shows a hypidiomorphic-granular texture. Euhedral and anhedral grains of green hornblende are surrounded by subhedral and anhedral plagioclase (fig. 23). The hornblende makes up from 50 to 75 percent of the rock, and the grains have an average length of 5 millimeters. It exhibits many embayed borders and contains numerous inclusions of pyrite and sphene. Some of the hornblende prisms show a preferred orientation, which gives the rock crude schistosity.

The plagioclase content ranges from 25 to 50 percent. Much of the plagioclase has been altered to saussurite and sericite. The optical properties of the slightly altered plagioclase show that it falls in the andesine range.

Epidote is present in all the amphibolites but does not exceed 5 percent. It occurs as fine-grained disseminations in the saussuritized plagioclase and as subhedral grains interstitial to the hornblende and plagioclase. The accessory minerals are fine-grained quartz, calcite, and biotite. Chlorite, which is the common alteration mineral of almost all of the igneous rocks of the map area, was not noted in any of the samples.

Structurally, the amphibolite appears to be an erosional remnant of a fault slice in which the crystalline complex was thrust over sedimentary rocks of the Chilliwack Group. In the bed of a creek on the eastern end of the outcrop, highly contorted and sheared serpentine underlies the amphibolite.

Diopsidite.—A rock composed essentially of diopside underlies the massive quartz deposit in the NE¼NW¼ sec. 17, T. 40 N., R. 5 E.

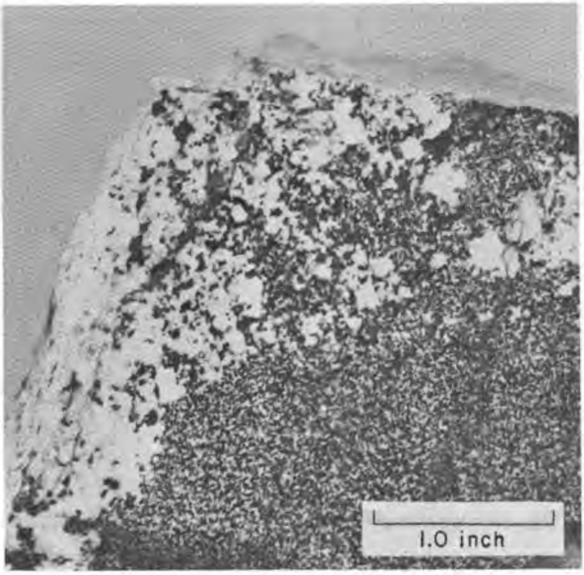

FIGURE 22. Massive amphibolite of the crystalline complex. Hornblende (black), plagioclase (white).

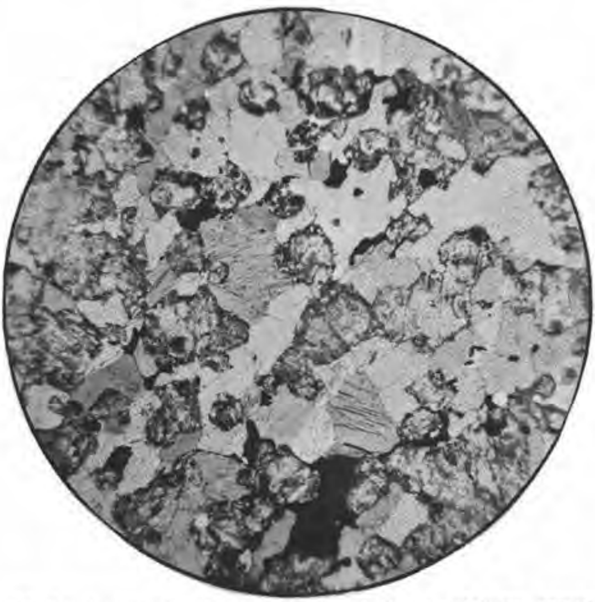

FIGURE 23. Photomicrograph of amphibolite of the crystalline complex. Anhedral saussuritized plagioclase (light gray), subhedral to anhedral hornblende (medium gray), and interstitial pyrite and magnetite (black). (× 15—plain light.)

Megascopically, it is a dense grayish-green rock that resembles serpentinite. Adjacent to its contact with the quartz the diopsidite is highly sheared and contorted. In thin sections it is seen to be composed of microbrecciated diopside and minor hornblende.

Parts of the outcrop, which have not been subjected to brecciation, consist of grayish-green diopside and greenish-black porphyroblasts of hornblende. Hornblende makes up about 10 percent of the rock. In thin section the diopside shows euhedral and subhedral grains that average 1.5 millimeters in length. Some of the diopside crystals are twinned and others show diallage parting; many of the crystals contain inclusions of hornblende. The hornblende porphyroblasts are 4 to 10 millimeters long and contain inclusions of diopside and magnetite (fig. 24). Many of the hornblende porphyroblasts exhibit embayed borders. Minor amounts of quartz, plagioclase (An_{30}), calcite, epidote, sphene, magnetite, and pyrite are present in the diopsidite.

FIGURE 24. Photomicrograph of porphyroblastic diopsidite of the crystalline complex. Hornblende (dark gray) partially replaced by diopside (medium gray). (× 30—plain light.)

Age.—At no place in the map area are the rocks of the crystalline complex in intrusive contact with the other rocks. All contacts appear to be fault contacts. In secs. 9 and 23, T. 40 N., R. 5 E., they have been faulted against Devonian limestone, and in other areas they have been thrust over argillite and graywacke of the Chilliwack Group. Megascopically, the rocks of the crystalline complex resemble in part the intrusive rocks of the Coast Range batholith, which crop out to the north in Canada. These rocks have been mapped as Mesozoic and Tertiary in age by the Canada Geological Survey (Rice, 1959). Microscopically, the rocks of the crystalline complex appear much more altered and deformed than the Coast Range batholith rocks.

Within the map area the crystalline complex has been tentatively assigned a pre-Devonian age. For the most part, the rocks of the complex are believed to be up-thrown fault blocks of the older basement rock.

STRUCTURE

The area of this report is in the northwestern part of the Cascade Mountains of Washington. To the northwest is the Georgia Depression and to the north the Coast Mountains, both of which are physiographic subdivisions of southwestern British Columbia. This area is part of the eugeosynclinal Fraser belt of the Cordilleran geosyncline (Kay, 1951, p. 35), and its geologic structure is complex. Rocks as old as Devonian and as young as late Eocene have been intricately faulted and tightly folded with the major structures trending northward and northeastward, in contrast with the dominant north-northwestern Cordilleran trend.

The orogenic deformations that produced the major structures of the area began late in the Paleozoic era and continued at different intervals, though of different intensities, until the close of the Pliocene epoch. The area appears to have been subjected to at least three orogenies and one epeirogeny. The Chilliwack Group was initially faulted and folded prior to the deposition of the lower Mesozoic sedimentary rocks. In middle Cretaceous time a northwest-southeast compression produced northeastward-trending folds and faults in the upper Paleozoic and lower Mesozoic rocks of the area. Large-scale thrusting appears to have accompanied this deformation. This compression was followed by a northwestward-trending structural downwarp, into which accumulated Upper Cretaceous-lower Eocene continental sediments. In what appears to have been middle Eocene time, an east-west compression produced northward-trending folds and associated eastward-trending high-angle faults. This deformation appears to have been related to the main compression of the Larmide orogeny, which probably began in Late Cretaceous and continued into the early Tertiary. During the last general uplift of the northern Cascade Mountains in late Pliocene time, epeirogenic movement superimposed northward-trending folds and high-angle eastward-trending faults upon the existing structures of the area.

Inasmuch as the map area contains five distinct mountains, the structure of each is discussed separately.

VEDDER MOUNTAIN

The rocks of the Chilliwack Group on Vedder Mountain strike northeastward and dip from 45° to 75° to the southeast. On the western end of the mountain, post-Chuckanut continental sediments were deposited unconformably upon the Chilliwack Group. In the vicinity of the fire clay deposits (NE¼ sec. 7, T. 40 N., R. 5 E.) the continental sedimentary rocks are nearly horizontal. On the extreme western end of the mountain they dip 45° to the west and disappear beneath the surficial deposits of Whatcom Basin.

Vedder Mountain is bounded on its northwestern and southeastern flanks by high-angle faults. The downdropped block on the northwestern side of the mountain forms Sumas Valley. Armstrong (1960, p. 9) reports that the Tertiary bedrock is as much as 1,100 feet beneath the valley floor. The Vedder Mountain fault, along the northwestern front of Vedder Mountain, is the youngest major fault in the area. It is post-Eocene in age, as upper Eocene rocks were involved in the faulting (pl. 1). Near the International Boundary, rocks of the Chilliwack Group have been thrust northwestward over metamorphic rocks of the crystalline complex. Most of this fault is within Canada, because less than a mile south of the Boundary it terminates against a northwestward-trending high-angle fault that forms a structural boundary between Canadian and American parts of Vedder Mountain. The American part is on the downdropped block of this fault.

SUMAS MOUNTAIN

On the western slope of Sumas Mountain, post-Chuckanut continental sedimentary rocks rest unconformably on the older rocks of the mountain. The sedimentary rocks have a general northerly strike and dips of 35° to 45° W. However, on the southern end of Sumas Mountain a small asymmetrical anticline and a syncline produce some nearly vertical eastward dips. The outliers, or erosional remnants, of these rocks on other parts of Sumas Mountain are generally flat lying. Along the western slope of the mountain, at the valley floor, they disappear beneath the glacial deposits of Whatcom Basin.

Prior to the deposition of the post-Chuckanut sedimentary rocks, a N. 75° E.-trending high-angle fault displaced rocks of the Chuckanut Formation against the Sumas Mountain Serpentinite and rocks of the Chilliwack Group. The Chuckanut Formation is, for the most part, confined to the southern block of this fault, which Crickmay (1930, p. 489) has called the North Nooksack fault (pl. 1). The Chuckanut beds on the southern half of Sumas Mountain, within the map area, have been steeply folded so as to strike generally N. 30° E. and dip from 60° to 80° W. On the extreme southern end of Sumas Mountain the beds exhibit both northward- and eastward-trending folds. The western boundary of the Chuckanut Formation on Sumas Mountain is a N. 30° E.-trending fault that roughly parallels Smith Creek. The western uplifted block of the fault consists of sedimentary and volcanic rocks of the Chilliwack Group that have been folded into a north-trending anticline. On the geologic map of the area (pl. 1) this fault is designated as the Smith Creek fault.

The northeastern quarter of Sumas Mountain is underlain by intricately folded and faulted rocks of the Chilliwack Group. The strike of the beds ranges from north through east, and the dips are from 30° to 90°. At the extreme northeastern corner of the mountain several N. 20° E.-trending closed folds have brought serpentinite sills to the surface and have infolded beds of the Chuckanut Formation into the Chilliwack Group. Whereas most of the Chuckanut Formation has been removed by erosion in this part of the map area, the infolded beds have been protected from erosion.

In the northwestern quarter of Sumas Mountain, faulted and folded rocks of the Chilliwack Group have been intruded by the Sumas Mountain Serpentinite (Jurassic-Cretaceous). The outcrop pattern of the serpentinite and the dips of the banding in it indicate that the serpentinite has been folded into an open, northward-trending anticline that plunges to the north. The massive graywacke and grit of possible early Mesozoic age that overlie the serpentinite and upper Paleozoic rocks have a general N. 30° W. strike, and dip westward from 25° to 30°. A thick gouge zone between the early Mesozoic rocks and the serpentinite in the SW¼ sec. 36, T. 40 N., R. 4 E., and intensely sheared and contorted argillite and siltstone in the SW¼ sec. 30, T. 40 N., R. 5 E., suggest a thrust. The outcrop of quartz diorite in the SW¼ sec. 30, T. 40 N., R. 5 E., probably represents a slice of the basement complex that was brought up along the base of the thrust. The grit and graywacke appear to have been thrust eastward, as is indicated by the tight northward-trending folds in the northeastern quarter of Sumas Mountain. The age of this thrusting is probably middle Eocene, as the Chuckanut Formation was involved in the accompanying deformation and the post-Chuckanut sedimentary rocks were not. The North Nooksack fault, and also the initial folding of the Chuckanut Formation, are probably related to the same orogeny.

Between Sumas and Vedder Mountains, several N. 60° E.-trending high-angle faults have brought rocks of the crystalline basement complex to the surface. The crystalline complex has been thrust eastward over argillite and graywacke of the Chilliwack Group, and the thrusting is probably related to the thrusting on Sumas Mountain. Within the fault blocks the strikes of the beds are in all directions and the dips are generally steep. Adjacent to the faults the strikes of the beds parallel the faults and the dips are nearly vertical.

SLIDE MOUNTAIN

On the northwestern corner of Slide Mountain the beds of the Chuckanut Formation have been folded into a N. 70° E.-trending, westward-plunging syncline. The beds on the south limb have a general N. 20° E. strike and 15° to 60° dips to the west, whereas on the north limb the average strike is N. 40° W. and the dips are 20° to 40° to the southwest. On the north-central slopes of Slide Mountain, homoclinal beds of the Chuckanut Formation strike east to northeast and dip from 15° to 70° to the north and northwest.

To the south and outside the map area the beds have been folded into a northwestward-trending anticline and syncline. The northwesterly trend of these structures probably represents the principal regional trend, which within the map area has been complicated by faulting and transverse folding.

On the northern end of Slide Mountain the Chuckanut Formation terminates against the North Nooksack fault. Numerous other faults are present in the Chuckanut Formation, but, because of the lack of marker beds and outcrops, it is impossible to trace them for any appreciable distance.

RED MOUNTAIN AND BLACK MOUNTAIN

Red and Black Mountains are underlain chiefly by folded and faulted sedimentary and volcanic rocks of the Chilliwack Group. On the eastern slope of Black Mountain, graywacke and argillite of early Mesozoic age unconformably overlie volcanic rocks of the Chilliwack Group. On the southeastern slope of the mountain the Chilliwack Group is in fault contact with sandstone and conglomerate of the Chuckanut Formation.

On the northern half of both mountains the major structural trends are northeast to east-northeast. Several high-angle faults have divided the mountains into fault blocks of rocks from different sections of the Chilliwack Group. These faults have a general N. 70° E. trend, but on the northwest corner of Red Mountain several of the faults swing to the northwest. On the northernmost fault block, the rocks on Red Mountain have been folded into an isoclinal syncline that is overturned to the north on Black Mountain.

The central fault blocks on both Red and Black Mountains contain Lower Pennsylvanian and lower Permian clastic sedimentary rocks and limestone that have been folded into several N. 70° E.-trending anticlines and synclines. The limestone on Red Mountain is on the north limb of an eastward-plunging syncline that has been faulted parallel to the axial plane of the fold. In the Kendall quarry the limestone has a general strike of N. 45° E. and dips about 45° SE. The limestone near the base of Red Mountain in the SW¼ sec. 14, T. 40 N., R. 5 E., appears to be offset several hundred feet to the west from the limestone in the Kendall quarry by two N. 70° E.-trending faults. The limestone at this locality is highly contorted and sheared. At the Silver Lake quarry, on the eastern slope of Red Mountain, the limestone is sheared and contorted; it strikes about N. 70° W. and dips 50° to 60° S. On Black Mountain the limestone occurs on the nose of an eastward-plunging anticline. An eastward-trending high-angle fault forms its northern boundary. Adjacent to another eastward-trending high-angle fault, which forms the southern boundary of the limestone, the beds have been folded into an open syncline.

Most of the southern half of Red Mountain and of the southeastern quarter of Black Mountain are underlain by volcanic rocks and associated clastic sedimentary rocks of the Chilliwack Group. The general trend of the beds is N. 10° E., and the dips are from 30° to 40° to the east and west. The contact between the volcanics and the underlying folded and faulted sedimentary rocks is poorly exposed, but it has a general northeasterly trend and dips at a low angle to the southeast (pl. 1). Near the summit of Black Mountain the volcanic rocks are underlain by lower Permian sedimentary rocks. On Red Mountain and on the southwestern slope of Black Mountain they are underlain by Devonian limestone and rocks of the crystalline complex. The structural relationship between the volcanics and the underlying rocks suggests that the volcanics have been thrust in a north-northwesterly direction and a series of high-angle faults were produced in the underlying rocks during the thrusting. On the southern ends of the mountains several northeastward-trending faults in the thrust plate further complicate the structure. Clastic sedimentary rocks of the Chilliwack Group and amphibolite and metadiorite of the crystalline complex (pre-Devonian?) are in fault contact with the volcanics.

The thrusting of the volcanics over the sedimentary rocks appears to be related to a major thrust in which upper Paleozoic rocks were thrust over Mesozoic rocks. This thrusting has been mapped by Misch (1960) a short distance to the east of the map area, and by the Canada Geological Survey (Rice, 1959) to the north in Canada. The trace of the thrust plane has been mapped from the north to near Monument 44 on the International Boundary, which is in the northeastern corner of the map area. Within the map area there is no evidence for this major thrust, but if the trace of the thrust were extended it would probably follow Columbia Valley. The Mesozoic rocks over which the Paleozoic rocks were thrust do not crop out in Columbia Valley; however, they are exposed on the Canadian side of the Boundary near Cultus Lake. Possibly Columbia Valley is a topographic expression of the fault zone that, because of its weakness, was eroded in the Mesozoic rocks during the erosion of the area. Although the erosion pattern is not what would be expected of a low-angle thrust plane, later folding in the area steepened the plane to a high angle.

The graywacke and conglomerate of early Mesozoic (?) age on the eastern slope of Black Mountain strike generally N. 35° W. and dip 25° to 30° NE. They unconformably overlie rocks of the Chilliwack Group, and to the southeast are in fault contact with sandstone and conglomerate of the Chuckanut Formation.

The beds of the Chuckanut Formation on Black Mountain have a general eastward strike, and the dips are as great as 70° to the north and south. The predominant structure is an east-trending syncline. The relationship of the Chuckanut Formation on Black Mountain to the underlying basement rocks has not been determined. A few miles east of the map area, disharmonic folding of the Chuckanut rocks has produced a décollement surface between the Chuckanut and the basement rocks (Misch, 1960). The extent of this surface is not known, as other contacts in the area are limited to high-angle faults. The décollement surface is by no means restricted to this area, as other exposures of the Chuckanut Formation in areas to the south also indicate disharmonic folding.

GEOLOGIC HISTORY

The geologic history of the map area is still only partially known, because much of the geologic evidence that is necessary to reconstruct the history of the area is hidden beneath a thick cover of underbrush and glacial debris. Fossils are lacking in almost all the rocks, and correlation based on the physical properties of the rocks is difficult. Rocks as old as Devonian and as young as late Mesozoic are similar in appearance.

PALEOZOIC ERA

From the time of the oldest known sedimentary rocks of the area, which are of Devonian age, to near the close of the Paleozoic era the area was essentially one of deposition. It represents only a small part of the vast eugeosynclinal Fraser belt of the Cordilleran geosyncline, which extended along the western coast of North America. In a subsiding trough, a small part of which is now represented by the map area, accumulated thick beds of sand, silt, clay, and gravel. In times of relative stability, such as part of the Devonian, and Early Pennsylvanian and early Permian, accretionary and clastic limestone deposits accumulated in local basins. There were also sudden changes in the environment of deposition, as is indicated by the presence of massive conglomerates overlying beds of limestone. At times, the normal sequence of deposition was interruped by outpourings of lava on the sea floor. These eruptions also furnished ash and coarse fragments of volcanic rock that mixed with the sediments. The greatest volcanic activity appears to have been in Early Pennsylvanian time, when over a thousand feet of andesitic volcanic rocks and associated tuffaceous clastic sediments accumulated. Deposition continued until early Permian time; there is no record in the map area of any deposition of Paleozoic sediments later than this.

MESOZOIC ERA

Evidence is lacking in the area for any deposition after early Permian until near the close of the Triassic. It is possible that at this time a Permo-Triassic orogeny occurred, which resulted in the folding of the Paleozoic rocks and the emergence of them to be subjected to erosion. However, at the close of the Triassic the region once more became an area of deposition. Sand, gravel, silt, and clay were deposited unconformably upon the older rocks, but there were no volcanic eruptions in the area. How long the deposition continued is not known. Several miles to the east of the map area the presence of Upper Jurassic and Lower Cretaceous clastic sedimentary rocks and basic volcanics indicates that deposition occurred at this time (Misch, 1952). However, these rocks are not present in the map area.

Following the deposition of the Mesozoic sediments, the area was subjected to orogenic deformation that compressed the rocks into tight folds with associated faults. During this time the rocks were subjected to low-grade regional metamorphism of the chlorite facies. Many of the shales were changed to argillites. At this time peridotite was intruded into the rocks of the area, the largest of these peridotite bodies being the Sumas Mountain Serpentinite. It is possible that erosion at this time removed any Upper Jurassic and Lower Cretaceous rocks that may have been present.

In Late Cretaceous time the land once again subsided and a continental trough formed, the axis of which extended approximately between Wenatchee and Bellingham. In Canada, the Strait of Georgia probably represents the extension of this trough. Unlike the earlier sedimentary deposits, which were marine, the Upper Cretaceous sediments were nonmarine. They included thick deposits of arkosic sandstone, conglomerate, siltstone, and shale derived from the erosion of granite and gneiss in the mountains to the east.

CENOZOIC ERA

The deposition of the arkosic continental sediments continued until near the close of the early Eocene, by which time nearly 16,000 feet of sediments had accumulated in some of the deep basins of the trough. Within the map area, at least 10,000 feet of these sediments are represented by the Chuckanut Formation. The orogeny, which marked the end of the Upper Cretaceous-early Eocene deposition, compressed the Chuckanut Formation into north-trending closed folds with associated thrusts and high-angle faults.

After the initial deformation of the Chuckanut Formation, a basin of deposition was formed in which accumulated continental sediments of probable late Eocene age. This basin appears to have been restricted to the southeastern end of the Georgia Depression, as the outcrops of the sedimentary rocks are confined to the lower Fraser Valley and the Whatcom Basin. At least 3,000 feet of arkosic sandstone, conglomerate, and shale were deposited. Much of the material probably was derived from the reworking of parts of the Chuckanut Formation.

In post-Eocene time the rocks were subjected to both faulting and folding. Folding of the beds produced northward-trending strikes and westerly dips. Northwestward-trending block faulting down-dropped what is now Sumas Valley and uplifted parts of Vedder Mountain. This latest deformation cannot be assigned a definite age, but it was probably associated with the last north-trending uparching of the Cascade Mountains in late Pliocene time. Prior to this latest uplift of the Cascade Mountains the region had developed a mature topography, which was later modified by continental glaciation.

GLACIATION

It is evident from widely distributed glacial features that Pleistocene continental ice sheets covered the entire area of this investigation, including the highest peaks. Granite erratics are scattered along the crest of Black Mountain to an elevation of 4,900 feet, and abundant glacial till is present on the summits of all the mountains in the area. Glacial striae are on Black Mountain at 4,950 feet and on Sumas Mountain at 3,200 feet. The ice is believed to have been much thicker than these observations would indicate, as Peter Misch (oral communication) has reported glacial erratics at elevations of over 6,000 feet on the mountain peaks to the east.

The glacial history of the area is complex, and the details are not within the scope of this report. However, the following brief discussion outlines the more significant events that took place during the time of the last continental glaciation. Detailed studies by the Geological Survey of Canada (Armstrong, 1960, p. 12) indicate that adjacent areas in Canada were glaciated by continental glaciers probably less than 25,000 years ago.

Evidence indicates that northwestern Washington was covered by at least two ice sheets, and possibly four. Studies by Bretz (1913) and Newcomb and others (1949) in western Whatcom County show that the area was glaciated by both the Admiralty and Vashon glaciers. To the south, in Pierce and King Counties, Crandell and others (1958) have mapped four glacial intervals—the Orting, Stuck, Salmon Springs, and Vashon. The Vashon is the youngest of the major Pleistocene glacial intervals and is of Wisconsin age (late Pleistocene). As would be expected in an area that has been subjected to several glaciations, the deposits and topography that were the result of the earlier glaciers have been destroyed by the later glaciers. Within the map area all the glacial drift and outwash are believed to be products of the Vashon glaciation and later valley glaciers.

The continental glaciers that covered large areas of Washington were part of the Cordilleran glacier complex. The main mass of this ice sheet originated in western Canada, but as it increased in size it advanced southward into Washington. As the ice sheet advanced southward from the snow fields of British Columbia, pre-existing valleys became the channels for the ice lobes. Blocked by the advancing ice, many streams formed temporary lakes along the margins of the glaciers. However, these lakes were continuously being covered by the advancing glacier, causing the water to find new channels. It is probable that during this time the Fraser and Chilliwack Rivers in British Columbia were diverted southward across Whatcom County.

As the ice thickened and continued its southward advance, the valleys of the area were deepened. The mountains were denuded and their surfaces plastered with a thick cover of glacial debris. The advance of the glacier continued until the ice reached a maximum thickness of about 6,000 feet in northwestern Whatcom County. Its southern extent was near Tenino, 200 miles south of the Canadian border.

At the close of the Pleistocene epoch the ice melted back and left a mantle of ground moraine over most of the area. Melt water from the receding glacier reworked parts of the moraine material and deposited it as outwash sand and gravel over much of the surface. Upon the deposits of sand and gravel new stream channels were formed by the melt water.

As the ice front continued to recede, many of the major rivers and streams were diverted back into their former channels. The Nooksack River, which was forced southward by the advancing glacier, returned to its present channel. The Fraser River established its channel in the Sumas Valley and joined the Nooksack River near Everson (Newcomb and others, 1949, p. 28). The combined rivers then flowed into marine waters that covered the lowlands of western Whatcom County. Studies by D. J. Easterbrook (oral communication) indicate that inundations by the sea occurred in late Vashon time and also during a post-Vashon glacial advance. During this time, fossiliferous glaciomarine drift was deposited over much of the Whatcom Basin, and up the valley of the Nooksack River as far as Deming. As the continental ice sheet melted, there was a general uplift in the area and a corresponding lowering of the sea level, at which time the Fraser River abandoned the Sumas Valley drainage and returned to its old and present course.

Columbia Valley, one of the widest valleys in the area, appears to have been a major diversion channel for glacial runoff. Although it is not presently occupied by a major stream, the valley shows evidence that at one time it was occupied by a river of major size. Diverted waters of the Chilliwack River apparently at one time flowed through the valley.

Although the last continental ice sheet to cover the entire area was of the Vashon glaciation, there is evidence for valley ice lobes during post-Vashon time. Armstrong (1960, p. 13) reports that one such lobe advanced westward into the Fraser Lowland as late as 11,000 years ago. The age determination is based on radiocarbon datings of wood collected from till and glaciomarine deposits. The former presence of valley lobes in other major valleys of the map area is not known. Should the Sumas and Chilliwack Valleys to the north have been filled by ice, it was probably at this time that the Chilliwack River was diverted southward into Whatcom County. The river would have been diverted into the Cultus Valley in Canada and then would have flowed southward into Columbia Valley. It then would have combined with the Nooksack River near Kendall.

Several well-defined stream terraces in Columbia Valley support the theory that the valley was at one time a major stream channel. These terraces begin well within Canada and may be traced almost to Kendall. Sweep scarps, caused by vertical and lateral corrosion by a degrading stream, define the edges of the terraces. The scarps range from 10 to 20 feet in height and are very distinct; several roads in the area traverse the slopes of them. Only the larger scarps were mapped and are shown on plate 1.

The melting of the valley ice marked the end of the major glaciation in the region. Numerous alpine glaciers existed for some time on the higher peaks, but slowly melted. At the present time the glaciers are confined to peaks at elevations above 6,000 feet.

GLACIAL TOPOGRAPHY

The effect of the glaciation on the topography of the area is very pronounced. Most of the mountains are subdued and the major valleys rounded. Prodigious amounts of glacial outwash material fill the larger valleys, and glacial drift is plastered as a thin veneer over most of the mountains. Large erratics of granite, some of which approach 15 feet across, can be found even on the summits of the highest mountains.

The surface of much of the outwash sand and gravel is pitted, and several of the depressions are filled with water. On the summits of Sumas, Black, and Slide Mountains there are several lakes of glacial origin. The largest of these is Lost Lake on Sumas Mountain. Most of the lakes occupy rock basins, but several lakes on Slide Mountain appear to be in cirque basins. Most of the lakes are stagnant and are in the process of becoming peat bogs.

An area of mound topography occurs in secs. 6 and 7, T. 40 N., R. 6 E. The mounds average about 4 feet in height and are as much as 15 feet in diameter. They are covered by a thin mantle of glacial drift but contain bedrock cores. Although they do not have the classic shape of rocdrumlins or roche moutonnees, the mounds appear to be the result of glacial abrasion.

Although the relief of the area was developed in preglacial time, the topography as it exists today is due largely to glaciation. Recent erosion has modified it only slightly.

MINERAL DEPOSITS

The examination of the north half of the Van Zandt quadrangle disclosed that clay, limestone, silica, sand and gravel, chromite, ferruginous shale, coal, gold, and copper are present in the area. The deposits of limestone, silica, sand and gravel, and clay have been mined and quarried in the past. Only two limestone quarries are in operation at present (1961), these being the Kendall and Silver Lake quarries. Two pits in the area furnish sand and gravel for County road repairs.

Several attempts have been made to develop the metallic minerals of the map area, but none has been successful. Although metallic mineral deposits are present, most of them are too low in quantity and (or) quality for profitable mining operations. The water resources of the area were not examined by the writer but are described in a bulletin by the Washington Division of Water Resources (1960).

CLAY

Fire Clay

General Discussion

The primary purpose of this report is a geologic evaluation of the fire clay deposits in the area. No attempt is made to cover such subjects as classification, constitution, and working properties of clays. Adequate coverage of these subjects may be found in "Clays and Shales of Washington" (Glover, 1941, p. 10-41). "Fire clay" refers to clays that are capable of withstanding high temperatures and usually are not fusible below about 3,000° Fahrenheit (pyrometric cone 27 or 28). The clays are used chiefly for fire brick or other heat-resisting clay products. Fire clay is also used in the production of floor tiles and sanitary ware, terra cotta, conduits, pressed and paving bricks, portland cement, and plaster.

The presence of fire clays in the Sumas area of Whatcom County has been known since the early 1900's, and mining of the deposits was undertaken intermittently from that time up until 1949. The Denny-Renton Clay & Coal Company and the Sumas Fire Brick Company were the major producers until 1925, at which time the mining was taken over by Gladding, McBean & Company, one of the State's leading producers of brick and tile.

Production figures are not available for all the years, but between 1922 and 1949 there was mined 53,418 tons of clay having a value of $151,000.00. In 1960 none of the clay deposits were being mined, as the mines have been abandoned.

Location.—The largest known fire clay deposits in Whatcom County are confined to an area on the southwestern end of Vedder Mountain about 3 miles southeast of Sumas. About 5 miles north of these deposits, in British Columbia, similar fire clays occur on Canadian Sumas Mountain. These are the only true fire clays known in British Columbia (Cummings and McCannon, 1952, p. 19).

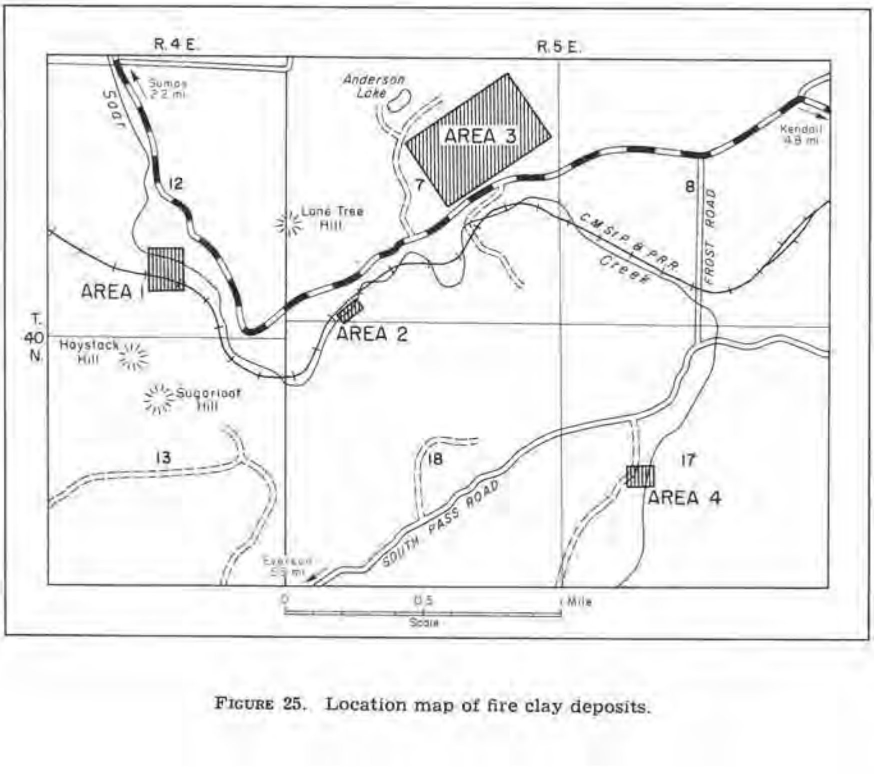

FIGURE 25. Location map of fire clay deposits.

The location of the fire clay deposits of the Sumas area is shown in figure 25. At Area No. 1, approximately 525 feet of clay-bearing Tertiary sedimentary rocks have been cut by Saar Creek. Area No. 2, which is about 1 mile east of the No. 1 location, contains several clay beds in the bed of Saar Creek. These outcrops are small and poorly exposed. Area No. 3, the site of the abandoned Gladding, McBean clay mine, is underlain by about 220 acres of Tertiary sedimentary rocks. Although the rocks are poorly exposed, it is probable that at least 200 feet of the basal part of the Tertiary section that includes the fire clays is present at this locality. At Area No. 4, fire clay crops out, but the clay is so poorly exposed that little is known about this occurrence.

The four areas shown in figure 25 contain the only known deposits of fire clay in the area covered by this report. Other occurrences may exist, but because of a thick cover of overburden and dense brush no outcrops have been found.

Conditions of deposition.—During the early Tertiary period a sequence of conglomerate, sandstone, siltstone, and shale was deposited upon a basement of considerable relief. The basement complex in the vicinity of the fire clay deposits consists of folded and faulted argillite, quartzite, graywacke, and altered basic igneous rocks. These rocks for the most part belong to the Paleozoic era; however, some rocks of the Mesozoic era are also present.

The Tertiary sedimentary rocks represent continental sediments that accumulated on a shallow coastal plain. It is probable that some of the shales, such as those associated with the fire clays, accumulated in a moderately deep basin. Unlike most of the lower Tertiary sedimentary rocks, which contain very little shale and large amounts of siltstone and sandstone, much shale is present in the Sumas area. Most of the material appears to have been derived from rapidly eroding landmasses to the east that consisted mainly of granitic rocks. Since the deposition of these sediments the area has been uplifted, faulted, and subjected to erosion. Within the area of the fire clay deposits all that remain of a former continuous sequence of sediments are a few isolated masses.

The source of the clays that possess refractory properties is not known. Within the map area the clays occur as transported materials that were deposited about 100 feet or more stratigraphically above the basement rocks. In Canada, 5 miles to the north, near Kilgard, similar fire clay deposits are associated with intensely weathered plutonic basement rocks. The basement is kaolinized as much as 70 feet deep in places (Cummings and McCannon, 1952, p. 19). It is probable that the Sumas fire clays were derived from this or a similar area. The only probable source of the clays in the map area is a dacitic body in the NE¼ sec. 7, T. 40 N., R. 5 E. However, this rock in known exposures appears to be resistant to weathering and shows no signs of kaolinization.

Age and correlation.—The fire clays and the interbedded sandstone and conglomerate of the Sumas area have been called the Sumas series by Glover (1941, p. 308-309) and are correlated by him with the Huntingdon Formation of southwestern British Columbia. Because of the Eocene age of the Huntingdon Formation, Glover considered the Sumas series as lower Eocene, or the basal part of the Chuckanut Formation. Glover (1941, p. 309) pointed out, however, that the Sumas series differs somewhat in origin and lithology from the rest of the Chuckanut Formation. The rock of the Sumas area is more shaly, and the refractory nature of the shale is markedly different from the usual shale of the Chuckanut Formation.

As pointed out in the discussion of the Tertiary rocks of the area (page 30), it is possible that the Sumas series is in part equivalent to the Burrard or Kitsilano Formations of British Columbia and is of late Eocene age. If such is the case, the fire clay deposits would be of post-Chuckanut age.

Tabulation of analyses.—The physical properties of the clays described in this report have been listed in tabular form and are included with the descriptions of the individual samples. The abbreviations used in the tables are as follows:

L.S. % d.l.—Linear shrinkage in percent of dry length

T.L.S. % d.l.—Total linear shrinkage (drying and firing) in percent of dry length

V.S. % d.v.—Volume shrinkage in percent of dry volume

Abs.—Absorption

A.por.—Apparent porosity

*—Indicates that the sample was fired to the given temperature in a commercial kiln.

S.H., Lt., Dk.—Steel hard, light, dark

P.C.E.—Pyrometric cone equivalent

D.T.A.—Differential thermal analysis

Area No. 1

Location and accessibility.—Area No. 1 is the site of the abandoned Denny-Renton Clay & Coal Company mine that is in the SW¼SE¼ sec. 12, T. 40 N., R. 4 E. No road leads to the area of the clay beds, but the area may be reached by walking along the tracks of the Chicago, Milwaukee, St. Paul and Pacific Railroad. The Sumas-Kendall road is about a quarter of a mile north of the abandoned mine workings (fig. 26).

Geology.—In Saar Creek Canyon, approximately 525 feet of the Sumas series has been described by Glover (1941, p. 310-311). During the field work for this report an attempt was made to re-examine

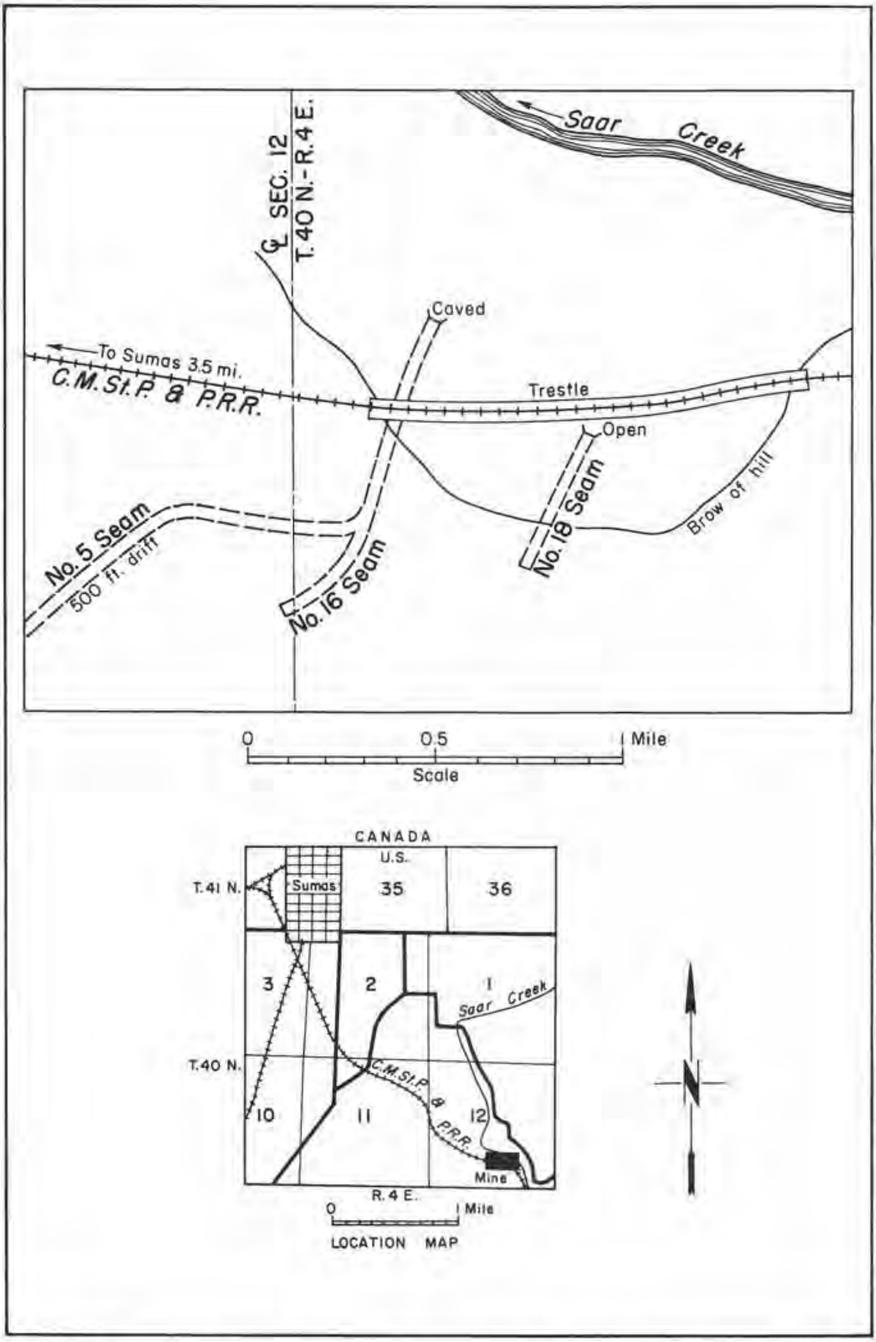

FIGURE 26. Location map of abandoned Denny-Renton Clay & Coal Company mine.

the section, but because of the great amount of weathering in the area only a small part of the section remains exposed.

The basement rocks of the area consist of dark-gray argillite and quartzite of the Chilliwack Group (late Paleozoic), which

TABLE 2.—*Stratigraphic section of the Sumas series, SW¼SE¼ sec. 12, T. 40 N., R. 4 E.*

D-R* No.		Feet
	Top of section concealed	
1	Shale, coarse, concretionary (red-firing)	50
	Conglomerate	15
2	Shale, sandy (low-grade dark buff-firing fire clay)	12
	Conglomerate	20
3	Shale, sandy (red-firing medium-plastic)	10
	Shale, reddish-colored sandy	20
4-A	Shale (plastic, similar to 6-A)	3–6
	Shale	10
4	Shale, sandy greenish-blue (low-grade fire clay)	10
	Shale, sandy	15
5	Shale, blue, fine-grained (main bed worked for fire clay; medium plastic) Sample No. 207	4–12
	Shale, mottled red and yellowish (low-grade fire clay)	20
6	Shale, yellowish (low-grade plastic fire clay)	6
	Shale, yellowish (semiplastic)	12
6-A	Shale, yellowish-blue (plastic fire clay) Sample No. 203	4
	Conglomeratic sandstone	40
16	Shale, fine-grained, light-blue (fire clay) "Tiger" Sample No. 204	0–7
16-AA	Shale (fire clay similar to 17-A)	1½–2
	Sandstone	3
17	Shale, blue, red-mottled (plastic)	20
17-AA	Shale, blue sandy (plastic fire clay) Sample No. 208	2–3
	Sandstone	5
17-A	Shale, blue sandy (fire clay)	1–2
	Sandstone	4
17-B	Shale, similar to 18	4
	Sandstone; carbonaceous partings	4
18	Shale, fine-grained (plastic) Sample No. S-18	11
	Sandstone; carbonaceous partings	4–5
19	Shale, iron-stained (very plastic)	12
20	Shale, light blue ("flint fire clay")	3
21	Shale, fine, even-grained, red	30
	Sandstone and fine conglomerate ("ganister") Sample No. 206	40
22	Shale, light blue sandy	3–4
23	Shale, red-stained	10
24	Shale, sandy red	5
	Conglomerate	3
	Shale	1+
	Conglomerate: pebbles average 1-2 inches in diameter and are as much as 18 inches at base of bed	80
	Approximately	525
	Unconformity	
	Argillite and quartzite, thin bedded, slaty	

*D-R numbers are those by which the Denny-Renton Clay & Coal Company designated the beds.

within Area No. 1 are well exposed in the bed of Saar Creek. Upon the basement rocks, with a well-defined angular unconformity, rests the basal conglomerate of the Sumas series. The conglomerate is composed of igneous, metamorphic, and quartz pebbles from 1 to 2 inches in diameter, although some boulders as much as 18 inches in diameter are present in the basal part of the unit. The remainder of the section consists of interbedded shale and sandstone with minor conglomerate beds. It is not uncommon to find gradations from sandstone to conglomerate within the same bed, as well as lensing out of the thinner beds. The series as a whole, however, is well stratified and uniform in structure. The average strike of the beds is N. 20° E., and the dip is 35° NW. Except for the exposures in Saar Creek Canyon, the Sumas series is overlain by glacial drift, and to the west it dips beneath the glacial deposits of Whatcom Basin.

A stratigraphic section of the Sumas series as reported by Glover (1941, p. 310-311), as well as the clay beds that were mined and sampled by the Denny-Renton Clay & Coal Company, is given in table 2.

Mining operations.—The old mine workings of the Denny-Renton Clay & Coal Company are beneath a trestle of the Chicago, Milwaukee, St. Paul and Pacific Railroad in the SW¼SE¼ sec. 12, T. 40 N., R. 4 E. Mining was undertaken from three drifts on seams 5, 16, and 18, the longest drift running about 500 feet on the No. 5 shale (fig. 26). The breast-and-pillar system of mining was used, and the clay was shipped to the Renton and Van Asselt plants of the company. At the time of the examination (1960) only one drift remained partly open, this being on seam No. 18. Wilson (1923, p. 66) reported that in 1923 the company was mining clay at this location, but it is not known when operations ceased.

Figures are not available on tests for all the shale units of the Sumas series, but listed below is a compilation of the tests on the more favorable clay beds as reported by Glover (1941, p. 313-315). According to Glover, the red-firing shales, some of which are of excellent quality, were not mined.

Denny-Renton No. 6-A.—Seam 6-A, a varicolored medium-hard shale, 4 feet in thickness, that overlies a 40-foot conglomeratic sandstone member. The shale is predominantly yellowish green but has stains of purple, brown, and yellow on the joints. The texture is fine and uniform, and the material contains very little sand.

Remarks: When tempered with water, a fair plastic strength is developed. Hard bodies are produced when fired between cones 02 and 10. As cone 28-29 is the fusion point, a No. 2 refractory brick can be made from this sample. The fired colors are buffs and browns.

Denny-Renton "Tiger 16".—Seam 16, a light bluish-gray shale that ranges from 0 to 7 feet in thickness. It underlies the conglomerate mentioned above. This shale member is nonuniform in texture and is moderately hard. It is partly very smooth, but contains layers and lenses of a friable material that is virtually fine-grained clayey sandstone.

TABLE 3.—*Working properties of Denny-Renton clay seam No. 16*

Plastic and dry properties

Plasticity .... Good	Volume shrinkage . 17.7% dry volume
Shrinkage water 9.1%	Linear shrinkage . 6.3% dry length
Pore water 12.1%	Linear shrinkage . 4.9% wet length
Water of plasticity 21.2%	Dry condition .... Good dry strength

Fired properties

Cone	Color	Condition	L.S. % d.l.	T.L.S. % d.l.	V.S. % d.v.	Abs.	A. por.
012	Lt. purple-gray	Soft, weak	.....	.....	.....	16.8	30.8
01	Cream	Soft, weak	0.2	6.5	0.7	16.8	31.3
3–4*	Lt. buff	Soft, weak	.....	.....	.....	15.4	32.3
6–7*	Buff	Soft, weak	1.2	7.5	3.7	15.0	28.2
10	Spotted buff	Good, hard	1.3	7.6	4.0	13.9	26.1
12*	Buff-brown	Good, hard	1.7	8.0	5.0	12.5	26.1

Remarks: Best firing range: 10-15. Cone fusion: 28. Class of ware: No. 2 refractory. Finer grinding may reduce required firing temperature for buff structural ware.

Denny-Renton No. 17-AA.—Seam 17-AA, a bluish-gray material with abundant red grains from a 2- to 3-foot bed of very sandy shale. Dry lumps are moderately hard.

TABLE 4.—*Working properties of Denny-Renton clay seam No. 17-AA*

Plastic and dry properties

Plasticity ....Weak	Volume shrinkage . . 8.1% dry volume
Shrinkage water........... 3.9%	Linear shrinkage . . 2.8% dry length
Pore water 9.4%	Dry condition.... Weak dry strength
Water of plasticity 13.3%	

Fired properties

Cone	Color	Condition	L.S. % d.l.	T.L.S. % d.l.	V.S. % d.v.	Abs.	A. por.
010	Lt. purple-gray	Weak, very soft	–0.2	2.6	–0.6	15.5	29.7
02	Lt. gray	Weak, soft	–0.3	2.5	–0.9	16.6	31.4

Remarks: Best firing range: 6-12. Cone fusion: 23. Poor plastic and dry strength which may be bettered by finer grinding with water. Class of ware: Gray and brown structural ware.

Denny-Renton No. 18.—Seam 18, from an 11-foot shale member. It is bluish-gray and a fine-grained uniform material.

TABLE 5.—*Working properties of Denny-Renton clay seam No. 18*

Plastic and dry properties

Plasticity .... Good	Linear shrinkage ...4.7% wet length
Water of plasticity 26.3%	

Fired properties

Cone	Color	Condition	L.S. % d.l.	T.L.S. % d.l.	V.S. % d.v.	Abs.	A. por.
010	Gray-buff	Very soft	.....	.....	.....	16.4	30.9
01	Lt. buff	Good, hard	.....	.....	.....	14.9	28.9
3–4*	Lt. buff	Good, hard	.....	.....	.....	13.7	.....
6–7*	Lt. buff	Good, hard	3.4	.....	8.5	13.5	26.3
12*	Brown-buff	Good, S.H.	4.1	.....	11.7	7.6	16.3
15	Spotted brown	S.H.	.....	.....	.....	.....	.....

Remarks: Best firing range: 4-15. Cone fusion: 26. Class of ware: Buff-colored structural ware.

Denny-Renton No. 22.—Seam 22, a bluish-gray moderately hard shale that is almost free from grit. The texture is very fine and uniform.

TABLE 6.—*Working properties of Denny-Renton clay seam No. 22*

Plastic and dry properties

Plasticity .... Good	Volume shrinkage.18.1% dry volume
Shrinkage water 9.4%	Linear shrinkage . 6.4% dry length
Pore water 13.9%	Linear shrinkage. 4.6% wet length
Water of plasticity 23.3%	Dry condition ... Good

Fired properties

Cone	Color	Condition	L.S. % d.l.	T.L.S. % d.l.	V.S. % d.v.	Abs.	A. por.
04	Cream	Soft	.....	.....	.....	14.4	29.0
3–4*	Lt. buff	Soft	.....	.....	.....	12.0	.....
6–7*	Lt. buff	Good, hard	3.2	9.6	9.2	11.2	22.6
10	Lt. buff	Good, hard	3.9	10.3	11.2	9.9	21.0
12*	Brown-buff	Good, hard	4.4	10.8	12.7	9.2	18.6

Remarks: Best firing range: 6-15. Cone fusion: 31. Class of ware: No. 1 refractory and buff structural ware.

TABLE 7.—*Chemical analyses of Denny-Renton clay seams*[1]

D-R no.[2]	Sample no.	SiO_2	Al_2O_3	Fe_2O_3
4	204	55.1	30.9	4.32
5	207	51.2	33.1	4.32
Top half of 5	207	46.57	32.73	4.10
6	....	66.4	25.2	1.74
18	S-18	54.9	30.8	4.32
20	....	47.0	40.6	1.44

[1]Analyses as reported by Glover (1941, p. 352-353).
[2]D-R numbers used by Denny-Renton Clay & Coal Company to designate beds.

Wilson (1923, p. 135-136) gives the following analyses on seams No. 3 and 4 of the Sumas Series:

No. 211.—Whatcom County. A hard, light-brown shale from seam No. 3, the Sumas mine, leased by the Denny-Renton Clay & Coal Company. Wet tensile strength, 1.6 lbs. a square inch. Good dry strength. Fired colors: buff-red, cone 05; brown-reds, cones 3 to 8; brown and black, cones 9 to 15. A hard structure is developed at cone 05, steel hardness at cone 3, and blisters at cone 9. Best firing range, cone 02 to 7. Cone fusion 15. Possible uses: red-burning structural ware.

No. 212.—Whatcom County. Light-brown, soft shale from No. 4 seam, Saar Creek beds, Denny-Renton Clay & Coal Company. Wet tensile strength 2.1 lbs. a square inch. Good dry strength. Fired colors: buff-reds to cone 4, brownish-reds to cones 5 to 8, gray-browns and blacks, cones 9 to 20. Hard structure is developed at cone 2 and steel hardness at cone 8. Best firing range, cones 2 to 10. Cone fusion 23 to 26. Possible uses: red and brown structural wares.

From the above data it is apparent that the clay beds of the Sumas series in the Saar Creek Canyon are quite variable in physical and chemical properties. The main refractory clays are confined to seams No. 5, No. 16, and No. 22. Mining operations were undertaken on seams 5, 16, and 18, as is shown in figure 26, but it is not known whether any of the other refractory clays were mined. No mine dumps are present to indicate mining of the clays, but it is possible that the beds were worked from crosscuts on seams 5, 16, or 18. The southern boundary of the clay seams is not known. However, if they retained their refractory properties along the strike of the beds, they probably extend as far as Haystack Hill, which is about 1,000 feet south of Saar Creek (pl. 1).

Clay reserves.—Inasmuch as the old mine workings of the Denny-Renton Clay & Coal Company are inaccessible, it is difficult to estimate the tonnage of fire clay that remains. The clay seams, which dip about 35° to the west, have been mined by means of drifts and stopes from one level. In the one drift that remains partly open on seam No. 18, it appears that a maximum of 20 feet was stoped out in places. Assuming that at least 20 feet of clay had been removed from each seam along the entire length of the seam in a southerly direction, table 8 shows the possible tonnage of clay that remains. The tonnages are computed for a height of 30 feet, which represents the distance from the creek bed to the maximum elevation of the beds minus the 20 feet that has possibly been extracted from each clay bed. The strike length of the beds is considered to be about 500 feet.

TABLE 8.—*Clay reserves of Area No. 1*

Seam no.	Average (ft.) width	Sample no.	Possible tonnage*
5	8	207	8,000
6-A	4	...	16,000
16	3	...	2,700
17-AA	2.5	...	1,500
18	11	S-18	10,800
21	30	...	27,000
22	3.5	...	3,600

*Moist clay in place @ 1.8 tons per cubic yard.

The above-mentioned clay seams represent only those on the south side of Saar Creek at the site of the abandoned mine workings of the Denny-Renton Clay & Coal Company. The Sumas series also crops out on the north side of Saar Creek, but it is not known whether the clay seams have been mined at this location. As is the southern half of the Sumas series, the northern half is also covered by glacial drift. However, about 1,000 feet north of Saar Creek the Sumas series is in contact with the basement complex.

It is probable that the fire clays extend into the area north of Saar Creek. However, no data are available with which to compute tonnages. If the clay seams extend into this area, it may be assumed that at least one-half as much tonnage as is believed to be present on the south side of the creek is present on the north side. On this assumption, there would be about 34,800 tons of moist clay on the north side. This reduction in tonnage figures is due to the lower elevation of the Tertiary sedimentary rocks in the north half of the area.

Area No. 2

Location and accessibility.—Area No. 2 is about half a mile east of Area No. 1 and within the right-of-way of the Chicago, Milwaukee, St. Paul and Pacific Railroad. The Sumas-Kendall road is about a quarter of a mile to the north (fig. 27).

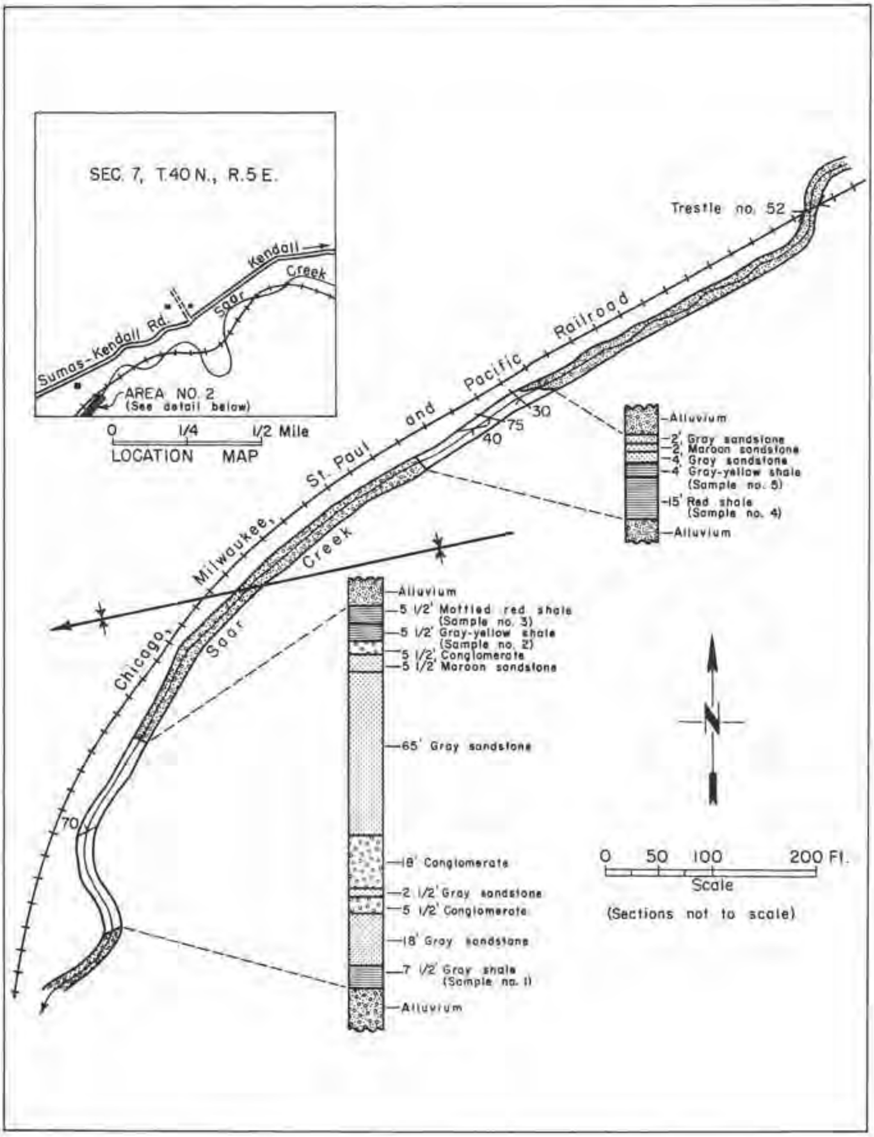

FIGURE 27. Geologic sections of fire clay Area No. 2.

Geology.—Tertiary continental sedimentary rocks similar to those in Saar Creek Canyon crop out in the bed of Saar Creek in the NW¼NW¼ sec. 18, T. 40 N., R. 5 E. A generalized stratigraphic section of about 140 feet of these rocks is given in table 9.

TABLE 9.—*Stratigraphic section of the Sumas series, NW¼NW¼ sec. 18, T. 40 N., R. 5 E.*

Sample no.		Thickness (feet)
	Alluvium	
3 and 4	Shale, red	15
2 and 5	Shale, grayish-yellow	4
	Conglomerate, mixed pebble	6
	Sandstone, maroon	28
	Sandstone, gray	37
	Conglomerate, mixed pebble	18
	Sandstone, gray	3
	Conglomerate, mixed pebble	6
	Sandstone, gray	18
1	Shale, gray	8
	Concealed	

The beds have been folded into an asymmetrical syncline in which the beds on the north limb strike N. 50°-75° W. and those on the south limb strike N. 20° E. The south limb dips 70° N., and the north limb dips 30° to 40° S. A thick cover of glacial outwash material conceals most of the shale-bearing sedimentary rocks, and the nearest pre-Tertiary basement rocks crop out about 1,500 feet to the north on Vedder Mountain.

Other than a few shallow prospect pits, there is no evidence of mining in this area. The shale beds have been sampled in the past, as Glover (1941, p. 316-317) reports the following analyses on two shales from this locality. Glover did not state from which part of the section the samples were taken; however, sample No. 201 is probably the uppermost shale bed in the section and sample No. 202 is the underlying shale.

Sample No. 201 is a dark reddish-brown shale. It is hard but very brittle and easily shatters into small angular pieces with sharp conchoidal fracture.

Remarks: The plasticity developed by this clay, when ground and tempered in the usual manner, is too poor for the handling of commercial wares. It is possible that better plastic strength can be produced by wet-grinding. May be usable by the dry-press process. The fired color is dark red-brown; the firing range is approximately between cones 3 and 10; and the cone fusion point is cone 16-17.

Sample No. 202 is from a thin bed lying between No. 201 and the sandstone. It is a hard, very brittle shale that breaks with a sharp, hackly fracture and is blue in color with yellow and reddish-purple mottlings.

TABLE 10.—*Working properties of shale from the NW¼NW¼ sec 18, T. 40 N., R. 5 E.*

Sample No. 202	Plastic and dry properties
Plasticity ....Weak	Volume shrinkage 10.4% dry volume
Shrinkage water 5.1%	Linear shrinkage . 3.6% dry length
Pore water 10.0%	Linear shrinkage . 2.1% wet length
Water of plasticity..........15.1%	Dry condition .... Weak

Fired properties

Cone	Color	Condition	L.S. % d.l.	T.L.S. % d.l.	V.S. % d.v.	Abs.	A. por.
06	Lt. red-brown	Weak, soft	.....	.....	.....	16.7	32.7
01	Buff-brown	Weak, soft	5.8	9.4	16.3	11.9	25.2
3–4*	Buff-brown	Weak, soft	6.1	9.7	17.3	11.3	22.4
6–7*	Buff-brown	Weak, soft	.....	.....	.....	11.5	23.3
12*	Dark brown	Hard	5.9	9.5	16.8	11.8	31.9
15	Brown, black	Hard	6.6	10.2	18.5	11.6	25.5

Remarks: Best firing range: 8-14. Structure, granular. Cone fusion: 23-26. Needs fine grinding with water or dry-pressing, and high temperatures for fired strength. Class of ware: Brown structural wares.

Fired properties of several of the shale beds listed in table 9 are given in table 11. For the location of these samples, see figure 27.

TABLE 11.—*P.C.E. and bloating tests on samples from the NW¼NW¼ sec. 18, T. 40 N., R. 5 E.*[1]

Sample no.	P.C.E.	Fired color	Bloating type
1	12	Black	Low
2	18	Brown	None
3	20	Black	None
4	20	Black	None
5	18	Dark brown	None

[1]Analyses by U. S. Bureau of Mines Northwest Experiment Station, Seattle.

Clay reserves.—Although semirefractory clays are present in Area No. 2, they are so poorly exposed that no attempt will be made here to report reserves. The clay deposits are also poorly suited for mining operations, as mining would have to be undertaken below the water table. Also, the steep dip of some of the beds would make surface mining impractical.

Area No. 3

Location and accessibility.—Area No. 3 is in parts of secs. 5, 6, 7, and 8, T. 40 N., R. 5 E., about 5 miles southeast of Sumas. It comprises about 200 acres and is the site of the abandoned Sumas clay mine of Gladding, McBean & Company. The caved adits of the mine workings are 300 feet north of the Sumas-Kendall road and 600 feet north of the tracks of the Chicago, Milwaukee, St. Paul and Pacific Railroad (fig. 25, on page 68, and pl. 3). Although a road leads to the mine, it is overgrown with brush and difficult to recognize.

History.—Almost all of the fire clay that has been mined in Whatcom County has come from this area. During the operation of the Sumas mine, which was worked intermittently from 1920 to 1949, the clay was shipped by rail to the company's Renton plant, where it was utilized along with other clays in refractory blends. At the time of this examination (1960) the portals of the adits were caved, and other than one ore bunker nothing remains of the surface plant.

Geology.—Very few outcrops are visible in this area, as the vegetation is dense and the overburden is thick. The sedimentary rocks consist of arkosic sandstone, carbonaceous siltstone and shale, and mixed pebble conglomerate. The general lithology resembles that of the Sumas series; however, definite correlation of the two sequences has not been established. Throughout the area most of the strata are nearly flat lying, but in the northern part some of the beds dip as much as 25° N.

A stratigraphic section of the rocks that contain the clay seams is not exposed on the surface. Hodge (1938b, p. 772) gives the following section for the refractory clays that were being mined.

TABLE 12.—*Stratigraphic section of clay beds in Sumas clay mine, NE¼ sec. 7, T. 40 N., R. 5 E.*

Thickness		Lithology
Ft.	In.	
		Sandstone hanging wall
2	0	Bone and carbonaceous shale
5–8	0	Refractory clay (No. 8 clay bed)
	4	Hard sandstone
	2	Coal
3–5	0	Clay (low grade) that requires sorting, No. 1 bed
		Sandy clay footwall

Hodges states that the quality of the clay varies; the best clay fuses at cone 31, but nearly all the material mined averaged at least cone 28. The clay is not a true flint fire clay, since it breaks down in water quite readily, but is a shale that has no definite fissile structure. When dry it is gray to black, and on exposure to the weather it breaks down to form a semiplastic mass. Hodge (1938b,

p. 770) reports on analyses of the two principal beds of the Sumas mine as shown in table 13.

TABLE 13.—*Chemical analyses of refractory clay from the Sumas mine, NE¼ sec. 7, T. 40 N., R. 5 E.*

Constituent	1	2	3	4	Sample identification
Silica (SiO_2)	45.56	47.96	44.2	46.6	(1) No. 8 bed
Alumina (Al_2O_3)	30.60	33.61	43.5	37.5	(2) Starkweather clay
Ferric oxide (Fe_2O_3)	4.28	3.95	....	....	(3) Sample No. 199
Lime (CaO)	1.39	1.94	....	....	(4) Sample No. 200
Magnesia (MgO)	0.54	....	....	....	
Loss on ignition / Moisture at 212° F.	15.72	12.88	....	....	
	98.09	100.34			

Hodge also reports that tests made on the light-gray clay (No. 8 bed) show the following:

> To use this clay alone for a medium-duty refractory, it is recommended that the firing temperature be carried above cone 14, 1,400° C., or 2,552° F., so that subsequent changes in use will not occur.
>
> The clay can be used as a bonding clay for refractory clays of higher cone fusion points but less plastic strength.
>
> As a blending clay it acts as a compensator for other clays, as it expands at higher temperatures where others contract, hence it aids in reducing shrinkage in use.
>
> Its pyrometric cone equivalent varies from cones 28 to 31, 1,615° to 1,680° C., or 2,939° to 3,056° F., when fired rapidly at 150° C. per hour.

Glover (1941, p. 315-316) gives analyses of several clays of the area that were taken from surface pits and outcrops. An attempt was made to relocate the sample locations, but, because of the great amount of weathering in the area, the pits are no longer distinguishable.

Analyses of shales from near the center of the N½ sec. 7, T. 40 N., R. 5 E.:

> Sample No. 198, from the lowest of three hillside pits, is from a thick stratum of dark reddish-brown shale. It is a highly ferruginous material, almost devoid of ordinary sand but containing fine grains of magnetite. It is hard but very brittle and easily shatters into small angular pieces with sharp conchoidal fracture.
>
> Remarks: When dry-ground and tempered in the usual manner with water, only a feeble plastic strength could be developed. In this condition it may be possible to mold ware by the dry-press process. Grinding in water may develop better strength. When fired between cones 3 and 10, red-brown colors are produced suitable for dark structural wares. The sample deformed at cone 18-19.

Sample No. 199 is from a prospect (known as "S. P. No. 1") some distance above the preceding one, where spheroidally weathered shale is exposed. It is greenish buff colored and stained to dark brown on joints. The texture is very fine and uniform. It resembles sample No. 198 in being free from sand, hard, very brittle, and breaking with a sharp conchoidal fracture.

Remarks: Further tests should be made to develop a No. 1 refractory body of this clay. Cone deformation point is cone 32. Plastic strength must be obtained by addition of a plastic bond or by grinding in water in a ball mill, or use must be made of the dry-press process.

Sample No. 200 is from a prospect (known as "N. W. No. 1") still farther up the hill. This shale is almost identical with sample No. 199 except that it has a bluish-gray color.

TABLE 14.—*Working properties of shale sample No. 200*

Plastic and dry properties

Plasticity ....Weak	Linear shrinkage ..10.2% wet length Dry condition ..Weak (gum added)

Fired properties

Cone	Color	Condition	L.S. % d.l.	T.L.S. % d.l.	V.S. % d.v.	Abs.	A. por.
06	Brown-buff	Good, S. H.	5.5	.....	15.5	14.7	28.5
05	Lt. buff-brown	Cracked, S. H.	.....	.....	.....	13.2	25.9
04	Lt. buff-brown	Cracked, S. H.	6.9	.....	19.2	12.8	25.4
3–4*	Deep buff	Cracked, S. H.	10.3	.....	27.9	6.8	14.7
6	Deep buff	Cracked, S. H.	11.6	.....	31.0	5.8	14.0
12*	Deep brown	Cracked, S. H.	.....	.....	.....	1.4	2.1

Remarks: Best firing range: 02-12. Cone fusion: 31. Shrinkage is high. Class of ware: No. 1 refractory. Needs bond clay or the development of plasticity by grinding in water. May be usable for dry-pressing.

Mining operations.—Four adits that were driven in a northerly direction into the southern slope of Vedder Mountain provided access to the underground workings of the Sumas mine. The clay seams were worked from 40 to 100 feet beneath the surface in benches off the main haulage level. The breast and pillar system of mining was used; the pillars were left for support during mining operations but were mined on retreat. From the mine workings the clay was trammed to bunkers near the portal of the mine and to a tipple alongside the railroad.

From mine maps made available through Gladding, McBean & Company, it appears that approximately 7½ acres has been worked out. Plate 3 shows the underground workings of the Sumas mine.

Clay reserves.—It is probable that a large amount of refractory clay still remains in the ground at Area No. 3. Of the 200 acres underlain by shale-bearing sedimentary rocks, only about 7½ acres appears to have been mined, this being on only two clay seams.

In estimating the ore reserves, the refractory clay beds that were mined (this being at an elevation of about 500 feet) were extended horizontally beyond the mining operations to the limits of the beds. The beds terminate against the basement rocks on the east, and the extensions in the other directions have been removed by erosion. Should the clay beds retain their refractory properties and not lens out, at least 1,440,000 tons of clay may remain. The P.C.E. of the clay is not known, but the clay mined in the past averaged at least cone 28 and was 5 to 8 feet thick.

It is believed that a properly executed drilling program would prove that refractory clays are present beyond the limits of the mined-out portions of the deposit. In addition, drilling would also disclose any other clay beds that may lie either above or below the known clays. The possibility also exists that the clay seams could be worked from the northern slope of Vedder Mountain near Anderson Lake. This would provide natural drainage for the mine workings, as the beds dip to the north in this area.

Area No. 4

Location and accessibility.—Area No. 4 is in secs. 17 and 20, T. 40 N., R. 5 E. It is about 1½ miles southeast of the Sumas clay mine and on the northeastern end of Sumas Mountain (fig. 25, on page 68). The Paradise Valley logging road parallels the western edge of the area, and the South Pass road is a quarter of a mile to the north.

Previous operations.—There is no evidence of extensive mining in the area, and only one mine dump was noted, this being in the NE¼SW¼ sec. 17, on the east bank of Saar Creek. The adit is caved, but the waste on the dump indicates that mining was undertaken on one of the coal seams of the sedimentary rocks. Glover (1941, p. 317) reports that efforts were made to block out high-quality, refractory shales that probably occur along the footwall of the coal seam. The operation no doubt failed, as the property shows no indication of production.

Geology.—The area, for the most part, is covered by dense underbrush and thick overburden. Outcrops are scarce and consist chiefly of poorly sorted pebble conglomerates and interbedded thick beds of gray siltstone. Several beds of lignite and thin coal seams are present in the siltstones. The sedimentary sequence lies unconformably upon a basement complex of highly folded and faulted argillite, graywacke, serpentinite, and chert of late Paleozoic age.

The dips of the beds range from 70° E. to 70° W., and the strikes trend slightly east of north. The rocks have been folded into a closed symmetrical syncline, the axis of which trends N. 15° E. By being folded into the more resistant basement rocks, the Tertiary sedimentary rocks have been protected from erosion.

At only one locality in Area No. 4 was shale found that is of refractory quality. This shale crops out in a roadcut on the Paradise Valley road near the center of the W½ sec. 17. It is medium- to dark-gray, brittle, and contains small amounts of angular quartz, feldspar, and magnetite grains. These grains average less than 1 millimeter in diameter.

Though the refractory shale is poorly exposed, it appears to have been developed upon white to light-gray highly fractured feldspathic rock. About 2 feet of the shale was sampled, but its lateral extent could not be ascertained. The results of tests on samples from two parts of the outcrop are shown in table 15.

TABLE 15.—*Properties of refractory shale from the W½ sec. 17, T. 40 N., R. 5 E.*[1]

Sample no.	P.C.E.	Fired color	Bloating type	D.T.A.
7a	29+	Light-brown	None	High kaolinite
7b	30	Dark-buff brown	None	High kaolinite

[1]Analyses by U. S. Bureau of Mines Northwest Experiment Station, Seattle.

Clay reserves.—The refractory shale of Area No. 4 is so poorly exposed that no attempt was made to calculate reserves. The shale area is limited in size and appears to have little if any economic value.

GLACIAL CLAY

Much of the map area is covered by Pleistocene glacial outwash material that consists mainly of sand and gravel. However, several silt and clay beds are present. The glacial clays are commonly dark to light bluish gray, and when exposed to weathering become buff or brown. Some of the clays are sandy or silty and in places contain pebbles and boulders. When silt and sand are present, the clay may be stratified.

Many glacial clays were noted in the area, but none were sampled. They occur chiefly in the major valleys, and near the center of sec. 9, T. 40 N., R. 5 E. Shedd (1914, p. 213) reports that clay as much as 20 feet thick extends for 300 feet along the railroad track. In the NW¼ sec. 9, T. 40 N., R. 5 E., the clays are as much as 50 feet thick. The following analyses on two glacial clay beds of the area were given by Shedd (1914, p. 214).

TABLE 16.—*Chemical analyses of glacial clays of Columbia Valley*

Sample location	Silica (SiO_2)	Alumina (Al_2O_3)	Iron (Fe_2O_3)	Lime (CaO)	Magnesia (MgO)	Ignition loss
Sec. 9, T. 40 N., R. 5 E.	59.92	17.85	7.31	6.08	3.15	5.42
Sec. 34	54.16	14.97	7.91	2.62	4.15	13.46

A. A. Hammer, analyst

The clays are nonrefractory and have cone fusions between 2 and 6. The working properties are generally good and can satisfy the requirements for common brick.

All the glacial clays of the area occur as horizontal beds that can easily be stripped of their overburden and mined by open pit methods. Only the high water table in several areas would present any problems.

Conclusions

A moderate tonnage of refractory and semirefractory clay still remains in the region covered by this report. However, extensive exploration work would be required to properly evaluate the deposits. Of the four areas discussed, only Areas Nos. 1 and 3 contain clay reserves that would justify further mining. Underground mining methods would have to be used, but in Area No. 3 stripping methods could be used on any clay seams that might be discovered near the surface.

The possibility of refractory clays being present in the Tertiary continental sedimentary rocks along the western front of Sumas Mountain should not be overlooked. Similar rocks 8 miles to the north in British Columbia contain extensive clay deposits. The area would have to be explored by drilling or trenching because of the thick cover of overburden.

The glacial clays of the map area are more extensive than the refractory clays and are confined to the major valleys. Many of them have good working properties and are suitable for common brick. In secs. 8 and 9, T. 40 N., R. 5 E., they are as much as 50 feet thick.

All the areas that contain clay are readily accessible. The Bellingham-Maple Falls line of the Chicago, Milwaukee, St. Paul and Pacific Railroad, and also several well-maintained county roads, pass within a few hundred feet of most of the deposits. The rail haul to Bellingham is but 35 miles. Electric power is available in the immediate area.

LIMESTONE

Deposits of limestone crop out in the northern half of the map area on Sumas, Red, and Black Mountains. The deposits on Sumas and Red Mountains were mined as early as 1912, when the International Lime Company utilized the limestone for the manufacture of hydrated lime. Since 1926 the limestone has been used chiefly by the cement and pulp industries of Whatcom County.

Production figures are not available for the earlier years, but between 1919 and 1958, about 2,500,000 tons of limestone valued at $4,800,000 was produced. Two quarries on Red Mountain are still in operation and continue to supply the region's limestone demands.

Large tonnages of limestone still remain in the area, and no deposit is more than 9 miles by road from the railroad that serves the area. Because most of the limestone is covered by glacial drift, stripping and (or) drilling would be required to properly evaluate the deposits.

In the following brief discussion of the limestone deposits, analyses of the limestones are not included under each specific deposit but appear in tabulated form in table 18 on pages 98-100 of this report.

Silver Lake Quarry

Location and accessibility.—The Silver Lake limestone deposit is near the southwest corner of sec. 7, T. 40 N., R. 6 E., 2½ miles north of Maple Falls (fig. 28 and pl. 1). A hardtop county road leads from the quarry to Maple Falls. At Maple Falls, loading facilities are available on the Chicago, Milwaukee, St. Paul and Pacific Railroad's line to Bellingham, a rail haul of about 35 miles.

Geology.—The quarry is in limestone of Early Pennsylvanian age. The limestone is gray to brownish gray, buff weathering, medium to coarsely crystalline, and highly jointed. Large clay- and silt-filled cavities commonly occur in the limestone, and white secondary calcite has crystallized along many of the fractures. The beds have a general N. 80° W. strike and they dip about 45° S. In places the limestone is so highly contorted and sheared that it is impossible to ascertain the direction of the strike and dip of the beds. The limestone is overlain by highly sheared argillite and underlain by argillite, graywacke, and volcanic breccia of the Chilliwack Group. Beyond the limits of the quarry the limestone is concealed by a thick cover of overburden and dense underbrush.

At its widest point in the quarry the limestone is about 400 feet thick. Samples W1-2 and W1-1 (table 18, on page 98) were collected from the quarry face. Outcrops to the west and uphill from the quarry indicate that the deposit extends for at least 1,000 feet in a westerly direction. About 1 mile west of the quarry and near the top of Red Mountain similar limestone crops out. The lack of outcrops between the two deposits makes it impossible to determine whether they represent one continuous bed or two separate limestone lenses.

Development and operation.—The limestone is being worked by the Mitchell Bay Lime Company, of Seattle. The operation is

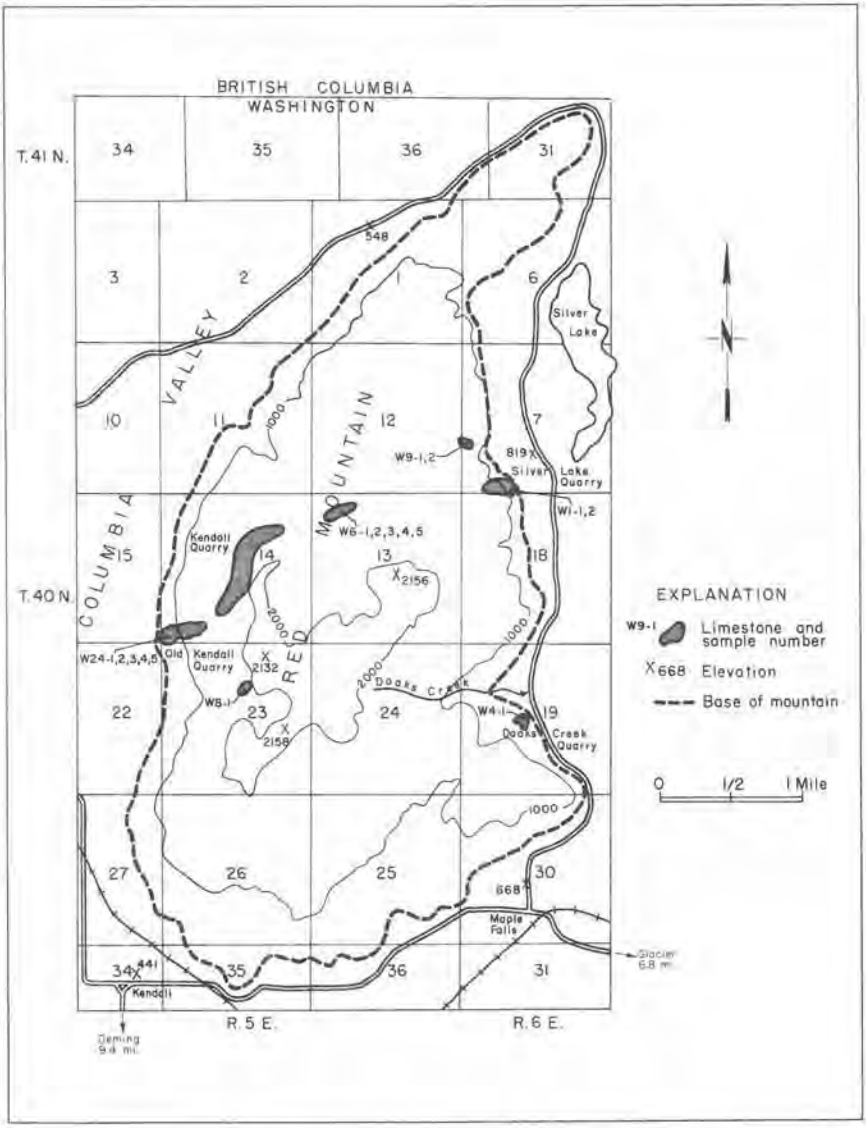

FIGURE 28. Location map of Red Mountain limestone deposits.

confined to one quarry, which begins at the level of the valley floor. When the writer visited the property in 1959, mining was proceeding from a bench about 80 feet above the valley floor (fig. 29). The quarry face is about 85 feet high. One ¾-yard shovel loads the dump trucks, which haul the limestone to railroad load-

FIGURE 29. Silver Lake limestone quarry. Limestone of Early Pennsylvanian age.

ing facilities at Maple Falls. After shipment to Bellingham, the limestone is used by the Puget Sound Pulp and Timber Company pulp plant.

KENDALL QUARRY

Location and accessibility.—The Kendall quarry of the Permanente Cement Company is 2 miles north of Kendall on the western side of Red Mountain and near the center of sec. 14, T. 40 N., R. 5 E. (fig. 28 and pl. 1). The quarry floor is at an elevation of 1,760 feet, which is 1,260 feet above the floor of Columbia Valley. A spur of the Chicago, Milwaukee, St. Paul and Pacific Railroad extends to loading facilities at the base of Red Mountain. The rail haul to Bellingham is about 30 miles.

Geology.—The limestone of the Kendall quarry is of Early Pennsylvanian age (Danner, 1957). It is medium to dark gray, dense to crystalline, and massive to well bedded. The limestone is fossiliferous, and some thin beds are composed almost entirely of crinoid columnals. Much of the limestone is highly fractured, and many fractures have been filled by secondary calcite. Some parts of the limestone are siliceous, whereas other parts of it are high in magnesia. Several lenses of argillite are present in the limestone, and in the northern end of the quarry the limestone contains an interbed of tuffaceous greenish-gray siltstone and a chert pebble conglomerate. The total thickness of this interbed is about 50 feet.

The limestone beds strike to the northeast, and the dips range from 45° to 55° to the southeast. The limestone is underlain by dark-gray siliceous and cherty argillite and black to dark-brown shale. It is overlain by dark-gray argillite and graywacke that contain interbeds of andesite. Although the maximum thickness of the limestone is not known, exposures in the quarry suggest a thickness of more than 300 feet (fig. 30). Except in the vicinity of the quarry, where the limestone has been exposed in quarrying operations or by stripping, a thick cover of underbrush and glacial drift covers the area, which makes outcrops hard to find.

FIGURE 30. Kendall limestone quarry.

A. North half of quarry. B. South half of quarry. Limestone of Early Pennsylvanian age. Maximum height of quarry face is 240 feet.

Two small abandoned quarries are half a mile southwest of the main quarry and at the base of the mountain. The limestone is the same as that in the main quarry but is more highly sheared and contorted. It appears to have been offset to the west from the limestone in the main quarry by N. 75° E.-trending high-angle faults. Samples W24-1 through W24-5 were collected from outcrops in and adjacent to the old quarry workings.

Development and operation.—Prior to 1926 the quarry was operated by the International Lime Company for the manufacture of hydrated lime. After 1926 the quarry was taken over by the Olympic Portland Cement Company to supply the limestone demands for its cement plant in Bellingham. In 1958 the Permanente Cement Company purchased the Olympic Portland Cement Company and is the present operator of the quarry.

The quarry is presently being operated in 40-foot lifts. The quarry face is about 1,500 feet long and about 240 feet high at its highest point above the floor (fig. 30). The limestone is moved from the quarry to railroad storage bins at the base of the mountain by gravity and belt conveyor system. Production is about 500,000 tons of cement rock per year (Conners, 1960, p. 58).

Boulder Creek Quarry

Location and accessibility.—The Boulder Creek limestone occurrence is in the NW¼ sec. 22, T. 40 N., R. 6 E., and is 3 miles northeast of Maple Falls (fig. 31 and pl. 1). It is on the west bank of the creek and about 1½ miles upstream from State Highway 1. Two miles of mountain road, the last mile of which has been abandoned, leads from the highway to the limestone deposit. Railroad loading facilities on the Bellingham-Maple Falls line of the Chicago, Milwaukee, St. Paul and Pacific Railroad are available at Maple Falls, a distance of about 4½ miles by road from the deposit. The rail haul is about 35 miles to Bellingham.

Geology.—The limestone crops out in the bottom of the ravine through which flows Boulder Creek, and it forms several impressive outcrops that are known as Marble Peaks. Very little of the limestone on Marble Peaks appears to be in place, but it occurs as piles of limestone blocks. Samples W5-2 through W5-4 were taken from this limestone, which occurs as scattered outcrops for about 1,200 feet along the banks of the creek. An abandoned quarry, now filled with water, is on one of the northernmost outcrops of the limestone. Sample W5-1 was taken from this quarry.

The limestone on Boulder Creek is white to gray, and crystalline. Much of it, especially in the quarry, is highly fractured and contains inclusions of serpentine. The beds in the quarry strike east to northwest and dip 70° to the north. The limestone in the other outcrops lacks bedding planes. According to Danner (1957) the limestone is of Early Pennsylvanian age. It contains large crinoid stems similar to those found in the Silver Lake and Kendall quarries.

No limestone occurs on the east bank of Boulder Creek; the rocks here are sandstone and conglomerate of the Chuckanut Formation (Upper Cretaceous-lower Eocene) that are in fault contact with the limestone of the west bank. West of the limestone the predominant rocks are highly sheared and contorted argillite, graywacke, chert, and basalt of the Chilliwack Group (upper Paleozoic).

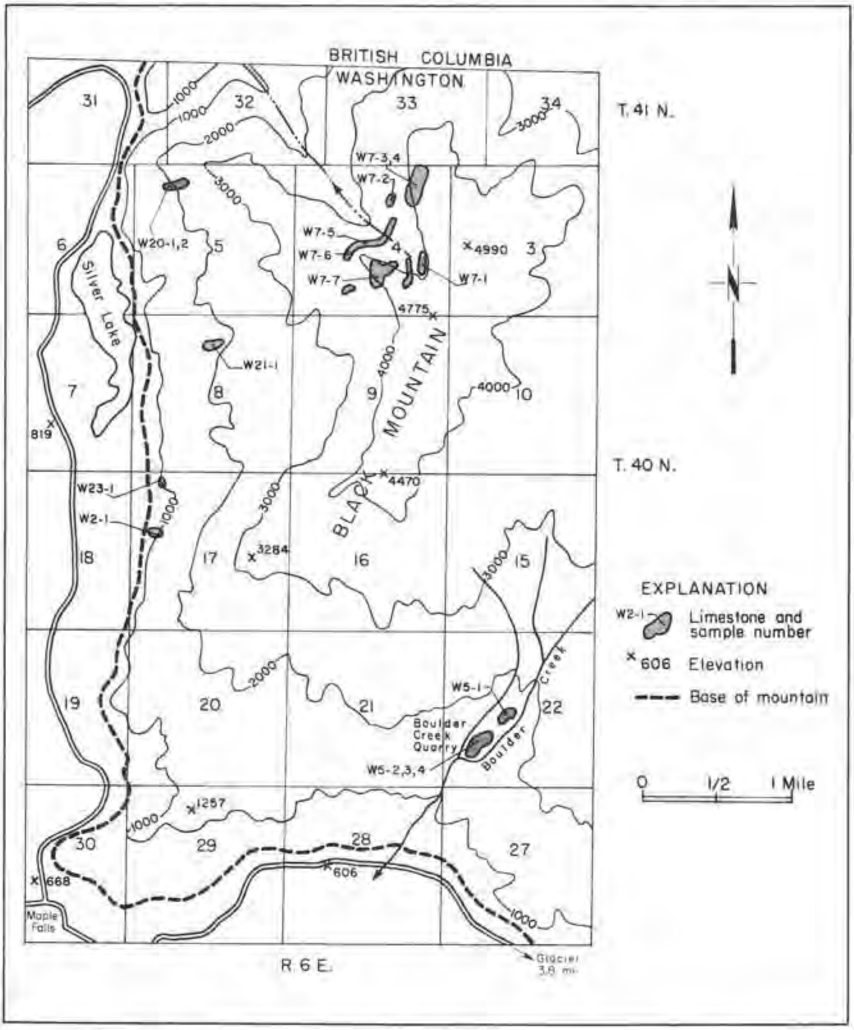

FIGURE 31. Location map of Black Mountain limestone deposits.

No estimate can be made of the stratigraphic thickness of the limestone in this area. It appears limited in size and probably represents several fault blocks that occur within a fault zone that parallels Boulder Creek. Individual outcrops are as much as 350 feet long and from 50 to 150 feet wide.

Development and operation.—The deposit was operated until 1952 by the Mitchell Bay Lime Company as the Maple Falls Lime Quarry. During the time of this operation two small quarries were developed that exposed about 25 feet of limestone in their faces. Most of the limestone was sold as pulp rock to the Puget Sound Pulp and Timber Company, in Bellingham. In 1959 the quarries were not in operation but had been abandoned.

Doaks Creek Quarry

Location and accessibility.—The Doaks Creek limestone deposit is 1¼ miles north of Maple Falls and near the center of sec. 19, T. 40 N., R. 6 E. (fig. 28 and pl. 1). A quarter of a mile of unimproved road leads to the deposit from a point on the Silver Lake road about 1¾ miles north of Maple Falls. The closest railroad shipping point is Maple Falls, which is about 35 miles by rail from Bellingham.

Geology.—The quarry is in dense to finely crystalline, medium- to dark-gray limestone of Devonian age. Interbedded with the limestone are beds of coral as much as 3 feet thick that are more

Figure 32. Doaks Creek limestone quarry. Limestone of Devonian age.

resistant to weathering than the nonfossiliferous limestone. These beds make the limestone distinctly banded. The general strike of the beds is N. 60° E., and the dips range from 30° to 70° north and south. Outcrops are scarce, and neither the footwall nor the hanging wall of the limestone is exposed. Several poorly exposed outcrops suggest a thickness of at least 200 feet. The maximum lateral extent of the limestone is about 500 feet. Sample W4-1 is representative of the limestone exposed in the face of the quarry.

Development and operation.—The quarry is now abandoned (1960) but was operated by the Mitchell Bay Lime Company during 1953 and 1954. The company developed one quarry with a working face about 100 feet long. At its highest point the quarry face is about 40 feet above the floor (fig. 32). After mining, the limestone was trucked to Maple Falls for rail shipment to the Puget Sound Pulp and Timber Company, in Bellingham.

Balfour Quarry

Location and accessibility.—The Balfour quarry limestone deposits are 1¼ miles northwest of Kendall and in the NE¼ sec. 28, T. 40 N., R. 5 E. (fig. 33 and pl. 1). Two miles north of Kendall a graveled road leads west to the deposits, which are near the base of Sumas Mountain. The lowermost outcrop of limestone is about 100 feet above the floor of Columbia Valley, whereas some limestone is exposed at about 1,000 feet above the valley floor. Railroad loading facilities are available half a mile east of the deposits, and the rail haul to Bellingham is about 30 miles.

Geology.—The quarries are in limestone, which, according to W. R. Danner (written communication, 1960), is of Devonian age. Thick overburden and dense underbrush conceal most of the limestone except where it has been uncovered by quarrying operations.

The limestone is medium to dark gray, fine to coarsely crystalline, and highly fractured. It is massive to well bedded, and recrystallized calcite fills many of the fractures. Coral occurs throughout the limestone, but it is not abundant. The average strike of the beds is N. 80° E., and the dips range from 50° to 80° S. In places the limestone is highly contorted.

The limestone is interbedded with dark-gray argillite, quartzite, and graywacke that, like the limestone, are highly contorted and fractured. Whether the limestone deposits at the Balfour quarry represent several beds or one bed that has been repeated by folding has not been determined. The beds vary in thickness, but the maximum thickness appears to be about 150 feet. The deposits are as much as 200 feet wide and 400 feet long. Much of the limestone in the larger deposits has been quarried. Samples W16-1 through W16-14 were collected from the quarries and from several outcrops within the area. Figure 33 gives the general locations of these samples.

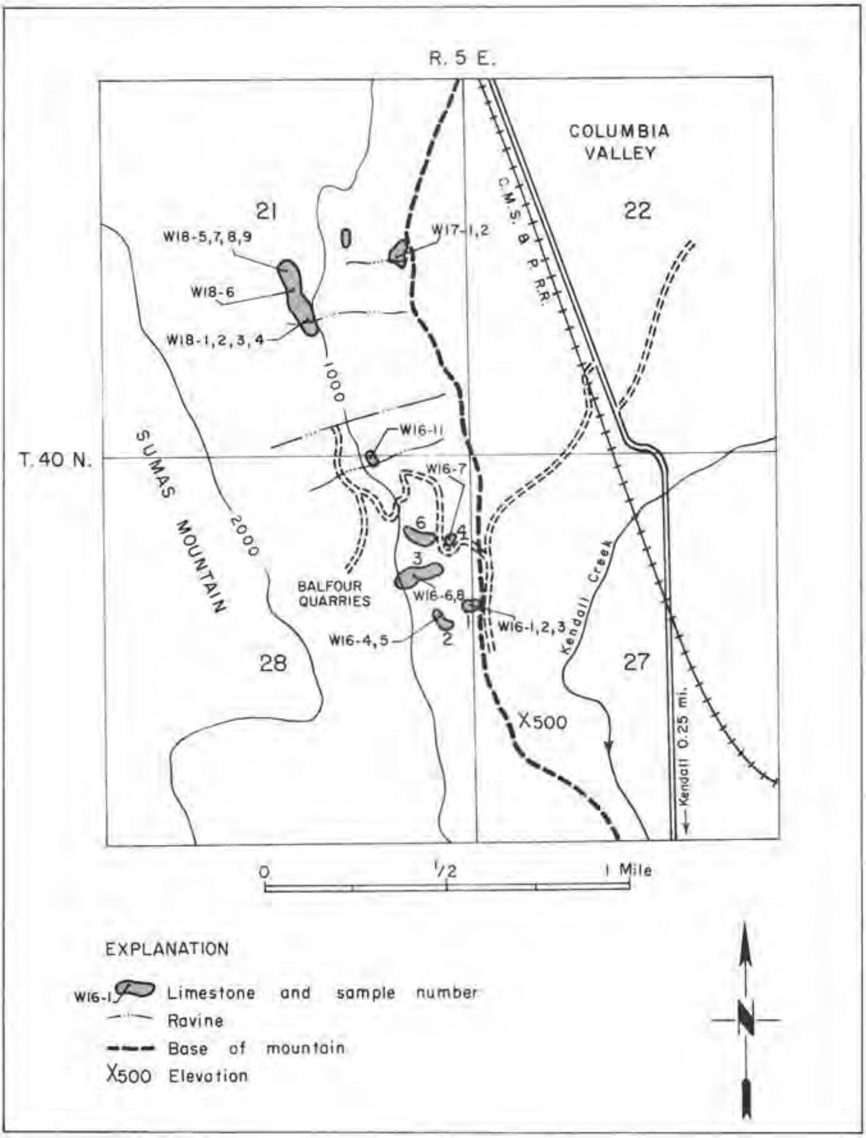

FIGURE 33. Location map of Sumas Mountain limestone deposits.

Development and operation.—The Balfour quarry was operated by the Olympic Portland Cement Company from 1913 until 1929, at which time the company shifted operations to the Kendall quarry on Red Mountain. The limestone was mined from four quarries, the highest quarry being about 300 feet above the valley floor. The limestone was utilized in the manufacture of cement at the company's Bellingham plant. Operations were suspended when the easily mined limestone had been removed. A small tonnage of limestone still remains, but much of it is contaminated with wall rock and the deposits are too small for large-scale quarrying operations.

Other Limestone Deposits

In addition to the limestone deposits of the area that either have been or are being mined, there are at least three occurrences that appear to contain moderate to large tonnages. Sumas, Red, and Black Mountains each contain a significant occurrence.

On the northeastern end of Sumas Mountain, near the center of sec. 21, T. 40 N., R. 5 E., limestone of Devonian age is poorly exposed. Part of the limestone is fairly uniform in composition, but much of it contains interbeds of shaly and siliceous limestone. It is similar to the limestone beds in the Balfour quarry, which is about half a mile to the south, and is probably a northerly extension of these beds. The limestone occurs as scattered outcrops over an area 200 to 300 feet wide and nearly 1,000 feet long. Many of the small outcrops are less than 30 feet in diameter, and the larger outcrops are as much as 50 feet wide and 250 feet long. The average strike of the beds is N. 70° W., and dips range from 30° to 60° S. Exposures of limestone in a creek bed suggest a thickness of at least 200 feet. Samples W18-1 through W18-9, the locations of which are shown in figure 33, were collected from several of the outcrops. Although most of the area is poorly accessible, abandoned logging roads extend to within 200 feet of several of the limestone outcrops.

Near the top of Red Mountain and in the NW¼ sec. 13, T. 40 N., R. 5 E., limestone of Early Pennsylvanian age is exposed. It is light gray, crystalline, well bedded, and contains numerous fossiliferous beds. The beds of the limestone strike N. 50° E. and dip 60° SE. Most of the limestone is concealed by glacial drift and underbrush, but outcrops indicate a length of about 1,500 feet and a width of 350 feet for the deposit. On the northwest corner of the deposit a cliff of limestone 50 feet high and 150 feet long is well exposed. The limestone appears to be a lens of the Kendall quarry limestone, which crops out less than half a mile to the west. Access to the deposit is by means of a logging road that begins near the north end of Silver Lake. This road passes within 100 feet of the deposit. Samples W6-1 through W6-5 are representative samples of this limestone occurrence (fig. 28, on p. 88).

Several large deposits of Lower Pennsylvanian and lower Permian limestones are exposed near the summit of Black Mountain. They are mainly in the E½ sec. 4, T. 40 N., R. 6 E. The limestones are similar to those in the Kendall and Silver Lake quarries except that the lower Permian limestone contains more chert and has a higher magnesia content. The limestone occurs in two main beds, which are interbedded with argillite, graywacke, and conglomerate. The Lower Pennsylvanian limestone has a maximum thickness of 300 feet, and the lower Permian limestone, about 400 feet. At least two other beds occur stratigraphically above the lower Permian limestone, but poor exposures make it impossible to determine their thicknesses.

Except where they form cliffs, the limestone beds are covered by glacial drift. Scattered outcrops indicate that the limestone extends for at least half a mile in a north-south direction. It is faulted in several places by high-angle eastward-trending faults that offset the beds and also form the northern and southern boundaries of the deposits. Samples W7-1 through W7-7 were collected from several of the larger outcrops in the area (fig. 31). Although logging roads at one time extended to within a few hundred feet of most of the limestone outcrops, the roads are not usable, as they are no longer maintained.

Several other limestone outcrops were noted in the map area, but for the most part they are small deposits of limited tonnage. Also, some of them are so poorly exposed that it is impossible to properly evaluate them without extensive drilling or stripping. A tabulation of these occurrences is given in table 17.

TABLE 17.—*Miscellaneous limestone deposits*

Sample no.	Location	Remarks
	T. 40 N., R. 5 E.	
W19-1, W19-2	NW¼ sec. 9	Devonian limestone as a fault block of limited tonnage. Outcrop area 80 feet by 150 feet
W17-1, W17-2	SE¼NE¼ sec. 21	Pennsylvanian (?) limestone poorly exposed in road and stream cuts. Argillaceous, siliceous, and dolomitic. Limestone not over 100 feet long and 20 feet wide
W8-1	SW¼NE¼ sec. 23	Devonian limestone in fault contact with crystalline basement rocks. Outcrop 100 feet long and 50 feet wide
	T. 40 N., R. 6 E.	
W2-1	SW¼ NW¼ sec. 17	Small outcrop of dense gray limestone. Poorly exposed, but may contain small tonnage
W9-1, W9-2	NW¼SW¼ sec. 7	Dense gray limestone containing chert and argillite. Poorly exposed on steep hillside, but could produce small tonnage
W20-1, W20-2	N½NW¼ sec. 5	Argillaceous limestone containing interbedded shale, sandstone, and conglomerate. Not of commercial value. Age unknown
W21-1	NW¼NE¼ sec. 8	Several small outcrops of Devonian limestone. Largest outcrop not over 50 feet long
W23-1	NE¼NW¼ sec. 17	Poorly exposed medium-gray crystalline limestone. Outcrop 150 feet long and 50 feet wide

Analyses

During the course of the geologic investigation of the map area the writer made no attempt to sample any of the limestone deposits. All sampling was done by W. R. Danner in connection with the preparation of a report on the limestone resources of western Washington to be published by the Washington Division of Mines and Geology. The exact locations of the samples listed in table 18, as well as detailed descriptions of the deposits, will be covered in his report.

The analyses of Danner's samples are included in this report to present to the reader a general idea of the composition of the different limestone deposits. Figures 28, 31, and 33 show the deposits from which the samples were taken.

Table 18.—*Chemical analyses of the limestones of the north half of the Van Zandt quadrangle*①

Sample no.	Ig. loss	SiO_2	$R_2O_3$②	CaO	MgO	P_2O_5	Remarks
			Silver Lake Quarry (SW¼ sec. 7, T. 40 N., R. 6 E.)				
W 1- 1	39.72	10.22	0.89	45.54	3.26	0.024	Lower quarry face
2	43.62	0.50	0.18	54.79	0.84	0.030	Upper quarry face
			Balfour Quarries (NE¼ sec. 28, T. 40 N., R. 5 E.)				
W16- 1	41.90	3.81	0.96	52.75	0.28	0.004	Quarry No. 1
2	38.54	11.25	0.97	48.43	0.36	0.009	Do
3	42.70	2.16	0.64	54.19	0.18	0.010	Do
4	41.13	5.50	0.93	51.88	0.31	0.004	Quarry No. 2
5	37.80	11.87	2.00	47.55	0.46	0.023	Do
6	39.04	9.43	1.43	49.19	0.47	0.026	Quarry No. 3
7	42.67	2.43	0.47	53.96	0.26	0.010	Quarry No. 4
8	42.60	2.72	0.72	53.68	0.15	0.012	Quarry No. 3
9	42.32	2.76	0.84	53.15	0.46	0.008	Do
10	42.73	2.06	0.62	54.05	0.23	0.007	
11	40.25	7.33	1.05	50.98	0.10	0.010	Outcrop (NW¼NE¼ sec. 28, T. 40 N., R. 5. E.)
12	40.68	6.25	1.22	51.43	0.18	0.006	Quarry No. 6
13	39.84	8.84	0.71	50.38	0.14	0.008	Do
14	42.32	2.28	0.71	53.75	0.45	0.004	Do
			Boulder Creek Quarry (NW¼ sec. 22, T. 40 N., R. 6 E.)				
W 5- 1	42.97	0.67	0.32	55.63	0.16	0.200	Quarry
2	43.12	0.37	0.26	55.71	0.10	0.248	Outcrops south of quarry
3	43.37	0.09	0.09	55.33	0.19	0.150	Do
4	43.10	0.40	0.37	55.36	0.19	0.209	Do

See footnotes at end of table, p. 100.

TABLE 18.—*Chemical analyses of the limestones of the north half of the Van Zandt quadrangle*[1]—Continued

Sample no.	Ig. loss	SiO_2	R_2O_3[2]	CaO	MgO	P_2O_5	Remarks
Doaks Creek Quarry (Center sec. 19, T. 40 N., R. 6 E.)							
W 4–1	42.57	2.43	0.55	53.89	0.31	0.010	Across face
Kendall Quarries (SW¼ sec. 14, T. 40 N., R. 5 E.)							
W24–1	39.65	8.74	0.97	49.74	0.77	0.024	Old lower quarry (SW¼-SW¼ sec. 14, T. 40 N., R. 5 E.)
2	33.60	20.96	2.91	41.01	1.20	0.034	Do
3	36.90	14.90	0.86	45.75	1.08	0.026	Do
4	35.56	17.27	2.30	43.52	1.03	0.049	Stream bed east of old quarry
5	43.22	2.56	0.38	50.79	2.92	0.020	Stream bed northeast of old quarry
Red Mountain Limestone (NW¼NW¼ sec. 13, T. 40 N., R. 5 E.)							
W 6–1	42.26	3.68	0.68	52.24	1.15	0.022	East end
2	39.74	8.75	2.85	50.10	0.32	0.024	Do
3	39.84	7.45	0.44	49.78	0.52	0.023	North center face
4	35.60	18.66	0.73	44.52	0.53	0.035	West end
5	42.72	2.57	0.83	53.21	0.81	0.030	Do
Red Mountain Limestone (SW¼NE¼ sec. 23, T. 40 N., R. 5 E.)							
W 8–1	39.84	8.52	1.08	50.16	0.31	0.011	Outcrop on logging road
Red Mountain Limestone (NW¼SW¼ sec. 7, T. 40 N., R. 6 E.)							
W 9–1	40.70	7.70	1.48	50.08	0.46	0.050	West end
2	39.97	8.16	1.66	49.78	0.55	0.049	East end
Sumas Mountain, northeast end (Center sec. 21, T. 40 N., R. 5 E.)							
W18–1	40.44	7.16	0.90	50.73	0.46	0.008	Upper part of beds in creek
2	40.20	6.91	1.72	50.22	0.62	0.009	Lower part of beds in creek
3	26.12	33.61	7.45	32.67	0.15	0.072	Composite sample of beds in creek
4	41.92	2.61	1.46	53.53	0.23	0.008	Outcrop north of creek
5	42.69	2.41	0.71	53.89	0.21	0.005	North end of outcrop
6	43.60	2.27	0.94	52.19	1.31	0.007	East side of deposit
7	43.10	1.48	0.52	54.47	0.18	0.090	North end of outcrop
8	43.45	0.26	0.16	55.27	0.20	0.004	Do
9	42.21	3.15	1.03	53.33	0.14	0.007	Do

See footnotes at end of table, p. 100.

TABLE 18.—*Chemical analyses of the limestones of the north half of the Van Zandt quadrangle*[1]—Continued

Sample no.	Ig. loss	SiO_2	R_2O_3[2]	CaO	MgO	P_2O_5	Remarks
Sumas Mountain, northeast end (SE¼NE¼ sec. 21, T. 40 N., R. 5 E.)							
W17– 1	43.89	6.67	0.54	28.18	20.85	0.016	Outcrop on logging road
2	38.47	17.04	0.99	30.26	13.76	0.020	Outcrop along creek
Black Mountain (NE¼NW¼ sec. 17, T. 40 N., R. 6 E.)							
W23– 1	40.83	6.49	0.82	51.36	0.12	0.016	Outcrop along logging road
Black Mountain (N½NW¼ sec. 5, T. 40 N., R. 6 E.)							
W20– 1	35.70	15.72	2.65	44.33	0.69	0.066	Most favorable looking bed
2	24.52	37.38	6.62	29.50	1.74	0.013	Composite of several beds
Black Mountain (NW¼NE¼ sec. 8, T. 40 N., R. 6 E.)							
W21– 1	39.32	9.70	0.77	49.73	0.21	0.014	Along strike of outcrop
Black Mountain (Sec. 4, T. 40 N., R. 6 E.)							
W 7– 1	44.33	2.05	1.02	44.02	7.76	0.026	SE¼ sec. 4
2	38.34	11.01	1.63	48.52	0.40	0.018	NE¼ sec. 4
3	27.72	34.53	2.70	34.04	1.08	0.046	Do
4	43.72	2.72	0.57	47.57	5.70	0.019	Do
5	41.66	4.51	0.91	52.59	0.34	0.010	SW¼ sec. 4
6	42.84	1.90	0.60	54.29	0.28	0.018	Do
7	37.28	14.70	0.47	47.17	0.20	0.012	Do
Black Mountain (SW¼NW¼ sec. 17, T. 40 N., R. 6 E.)							
W 2– 1	42.39	3.04	0.52	53.69	0.30	0.010	Site of old quarry
Hilltop (NW¼ sec. 9, T. 40 N., R. 5 E.)							
W19– 1	40.43	6.95	1.09	50.79	0.44	0.030	East-west on outcrop
2	41.32	5.05	0.82	51.95	0.55	0.021	North-south on outcrop

[1] Analyses by Clarence S. Homi, Division of Industrial Research, Institute of Technology, Washington State University, Pullman, Washington. Sampled by W. R. Danner.

[2] R_2O_3—Combined Fe_2O_3 and Al_2O_3. All figures are percentages.

SILICA

Olympic Portland Cement Company Silica Deposit

Location and accessibility.—A silica deposit owned by the Olympic Portland Cement Company is in the NE¼NW¼ sec. 17, T. 40 N., R. 5 E., which is about 4 miles southeast of Sumas. An unimproved road leads west from the Edwin Rodgers farm on the Frost road for about an eighth of a mile to the deposit (fig. 34). The Bellingham-Maple Falls line of the Chicago, Milwaukee, St. Paul and Pacific Railroad is a quarter of a mile to the north.

History.—The silica deposit was originally staked as the Copper King and Sumas mining claims by John Post in 1897. Donovan (1897) reports that in 1897 the Quartz Mountain Gold and Copper Mining and Milling Company was following a pay streak 20 inches wide that carried 8 to 20 percent copper and $4.50 in gold. In 1906, G. C. Hyatt relocated the deposit as the Tommy Atkins and Tuesday mining claims. Some time after 1912 the claims were granted patent number 434110.

The Olympic Portland Cement Company acquired the property in 1935, and until 1947 mined the silica for use in the manufacture of a low-temperature cement. Much of this cement was used in the construction of Grand Coulee Dam.

Geology.—The deposit is on the northeast end of a small rocky knob that crops out through the glacial outwash deposits of the valley. White massive quartz has been exposed by quarrying operations over a horizontal distance of about 280 feet. The quarry face is about 60 feet high. The quartz mass has a general strike of N. 50° W., and it dips 70° to 80° SW. It is underlain by sheared and slickensided grayish-green diopside, which in hand specimen resembles serpentinite. Microscopic examination of the diopside shows it to be microbrecciated. Also present but visible only in thin section are hornblende and enstatite. The quartz and the underlying diopside are in fault contact.

The quartz is massive and is traversed in all directions by joints and fractures. Some of the fracture surfaces are coated with iron oxide from the oxidation of the chalcopyrite that is disseminated in parts of the quartz. Minor amounts of malachite and azurite also occur as thin coatings on some fracture surfaces. Petrographic examination of several samples that appeared to be the highest grade quartz showed about 98 percent quartz and 2 percent feldspar. The quartz occurs as subhedral and anhedral grains that contain many minute inclusions of unidentifiable material. The feldspar occurs interstitial to the quartz and is turbid. Chemical analysis of a 45-foot chip sample across the face of the quarry that was sampled by the writer is as follows: 97.0 percent SiO_2, 1.01 percent Fe_2O_3, and 1.36 percent Al_2O_3.

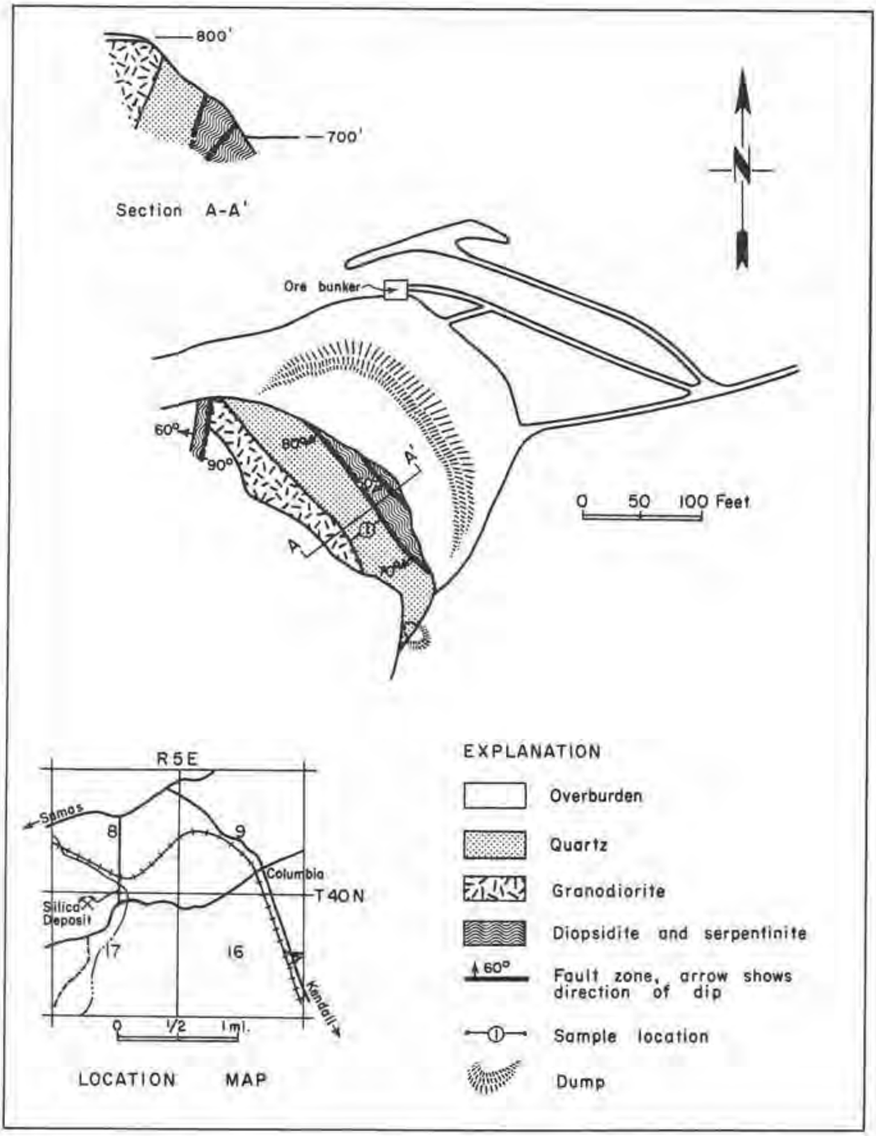

FIGURE 34. Sketch map of Olympic Portland Cement Company silica deposit.

Hodge (1938c, p. 156) gives the following analyses for the quartz as reported by The Olympic Portland Cement Company.

TABLE 19.—*Chemical analyses of silica from The Olympic Portland Cement Company silica deposit*

Constituents	Red, iron-stained (percent)	Green, copper-stained (percent)	White (percent)
SiO_2	82.50	90.96	96.98
Fe_2O_3	7.00	3.00	0.60
Al_2O_3	4.96	1.88	1.30
CaO	0.30	1.20	0.50
MgO	2.00	0.79	trace
SO_3	.....	.....	trace
L.O.I.	2.08	1.30	0.58
	98.84	99.13	99.96

The copper that was reported to have been mined when the quartz was first discovered occurs in its greatest concentrations on the southeastern end of the quartz. However, the ore bodies are small, the largest being about 5 feet in diameter. A short adit was started on one of the ore bodies but abandoned after passing through 5 feet of it. The predominant copper mineral is chalcopyrite, which in no place makes up more than about 8 percent of the ore bodies. Both malachite and azurite are associated with the chalcopyrite but do not exceed 3 percent.

The quartz is overlain by dark greenish gray medium-grained meta-quartz diorite of the crystalline complex. Parts of the diorite are migmatitic and contain dark-gray inclusions. In thin section the rock exhibits a hypidiomorphic texture. Feldspar, which is the most abundant mineral, consists of andesine and orthoclase. Much of the plagioclase is altered and contains inclusions of epidote and hornblende. Actinolitic hornblende, altered in part to chlorite, is the most abundant mafic mineral. Quartz occurs as anhedral grains and contains many unidentified minute inclusions. Sheaflike masses of prehnite fill many of the fractures in the diorite.

The relationship between the massive quartz and the diorite hanging wall suggests replacement of the diorite by the quartz. The contact is gradational, and inclusions of diorite occur in the quartz adjacent to the contact. The abundant prehnite in the diorite could indicate metasomatic transformation of calcic plagioclase by heated magmatic waters during emplacement of the quartz.

The structural relationship of the quartz and its wall rock to the neighboring rocks of the area is obscured by glacial drift.

However, the deposit appears to be part of the basement complex that has been faulted up by high-angle, northeastward-trending faults.

Development and operation.—The quarry has been developed horizontally for 280 feet and to a maximum height of 150 feet. At present (1960) the quarry has been abandoned, but Hodge (1938c, p. 156) reports that mining operations in the past were as follows:

> The top half of the face is a natural cliff. The quarry is equipped with a compressor and drilling equipment, a truck, and a bulldozer. The rock is broken, dozed from the quarry floor to a loading platform, where it drops through an opening into the truck below. The truck transports the rock from the quarry ½ mile to the Chicago, Milwaukee, St. Paul and Pacific Railroad, where it is loaded into cars and hauled by rail to the cement plant, a distance of about 30 miles. The truck makes a round trip every 10-15 minutes and fills 2 cars a day. Eight men are employed in the operation.

Although this deposit may contain as much as 50,000 tons of silica, it cannot be considered as a source of high-grade silica. Extensive sampling by The Olympic Portland Cement Company indicates that the deposit averages 90 percent SiO_2 (Hodge, 1938c, p. 155).

IRON

Sumas Mountain Iron Deposit

Location and accessibility.—The Sumas Mountain iron deposit, as described in this report, is for the most part in the N½ sec. 2, T. 39 N., R. 4 E. Only a small part of the deposit extends northward into sec. 35, T. 40 N., R. 4 E. It is 6½ miles south of Sumas and 4 miles east of Everson. The deposit is exposed in several stream beds on the western slope of Sumas Mountain at elevations between 1,000 and 2,000 feet above sea level. The location of the deposit is shown in figure 35.

From the South Pass road, the general area can be reached by following the Lebrant road south for about 1.2 miles to an abandoned timber loading dock. A trail is then followed along an old logging road for three-quarters of a mile up a narrow valley to the deposit.

Washington State Highway 1A and the Sumas branch line of the Northern Pacific Railway are 3 miles to the west.

History.—From as early as 1915, when the property was first staked for its iron oxide, until 1959, when the area was examined for this report, the Sumas Mountain iron deposit has been considered a possible source of iron. During this time very little work has been done on the property. Many samples have been taken, a few trenches dug, and one adit driven, but no mining has been undertaken.

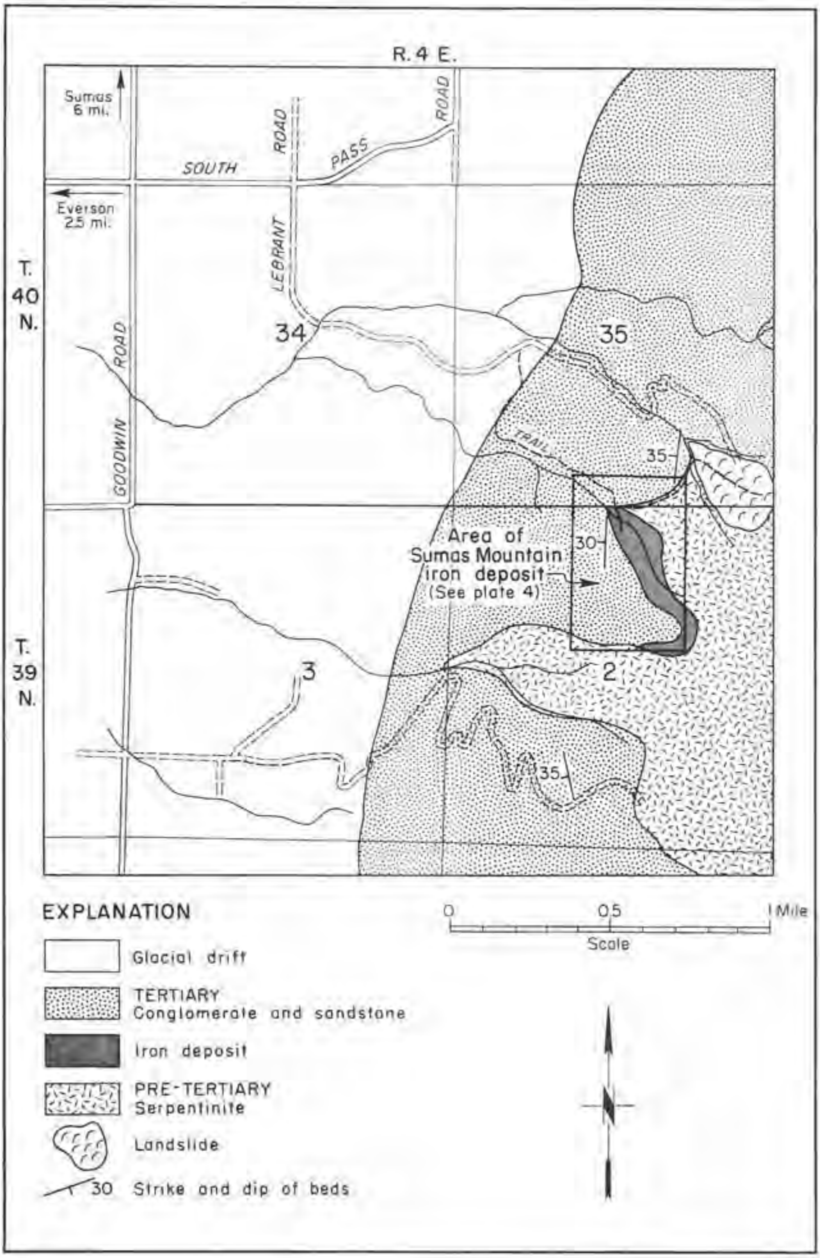

FIGURE 35. Location and geologic map of the Sumas Mountain iron deposit.

To provide a brief outline of the history of the property there are listed below some of the more significant developments between 1915 and 1957.

1915—J. C. Compton and J. A. Hatton staked area as the Ochre Point placer.

1917—J. A. Hatton, et al. filed on 60 acres in sec. 2, T, 39 N., R. 4 E. Minerals unknown.

1919—R. A. Cole filed on seven contiguous claims in sec. 2, T. 39 N., R. 4 E., and sec. 35, T. 40 N., R. 4 E., known as the Hematite group.

1929—C. E. Phoenix, mining engineer, examined area and reported large tonnage (100,000,000 tons) of iron ore.

1938—Hematite Iron and Gold Mines Development Company, Seattle, Washington, acquired Hematite group. Sixty-foot tunnel present on property.

1941—Henry J. Landall of Vancouver, B. C., Canada, requested financial assistance from the Northern Pacific Railway to explore the property. Request denied when property was examined and found to be of no commercial interest as a source of metallic iron.

1941-42—Northern Pacific Railway examiners studied deposit, results unknown.

1952(?)—L. C. Noble leased 7 claims to Western Slope Construction Company of San Francisco. Company planned to extract ore for shipment to Japan.

1952—Yamate Trading Co., Ltd., San Francisco, acquired 20-year lease on property.

1957—Waddington Mining Corp., Ltd., Vancouver, B. C., Canada, acquired lease on property. New trail cut and deposit sampled.

1957—Northern Pacific Railway examined and sampled property.

Topography.—The Sumas Mountain iron deposit is on the western slope of Sumas Mountain at elevations between 1,000 and 2,000 feet above sea level. Whatcom Basin, 1 mile to the west, has an elevation of about 100 feet, and 1½ miles east, the mountain reaches its maximum elevation of about 3,350 feet. The western slope, for the most part, has a heavy cover of underbrush, but a few stands of fir and hemlock are present. Outcrops are scarce, but where present are usually cliff forming.

Several streams have formed deep, steep-sided ravines on the western slope of the mountain, and stream erosion of the westward-dipping Tertiary sedimentary rocks has produced a series of "flatirons" along the western front of Sumas Mountain. The terrain in the vicinity of the iron deposit is moderately rugged and for the most part covered by overburden. Only where streams have cut through the overburden is the iron deposit exposed. Several small streams, sufficient for camp needs, occupy the larger ravines.

Geology.—The basement rock that underlies the Sumas Mountain iron deposit is pre-Tertiary serpentinized peridotite. Lower Mesozoic (?) graywackes crop out 1 mile to the northeast, and graywackes, argillites, and basic volcanics of late Paleozoic age crop out 2 miles to the southeast. Overlying the iron deposit are Tertiary cobble conglomerates and arkoses.

During pre-Tertiary times, peridotite that is now highly serpentinized was intruded into a complex of older sedimentary rocks. The area was subjected to erosion that exposed the peridotite, which was then subjected to intense tropical weathering, resulting in the formation of iron-rich laterite over the surface of the peridotite. Following the formation of the laterite and sometime during early Tertiary time, the area was covered by continental conglomerates and arkoses. Since then, the area has been gently folded and erosion has cut through the overlying sedimentary rocks to expose parts of the lateritic iron deposit.

Character of the ore.—Much has been written on the process of laterization, and it is beyond the scope of this report to discuss the process in detail. In general, laterites develop under tropical conditions of high temperature and high rainfall. Although these climatic conditions do not exist in this area today, fossil plants indicate that the climate at the time the laterites formed was tropical to subtropical. In the process of the rock decay, a clayey residual mass of alumina and ferric oxides is concentrated in the upper part of the weathered zone. Although the laterite on Sumas Mountain is but a ferruginous clay having a heavy reddish stain, it has been commonly called an iron ore.

On Sumas Mountain the rocks upon which the laterite developed consist of several varieties of dark-green peridotite. The peridotite is almost wholly serpentinized, but residual grains of olivine, chromite, and magnetite are plainly visible under the microscope. The rock is traversed by many joints, along which reddish iron oxide staining has developed. Weathering of the jointed serpentinite produces spheriodal remnants, many of which are visible in several stream beds.

The dark-green serpentinite grades upward into a grayish-green to reddish-brown horizon that consists chiefly of clay minerals. Scattered throughout the clay are angular fragments of serpentinite, the average size being 3 to 5 millimeters across. Scattered grains of chromite and magnetite are also present but compose less than 1 percent of the rock.

Above this is a green to grayish-brown, dense, massive claystone. Fragments of the serpentinite from which the clay was developed are not visible in this rock; however, a few grains of chromite and magnetite are present in most specimens.

The two weathered zones that overlie the serpentinite do not exceed 8 feet in thickness, and in no two places are they the same thickness. These zones grade upward into the ferruginous claystone that comprises the so-called "iron ore" deposit.

The claystone is composed chiefly of extremely fine grained (clay size) hydrous aluminum silicates, limonite, hematite, and magnetite. A few grains of quartz and chromite are also present. The color ranges from grayish brown through grayish red. Specific gravity determinations of several samples range from 2.67 to 3.09. The basal part of the claystone shows no bedding but exhibits some spheroidal weathering due to closely spaced joints. Bedding visible in the upper parts of the unit is shown by alternating layers of claystone and siltstone. Several sandy beds are also present. The beds range in strike from N. 20° E. to N. 20° W. and in dip from 25° to 40° W.

Although the ferruginous claystone has a maximum thickness of about 35 feet, the iron-rich part generally averages only 5 feet in thickness. In this section much of the claystone is magnetic and contains magnetite oölites and pisolites up to a quarter of an inch in diameter. However, the magnetite in the claystone is, for the most part, in the form of minute angular grains. Much of the magnetite is probably residual, having weathered out of the serpentinite. Secondary magnetite occurs in the form of oölites and pisolites and also fills small fractures in the iron beds. The chromium occurs as small grains of chromite, which are probably residual grains that have weathered out of the serpentinite. Nickel is present in the claystone, but the form in which it occurs is unknown. The absence of sulfides suggests that the nickel may occur as one of the hydrous nickel silicates.

The ferruginous claystones are overlain by lower Tertiary cobble conglomerates and arkosic sandstones, and appear to be concordant in structure. On the north bank of the creek near the N. ¼ cor. sec. 2, T. 39 N., R. 4 E., the contact is well exposed. Here the conglomerate can be seen resting upon bedded ferruginous claystones, which in turn are underlain by serpentinite basement rocks. The bedding in the upper part of the claystone suggests some reworking of the unit prior to the deposition of the conglomerate.

There appears to be little doubt as to the origin of the "iron ore." Evidence indicates that it formed as laterite on a peridotite erosion surface during early Tertiary time. It is possible, however, that prior to the deposition of the overlying sandstones and conglomerates some concentration occurred. Where closed basins or lagoons existed on the peridotite surface, they would act as settling ponds for surface drainage. The ferruginous claystones of Sumas Mountain appear to have been concentrated under such conditions, for on both the north and south boundaries of the deposit the claystone appears to lens out.

It is believed that the iron deposit of Sumas Mountain formed under conditions similar to those forming the iron ores of the Cle Elum district of Kittitas County (Lamey and Hotz, 1952, p. 54-59) and the Blewett district of Chelan County, Washington (Broughton, 1943, p. 13). Much has been written on these deposits, and it is generally believed that the iron ore there developed as laterite upon a peridotite erosion surface. Descriptions of the Cle Elum ore compare closely with the ore of Sumas Mountain, and in both localities the iron beds are covered by lower Tertiary continental sedimentary rocks of similar lithology.

Sampling and analyses.—The Sumas Mountain iron deposit has been sampled many times in the past, and the analyses disclose that the material sampled contains from 16.2 to 48.1 percent iron.

For comparison purposes the results of analyses, other than those taken by the Washington State Division of Mines and Geology, are given in table 20 and Division samples are reported in table 21.

TABLE 20.—*Compilation of analyses of Sumas Mountain iron ore*

Constituents	Sample no.						
	1	2	3	4	5	6	7
Fe	37.31	29.92	21.9	40.3	19.4 to 29.1	18.76 to 25.9	48.10
SiO_2	20.83	36.90	.....	23.5	26.9 to 36.5	40.06 to 47.3	.....
Al_2O_3	.....	.....	22.46	10.1	11.9 to 19.3	19.16	.....
CaO	.....	.....	trace	0.4	....	....	.....
P	0.20	0.11	trace	0.058	0.026 to 0.073	0.04 to 0.85	0.058
S	0.008	trace	.....	0.004	less than 0.01	0.10 to 0.12	0.002
Mn	.....	0.32	.....	trace	....	....	.....
Ni	.....	.....	.....	.....	0.42 to 0.82	....	.....
Cr	.....	.....	.....	.....	0.87 to 1.5	....	.....
As	.....	.....	.....	0.001	....	....	0.001
H_2O	.....	.....	.....	6.25	....	....	.....
L.O.I.	.....	12.10	23.40	4.7	10.1 to 11.8	....	.....
Insoluble	.....	.....	17.76	.....	....	....	.....

Analyst and source of information

1. R. P. Cope. Reported by Shedd and others (1922, p. 107).
2. Pacific Coast Steel Company. Daniel's report. Reported by Hodge (1938a, p. 17).
3. Hematite Iron and Gold Mines Development Company. Reported by Hodge (1938a, p. 17).
4. Old-time high-grade specimen. Reported by Zapffe (1949, p. 54).
5. U. S. Bureau of Mines, range of six samples. Reported by Binon (1959, p. 119).
6. Northern Pacific Railway, range of three samples. Reported by Binon (1959, p. 119).
7. J. H. Williams for J. E. England and M. Stephens, average of 10 samples. From private report of C. E. Phoenix, 1929.

The exact locations of the samples in table 20, as well as the thicknesses sampled, are unknown. Although the data furnish information as to the composition of the ore, the samples probably represent the richer parts of the deposit and do not by any means represent the entire deposit.

During the examination of the Sumas Mountain iron deposit for this report, the writer collected eight samples for analyses. The data from the analyses were used in estimating the tonnages. Approximately 10-pound samples were cut as channel samples across that part of the exposure that appeared to contain the most iron. At least one sample was taken from each outcrop of the ferruginous claystone, which extends over a lateral distance of about 2,250 feet. The location of the samples and their thicknesses are shown on plate 4. All samples were analyzed for Fe_2O_3, Al_2O_3, SiO_2, and ignition loss. Sample No. 6, which was believed to be fairly representative of the deposit as a whole, was analyzed in more detail. The results of the analyses and brief descriptions of the samples are given in table 21.

TABLE 21.—*Analyses of Sumas Mountain iron ore*[1]

Sample no.	1	2	3	4	5	6	7	8
Sample length (feet)	5.0	4.5	6.0	4.5	5.0	3.0	3.0	5.0
Fe	27.2	31.8	25.5	33.7	16.2	26.8	20.0	28.6
Fe_2O_3	38.8	45.5	36.4	48.1	23.1	38.3	28.6	40.9
Al_2O_3	17.8	14.4	21.8	24.1	16.2	17.2	16.9	20.1
SiO_2	34.8	31.3	33.4	20.3	48.8	32.0	46.5	27.9
CaO	.....	.....	.....	.....	.....	0.04	.....	.....
MgO	.....	.....	.....	.....	.....	1.59	.....	.....
P	.....	.....	.....	.....	.....	0.21	.....	.....
S	.....	.....	.....	.....	.....	0.015	.....	.....
Mn	.....	.....	.....	.....	.....	0.14	.....	.....
NiO	.....	.....	.....	.....	.....	0.57	.....	.....
Cr_2O_3	.....	.....	.....	.....	.....	0.91	.....	.....
TiO_2	.....	.....	.....	.....	.....	0.22	.....	.....
H_2O	.....	.....	.....	.....	.....	6.31	.....	.....
Ignition loss[2]	5.48	5.56	8.20	6.56	7.20	8.49	7.02	8.49

[1]Sampled by Washington State Division of Mines and Geology. Analyzed by Willis H. Ott, Metallurgical Laboratory, Seattle.
[2]Includes H_2O.

Sample No. 1.—Medium-brown siltstone containing 10 percent quartz and 10 percent chromite grains that average less than 0.5 millimeter in diameter. Very fine grained magnetite disseminated throughout sample.

Sample No. 2.—Grayish-red claystone containing less than 5 percent combined quartz and chromite grains. Sample appears to be mainly iron oxide.

Sample No. 3.—Grayish-brown claystone containing less than 0.5 percent chromite grains. Occasional pisolites of magnetite and about 1 percent clear and white quartz grains that average less than 0.5 millimeter in diameter.

Sample No. 4.—Grayish-brown claystone composed chiefly of iron oxide. Occasional grains of quartz and magnetite composing less than 1 percent of the sample. Some fragments of altered greenish peridotite, in part serpentinite, occur throughout the sample. Sample from lowest exposure in lateritic zone.

Sample No. 5.—Medium yellowish-brown siltstone exhibiting sandy phases. Abundant quartz grains and very little disseminated fine-grained magnetite.

Sample No. 6.—Grayish-brown claystone containing about 1 percent rounded magnetite grains from 1 to 4 millimeters in diameter. Quartz and chromite grains compose less than 2 percent of the sample.

Sample No. 7.—Grayish-brown claystone containing 1 percent rounded magnetite grains from 1 to 4 millimeters in diameter. Less than 2 percent chromite and quartz grains are present.

Sample No. 8.—Grayish-brown claystone that is silty in part. Silty phases give bedded appearance to outcrop. Grains of quartz, chromite, and magnetite less than 0.05 millimeter occur throughout sample.

The average specific gravity of five samples, as determined by the Division of Mines and Geology, is 3.0. This figure was used in the calculation of ore tonnages.

It is apparent from the analyses that the Sumas Mountain iron ore is definitely low grade. Although occasional assays of 40 to 48 percent iron are reported, the minable ore is more likely to be less than 30 percent iron. The silica and alumina are exceptionally high, whereas sulfur, phosphorus, and lime tend to be low. The presence of nickel and chromium present metallurgical problems.

Under present economic conditions, the Sumas Mountain iron deposit cannot be considered as a source of commercial-grade iron ore.

Estimation of tonnages.—In estimating the possible iron ore tonnages of this deposit, only the ferruginous material exposed in the creek beds between 1,000 and 2,000 feet in elevation was used. (See pl. 4.) The lateral extent of these exposures is about 2,500 feet. As only the richer parts of the deposit would be mined, sampling indicates that these parts would average about 5 feet in thickness. The average iron content for this thickness is 37.5 percent Fe_2O_3, or 26.25 percent Fe.

In calculating the tonnage of indicated ore, a width of 400 feet was used, this being the extreme distance between outcrops along the dip of the beds. Another 400 feet of width down dip was used for inferred ore calculations.

Based on these dimensions, the reserves of the Sumas Mountain iron deposit are about 375,000 tons of indicated ore and 375,000 tons of inferred ore having an average Fe content of 26 percent. These figures are almost identical with those of Zapffe (1949, p. 55), who estimated a possible reserve of 750,000 tons of ore with a 25 percent Fe content.

Conclusions.—The Sumas Mountain iron is a lateritic deposit that developed upon the erosion surface of a pre-Tertiary peridotite mass some time near the end of the Cretaceous period or the early part of the Eocene epoch. Burial of the laterite by upper Eocene (?) continental sediments preserved the deposit until late Tertiary time, when uplifting subjected the area to erosion and exposed the deposit.

Iron oxide staining is extensive on the western slope of Sumas Mountain; however, material containing as much as 25 percent Fe is confined to a small area, chiefly in sec. 2, T. 39 N., R. 4 E. The estimated reserves of this deposit are calculated at 750,000 tons of indicated and inferred ferruginous claystone containing 26 percent Fe.

Because of adverse physical and chemical properties, it is doubtful that the deposit would be of interest for use in the iron industry.

CHROMITE

General Statement

Chromite occurs in almost all the ultrabasic rocks of the area, but not in amounts to constitute significant deposits. The chromite, for the most part, occurs as specks in the serpentinized peridotite host rock. In several places the chromite is more abundant and occurs as lenses and stringers. However, these bodies are small and do not contain over 5 tons of chromite. Although chromite was noted in all the rocks designated as pTbi on the geologic map (pl. 1), the serpentinite on Sumas Mountain is the only mass that contains any notable concentrations of chromite.

Sumas Mountain

About 4 square miles of the northwestern part of Sumas Mountain is underlain by serpentinite, the host rock for the chromite deposits of the area. Most of the area that is underlain by serpentinite has a thick cover of overburden and vegetation, and very little bedrock is exposed. The few exposures are mostly in the bottoms of creeks and in steep rocky cliffs (fig. 16, on p. 44).

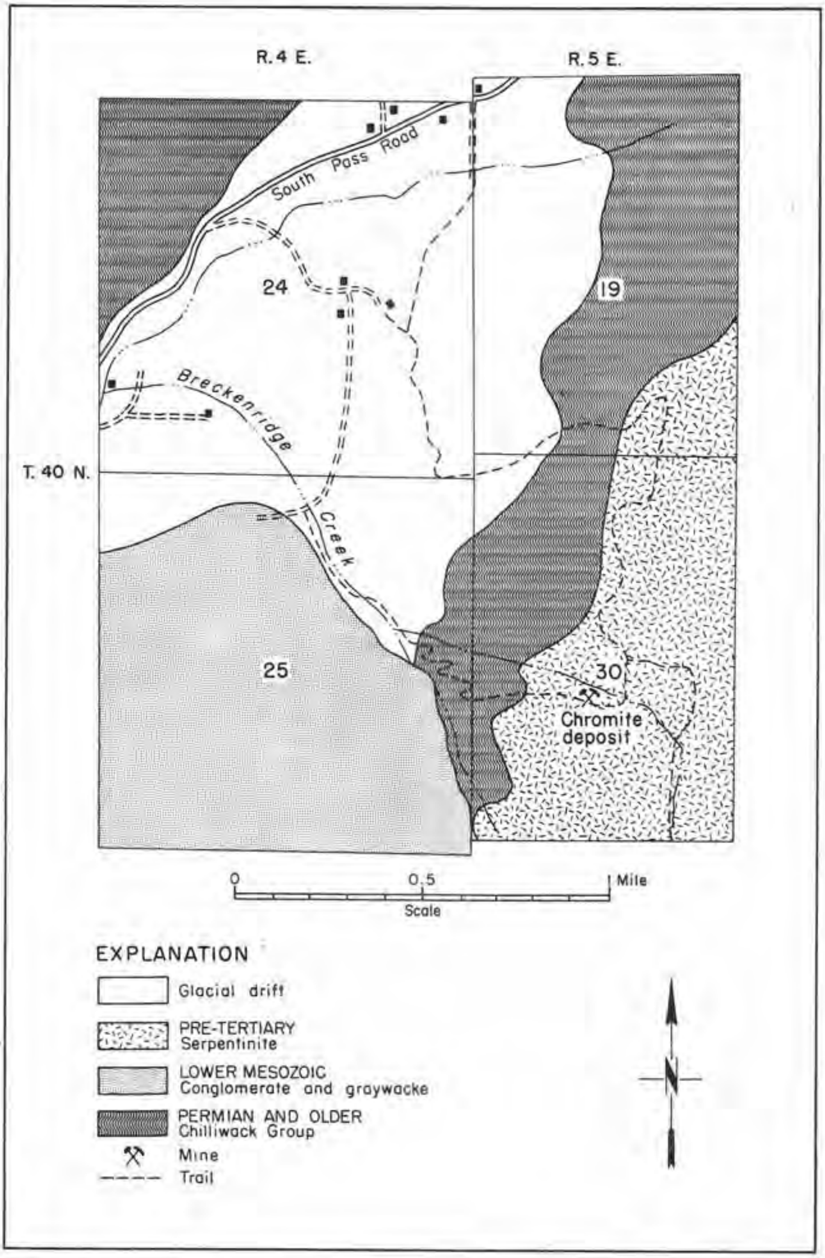

FIGURE 36. Location and geologic map of Breckenridge Creek chromite deposit.

In the course of this examination many outcrops were checked for chromite, but no significant deposits were discovered. Several outcrops of serpentinite were noted to contain sparsely disseminated chromite, the largest of the outcrops being in the E½ secs. 30 and 31, T. 40 N., R. 5 E. Small stringers ¼ to ½ inch wide, as well as sparsely disseminated chromite, are present in the NE¼ sec. 1, T. 39 N., R. 4 E.

Breckenridge Creek Deposit

Location and accessibility.—The largest known deposit of chromite on Sumas Mountain is on the northern end of the mountain in the N½SW¼ sec. 30, T. 40 N., R. 5 E. (fig. 36), on a tributary to Breckenridge Creek. The occurrence is about 5 miles southeast of Sumas and accessible by trail from the farm of A. P. Westergreen on the South Pass road. The trail is blazed but may be followed only with difficulty. At one time a jeep road reached the deposit, but it is now overgrown with brush.

At about 300 feet above and on the south side of the creek, an area 60 feet long and 25 feet high has been stripped of overburden. From sections of the South Pass road the stripped area stands out as a scar on the otherwise wooded slopes of Sumas Mountain.

History.—The deposit was discovered in 1930 by Elmer Goodwin and John Dahlgreen while hunting in the area (A. P. Westergreen, oral communication). A 50-foot adit was driven on the outcrop, and a small amount of chromite was mined at that time. Later work at the discovery site covered the portal of the adit, which is now inaccessible.

In 1943 the U. S. Bureau of Mines reported (Wilson and others, 1943, p. 13) that J. M. Stine, Fred Shea, Ott (initials unknown), and John Dahlgreen had filed on most of sec. 30. Stine submitted to the Bureau chromite specimens that contained 45 percent Cr_2O_3. No mention was made of mining being undertaken on the property at that time.

In 1946 the Super Chrome Company of Seattle, headed by Elmer Larson, attempted to develop the property. A jeep road was built to the chromite deposit, and a small-scale mining operation was started. Surface mining on the most promising outcrops produced several tons of chromite. However, the operation was suspended when most of the chromite lenses pinched out.

The property has been examined by several mining engineers and geologists since 1946, but no further mining has been undertaken. In 1952 the Yamate Trading Co. Ltd., San Francisco, obtained a 20-year lease on the property from the State.

Geology.—The area of the chromite is underlain entirely by serpentinized peridotite. About 500 feet to the west the serpentinite lies beneath graywacke and argillite of late Paleozoic age. Although most of the contact between the two units is concealed, several outcrops along the contact indicate an intrusive contact. The serpentinite has been mapped as being of possible Jurassic-Cretaceous age (see page 49).

The outcrops of the serpentinite form many prominent cliffs, exhibit a well-defined jointing system, and are yellowish brown on weathered surfaces (fig. 16, on p. 44). Beneath the weathered surface the rocks show the dark-green shades characteristic of serpentinite. A set of closely spaced joints strike N. 80° W. and dip 35° SW. parallel to the chromite bands in the serpentinite. A second set of joints, some of which have developed into faults that offset the chromite seams, strike N. 15° W. and dip 50° NE. Intensely slickensided serpentine zones as much as 6 inches in width are present along the faults (figs. 37 and 38).

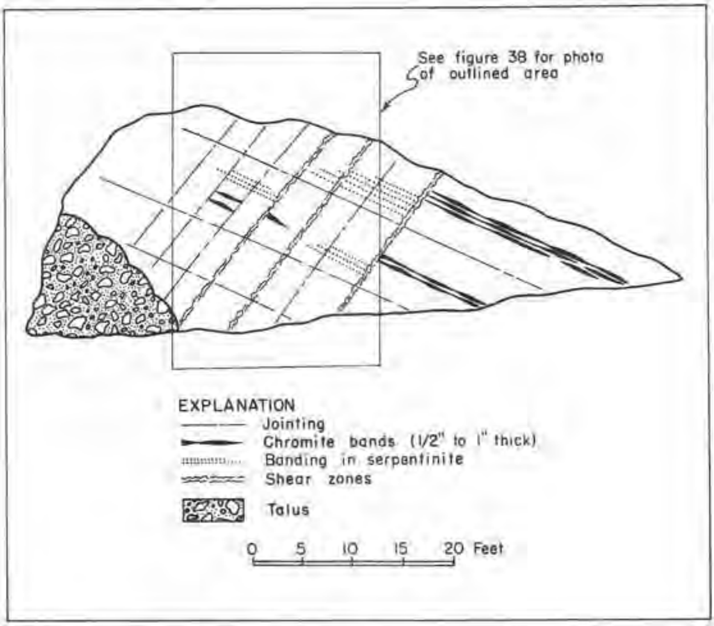

FIGURE 37. Sketch of Breckenridge Creek chromite deposit workings.

Examination of thin sections of several specimens shows that the serpentine minerals of the serpentinite were derived from olivine. The olivine, which comprises about 20 percent of the rock, occurs as anhedral grains averaging about 0.16 millimeter across. Serpophite, antigorite, and chrysotile, formed from the alteration of olivine, are present in equal amounts and make up about 60 percent of the rock. The chrysotile and antigorite occur as a mesh of veinlets enclosing cores of serpophite or relics of undestroyed olivine (fig. 17, on p. 45).

Chromite and magnetite are present in minor amounts in most of the serpentinite. The magnetite occurs as dustlike particles throughout the serpentinite, and in some places forms hairlike stringers along fracture lines. The magnetite is probably secondary, formed from the alteration of olivine. The chromite, which comprises less than 1 percent of the typical serpentinite, occurs as euhedral to subhedral grains, the average size being less than 0.50 millimeter across.

FIGURE 38. Sumas Mountain Serpentinite at site of Breckenridge Creek chromite deposit. Well-developed joints at right angles to shear zones. Weathered surfaces show banded structure of the serpentinite.

Mineralization.—Although some disseminated grains and small stringers of chromite occur between the 2,000- and 2,500-foot elevations in the creek bed below the mine workings, the largest concentrations of chromite appear to be at the site of the latest mining operations. Here the chromite is concentrated into a series of parallel bands from ¼ inch to 2 inches wide. In a few places the chromite grains increase in size and number to form lenticular bodies. The largest lens that was observed at the mine workings was 5 feet long and 4 inches wide. Massive chromite noted in a small stockpile indicates that some lenses may have been as much as 10 inches wide.

The bands of chromite, which alternate with layers of serpentinite, have a general strike of N. 80° W. and a dip of 35° S. The attitude of the chromite bands parallels banding in the serpentinite. In places, several parallel bands occur together to form a set; these sets of chromite bands are separated by serpentinite that contains little, if any, disseminated chromite. None of the chromite bands appear to be persistent. Most of them terminate against small cross faults and thicken and thin along their strikes and dips. The average thickness of the bands is about 1 inch.

As observed in the outcrops, the chromite bodies appear to consist of massive chromite, but under the microscope the chromite grains can be seen to be surrounded by serpentine. The grains average 1 millimeter across, are anhedral, rounded, and contain numerous minute antigorite-filled fractures (fig. 39). What little magnetite is present occurs as dustlike particles in the serpentinite.

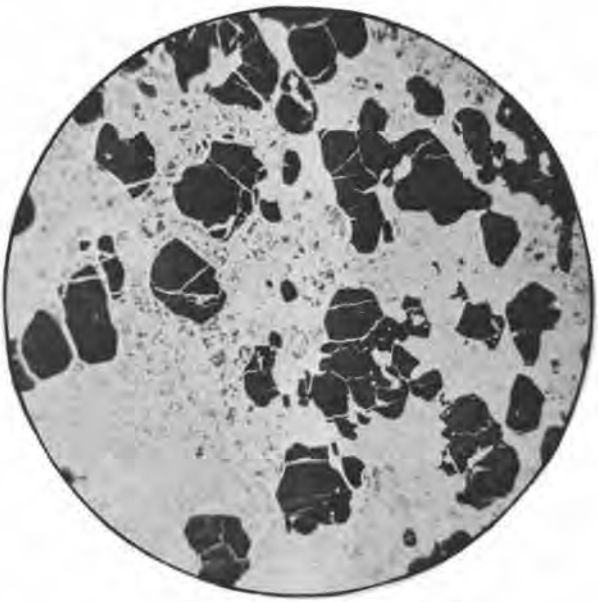

FIGURE 39. Photomicrograph of Breckenridge Creek chromite. Edges of chromite grains rounded, and fractures across grains filled with antigorite. Groundmass consists of olivine and serpentine. (× 15—plain light.)

Analysis of a relatively pure piece of chromite by the U. S. Bureau of Mines (Wilson and others, 1943, p. 23) is as follows:

TABLE 22.—*Analysis of Breckenridge Creek chromite, N½SW¼ sec. 30, T. 40 N., R. 5 E.*

Constituents	Percent	Constituents	Percent
Cr_2O_3	45.1	Al_2O_3	5.6
FeO	17.6	Ign. loss	2.8
MgO	18.1	P.C.E.	39-40
CaO	trace	Cr/Fe	2.5 : 1
SiO_2	8.3		

It is believed that the banded chromite is of magmatic origin and crystallized in an olivine-rich differentiate of an ultramafic parent magma. Euhedral crystals of chromite, free of silicate inclusions, suggest that the chromite was first to crystallize. The early crystallization of the chromite was soon followed by the crystallization of the olivine. Whether the parallel bands of chromite are early crystal segregations or a result of later flowage of the rock in a semisolid or solid state has not been determined.

Conclusions.—Insufficient data are available to calculate ore reserves for the chromite deposits of Sumas Mountain. Disseminated and thin bands of chromite occur in different parts of the Sumas Mountain serpentinite, but past exploration has shown that the deposits are limited in size. Most do not contain more than 5 tons of chromite.

The possibility that concentrations of chromite in larger bodies may be present should not be discounted. Probably all the exposed serpentinite has at one time or another been examined. Only by removal of the overburden or by geochemical or geophysical methods, such as magnetometer surveys, are concealed deposits likely to be located.

COAL

The continental sedimentary rocks of the Chuckanut Formation contain many interbeds of carbonaceous shales. Some of these shales are lignitic and in places contain seams of bituminous and subbituminous coal. However, the coal seams of the north half of the Van Zandt quadrangle are small and have not proved to be of economic value.

Several attempts were made in the past to develop the coal seams, but all attempts failed. Abandoned prospect pits and tunnels are on Coal Creek in sec. 4, T. 39 N., R. 5 E., as well as on several small creeks in sec. 9, T. 39 N., R. 5 E. There are caved tunnels on the lignitic coal beds on Boulder Creek in the SW¼SW¼ sec. 22, T. 40 N., R. 6 E., and on Saar Creek in the NE¼SW¼ sec. 17, T. 40 N., R. 5 E.

Elsewhere in the Chuckanut Formation, but outside the map area, Jenkins (1923) reports as many as 15 coal beds that range in thickness from a few inches to as much as 14 feet. Several of these beds have been extensively mined.

QUARRY STONE

Most of the rocks of the area, with the exception of the surficial deposits, are suitable for general uses such as fill, riprap, or ballast. When crushed, they may be used for road metal and concrete and asphalt aggregate. The siliceous limestone from the limestone quarries of the area has been used for many years in surfacing the logging roads of the area. Only the shales and siltstones, which contain a high percentage of clay minerals, are unsuitable for these purposes. In general, those rocks that break down upon exposure to weathering should not be used.

The more highly indurated sandstones of the Chuckanut Formation have been used for riprap along the banks of the Nooksack River. The massive phase of the Chuckanut sandstone that possesses parting planes may be used for building stone. Many of the older public buildings in the State were constructed from this stone.

One of the most resistant rocks of the map area forms two small hills in secs. 31 and 32, T. 41 N., R. 6 E. This rock is a grayish-green siliceous siltstone. In places it is massive and in other places it is well bedded. Although the rock is siliceous, it has no value for its silica content.

Some of the volcanic rock of the Chilliwack Group is resistant to weathering and has a grayish-green color that could give it some value as a building stone. One such rock crops out in the SE¼ sec. 19, T. 40 N., R. 6 E. At this location it is massive and could be used as rubble.

SAND AND GRAVEL

Abundant supplies of sand and gravel occur along the flood plain channels of the Nooksack River or on the glacial outwash plains of the major valleys. (See plate 1.)

The outwash sands and gravels are the most abundant, and in places exceed 100 feet in thickness. The pebbles and cobbles of the gravel consist of mixed rock types that are well rounded and 2 to 3 inches in diameter. Some boulders as much as 3 feet in diameter also occur. The sand is generally silty; however, some fairly clean sand as much as 20 feet thick is interbedded in the gravel. Silt and clay beds, some of which are as thick as 50 feet, are also present.

The flood plain deposits of sand and gravel that occur along the channels of the Nooksack River represent, for the most part, reworked glacial gravels and material derived from the erosion of the bedrock. These deposits are not as thick as the glacial outwash deposits, but they are somewhat cleaner. Much of the silt has been removed by stream action. The sands and gravels occur along the bars of the river, and during times of maximum runoff are covered by the river. The material is usually removed during low-water periods, only to be replenished during the next flood stage, thus a continuing supply is available.

The sand and gravel of the area are suitable for some purposes as they occur, and other products may be obtained by screening and crushing.

GOLD

Old Nooksack Mine

Location and accessibility.—The Old Nooksack mine workings are 6 miles south of Sumas and 4 miles east of Everson. They are on the western slope of Sumas Mountain, mainly within the N½-SW¼ sec. 36, T. 40 N., R. 4 E. The property is accessible by trail from the farm of P. O. Sealund, which is near the common corner of secs. 26, 27, 34, and 35, T. 40 N., R. 4 E. (fig. 40). The trail follows an old wagon road, which at one time provided access to the mine. Abandoned logging roads also lead to the area of the mine workings. The roads now are accessible only on foot, and lead from the site of a portable sawmill on the upper part of the Lebrant road in the SE¼ sec. 35, T. 40 N., R. 4 E.

History.—Very little is known about the early history of the property. In the 1890's many mining claims were staked in the area, and around 1900 the Nooksack Mining Company was formed as a gold mining company. A stamp mill was erected, and underground mining was undertaken. During this time over a quarter of a mile of drifts and crosscuts were driven (U. S. Works Progress Administration, 1936, p. 2). Around 1908, mining operations ceased and the property was abandoned. Nothing remains of the mill except several foundations, which are about 300 feet west of the lowest mine adit. The property has been examined and sampled several times in the past, but gold is not present in amounts to warrant mining.

Geology.—All the mine workings are in sedimentary rocks that have been mapped as possible lower Mesozoic rocks (pl. 1). They are siliceous graywackes that, on a cursory examination, appear to be basic igneous rocks. For the most part, the graywackes are composed of 40 to 50 percent angular to subangular chert fragments in a

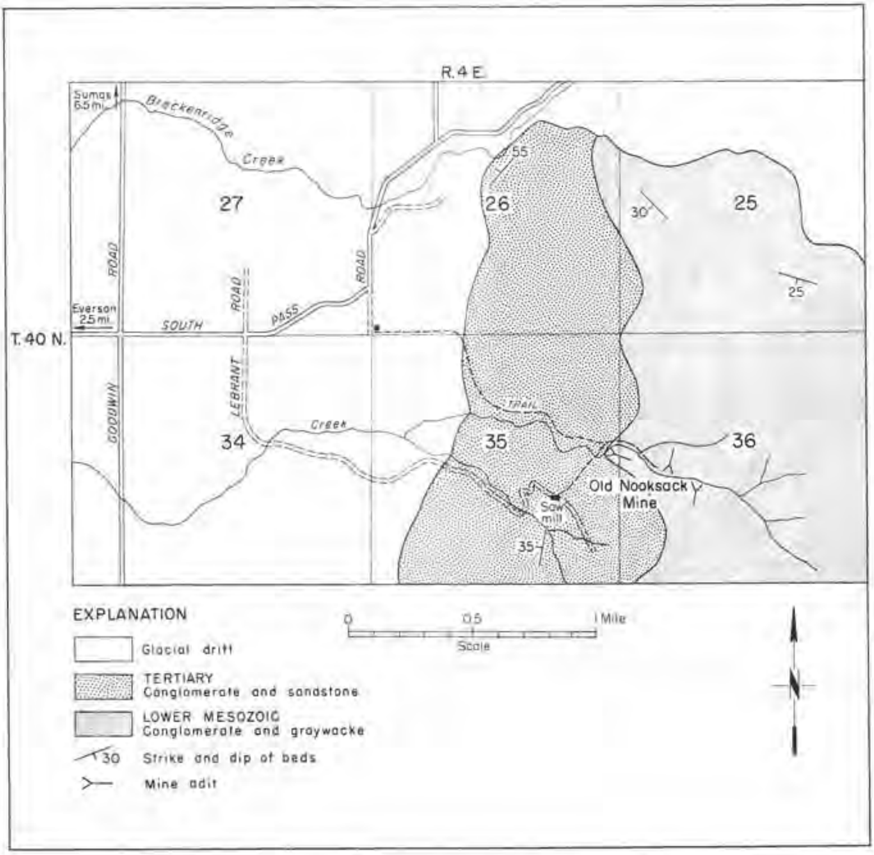

FIGURE 40. Location and geologic map of the Old Nooksack gold mine.

matrix of 30 to 40 percent argillite. Very fine grained iron pyrite is disseminated in the argillite fraction of the rocks. Most of the graywackes are coarse grained and so well indurated that they are similar to unaltered igneous rocks in toughness. At higher elevations above the mine workings the graywackes form prominent cliffs. They tend to weather to a light-gray color, and on weathered surfaces, thin white quartz stringers are conspicuous. Almost all the graywackes are massive, and in the vicinity of the mine the strike and dip of the beds could not be determined. Half a mile to the northeast similar rocks strike N. 40°-70° W. and dip 25° to 40° SW. Beds of granule, pebble, and cobble conglomerates are interbedded with the graywackes, but most of them are poorly exposed. One such conglomerate is well exposed in the bed of the creek near the lowermost mine adit (fig. 40). At this location the conglomerate consists of well-rounded to subangular cobbles of andesite, argillite, chert, and dacite in a dark-gray, medium-grained graywacke matrix (fig. 4, on p. 20). About 50 feet west of the adit the conglomerate is overlain unconformably by Tertiary continental arkosic sandstone and conglomerate.

Mine workings and mineralization.—At least three adits were driven at the Old Nooksack mine (fig. 40). These adits are within 100 feet of a small creek that flows down the western slope of Sumas Mountain. Heavy vegetation in the area makes it difficult to locate the mine workings. The lowermost adit on the creek, which appears to have been the main workings, is now flooded by water from the creek. The adit was driven at a heading of S. 70° E. into the south bank of the creek at an elevation of about 1,600 feet above sea level. Little remains of the mine dump, for it has been washed away by the creek. About 1,300 feet upstream and on the north bank of the creek is the site of the second adit. It is about 50 feet above the creek and was driven at a heading of N. 20° E. for about 135 feet. Six hundred feet farther upstream and on the south bank of the creek is the site of the uppermost adit. This adit heads south for about 120 feet. The two upper workings were open at the time of the examination (1959) and appeared to be in good condition.

Except for the thin white quartz stringers that traverse the graywacke in the vicinity of the mine, it appears that no definite veins were followed during the mining operations. It was reported (U. S. Works Progress Administration, 1936, p. 6) that over 50 channel samples were taken in all the drifts and crosscuts and that the average value of these samples was $3.50 per ton in gold. Assaying of several quartz stringers by the writer disclosed that they are barren of gold. It is believed that what little gold is present is associated with the disseminated iron pyrite that occurs in many parts of the graywacke.

It is probable that the Old Nooksack gold mine was opened in an attempt to locate the source of placer gold that was discovered in several of the streams in the area. When the source of the gold was not located, the mine was abandoned.

Placer Gold Deposits

Placer gold was discovered in northwestern Whatcom County in the middle 1800's. An article that appeared in the Whatcom Chronicle in July 1858 stated that William Young discovered several sizable gold nuggets to the east of Everson. The exact location of this discovery is not known, but it was reported to have been about 11 miles northeast of the mouth of the Nooksack River. The absence of any extensive early-day placer operations indicates that the discovery probably did not amount to much.

In the 1930's a small amount of gold was recovered from placer operations at the headwaters of Bells Creek, in the NE¼ sec. 17, T. 39 N., R. 5 E. Production figures are not available for this area, but the gold was reported to have been mostly dust. Some small nuggets were recovered also. Mining operations were on a small scale; sluice boxes and rockers were used to recover the gold (J. Francisco, oral communication).

The source of the placer gold appears to be the glacial drift and the Tertiary conglomerates that underlie the area. Reworking of these sedimentary deposits by present-day streams has resulted in the concentration of some placer gold. Sampling and panning of parts of the Tertiary sedimentary rocks, especially the basal parts of the conglomerates, show that gold is present in some of these rocks, but not in amounts of economic value.

Concentrations of ,placer gold in amounts to justify mining might exist; however, an extensive sampling program would be required to locate the pay streaks. The original source of the gold would be the gold-bearing veins of the granitic rocks from which the sediments were derived.

COPPER

Boulder Creek Deposit

Location and accessibility.—The copper mineralization on Boulder Creek is mainly within the SW¼ sec. 22, T. 40 N., R. 6 E. (fig 41). It is about 1¾ miles by road north of State Highway 1. Access to the area is by way of an abandoned limestone quarry road that leads from the Boulder Creek logging road in the SE¼ sec. 21, T. 40 N., R. 6 E. The roads are accessible by conventional vehicles to within a quarter of a mile of the copper occurrence.

History.—The presence of copper on Boulder Creek has been known since the the late 1800's. Whatcom County records indicate that in 1892 D. B. Humsphing staked a claim for marble, iron, and copper on the west bank of the creek, 1½ miles from its mouth. There is no evidence in the area that indicates that mining was attempted at this time. The copper, which occurs as chalcopyrite float in Boulder Creek, attracted the attention of prospectors in the years that followed, but extensive exploration for the source of the float was not undertaken until much later.

In an attempt to locate the copper deposit, the Howe Sound Mining Company conducted an exploration program in the early 1940's. Surface cuts, diamond drilling, and geophysical exploration methods were employed (W. A. Moore, oral communication). The results of this exploration program are not known to the writer, but the fact that the company did not acquire a lease to the property indicates that the source of the copper float was not found or that the deposit is too small to be of interest to them.

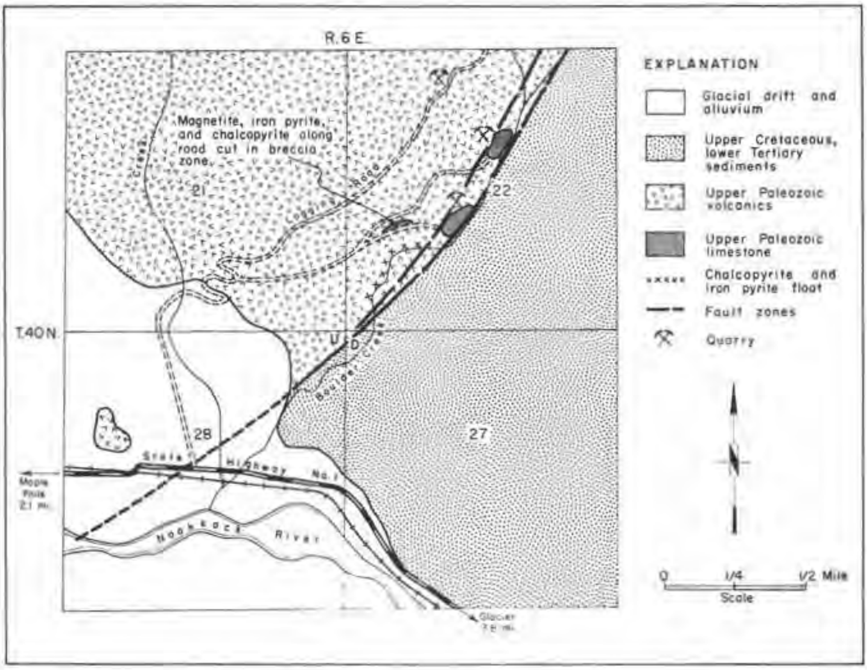

FIGURE 41. Location and geologic map of the Boulder Creek copper occurrence.

Geology.—The principal rocks of the area are Tertiary sedimentary rocks and upper Paleozoic basic volcanic rocks that are separated from each other by a high-angle fault zone that parallels Boulder Creek. The Tertiary rocks crop out east of the creek and consist of graywacke, graywacke-mixed pebble conglomerate, and carbonaceous shale. Along the banks of the creek the beds strike N. 40°-70° W. and dip 5°-80° S. (pl. 1). West of the creek the predominant rock is altered basalt. Highly contorted ribbon chert and argillite, serpentine, and limestone are also present.

The copper, which occurs as float in Boulder Creek, consists of angular to subangular fragments of chalcopyrite mixed with quartz and pyrite. Some of the chalcopyrite-bearing boulders are as large as 6 feet in diameter. They vary in composition from almost pure massive chalcopyrite to fine-grained iron pyrite. The quartz that accompanies the chalcopyrite and pyrite is carmine red in color. Because of the abundant iron, most of the copper-bearing boulders have acquired a rusty color that makes it easy to recognize them.

The most likely source of the chalcopyrite appears to be near the center of the SW¼ sec. 22, T. 40 N., R. 6 E. (fig. 41). On the west side of Boulder Creek and about 80 feet above it, an iron oxide zone is exposed in a road cut. This zone consists of about 2 feet of brecciated basalt cemented by iron oxide that pinches out in less than 8 feet along its strike. The breccia zone trends about N. 70° E. and is nearly vertical. Included within the zone are kidneys of magnetite. The magnetite is very fine grained and contains pyrite and quartz. Some kidneys are composed almost entirely of magnetite. Several small nodules of pyrite and chalcopyrite are also present in the breccia, and oxidation of the minerals has produced abundant iron oxide and minor malachite. The copper-bearing nodules resemble many of the copper-bearing boulders that occur along the creek.

Whether the chalcopyrite float came from this mineralized zone or similar zones associated with the Boulder Creek fault is unknown. However, it is evident that copper mineralization is present in the area, although the extent of the mineralization is not known. Detailed prospecting in the area, especially by geochemical methods, may disclose an unknown ore body.

Miscellaneous Occurrences

Chalcopyrite and its secondary minerals malachite and azurite are associated with the massive quartz deposit in the NE¼NW¼ sec. 17, T. 40 N., R. 5 E. The copper minerals occur as several small pods in the main body of the quartz. Chalcopyrite also occurs as disseminated grains in other parts of the quartz deposit, but not in amounts to be of commercial value. This occurrence has been discussed in the section on the silica deposit of the area (p. 103).

Malachite was also noted on the surfaces of a large argillite boulder in the SE¼ sec. 33, T. 40 N., R. 5 E. The size of the boulder, which is almost 3 feet in diameter, as well as its angularity, suggests that the boulder is float from the argillite that crops out in the immediate area. However, a search of the area failed to disclose the source of the float.

SUMMARY

Both metallic and nonmetallic mineral deposits occur in the north half of the Van Zandt quadrangle. Limestone, refractory clay, quartz, and sand and gravel deposits are present in quantities to satisfy the raw material demands of several industries. At this time (1960) none of the metallic mineral deposits are considered to be of commercial value. They appear to be too low in either quality or quantity to be mined at a profit.

Clay.—Refractory clay deposits occur about 3 miles southeast of Sumas. Although these deposits have been mined in the past, there still remains a moderate tonnage of clay that has a fusion point as high as cone 31. Underground mining methods would have to be used on most clay seams; however, some refractory clay might be mined from the near-surface seams by employing stripping methods.

Limestone.—Significant deposits of limestone occur on Sumas, Red and Black Mountains. This limestone averages about 89 percent calcium carbonate. At present (1960), two quarries are in operation on Red Mountain. Limestone has been mined in the past on Sumas Mountain, but substantial reserves still remain. Only a small part of the limestone on Black Mountain has been mined. Large deposits on the north-central section of the mountain have yet to be mined.

Quartz.—White massive quartz occurs in the valley between Sumas and Vedder Mountains. This deposit contains at least 50,000 tons of quartz that averages about 90 percent SiO_2. In the past the silica has been utilized in the manufacture of cement; it could also be used for roofing chips or similar crushed products.

Iron.—The iron deposit on the western slope of Sumas Mountain is estimated to contain about 750,000 tons of indicated and inferred ferruginous shale that averages 26 percent iron. Because of its relatively small size, as well as its physical and chemical properties, it is doubtful that the deposit would be of interest to the iron industry.

Chromite.—The chromite deposits of Sumas Mountain occur as seams and small irregular-shaped bodies, most of which do not contain more than 5 tons of chromite. Larger bodies of chromite may exist, but, because of the heavy underbrush and thick overburden, exploration for these deposits will be difficult.

Coal.—Coal beds are found on Sumas and Slide Mountains, but they are mainly lignitic. Bituminous and subbituminous coal is also present, but the beds are too narrow for commercial operations.

Sand and gravel.—Extensive deposits of sand and gravel can be found in Columbia Valley, as well as in the bed of the Nooksack River. At present (1960), these deposits supply the local demands of the County, chiefly for road material.

Gold.—Gold occurs in trace amounts in many of the rocks, and some streams contain placer gold. At the Old Nooksack mine the mineralized rock averages about $3.50 per ton in gold. Placer mining on upper Bells Creek produced a small amount of gold in the 1930's. None of the gold deposits are considered to be of commercial value.

Copper.—Copper mineralization in the form of chalcopyrite, malachite, and azurite occurs in the area. However, the known deposits are too small to be of economic importance. The presence of the large chalcopyrite boulders on Boulder Creek warrants further investigation into the source of the copper.

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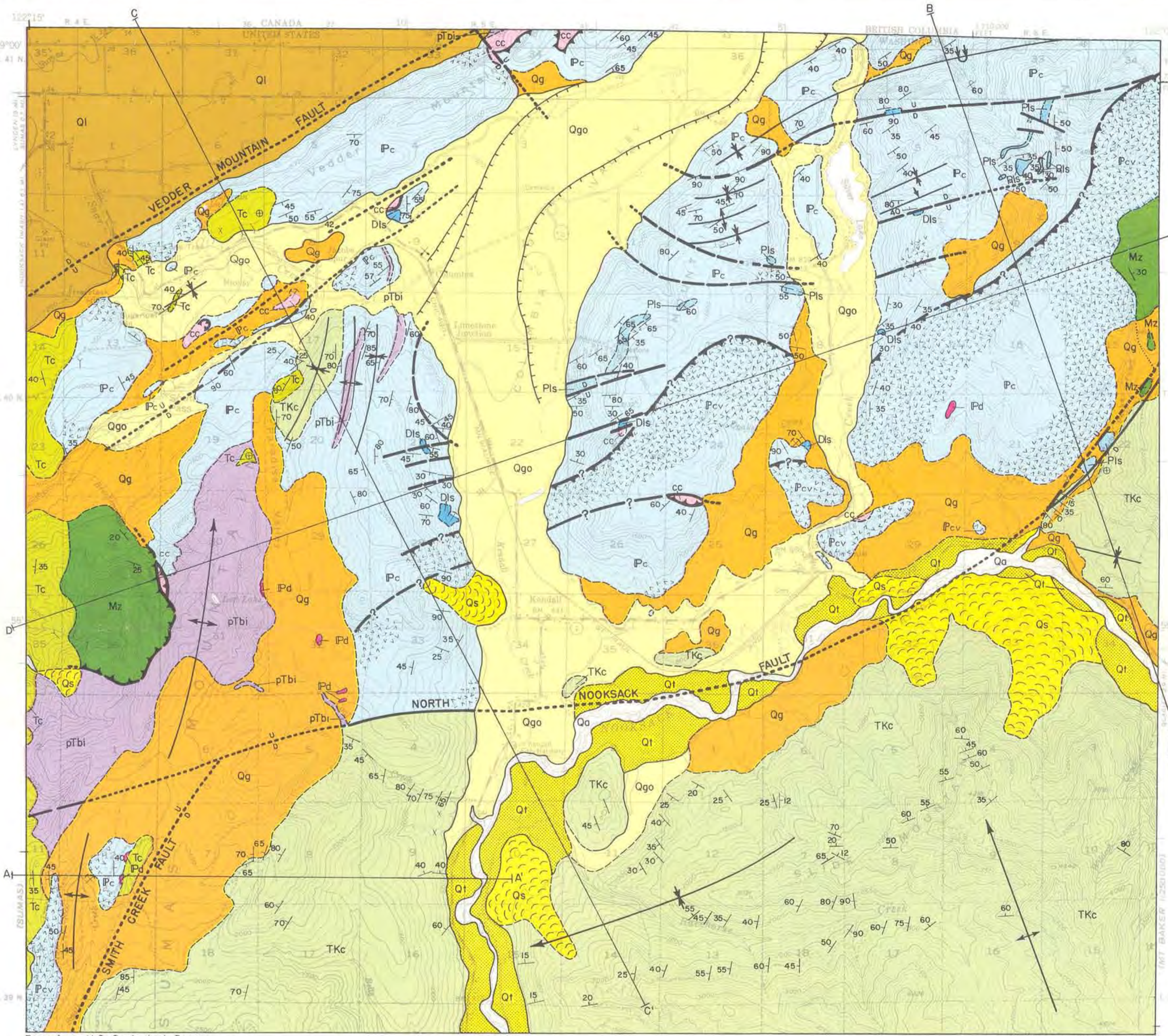
GEOLOGIC MAP OF THE NORTH HALF VAN ZANDT QUADRANGLE

WHATCOM COUNTY
WASHINGTON
1961



Base from U.S. Geological Survey-Van Zandt Quadrangle

Geology by Wayne S. Moen
Mapped in 1959

LEGEND

CENOZOIC

Recent

Qa — Alluvium
Gravel, sand, and silt deposits along streams

Qs — Landslides
Areas of slumped masses of bedrock and overburden

Qt — Terrace deposits
Gravel, sand, and silt of stream flood plains

Pleistocene

Ql — Lacustrine deposits
Silt, clay, and some sand and gravel of old lake beds

Qgo — Glacial outwash
Stratified gravels; includes sand, silt, and clay

Qg — Glacial drift, undivided
Till, outwash, or glaciofluvial deposits of sand and gravel

Eocene

Tc — Tertiary continental sedimentary rocks
Arkosic sandstone, conglomerate, siltstone, and shale, includes several refractory shale beds

MESOZOIC

TKc — Chuckanut Formation
Arkosic sandstone, conglomerate, siltstone, and shale; some shale beds carbonaceous with coal seams

pTbi — Sumas Mountain Serpentinite
Serpentinite and saxonite; includes some olivine

Mz — Lower Mesozoic rocks, undifferentiated
Graywacke conglomerate, graywacke, grit, and carbonaceous argillite

PALEOZOIC

ℙls, ℙd, ℙcv, Pls, Dls, ℙc

Upper Paleozoic Chilliwack Group
Argillite, graywacke, siltstone, shale, chert, tuff, basic volcanic rocks, and breccias undivided - ℙc; lower Permian limestone - ℙls; lower Pennsylvanian limestone - Pls; Devonian limestone - Dls; chiefly upper Paleozoic volcanic rocks - ℙcv; dioritic rocks - ℙd

Age uncertain

cc — Crystalline complex
Metadiorite, meta-quartz diorite, amphibolite

SYMBOLS

Geologic boundary
Dashed where approximate, dotted where concealed

Fault
Dashed where approximate, dotted where concealed

Thrust
Saw teeth on upper plate

50 — Attitude of bedding

Anticline
Arrow on axis shows direction of plunge

Syncline
Upright and overturned

Prospect pit

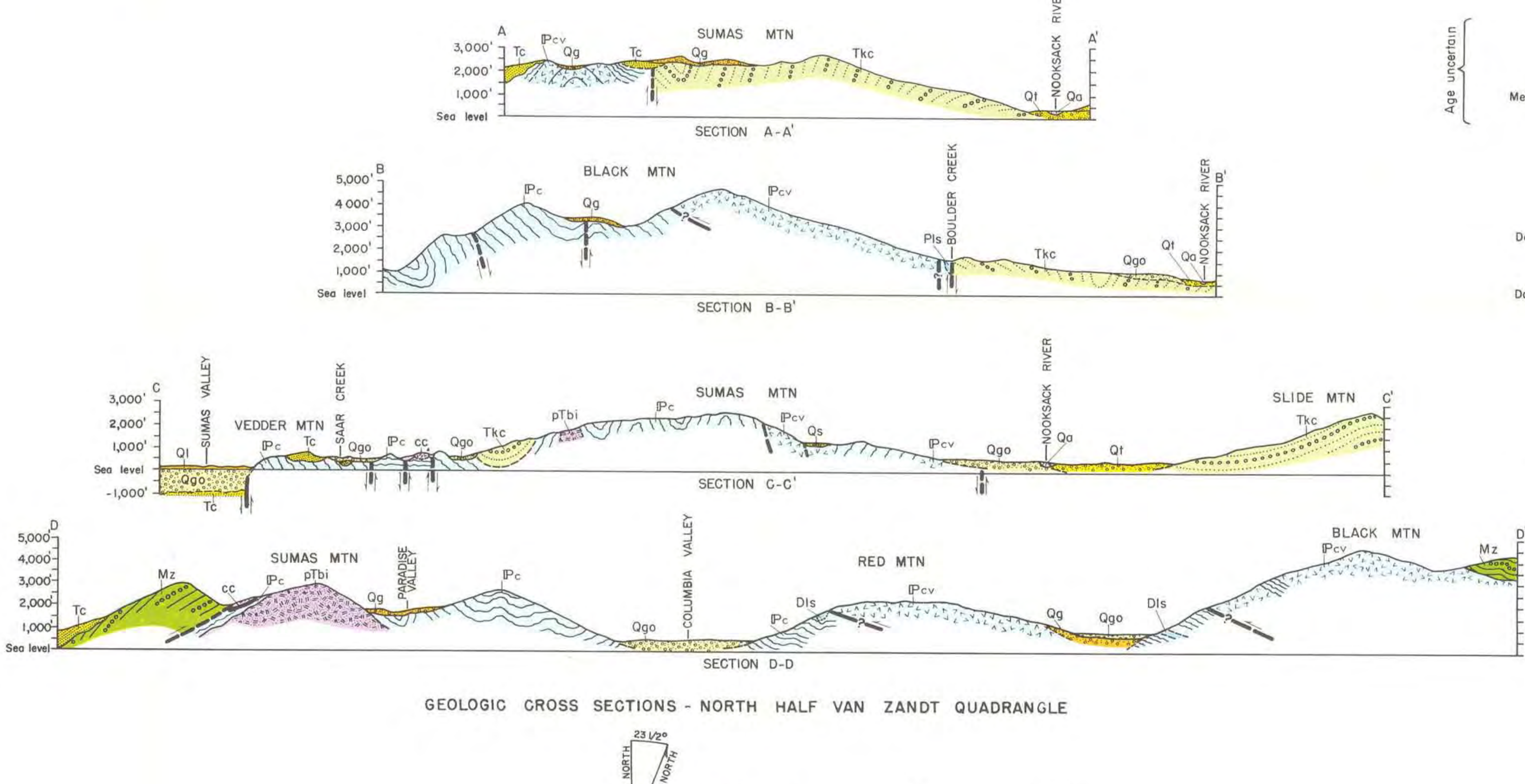
Mine or quarry

Gravel pit

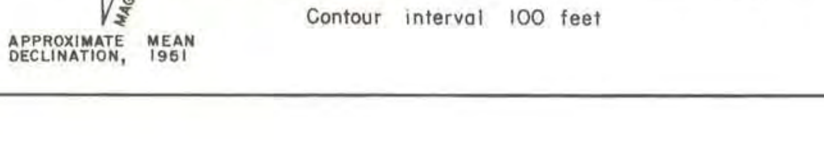
Mine adit

A — A' Line of structure section

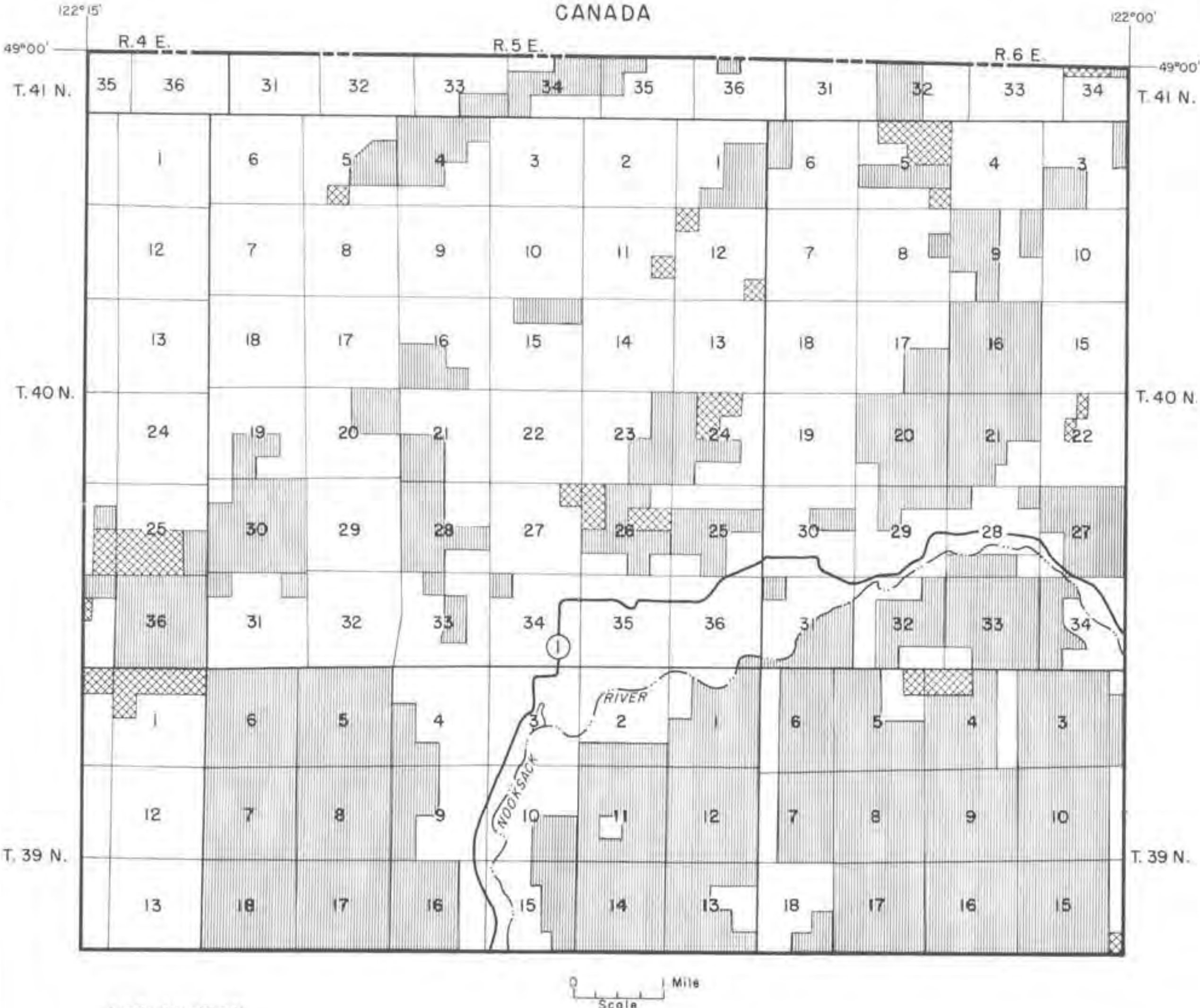
Terrace scarps
Hachures on scarp side



GEOLOGIC CROSS SECTIONS - NORTH HALF VAN ZANDT QUADRANGLE



Contour interval 100 feet



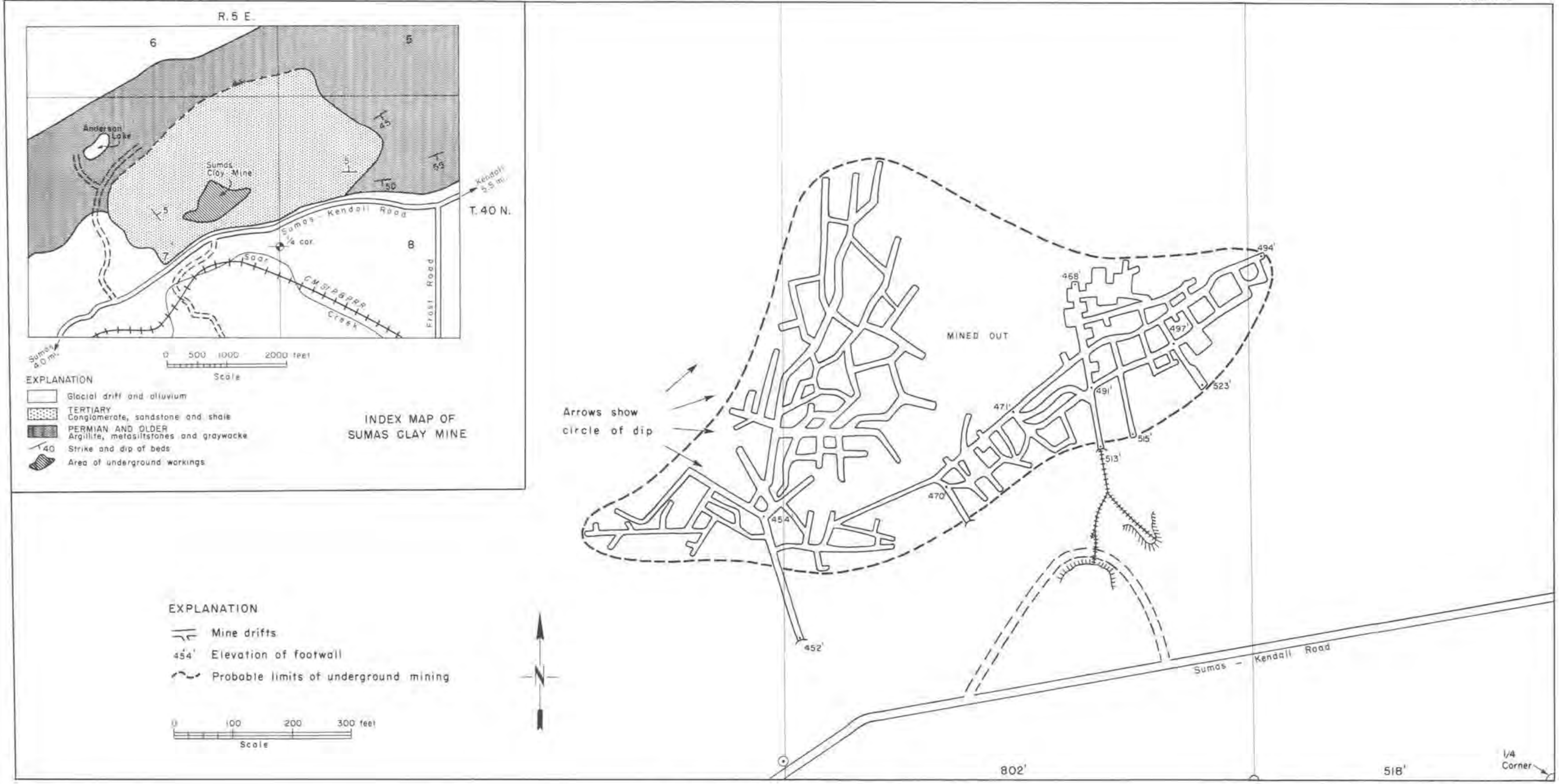
EXPLANATION

- Private Land
- Washington State Land
- U.S. Government Land
- State Highway

Base:
U.S. Geological Survey
Van Zandt Quadrangle.

Compiled from:
Atlas of Whatcom County (1956).
Kroll Map Company, Inc.,
Seattle, Washington.
Records of Whatcom County
Accessor (1961)

LAND OWNERSHIP - NORTH HALF VAN ZANDT QUADRANGLE (1961)

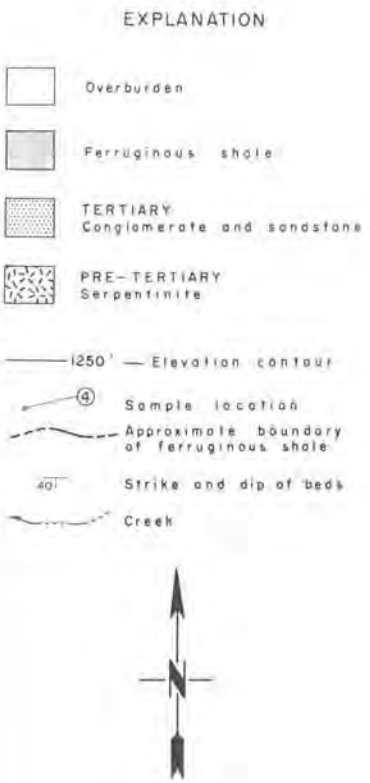


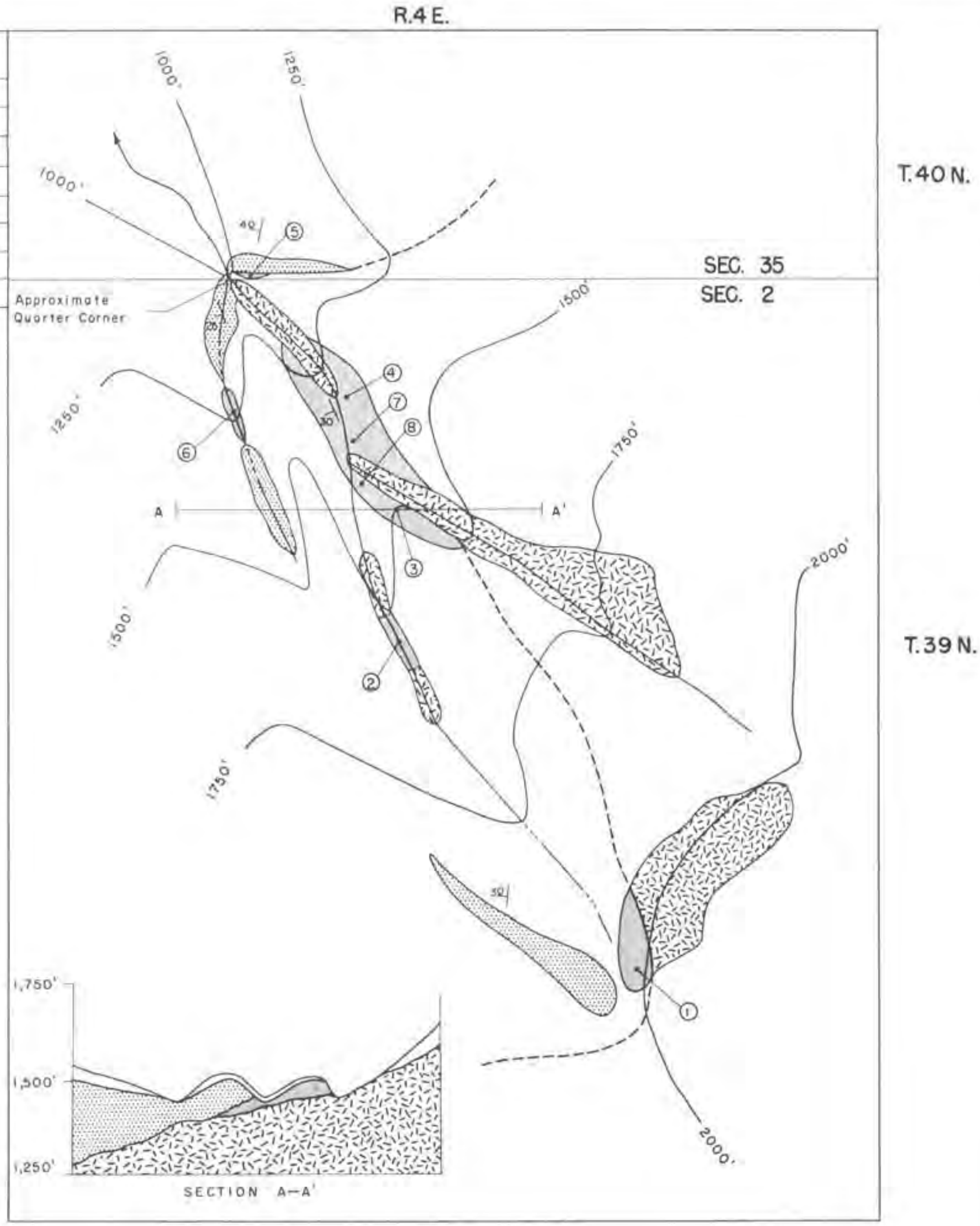
SUMAS CLAY MINE

Data for underground mine workings furnished by Gladding McBean and Company

SAMPLE ANALYSES

Sample No.	Sample Thickness	Fe_2O_3	Al_2O_3	SiO_2	Loss on Ign.
1	5.0 ft.	38.8	17.8	34.8	5.48
2	4.5	45.5	14.4	31.3	5.56
3	6.0	36.4	21.8	33.4	8.20
4	4.5	48.1	24.1	20.3	6.56
5	5.0	23.1	16.2	46.8	7.20
6	3.0	38.3	17.2	32.0	8.49
7	3.0	28.6	28.6	46.5	7.02
8	5.0	40.9	40.9	27.9	8.49





OUTCROP MAP OF SUMAS MOUNTAIN IRON DEPOSIT

Scale: 250 0 250 500 750 feet

Geology by
W. S. Moen, 1959