AN ABSTRACT OF THE THESIS OF

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Title: ORDOVICIAN TO SILURIAN STRATIGRAPHY OF PART OF THE NORTH-CENTRAL MONITOR RANGE, NYE COUNTY, NEVADA

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Ordovician to Silurian limestones, quartz arenites, and other sedimentary rocks were mapped in the extreme southwestern part of Antelope Valley and on the eastern flank of the north-central Monitor Range, Nye County, Nevada.

The oldest Ordovician formation, the Goodwin Limestone, is over 385 feet (117m) thick and was deposited near the western edge of carbonate shoal environments of the continental shelf. It is succeeded by the Ninemile Formation, in excess of 55 feet (17m) of thin-bedded nodular lime mudstone and intercalated shaly limestone, which was deposited in a moderately deep water, east-west-trending embayment of fine-grained clastic and carbonate rocks of the outer continental shelf. The superjacent Antelope Valley Limestone is over 1,200 feet (366m) thick and is subdivided into three informal members: a lower unit, middle unit, and upper unit. Infilling of the

Ninemile embayment by westward progradation of carbonate shoals is recorded in the lower and basal middle units, and continued shallow water deposition characterizes the middle and upper units. The overlying Copenhagen Formation is greater than 350 feet (107m) of quartz sandstone and silty and argillaceous wackestone deposited in a shallow-marine embayment. This was followed by about 220 feet (67m) of beach-bar-dune quartz arenites of the Eureka Quartzite.

The Late Ordovician to earliest Silurian Hanson Creek Formation is a 515 foot (157m) thick, shoaling-upward sequence of lime mudstone, shaly limestone, and minor oolitic grainstone. The Hanson Creek Formation records infilling of a relatively shallow intraplatform basin, which extended from the northern Monitor Range to the southern limit of the study area, but did not extend to Dobbin Summit in the central Monitor Range. The overlying basal few hundred feet of the Early Silurian Roberts Mountains Formation is a basinal facies of platy weathering lime mudstone and allodapic limestone.

A limited exposure of bedded chert, quartzite, and limestone of the allochthonous Vinini Formation is in thrust contact with autochthonous rocks, and was emplaced during the Late Devonian-Early Mississippian Antler orogeny.

Structural interleaving of units in the southern and central portions of the study area resulted from thrusting in the lower plate of the Roberts Mountains thrust. Two Tertiary normal fault systems are present in the study area: a north- and northeast-trending range-front system, and a smaller east-west-trending system.

Ordovician to Silurian Stratigraphy of Part of the North-central Monitor Range, Nye County, Nevada

by

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ORDOVICIAN TO SILURIAN STRATIGRAPHY OF PART OF THE NORTH-CENTRAL MONITOR RANGE, NYE COUNTY, NEVADA

INTRODUCTION

Purpose

This thesis project was chosen in order to provide more detailed information concerning the Ordovician to Silurian lithofacies of the extreme southwestern portion of the Antelope Valley area and the eastern flank of the north-central Monitor Range. Information concerning lithofacies distribution is important in reconstructing the paleogeography and depositional environments of the middle Paleozoic continental shelf. The detailed map presented here provides a reference for such reconstruction.

Previous Work

The northern portion of the map area includes the southern third of Martin Ridge (Figure 2, loc. 7), which has been studied by previous workers and contains the type section of the Copenhagen Formation. The only published maps of Martin Ridge are by Merriam (1963) and Ethington and Schumacher (1969). Several fossil collections have been taken from northern and central Martin Ridge; in addition to the above authors are Ross and Berry (1963), Ross (1970), Dunham and Murphy (1976), Dunham (1977b), and other workers. No previously published stratigraphic sections have been measured within the study area.

The southern portion of the map area was originally mapped by Merriam (1963) as Tertiary volcanics; the entire study area, including the southern Paleozoic exposures, later appeared in the reconnaissance map by Kleinhampl and Ziony (1967) at a scale of 1:250,000. No previous description of the southern portion of the map area has been published.

To the north of the study area, Matti (1971) and Matti and others (1975) have published detailed studies of Copenhagen Canyon, and Lohr (1965) studied the Brock Canyon-Charnac Basin area on the west flank of the Monitor Range (Figure 2, loc. 1). South of the study area on the east flank of the Monitor Range, early investigation concentrated on the Clear Creek Canyon region (Figure 2, loc. 3); first mapped by Greene (1953), and later by Lowell (1965). Webb (1958) measured the Middle Ordovician section at Clear Creek Canyon, and Wise (1976) measured the Paleozoic section at Clear Creek and at Dobbin Summit (Figure 2, loc. 5). Wise mapped the Paleozoic rocks to within six miles (10 km) of the southern boundary of the map area, where Paleozoic exposures are covered by Tertiary volcanic rocks.

Location and Accessibility

The thesis area is located on the eastern flank of the north-central Monitor Range, approximately 45 miles (72 km) southwest of Eureka, Nevada (Figures 1 and 2). The mapping area encompasses about 25 square miles, and is within the southern portion of the Horse Heaven Mountain U.S.G.S. 15 minute topographic map. The northern portion of the map area is roughly bounded by 39°05'-39°10' north latitude, and 116°21'-116°23' west longitude. The southern portion of the map area is roughly bounded by 39°01'-39°06' north latitude, and 116°20'30"-116° 22' west longitude.

The southern Antelope Valley area is easily accessible by car from U.S. highway 50, south to Segura Ranch along the county-maintained Antelope Valley Road. Although much of the area is part of the Toiyabe National Forest, permission should be obtained from Segura Ranch before entering the B.L.M.-maintained road to Cabin Spring, which provides four-wheel-drive access to the southern portion of the study area. A partially graded road leading west from Segura Ranch provides four-wheel-drive access to measured sections TP1 and TP2. Unmarked jeep trails lead to within one half mile (0.8km) of measured sections TP3 and TP4. The southwestern portions of Martin Ridge are best reached on foot from Martin Ranch at the southern end of Copenhagen Canyon road. Permission should be obtained before entering Martin Ranch property.

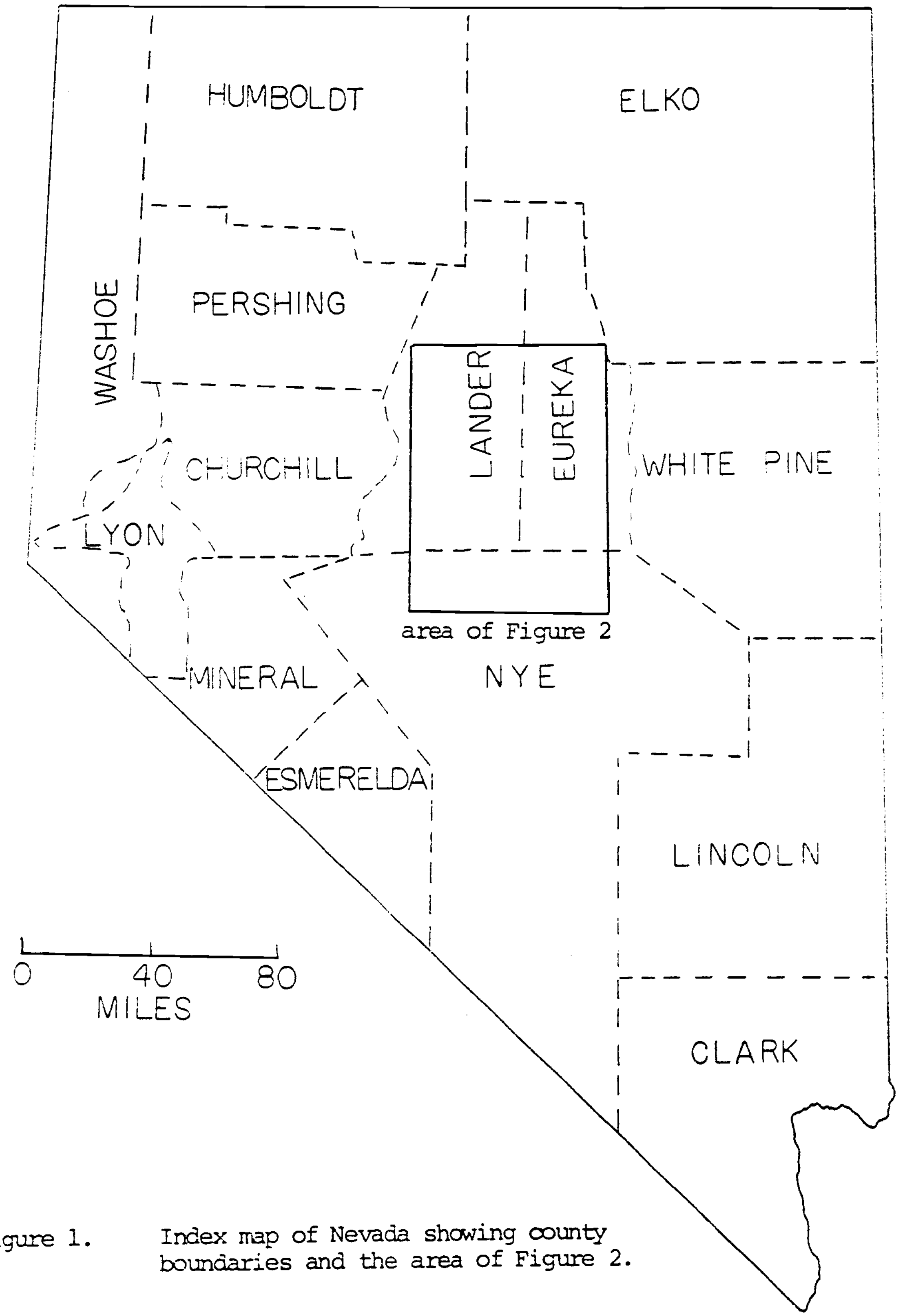


Figure 1. Index map of Nevada showing county boundaries and the area of Figure 2.

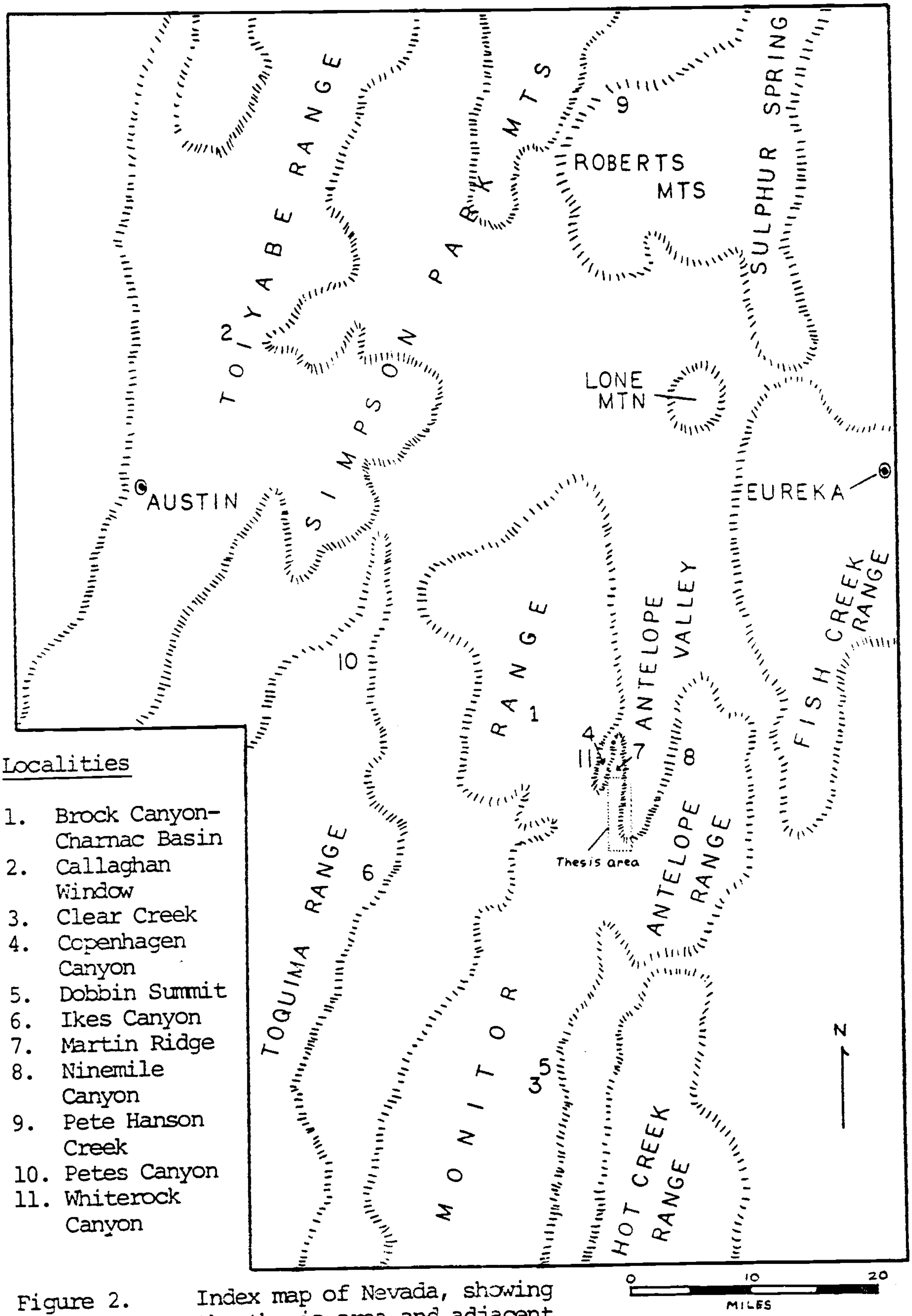


Figure 2. Index map of Nevada, showing the thesis area and adjacent localities.

Climate and Vegetation

The climate of the Monitor Range is semi-arid; receiving between 10 and 18 inches of precipitation per year, depending upon elevation (Lohr, 1965; McKee, 1976). Elevations within the study area range from about 8, 900 feet (2,700m) in the southern portion, to about 6, 800 feet (2, 100m) near the valley floor in the northern portion. Summer daytime temperatures rarely exceed 100°F, and are usually 20°F or so lower on the ridge tops. Nighttime temperatures usually range from the upper 50's to upper 40's (Fahrenheit), depending upon elevation. Early summer rainfall can be substantial, and afternoon thunderstorms are common throughout the summer months.

Vegetation is typical of the upper Sonoran and Transition zone (McKee, 1976) and includes sagebrush and rabbit brush at lower elevations, and pinon pine and juniper at higher elevations. Several small springs, often associated with fractured Eureka Quartzite, are present in the study area and may be marked by small stands of willows.

Methods

Nine weeks were spent in the field from June through August, 1977, by the writer and his field assistant, Ms. Kelly Collins, an undergraduate at Humboldt State University, California. Field work consisted of mapping the Ordovician and Silurian units; collecting spot samples for petrographic study; collecting spot samples from the basal Hanson Creek Formation for microfossil processing; measuring, sampling, and describing sections, and collecting samples for microfossil processing from the Hanson Creek Formation section; and measuring and collecting microfossil samples from the Dobbin Summit section in the central Monitor Range. Laboratory study of lithologies included thin section and acetate peel analysis and preparation of polished, oiled, or acrylic-coated slabs. Microfossil samples were first broken into walnut-sized fragments, separated into portions of a specific weight, dissolved in dilute formic acid, and the insoluble residue separated with heavy liquid and hand picked by Claudia Regier.

Terminology

The sandstone classification of Williams, Turner, and Gilbert (1954) was used for hand specimen and thin section description. The term "quartzite" is used in lieu of "quartz arenite" where it has been previously designated by earlier workers (e.g., Eureka Quartzite). The carbonate classification of Dunham (1962) was used for hand sample and petrographic description. The terms "micrite," "allochem," and "intraclast" have been retained from the earlier carbonate classification of Folk (1959). Bed thicknesses are designated as follows: 1/4 inch to 4 inches is thinly bedded, 4 inches to 18 inches is medium bedded, 18 inches and thicker is thickly bedded.

Geologic Setting

From latest Precambrian to middle Paleozoic time, the Great Basin was part of the Cordilleran Geosyncline, which received sediment in subparallel north-south trending facies belts (Roberts, 1968; Churkin, 1974; Stewart and Poole, 1974). Roberts and others (1958) have identified three facies belts in Nevada as (1) an eastern carbonate and quartzite assemblage (Figure 3), (2) a western deep water, clastic-chert-volcanic assemblage, and (3) a transitional carbonate-clastic assemblage separating the eastern and western belts. Western assemblage rocks have been interpreted as marginal ocean basin deposits (Burchfiel and Davis, 1972; Stewart and Poole, 1974; Wrucke and others, 1978), whereas eastern assemblage rocks represent shallow water continental shelf type deposits (Roberts and others, 1958; Roberts, 1968). Transitional assemblage rocks show many characteristics of slope deposition (Winterer and Murphy, 1960; Smith and Ketner, 1975) and have been interpreted as outermost continental shelf-upper continental slope deposits (Churkin, 1974).

Within the eastern assemblage, Robison (1960) and Palmer (1960, 1971) have recognized three additional lithofacies groups.

These groups are, from east to west, (1) an inner detrital belt of near-shore orthoquartzite and off-shore shale, (2) a middle carbonate belt consisting of several subfacies of dolomite and limestone, and (3) an outer detrital belt of fine-grained clastics and dark, argillaceous limestone. Lithofacies belts of Robison and Palmer reflect an east-to-west deepening trend across the broad, gently-sloping early Paleozoic continental shelf. Geographic distribution of these lithofacies belts has been utilized to indicate transgressive-regressive cycles in Early Cambrian to Middle Ordovician eastern assemblage rocks (Robison, 1960; Palmer, 1960, 1971; Aitken, 1966, 1971; Kepper, 1972).

Large-scale and long-duration transgression and regression upon the North American craton has produced interregional rock-stratigraphic units termed sequences by Sloss (1963). A sequence is a very large-scale sedimentary packet, bounded above and below by time-transgressive unconformities which correspond to periods of cratonal regression and erosion (or non-marine deposition). Bounding unconformities widen (with reference to time) cratonward, and individual sequences are separated by periods of maximum regression. The lowermost, or Sauk, sequence began during the latest Precambrian and ended during the Middle Ordovician. The overlying Tippecanoe sequence began in the Middle Ordovician and continued to the Early Devonian. Rocks of the upper Sauk and lower Tippecanoe sequences are present in the study area.

Tectonic disruption of the broad continental shelf began during Early Silurian (Llandovery) time with downdropping of the western shelf margin, and corresponding eastward shift of lithofacies patterns (Johnson and Potter, 1975). Marine deposition was abruptly terminated in Late Devonian or Early Mississippian time when eastward thrusting of western facies rocks, and the accompanying formation of the Antler orogenic highland, occurred during the Antler orogeny (Johnson, 1971). Maximum eastward overthrusting of western facies rocks occurred along the Roberts Mountains thrust (Smith and Ketner, 1968).

SYSTEM	SERIES	STAGE	ROCK UNIT	THICKNESS (FEET)
SILURIAN		LLANDOVERIAN	ROBERTS MOUNTAINS FORMATION	BASAL FEW HUNDRED
ORDOVICIAN	UPPER	ASHGILLIAN, CARADOCIAN	HANSON CREEK FORMATION	515 (ESTIMATED)
ORDOVICIAN	MIDDLE	CARADOCIAN	EUREKA QUARTZITE	220 (ESTIMATED)
ORDOVICIAN	MIDDLE	CARADOCIAN, LLANDEILIAN	COPENHAGEN FORMATION	350+ (ESTIMATED)
ORDOVICIAN	MIDDLE	LLANVIRNIAN	ANTELOPE VALLEY LIMESTONE	1200+ (ESTIMATED)
ORDOVICIAN	LOWER	ARENIGIAN	NINEMILE FORMATION	55+
ORDOVICIAN	LOWER	ARENIGIAN	GOODWIN LIMESTONE	385 (BASE NOT EXPOSED)

Figure 3. Table of Ordovician to Early Silurian eastern assemblage formations in the study area (data from Merriam, 1963; Ross, 1977).

GOODWIN LIMESTONE

General Statement

The Goodwin Limestone is the oldest formation of the Early to Middle Ordovician (Canadian to Chazyan) Pogonip Group of Nolan and others (1956). The Pogonip Group is subdivided into Goodwin Limestone, Ninemile Formation, and Antelope Valley Limestone, listed in ascending order, in Antelope Valley and the Eureka district (Figure 3).

Merriam (1963) described the Goodwin Limestone at Ninemile Canyon in the northern Antelope Range (Figure 2, loc. 8) and subdivided it into three members. Member A is the basal member; a dark, carbonaceous and partly calcareous shale, overlain by member B, a thin-bedded to platy weathering limestone containing minor light gray chert. Member C is the uppermost interval, 950 feet (290m) thick, consisting of thick-bedded limestone with abundant light gray to white chert stringers.

The upper portion of member C of the Goodwin was measured at the southern tip of Martin Ridge in the northern half of the study area in section TP1 (Figure 5). Members B and C were recognized in the southern half of the study area, but no complete section could be measured due to poor exposure and complex faulting in that area.

Lithology

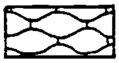
At Martin Ridge, member C consists of thin- to medium-bedded wackestone, packstone, and minor grainstone, containing varying amounts of light gray chert stringers and argillaceous impurities. The amount of argillaceous material in the limestone controls bedding and weathering characteristics. Thin-bedded intervals containing relatively abundant argillaceous impurities weather recessively and show distinct, planar bedding surfaces. Thick-bedded intervals containing argillaceous material only along discontinuous undulatory partings are more resistant to weathering and form low, blocky outcrops.

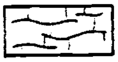
The lower portion of the section consists of intercalated thin- to medium-bedded argillaceous wackestone with abundant light gray chert stringers and occasional beds of intraformational conglomerate. Chert and intraformational conglomerate decrease in abundance up-section, and intraformational conglomerate beds are not present in the upper portion of the section. The amounts of argillaceous impurities decrease upward, producing well-defined undulatory bedding of medium thickness. Biotic grains, consisting primarily of coarse sand- to granule-size trilobite fragments, increase in abundance upward, producing packstone and grainstone textures toward the top of the section.

KEY TO STRATIGRAPHIC SYMBOLS

 - Well bedded limestone with replacement chert

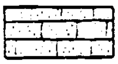
 - Undulatory bedded limestone

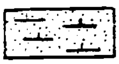
 - Nodular or irregularly bedded limestone

 - Limestone with discontinuous argillaecous partings

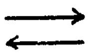
 - Argillaceous limestone

 - Silty limestone

 - Sandy limestone

 - Calcareous sandstone

 - Quartzite

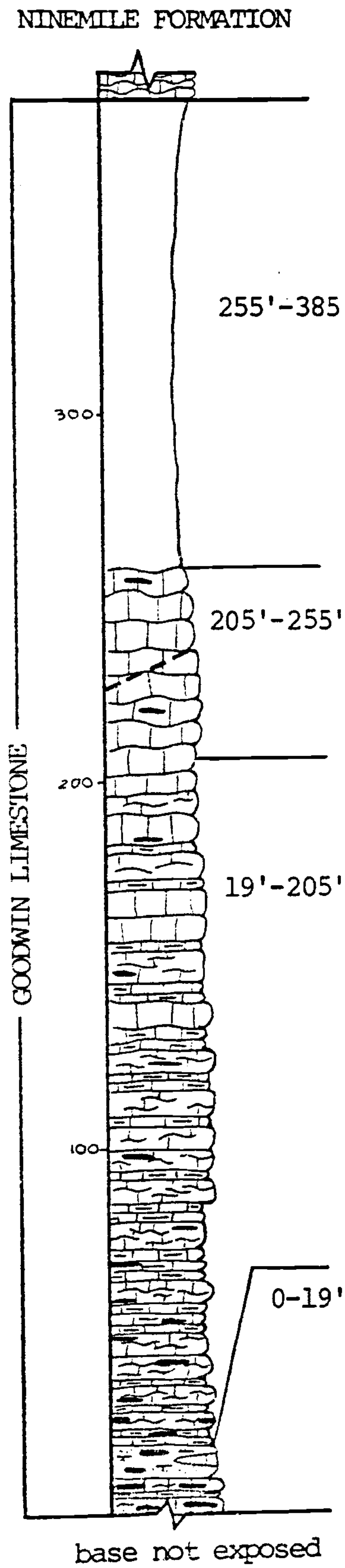
 - Fault

 - Unconformity

(f) - Fresh surface

(w) - Weathered surface

Figure 4. Key to stratigraphic symbols



255'-385' Covered interval. May contain much of the basal Ninemile Formation.

205'-255' Medium-bedded grainstone, (f) dark-gray (w) dark-gray. Bedding irregular; very little argillaceous material. Contains primarily sand-size trilobite fragments. Minor fault at 225'; negligible offset.

19'-205' Intercalated thin-to medium-bedded argillaceous wackestone and packstone. (f) light-gray, dark-gray (w) light-gray. Bedding well-developed; medium thickness beds contain argillaceous partings. Chert stringers and intraformational conglomerate present in the lower portion, decreasing up section.

0-19' Thin-bedded wackestone, (f) dark-gray (w) light-gray, contains light-gray to white chert stringers and argillaceous partings. Upper 9' is structureless, very fine-grained calcareous sandstone. (f) light-brown (w) dark-red-brown. Contains chert and 5-10" limestone lenses. Sharp contacts above and below.

Figure 5. Measured section TP1

A single 9 foot (2.7m) thick calcareous quartz sandstone bed was observed near the base of the section. The sandstone is very fine-grained, well sorted, and contains thin, lenticular chert and silty limestone layers.

Thickness and Contacts

An incomplete section of 385 feet (117m) was measured, with the upper 115 feet (35m) covered by talus from the overlying, recessive-weathering Ninemile Formation. Although the contact relations with the Ninemile could not be observed in the study area, Merriam (1963) describes the contact at Ninemile Canyon as conformable and gradational over a short interval from thick-bedded limestone to dark gray shale. The contact with the underlying Cambrian Windfall Formation was not observed in the map area.

Petrography

Acetate peels were described from spot samples collected from section TP1. Most samples are pelmicrites with varying amounts of included biotic fragments, spheroidal ooids(?), and silt-size angular quartz grains. Ooids(?) and pellets display radial internal crystal structure caused by neomorphic inversion of aragonite to calcite (Pettijohn, 1975). Ooids(?) are identified by size and shape alone, since any original concentric layering or carbonate nuclei have been destroyed during diagenesis.

Thin intraformational conglomerate beds contain pelmicrite intraclasts, with relatively abundant clay and quartz silt impurities, in a cleaner pelmicrite matrix. Intraclasts are sub-rounded to well-rounded, and range in length from 0.5cm to 2.5cm.

Packstones collected near the top of the section consist of approximately 75% broken trilobite and other biotic fragments in a micrite matrix. The average length of these biotic fragments is about 1mm.

Chert stringers are secondary replacements of original carbonate material, as evidenced by the chert-carbonate interface cutting across biotic grains, intraclasts, and pellets.

Depositional Environment

The lower portion of section TP1 contains pelletal carbonate mud with a relatively high percentage of fine-grained terrigenous clastics, indicative of a low energy depositional environment. Broken biotic grains and ooids(?) are characteristic of high energy shoal water environments and are interpreted as having been transported to, and deposited in, the lower energy pelletal-mud environment.

Intraformational conglomerate beds give the best evidence for the proximity of shallow water environments. Studies of recent carbonate environments show that early lithification of carbonate mud requires subaerial exposure (Friedman, 1964). The rounded pelmicrite intraclasts may represent subaerially exposed carbonate mud, reworked by spring tides or storm waves, transported and deposited in the low energy, and perhaps deep water, pelletal-mud environment.

The decrease in terrigenous impurities and increase in allochems in the upper portion of the section suggest an increase in transporting energy in the depositional environment. The skeletal trilobite packstones and minor grainstones in the upper portion of the section probably represent shoal water deposition, and indicate an overall shallowing upward trend in the section.

Regional Framework

The Goodwin Limestone is part of the shallow shelf carbonates of the eastern assemblage (Roberts and others, 1958). Johnson and Potter (1975) place the minimum western extent of Cambrian to Late Ordovician shallow shelf sedimentary environments at the Toiyabe Range, approximately 50 miles (80km) west of the study area.

Stewart and Palmer (1967) have measured and described the Goodwin Limestone at the Callaghan window of the Roberts thrust in the northern Toiyabe Range (Figure 2, loc. 2). Here, the upper 310 feet (95m) of the Goodwin consists of very thin-bedded to laminated silty limestone. In the Toquima Range, approximately 30 miles

(48km) west of Antelope Valley (Figure 2), Kay and Crawford (1964) have shown the Stoneberger Shale to be time correlative with the upper part of the Goodwin Limestone and overlying Ninemile Formation.

The silty limestones and shales of the Toiyabe and Toquima Ranges are part of the outer detrital belt of Palmer (1960, 1971). The outer detrital belt is one of three lithofacies belts first recognized in the Upper Cambrian of the southern Great Basin, and later applied to Cambrian and Ordovician rocks at several Great Basin localities and in the Rocky Mountains of Alberta (Robison, 1960; Kepper, 1972; Aitken, 1966). The three lithofacies belts consist of 1) an outer detrital belt of shales and dark, argillaceous to silty, fine-grained limestones, 2) an inner detrital belt of shales and near-shore orthoquartzite, and 3) an intervening middle carbonate belt of shallow water limestones and dolomites with little terrigenous impurities.

The lower portion of the Goodwin Limestone at Martin Ridge contains silty and argillaceous limestone and very fine-grained sandstone, indicative of outer detrital belt facies. However, the generally light color of the limestone, lack of laminations, and presence of shallow water facies ooids(?), intraclasts, and biotic grains suggest that the study area lay within the outer edge of the middle carbonate belt. The boundary separating the middle carbonate and outer detrital belts probably existed somewhere between the Monitor and Toquima Ranges during deposition of the upper Goodwin Limestone.

The Goodwin Limestone is present in the Pahranagat Range of southeastern Nevada (Ross, 1970) but does not extend into western Utah, where coeval shales and intraformational conglomerates of the Fillmore Limestone represent the eastern margin of the middle carbonate belt (Hintze, 1951; Church, 1974).

NINEMILE FORMATION

General Statement

Nolan and others (1956) designated exposures at Ninemile Canyon in the northern Antelope Range (Figure 2, loc. 8), approximately 8 miles (13km) northeast of section TP2 at Martin Ridge, as the type locality of the Ninemile Formation. At this locality, the Ninemile is composed of platy and thinly bedded, fine-grained limestone, with abundant shale and calcareous shale partings, displaying a distinctive greenish color on fresh surface. Because of its thin-bedded and argillaceous character, the Ninemile weathers recessively and crops out in poorly exposed sections occupying saddles or low, talus-covered slopes.

The Ninemile Formation is the medial formation of the Pogonip Group; it is underlain by the Goodwin Limestone and overlain by the Antelope Valley Limestone (Nolan and others, 1956).

Lithology

The Ninemile Formation was measured and described in the lower portion of section TP2 (Figure 6) at the southern tip of Martin Ridge. The Ninemile was not recognized elsewhere in the map area.

At Martin Ridge, the Ninemile consists of intercalated, very thin-bedded shaly limestone and nodular, laminated or crystalline, thin-bedded lime mudstone (Plate 2, photo 1). On fresh surface, both shaly limestone and nodular limestone beds are usually dark greenish gray, although nodular limestone beds may be light gray or brownish gray. Talus consists of small, light gray or yellow brown chips of weathered shaly limestone and rust brown-weathering limestone nodules.

Thickness and Contacts

Nolan and others (1956) described the upper and lower contacts of the Ninemile Formation at its type locality as gradational and difficult to establish in detail. However, the distinctive coloration and dominantly thinner bedding of the Ninemile is considered to contrast adequately with the thicker bedded and light gray-colored subjacent Goodwin Limestone and superjacent Antelope Valley Limestone to define a mappable formation boundary. A local exception exists at Martin Ridge where the lower portion of the Antelope Valley Limestone is thin-bedded, similar to the Ninemile. Here, the sharp transition from greenish gray limestone to light gray limestone is defined as the Ninemile-Antelope Valley boundary (Nolan and others, 1956, p. 28).

In the Antelope Valley region, the thickness of the Ninemile varies, from east to west, from 550 feet (168m) at Ninemile Canyon, to 200 feet (61m) in a structurally disturbed section at Whiterock

Canyon (Figure 2, loc. 11), in the Monitor Range (Merriam, 1963). At Martin Ridge, about 7 miles (11km) southeast of Whiterock Canyon, only 55 feet (17m) of the Ninemile are exposed, although some of the formation is probably included in the 115 feet (35m) of covered interval which was assigned to the Goodwin Limestone (section TP1, Figure 5).

Nodular Bedding

Nodular limestone beds are composed of dark, laminated lime mudstone about 2cm to 5cm thick, intercalated with thinner (1cm or less) shaly limestone or calcareous shale. Examination of acetate peels indicates that limestone nodules and shaly limestone layers are micritic and differ only in the amount of included clay laminae. Shaly limestone contains abundant closely spaced thin laminae, while most nodular lime mudstone laminations are more widely separated and less numerous. Nodular bedding is enhanced by weathering, with the less argillaceous lime mudstone nodules protruding from more argillaceous and less resistant, weathered shaly limestone interbeds.

A single nodular limestone bed can contain both rounded, detached lentils, and continuous limestone layers displaying varying degrees of pinch-and-swell structure. Polished slabs of nodular limestone reveal disrupted laminae, suggestive of internal flowage, within nodular limestone lentils or in beds displaying well-formed pinch-and-swell structure. Lime mudstone beds which are of uniform thickness or display poorly formed pinch-and-swell structure include laminae which are more nearly parallel and show no internal disruption.

Each nodular limestone bed is bounded, above and below, by thinner, more continuous shaly limestone layers containing laminae which are coincident with the surface of the adjacent nodules. Shaly limestone laminae usually show little evidence of flowage or disruption except near the interface with the adjacent nodule, where differential movement may have occurred causing crumpling of the laminae on a microscopic scale.

Ramberg (1955) studied boudinage and pinch-and-swell structures in metamorphic rocks. He described boudins as competent (brittle) rock, pulled apart by elongation normal to compression, and rounded into oblong "sausage" shapes by shear along the interface of the incompetent (ductile) enclosing matrix.

McCrossan (1958) used the term "sedimentary boudinage" in describing the formation of nodules in the Ireton Formation of Alberta, which resemble those observed in the Ninemile Formation. The Ireton nodules are lenticular, fine-grained lime clastics interbedded with calcareous shale. McCrossan believed these structures form when plastic lateral spreading occurs in soft sediment beneath an irregular depositional surface, where spreading moves toward slightly lower parts of the sea floor. Thinning and pulling apart of the more brittle lime clastic beds by tensional stress is caused by surface drag from the plastic, flowing calcareous shale interbeds. Calcite-filled tension cracks, similar to Ramberg's description of tension fractures in metamorphic boudins, were seen on the surfaces of some of the Ireton Formation limestone nodules, supporting the interpretation of pulling apart of brittle lime clastic beds.

The presence of disrupted internal laminae within lime mudstone nodules of the Ninemile Formation suggests that this lithology did not deform as a brittle solid, as described by McCrossan (1958). Instead, ductile deformation or flowage appears to have occurred to a greater degree in lime mudstone beds than in the intervening shaly limestone layers. Since lime mudstone nodules do not show evidence of greater competency, relative to shaly limestone layers, the terms "boudinage" (Ramberg, 1955) or "sedimentary boudinage" (McCrossan, 1958) cannot be used in describing the formation of this structure.

Nodular bedding of the Ninemile Formation is interpreted as a compaction feature, occurring after burial but before lithification, caused by ductile interstratal flow within nodular lime mudstone beds. Disruption of internal laminations is more pronounced near the ends of nodules or in the "pinched" portion of pinch-and-swell structure, indicating that the internal flow direction was toward the thicker portions of each nodule or "swell." The enclosing shaly limestone laminae are usually not disrupted or broken, suggesting that the more argillaceous shaly limestone layers deformed elastically and retained cohesion, while flowage occurred in the adjacent lime mudstone beds. Partial dewatering and segregation of the argillaceous material in shaly limestone layers during early compaction may have increased the water content in the adjacent lime mudstone beds, causing a reduction of cohesion and an increase in ductility. Newell and others (1953, p. 81) briefly describe a similar process as an "unequal reaction to loading and...adjustment by flowage in water-laden, fine-grained sediments." Although other workers do not agree on a single mechanism of formation for all nodular bedded limestone (Pettijohn, 1975, p. 339-340), interstratal compaction flow of lime mudstone beds seems most consistent with field and microscopic studies of limestone nodules of the Ninemile Formation.

Depositional Environment

The dark, laminated, and rhythmically interbedded shaly limestone and lime mudstone of the Ninemile are characteristic of deep water basinal deposition (Wilson, 1975, p. 26). The lack of bioturbation of laminated mudstone contrasts with commonly burrowed lagoonal lime mudstone of the shallow water shelf. Laminations within shaly limestone and lime mudstone indicate fluctuations in the sedimentation rates of suspended carbonate mud and terrigenous argillaceous material. Lime mud is produced in abundance only on the shallow water carbonate shelf, primarily by abrasion of calcareous organisms (especially algae) and perhaps by direct precipitation from sea water (Bathurst, 1975). Laminations in the lime mudstone and shaly limestone, and the interbedding of these contrasting lithologies, may represent cyclic fluctuations in the turbidity of the carbonate shelf waters related to storms, spring tides, or seasons, which affect sedimentation rates in the adjacent deep water basin (Wilson, 1969).

Regional Framework

West of Antelope Valley, the Ninemile crops out in the northern Toiyabe Range (Stewart and Palmer, 1967), and at Petes Canyon in the northern Toquima Range (McKee and Ross, 1969), where lower Paleozoic eastern assemblage rocks are exposed through windows in the Roberts thrust (Figure 2, locs. 2 and 10). About 12 miles (19km) south of Petes Canyon (Figure 2, loc. 6), the Stoneberger Shale is, in part, time correlative with the Ninemile Formation (Kay and Crawford, 1964). At Clear Creek in the central Monitor Range (Figure 2, loc. 3), approximately 25 miles (40km) south of Antelope Valley, the Ninemile is absent (Wise, 1976), but may be present farther to the southeast in the Hot Creek Range (Lowell, 1965). The Ninemile may extend as far east as the Thomas Range in western Utah, where the Wah Wah Limestone contains shaly beds of Ninemile age (Ross, 1977).

The deep water facies carbonates of the Ninemile, and the coeval Stoneberger Shale, are characteristic lithologies of the outer detrital belt (Palmer, 1960). The areal distribution of the Ninemile resembles a narrow eastward incursion of the outer detrital belt into the shallow water middle carbonate belt, similar to eastward embayments of the Late Cambrian outer detrital belt in east-central Nevada (Palmer, 1971). The increase in water depth represented by the gradational Goodwin Limestone-Ninemile Formation contact may reflect submergence of the shelf during late Arenigian time (Ross, 1977, p. 24) as well as formation of the Ninemile embayment.

The contact with the overlying Antelope Valley Limestone is diachronous, becoming progressively younger westward. In the Pahranagat Range in southeastern Nevada the contact is dated as late Arenigian, while in the Toquima Range it is early Llanvirnian. In the Monitor Range, the contact approximates the Arenigian-Llanvirnian boundary (Ross, 1977). The time-transgressive upper contact of the Ninemile Formation represents westward progradation of the shallower water facies Antelope Valley Limestone, and eventual infilling of the Ninemile embayment.

ANTELOPE VALLEY LIMESTONE

General Statement

The Antelope Valley Limestone was named and described by Nolan and others (1956). It is the youngest formation of the Pogonip Group and is underlain by the Ninemile Formation and overlain by the Copenhagen Formation.

Merriam (1963) designated the type section of the Antelope Valley Limestone in an area south of Ninemile Canyon on the west flank of the Antelope Range (Figure 2, loc. 8), about 6 miles (10km) northeast of section TP2 at Martin Ridge. Merriam subdivided the Antelope Valley Limestone into three faunal units, which correspond fairly well to lithologic divisions at the type locality. In the Monitor Range, Merriam described the lower, or *Orthidiella*, zone as consisting of between 75 and 150 feet (23m to 46m) of thin-bedded, argillaceous, tan or yellow-weathering limestone containing numerous calcareous nodules in its lower portion. Overlying the *Orthidiella* zone is the *Palliseria* zone, about 650 feet (198m) of predominantly thick-bedded, fine-grained, slightly argillaceous limestone interbedded with subordinate amounts of thin-bedded argillaceous limestone. The uppermost, or *Anomalorthis*, zone includes about 350 feet (107m) of thin-bedded argillaceous limestone containing abundant high-spired gastropods and girvanellid algal nodules.

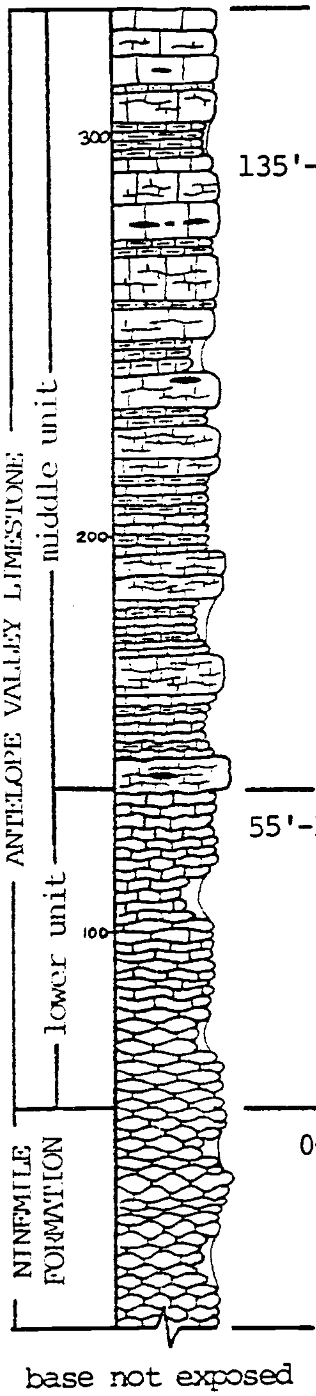
Thickness and Contacts

Although the contact with the underlying Ninemile Formation is not exposed at the type section, Merriam estimated the total thickness of the Antelope Valley Limestone to exceed 1, 200 feet (366m) at the type locality in the Antelope Range.

The Antelope Valley Limestone was measured in two sections at Martin Ridge. The lower portion of the formation was measured in section TP2 at the southern tip of Martin Ridge (Figures 6 and 7), and the upper portion was measured in section TP3 near the northern boundary of the map area (Figures 8, 9, and 10). The Antelope Valley Limestone was recognized in the structurally complex southern portion of the map area, but no measurable section was found there. At Martin Ridge, sections TP2 and TP3 overlap in their upper and lower portions, respectively, but contain no distinctive lithologic unit, common to both, which will allow correlation between the sections. Thus, no accurate measurement of the total thickness of the Antelope Valley Limestone is possible in the study area. However, the author agrees with Merriam's estimate of 1, 200 feet (366m) as a minimum thickness for the Antelope Valley Limestone.

The upper boundary of the Antelope Valley Limestone is marked by the basal quartzite of the overlying Copenhagen Formation, and is exposed in section TP3 and at several other localities in the study

middle unit continued in figure 7.

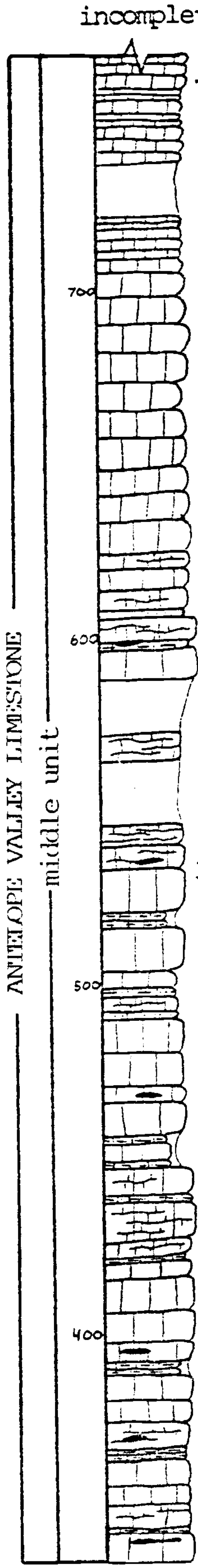


135'-335' Intercalated medium-to thick-bedded pelletal wackestone or packstone and thin-bedded lime mudstone. Thin lime mudstone beds are undulatory and are separated by argillaceous layers in the lower portion; becoming planar-bedded and argillaceous up section. (f) light-gray-brown, (w) light-gray, yellow-brown. Medium to thick-bedded wackestone or packstone ledges contain numerous argillaceous partings; decreasing up section. (f) dark-gray, (w) medium-gray. lower-most limestone ledge marks the base of the middle unit.

55'-135' Intercalated laminated lime mudstone and wackestone separated by very thin (less than 1cm) shaly limestone or minor argillaceous packstone layers. Thin-bedded lime mudstone is nodular or irregularly bedded at the base, and undulatory at the top. (f) light-gray or light-brown, (w) light yellow-brown. Float contains an abundant shelly fauna.

0-55' Intercalated laminated or crystalline lime mudstone and shaly limestone. Thin-bedded lime mudstone is nodular or irregularly bedded; shaly limestone is very thin-bedded (less than 1cm). (f) dark greenish-gray, (w) rust-brown, brown, yellow-brown; greenish color (f) distinguishes Ninemile from Antelope Valley.

Figure 6. Measured section TP2



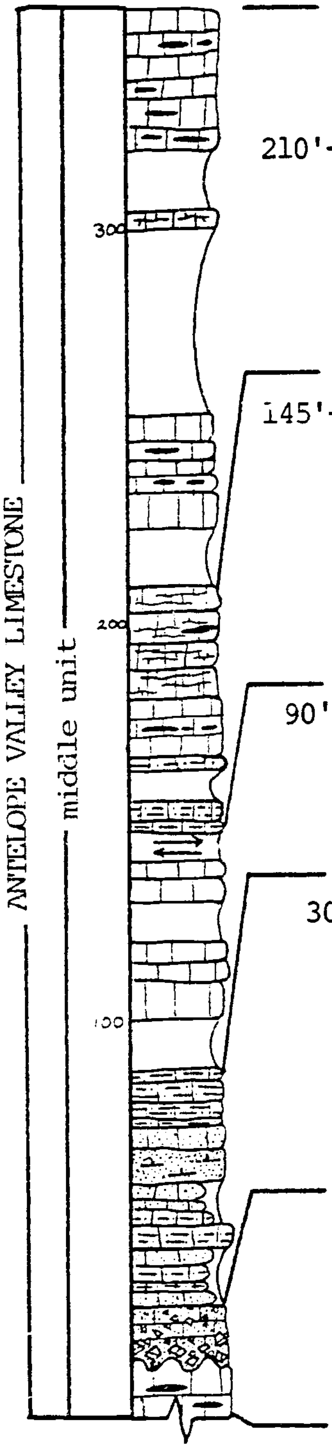
705'-770' Thin-to medium-bedded coarsely crystalline limestone. (f) light-gray, (w) light-gray to light-brownish-gray. Limestone is sugary textured and well-bedded. Has the appearance of a medium-grained calcarenite.

625'-705' Thick-bedded wackestone and packstone ledges. (f) dark-gray, (w) light-gray. No chert; argillaceous impurities are negligible. Bedding is poorly developed.

335'-625' Thick to medium-bedded packstone and wackestone ledges, with minor intercalated thin-bedded sandy, silty, or argillaceous wackestone. Limestone ledges are usually thick and poorly bedded, but may contain discontinous argillaceous partings. (f) dark-gray to medium-gray, (w) light-gray. Thin sandy or silty wackestone interbeds occasionally display planar cross-bedding. This interval is distinguished from the underlying unit by a decrease in intercalated, thin-bedded limestone to less than 10 percent.

continued from figure 6. Figure 7. Measured section TP2

continued in figure 9.



210'-340' Medium-to thick-bedded coarsely crystalline limestone, (f) light brownish-gray, (w) light brown, sugary textured, similar in appearance to medium-grained calcarenite. Poorly exposed in lower 110'.

145'-210' Thin-bedded silty wackestone, (f) light-gray (w) yellowish-brown. Overlain by poorly bedded, coarse-crystalline limestone; (f) light-gray (w) light-gray; contains some chert and poorly preserved Palliseria sp. gastropods. Crystalline limestone overlain by medium-bedded packstone, (f) dark-gray (w) light-gray, contains chert and argillaceous partings.

90'-145' Medium-to thick-bedded coarse crystalline limestone, (f) light gray (w) light gray. Sugary textured. Bedding is poorly defined. Normal fault at 145'; west side up; may cause repetition of section.

30'-90' Medium-to thin-bedded sandy, silty, and argillaceous limestone, and very fine-grained calcareous sandstone. Calcareous sandstone, (f) light-gray (w) yellow-gray, displays planar cross-bedding. Silty, sandy, and argillaceous limestone, (f) light-gray (w) light-gray, yellowish-brown, brownish-gray; poorly exposed interval.

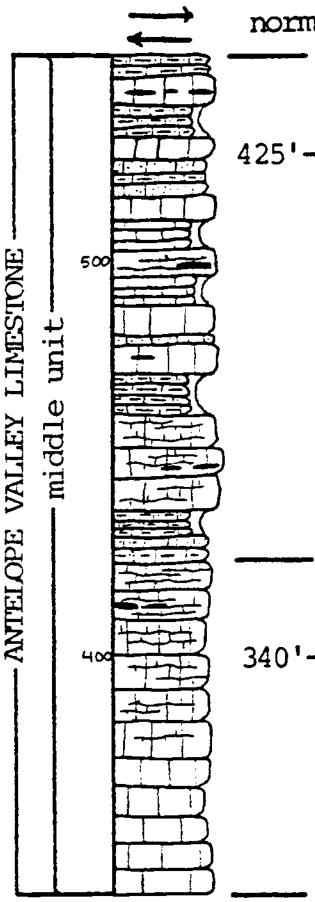
0-30' Thick-bedded packstone, (f) dark-gray (w) light-gray, contains channel incision. Upper 15' is channel fill; very fine-grained sandy limestone, (f) light-brown (w) yellow-brown, contains graded cobble-to pebble-size packstone or wackestone clasts; angular to subrounded; channel incision is local feature.

base not exposed

Figure 8. Measured section TP3

continued in figure 10.

normal fault and covered interval



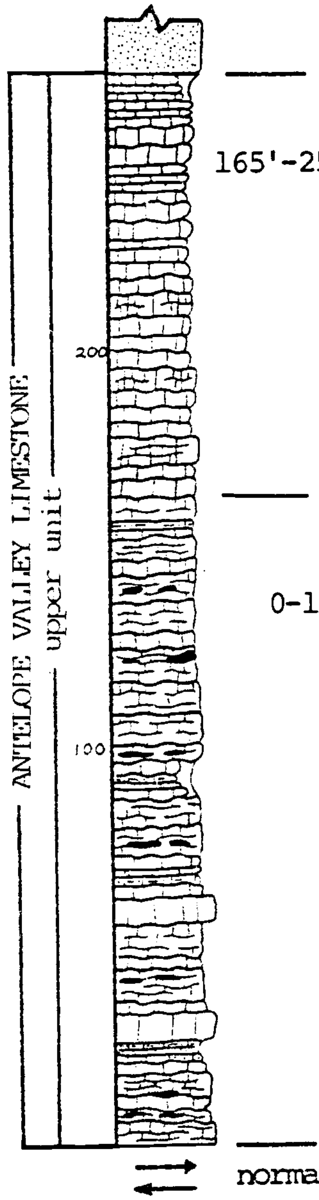
425'-555' Medium-to thick-bedded packstone and wackestone intercalated with thin-bedded, sandy, silty, and argillaceous wackestone. Thicker-bedded packstone and wackestone ledges, (f) dark-gray (w) light-gray, brownish-gray, vary from well bedded to poorly bedded with argillaceous partings. Thin-bedded wackestone, (f) light-gray, light-brown (w) yellow-brown, weathers recessively and may be heavily burrowed.

340'-425' Thick-bedded packstone and subordinate wackestone, (f) dark-gray (w) light-gray, brownish-gray. Well bedded at the base to poorly bedded with argillaceous partings near the top.

continued from figure 8.

Figure 9. Measured section TP3

COPENHAGEN FORMATION



165'-255' Intercalated medium-to thin-bedded wackestone and packstone. Packstone, (f) dark-gray (w) light-gray, contains girvanellid algal nodules in the lower portion and contains occasional argillaceous partings. Wackestone, (f) light-gray, dark-gray (w) light-gray, is medium-to thin-bedded in the lower part, becoming thin-bedded in the upper part. Abundant high-spired gastropods in the upper 30'.

0-165' Medium-to thin-bedded argillaceous packstone intercalated with medium-bedded, non-argillaceous packstone and thin-bedded, silty or sandy wackestone. Medium-to thin-bedded argillaceous packstone, (f) dark-gray, dark-greenish-gray (w) light-gray and yellow mottled, contains numerous argillaceous partings producing irregular bedding surfaces. Girvanellid algal nodules are common. Non-argillaceous packstone, (f) light-gray (w) light-yellowish-gray, is well-bedded and resistant, producing limestone ledges in the basal portion. Silty and sandy wackestone, (f) light-brown, light-gray (w) light-brownish-gray, yellowish-brown, is evenly bedded and often heavily burrowed.

normal fault and covered interval

continued from figure 9.

Figure 10. Measured section TP3

area. The contact with the underlying Ninemile Formation is defined as the color change from greenish gray limestone of the Ninemile Formation to light gray limestone of the Antelope Valley Limestone at Martin Ridge (Nolan and others, 1956).

Lower Unit

Thickness and Contacts

The lower unit is underlain by the Ninemile Formation and overlain by the middle unit of the Antelope Valley Limestone. The upper contact was chosen as the lowest occurrence of medium- to thick-bedded limestone ledges, characteristic of the bulk of the middle unit lithology.

The lower unit lithology corresponds to that of Merriam's *Orthidiella* zone. In section TP2, a measured thickness of 80 feet (24m) for the lower unit compares closely with the 75 foot (23m) thickness reported by Merriam (1963) for the *Orthidiella* zone at Whiterock Canyon.

Lithology

The lower unit consists of thin-bedded lime mudstone, wackestone, and minor packstone, separated by very thin layers of shaly limestone. Thin-bedded limestone and shaly limestone weather to light shades of brown or yellow, and are lighter colored than the underlying Ninemile Formation.

Acetate peels of lime mudstone and wackestone samples show faint lamination, caused by slight variations in the amount of argillaceous impurities in the micrite, similar to laminated lime mudstone of the Ninemile Formation. Allochems are primarily thin, unbroken, disarticulate brachiopod valves, trilobite shells, and graptolites. Allochem percentages are generally low in these rocks, making wackestone depositional textures subordinate to mudstone textures.

Minor amounts of argillaceous, thin-bedded packstone are intercalated with mudstone and wackestone. These beds are identified by their speckled appearance on weathered surface. In polished section, they are composed primarily of brachiopod and trilobite fragments similar in appearance to those in the mudstone and wackestone beds. Contacts between packstone and mudstone or wackestone beds are relatively sharp, but are usually disrupted due to post-depositional compaction.

Nodular bedding is present in the lower portion of the unit, but decreases upward, and is absent near the boundary with the middle unit. Nodular bedded lime mudstone and wackestone of the lower unit closely resembles nodular lime mudstone of the underlying Ninemile Formation. Like the Ninemile Formation, the lower unit weathers recessively and typically occupies talus-covered slopes beneath the more resistant middle unit.

Depositional Environment

The dominant lithology of thin-bedded, laminated lime mudstone indicates quiet water conditions existed throughout the period of deposition of the lower unit. An included benthic fauna of thin-shelled brachiopods and trilobites, and pelagic graptolites, suggest open marine, perhaps deep water deposition of lime mudstone and wackestone beds. Subordinate thin packstone beds, consisting of trilobite and brachiopod shells within an argillaceous micrite matrix, may result from winnowing of carbonate mud by bottom currents, or fluctuations in the sedimentation rate of carbonate mud.

Regional Framework

The lower unit of the Antelope Valley Limestone overlies the basinal facies Ninemile Formation at several locations in southern, central, and east-central Nevada (Ross, 1970). As stated previously, the lower contact of the lower unit is diachronous, becoming younger westward, and represents infilling of the shaly Ninemile embayment by prograding carbonate banks (Ross, 1977, p. 24). The lighter color, abundant benthic fauna, and lower argillaceous content of the lower unit may imply a reduction of water depth relative to the Ninemile Formation. However, the thin-bedding, shaly limestone interbeds, laminated mudstone, and numerous included graptolites indicate quiet water, subtidal deposition of the lower unit. Final infilling of the Ninemile embayment at Martin Ridge did not take place during deposition of the lower unit.

Middle Unit

Contacts

The lower contact was chosen as the base of the lowest occurring medium- to thick-bedded limestone ledge of the middle unit (Plate 2, photo 2). The central and lower portions of the middle unit were measured in section TP2.

In section TP3, the upper contact is gradational and complicated by faulting and poor exposure. It is marked by an interval of uncertain thickness in which medium- to thick-bedded limestone ledges become subordinate to thin-bedded limestone of the upper unit.

Thickness

The lack of a common marker bed, or sequence of beds, in sections TP2 and TP3 does not allow reliable correlation, or measurement of the total thickness, of the middle unit in the study area. However, a measured minimum thickness of 635 feet (194m) for the lower and central portions of the middle unit was obtained in section TP2.

Merriam (1963) reports a 650 foot (198m) thickness for the *Palliseria* zone at the northern tip of Martin Ridge. The *Palliseria* zone corresponds lithologically to the middle unit at Martin Ridge.

Lithology

The middle unit is dominantly medium- to thick-bedded pelletal wackestone and packstone, intercalated with subordinate amounts of thin-bedded, argillaceous wackestone. Resistant limestone ledges or cliffy outcrops, which are characteristic of the middle unit, are formed when several medium to thick beds are superimposed without intervening, recessive weathering, thin-bedded argillaceous limestone.

Thicker bedded pelletal wackestone and packstone contain little argillaceous impurities and are typically light gray to dark gray on fresh or weathered surface. A low percentage of included sand grains weather differentially to produce sharp projections over much of the surface of the limestone ledges. Small chert stringers and nodules, and partially silicified fossil fragments, weather a rust red color and often protrude from the weathered surface.

Thin-bedded wackestone is argillaceous, appears light to dark gray on fresh surface, and usually weathers to light shades of brown or yellow. Thin-bedded wackestone is recessive weathering and produces covered intervals between successive limestone ledges.

In the basal 200 feet (61m) of the middle unit, thicker bedded limestone ledges gradually increase in number and predominate over thin-bedded intervals. Thin beds often display undulatory bedding surfaces, and thicker beds may contain discontinuous argillaceous partings. Included fossils are primarily thin shelled brachiopod valves and thick shelled gastropods, especially large Maclurites sp. and Palliseria sp., which are common throughout the middle unit. Wackestone depositional textures dominate the lower portion of the middle unit.

Higher in the section, bedding is less well developed and limestone ledges are often single massive beds, forming small cliffs 10 to 15 feet (3-5m) in height. Argillaceous content is low in the central portion of the section. Locally, thin cross-bedded or structureless sandy limestone beds are present. Packstone depositional textures are common, and a diverse fauna, including gastropods, brachiopods, ostracods, crinoids, and trilobites, is present. Occasional sandy or pelletal micrite intraclasts are seen in acetate peels of packstone samples. Sand content of intraclasts varies, but is consistently more abundant and coarser grained than sand grains in the surrounding pelletal micrite matrix.

In the lower portion of section TP3, a channel is cut into thick-bedded, light gray packstone. Channel fill consists of pebble- to cobble-size clasts of the underlying packstone, and other lithologies, in a very fine-grained sandy limestone matrix. The slopes of the channel banks show apparent dips of approximately 20 degrees over an exposed outcrop width of about 50 feet (15m). Clasts of the underlying lithology occupy about a 15 foot (5m) thickness of the basal portion of the channel fill. No current direction indicators were recognized.

In the upper portion of the middle unit, limestone ledges consist primarily of medium-thickness beds of dark gray packstone. Intercalated with medium-bedded packstone is an upward increasing volume of thin-bedded packstone, wackestone, and minor mudstone. Medium- and thin-bedded packstone contains abundant Palliseria sp. and Maclurites sp. gastropods, locally to the exclusion of other fauna, as well as an increasing amount of girvanellid algal nodules. Minor thin-bedded pelletal wackestone and mudstone are often heavily burrowed parallel to bedding surfaces. Burrowing is most common in thin-bedded, sandy or silty limestone.

Depositional Environment

The upward trend of increased bedding thickness, increased number and diversity of included fauna, and predominance of sand- and silt-sized terrigenous impurities at the expense of argillaceous material, implies a general shoaling upward sequence in the middle unit lithologies. However, deposition of the entire unit must have taken place in relatively quiet water, below the level of high wave and current energies, as evidenced by the presence of pellets and carbonate mud throughout the unit.

In the central and upper portions of the unit, a diverse and abundant shelly fauna suggests a fairly shallow, normal marine depositional environment. The appearance of girvanellid blue-green algae indicates shallow-water deposition, within the photic zone, for the upper portion of the unit. The presence of small intraclasts and cross-bedded, sandy or silty limestone beds, indicates that currents capable of transporting these constituents were occasionally active at the depositional site. That these currents were not sufficient to completely winnow carbonate mud and pellets suggests deposition of most of the upper portion of the unit took place within the photic zone, but at a depth below high energy water agitation.

Channel incision reflects a period of probable subaqueous erosion. Channel fill displays a crude vertical grading. Limestone clasts are predominant in the basal 1 to 2 feet (30 to 60cm) of fill, and become subordinate to sandy limestone a short distance upward. Grading within channel fill indicates waning current energies, possibly caused by an increase in water depth. The erosional contact observed in section TP3 could not be traced laterally, although the overlying, cross-bedded, calcareous sandstone was recognized at several other localities along Martin Ridge. Channel incision and later infilling defines a local, short duration hiatus, and indicates a period of intertidal or shallow subtidal conditions.

Regional Framework

Cross sections by Ross (1970) show the thicker bedded middle unit extending from Antelope Valley west to Ikes Canyon in the Toquima Range (Figure 2, loc. 6); east to the Steptoe section in the Egan Range, eastern Nevada; and south at least as far as the Pahranagat Range in southeastern Nevada. Stewart and Palmer (1967) also report thick-bedded middle unit lithology at the Callaghan window in the Roberts Mountain thrust, in the Toiyabe Range (Figure 2, loc. 2).

The lower 200 feet (61m) of the middle unit reflects westward progradation of carbonate mud banks and final infilling of the Ninemile embayment at Martin Ridge. The remainder of the unit was deposited in relatively shallow water, and separates synchronous upper unit lithologies to the east from deeper water, lower unit lithologies to the west (Ross, 1970). Like the underlying lower unit, the middle unit is diachronous, becoming younger westward.

Upper Unit

Thickness and Contacts

The upper unit is underlain by the middle unit, and overlain by the Copenhagen Formation at Martin Ridge. As stated previously, the lower contact of the upper unit is defined as the gradational interval in which thin-bedded limestone predominates over thick- to medium-bedded limestone ledges of the middle unit. The upper contact corresponds to the formational boundary of the Antelope Valley Limestone, and is marked by the basal quartzite of the Copenhagen Formation.

The total thickness of the upper unit cannot be measured in section TP3, because of faulting, poor exposure, and the gradational nature of the lower contact. The upper unit is in excess of 255 feet (78m) thick at Martin Ridge. Merriam (1963) reported a 350 foot (107m) thickness for the *Anomalorthis* zone at the northern tip of Martin Ridge, which correlates lithologically with the upper unit in the study area.

Lithology

The upper unit is predominantly medium-bedded slightly argillaceous packstone, with subordinate amounts of intercalated non-argillaceous grainstone and argillaceous wackestone. Bedding thickness varies from thin- to medium-bedded, but resistant weathering limestone ledges of the middle unit are subordinate, and are present primarily in the lower portion of the unit. Bedding surfaces are rough and irregular, and usually weather a mottled yellow and dark gray color. Yellow mottles are weathered argillaceous material, within a packstone or wackestone matrix, which is interstitial to abundant girvanellid algal nodules. Girvanellid algae is common throughout the unit, weathers a dark gray color, and produces the characteristic mottled beds of the upper unit. Small amounts of evenly bedded wackestone are intercalated with packstone beds. Wackestone weathers a light gray or brown color and may be heavily burrowed. Burrows are commonly parallel to bedding, similar to burrows in the upper portion of the middle unit, and are associated with sandy or silty wackestone beds.

The upper unit contains an abundant and diverse fauna dominated by brachiopods. Ostracods, crinoids, bryzoa, and small, high-spired gastropods are also common. _Palliseria_ sp. and _Maclurites_ sp. gastropods are absent in the upper unit.

Acetate peels and polished slabs of packstone and grainstone samples show that they contain abundant bioclastic grains, usually of coarse sand size; girvanellid algal nodules encrusting shell fragment nuclei; and rounded, sandy, micritic intraclasts. Packstones usually contain a small percentage of fine sand grains within micrite matrix, but sand grains are always finer grained and less numerous than in the included intraclasts.

Wackestones in the upper portion of the unit commonly contain high-spired gastropods and thin ostracod shells in a non-argillaceous matrix. Girvanellid algal nodules and intraclasts were not observed in wackestone samples from the upper portion of the unit.

Depositional Environment

The dominant lithology of girvanellid-rich packstone, containing bioclastic grains and sandy intraclasts in an argillaceous micrite matrix, implies shallow water subtidal deposition for most of the upper unit. Burrowed sandy or silty wackestone beds, occasionally containing whole specimens of thin shelled, high-spired gastropods and brachiopods, suggest intermittent low energy conditions occurred at the depositional site. Depositional textures and the included normal marine fauna suggest the upper portion of the middle unit, and the entire upper unit, were deposited in a shallow subtidal shelf-type environment.

COPENHAGEN FORMATION

General Statement

The Copenhagen Formation was named and a type section assigned by Merriam (1963). The formation name had been previously mentioned by Nolan and others (1956, p. 28) without definition.

The type locality of the Copenhagen Formation is on the west flank of Martin Ridge (Figure 2, loc. 7), about 2 miles (3.2km) north of the northern boundary of the map area. At the type section, the formation is divisible into three members. The lowest member, A, is 25 feet (8m) of calcite-cemented, fine-grained quartz sandstone containing abundant _Endoceras_ sp. straight-shelled cephalopods. The medial member, B, is approximately 200 feet (61m) of well-bedded, yellow- to buff-weathering, silty and argillaceous limestone. Member B limestone contains a large and varied fauna (Merriam, 1963). The upper member, C, is about 125 feet (38m) of silty limestone, calcareous siltstone, and very fine-grained calcareous sandstone, with minor carbonaceous shale interbeds.

Thickness and Contacts

Estimated thickness of the Copenhagen Formation at Antelope Valley varies greatly between authors. Merriam (1963) reports a 350 foot (107m) thickness at Martin Ridge; Kirk (1933, p. 32) estimates a 250 foot (76m) thickness in the Antelope Range; Webb (1956, p. 2339) estimates a possible thickness in excess of 600 feet (183m) at Martin Ridge; Lowell (1960) states that the formation is about 400 feet (122m) thick on either side of Antelope Valley; and Ross (1970, p. 28) measured a 490 foot (149m) thickness, excluding member A, on the west flank of the Antelope Range.

Talus from the overlying Eureka Quartzite, and the recessive weathering characteristics of the unit, make measurement of the total thickness of the Copenhagen Formation impossible within the study area. However, topographic relief from the lower contact of the Copenhagen Formation to the base of the cliffs underlain by Eureka Quartzite, suggest that Merriam's estimate of 350 feet (107m) is less than the true thickness of the unit.

The lower contact of the Copenhagen Formation is conformable (Ross and Shaw, 1972) and is placed at the base of the quartz sandstone member A. Although the upper contact is obscured by talus from the Eureka Quartzite throughout the study area and at the type section on Martin Ridge, Ross and Shaw (1972) describe the upper boundary as conformable in the Antelope Range, about 5.5 miles (9km) east of the type locality.

Rock Description

The Copenhagen Formation is exposed in the study area along the entire eastern flank of Martin Ridge, and at a few localities in the southern portion of the map area. The unit forms long, low, talus-covered slopes, often marked by a saddle at the lower boundary and by an abrupt increase in slope gradient at the covered contact with the Eureka Quartzite.

Member A and the lower portion of member B were sampled and described at Martin Ridge. Member C lithologies are not exposed in the study area.

Member A is composed of about 20 to 30 feet (6m to 9m) of primarily silica-cemented quartz arenite. The upper 3 feet (1m) of the unit is gradational from calcareous sandstone to sandy lime wackestone. Member A weathers a yellowish brown color, crops out prominently, usually in saddles, and contains segments of straight-shelled Endoceras sp. cephalopods in its upper portion. Study of polished sections shows member A to be composed entirely of quartz grains of medium to fine sand size. Grains are predominantly subrounded, with less numerous subangular and angular grains, and are well-sorted. No sedimentary structures or trace fossils were observed in outcrop, but discolorations which may be bedding-plane burrows were seen in polished section.

Member B is only partially exposed in the study area, and lithologic description of the lower portion of the unit is confined to samples from a few widely scattered outcrops. Samples from member

B are very light gray weathering argillaceous wackestone. Thin, undulatory silty and argillaceous partings are common in these rocks. Wackestone contains thin-shelled brachiopod valves, thin gastropod shells, echinoderm fragments, crinoid columnals, cephalopod fragments, trilobite shells, and an abundance of sand-size bioclastic grains.

Regional Framework

The Copenhagen Formation has been studied by many workers, following the initial description of the unit by Kirk (1933, p. 32-33) in the Antelope Range. Kirk suggested that the unit was a lateral equivalent of the lower Eureka Quartzite, restricted to the Antelope Valley area. This concept was supported and expanded upon by Webb (1958) and later by Merriam (1963) and other authors. Ross (1964) has established probable equivalence of lower Copenhagen Formation megafossils with megafossils from limestone beds of the lower Eureka Quartzite at the Nevada Test Site. Ross (1977) interprets the depositional setting of the Copenhagen Formation as an embayment, extending from Antelope Valley west to the Toquima Range, which did not receive significant quantities of sand during initial deposition of the Eureka Quartzite to the east, north, and south. The existence of an embayment is further evidenced by convergence of the formational boundaries of the Copenhagen southeastward in the Hot Creek

Range (Lowell, 1960) and northeastward at Lone Mountain (Figure 2), and by the regional unconformity underlying the Eureka Quartzite in parts of the remainder of north-central and south-central Nevada (Webb, 1958). Sands of the Eureka Quartzite eventually covered the Copenhagen embayment in the Antelope Valley area, and may have done so in the Toquima Range, where Copenhagen equivalents are overlain unconformably by unnamed Upper Ordovician limestone (Ross, 1972).

EUREKA QUARTZITE

General Statement

The Eureka Quartzite is probably the most widely distributed Paleozoic formation of the Great Basin (Merriam, 1963). It extends from the Antelope Valley-Eureka region eastward to western Utah, and southwestward across southern Nevada to southeastern California.

Kirk (1933) designated Lone Mountain as the type section of the Eureka Quartzite (Figure 2). This followed previous description and naming of the unit by Hague (1883) from exposures in the vicinity of Eureka, Nevada. Kirk (p. 28) described a typical Eureka Quartzite cliff exposure in the Roberts Mountains as containing two basic divisions; a lower and upper unit. The lower unit is of variable lithology, but typically weathers a dark brown and shows considerable cross-bedding. The upper unit is primarily white vitreous quartzite, which characterizes the upper portion of the formation throughout the Great Basin.

Merriam (1963) described the Eureka Quartzite at Antelope Valley as dense, white, sugary-textured orthoquartzite, or as a darker, brownish gray, less pure quartzite. The Eureka Quartzite is underlain by the Copenhagen Formation and overlain by the Hanson Creek Formation at Antelope Valley.

Contacts and Thickness

The lower contact with the Copenhagen Formation is not exposed in the study area. The upper contact is marked by an abrupt change from calcite-cemented quartz sandstone of the Eureka Quartzite, to very dark gray or black argillaceous limestone of the Hanson Creek Formation.

Thickness of the Eureka Quartzite is variable. Isopachous maps by Webb (1958, p. 2373) show the distribution of Eureka thicknesses throughout central and eastern Nevada and western Utah. Webb reports the Eureka Quartzite as 220 feet (67m) thick at Antelope Valley, while Merriam (1963) reported an approximate 150 foot (46m) thickness. The author measured 195 feet (59m) of Eureka Quartzite in section TP4, at the northern boundary of the map area, although the base of the formation is not exposed. The author therefore agrees with Webb's reported thickness of 220 feet (67m) for the Eureka Quartzite at Antelope Valley.

Rock Description

The Eureka Quartzite is very resistant to erosion and is characteristically a cliff forming unit. The Eureka is exposed along the eastern and western flanks of Martin Ridge and crops out at several localities in the highly faulted southern portion of the map area. The rock is typically jointed, and weathers to angular talus blocks which cover the underlying slope.

On fresh surface, the quartzite is usually white or light gray in color, and may contain black mineral grains with a metallic luster, which may be magnetite or hematite. On weathered surface, a reddish tint often discolors quartzite containing slight amounts of iron oxide. Indistinct planar cross-bedding is rarely observed on weathered surfaces displaying granular, sandy texture. Forsets are less than 6 inches (15cm) in height, and are most readily observed in talus blocks. No current directions were obtained.

In thin section, light gray quartzite contains rare (less than 1 percent) hematite as a secondary mineral interstitial to interlocking quartz crystals. Quartz overgrowths typically obscure the original grain shapes, although some grain boundaries may be seen as dusty rims within quartz crystals. Those grains whose boundaries can be observed range from subrounded to well-rounded and are well-sorted, ranging from medium to fine sand size. No chert grains or heavy minerals were observed.

The upper 10 feet (3m) of the Eureka Quartzite is yellow weathering calcareous quartz arenite. This interval is more loosely cemented than the underlying silica-cemented quartzite, and is directly below the very sharp contact with limestone of the Hanson Creek Formation.

In thin section, quartz arenite from the lower portion of the calcite-cemented interval contains calcite interstitial to, but not within, quartz grains and quartz overgrowths. Calcite may display embayment textures with quartz in overgrowths, but where calcite can be seen to contact detrital quartz grains no embayment textures are present. In the upper portion of the interval, calcite is the only cementing material; quartz overgrowths are absent. Grain size, shape, and sorting of the upper interval are similar to those of the underlying quartzite.

Depositional Environment

The well-sorted and well-rounded, texturally supermature sands of the Eureka Quartzite have been interpreted as beach-bar-dune deposits (Webb, 1956; Potter, 1976). Source areas for the sand must have been older sandstone terrane, as evidenced by the compositional supermaturity of the unit. Webb (1958) postulated that erosion of the Late Precambrian and Cambrian quartz sandstones of the Rocky Mountains, plus erosion of the Ordovician Swan Peak Quartzite of western Utah, produced the supermature Eureka Quartzite sands.

Deposition of the upper calcareous quartz arenite at Martin Ridge represents an abrupt transition from pure quartz sand deposition to argillaceous carbonate mud deposition. The upper portion of the Eureka sand must have been unconsolidated and permeable during deposition of the carbonate mud of the Hanson Creek Formation.

Permeability of the sand decreased with depth, since lower than about 10 feet (3m) below the contact little or no carbonate cement is present in the rock. The contact with the dark lime mudstone is very sharp, and little or no quartz sand is present in the basal portion of the Hanson Creek Formation. Carbonate cement is interpreted as resulting from original fine-grained carbonate mud which was interstitial to sand grains in the uppermost portion of the unconsolidated sand.

Regional Framework

The time significance of the Eureka Quartzite, and its relationship to transgression, regression, and regional unconformities have long been subjects of controversy among students of Great Basin Ordovician stratigraphy. Early workers noted that the Eureka was not entirely a marine deposit, and that both upper and lower contacts, as seen in north-central and eastern Nevada, were probably regional disconformities (Kirk, 1933; Nolan and others, 1956; Merriam, 1963).

Webb (1958) further subdivided the Eureka Quartzite into as many as four members in the southern Monitor Range and Hot Creek Range in central Nevada (Figure 2). Webb's correlation chart (p. 2352) shows a basal, regressive, shaly quartzite extending from Utah to Nevada, which is conformable with the underlying Pogonip Group. An upper, transgressive, vitreous quartzite unit disconformably overlies the shaly unit in eastern Nevada and western and northern Utah; a disconformity separates the Eureka Quartzite from the overlying Hanson Creek Formation in Nevada, and Fish Haven Dolomite in Utah.

Ross (1977) showed the Kinnikinic Quartzite of Idaho, Swan Peak Quartzite of northern Utah, and Eureka Quartzite of western Utah and Nevada as entirely regressive, largely eolian deposits prograding westward and conformably overlying older carbonate formations. These quartzites are disconformably overlain by Late Ordovician carbonates, except at Antelope Valley, where the Eureka Quartzite is shown to be conformable with the overlying Hanson Creek Formation.

The western extension of terrigenous clastic deposition represented by the Eureka Quartzite, and other eastern quartzite formations, indicates that deposition of these units occurred, at least in part, during marine regression across a broad, gently-sloping carbonate shelf. In the study area, the Copenhagen Formation is the lateral equivalent of the regressive, lower unit of the Eureka Quartzite (Webb, 1958). The lower contact of the Eureka Quartzite with the Copenhagen Formation is conformable in the Antelope Range (Ross and Shaw, 1972), and the upper contact with the Hanson Creek Formation is herein interpreted as conformable at Martin Ridge. It seems reasonable, therefore, that at least the upper part of the Eureka Quartzite in the study area is a transgressive deposit. Whether the

Eureka Quartzite in the remainder of central Nevada also includes an upper transgressive sequence (Webb, 1958) or is entirely regressive (Ross, 1977) is not known.

Deposition of the Eureka Quartzite occurred during the approximate period of maximum marine regression separating the Sauk and Tippecanoe sequences of Sloss (1963).

HANSON CREEK FORMATION

General Statement

Merriam (1940) designated the type section of the Hanson Creek Formation for exposures at Pete Hanson Creek in the Roberts Mountains (Figure 2, loc. 9). At the type section, the Hanson Creek consists of dark gray, poorly bedded dolomitic limestone at the base, overlain by light gray weathering fossiliferous shaly limestone, followed by poorly bedded to massive, non-fossiliferous dark gray limestone in the upper portion of the formation. At Pete Hanson Creek, and throughout most of central Nevada, the Hanson Creek Formation is underlain by the Eureka Quartzite and overlain by the Roberts Mountains Formation.

Merriam (1963) described the lower portion of the Hanson Creek Formation in the Monitor Range as dark gray, platy limestone with scattered shaly partings, overlain by thicker-bedded dark gray limestone containing chert and a few fossiliferous, coral-rich beds.

The Hanson Creek Formation is exposed along the top of Martin Ridge and in the central and southern portions of the study area. An incomplete section of the Hanson Creek was measured at the northern boundary of the map area on the east side of Martin Ridge, in section TP4 (Figures 11 and 12).

Contacts

Merriam (1963, p. 31) described the contact of the Hanson Creek Formation with the underlying Eureka Quartzite at Antelope Valley as "rather abrupt and of such lithologic contrast as to suggest a disconformity, although no evidence of post-Eureka erosion was detected." The nature of the upper 10 feet (3m) of calcareous quartz arenite of the Eureka Quartzite is discussed in the preceding pages. Kirk (1933, p. 28) postulated that this interval is not part of the Eureka Quartzite proper, but that it should be included as the "initial deposit of the overlying Upper Ordovician," later named the Hanson Creek Formation. Merriam and Anderson (1942, p. 1686), and Nolan and others (1956, p. 30) also included the sandstone interval in the basal Hanson Creek. Webb (1958, p. 2342) included the sandstone interval at Lone Mountain in the Eureka Quartzite, because of the sharp contact separating the sandstone from the overlying dolomite.

The calcareous quartz arenite interval is herein included in the Eureka Quartzite. The calcite-cemented sandstone is interpreted to have been unconsolidated at the time of initial Hanson Creek carbonate mud deposition, and is conformable with the basal portion of the formation. The hiatus reported by Merriam (1963) and Webb (1958) at Antelope Valley is not represented by the sharp contact at the base of the Hanson Creek Formation, but may be present within the silica-cemented quartz arenite of the Eureka Quartzite. However, the almost universal absence of fossils from the upper Eureka Quartzite, and the lack of a definite erosional contact at the base of the Hanson Creek Formation, does not provide evidence to indicate that a hiatus separates these formations at Martin Ridge.

The upper contact of the Hanson Creek Formation was defined by Merriam (1940) as the base of the overlying Roberts Mountains Formation chert. Merriam (1963, p. 32) recognized that in parts of the Great Basin the cherty zone is not present, and that "similar carbonate rocks persist upward from the Hanson Creek...interval into beds of paleontologically established Silurian age." However, Merriam described the cherty zone as an important stratigraphic marker, extending from the Roberts Mountains to the Inyo Mountains of southeastern California, and believed it to be a suitable formational boundary.

Matti and McKee (1977, p. 196) have shown that the basal cherty unit of the Roberts Mountains Formation is apparently time-transgressive, of variable thickness, and is absent at some localities in central Nevada. The use of this unit as a formational boundary is complicated by an unconformity which exists <u>below</u> the chert at the type section (Berry and Murphy, 1975), and <u>above</u> the chert at Copenhagen Canyon (Matti and others, 1975). Also, the lower boundary of the cherty interval at Copenhagen Canyon is gradational, unlike the sharp contact at Lone Mountain and at the type locality in the Roberts Mountains (Merriam, 1940).

Matti and others (1975) have chosen the disconformity overlying the cherty interval at Copenhagen Canyon as the lower contact of the Roberts Mountains Formation. This boundary was chosen because the hiatus at Copenhagen Canyon represents a period of non-deposition or erosion from early to late Llandovery, with resumed deposition approximately coinciding with the basal Roberts Mountains Formation at the type section (Berry and Murphy, 1975), which disconformably overlies the Hanson Creek Formation (Winterer and Murphy, 1960). Also, the lower portion of the cherty interval at Copenhagen Canyon is gradational, and does not define a practical mapping contact.

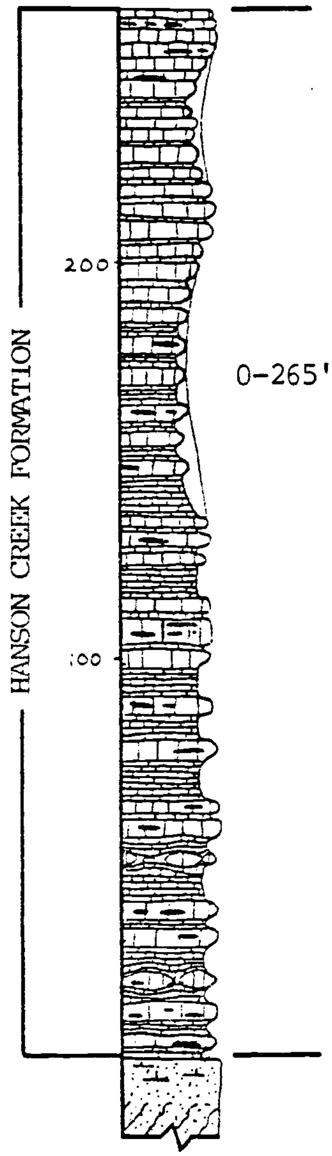
At Martin Ridge, and at other localities in the study area, chert beds gradationally increase in abundance in the upper portion of the Hanson Creek Formation, and provide no distinct lithologic break as a mappable contact. Faulting and talus from the overlying, platy weathering limestone of the Roberts Mountains Formation obscure the upper contact of the cherty interval in the map area. Due to poor exposure, it is not known if the disconformity present at Copenhagen Canyon is located above, or within the cherty interval in the study area. In order to utilize a mappable contact in areas of poor exposure, the upper boundary of the Hanson Creek Formation was mapped at the abrupt lithologic change from thin-bedded limestone to the distinctive platy weathering limestone of the Roberts Mountains Formation. This lithologic change occurs approximately 3 feet (1m) above the disconformity at Copenhagen Canyon. This designation includes the cherty interval as an upper unit of the Hanson Creek Formation.

Thickness

The thickness of the Hanson Creek Formation is variable in central Nevada; ranging from 560 feet (171m) at the type section in the Roberts Mountains, to 318 feet (97m) at Lone Mountain, to over 350 feet (107m) in an incomplete section at Whiterock Canyon (Merriam, 1963). An incomplete section of 485 feet (148m) thickness was measured in section TP4, with the top of the formation absent due to erosion. A 4 foot (1.2m) thick sandy limestone bed is present 10 feet (3m) below the top of the Hanson Creek Formation in section TP4. Merriam (1963, p. 31) reported a 10 foot (3m) thick calcareous sandstone bed lying 40 feet (12m) below the top of the formation at Whiterock Canyon (Figure 2, loc. 11). Assuming the calcareous sandstone bed from Whiterock Canyon and the sandy limestone bed in section TP4 are correlative, the Hanson Creek is estimated as 515 feet (157m) thick at Martin Ridge.

The sandy limestone bed measured in section TP4 is about 50 feet (15m) higher than the same bed measured in a section at the northern tip of Martin Ridge by Dunham (1977a). This discrepancy

Continued in figure 12.

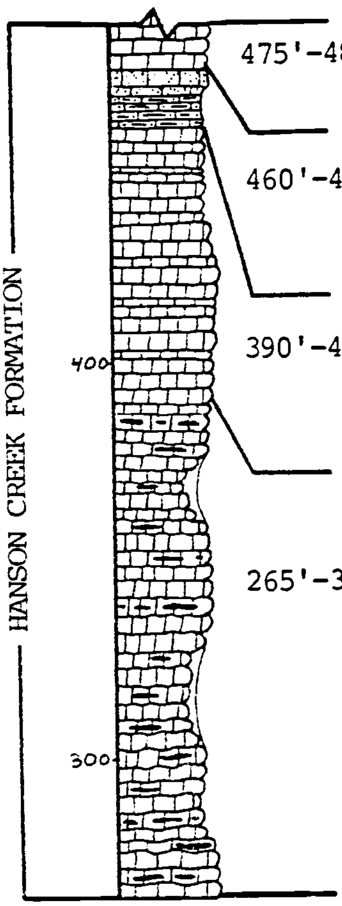


0-265' Shaly limestone and intercalated, medium-bedded lime mudstone. Shaly limestone, (f) very dark-gray, black (w) dark-gray, light-gray, locally contains graptolites and pyrite; dominant lithology in the basal portion becoming subordinant to lime mudstone up section. Black-chert-bearing lime mudstone, (f) dark-gray, black (w) dark-gray, light-gray, displays pinch-and-swell structure in lower portion. Shaly limestone and lime mudstone emit fetid odor when broken.

EUREKA QUARTZITE

Figure 11. Measured section TP4

incomplete



475'-485' Medium-bedded wackestone, (f) light-gray, (w) light-gray, contains poorly preserved brachiopod and crinoid debris.

460'-475' Silty limestone, (f) light-brown (w) light-brown, grading into sandy, oolitic grainstone, (f) very light-gray (w) very light-gray, reddish-gray, in the upper 4'.

390'-460' Medium-to thin-bedded lime mudstone, (f) dark-brown (w) light-brown. Bedding is planar and well developed. Locally lime mudstone is highly bioturbated. Contains no chert.

265'-390' Medium-beded lime mudstone, (f) dark-gray, black (w) light-gray, dark-gray. Bedding is uniform, and poorly developed where intervening argillaceous layers are absent. Bedding surfaces are slightly undulatory.

continued from figure 11.

Figure 12. Measured section TP4

may reflect thickening of the formation southward along Martin Ridge.

Lithology

The Hanson Creek Formation typically forms low slopes covered with flaggy talus in the lower portion, changing to cliff exposures in the upper, chert-rich portion of the unit. The formation is easily recognized by its characteristic dark gray color and fetid odor when broken.

The lower 265 feet (81m) of the Hanson Creek in section TP4 (Figure 11) consists of medium-bedded, dark gray cherty lime mudstone intercalated with dark gray to black, shaly lime mudstone. Medium-bedded lime mudstone is laminated, and may display pinch-and-swell structure (Plate 3, photo 1). Locally, medium-bedded lime mudstones pinch-out laterally, producing sedimentary boudins. Brown weathering black chert stringers replace carbonate in the thicker lime mudstone beds. Chert is prominent in the lower portion of the unit, but decreases in abundance upward. Shaly limestone is platy weathering and locally contains pyrite along parting surfaces. Shaly limestone composes over 75 percent of the rock from the base of the section to about 215 feet (66m), where it is present in approximately equal proportion with medium-bedded lime mudstone. In the upper 50 feet (15m) of the unit, shaly limestone decreases in abundance, and is present at the top of the interval only as very thin (1-3mm) argillaceous layers separating medium-bedded lime mudstone.

The interval from 265 feet (81m) to about 390 feet (119m) consists of cherty, dark gray, medium-bedded lime mudstone (Figure 12). Beds are of uniform thickness (10-15cm) and are separated by very thin argillaceous layers. Bedding is poorly developed where argillaceous layers are not present, and bedding surfaces are typically undulatory.

The overlying 70 feet (21m) of lime mudstone is dark brown in color, contains no chert, and is locally highly burrowed (Plate 3, photo 2). Bedding thickness ranges from thin- to medium-bedded; bedding is well developed due to an increase in argillaceous layers separating individual beds.

The interval from 460 feet (140m) to the top of the section contains two separate lithologic units. The lower 15 foot (4.5m) thick unit consists of brown weathering silty limestone at the base, grading upward into sandy, oolitic grainstone in the upper 4 feet (1.2m) of the unit. Sandy oolitic grainstone displays no bedding or sedimentary structures. Oolitic grainstone weathers a very light gray or reddish gray color. The upper 10 foot (3m) thick unit overlies the grainstone along a knife-sharp planar contact, and consists of light gray wackestone containing abundant, poorly preserved brachiopod and crinoid debris.

The cherty interval included in the upper portion of the Hanson Creek Formation is not exposed in section TP4.

Depositional Environment

The lower 265 feet (81m) of interbedded shaly limestone and medium-bedded lime mudstone in section TP4 represent deposition in a very quiet water, restricted, basinal environment. The presence of small pyrite crystals along parting surfaces in shaly limestone indicates a reducing environment at the depositional site. Section TP4 was sampled for microfossils and upon solution of the rock in dilute formic acid, samples from the lower portion of the section typically produce a floating, oily residue at the surface of the acid solution. These rocks are dark in color, and emit a strong fetid odor when broken, due to the included unoxidized organic hydrocarbons. Polished sections of lime mudstone show laminated, pure micrite with no evidence of disruption by burrowers or included benthic megafossils. The only megafossils present in the lower portion of the section are graptolites. Microfossils include rare conodonts and Radiolaria in the lime mudstone beds (Dunham and Murphy, 1976). Dunham (1977b) interpreted the lime mudstone beds within shaly limestone as representative of accelerated rates, or "pulses," of carbonate mud deposition. The percentage of Radiolaria and argillaceous material decrease in a regular manner toward the center of lime mudstone beds, indicating dilution of clay and Radiolaria by a relatively rapid input of lime mud (Dunham, 1977b, p. 37).

The interval from 265 feet (81m) to about 390 feet (119m) represents continued quiet water deposition of carbonate mud in a basinal environment. However, the absence of shaly limestone indicates a probable increase in the rate of carbonate mud input into the basin. Lime mudstone from this interval is similar to that of the underlying unit. Polished sections of lime mudstone samples show parallel laminations undisrupted by burrowers, and no included benthic megafauna.

The overlying 70 foot (21m) thick interval, up to 460 feet (140m), is locally highly burrowed, nonlaminated lime mudstone. Polished sections show an occasional biotic fragment within burrowed and nonburrowed lime mudstone. Burrowed lime mudstone containing biotic grains suggest shoaling from the underlying unit, and proximity to areas of biotic productivity. The irregular bedding thickness in this unit may reflect variations in the rate of supply of carbonate mud. Dunham (1977b) has interpreted a lagoonal environment for light brown wackestone, occupying the same stratigraphic interval of the Hanson Creek Formation, at the northern tip of Martin Ridge.

The overlying 15 foot (4.5m) thick interval of silty limestone grading to sandy oolitic grainstone represents a short period of relatively high energy shoal water conditions, sufficient to completely winnow carbonate mud. The overlying 10 feet (3m) or so of fossiliferous wackestone reflect a subsidence in current energy. The presence of abundant benthic fauna suggest that quiet water conditions probably do not reflect a substantial increase in water depth for the uppermost interval.

In summary, depositional environments of the Hanson Creek Formation at Martin Ridge indicate a shoaling-upward sequence of basinal, to lagoonal, to shoal water conditions, and perhaps a return to lagoonal conditions in the uppermost portion of the section.

Age

Graptolites collected 2 feet (60cm) above the Eureka Quartzite contact were examined by W. B. N. Berry (written communication, 1978) and considered to be representative of zone 14, or possibly zone 13, of the North American graptolite zones (Berry, 1976). This would place the lower contact of the Hanson Creek Formation in the late Edenian or Maysvillian Stage, or upper Caradoc of the British Stages.

Microfossil samples were collected in section TP4 and along the basal contact of the Hanson Creek at various localities throughout the map area. Conodont recovery was generally poor in these rocks. The presence of *Protopanderodus insculptus* at 60 feet (18m) (collection TP4-2c) of the *Amorphognathus ordovicicus* zone "...suggests that the collections...are of post-middle Maysvillian Cincinnatian age" (Stig M. Bergström, written communication, 1978).

Mullens and Poole (1972) have shown that a quartz-sand-bearing zone is present in the upper Hanson Creek Formation at several localities throughout central Nevada. The upper portion of the Hanson Creek is shown to be Early Silurian in age, and the Ordovician-Silurian boundary is located near the quartz-sandy interval (Mullens and Poole, 1972, p. B24). Conodonts recovered from the top of section TP4 (485 feet, collection TP4-2n), 10 feet (3m) above the sandy grainstone contact, are not diagnostic biostratigraphically, but contain Ordovician elements indicating that the Ordovician-Silurian boundary lies above the upper portion of section TP4.

Regional Framework

The Hanson Creek Formation, and possibly the upper Eureka Quartzite, are the initial transgressive deposits of the Tippecanoe sequence of Sloss (1963). Resumed carbonate deposition in the Late Ordovician marks a period in which the continent became submerged to a greater extent than at any other Phanerozoic time (Ross, 1976). Paleogeographic maps by Ross (1977, p. 34-35) show the Hanson Creek Formation, and its equivalents, extending from Antelope Valley west to the Toiyabe Range; north to northern Nevada, northern Utah, and southern Idaho; east to western Utah; and south to southeastern California. Throughout much of this area, Upper Ordovician carbonates are dolomite or dolomitic limestone, except in central and northern Nevada, where the Hanson Creek Formation is primarily limestone. Eastern equivalents of the Hanson Creek, the Ely Springs and Fish Haven dolomites, are thought to have been deposited on a restricted shallow shelf, and are therefore primary dolomites (Ross, 1977). In some areas, the presence of sessile benthic fauna within dolomite suggest dolomitization was diagenetic (Ross, 1977; see Dunham, 1977b, p. 83-89).

Dunham (1977a) has completed a detailed paleogeographic study of the Hanson Creek Formation in Eureka County, Nevada. Stratigraphic sections from Martin Ridge, Lone Mountain, and Pete Hanson Creek (Figure 2, locs. 7 and 9) are compared and depositional environments analyzed. The paleogeography of the carbonate shelf during Late Ordovician (Ashgillian) time consisted of a northern shallow subtidal lagoon, separated from a southern shallow open marine shelf by a transition zone of migrating barrier shoals. The transition zone of laterally migrating shoals trends northwest-southeast and passes through Lone Mountain. South of the open marine shelf, in the area of the northern Monitor Range and southern Antelope Valley, lies the basinal-facies Hanson Creek Formation as described in section TP4 at Martin Ridge. The Hanson Creek lithology at Martin Ridge is significantly different than at Lone Mountain, at the Roberts Mountains, or at other localities in Eureka County (Nolan and others, 1956) and has been interpreted by Dunham to have been deposited in an intra-platform basin. The Martin Ridge basin is postulated to have formed rapidly following deposition of Eureka sands, with initial sedimentation rates being very slow due to relative isolation from areas of high carbonate mud production. Dunham (1977a) described the Martin Ridge section as follows:

> ...the waters in the energetic depositional environment of the uppermost Eureka Quartzite were probably no deeper than a few meters. Similarly, water depth near the top of the Hanson Creek section was no greater than a few tens of meters at most. Consequently, it seems unlikely that the graptolitic shaly limestone at the base of the Martin Ridge section was deposited in extremely deep water. The section proceeds from shallow to relatively deep and back to shallow water facies over a stratigraphic thickness of little more than 100m. It is therefore suggested that the graptolitic beds in the Hanson Creek were probably deposited in waters little deeper than 100m. In this interpretation, the apparent shallowing trend up section represents the infilling of a shallow depression by lime mud (p. 162).

By Early Silurian (Landovery) time, facies patterns had shifted southwestward. Areas north of an including Lone Mountain, which were previously shelf lagoon environments, had been infilled by prograding tidal flat deposits. A shelf lagoon, marginal to tidal flats to the north, was bounded to the south by barrier shoals in the vicinity of the infilled Martin Ridge basin.

Data gathered during this study, and by Wise (1976), may serve to delineate the maximum southern limit of the Martin Ridge basin. Wise (1976, addendum) reported a Silurian (Ludlovian) conodont collection taken 19 feet (6m) above the upper Eureka Quartzite contact at Clear Creek in the central Monitor Range, about 10 miles (16km) south of the southern limit of the study area. Conodonts collected by the author at 60 feet (18m) above the upper Eureka Quartzite contact at Dobbin Summit (Figure 2, loc. 5), 4.5 miles (7km) north of Clear Creek (Figure 2, loc. 3), were identified as "...probably latest Llandoverian to early Wenlockian" (J. E. Barrick, written communication, 1978). No faulting or observable unconformity was recognized by the author at Dobbin Summit, or by Wise at either locality. The light colored Silurian dolomite occupying the stratigraphic position of the Hanson Creek Formation at Dobbin Summit and Clear Creek disconformably overlies the Eureka Quartzite, or contains the Late Ordovician-Early Silurian record as a condensed section in the basal few feet of dolomite with no break in sedimentation. Either way, basinal sediments of the lower Hanson Creek Formation in the northern Monitor Range are not present in the central portion of the range.

As pointed out by Dunham (1977a, p. 162), paleogeographic reconstruction of this kind suffers from a lack of data concerning tectonic rearrangement of regional facies patterns. Eastward telescoping of thrust slices in the lower plate of the Roberts Mountains allochthon (Kay and Crawford, 1964) may have transported Martin Ridge basinal-facies rocks to their present position.

ROBERTS MOUNTAINS FORMATION

General Statement

The Roberts Mountains Formation was named by Merriam (1940) and the type section designated at Pete Hanson Creek in the Roberts Mountains (Figure 2, loc. 9). At the type locality, the Roberts Mountains Formation is underlain by the Hanson Creek Formation and overlain by the Lone Mountain Dolomite. Merriam described the type section as consisting of laterally persistent bluish black chert at the base, overlain by well-bedded, slabby, slate gray, partially crinoidal crystalline limestone. Near the top of the section, bedding is less well-defined and dolomite increases up section to the overlying light gray Lone Mountain Dolomite.

At Copenhagen Canyon, the Roberts Mountains Formation is overlain by the Windmill Limestone (Matti and others, 1975). Here, the unit consists predominantly of very fine-grained, laminated lime mudstone and wackestone intercalated with subordinate, thick-bedded skeletal packstone and grainstone.

Contacts and Thickness

The lower contact of the Roberts Mountains Formation has been discussed in detail in the preceding pages. For mapping purposes within the study area, the lower contact is marked at the change from thin-bedded, cherty lime mudstone of the Hanson Creek Formation, to platy weathering limestone of the Roberts Mountains Formation.

The upper contact of the Roberts Mountains Formation is not exposed in the study area, because the overlying Lower Devonian Windmill Limestone is not present.

The thickness of the Roberts Mountains Formation at the type section is 1, 900 feet (579m) (Merriam, 1940) and has been reported as 1, 575 feet (480m) thick by Matti and others (1975) at Copenhagen Canyon. No measurable section of the Roberts Mountains Formation was found in the study area. Where it is exposed, the Roberts Mountains Formation crops out along ridge and hill tops above cliffy, chert-rich Hanson Creek exposures. It is estimated that only the lower few hundred feet of the formation is exposed in the study area.

Lithology

As exposed in the study area, the Roberts Mountains Formation is characterized by low, talus-covered slopes with occasional outcrops of platy weathering, light brown to light gray, silty lime mudstone. Talus is composed of thin plates of various sizes, which produce a metallic ringing sound when struck. Individual plates may be laminated, contain a few sand-size biotic grains, and are usually fractured and recemented by intersecting linear calcite veins. Black chert, similar to the underlying Hanson Creek Formation chert, replaces lime mudstone and is locally conspicuous in platy limestone float. Minor amounts of graded and nongraded packstone appear as float, but were not observed in outcrop. Matti and others (1975) have interpreted these beds as skeletal limestone debris flows (allodapic limestone). Allodapic limestone composes only 5 percent of the total Roberts Mountains Formation at Copenhagen Canyon.

Regional Framework

The Roberts Mountains Formation was studied and described by Winterer and Murphy (1960) as a lateral equivalent to the Lone Mountain Dolomite in the Roberts Mountains. The Roberts Mountains Formation was interpreted as a western deep water, basinal, off-reef, and reef-flank deposit derived from the eastern reef-facies Lone Mountain Dolomite. Later workers (Matti and others, 1975) have modified the reef facies designation for the Lone Mountain Dolomite, but have emphasized the paleotopographic break separating the eastern, shallow water dolomite suite from the western, basinal limestone suite. Matti and McKee (1977) published a detailed paleogeographic study of central Nevada during Silurian to Early Devonian time. Deposition of the Roberts Mountains Formation is interpreted to have taken place upon a "gently rolling paleosurface" following a hiatus of areally varying duration. The "laminated limestone facies" of the Roberts Mountains Formation is present at Copenhagen Canyon and in the study area. This facies records basinal accumulation of carbonate mud with occasional deposition of distal carbonate turbidity flows (allodapic limestone) derived from shallow water areas to the east. Downdropping of the western shelf margin was postulated by Johnson and Potter (1975) as an explanation for the eastward shift of shallow water lithofacies during Early Silurian (Llandovery) time, and may have caused the formation of the "gently rolling paleosurface" and corresponding basinal areas described by Matti and McKee (1977). Westward progradation of eastern shallow water facies rocks, and the accompanying increase in frequency of allodapic limestone beds, marks the upper boundary of the Roberts Mountains Formation at Copenhagen Canyon (Matti and others, 1975).

Age

Extensive studies of Roberts Mountains Formation faunas (Johnson, Boucot, and Murphy, 1973, 1976; Klapper and Murphy, 1974; Berry and Murphy, 1975) establish the age of the formation as late Llandoverian (Silurian) to early Lochovian (Devonian).

ALLOCHTHONOUS ROCKS

General Statement

Relatively limited exposures of bedded chert, silty limestone, and quartzite in the southern portion of the map area, and bedded chert at Martin Ridge, have been assigned to the Vinini Formation.

The Vinini Formation was first described by Merriam and Anderson (1942) in the Roberts Mountains (Figure 2). There, the Vinini was separated into lower and upper divisions. The lower Vinini consists of dark gray, brownish weathering bedded quartzite, gray arenaceous limestone or calcareous sandstone, and finely laminated silty rocks displaying shaly partings. The upper Vinini consists primarily of bedded chert and black organic shale.

Merriam (1963) described the Vinini Formation at Antelope Valley as containing a wide variety of sedimentary rocks, including coarse sandstone, siltstone, black shale, bedded chert, and limestone. Merriam listed six localities in the Antelope Valley vicinity at which the Vinini Formation is exposed. None of these coincide with exposures located in this study. No stratigraphic subdivision of these rocks was reported by Merriam at Antelope Valley.

Lithology

The Vinini Formation is present in the southern portion of the study area east of Applebush Spring and northeast of hill 8525. On Martin Ridge, several outcrops of black bedded chert which may be part of the Vinini Formation are exposed west of the crest of the ridge, overlying the Hanson Creek Formation, within the northernmost portion of the study area.

In the southern portion of the map area, Vinini Formation quartzite appears as a single 5 foot (1.5m) thick bed within platy weathering silty limestone. Quartzite is tightly silica-cemented, light gray on fresh surface, and weathers light yellowish brown. Silty limestone is dark gray on fresh surface and weathers into yellowish brown plates. Both lithologies are cut by numerous small faults, and one small fold was observed in thinly bedded silty limestone.

Vinini Formation thin-bedded chert in the southern portion of the map area is very evenly bedded (3-6cm), and individual beds are separated by thin (less than 1cm) black shale layers. Chert weathers a rusty brownish black, and on fresh surface may display thin laminations (less than 1mm) of alternating black and white layers (Plate 4, photo 1). In thin section, black laminae are composed of chert containing a dark brown isotropic substance believed to be kerogen, separated by kerogen-free, lighter colored laminae. Laminations are not parallel; instead they are convolute and, in some instances, resemble cross-laminae. Merriam and Anderson (1942) described

Vinini Formation black shales and chert as follows:

> Along Vinini Creek and at other localities throughout the Roberts Mountains region the shales are readily ignited. The oil yield on distillation of selected samples is above 25 gallons per ton. Where black shale interbeds have a high content of bituminous matter, the dark chert layers probably carry much of the same (p. 1696).

Ketner (1969) described laminated chert as follows:

> Within chert beds that are separated from one another by shale partings are nonparting laminae about 1 millimeter thick. These thin laminae are caused by slightly varying concentrations of Radiolaria, illite, carbonaceous material, or detrital quartz grains (p. B24).

Detrital quartz grains, averaging about 0.1mm in diameter, were observed in thin section under plane-polarized light as angular, slightly clearer areas within darker kerogen.

Bedded chert at Martin Ridge is similar in outcrop, and petrographically, to chert from the southern portion of the map area, and is tentatively assigned to the Vinini Formation. Chert is slightly thicker bedded (6-8cm) than in the southern portion of the map area, weathers rusty reddish brown, and individual beds may be separated by very thin (less than 3mm) shaly layers. Where shaly layers are absent, bedding is poorly defined. On fresh surface, and in thin section, dark and light laminations are evident. Laminae are much thinner and more closely spaced than in the southern Vinini chert, and are composed of alternating kerogen-rich and kerogen-poor layers. A few small spheres of chalcedony, which are believed to be Radiolaria, are present in thin sections of Martin Ridge chert; as in chert from the southern portion of the study area. Detrital quartz grains were not recognized. Axes of small folds within the chert, and in the underlying Hanson Creek Formation (Plate 4, photo 2), approximately correspond in attitude to the folded Vinini limestone observed in the southern portion of the map area. The basal contact of bedded chert with the Hanson Creek Formation limestone is not exposed, but brecciated chert is common near the base of bedded chert outcrops.

Lohr (1965) described a similar chert unit at Brock Canyon (Figure 2, loc. 1), about 12 miles (19km) northwest of the study area, as the basal chert of the Roberts Mountains Formation. However, rocks that Lohr designated as overthrust Roberts Mountains Formation at Copenhagen Canyon (Figure 2, loc. 4) and in the Brock Canyon-Charnac Basin area were previously assigned to the Vinini Formation by Bortz (1959) and Merriam (1963). Because the bedded chert overlying the Hanson Creek Formation at Martin Ridge occupies the stratigraphic position of the Roberts Mountain Formation, it is possible that it is formed entirely by replacement of thin-bedded lime mudstone, and is therefore not part of the Vinini Formation. The author believes that because the bedded chert at Martin Ridge displays many of the petrographic features of Vinini chert described by Ketner (1969), and it so closely resembles bedded cherts in the southern portion of the map area, that it should be assigned to the Vinini Formation and is not the basal chert of the Roberts Mountains Formation.

Regional Framework

The Vinini Formation, and other western facies Ordovician rocks, differ faunally and lithologically from the predominantly carbonate rocks of the eastern facies (Merriam and Anderson, 1942). Western facies rocks comprise, in decreasing order of abundance, shale, chert, quartzite, sandstone, greenstone, and limestone (Ketner, 1977). This predominantly clastic suite, intercalated with pyroclastic and volcanic flow rocks, is generally considered to represent deep water deposition (Roberts and others, 1958; Merriam, 1963; Burchfiel and Davis, 1972). Deposition of some of these rocks, such as bedded chert, must have occurred in moderately deep water (Ketner, 1969), but the presence of quartzite and limestone may indicate "a variety of environments ranging from shallow water, nearshore to moderately deep water, offshore" (Ketner, 1977, p. 255).

Western facies rocks have been thrust eastward a minimum of 80km (50 miles) (Ketner, 1977) by the Late Devonian age Roberts Mountains thrust (Smith and Ketner, 1968). Significant interleaving of Ordovician, Silurian, and Lower Devonian rocks in the Monitor and Toquima Ranges, and at many other localities in central Nevada, suggest emplacement of a series of complex imbricate thrust sheets (Merriam, 1963; Kay and Crawford, 1964; Matti and McKee, 1977). Merriam (1963) reports Vinini Formation outliers in the southern Antelope Range and at Devils Gate, indicating that the trace of the Roberts Mountains thrust extends to the east of the study area.

Age

The Vinini Formation has been dated at the type section in the Roberts Mountains as Early to Middle Ordovician by Merriam and Anderson (1942), and by Smith and Ketner (1975) in the Piñon Range as Early to Late Ordovician.

STRUCTURE

General Statement

Normal faulting, thrust faulting, and small-scale folding were observed in the study area. Thrust faulting in the southern and central portions of the map area is related to the Late Devonian-Early Mississippian emplacement of the Roberts Mountains allochthon. Large-scale Tertiary normal faulting is in evidence throughout the study area, and is characteristic of the Basin-and-Range structural framework.

Thrust Faulting

Relatively limited exposures of the allochthonous western assemblage Vinini Formation in the southern portion of the map area, and at Martin Ridge, indicate thrust emplacement of this unit. The remainder of the thrust faults mapped in the study area are the result of movement in the lower plate of the Roberts Mountains thrust. Thrust faults on the eastern and southeastern slopes of hill 8525 in the southern portion of the map area best display lower plate thrusting. One cliff exposure contains two thrust slices; Eureka Quartzite has been thrust over highly silica-veined and brecciated Hanson Creek Formation limestone, and in turn has been overthrust by a thick sequence of the Goodwin Limestone.

Small-scale fold axes in the Vinini bedded chert and in the underlying Hanson Creek Formation at Martin Ridge (Plate 4, photo 2) have attitudes of N. 60°E., 15°S. and N. 45°E., 15°S. respectively. A small-scale fold axis in Vinini Formation limestone in the southern portion of the map area has a trend and plunge of N. 40°E., 25°S. All of the above listed folds display westward-dipping axial planes. It is probable that folding was contemporaneous with thrusting and that both resulted from a compressive system along a northwest-southeast trend. This sense of compression is compatible with that of the Roberts Mountains thrust in the Carlin-Piñon Range (Smith and Ketner, 1968) and in the Toquima Range (McKee, 1976).

Normal Faults

Two separate normal fault systems are present in the study area. The larger, and probably older, of the two systems includes generally north- and northeast-trending faults. This system includes the north-trending range-front faults of Martin Ridge and the eastern flank of the Monitor Range, and the northeast-trending range-front faults of the western flank of the Antelope Range. Both north- and northeast-trending normal faults intersect in the southern portion of the map area.

The second normal fault system is best developed at Martin Ridge, and consists of generally east-west-trending faults which have relatively smaller throw than the north-trending range-front system. These faults break the north-south-trending ranges into separate blocks; displacement probably occurred after the major range-front faults had undergone significant movement.

CONCLUSIONS

Ordovician to Early Silurian rocks in the study area are part of the shallow-shelf eastern assemblage (Roberts and others, 1958). The Early Ordovician Goodwin Limestone was deposited near the western edge of the middle carbonate belt (Robison, 1960; Palmer, 1960, 1971), which corresponds to the outer boundary of the shallow water carbonate platform (Kepper, 1972). The shallowing trend seen in the upper Goodwin Limestone was terminated by formation of the deep water Ninemile embayment (Ross, 1977), which represents a narrow eastward extension of the outer detrital belt into the middle carbonate belt. The Ninemile Formation, and the lower and basal middle unit of the Antelope Valley Limestone, record westward progradation of the middle carbonate belt and infilling of the Ninemile embayment, which was completed by early Middle Ordovician (Llanvirnian) time. The middle and upper units of the Antelope Valley Limestone were deposited in shallow subtidal to intermittently intertidal conditions, followed by deposition of the shallow water subtidal Copenhagen Formation during Middle Ordovician (late Llanvirnian, Llandeilian, and early Caradocian) time. Deposition of the Eureka Quartzite in the study area probably occurred during or immediately following the period of maximum marine regression separating the Sauk and Tippecanoe sequences of Sloss (1963). The overlying Hanson

Creek Formation reflects an abrupt change from shallow water facies to basinal facies; coinciding with renewed transgression of the craton during Middle to Late Ordovician (upper Caradocian) time (Ross, 1977). The Martin Ridge basin of Dunham (1977a) extended from the northern Monitor Range southward to the southern boundary of the map area, but is not present six miles (10km) farther south, at Dobbin Summit.

The Roberts Mountains Formation disconformably overlies the Hanson Creek Formation at Copenhagen Canyon (Matti and others, 1975) and was deposited in a basinal environment resulting from the Early Silurian (Llandoverian) downdropping of the western shelf margin, and corresponding eastward retreat of shallow water lithofacies (Johnson andPotter, 1975).

Emplacement of the Ordovician Vinini Formation along the Roberts Mountains thrust, and the accompanying lower plate thrust faulting, were important effects of the Late Devonian-Early Mississippian Antler orogeny.

Photo 1. Ninemile Formation nodular lime mudstone and intercalated shaly limestone.

Photo 2. Basal medium-bedded limestone ledge of the middle unit of the Antelope Valley Limestone.

Plate 2.

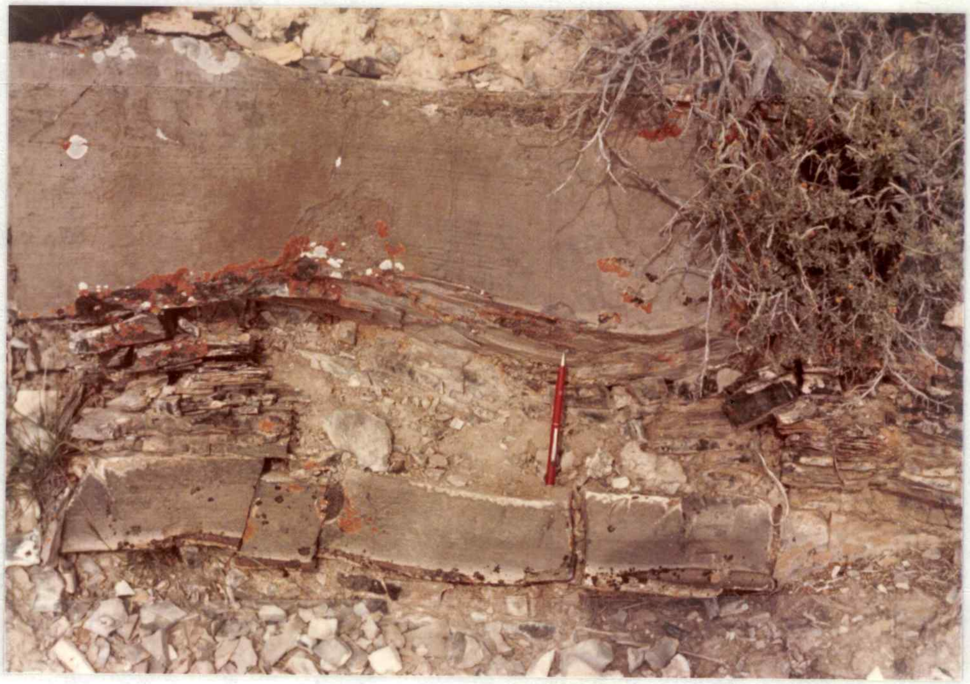


Photo 1. Hanson Creek Formation shaly limestone (red pen) and laminated lime mudstone displaying pinch-and-swell structure.

Photo 2. Hand specimen of burrowed lime mudstone from the upper Hanson Creek Formation.

Plate 3.

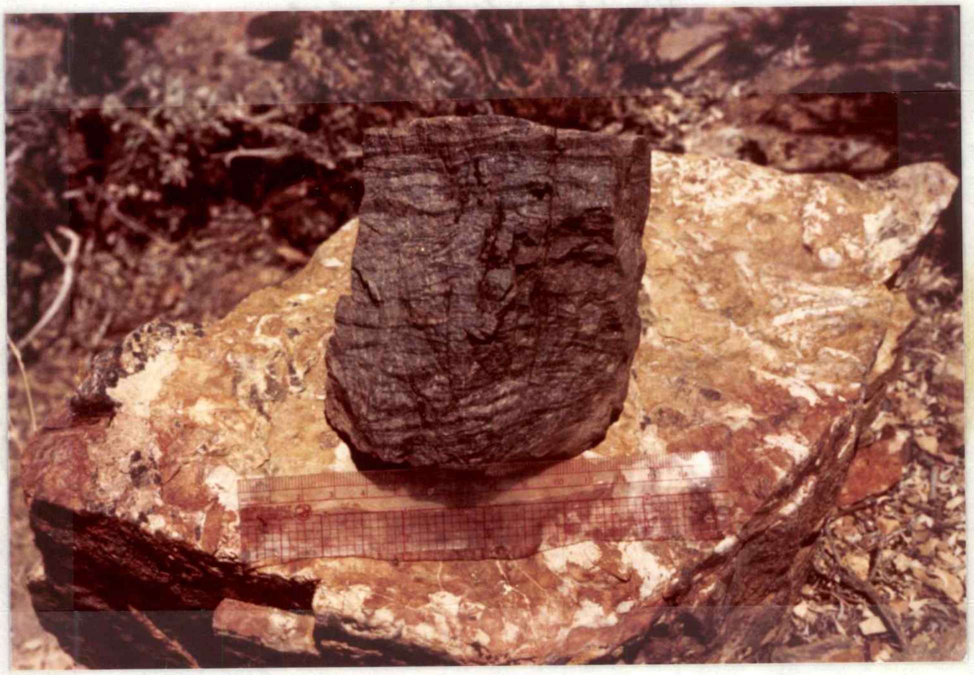


Photo 1. Vinini Formation laminated bedded chert. Scale is six inches long.

Photo 2. Lower Hanson Creek Formation lime mudstone (above lens cap) has been thrust over upper Hanson Creek Formation chert-rich lime mudstone, producing a small-scale fold.

Plate 4.

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FAUNAL LISTS AND LOCALITIES

The following identifications and age assignments are by Stig M. Bergström, Ohio State University, of microfossil samples from the Hanson Creek Formation.

Section: TP4
Location: Martin Ridge; at the extreme northern border of the map area, just south of the Nye County-Eureka county boundary on the Horse Heaven Mountain 15 minute quadrangle.
Sample: TP4-2c conodonts
Footage: 60

Drepanoistodus suberectus (Branson & Mehl)
Protopanderodus sp.
Dapsilodus mutatus (Branson & Mehl)
Protopanderodus insculptus
Paroistidus sp. cf. P. venustus
Pseudooneotodus sp.
Coelocerodontus trigonius Ethington
Dapsilodus? sp.

Age: "Late Ordovician, Amorphognathus ordovicicus Zone, post-middle Maysvillian."

Sample: TP4-2j conodonts
Footage: 395

blade element of Oulodus, Aphelognathus, or Plectodina

Age Probably Late Ordovician

Sample: TP4-2n conodonts
Footage: 485

platform conodont (Icriodus? sp.)
Panderodus sp.
Icriodus sp.
Palmatolepsis sp.

Age: Appears to be a mixture of Ordovician and Upper Devonian elements (Note: Devonian elements are probable laboratory contaminants).

Sample: #127
Location: 1, 500 feet due south of Applebush Hill Spring, and 3, 000 feet W, NW of hill 8525, section 20, T. 14N., R. 50E.

blade, may be a Plectodina or Oulodus
Oulodus sp.
Oulodus ulrichi
Dapsilodus mutatus
Periodon grandis Ethington
Paroistodus
Belodina sp.
Paroistodus venustus
Drepanoistodus suberectus
Plectodina

Age: Probably Late Ordovician

The following identifications and age assignments are by Jim Barrick, University of Iowa, of microfossil samples from a light-colored dolomite overlying the Eureka Quartzite at Dobbin Summit in the central Monitor Range.

Section: DB
Location: 1, 000 feet due south of the east entrance to Miniature Grand Canyon, Dobbin Summit, central Monitor Range.
Sample: DB-1
Footage: 5

Distomodus sp. - 1 Sa element

Age: "Distomodus ranges from the Late Llandoverian (Landovery C) into the early Wenlockian (base of Kockelella ranuliformis Zone).

Sample: DB-3
Footage: 50

Panderodus unicostatus

Age: Silurian

Sample: DB-4
Footage: 60

Dapsilodus obliquicostatus
Dapsilodus praecipuus
Dapsilodus sparsus
Pseudooneotodus bicornis Drygant

Age: "Sample is... probably latest Llandoverian to early Wenlockian (amorphognathoides Zone to amsdeni Zone).