ORDOVICIAN AND SILURIAN STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS, NOPAH RANGE, SOUTHWESTERN GREAT BASIN

Richard H. Miller
Allison Center, Department of Geological Sciences
San Diego State University
San Diego, CA 92182

ABSTRACT

Approximately 900 m of Lower Ordovician to Upper Silurian rocks provide a record of supratidal, intertidal and subtidal deposition at the Nopah Range, Inyo County, California. These rocks formed near the eastern edge of the Cordilleran miogeocline as carbonates of the Pogonip Group, Ely Springs Dolomite and Hidden Valley Dolomite, and a thin interval of terrigenous quartz of the Eureka Quartzite. Although macrofossils are not common, abundant conodonts were collected from the Pogonip, Ely Springs and Hidden Valley. No samples were collected from the Eureka. The Pogonip is Early to Medial Ordovician (Conodont Faunas E and older to 5 or younger); the Eureka is Medial Ordovician (spans all or part of Faunas 5 to 9); the Ely Springs is Late Ordovician (Faunas 10? to 12?); and the Hidden Valley is late Early to earliest Late Silurian (*S. celloni* and *P. amorphognathoides*, and possibly younger Biozones). The stratigraphic section at the Nopah Range provides an excellent example of strata that are transitional from cratonic margin paleoenvironments to the east and shelfal to shelf-basin paleoenvironments farther west.

INTRODUCTION

Ordovician and Silurian strata are well exposed at the northwestern end of the Nopah Range, where they comprise a section approximately 900 m thick. Regionally, the location and lithologies represent the carbonate assemblage of the Cordilleran miogeocline (Stewart & Poole, 1974). The rocks were deposited near the eastern margin of the miogeocline close to the Early Paleozoic craton (Fig. 1), but the original geographic position of the area has been altered by displacement along right lateral strike-separation faults and west-dipping thrust faults. Dolomitization, silicification and low-grade regional metamorphism have altered some of the original depositional fabrics of these allochthonous rocks but much

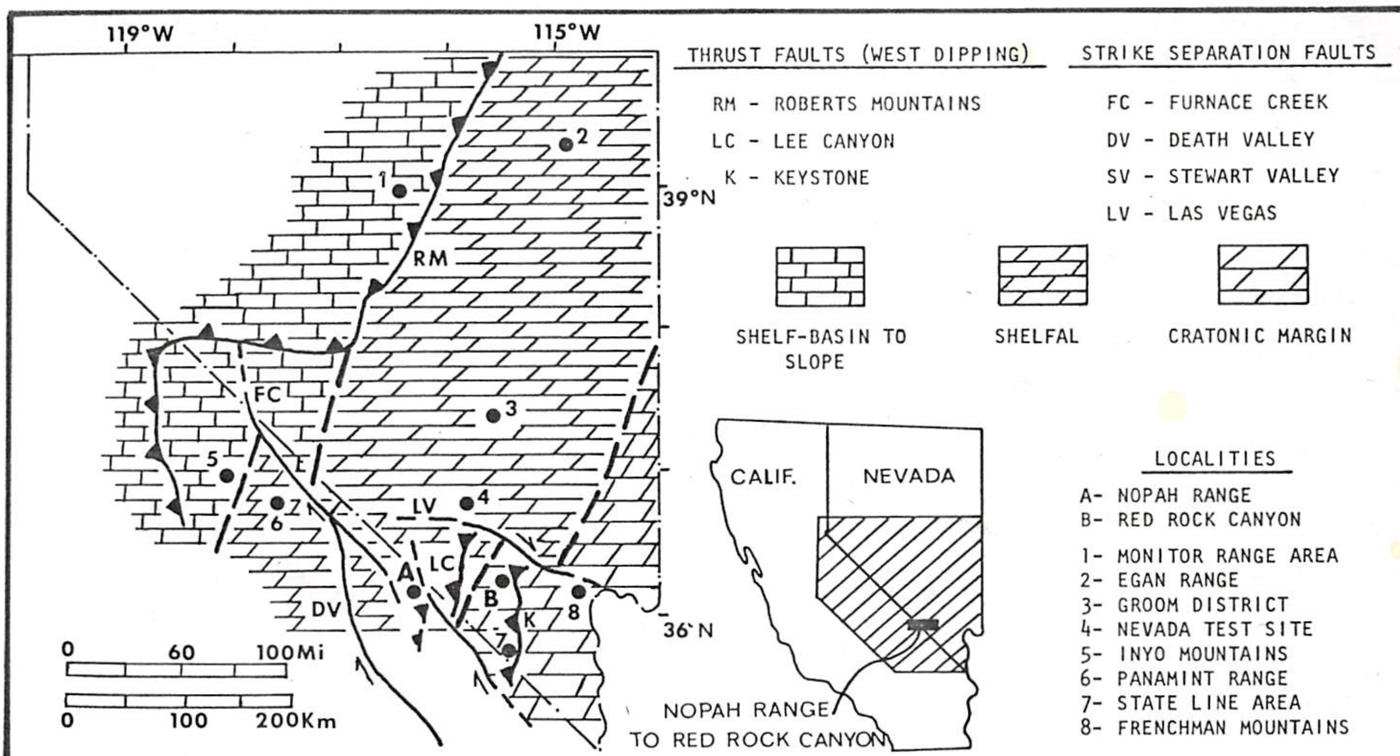


Figure 1. Location map for areas discussed in text. Point A represents the northern Nopah Range, site of the field trip stop. Cratonic margin rocks are dominated by light gray, cryptalgal dolostones; shelfal rocks have a variety of light to dark gray, fossiliferous dolostones and brown quartzites; shelf-basin rocks are dark gray, fossiliferous, and are commonly allodapic. Offsets along major faults have not been reconstructed; apparent offsets of facies are only approximate (plus or minus 10 Km).

(1976) considered lower Middle Ordovician fibrous conodonts such as *Leptochirognathus* along with *Multioistodus* and hyaline prioniodids to represent littoral to shallow shelf depositional regimes.

In comparison, the Lower Ordovician and lower Middle Ordovician rocks at Red Rock Canyon are predominantly cryptalgal dolostones with intervals of cherty, bioturbated and occasionally bioclastic dolostone. These rocks are cratonic margin deposits representing subtidal to intertidal cryptalgal banks and tidal channels, supratidal algal flats, and possibly shallow subtidal lagoons (?). Of note is the absence of fibrous conodonts in these rocks.

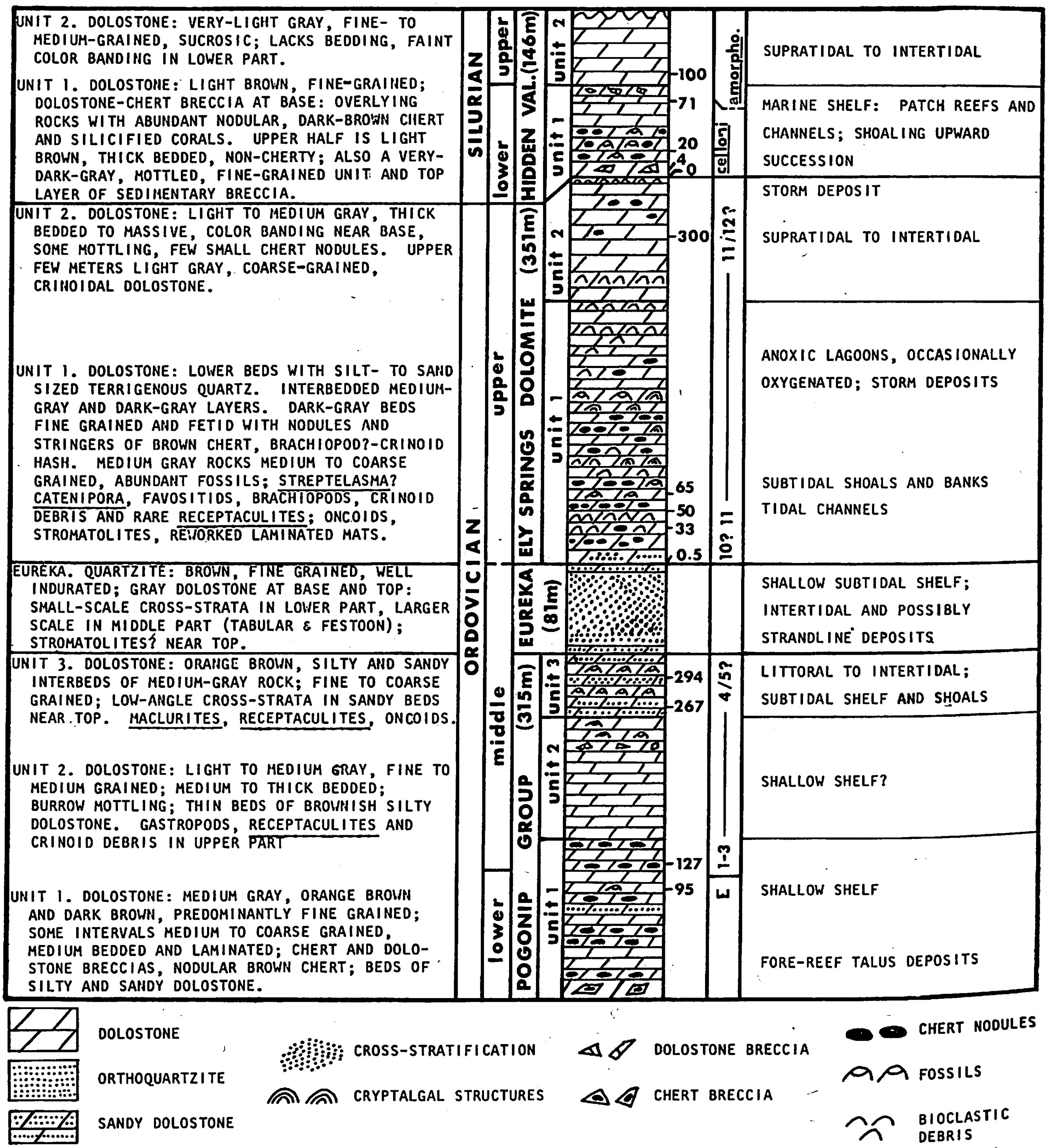


Figure 3. Composite stratigraphic column (sections E-E' and F-F' of Hazzard, 1937), northern end of the Nopah Range. Location of samples containing conodonts used for age determinations (Figures 4, 11, and 14) are indicated in meters. Right column represents Midcontinent Conodont Faunas (Sweet & Bergström, 1971).

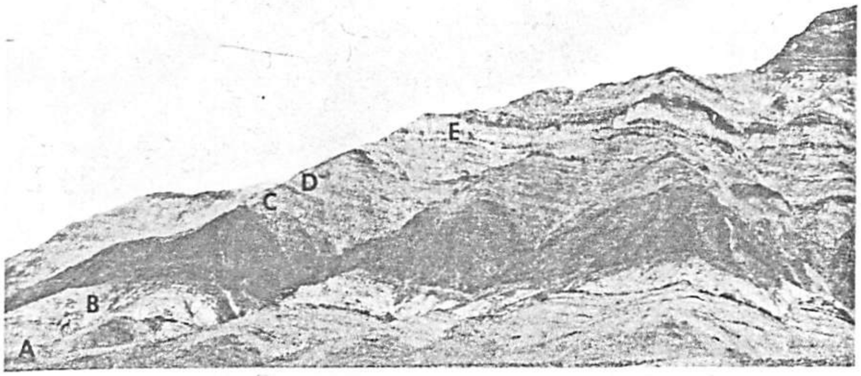


Figure 2. Photograph of the northwestern end of the Nopah Range. Rock units range from Lower Ordovician to Mississippian and include: A) units 2 and 3 of the Pogonip Group; B) light gray Eureka Quartzite; C) dark gray unit 1 and light gray unit 2 of the Ely Springs Dolomite; D) medium gray undifferentiated Hidden Valley Dolomite; E) banded appearing Lost Burro Formation.

detail remains.

In one of the early studies of the Paleozoic rocks in the southern Great Basin, Hazzard (1937) described a composite section of Precambrian through Upper Paleozoic rocks from the Nopah Range. Ordovician through Devonian rocks are best exposed along his sections E-E' and F-F', which are essentially the study area for this field trip stop (Figs. 2 and 3). Lithologic characteristics allowed recognition of the "Pogonip (?) dolomite", "Eureka quartzite" and "Ely Springs (?) dolomite", which represent formations of Ordovician age named earlier from the central Great Basin (King, 1878; Hague, 1883 and 1892; Westgate & Knopf, 1932). Silurian (?) rocks were unnamed, but have subsequently been assigned to the Hidden Valley Dolomite (Wilhelms, 1963; Miller, 1976) of the Death Valley area (McAllister, 1952). The Devonian System is represented by the "Sultan dolomite", originally named by Hewett (1931) for rocks in the Goodsprings District, east of the Nopah Range. Zenger (this volume) considers the rocks to more closely resemble the Lost Burro Formation of the Death Valley area (McAllister, 1952). His usage will be followed herein.

ORDOVICIAN SYSTEM

Pogonip Group

Lithology and Age

Hazzard (1937) described 1040 feet (315 m) of light- to medium-gray dolostone, sandy and silty dolostone and minor amounts of limestone and limy shale for the formation. Most distinctive in outcrop is the yellow to orange-brown weathered surface and the abundance of terrigenous clastics in the carbonates. Three large-scale field units are recognized: (1) Lower, brownish gray weathered cherty dolostone (units 9A and 9B of Hazzard); (2) Middle, medium-gray weathered dolostone with thin intervals of dark-gray dolostone, limestone, and sandy dolostone (units 9C and 9D of Hazzard); (3) Upper, light-gray to orange-brown weathered dolostone and sandstone containing abundant fossils (units 9D and 9E of Hazzard). These lithologies suggest the section is similar to the Goodwin Limestone and Antelope Valley Formation, but with the lack of detailed study the rocks are assigned to the Pogonip Group undivided.

Macrofossils, collected by Hazzard and identified by E. Kirk and G. A. Cooper (Hazzard, 1937, p. 323), occur within the upper 65 m of the section and include *Hesperonomia* sp., *Mitrospira longwelli* Kirk, *Receptaculites* sp., *Euconia*? sp., *Liospira* sp., *Orthis* sp., *Ctenodonta* sp., and *Maclurites* sp. Age of these fossils was considered "high Canadian to Chazyan. Preliminary sampling for conodonts indicates that abundant well preserved specimens occur in the lower and upper units, but only a few were found in the middle unit (Fig. 4). A sample 95 m above the base of unit 1 contains *Drepanodus, Oistodus, Prioniodus evae, Scolopodus, Triangulodus* and other taxa that are tentatively considered equivalent to Midcontinent Faunas 1, 2 or 3 of Sweet and others (1971). The upper 50 m of unit 3 contain abundant fibrous taxa including *Leptochirognathus, Multioistodus,* and *Polycaulodus* along with hyaline *Drepanodus, Oistodus, Prioniodus* and others. These genera appear to correspond with Faunas 4 and 5 of Sweet and others (1971). Thus the Pogonip Group in the Nopah Range represents the lower and middle parts of the Champlainian Series. No samples have been collected from the lower 90 m of the section, but these strata probably represent at least part of Early Ordovician time.

Strata containing Midcontinent Province taxa of equivalent age have been described by Harris and others (1979) from the Egan Range, Groom Range, and Nevada Test Site in Nevada and from the Funeral Mountains in California (Fig. 1). These strata have been assigned to the Kanosh Shale and Lehman Formation (Egan Range) and the Antelope Valley Limestone (Groom Range, Nevada Test Site and Funeral Mountains). In contrast, rocks approximately 20 km east and southeast of the Nopah Range and represented by 10 measured sections of the Mountain Springs Formation, do not contain Faunas 3 to 8 (Miller & Zilinsky, 1981; Miller, unpublished data). A section in the Spring Mountains (location B on Fig. 1) at Red Rock Canyon, which was described by Miller & Zilinsky (1981), contains 182 m of strata that have Early Ordovician conodont Faunas A - E of Ethington & Clark (1971) and Medial Ordovician conodont Faunas 1 and 2 (Sweet and others, 1971).

Depositional Environments

Field unit 1 contains a basal laminated, brownish gray weathered, medium- to coarse-crystalline dolostone. Overlying rocks contain angular brown weathered chert clasts (2 to 6 cm) and dolostone clasts (up to 20 cm); the dolostone clasts are light-gray, brown, and medium-gray (Fig. 5). These rocks represent shallow subtidal talus or reef (?) flank deposits. Unit 2 has not been studied in detail.

Field unit 3 contains abundant terrigenous silt- to fine-sand quartz in coarse-crystalline brownish weathered dolostone with small-scale, low-angle cross-stratification, oncoids, and abundant fossils. These features suggest a shallow subtidal shelf paleoenvironment (Figs. 6A and 6B). Byrnes (1968, p. 378) noted that receptaculitaceans associated with other cryptalgal structures were restricted to shallow marine, tropical environments. Bergström and Carnes

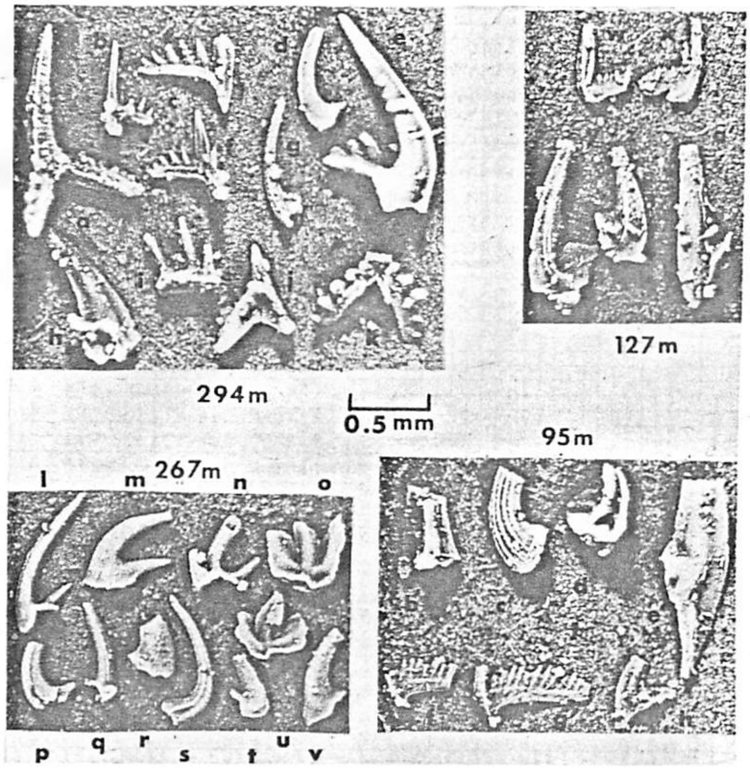


Figure 4. Conodonts from the Pogonip Group.

294 m (Figs. a-k): a, b, f, prioniodiform elements; a, e, cordylodiform elements; d, drepanodiform element; g, tetraprioniodiform? element; h, oistodiform element; i, *Polycaulodus?* sp.; j, unidentified element; k, trichonodelliform element.

267 m (Figs. l-v): l, m, n, *Multioistodus* spp.; o, u, *Leptochirognathus* sp.; p, *Protopanderodus* sp.; r, v, drepanodiform elements; q, *Tetraprionodus*? sp.; s, scolopodiform? element; t, oistodiform element.

127 m (Figs. w-a'): w, x, *Prioniodus evae* Lindström, oepikodiform element; y, *Oistodus multicorrigatus* Harris; z, drepanodiform element; a', oistodiform element.

95 m (Figs. b'-h'): b', *Triangulodus?* sp.; c', *Scolopodus cornutiformis?* Branson & Mehl; d', *Juanognathus*? sp.; e' *Oistodus longiramis* Lindström; f', g', h', *Prioniodus evae* Lindström, oepikodiform and oistodiform elements.

Eureka Quartzite

The Eureka Quartzite is a very distinctive lithologic unit that crops out in much of the Great Basin. The rocks are generally fine-grained, well-sorted, supermature quartz arenite (Klein, 1975, p. 146) that is 40 to 200 m thick (Ketner, 1968; Klein, 1975). Other quartz arenites occur within the Ordovician System in the Great Basin; all are Medial Ordovician in age, represent shallow-water deposits, and were derived from Cambrian sandstones in what is now western Canada (Ketner, 1968, p. B176). Klein (1975) summarized characteristics of six sections of the Eureka, including a locality at the Nopah Range. He interpreted the rocks to represent tidalite deposits that formed under shallow tide-dominated conditions.

At the Nopah Range, the Eureka is sandwiched between intertidal to shallow subtidal carbonates of the underlying Pogonip Group and overlying Ely Springs Dolomite. Hazzard (1937, Fig. 3b, units 10A and 10B) measured eight meters of "Dense, massive, fine-grained white to light-gray quartzite which weathers reddish- to yellowish-brown...". These basal few meters contain layers of dolomitic quartzite and thin discontinuous lenses of light-gray dolostone. This interval is transitional with the underlying sandy dolostones of the Pogonip. No evidence of an unconformity between the two formations has been recognized; a similar conformable contact was reported for sections in central and southern Nevada and eastern California by Ross (1964A; 1964B) and Harris and others (1979).

The lower third of the formation is fine-grained, thin- to medium-bedded, and weathers reddish brown. Poorly developed low-angle tabular cross-stratification occurs at a few locations (Fig. 7). The middle and upper beds are fine-grained, thick-bedded to massive and have well developed, large scale, tabular cross-stratification.

No macrofossils have been reported from the section in the Nopah Range and no samples have been processed for conodonts. Hazzard (1937, p. 324) assigned the rocks to the "Middle" Ordovician. Evident from conodonts in underlying and overlying rocks reported herein, the Eureka is younger than Fauna 5 of medial Champlainian age (represented by the upper part of the Pogonip) and older than Fauna 9 (?) or 10 of late Champlainian to early Cincinnatian age (represented by the lower part of the Ely Springs). Ross (1964B), Ketner (1968) and Harris and others (1979) considered the base of the Eureka diachronous on a regional scale. In north to south sections in Nevada and eastern California, that parallel the depositional strike of the miogeocline, the base of the formation is slightly younger to the south. In east to west sections, perpendicular to strike, the base is considerably younger to the west. As reported by Harris and others (1979) the age of the oldest Eureka corresponds to Fauna 6, but may be as young as Fauna 8. The top of the formation ranges from basal Fauna 7(?)

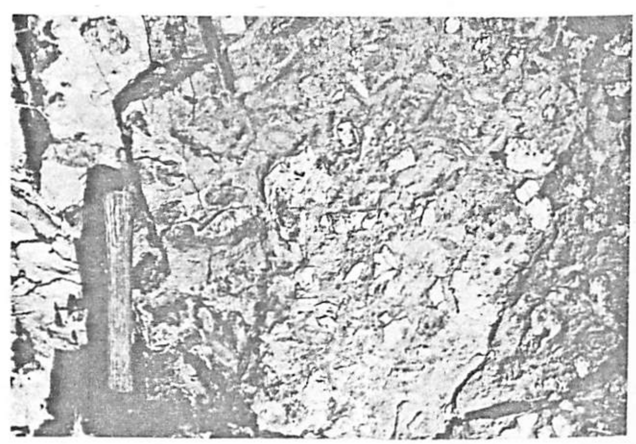
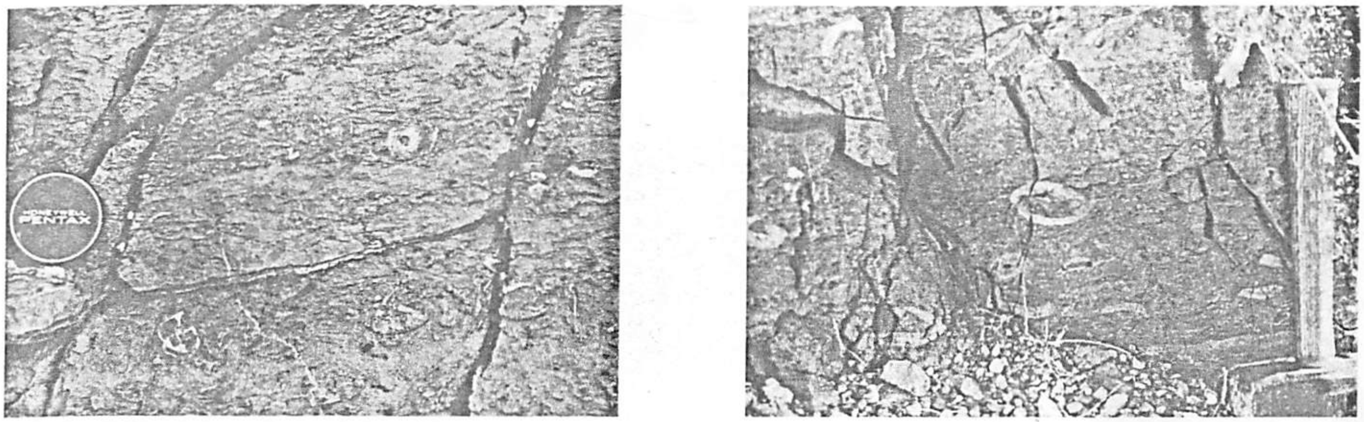


Figure 5. Pogonip Group. Dolostone of field unit 1. Brown weathered, with abundant angular chert and dolostone clasts. Hammer is 26 cm long.



Figures 6A, 6B. Pogonip Group, field unit 3. 6A: grayish brown, coarse-grained dolostone that contains abundant transported crinoid debris and other fossil fragments. Lens cap is 54 mm wide. 6B: gray, medium- to very coarse-grained dolostone; large *Receptaculites* sp. Note small oncoids to left of tip of hammer handle. Hammer is 26 cm long.

to the middle of Fauna 9 (?); however, there is a lack of reported diagnostic conodonts in the lower beds of the Ely Springs (Miller, 1976; Harris and others, 1979).

The clean, well-sorted, fine-grained quartz arenite contains cross-beds in the lower and middle parts of the section. Thin dolomitic sandstone and dolostone stringers and lenses occur at the base and top of the section. Small dark-brown weathered domal structures that may represent hummocky cross-stratafication or cryptalgal mounds occur near the top of the massive interval and are similar to stromatolite? structures reported in southeastern Nevada by Langenheim & Horn (1978). Lithologic characteristics and age relationships described by Ross (1964A, 1964B, and 1977); Ketner (1968); Klein (1975) and Harris and others (1979) indicate the Eureka was deposited by tidal currents. Transported and reworked quartz sand prograded southward and westward over carbonates of the Pogonip. This apparent regressive succession may have been followed by exposure and subaerial erosion during late Medial Ordovician time.

Ely Springs Dolomite

Lithostratigraphy

Hazzard (1937, unit 11A) described 243 m of dolostone that he assigned to the Ely Springs. Miller (1976) reported 363 m in the same area. Discrepancy in these thicknesses may be the result of unrecognized structural features. In outcrop the rocks form a distinctive very dark gray band that grades upward to medium and light gray dolostones (Fig. 2, unit C). The basal three meters of the formation consist of interbedded grayish brown weathered dolostone and stringers of sandy dolostone; these rocks form a transitional interval above the Eureka Quartzite. Overlying rocks (field unit 1) are dark-gray weathered, fine-grained, fetid dolostones and interbedded medium-gray, fine- to medium-grained dolostones. The dark gray rocks contain dark-brown weathered chert as nodules and stringers that develop parallel to bedding (Fig. 8). The medium gray beds contain bioclas-

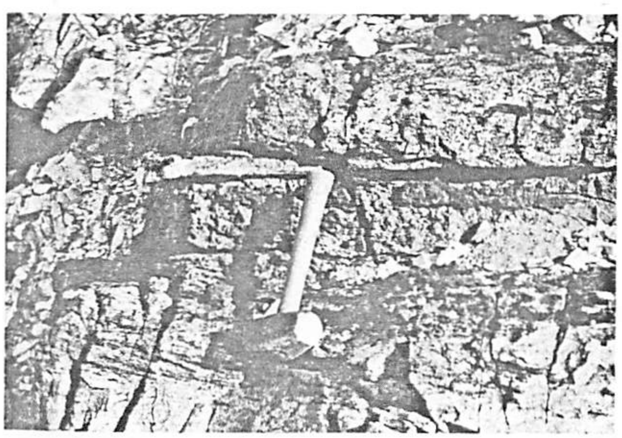


Figure 7. Eureka Quartzite. Brown weathering, fine-grained quartz arenite with minor amounts of dolomite. Note low-angle, tabular cross-stratification and possible mud chips (above hammer handle to left). Hammer is 26 cm long.

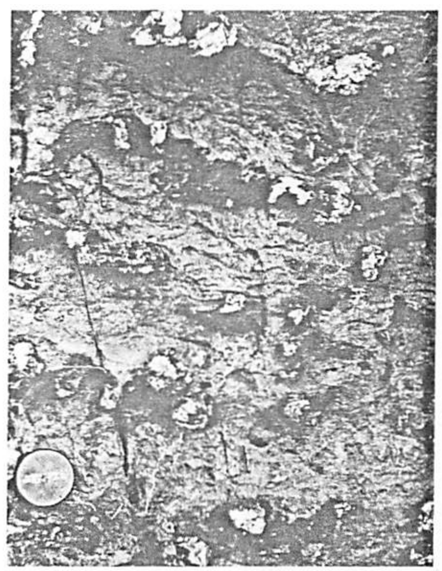
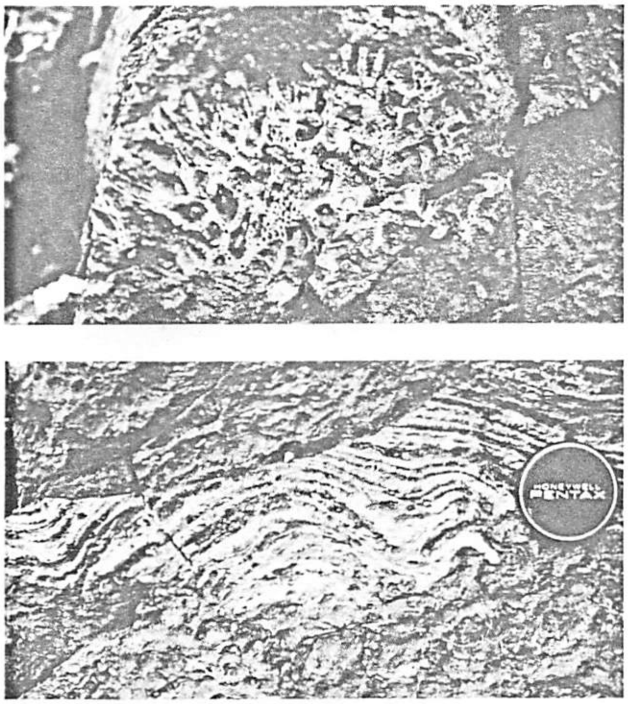


Figure 8. Ely Springs Dolomite, field unit 1. Medium gray, fine- to medium-grained dolostone with abundant nodular chert; some rugose coral fragments and crinoid debris. Lens cap is 54 mm wide.



Figures 9A, 9B. Ely Springs Dolomite, field unit 1. 9A: Specimen of *Halysites (Catenipora)* aff. *C. jacovickii* Fischer de Waldheim. Specimen approximately 70 mm wide. 9B: Compound stromatolite (laterally linked hemispheroids, LLH of Logan and others, 1964). See Miller & Walch (1977, Fig. 4A). Note current scour on upper surface of specimen. Lens cap is 54 mm wide.

tic, mostly crinoidal debris; some beds contain transported allochems including rugose corals (streptelasmids?), oncoids, and rare tabulate corals (cateniporids, Fig. 9A). Laminated cyanophyte mats and domal stromatolites occur at some intervals (Fig. 9B). Evidence of horizontal feeding burrows and very rare specimens of *Receptaculites* sp. occur near contacts between the dark and medium gray beds.

Field unit 2 consists of three subunits. The lower subunit is medium-gray weathered, fine-grained, massive dolostone that contains faint color banding (Fig. 10A). This unit becomes lighter and the color bands disappear upsection. The middle subunit is a massive, very fine-grained, bluish gray weathered dolostone (Fig. 10B). The upper subunit is a light-gray weathered, medium- to coarse-grained bioclastic dolostone approximately five meters thick (Fig. 10C). This bioclastic unit consists of crinoid plates and columnals (round in outline with star-shaped or round lumens) and brachiopod (?) fragments. Grain size decreases up section. Insoluble residues from 71 samples range from 0.1 to 98.4 percent, with a median of 0.6 percent (Zenger, personal communication, 1981). The upper contact is gradational with the brownish gray weathered cherty dolostones of the Hidden Valley Dolomite.

Biostratigraphy

Macrofossils collected by Hazzard 15 to 22 m above the base of the formation and identified by Kirk and Cooper (in Hazzard, 1937, p. 326) include brachiopods *Zygospira* sp., *Platystrophia* sp., *Dalmanella* sp., and *Rhynchotrema argenturbica* White. These were considered Late Ordovician (Richmondian) in age. Streptelasmid corals and *Halysites (Catenipora)* aff. *C. jacovickii* Fischer de Waldheim (Fig. 9A) also indicate a Late Ordovician age for the lower two-thirds of the formation.

Conodonts occur throughout the formation but are most abundant in the dark gray lower part (Fig. 11). Just above the base are specimens of *Belodina, Plectodina furcata,* and drepanodiform elements that are no older than Midcontinent Fauna 9 of Sweet and others (1971). Slightly higher in the section apparatuses of *Aphelognathus, Oulodus, Plectodina,* and *Pseudobelodina,* along with panderodiform and drepanodiform elements closely resemble Faunas 10 and 11. These taxa continue to within 50 m of the top of the section and indicate the formation is Cincinnatian in age (Miller, 1976). Based on regional conodont collections, Harris and others (1979) indicated that the Ely Springs is latest Ordovician (Faunas 11 and 12) in central and southern Nevada and in the Funeral Mountains of eastern California. Other sections of the formation in southeastern California have been described by Miller (1975, 1976). Conodont taxa provided evidence that the base of the formation may be diachronous, and represents late Champlainian time in the Inyo Mountains and Cincinnatian time farther eastward. It is noteworthy that in these more westward sections at least the upper 30 m contain conodonts of Early Silurian (Llandoverian) age, thus indicating

Figures 10A, 10B, 10C. Ely Springs Dolomite, field unit 2. 10A: Light-gray, fine-grained dolostone; color banding. Hammer is 26 cm long. 10B: Light-gray, fine- to medium-grained dolostone; mottled, and contains dolostone clasts? and crinoid debris. Lens cap is 54 mm wide. 10C: Light-gray, very coarse-grained dolostone that contains crinoid debris and brachiopod? fragments. Coin is 19 mm wide.

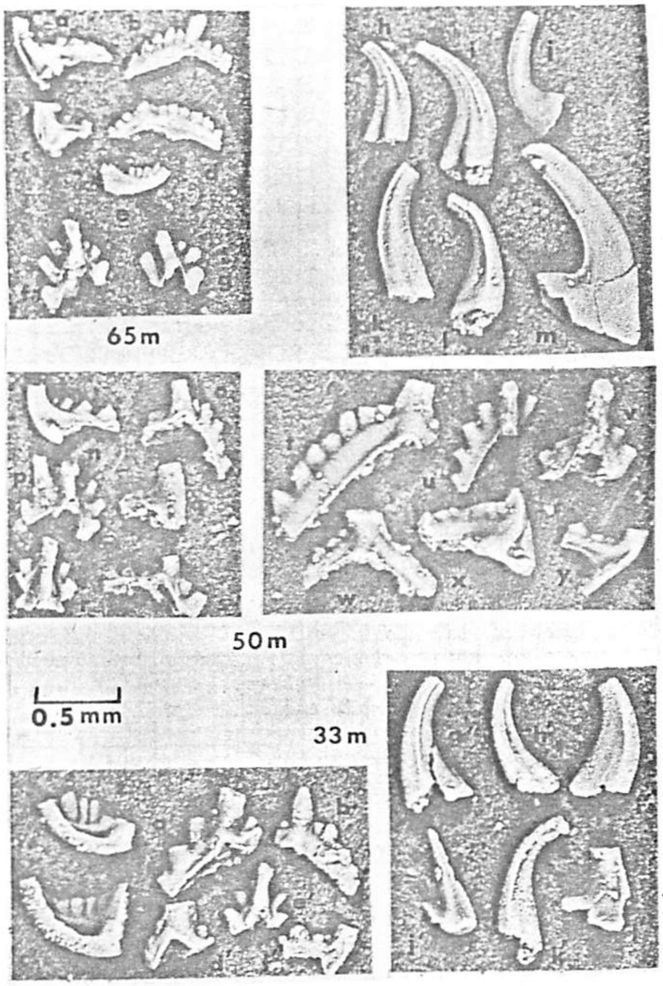


Figure 11. Conodonts from the Ely Springs Dolomite. 65 m (Figs. a-g): a-d, f, g, *Aphelognathus* sp. apparatus; e, *Belodina* sp. 50 m (Figs. h-y): h, i, *Panderodus* sp.; j, m, drepanodiform elements; k, l, *Panderodus* sp.; n, o, q, s, *Oulodus* sp. apparatus; p, r, *Plectodina* sp. apparatus; t-w, *Aphelognathus* sp. apparatus; x, y, unidentified elements. 33 m (Figs. z-l'): z, c' *Pseudobelodina?* sp. apparatus; a', b', d', e', f', *Aphelognathus* sp. apparatus; g', h', i', k', *Panderodus* spp.; j', oistodiform element; l', drepanodiform element.

that the upper boundary is also diachronous, becoming younger westward.

Unit 3 of the Mountain Springs Formation in Red Rock Canyon, approximately 50 km east of the Nopah Range, is 67 m thick and contains Upper Ordovician conodonts (Miller & Zilinsky, 1981). This unit is temporally equivalent to at least part of the Ely Springs at the Nopah Range, but is much thinner and bounded by unconformities.

Paleoenvironments

The alternating lower dark-gray beds and medium-gray beds in field unit 1 of the Ely Springs represent poorly developed cyclic deposits. Fetid, dark-gray, fine-grained, cherty beds lack fossils or evidence of bioturbation and represent carbonate mud that accumulated in quiet water with possibly anoxic substrates. The medium gray layers containing transported fossils, oncoids, stromatolites (isolated hemispheres and laterally-linked-hemispheres of Logan and others, 1964; Fig. 9B) and burrows are indicative of sediments that accumulated under shoal water conditions, which periodically were influenced by tidal or storm-generated currents. These depositional environments formed as restricted lagoons or bays and associated shoals or tidal channels near the eastern (cratonal) edge of the Cordilleran shelf.

The three subunits of field unit 2 contain few obvious diagnostic features. The lower two light- to medium-gray subunits may represent intertidal or, more likely, supratidal deposits; absence of evaporites may reflect the more humid tropical conditions of equatorial paleolatitudes of this area during Ordovician time. In the upper subunit bioclastic debris is very prominent and consists of crinoid plates and stems up to 1.5 cm in diameter (Fig. 10C); size of the bioclastic fragments decreases toward the top. This unit represents a high energy (storm?) deposit and indicates that crinoid gardens and normal marine conditions existed in close proximity to this area.

Eastward at Red Rock Canyon, the 67 m of Upper Ordovician Mountain Springs Formation are medium-gray fine-grained, vuggy weathered dolostone. Thin lenses and stringers of fine-grained pelmatozoan debris occur in the lower and upper parts of the section, and thin, medium- to dark-gray bands occur near the top. These rocks represent intertidal to supratidal paleoenvironments that existed on a craton or cratonic margin setting, and they are bounded by unconformities.

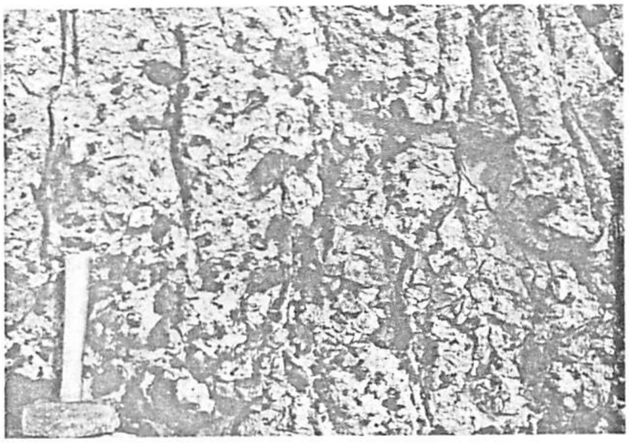
Evidence for regional shallowing in latest Ordovician and earliest Silurian is widespread in the southern Great Basin (Miller, 1975; Miller & Walch, 1977) and could represent the response to worldwide lowering of sea level resulting from glaciation in the southern Hemisphere (Lenz, 1976). The pervasive dolomitization of Ordovician rocks in the southern Great Basin, in the absence of widespread evidence for supratidal evaporite deposition, suggests that the dolomite formed by diagenetic replacement. A model for regional dolomitization by subsurface freshwater mixing during episodes of regression in the southern Great Basin was proposed by Dunham & Olson (1978). As discussed by Miller their model can be applied to the Ely Springs and Mountain Springs. Emergence of the craton and cratonic margin, beginning in latest Ordovician and continuing through Silurian and Early Devonian time, provided a recharge area for fresh water. This eastern source for groundwater is reflected in decreasing dolomitization of strata westward (northern Inyo Mountains and Bullfrog Hills).

SILURIAN SYSTEM

Hidden Valley Dolomite

Introduction

Rocks assigned to the Silurian System in the Nopah Range were reported by Hazzard (1937, p. 326, units 12A and 12B; 1954). He recognized 102 m at the northern end of the range and noted a decrease in thickness southward; these rocks are absent one kilometer south of his section F-F'. Miller (1976, 1978) described 146 m of dolostone and assigned the rocks to the Hidden Valley Dolomite. Contact between the Hidden Valley and underlying Ely Springs appears gradational; the rocks change from gray weathered dolostone upward to brownish gray weathered, cherty dolostone. Two field units are recognized in this section: Unit 1 (82 m thick) consists of brownish weathered and medium- to dark-gray weathered, cherty, fossiliferous dolostone; Unit 2 (64 m thick) is very



Figures 12A, 12B. Dolostones of the Hidden Valley Dolomite, field unit 1. 12A: Brownish gray, fine-grained dolostone with intraformational chert and dolostone clasts and some transported fossils. Hammer is 26 cm long. 12B: Brownish gray, fine-grained dolostone; chert as nodules parallel to bedding; silicified rugose and tabulate corals. Hammer is 26 cm long.

light-gray weathered, thick-bedded to massive, unfossiliferous dolostone.

Lithostratigraphy

Unit 1 contains a thin interval of brownish gray, finely crystalline dolostone that grades upward into cherty dolostone. The chert consists of breccia clasts 2 to 6 cm in diameter. Silicified fossils include two species of *Favosites*, *Halysites*, and rugose coral fragments. Other clasts include large, silty, brown weathered, cross-stratified dolostone (Fig. 12A). Overlying rocks lack these breccias and contain stringers and thin intervals of nodular chert (Fig. 12B); crinoid debris and silicified corals occur in patches. The corals appear to be in, or close to their original growth positions. Fossils and chert decrease upsection and the rocks become light-gray, thick-bedded dolostones with faint color banding. The uppermost rocks of this unit are very dark-gray, finely crystalline, unfossiliferous dolostone that contain irregular-shaped light to medium gray patches. The uppermost bed is a thin sedimentary breccia.

The contact between units 1 and 2 is poorly exposed and is recognized by an abrupt color change.

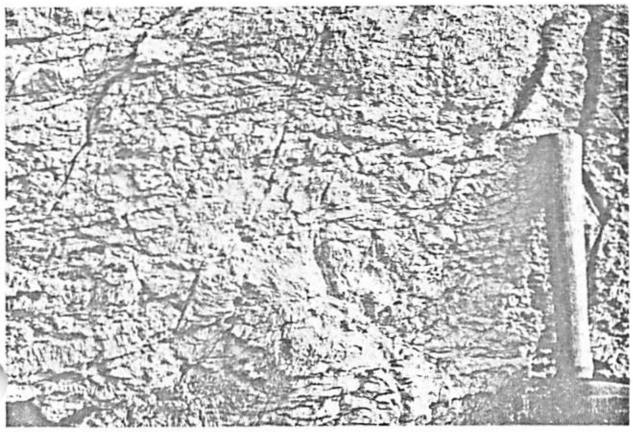


Figure 13. Hidden Valley Dolomite, field unit 2. Very light-gray, fine-grained, massive dolostone that lacks macrofossils. Hammer is 26 cm long.

The sedimentary breccia of unit 1 is overlain by very light-gray weathered dolostone. Although considered conformable (Hazzard, 1937; Miller, 1976, 1978; Miller & Walch, 1977; Poole and others, 1977) the abrupt nature of the color change and associated sedimentary breccia provide evidence for a possible hiatus between the two units. Unit 2 is very light-gray, fine- to medium-crystalline, thick-bedded to massive, sucrosic dolostone (Fig. 13). Rare small chert nodules and crinoid fragments occur near the base of the unit. Insoluble residues for both units range from 0.2 to 18.2 percent, with a median of 1.0 percent (Zenger, 1981, personal communication).

Overlying rocks are light-gray to reddish brown weathered dolomitic quartzites and quartzites that represent the basal unit of the Lost Burro Formation (= Sultan limestone of Hazzard, 1937, 1954; see Zenger, this volume). The contact appears gradational, with a gradual increase in terrigenous quartz content of the dolostones. In contrast, this contact was considered unconformable by Hazzard (1937, 1954), Wilhelms (1963), Boucot and others (1969), and Miller (1978). Resolution of the nature of the contact awaits further study.

Biostratigraphy

Macrofossils collected from the lower unit by Hazzard (1937, 1954), Haug (1981), and Miller (unpublished data) include *Halysites* sp., *Favosites* spp., *Syringopora* sp., rugose corals, articulate brachiopods (pentamerids?), and crinoid debris. These fossils are Silurian (undivided) in age. Conodonts are abundant in the lower unit and provide detailed age information (Miller, 1978), which is summarized below (Fig. 14). Simple cone taxa are not described, but are the most abundant specimens in the collection. The taxonomy of Early Silurian conodonts is currently in a state of flux and for this report I follow the usage of Barrick & Klapper (1976) and Miller (1978).

The basal 20 m of the section contains fragments of the *Distacodus kentuckyensis* apparatus, a *Hadrognathus* sp. apparatus, and form species *Ambalodus* sp., *Trichonodella papilio* Nicoll & Rexroad, and *Spathognathodus polinclinatus* Nicoll & Rexroad. Miller (1978) listed fragments of apparatus B of Walliser (1964). On this evidence the base of the Hidden Valley is assigned to the *Spathognathodus celloni* Biozone of late Llandoverian age. No lower or middle Llandovery rocks are recognized in the Nopah Range,

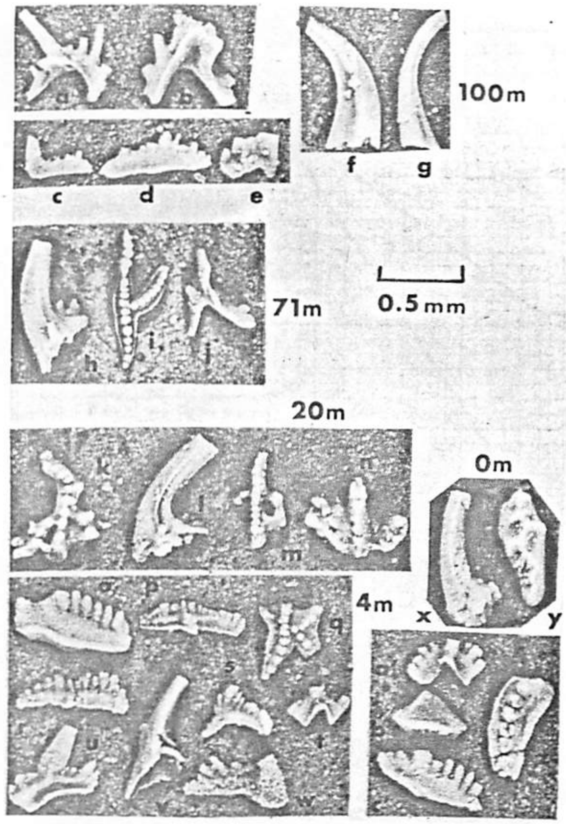


Figure 14. Conodonts from the Hidden Valley Dolomite. 100 m (Figs. a-g): a, *Lonchodina* sp.; b, *Delotaxis?* sp. (*Diadelognathus* element); c, d, e, *Ozarkodina excavata?* (Branson & Mehl) apparatus; f, g, *Panderodus serratus* apparatus of Cooper (1975).
71 m (Figs. h, i, j): h, *Distomodus kentuckyensis* apparatus of Cooper (1975); i, apparatus C of Walliser (1964) = *Pterospathodus*; j, *Diadelognathus nicolli* Aldridge.
20 m (Figs. k-n): k, m, n, *Aulacognathus* spp.; l, *Distomodus kentuckyensis* Branson & Branson (element).
4 m (Figs. o-w): o, *Spathognathodus manitoulensis* Pollock, Rexroad & Nicoll (element); p, r, apparatus B of Walliser (1964); q, *Hadrognathus* sp. apparatus; s, *Carniodus* sp.; t, *Trichonodella papilio* Nicoll & Rexroad; u, *Ozarkodina hanoverensis* Nicoll & Rexroad; v, *Distomodus* sp.; w, *Neoprioniodus planus* Walliser.
0 m (Figs. x-c'): x, y, *Distomodus* sp., apparatus; z, *Hadrognathus?* sp.; a', *Trichonodella papilio* Nicoll & Rexroad; b', *Ambalodus* sp.; c', *Spathognathodus* sp.

but upper Llandovery strata occur approximately 50 m above the last conodont-bearing stratum of Late Ordovician age (Fauna 11 or 12?) in the Ely Springs Dolomite. Conodonts of the *S. celloni* Biozone continue to 62 m above the base of the section. Above 62 m, specimens of Apparatus C (*Pterospathodus amorphognathoides* Walliser), *Pterospathodus pennatus* (Walliser), and *Delotaxis petila* (Nicoll & Rexroad) indicate the *P. amorphognathoides* Biozone of late Llandoverian to early Wenlockian age. This biozone is represented from 62 to 82 m above the base of the formation and is terminated at the contact between units 1 and 2. Taxa in the lower 18 m of unit 2 include few diagnostic forms that are assigned to the apparatuses *Delotaxis* sp. and *Ozarkodina excavata?*. Simple cone taxa are also present. These rocks are considered Late Silurian (Wenlockian or Ludlovian) in age, but are not assigned to a biozone.

Strata of equivalent age in the southern Great Basin include other outcrops of the Hidden Valley, the base of the Roberts Mountains Formation, the lower part of the Vaughn Gulch Limestone, and unit 3 of the Ely Springs Dolomite in the Inyo Mountains (Miller, 1975, 1976, 1978; Miller & Walch, 1977). Eastward from the Nopah Range, in the Spring Mountains, no Silurian rocks have been recognized (Gans, 1974; Miller & Zilinsky, 1981).

Paleoenvironments

Unit 1 of the Hidden Valley represents shallow water platform palaeoenvironments (Miller & Walch, 1977; Miller, 1978). Haug (1981) described the section at the Nopah Range as representing a shoaling upwards succession including silicified reef talus with fossils and dolostone clasts at the base, grading upward into strata representing patch reefs and inter reef channels; this interval is topped by dark-gray dolostone representing restricted shelf conditions. Little work has been done on unit 2; the overall lithologic characteristics and absence of fossils suggests shallow, restricted paleoenvironments.

REGIONAL CORRELATION AND PALEOGEOGRAPHY

Red Rock Canyon Area

The thickness of Lower Ordovician to Lower Devonian strata at the Nopah Range exceeds 900 m. For comparison, equivalent rocks 150 km northwestward in the Panamint Range (west side of Death Valley) are 1255 m thick (McAllister, 1952). In contrast, less than 50 km eastward (eastern Spring Mountains) the equivalent section is only 295 m thick and slightly farther southeastward (Stateline area) the section is less than 50 m thick. Comparison of the Nopah section with that at Red Rock Canyon provides good documentation of a change from shelfal paleoenvironments eastward to cratonic margin paleoenvironments (Fig. 15).

The stratigraphic succession at Red Rock Canyon (Fig. 15, location B) is thinner than equivalent shelfal rocks. The Lower Ordovician part of the section consists of intraformational carbonate breccias, laminated, domal and thrombolitic cryptalgal beds, extensively burrowed intraclastic beds, and thin bioclastic beds. These rocks contain conodonts of Faunas A through E (Early Ordovician age) and Faunas 1 and 2 (early Medial Ordovician age). Depositional features and absence of macrofossils signify a complex of peritidal and shallow subtidal conditions; possible supratidal rocks are present, but lack diagnostic textures. At some sections other than Red Rock Canyon, collapse breccias have been recognized that document the development of karst weathering during the Early Paleozoic (Medial Ordovician?).

Overlying rocks are mottled, light- to medium-gray dolostones that show evidence of bioturbation and, except for crinoid debris, lack macrofossils. Conodonts from this interval represent latest Medial? Ordovician and Late Ordovician Faunas 9 (?) to 11. Contact with the underlying strata represents a disconformity as noted by solution features and an irregular surface. On a regional scale, different lithologic units occur below the contact, and these indicate variable depths of erosion into the Lower Ordovician strata. The rocks represent intertidal to shallow subtidal, but possibly restricted paleoenvironments.

The top of this interval is characterized by another disconformity containing solution features

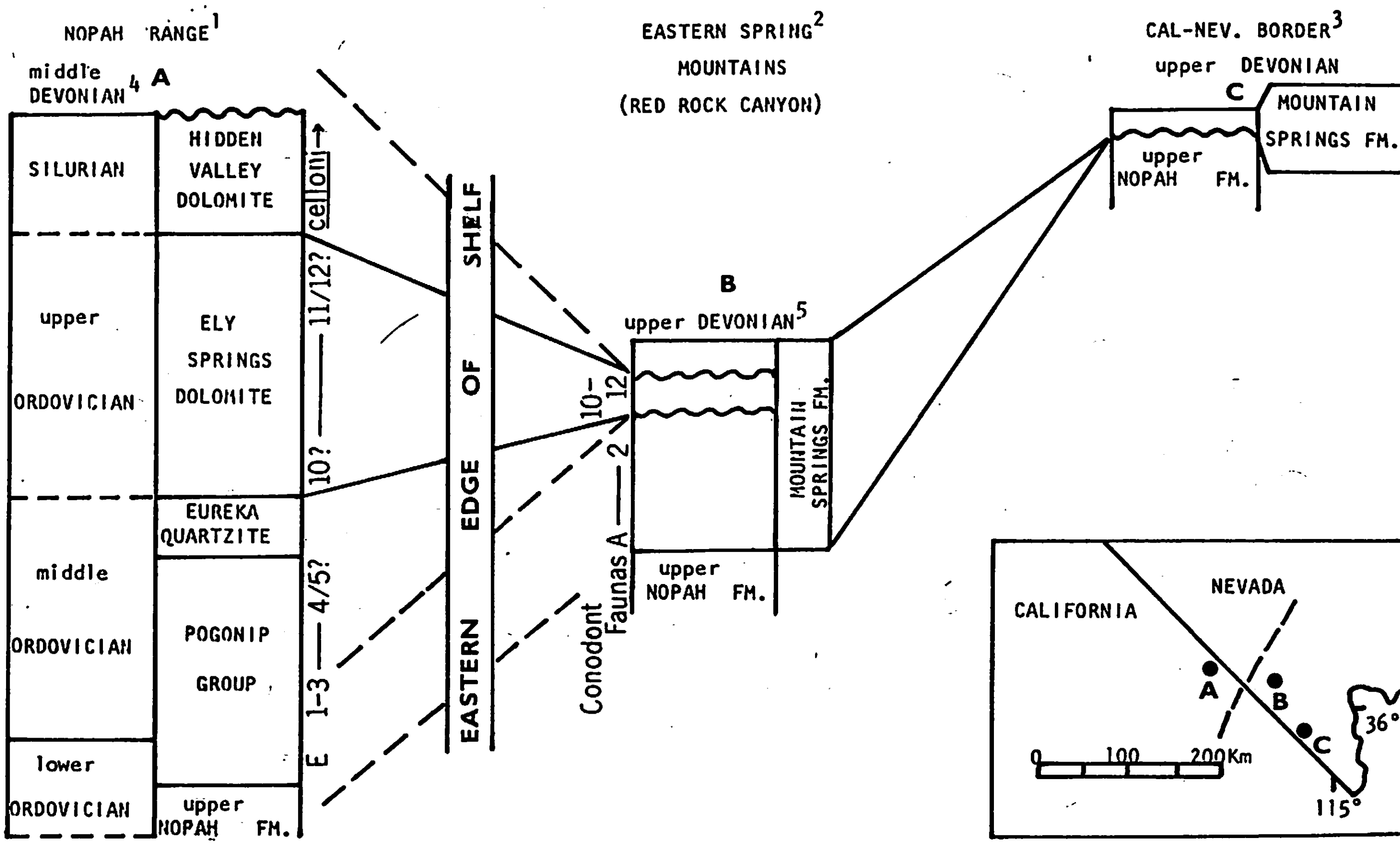


Figure 15. Comparison of the Nopah Range Ordovician and Silurian section with other sections to the east that represent a cratonic margin paleotectonic setting. Compare with Gans (1974). The rocks are 900 m thick at the Nopah Range, 295 m thick at Red Rock Canyon (eastern Spring Mountains), and only 35 m thick at the State Line area. Edge of the shelf (hinge line of various authors) is approximately 40 km southeast of the Nopah Range. 1. Thicknesses from Hazzard (1937) and Miller (1976, 1978). 2. Thicknesses from Miller & Zilinsky (1981). 3. Thickness from Miller (unpublished data). 4. Base of Lost Burro Formation (=Sultan limestone of Hazzard) is upper Medial Devonian (Zenger, this volume) but may be older. 5. Ironside Member of the Sultan Limestone is Late Devonian in age (Harrington, 1982).

and having irregular topographic expression. Overlying strata are generally light-gray dolostone and limy dolostone. Some intervals are very coarse grained and contain brachiopod fragments. The upper part of this unit contains alternating beds of light- and dark-gray dolostone; some contain cryptalgal (?) laminations. The upper beds form a gradational contact with overlying dark-gray, stromatoporoid-bearing dolostones of the Ironside Member of the Sultan Limestone. Conodonts from this unit have been identified to generic level only (*Polygnathus*, *Icriodus*, *Hindeodella*, and *Pandorina?*) and are considered no older than late Early Devonian, but could be as young as early Late Devonian. These rocks represent subtidal to intertidal and possibly supratidal paleoenvironments.

Ordovician to Devonian Depositional Patterns

Recognition of conodonts in these rocks has provided good chronostratigraphic correlation among the various shelfal and cratonic margin lithosomes in the southern Great Basin. The paleogeographic distribution of depositional environments coupled with the recognition of two major unconformities provides a good record of Early Paleozoic transgression and regression.

During Early Ordovician to early Medial Ordovician time (Conodont Faunas A-E, 1 and 2), shallow seas covered the area from what is now the Nopah Range eastward to Red Rock Canyon. In the Nopah Range, fore reef talus accumulated in a shallow shelf setting; these rocks were covered by normal marine subtidal sediments containing *Receptaculites*, gastropods, conodonts, and crinoid debris. Thin stringers of interbedded terrigenous quartz sand were transported by longshore currents. Eastward a thinner succession was developing as a complex of cyanophyte banks and shoals, intertidal channels, and possibly supratidal environments. Regression and subsequent erosion occurred during Medial Ordovician at Red Rock Canyon; westward at the Nopah Range carbonate deposition was supplanted by an influx of terrigenous quartz followed by erosion in late Medial Ordovician time. These clastic rocks represent clean, extensively winnowed sediments that were deposited in nearshore, intertidal conditions. This complex closely resembles idealized standard facies 6, 7, and 8 (edge of platform, open platform, and restricted platform) of Wilson (1975). At Red Rock Canyon emergence was followed by erosion and development of karst features (Miller, unpublished data).

In early Late Ordovician time (Fauna 10), eastward transgression allowed the development of shallow shelf environments and carbonate deposition resumed at the Nopah Range. Dark-gray, chert-bearing, fetid dolostones indicate anoxic bottom conditions; lighter gray beds containing abundant reworked organisms indicate storm transport. Thin intervals of burrowed strata suggest temporary oxygenated conditions developed during the influx of allochthonous sediments. Eastward at Red Rock Canyon, transgression covered the Medial Ordovician erosion surface and carbonates were deposited. Although not well documented, regional shallowing occurred during late Late Ordovician (Faunas 11 and 12?), and these conditions may have continued into early Silurian time.

Occurrence of abundant corals as patch reefs, echinoderm debris and conodonts all indicate open platform conditions existed at the Nopah Range district during late Early Silurian time (*S. celloni* and *P. amorphognathoides* Biozones). Although removed by subsequent erosion, Silurian rocks may have been deposited eastward to Red Rock Canyon. Beginning in early Late Silurian time (Wenlockian), regional regression shifted restricted platform environments westward to the Nopah Range and exposed the eastern areas. Continued regression exposed the Nopah Range section during Late Silurian and older rocks were eroded. The overlying quartz sand-bearing rocks of the Lost Burro Formation were considered Medial Devonian in age by Boucot and others (1969), but may be as old as Early Devonian (Zenger, this volume).

ACKNOWLEDGEMENTS

I wish to thank the large number of students at California State University, Northridge and at San Diego State University who have schlepped rocks in the field and dissolved samples in the laboratory. National Science Foundation Grant EAR 808204 provided support to Miller and John D. Cooper for research on the Mountain Springs Formation. Dr. Cooper has provided much of the information on lithologic characteristics. A Sigma-Xi, Grant-In-Aid-Of-Research provided support for work on the Hidden Valley Dolomite by Miller. John Cooper and Don Zenger have provided data and made significant editorial suggestions which have greatly improved the manuscript.

REFERENCES CITED

Barrick, J. E. and Klapper, G., 1976, Multielement Silurian (late Llandoverian-Wenlockian) conodonts of the Clarita Formation, Arbuckle Mountains, Oklahoma, and phylogeny of Kockelella: Geologica et Palaeontologica, v. 10, p. 59-100.

Bergström, S. M. and Carnes, J. B., 1976, Conodont biostratigraphy and paleoecology of the Holston Formation (Middle Ordovician) and associated strata in eastern Tennessee, *in* Carnes, C. R., ed., Conodont Paleoecology: Geol. Soc. Canada Spec. Paper 15, p. 27-57.

Boucot, A. J., Hazzard, J. C. and Johnson, J. G., 1969, Reworked Lower Devonian fossils, Nopah Range, Inyo County, California: Am. Assoc. Petroleum Geologists Bull., v. 53, p. 163-167.

Byrnes, J. G., 1968, Notes on the nature and environmental significance of the Receptaculitaceae: Lethaia, v. 1, p. 368-381.

Cooper, B. J., 1975, Multielement conodonts from the St. Clair Limestone (Silurian) of southern Illinois: Jour. Paleontology, v. 49, p. 984-1008.

Dunham, J. B. and Olson, E. R., 1978, Diagenetic dolomite formation related to Paleozoic paleogeography of the Cordilleran miogeocline in Nevada: Geology, v. 6, p. 556-559.

Ethington, R. L. and Clark, D. L., 1971, Lower Ordovician conodonts in North America, *in* Sweet, W. C. and Bergström, S. M., eds., Symposium on conodont biostratigraphy: Geol. Soc. America Memoir 127, p. 63-82.

Gans, W. T., 1964, Correlation and redefinition of the Goodsprings Dolomite, southern Nevada and eastern California: Geol. Soc. America Bull., v. 85, p. 189-200.

Hague, A., 1883, Abstract of report on the geology of the Eureka district, Nevada: U. S. Geol. Survey Third Annual Rept., p. 237-272.

_____, 1892, Geology of the Eureka district, Nevada: U. S. Geol. Survey Monograph 20.

Harrington, R. J., 1982, Environmental stratigraphy of the uppermost Mountain Springs Formation (Middle Devonian) and overlying strata of the Sultan Formation (Upper Devonian), at Mountain Springs, Nevada: Geol. Soc. America Abstracts with Program, v. 14, no. 3 (in press).

Harris, A. G., Bergström, S. M., Ethington, R. L., and Ross, R. J., Jr., 1979, Aspects of Middle and Upper Ordovician conodont biostratigraphy of carbonate facies in Nevada and southeast California and comparison with some Appalachian successions, *in* Sandberg, C. A. and Clark, D. L., eds., Conodont Biostratigraphy of the Great Basin and Rocky Mountains: Brigham Young Univ. Geol. Studies, v. 26, pt. 3, p. 7-44.

Haug, G., 1981, Early Silurian depositional environments of the lower unit of the Hidden Valley Dolomite, Great Basin, southeastern California: San Diego State University, San Diego, California, M.S. Thesis.

Hazzard, J. C., 1937, Paleozoic section in the Nopah and Resting Springs Mountains, Inyo County, California: California Jour. Mines and Geology, v. 33, p. 273-339.

_____, 1954, Revision of Devonian and Carboniferous sections, Nopah Range, Inyo County, California: Am. Assoc. Petroleum Geologists Bull., v. 38, p. 878-885.

Hewett, D. F., 1931, Geology and ore deposits of the Goodsprings quadrangle, Nevada: U. S. Geol. Survey Prof. Paper 162, 72 p.

Jenkins, O. P., 1937, Current Notes, California Jour. Mines and Geology., v. 33, p. 270-272.

Ketner, K. B., 1968, Origin of Ordovician quartzite in the Cordilleran miogeosyncline: U. S. Geol. Survey Prof. Paper 600-B, p. B169-B177.

King, C., 1878, Systematic Geology: U. S. Geol. Exploration of the 40th Parallel Report, v. 1, p. 187-195.

Klein, G. deV., 1975, Tidalites in the Eureka Quartzite (Ordovician), eastern California and Nevada, *in* Ginsburg, R. N., ed., Tidal Deposits: Springer-Verlag, New York, p. 145-151.

Langenheim, R. L., Jr. and Horn, B., 1978, Algal Stromatolites(?) in Eureka Quartzite, southeastern Nevada: Am. Assoc. Petroleum Geologists, Program, AAPG-SEPM Annual Convention, Oklahoma, p. 86.

Lenz, A. C., 1976, Late Ordovician-Early Silurian glaciation and the Ordovician-Silurian boundary in the northern Canadian Cordillera: Geology, v. 4, p. 313-317.

Logan, B. W., Rezak, R., and Ginsburg, R. N., 1964, Classification and environmental significance of algal stromatolites: Jour. Geol., v. 69, p. 68-83.

McAllister, J. F., 1952, Rocks and structure of the Quartz Spring area, northern Panamint Range, California: California Div. Mines Spec. Rept. 25, 38 p.

Miller, R. H., 1975, Late Ordovician-Early Silurian conodont biostratigraphy, Inyo Mountains, California: Geol. Soc. America Bull., v. 86, p. 159-162.

_____, 1976, Revision of Upper Ordovician, Silurian, and Lower Devonian stratigraphy, southwestern Great Basin: Geol. Soc. America Bull., v. 87, p. 961-968.

_____, 1978, Early Silurian to Early Devonian conodont biostratigraphy and depositional environments of the Hidden Valley Dolomite, southeastern California: Jour. Palontology v. 52, p. 323-344.

_____, 1979, Comment and reply on 'Diagenetic dolomite formation related to Paleozoic paleogeography of the Cordilleran miogeocline in Nevada: Geology v. 6, p. 117-118.

Miller, R. H. and Walch, C. A., 1977, Depositional environments of Upper Ordovician through Lower Devonian rocks in the southern Great Basin, *in* Stewart, J. H., Stevens, C. H. and Fritsche, A. E., eds., Paleozoic Paleogeography of the western United States, Pacific Coast Paleogeography Symposium 1: Pacific Section Soc. Econ. Paleontologists and Mineralogists, Los Angeles, California, p. 165-180.

Poole, F. G., Sandberg, C. A., and Boucot, A. J., 1977, Silurian and Devonian Paleogeography of the western United States, *in* Stewart, J. H., Stevens, and Fritsche, A. E., eds., Paleozoic Paleogeography of the western United States, Pacific Coast Paleogeography Symposium 1: Pacific Section Soc. Econ. Paleontologists and Mineralogists, Los Angeles, California, p. 39-65.

Ross, R. J., Jr. 1964A, Middle and Lower Ordovician Formations in southernmost Nevada and adjacent California: U. S. Geol. Survey Prof. Paper 1180-C, 101 p.

_____, 1964B, Relations of Middle Ordovician time and rock units in Basin Ranges, western United States: Bull. Am Assoc. Petroleum Geologists Bull., v. 48, p. 1526-1554.

_____, 1977, Ordovician Paleogeography of the western United States, *in* Stewart, J. H., Stevens, C. H., and Fritsche, A. E., eds., Paleozoic Paleogeography of the western United States, Pacific Section Soc. Econ. Paleontologists and Mineralogists, Los Angeles, California, p. 19-38.

Stewart, J. H. and Poole, F. G., 1974, Lower Paleozoic and uppermost Precambrian Cordilleran miogeocline, Great Basin, western United States, *in* Dickinson, W. R., ed., Tectonics and Sedimentation: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 22, p. 28-57.

Sweet, W. C., Ethington, R. L., and Barnes, C. R., 1971, North American Middle and Upper Ordovician conodont faunas, *in* Sweet, W. C. and Bergström, S. M., eds., Symposium on conodont biostratigraphy: Geol. Soc. America Mem. 127, p. 163-194.

Walliser, O. H., 1964, Conodonten des Silurs: Hess. Landesamt Bodenforsch. Abh. 41, p. 1-106.

Westgate, L. G. and Knopf, A., 1932, Geology and ore deposits of the Pioche district, Nevada: U. S. Geol. Survey Prof. Paper 171, 79 p.

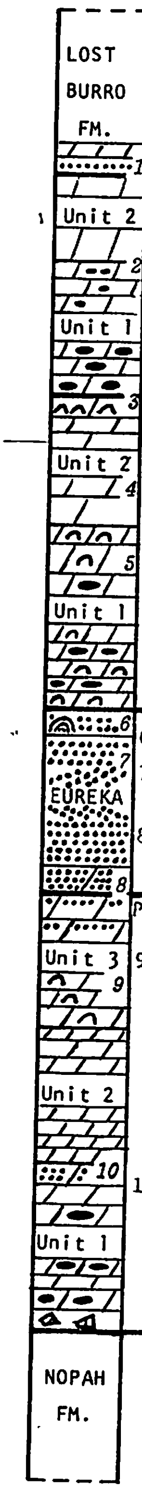
Wilhelms, D. E., 1963, Geology of part of the Nopah and Resting Springs Ranges, Inyo County, California: University of California, Los Angeles, California, PhD Dissertation.

Wilson, J. L., 1975, Carbonate facies in Geologic history: Springer-Verlag, New York, 471 p.

APPENDIX

Synopsis of Field Trip Stop

The following description indicates the stratigraphic position of lithologic and paleontologic characteristerics within the 900 m thick section of Ordovician and Silurian rocks at the Nopah Range.



1. Contact of upper unit Hidden Valley with Lost Burro Formation. Change from very-light-gray dolostone to light-gray, brown weathered, silty dolostone. Considered unconformable, but appears gradational in this area.

HIDDEN VALLEY DOLOMITE

2. Abrupt change from lower unit to upper unit of Hidden Valley; possible unconformity (Fig. 13).

3. Silicified fossils and chert near base of Hidden Valley; represents patch reefs and underlying reef talus (Figs. 12A, 12B).

ELY SPRINGS DOLOMITE

4. Light-gray upper dolostone of the Ely Springs. Represents supratidal(?) deposits. Note top, coarse grained bioclastic layer (Figs. 10A, 10B, 10C).

5. Alternating medium and dark-gray dolostones of the Ely Springs. Stromatolites, oncolites, and abundant bioclastic debris. Chert nodules near base. Cyclic deposits in restricted lagoons and tidal to shelf areas (Figs. 8, 9A, 9B).

6. Stromatolites(?) near top of Eureka.

7. Cross-stratification in middle part of Eureka

8. Gradational contact of Eureka with underlying Pogonip Group.

POGONIP GROUP

9. Abundant gastropods and *Receptaculites* in upper red-brown unit of Pogonip; note abundant quartz silt and layers of oncoids (Figs. 6A, 6B).

10. Reddish brown, silty dolostones containing dolostone-chert breccias and chert nodules in unit 1 of the Pogonip (Fig. 5).