GEOLOGY OF THE
COPENHAGEN CANYON AREA, MONITOR RANGE,
EUREKA COUNTY, NEVADA

A THESIS
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MASTER OF SCIENCE

By
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## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>1</td>
</tr>
<tr>
<td>Introduction</td>
<td>2</td>
</tr>
<tr>
<td>Location and Accessibility</td>
<td>2</td>
</tr>
<tr>
<td>Geography</td>
<td>2</td>
</tr>
<tr>
<td>Physical Features</td>
<td>4</td>
</tr>
<tr>
<td>Scope of Investigation</td>
<td>4</td>
</tr>
<tr>
<td>Method of Investigation</td>
<td>4</td>
</tr>
<tr>
<td>Previous Investigations</td>
<td>4</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>5</td>
</tr>
<tr>
<td>Stratigraphy</td>
<td>6</td>
</tr>
<tr>
<td>Introduction</td>
<td>6</td>
</tr>
<tr>
<td>Ordovician System</td>
<td>7</td>
</tr>
<tr>
<td>Eastern Assemblage</td>
<td>7</td>
</tr>
<tr>
<td>Pogonip Group</td>
<td>7</td>
</tr>
<tr>
<td>Nine Mile Formation</td>
<td>8</td>
</tr>
<tr>
<td>Antelope Valley Limestone</td>
<td>9</td>
</tr>
<tr>
<td>Copenhagen Formation</td>
<td>12</td>
</tr>
<tr>
<td>Eureka Quartzite</td>
<td>16</td>
</tr>
<tr>
<td>Hanson Creek Formation</td>
<td>18</td>
</tr>
<tr>
<td>Western Assemblage</td>
<td>20</td>
</tr>
<tr>
<td>Vinini Formation</td>
<td>20</td>
</tr>
<tr>
<td>Silurian System</td>
<td>23</td>
</tr>
<tr>
<td>Roberts Mountains Formation</td>
<td>23</td>
</tr>
<tr>
<td>Devonian System</td>
<td>26</td>
</tr>
<tr>
<td>&quot;Nevada&quot; Formation</td>
<td>27</td>
</tr>
<tr>
<td>Pennsylvanian System</td>
<td>29</td>
</tr>
<tr>
<td>Quaternary Alluvium</td>
<td>30</td>
</tr>
<tr>
<td>Igneous Rocks</td>
<td>30</td>
</tr>
<tr>
<td>Albite Microsyenite Dike</td>
<td>30</td>
</tr>
<tr>
<td>Tertiary Volcanics</td>
<td>31</td>
</tr>
<tr>
<td>Structures</td>
<td>32</td>
</tr>
<tr>
<td>Folds</td>
<td>32</td>
</tr>
<tr>
<td>Normal Faults</td>
<td>34</td>
</tr>
<tr>
<td>Thrust Faults</td>
<td>36</td>
</tr>
<tr>
<td>Deformation of the &quot;Nevada&quot; Formation</td>
<td>40</td>
</tr>
<tr>
<td>Geologic History</td>
<td>42</td>
</tr>
<tr>
<td>Summary</td>
<td>45</td>
</tr>
<tr>
<td>Appendix</td>
<td>46</td>
</tr>
<tr>
<td>References Cited</td>
<td>55</td>
</tr>
</tbody>
</table>
# ILLUSTRATIONS

<table>
<thead>
<tr>
<th>PLATE</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Geologic map of the Copenhagen Canyon area, Monitor Range, Eureka County, Nevada</td>
<td>In Pocket</td>
</tr>
<tr>
<td>II</td>
<td>Cross-sections</td>
<td>In Pocket</td>
</tr>
<tr>
<td>III</td>
<td>Restored sections of thrust faults</td>
<td>In Pocket</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Index map of Nevada showing location of mapped area</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>Contact of Copenhagen formation and Eureka quartzite</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>Boulder-like masses of quartzite on upper surface of Eureka quartzite</td>
<td>17</td>
</tr>
<tr>
<td>4</td>
<td>Tire-shaped forms in the Hanson Creek formation</td>
<td>19</td>
</tr>
<tr>
<td>5</td>
<td>Anticline and syncline on Martins Ridge</td>
<td>33</td>
</tr>
<tr>
<td>6</td>
<td>Synclinal structure on Martins Ridge</td>
<td>34</td>
</tr>
<tr>
<td>7</td>
<td>Thrust contact of Vinini and &quot;Nevada&quot; formations</td>
<td>37</td>
</tr>
<tr>
<td>8</td>
<td>Small recumbent fold in the &quot;Nevada&quot; formation</td>
<td>40</td>
</tr>
</tbody>
</table>
GEOLOGY OF THE COPENHAGEN CANYON AREA,
MONITOR RANGE, EUREKA COUNTY, NEVADA

By Louis C. Bortz

ABSTRACT

Rocks of an eastern miogeosynclinal and a western eugeosynclinal assemblage have been thrust into juxtaposition in the western portion of the Copenhagen Canyon area. In the eastern portion of the area, only rocks of the eastern assemblage are present.

The eastern assemblage is composed predominantly of clastic limestones ranging in age from Lower Ordovician to Helderbergian. The western assemblage is represented by the Ordovician Vinini formation. Lower Pennsylvanian fusulinid-bearing rocks overlie the Vinini formation in the highest thrust plate and are considered part of the overlap assemblage.

Four imbricate thrusts overlie the Helderbergian limestones which have been severely deformed locally. Deformation is mild in the lower thrusts, but extreme in the uppermost thrust.

Folding of major magnitude is limited to Martins Ridge. Numerous normal faults of considerable displacement have been mapped.
INTRODUCTION

Location and Accessibility

Copenhagen Canyon is in the Monitor Range along the southern boundary of Eureka County, Nevada. The northern boundary of the mapped area is the northern edge of the Horse Heaven Mountain quadrangle; the eastern one is the west side of Antelope Valley. The western limit is the margin of Tertiary volcanics, and the southern one is the Nye and Eureka County line. The mapped area is approximately 22 square miles.

The area is 32 airline miles southwest of Eureka, Nevada (Fig. 1). The most direct route is by the graded Antelope Valley road which connects with U. S. Highway 50 at Lone Mountain (20 miles west of Eureka). Access from Monitor Valley is via Potts and Ryegrass Canyon over a poorly-graded road. There are many unmapped jeep roads within the area.

Geography

The climate of the Monitor Range is semi-arid. Precipitation is estimated to be about the same as in ranges of similar elevation in central Nevada which average 10 to 12 inches per year. Normally, there is a small flow of water in Copenhagen Creek, which becomes intermittent toward Antelope Valley. There are three small, unimproved springs in the mapped area: one in Ryegrass Canyon and two at the head of White-rock Canyon.

The vegetation on the eastern edge of the area consists of grasses, sagebrush, and salt brush at the lower elevations with increasing amounts of Juniper and Piñon Pine at the higher elevations. West of Copenhagen Canyon Juniper and Piñon Pine are more abundant and at the highest elevations there are several groves of Mountain Mahogany.
Fig. 1.- Index map of Nevada showing location of mapped area.
The primary industry of the area is cattle grazing. The Martin Ranch (south of the area in Copenhagen Canyon) offers horses and guides during deer season.

**Physical Features**

The area is characterized by moderate to rugged topography. The maximum relief in the area is 2,550 feet—the lowest elevation is about 6,460 feet along the Antelope Valley Road and the highest, of 9,010 feet, is in the northwest corner of the area. Except for Copenhagen Canyon, most of the drainage is consequent off north-south trending structural ridges. Most north-south streams are subsequent along normal fault zones.

**Scope of Investigation**

This study is primarily concerned with the stratigraphy, structure, and paleontology of the Paleozoic rocks in the area.

**Method of Investigation**

The geology was mapped on aerial photographs of a scale of 1:31,250 and transferred to an enlarged topographic map (scale 1:24,000) by use of an opaque enlarger.

Since this area is predominantly composed of calcareous rocks, dilute hydrochloric acid etches were used for rock study and identification, complemented by 13 thin sections and numerous grain mounts.

An abundant and varied fauna was studied for paleontologic control.

**Previous Investigations**

Prior to this paper, published investigations have been concerned with the stratigraphy and paleontology of the surrounding area. The
regional stratigraphy has been recently revised by Nolan et al. (1958). Copenhagen Canyon was one of Webb's (1958) locations in a regional study of the Middle Ordovician stratigraphy of the Great Basin.

Detailed paleontology has been limited to the Lower and Middle Ordovician brachiopods (Ulrich and Cooper, 1938; Cooper, 1956) and Upper Ordovician and Silurian graptolites (Ruedemann, 1947). Merriam (T. B. Nolan, 1958, oral communication) and E. R. Larson (1958, oral communication) have mapped the Antelope Valley area, but neither of their works has been published.

Acknowledgements

The writer wishes to express his appreciation to Professor E. R. Larson for suggesting the problem and offering constant guidance and encouragement in the field, laboratory, and manuscript preparation. Dr. Joseph Lintz, Jr. gave generously of his time for paleontologic discussions, organization of the manuscript, and a field check. The writer is indebted to John S. Flagg, Merritt Bradley, and Albert Englebright for assistance in measuring sections. The Martin Ranch extended many courtesies during the field work. The writer's wife, Shirley, has rendered constant encouragement throughout the problem. Barbara Hamilton assisted with the drafting. Donna Askins ably typed the manuscript.
INTRODUCTION

The Paleozoic rocks in the vicinity of Copenhagen Canyon consist dominantly of a carbonate sequence, termed "eastern assemblage" by Roberts et al (1958). They consider these rocks authochthonous and parautochthonous. The Cambrian and earliest Ordovician rocks of this assemblage are not exposed in the area. Five Ordovician formations ranging in age from late Canadian to Richmondian are well exposed, and the Silurian is represented by a thick sequence of Niagaraan limestones. The Devonian strata are limited to the Helderbergian.

The eastern assemblage comprises sediments that were deposited in the miogeosyncline of north-central Nevada. A major orogeny in central Nevada of latest Devonian to Early Pennsylvanian age (Roberts et al, 1958, p. 2850) marked the end of the eastern carbonate assemblage.

The remainder of Paleozoic rocks deposited in Nevada have been designated "overlap assemblage" by Roberts et al (1958, p. 2838). The Mississippian system is absent in the mapped area. Lower Pennsylvanian rocks are present, representing the overlap assemblage. Younger rocks were either not deposited, or have been subsequently eroded, prior to the Tertiary volcanics.

An Ordovician formation of western origin, which is contemporaneous with a portion of the eastern assemblage, is present in the area. This formation is allochthonous and is considered to be part of the "western assemblage" by Roberts et al (1958).

Major thrusting has brought the eastern and western assemblages into juxtaposition in the western portion of the area. Minor facies differences are found between exposures of the eastern assemblage in the thrust
sequence and those of the eastern part of the area. The thrust sequence has an average thickness of 2,000 to 2,500 feet. Exposures east of the thrust sequence are about 6,500 feet thick.

The descriptive terms used in this paper for bedding thickness are: laminations, distinct alternations of material which differ one from the other in grain size or composition, that are less than 1/16 inch; thin-bedded, 1/16 to 6 inches; thick-bedded, 1/2 to 3 feet; and massive, greater than 3 feet. Rock colors are based on the Rock-Color Chart, 1951, prepared by the Rock-Color Chart Committee, E. N. Goddard, Chairman.

ORDOVICIAN SYSTEM

Eastern Assemblage

Pogonip Group

The Pogonip formation was originally defined by King (1878, p. 188) from exposures in White Pine County, Nevada, that included sediments ranging in age from Early Cambrian to Middle Ordovician. After redefinitions by various authors (Nolan et al, 1956, p. 23-24), Hintze (1951, p. 11) proposed that the Pogonip be considered as a group, to include only the Ordovician portion of the unit. Nolan et al (1956, p. 24) have accepted Hintze's usage and have defined the group within the vicinity of Eureka, Nevada. They have subdivided the group into three formations which are exposed in the Antelope Valley region, and which are typical of the eastern assemblage. They include in ascending order, the Goodwin limestone, the Ninemile formation, and the Antelope Valley limestone. The upper two formations have been recognized in the mapped area, but the Goodwin limestone is not exposed.
Ninemile formation

The Ninemile formation was named by Nolan et al. (1956, p. 27) from exposures in Ninemile Canyon on the east side of Antelope Valley. The Ninemile formation in the Copenhagen Canyon area has been thrust on the Vinini formation of the western assemblage. The formation is well exposed in the narrows of Whiterock Canyon and is poorly exposed near the center of sec. 34, T.16N., R.49E. In a composite section at the narrows of Whiterock Canyon 343 feet were measured.

The formation is composed of thin-bedded, medium-gray to olive-gray argillaceous calcilutite alternating irregularly with calcareous shale. The characteristic olive-gray color is often concealed on the bedding surface by abundant, pale yellowish-weathering, silty laminae between calcilutite strata. In thin section the calcilutite is composed of clay- and silt-sized calcite grains that have been slightly recrystallized. Clay is abundant and irregularly concentrated; a small percent of silt-sized subangular quartz grains is present. Trace minerals include glauconite, limonite, and anhedral barite.

Gradationally overlying the Ninemile formation is the Antelope Valley limestone. The contact is approximately 100 feet below the massive cliff-forming unit of the Antelope Valley limestone in a ledge-forming, thick-bedded, dark limestone sequence interbedded with shale. The 6-foot zone of overlap between the highest occurrence of Lachnostoma latueolsum Ross and the lowest occurrence of Orthidiella longwelli Ulrich and Cooper was chosen as the contact for mapping purposes.

Abundant, well-preserved fossils and fossil hash are concentrated along bedding planes. The following forms have been identified:
Lachnostoma latucelsum Ross
Archaeorthis cf. A. elongata Ulrich and Cooper
A. sp.
Hesperonomia cf. H. antelopeensis Ulrich and Cooper
Lingulella sculptilis Ulrich and Cooper
Tetragraptus cf. T. acanthonotus Curley

Several poorly preserved crinoid calices were found.

The trilobite, Kirkella vigilans (Whittington), which is reported by Nolan et al (1956, p. 27) to be one of the guide fossils of the Nine-mile fauna, was not found in the mapped area. Lachnostoma latucelsum Ross is characteristic of the formation in the mapped area. The Nine-mile formation is of Late Cananadian or Beekmantown age (Nolan et al, 1956, p. 28).

Antelope Valley Limestone

The Antelope Valley limestone has been named by Nolan et al (1956, p. 28) as the uppermost formation of the Pogonip group. The type locality is along the base of the eastern slope of Martins Ridge. Here the formation forms moderate to rugged slopes and has a maximum exposed thickness of 1,373 feet (section a-a', Plate I). Nolan et al (1956, p. 28) measured about 1,100 feet at Martins Ridge. Good exposures are also found in the western portion of the area.

The base of the Antelope Valley limestone is concealed by alluvium on the eastern edge of Martins Ridge; here the limestone is paraconformably overlain by the quartz arenite member of the Copenhagen formation. The contact is sharp. To the west, in the thrust sequence, the limestone has a gradational contact with the underlying Ninemile formation and is disconformably overlain by the Silurian Roberts Mountains formation. The formation is almost entirely composed of clastic limestone that has
been recrystallized to varying degrees. Fine detrital material and secondary silica are the most obvious impurities. Calcite veinlets are common.

The formation can be divided into three units based primarily on outcrop expression. The basal portion is a thin-bedded to thick-bedded, ledge-forming unit. A middle unit of massive, relatively pure limestone forms cliffs. The upper unit is thin-bedded limestone with silty interbeds forming low benches and ledges.

Four hundred and twenty eight feet of the lower unit are exposed on Martins Ridge. The typically formed ledges are composed of medium light-gray to medium dark-gray argillaceous calcarenites and calcilutites that have been partially to totally recrystallized. Etched surfaces show that the darker colored limestones contain argillaceous and silty material. The unit weathers medium gray to brown depending upon the amount of iron oxide present. A small percentage of very fine quartz arenite in a calcareous matrix showing graded bedding is present in the unit. Chert nodules and stringers are locally common. Poorly preserved orthid brachiopods are found in the lower half of this unit. ? Orthambonites eucharis Ulrich and Cooper was identified. In the upper portion of this unit Macurrites sp., Receptaculites sp. and ? Cirvanella sp. are present.

The lower unit is well exposed in the thrust sequence in the narrows of Whiterock Canyon. Here the unit consists of about 100 feet of thick-bedded, medium-gray to brownish-gray calcarenite interbedded with minor amounts of olive-gray, calcareous shale. The unit contains an abundant well-preserved fauna that has been silicified in part. The following forms have been identified:
**Orthidiella longwelli** Ulrich and Cooper

**Q. costellata** Cooper

**Q. cf. D. extensa** Ulrich and Cooper

**? Ingrina cludi** Ulrich and Cooper

**Pseudocybele aff. P. nasuta** Ross

**? Isotelus** sp. (large form)

**Raphistomina** sp.

large orthocones (2 large species)

The cliff-forming middle unit contains 747 feet of typically medium light-gray to medium-gray clastic and crystalline limestone. There are some zones of silty and argillaceous limestones, but generally fewer than those observed in the lower unit. Chert nodules and stringers, of limited lateral extent, are locally abundant. In etched specimens, finely disseminated anhedra of secondary chalcedonic silica are common.

In thin section the limestone is clear, twinned, coarsely-crystalline (up to 2 mm.) calcite with some relic clastic texture. Authigenic anhedral quartz has selectively replaced the calcite along fractures and in vugs. Anhedral hematite, dolomite rhombs, and clay are present in minor amounts.

The middle zone is characterized by an important 25- to 46-foot horizon marker crowded with **Palliseria longwelli** (Kirk). This marker is widespread but not continuous throughout the Cordilleran region (Nolan et al., 1956, p. 29; Cooper, 1956, p. 126). **Palliseria longwelli** ranges through most of the middle unit, but in less abundance. **Receptaculities** sp. is found in the **Palliseria** zone, and Nolan et al. (1956, p. 29) state that this common association is probably limited to this zone throughout the Pogonip group. Other fossils present in the middle unit are: **Macluritites** sp., leperditid ostracods, and high-spired gastropods.

The upper zone is thin-bedded calcilutite and coarsely-crystalline limestone with irregular silty beds and partings. The limestone is medium-
gray to light olive-gray and weathers to shades of yellow and brown because of abundant silt and clay. Chert nodules and stringers are abundant in the lower one-third of the unit. Fossil hash is present in the upper few feet.


Nolan et al. (1956, p. 29) have classified the Antelope Valley limestone as Chazyan. Webb (1958, p. 2366) considers the top of the *Palliseria* zone as the approximate Chazyan-Bolarian boundary, and places the upper zone within the lower Bolarian; Webb's age determination is used by this paper.

Copenhagen formation

The Copenhagen formation, which paraconformably overlies the Antelope Valley limestone, is composed of a lower quartz arenite member, a middle thin- to thick-bedded argillaceous limestone with abundant intercalated silt, and an upper argillaceous member. Merriam (1956, in preparation) will name the Copenhagen formation from exposures limited to both sides of Antelope Valley; Nolan et al. (1956, p. 28) and Webb (1958) have used this name.

In the mapped area the formation occurs in poor exposures along the east slope of Martins Ridge. In some localities the entire formation is concealed, but its presence is recognized by the smooth featureless slopes below the Eureka quartzite. The middle argillaceous limestone is exposed on the western side of Martins Ridge one mile north of the southern boundary of the area.
The true thickness of the formation cannot be accurately determined. The writer measured 696 feet along section b-b' (Plate I), but most of this section was covered and the attitude of the isolated exposures varied greatly. Webb (1958, p. 2339) estimated a total possible thickness of 600 feet or more at Martins Ridge.

The quartz arenite member crops out discontinuously along the eastern slope of Martins Ridge. A thickness of 20 feet was measured along section c-c' (Plate I). No exposures are present on the western side of the ridge. The member weathers to a characteristic pinkish-brown due to staining by iron oxides. On fresh fractures it is light gray and mottled with hues of yellow, pink, and red. In thin section it is a very fine-grained quartz arenite with loosely packed to floating grains that are well rounded, except for minor amounts of authigenic quartz. The matrix is calcite with a grain to matrix ratio of about 7:3. Porosity is limited to vugs composing 5 per cent of the rock. Hematite and limonite blebs are disseminated throughout the rock.

The contact with the underlying Antelope Valley limestone is abrupt, though a 6-inch basal zone is more easily weathered and contains a much higher percentage of matrix than the bulk of the member. The contact with the overlying member is sharp.

No fossils were found in the quartz arenite member, but Webb (1958, p. 2340) found Endoceras sp. in the Antelope Range.

The middle member is composed of argillaceous, clastic and crystalline limestones that are abundantly fossiliferous. Intercalated silt yields a characteristic yellowish-orange color to the smooth weathered slopes of this member, which is normally exposed for a few feet above the resistant quartz arenite member. Good exposures of this member are found in
the vicinity of the saddle of Martins Ridge near the northwest corner of sec. 7, T.15N., R.50E. and on the western slope of Martins Ridge one mile north of the Nye County line.

The limestone is medium-gray to brownish-gray interbedded calcilutite, calcarenite, and crystalline limestone. Fossil fragments compose up to 30 per cent of some beds. Iron oxide staining is limited to the silty portions. On etched specimens the argillaceous material (up to 25 per cent) forms a lacy pattern with local concentrations surrounding fossil fragments. In thin section, the calcilutite is seen as an accumulation of argillaceous calcareous mud and some random patches of silt-sized particles. Recrystallization has yielded coarse, clear calcite. A trace of authigenic quartz is present, filling silt-sized voids.

As no completely exposed section was measured, the thickness of the middle member was not accurately determined, but its thickness is estimated to be about 500 feet with a gradational contact with the upper argillaceous member.

Cooper (1956, p. 128) and Webb (1958, p. 2340) have studied and listed the fauna from this member. The following forms were identified by the writer:

Valcourea plana Cooper
Macrocoelia occidentalis Cooper
Oxoplecia monitorensis Cooper
Sowerbyites lamellosus Cooper
Strophomena sp.
? Eoplectodonta sp. (large form)
Prasopora sp.
Homotrypa subramosa Ulrich
? Dumastus sp. A
Isotelus sp.
Streptelasmoid coral
Unidentified orthocone
The upper argillaceous member paraconformably underlies the Eureka quartzite. The sharp contact with the Eureka quartzite is exposed 1/4 mile north of T.15N. along the eastern edge of R.49E. (Fig. 2). This member is poorly exposed along the eastern slope of Martins Ridge, where the isolated exposures produce light- to dark-gray float. It is not exposed on the western side.

Figure 2.- Contact of Eureka quartzite and upper argillaceous member of Copenhagen formation.

This upper member is composed of an alternating sequence of calcareous shale and calcareous mudstone. The thin-bedded shale is medium gray to brownish gray; it weathers to small chunky fragments and displays some crude fissility. Portions of the shale are soft, being easily scratched by a finger nail. The thin- to thick-bedded mudstone is medium dark gray to brownish black. Bedding is irregular to smooth.
Fossils and fossil fragments make up 15 per cent of some of the beds.

The following forms are present in the argillaceous member:

- **Plectoglosa** cf. *P. oklahomensis* Cooper
- **Hesperorthis antelopensis** Cooper
- **Strophomena** sp. I Cooper
- **Rafinesquina** sp.
- **Dinorthis** sp.
- **Climacograptus** sp.
- Unidentified diplograptid graptolite
- **Cryptolithus** cf. *C. bellulus* (Ulrich)
- ?*Bumastus* sp. B
- Two unidentified trilobites

Various age classifications of the Copenhagen formation have been proposed: approximately Black Riverian by Kirk (1933, p. 42); late Chazyan to medial Trentonian by Cooper (1956, p. 128; in Twenhofel et al, 1954, Chart 10d) with all but the earliest Black Riverian missing; Black Riverian to Trentonian by Nolan et al (1956, p. 31); and medial Bolarian to medial Trentonian by Webb (1958, p. 2367 and Fig. 6). The age determination of Webb is used in this paper.

**Eureka Quartzite**

The Eureka quartzite is resistant, cliff-forming, and vitreous. The type section at Lone Mountain (35 miles to the north) was designated by Kirk (1933, p. 34). Webb (1958) has included the Eureka quartzite in his recent study of the Middle Ordovician stratigraphy of the Great Basin.

The Eureka quartzite is exposed on Martins Ridge along the eastern slope and is intermittently exposed along the western slope. The writer measured 200 feet of the quartzite along section b-b' (Plate I), which apparently is a good average for the area. Webb (1958, p. 2345) measured 220 feet at Martins Ridge.
The quartzite is divided into three units. The basal 3 feet is a porous, poorly cemented, pinkish-gray, quartz arenite. The quartz grains are medium to fine, well rounded, and weakly cemented by calcite. The massive middle 182 feet is composed of very light-gray to light-gray, vitreous orthoquartzite. The lower 90 feet of this unit is badly stained by iron oxides and small pockets of hematite are found throughout the unit. In thin section, it is composed of well-rounded, fine-grained quartz and authigenic quartz that has grown in optical continuity with most of the grains. Small (about 0.002 mm.) inclusions of undetermined composition are linearly arranged and transgress individual grains. There is one dominant direction of lineation with a subordinant lineation at about 90 degrees. Scattered traces of calcareous cement, clay, and hematite are present.

The upper 15 feet is composed of light-gray slightly porous orthoquartzite. The weathered surface is stained by iron oxide. The upper few inches are weakly cemented by calcite and coated with iron oxides; boulder-like masses of quartzite form an irregular surface (Fig. 3).

Figure 3.- Boulder-like masses of quartzite on upper surface of Eureka quartzite.
The platy argillaceous limestones of the Hanson Creek formation paraconformably overlie the Eureka quartzite.

The absence of fossils in the Eureka quartzite precludes a definite age assignment. Its age is between the medial Trentonian of the Copenhagen formation and the overlying Richmondian Hanson Creek formation containing graptolites identified by Ruedemann (1947, p. 108).

Hanson Creek Formation

The Hanson Creek formation was defined by Merriam (1940, p. 13) from the exposures that cross the east fork of Pete Hanson Creek in the Roberts Mountains. Here the formation is 560 feet thick and consists of a basal 10 to 15 feet of calcareous sandstones, 40 feet of dolomitic limestones, and the remainder composed of thin-bedded shaly limestone (Merriam and Anderson, 1942, p. 1686). At Lone Mountain, the formation is largely dolomite and dolomitic limestones.

Within the mapped area, the formation is 496 feet thick (Plate I, section d-d') and consists of a basal 372 feet of thin-bedded calcareous shale and shaly limestone, an 85-foot cliff-forming unit of hard aphanitic limestone with some chert, and an upper ledge-forming finely-crystalline limestone. Graptolites are common in much of the formation, which is well exposed along Martins Ridge and immediately west of Copenhagen Canyon. Good exposures of all the units may be found, but exposures of the entire sequence are rare because of faulting and concealment.

The basal unit forms the gentle slopes overlying the Eureka quartzite. The unit is composed of thin-bedded dark-gray to brown, calcareous shale alternating with medium-gray argillaceous limestone. Bedding planes are distinct. The shale is thin-bedded and platy and commonly
laminated. Secondary dark-gray chert is rare in this unit, occurring in thin beds and often laminated with limestone. Much of the chert is a veneer limited to the exposed surface. A characteristic feature of this lower unit is the tire-shaped forms that weather out of the shaly limestone (Fig. 4). The basal few feet of this unit yields a strong petroliferous odor when fractured. Orthograptus is abundant in most of this unit.

Figure 4.- Tire-shaped forms that weather out of the basal unit of the Hanson Creek formation.

The middle unit forms an imposing 85-foot cliff at the measured section, and similar exposures are found along Martins Ridge. Bedding is less regular than in the lower unit. The cliff-forming character of this unit is related to the hard, dark-gray aphanitic limestones and abundant dark-gray chert beds and lenses. As in the lower unit the chert is often limited to the surface of the exposed rock. This unit is easily mistaken for the base of the Roberts Mountains formation which is lithologically similar, but contains a greater amount of chert. No fossils were found in this unit.
The upper unit forms a ledge that is less prominent than the middle unit, but is equally persistent throughout the area. This element is composed of finely-crystalline, thin-bedded to massive, medium-gray to light-gray limestones. Clay and silt interbeds containing crinoid stems, and forming irregular bedding surfaces, are present in the lower and middle portions. *Climacograptus* is common near the bottom of the unit and rare in the upper portion.

The Hanson Creek formation has been assigned to the Late Ordovician or Richmondian (Nolan et al, 1956, p. 32). Ruedemann (1947, p. 108) identified four graptolites from this locality; the author's collection yielded: *Orthograptus calcarius* Lapworth var. *trifidus* Gurley and *Climacograptus tridentatus* Lapworth var. *maximus* Decker. Three species of streptelasmoid corals were found in the upper unit.

**Western Assemblage**

The western assemblage is considered to have been deposited in a eugeosynclinal environment. The eastern and western assemblages are contemporaneous and have not been recognized in strata deposited after the major orogeny (latest Devonian to early Pennsylvanian) in central Nevada (Roberts et al, 1958). According to Roberts et al (1958, p. 2832) all presently known exposures of the western assemblage are allochthonous. The Vinini formation of western origin is here limited to exposures in thrust plates west of Copenhagen Canyon.

**Vinini Formation**

The Vinini formation was named and described by Merriam and Anderson (1942, p. 1693-1698) from exposures on Vinini Creek on the eastern slope
of Roberts Creek Mountain (35 miles to the north). Here they have subdivided the formation of undetermined thickness into lower and upper segments. The lower Vinini contains quartzite, limestone, calcareous sandstone, siltstone, lava flows, and tuffs. The upper Vinini is a succession of bedded cherts and black shales. In the Tuscarora Mountains, northern Eureka County, the entire Vinini formation is estimated by Roberts et al (1958, p. 2832) to be at least 7,000 feet thick.

In the mapped area the formation is poorly exposed and consists of green and black bedded chert, light-gray argillite, black shale, platy argillaceous limestone, and laminated, thick-bedded, medium dark-gray limestone. Walnut-sized black chert nodules are common in the Vinini float. Merrim and Anderson (1942, p. 1696) have described similar nodules from the upper Vinini of the Roberts Creek Mountain that are highly graptoliferous, though none have been found in the nodules within the mapped area. The thickness of the formation is tectonically controlled, varying from 0 to possibly more than 500 feet. Along section f-f' (Plate I) 376 feet were measured. The formation is in thrust contact with the Ninemile, Antelope Valley, Roberts Mountains, and "Nevada" formations. The only sedimentary contact of the Vinini formation in the area is with lower Pennsylvanian strata. This contact may be an angular unconformity, as the Pennsylvanian beds probably overlapped the Vinini formation after it had been initially thrust from the west.

The exposed rocks vary in lithology: chert and platy limestones are common to the lowest thrust plate while argillites with intercalated chert are most abundant in the highest thrust plate. Chert nodules are common in both plates.
In the lowest thrust plate, thin-bedded, yellowish-gray, calcareous shale and mudstone apparently form the greatest percentage of the formation. At good exposures the shale and mudstone weather to a characteristic pale yellowish-brown color. The black and greenish-black cherts, which show no evidence for silicification of previous sediments, are considered primary bedded cherts. In thin section the chert is composed of amorphous and cryptocrystalline silica with authigenic quartz anhedra concentrated along fractures. Hydromuscovite, hematite, and limonite are minor accessory minerals. The formation is poorly exposed in the lowest thrust plate, forming smooth slopes often characterized by scattered concentrations of black chert and platy limestone float.

In the highest thrust plate, argillite is the dominant rock type. Typically, the argillite is hard, thin- to thick-bedded, light gray in color, and badly stained with iron oxides. The argillite forms smooth slopes covered with small chunky angular brownish float. Outcrops are rare. Black and greenish-black cherts are locally common in float. One small exposure of black shale occurs in the northwest corner of the area (NW 1/4, NE 1/4, sec. 27, T.16N., R.49E.).

No fossils were found in the Vinini formation within the mapped area, but R. J. Roberts (1959, oral communication) mentioned that graptolites have been found in Vinini exposures in the Charnac Basin northwest of the area. The formation has been correlated lithologically with the upper Vinini of the Roberts Creek Mountains on the Basis of the black chert and the walnut-sized chert nodules. The variation in lithology of the Vinini formation as seen in the separate thrust plates may result from facies changes within the formation, and thus be a function of the distance travelled by each plate. An alternative possibility is that the
lithologies originated from different horizons within the Vinini forma-
tion.

Ruedemann (1947, p. 108) has studied the graptolites of the upper
Vinini of Roberts Creek Mountain and considers this portion to be upper
Normanskill (Chazyan) in age.

SILURIAN SYSTEM

Roberts Mountains Formation

The Roberts Mountains formation was defined by Merriam (1940, p.
11-12) from the west side of Roberts Creek Mountain (45 miles north of
the area). Here the formation is 1,900 feet thick and consists of a
basal chert zone with overlying slabby to massive limestones. At Lone
Mountain the formation is 741 feet of massive dolomite with a basal chert
zone. The Roberts Mountains formation is widely distributed within the
mapped area, with good exposures on Martins Ridge and west of Copenhagen
Canyon; it is poorly exposed near the western edge of the area. A thick-
ness of 2,447 feet was measured along section e-e' (Plate I), but there
may be some duplication of beds due to a concealed fault.

Near Copenhagen Canyon, the formation lies between the Hanson Creek
formation and the "Nevada" formation. In the thrust sequence, it lies
disconformably upon the Antelope Valley formation and is overlain by the
highest thrust plate of the Vinini formation. Slightly different facies
are represented at each locality.

At Martins Ridge and west of Copenhagen Canyon, the formation con-
sists of a basal 122-foot, ledge-forming, cherty unit. Here the black
chert is interbedded with finely-crystalline, dark-gray, thin-bedded,
slightly siliceous and dolomitic limestone in a ratio of 1:2. The chert and silica are due to secondary replacement. In hand specimen the chert is normally confined to bedding planes, but often it transgresses them. In a thin section of a chert bed within this zone, chert, microcrystalline silica, and anhedral quartz have replaced argillaceous limestone. The siliceous material forms about 60 per cent of the rock. Irregular laminae of clay and iron oxides comprise 20 per cent. The remainder of the specimen (10 per cent) is composed of dolomite rhombs and aphanitic calcite and (or) dolomite.

The bulk of the formation is composed of platy, light-brown and medium-gray, shaly limestone. Sporadic chert beds and lenses, and a few thick-bedded calcarenites are found throughout this unit. Clay and silty interbeds are common, weathering to light gray and pale yellowish gray. This unit forms smooth slopes, normally covered with float, and good exposures are limited to washes and steep slopes. Monograptus-bearing beds are found throughout this formation (see appendix), the first zone of abundant Monograptus occurring 20 feet above the top of the basal chert unit.

The base of the chert zone conformably overlies the Hanson Creek formation. The contact with the overlying "Nevada" formation is vague throughout the area, and it lies within a 60-foot shaly limestone zone between Monograptus-bearing beds and a massive limestone unit bearing Devonian spirifers.

In the thrust sequence, the thick basal chert zone is limited to two laminated chert beds (12 and 18 inches thick) near the contact with the underlying Antelope Valley limestone. The chert is interbedded with thin-bedded, pale yellowish-orange, calcareous mudstone, and light
olive-gray, finely-crystalline limestone. Above this 15-foot zone, the thin-bedded shaly limestone is present. This sequence is lithologically similar to the same unit in the eastern portion of the area, and weathers to light hues of yellow, gray, brown, and purple. Several species of Monograptus are found within the sequence and confined to exposures near the base and the upper portion of the formation. Much of the formation is covered by float from the overlying Vinini formation. No thickness was measured, but it is estimated to be 200 to 300 feet. One exposure near the center of SW 1/4, sec. 21, T.16N., R.49E. below the thrust contact with the Vinini formation was composed of thin-bedded, medium-gray, laminated, argillaceous limestone containing Monograptus pandus Lapworth.

Three-quarters of a mile south of the narrows of Whiterock Canyon a conspicuous exposure of medium dark-gray, chunky to pencil shale and calcareous shale totals about 75 feet in thickness. Other, less conspicuous exposures are found to the north. The shale overlies a light-gray weathering, thick-bedded to massive, dark-gray, argillaceous limestone containing ostracods, brachiopods, and rare Monograptus sp. Monograptus-bearing beds occur in thin platy shaly limestones for about 75 feet above the shale. Although mapped with the Roberts Mountains formation, the exact stratigraphic relationship of this element is not understood.

Ruedemann (1947, p. 109) has identified Monograptus pandus Lapworth and M. acus Lapworth collected within the area and considers the age of the formation to approximate the Niagaran Epoch.

The writer has identified the following graptolites from the Roberts Mountains formation:
Other fossils collected but not identified include: brachiopods, horn corals, and small ostracods.

DEVONIAN SYSTEM

The term "Nevada" was first used by Clarence King (1878 Atlas, map 4) for Devonian rocks in the eastern Great Basin. Hague (1883, p. 264) originally defined the formation, but failed to designate a specific type locality. Merriam (1940, p. 15) redefined and restricted the Nevada formation to include rocks of Lower and Middle Devonian age and designated one of Hague's localities, Modoc Peak (about 10 miles west of Eureka), as the type section. Nolan et al (1956, p. 40) report that the formation maintains a constant thickness of about 2,500 feet in the vicinity of Eureka. Near Eureka, dolomite is the dominant rock type, but limestone and silty limestone prevail at Lone Mountain.

The Roberts Mountains formation is present in the area and at Lone Mountain. In the mapped area it is succeeded by Helderbergian limestone, but at Lone Mountain it is succeeded by the Silurian-Devonian (?) Lone Mountain formation which is overlain by Devonian limestone. Merriam (1954, p. 1284) has briefly discussed the relationship of the Silurian-Devonian boundary of Lone Mountain and in the Monitor Range. He states that the Lone Mountain dolomite may be transitional from Silurian to Lower Devonian and that possibly the limestone containing a Helderbergian-like fauna in the Monitor Range is equivalent to at least the upper part of the Lone Mountain dolomite.
As the evidence is not conclusive for correlation of the Lower Devonian limestones of the mapped area with the Lone Mountain or Nevada formation, the author has arbitrarily used the name, "Nevada" formation, for these limestones.

"Nevada" Formation

The rocks that comprise the "Nevada" formation within the area are thin-bedded to massive limestones. The formation is extensively exposed west of Copenhagen Canyon and east of the thrust plates, where it has been severely deformed by thrust and normal faults.

The thickness of the formation was not determined because of the lack of any continuous section, but was estimated to be 1,000 feet thick. Larson (1958, oral communication) has measured 1,413 feet of Lower Devonian strata in the Antelope Range.

The formation consists of a variety of limestones and argillaceous limestones. Massive, medium-gray, crystalline and bioclastie limestones generally form the crests of ridges as illustrated by the northeast trending ridge in sec. 35, T.16N., R.49E. The massive limestone has a strong petroliferous odor and contains abundant fossil fragments. A 2-foot biostromal bed contains streptelasmoid corals, spirifers, and other fossil fragments.

Excellent exposures along the north side of Whiterock Canyon are composed of a sequence of light olive-gray to medium-gray crystalline and clastic limestones in 8- to 24-inch beds alternating with platy, shaly limestones in beds of a few inches to a few feet thick. The sequence is poorly fossiliferous; some brachiopods and crinoid stems are present along with fossil hash. The beds weather to a characteristic yellowish gray color.
In the wash south of Sweeney Wash good exposures are found containing platy to thin-bedded, brownish-gray, laminated shaly limestone, alternating with medium dark-gray aphanitic limestones. Sporadic beds of coquinal limestone are present. *Favosites* sp., bryozoa, and poorly preserved brachiopods and trilobites are common.

As a general pattern, the formation is best exposed along the sides of canyons (particularly the north side) and along the crests of ridges. Smooth slopes with platy float are common and often difficult to distinguish without paleontologic control from the shaly limestone sequence of the Roberts Mountains formation.

Except for a few localities, the formation is generally barren of well-preserved fossils. The most common forms are *Spirifer kobehana* Merriam, *Favosites* sp., a species of streptelasmoid coral, and *Leptaena* sp. Other forms identified by the writer are:

- *Meristella* cf. *M. robertsensis* Merriam
- *Atrypa* aff. *A. nevadana* Merriam
- *A* sp.
- *Spirifer* sp.
- *Chonetes* cf. *C. filistriata* Walcott
- *Phacops* sp. (pygidiums only)

Other poorly preserved and unidentified forms are pleurotomariid gastropods, orthid brachiopods, orthocones, and crinoids.

Although none of the forms collected by the writer are distinctly Helderbergian, the formation is considered to be that age by Nolan et al (1956, p. 36).

At Roberts Creek Mountain, the lowest known faunal zone of the Nevada formation is considered to be Oriskanian or possibly Helderbergian by Merriam (1940, p. 50). At Lone Mountain and in the vicinity of Eureka, the youngest faunal zone of the Nevada formation is regarded by Nolan et al (1956, p. 46) to be Early Devonian (Oriskanian).
A sequence of severely deformed rocks composed of thin- to thick-bedded clastic limestones in the northwest corner of the area is assigned to the Pennsylvanian System. Poorly preserved Lower Pennsylvanian fusulinids are present in one thin section of a chert pebble conglomerate.

The unit unconformably overlies the Vinini formation in the mapped area and is part of the overlap assemblage of Roberts et al (1958, p. 2838). Kay (1952, p. 1270) has reported a similar sequence along Mill Creek Canyon in the Toquima Range 25 miles to the southwest. The contact with the underlying Vinini was mapped on the occurrence of chert and argillite float. Rocks here classified as Pennsylvanian are poorly exposed and form smooth slopes with occasional low outcrops. The attitude of the Pennsylvanian rocks is chaotic. Rapid changes in the dips of beds are patternless and complicated by numerous unmapped local faults. The thickness of the formation was not determined, but estimated to be 600 or 700 feet.

Partially recrystallized, medium dark-gray calcilutites and calcarenites predominate. Chert and specular hematite are locally common, and most of the strata have iron oxide stains along fractures. In thin section rounded silt- and sand-sized quartz, secondary chert, and glauconite are present in minor amounts. Small (0.5 mm.) spherical chalcedonic concretions are found in some of the limestones.

Fusulinid-bearing chert pebble conglomerate has been found only in float. In thin section the grains are composed of well-rounded green and black chert, quartzite, collophane, and fine quartz sandstone in a calcite matrix. Grain size varies from less than 1 mm. to over 6 mm.
Productid ? spines and crinoid stems are present in addition to the rare fusulines. The Lower Pennsylvanian fusulinid, Schubertella ? sp., has been recognized by John Riva.

**QUATERNARY ALLUVIUM**

The alluvium of the area consists of unconsolidated sediments ranging in size from clays to large boulders. Clastic material derived from both sedimentary and volcanic rocks is present. Alluvium is found in most drainage channels and forms coalesced alluvial fans west of Copenhagen Canyon and on the east slope of Martins Ridge. Cyclic deposits of coarse and fine sediments are well exposed in the deep washes of White-rock Canyon.

**IGNEOUS ROCKS**

**Albite Microsyenite Dike**

An igneous dike crops out at three localities in sections 34 and 35, T.16N., R.49E. (Plate I). At each of the localities, exposures of black "burnt" limestones are associated with the dike. The dike cuts across the "Nevada," Roberts Mountains, Ninemile, and Vinini formations and probably the Antelope Valley limestone. Although no complete exposure of the dike was found, the thickness is estimated to be 30 or 40 feet.

In hand specimen the rock is very light gray flecked with iron oxide stains. Of the minerals that can be identified, feldspar is dominant; biotite and iron oxides are accessory minerals. Much of the exposed rock is badly weathered and is easily broken by hand.

In thin section it is a hypidiomorphic-granular, fine-grained albite microsyenite. Albite forms about 85 per cent of the rock. Accessory minerals include: hematite and limonite, quartz, biotite, barite, and apatite.
The dike was probably intruded at a relatively low temperature or lacked fluids, because the black zone of alteration and mineralization adjacent to the dike is limited. The best exposure of the "burnt" limestone, 60 feet wide, is at the central locality of the dike. In thin section the "burnt" limestone is composed of porous black carbonaceous matter that has been partially filled by secondary calcite. Streaks of hematite are abundant. A small (20 feet in diameter) crystalline barite deposit is also present at the middle locality.

There is no direct evidence for dating the dike, except that it is younger than the "Nevada" formation. The dike is probably correlative with the Tertiary volcanics to the west, or possibly, with the intrusives of Cretaceous age mapped by Nolan et al (1959) in the Eureka Mining District.

Tertiary Volcanics

Tertiary volcanics are found to the west of the mapped area, where they blanket the Paleozoic rocks. The volcanics were neither mapped nor studied, but where observed they consist of a sequence of varicolored lithic tuffs, crystal tuffs, and intermediate to acid flows. These volcanics are probably equivalent in age to the Tertiary volcanic flows and tuffs mapped by Nolan et al (1959) in the Eureka Mining District.
STRUCTURES

Two structural patterns are apparent in the vicinity of Copenhagen Canyon. On Martins Ridge and immediately west of Copenhagen Canyon, the structure is characterized by gentle folds and high-angle normal faults. In the western portion, imbricate thrust faults are present, which have brought the eastern and western facies into juxtaposition. The "Nevada" formation and the Pennsylvanian rocks have received intense local deformation resulting in a complex of structures.

Numerous minor faults and folds are unmapped. Calcite veins and veinlets filling fractures and fault planes are ubiquitous.

Folds

Major folding in the area is limited to Martins Ridge. Folds of similar magnitude may have existed west of Copenhagen Canyon, but have since been obscured by later deformation.

A broad syncline forming the southern portion of Martins Ridge (Plate I; Plate II, section E-E') is the most apparent fold in the mapped area. Its axis roughly parallels the north-south axis of the ridge. The apparent plunge to the south at the northern end of the structure is probably the result of later normal faulting as no actual plunge is seen in the body of the syncline. The syncline is symmetrical with each flank dipping about 15 degrees toward the axis. On the western limb, a relatively tight anticline (Fig. 5) has formed that has subsequently been obscured by faulting and erosion. The associated anticline to the eastern limb is not present within the mapped area, but may be concealed in Antelope Valley, which is evidently a graben separating the Monitor and Antelope Ranges.
Martins Ridge is synclinal, but normal faults have distorted the ridge increasingly to north so that the evidence is partially masked. The outcrop distribution of the Eureka quartzite provides some evidence that the syncline extended the entire length of Martins Ridge. In the southeast 1/4 of sec. 36, T.16N., R.49E., the quartzite crops out on both sides of the ridge. If the quartzite were not folded, it would be concealed about 300 feet below the surface near Copenhagen Canyon. A small syncline whose flanks have probably been steepened by subsequent faulting is present 1/4 mile west of the northwest corner of sec. 6, T.15N., R.50E. (Plate I and Fig. 6). Although modified, this structure is apparently related to the synclinal nature of Martins Ridge.

Possible low, east-west trending folds along Martins Ridge (Plate II, section D-D') are related to numerous minor faults. An apparent east-west fold, east of sec. 25, T.16N., R.49E., is in a faulted area.
Normal Faults

Normal faults are the dominant structures present on Martins Ridge and east of the thrust sequence. Two fault directions have been recognized: north-south trending faults parallel to Martins Ridge and east-west trending faults. A few major faults are oblique to these trends. Maximum displacements along some of these faults must be in excess of 1,000 feet.

A fault east of Martins Ridge located on physiographic evidence separates the Monitor Range from Antelope Valley. The fault is probably parallel to the line formed by the easternmost exposures of the Antelope Valley limestone.

A fault parallel to this lies within Copenhagen Canyon. The west side has dropped relative to Martins Ridge with the displacement varying from zero to 1,000 feet because of intersecting faults.
Martins Ridge has numerous east-west faults (Plate I; Plate II, section D-D'-D'') forming a series of steps, but some horst and graben blocks are present. Displacements average about 300 feet. The Eureka quartzite provides an excellent structural horizon for recognizing these faults in the field. Fault planes were not observed, but structural relationships indicate they are normal faults. Slickensides are common in the Eureka quartzite near faults, but most of them are confined to large blocks of float or related to minor associated faults. Mineralization is limited to calcite in these faults.

West of Copenhagen Canyon, an east-west normal fault trend is also present. The faults in this area are "scissor" faults with displacements up to 800 feet near the canyon decreasing to zero near or within the lower thrust plates. Silicification and hematite mineralization are locally common along the fault traces.

North- and northeast-trending faults west of Copenhagen Canyon have been mapped on the basis of topographic expression and stratigraphic control. The northeast-trending fault crossing the center of sec. 35, T.16N., R.49E. is bounded to the east and west by ridges whose crests are formed by the massive limestone beds of the "Nevada" formation. The upper part of the Roberts Mountains formation bearing Monograptus is exposed west of the fault line. The displacement was calculated to be about 800 feet. Other faults involving the Silurian and Devonian strata in this vicinity were mapped on similar evidence.

A northeast-trending fault zone of considerable magnitude is present near the common west corner of sections 6 and 7, T.15N., R.50E. (Plate I; Plate II, sections B-B' and C-C'). The fault bifurcates near its
northern end, resulting in the structural thinning of the Eureka quartzite and Copenhagen formation. The quartzite is absent near the common west corner of sections 6 and 7. An exposure of Eureka quartzite to the immediate southwest is a large slump remnant, which rests upon the middle member of the Copenhagen formation. The displacement varies from zero at the northern end to about 500 feet at the southern.

**Thrust Faults**

Major thrusting confined to the western portion of the area (Plates I and II) involves the eastern and western assemblages and presumably the Pennsylvanian beds assigned to the overlap sequence. This thrust sequence contains four plates, which in ascending order are composed of: a portion of the Roberts Mountains formation; the lime-rich portion of the Vinini formation; the Ninemile, Antelope Valley, and Roberts Mountains formations; and the clastic portion of the Vinini formation with overlying Pennsylvanian rocks.

The lowest plate is a small thrust sliver composed of *Monograptus*-bearing shaly limestone of the Roberts Mountains formation dipping 35 degrees to the west. It is exposed only in the southwest 1/4 of sec. 23, T.16N., R.49E., where it has been thrust over the "Nevada" formation. Maximum thickness is estimated to be about 100 feet. The slice thins and is absent to the north and south. The lowest thrust plane is estimated to dip 15 to 20 degrees to the west.

The second thrust plate composed of the lime-rich portion of the Vinini formation overlies the lowest thrust slice and the "Nevada" formation. This thrust is poorly exposed from south of the narrows of White-rock Canyon to about 1/2 mile from the northern boundary of the area.
Two exposures are present north of Whiterock Canyon, 1 1/2 miles west of Copenhagen Canyon. Here the thrust is seen in a small normal fault block near the canyon, and forms a klippe to the north. The maximum thickness of the plate is between 300 and 500 feet. Outcrops are rare, but where exposed the strata show little distortion. The contact with the "Nevada" formation is clearly delineated at several localities. An excellent exposure is located south of Whiterock Canyon (Fig. 7). This and other similar exposures show the Vinini formation lying upon the "Nevada" with the thrust plane dipping about 30 degrees to the west.

Figure 7. - Vinini formation to left in thrust contact with "Nevada formation on right.

The third plate is composed of the Ninemile, Antelope Valley, and the Roberts Mountains formations. The maximum thickness of this plate is about 1,000 feet. The Ninemile formation forms the base of this plate, but is only locally exposed; it is known to be absent at some localities and presumed to be absent in other localities.
The Antelope Valley limestone forms the greatest percentage of the third plate. Its massive cliffs are extensively exposed throughout the north-south limits of the thrust sequence. The Roberts Mountains formation, which is poorly exposed near the western edge of the area, forms the upper unit of this plate. This thrust plate shows no evidence of severe distortion which can be attributed to the formational competency and thickness of the plate. Most beds dip 15 to 25 degrees to the north and northwest. Locally erratic attitudes are attributed to local faulting and fracturing. The plane of this thrust fault apparently parallels the bedding plane. This is evidenced by the topographic expression of the contact between this plate and the underlying plate.

Two klippen are associated with this thrust plate. One is located in the southwest 1/4 of sec. 34, T.16N., R.49E., and the other is 1/2 mile further south. In both cases the klippen are composed solely of the Antelope Valley limestone. A portion of the lower zone of the Antelope Valley limestone has been thrust over itself (Plate II, section B-B') in the northernmost klippe.

The uppermost thrust plate, composed of the clastic-rich portion of the Vinini formation and Pennsylvanian rocks, is exposed south of the narrows of Whiterock Canyon and in the northwest corner of the area. The maximum thickness of this plate is estimated to be 600 feet. The underlying thrust plane is apparently horizontal, but was mapped only on the occurrence of Vinini float. Where the Vinini formation is exposed, the outcrops show severe contortions. The Pennsylvanian rocks have been subjected to extreme deformation.
Study of the regional pattern of thrust faults in central Nevada indicates thrusting from the west or northwest (Merriam and Anderson, 1942, p. 1704; Roberts et al, 1958, p. 2813).

Aside from the absolute minimum displacements of about 3,500 and 4,500 feet for the second and third plates, respectively, that have been determined in the mapped area, the measurement of actual displacement is a regional problem. Merriam and Anderson (1942, p. 1704) have reported a minimum horizontal displacement of 16 miles for the Roberts Mountains thrust in the Roberts Mountains. Estimates in tens of miles have been made for thrusts in Nevada (Roberts et al, 1958). As the thrust sequence in the area and the Roberts Mountains thrust contain rocks of the western assemblage, their displacement is probably of similar magnitude.

If the concept of "assemblages" is correct, then it must be assumed that the plates composed of rocks of western origin must have travelled the greatest distance. The eastern assemblage rocks involved in the thrusts have travelled a shorter distance.

The lowest thrust plate which contains the lime-rich portion of the Vinini formation is probably more closely related to the eastern assemblage than the argillite-rich portion of the Vinini formation found in the highest thrust plate. If such a facies relationship exists between the rocks of these thrusts, then the lowest thrust containing the Vinini formation may have been displaced a lesser distance than the upper plate containing rocks of more distinctly western origin. An alternative explanation of these separate thrust plates of the Vinini formation is the possibility that they were derived from separate horizons.
Deformation of the "Nevada" Formation

The complex fold and fault pattern seen in the "Nevada" formation can be attributed to its position relative to the thrust plates.

Small recumbent folds (Fig. 8) with amplitudes of up to 50 feet are found throughout the area. Frequently they lie between beds which are relatively undisturbed. Good exposures can be seen at Rabbit Hill (near the mouth of Copenhagen Canyon) and along the north side of Whitewash Canyon. The axial planes of many of the larger folds observed within the formation approximate the strike of the thrust plates, but often they are oblique or perpendicular. Because of intense shattering, the magnitude of these thrust-formed features could not be measured.

Figure 8.- Small recumbent fold in the "Nevada" formation.

Although most of the formation is badly deformed, portions show little or no deformation. The localization of structures within this
formation can be related to thrust forces. The lack of similar deformation in the underlying Roberts Mountains formation indicates a stripping or peeling off of the "Nevada" formation.
GEOLOGIC HISTORY

Rocks of the eastern assemblage were deposited in a clear, shallow sea supplied with minor and varying amounts of terrigenous clastic detritus from unknown cratonal or positive areas. The presence of fossil hash throughout the assemblage, current structure in the "Nevada" formation, and cross-laminated beds locally present in the Antelope Valley limestone and the Roberts Mountains formation is indicative of shallow water deposition. Stable conditions are indicated by the persistence of lithologic units.

Several unconformities reflect periodic emergence of the depositional basin. The quartz arenite member of the Copenhagen formation was developed on a shelf edge during an interval of regression (Webb, 1958, p. 2371). The remainder of the formation was probably deposited in a near-shore environment. Isopachous and paleogeographic studies by Webb (1958, p. 2371-2372, Figs. 7-8) indicate that the Copenhagen formation was deposited in a basin that was not subjected to erosion prior to the deposition of the transgressive Eureka quartzite.

Erosion and uplift of considerable magnitude occurred to the west prior to medial Silurian, and possibly as early as very latest Ordovician (Webb, 1958, p. 2376). Graptolitic Silurian strata overlie Middle Ordovician limestone in the Toquima Range (E. R. Larson, 1958, oral communication). A similar sequence occurs in the thrust plates of the mapped area which was originally deposited west of the Monitor Range.

Synchronous with the deposition of the eastern assemblage, the western assemblage was being deposited in a rapidly subsiding sea supplied with an abundance of fine terrigenous clastic material.
The Helderbergian limestones are the youngest rocks of the eastern assemblage in the mapped area. This dates the time of thrusting as post-Helderbergian and prior to the emplacement of the Mesozoic or Tertiary dike. Roberts et al (1958, p. 2850) consider the major Paleozoic orogeny, Antler, in central Nevada, of latest Devonian to Early Pennsylvanian age, but state that minor orogenic disturbances are not limited to this time. Thrusting in the area probably occurred in part during the Antler orogeny, but continued at least into Middle Pennsylvanian. The low folds on Martins Ridge are presumed to have been formed during the time of thrusting.

After deposition of the "Nevada" formation, and possibly younger sediments, the area was exposed to erosion prior to thrusting, which may have began in later Devonian time. Thrusting probably took place in several stages as illustrated in diagrammatic restored sections (Plate III). The first stage of thrusting probably involved the two lowest plates. As the lowest plate of the Vinini formation was thrust toward the mapped area, the sliver of the Roberts Mountains formation was probably caught below the Vinini plate near the origin of the eastern assemblage thrust plate. The emplacement of the initial thrust plates began the décollement or "peeling off" of the underlying "Nevada" formation which may be the result of pre-thrust topography. Such topography would localize the drag exerted by the thrust plates moving across the surface.

The thrust plate containing eastern assemblage rocks was derived from the western edge of this assemblage, and thus, thrust from a lesser distance than the underlying plate. Deformation of this plate during thrusting was limited by thickness and the competency of the rocks. By Lower Pennsylvanian time, submergence of the orogenic area allowed the deposition of Lower Pennsylvanian limestones on the Vinini formation to the
west. The uppermost plate, composed of the argillite-rich portion of the Vinini formation and Pennsylvanian rocks, was probably thrust into the area in Middle or Upper Pennsylvanian time or later.

The Tertiary volcanic rocks probably blanketed the entire mapped area, as isolated pieces of volcanic float were found on the crest of Martins Ridge. Warping and normal faulting probably began in Early Tertiary time (Nolan, 1943, p. 183) and involve the later Tertiary volcanic rocks.
SUMMARY

Sedimentary rocks in the Copenhagen Canyon area are composed of eastern assemblage formations, plus the western assemblage Ordovician Vinini formation and the overlap assemblage Lower Pennsylvanian limestones. Eastern assemblage formations include: Ordovician Ninemile, Antelope Valley, Copenhagen, Eureka, and Hanson Creek; Silurian Roberts Mountains; and Helderbergian "Nevada." Autochthonous rocks younger than Helderbergian are not present.

The thrust sequence in the western portion of the area consists of four imbricate thrust plates involving eastern and western assemblage rocks and the Lower Pennsylvanian limestones unconformably overlying the Vinini formation in the uppermost thrust. Thrusting occurred in part during the Antler orogeny, but continued into post-Lower Pennsylvanian time.

Slightly different facies are represented by the eastern assemblage formations (Antelope Valley and Roberts Mountains) that are present in both the thrust sequence and in autochthonous exposures in the eastern portion of the area.

Martins Ridge is a normal-faulted synclinal structure with a small anticline on the west flank. The associated anticline on the east flank was not observed, but presumed to be concealed in Antelope Valley.
APPENDIX

Composite section of Ninemile formation measured in the narrows of White Rock Canyon

Thickmess in Feet

Unit       To Base

Antelope Valley limestone

Ninemile formation
Calclutite, argillaceous, medium-gray to olive-black, thick beds form four 3-foot ledges with intercalated pale-green calcareous shale; bedding irregular with silty interbeds; contains Lachnostoma latucelsum Ross (rare), abundant orthid brachiopods, and crinoid stems.

Cover, float as below.

Mudstone, calcareous, olive-gray, weathers light olive gray, 1/2-to 1 1/2-inch beds intercalated with 4-inch beds of shaly limestone; poor exposures.

Cover

Calclutite, argillaceous, olive-black, with fossil hash along silty interbeds; alternating with thin-bedded medium light-gray shale; contains abundant Lachnostoma latucelsum Ross; smooth slope, poor exposures.

Shale, calcareous, platy in part, olive-gray and medium dark-gray.

Laminated shale and argillaceous calcilutite, medium-gray and light olive-gray, weathers light olive-gray, silty interbeds, thin-bedded, crinkly bedding surface; appears fucoidal; forms smooth slopes.

As above, but less shale; contains Lachnostoma latucelsum Ross and crinoids.

Base concealed
Section of Antelope Valley limestone measured on section a-a'  

**Thickness in Feet**

<table>
<thead>
<tr>
<th>Unit</th>
<th>To Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copenhagen formation</td>
<td></td>
</tr>
<tr>
<td>Antelope Valley formation</td>
<td></td>
</tr>
<tr>
<td>Calcilutite, medium light-gray to medium-gray, thin-bedded (1/2 to 2 inches common) with irregular silty beds and partings; chert nodules and stringers in lower 1/3 of unit; poorly preserved fossils common in upper few feet; contains Orthis aff. Q. sublata, ?Anomalorthis nevadensis, stony bryozoan, Humastus sp., other trilobite fragments, gastropods, orthocones; forms smooth slope with occasional benches</td>
<td>198 1373</td>
</tr>
<tr>
<td>Calcarenite, brownish-gray to medium-gray, weathers medium light gray to yellowish-gray; contains ?Palliseria longwelli (Kirk), rare, large orthocones, and gastropods; forms cliff</td>
<td>33 1175</td>
</tr>
<tr>
<td>Limestone, finely- to medium-crystalline, mottled brownish-gray and light medium-gray to medium-gray, 1- to 4-inch beds with irregular silty interbeds, chert stringers and nodules throughout unit (some chalcedonic); contains fossil hash; forms low benches</td>
<td>56 1142</td>
</tr>
<tr>
<td>Coarse calcarenite with zones of fossil hash, medium-gray to olive-gray, weathers medium light-gray, thick-bedded to massive, hematite-stained 1/2 to 1 inch chert stringers; contains Maclurites sp., high-spired gastropods, and teperditid ostracods; cliff-forming unit</td>
<td>97 1086</td>
</tr>
<tr>
<td>Calcarenite and calcilutite, medium light-gray, massive beds with cross-laminated silty beds, chert and secondary silica; Palliseria longwelli abundant</td>
<td>41 989</td>
</tr>
<tr>
<td>Limestone, clastic and crystalline, medium light-gray to olive-gray, smooth knobby weathered surface medium light gray; abundant Palliseria longwelli; forms low benches</td>
<td>18 948</td>
</tr>
<tr>
<td>Calcarenite, medium light-gray, weathers medium gray to pale brown, thin- to thick-bedded; silty interbeds stained by iron oxides; contains bryozaon</td>
<td>65 930</td>
</tr>
<tr>
<td>Calcarenite, medium light-gray, weathers medium gray to olive gray, beds 4 to 18 inches; Palliseria longwelli rare, Maclurites sp., bryozoan, crinoid stems; numerous calcite veinlets; forms subdued ledges and dip slope</td>
<td>70 865</td>
</tr>
</tbody>
</table>
Limestone, crystalline, with subordinate calcarenite, medium-gray to olive-gray, massive with 1/8- to 1/4-inch intercalated silty beds; appears fucoidal; weathered surface "sandy"; contains Receptaculities sp., rare bryozoa and brachiopod fragments; forms rugged cliff.  

Calcarenite and silty calcarenite, light- to medium-gray and yellowish-gray, graded-bedding, laminated, thin-bedded to massive, rough weathered surface; forms isolated benches.  

Limestone, finely- to coarsely-crystalline, some calcarenite, massive light olive-gray to yellowish-gray, brachiopod fragments, smooth knobby weathered surface; ledge-forming unit.  

Calcarenite, lithology as above, but with more silty beds; contains ?Girvanella sp.  

Calcarenite, thin-bedded to massive, light-gray to medium light-gray, weathers to shades of tan and brown with abundant intercalated silt and very fine sandy beds, irregular silty partings, secondary silica and black chert nodules common, weathered surface irregular due to silty beds; contains Maclurities sp., ?Orthambonites eucharis Ulrich and Cooper, and unidentified orthid brachiopods; forms prominent ledges.  

Calcilutite and calcarenite, medium dark-gray, weathers medium gray to brownish gray, thin- to thick-bedded with 1/8-inch silty interbeds locally stained with iron oxide, numerous calcite veinlets; contains poorly preserved orthid brachiopods; ledge and bench forming unit.  

Base concealed
Composite section of Copenhagen formation measured along b-b' c-c'

<table>
<thead>
<tr>
<th>Thickness in Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit</td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td>14</td>
</tr>
<tr>
<td>30</td>
</tr>
<tr>
<td>26</td>
</tr>
<tr>
<td>93</td>
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<tr>
<td>361</td>
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<tr>
<td>35</td>
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<tr>
<td>49</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>46</td>
</tr>
<tr>
<td>16</td>
</tr>
<tr>
<td>19.5</td>
</tr>
<tr>
<td>.5</td>
</tr>
</tbody>
</table>

**Eureka quartzite**

**Paraconformity**

**Copenhagen formation**

Alternating sequence of thin- to thick-bedded hard calcareous shale and mudstone, medium dark-gray to mottled light brownish-gray and brownish-black, weathers to pale yellowish brown, smooth bedding planes, chunky weathered fragments; contains abundant Plectoglossa cf. P. oklahomensis Cooper; also present are Climacograptus sp., poorly preserved diplograptid graptolites, Cryptolithus cf. C. bellulus Ulrich, ?Rumastus sp. B, Rafinesquina sp., Dimorthis sp. ............................................ 14 696

Calcareous mudstone, medium dark-gray, weathers to lighter shades of gray and pinkish gray; irregular parting planes ............................................ 30 682

Calcareous shale, soft, brownish-black, rough fissility ............................................ 26 652

Calcareous mudstone, brownish-gray to brownish-black, abundant fossil fragments, irregular bedding surface; contains Hesperorthis antelopsensis Cooper, Strophomena sp. I Cooper, ?Rumastus sp. B, unidentified trilobite. ............................................ 93 626

Cover. ............................................ 361 533

**Argillaceous limestone, medium-gray to brownish-gray, in part coquinal, irregularly bedded (1/2 to 2 inches), silty interbeds; contains Valcourea plana Cooper, Macrococelia occidentalis Cooper, Prasopora sp., Homotrypa subramosa Ulrich. ............................................ 35 172

Cover, except for isolated outcrops as below ............................................ 49 137

Limestone, crystalline, medium-gray, thin-bedded (1/2 to 1 inch), abundant fossil hash, and fossiliferous silty interbeds that weather pale yellowish orange to dark yellowish orange; contains Valcouragea plana Cooper, and crinoid stems. ............................................ 6 88

Interbedded calcilutite and calcarenite, medium-gray, irregular 4- to 12-inch beds, fossiliferous, intercalated and interbedded with pale yellowish-orange silt; contains Valcouragea plana Cooper, and Macrococelia occidentalis Cooper .......................... 46 82

As above, but less silt. ............................................ 16 36

Quartz arenite, light-gray and mottled with iron ore stain, very fine-grained, calcite cement, grayish-red, weathered surface ............................................ 19.5 20

Quartz arenite as above, but higher percentage of calcite cement ............................................ .5 .5

**Paraconformity**

**Antelope Valley limestone**
Measured Section of Eureka quartzite along section b-b'

Hanson Creek formation
Paraconformity
Eureka quartzite
Orthoquartzite, fine- to medium-grained, light-gray to medium-gray, rounded to well-rounded quartz grains, slightly porous, siliceous and calcareous cement, surface partially stained by iron oxide, top few inches porous with a coating of iron oxide .......... 15 200
Orthoquartzite, vitreous, fine-grained, very light-gray, pocked with small porous spots partially filled with hematite, lower 90 feet light gray and stained with iron oxide; massive cliff-forming unit .......... 182 182
Quartz arenite, fine- to medium-grained, pinkish-gray, porous with calcite cement, friable in part .......... 3 3

Paraconformity

Copenhagen formation
Section of Hanson Creek formation measured along section d-d'

<table>
<thead>
<tr>
<th>Thickness in Feet</th>
<th>Unit</th>
<th>To Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roberts Mountains formation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hanson Creek formation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limestone, massive, finely-crystalline, medium-gray, with some irregular parting along silty interbeds, rough pitted weathered surface, forms rounded ledges; contains crinoid stems in silty portions and rare Climacograptus tridentatus Lapworth var. maximus Decker.</td>
<td>72</td>
<td>497</td>
</tr>
<tr>
<td>Limestone, finely-crystalline, medium dark-gray, 4- to 18-inch beds; wavy and crinkly silty interbeds, forms isolated outcrops.</td>
<td>53</td>
<td>425</td>
</tr>
<tr>
<td>Calcilutite, argillaceous and platy, 1/2- to 3/4-inch beds, dark brownish-gray, weathers yellowish, poorly exposed; Climacograptus tridentatus Lapworth var. maximus Decker common.</td>
<td>15</td>
<td>372</td>
</tr>
<tr>
<td>Limestone, aphanitic, dark gray, thin- to thick-bedded with abundant chert beds, stringers, and nodules (up to 4 inches thick), bedding distinct, but irregular; forms rugged cliff.</td>
<td>85</td>
<td>357</td>
</tr>
<tr>
<td>Argillaceous limestone, medium-crystalline, thin-bedded, dark-gray to brownish-gray; interbeds of dark gray laminated chert and a small per cent of light brown shaly limestone; forms low outcrops.</td>
<td>52</td>
<td>272</td>
</tr>
<tr>
<td>Alternating well-bedded sequence of 4 to 8 inches of dark gray, platy and thin-bedded, shaly limestone, and 1 to 4 inches of dark-gray argillaceous calcilutite; both weather medium gray to very pale orange; Orthograptus calcaratus Lapworth var. trifidus Gurley abundant.</td>
<td>88</td>
<td>220</td>
</tr>
<tr>
<td>Alternating sequence as above, but shaly limestone is laminated brown to dark gray with intercalated silt and clay interbeds; occasional black chert beds; weathers very pale orange; Climacograptus tridentatus Lapworth var. maximus Decker common.</td>
<td>47</td>
<td>132</td>
</tr>
<tr>
<td>As above, with more thick-bedded argillaceous limestone (up to 18 inches); Orthograptus calcaratus Lapworth var. trifidus Gurley abundant in upper 5 feet.</td>
<td>46</td>
<td>85</td>
</tr>
<tr>
<td>As above, with tire-shaped forms weathering out of the argillaceous limestone; contains Orthograptus calcaratus Lapworth var. trifidus Gurley.</td>
<td>36</td>
<td>39</td>
</tr>
<tr>
<td>Calcareous organic mudstone, brownish-black, bedding obscure, strong petrolierous odor.</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

Paraconformity

Eureka quartzite
Section of Roberts Mountains formation measured along section e-e'

**"Nevada" formation**

**Roberts Mountains formation**

Limestone, finely-crystalline, argillaceous, thin-bedded, platy, light brownish-gray and mottled medium-gray and brownish-gray, weathers light brownish gray, some clay interbeds, poorly exposed low outcrops; *Monograptus chimaera* Barrande common... 31 2334

Alternating sequence of thin-bedded (1/2 to 1 1/2 inch), brownish-gray, laminated, argillaceous finely-crystalline limestone; and brownish-gray calcareous, fissile shale; near base, 1 1/2-inch bed of laminated dark gray chert and lighter colored argillaceous finely-crystalline siliceous limestone... 69 2303

Mudstone, calcareous, laminated, graded bedding, light to dark brownish-gray, weathers pale yellowish brown, thick resistant calcarenite beds near top; *Monograptus* sp. rare... 133 2234

Cover, except for isolated outcrops as above... 157 2101

Calcarenite and calcilutite, 4- to 28-inch beds, interbedded with dark gray chert nodules and laminated olive-gray argillaceous calcarenite, few outcrops, seaweed (?) impressions in clay interbeds... 61 1944

Cover... 151 1883

Calcllutite, argillaceous, laminated, thin-bedded, light brownish-gray to light olive-gray, weathers yellowish gray, sporadic outcrops; *Monograptus* sp... 90 1732

Cover, float as above, smooth slope... 1079 1642

Calcllutite, argillaceous, platy and thin-bedded, pale yellowish-brown to brownish-black, isolated outcrops, smooth slope; *Monograptus* sp. rare... 100 563

Calcarenite, thick-bedded, medium light-gray, stained with iron oxides; some hematite and secondary silica; contains poorly preserved brachiopods, gastropods, and corals... 2 463

Cover, isolated outcrops as below... 16 461

Calcllutite, argillaceous, thin-bedded, light-gray to brownish-gray, with interbedded dark-gray laminated chert, isolated outcrops; *Monograptus* sp. rare... 204 445

Limestone, finely-crystalline, 4- to 6-inch beds, medium-gray, laminated, two 4-inch chert beds... 7 241

Cover... 35 234

Calcllutite, thick-bedded, medium light-gray... 2 199

Calcllutite, shaly, thin-bedded, platy, light brownish-gray to brownish-gray, clay interbeds weather pale yellowish gray, *Monograptus* sp. abundant... 14 197
<table>
<thead>
<tr>
<th>Thickness in Feet</th>
<th>Unit</th>
<th>To Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcilutite, argillaceous, platy and thin-bedded, brownish-gray to brownish-black, poorly exposed, dark-gray 4-inch chert bed at top, <em>Monograptus pandus</em> Lapworth abundant.</td>
<td>13</td>
<td>183</td>
</tr>
<tr>
<td>Limestone, finely-crystalline, dark-gray, thick-bedded platy fracture.</td>
<td>9</td>
<td>170</td>
</tr>
<tr>
<td>Mudstone, calcareous, 1/4- to 1-inch beds, pale-brown, <em>Monograptus</em> sp. abundant.</td>
<td>20</td>
<td>161</td>
</tr>
<tr>
<td>Cover.</td>
<td>8</td>
<td>141</td>
</tr>
<tr>
<td>Calcarenite, medium-gray, thick-bedded, poorly exposed.</td>
<td>11</td>
<td>133</td>
</tr>
<tr>
<td>Limestone, finely-crystalline, silicified in part, slightly dolomitic, dark-gray, 2- to 6-inch beds; interbedded with abundant dark gray to black, laminated chert (about 30 per cent), forms massive cliff.</td>
<td>122</td>
<td>122</td>
</tr>
</tbody>
</table>

Hanson Creek formation
Thrust fault

### Vinini formation

| Chert, black and greenish-black, badly stained by iron oxide near top, 2- to 6-inch beds, poorly exposed | 61 | 376 |
| Mudstone, calcareous, mottled olive-gray to brownish-gray, thick-bedded, poorly exposed | 33 | 315 |
| Chert, black, thin-bedded, badly fractured | 33 | 282 |
| Shale, calcareous, laminated, pale yellowish orange | 46 | 249 |
| Chert, black, 3/4- to 4-inch beds alternating with calcareous shale as below, poorly exposed | 10 | 203 |
| Shale, calcareous, 1/8- to 1/2-inch beds, laminated, yellowish-gray and brownish-gray, weathers pale yellowish brown, poorly exposed | 69 | 193 |
| Limestone, argillaceous, aphanitic, dark-gray, laminated, 4- to 12-inch beds, weathers yellowish-gray | 2 | 124 |
| Shale, calcareous, platy, laminated, brownish gray and yellowish gray, weathers pale yellowish-brown, poorly exposed | 122 | 122 |

Thrust fault
REFERENCES CITED


