STRATIGRAPHY OF THE RED MOUNTAIN FORMATION (LOWER PENNSYLVANIAN?)
OF NORTHWESTERN WASHINGTON

by

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A THESIS SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE
in the Department
of
GEOLoGY

We accept this thesis as conforming to the
required standard from candidates for the
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THE UNIVERSITY OF BRITISH COLUMBIA
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ABSTRACT

The Red Mountain formation (Lower Pennsylvanian?) of the Chilliwack group (Carboniferous) was mapped in five areas of northwestern Washington. Except for a few outcrops of Devonian strata, the formation represents the oldest known sedimentary rocks in this region. It consists primarily of argillite, graywacke, chert, tuff and limestone, and is overlain by conglomerate of the Black Mountain formation (Lower Permian). The base of the formation is nowhere exposed.

Correlation of the Red Mountain formation is dependent essentially on the presence of large crinoid stems, foraminifera, and similarity of stratigraphic relationships.

Limestones of the upper portion of the formation represent deposition under conditions of marked tectonic stability, whereas enclosing strata are indicative of deposition in an unstable, subsiding realm.
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STRATIGRAPHY OF THE RED MOUNTAIN FORMATION (LOWER PENNSYLVANIAN?)
OF NORTHWESTERN WASHINGTON

INTRODUCTION

Introductory Statement

This thesis deals with the description and correlation of the Red Mountain formation (Lower Pennsylvanian?) of the Chilliwack group in the northwestern Cascade Mountains of Washington and the San Juan Islands. The formation consists primarily of argillite, graywacke, limestone, chert and tuff. Fossiliferous limestones provide the essential basis for correlation and five areas where limestones constitute major portions of the section were studied.

The age of the Red Mountain formation is not well known as it is involved in a controversy over the presence of Upper Mississippian or Lower Pennsylvanian sedimentary rocks in some areas of the Cordillera. The difficulty of establishing the age is due to the presence of little-known Asiatic fossils in the rocks to the near exclusion of typical North American types. W. R. Danner (1957) has in part resolved this controversy and, although with some reservation, assigns a Lower Pennsylvanian age to the Red Mountain formation. Because of a general lack of North American fossils in the Chilliwack group, structural complexities in the northern Cascades, a lack of outcrop and a prevalence of thick underbrush in the northern Cascades, most previous geological work has been of a reconnaissance nature and no detailed descriptions or correlations of units or
formations of the Chilliwack have been made.

It is the aim of this study to give a detailed description of some well exposed sections of the Red Mountain formation, and its immediately overlying rocks, as well as to extend the known limits of correlation in the northwestern Cascades. It is hoped that this study may in some way serve as a base for further correlations within the Chilliwack group.

Locations

Only general locations will be given here. Specific outcrop locations and their accessibility are included in later sections. The five areas which will be described may be referred to generally as the Red Mountain, Black Mountain, Washington Monument, Prairie Mountain and Orcas Island areas.

Red and Black mountains are located near the international boundary in north-central Whatcom County about seven and eleven miles, respectively, east of Sumas. Silver Lake and the Maple Creek valley separate the mountains. The outcrops studied on Red Mountain are in central section 14, T40N, R5E, at a quarry operated by the Permanente Cement Co. Outcrops were mapped on a ridge on the northwestern slope of Black Mt. in central section 4, T40N, R6E.

Washington Monument is a prominent ridge located about twelve miles due south of Mt. Baker and about seven miles north-northwest of Concrete in north-central Skagit County. The western section corner between sections 6 and 7, T36N, R6E, occurs on the ridge. A stratigraphic section measurement was made on the eastern slope of the Monument.

Prairie Mountain is located about seven miles southeast of
Figure 1. LOCATION MAP OF OUTCROP AREAS OF RED MOUNTAIN FORMATION IN NORTHWESTERN WASHINGTON.
Darrington and about seventeen miles northwest of Glacier Peak in north-central Snohomish County. A group of small outcrops were mapped near Conn Creek on the south end of Prairie Mountain in the northwestern \( \frac{1}{4} \) of section 36, T32N, R10E.

A group of Carboniferous rocks crops out along the northeastern margin of Orcas Island in the San Juan Islands. The area studied is about three miles east of East Sound, near Raccoon Point, in the northeastern \( \frac{1}{4} \) of section 17, T37N, R1W.

Previous Work

Daly (1912) gave the name Chilliwack series to a 6,780 foot section of shales, argillites, sandstones, crinoid-bearing limestones, andesites, quartzites and conglomerates which is typically present over an area of 60 square miles southwest of Chilliwack, B.C., between the Slesse diorite and the Chilliwack granodiorite on the east and an assumed master-fault a few miles west of Tamihy Creek on the west. He did not determine the northern or southern limits of the series and noted that neither the upper nor lower contacts are exposed. Daly collected numerous fossils which left little doubt as to the Carboniferous age of the Chilliwack and at the time it was correlated with the Upper Carboniferous Nosoni of northern California. The Nosoni has since been raised to the Guadalupian Epoch of the Permian.

Crickmay (1930) questioned Daly's mapping and believed that several thousand feet of Middle Jurassic porphyries had been included in the Chilliwack. He limited the Chilliwack group to a 3,000 foot section of argillites and limestone lenses near Cultus Lake and east of the Harrison fault.

Hillhouse (1956) in his study of Vedder Mountain noted prominent
units of crinoidal limestone, boulder conglomerate and fusulinid limestone in the Chilliwack group on Red Mountain, Black Mountain and in Lihumits Creek. A tentative Wolfcampian age was assigned to all limestones in the Chilliwack. Hillhouse questioned Daly and Crickmay's work on the Chilliwack and included much of it in the Lower Jurassic Cultus formation.

Danner (1957a) was the first to establish satisfactory ages within the Chilliwack (to which he gave the term "group" in favor of "series" due to the lack of evidence that the Chilliwack was deposited during an epoch) and distinguished the Red Mountain and Black Mountain formations. The Red Mt. formation was named for a type section of Lower Pennsylvanian argillites, graywackes, limestones and shales cropping out on the west slope of Red Mountain at a quarry operated by the Permanente Cement Co. The name Black Mt. formation was given for a section of Lower Permian cobble conglomerate and fusulinid limestone exposed in a ridge on the northwestern slope of Black Mt.

Danner (1957b and personal communication) noted stratigraphic relationships similar to the Red Mountain formation and the presence of large crinoid stems in a limestone unit on Washington Monument. He proposed a correlation of these beds with the type locality.

Vance (1957) mapped Chilliwack group rocks in a southern portion of Prairie Mountain and noted the presence of large crinoid stems in a small limestone body near Conn Creek.

McLellan (1924) mapped a broad strip of sedimentary rocks in northeastern Orcas Island, correlated them with the Leech River group of Vancouver Island, and classed them as Pennsylvanian and Permian on the basis of Fusulina and associated coral fragments. Danner (personal communication) has found Paramillerella and Ozawainella in limestone lenses within this area which
indicate a Lower Pennsylvanian age. These foraminifera also occur in the Orcas Knob formation (Upper Mississippian - Lower Pennsylvanian?) on western Orcas Island (Danner, 1957a).

Several writers have described the regional geology of the northern Cascades (Crickmay, 1930; Culver, 1936; Misch, 1952; Crowther, 1959; Danner, 1960) and ascribed Carboniferous sedimentary rocks to deposition in the Pacific eugeosyncline which subsided in the middle Paleozoic. These rocks have been subsequently deformed and uplifted during the Nevadan, Laramide and Cascadian revolutions. It is surprising, however, that most Carboniferous sedimentary rocks show only mild degrees of metamorphism and dips in many areas are not steep. Also, although the regional structural trend in the northern Cascades is northwesterly, several areas of Paleozoic rocks have northeasterly trends. This is the case in the Red and Black Mountain area. It is notable that the Lower Pennsylvanian in northwestern Washington was a time of unusually abundant limestone deposition and relatively unimportant volcanic activity.

Field Work and Methods of Study

All of the areas described were visited during the field season of 1960 while the writer was employed by the Division of Mines and Geology of the State of Washington. The work involved mapping and appraising the economic value of many limestone deposits in western Washington. Five days of the season were spent mapping the general geology and stratigraphy of the Washington Monument. The remainder of the field work was done on weekends in the fall of 1960. Section measurements were made in well exposed areas and compass and tape traverses were made in areas of limited outcrop. Fifty thin sections of typical rock types were examined under the petrographic
microscope.

For use in the field topographic base maps were enlarged, depending on the size of the area mapped, from United States Geological Survey 15 minute quadrangle maps. A quarry map was employed at the Permanente Cement Co. quarry on Red Mountain.

Acknowledgments

The writer is indebted to the Washington State Division of Mines and Geology and especially to its director, Mr. Marshall T. Huntting, who provided the initial opportunity for field work in many of the areas described. Much of the field season was spent in the accompaniment of Dr. Wilbert R. Danner of the Geology Department at the University of British Columbia and many informal discussions in the field and laboratory are gratefully acknowledged to him. Messrs. Chester Royse and Evan Adams also provided assistance in aspects of the field work.
STRATIGRAPHY

Introductory Statement

The Red Mountain formation is divisible into two members. The lower is here termed the "argillite member" and the upper the "limestone member. The argillite member has a minimum thickness of about 950 feet and its base is nowhere exposed in the mapped areas. It consists of a monotonous sequence of alternately bedded dark argillites and graywackes in which occasional black banded cherts are interbedded. The argillites are often calcareous or ferruginous and the graywackes may be tuffaceous. Graded bedding is a common feature in the graywackes and some sections have well developed slaty cleavage. Fossils are rare and restricted to occasional bryozoa and crinoid stems.

The limestone member probably occurs as lenses within the formation for pronounced variations in thickness are observable over short distances. Its maximum measured thickness is 582 1/2 feet. The member contains a wide variety of both autochthonous and allochthonous limestone varieties. Encrinite and crinoidal limestone are most prevalent but oolitic calcarenite, foraminiferal, fine grained and crystalline types may be abundant. Much of the limestone is cherty, tuffs are interbedded in one section and bedding is generally massive. Fossils are ubiquitous and occur in the following degree of abundance: large crinoid columnals, foraminifera, corals, bryozoa, brachiopods, sponge spicules?, ostracods, algal remains. In the areas studied, the Red Mt. formation is overlain by conglomerate of the Black Mt. formation. Lower portions of this "conglomerate member" were mapped in all outcrop areas.
The thickness of the conglomerate member of the Black Mt. forma-
tion was not measured but Hillhouse (1957) measured a 600 foot section of
correlatable boulder conglomerate at Lihumitson Creek. The section on Wash-
ington Monument is at least 500 feet thick. Conglomerate varies from a
boulder-cobble conglomerate to a graywacke but remains fairly constant in
composition. It is composed primarily of volcanic rock fragments, many of
which are glassy. Bedding is always massive.

Dips are seldom steep and are usually near 20 degrees, rarely ex-
ceeding 50 degrees. In the Red Mt. - Black Mt. area the regional strike is
to the northeast; on Washington Monument it is northwesterly; on both Prairie
Mt. and Orcas Island it is east-west. Two areas are strongly faulted. No
apparent unconformities occur and contacts between members are characteristi-
cally sharp.

Correlations are primarily based on lithologic similarities, similar-
ity of stratigraphic relationships and the presence of large crinoid stems in
limestone. Several other megascopic methods became apparent in the course of
study and will be discussed in a following section.

Red Mountain Area

Introduction

A stratigraphic thickness of over 580 feet of the limestone member
of the Red Mt. formation is exposed in a large quarry operated by the Perman-
ente Cement Co. on the west side of Red Mt. in the central rectangle of section
14, T40N, R5E. A small abandoned quarry about one-half mile to the southwest
also exposes a portion of this bed. The argillite member of the Red Mt. for-
mation conformably underlies the limestone and crops out in many road cuts
along a switchback road from the quarry to the valley floor to the west.
Unless faulting has caused an undetectable repetition of these strata the
Plate I. RECONNAISSANCE GEOLOGIC MAP OF RED MT. - BLACK MT. AREA
Figure 4. North end of quarry, Red Mountain Area. Interbedded tuffs (dark) in limestone. Fault zone transects bedding and dips to right.

Figure 5. South end of quarry, Red Mountain Area. Well bedded limestone (unit 14) dips to right in left hand portion of photo.
argillite member has a minimum thickness of about 950 feet. Interbedded lithic graywackes and pebble conglomerates are exposed in a logging road leading south from the main quarry road at an elevation of 1,525 feet. Because these beds seem to overlie the limestone and are lithologically similar to the conglomerate bed on Black Mt. they are thought to represent the conglomerate member of the Black Mt. formation.

General Geology

The limestone bed strikes northeasterly, dips to the southeast, and is cut by bedding and transverse faults. A northwesterly trending transverse fault has cut the section into a southern black and a northern block in which the large operating quarry is located. A bedding fault can be traced from the southern block in the abandoned quarry, where it cuts between limestone and a thin conglomerate bed, to the northern end of the large northern quarry, where a thick zone transects argillites, the thin conglomerate bed, limestone breccia and tuffs. Although the fault often cuts across beds it usually occurs along the contact between the argillite and limestone members.

The structural features of the southernmost part of the northern quarry are complex and not completely understood. On the eastern wall of the quarry an east-west trending vertical fault has brought a southern block of light blue limestone against a dark brown, well bedded magnesian limestone (unit 14). Because the thin conglomerate bed to the west (see Plate III) has not been displaced by this fault, the fault must trend either to the north, where it is buried beneath the quarry floor, or to the south, where it cuts into the southern quarry wall of limestones. These limestones are not bedded and are of continuous character throughout which makes the recognition of a fault surface in them extremely difficult. What seems to be an undulatory fault plane occurs on the south wall but it can be traced for only a short
distance. In the upper one-half of the south quarry wall a small overturned syncline is outlined by two bedding surfaces. The limestones to either side of the fold are massive and no other evidence of folding exists.

Rocks of the argillite member were investigated to the north of the large northern quarry and along the quarry road. Slaty cleavages are well developed in nearly all argillites below the quarry. A general attitude for the cleavages is N15-25W, 60-70° southwest and the bedding attitudes range from N35E, 65° southeast to N70E, 45° southeast. These bedding-cleavage relationships indicate that the beds are right side up, a synclinal axis is located to the southeast, and that the syncline plunges to the southwest.

General Stratigraphy

All of the investigated outcrops of the argillite member show that it is made up of a monotonous sequence of black and dark blue argillites, with occasionally interbedded graywackes, and black bedded cherts interbedded with thin shale beds. Graded bedding is a common structure in many graywackes and silty argillites. Some argillites are ferruginous as displayed by limonitic weathered surfaces. Due to the lack of distinctive lithology in the argillite member a stratigraphic section was not measured.

A conglomerate bed of up to six feet in thickness divides the argillite and limestone members along many observed contacts. The previously mentioned north-south bedding fault usually occurs within this bed. A thin section from the southernmost outcrop in the large northern quarry (which in the following discussion will be referred to simply as "the quarry") and one from the northernmost outcrop in the quarry revealed that the conglomerate has a tuffaceous matrix. The pebbles of the conglomerate consist of black, brown and red chert, quartz, fine grained mafic volcanic rocks and foraminiferal limestone. The tuffaceous matrix is made up mostly of vitric shards with some
lithic shards. Up to forty percent of the shards are replaced by calcite and the remainder are altered to chlorite and palagonite. This conglomerate bed contains the first evidence of pyroclastic activity in the rocks of this section.

A section measurement of $552\frac{1}{2}$ feet in the limestone member was made from a fault contact at the north end of the quarry to a vertical fault contact in the southern part of the quarry. A sequence of tuffs 95 feet thick is interbedded in the lower portion of the member. Some of these rocks are tuffaceous graywackes and some are conglomeritic. Several bedding planes in the tuffaceous graywacke of unit 3 contain abundant fossils which resemble small belemnite rostrums and are associated with poorly preserved pelecypods and gastropods. These fossils are also found in a tuffaceous graywacke in the argillite member on Black Mt. Many of the limestone units are recrystallized - most likely from fine grained varieties. Magnesian-rich limestones constitute 166 feet of the measured thickness of the limestone member. Chert nodules are abundant in the upper 285 measured feet of the limestones. Crinoid columnals represent the most prevalent fossil remains and bryozoans and brachiopods rarely occur.

The lithic graywackes and pebble conglomerates, which are exposed in a logging road leading south from the main quarry road at an elevation of 1,525 feet, form a sequence of massively bedded units which strike about N70°-80°E and dip southward at varying angles. Most of the rocks are conglomeritic and occasional silty shales are interbedded.

Description of Measured Section

The following description contains field, hand specimen and some petrographic data. Many of the petrographic characteristics will be discussed
in the next section.

In all following descriptions clastic sedimentary rocks are classified according to Pettijohn's outline (1949, pp. 187-228). Carbonate and siliceous rocks are classified according to Carozzi's descriptions (1960, pp. 193-343). Bedding types are classified on the basis of layer thickness (Krumbein and Sloss, 1958, p. 97).

The term magnesian limestone will be used for limestones in which between 50 and 90 percent of the rock effervesces in cold, dilute hydrochloric acid - the remainder of the material being sufficiently rich in magnesia to show little or no effervescence. Wherever sponge spicules are mentioned it should be understood that their presence is not certain but that forms resembling them are present. A question mark should always be read after sponge spicules.

Uppermost outcrop of limestone member of Red Mt. formation. Overlying beds not exposed.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Thickness (in feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 <strong>Limestone - Crinoidal</strong>, bluish gray, weathers tannish gray; densely packed and unoriented crinoid columnals (between 1 and 2 cm in dia. and up to 6 1/2&quot; long), foraminifera, sponge spicules; carbonaceous material in a coarsely crystalline calcite matrix; massive bedding in which occasional strata contain columnals parallel to the bedding; interbedded cherty strata in upper 20 feet of unit.</td>
<td>72 (measured)</td>
</tr>
<tr>
<td>15 <strong>Magnesian Limestone - Oolitic Calcarenite</strong>, brownish black, weathers dark brown; densely packed black normal oolites (maximal - 1 mm) in a fine grained dolomitic matrix; massive bedding.</td>
<td>4</td>
</tr>
</tbody>
</table>
14 Magnesian Limestone - Encrinitic and Cherty, dark bluish brown, weathers orange yellow; crinoid fragments, foraminifera, sponge spicules, carbonaceous material in a finely laminated matrix; chert nodule "pancakes" up to 7" in dia.; carbonaceous microstylolites; massive bedding caused by alternations of 6" to 12" strata separated by carbonaceous and shaly insoluble residues up to $\frac{3}{2}$" thick; gives fetid odor upon fracturing.

13 Limestone - Crystalline and Cherty, light gray, weathers light tannish gray; a granoblastic texture of coarse calcite crystals; chert nodules up to 15% of unit and up to $9\frac{1}{2}$" long; carbonaceous stylolites up to 0.6 mm thick; massive bedding.

12 Limestone - Breccia, light blue, weathers bluish white; angular fragments of crystalline limestone separated by impregnated veins of white crystalline calcite; stylolites often margin fragments; patches of dolomite scattered throughout.

11 Limestone - Crystalline and Cherty, grayish brown, weathers grayish tan; a granoblastic texture of coarse calcite crystals contains irregular patches of dolomitic material; chert nodules up to 13" long concentrated in alternate strata; massive bedding.

10 Magnesian Limestone - Bioaccumulated and Cherty, dark brown, weathers tan; crinoid columnals and foraminifera in a fine grained matrix; chert nodules up to 15% of unit and up to 21" long; massive bedding; insoluble residues of carbonaceous material on many bedding planes.

9 Magnesian Limestone - Bioaccumulated and Cherty, gray, weathers grayish tan; crinoid fragments, foraminifera, sponge spicules in a slightly laminated fine grained matrix; chert nodules up to 20% of unit; stylolitic; flaggy bedding; insoluble residues of carbonaceous material on many bedding planes; nodules up to 12 mm in diameter.

8 Limestone - Crystalline, light blue, weathers tannish gray; a granoblastic texture of coarse calcite crystals contains few dolomite rhombs and pyrite cubes; stylolitic; massive bedding - no discernable bedding planes.

7 Magnesian Limestone, brownish gray, weathers tan; occasional calcite fragments and pyrite cubes in a fine grained matrix; flaggy bedding; many bedding planes contain carbonaceous material; carbonaceous material up to 10% in lower $\frac{1}{2}$ of unit.
Unit Thickness

6 Limestone - Crystalline, light blue, weathers tannish gray; a granoblastic texture of coarse calcite crystals contains irregular patches of dolomitic material; stylolitic; massive bedding - no discernable bedding planes. 85 (approx.)

5 Conglomerate - Tuffaceous?, light greenish tan, weathers orange tan; pebbles of chert and volcanic glass in a tuffaceous? matrix; massive bedding. 3½

4 Tuffs - Conglomeritic, fine, coarse, and conglomeritic tuff strata interbedded; bluish green, blue, deep red colors weather deep green, light blue, orange red, respectively; pebbles of chert, quartz, volcanic glass, volcanic rock in a tuffaceous matrix; shaly to flaggy bedding; conglomeritic strata often graded. 59½

3 Tuffaceous Graywacke, gray, weathers bluish gray; large plagioclase crystals, volcanic glass fragments, carbonaceous material in a chloritic matrix; flaggy bedding; elongate fossils which resemble belemnites are scattered on many bedding surfaces. 9

2 Tuffs, conglomeritic vitric tuffs and fine vitric tuffs interbedded; conglomeritic strata are light green, weather dark green; fine tuff strata are dark green, weather deep blue, strongly laminated, have occasional carbonaceous laminae, slaty cleavage and occasional worm burrows. 23

Total thickness of interbedded tuffs (units 2, 3, 4, 5) 95

1 Limestone - Breccia, gray, weathers tan gray; angular fragments of crystalline stylolitic limestone separated by impregnation veinlets of white crystalline calcite; massive bedding; some strata more intensely brecciated than others. 20 (measured)

Total thickness exposed limestone member 582½

Lowest outcrop of limestone member of Red Mt. formation. Measurement from fault contact at north end of quarry.

Discussion of Some Characteristics of the Rocks

THE LIMESTONE MEMBER OF THE RED MOUNTAIN FORMATION: The upper portion of a limestone "impregnation" breccia (unit 1) is exposed for a thickness of 20 feet in the measured section between the quarry floor and
Figure 6. Contact between fine tuffs (above - unit 5) and tuffaceous conglomerate (below - unit 4), Red Mountain Area.

Figure 7. Large crinoid stems (unit 15), Red Mountain Area.
Figure 8. Tuffaceous graywacke (unit 3), Red Mountain Area. X12

Figure 9. Hematite cement (black) in tuff (unit 4), Red Mt. Area. X15
a contact with overlying conglomeritic tuffs. The rock consists of angular fragments of magnesian and stylolitic crystalline limestone which are separated by veinlets of white calcite. The fragments appear as if they could be fitted together like the pieces of a jigsaw puzzle. This texture implies that the fragments were formed by a disruption of the original limestone and that later calcite veinlets filled the interstices between the fragments.

It is not certain that this bed represents the lowermost unit of the limestone member but outcrops of similar breccias in the south end of the quarry and in a small quarry about 1,000 feet to the northeast suggest that this is the case. In the south end of the quarry a massively bedded magnesian limestone and chert breccia of up to 50 feet thick overlies the previously mentioned thin bed of tuffaceous conglomerate which lies along the contact between the argillite and the limestone member. A measurement of 50 feet was made to an apparent fault contact at the top of the unit. A thin section from the lower portion of the breccia contains angular fragments of coarsely crystalline magnesian limestone (50%) and chert (30%). A fine grained limonitic and dolomitic cement fills the interstices between the fragments. Fragments in this bed also seem as though they could be fitted together as the pieces of a jigsaw puzzle. The rock has most likely formed by disruption of an originally cherty magnesian limestone with later veining by fine grained dolomitic material or calcite which has been dolomitized.

A bed which closely resembles these breccias and immediately overlies the argillite member crops out along the west wall of the small quarry to the northeast. Here the bed is mildly brecciated but still an impregnation breccia of gray limestone fragments surrounded by calcite veinlets. Large chert nodules up to one foot long lie in the bedding planes and
bedding structures are often continuous through the nodules which indicates their replacement origin. This bed is exposed for less than 40 feet in thickness before it is cut off by what appears to be a fault.

Although unit 1 crops out in three areas its entire thickness is nowhere exposed. A measurement in the south end of the quarry shows that it is at least 50 feet thick.

The 95 feet of tuffs and tuffaceous rocks (units 2 through 5) which are interbedded in the lower portion of the limestone member indicate the combined effects of marine sedimentation and pyroclastic activity during their deposition. Nearly all of the rocks are conglomeritic or contain graywacke material which is loosely packed in a matrix of fine to coarse shards of vitric, lithic and crystal composition. Up to one half of the strata in the conglomeritic tuffs of unit 4 are a deep red – the remainder are either green or greenish blue. The coloration of these rocks is possibly due to the mineralogy of their iron-rich cements. A thin section from a red tuff in unit 4 shows that it contains as much as 20 percent hematite. It is believed that abundant iron was supplied to the waters in the area of sedimentation of these rocks by volcanic emanations associated with explosive activity. Further evidence for this hypothesis will be given in the description of Black Mt.

A thin section from the conglomeritic vitric tuff of unit 2 contains about 40 percent of the following as rounded and subrounded pebbles and grains (between 3 mm and 2\(\frac{1}{2}\) cm): black, tan and creamy colored chert; trachytic, diabasic, vesicular and porphyritic volcanic rocks; and vitric tuffs. About fifty percent of the section is made up of a matrix of shards (between 0.3 and 8 mm) of devitrified volcanic glass, which has been altered to palagonite, calcite and chlorite; and trachytic and diabasic volcanic rocks. Finer
quartz, calcite, pyrite and chlorite fragments are minor constituents. The pebbles and grains are loosely packed in the matrix and shards commonly show alignment around them which suggests that they settled around the already present clastic particles. Fine vitric tuffs are interbedded with the conglomeritic strata in this unit. These fine tuffs contain laminations of carbonaceous material and occasional sand filled worm burrows.

A thin section from a conglomeritic tuff strata in unit 4 has the following mode: 30% subrounded particles of altered volcanic glass, brown and creamy colored chert and quartz; 50% matrix of devitrified coarse vitric shards (10%), trachytic and diabasic coarse volcanic rock shards (30%) and subrounded chert and quartz grains (10%); 20% fine grained hematite cement which colors the whole strata deep red. The fine hematite cement has a distinct laminated texture which surrounds loosely packed clastic and shard particles. Strata of deep green fine tuffs alternate with the hematitic tuffs in this unit.

Two possible explanations exist to explain the coloration of these tuffs. (1) The green color of the fine tuffs may be caused by vitric shards which have altered to chlorite and the red hematite-rich strata may contain all of the precipitated iron which filled the waters in the area of sedimentation. This would necessitate either an intermittent supply of iron to explain the alternation of hematite-rich and green strata or else conditions which restricted iron precipitation during the deposition of the green tuffs. (2) On the other hand, the color of the alternate beds may have been caused by fluctuating conditions of iron precipitation which gave rise to alternate formation of green iron silicates and hematite in the tuffs.

The value of pH is a simple control on the precipitation of hematite and iron silicates. Castano and Garrels (1950) state that if the pH is
lowered in an oxidizing environment in which hematite is precipitating, chamosite will form. It is notable, in this connection, that a fluctuation of pH values has been invoked by many students of the iron formations of the Lake Superior District as an explanation for alternately bedded cherts and hematite-rich beds (Huber and Garrels, 1953).

Whether the green color of the fine tuffs is caused by chlorite alteration of vitric shards or by iron silicates is open to question but the abundant hematite cement in over one half of the tuff strata in unit 4 bespeaks a high concentration of iron in the waters where they were deposited. Unfortunately, thin sections of the green fine tuffs could not be made due to fracturing of the specimens when cut.

The tuffaceous conglomerate of unit 5 has essentially the same petrographic characteristics as the tuffaceous conglomerates beneath it in the section. The only exception is that the particles which resemble shards are slightly rounded and their positive identification is not possible.

Crystalline limestones make up 190 feet of the measured thickness of the limestone member. Most of the units have continuous even grained granoblastic texture and some are porphyroblastic. Two thin sections, from units 8 and 13, suggest that these rocks have recrystallized from fine grained limestones. Both sections have minute calcite globules scattered throughout which are surrounded by large clear calcite crystals forming a mosaic texture. The minute globules represent the relics of original limestone material which has been replaced and included in the large crystals. Irregular patches of dolomite in some of these limestones probably formed in small areas which were imperfectly recrystallized and in which the original fine grained material was available for dolomitization.
The most common feature of the limestone member is its large content of chert nodules. All but two beds in the upper 285 feet in thickness have chert in some form and most units have at least 15 percent chert nodules. The encrinitic and cherty magnesian limestone of unit 14 contains up to 30 percent pancake shaped chert nodules (up to 7 inches in diameter) lying in the bedding planes. A thin section, which was made across one of these "pancake" nodules, shows the following characteristics: (1) Chert is a deep brown microcrystalline quartz; (2) Chert contains about 45% dolomite rhombs and minor extremely irregular calcite grains. Dolomite rhombs above .01 mm in diameter are corroded. Many dolomite rhombs below .01 mm in diameter are perfectly euhedral; (3) The contact between nodule and limestone is irregular and completely gradational; (4) Thin fractures filled with coarse crystalline calcite cut the chert nodule and are absorbed into the limestone to either side.

The completely gradational contact between nodule and limestone indicates the replacement origin of the chert. The dolomite rhombs above .01 mm and the irregular calcite grains within the nodule have been corroded by the brown microcrystalline quartz and most likely were the original material of the rock. The calcite grains are probably more corroded because silica attacked calcite more readily than dolomite. Perhaps the chert has received its brown color by absorption of dolomite. Small euhedral dolomite rhombs which have a diameter of less than .01 mm are not corroded which indicates that they must have crystallized after silicification for it is unlikely that they were too small to have been affected by replacement.

An oolitic calcarenite which is four feet thick overlies unit 14. The rock consists entirely of black densely packed normal oolites (oolites in which two or more concentric layers occur in the envelope). In thin
Figure 10. Gradational contact between chert nodule (light) and magnesian limestone (unit 14), Red Mountain Area. X3

Figure 11. Black banded radiolarian chert (light) interbedded with argillite strata (black), Black Mountain Area.
section two types of oolites are distinguishable. Most have a black nucleus and an envelope of light brown calcite; some have light brown calcite nuclei, black envelopes and a thin light brown outer layer. These normal oolites have originated in environments which were alternately neutral, or oxidizing, and reducing (rich in organic matter). For instance, those oolites which have a black nucleus originated in a reducing environment and were swept into an area of oxidizing conditions in which the light brown envelopes of calcite formed.

CONglomerate member of the BLACK mountain formation: Thin sections were made from specimens of pebble conglomerate units exposed to the south of the quarry which are thought to be correlatable with the conglomerate member on Black Mountain. Both of the sections contain about 60 percent rounded to subrounded small pebbles, 25 percent subangular granules and 15 percent angular matrix sand. Pebbles consist of the following: (1) Vesicular glassy basalt - the glass is slight devitrified and altered to chlorite and palagonite; (2) Trachytic glassy felsite; (3) Glassy diabase - some of which is porphyritic; plagioclase, pyroxene and glass which is altered to chlorite; high magnetite content; (4) black, tan and creamy colored chert. Granules are made up of chlorite, quartz, calcite, plagioclase, microcline and one particle of albite granite. The matrix of these sections is composed of lithic volcanic rock fragments which are highly altered to chlorite and sericite.

Because no contact was found between the limestone member and these overlying pebble conglomerates and lithic graywackes there is no conclusive proof that they represent the conglomerate member. However, the predominance of volcanic rock pebbles which are similar in composition to the volcanic rock boulders and cobbles on Black Mt. tends to indicate the
correlation between these two beds.

Silver Lake Quarry

Limestone of the Red Mt. formation is exposed in a small quarry on the east side of Red Mt. near Silver Lake in the southwestern \( \frac{1}{4} \) of section 7, T40N, R6E. The bed was not measured but is at least 400 feet thick, strikes N20-45E and dips 50-60° southwest. It is composed of white and light blue crinoidal and crystalline limestones. A brown, well-bedded and chert nodule-bearing limestone in the upper portion of the bed closely resembles unit 14 in the previously described section on the west side of Red Mt. Cobble and pebble conglomerate composed of volcanic rock, chert and limestone fragments in a graywacke matrix overlies the limestone. The underlying contact is buried beneath glacial drift. A few east-west and northwest-southeast trending fault traces are observable in the quarry.

Black Mountain Area

Introduction

Portions of the Red Mt. and Black Mt. formations are exposed on a northwestern ridge of Black Mt. in the south central rectangle of section 4, T40N, R6E. It is here that W. R. Danner first described these formations. The ridge is accessible by an old logging road which leaves the Silver Lake Road just south of Silver Lake in the northwest \( \frac{1}{4} \) of the southeast \( \frac{3}{4} \) of section 18, T40N, R6E and climbs the west slope of Black Mt. The road leads to the base of a large cliff formed by the limestone member of the Red Mt. formation at an elevation of about 3,775 feet.
General Geology

The argillite and limestone members of the Red Mt. formation and the conglomerate member of the Black Mt. formation were studied in this locale. They consist of argillites and graywackes, black banded cherts, limestones and conglomerate. The beds strike about N45E and dip 20° to 35° southeast. Permian limestone of the Black Mt. formation caps the exposed sequence on the ridge.

The limestone member of the Red Mt. formation forms a prominent cliff which is from 250 to 300 feet high. The limestone body thins from about 300 feet in thickness to less than 100 feet in a distance of about 1,700 feet along the strike from the top of the cliff toward the northeast. This thinning may be due to a lensing out of the strata or may represent an erosional unconformity with the overlying conglomerate. A small area of Karst topography is developed in the lower limestone beds beneath the cliff.

The argillite member conformably underlies the limestone and is exposed only in scattered outcrops, the best of which occur in road cuts just north of the limestone cliff. Traverses were made along the ridge to the west and down the slopes to the north. All of the investigated rocks are either interbedded graywackes and argillites or bedded chert striking about N45E and dipping 20° to 35° southeast.

General Stratigraphy

A section measurement of over 360 feet was made from the base of the upper three units of the argillite member to just above the limestone contact with conglomerate. The argillites and the two lower limestone units were measured in a road cut to the north of the limestone cliff. The magnesian limestone of unit 5 was traced to the base of the limestone cliff.
to the west and the section measurement continued from there to the top of the cliff.

The argillite member is divisible into three units within the 57\(\frac{1}{2}\) feet measured. The lowermost unit consists of black radiolarian chert interbedded with ferruginous shales. It is overlain by argillite and tuffaceous? graywacke, both of which have graded bedding. Several bedding planes of the graywacke contain abundant fossils which resemble small belemnite rostrums and occur with occasional poorly preserved pelecypods and gastropods.

The limestone member has a maximum measured thickness of 302 feet between a sharp basal contact with graywacke and a sharp upper contact with cobble conglomerate. Characteristics of the strata are very similar throughout. Most units contain foraminifera, crinoid fragments and oolites which occur either together or individually. The matrix material is nearly always crystalline calcite or fine grained dolomitic material. Magnesian limestone units constitute 90 feet of the thickness of the beds and most other units are dolomitic to some extent. Fossils are prevalent in nearly all of the strata and the following were identified: foraminifera - Paramillerella, Ozawainella, Tetrataxis, Cribrogenerina, Endothyra; corals - Waagenophyllum; bryozoa - Archimedes communis. Crinoid columnals, brachiopods, and what may be sponge spicules are also abundant. Foraminifera and the coral were identified by W. R. Danner.

The Red Mt. formation is overlain by a cobble conglomerate which is the lower member of the Black Mt. formation. An estimated thickness of the conglomerate is about 150 feet and it is overlain by limestone. The conglomerate consists primarily of boulders and cobbles of altered volcanic rocks, among which five types were identified, with subordinate cobbles of limestone and chert in a matrix of lithic graywacke.
Description of Measured Section

The following description contains field and hand specimen data as well as thin section identifications of fossils. Many of the petrographic characteristics will be discussed in the next section.

Lower portion of conglomerate member of Black Mt. formation.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Thickness (in feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td><strong>Conglomerate - Polymictic Cobble</strong>, overall dark green color; rounded and subrounded boulders and cobbles in a lithic graywacke matrix; massive bedding with poorly developed imbricate structure; alternate beds are rich in volcanic debris and limestone and chert.</td>
</tr>
<tr>
<td></td>
<td>Approximate thickness conglomerate member</td>
</tr>
<tr>
<td>14</td>
<td><strong>Limestone - Bioaccumulated</strong>, bluish gray, weathers light blue; normal oolites and pseudoolites (maximal - 0.8 mm) foraminifera, bryozoa, crinoid fragments in a crystalline calcite matrix; stylolitic; massive bedding; foraminifera: <em>Paramillerella</em> <em>Ozawainella</em> <em>Cribogenerina</em></td>
</tr>
<tr>
<td>13</td>
<td><strong>Limestone - Crinoidal</strong>, light blue, weathers brown gray; unoriented crinoid columnals, corals, bryozoa in a matrix of crystalline calcite with abundant chert nodules; massive bedding.</td>
</tr>
<tr>
<td>12</td>
<td><strong>Magnesian Limestone - Fine Grained</strong>, blue gray, weathers tan; massive bedding; stylolitic; bryozoa abundant; fractured and veined with calcite.</td>
</tr>
<tr>
<td>11</td>
<td><strong>Magnesian Limestone - Fine Grained</strong>, tan gray, weathers tan; shaly bedding, fractured and veined with calcite.</td>
</tr>
<tr>
<td>10</td>
<td><strong>Limestone - Oolitic Calcarenite</strong>, tan gray, weathers tan; normal oolites and superficial oolites (maximal - 0.8 mm), detrital quartz, foraminifera, in a fine grained crystalline calcite matrix; massive bedding; foraminifera: <em>Cribogenerina</em> <em>Endothyra</em></td>
</tr>
<tr>
<td>Unit</td>
<td>Thickness</td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td><strong>9 Magnesian Limestone - Fine Grained and Bioconstructed</strong>, tannish gray, weathers tan; composed of alternating strata of aphanitic and bioconstructed limestones; fine grained strata contain bryozoa, foraminifera, algal remains in a fine grained matrix; bioconstructed contains colonial corals, bryozoa, crinoids in a fine grained magnesian limestone and chert matrix; fossils: Waagenophyllum, Archimedes communis, Ozawainella, Tetrataxis</td>
<td>57 3/4</td>
</tr>
<tr>
<td><strong>... Section covered ...</strong></td>
<td>5</td>
</tr>
<tr>
<td><strong>8 Limestone - Oolitic Calcarenite</strong>, tannish gray, weathers bluish tan; dolomitic normal oolites and pseudoolites (maximal - 1.5 mm), foraminifera, bryozoa, corals and crinoid fragments in a crystalline calcite matrix; stylolitic; foraminifera: Tetrataxis</td>
<td>21</td>
</tr>
<tr>
<td><strong>7 Limestone - Crinoidal</strong>, gray brown, weathers tan; crinoid columnals and fragments in a dolomitic and occasionally oolitic matrix; flaggy bedding caused by alternate strata of dense and highly weathered limestone - the dense strata have a higher magnesian content and weather less easily.</td>
<td>7 3/4</td>
</tr>
<tr>
<td><strong>... Section covered ...</strong></td>
<td>51</td>
</tr>
</tbody>
</table>
| **6 Magnesian Limestone - Foraminiferal Bioaccumulated**, gray black, weathers tan; flaggy bedding caused by alternate strata of foraminiferal, algal and shaly material; several pinch and swell structures; some strata brecciated; stylolitic; foraminifera: Paramillerella, Ozawainella, Tetrataxis, Cribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricribricric
Unit | Thickness
--- | ---
3 | 17

**Graywacke - Tuffaceous?, blue gray, weathers brown;**
massive, well-graded bedding; elongate fossils which resemble belemnites are abundantly scattered on some bedding surfaces.

2 | 6½

**Argillite, greenish blue, weathers orange; shaly bedding**
caused by alternate laminations of shale and silt which is often graded; ferruginous-abundant limonite weathers out; 10% soluble carbonate; carbonaceous; well developed slaty cleavage causes shattering when struck with hammer.

1 | 34

**Banded Chert - Black Radiolarian, black and dark green,**
weathers olive green and orange; interbedded with highly ferruginous shales up to 3" thick; flaggy to massive bedding with few ribbon structures; vertical jointing common.

Total thickness exposed argillite member

57½

Discussion of Some Characteristics of the Rocks

**UPPER PORTION OF ARGILLITE MEMBER OF RED MOUNTAIN FORMATION:**

Several characteristics of the rocks in the upper three units of the argillite member indicate the influence of volcanic activity in their formation. The graywacke of unit 3 is almost certainly tuffaceous for it contains large anhedral crystals and angular fragments of plagioclase, and shard-like fragments of altered volcanic glass and chlorite. The argillites of unit 1 are extremely ferruginous and most likely indicate the effects of volcanic emanations as a source for their abundant iron. By the use of guide fossils, which will be described below, these strata may be correlated with a thick sequence of iron-rich tuffs on Red Mountain.

The particles in a thin section from the graywacke of unit 3 may be divided into two size groups. The larger particles (2 mm to 0.6 mm) make up about 30 percent of the thin section and consist of: anhedral and fragmented plagioclase crystals which have an average composition of An₇
Figure 13. Limestone cliff, Black Mountain Area.

Figure 14. Cobble conglomerate (unit 15), Black Mountain Area.
and show all degrees of alteration to epidote and calcite; rounded chert grains; crinoid fragments; shard-like fragments of chlorite and of devitrified volcanic glass which has altered to palagonite and chlorite. About fifty percent of the section has smaller angular particles (0.6 mm to 0.2 mm) of: quartz, biotite, chlorite, epidote, calcite, feldspar, altered volcanic glass and pyrite. The matrix consists of chlorite, sericite and altered clay. Although many particles appear to be shards their corners are somewhat rounded and a positive identification is not possible. Graded bedding is well developed in this unit.

The shales interbedded with chert in unit 1 and the argillites of unit 2 are deep green on a fresh surface and weather bright orange yellow. It is not possible to determine the mineralogy of these rocks in thin section due to small particle sizes but the extreme abundance of limonite on weathered surfaces bespeaks a high iron content. The green color may be an indication of the presence of primary iron silicate.

The following quotation is taken from Castano and Garrels (1950).
"Iron bearing solutions moving into aereated ocean waters containing calcium carbonate will tend to precipitate ferric oxides; with addition of silt and perhaps lowering of the pH they may be expected to precipitate chamosite. If they move into an area of stagnate water where organic debris tends to accumulate, minerals formed may be chamosite (if silt is present), or siderite and pyrite." Units 1 and 2 are rich in silt, a low pH is indicated by the prevalence of chert in unit 1, and possible stagnate conditions are indicated by the presence of abundant carbonaceous material in the radiolarian cherts and the argillites. Chamosite is a green silicate mineral formed under conditions of marine sedimentation and its common associates are the green iron silicate minerals greenalite and glauconite.
Figure 15. Radiolarian chert (unit 1), *Hexastylus* and (or) *Hexacomus* in fine grained carbonaceous matrix, Black Mountain Area. X10

Figure 16. Tuffaceous graywacke (unit 3). Large anhedral plagioclase crystals in shard matrix. Black Mountain Area. X12
If iron were added to waters in the area of sedimentation of these rocks it seems most likely that it would have precipitated in iron silicate minerals. The green color of the shales and argillites as well as the indications of an environment suitable to the precipitation of chamosite and its associated iron silicate minerals, support this hypothesis. The presence of immediately overlying tuffaceous rocks and the correlation of these beds with an iron-rich sequence of tuffs on Red Mt. leads to the belief that volcanic emanations supplied this abundant iron.

The guide fossils mentioned above are peculiar forms which resemble belemnite rostrums. They are between 2 and 4 cm long and elliptical in cross section with diameters between 2 and 4 mm. They occur on occasional bedding planes within the graywacke of unit 3 and often show a pronounced preferred orientation on these planes. The orientation on one bedding surface may be in an entirely different direction from that on bedding surfaces above or below. Poorly preserved pelecypods and gastropods are occasionally associated with these fossils. Over thirty specimens of the forms were examined and it was found that most contain a thin black coating and are filled with the fine grained material of the graywacke. A few consist of dense brownish-red carbonaceous material which is structureless in thin section. None are phosphatic. These fossils also occur in a tuffaceous graywacke (unit 3) in the lower part of the section on Red Mt.

A thin section of black radiolarian chert from unit 1 consists of 10 percent radiolarian remains, which resemble Hexastylus and (or) Hexaconus, in an extremely fine microgranular quartz matrix which is filled with concentrations and streaks of carbonaceous material parallel to the bedding. This chert is similar to that of unit 1 in the section on Washington Monument.
LIMESTONE MEMBER OF THE RED MOUNTAIN FORMATION: Figure 17 is a cross section of the limestone member which is divided into autochthonous (bioconstructed and bioaccumulated) and allochthonous (calcarenaceous and oolitic calcarenaceous) limestones. Gaps in the column occur where the rocks are soil covered and where magnesian limestone units 12 and 13 outcrop. These beds could not be classified into the above groups because they lack original textures. Of the 227 feet of limestones in the column which were classified, 153 feet represent autochthonous limestones and 74 feet represent allochthonous varieties.

The predominance of autochthonous limestones in the column is a direct indication that quiescent, non-agitated conditions prevailed during deposition of most of the limestones. Of seven thin sections studied from the limestone member only one contained textures which indicate turbulent sorting conditions and most of the oolitic calcarenites are predominantly pseudoolitic and, therefore, formed under mild to moderate conditions of agitation. A discussion of some characteristics of individual units will best show the effects of these quiescent or mildly agitated conditions of deposition.

(1) **Autochthonous Limestones.** Unit 9 is a massively bedded unit containing alternate strata of fine grained and bioconstructed magnesian limestones. The bioconstructed strata are usually lens-like and made up of the colonial coral *Waagenophyllum* in a microstylolitic magnesian limestone matrix which often contains silicified bryozoa, foraminifera and crinoid fragments. The coral colonies are well preserved and extensive within the lenses. Fine grained strata contain up to 20% occasionally silicified bryozoa, foraminifera, crinoid fragments and algal remains in a laminated magnesian limestone matrix. The matrix is a fine to medium grained mixture
Figure 17. CLASSIFICATION OF LIMESTONE TYPES IN CROSSSECTION OF LIMESTONE MEMBER OF RED MOUNTAIN FORMATION, BLACK MT. AREA.
of bioclastic debris in which there is no evidence of sorting or particle rounding. These features most likely indicate the activity of scavenger organisms in reducing the material. The laminated groundmass was produced by settling of elongate particles on an undisturbed sea floor. Dolomitization probably occurred prior to the final consolidation of the material for each particle is now dolomitic and the textures of the rock are not obscured.

Thin sections from the bioaccumulated limestones of units 6 and 14 show that they are made up mostly of a diverse assemblage of unbroken fossils, lack any evidence of transporting or sorting, and have a relatively scarce fine grained groundmass. Algal remains are abundant in unit 6 and often make up entire strata. The remains are characterized, in thin section, by a fine grained texture of thin laminae, which have branching threads and rod-like projections. More than two-thirds of unit 6 consists of foraminiferal debris and minor crinoid fragments in a fine grained calcite matrix.

A thin section from unit 14 has up to 10% oolites, although the rock has definite bioaccumulated textures, as noted above. Less than one percent of the oolites are normal and the nuclei are very small. If they formed with the rest of the material in the rock the environment of deposition must have been one of minor agitation. It is also possible that they were washed into the area of deposition from another source area. The remaining 90% of this thin section contains foraminifera, bryozoa and crinoid fragments in a crystalline calcite matrix.

(2) Allochthonous Limestones. Rocks of unit 5 are the only ones in the limestone member which have strongly abraded and sorted particles. All foraminifera, pseudoolites, crinoid fragments and what appear to be sponge spicules are between 0.12 and 0.15 mm in diameter, rounded and spherical, and well sorted into thin laminae. The matrix is a clear crystalline
Figure 18. *Waagenophyllum* coral (unit 9), Black Mountain Area. X6

Figure 19. Organic debris (foraminifera, crinoid fragments, bryozoa, etc.) and oolites in magnesian limestone (unit 6). Black Mountain Area. X10
Figure 20. Pseudoolites with calcite crystal nuclei - probably crinoid fragments in oolitic calcarenite (unit 8), Black Mountain Area. X10

Figure 21. East side of Washington Monument. View looking west from Dock Butte.
calcite.

Units 8 and 10 are oolitic calcarenites which formed under agitated conditions. Together they constitute 52 feet of the thickness of the limestone member. These oolites differ from those in the section on Washington Monument in that most have dolomitic envelopes whereas the majority of those investigated on Washington Monument have calcite envelopes. Thin sections from these units as well as etching tests on specimens taken at random intervals in the units showed that most of the oolites are of the pseudoolitic variety. For instance, of the oolites which make up 70% of the thin section from unit 8, greater than 60% are pseudoolites. Also, greater than 45% of the oolites, which constitute 50% of the thin section from unit 10, are pseudoolites. The many hand specimens on which etching tests were made showed similar percentages. The predominance of pseudoolites in these oolitic calcarenites shows that they were formed under conditions of mild to moderate agitation.

In summary, it is notable that only one unit (unit 5, which is 10 feet thick) has textures which represent detrital action to any great degree. The remaining limestones have textures which strongly indicate that quiescent or mildly agitated conditions prevailed during their deposition.

CONGLOMERATE MEMBER OF THE BLACK MOUNTAIN FORMATION: The conglomerate member is a dark green polymictic cobble conglomerate throughout its estimated 150 foot thickness. It is a fairly well sorted conglomerate in which well rounded boulders (up to one foot in diameter) and cobbles (with a mean size of about three inches) are loosely packed in a graywacke matrix. No well defined bedding surfaces occur within the member although an occasional rude imbrication of flatter cobbles gives a false bedding.
An examination of twenty-six specimens of cobbles and boulders taken at random in the lower 60 feet of the bed gave the following predominantly metastable rock types:

- spilite 7 specimens
- hornblende andesite 5 specimens
- limestone 4 specimens
- porphyritic pyroxene andesite 3 specimens
- chert 3 specimens
- greenstone 2 specimens
- basalt 2 specimens

In the lower 15 feet of the bed limestone and chert cobbles are scattered sporadically whereas in the portion above 15 feet they occur mostly in layers in which they constitute as much as 40 percent of the cobbles. These layers occur only occasionally and it is for this reason that the above recorded abundance of limestone may be inaccurate - sampling was done at random. It was not possible to identify spilite in hand specimen and a thin section was needed for its classification. The section contains the following mode: 50% albite (Ar₂), 30% chlorite, 15% devitrified glass which has altered to palagonite, 5% quartz. The rock is porphyritic and diabasic. The classification of other spilites was based on their comparison to the megascopic characteristics of the rock from which the thin section was made. The interstitial material of the conglomerate is a lithic graywacke made up of diminished cobble and boulder material.

The composition and texture of the conglomerate indicate that it was formed from a sharply elevated highland of volcanic rocks adjacent to the shallow waters of its deposition. Limestone and chert cobbles suggest channeling of the underlying limestone. The presence of limestone and chert cobbles in the same layers shows that both rapid erosion and solution occurred.
Washington Monument

Introduction

Washington Monument is a prominent steep-sloped northwest trending ridge of 4,811 feet in elevation, located about twelve miles south of Mt. Baker and seven miles north-northwest of Concrete. The western section corner between sections 6 and 7, T36N, R3E occurs on the ridge. Portions of the Red Mt. formation and conglomerate of the Black Mt. formation are exposed along the east side of the ridge where slopes are commonly in excess of 45° and accessibility is further hindered by areas of dense underbrush.

The Monument is most readily accessible by the Dock Butte Trail which begins 9 miles north of Concrete along the Baker Lake Road at Rocky Creek. The trail ends after about 6 miles at the Dock Butte Lookout, which is about 1 1/2 miles northeast of Washington Monument. A traverse of the valley floor to the west brings one to the eastern slope of the ridge.

General Geology

A stratigraphic sequence of argillites, graywackes, a 300 foot thick limestone bed and conglomeritic graywackes, which strikes about N20W and dips 20° to 30° southwest, makes up the greater portion of the ridge. The rocks are locally faulted and a vertical east-west trending fault has dropped a northern block a few hundred feet. The fault zone is marked by well developed gouge and quartz veins and conglomeritic graywackes have been chloritized up to 30 feet either side of the zone.

Limestone crops out in small bodies on the southern slopes of the ridge where it is usually interbedded with argillite, graywacke, banded chert and andesite. A large area of Karst topography is developed in limestone north of the Monument.
HAMILTON QUADRANGLE
WASHINGTON
15 MINUTE SERIES (TOPOGRAPHIC)

Control by USGS and USC&GS
Topography from aerial photographs by multiplex methods
Aerial photographs taken 1947. Field check 1952
Polyconic projection. 1927 North American datum
10,000-foot grid based on Washington coordinate system, north zone
Dashed land lines indicate approximate locations
Unchecked elevations are shown in brown

MAP Scale: 62900

Approximate mean declination, 1952:

Conglomerate Member
LOWER PERMIAN
Limestone Member
Argillite Member
Limestone Undifferentiated
Argillite Undifferentiated
LOWER PENNSYLVANIAN?
Conglomerate Undifferentiated

BLACK MOUNTAIN FORMATION
RED MOUNTAIN FORMATION

IGNEOUS ROCKS
Diorite
POST-LOWER PERMIAN

Plate XII. RECONNAISSANCE GEOLOGIC MAP OF WASHINGTON MONUMENT - DOCK BUTTE AREA.
Strata are intruded by diorite in two locales but metamorphic effects are not observable at short distances from contacts. Nearly all contact areas are soil covered.

General Stratigraphy

A conformable sequence consisting of an upper portion of the argillite member and the limestone member of the Red Mt. formation and a portion of the conglomerate member of the Black Mt. formation crops out on the east slope of the Washington Monument. A section of 630 feet in thickness was measured on the southeastern side of the Monument just south of the large transverse normal fault.

The argillite member is exposed for 219\(\frac{1}{2}\) feet in thickness from a lower soil covered contact to a sharp contact with overlying limestone. It consists mainly of dark graywacke and argillite. Stratigraphic units of the member are less than 20 feet thick and form a rhythmic alternation of graywacke and argillite in which banded chert is interbedded. Fossils are rare and only occasional bryozoa and small crinoids are found in the argillites. The chert contains fragmented radiolaria.

The limestone member has a measured thickness of 290\(\frac{1}{2}\) feet between a sharp basal contact with graywacke and a sharp upper contact with feldspathic graywacke. The lower portion (239 feet) of the member consists of encrinite and oolitic calcarenite units of up to 60 feet thick. Some of the units are dolomitic. The upper portion (51\(\frac{1}{2}\) feet) is made up of intermittent shale and crinoidal limestone beds with occasional strata of limestone breccia and magnesian limestone. The thickness of these units does not exceed 16 feet. The limestone member contains crinoid fragments and stems of variable diameters, colonial corals, carbonaceous "algal fossils" and plant remains. Foraminifera were not found.
Figure 24. Outcrop of limestone member. South end of Washington Monument looking north.

Figure 25. Deeply eroded zone of normal fault. East slope of Washington Monument.
Because of the steepness of the upper slopes of the Washington Monument only 120 feet of the conglomerate member of the Black Mt. formation were measured. If the member is continuous to the top of the ridge, which it appears to be, then its minimum thickness is about 500 feet. A thorough investigation of the widespread talus slope along the eastern side of the Monument produced no rock types which were distinctly different from those in the lower 120 feet of the member. Three massively bedded units of feldspathic graywacke make up the investigated portion of the section. All of these rocks contain more than 60% detrital feldspar and less than 10% detrital quartz. Although not conglomerates these feldspathic graywackes are thought to be correlatable with the conglomerate member of the Black Mt. formation on Black Mt.

Description of Measured Section

The following description contains field, hand specimen and some petrographic data. Many of the petrographic characteristics will also be discussed in the next section.

Lower portion of conglomerate member of Black Mt. formation.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Thickness (in feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>33</td>
<td>Conglomeritic Feldspathic Graywacke, light greenish gray; weathers dark green; feldspar and quartz grains; primary matrix of quartz and epidote; quartz veins abundant.</td>
</tr>
<tr>
<td>32</td>
<td>Feldspathic Graywacke, green-gray, weathers brown; subrounded grains of feldspar and quartz; primary matrix of quartz and chlorite; bedding extremely massive with no bedding planes noticeable; weathered out calcite veinlets give the rock a pseudo-vesicular appearance.</td>
</tr>
<tr>
<td>31</td>
<td>Feldspathic Graywacke, light gray, weathers bright orange; angular grains of feldspar, plant fragments and quartz; primary matrix of clay which is deeply stained by hematite; alternate sandy and shaly strata produce flaggy bedding;</td>
</tr>
</tbody>
</table>
Unit Thickness

31 (cont) sandy strata become increasingly silty towards the upper contact; a crinoidal limestone is interbedded between 8 1/2' and 15 1/2'.

Approximate thickness conglomerate member

Uppermost outcrop limestone member of Red Mt. formation

30 **Magnesian Limestone - Fine Grained**, blue gray, weathers orange tan; numerous carbonaceous "algal fossils" in a fine grained dolomitic matrix; shaly bedding caused by "algal fossil" concentrations on the bedding planes.

29 **Shale**, black, weathers brownish black; silty grains; 15% soluble carbonate; fissile bedding produced by alternations of dark green and black laminae; high silica content.

28 **Limestone - Crinoidal**, bluish gray, weathers tan; large (up to 2 cm in dia.) crinoid columns and fragments in a coarsely crystalline matrix of calcite; small patches of dolomitic material pepper the unit; massive bedding; underlying contact gradational.

27 **Limestone - Breccia**, tan-black, weathers orange-black; contains 30% angular black argillite pebbles and 60% magnesian limestone grains; numerous calcite veinlets carry pyrite cubes; massive bedding.

26 **Shale**, same description as unit 24.

25 **Limestone - Crinoidal**, light gray, weathers gray; unoriented closely packed crinoid stems (up to 8 mm in dia.) in a matrix of fine grained calcite and carbonaceous material; massive bedding.

24 **Shale**, black, weathers orange-brown; shaly bedding; high silica content.

23 **Limestone - Oolitic Encrinite**, tan-black, weathers light blue; crinoid fragments and normal oolites in a magnesian limestone matrix of 60%; massive bedding.

22 **Limestone - Oolitic Calcarenite**, gray, weathers tan; normal and superficial oolites (maximal - 1 mm) in a coarsely crystalline matrix of calcite; stylolitic; massive bedding; irregular patches of dolomite weather out limonite; calcite concretions up to 3/4" along lower contact.
<table>
<thead>
<tr>
<th>Unit</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 Limestone - Oolitic Calcarenite, brown, weathers tan; normal and superficial oolites (maximal - 0.8 mm) in a magnesian limestone matrix; alternate shaly to flaggy bedding.</td>
<td>55</td>
</tr>
<tr>
<td>20 Limestone - Calcarenite, black, weathers gray; rounded to subrounded grains of calcite (75%), quartz and chert; magnesian limestone matrix; shaly bedding produced by interbedded strata of black calcareous shale.</td>
<td>10</td>
</tr>
<tr>
<td>19 Limestone - Encrinite, bluish gray, weathers gray; crinoid fragments in a magnesian limestone and chert matrix, argillaceous stylolites abundant; flaggy bedding; the upper 35' are massively bedded.</td>
<td>60</td>
</tr>
<tr>
<td>18 Limestone - Oolitic Calcarenite, black, weathers light gray; normal oolites (maximal - 0.9 mm) in a matrix of magnesian limestone and carbonaceous material; stylolitic; shaly bedding produced by concentrations of shale and carbonaceous matter on the bedding planes.</td>
<td>8</td>
</tr>
<tr>
<td>17 Limestone - Encrinite, light blue gray, weathers dark blue gray; crinoid fragments in a matrix of magnesian limestone and carbonaceous material and pyrite cubes; carbonaceous stylolites abundant; massive bedding.</td>
<td>34</td>
</tr>
<tr>
<td>16 Limestone - Encrinite, light blue gray, weathers dark blue gray; crinoid fragments in a crystalline calcite matrix, argillaceous stylolites abundant; flaggy bedding caused by alternate strata of magnesian limestone; thin lenses of brown chert in some strata; upper 1/3 of the unit contains large well preserved crinoid stems.</td>
<td>27</td>
</tr>
<tr>
<td>Total thickness limestone member</td>
<td>$290\frac{1}{2}$</td>
</tr>
<tr>
<td>Uppermost outcrop argillite member of Red Mt. formation.</td>
<td></td>
</tr>
<tr>
<td>15 Graywacke, black and orange-brown, weathers brown and orange-tan; angular to subangular pebbles and sand grains of chert, quartz, rock fragments, carbonaceous material, plagioclase and chlorite; chlorite and sericite matrix; massive and graded bedding.</td>
<td>12</td>
</tr>
<tr>
<td>14 Argillite, bluish black, weathers grayish blue; shaly bedding; 30% soluble carbonate.</td>
<td>5</td>
</tr>
<tr>
<td>13 Graywacke, dark greenish brown, weathers brown; subangular grains of feldspar, quartz and rock fragments; chlorite matrix; massive and graded bedding; upper contact gradational.</td>
<td>14</td>
</tr>
</tbody>
</table>
Unit Thickness

12 **Argillite**, black, weathers tannish orange; veinlets of calcite perpendicular to bedding; flaggy bedding. 1 1/2

11 **Magnesian Limestone - Calcarenite**, brownish blue, weathers brown; 20% soluble calcite content; fissile fragments and carbonaceous material abundant. 2

10 **Argillite**, black, weathers dark brown; shaly and graded bedding formed by alternate brown and black laminae; upper contact gradational through a 2 1/2' zone in which the calcareous content increases and the grain size becomes more silty. 4

9 **Graywacke**, light tan, weathers bright orange tan; sand-sized subangular to subrounded grains of feldspar, quartz and mafics; chlorite matrix with abundant hematite; massive bedding; unit cut by veinlets of calcite; silty argillite strata interbedded in upper 1/2 of unit; upper contact gradational. 19

8 **Graywacke**, grayish brown, weathers orange brown; sand-sized subangular grains of feldspar, quartz, biotite and carbonaceous material; chlorite matrix with minor hematite; massive bedding. 20

7 **Graywacke Conglomerate**, brown, weathers tannish brown, pebble and sand-sized angular grains; shale, limestone and chert pebbles; feldspar, quartz and chlorite matrix; massive and well graded bedding; occasional strata contain abundant plant remains. 8

6 **Argillite**, black, weathers dark blue; shaly bedding; upper contact gradational. 9

... Section covered ... 26

5 **Graywacke**, greenish brown, weathers brownish orange; massive bedding slightly graded; numerous laminae with abundant carbonaceous material; sporadically scattered crinoid fragments. 6

4 **Argillite**, dark green, weathers brown; silty grains; shaly bedding; upper contact gradational. 5

... Section covered ... 50

3 **Argillite**, dark blue, weathers brown; one interbedded strata of graywacke with graded bedding; shaly bedding. 12

... Section covered ... 23
Unit | Thickness
--- | ---
2 Argillite, dark green and black laminae alternate, weather brownish green; occasional interbedded silty and sandy laminae with graded bedding; one strata contains elliptical chert nodules up to 3" in dia.; 20% soluble carbonate; shaly bedding. | 6
1 Banded Chert - Black Radiolarian, weathers tan; dense texture; massive bedding - occasionally interbedded with dark green argillite. | 9

Total thickness argillite member | 219.5

Lowermost outcrop of argillite member of Red Mt. formation.

Discussion of Some Characteristics of the Rocks

Petrographically the black banded radiolarian chert of unit 1 contains about 15% radiolarian remains which now appear as sharply angular detrital particles of microgranular quartz with undulose extinction. The remaining groundmass is an extremely fine mosaic of microgranular quartz in which streaks and concentrations of carbonaceous material form a dull brown network parallel to the bedding. Minute amounts of pyrite and sericite are present, and the rock is highly shattered and filled with veinlets of coarsely crystalline quartz.

ARGILLITE MEMBER OF THE RED MOUNTAIN FORMATION: The mineralogy, textures and structures of the argillites and graywackes of the argillite member indicate the similarity of environment in which they formed. The matrix material from a typical graywacke is comparable to the constituents of a typical argillite for they both consist essentially of chlorite and sericite. A petrographic description of thin sections from units 3 and 5 may serve to exemplify this relationship. Unit 3 is a silty argillite which contains the following mode in the silt fraction: chlorite 40%, sericite 15%, carbonaceous material 5%, biotite 5%, volcanic rock fragments 3% and quartz 2%.
The remaining 30% is made up of unidentifiable altered clay. Unit 5 is a graywacke whose particle fraction consists of the following detrital minerals: plagioclase 50%, volcanic rock fragments 10%, chert 2%, quartz 2% and biotite 1%. The matrix is made up of 25% chlorite, 5% sericite and 5% calcite which has replaced earlier matrix material.

Replacement textures indicate that most of the chlorite and sericite formed in place from a primary matrix of clay. Well developed platy and fibrous pure chlorite crystals indicate a minor amount of migration of material. It is apparent that both the essential minerals of the argillite and of the matrix of the graywacke (chlorite and sericite) were produced through diagenesis, or incipient metamorphism, from a primary clay matrix. Another indication of incipient metamorphism is the fact that the argillites possess a thin to heavy, or shaly, bedding which is often attributed to this indurating process (Pettijohn, 1949, p. 245).

All particles in the thin section from argillite of unit 3 are angular and the platy grains form a well laminated bedding. Graded bedding from silt to shale is often apparent within these laminae and is the cause of alternate light and dark laminations in most of the argillite units. The only exception noted in the argillite member occurs in unit 14 in which the alternate laminations are caused by the concentrations of soluble carbonate in individual laminae. Exactly one half of the total thickness of the outcropping graywacke units have graded bedding. This grading is most apparent in the conglomeritic unit 7. The bedding of the remaining graywackes is massive and ungraded.

Unit 15 is a graywacke whose composition differs markedly from those beneath it in the section. It contains 25% detrital quartz, 20%
carbonaceous material, 5% detrital plagioclase, and a typical matrix of mostly chlorite and sericite. The high proportions of carbonaceous material and quartz give the rock a pseudo-porphyritic appearance consisting of quartz grains surrounded by a dull black groundmass. The high feldspar content of the other graywackes usually gives them a grayish brown sheen.

LIMESTONE MEMBER OF THE RED MOUNTAIN FORMATION:

(1) Lower Portion (239 feet). Encrinites, which are interbedded with oolitic calcarenites in the lower portion of the limestone member, are very similar in aspect and are differentiated into units primarily on the basis of matrix type and bedding character. An encrinite may be defined as a "relatively coarse grained rock in which the crinoid fragments appear usually well worn and sorted into layers that differ in the grain size of their fragments" (Carozzi, 1960, p. 233). It was found that the crinoid debris in these rocks can be recognized in thin section because: each crinoid fragment consists of a single calcite crystal and traces of the central canals are usually marked by the concentration of minute high relief globules. Also, thin outlines of dolomitic material around crinoid fragments stand out in relief when etched with hydrochloric acid.

Two characteristic matrix types are displayed in thin sections from encrinite units 16 and 19. The matrix of unit 16 consists of a mosaic of large anhedral calcite crystals which give the rock a coarsely crystalline aggregated texture. Unit 19 contains a matrix of calcilutite which is most likely the product of extreme mechanical abrasion of crinoid material. Although the calcilutite has been dolomitized and partially silicified its original texture has been retained. Crinoid fragments in this unit are not replaced and remain as coarse calcite crystals. The matrices constitute between 30 and 40% of the rocks. Both units contain minor amounts of detrital
Figure 26. Large crinoid stems in limestone float. Washington Monument Area.

Figure 27. Oolitic calcarenite (unit 21). Washington Monument Area. X15
quartz and chert as well as abundant microstylolites. The microstylolites of unit 19 occasionally outline crinoid fragments and were probably produced by differential solution along fragment boundaries.

It is not usually possible to distinguish these units by their matrix content in the field and the changes in bedding types are most useful for this purpose. The encrinites have either flaggy or massive bedding, whereas other limestone types in the section usually have fissile or shaly bedding.

Unit 21 is a typical oolitic calcarenite from the lower portion of the limestone member. In thin section the rock consists of normal (65%) and superficial oolites (15%) in a matrix of fine grained dolomitic material which has most likely replaced an original calcite cement as well as many of the nuclei of the oolites. The maximal oolite is 0.8 mm in diameter. Oolite nuclei are made up of detrital calcite - possibly crinoid fragments, detrital quartz and chert, carbonaceous fragments, and pyrite grains. Oolite envelopes have well developed concentric textures, in which hazy black crosses are noticeable on rotation of the microscope stage, and occasional poorly developed radial textures.

The size of the maximal oolite is an indication of the competency of the currents which distributed the supply of nuclei. The formation of oolites from these nuclei is dependent upon the intensity of the agitating waters in the local shallow marine environment of their origin. If the agitating waters are not as strong as the distributing currents then only the smallest grains will form envelopes. If the agitating waters are as strong as or stronger than the distributing currents then all grains will form envelopes. Depending on the nature of interaction of these two forces pseudoolites (rounded grains with no envelopes), superficial oolites (nuclei
with an envelope of one layer), and normal oolites (nuclei with two or more concentric layers in an envelope) may form (Carozzi, 1960).

Because all of the oolites in the thin section from unit 21 are either normal or superficial the local agitation of the waters in which they formed must have been strong enough to move, or to coat, the largest grains deposited by the distributing currents. In rocks with a dolomitic matrix the oolite types may be distinguished by etching with hydrochloric acid. The brown calcite of the envelopes dissolves and usually the number of layers or the thickness of the envelopes can be observed. This test was made on specimens which were taken at five foot intervals throughout the thickness of all dolomitic oolite units of the limestone member. Nearly all etched oolites were of the normal or superficial varieties and only one specimen contained greater than 10% pseudoolites.

In the light of this date it seems reasonable to assume that the majority of the oolitic calcarenites were formed in a highly agitated shallow marine environment. The layering of the well worn and sorted crinoid debris in the encrinites is another indication that highly agitated conditions occurred during limestone deposition.

(2) **Upper Portion (51½ feet).** The upper portion of the thickness of the limestone member is made up of an interbedded carbonate and siliceous shale sequence. Crinoidal limestone is most abundant and is readily distinguishable from the underlying encrinites because it consists of predominantly large, unbroken, closely packed and unoriented crinoid stems. These rocks are clearly bioaccumulated limestones as opposed to the calcarenaceous encrinites.

The aphanitic, dolomitic limestone of unit 30 has shaly bedding
Figure 29. Feldspathic graywacke with hematite rich cement. Washington Monument Area. X10
which is caused by the concentrations of dense brown carbonaceous "algal fossils" on the bedding planes. Two varieties of these flat worm-like "fossils" are recognizable. One is about 12 mm long and 1 mm wide; the other is 1\(\frac{1}{2}\) to 2 cm long and 3 mm wide. These varieties never seem to occur together on the same bedding surface.

The origin of these features is by no means certain although three suggestions may be made: (1) They are a distinct variety of plant fossil; (2) they are worm trails which have been filled with detrital carbonaceous material and later flattened by the weight of overlying sediment; (3) they are "incomplete mud cracks" which have been filled with detrital carbonaceous material (Shrock, 1948, p. 194). The first explanation seems most reasonable mainly because definite plant fragments are abundant in the immediately overlying beds and these "algal fossils" may represent the first stages of an influx of plant material. If they are worm trails there is no reason why they should be of such constant dimensions and spaced so evenly on the bedding planes. There are no indications that the beds have been exposed to the surface so that mud cracking could occur. Any structures which the "fossils" originally contained have most likely been destroyed by dolomitization which affected the entire unit.

**CONGLOMERATE MEMBER OF THE BLACK MOUNTAIN FORMATION:** The compositions of three thin sections from each of the feldspathic graywacke units of the investigated lower 120 feet of the member were plotted on a clay (sericite and chlorite) - feldspar - quartz triangular diagram (Pettijohn, 1949, p. 227). All modes fell in a limited range within the graywacke field - they contain between 60 and 80\% plagioclase, between 20 and 40\% clay (sericite and chlorite), and less than 10\% quartz. In this study these rocks are termed feldspathic graywackes because of their high feldspar content.
Although the essential compositions of the feldspathic graywackes are very similar, a study of the matrices and of the veinlets which cut the rocks disclosed pronounced differences between them. The matrix of unit 31 (the lowest unit) makes up about 30% of the rock and consists of fine grained, slightly altered clay which is stained a deep reddish brown by hematite. The clay has been only slightly altered to sericite and no chlorite is present.

A thin section from unit 32 contains about 25% matrix material made up of 10% quartz, 10% chlorite and 5% epidote, marcasite, hematite and unaltered clay. These minerals are well crystallized, show no replacement textures, and occur in veinlets which often cut detrital grains. They were clearly formed by a diagenetic reorganization of primary clay. The entire unit is cut by numerous later calcite veinlets. The matrix in a thin section from conglomeritic unit 33 contains 12% quartz, 5% epidote, 3% chlorite and 2% albite. These minerals also indicate diagenetic mobilization as they are well crystallized, show no replacement textures, and occur in matrix veinlets as well as veins up to 2 cm wide.

Widespread albitization of detrital plagioclase has probably occurred for several determinations of plagioclase composition in the three thin sections gave values ranging from An₀ to An₈. Plagioclase also shows all degrees of alteration to sericite and epidote.

Dock Butte

A succession of argillites, shales, crinoid-bearing limestones and andesitic volcanics crops out on the northern slope of Dock Butte between the Dock Butte Lookout and Blue Lake. The area is along the north section line of section 5, T36N, R8E (see Plate XII). There is no certainty that
Figure 30. Dock Butte. Looking east from top of Washington Monument.

Figure 31. Sink hole in limestone on Dock Butte. Mt. Baker in background.
these beds are Red Mt. formation but the presence of large crinoid stems (up to 3/4 inch in diameter) indicates a Lower Pennsylvanian age. The limestone bed may be a large lens in the argillite member. Strata strike N80-90W, dip 17° to 24° north. Small sink holes are numerous in the limestone which is light blue to gray, weathers light gray, is massively bedded, and occasionally stylolitic, dolomitic, oolitic or crystalline. The limestone bed is underlain by greenish-brown and black calcareous argillites and occasionally interbedded porphyritic andesitic volcanics which crop out above a cliff to the southwest of Blue Lake. Bluish-brown, calcareous, silty argillites overlie the limestones and contain occasional lenses of light-gray, dolomitic, unfossiliferous limestone which are seldom over 100 feet long and 15 feet thick.

Concrete Quarry

A large quarry operated by the Lone Star Cement Co. about one mile northeast of Concrete exposed the limestone member of the Red Mt. formation. The bed is at least 550 feet thick, strikes N45W, dips 35° to 45° northeast, is overlain by a polymictic conglomerate with volcanic rock and limestone cobbles and pebbles, and is cut by a northeast-southwest trending fault in the northern part of its outcrop. Most units are either crystalline or crinoidal limestone and the sequence almost exactly resembles that exposed on Red Mt.

Prairie Mountain Area

Introduction

Cherty, crinoid bearing limestones and polymictic pebble conglomerate are exposed in a group of small outcrops near Conn Creek on the south
end of Prairie Mountain in the northwestern $\frac{1}{4}$ of section 36, T32N, R10E.

Because of the presence of large crinoid stems in the calcareous rocks and of glass bearing volcanic rock pebbles in the conglomerate these beds are thought to be correlatable with the limestone and conglomerate members of the Red Mt. and Black Mt. formations, respectively. Unfortunately, a well substantiated lithologic correlation of these rocks cannot be made due to a lack of sufficient outcrop in which to determine stratigraphic relationships, structural complexity of the area, and widespread chertification of the carbonate rocks which has destroyed most original textures.

Vance (1957) mapped the greater portion of the south end of Prairie Mt. as Chilliwack group and noted limestone in Conn Creek at an elevation of about 2,500 feet. An investigation of this locale disclosed many large blocks of limestone float which were followed upstream to the first limestone outcrop (outcrop A on Plate XVIII) at an elevation of about 2,900 feet. Outcrop in the area is limited to the Conn Creek bed, occasional knobs which protrude through glacial drift, and road cuts.

The Conn Creek area is 6 $\frac{1}{2}$ miles from Darrington and may be reached by taking the Sauk River Road southeast out of Darrington for 8 $\frac{1}{2}$ miles to the Dan Creek Road. Four miles to the north on the Dan Creek Road the Conn Creek Road turns off to the northeast and crosses Conn Creek after about one mile. All roads are in good condition and well marked.

General Geology

Structural relations in the Conn Creek area are complex and not well understood. A northwesterly trending fault, in the west central part of section 36, separates black calcareous shales and andesitic and basaltic volcanic rocks to the southwest from a serpentine body, cherty limestone, fine tuffs and
LOWER PENNSYLVANIAN?
UNDIFFERENTIATED SEDIMENTARY ROCKS

Figure 32. LOCATION AND RECONNAISSANCE GEOLOGY OF PRAIRIE MT. AREA
Figure 34. Mt. Baker from Prairie Mountain Area.

Figure 35. Alternate strata of cherty limestone and chert. Prairie Mountain Area.
polymictic pebble conglomerate to the north. The shales and volcanics strike northwest and dip to the northeast. Limestones strike east-west and dip northward.

Shales to the southwest of the fault form a continuous sequence in Conn Creek for at least 500 feet. They are black calcareous shales in which many pinch and swell veins of calcite occur between the bedding planes. The attitude of these beds is extremely constant and is about N35W, 80° northeast. A porphyritic rhylite dike cuts the shales just below the Conn Creek Road. The upper dike contact is not exposed. The first outcrop to the east of the Conn Creek Road bridge is an olivine basalt and volcanic rocks crop out for about 1,800 feet until they are cut by the northwesterly trending fault. Porphyritic andesite, diabase and basalt make up the bulk of these volcanic rocks. A highly sheared serpentine body crops out northeast of the fault.

To the north of the northwesterly trending fault there are several small outcrops in which cherty limestone is interbedded with chert. The relations of limestone, tuff and conglomerate in the north end of the outcrop area are complicated by tight folding and intensive shearing. All limestone-tuff contacts are sheared and because attitudes can not be determined in the massive tuffs it is not certain whether they are conformable and sheared along a folded bedding plane or whether they are in fault contact. Limestone and conglomerate are in contact in only one place and that is against a fault. At outcrop J (see Plate XVIII) a few layers in the massively bedded conglomerate show grading of pebbles which indicates that the beds probably are right side up.

Most large crinoid columnals were found in float blocks in the creek bed and few occur in outcrop. An extensive search of the entire slope in this area was made in hopes of finding the source of these blocks but no outcrop
Figure 36. Close-up of alternate strata of cherty limestone and chert, Prairie Mountain.

Figure 37. Large crinoid stems in limestone float, Prairie Mountain Area.
Figure 38. Chert (dark) replacement of calcite along fractures. Black crystals are limonite—stained dolomite (outcrop D), Prairie Mountain Area. X 10

Figure 39. Lineated pebbles in pebble conglomerate (outcrop J), Prairie Mountain Area.
was found in which crinoid columnals were abundant.

General Lithology

Outcrops of calcareous rocks in the northwestern \( \frac{1}{4} \) of section 36 are made up of alternate strata of cherty limestone and chert. Limestone beds contain as much as 50% silica and the chert beds are made up of at least 80% silica. The alternate bedding is caused by the amount of silica in the individual strata - the limestone strata being capable of containing up to 50% silica and still retaining the appearance of limestone. Calcareous beds weather light gray and chert beds weather black. The presence of manganese dioxide dendrites on occasional chert bedding planes indicates that its weathering surface is most likely colored by manganese.

Most of the pebbles in the overlying polymictic pebble conglomerate consist of volcanic rock and many of these are glassy. All have an elliptical shape and are lineated but show no imbricate structure. Specimens of conglomerate with lineated pebbles show no effects of shearing or pronounced ground-mass recrystallization which implies the primary nature of the lineation.

Outcrop Descriptions

Because no determinations of thickness or stratigraphic sequence could be made in this area a discussion of the stratigraphy is not possible and only the lithologic description of outcrops will be undertaken. Outcrops are designated by letter on the map of the Conn Creek area. The following description contains field, hand specimen and some petrographic data. A discussion of the petrographic characteristics of two cherty calcareous rocks will be presented in the next section.

**Outcrop A** Alternate strata of gray cherty limestone (4 to 12" thick) and gray-brown chert (4 to 8" thick); limestone weathers light gray, chert weathers black; limonitic and carbonaceous stylolites
throughout; limestone strata made up of coarse anhedral calcite crystals in a sutured texture and contain between 5 and 30% chert; chert strata made up of microgranular quartz and fibrous chalcedony and contain up to 20% calcite, up to 5% sericite, and minor black carbonaceous fragments and manganese globules.

**Outcrop B**
Alternate strata of brown magnesian limestone (4 to 36" thick) and gray-brown chert (1 to 4" thick); limestone weathers light gray, chert weathers black; dolomitic strata made up of patches of chert (about 30%), 15% coarse calcite fragments—possibly crinoid fragments, and minor carbonaceous fragments in a fine grained dolomitic matrix; chert strata contain minor amounts of magnesian limestone and carbonaceous material.

**Outcrop C**
Alternate strata of brown magnesian limestone (3 to 12" thick) and gray-brown chert (4 to 6" thick); carbonaceous stylolites throughout; limestone strata contain up to 40% chert nodules and patches, 10% crinoid fragments, and about 15% carbonaceous material in a fine grained matrix; chert strata contain about 10% crinoid fragments and minor carbonaceous and manganiferous material.

**Outcrop D**
Alternate strata of gray magnesian limestone (1 to 6" thick) and gray-brown chert (3 to 3" thick); magnesian limestone made up of about 30% calcite, 20% dolomitic material, 5% limonite and carbonaceous material in stylolites, and 45% chert; chert strata contain a few crinoid fragments.

**Outcrop E**
Sheared, massive, fine vitric and crystal tuff; fragments altered to chlorite and palagonite; tuff in contact with alternately bedded chert and limestone.

**Outcrop F**
Sheared, massive, vitric tuff in contact with brecciated, alternately bedded limestone and chert.

**Outcrop H**
Massively bedded polymictic pebble conglomerate with lineated pebbles made up of about 70% altered volcanic rock pebbles and minor chert pebbles in a chloritic lithic graywacke matrix.

**Outcrop J**
Polymictic pebble conglomerate contains about 80% pebbles of: porphyritic glassy spilite (40%), diabase (10%), trachytic glassy basalt (10%), brown and red chert (20%); matrix consists of chloritic lithic graywacke and minor limonite cement. Massively bedded, some layers graded, elongate pebbles lineated.

**Discussion of Some Characteristics of the Rocks**

The notable characteristic of the calcareous rocks is that they contain large amounts of chert evenly distributed within limestone beds and as distinct interbedded strata. This manner of occurrence is unusual, for
Figure 40. Amygdaloidal basalt and other glass bearing volcanic rock pebbles in pebble conglomerate (outcrop J), Prairie Mt. Area. X10

Figure 41. Organic debris (foraminifera, crinoid fragments, ostracod, etc.) in magnesian limestone (outcrop D), Orcas Island Area. X8
chert commonly forms nodules in calcareous rocks, as in the section on Red Mt., and only rarely are nodules numerous enough to coalesce and produce a distinct bed (Dunbar and Rodgers, 1958, p. 247). An interpretation of the characteristics of these rocks in hopes of understanding their origin requires that the following three questions be answered. What is the origin of the chert? Why does it occur in distinct strata and not in nodules? Why are cherts alternately bedded with calcareous rocks which contain minor amounts of chert?

A thin section from outcrop A was made across a gradational limestone-chert contact and shows the following textures. In the chert, patches of clear calcite up to 0.5 mm are isolated in a network of microgranular quartz and show corroded, rounded margins. In the limestone, patches of chert and calcite globules occur interstitial to and within coarse (3 mm) anhedral calcite crystals which form a sutured texture. These textures indicate that the following sequence occurred: original fine grained limestone was replaced by microgranular quartz - up to 80% replacement in the chert bed and about 30% replacement in the limestone bed; calcite in the limestone bed was recrystallized into a sutured texture which contains original limestone globules and microgranular quartz - this recrystallization did not occur in the chert beds due to the lack of calcite. It is obvious that chert has formed by replacement because it includes corroded calcite grains in the chert bed and has a gradational contact with the limestone bed. Perhaps the presence of minute sericite grains, which occur exclusively in the chert, is another indication that it is of secondary origin.

A thin section from a magnesian limestone bed at outcrop D displays the following textures. Microgranular quartz occurs with small (0.3 mm), deeply corroded, oval, dark calcite patches; larger (0.6 mm) corroded clear calcite crystals; and dolomite rhombs which have light colored borders and
limonite stained interiors in the shape of rhombs. A relic bedding is
stained by limonite. The euhedral shape of the dolomite rhombs may indicate
that they are post-silicification, but they may have been present prior to
silicification and been so resistant to replacement that their borders were
only leached. Replacement is indicated in this rock by the presence of
rounded and corroded calcite grains in contact with chert.

Thin sections from both calcareous and chert strata in other out-
crops show essentially the same textures described above and are equally
conclusive in establishing a replacement origin for chert.

The lack of nodules in these cherty calcareous rocks is unusual.
In the limestone beds chert never constitutes over 50% of the rock and, in
thin section, occurs disseminated in calcite. These beds do not have the
appearance of chert in outcrop. On the other hand, specimens from chert
strata show that the silica has formed a complete network throughout the
rock in which corroded calcareous grains are included. The lack of nodules
in chert beds is most likely due to the large amount of silica which was much
too abundant to be restricted in nodules. However, why chert in calcareous
beds is completely disseminated and does not form nodules is not clear. If
silica migrated through the original calcareous material it would have found
centers around which to form nodules (Dapples, 1959). But if siliceous sol-
utions were present in the newly deposited sediment and precipitated and
replaced rapidly without migrating they could have formed a disseminated tex-
ture. Therefore, the disseminated texture in the calcareous beds probably
indicates replacement by interstitial silica penecontemporaneous with
deposition.

The question of why cherts and calcareous rocks are rhythmically
bedded must be answered by invoking some control on the amount of silica replacement, and (or) precipitation, which can occur. If replacement occurred in a late or post-diagenetic stage the lithology of the primary calcareous rock would seem to be the most logical control (i.e., if limestone and dolomite were interbedded silica would replace limestone more readily than dolomite). But silica has indiscriminately replaced limestone and magnesian limestone of all grain sizes and many textures. It is for this reason that silicification is not likely late or post-diagenesis. A control which operated during deposition or early diagenesis must have caused the rhythmic bedding. It has been proposed that a slightly lower pH value in beds containing silica may cause precipitation when compaction begins (Emery and Rittenburg, 1952). However, Dapples (1959) believes that although pH less than 8 is necessary for precipitation of silica it is not the controlling factor. He postulates that local temperature increases, caused by organic activity, will drive silica into cooler interstitial areas and form high concentrations which will precipitate upon compaction. Whatever the control on silica deposition, it must have been very sensitive, for many alternations of chert and calcareous strata occur continuously over a supposedly great thickness.

The occurrence and textures of the alternately bedded chert and calcareous strata indicate a replacement origin for chert from interstitial solutions at an early stage of diagenesis.

Orcas Island

Introduction

The presence of a fossil assemblage similar to that of the limestone member on Black Mountain in the rocks of a group of outcrops near
Raccoon Point in the northeastern \( \frac{1}{4} \) of section 17, T37N, R1W, Orcas Island, indicates the existence of Red Mountain formation in this area. Although the beds are folded and much of the area is covered with glacial drift, a hypothetical structure section may be proposed, the strata of which closely resemble previously discussed stratigraphic sections of the Red Mt. formation (see Plate XXIV).

McLellan (1924) assigned a Pennsylvanian-Permian age to a wide strip of sedimentary rocks along the northeast coast of Orcas Island and correlated these rocks with the Leech River group on Vancouver Island. In recent years students from the University of Washington have found large crinoid stems in limestone lenses in this area and W. R. Danner has identified foraminifera in some lenses which indicate a Lower Pennsylvanian? age.

A reconnaissance traverse of much of the northeastern margin of Orcas Island by the writer showed that the Raccoon Point locale probably contains the most typical section of Red Mt. formation rocks exposed in this large area.

The Raccoon Point locale is 1\( \frac{1}{2} \) miles north of Mount Constitution and 3 miles east of East Sound. It may be reached by taking the Crescent Beach Road for one mile due east from East Sound, turning north on the road to Buckhorn Lodge and travelling for one mile before turning east again. Another mile brings one to Buckhorn Lodge from whence a logging road to the southeast climbs the slope of Buck Mountain. After exactly 1.8 miles along this road the outcrop area is reached. Raccoon Point is about 750 feet to the northeast.

General Geology

Along the northeast coast of Orcas Island the regional strike is
to the northwest and dips rarely exceed fifty degrees to the southwest. Strata in the Raccoon Point area have been folded into open east-west trending anticlines and synclines. Graded bedding in graywackes indicates that the beds are right side up. An assumed transverse fault separates a section of northeasterly striking basalts in the western portion of the mapped area from strata of the Red Mt. formation immediately to the east.

A hypothetical structural cross section of the area shows the relations of "members" of strata to each other (Plate XXIV). These "members" cannot be assigned with certainty to members within the Red or Black Mt. formations due to the lack of a thick, extensive limestone bed (i.e., the limestone lens present here may occur interbedded in either the argillite or conglomerate members - in this case only part of the Red Mt. or Black Mt. formations would be exposed in the map area). Dark green and black argillites crop out in the southern part of the area and are often interbedded with silty argillite and graywacke. These beds form the southern limb of an anticline and probably underlie rocks to the north in the northern limb of the anticline. Polymictic conglomerates, black banded cherts, and lithic graywackes make up the northern part of the map area and occur in an east-west trending asymmetrical syncline. A small limestone lens is interbedded between the argillite and the conglomerate-chert-graywacke "members".

Lithology

Two distinct units are present in the limestone lens. The underlying unit (dip is to the north) has a maximum thickness of about 70 feet and consists of a homogeneous appearing coarsely crystalline magnesian limestone in which no fossils were found. The overlying unit has a maximum thickness of about 50 feet and is a magnesian limestone breccia. Two thin sections
from this unit show that it consists of subrounded fragments, up to 6 cm in diameter, in a matrix of either coarsely crystalline calcite or chert and calcite fragments in a limonite cement. Most fragments are oolitic and foraminiferal calcarenite made up of normal oolites, pseudoolites (maximal size 0.7 mm), crinoid fragments, ostracods, sponge spicules?, bryozoa and foraminifera (Ozawainella, Paramillerella, Tetrataxis), in a matrix of 60% fine grained calcite and organic debris. Some fragments in the breccia are dolomititic calcilutite.

Occasional irregular and discontinuous beds of brown chert which contain numerous small crinoid stems are interbedded in both units. These beds strongly resemble those occurring in the calcareous rocks on Prairie Mountain.

In the conglomerates overlying the limestone lens nearly all pebbles consist of volcanic rock types and limestone and chert are never abundant. One outcrop of conglomerate contains several pebbles and cobbles of diorite.

Outcrop Descriptions

Only lithologic descriptions will be given because no complete or even partial stratigraphic section is exposed in this area. Outcrops are designated by letter on Plate XXIV. The following description contains field, hand specimen and some thin section data.

**Outcrop A**  Black pyritic argillite, weathers orange-yellow; shaly bedding; occasional silty laminae interbedded.

**Outcrop B**  Greenish brown argillite, weathers orange-yellow; shaly bedding; occasional massively bedded graywacke strata interbedded.

**Outcrop C**  Interbedded argillite and graywacke; argillites are dark green and black, weather green; have shaly bedding, silty and shaly laminae alternate; graywackes are dark green, weather brown, are massively bedded.
Outcrop D  A thickness of about 70' of massively bedded crystalline magnesian limestone underlies about 50' of magnesian limestone breccia; both types occasionally alternate with irregular discontinuous strata of chert; crystalline magnesian limestone is brown, weathers tan and has sandy appearing surface, carbonaceous residues occur on undulatory bedding planes, everywhere fractured and filled with calcite veinlets; magnesian limestone breccia is tan, weathers light tan, has carbonaceous stylolites, is made up of pebbles and a limonitic cement, beds are 3" to 7" thick, fossils - large crinoid stems, ostracods, sponge spicules?, bryozoa, Paramillerella, Textularia, Ozawainella; interbedded cherts are brown, weather black, are locally brecciated, filled with small crinoid stems, occur as 4" to 6" thick strata.

Outcrop E  This is a small outcrop of highly weathered polymictic cobble conglomerate and lithic graywacke; the massively bedded dark green conglomerate contains well rounded and poorly sorted cobbles and pebbles of volcanic rock, diorite, limestone and chert in a graywacke matrix.

Outcrop F  Black banded cherts, lithic graywackes and pebble conglomerates are interbedded; cherts (which constitute about 3/4 of the total of about 200' exposed thickness) are black, weather green, have massive bedding with interbedded argillite laminae; many graywacke units have well developed graded bedding with interbedded argillites; conglomerates are massively bedded and usually contain volcanic rock, limestone and chert pebbles in a lithic graywacke matrix.

Outcrop G  This is a section of altered porphyritic amygdaloidal basalts, thin section showed basalt almost completely altered to chlorite.
Recent authors have differed in their interpretations of stratigraphic correlation. Dunbar and Rodgers (1957) restrict correlations to time equivalent strata and define time transgressive strata and faunal zones as "facies equivalents" and "faunal equivalents". Krumbein and Sloss (1951) extend the term correlation to encompass rock units and biostratigraphic zones which may be time transgressive.

Although it is desirable to deal with the mutual time relations of correlatable strata, this procedure is extremely difficult in areas of limited outcrop where facies changes cannot be observed. Because of this difficulty in the area studied, the Red Mountain formation will be correlated essentially on the basis of rock units and their fossil content (correlation of biostratigraphic zones is not possible due to the lack of a biostratigraphic column). It should be understood, however, that this less favorable method of correlation is not accepted because facies changes are inferred but mainly because of a lack of outcrop in which facies changes may be determined.

Because the age of the Red Mt. formation has been assigned within the limits of accuracy (Danner, 1957), it does not remain for this study to correlate the stratigraphic sections under consideration with reference to the local geologic column but merely with reference to the type sections of Red Mt. formation. The course of this discussion will be to present features of the formation occurring in the type sections on Red Mt. and Black Mt. which may be of use in correlation, demonstrate the equivalency of the two sections, and correlate sections on Washington Monument, Prairie Mountain
and Orcas Island to the type localities.

Preliminary correlation of the formation was dependent entirely upon the characteristic lithology and fossil assemblage of the thick limestone beds. Although strong lithologic similarities between beds above and below the limestone were noticed with further study, their correlation is primarily dependent on stratigraphic relations to the limestone.

Correlation of Red and Black Mountain Sections

Features which are of value for correlation in the section on Red Mountain are the following:

1. Stratigraphic succession of argillite, 437\(\frac{1}{2}\) foot thick limestone and conglomerate members.

2. A 95 foot thick layer of red and green, ferruginous tuffs and tuffaceous rocks which contain "belemnites" occurring with gastropods and pelecypods, interbedded in the lower portion of the limestone member. This unit is made up completely of large, loosely packed stems.

3. Large crinoid stems throughout the limestone which are especially abundant in the uppermost 72 foot thick unit of crinoidal limestone. This unit is made up completely of large, loosely packed stems.

4. Chert nodule content of over 15% in all units of the upper 285 feet of the limestone member.

5. Foraminiferal remains abundant in many units.

6. Glass bearing basalt, diabase and felsite pebbles and grains in conglomerates and graywackes in the conglomerate member.

Correlatable features of the section on Black Mountain are the following:

1. Stratigraphic succession of argillite, 302 foot thick limestone and conglomerate members.
2. Black, banded radiolarian cherts containing *Hexastylus* and (or) *Hexacoma* in argillite member.

3. A 57½ foot thick layer of red and green ferruginous argillites and black banded radiolarian cherts underlying a tuffaceous graywacke which contains "belemnites" occurring with pelecypods and gastropods.

4. Large crinoid stems throughout the limestone member which are especially abundant in a 32 foot thick unit in the upper portion of the member. The unit consists of large, loosely packed crinoid stems.

5. Abundant chert nodules in upper units of limestone member.

6. *Paramillerella*, *Ozawainella*, *Tetrataxis*, *Cribrogenerina* and *Endothyra* in many units of the limestone member.

7. *Waagenophyllum* corals in a unit in central portion of limestone.

8. Glass bearing spilite with other volcanic rock, chert and limestone pebbles in conglomerate member.

The occurrence of "belemnites" affords a strong tool of correlation between these two sections because: forms similar to the belemnites are present nowhere else in the areas studied; in both locales the belemnites occur with pelecypods and gastropods; they are found in tuffaceous graywacke units associated with other ferruginous tuffs and argillites; they occur near the argillite-limestone contact in both sections. On Black Mt. no limestone beds underlie the tuffaceous layer but on Red Mt. a thickness of at least 50 feet of limestone underlies the tuffs. If it is assumed that the tuff layer was deposited as the result of a single, short period of pyroclastic activity, the bed is time equivalent throughout its extent, and, therefore, shows that at least 50 feet of limestone had been deposited in the Red Mt. area prior to limestone deposition in the Black Mt. area.
Large crinoid stems (up to 3/4 inch in diameter) provide an especially useful feature for these local correlations because they are confined to the Lower Pennsylvanian in northwestern Washington – Mississippian strata are not known and Permian beds do not contain them in abundance. In this work they are considered only as components of the rock for crinoid stems are almost useless as paleontologic guides. Although present as stems and fragments in many units of the member, they form thick beds of crinoidal limestone only in the upper parts of both sections.

The presence of glass in volcanic rock fragments which is not devitrified or strongly altered is unusual for rocks of this age and is taken as evidence of correlation between the two sections.

A comparison of other factors listed for each section above gives further proof of the correlation between Red and Black Mountains.

Correlation of Washington Monument Section to Type Sections

Features of the Washington Monument section which correlate with those on Red and Black Mountains are the following:

1. Stratigraphic succession of argillite, 290 1/2 foot thick limestone, and conglomerate members.

2. Black banded radiolarian cherts containing *Hexaconus* and (or) *Hexastylus* in the argillite member.

3. Crinoid fragments throughout and crinoidal limestone units in the upper portion of the limestone member which are made up of large, loosely packed crinoid stems.

4. *Waagenophyllum* collected in talus at base of limestone bed.

Correlation of this section is dependent primarily on the presence
of large crinoid fragments and crinoidal limestones in the upper portion of
the limestone member, similarity of the stratigraphic succession to the type
areas, and the occurrence of Waagenophyllum. Waagenophyllum is a colonial
coral from the Lower Permian (Artinsk) of Asia, India, U.S.S.R. and New
Zealand which has seldom been noted in the Cordillera. Its occurrence in
the sections on Black Mt. and Washington Monument is diagnostic of corre-
lation for it has not been mentioned from Lower Permian beds in northwestern
Washington. Feldspathic graywackes in the conglomerate member are probably
the result of local conditions of deposition and the lack of volcanic rock
fragments should not be taken as evidence against correlation of the member.

Correlation of Prairie Mountain Rocks to Type Sections

Little evidence exists for this correlation and it is dependent
upon the presence of large crinoid stems in float at the base of limestone
outcrops, crinoid fragments in limestone, and glass bearing spilite and dia-
base pebbles in a conglomerate overlying the limestone outcrops. Vance (1957)
mapped the surrounding area as Chilliwack Group and the large crinoid stems
indicate a Lower Pennsylvanian age. The only real evidence that the Red Mt.
formation is present lies in the occurrence of glass bearing volcanic rock
pebbles in conglomerate which overlies limestone.

Correlation of Orcas Island Section to Type Sections

The occurrence of Ozawainella, Paramillerella and Tetrataxis with
large crinoid stems in a limestone lens in the section at Raccoon Point
establishes a correlation with the limestone member on Black Mt. which contains
a similar assemblage of foraminifera. Because a thick limestone bed is not
Features which are of use in establishing correlation:

- Conglomerate
- Conglomerate with glass bearing volcanic rock pebbles
- Large crinoid stems
- Chert nodules and beds in limestone
- Foraminifera (*Paramillicella*, *Endothyra*, *Tetrataxis*, *Osawainella*)
- *Waagenophyllum*
- "Belemnites" in tuffaceous beds
- Tuffaceous beds
- Argillite, graywacke, and black banded chert of the argillite member

Figure 44. CORRELATION MAP OF RED MOUNTAIN FORMATION AND OVERLYING CONGLOMERATE OF THE BLACK MOUNTAIN FORMATION IN NORTH-WESTERN WASHINGTON.
present in this area the stratigraphic succession is not directly correlatable with the type locales and the limestone lens may be interbedded in the argillite or conglomerate members. Because the lens is underlain by argillites and overlain by conglomerates, however, it probably correlates with the limestone member.
TECTONIC CONTROL AND ENVIRONMENTS OF DEPOSITION

Introductory Statement

Strata of the Red and Black Mountain formations show effects of rapid changes in tectonic and environmental control of sedimentation. The argillite member is characteristic of eugeosynclinal facies and deposition in a subsiding, deep water realm; limestones are indistinguishable from those commonly deposited in neritic, stable shelf environments; and lithology of the conglomerate member indicates shallow water sedimentation of abruptly uplifted terranes in most areas. A brief lithologic review of the units will serve to exemplify these relations.

Argillite Member of Red Mountain Formation

Several writers have attributed many of the following features to deep water sedimentation and always to tectonically unstable environments. Argillites are dark green, gray, brown or black, usually silty, contain a wide variety of minerals in silt fraction and abundant chlorite and sericite, are commonly siliceous, calcareous, or pyritic, and have shaly to massive bedding. Graywackes are always interbedded in rhythmically alternating sequences with argillites, are dark green, brown or black, contain angular, poorly sorted grains in clay or chlorite and sericite matrix, fossils are rare, and graded bedding is a common structure. Black banded cherts are often interbedded with the above rock types, contain radiolaria, are carbonaceous, and have massive bedding separated by thin dark shale laminae.

Limestone Member of Red Mountain Formation

If the limestone member were studied without reference to the
lithology of its enclosing beds it would be extremely difficult to distinguish from a limestone of the shelf environment. All units in which original textures are preserved are light colored and fossiliferous, most are bioaccumulated or calcarenaceous types, many are dolomitized, and chert nodules formed by replacement are common. No unit has features which indicate subsidence in excess of deposition or deep water environment - such limestones are fine grained, black, contain abundant organic material and primary chert, and are rarely dolomitized (Sloss, 1947; Dapples, Krumbein and Sloss, 1948). Only one unit (14, Red Mt.) is dark colored but it is encrinitic. Although chert beds are important constituents of limestones on Prairie Mt. and Orcas Island the rocks are light colored, fossiliferous, and chert has a replacement origin.

When viewed in gross aspect the limestone member represents deposition in a tectonically stable or gradually subsiding realm in which subsidence never significantly exceeds deposition. In detail, environmental features are notable within this framework. Nearly all limestones in the Washington Monument section are calcarenaceous and many are oolitic. These types represent shallow, agitated, neritic environments of deposition. An abrupt change is apparent in the upper portion of the member where bioaccumulated types are interbedded with shales and thus indicative of deeper, less agitated waters.

Limestones at Black Mt. are mostly bioaccumulated or bioconstructed and show only occasional effects of shallow, agitated waters. Many units at Red Mt. are recrystallized but a few thin sections show original textures representative of fine grained bioaccumulated limestones. All other units but two (14 and 15) are bioaccumulated varieties. Although insufficient,
Figure 45. STRATIGRAPHIC COLUMNS OF LIMESTONE MEMBER OF RED MOUNTAIN FORMATION IN MAPPED AREAS.
this data indicates predominant shallow water deposition in the Washington Monument area and deposition under deeper, less agitated conditions in the Red Mt. – Black Mt. area. Lack of outcrop in the Prairie Mt. and Orcas Island areas does not allow predictions as to environments of limestone deposition.

**Conglomerate Member of Black Mountain Formation**

Sharp contacts between limestone and conglomerate members in all sections is evidence of a sudden shift in tectonic control and environments of deposition. In the Black Mt. area a bioaccumulated limestone passes abruptly into a volcanic rock bearing, polymictic cobble conglomerate which indicates shallow water sedimentation of a sharply elevated adjacent highland (Pettijohn, 1949). Conglomeritic graywackes at Red Mt. contain pebbles of similar lithology to the cobble conglomerate which were probably derived from this same highland. Similar changes occur at Washington Monument and Prairie Mt. and probably represent uplift of adjacent areas as well.
Limestone in northwestern Washington is used primarily in the manufacture of Portland cement, as builders' lime, for agricultural and metallurgical purposes, and in the pulp and paper industry. Due to the relatively high cost of transportation in this area, small quarries which supply local markets have proved more economically feasible than large low cost quarries remote from markets.

The limestone member of the Red Mountain formation is quarried at Red Mt., the Silver Lake Quarry, and Concrete. All are shelf quarries in hillsides, lack significant overburden, and supply local markets. The Permanente Cement Co. quarries the entire thickness of the limestone bed on Red Mt. and subsequently separates cherty limestone of the upper portion of the member from high calcium limestone of the lower portion. High calcium limestone is quarried at the Silver Lake Quarry for use in the pulp and paper industry. The quarry just north of Concrete is operated by the Lone Star Cement Co. and supplies material for their Portland cement plant in Concrete.

Although limestones of the Red Mt. formation on Black Mt., Washington Monument, and Dock Butte are of a suitable grade for economic use, outcrops are either covered by extensive overburden or located in areas where present means of transportation are lacking. Outcrops on Black Mt. and Washington Monument also occur at such elevations that snow conditions in the winter months would probably not allow quarrying. The limestones of the Conn Creek area on Prairie Mt. have too high a chert content to be of economic value. The limestone lens near Raccoon Point on Orcas Island may serve as a small source of local consumption for it lacks overburden and is readily accessible to transportation by road.
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