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

A THESIS
SUBMITTED TO THE FACULTY OF THE UNIVERSITY OF NEVADA
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

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Reno, Nevada
May 15, 1965
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Paleozoic rocks within the Brock Canyon area were studied with respect to extending previously mapped structural and stratigraphic features found in the Antelope Valley and east Monitor Range area to the west side of the Monitor Range.

To the east, in Copenhagen Canyon, the western assemblage Vinini formation has been noted. Some doubt as to its presence has arisen due to stratigraphic, lithologic, and structural relationships within the Brock Canyon area.

Intermediate assemblage rocks are represented within the area mapped and are composed predominantly of clastic limestones ranging in age from Lower Ordovician to Middle Silurian.

Major thrusts exist in the area bringing Lower Middle Ordovician sediments into juxtaposition with sediments of Middle Silurian age. Several minor thrusts exist. Normal faults of considerable displacement have been mapped, but no mappable folds were found.
INTRODUCTION

Location and Accessibility

Brock Canyon is in the Monitor Range along the southern and western boundaries of Eureka County, Nevada. The margin of Tertiary volcanics in Wallace Canyon is the northern boundary of the mapped area. The eastern boundary is also defined by the edge of Tertiary volcanic rocks, and is essentially the central portion of the Charnac Basin. The southern boundary of the area studied is approximately two and one-half (2$\frac{1}{2}$) miles north of the Potts-Rye Grass Canyon Road. Both the southern and western boundaries of the area mapped are the margin of Tertiary volcanics. The mapped area is approximately fifteen (15) square miles.

The Brock Canyon area is 30 airline miles southeast of Austin, Nevada (Fig. 1). Routes to the Brock Canyon area include: two roads south from U. S. Highway 50, down Monitor Valley, one an unimproved fence line road, the other a graded and improved road. These connect with forest service roads in the Charnac Basin via the Wallace Canyon road. An unimproved road from Ardan's Ranch to the Charnac Basin makes access to the area possible from Antelope Valley on the east side of the Monitor Range. The south end of the area may be reached from State Highway 82 by two poor dirt roads. All of the area mapped lies within the boundary of the Toiyabe National Forest.
Fig. 1. - Index Map of Nevada Showing Location of Mapped Area.
Geography

The climate of the Monitor Range is semi-arid. Precipitation is approximately 10 to 12 inches at the lower elevations and up to 18 inches at the higher elevations. These figures are comparative with those for ranges with similar elevations in central Nevada. There are several small, unimproved springs in or near the mapped area. One spring is at the head of Wallace Canyon; three are within the Charnac Basin, and two springs are south of the mapped area. Usually, there is a small flow of water in the upper portion of Wallace Canyon.

Vegetation in the area includes Pinion Pine, Juniper, and sagebrush on the slopes. In the Charnac Basin area, sagebrush, salt grass, bunch grass and wild iris occur.

The primary industry in the surrounding region is cattle ranching.

Physical Features

The topography of the Brock Canyon area is generally moderate to rugged. Both Brock Canyon and Wallace Canyon are steep sided as are the intermediate canyons. The maximum relief of the area is slightly more than 2,000 feet. The lowest elevation is 7,000 feet at the mouth of Brock Canyon, while the highest elevation is at the triangulation station, "Charnac", at an elevation of 9,023 feet above sea level. The drainage in Brock Canyon proper is antecedent, being east-west across north-south trending structures. The north-south drainage is, for the most part, subsequent, due to the northerly strike of beds of
unequal resistance.

Scope of Investigation

This investigation is concerned essentially with the stratigraphy, paleontology and structure of the Paleozoic rocks within the area mapped.

Method of Investigation

The geology was first mapped on aerial photographs of a scale of 1:20,000 and was transferred to a prepared topographic base map with a scale of 1:24,000. Scale reduction was accomplished by the use of an opaque projector.

Fossils, which were replaced by silica, were removed from their limestone matrix by the use of very dilute hydrochloric acid and were studied. Paleontologic dating was established by the study of a varied and abundant fauna.

Thin sections of the various lithologies were studied.

Previous Investigations

Published works on the stratigraphy, paleontology and structure of the Monitor Range and vicinity, prior to this paper, include the following: Hague (1883 and 1892); Hintze and Webb (1950); Twenhofel (1954); Roberts and Lehner (1955); Nolan et al (1956), and Webb (1958).
Regional stratigraphy was revised by Nolan et al (1956); Webb (1958) studied the Middle Ordovician stratigraphy in the Great Basin, which included a locality in the Monitor Range.

Published works on Paleontology, though not specifically applicable to the Brock Canyon area, include Walcott (1884), Upper Ordovician and Silurian graptolites (Ruedemann, 1947), and Lower and Middle Ordovician brachiopods (Ulrich and Cooper, 1938, and Cooper, 1956).

A thesis by Bortz (1959) describes the area to the south-east of Brock Canyon, and was very helpful to the author. Two other theses in the Monitor Range have been completed by Scales (1961) and Behnke (1961).

Dr. E. R. Larson mapped a portion of the Antelope Valley area, but his work has not been published.

Acknowledgements

The writer wishes to express his appreciation to Professor E. R. Larson for suggesting the problem, and for his valuable assistance, both in the field and in the preparation of the manuscript and geologic map. The author's wife, Marion, helped in the organization of reference material and offered continued encouragement to the completion of the problem.
STRATIGRAPHY

Introduction

In the vicinity of Brock Canyon, the Paleozoic rocks are predominately limestone, though quartzite and chertstone are present. These rocks, for the most part, represent the "eastern assemblage", which is described by Roberts et al (1958) and are considered to be autochthonous or para-autochthonous. The rocks in this assemblage range in age from Middle Ordovician to Silurian. The Ordovician is represented by four formations ranging from Chazyan to Richmondian, which are well exposed in many places throughout the area.

The Silurian is represented by a thick sequence of Niagaran limestones. Rocks of Medinan age are apparently absent, within the area mapped.

The sediments of the eastern assemblage were deposited in the miogeosyncline of north-central Nevada. A major orogeny in central Nevada, which began during the latest Devonian and continued to the early Pennsylvanian, marked the end of the eastern carbonate assemblage deposition in some localities.

Intermediate assemblage sediments of Ordovician and Silurian age have been recognized within the area mapped. Though complex thrust faulting is in evidence and "western assemblage" sediments have been reported on the west side of the Monitor Range, no positive evidence of their occurrence near Brock Canyon has been found.
Fig. 2. View south showing general geology and terrain of the Brock Canyon area. Note the Ordovician Antelope Valley thrust over the Silurian Roberts Mountain formation. Also, visible are Ordovician Hanson Creek, Eureka, and Copenhagen formations.
Rocks identified as intermediate assemblage, in the Brock Canyon area, are intermediate between eugeosynclinal Western assemblage and miogeosynclinal Eastern assemblage rocks.

Middle Ordovician sediments overlie Upper Ordovician and Silurian sediments at many localities because of major thrusting. The relationships found in the Brock Canyon area are reflected on the east side of the Monitor Range in the area mapped by Bortz (1959).

The following terms will be used to describe bedding thickness: laminations, distinct alternations of material 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. The rock color terminology is used in this paper 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 on Pogonip Ridge (Mount Hamilton) in White Pine County, Nevada. The sediments described ranged from Early Cambrian to Middle Ordovician (i.e., from Prospect Mountain Quartzite to Eureka Quartzite). Hague (1883, p. 260; 1892, p. 48-49) redefined the Pogonip to include only the sedimentary rocks between the Dunderberg shale and the Eureka Quartzite. Merriam and Anderson (1942, p. 1683) elevated the Pogonip formation to group rank, and L. F. Hintze (1949; 1951, p. 11) and others 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 Hintz's usage and have defined the group's boundaries in the vicinity of Eureka, Nevada. Also, they have subdivided the group into three formations, which in ascending order are the Goodwin limestone, the Ninemile formation, and the Antelope Valley formation all of which are exposed in or near Antelope Valley and the Monitor Range.

Neither the Goodwin formation nor the Ninemile formation was found within the Brock Canyon area.
Antelope Valley Limestone.

The Antelope Valley limestone, named by Nolan et al (1956, p. 28), is the uppermost formation of the Pogonip group. The type locality is along the base of the eastern slope of Martins Ridge. It is exposed extensively in the Antelope Valley area. This limestone is present on the west side of the Monitor Range from Wallace Canyon to the Copenhagen Canyon Road, and constitutes approximately 1/2 of the exposed limestone in the vicinity of Brock Canyon.

The base of this formation, in the area mapped, is concealed by Tertiary volcanics or by Quaternary alluvium. The base of the Antelope Valley limestone in the thrust sheets was not seen.

The top of the Antelope Valley limestone, in the autochthonous sequence, is paraconformably overlain by the quartz arenite member of the Copenhagen formation. Nowhere, within the area mapped, is the actual contact seen, but the quartz arenite member of the Copenhagen crops out in numerous places west of V.A.B.M. Charnac. In the thrust sequence, Antelope Valley limestone is disconformably overlain by Silurian Roberts Mountains formation.

The Antelope Valley formation is composed almost completely of clastic limestone, which has been recrystallized to varying degrees. Secondary silica and fine detrital material are the most obvious impurities. Very little chert is found in the beds of this limestone, but various sized veinlets of calcite are common. The formation is composed predominately of thick-bedded massive medium gray to medium dark gray fine grained, clastic limestone. Cliff-forming units are
not uncommon, especially in the thrust sequence. Locally, thin-bedded zones are found, especially near the top of the formation.

The formation was subdivided by Bortz (1959) into three units based mainly on outcrop expression, but only a portion of his middle unit and all of his upper unit appear to be present in the Brock Canyon area.

The cliff-forming middle unit contains typically medium light-gray to medium-gray to gray clastic and crystalline limestone. Silty and argillaceous limestone was not particularly noted, but the degree of recrystallization and the amount of calcite would indicate local alteration. This unit is found from the mouth of Brock Canyon southward to the Potts-Rye Grass Canyon Road, and also makes up the bulk of limestone exposed in the thrust sequences.

The middle unit contains numerous *Pallisera longwelli* (Kirk) and other low-spired gastropods. An important fossil horizon, which contains abundant *Pallisera longwelli*, is located 80 feet below the Antelope Valley-Copenhagen contact. On Martins Ridge, the crowded *Pallisera* zone is approximately 400 feet below this contact. This would suggest that the upper portion of the Antelope Valley formation is missing, and has thinned from the east; however, additional beds are apparently present at the top of the Antelope Valley in the Toquima Range (Kay, 1964) to the west. Zones of maximum *Pallisera* abundance are apparently irregular in the 650 foot *Pallisera* zone as

*Receptaculities* sp. is found in the upper part of the zone, but not in the abundance described by Cooper (1956, p. 126). Other fossils present in the middle unit are *Maclurites* sp., occasional high spired gastropods, and leperditid ostracods.

The upper zone is a thin bedded clastic and coarsely-crystalline limestone with irregular silty beds and partings. The limestone is medium-gray to medium, light gray or pale, yellowish-brown, and weathers to surface colorations of whitish-yellow, tan, and light brown because of a quantity of clay and silt. Several zones of fossil hash are present in the upper few feet.

The upper zone contains *Anomalorthis nevadensis*, Ulrich and Cooper, *Hesperorthis anteloopenensis*, Cooper, trilobite fragments, high spired gastropods, and plates and stems of crinoids.

The thrust plate, within the Brock Canyon area, is made up of the upper middle zone and the upper zone, as indicated by fossil evidence. In the Charnac Basin Area, (F-1) *Hesperorthis anteloopenensis*, Cooper, and *Anomalorthis nevadensis*, Ulrich and Cooper, are abundant. In the thrust plate at other locations, the Antelope Valley limestone contains well preserved *Palliseria longwelli* specimens, which are indicative of the Middle zone. The distribution of these fossil horizons, within the vertical extent of the thrust sheet, does not appear to greatly differ from that of the Antelope Valley limestone beneath it.

The Antelope Valley limestone is classified as Chazyan by Nolan et al (1956, p. 29). Wabb (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

Overlying the Antelope Valley limestone, paraconformably, is the Copenhagen formation. This formation is composed of a lower quartz arenite member, a middle thin-to-thick bedded argillaceous limestone with abundant intercalated clay, silt, and fossil hash, and an upper argillaceous member.

This formation was first described by Kirk (1933), who stated that about 250 feet of "Black River" (Bolarian) sediments represent an argillaceous facies of the lower part of the Eureka formation. Merriam (1963) defines the Copenhagen formation from exposures in Copenhagen Canyon; Nolan et al (1956, p. 28) and Webb (1958) have used this formational name.

Poor to fair exposures of this formation occur from one mile north of the Potts-Rye Grass Canyon Road to Brock Canyon proper. In many locations where the Copenhagen formation should be present, it is completely concealed by talus from the overlying Eureka quartzite. The best exposures of the Copenhagen formation are found in Brock Canyon, where all but the top-most beds of this formation can be seen. Where it can be seen, the contact with the Antelope Valley formation is abrupt.

The thickness of the formation is about 490 feet, but, due to faulting and a covered Copenhagen - Eureka contact, the true thickness is not
known. Nowhere were the exposures of the Copenhagen formation continuous enough to afford an accurate measured section. Webb (1958, p. 2339) estimated a total possible thickness of 600 feet or more at Martins Ridge in the Antelope Valley. Merriam has measured only 350 feet in the same area.

The lower quartz arenite member is exposed only toward the south end of the area mapped. The maximum thickness of this member is approximately 30 feet, measured along a section a-a' (See Plate I.). The first occurrence of this formation, to the East, is on the east side of Martins Ridge nearly 6 miles away. This member weathers pinkish-brown, sometimes with reddish or orange-brown surfaces, most of the staining being due to iron oxides. A freshly fractured surface is light gray to white with tints of yellow, pink, tan, and light red.

The rock is a fine grained quartz arenite and the matrix is of calcite, which aids in distinguishing it from the siliceous matrix of the Eureka quartzite overlying the Copenhagen formation.

No fossils were found in the lower quartz arenite member by this author, but Webb (1959, p. 2340) found the nautiloid Endoceras sp. in the Antelope Range.

The middle member crops out from Brock Canyon to the south end of the area with the best exposures in Brock Canyon. The composition of this member is argillaceous, clastic, and crystalline limestones, some portions of which are abundantly fossiliferous. Intercalated shale yields a characteristic yellowish-orange color to the typically
smooth weathered slopes of this member.

The middle limestone member is a dark gray to dark-brownish-gray, interbedded clastic limestone, calcilutite, crystalline limestone. In the zones where fossil trash is abundant, the fossil fragments make up approximately 30 per cent of the rock by volume, and the silica contained in these rocks is anywhere from 22 per cent to 41 per cent by volume. On etched specimens, the siliceous material often forms a lacy pattern, which may join silicified fossil fragments. Coarse clear calcite and calcite veinlets have been formed by recrystallization.

The thickness of the middle unit is 425 feet as measured along section a-a' (See Plate I), but the measured sediment thickness may be in error due to omission of beds by faulting.

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

From fossil location number 2. (See Plate I.)

- *Eoplectodonta alternata* (Butts)
- *Sowerbyella merriami* Cooper
- *Sowerbyella* sp. Cooper
- *Sowerbyites lamellosus* Cooper
- *Valccurea plana* Cooper
- *Prasopora* sp.

From fossil location number 5. (See Plate I.)

- *Macrocoelia Occidentalis* Cooper
- *Strophomena* Cooper sp. 1
- *Isophragma Ponderosum* Cooper
- *Lingulasma occidentale* Cooper
- *sowerbyella* sp.
Overlying the middle argillaceous limestone member is the upper argillaceous member. Exposures of a portion of this member are found in Brock Canyon proper and 2 miles south. The upper members contact with the Eureka quartzite was not seen. This member and the middle member is generally covered by float from the overlying Eureka quartzite.

The upper member is composed of calcareous or limey shale and mudstone in an alternating sequence. Some calcarenite and crystalline limestone is interspersed with the above. For the most part, the calcareous shale is a light yellow-brown which weathers to an orange-brown surface. The calcareous mudstone is yellow-brown to pinkish-brown within and weathers yellow-orange to dark brown. The crystalline limestone is medium gray to gray-brown and also weathers yellow. This member is, for the most part, thin bedded but occasional thick bedding occurs. The dark coloration, as described by Bortz (p. 15) and the prominent outcrops as described by Webb, were not apparent. Neither fossils nor fossil fragments were found by this author.

Numerous age classifications of the Copenhagen formation have been proposed. Kirk (1933, p. 42) proposed an approximate age of Riverian. Cooper (1956, p. 128; Twenhofel et al, 1959, Chart 10 d) suggested a late Chazyan to medial Trentonian age. A Black Riverian to Trentonian age is cited by Nolan et al (1956, p. 31), and medial
Bolarian to medial Trentonian age by Webb (1958, p. 2367), Scales (1961, fig. 2, p. 9) suggests a medial Bolarian to upper Trentonian age.

Eureka Quartzite

The name "Eureka Quartzite" was suggested by Hague (1883, p. 262; 1892, pp. 54-57) for a resistant, cliff-forming, vitreous white quartzite found in the vicinity of Eureka, Nevada. Due to extensive fracturing of this formation, the type location was redesignated as the well-exposed section along the west base of Lone Mountain by Kirk (1933, p. 34). Nolan et al (1956, pp. 29-32) described the Eureka quartzite as does Webb (1958).

The Eureka quartzite is exposed in the Brock Canyon area, from Brock Canyon proper to approximately the southern boundary of the area mapped. Because of faulting or landsliding, the formation is repeated three times along the south side of Brock Canyon. The southernmost exposure of Eureka quartzite terminates at a major east-west fault.

Though the base of this formation is not exposed, and the top is ill-defined, this writer would estimate that the overall thickness of the formation is in the neighborhood of 55 to 60 feet and is certainly not over 80 feet in thickness. This would indicate a rapid and expected thinning to the west. Bortz (1959, p. 16) measured 200 feet of quartzite on Martins Ridge comparing favorably with Webb's 220 feet, measured also on Martins Ridge.
Kirk (1933) and Bortz (1959) divide the Eureka quartzite into three parts, but they disagree as to thickness of the parts and the lithology. This author was unable to distinguish any variation in the quartzite within the confines of Brock Canyon, so, this formation herein is described as a single unit.

The quartzite is a light gray to white, vitreous orthoquartzite. A lack of iron staining distinguishes the Eureka from the lower quartz arenite member of the Copenhagen formation. For the most part, this rock does not effervesce on application of dilute hydrochloric acid, so, this too, aids in distinguishing it from the quartz arenite member of the Copenhagen formation. In thin section, this rock is composed of fine-grained, well-rounded quartz, and the matrix, for the most part, is authigenic quartz though scattered traces of calcareous cement, clay, and hematite are present.

Overlying the Eureka quartzite paraconformably is the argillaceous limestone of the Hanson Creek formation, though at no location is the contact between the two visible.

As no direct fossil evidence for the age of the Eureka quartzite exists, its age is based on the assigned age of adjacent formations. This places its age between the upper Trentonian of the Copenhagen formation and the Richmondian of the overlying Hanson Creek formation.

Hanson Creek Formation

This formation was proposed by Merriam (1940, pp. 10-11) and
consists of the sediments between the Eureka quartzite and the Roberts Mountains formation of Silurian age. The type locality is on the north fork of Pete Hanson Creek, on the northwest flank of Roberts Creek Mountain, approximately 45 miles northeast of Brock Canyon. Here the formation is 560 feet thick and is composed of dolomitic limestone, and thin-bedded, shaly limestones (Merriam and Anderson, 1942, p. 1686). At Lone Mountain, the formation is, for the most part, dolomite and dolomitic limestones.

The Hanson Creek, in the Brock Canyon area, is from 95 feet to 270 feet of shaly limestone and aphanitic limestone.

The formation is poorly exposed but rare outcrops indicate that the rock is a medium gray to dark gray, thin to thick-bedded limestone or calcareous shale with some recrystallized limestone. The unit forms smooth slopes and nowhere is its contact with the underlying Eureka quartzite discernable. Fossil evidence was, for the most part, poor due to recrystallization but Favosites sp. and Halysites sp. are present, as are fragments of trilobites and brachiopods.

The contact with the overlying Silurian Roberts Mountains formation is sharp and distinct, and may be examined just north of Brock Canyon.

The Hanson Creek formation has been assigned to the Late Ordovician or Richmondian (Nolan et al, 1956, p. 32). As yet, few indicative fossils have been found with the exception of the colony corals mentioned. These do little to establish the formation's age.
The basal chert member, of the overlying Roberts Mountains formation, is like beds in the Hanson Creek, and could be included in this formation in the Brock Canyon area, though regional relationships and the occurrence of Silurian fossils in the upper part of the widespread chert member indicate its Silurian affinity.

Intermediate Assemblage

The intermediate assemblage is considered to be contemporaneous with the eastern assemblage and to have been deposited in a eugeosynclinal environment. Roberts et al (1958, p. 2832) considers all presently known exposures of the intermediate assemblage as allochthonous.

Vinini Formation

The Vinini formation is named and described by Merriam and Anderson (1942, pp. 1693-1698) from exposures on Vinini Creek on the eastern slope of Roberts Creek Mountain. This formation is equivalent in age to the Antelope Valley formation. The Vinini has been subdivided into two members. The lower member is composed of limestone, calcareous sandstone, siltstone, quartzite, lava flows and tuffs. The upper member is composed of successive beds of cherts and shales.

Exposures of bedded chert, argillite, black shale and platy argillaceous limestone, in Copenhagen Canyon, have been designated Vinini by Bortz (1959, pp. 21-22). His evidence for correlating these rocks with those named Vinini on Roberts Creek Mountain was, for the most part, lithological.
The major premise in Bortz's correlation of the Vinini formation, from Roberts Creek Mountain to Copenhagen Canyon, is the occurrence of chert nodules at both locals. It is doubtful that such a correlation over a distance of 35 miles based on only "walnut-sized black chert nodules" should be made, especially without supporting fossil evidence.

Field examination, by the author, of the "Vinini" formation in Copenhagen Canyon would indicate it is lithologically similar to the Silurian Roberts Mountains formation found in the Brock Canyon-Charnac Basin Area.

For the most part, the Silurian Roberts Mountains formation, in the Brock Canyon area, is unfossiliferous, but restricted zones do contain monograptids. R. J. Roberts (oral communication, 1959) stated "that graptolites have been found in Vinini exposures in Charnac Basin." This writer considers the formation mentioned to be Roberts Mountains and the graptolites to be Silurian and questions the identifications by Bortz and Roberts.

SILURIAN SYSTEM

Roberts Mountains Formation

The Roberts Mountains formation, (Merriam, 1940, pp. 11-12), is found only in the region west of Eureka. The type locality is on the west side of Roberts Creek Mountain, 45 miles northeast of Brock Canyon, where the formation is 1,900 feet thick. At Lone Mountain, the formation
is 741 feet of dolomite with a basal chert zone. Within the Brock Canyon - Charnac basin area, the Roberts Mountains formation is approximately 850 feet thick. As the contact with the overlying formation is not visible within the mapped area, and the possibility of repetition or omission of beds by normal faulting, the exact thickness is indeterminate. Bortz (1959, p. 23) reported 2,447 feet of Roberts Mountains limestones, but this figure may be excessive as Merriam (1963) reports 600 feet.

In the vicinity of Brock Canyon, the Roberts Mountains formation, in the autochthonous block, overlies the Hanson Creek formation, and in the thrust sequence, unconformably overlies the Antelope Valley formation.

The Roberts Mountains formation is made up of two distinct members. The lower member is made up predominately of chert and silicified dolomitic-limestone breccia and is approximately 30 feet thick.

The rock is a dark brown to blackish brown rock, fine grained with the brecciated portion being firmly cemented by secondary silica. Some calcareous material is present in the form of unreplaced limestone fragments and matrix material, but, for the most part, replacement has been complete. In some instances, the bedding planes of the replaced dolomitic limestone are still evident, though the upper 10 feet of the member, brecciation and recementation have obscured them.

For the most part, this chert member forms cliffs, the best exposures being in Brock Canyon.
The upper member is made up of thin-thick bedded limestones, bedded chert, argillite and black shale. Smooth slopes are typical of exposures of this formation, and also the yellowish-brown to light tan coloration of the weathered surfaces. Clay and silty interbeds are common, weathering to light violet-gray and pale yellowish gray. *Monograptus* bearing beds form a minor part of this formation with major zones 40 feet and 110 feet above the lower chert member.

In the thrust sequence, the lower chert member appears to be tectonically thinned or was not in evidence. The rock in the thrust sequence is similar in lithology to that in the autochthonous sequence, with platy or thin-bedded exposures predominating. Monograptids were not found in the Roberts Mountains thrust sequence, but, continued searching probably would produce specimens. Often, the formation is covered by float from the overlying Antelope Valley formation. The thickness is estimated to be 200-250 feet, though no section was measured.

Just east of the chert member, in Brock Canyon on the north side of the Valley, are two good fossil localities containing graptolites. The following were identified by the writer:

- *Monograptus* sp.
- *Monograptus acus*, Lapworth
- *Monograptus pandus*, Lapworth

No fossil evidence was found other than graptolites. Ruedemann (1947, p. 109) and Nolan et al (1956, p. 37) suggest that the formation's age is approximately Niagaran.
Fig. 3. View north in Brock Canyon of Ordovician Antelope Valley formation thrust over Silurian Roberts Mountains formation. Fossil location 6 is in left foreground.
Bortz (1959, p. 24) states that "The base of the chert zone conformably overlies the Hanson Creek formation," and it has been reported by many authors (Nolan et al., 1956, p. 37; Webb, 1958; Bortz, 1959, p. 24) that the Silurian has a basal chert member.

If this chert is conformable with the Hanson Creek, and Ruedemann and Nolan are correct with their establishment of a Niagaran age for the Silurian Roberts Mountains formation, then the chert most logically belongs with the underlying Hanson Creek, and it would appear that rocks of a lower Silurian age (Medinan) are missing. If the chert is actually Silurian in age and conformable with the Hanson Creek as stated, then perhaps it represents this here-to-fore unmentioned Lower Silurian Median Age.

The Niagaran age, as proposed by Ruedemann, will be used by this author.

TERTIARY LAKE DEPOSITS

Lake deposits of a Tertiary age are to be found in the upper reaches of Brock Canyon. These rocks, for the most part, are thin bedded, yellow to cream-colored, tuffaceous sediments. Though no extensive study of these rocks was made, they are a part of the volcanic sequence of the area which is assigned to the Tertiary.

UNDIFFERENTIATED CENOZOIC SEDIMENTS

This unit comprises pediment and perched alluvial deposits, which are likely Tertiary in age. It is also possible that these
fresh water deposits are Lower Cretaceous in age, perhaps equivalent to the Newark Canyon Formation (Nolan et al, 1956, pp. 68-70).

The unconsolidated material is well above any of the Quaternary drainage deposits, and has been eroded. Typically, the surfaces of these deposits are covered with a variable talus, consisting of Antelope Valley limestone, platy Silurian limestone, and what might be Pennsylvanian limestone conglomerate. At one location, the conglomerates form spires and pinacles due to differential erosion.

The rocks in these deposits are, for the most part, conglomerates, though silts, sandstones, grits and probable fresh water limestones are also present. Good to fair exposures of these deposits are at the south end of the area. The bedding of these deposits dip at low angles, and the alluvial deposits appear to rest with angular unconformity on the underlying Paleozoic rocks.

The deposits of conglomerate and sandstone appear to be overlain by Tertiary volcanic rocks and have an approximate thickness of 250 feet.

The Cenozoic sediments contain pebbles and boulders of limestone conglomerate which contains pebbles and cobbles of limestone, quartzite, and dark black, dark gray and light to dark green chert. The green chert appears to be typical of this particular conglomerate. A similar green chert, in a limestone conglomerate, was seen by the author in the Toquima Range. This latter formation, the Wildcat Peak (Kay, 1964, p. 441) has been dated as Pennsylvanian. A wedge of similar rock was
found, in fault contact with Silurian, Roberts Mountains limestone in
the Copenhagen Canyon area, but no large exposures of this type of rock
have, as yet, been found in the Monitor Range (E. R. Larson, personal
communication). It is quite possible that these clasts, in the
Cenozoic sediments, are of Pennsylvanian age, though there is no direct
evidence to support this.

QUATERNARY ALLUVIUM

The alluvium, of the area, consists of unconsolidated sediments
which range in size from clays to large boulders. The clastic material
represented, has been derived from both sedimentary and volcanic sources.
Alluvium is found in most drainage channels and forms alluvial fans and
valley cover in Monitor Valley proper. Cyclic deposits of coarse to
fine alluvium are often well exposed on the flanks of deep washes in
Brock Canyon.

IGNEOUS ROCKS

Tertiary Volcanics

Tertiary Volcanics are found surrounding the mapped area where
they blanket the Paleozoic rocks. The volcanics were not studied, but
in the course of mapping exposures of Paleozoic rocks, the Tertiary
volcanics were fairly well delimited. No attempt was made to map
the individual volcanic rock units, which consist, for the most part,
of rhyolite tuffs, water laid tuffs, and intermediate to acid flows.
Nolan et al (1959) has suggested a Tertiary age for volcanic flows, in the Eureka Mining District, and this age is applied here.

STRUCTURES

The structural pattern, represented by Paleozoic sediments in the Brock Canyon area, is twofold. The major structural pattern in evidence is one of imbricate thrust faulting, which is apparent both north and south of Brock Canyon. These thrust faults have brought a westerly facies into juxtaposition with the eastern facies. The secondary structural pattern is high-angle normal faults, which have modified the exposures of the allochthonous and autochthonous sequences.

Minor normal faulting is common, and, for the most part, was not considered important enough to map. Folding was not recognized as one of the major structural features though minor instances of folding were observed, especially in conjunction with faulting.

THRUST FAULTS

Major thrust sheets, made up of intermediate assemblage Antelope Valley and Silurian Roberts Mountains formation, occupy the topographic high points from Wallace Canyon to the south end of the mapped area.

From Brock Canyon to a point 3 miles south, only one thrust sheet is apparent. This thrust placed the Antelope Valley formation above the Roberts Mountains formation. In the area north of Brock Canyon,
this same thrust fault carried a more complete intermediate assemblage of Antelope Valley, and superjacent Silurian Roberts Mountains formations over the eastern assemblage of Antelope Valley, Copenhagen, Eureka, Hanson Creek, and Roberts Mountains formations.

A second thrust sheet, composed of intermediate assemblage Antelope Valley and Silurian Roberts Mountains formation, may tectonically overlie the above mentioned thrust sheet of intermediate assemblage rock. The Antelope Valley limestone in this thrust sheet contains *Palliseria longwelli* (Kirk) in a zone approximately 145 feet above the thrust fault.

The intermediate assemblage rocks, in these thrust sheets north of Brock Canyon, for the most part, dip moderately toward the east. The eastern assemblage rocks beneath the thrust sheets, are dipping steeply toward the east, north of Brock Canyon, and moderately to the east, south of Brock Canyon.

It is believed, that much of this thrusting has affected the area west of Copenhagen Canyon, for numerous thrust faults were mapped by Bortz (1959).

For the most part, it appears that the plane of the thrust fault is parallel to the bedding of the sediments within the thrust sheet.

Antelope Valley limestone remnants of the major thrust sheet are present in the Charnac Basin. Their relationship to the Roberts Mountains formation beneath has been complicated by normal faulting.

Minor thrusting occurs within the eastern assemblage Silurian Roberts Mountains formation, in the plane of the bedding. Evidence of this is the brecciation of the lower chert member and its variable thickness.
Fig. 4. View west down Brock Canyon showing Silurian Roberts Mountains formation overlying Antelope Valley formation which is in a thrust relationship with underlying Silurian Roberts Mountains formation.
Also, north of Brock Canyon, Eureka quartzite and the chert member of the Roberts Mountains formation, have been brecciated by minor thrusting, perhaps as a reflection of major thrusting above. This faulting, as shown on sections A-A' to D-D' (Plate II), is a result of gravitational sliding to the west prior to the emplacement of the higher thrust sheets.

The direction of movement, on these thrust faults, is probably from the west or northwest as indicated by regional studies of central Nevadan thrusting made by numerous authors (Merriam and Anderson, 1942, p. 1704; Roberts et al, 1958, p. 2813).

No attempt was made to determine the horizontal displacement on these thrust faults, as the problem is a regional one. A minimum displacement of 16 miles for the Roberts Mountains thrust has been reported in the Roberts Mountains (Merriam and Anderson, 1942, p. 1704). Estimates of horizontal displacement, in the tens of miles, have been made for the Roberts Mountains thrusts and other thrusts in central Nevada (Carlisle et al, 1955, pp. 1645-1646; Roberts et al, 1958). Since the Roberts Mountains thrust and the thrust in the Brock Canyon area both contain western assemblage sediments, it is possible that their displacement is of a similar magnitude.

NORMAL FAULTS

Numerous normal faults are found within the area mapped, and several of them show displacement in excess of 1,000 feet. Two fault directions have been recognized: north-south trending faults which
Fig. 5. View east toward V.A.B.M. Charnac showing Ordovician Antelope Valley formation over Silurian Roberts Mountains formation. Note cliff-forming brecciated chert member of the Roberts Mountains formation in foreground.
approximate the strike of the bedding, and north-east and south-east trending faults.

The normal fault with the greatest displacement is in the north Fork of Brock Canyon. This fault, which post dates all thrusting, has a down-dropped northern block with approximately 950 feet of displacement, so that the numerous thrust sheets of intermediate assemblage rocks are exposed on the northwest side of the Canyon, but only one major thrust sheet is exposed on the southwest.

Another high angle fault with approximately 900 feet of displacement is at the south end of the area. The south block is down, with respect to the north, bringing the thrust sheet of intermediate assemblage rocks adjacent to eastern assemblage rocks, and offsetting the eastern assemblage Roberts Mountains formation to the west.

A portion of the top of the Antelope Valley formation and the bottom of the Copenhagen formation has been eliminated by a dip-slip strike fault. This fault crosses Brock Canyon 1,800 feet southwest of the fork, offsetting a fault splinter of intermediate assemblage rocks 2,300 feet north of Brock Canyon, and trends southerly 6,500 feet marking the boundary between the Antelope Valley formation and the Copenhagen formation, and cannot be distinguished one and a half miles south. It is to be noted that at fossil location (F-4), a major zone of *Palliseria longwelli* is 80 feet below the Copenhagen formation. All of the dark shaly limestones and the quartzite member at the base of the Copenhagen formation are missing. This would suggest at least 200 feet
of displacement on this fault as approximately 110 feet of Antelope Valley limestone and more than 90 feet of the Copenhagen formation are missing.

Numerous faults, of small displacement with approximately east-west trend, are found throughout the area but were not mapped. Often, these minor normal faults offset the thrust planes and bedding alike.

Several faults north of Brock Canyon trend north and south, with displacements up to 200 feet. These faults modify the exposures of the western assemblage thrust sheets.
GEOLOGIC HISTORY

The eastern assemblage rocks were, for the most part, deposited in a clear, shallow sea. This shallow early Ordovician sea extended from unknown cratonal positive areas, either low or distant, or both, across the subsiding miogeocynolines from central Nevada to central Utah. These cratonal areas produced varying amounts of terrigenous, clastic detritus.

The presence of fossil hash and occasional cross-laminated beds found locally in the Antelope Valley limestone and Copenhagen formation, is indicative of shallow water deposition, and that the depositional conditions remained stable for long periods of time, is marked by the persistance of lithologic units.

The western edge of the Pogonip Group may have marked the outer edge of the continental shelf of the early Ordovician, with the rocks of the eastern assemblage deposited in shallow water, and the rocks of the western facies deposited on the frontal slopes, and deeper water seaward. Whether the deeper water beyond the miogeocynclinal continental shelf was open sea or whether it was already partly enclosed by an island group is not known. (Webb, 1958).

Periodic emergence of the depositional basin is marked by several unconformities. In the Chazyan and Black River, one or more cratonal and possibly uplifted geosynclinal areas became subject to erosion, yielding, for example, the lower quartz arenite member of the Copenhagen
formation. This unit was probably developed on the edge of a continental shelf during an interval of regression (Webb, 1958, p. 2371).

The sands and argillites of the Copenhagen formation were deposited on the emerging shaly member in a near shore environment.

Isopachous and paleogeographic studies by Webb (1958, pp. 2371 and 2372, Fig. 7-8) would indicate that the Copenhagen formation was deposited in a basin, and that emergence and erosion, in the Bolarian and early Trentonian, may have occurred.

After a period of erosion, the transgressive Eureka quartzite was deposited in a widespread middle to upper Ordovician sea. The clastic sediments of this formation were probably derived from land masses, both to the east and south, and possibly to a minor degree from the west. (Kirk, 1933) Although, in his discussion, the Eureka is spoken of as laid down in a sea, it may have been essentially a continental deposit, for Kirk mentions widespread occurrence of cross-bedding, ripple marks, the lack of fossils within the quartzite, and sun cracks indicating shallow water and emergent conditions.

Uplift and an unknown amount of erosion occurred after the deposition of the Eureka Quartzite. Upon this beveled surface the Upper Ordovician (Richmondian) Hanson Creek formation was deposited in a marine environment, and the positive source areas, which were active in the Middle Ordovician, did not contribute clastic material to it.

Concurrent with the deposition of the eastern assemblage, the
western assemblage was being deposited in a rapidly subsiding sea supplied with a vast amount of terrigenous clastic material.

Prior to medial Silurian, and possibly as early as very latest Ordovician, part of central Nevada suffered uplift and erosion of considerable magnitude (Webb, 1958, p. 2376). It is possible that this erosion affected the Brock Canyon area where the Hanson Creek formation is approximately 95 feet thick, while on the east side of the Monitor Range its thickness is 497 feet (Bortz, 1959).

Upon this erosion surface the graptolitic, Silurian Roberts Mountains formation was deposited. The chert member, at the bottom, was probably formed in a shallow sea, or in an emergent environment, and the overlying thin bedded argillaceous limestone was formed in a rather stable confined area. It is of interest to note that the character of this formation changes rapidly to the east.

In the Antelope Range, the Roberts Mountains formation is a dark gray, massive bedded limestone with little argillaceous material present. In Copenhagen Canyon, the formation is a light gray, thick to thin bedded limestone with some argillaceous material present, while in Brock Canyon the formation is predominantly thin bedded, argillaceous limestone which weathers to a light tan. It is this author's belief that the Roberts Mountains formation in Brock Canyon is transitional between western and eastern facies.

The Niagaran limestones are the youngest rocks of the eastern assemblage to be found in the mapped area. It was indicated by Bortz (1959) that the youngest rocks in Copenhagen Canyon are Helderbergian
in age, and therefore thrusting could not be older than upper Devonian
in age.

Uplift of the Manhattan Geanticline began in Middle to late
Devonian and split the Nevada depositional basin. This uplift caused
erosion of Devonian beds, and acted as a source of sediments in later
periods. Also, this mountainous area made thrusting due to gravita­
tional sliding possible. Presumably, the land was elevated along the
border of the Millard and Fraser belt. Carlisle et al (1955, p. 1539)
suggest that the thrusting is of the overthrust type, rather than
gravitational thrusting, but this author believes that gravitational
thrusting is the more probable. At least two thrust faults have been
recognized in the Brock Canyon area, and it is possible that other minor
thrusting will be recognized. The first stage of thrusting has brought
intermediate facies Silurian and Ordovician rocks over rocks of the
eastern facies, and a second thrust then placed more intermediate
assemblage rocks over the top of the aforementioned. Major shear or
vertical faulting served to offset eastern assemblage rocks and western
assemblage rocks contemporaneously, with thrusting and weak north­
easterly and northwesterly vertical faults were developed in the lower
plate.

By lower Pennsylvanian time, according to Bortz (1959), and Roberts
et al (1955, p. 1661), submergence of the orogenic area allowed the
deposition of lower Pennsylvanian limestones on underlying formations.
If we are to continue with the theory that most of the thrusting was a
result of gravitational sliding, then it is likely that the age of the
thrusting was between the middle Devonian and the beginning of Pennsylvanian time or later.

Mesozoic (?) or Cenozoic continental sediments were deposited on the Paleozoic erosion surface, and after all the above mentioned sediments were eroded, Tertiary volcanic rocks were deposited. These probably covered the entire mapped area, for isolated outcrops of volcanic rock were found throughout. After this emplacement of volcanic rock, normal faulting and warping modified the Tertiary Paleozoic structural relationships. Warping and normal faulting probably began in early Tertiary time (Nolan, 1943, p. 183; Louderback, 1924, pp. 1-44) and affected both the Paleozoic and Tertiary rocks. The typical basin and range topography were produced by faulting in Tertiary and Quarternary time, and fault scarps and fault line scarps show that this faulting continues at the present time.
Intermediate and eastern assemblage rocks in the Brock Canyon area are found adjacent in thrust relationship. The intermediate assemblage represented by the Silurian Roberts Mountains formation overlying unconformably Ordovician Antelope Valley formation. Eastern assemblage is represented by Ordovician Antelope Valley, Copenhagen, Eureka and Hanson Creek, and also Silurian Roberts Mountains formation, which are all in the autochthonous block.

The thrust sequence, north of Brock Canyon, involves intermediate assemblage sediments and consists of two major and several minor thrust sheets in imbricate relationship. The lower most thrust plate rests upon eastern assemblage rocks. Thrusting occurred from late or middle Devonian until the early Pennsylvanian time.

Facies differences between the eastern and intermediate assemblages are not apparent.

Rocks called Vinini formation in the Charnac Basin and west of Copenhagen Canyon, by some authors, are probably intermediate facies of the Silurian Roberts Mountains formation.

This author suggests that the chert member of the Silurian Roberts Mountains formation should perhaps be placed in the Ordovician Hanson Creek formation.
REFERENCES CITED


