THE GEOLOGY OF THE MOUNT VERNON AREA

by

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THE GEOLOGY OF THE MOUNT VERNON AREA

INTRODUCTION

Field Investigations

The Mount Vernon area has been studied for the purpose of obtaining new information concerning the geology of portions of western Washington. During the fall of 1938 and the spring of 1939, thirteen days were spent in the field. The character and distribution of rock types were noted and samples collected for later laboratory studies. These laboratory studies were made at the University of Washington.

Parts of the Mount Vernon area are readily accessible by automobile over local farm roads or fire protection roads. Other parts have to be traversed on foot, often with much difficulty due to the thick undergrowth. Abandoned logging roads aided in the investigation of the more remote sections.

The writer wishes to express his gratitude to both Dr. Howard Coombs and Dr. Charles E. Weaver of the University of Washington for their many suggestions in preparing the manuscript.

Geographic location

The Mount Vernon area is located in the southwestern part of Skagit County in western Washington. The area as considered in this thesis comprises about seventy-five square miles of hilly country lying to the south east of the town of Mount Vernon.

This hilly country is distinct from the flat delta land of the Skagit River which lies immediately to the west and is separated from the hills lying to the south and east by McMurray Lake and Big Lake with their small stream valleys. The Main Pacific Highway, U. S. No. 99, is just west of the area and passes through the town of Mount Vernon. On the east side of the area is a branch of the Northern Pacific Railroad which goes around McMurray Lake and Big Lake.

General Geology

The maturely eroded hills of the Mount Vernon area are part of a broad east-west anticlinal upwarp. That part of the anticline within the area is composed of two main types of rocks. An older metamorphic rock group of pre-Tertiary age consists of highly metamorphosed sediments, greenstones, intrusives, and volcanics. The younger Tertiary sediments are exposed mainly in the southern part of the area as arkosic, medium grained sandstones, pebble conglomerates, and some shales. These sediments unconformably overlie the metamorphic rocks but locally faulting has brought the older rocks adjacent to the Tertiary sediments. The sedimentary rocks are strongly folded along the south flank of the major east-west upwarp and in places show evidence of deformation by much jointing and faulting.

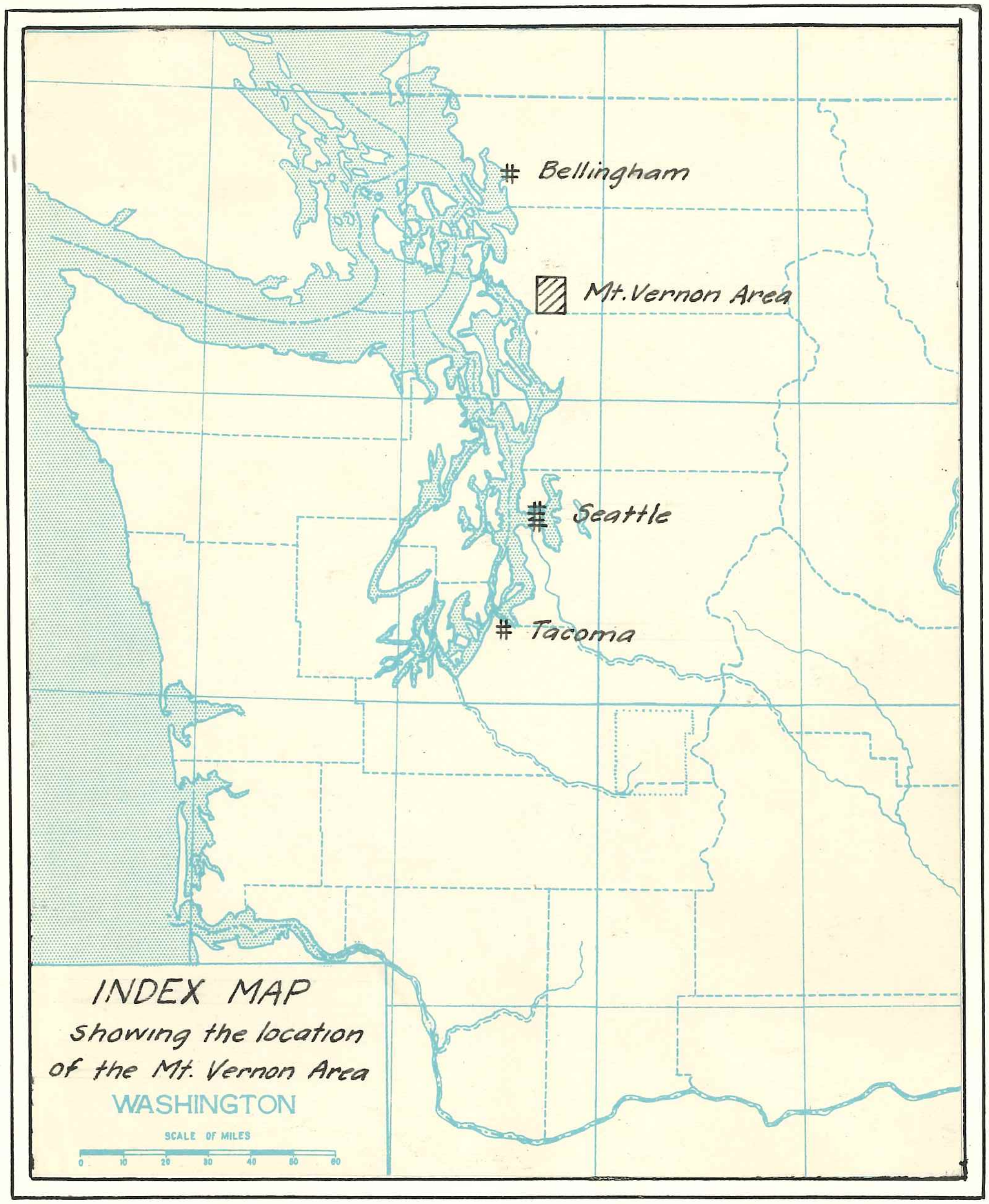
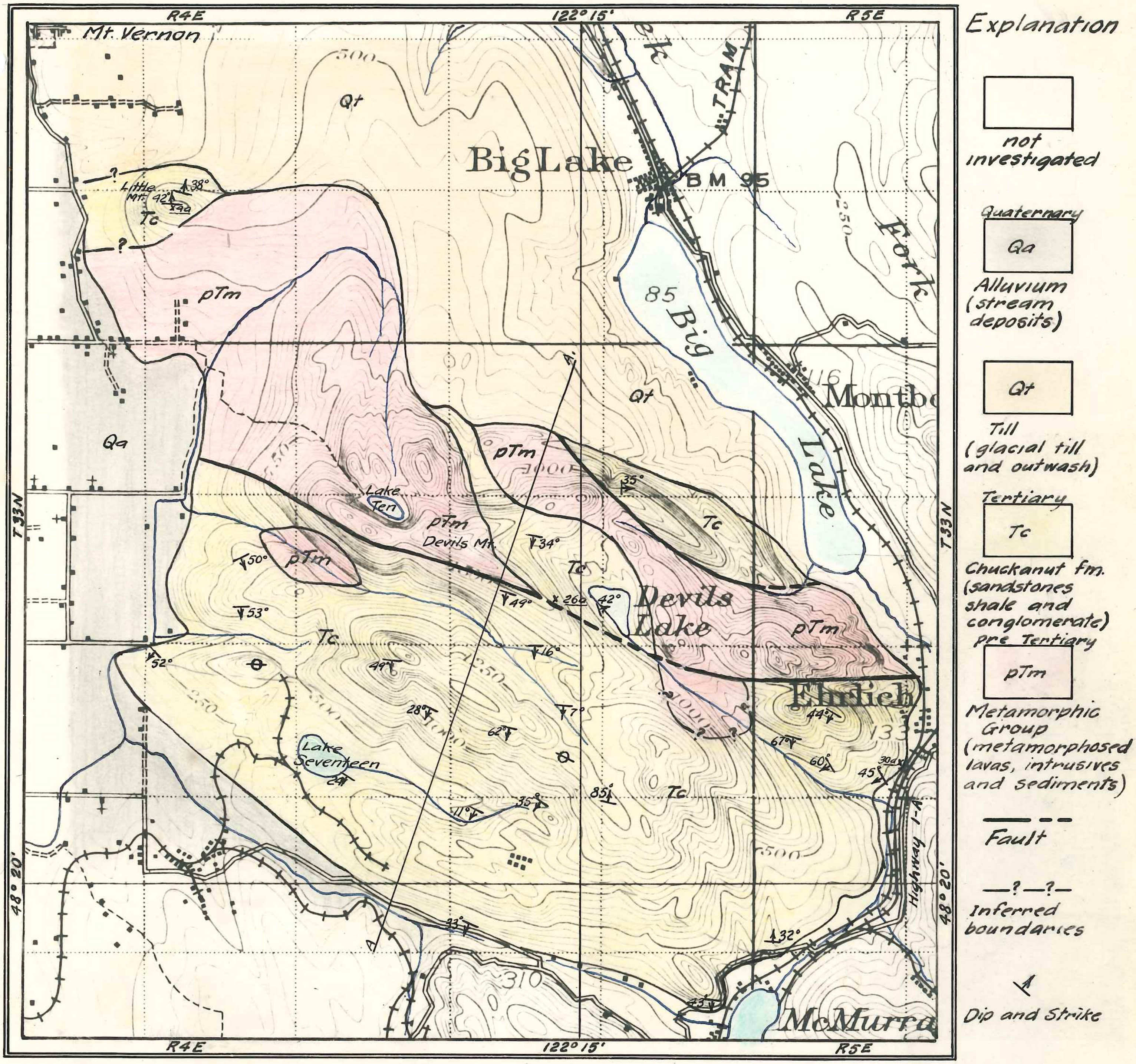

Bellingham
Mt. Vernon Area
Seattle
Tacoma
INDEX MAP
showing the location
of the Mt. Vernon Area
WASHINGTON
SCALE OF MILES
0 10 20 30 40 50 60

Plate I



GEOLOGIC MAP OF THE MT. VERNON AREA, WASHINGTON

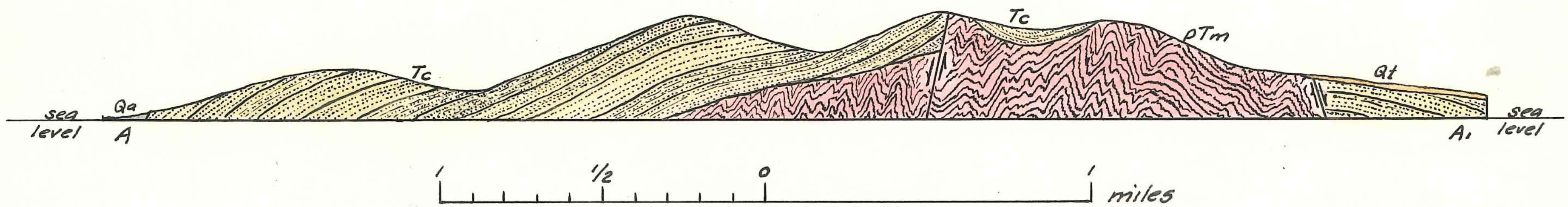
Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 Miles

Contour interval 50 feet

Datum is mean sea level

Plate II



Structure Section in the Mt. Vernon Area

Plate III

TOPOGRAPHY

General Features

The hills of the Mount Vernon district stand out in sharp contrast above the low, flat floodplain of the Skagit River. Along the western side of the area the hills rise abruptly from the river lowland which is almost at sea level. The main group of hills is still in a youthful stage of dissection. A few small seasonal streams have carved steep sided valleys. The valleys are sometimes bounded by sharp ridges of resistant sandstone or conglomerate. In places there are broad valleys with gentle slopes which merge into a hilly upland.

Where the metamorphic rocks outcrop, there is a tendency toward differential erosion which produces individual hills instead of the long strike ridges which are so common in the sandstone areas. The hills which are carved from the metamorphic rocks sometimes show very jagged irregular summits, but it is commoner for these rocks to be represented by rounded conical hills.

Somewhat in contrast to the hilly southern part of the region is the gently rolling glacial plain to the north. Rock exposures in this area are limited to the stream valleys on the west side of the plain where the covering of gravels has been stripped away exposing the underlying rocks. The glacial plain consists of both outwash and ground moraine formed as the result of the advance and recession of ice. Road cuts and gravel pits show the glacial material to be typical till composed of a heterogeneous assemblage of rocks. At other places in the area there are excellently bedded gravels with well sorted glacial material indicating that at least part of the material formed as outwash fans in front of receding ice sheets of Pleistocene time.

Evidence of ice erosion is plentiful on the elongate dome like sandstone hill which is locally called Little Mountain. The elevation of Little Mountain is 750 feet and it stands out above the glacial plain as a prominent landmark lying about two miles southeast of Mount Vernon. The top of Little Mountain has been scoured smooth by ice action. The well exposed sandstones along the top and northeast side show many grooves and striations and a few heavy flutings. The trend of these markings indicates that the ice advanced over the area from a northwesterly direction.

The abundant rainfall of western Washington is ideal for tree growth. The entire western part of Skagit County was at one time covered with stands of good timber of which little now remains. Since the logging operations in the Mount Vernon area, new growths of evergreen and deciduous trees are abundant. Good trees are absent only where forest fires have burnt out the vegetable mold of the soil. Much of the area is covered with a dense growth of underbrush.

Relief and Drainage

From the low delta of the Skagit River the hills in the southern part of the area reach elevations of 1500 feet. The highest peak in the area is Devils Mountain with an elevation of 1750 feet. North of the hills the elevations of the glacial plain range from 250 to 500 feet.

The area is drained entirely by small streams, some of which are seasonal. These small streams flow eastward into the creeks draining McMurray Lake and Big Lake, and thence northward into the Skagit River. On the west side of the area the streams enter the Skagit River directly by artificially constructed drainage ditches after leaving the hills.

DESCRIPTIVE GEOLOGY

Sedimentary Rocks

The sedimentary rocks which are exposed in the Mount Vernon area are part of a widespread sequence of Tertiary sediments which occur in the western part of both Whatcom and Skagit Counties. These rocks are exposed in the foothills along the western flanks of the Cascade Mountains and in the adjacent Puget Sound lowland where up-warpings have given the land sufficient elevation to be stripped of a superficial covering of glacial material and alluvium. This group of rocks was first referred to by McLellan (1) as the Chuckanut formation, a term which has been adhered to by later writers. The Chuckanut formation is well exposed in the hilly country of the Mount Vernon area.

Character and distribution

The Chuckanut formation is composed mainly of coarse and medium grained arkosic sandstones, conglomerates and shales. Generally the sandstones are massive and firmly cemented. In places these rocks are interbedded with carbonaceous shales and locally brown shales may predominate. The shales and sandstones commonly contain thin seams and inclusions of coal. At some places ripple marks and cross bedding are present. Marine fossils have not been found in these rocks, although plant remains are locally abundant. All evidence points toward terrestial and deltaic types of deposition.

(1) McLellan, R. D., Geology of the San Juan Islands, Univ. of Wash. Publ. in Geol., vol. 2, pp. 136-138, 1927.

The Chuckanut formation is continuously exposed in the entire southern part of the hilly area. Along the northern part of the hilly region the sediments are irregularly distributed with the metamorphic rocks. At places the Chuckanut formation terminates abruptly where older metamorphic rocks have been brought up by faulting or exposed by deep erosion.

Stratigraphic relations of the Chuckanut formation

The Chuckanut formation is believed to be unconformably underlain by a complex group of undifferentiated metamorphic rocks. These old metamorphic rocks have not been studied systematically and will be considered in this paper as pre-Tertiary in age. Locally overlying the Chuckanut formation is a blanket of glacial till of Pleistocene age and a few stream deposits of Recent age. These unconsolidated deposits have been partially removed from the higher elevations by erosion.

Petrography

General Composition A study of the lighter bulk of the constituents of the sandstones in the Mount Vernon area discloses their arkossic nature.

A microscopic observation of both the coarse sands and the very fine sands showed that feldspars were present with quartz in the ratio of one to two in some slides. The feldspars were less prominent in others. A high degree of kaolinitic alteration in most of the feldspars made it difficult to determine the varieties most common but orthoclase, microcline, and oligoclase were determined.

Observations made on the quartz showed some to be clear and fresh appearing, and some with minute inclusions which gave a discolored aspect to the grains. Occasional grains of chalcedonic quartz was also seen. The quartz is the most abundant mineral in the rock.

The striking feature about the bulk of the constituents is the high irregularity of shape, the absence of pronounced rounding and other features indicative of wear. This can be accounted for in part by the crushing method used in breaking down the rocks, but the absence of much wear in the sediments is well shown.

A study of the cementing materials show that there is a very fine argillaceous or kaolinic residue of rock weathering. Treatment with acid shows that calcite is practically absent as a cementing material while iron is present in large amounts and constitutes one of the cementing compounds. The limonitic nature of the rock is also evident from the hand specimen.

Texture. Outcrops of sandstone were observed in many places. Three typical sandstone samples were chosen for study at separated localities in the Mount Vernon area. Specimen number 4a was taken at the summit of Little Mountain, the prominent hill lying directly southeast of Mount Vernon about one and one half miles distant. Number 26a was taken due west of Devil's Lake near the top of the main southeast trending spur of Devil's Mountain. The third sample, number 30a, was removed from the bluff exposed by a road cut just ten miles south of Clear Lake on Highway 1A (Plate No. II).

The hand specimens are hard, fresh appearing, unweathered, whitish, somewhat speckled, coarse grained, arkossic sandstones. They show abundant glassy quartz grains, dull white feldspars, with some muscovite, and larger fragments of sand in a matrix of whitish cementing material. There are abundant specks of limonite plainly visible in the rock.

The mechanical analyses of the sandstones was made by crushing the stone carefully and screening with standard screens. The fractions of the grain sizes calculated. In this way the grain sizes were named following Wentworth's classification of size limits of particles.

The results show that the three samples have a predominance of coarse sands followed by very coarse sands, and then medium sands. There is little variation as to grain size or ratio of the grain sizes. The results are graphically expressed in the following page. (Plate No. IV)

The grain shape of these sandstones was found to deviate considerably from true sphericity and show a marked degree of angularity in general. Both larger sand grains and smaller heavy mineral accessaries showed, however, considerable rounding of some particles in marked contrast to the general angularity of the sands.

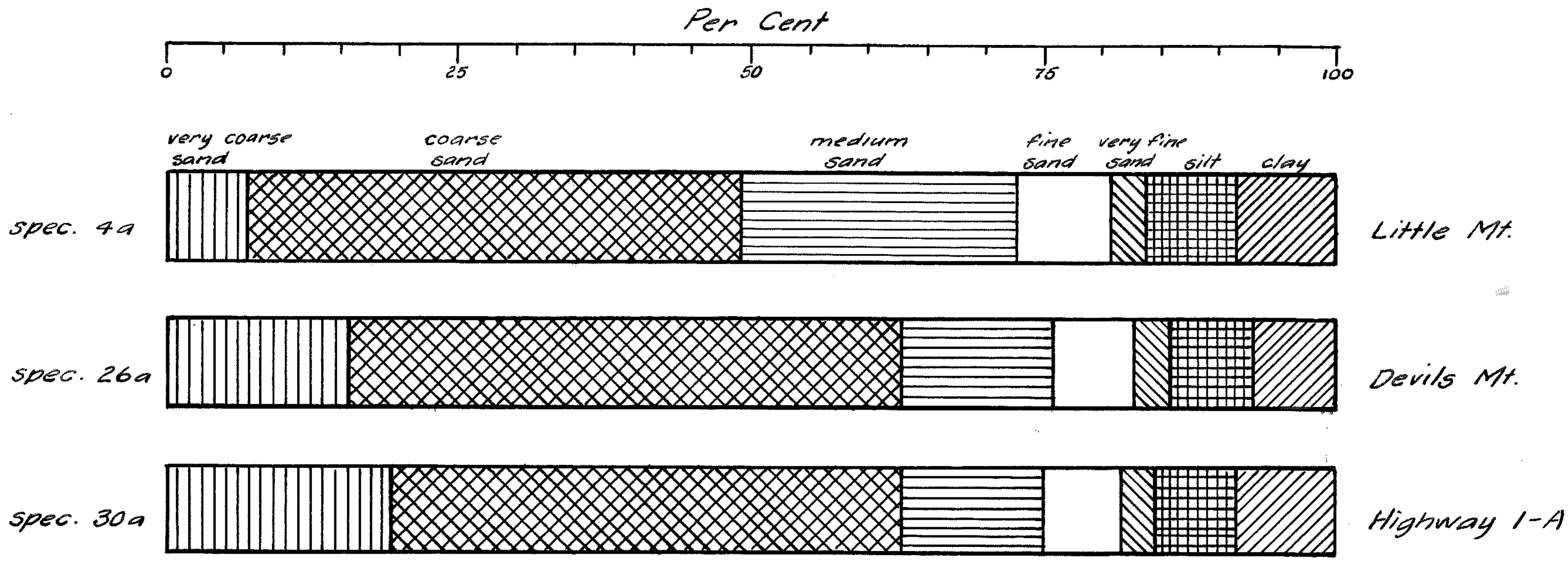
The sphericity of two samples was calculated by transcribing the image of the outline of the sand grains by means of a camera lucida. The average sphericity was found to be 63%. This was calculated from examination of the coarse sand fragments only, these sands being predominant in the rock.

<u>Heavy mineral accessories</u> Due to predominant coarse grain of the sandstones there is a relative scarcity of the heavier minerals. This is to be expected when coarse sands are deposited with little variation in conditions of deposition.

A separation of heavy mineral contained in the very fine sand fraction was made using bromoform with a specific gravity of about 2.8. These separated heavy minerals were mounted for microscopic study and used in the analysis of the sands both from the standpoint of mineral composition and the study of their source and amount of transportation.

Of the minerals found, garnet, leucoxene (?), muscovite, and magnetite were far in excess of the others. The percentage occurrence of the heavy mineral was calculated for each of the three samples studied. The results can be seen best from a chart (Plate No. V.)

SAND ANALYSIS



Textural Analysis in Percent by Weight

Plate No. IV

HEAVY MINERAL ANALYSIS

Rock Sample	Location	Grain Size	Garnet	Limonitic Products	Magnetite	Muscovite	Zircon	Fluorite	Biotite	Rutile	Tourmaline
4a	Little Mountain	+100	24.2	28.6	20.9	15.4	5.5	1.1	1.1	2.2	1.1
26a	Devils Mountain	+100	40.0	20.7	3.7	24.4	2.2	7.4	1.5	0.0	0.0
30a	Highway 1-A	+100	24.2	10.3	38.0	20.7	3.8	0.0	3.8	0.0	0.0

Percentage Occurrence of Heavy Minerals

Plate V

Garnet--The garnet grains occur most commonly as irregular and anhedral grains. The grains are usually colorless in section and show little wear. In some cases they are rounded but irregular in shape. There are some very pale pinkish or brown colored garnets included with these irregular grains. There is apparently a longer-transported group of garnets which have attained a good degree of sphericity. This group is much rounded and worn looking, and they seem to be of the colored variety.

Limonite--An abundance of limonite was noticed in all samples. This mineral varied in color from buff to deep nusty brown in the reflected light of the microscope. The shape of the grains is always irregular. A shiny to dull luster and granular aggregate structure is characterisitc of the mineral. The limonite is apparently intimately mixed with various alteration products.

Magnetite--The opaque minerals were considered as a whole under the name magnetite. It is very probable the limenite, pyrrhotite or other iron opaques were included in this category, but the nature of the report does not warrant a more detailed separation. The striking thing about the magnetite was that the grains were all well rounded and smoothly worn, generally fairly spherical and abundant in specimens 30a and 4a while the magnetite of specimen 26a is much less worn and regular and not very abundant. The worn grains may represent an older generation of clastics.

Zircon--Among the heavy minerals are some colorless euhedral and subhedral prisms of zircon. A few grains showed a remarkable perfection of form with the bi-pyramidal terminations intact. In general the zircons were slightly worn.

Biotite--Clean clear biotite flakes with blue, bluish green, or green colors and strong pleochroism were identified.

Fluorite--The occurrence of isotropic, colorless, irregular, little-worn, fluorite fragments was noticed especially in specimen 26a. Cleavage directions were measured on some of the grains and found to be 62 and 75 degrees.

Rutile--Angular, clear ruitle or similar titanium minerals were identified in the rock specimen 4a. The high angularity of this mineral indicates its origin with the bulk of the sediments.

Tourmaline--Occasional brown pleochroic tourmaline grains were found in specimen 4a. The tourmaline pieces were angular and showed some evidence of their prismatic habit of crystallization.

Glacial Deposits

Glacial till and stratified drift are present over much of the northern part of the area. These deposits are mostly typical unconsolidated glacial tills containing rounded and sub-angular gravels and boulders in a sandy and clayey matrix. No outstanding large erratics were seen. In a gravel pit about one and one half miles east of Devil's mountain there are exposures of well stratified sorted gravels in beds ranging from a few inches up to three feet in thickness. Individual beds are composed of small boulders and gravels with sand. The coarser beds are usually separated by sandy beds or pebbly sand beds.

Recent alluvium

A portion of the western part of the Mount Vernon area is covered with a blanket of alluvium. This fine silt and mud has been deposited by the seasonal flooding of the Skagit River which has thus built up a wide floodplain.

Metamorphic rocks

Character and distribution

The rock exposures along the north side of the hilly part of the Mount Vernon area are predominantly metamorphic in character. An examination of these rocks reveals the more or less distinct rock types:

1. Brecciated Hornfels
2. Greenstone
3. Serpentine
4. Conglomerate and graywacke
5. Andesites
6. Porphyritic rhyolite and rhyolite tuff

These rocks are considered together as a metamorphic group. The group is composed of recognizable units, but the complicated relationships of the rocks together with the limited exposures do not warrant a separation into formations. A description of the rock types will best show the metamorphic nature of the group.

Types

Brecciated Horfels A zone of recrystallized metamorphic rock composes Devil's Mountain and its northwest-southeast trending spur and a small local area northeast of Devil's Mountain. These rocks are hard, brown, finely crystallized, brecciated hornfels. Casually observed, the rock has a mottled appearance with prominent secondary mineralization. Irregular bands and streaks add to the brecciated appearance of the rock. Cavities are sometimes present and are commonly filled with quartz, zeolites, or chalcedonic material in the form of milky white druses. The rock is extremely fractured on a small scale, and locally where sulphide mineralization has taken place it weathers to a rusty limonitic brown.

A thin section of the brecciated hornfels shows a fine grained crystalloblastic aggregate of quartz, feldspar and disseminated opaque iron minerals. A network of calcite veinlets and iron-stained kaolinitic material is responsible for the light and dark mottled appearance of the rock. The small quartz grains when observed with a high-power objective have a very pronounced undulating extinction which suggests that the rocks have been subjected to strong deforming forces.

Greenstone Greenstone is widely distributed between Little Mountain and Lake Ten. In the lower elevations south of Little Mountain where stream erosion has removed the glacial deposits there are excellent continuous exposures of greenstone. These rocks form prominent cliffs and escarpments along the northwest side of the hilly region. Variable in both appearance and composition they represent the product of thermal metamorphism of sediments and lavas.

Megascopically the greenstone is a hard, tough, pale greenish gray colored rock. Some specimens are aphanitic in texture while others are finely granular or spotted. Megascopically there are no recognizable minerals. Numerous small joints are always present. Small veinlets sometimes fill the cracks, but more often the joint planes are limonitic stained. The rock weathers to gray or brown masses of hard angular fragments which make good hand specimens hard to obtain. The greenstone is characterized by an olive gray color, hackly irregular fracture, and a pronounced toughness. The parallel banding observed in some weathered outcrops strongly suggests a sedimentary origin for some of the rocks.

A careful microscopic examination of the greenstone confirms its metamorphic character. It is composed of a very fine grained crystalloblastic aggregate of quartz, sericite, chlorite, muscovite, and disseminated iron opaques. Some sections have abundant altered feldspars occuring both singly and in clusters. Olivine, apatite, calcite and quartz crystals are subordinate in the fine grained groundmass. Small veinlets of a pale green chlorite are generally present. The development of much chlorite, sericite and kaolinitic products indicates the rock has undergone the initial stages of thermal metamorphism.

Serpentine In the metamorphic rock area both to the east and west of Lake Ten there are exposures of serpentine. The serpentine is blackish green in color. When fresh specimens are available small shiny dark crystals are visible in a dull green groundmass. Small fractures and slippage planes are numerous throughout the entire rock. A few very small veinlets of light colored material pass irregularly through the rock. Often the serpentine is highly weathered to granular greenish brown sand and pebbles and as such is not easily distinguished from the brecciated hornfels which are found nearby.

A petrographic examination of the serpentine discloses its altered nature. An interlacing network of antigorite fibers make up most of the rock. Numerous small discontinuous veinlets of amphibole or antigorite are disseminated through the rock. Evidence of a high original olivine content can be seen in the vague crystal outlines and relict sieve structure that is so typical of olivine. Granules and stringers of opaque iron minerals are everywhere present with borders of thin limonite films. A few relict hypersthene crystals in an advanced stage of alteration are present. The rock is a typical serpentine derived from what was probably a hypersthene bearing peridotite.

Conglomerate and Graywacke Conglomerate and graywack occurs as a small inlier that has been exposed by deep erosion of the Chuckanut formation on the south side of the Creek valley about one mile west of Devil's

Mountain. These rocks are massive firmly cemented conglomerates and graywackes. In color they are brown or black and have subangular pebbles up to four inches in diameter. The individual pebbles are coated with a black stain and are firmly set in a matrix of finer sandy material. A few thin seams of chalcedonic quartz traverse the otherwise massive rocks.

Andesites. In the creek valley one mile west of Devil's Mountain altered andesites are exposed with the conglomerates and graywackes. The andesite is an altered dull brownish gray porphyritic or vesicular rock. Small dull white feldspar and a few dark indeterminable minerals show as phenocrysts in a dense brownish gray groundmass. The andesite weathers to a brown color.

In thin section the andesite has both small and large euhedral phenocrysts of altered feldspar. The feldspars which show both albite and carlsbad twinning, were determined as andesine. A few small quartz phenocrysts are present. The groundmass is a microcrystalline aggregate of quartz, feldspar and alteration products. The original character of the mafic minerals is not determinable. Oxidation of the opaque iron accessory minerals has resulted in a brown stain which permeates the rock and is probably responsible for much of the brown color in the hand specimens.

Porphyritic rhyolite and rhyolite tuff. Rhyolitic rocks are exposed in the hills northwest of the railroad station of Ehrlich. Here they form high steep sided prominent hills with smooth rounded tops. The outcrops weather to a white or gray color. Locally the lavas have a red color due to hematite stains. In the high hills bordering the east side of Devil's Lake there are great masses of thinly banded tuffaceous rhyolite.

The typical rhyolites are hard, dense, gray, pink, or earthy white colored altered porphyritic lavas. Rounded phenocrysts of gray glassy quartz and dull white feldspars as large as three millimeters are abundant. The matrix of the lava is dull earthy white. Pink colors are sometimes common in the groundmass and along fracture planes. At some localities the rhyolites are considerably altered.

Under the microscope the rhyolite has a fine microcrystalline groundmass with abundant phenocrysts of quartz and feldspar. The quartz phenocrysts are both euhedral and subhedral in form and are clear and unstrained. Well rounded resorption borders are a common feature of the quartz phenocrysts. Orthoclase phenocrysts are generally unaltered, and sometimes twinned on the carlsbad plan. The groundmass shows kaolinitic alteration and a subsequent development of zeolite minerals. The reddish colored rhyolites show much disseminated hematite in thin section.

Structure and Deformation

The earliest evidence of deformation can be seen in the extreme fracturing of the older metamorphic formations. The angularity of the fragments and their small size in fractural zones indicate that the older metamorphic rocks were locally subjected to intense faulting. These fractures have all been healed by a filling of quartz, zeolites, chalcedony, and iron sulphides.

The existence of a large normal fault passing through the hilly area in a northwest-southeast direction is plainly shown in a mine tunnel which was driven across a fault contact about one-half mile west of Lake Ten. This tunnel passes through the faulted contact and penetrates a zone of highly pyritized fault breccia in the metamorphic rock. Later movements along this fault have brought the metamorphic rock (up) adjacent to the Chuckanut formation.

That this fault has been subjected to more than one displacement is shown by the two periods of brecciation and mineralization. The metamorphic rocks along the fault are a hard, siliceous, firmly cemented fault-breccia. Much of the breccia has been firmly cemented with pyrite. Later movements along this zone have fractured the relatively weak Chuckanut formation. These last movements have been accompanied by a dolomitic cementation. Pyrite mineralization is entirely lacking in the zones of later movements affecting the sandstones. Locally the fault is expressed on the surface by an escarpment.

West of the south end of Big Lake the sandstones are terminated abruptly and regularly by a fault which has a northwesterly strike and disappears under the unconsolidated deposits of the glacial plain. On the hillside above the glacial plain the faulted contact between the metamorphosed rhyolite and the younger Chuckanut formation is well shown. No mineralization was seen along this fault.

In the hilly southern part of the Mount Vernon area the Chuckanut formation is strongly deformed into a number of large northwest-southeast trending folds. All of these folds have a general southwesterly dip indicating that they are part of the south limb of a major anticlinal structure Generally these rocks are free from faulting and jointing, but as the faulted northern boundary is approached the sandstones show much small-scale faulting and jointing which accentuates their massive appearance by obscuring the bedding.

The regional southwesterly dip of the Chuckanut formation in the southern part of the hilly country, and the northerly dip of the strata on Little Mountain with an intervening upfaulted area of metamorphic rock all indicate a major east-west trending anticlinal structure. This anticlinal structure is probably a part of the major San Juan uplift of Miocene time which elevated the San Juan Islands (2) area.

GEOLOGIC HISTORY

Sedimentary Record

Consolidated deposits

Overlying the metamorphic rocks is a blanket of unmetamorphosed sediments, the Chuckanut formation. The Chuckanut formation is considered by C. E. Weaver (3) to be mainly of Eocene age and in part the time equivalent of the Puget Group which is exposed to the south in King and Pierce Counties, and to the Swauk and Roslyn sediments of eastern Washington.

The Chuckanut formation is distinct from all other formations in the area because the sediments are free from the effects of metamorphism. These rocks have been systematically studied for the purpose of determining the source of their materials and the manner of deposition.

In order to critically discuss the origin of sediments it is necessary to have an understanding of the succession of changing events which took place with the passing of geologic time prior to and during the interval of deposition. The paleogeography of northwestern Washington during Eocene time is only generally known; therefore, any deductions as to the source of the sandstones in the Mount Vernon area can only be made in a general way.

(2) McLellan, R. D., The Geology of the San Juan Islands, Univ. of Wash. Publ. in Geol., vol. 2, p. 160, 1927.

(3) Weaver, C. E., Tertiary Stratigraphy of Western Washington and Northwestern Oregon, Univ. of Wash. Publ. in Geol., vol. 4, p. 90, 1937.

With the information obtained from a study of the sandstones it is possible to arrive at some conclusion regarding the source of the sediments. The evidence for the conclusions will be listed.

1. The high angularity of the sands and their arkossic nature shows that the sediments were not transported any great distance and were probably carried by swiftly flowing streams.

2. The massive and thick bedded coarse grained sandstones commonly show pebble bands and streaky zones indicating near-shore, deltaic, or terrestial conditions of deposition.

3. The assemblage of heavy accessory minerals, and the high potash and soda-feldspar content are characteristic of derivation from a hinterland of granitic rock types through processes of weathering which were mainly mechanical.

4. The absence of an assemblage of metamorphic rock minerals indicates that the sediments were not derived from the belt of metamorphic rocks which are present in western Washington.

5. The distinct roundness and worn surface of the magnetite and some of the garnet may be interpreted as a second generation of minerals derived from the erosion of older sediments.

Literature (4) dealing with the geologic history of northwestern Washington states that at the close of the Cretaceous interval of time there had been produced a low coastal plain which extended along the entire western part of Washington.

The differential warping of this coastal plain during Eocene time was responsible for the accumulation of great thicknesses of clastic sediments in the downwarped areas. At this stage of history the coastline was probably somewhat west of its present position. There were evidently east-west trending downwarps separated by higher intervening elevated portions of the coastal plain and adjacent high areas to the east. The major streams occupying the downwarped portions may have had their sources

(4) Ibid, Weaver, C. E., p. 23.

to the east in central Washington. Local upwarpings of the central part of Washington or at other points along the drainage basins of these streams would initiate a cycle of terrestial deposition.

It is postulated that the sediments of the Chuckanut in the viscinity of the Mount Vernon area was deposited by westerly or southwesterly flowing streams which had their source in areas of fair or considerable elevation. These elevated land areas were anticlinal or upwarped counterparts of the depressed areas occupied by the major streams. It is believed that deposition in the Mount Vernon area took place in embayments of a low-lying land area.

Geologic studies of the Cascade Mountains in the northern part of Washington have shown the presence of extensige areas of granodioritic rocks. They have been described and assigned to various ages from Jurassic to Miocene (5). There is as yet no sound proof of the ages of these plutonic rocks. It is reasonable to suppose that at least those of pre-Tertiary age were undergoing erosion and furnished the bulk of sediments which were accummulating along the margins of the low border lands. The acid feldspars, zircon, garnet, fluorite and mica found in the Chuckanut formation substantiate this statement.

It is believed that the swiftly flowing streams derived their load mainly from the disintegration of granitic rocks within a radius of not more than eighty miles from the Mount Vernon area. Locally through the erosion of adjacent sediments there was a small addition of previously rounded sands. The metamorphic rock groups exposed at present along the western part of the state furnished some iron as a cementing material but not much coarse sand.

(5) Daly, R. A., Memoir No. 38, Geology of the North American Cordillera at the Forty-Ninth Parallel, Part I, Dept. of Mines, Canada, pp. 506 and 546, 1912.

Unconsolidated deposits

Since the Chuckanut sediments were laid down there has been a time of glacial deposition. With the advance of ice from the north during Pleistocene time the Mount Vernon area was subjected to strong erosion. The deep flutings, grooves, and striations on Little Mountain, together with the rounded north side profiles which the hills show in the Skagit River lowland are evidence of ice action. The repeated advance and retreat of the ice caused a complete topographic adjustment (6). The receding ice sheets left the lowland areas deeply filled with ground moraine and stratified drift from ice margin streams. The occasional glacial boulders in the highest hills of the Mount Vernon region are proof that the ice was at least a thousand feet above the present sea level.

The glacial plain north of the hilly area is composed of morainic material of the Pleistocene ice sheets. Rock exposures are absent here because the covering of unconsolidated glacial material has not yet been removed. The history of the Mount Vernon area since Pleistocene time has been one of drainage adjustments.

Metamorphic record

The pre-Tertiary rocks exposed in the Mount Vernon area are part of the extensive systems of metamorphic basement rocks which underly late Mesozoic and Cenozoic sediments of northwestern Washington. McLellan (7) in his description of the metamorphic rocks of the adjoining San Juan Islands area divides these rocks into the Orcas Group of Devonian-Mississippian age

(6) Bretz, J. Harlen, Glaciation of the Puget Sound Region, Wash. Geol. Surv. Bull. no. 8., pp. 13-22, 1913.

(7) McLellan, R. D., The Geology of the San Juan Islands, Univ. of Wash. Publ. in Geol., vol. 2, pp. 91-113, 1927

and the Leeck River group of Pennsylvanian-Permian age. These Paleozoic rocks together with sediments and intrusive rocks of Triassic and Jurassic age constitute the metamorphic basement of the more thoroughly studied areas of northwestern Washington, and Vancouver Island, Canada.

The limited work done in the Mount Vernon area does not permit a direct correlation of the rock types with those of adjacent areas, although certain similarities between formations can be noted.

The slaty schists and argillites exposed about one half mile southeast of Little Mountain are lithologically similar to McLellan's description of the common rock type of the Leech River group and may be their age equivalent. It is also possible that the serpentine of the Mount Vernon area is the equivalent of the Fidalgo formation of Triassic age which is exposed to the northwest in the San Juan Islands.

Considerable thicknesses of rhyolitic lavas which occur in the hills southeast of Big Lake suggest that these rocks were at one time more widespread. Although the rocks are altered, their appearance is distinctly younger than the greenstone and hornfels formations. The observed attitude of the tuffaceous members of the lavas shows that they dip to the northward, and suggests that at one time they overlay much of the metamorphic rock. These relationships may link the outpourings of rhyolite with late Jurassic igneous activities which affected western Washington. More detailed future work will be necessary to establish the true relationships of the metamorphic rock formations.

MINERAL RESOURCES

Gravel

The glacial plain in the northern part of the Mount Vernon area is composed of outwash and till deposits of considerable thickness. The gravel of these deposits has been used to surface roads in the vicinity. The largest gravel pit which was investigated is about one and one half miles east of Little Mountain. There is sufficient gravel and sand exposed at this point to supply local demands for some time. As the adjacent areas all have workable gravels, there is little chance of this resource being exploited.

Coal

It has been reported that the Chuckanut formation in the hills northwest of Lake McMurray has coal seams which have been worked in past years. The writer has not investigated these workings, but believes that commercial seams of coal could occur in this area. The sandstones exposed along highway 1-A between Big Lake and McMurray Lake show inclusions and thin seams of coal at numerous places.

Nickel

A major fault passes southeasterly through the hilly part of the Mount Vernon area separating the metamorphic rocks on the north side from the Chuckanut sediments on the south. Along the western half of this fault in the hornfels is a highly mineralized fault zone. The mineralization here consists of pyrite and some disseminated magnetite which thoroughly cement a fault breccia. Hand specimens show a breccia composed of small angular rock fragments which are completely surrounded with pyrite, quartz, and chalcedony. Under the microscope the pyrite is seen to thoroughly impregnate the entire fault breccia. Fissure and cavity fillings of quartz and chalcedony are a common feature of the rock. Calcite, sericite, limonite, and kaolinitic alteration products are prominent in the thin section of an unweathered specimen.

The entire western half of the fault zone is well mineralized, as is evident from the universal presence of limonite in the surface outcrops. The pyritized rock has been oxidized to limonite everywhere at the surface giving the northwestern spur of Devil's Mountain a rusty red color when viewed from a distance.

Chemical tests show the fault breccia to contain nickel. The nickel is probably intimately associated with the pyrite either as a mineral of nickel or in a disseminated form. Quantitative analyses would be necessary to determine the nickel content of the rock.

In order to be of commercial importance the nickel deposits in the Mount Vernon area would have to be a high grade ore. Drilling of the pyritized zone would have to be undertaken to determine its extent before the possibilities of development could be considered. Although the area is readily accessible by highway, rail, and water, transportation costs to smelters which are equipped to handle nickel ores would prohibit the exploitation of a low grade ore body.