AN ABSTRACT OF THE THESIS OF

Thurman L. Heironimus for the degree of Master of Science in Geology presented on June 8, 1981.

Title: Biostratigraphy, Depositional Environments, and Paleogeography of Lower and Middle Devonian Rocks, Death Valley Area, California

Abstract Approved: J. H. Johnson

During Early and Middle Devonian time, the main part of the Death Valley area was characterized by shallow marine shelf position. In the extreme western part, deposition took place in carbonate slope environments. Early and Middle Devonian eastern platform dolomites, represented by uppermost Hidden Valley Dolomite and lower Lost Burro Formation, have been divided into six units in ascending order based on lithology, depositional environment, and age.

The Lochkovian depositional setting was that of southeast to northwest transition from a broad inner platform to a narrow outer shelf basin. Unit 1 intertidal to very shallow subtidal sediments were deposited to the east, whereas a skeletal carbonate bank or reef complex fringing the platform edge supplied bioclastic material to extreme slope areas to the west. Late Lochkovian regression exposed extreme southeast thesis platform areas to erosion. A depositional hiatus marks the top of farther seaward Unit 1 platform areas in the northern Panamint Range.
Unit 2 fossiliferous sediments were widely deposited throughout the thesis area during early Pragian transgression. Unit 2 correlative Sevy-like deposits in southeast areas at Bat Mountain and the Nopah Range mark the landward extent of initial marine onlap during this time.

With increased input of clastic material into the normal marine environment, the Unit 2 lithotope was gradually replaced by Unit 3 silty and cherty argillaceous dolomites. The lower part of Unit 3 was deposited during continued marine transgression. The upper part reflects shallowing upward conditions and initiation of late Early Devonian regression. To the west, slope areas contain cherty argillaceous limestones correlative to Unit 3 and, similarly, indicate shallowing conditions.

A beach-barrier bar complex, represented by sandy Unit 4 rocks, prograded seaward over nearshore Unit 3 sediments in response to marine offlap in late Early Devonian time. Unit 4 reflects an increased clastic sediment supply derived from erosion of cratonward strata, as well as marking regression. The seaward prograding sandy environment was followed and progressively overstepped by eastern intertidal-supratidal deposits, represented by Unit 5 coarse crystalline dolomite. Thinness and gradational lower contact of this lithology suggest that the transgressive part of coarse crystalline dolomite deposition seen in central Nevada may not be present in southeast California.

Deposition of Unit 6 intertidal to shallow subtidal sediments during early Middle Devonian time records a gradual
submergence of inner shelf regions by initial transgression. Rocks overlying Unit 6 in the thesis area reflect the larger transgressive pulse of the Taghanic onlap.

Two distinct dolomite types are recognizable in the thesis area. Primary dolomite, represented by aphanitic, thinly laminated dolomite at the Nopah Range and Bat Mountain, was formed by penecontemporaneous replacement of calcareous sediment essentially at time of deposition. This dolomite type preserved microcrystalline textures, and fine sedimentary structures. The second dolomite type, eogenetic secondary dolomite, represents postdepositional near-surface replacement of limy sediments by slow growth and coalescence of dolomite crystals. This dolomite type characterizes the bulk of the carbonate interval studied. A favored mechanism for eogenetic secondary dolomite formation in the thesis area is that of mixing zone dolomitization, whereby meteoric freshwater mixes with intrastratal sea water in a seaward extending subsurface wedge. This dolomitizing zone moved seaward with marine regression and landward during transgression, leaving behind a blanket of dolomitized strata. Coarse crystalline dolomite in Unit 5 was extensively subjected to this paleogeographic-related dolomitizing environment.
Biostratigraphy, Depositional Environments, and
Paleogeography of Lower and Middle Devonian Rocks,
Death Valley Area, California

by
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BIOSTRATIGRAPHY, DEPOSITIONAL ENVIRONMENTS, AND PALEOGEOGRAPHY OF LOWER AND MIDDLE DEVONIAN ROCKS, DEATH VALLEY AREA, CALIFORNIA

INTRODUCTION

Purpose

A major purpose of this thesis has been to define rock units and facies distribution patterns of Lower and Middle Devonian rocks in the Death Valley region. From such information, a model has been developed to explain the depositional history during Early and Middle Devonian time for the area. An attempt has been made to biostratigraphically delineate and determine the extent of a pre-Middle Devonian paraconformity which is known to exist in areas of east-central Nevada (Kendall, 1975, p. 139; Poole et al., 1977, fig. 2b). A second objective has been the utilization of paleontologic data for time correlation among the formations in the thesis area, as well as for correlation to better understood rocks in central Nevada. Such correlation allows development of a broader picture of Early and Middle Devonian history and paleogeography for this region of the Cordilleran geosyncline.

Regional Geologic and Structural Setting

A thick stratigraphic sequence of Late Precambrian through Paleozoic geosynclinal rocks is widely and extensively exposed in the area encompassed by the Death Valley 2-degree sheet. These rocks were deposited in part of the
north-south trending Cordilleran geosyncline, a coupled continent-ocean setting from shelf to deep water. An island arc, subduction zone, and marginal basin may have existed during Silurian and Devonian time in the Western United States (Poole et al., 1977). Such a system would have been a major control on sedimentation pattern for eugeosynclinal rocks, but would have had small effect on the distal shelf margin depositional system. The Death Valley region was the site of a shallow to deep water shelf environment with eustatic fluctuations and epeirogenic activity as the main influences on sedimentation patterns and facies distribution. A north-westward shelf-to-basin peleoslope is believed to have existed for most of Paleozoic time (Stevens and Ridley, 1974). Thick deposits (25,000 ft.) of carbonates accumulated, along with lesser siliceous deposits indicative of periods of clastic input. Of concern here are Lower and Middle Devonian carbonates and minor sandstones largely represented in the Death Valley area by the upper Hidden Valley Dolomite and lower and middle beds of the overlying Lost Burro Formation. These units are believed to represent shallow water deposition on an extensive platform which was periodically flooded during marine transgression and at, or very near, sea level during regression and accompanying sediment progradation.

At the extreme southeastern locality of study in the Nopah Range, the Devonian section has been assigned to the Sultan Dolomite, but is lithologically and depositionally
similar to lower beds of the Lost Burro Formation. Extreme western thesis locations of Devonian outcrop are represented by the Vaughn Gulch Limestone and Sunday Canyon Formation, indicative of slope-to-basin deposition. The dolomite-limestone facies boundary in the Death Valley region has been obscured by Mesozoic and younger intrusive-metamorphic episodes, but is believed to occur in the Inyo Range. This depositional regime existed from Early to Late Devonian, at which time flysch deposits of the ensuing Antler orogeny terminated carbonate deposition in the region.

The thesis area lies within a complex tectonic province of Basin and Range normal faulting and overlapping right-lateral strike-slip faulting (fig. 1). This complicated structural regime, probably operative since the late Early Jurassic (Albers, 1967), has altered the former configuration of the Cordilleran continental margin in the Death Valley region and exposed the Precambrian through Mesozoic section in a series of northwest-trending mountain ranges. Stewart, Albers, and Poole (1968) have estimated that as much as 80-120 miles of right-lateral displacement may have occurred across the western Great Basin, based on consistent disruption of sedimentary facies and isopach formation thicknesses. The dominant structural feature within the thesis area is the Furnace Creek-Death Valley fault zone (fig. 1) where up to 80 miles of right-lateral displacement has been estimated (Stewart et al., 1968). Strike-slip movement on this fault is believed to pass along
Figure 1. Index map to thesis measured sections. Locations as follows: NR-Nopah Range, BM-Bat Mountain, RA-Red Amphitheater, MS-Mesquite Springs, CM-Cottonwood Mountains, AH-Andy Hills, LB-Lost Burro, UP-Ubehebe Peak, P1-Panamint Range, DM-Dry Mountain, KM-Kerr-McGee, VG-Vaughn Gulch, SC-Sunday Canyon.
strike into a complicated series of sigmoidal bends, termed "oroflexural bending" by Albers (1967). Wright and Troxel (1970) prefer to explain the apparent large scale displacements in the Death Valley region by differential extension across the Death Valley graben, with crust on the southwest side having been extended northwestward considerably farther than the region on the northeast side. However, facies relationships and isopach thicknesses of Lower and Middle Devonian rocks studied in this thesis indicate that strike-slip faulting has had greater impact in the Death Valley region than extension. But, it is of little doubt that both faulting mechanisms have served to alter the Cordilleran shelf margin configuration to its present geometry. Palinspastic restoration of the region to its approximate Paleozoic geographic configuration is required in order to correctly infer facies relationships and depositional history during the Devonian.
Previous Work

One of the earliest reconnaissance mapping efforts in the Death Valley region was that of Knopf and Kirk (1918) in the Inyo Range. They described Devonian limestone, shale, and sandstone in the Independence quadrangle, immediately west of the Death Valley 2-degree sheet. Other early studies include Stauffer (1930) and Hazzard (1937) in the Nopah Range and Resting Springs Mountains (vicinity of Stewart Valley quadrangle). Hazzard utilized the name Sultan Dolomite of Hewett (1931) to represent the Devonian section and provided evidence for what he termed a "pre-Devonian unconformity", based on Devonian rocks unconformably overlying a Silurian erosional surface.

Significant work on Paleozoic rocks of the Quartz Springs area of the northern Panamint Range was undertaken by McAllister (1952) who named and described the Hidden Valley Dolomite and Lost Burro Formation, as well as several other Paleozoic units. Fossil collecting was also done and age assignments were made for Silurian to Lower Devonian Hidden Valley Dolomite and Middle to Upper Devonian Lost Burro Formation. This report enabled the first significant regional correlation to be made to Devonian strata in central Nevada. The Hidden Valley Dolomite and Lost Burro Formation have been mapped in the Ryan quadrangle (McAllister, 1974), Ash Meadows quadrangle (Denny and Drewes, 1965), Stovepipe Wells and Emigrant Canyon quadrangles (Hunt and Mabey, 1966),
Tin Mountain and Marble Canyon quadrangles (McAllister, 1952), Panamint Butte quadrangle (Hall, 1971), Ubehebe Peak quadrangle (McAllister, 1955, 1956), Darwin quadrangle (Hall and McKeeverett, 1962), Dry Mountain quadrangle (Burchfiel, 1969), and New York Butte quadrangle (Merriam, 1963). McAllister (1955) named and described the Lippincott Member of the Lost Burro Formation in the Ubehebe Peak quadrangle where it comprises sandy dolomite, quartzite, and cherty argillaceous dolomite directly overlying the Hidden Valley Dolomite. The Lippincott Member has also been recognized at several other localities in the Death Valley region (Hall and McKeeverett, 1962, Merriam, 1963; Burchfiel, 1969). In a later report by McAllister (1974), on Silurian, Devonian, and Mississippian formations in the Funeral Mountains, the Hidden Valley Dolomite was divided into lower and upper members and further informally subdivided into six units, h1 through h6 in ascending order. Mapping and description of Devonian rocks in the Independence quadrangle (Vaughn Gulch Limestone and Sunday Canyon Formation) was reported by Ross (1963, 1966).

Biostratigraphic work in the Death Valley area has not reached the detailed status of the Nevada Devonian, largely because of the apparent absence of facies suitable for such studies. McAllister (1952) provided the first reliable correlation to other Great Basin rocks and his report of the Kobehana fauna in the upper Hidden Valley beds demonstrated age equivalence of these beds to part of the
lower Nevada Formation of Merriam (1940). Additionally, C.W. Merriam (in McAllister, 1952, p. 17) reported the presence of the older Trematospira fauna in the Andy Hills, indicating that the upper Hidden Valley Dolomite in this locality is Trematospira to Kobehana Zone age. This was also noted in Boucot et al. (1969) where it was reported that fossils of the Trematospira fauna were reworked into the basal sandy dolomite member of the Devonian section in the northern Nopah Range. It was supposed in the report that this sandy dolomite and overlying rocks were therefore Middle Devonian. However, Johnson (1979, personal communication), believes a Lower Devonian unit is present in the Nopah Range, an idea which is supported by evidence gathered in this study. Osmond (1962, p. 2042) and Poole (in Stewart, Albers, and Poole, 1968, p. 1408) also report the presence of a Lower Devonian unit in the Nopah Range. The absence of Pinyonensis Zone fauna (late Early Devonian) in the Death Valley region was noted by Merriam (1963) and Boucot et al. (1969) suggesting that a pre-Middle Devonian unconformity could be present. The next regionally significant faunal zone in stratigraphic succession in the Death Valley area is represented by Givetian age Stringocephalus fauna which has been reported from several localities in the region (McAllister, 1952, 1974; Merriam, 1954, 1963; Hunt and Mabey, 1966). Extensive dolomitization of Stringocephalus-bearing beds in the Death Valley area may have prevented further recognition at other localities of Devonian exposure.
To the west of Death Valley in the Inyo Range, Ross (1966) determined a Devonian age for the upper beds of the Vaughn Gulch Limestone. It was also found that the bulk of the nearby Sunday Canyon Formation is Devonian based on the presence of Monograptus cf. M. uniformis. The upper Vaughn Gulch beds were considered to intertongue northward with the Sunday Canyon Formation on the basis of age and lithology. Tentative correlation of the Vaughn Gulch to eastern exposures of the Hidden Valley Dolomite was also stated. Conodont studies of these formations by Miller (1976) reached similar conclusions regarding correlation of these units and provided further age refinement for them. A conodont collection made at the Vaughn Gulch type section by R.A. Flory and P. Kimmel and identified by G. Klapper (in Johnson and Niebuhr, 1976, Appendix 2) established an Emsian age for upper Vaughn Gulch beds. Johnson and Niebuhr (1976) suggested correlation with lower Coils Creek strata at Lone Mountain and the upper Bartine tongue of the Sulphur Springs Range in central Nevada.

Studies involving interpretation of depositional environments of Devonian rocks in the Death Valley area, other than at a broad and regional scale, are few. Ross (1966) and Stevens and Ridley (1974) have interpreted the Hidden Valley Dolomite as a shelf or back reef facies and the overlying Lost Burro Formation as representing shelf deposition. Miller and Walch (1977) provided a regional interpretation for Hidden Valley deposition, dividing the
formation into three major lithosomes. Unit 3, encompassing the Devonian part of the formation, was interpreted to represent transgression in the basal fossiliferous part, followed by progressively shallowing conditions in the upper unfossiliferous beds. The Lippincott Member of the Lost Burro Formation was interpreted by Zenger and Pearson (1969) as having formed in very shallow water based on the siliceous, cross-bedded sandstone lithology. The Vaughn Gulch Limestone and Sunday Canyon Formation in the Inyo Mountains were considered to be deeper water deposits correlative to the shallow water Hidden Valley Dolomite by Ross (1966). Stevens and Ridley (1974) considered the Vaughn Gulch Limestone and Sunday Canyon Formation to be slope and basin deposits, respectively. Miller (1978) made a similar interpretation and suggested similar depositional settings for the Vaughn Gulch and the Roberts Mountain Formation in central Nevada.
Methodology and Nomenclature

Thirteen measured sections and reconnaissance visits to selected localities provide the data framework for this thesis (fig. 1). Localities of measured sections were chosen on the basis of accessibility, exposure, and relative lack of structural complication. Lithologic, megafossil, and microfossil (conodonts) collections were keyed to these sections. Silicified megafossils were etched from dolomite using concentrated HCl and submitted to Dr. J.G. Johnson, Oregon State University, for identification and age determination. Conodont samples were dissolved in dilute formic acid; the heavy insoluble residue was hand-picked by Claudia Regier for specimens. Conodonts were sent to Dr. Gilbert Klapper, University of Iowa, for identification and age determination. Corals were identified by W.A. Oliver, U.S.G.S., and Dr. R.A. Flory, California State University, Chico. Description of lithology and thin section work follows terminology of Dunham (1962); Folks's (1962) classification of carbonate rocks is also utilized, when deemed appropriate. Color terminology follows the Geological Society of America Rock-Color Chart (1963) and grain size description is based on the Wentworth Scale. Description of bedding and cross-stratification adheres to terminology of McKee and Weir (1953).

The stratigraphic intervals of the Hidden Valley Dolomite and overlying Lost Burro Formation which have been
measured and described in this thesis have been divided into six informal rock units. These units have been briefly named according to key characteristics and numbered one through six in ascending order (figs. 2 and 3). It was decided to follow this nomenclature because detailed description and analysis warranted a finer lithologic subdivision than has been previously used. These units are recognizable in nearly all measured sections and each is believed to represent deposition in a uniform lithotope. A similar lithologic division and nomenclature was used for the Vaughn Gulch Limestone and Sunday Canyon Formation. Relationship of informal units named here to formational subdivisions in existing literature (McAllister, 1955, 1974; Miller and Walch, 1977) has been made, where possible.
Figure 2: Thesis rock units indicated by numbers, at Ubehebe Peak measured section. Brownish weathering Lippincott Member (numbers 3 and 4) of the Lost Burro Formation is in the middle of the section.
Correlation chart of Lower and Middle Devonian rocks in the thesis area. Less certain age relations are indicated by dashed lines. Vertical bars indicate a hiatus or eroded strata.
HIDDEN VALLEY DOLOMITE

Introduction

McAllister (1952) named and described the Hidden Valley Dolomite to represent the Silurian to Lower Devonian section in the Quartz Spring area of the northern Panamint Range. The Hidden Valley Dolomite is 1365 ft. thick at its type locality two and one-half miles north of Ubehebe Peak. The formation conformably overlies the Ordovician Ely Springs Dolomite and is, in turn, overlain by the Early to Late Devonian Lost Burro Formation. In the southern Inyo Range, the Hidden Valley is approximately 1750 ft. thick (Merriam, 1963). McAllister (1974) reported that the Hidden Valley Dolomite is 1440 ft. thick in the Funeral Mountains, but thins in a southeastward direction to 870 ft. at Bat Mountain. Equivalent age strata in the northern Nopah are 335 ft. thick, and the Silurian section in this area disappears southward beneath a pre-Devonian unconformity (Hazzard, 1937; Boucot et al., 1969).

A poorly defined threefold nature was noted for the Hidden Valley Dolomite (McAllister, 1952): 1) a lower medium gray, cherty dolomite, 2) a middle creamy, coarse grained dolomite, and 3) an upper dark, fine grained dolomite. McAllister (1974) named a reference section for the Hidden Valley in the Funeral Mountains, two miles northwest of Pyramid Peak. The three members of the formation were further subdivided into six units at this locality.
The Silurian part of the Hidden Valley Dolomite suggests shallow subtidal deposition; the upper beds of Early Devonian age reflect initial transgression followed by shallowing upward conditions (Miller, 1977).

Unit 1--Light gray massive dolomite

Unit 1 of the Hidden Valley Dolomite in the thesis area is a light gray, microcrystalline to finely crystalline dolomite that weathered in bench-like exposures. This unit is present in most study localities, but is notably absent in southeast sections at Bat Mountain and the Nopah Range. The Hidden Valley Dolomite is not present in western sections in the Independence quadrangle. Thickness was not determined for this unit because each section measurement was begun at an arbitrary point in the upper Hidden Valley beds. Unit 1 color is dominantly light gray (N 7) on weathered surfaces and medium gray (N 5) to light olive gray (5 Y 6/1) on fresh breaks. Texture varies from dense microcrystalline to finely crystalline dolomite which fractures irregularly to subconchoidally. Finely crystalline dolomite weathers to pitted rough surfaces. Unit 1 is massive to thickly bedded, but in the Cottonwood Mountains this lithology is thin bedded with yellow brown silty micrite defining thin laminations. Also present at this locality are probable algal mat and fenestral structures and small microcross-laminated beds. However, such well developed sedimentary structures are not as conspicuous at
other sections containing Unit 1. At these localities, bedding plane surfaces are undulatory, 2 to 4 ft. apart, and rarely provide a flat surface. Thin laminations are absent and the dolomite is commonly homogeneous in appearance. At Lost Burro Gap, a 2-foot bed containing 2-3 mm. diameter tubular forms crops out in the middle of the measured Unit 1 interval. These forms, enclosed in a medium gray, finely crystalline dolomite matrix, are filled by medium crystalline clear dolomite spar, and may be relict ghosts of tubular corals or stromatoporoids, or possible burrow structures. However, clear sparry dolomite cement infilling of these forms would not be likely if these features were, in fact, burrow structures. It is more likely that sparry dolomite is indicative of dissolution of fossil material and replacement by dolomite cement. Nonetheless, origin of these structures remains unresolved. Other small bits of sparry dolomite are probable relict shell fragments. In the Ubehebe Peak section, Unit 1 lithology displays 6 to 12 inch silty beds containing small cream colored dolomicrite clasts. Many of the faint, very thin laminae in these silty beds have been disrupted. Local periods of moderate current action may have been responsible for these sedimentary features.

In thin section, Unit 1 consists of microcrystalline to finely crystalline interlocking dolomite crystals (fig. 4). Subrounded to subangular quartz silt with sharp, slightly corroded, borders is scattered throughout the dolo-
Figure 4: Photomicrograph of Unit 1 finely crystalline dolomite. Many of the larger dolomite crystals have small dark nuclei. Field of view is 3.5 mm., plane light.
mite. The dolomite matrix has a "dirty" appearance and probably represents original lime mud which has been subsequently dolomitized. Small patches of fine to medium crystalline dolomite spar occur in the microcrystalline dolomite matrix. Crystal borders in these patches are anhedral to euhedral, and dolomite crystals are relatively free of impurities. Many sparry dolomite patches resemble fenestral fabric or birdseye structures as they are flat bottomed, alligned, and subparallel to bedding. Some of the patches have definite curved boundaries with matrix material and show geopetal fabric. These types of dolomite patches are probable fossil allochems. Thin sections of Unit 1 at the Dry Mountain section display finely crystalline dolomite with scattered 0.5 to 1 mm. dolomite rhombs. Dolomite rhombs are internally zoned and have dark rounded to rhombic shaped nuclei surrounded by clear euhedral dolomite. Scholle (1978, p. 132, fig. of Ellenburger Limestone) states that internal zonation and size consistency of euhedral dolomite indicates that such crystals formed simultaneously during a period of uniformly fluctuating diagenetic conditions. A thin section from Unit 1 at Lost Burro Gap reveals a relict intrapelsparite texture for this particular sample (fig. 5). Intraclasts are subrounded and 5-10 mm. in size. Pellets are uniform in size and shape; finely crystalline dolomite forms the cement.
Figure 5: Photomicrograph of dolomitic intrapel sparite texture in Unit 1 at Lost Burro. Field of view is 3.5 mm., plane light.
Depositional Environment

On a regional scale, the bulk of the Hidden Valley Dolomite was interpreted as a shallow shelf or backreef facies (Ross, 1966; Stevens and Ridley, 1974; Miller, 1976). However, few reports are available which provide detailed interpretation of depositional environments. Utilizing a threefold subdivision of the Hidden Valley Dolomite, upper beds of the middle creamy, coarse to fine grained dolomite were considered to be shallow subtidal to partly intertidal deposits by Miller and Walch (1977). These upper beds of the middle Hidden Valley unit probably are equivalent to Unit 1 of the thesis area, because it was suggested that they may be of Early Devonian age (Miller and Walch, 1977, p. 172). Miller and Walch further offered that deposition of this lithology may be explained by shoaling from sediment progradation. In a later report, Miller (1978) indicated that upper beds of the middle unit of the Hidden Valley Dolomite may reflect a very shallow or possibly restricted marine environment, based on the lack of fossils or organic material.

Sedimentary structures in Unit 1 at the Cottonwood Mountains section, such as thin laminations, intraclasts, and fenestral structures, imply an intermittently agitated tidal flat environment. The massive to thick bedding and general lack of sedimentary structures or macrofossils at other locations make depositional interpretation of Unit 1
less certain. However, the uniformly fine crystalline
texture is believed to have resulted from early dolomiti-
ization of tidal flat carbonate mud and is discussed in a
later section.

The intrapelsparite texture noted in thin section
at the Lost Burro section resembles that displayed in the
Beacon Peak Dolomite in the Mahogany Hills area of central
Nevada (Schalla, 1977, fig. 8). Peloids in this lithology
probably are fecal pellets, based on size and shape
(Bathurst, 1975), and thus may indicate a very shallow
agitated subtidal to intertidal environment at this location.

Age and Correlation

The age of this unit must be inferred from its
stratigraphic position below Unit 2, as macrofossils are
absent and conodont identification was indeterminate
(Appendix I, collections HUP 1, HLB 1). Dating of similar
dolomites in the Great Basin (i.e., Lone Mountain Dolomite,
"transitional unit" of Sheehan, 1971) has also been a
problem because of a lack of faunal control. However,
intertonguing relationships with deeper water facies confine
these units to a Silurian to Early Devonian (Lochkovian)
time bracket (fig. 6; from Kendall and Johnson, in manu-
script). Unfortunately, an intertonguing relationship be-
tween Unit 1 and deeper water deposits at Vaughn Gulch
cannot be observed because of metamorphism and faulting in
the Inyo Range.
The oldest fossil dates obtained from collections in the overlying Unit 2 are *Trematospira* age or Faunal Intervals 6 and 7, as defined by Johnson (1977). This then limits the upper beds of Unit 1 in the Panamint Range and in the Funeral Mountains at Red Amphitheater (figs. 7 and 8). At the Nopah Range and probably also at Bat Mountain, beds equivalent to Unit 1 have been eroded during a low sea level stand in earliest Pragian time (fig. 8) (Johnson and Sandberg, 1977). The lower age range for Unit 1 is problematic, as section measurements were begun at an arbitrary position, generally about 100 feet below the base of fossiliferous Unit 2. McAllister (1952, 1974) indicated that the bulk of the Hidden Valley Dolomite is Silurian, with only the fossiliferous upper part being Early Devonian.

In central Nevada, a Lochkovian-Pragian hiatus (fig. 6) separates Lone Mountain Dolomite (Silurian to Lochkovian) from the overlying Sevy Dolomite (Pragian to Dalejan) (Johnson and Sandberg, 1977). This hiatus expands into an erosional unconformity in eastern Nevada and Utah (Osmond, 1954; Nolan et al., 1956). This same unconformable surface extends into southeast California at the Nopah Range and may also be present at Bat Mountain (fig. 8). At other thesis localities, a sharp planar contact between massive light gray beds of Unit 1 and dark gray fossiliferous dolomite in Unit 2 is believed to represent the Lochkovian-Pragian surface of non-deposition (fig. 7). As such, Unit 1 is considered to be correlative to the upper
Figure 6: Time-rock relations in central Nevada. Symbols are as follows; FI-faunal intervals (Johnson, 1977), CZ-conodont zones (Klapper, 1977), DS-Dobbin Summit, Monitor Range, TA-Antelope Range, LM-Lone Mountain, SS-Sulphur Springs Range, DR-Diamond Range, RM-Ruby Mts., ER-Egan Range, GH-Gold Hill, Utah, AC-Arrow Canyon. (fig. from Kendall and Johnson, in manuscript).
Figure 7: Time-rock relations in the Inyo Range and northern Panamint Range. Symbols as follows; FI-faunal intervals (Johnson, 1977), CZ-conodont zones (Klapper, 1977) SC-Sunday Canyon, VG-Vaughn Gulch, DM-Dry Mountain, AH-Andy Hills, CM-Cottonwood Mts.
Figure 3: Time-rock relations in the Funeral Mountains and the Nopah Range. Symbols as follows; FI-faunal intervals (Johnson, 1977), CZ-conodont zones (Klapper, 1977) RA-Red Amphitheater, BM-Bat Mountain, NR-Nopah Range.
part of the Lone Mountain Dolomite, both on stratigraphic position and lithologic similarity between the two light gray, medium-grained, massive dolomites. Osmond (1954, p. 1914) has made a similar correlation between the Lone Mountain Dolomite and McAllister's Unit 2 (1952) of the Hidden Valley Dolomite.

Within the thesis area, Unit 1 is correlative to beds in the middle part of the Vaughn Gulch Limestone, based on the presence of *Icriodus woschmidtii*? 335 feet below the formation top (Miller, 1976). Berry and Boucot (1970) reported faunal collections indicating *Quadrithyris* Zone age (Lochkovian) for strata 400 feet below the top of the Vaughn Gulch Limestone. Thesis samples for conodonts in approximately the same interval at the Vaughn Gulch type section did not yield any specimens. Ross (1966) indicated that the base of the Sunday Canyon Formation was Late Silurian (Wenlockian or Ludlovian) and the middle part was Early Devonian, using graptolites identified by W.B.N. Berry. However, Miller (1976) has suggested that the lower Sunday Canyon beds unconformably overlying the Ordovician Ely Springs Dolomite are Early Devonian, indicated by *Icriodus* sp., rather than Late Silurian. The lower beds of the Sunday Canyon Formation were not sampled for conodonts in this report. Nevertheless, the Sunday Canyon Formation is believed to contain beds correlative to Unit 1 (fig. 3), but correlation is tentative until more information on the age of the lower beds has been gathered.
Unit 2- Fossiliferous dolomite

A fine grained, sparsely fossiliferous dolomite present in the uppermost Hidden Valley Dolomite of the thesis area is herein designated Unit 2. Unit 2 is recognizable in most areas where it was possible to begin measurement low enough in the section. Exposures of this lithology are very limited at Mesquite Springs and not present at the Panamint Range section due to faulting and cover. Additionally, fossiliferous dolomite is not present in the extreme southeast section locality at the northern Nopah Range. In the two sections in the Independence quadrangle, Unit 2 lithology is absent, but deeper water, time equivalent strata may be present there.

Unit 2 generally shows a northwest thickening trend from thin exposures at Bat Mountain (15 ft.) to the greatest accumulations (60 ft.) at Dry Mountain. Good exposures at Andy Hills and Red Amphitheater measure 53 and 32 feet, respectively. In the Cottonwood Mountains, Unit 2 is 36 feet thick with a similar value at Lost Burro Gap. In contrast to the nearby Lost Burro section, the Ubehebe Peak section contains only 20 feet of Unit 2 lithology. Unit 2 is believed to be present at a section near the Kerr-McGee limestone quarry in the Argus Range (fig. 1). Here, the Lower and Middle Devonian interval has been thermally metamorphosed to a calc-silicate-bearing dolomite. Strata in appropriate stratigraphic position display unsilicified
fossil relicts of crinoid columnals and coral remains on weathered surfaces; thus, Unit 2 age rocks are probably represented at this locality, though fossil identification was indeterminate (see Appendix I, Kerr-McGee locality).

The sparsely fossiliferous dolomite of Unit 2 overlies Unit 1 in relatively sharp planar contact and represents slightly deeper water deposition. The upper contact with overlying cherty argillaceous dolomite (Unit 3) is gradational and arbitrarily placed above the highest occurrence of megafossils. In outcrop, Unit 2 can often be subdivided into two informal subunits based on color, bedding, and argillaceous content. The lower subunit is medium dark gray (N 4) to olive gray (5 Y 4/1) in color and weathers to a medium light gray (N 6). Argillaceous and silt content is relatively low. Bedding is thick to massive, and outcrops form low resistant benches and steps. In contrast, the upper Unit 2 subunit is grayish red (5 R 4/2) and weathers to a distinctive pale red (5 R 6/2) to pale yellowish brown (10 YR 6/2). Bedding is thin, and very thin laminae and lenses of skeletal debris are common at some localities. Argillaceous and silt content is higher than in the lower subunit and beds weather recessively. The contact between the lower and upper subunits is gradational to interbedded. In a typical exposure of Unit 2 at Andy Hills, the interbedded zone is approximately 10 feet thick with alternating 6 inch to 1 foot beds of both lithologies. Here, the upper subunit beds have been locally burrowed.
At the Ubehebe Peak section approximately 7 miles west of Andy Hills, lithology indicative of the upper subunit is apparently absent or covered by talus. Another exception to the twofold subdivision of Unit 2 was found at the Dry Mountain locality. This section shows the thickest exposure of Unit 2, but rocks indicative of the upper yellowish gray subunit are not exposed.

The most distinctive characteristic of Unit 2 is the presence of silicified megafossils which weather out on exposed surfaces. These include brachiopods, rugose and tabulate corals, crinoid ossicles, and rare bryozoans; sparse microfossils present are conodonts, ostracods, and possible foraminifera. In general, fossils are most abundant in the middle of Unit 2 and decrease upward with increasing silt content. Of all fossils present, corals are most abundant, followed by brachiopods. Fossils are commonly found concentrated in thin beds and lenses where frequent current activity winnowed away fine carbonate muds and left the shelly remains as lag deposits. At other localities, such as Red Amphitheater, Andy Hills, and Lost Burro, currents had lesser effects on bottom sediments and faunal remains. Some tabulate corals, appearing to be in life position, were probably smothered by muddy bottom carbonate sediments settling out after weak current agitation. Rugose corals are abundant at some horizons where they lie in random orientation on bedding surfaces. Such accumulations of corals showing no obvious signs of transport, alignment, or
abrasion may be indicative of local small patch reefs. Although most brachiopods occur as single valves, some articulated specimens were found at these localities. This is further evidence of a slightly deeper, quieter environment which was subjected only to episodic current activity.

In thin section, rocks of Unit 2 are fossiliferous, very finely crystalline dolomite. Texture prior to dolomitization was a skeletal wackestone with local packstone beds and lenses. Original lime micrite has been recrystallized to a fine mosaic of anhedral-subhedral dolomite. Fossil allochems have been partly to completely replaced by fine grained silica, with the exception of the Dry Mountain locality (fig. 9). However, remnants of coarse crystalline sparry dolomite in and around the silica indicate that fossils underwent earlier replacement by dolomite prior to silification. This is also supported by the general lack of preservation of fossil microstructure (fig. 10). Thus, fossil replacement by silica took place after some dolomitization of original lime mud.

Nopah Range and Bat Mountain

Strata in the same stratigraphic position as Unit 2 at the Nopah Range section display a different lithologic character. At this location, interbedded sandy dolomite, very thinly laminated dolomite, and sedimentary quartzite compose the basal lithology. These rocks are 100 feet thick and unconformably overlie Silurian dolomite.
Figure 9: Photomicrograph of dolomitized fossiliferous wackestone in Unit 2 at Dry Mountain. Fossil ghosts are brachiopids, ostracods, and probable foraminifera. Molds are infilled by clear sparry dolomite. Field of view is 3.5 mm., plane light.
Figure 10: Photomicrograph of brachiopod shell in Unit 2 at Andy Hills. Coarse crystalline dolomite has replaced part of the shell, whereas silica has replaced outer shell wall. Field of view is 3.5mm., polarized light.
The lower 80 feet consist of fine to medium crystalline dolomite, medium dark gray (N 4) to brownish gray (5 YR 4/1) in color, weathering to a light brownish gray (5 YR 6/1) on rough surfaces. Lag pebbles and cobbles of underlying light gray Silurian dolomite are incorporated into this lithology immediately above the well developed erosional unconformity. Also present are numerous medium to coarse sparry dolomite blebs and stringers, as well as randomly oriented small dolomite clasts (fig. 11). Abraded fossils have been reported from these beds by Boucot et al. (1969), so it is probable that many of the sparry blebs and stringers represent shell debris. Very fine sand-to silt-sized quartz is also a common constituent. Interbedded with these rocks are 2-4 foot beds of very thinly laminated dolomite. These beds exhibit variegated grayish red (5 R 4/2), pale yellowish brown (10 YR 6/2) and medium gray (N 5) laminae that weather in a rib and furrow manner. Sedimentary structures present, such as very thin laminae and fenestral fabric, are indicative of algal mat structures; also present are mud cracks and rip-up mud clasts (fig. 12). In thin section, dolomite is aphanitic and quartz silt is concentrated in some laminae. Two to four inch cross-bedded fine sandstone and siltstone beds become common in the upper 30 feet with upward increasing siliclastic content. At the top of this interval is a 15 foot sequence of thin to thick bedded sandy dolomite and quartzites which are commonly planar cross-bedded and planar laminated. Surfaces which permit paleocurrent measurements
Figure 11: Photomicrograph of dolomitized pebbly and silty wackestone-packstone. Large clast to the left is a dolomite lithoclast. A gastropod ghost (G) occurs in the center of the picture. White grains are quartz silt. Field of view is 3.5 mm., plane light.
Figure 12: Finely preserved thin algal laminae, fenestrae, and mud rip-ups (bottom) in aphanitic Sevy-like dolomite at the Nopah Range.
are uncommon; the few measurements made indicate southeast current transport. Sandy dolomite and quartzite fresh surfaces are light brownish gray (5 YR 6/1) weathering to a distinctive light brown (5 YR 6/4). This lithology forms small steps and resistant benches, and yields small blocks of talus upon weathering.

The dominant constituent in thin section is well sorted and rounded, very fine to fine quartz sand. The supermature compositional and textural maturity of these beds indicates a multicyclic history for the quartz and a likely cratonic derivation. A logical source would be older sandstone deposits cropping out to the east, such as the Ordovician Eureka Quartzite. The matrix in sandy dolomite beds consists of anhedral microcrystalline dolomite which has partially replaced quartz grains at corroded borders. Optically continuous silica overgrowth and slight pressure welding of grains has taken place where little or no dolomite matrix is present.

At Bat Mountain, approximately 20 feet of interbedded sandy dolomite and very thinly laminated dolomite occurs in the base of the section. These beds lithologically resemble sandy and very thinly laminated dolomite at the Nopah Range. An unconformity also may be present below these Bat Mountain strata, but no well developed erosional surface was observed in fieldwork. However, a sharp, slightly undulatory, contact between dark gray, fine grained dolomite at this section may be indicative of a period of nondeposi-
tion and a possible paraconformity. Such abrupt, apparently conformable contacts commonly pass laterally into unconformable relationships (Krumbein and Sloss, 1963, p. 303). Above this sharp contact are 10 feet of alternating light brownish gray (5 YR 6/1) and pale red (5 R 6/2), silty intraclastic dolomite cropping out in small benches and talus slopes. The remaining 10 feet of this interval is predominantly sandy and contains reworked brachiopods and corals (fig. 13). Small lenses of concentrated shell debris occur in upper sandy dolomites. Immediately overlying the sandy dolomite with relatively sharp contact is 15 feet of sparsely fossiliferous dolomite representing typical Unit 2 lithology. Here, fossil-bearing beds are only 15 feet thick and consist of a basal 3 feet of medium dark gray (N 4), fine to medium grained dolomite grading upward into pale red (5 R 6/2), very fine-grained dolomite. The lower medium dark gray dolomite is thick bedded and contains a few silicified corals lying on bedding surfaces. The upper pale red lithology is very thin-bedded with local concentrations of corals and disarticulated brachiopod shells in 1- to 4-inch lenses and beds. Sample HBM-B1 (Appendix I) comes from a 4 inch bed in the pale red dolomite. Local abundances of shelly lenses and thin beds suggest periodic current energy on shelf areas which concentrated these remains as shell lag deposits.

An intertonguing relationship between sandy dolomites and more offshore shelly deposits is believed to
Figure 13: Brownish weathering sandy dolomite at Bat Mountain. Abraded corals, brachiopods, and other shell fragments are concentrated in some horizons. Sparsely fossiliferous Unit 2 dolomite directly overlies this lithology (not in picture).
occur between the Bat Mountain and the Nopah Range sections, where only sandy dolomite and thinly laminated unfossiliferous dolomite are present. The depositional paleoslope indicated in the Funeral Mountains and the Nopah Range gently sloped in a northwest direction (Plate 4). A northwest-sloping depositional ramp is also indicated by unit thickness changes in the northern Panamint Range (Plate 2).

Depositional Environment

Incursion of shallow, open marine seas into the thesis area and deposition of Unit 2 resulted from Pragian transgression (Johnson and Sandberg, 1977; Johnson et al., 1978). The lower sharp contact with underlying Unit 1 is suggestive of a disconformity and depositional hiatus between these units. In central Nevada, a similar depositional contact exists between the Lone Mountain Dolomite and the overlying Kobeh Member of the McColley Canyon Formation and is, likewise, considered to be a disconformity (Gronberg, 1967; Potter, 1976; Johnson and Sandberg, 1977, fig. 3). The same relationship also exists between these units in southern Nevada (Jarvis, 1981). It should be noted, however, at this location the McColley Canyon disconformably overlies the Sevy Dolomite and is younger (upper Pragian) at its base than is Unit 2. Apparently in southern Nevada, earliest Pragian transgression is reflected initially by Sevy progradation and later by establishment of the McColley Canyon lithotopoe. Lithofacies patterns between southeast California
and southern and central Nevada differ in that thicker deposits of fossiliferous strata and, hence, longer persistence of the McColley Canyon lithotope are seen in Nevada exposures. It is believed that localized subsidence, along with a broader, flatter paleoslope in the thesis area, may have been responsible for differences in age and thickness of the similar transgressive deposits.

Unit 2 is representative of a shallow subtidal lithotope, with deposition occurring below wave base. Weak to moderate current activity periodically affected this environment, as demonstrated by concentration of shelly remains in packstone layers and lenses. Unpublished fossil collections in the Quartz Springs area of the northern Panamint Range by A.J. Boucot and T. Hamada and by F.G. Poole and Boucot suggest that mixing of Trematospira, Costispirifer, and Kobehana faunas may have taken place (unpublished data, see Appendix I). Alternatively, certain species in question may have different ranges in southeast California than in central Nevada.

The Red Amphitheater section is noteworthy in that it contains Atrypa sp. and Gypidula sp., indicative of a more offshore biotope than other fossil collections (Johnson, 1981, personal communication). Rugose metriophyllid corals collected at Red Amphitheater and Cottonwood Mountains may also indicate a deeper and dirtier environment, though it is not uncommon for these coral types to be associated with species collected in the thesis area (Oliver,
Collections of Acrospirifer kobehana and Leptocoelia sp. demonstrate presence of the shallow water Acrospiriferid-Leptocoeliid biofacies of Johnson (1974) in the thesis area. This biofacies occupied a relatively shallow inner belt position across the marine benthic environment (Johnson, 1974, p. 817). The great abundance of the robust-shelled Meristella in collections further indicates a shallow water agitated marine environment.

The gradual upward decrease in fossil content in Unit 2 is probably related to increasing clastic content and sedimentation rate upward. Corals appear to have been more tolerant of the increased sediment supply as they are often the last organisms present in upper beds. Specimens of Favosites kobehensis collected in the Cottonwood Mountains section have large 1/2 to 3/4 inch stalks at the base of the corallum. This suggests that they lived in a fine-grained environment with a fairly uniform sedimentation rate (Flory, 1981, written communication). Increased clastic input into the fossiliferous biotope is believed to have been responsible for the eventual demise of shelly fauna in the Unit 2 thesis area.

Sandy dolomites and thinly laminated aphanitic dolomites at the base of the Nopah Range and Bat Mountain sections are a southeast facies equivalent of Unit 2, based on stratigraphic position and the presence of reworked Trematospira age fossils in sandy beds. Furthermore, 15
feet of fine-grained sparsely fossiliferous dolomite directly overlie sandy dolomite at Bat Mountain. Plate 4 illustrates the inferred relationship between this southeast lithology and fossiliferous Unit 2 dolomite to the northwest. The depositional setting for sandy beds and very thinly laminated dolomite ranges from supratidal, to intertidal, to beach environments. Laminated dolomite (fig. 12) represents deposition in a supratidal to intertidal regime, based on its aphanitic texture and finely preserved sedimentary features such as very thin laminae, rip-ups, and dessication cracks. Aphanitic dolomite is believed to have been primary, following the genetic terminology of Nichols and Silberling (1977). This will be discussed in a later section dealing with dolomitization. Sandy dolomite and quartzose beds were deposited in a beach environment which fringed shoreward tidal flats. Planar low-angle cross-bedding and planar laminated sandy beds closely resemble sedimentary structure described from the inner planar and swash zone of a modern beach environment along the Oregon coast (Clifton et al., 1971). Dunes and small bars may have also been part of the beach environment, but there is no evidence in outcrop to support this idea. Fossils found in sandy beds were moved from the adjacent shallow subtidal environment by currents and vigorously reworked in the beach environment. Boucot et al. (1969), proposed that fossils were eroded from exposed Hidden Valley beds, but presence
of Lower Devonian beds at the Nopah Range and Bat Mountain now precludes this idea.

Age and Correlation

Unit 2 in thesis area is mid to late Pragian age (Faunal Intervals 6-9), based on dates obtained from silicified corals and brachiopods, as well as a few conodont species (fig. 3). Basal beds contain brachiopods indicative of Trematospira age fauna (F.I. 6, 7). Important and diagnostic species for lower age limits include the commonly occurring Acrospirifer aff. murchisoni (Appendix I). Unpublished collections from the northern Panamint Range contain Pseudoparazygga cf. cooperi, Dyticospirifer mccolleyensis, Termatospira cf. multistriata, and Costispirifer sp. (supplementary collections in Appendix I.) These brachiopods and collections indicative of younger ages in Unit 2 are commonly accompanied by the conodont Icroidus claudiae, which ranges from sulcatus through kindlei conodont zones (Johnson et al., 1977; Klapper, 1981, written communication). In the Nopah Range, Trematospira-age fossils were found in sandy beds unconformably overlying Silurian dolomite by Boucot et al. (1969). Presence of these fossils in sandy beach deposits at this locality marks the landward extent of initial Pragian transgression in southeast California and establishes age equivalence of such strata to more offshore Unit 2 deposits. Apparently, the initial pulse of Pragian transgression was strong, as suggested by Johnson and Sandberg
(1977, p. 131), because Faunal Intervals 6 and 7 are represented at most collection localities. The upper age of Unit 2 is late Pragian, based on brachiopod and conodont collections indicative of Faunal Intervals 8 and 9. A Kobehana Zone age is clearly established in several Unit 2 collections by occurrence of the zonal name bearer, Acrospirifer kobehana. It should be noted, however, that Faunal Interval 9, or uppermost Kobehana Zone, can be unequivocally verified only at deeper water localities at Andy Hills and Red Amphitheater. Particularly at the Red Amphitheater section, overlap of A. kobehana and Atrypa sp. with coarse costae occurs only in F.I. 9 in central Nevada (Johnson, 1981, personal communication). In further support of the late Pragian date at Red Amphitheater, Icriocus claudiae overlaps with I. nevadensis, which presumably occurs in the upper part of the kindlei Zone (Johnson et al., 1980, table 14; Klapper, 1981, written communication). The two species of Icriodus again co-occur in the Bat Mountain collection, suggesting that Unit 2 is also mid to late Pragian at this locality. At other locations (Mesquite Springs, Ubehebe Peak, Lost Burro), a complete sequence of Faunal Intervals 6 through 9 may be present, but more collections would have to be made to verify this. At the Panamint Range section, Unit 2 could not be found because of faulting. Macrofossils in Unit 2 at the Dry Mountain section are not silicified and do not weather out, so collections could not be made. Unfortunately, samples analyzed for conodonts were barren.
Nonetheless, dolomitized brachiopod fossil ghosts are visible in polished slabs and thin sections (fig. 9), so Unit 2 is represented in the section though a precise age was not determined.

Ages obtained from brachiopods and conodonts show good agreement, but coral dates consistently yield younger *pinyonensis* ages. Only in one collection, HCM-13 which contains *Favosites kobehensis*, did coral age assignment agree with ages from brachiopods and conodonts. It is believed that an environment suitable for corals was available earlier in southeast California than in central Nevada. Thus, corals in the thesis area evidently have different ranges than do similar species in Nevada. Another possibility is that Unit 2 has a younger upper age limit than is indicated by brachiopods and conodonts. This possibility is less likely, because brachiopod and conodont dates agree quite well with the zonal scheme established in Nevada.

Within the thesis area, Unit 2 corresponds to unit 3b of the Hidden Valley, as used by McAllister (1952), and unit h6 of the Hidden Valley designated in a later report (McAllister, 1974). In the 1974 report, the fossiliferous upper beds were mistakenly assigned a late Emsian age. But from evidence gathered in this report, the upper Hidden Valley Dolomite is mid to late Pragian in age. Miller and Walch (1977) reported an upper Hidden Valley Early Devonian age and Unit 2 corresponds to their Unit 3. At the Vaughn Gulch section, beds equivalent to Unit 2 occur
in the upper middle part of the formation, indicated by the co-occurrence of *Icriodus claudiae* and *I. nevadensis*? in sample HVG-17 taken 291 feet below the formation top (Appendix I). Overlap of these species again implies an upper *kindlei* zone age, as in Unit 2 at Red Amphitheater and Bat Mountain. Correlation between upper Hidden Valley and part of the Vaughn Gulch Limestone had been earlier suggested, but the presence of Pragian age strata in the Vaughn Gulch had not been demonstrated (Miller, 1976; 1978) prior to this report. The Sunday Canyon Formation probably contains strata equivalent in age to Unit 2, though no age data were obtained to verify this. Miller (1978) also correlated fossiliferous upper beds of the Hidden Valley Dolomite to the lower part of the Sunday Canyon Formation.

In central Nevada, the Kobeh Member of the McColley Canyon Formation (fig. 6) is correlative in age and lithologically similar to Unit 2 (Murphy and Gronberg, 1970). Sandy dolomite and thinly laminated, aphanitic dolomite at Bat Mountain and in the Nopah Range are correlative to the Sevy Dolomite, as evidenced by both faunal ages and lithologic similarity. The Sevy Dolomite is equivalent to the Beacon Peak Dolomite mapped by Nolan et al. (1956) in Eureka County, Nevada (Osmond, 1962), so Unit 2 is also correlative to this central Nevada formation (see fig. 6 for Sevy-Beacon Peak relations). The Beacon Peak Dolomite, as described in the Diamond Range, is very similar to strata in the Nopah Range (Potter, 1976).
LOST BURRO FORMATION

Introduction

The Lost Burro Formation was named and first described by McAllister (1952) from excellent exposures at Lost Burro Gap in the Ubehebe Peak quadrangle. This formation comprises the mid-Lower to Upper Devonian section in the Death Valley region and is 1,525 feet thick at its type locality. However, 3 miles to the east at Andy Hills, a 2,245-foot section of the Lost Burro was measured (McAllister, 1952). Average thickness in the Funeral Mountains is about 2,500 feet (McAllister, 1974). The Lost Burro Formation is conformably overlain by the Mississippian Tin Mountain Limestone. The lower part of the Lost Burro is dolomitic and grades upward into more limy carbonate rocks. The lower, brownish weathering silty dolomite and sandy beds (fig. 2) were named the Lippincott Member for exposures at the Lippincott lead mine area at the southern end of Racetrack Valley (McAllister, 1955). However, the Lippincott Member is faulted and metamorphosed at this locality and much better exposures occur north of Ubehebe Peak and at Andy Hills. Beds above the Lippincott Member were divided into Units 1b2 through 1b5 in later work in the Funeral Mountains (McAllister, 1974). This report deals only with the Lippincott Member and Unit 1b2 of the Lost Burro Formation, equivalent to Units 3, 4, 5, and 6 of this thesis.
Unit 3--Cherty argillaceous dolomite

The rock unit which overlies Unit 2 is a cherty argillaceous, fine grained dolomite and is termed Unit 3 in this thesis. The cherty character and distinctive light brown weathering of this unit are easily recognizable in all sections, with the exception of Vaughn Gulch and Sunday Canyon. A high content of silt and argillaceous matter (up to 25%) is another distinctive characteristic of this unit. Contact with the underlying fossiliferous dolomite of Unit 2 is gradational, coinciding with the top of the Hidden Valley Dolomite and the base of the Lippincott Member of the Lost Burro Formation as used by McAllister (1955). As there is no well defined lithologic change between Unit 2 and Unit 3, eventual redefinition of the Hidden Valley-Lost Burro boundary would then distinguish Unit 3 as a separate mappable rock package. However, in order to avoid confusion, formational boundaries defined by McAllister (1952, 1955) for southeast California are still followed in this thesis.

Unit 3 reaches greatest thickness in the northern localities of the thesis area, at Mesquite Springs (242 ft.) and Dry Mountain (205 ft.). In the northern Panamint Range, Unit 3 is 112 feet thick at Andy Hills and 182 feet thick at Ubehebe Peak. Faulting in this interval at Lost Burro renders thickness determination impossible. Likewise, at the Panamint Range section, faulting prevents an accurate thickness measurement. In the Funeral Mountains, Unit 3 is
162 feet thick at Red Amphitheater and unusually thick (192 ft.) at Bat Mountain. A thin, 59 foot sequence composes Unit 3 in the Nopah Range. No clear thickening trend is apparent, although greatest accumulations occur in the northern thesis area.

The cherty argillaceous dolomite of Unit 3 forms prominent benches and small cliff-like exposures in measured sections. The lower part of the unit is medium gray (N 5) and weathers to a distinctive pale yellowish brown (10 YR 6/2) on gritty exposed surfaces. These lower beds are thickly bedded, and abundantly burrowed zones are quite common (fig. 14). Burrows weather dark brown in epirelief and are of several main types: 1) long slender 2 to 6 mm. diameter, randomly oriented tubes, 2) large 1 to 2 inch diameter vertical and inclined tubes with variable widths, and 3) long cylindrical tapering burrows exclusively horizontally oriented. Of these burrow types, the randomly oriented 2 to 6 mm. tubes are most common. These may be representative of Chondrites (Chamberlain, 1978), although the typical branching mode for these forms is rarely observed. It is more likely that these burrows have closer affinity to Planolites, as burrow tubes generally display a meandering unbranching habit (Kennedy, 1975). The large vertical burrows do not exhibit any internal structure. The outside form either is relatively straight in outline or resembles stacked oval lumps in relief on weathered surfaces. Affinity of these forms is difficult to determine, but some may be
Figure 14: Silty burrowed dolomite in lower part of Unit 3 at Andy Hills. Burrows concentrated in some beds. Silicification and nodular cherty horizons also present.
representative of Conostrichus (Chamberlain, 1978). At Andy Hills, well exposed bedding surfaces are dominated by horizontally oriented cylindrical burrows. These tube-shaped forms taper to rounded cone shapes. Tubes are 10 to 15 mm. in diameter, show concentric ring internal structure, and many appear to radiate from a common center. Such burrows closely resemble zoned Asterosoma as described by Chamberlain (1978). In intervals where burrowing is not as abundant or is absent, faint thin silty laminae weather out on exposures. In some places, current formed structures, possibly hummocky cross-stratification, can be seen (fig. 15). Silt and argillaceous content is high in the lower beds of Unit 3 and decreases slightly upsection. At the Cottonwood Mountains two large gastropods were found in silty dolomite.

The middle and upper beds of Unit 3 are dominated by 2 to 8 inch nodular cherty horizons along bedding planes in 1 to 3 foot intervals. Fresh surfaces of chert are dark gray (N 3) to light gray (N 7), weathering to olive gray (5 Y 4/1) and dusky brown (5 YR 2/2) colors. Thin laminations of former sediment are commonly preserved in the silicified horizons, indicating that chert is of a secondary replacement origin (fig. 16). Thin sections showing relict dolomite euhedra within microcrystalline silica also demonstrate secondary replacement. In uppermost cherty beds, chert occurs as irregularly shaped nodules which do not parallel bedding. Origin of chert and the
Figure 15: Possible hummocky cross-stratification in upper Unit 3 silty beds at Andy Hills. Silicification and minor burrowing.
Figure 16: Photomicrograph of secondary chert in Unit 3 preserving relict dolomitic lamination. Small dolomite crystals are euhedral. Field of view is 3.5 mm., polarized light.
silicification process will be discussed in the section on dolomitization.

Dolomite in the middle and upper Unit 3 beds is fine grained and massive. A slight decrease in silt content is reflected by medium gray and dusky blue (5 PB /32) weathering colors. At several localities, the upper 10 to 20 feet of Unit 3 are conspicuously chert-free. Burrowing, a common feature in lower Unit 3 beds, decreases in the middle beds and is rare in uppermost cherty and massive dolomite.

Depositional Environment

The deposition of Unit 3 cherty argillaceous dolomite reflects significantly increased clastic input and the gradual disappearance of habitats suitable for shelly benthic organisms. This unit, in its lower and middle part, was deposited during a transgression that is well documented in central Nevada (Johnson and Niebuhr, 1976; Johnson and Sandberg, 1977). Osmond (1962, p. 2038) in the description of his cherty argillaceous member of the Sevy Dolomite, noted that "this member appears to represent an eastward incursion of more normal marine environment with better circulated waters than existed during the deposition of the dolomite member". Thick occurrences of Unit 3 in the northern extremities of the Panamint Range coupled with thinning southeastward into the Nopah Range lend support for the deposition of the lower part of Unit 3 during transgressive
conditions. The uppermost part of the unit was deposited in progressively shallowing conditions during the regressive phase of Pragian sedimentation (Johnson and Sandberg, 1977). Cherty argillaceous dolomite in southern Nevada lies in a belt of varying width between eastern unfossiliferous dolomite and fossiliferous argillaceous limestone to the west, represented by the Barine Member of the McColley Canyon Formation (Osmond, 1962; Poole et al., 1967, fig. 7; Johnson and Neibuhr, 1976, fig. 1). An intertonguing between this dolomite and limestone (Bartine) containing pinyonensis fauna was found in the northern part of the Sulphur Springs Range in central Nevada (Carlisle et al., 1957, p. 2182). Based on conodont age data and lithologic similarity, the cherty argillaceous dolomite in southeastern California is believed to intertongue westward with platy argillaceous and cherty limestone at Vaughn Gulch and Sunday Canyon. Correlation of the upper part of the Vaughn Gulch Limestone and the upper Bartine tongue was suggested by Johnson and Niebuhr (1976, Appendix 2), so it seems likely that Unit 3 is an eastern facies equivalent to upper Vaughn Gulch beds. In the Sulphur Springs Range of central Nevada, transgressive deposits of the Bartine Member consist of a lower and upper part separated by a westward progradation of the Beacon Peak (Sevy) Dolomite (Kendall, 1975; Johnson and Niebuhr, 1976). Deposition of Unit 3 in the thesis area possibly reflects a similar phenomenon, with sedimentation nearly in equilibrium with apparent sea level rise.
Burrow types identified from lower and middle Unit 3 beds indicate a subtidal nearshore environment (Chamberlain, 1978). Many burrows are concentrated in zones separated by intervals of little bioturbation (fig. 14). Howard (1978) has described such varied combinations of burrowed and unburrowed units as characteristic of intermittent deposition and erosion. This situation represents alternate periods of storm and non-storm conditions immediately below wave base. Storm-generated waves scour bottom sediments and transport them landward. With return to normal conditions, the sediment profile is reestablished and bioturbation dominates until the next storm (Howard, 1978).

The conodont genus *Icriodus* found in most samples from this unit, preferred an agitated shallow water environment, also suggesting periods of moderate to rough turbulence (Weddige and Ziegler, 1976).

Progressively shallowing conditions prevailed for deposition of the upper part of Unit 3 (Miller and Walch, 1977, p. 176). Current-formed structures (fig. 15) are common in many silty beds, and bioturbation is absent in these beds. Sandy dolomite and quartzite (Unit 4), deposited in very shallow water, directly overlie regressive Unit 3 beds.

Age and Correlation

Conodonts from Unit 3 indicate an upper age limit of lower *serotinus* Zone for this unit (fig. 3). Collections
from 50 feet below the unit top at Mesquite Springs yielded *Polygnathus serotinus*, which ranges from the *serotinus* into the *costatus costatus* Zone (Klapper, 1977). Conodont samples from 13 feet below the top of Unit 3 at Red Amphitheater and at its top in the Ubehebe Peak section contain *Icriodus trojani*, ranging from *dehiscens* to the *serotinus* Zone (Klapper, 1981, written communication). The occurrence of *I. trojani* and *Polygnathus serotinus* in upper beds of Unit 3 thus establishes a *serotinus* age (lower part of F.I. 14) as an upper limit. The lower beds of Unit 3 were not sampled for conodonts, but upward gradation from the top of Unit 2 into the lower burrowed interval of Unit 3 suggests that the lower age limit should be placed somewhere in the range of upper *dehiscens* to lower *gronbergi* Zones, or Faunal Intervals 10 and 11. Miller (1976) reported *Polygnathus linguiformis*? from a section measured 2 km. (1.25 miles) north of the Hidden Valley type section, or about 1 mile north of the Ubehebe Peak section in this report. Klapper (1977, p. 42) reidentified this specimen as *Polygnathus laticostatus*, indicating an *inversus* Zone age or equivalent Faunal Intervals 12-13. This collection can only be approximately located in the Ubehebe Peak section, but would occur in the lower part of Unit 3, probably just below where Unit 3 becomes abundantly cherty (Miller, 1976, fig. 5). Using this reasoning, lower beds in Unit 3 may be as young as early Dalejan. Thus, the age of Unit 3 is in the span of late *dehiscens* to early
serotinus Zones (F.I. 10-lower 14) or late Zlichovian to mid-Dalejan.

Following the formational boundaries established by McAllister (1952; 1955), Unit 3 corresponds to the lower part of the Lost Burro Formation. As suggested earlier, the base of the Lost Burro would be better placed at the basal quartzites and sandy dolomites which crop out in the middle of the Lost Burro Lippincott Member defined by McAllister (1955). This would effectively eliminate confusion as to the Hidden Valley-Lost Burro boundary (Zenger and Person, 1960, p. 49; Miller, 1976).

A fossil collection made 99 feet below the Vaughn Gulch Limestone upper boundary contains Polygnathus laticostatus, establishing an inversus age for upper beds (Johnson and Niebuhr, 1976, Appendix 2). These strata are also silty and contain chert nodules, so Unit 3 is correlative to the upper Vaughn Gulch Limestone. Erosion has removed younger age rocks at this locality. No age dates are available for the middle part of the Sunday Canyon Formation. However, on the basis of lithologic similarity, 95 feet of platy argillaceous and cherty limestone near the formation top may be correlative to Unit 3. Unit 3 is also lithologically similar and probably correlative to the cherty argillaceous member of the Sevy Dolomite of Osmond (1954; 1962), generally limited to east-central and southern Nevada (Osmond, 1962, fig. 8; Johnson and Niebuhr, 1976, fig. 1; Johnson and Sandberg, fig. 5). Cherty argillaceous dolomite crops out in the
Spotted Range and Pintwater Range (Jarvis, 1981). This unit ranges from *inversus* to lower *serotinus* Zones and is correlative to Unit 3.

Carlisle et al. (1957, p. 2182) reported that the *pinyonensis* fauna is present in limestones interbedded with the cherty argillaceous Sevy member in the Sulphur Springs Range in central Nevada, indicating that the Sevy Dolomite is in part correlative with the Bartine Member of the McColley Canyon Formation. Kendall (1975) also determined an inter-tonguing, age equivalent relationship between Sevy-type rocks and the Bartine Member. Thus, Unit 3 in the thesis area is in part time equivalent to the Bartine Limestone in central Nevada.
Interbedded sandy dolomite, sedimentary quartzite, and dark gray dolomite comprise Unit 4 in the Lower and Middle Devonian sequence of the Death Valley region. The resistant weathering of this quartz-rich unit produces bold outcrops and cliffs in all areas where exposed. Unit 4, like Unit 3, is present in all study localitites except the two sections in the Independence quadrangle. Thickness is relatively uniform throughout the thesis area, averaging about 150 feet in measured sections. However, a 356 foot sequence of sedimentary quartzite and sandy dolomite is present in the northernmost section at Dry Mountain. Thickness values at the Cottonwood Mountains and at Bat Mountain are 118 and 119 feet, respectively. Unit 4 thins to 65 feet in the Nopah Range, so a general southeastward thinning trend appears likely.

Unit 4 consists of 1 to 3 foot beds of sandy dolomite to dolomitic sandstone interbedded with 1 to 6 foot thick quartzites. In the basal part of this unit, quartzite and dolomitic sandstone predominate; sandy dolomite and dark gray dolomite beds are prevalent in the middle and upper parts. In many sections, the lower contact with the underlying cherty argillaceous dolomite of Unit 3 is a sharp, planar to slightly scoured surface. Many dolomite clasts are incorporated into the quartzite and sandstone (fig. 17). Such a contact is suggestive of a local, if not regional,
Figure 17: Planar cross-bedding and dolomite clasts in Unit 4 dolomitic sandstone at Andy Hills.
unconformity surface between these two units at several study localities. Exceptions to this generalization occur at Red Amphitheater and Andy Hills where basal quartzites are interbedded with 2- to 4-inch beds of very fine grained dolomite of the underlying rock type over a 3 foot interval. The contact of Unit 4 with overlying coarse crystalline dolomite is gradational and is arbitrarily placed where quartz-rich beds compose less than 25% of the total thickness.

Quartzite and sandy dolomite beds are light gray (N 8) to medium light gray (N 7) on fresh surfaces, weathering to brownish gray (5 YR 4/1) and dusky brown (5 YR 2/2). These rock types are commonly cross-bedded and planar laminated. Low-angle planar cross-bedding is most common in the basal beds of Unit 4 where resistant weathering, quartz-rich laminae enhance such sedimentary structures. Cross-bedded strata typically occur as composite 4 to 12 inch sets with basal planar boundaries and top truncation by the next overlying coset. Many cross-bedded units are truncated by planar laminated beds. Trough cross-bedding was rarely observed. Cross-bedded cosets may be either multidirectional or unidirectional. Lack of suitable surfaces did not permit enough paleocurrent measurements for statistical analysis. However, those measurements made suggest southerly and southeasterly current flow directions at all localities. Paleocurrent directions are similar to
those determined by Kendall (1975) for the Oxyoke Canyon Formation of east-central Nevada.

Other sedimentary structures present in Unit 4 quartzite and sandy dolomite include rounded dolomite clasts, thin wavy alternating dolomite and sand laminae, vertical burrows, and ripple structures (fig. 18). Vertical burrows are found exclusively in planar laminated beds where laminae are bent downward. This type of vertical burrowing may be attributable to Skolithos, a typical tidal flat and beach trace fossil (Chamberlain, 1978). At the Dry Mountain section, a 5 foot interval of fine grained dolomitic sandstone in the middle of Unit 4 displays a different burrow type. On weathered surfaces, these burrows take the form of 1 to 2 inch rosettes composed of concentric rings of sand and micrite. The cylindrical to cone-shaped outside form tapers downward and is parallel to inclined to bedding. These trace fossils may either be Rosselia or Cylindrichus (Chamberlain, 1978), but identification is tentative. These burrow types are also present at the Panamint Range section in quartzite containing crudely preserved shell molds.

In thin section, Unit 4 quartzites and sandy dolomites are composed of subrounded to rounded, well sorted monocrystalline quartz ranging from very fine to medium sand size. Degree of rounding increases with increasing grain size. Polycrystalline quartz and microcline grains are rare components. Uncommon accessory minerals include rounded zircon and tourmaline. Source for such multicyclic sand
Fig 18: Ripple marks and planar cross-banding overlain by planar laminae in Unit 4 dolomitic sandstone at Andy Hills.
deposits exposed in eastern cratonic areas (Osmond, 1954; Kendall, 1975). Where little or no dolomite matrix is present, extensive silica overgrowths and slight pressure welding of grains has thoroughly indurated the rock. Matrix in dolomitic sandstone and sandy dolomite is a finely crystalline mosaic of anhedral-subhedral dolomite. Significant corrosion of quartz grain boundaries has taken place where dolomite matrix is present.

Beds of dark gray (N 3) fetid dolomite become common in the middle part of Unit 4. Dolomite crystal size in these beds tends to increase upward in the unit from very fine to medium grained. Beds of very fine grained dolomite average about 4 feet in thickness and are structureless. Fossil ghosts of ostracods, gastropods, and small shelly fragments are sometimes present in the very fine grained dolomite. At the Lost Burro section, a 2 foot bed of dark gray dolomitized crinoidal wackestone containing coral debris occurs in a 20 foot sequence of dark gray silty and sandy dolomite. Medium grained dolomite occurs in 2 to 5 foot beds and tends to be slightly lighter in color. Thin laminations are visible on weathered surfaces, but no fossil ghosts or shelly debris was noted in these beds. In the uppermost interval of Unit 4, dolomite becomes coarsely crystalline and light gray in color. Clastic material is present only as some thin wavy lenses and laminae in the coarse grained dolomite.
Depositional Environment

Unit 4 in the thesis area represents the southeast California part of a regionally persistent quartz-bearing carbonate unit deposited in early Eifelian time (Poole et al., 1977, figs. 2b and 7; Johnson and Sandberg, 1977, figs. 3 and 6). This extensive sheetlike body encloses an unconformity at the base of the Middle Devonian which increases in magnitude eastward. Deposition is believed to have occurred by westward progradation of the sandy lithotope across the carbonate platform during late Early Devonian regression. Maximum regression appears to have taken place during serotinus time (Johnson and Sandberg, 1977). Paleocurrent directions measured by Osmond (1962) for the sandy member of the upper Sevy Dolomite in central Nevada indicate deposition by westward-moving currents, and the member was considered to be a westward regressive deposit (Osmond, 1962, p. 2054). A similar depositional history for the quartzose part of the Oxyoke Canyon Formation has been suggested (Kendall, 1965; Johnson and Sandberg, 1977). Unit 4 sandy dolomite and quartzite is also believed to be regressive in the lower part, which, in facies relationship with subjacent nearshore deposits (Unit 3) are progressively younger westward (figs. 7 and 8). Rounded, monocrystalline quartz, composing over 95% of the clastic material in this unit, has had a multicyclic history and was derived from older arena-
ceous deposits to the east and north, as interpreted by numerous workers.

Highly siliceous, cross-bedded strata in Unit 4, along with sedimentary structures and features in associated silty and sandy dolomite beds, demonstrate deposition in a beach-barrier bar-intertidal complex. Planar low-angle cross-stratification commonly truncated by planar laminations are nearly identical to structures for the inner planar to inner rough facies transition described from modern beach environments (Clifton et al., 1971). Multi-directional cross-bedding occasionally seen in outcrop is more typical of inner rough and surf zone structures. Rounded dolomite clasts have been commonly incorporated into cross-bedded strata (fig. 17). Planar laminated beds are probably deposits of the beach swash zone where sheet-like sediment transport by breaking waves spreading across the beach face takes place. Other planar laminated, vertically burrowed beds and ripple-laminated sandy dolomite was probably deposited in shoreward and adjacent intertidal areas. Dupre and Clifton (1979) described seaward-prograding Pleistocene terrace deposits at Monterey Bay, California. This sequence shows upward transition from bioturbated nearshore deposits into the surf zone and toe-of-beach deposits, overlain by planar-laminated beach sediments. If the nearshore upper Unit 3 beds are included, a similar transition from nearshore through highly agitated to beach deposition is represented upward in this particular interval in the thesis area.
The Unit 4 sandy lithotope may have been a complex of high-energy beaches and discontinuous barrier bars paralleling shoreline, which separated intertidal-supratidal environments to the east from western deeper water facies. Barrier bar systems are best developed in areas with relatively low tidal range, low wave energy, a low shelf gradient adjacent to a low-relief coastal plain and an abundant sediment supply (Reinson, 1979). The Early Devonian platform and adjacent landward areas in the thesis area are believed to have had a gentle northwest paleoslope (Miller and Walch, 1977; Miller, 1978). It has also been suggested, however, that the width of the shallow shelf area was less than that in Late Silurian time, based on the relative position of the dolomite-limestone transition (Miller and Walch, 1977). Nonetheless, abundant supply of siliceous silt and sand, coupled with sea level drop, provided nearly ideal conditions for the westward progradation of a beach-barrier bar system across the shallow platform area. Osmond (1962, p. 2052) noted that the sandy Sevy member (lower Oxyoke Canyon Formation) is more than 500 feet thick in a narrow north-south-trending zone in central Nevada. Kendall (1975) defined a long, narrow barrier bar in the Oxyoke Canyon Formation 5 to 15 miles wide and 120 miles long. He suggested gradual subsidence allowing a barrier to build up a thickness of 100 to 400 feet. Unit 4 in the Dry Mountain section, northern Panamint Range, approaches a comparable thickness (365 ft.). Although the geometry of
this occurrence is incompletely known, substantial thinning occurs in a southeastward direction (Plate 2). Presumably, Unit 4 would also thin westward considerably and interfinger with deeper water deposits. It is suggested here that thick accumulation of sandy dolomite and quartzite both in the thesis area and in central Nevada occupied an extreme westward position at the shelf-slope break during maximum regression. The seaward prograding beach-barrier bar system would have thus been effectively slowed or even stopped at the shelf edge where the paleoslope increased substantially toward deeper water areas. If later transgression occurred rapidly enough, thick accumulations of sandy material would be stranded at the shelf-slope break or at a point on the shelf marking lowest sea-level stand during the preceding regressive phase.

Modern beach-barrier bar systems can be divided into subenvironments, based on position relative to shoreline and sedimentary structures: 1) shoreface, 2) foreshore, 3) backshore-dune, 4) washover fan (Reinson, 1979). The shoreface and foreshore environments represent transition from the zone of shoaling waves to the beach area and, therefore, would display essentially the same sedimentary structures seen in non-barred beach environments (Clifton et al., 1971). Thus, the criteria listed for evidence of beach deposition in Unit 4 would apply equally as well in the case of a beach-barrier bar system. Backshore dune areas are largely above sea level, subject to storm and wind deposition.
Such highly mobile deposits of a prograding beach-barrier bar system are not likely to be preserved in the stratigraphic record (Reinson, 1979). Much of the fine sand and silt from former backshore-dune environments of Unit 4 was probably wind-transported into tidal flat areas. Washover fans result from storm breechment of backshore berms and dunes, creating thin sheet sands extending into landward lagoon or tidal flats. These sheet sands are commonly unidirectionally foreset-stratified, landward-oriented, and are believed to be represented in some of the dolomitic intervals in Unit 4 (fig. 19).

Growth and accretion of modern barrier systems may occur by lateral migration of tidal inlets (Reinson, 1979). Sedimentary structures associated with inlet migration are especially varied because of the alternating ebb and flood tidal flow. In general, tidal inlet deposition is marked by an erosional base and lag deposits overlain by medium and large scale bi-directional planar cross-beds. Shallower channel deposits cap underlying subtidal channel deposits. Ebb deltas are characterized by multidirectional cross-beds, whereas flood delta deposits are usually dominated by landward-oriented bedforms. Although sedimentary structures resembling tidal inlet migration were found in a few outcrops, there is not enough evidence to determine if barrier accretion by tidal inlet migration was a common phenomenon in the thesis area. Most sedimentary structures
Figure 19: Low angle foreset-laminated sheet sands in dolomite at Bat Mountain. Probable washover fan deposits in upper part of Unit 4.
and bedding characteristics indicate that foreshore-beach deposition dominated in Unit 4.

Dark gray, fine grained fetid dolomite interbedded with sandy dolomite in the middle and upper part of Unit 4 may represent the eastward interfingering of deeper water deposits lying to the west. Some of these beds are sparsely fossiliferous and at least one 20 foot sequence of dark gray dolomite at Lost Burro contains abundant crinoidal debris and scattered coral remains. Kendall (1975) noted a similar interfingering between crinoidal dolomite (Sadler Ranch Formation) and sandy deposits of the Oxyoke Canyon Formation. Similar relations have been noted in the southern Mahogany Hills of central Nevada where the Sadler Ranch Formation approaches an encrinite in composition (Schalla, 1978). It is believed here that at least some of the dark gray beds are indicative of a similar crinoidal-rich open marine lithotope to the west of the thesis area.

Age and Correlation

Unit 4 has not yielded macrofossils or conodonts; therefore age assignments are made on the basis of stratigraphic position and lithologic comparison to other similar units. The base of Unit 4 is believed to be slightly diachronous and, consequently, younger to the northwest (figs. 7 and 8). As indicated by the lower serotinus Zone date on underlying cherty argillaceous rocks in Unit 3, the lower age limit for quartzite and sandy dolomite is probably upper
serotinus Zone, or the middle of Faunal Interval 14. The upper age limit is difficult to determine and must be approximated from correlative units whose age limits are better known. Kendall (1975) subdivided the Oxyoke Canyon Formation in Eureka County, Nevada, into a lower quartzose member and an upper coarse crystalline dolomite member (fig. 6). The quartzose member and Unit 4 in the thesis area have the same lower age (lower serotinus Zone) and are lithologically comparable. Upper age limit for the quartzose Oxyoke Canyon member was determined as early Eifelian from conodont and brachiopod dates obtained from interfingering beds of the informal Sadler Ranch Formation (Kendall, 1975). Therefore, Unit 4 may also range from late Dalejan to early Eifelian and span the Lower-Middle Devonian boundary.

In the formational nomenclature established in southeastern California, Unit 4 corresponds to the upper part of the Lippincott Member of the Lost Burro Formation, but is exclusive of underlying cherty argillaceous dolomite that was designated as its lower two-thirds (McAllister, 1955). A conodont collection about 50 feet below the top of the Sunday Canyon Formation, 1-1/4 miles from its type section in Bonanza Gulch (location of thesis Sunday Canyon section), contains advanced specimens of Polygnathus costatus, indicating high costatus costatus Zone (collection by Stevens and Ridley, 1974, p. 28; identified and reported by Klapper, 1977, p. 45). As sedimentation in this forma-
ation is believed to have been continuous, the Sunday Canyon should have strata which are time correlative to Unit 4.
Unit 5--Coarse crystalline dolomite

Unit 5 in the thesis area is a very light gray (N 8) to medium gray (N 5) coarse crystalline dolomite with subordinate sandy layers in the lower beds. This unit is easily recognized by its coarse texture and massive character. The base is gradational with underlying sandy dolomite and quartzite. The upper contact is placed just below the first appearance of dark gray dolomite of the overlying unit. Exposures weather to light gray (N 7) rough crystalline surfaces with numerous pits and vugs. Distribution of Unit 5 is widespread throughout the thesis area and this lithology is absent only in the two measured sections at Vaughn Gulch and Sunday Canyon. Thickness varies slightly from section to section, but is generally between 45 and 75 feet. Greater thickness values for the coarse crystalline dolomite occur in the Funeral Mountains, at Red Amphitheater (104 ft.) and Bat Mountain (126 ft.).

On outcrop, coarse crystalline dolomite of Unit 5 forms blocky to rounded steep slopes. Primary stratification is poorly developed and good bedding planes are uncommon. The only sedimentary structures visible on outcrop or on polished slabs are thin wavy lamination and possible intraclasts. To the southeast, coarse crystalline dolomite contains very thin wavy quartzose laminae and fine quartz grains scattered in the dolomite matrix. At other localities, dolomite is sandy only in its lower part. Nowhere was
cross-bedding observed in Unit 5, as has been noted by Kendall (1975, p. 135) in his lithologically similar coarse crystalline part of the Oxyoke Canyon Formation. Lamination is defined by alternating layers of different crystal sizes. Many of these wavy laminae and discontinuous wavy lenses of pinkish gray dolomicrite alternating with coarse crystalline layers are also visible on weathered outcrop. Lamination in thin section is detectible only by the slight segregation of crystal sizes into diffuse bands (fig. 20). Where transition from one zone of distinct crystal size to another is sharp, the contact is commonly a small stylolite zone with concentrates of hematitic clay. Finely crystalline dolomite bands and patches contain argillaceous material and are commonly stained by iron oxides. Medium and coarse crystalline clear dolomite spar is largely free of any clay or impurities and is commonly internally zoned. The original sediment is believed to have been a relatively micrite-free packstone or grainstone. Several curved crystal boundaries and optically continuous crystal patches suggest former skeletal grains (fig. 21), but in general, thorough recrystallization has destroyed the original texture. Laminated fine crystalline and coarse crystalline dolomite may have been a laminated mudstone and packstone. Alternatively, such lamination could represent tidal flat deposition; fenestral fabric may be present in some layers. Unfortunately, little evidence is available to adequately determine sediment texture.
Figure 20: Photomicrograph of relict lamination defined by different crystal sizes in Unit 5. A small stylolite seam occurs in the fine crystal laminae. Field of view is 3.5 mm., polarized light.
Figure 21: Photomicrograph of a relict crinoid ossicle, cross-section, in Unit 5 coarse crystalline dolomite. Field of view is 3.5 mm., polarized light.
Unit 5 beds in the Cottonwood Mountains, Bat Mountain, and Red Amphitheater sections contain a single 2 foot interval of large quartz-rich burrow networks weathering in epirelief. Fine to medium quartz sand is clearly visible on burrow outer surfaces, and burrows weather to a dusky brown color. Dolomite matrix in this burrowed zone is a light gray clastic-free coarse spar. These burrow forms which commonly branch at right angles to form boxworks are similar in form to *Ophiomorpha* (Chamberlain, 1978).

A probable channel deposit is cut into the top of Unit 5 coarse crystalline dolomite exposed on the southerly adjacent ridge to the Ubehebe Peak measured section. The lower surface, indicative of a local unconformity, is tracable only a few hundred feet where it is lost in a chaotic zone of dolomite brecciation. This channel-like feature is approximately 100 feet wide along depositional strike, 30 feet thick, and has a tabular to roughly lent- icular shape. The basal rock type is a light-colored dolomite pebble conglomerate; 1- to 4-inch elongate dolomite clasts lie parallel to bedding (fig. 22). Overlying the pebbly conglomerate is a 1 foot bed of dark gray, fine grained dolomite containing 1- to 2-inch clasts of light and medium gray dolomite. The uppermost deposits of this channel feature consist of 6- to 12-inch beds of fine pebbly dark gray dolomite (fig. 23). Dark beds emit a strong fetid odor on fresh surfaces when broken open.
Figure 22: Dolomite pebble conglomerate at the base of a channel deposit cut into the top of Unit 5 at Ubehebe Peak. Matrix is coarse grained dolomite; note alignment of dary gray finely crystalline dolomite clasts.
Figure 23: Dolomite pebble conglomerate at the top of a channel deposit at Ubehebe Peak. Matrix and dark layers are fine grained and fetid.
Dolomite breccias commonly occur in Unit 5 throughout the thesis area. They are especially well developed at the Ubehebe Peak locality in a zone about 160 feet thick. Although breccias are most prevalent in Unit 5, both the upper beds of the underlying rocks and the lower intervals of overlying strata (Unit 6) may also be involved. These breccias are typically composed of large angular blocks to millimeter-sized fragments of dolomite and subordinate quartzite in a coarse crystalline dolomite matrix (fig. 24). Schalla (1978) reported that matrix in his cataclastic breccias was composed of fine rock micrite. However, coarse recrystallization in the Unit 5 samples obscures the original nature of the matrix material. Clasts consist of various dolomite types, indicating their derivation from Unit 5 and, more commonly, from beds of the overlying alternating light and dark gray dolomite. Breccias may be confined to discrete beds or zones, separated by relatively undisturbed strata. However, most brecciation has taken place in diffuse zones of no definable geometry. Medium gray and dark gray beds appear to have been already consolidated during the brecciation process, whereas the light gray coarse crystalline beds acted in a more plastic manner, as was described by Osmond (1954, p. 1941-1943). In addition, brecciation post-dates dolomitization, as clasts vary in texture, grain size, and have sharp boundaries with matrix material.
Figure 24: Dolomite breccia overlying laminated dolomite in Unit 5 at Ubehebe Peak.
Breccias of this sort have been reported from many areas of the Great Basin (Armstrong, 1972, Coney, 1974). Their origin and timing of development is still not well understood. Osmond (1954) suggested formation by slumping of an oversteepened depositional slope of relief in excess of 200 feet. However, slumping is not a favored origin for breccias in the thesis area, because the depositional slope was a relatively low relief feature. Another possible origin for these breccias may have been by solution of underlying evaporites and subsequent collapse of superadjacent bends. This mechanism is not likely here because no evidence for the former presence of evaporites could be found either in field work or laboratory work (see Friedman, 1980). To the writer's knowledge, no reports of evaporite deposits or evidence of their former existence have been documented for this region of the Cordilleran miogeoclone. Armstrong (1972) attributes breccia development in the Great Basin to low angle (denudation) faults brought about by Tertiary extension and gravitational gliding. A tectonic origin for dolomite breccias in thesis rocks is considered to be a viable possibility, but the exact mechanism and timing cannot be determined. Any hypothesis for the origin of these breccias must account for maintenance of stratigraphic order in the breccia zone, lack of brecciation in certain beds, and apparent confinement to a particular stratigraphic interval.
Depositional Environment

Thorough dolomite recrystallization in Unit 5 has obscured original sediment textures and renders depositional interpretation difficult. This unit and lower beds of the overlying strata may have been through 2 stages of dolomitization, producing its present texture. Based on crudely preserved wavy lamination, thin laminae of quartzose material, and occasional intraclastic texture, Unit 5 probably represents deposition in a restricted environment of low to periodically moderate energy conditions. An intertidal to supratidal environment is favored here, at least for deposition of lower beds in the unit, because of its apparently conformable contact with the underlying quartzose Unit 4. Kendall (1975) indicated that the contact between the quartzose part and coarse crystalline part of the Oxyoke Canyon Formation is sharp, locally unconformable, and probably regionally disconformable. No such contact between Unit 4 and Unit 5 was found in the thesis area. However, it should be emphasized that, in general, Lower and Middle Devonian rocks exposed in the Death Valley region were deposited on a flatter paleoslope than for equivalent age strata in central Nevada. Thicker deposits and rocks indicative of more offshore lithotopes are not present in the Panamint Range but may be represented by metamorphosed and faulted Devonian outcrops in the eastern and southern Inyo Range (Merriam, 1963). Thickness values for Unit 5,
which are commonly about 45 to 75 feet, are much less than the 200 to 800 foot thicknesses measured on central Nevada (Knedall, 1975). On a regional scale, Osmond (1962, p. 2048) noted that the coarse crystalline member of the Simonson Dolomite (equivalent to the coarse crystalline member of the Oxyoke Canyon Formation of Kendall, 1975) thins eastward and is absent in Northern Utah. Again, the gentle paleoslope that existed in the Death Valley region during Early and Middle Devonian time is probably responsible for the thinness of this unit, as well as other units, in comparison to central Nevada. The coarse crystalline part of the Oxyoke Canyon Formation is believed to represent a transgressive-regressive cycle in central Nevada (Johnson, 1981, personal communication). However, the full cycle of coarse crystalline dolomite deposition seen in central Nevada is either greatly compressed or largely absent due to non-deposition in southeast California.

The intertidal to supratidal depositional setting envisioned for Unit 5 existed landward of the westward prograding beach-barrier bar system and, likewise, prograded seaward with regressive conditions. A thin interbedding of sandy dolomite and relatively clastic-free dolomite would be expected, as seen in the lower Unit 5 interval. Periodic storms broke through low dunes and barrier bars and deposited thick sands and sandy dolomites. Scouring of thin, semi-consolidated mud laminae took place during tidal flat flooding, creating thin alternations of
sand and dolomite seen in outcrop. Wavy and lenticular bedding was probably an original sedimentary structure produced by migrating ripples (Reineck and Singh, 1975) or could have been a diagenetic product of extensive dolomitization. Boxwork burrows at Bat Mountain and Cottonwood Mountains, having a form similar to Ophiomorpha, are compatible with a tidal flat environment (Chamberlain, 1978).

The contact with the overlying alternating light and dark gray dolomite is gradational, suggesting that depositional conditions changed slowly from a restricted to a less restricted environment. However, a dark gray conglomeratic channel-like deposit at the top of Unit 5 at Ubehebe Peak may represent a period of non-deposition and erosion between the two units. The lower surface of this deposit is tracable only a few hundred feet because of dolomite brecciation. If such a deposit and surface indicates a depositional discontinuity, the notably quartz-free middle and upper coarse crystalline beds could have been deposited under transgressive conditions, followed by a slight sea level drop. Thus, the deposition of Unit 5 would contain a full, but compressed, transgressive-regressive cycle that has been documented in central Nevada (Kendall, 1975). Alternatively, the entire thin sequence of Unit 5 coarse crystalline dolomite could be regressive, with the dark gray channel deposit cut into the surface of non-deposition.
Age and Correlation

Unit 5 and the coarse crystalline dolomite part of the Oxyoke Canyon Formation in central Nevada are correlative, as evidenced by lithologic similarity and their similar positions in the Devonian Great Basin stratigraphic succession. It must be noted that the coarse crystalline Oxyoke Canyon member is thicker than Unit 5, and there could be some age discrepancy between them. However, age discrepancy, if any, would probably not be large enough to prevent a reasonable estimate to be made from the correlative central Nevada unit. Kendall (1975) established an early Eifelian age for the coarse crystalline Oxyoke Canyon member, so Unit 5 is also thought to be early Eifelian (fig. 3).

Unit 5 corresponds to the lower most beds of the 675-foot-thick Unit 1b2 of McAllister (1974) above the Lippincott Member. In the Independence quadrangle area, Unit 5 correlates to upper beds in the Sunday Canyon Formation where *Polygnathus costatus costatus* (F.I. 15) was found 50 feet below the formation top (Klapper, 1977, p. 45). At the Nopah Range, Unit 5 is believed to correspond to the upper 80 feet of light creamy gray dolomite just below the Ironside Dolomite Member of the Sultan Dolomite (Hazzard, 1954, fig. 1). Unit 5 is tentatively correlated to the 10 to 20 feet of coarse crystalline sucrosic dolomite composing Unit MS-9 in the Mountain Springs Formation at Red
Rock Canyon, Clark County, Nevada (Gans, 1974). Also in this same general area of southern Nevada, Jarvis (1981) recognized coarse crystalline dolomite, mapped as lower Simonson Dolomite, in the Spotted, Pinwater, Desert, and Sheep Ranges.
Unit 6--Alternating light and dark gray dolomite

Unit 6 in the thesis area consists of alternating beds of light gray and dark gray dolomite. The base is arbitrarily placed at the first appearance of dark gray beds in measured sections. A thick sequence of dark gray fossiliferous beds was used as a reference to end measured sections. Dolomite becomes slightly limy and generally finer grained upward through Unit 6. Thickness increases significantly from southeasterly exposures at the Nopah Range (60 ft.) to values in excess of 300 feet in the northern Panamint Range. The dark gray fossiliferous marker bed was located in the Kerr-McGee section and indicates that Unit 6 may be over 500 feet thick in the Argus Range. This number may not be reliable, however, as thermal metamorphism and possible associated faulting has affected this interval. At several of the measured sections, faulting dictated that measurement be ended somewhere below the fossiliferous marker.

Five- to 10-foot thick light-colored beds are dominant in the lower part of Unit 6, consisting of medium light gray (N 6) dolomite that weathers to light gray (N 7). With upward grain size decrease there is a tendency for light-colored beds to display thin laminations on weathered surfaces. In southeastern sections at Bat Mountain and the Nopah Range, coarse-grained light-colored beds in the lower part of Unit 6 exhibit wavy lamination, disrupted
laminae, and possible intraclastic texture. Such texture has been better preserved in aphanitic, thinly laminated dolomite in the Cottonwood Mountains section (fig. 25). Subordinate 1 to 2 foot beds of fine grained dark gray dolomite occur on a spacing of 10 to 25 feet in the lower part of the unit. These dark-colored beds are thinly laminated and emit a slightly fetid odor when broken open.

Distinctly mottled medium dark gray and light gray dolomite makes its first appearance in the middle of Unit 6 and is a common feature in light-colored beds near the unit top. Mottling most commonly takes the form of irregular light gray to light bluish gray (5 B 7/1) patches of very fine grained dolomite in a medium dark gray, fine grained matrix. Some of the mottled texture resembles disruption and breakage of alternating laminae of yellowish gray dolomicrite and fine grained, darker colored dolomite (fig. 26). Mottled textures occurring in Middle Devonian carbonates of eastern Nevada are considered by Osmond (1953) to be the product of incomplete dolomitization of original laminated micrite and growth of irregular to laminar zones of fine crystalline dolomite. Such a process may have been responsible for the mottling seen in the upper interval of Unit 6. However, mottled beds are only slightly limy, and the dark gray calcitic bodies described by Osmond are dolomitic in these rocks. It is believed that in some instances, and possibly the majority, mottling reflects original sediment inhomogeneity, as well
Figure 25: Aphanitic, thinly laminated and intraclastic dolomite in lower part of Unit 6 at Cottonwood Mountains section. Coarse sparry dolomite probably replaced former algal mat fenestrae.
Figure 26: Mottled dolomite in the upper part of Unit 6 at Andy Hills. Such texture is believed to be partly due to original sediment bioturbation.
as effects of dolomitization. Disruption of alternating light and dark laminae by burrowing organisms is another possibility for the mottled texture in this unit, but direct evidence (i.e., burrows) is lacking.

In the upper part of Unit 6, light gray beds are less common and are gradually replaced by medium bluish gray (5 B 5/1), fine grained dolomite that weathers to light bluish gray (5 B 7/1). In addition, dark-colored beds occur more frequently in the interval and are thicker (4 to 6 ft.). Dark beds have sharp basal contacts and grade upward into lighter-colored strata. In the northern Panamint Range, ostracods and other fossil allochem ghosts are present in some of the dark, very fine grained beds (fig. 27). At the top of Unit 6 is a 20 to 30 foot interval of dark gray, fine grained fossiliferous dolomite used as a reference marker in measured sections. Master bedding is thin to thick and very thin laminations are visible on weathered surfaces. Local biostromal horizons of abundant slender, tube-like stromatoporoids (Amphipora?), rounded and irregular stromatoporoids, and a few gastropods are preserved as coarse clear sparry dolomite ghosts in the fine grained dark lithology. At a few southeastern localities, fossil remains are partly silicified. Microstructure is absent or poorly preserved in thin sections. Some tube-like stromatoporoids appear to have been aligned by weak current activity. The great abundance of the slender tubular mats acted to baffle currents and trap much of the
Figure 27: Photomicrograph of possible oblique section through an echinoid spine in dark gray, fine grained dolomitized mudstone in Unit 6. Field of view is 3.5 mm., plane light.
organic-rich carbonate mud. Six- to 12-inch thick horizons of these stromatoporoids also occur in a few of the dark gray bends in the middle and upper part of Unit 6. However, greatest accumulations are present in the reference marker. Above these biostromal deposits, the reference marker top contains valves and articulated specimens of brachiopods. These are probably *Geranocephalus* sp. (Johnson, 1981, personal communication), but poor preservation by coarse clear sparry dolomite hampers identification. In the Nopah Range, silicified specimens of *Geranocephalus* sp. occur 220 feet above the base of the Lost Burro Formation (Sultan Dolomite of Hazzard, 1937), approximately 10 feet above the termination of the section measured at this location (Johnson, 1978).

**Depositional Environment**

Deposition of Unit 6 reflects a slow change from the restricted environment of Unit 5 to one of increased circulation and less restricted conditions. With gradual inundation of extensive intertidal-supratidal areas of the eastern carbonate platform, distinct environments developed on very broad topographic highs and adjacent low-lying areas (Osmond, 1954).

Significant thickening of Unit 6 in a northwest direction in the thesis area suggests a gradual eastward inundation of the carbonate platform by initial Middle Devonian transgression. As well, slight decrease in dolo-
mite content, tendency toward finer grain sizes, and better preservation of sedimentary structures upward through the unit are believed to indirectly reflect a gradual submergence of the Unit 5 intertidal-supratidal environment. Dark gray beds in the middle and upper part containing ostracods and small shell fragments are indicative of better circulation than existed in the Unit 5 lithotope. However, the presence of ostracods only, along with scarcity of other skeletal remains suggests that conditions may have been still relatively restricted with respect to open shelf areas lying to the west. The inferred depositional environment encompassed a range of low intertidal to very shallow subtidal conditions. Intralastic texture, fenestral and algal mat structures, and wavy lamination all suggest that the lighter-colored beds represent deposition in the tidal flat zone. A gradual shift to normal marine conditions is demonstrated by the replacement of light gray dolomite by darker-colored beds in upper Unit 6.

At the top of Unit 6, dark gray biostromal deposits dominated the shallow platform environment. Extensive Amphipora mats acted to trap organic-rich mud by baffling gentle currents. Dendroid stromatoporoids such as Amphipora preferred sheltered areas on a shallow platform of low relief (Krebs, 1974). Local abundances of fine skeletal debris and biscuit-shaped stromatoporoids suggest nearby higher energy environments which spread detritus into adjacent low-lying muddy environments (Murphy
and Dunham, 1977). The low diversity *Geranocephalus* community (Johnson, 1977) is probably present in some dark gray beds at the top of Unit 6 and may indicate a specialized shallow platform environment suitable only for certain species. Biostromal deposits similar to those in Unit 6 are even better developed and are widespread in shallow water Givetian and Frasnian strata in the Great Basin (Murphy and Dunham, 1977). Their great aerial extent was the result of the larger transgressive pulse of the Taghanic onlap over the broad shallow platform and cratonic areas (Johnson, 1970).

**Age and Correlation**

The upper age of Unit 6 can be estimated by the presence of *Geranocephalus*? sp. in the uppermost dark gray reference bed at several localities. *Geranocephalus* is assignable to Faunal Intervals 19 and 20 (Johnson et al., 1980) and thus establishes an early Givetian age for the top of the unit (fig. 3). The Middle Devonian guide fossil *Stringocephalus*, indicative of Faunal Intervals 19-23, occurs about 100 feet above Unit 6 and further supports this age date (Merriam, 1963; McAllister, reported in Zenger and Person, 1969; McAllister, 1974). *Geranocephalus* sp. is present at the Nopah Range in a collection made 200 feet above the pre-Devonian erosional unconformity. This sample is approximately located at the thesis section 10 feet above the top of Unit 6. At Bat Mountain, the dark
gray reference marker contains small brachiopods tentatively identified as *Rensselandia* sp., which occurs from Faunal Interval 17 to Faunal Interval 23 (Johnson et al., 1980). A mid-Eifelian age is assigned as the lower Unit 6 limit, based on the age of Unit 5 and correlative deposits in central Nevada. Attempts to date the lower Unit 6 beds using conodonts were unsuccessful.

Within the southeastern California area, Unit 6, together with Unit 5, corresponds to the lower half of Unit 1b2 of the Lost Burro Formation in the Funeral Mountains (McAllister, 1974). In the Nopah Range, the major portion of the Ironside Member of the Sultan Dolomite is probably correlative to Unit 6 (Hazzard, 1954). To the south of the thesis area in San Bernardino County, the Sultan Dolomite and Ironside Member are also recognized (Bereskin, 1969). *Rensselandia* sp. has been collected from beds above the Ironside Member so precise correlation to these Devonian outcrops is less certain. At the western side of the Inyo Range, a rich conodont fauna occurs in bioclastic limestone 40 feet below the top of the Sunday Canyon Formation (Appendix I). These specimens establish a *kockelianus* Zone age for upper Sunday Canyon beds, based on the presence of *Tortodus Kockelianus kockelianus* and other compatible species. Therefore, the upper Sunday Canyon is correlative to some part of Unit 6. Erosion has removed younger Sunday Canyon beds.
Unit 6 is believed to be correlative to the lower alternating member of the Simonson Dolomite (fig. 6) widely recognized in east-central Nevada and western Utah (Osmond, 1954; Johnson and Sandberg, 1977, fig. 7, lithofacies 1). This lithology was mapped as the lower Telegraph Canyon Member of the Nevada Formation in the Sulphur Spring Range, central Nevada (Carlisle et al., 1957). In southern Nevada, alternating light and dark dolomite correlative to Unit 6 is also recognized as lower Simonson Dolomite north of Las Vegas (Burchfiel, 1964; Jarvis, 1981). Elsewhere in the southern Nevada Great Basin, similar lithology has been mapped as the Sultan Dolomite, Muddy Peak Limestone, or Piute Formation (Langenheim et al., 1960; Burchfiel et al., 1974). Nonetheless, presence of *Stringocephalus* at several locations in this region, as well as other Great Basin areas, has been useful in recognizing the equivalence of these Middle Devonian units.
Introduction

The Vaughn Gulch Limestone and Sunday Canyon Formation were named and described by Ross (1963, 1966) to represent exposures of Early and Middle Devonian age strata in the Independence quadrangle. Because of their close proximity and similar lithologic character, these formations are considered to be, in part, lateral equivalents by workers familiar with them (Ross, 1966; Stevens and Ridley, 1974; Miller and Walch, 1977). Tertiary age intrusion, metamorphism, and faulting in the Inyo Mountains has largely obliterated the direct lithologic relationship between these limy carbonates and the dolomitic Hidden Valley and Lost Burro rocks to the east. Approximately 20 miles southeast of the Independence quadrangle, Lower Devonian exposures in the New York Butte quadrangle are dolomitized and show close affinity to the Hidden Valley Dolomite (Merriam, 1963). Presumably, westward transition from dolomite to limestone and an intertonguing relationship between eastern dolomites and western limy carbonates occurs in the Inyo Mountains between these outcrops.

Vaughn Gulch Section

1084 feet of the Vaughn Gulch Limestone was measured at the type section along the ridge northwest of
Vaughn Gulch, near the mouth of Mazourka Canyon. Total thickness of this formation is 1518 feet at the same locality (Ross, 1966). Measurement was begun at an arbitrary point and terminated at the unconformable contact with the overlying siliceous Mississippian Perdido Formation. The lower 720 feet consists of interbedded medium gray, thin to thick bedded bioclastic limestone and argillaceous shaly limestone. A fault is present at 700 feet in the section, and an unknown, but presumably small, amount of strata may be missing. The ratio of bioclastic beds to shaly limestone beds is approximately 1:1 in this interval. Bioclastic limestone is composed of an abundant mixture of skeletal remains, including pelmatozoan debris, corals, bryozoans, calcareous algae, and less common brachiopods and trilobites. Beds of this material vary from 2 inches to 5 feet in thickness. Thin beds tend to be graded (fig. 28) whereas thicker beds are generally structureless. Occasionally, the fine-grained upper portions of bioclastic beds show faintly developed cross-lamination. Thus, A, B, C, and possibly, D and E parts of the Bouma sequence can be recognized in some beds. Basal scoured surfaces are common (fig. 28) and soft sediment flowage of underlying strata has sometimes taken place. Some of these skeletal-rich beds are overwhelmingly dominated by either corals or by pelmatozoan debris. Many thicker bioclastic beds contain lithified blocks of skeletal material, calcareous algae, and corals up to 1 foot diameter (fig. 29). Most fossil
Figure 28: Graded bioclastic bed in Vaughn Gulch Limestone. Load structures at the base; faintly cross-laminated in the upper part (arrow). Silicification of skeletal material.
Figure 29: Structureless lime breccia (5 ft. bed) in the lower Vaughn Gulch Limestone. Silicification and siliceous rims occur in some skeletal fragments.
fragments are silicified or have silica rims which weather in relief. Textural variation from packstone to grainstone can be seen in thin sections of bioclastic beds. Partial silicification of skeletal fragments is common. Micrite contains thin wisps of carbonaceous matter and has neomorphosed to microspar and pseudospar in places. Some of the crinoidal grains have undergone degrading neomorphism. Shaly limestone in this interval is not well exposed and its presence must be inferred from talus-covered saddles between rib-forming bioclastic beds. Limited exposures of this medium dark gray lithology are thin to very thin bedded, disintegrating upon weathering to light gray platy and shaly chips. Beds with a slightly higher silt content are more resistant and weather to a light brownish gray color (5 YR 6/1). Shaly limestone is generally fossil-barren except where laminae of fine bioclastic debris intervene.

The overlying 227 feet is dominated by thin-bedded argillaceous limestone and calcareous siltstone, reflecting increased clastic input. Bioclastic beds are less common and form only about 10% of the total lithology of this interval. Otherwise, this part of the measured section is lithologically very similar to beds below, and deposition was continuous for these strata. Near the top of this interval are 1 or 2 very thin beds containing abundant trilobite debris. A last 1 foot bioclastic bed occurs at the top. The increasing amount of fine clastic material and gradual
disappearance of skeletal-rich beds upward may be indicative of shallowing-upward conditions and change in the system responsible for underlying deposition (Johnson and Sandberg, 1977, p. 129).

The remaining 136 feet of the Vaughn Gulch Limestone is a platy argillaceous and cherty limestone. Chert occurs as small nodules and nodular horizons along bedding planes in this interval. Chert may be of a secondary origin as in Unit 3, but no relict lamination was seen in outcrop. Limestone in this interval is medium gray, thin bedded, and quite silty. Beds crop out in a resistant large ledge in the section and splinter into sharp platy and flaggy blocks. Prominent large-scale soft sediment flowage and plastic deformation has taken place in upper beds in the Vaughn Gulch section (fig. 30). Folds and deformation features can be seen on a smaller scale in some of the cherty beds (fig. 31). This may be indicative of an oversteepening of the depositional slope and consequent downslope slumping of semi-consolidated beds. Stevens and Ridley (1974), described boulder conglomerates and deep channeling (75 m.) in Devonian outcrops in Mazourka Canyon and have suggested submarine erosion, channeling, and large downslope slumping from southeast to northwest to account for these despoits.
Figure 30: Large scale slumping of cherty argillaceous limestone in the upper part of the Vaughn Gulch Limestone. Large fold is approximately 75 ft. in width. Erosional contact with overlying Mississippian Perdido Formation occurs to the far left of the picture.
Figure 31: Folding and soft sediment flowage in cherty argillaceous limestone at Vaughn Gulch.
Sunday Canyon section

A 523 foot section of the total 863 feet present at the Sunday Canyon Formation type locality at Bonanza Gulch (Ross, 1966) was measured in thesis work. Measurement began approximately 150 feet above the formation base and ended at an upper erosional contact with the overlying Mississippian Perdido Formation. Lithology is similar to the Vaughn Gulch Limestone and will not be discussed in detail here. A more complete description is given in Appendix II. The lower 373 feet of the measured section is a thin-bedded, argillaceous limestone to calcareous shale with minor bioclastic beds. Bioclastic limestone composes about 10% of the interval and occurs in 6 inch to 1 foot beds. Fossil constituents are smaller in size to those in bioclastic beds at Vaughn Gulch and are composed of bryozoans, pelmatozoan debris, and less common corals. Large lithified allochthonous blocks are not present in any of the skeletal-rich beds. Grading is the only feature in the otherwise structureless bioclastic deposits. The monotonous sequences of calcareous shale and platy argillaceous limestone are dark gray on fresh surfaces and very thin bedded. Graptolites have been reported from calcareous shale (Ross, 1966), but only poorly preserved fragments could be found in thesis work. Exposures of this lithology are poor, and slopes covered with shaly and platy talus are
the rule. Bioclastic beds stand up as small ledges and benches in the talus-covered hillsides.

The next 95 feet consists of silty, platy limestone and thin 1 to 2 inch interbeds of dark gray chert. This interval is well exposed in the gully floor and walls, with chert beds forming small ribs. Clastic material increases slightly in size and abundance in platy limestone. The upper 55 feet of the measured section shows a return to platy argillaceous limestone and minor bioclastic limestone lithology seen in the basal beds. Beds of bioclastic debris, forming about 10% of the interval, are present in occasional 2 inch to 1 foot thicknesses. A 3 foot bed of larger-sized skeletal fragments crops out about 40 feet below the top of the formation. Platy argillaceous limestone is slightly less silty than beds below.

Depositional Environment

In his report on Paleozoic formations of the Independence quadrangle, Ross (1966) collectively considered the Vaughn Gulch Limestone and Sunday Canyon Formation to be a deeper water facies of the eastern Hidden Valley Dolomite. These formations are interpreted by several workers as representing continental slope or outer shelf deposition (Poole et al., 1977; Miller, 1977). Stewart and Poole (1974, p. 45) suggested that the Vaughn Gulch Limestone represents moderately deep water deposition on the outer slope with bioclastic layers representing part
of non-dolomitized reef complexes. The Sunday Canyon Formation is considered to be a more basinward environment than that of the Vaughn Gulch beds (Stevens and Ridley, 1974; Miller, 1976).

The abundance of bioclastic debris in the lower Vaughn Gulch section points to an allodapic origin for these deposits. Graded bedding and minor cross-lamination (Bouma sequence $T_a$ and $T_c$) suggest that skeletal material was transported downslope in turbidity currents. Scoured surfaces, plastic flowage of underlying soft carbonate muds, and load features likewise argue for the rapid, episodic deposition of skeletal debris. The few beds which contain lithified blocks and large coral debris indicate that debris flows or submarine mudflows were periodically operative in the Vaughn Gulch depositional system. These types of lime breccias are believed to have originated from slope-slumping rather than channelized deposition, based on the lack of channel features and the tabular nature of clasts (McIlreath and James, 1979). Organic-rich, thin-bedded argillaceous limestones and calcareous shales interbedded with the bioclastic layers are the result of hemipelagic slope sedimentation of platform derived muds (McIlreath and James, 1979). The incomplete Bouma sequences, abundance of skeletal debris, and local lime breccias in the Vaughn Gulch Limestone imply that this deposit may have been relatively close to platform edge source material. Thinner and less abundant bioclastic beds, dominance of calcareous
shales, and presence of graptolites in shaly layers of the Sunday Canyon Formation suggests that these beds occupied a more distal or basinward position from the platform margin. Whether or not the source of skeletal material was actually a series of platform fringing reef complexes as suggested by Stewart and Poole (1974) or simply loose skeletal banks or buildups (Miller and Walch, 1977) cannot be determined, since source beds have been metamorphosed or destroyed by later tectonic events. The source of the material undoubtedly lay to the east or southeast, indicated by directional measurements on slump folds and current-aligned skeletal material. Lithologically similar and temporally equivalent deposits in central Nevada are described by Matti and McKee (1977). These deposits are considered to have been derived from skeletal buildups (the carbonate factory) on sills and adjoining depositional basins. A similar depositional system is envisioned to have been operative along the Cordilleran shelf margin in southeastern California during Late Silurian and Early Devonian time. This depositional system is believed to have been initiated by Silurian (Llandovery) downdropping of the western margin of North America (Johnson and Potter, 1975).

The upward decrease in bioclastic beds in the Vaughn Gulch and Sunday Canyon sections records a gradual shift in the depositional system toward shallower water conditions and a probable eradication of the lithotope (carbonate factory of Matti and McKee, 1977) supplying
skeletal debris to slope areas such as Vaughn Gulch. Upward increasing silt content also reflects shallowing and, probably, input of very fine sand and silt from the westward progradational movement of the Unit 4 beach-barrier bar system across the shallow eastern platform.

Johnson and Sandberg (1977, p. 129) have hypothesized that marked sedimentologic change took place during a Lochkovian-Pragian depositional hiatus on the outer shelf and slope in central Nevada. The Lochkovian shelf slope was rather steep and was fringed by a biohermal carbonate bank or reef. In contrast, a depositional ramp existed during Pragian time. Such a change can also be seen in the Vaughn Gulch beds, gradual decrease of bioclastic material upward records the shifting of fringing skeletal banks or reefs away from the Vaughn Gulch area in response to marine regressive conditions. However, at the Sunday Canyon type locality, return of bioclastic beds to the upper part of the skeletal material or a similar depositional system was again present in this area of the Cordilleran shelf margin.

Age and Correlation

Much of the information on the age of the Vaughn Gulch Limestone and Sunday Canyon Formation has been presented in discussion of Units 1 through 6. A summary of the age range of these formations will be briefly given here. The age of the Vaughn Gulch Limestone ranges from
Late Silurian (Ludlovian) (Berry and Boucot, 1970; Miller, 1977) through late Early Devonian (early Dalejan) indicated by *inversus* conodont fauna (Johnson and Niebuhr, 1976, Appendix 2). Dates obtained from tabulate corals collected near the unit top are compatible with the upper age limit (Appendix I). The Sunday Canyon Formation is Late Silurian or Early Devonian at its base (Berry and Boucot, 1970; Miller, 1976). Upper beds contain a *kockelianus* Zone conodont fauna, thus indicating that the Sunday Canyon ranges from Late Silurian? to mid or late Eifelian (fig. 3). At both the Sunday Canyon and Vaughn Gulch sections, erosion has stripped away younger strata.

Johnson and Niebuhr (1976, Appendix 2) suggested that the upper part of the Vaughn Gulch Limestone is correlative to the upper Bartine tongue in the Sulphur Springs Range and lower Coils Creek strata at Lone Mountain in central Nevada. Findings in this thesis are in agreement with such correlation. It is further suggested here that middle Vaughn Gulch beds are correlative to the central Nevada Windmill Limestone and overlying Rabbit Hill Limestone, both from a standpoint of age and lithology. Miller (1976) correlated the Silurian part of the Vaughn Gulch to the Roberts Mountain Formation in Bullfrog Hills, near Beatty, Nevada. The Sunday Canyon is also similar to the slope deposited Windmill and Rabbit Hill limestones and contains strata time equivalent to both. Upper beds lithologically resemble and are time equivalent to the
lower part of the deep-water deposited Denay Limestone at Lone Mountain. Poole et al. (1977, fig. 2a) have proposed similar correlations to those made above.
DOLOMITIZATION

Two distinct dolomite types can be recognized in Lower and Middle Devonian rocks in the thesis area. The first of these, primary dolomite, is represented by Unit 2 correlative, thinly laminated, aphanitic dolomite in the lower part of the Bat Mountain and Nopah Range sections. Primary dolomite is a genetic term used by Nichols and Silberling (1980) to describe dolomite which has been formed by penecontemporaneous replacement of calcareous sediment essentially at the time of deposition. This type typically preserves microcrystalline textures as well as sedimentary structures indicative of peritidal deposition. Sedimentary structures commonly present in primary dolomite include algal laminae, fenestrae, dessication cracks, and mud rip-ups. Many of these structures are well preserved on aphanitic dolomite at Bat Mountain and in the Nopah Range (fig. 12). Nichols and Silberling (1980) did not offer a geochemical model to account for the dolomitizing process of primary dolomite, but did suggest that the formative process is distinct from that of secondary dolomite formation. It was also suggested that the depositional site of primary dolomite could either coincide with an area of magnesium concentration or serve as a conduit through which meteoric water is introduced into the secondary dolomitization environment (Dunham and Olson, 1978). The intertidal-supratidal depositional setting of these rocks was not
necessarily an arid, sabhka-like environment as frequently proposed in the literature for penecontemporaneous (primary) dolomite formation; instead, it may have been typical of a more humid climatic and hydrologic regime, similar to that described for modern carbonate deposition in the ephemeral lakes of the South Australian Coorong Lagoon (Muir et al., 1980). In this region, seasonal fluctuations are responsible for the deposition of minor amounts of evaporites during the dry summer months and the dissolution and flushing out of these minerals by rainfall and seaward groundwater flowage in winter. Thus, the lack of evaporite minerals or their traces does not necessarily imply that concentrated brines were never present in primary dolomite deposits. This may be the case in Nopah Range-Bat Mountain primary dolomite and suggests a means to dolomitize tidal flat lime muds. Only aphanitic, poorly ordered dolomite is likely to form because of rapid precipitation, possible high concentration of foreign ions, and the relatively high Mg/Ca ratios (5-10:1) necessary (Folk and Land, 1975).

The second dolomite type recognized is volumetrically much more important in the thesis area, and characterizes the rest of the carbonate interval studied. This type of dolomite, termed secondary dolomite, represents post-depositional replacement of limestone by progressive slow growth and coalescence of discrete dolomite crystals (Nichols and Silberling, 1980). Secondary dolomite may be formed during different diagenetic stages, as well
as by hydrothermal processes. In order to characterize secondary dolomite formed from sediment within reach of processes operating at the surface or shallow subsurface, Nichols and Silberling (1980) applied the term eogenetic, from Choquette and Pray (1970), to describe this diagenetic environment and dolomite type. Units 2, 3, 5, 6, and dolomitic parts of Unit 4 may be categorized as eogenetic secondary dolomite. In each unit, the crystalline texture, size, and shape indicate that former lime carbonate had undergone a pervasive dolomitizing event. Internally zoned dolomite (fig. 32) denotes uniformly fluctuating conditions existing during the dolomitization process (Scholle, 1978). Evidence of normal marine deposition in Units 2 and 3 demonstrates that these deposits were dolomitized after deposition.

Several models have been proposed to explain the apparent large volumes of eogenetic secondary dolomite in the Paleozoic record. The seepage reflux dolomitization model was proposed by Adams and Rhodes (1960) calling for the replacement of calcium carbonate by dolomite under tidal flats by downward seepage of dense brines concentrated by evaporation. The Mg/Ca ratio is raised by precipitation of aragonite and gypsum. Thus, the system depends heavily upon an arid environment where substantial evaporite deposition is ongoing. This model does not apply well to dolomites in the thesis area, as there are no associated evaporite deposits nor evidence of their former
Figure 32: Photomicrograph of coarse, internally zoned dolomite spar which has cemented former porosity. Field of view is 3.5 mm., plane light.
existence, as advocated by Friedman (1980). As well, Folk and Land (1975) have pointed out problems in forming ordered dolomite in hypersaline environments.

A second model of eogenetic secondary dolomitization, evaporative pumping, was proposed by Shinn and Ginsburg (1964) to explain the origin of supratidal dolomitic crusts in the Florida-Bahamas area. High temperatures and an excess of evaporation over rainfall causes interstitial supratidal pore waters to transpire upward. Evaporation increases the pore fluid salinity and precipitation of aragonite and gypsum causes the Mg/Ca ratio to increase. The concentrated brine then dolomitizes the upper sediment to a thin supratidal protodolomite crust. This model cannot account for the formation of large volumes of ordered dolomite and, more importantly, would not be applicable to dolomitization of shallow buried marine sediments.

Mixing zone dolomitization was proposed by Land (1973) to account for dolomitization of north Jamaica Pleistocene limestones. Badiozamani (1973) applied this concept to explain Middle Ordovician dolomites in southwestern Wisconsin. In mixing dolomitization, meteoric waters mix with intrastratal sea water, creating a zone of brackish water. At progressively reduced salinities, the water becomes undersaturated with respect to calcite and oversaturated with respect to dolomite. Dolomite is able to nucleate and slowly crystallize at lower Mg/Ca ratios
and accompanying reduction of foreign ion concentration by fresh water dilution (Folk and Land, 1975). An advantage to this model is that an arid climate and formation of Mg-rich brines is not needed. Dunham and Olson (1978) applied the mixing zone dolomitization model to Paleozoic paleogeography of the Cordilleran miogeocline in Nevada, suggesting that this model can explain the distribution of regionally extensive dolomitic platform deposits and deeper water undolomitized strata. In their model, the zone of mixing of phreatic fresh water and intrastratal sea water, thus the dolomitizing zone, is a subsurface wedge which extends outward from the surface area of freshwater recharge into shallow subsurface sediments. With marine regression or transgression, this zone of dolomitization would move seaward or landward accordingly, leaving behind a blanket of dolomitized sediment. Deeper water limy deposits would escape dolomitization by virtue of their distal position from the areas of freshwater recharge. This model is believed to account for the dolomitization of Lower and Middle Devonian carbonates in the thesis area. With marine regression in late Early Devonian time, the zone of dolomitization moved seaward with the westward prograding Unit 4 and Unit 5 sediments and dolomitized the underlying Units 2 and 3. The Unit 5 intertidal-supratidal environment is believed to have been the site of freshwater introduction into the dolomitizing system. This surface, largely subaerially exposed, could have originally been
dolomitized early in its history, as in the case of primary dolomitization, while also serving as a conduit for meteoric water introduction (Nichols and Silberling, 1980). With a slow sea level rise, Unit 6 was deposited over Unit 5 and the zone of dolomitization probably passed through the shallowly buried unit and subjected it to a second dolomitizing event. This may account for the coarse crystalline nature of Unit 5. Alternatively, Unit 5 may have originally had a high degree of porosity and permeability, thus lending itself to pervasive dolomitization. A gradual increase in lime content upward through Unit 6 indicates that these sediments were not subjected to dolomitization by mixing zone processes for as long a period of time as was Unit 5. By the time that the uppermost beds of Unit 6 were deposited and shallowly buried, the dolomitizing mixing zone system had begun to slowly migrate eastward in response to marine onlap.

Silicification effects are best seen in Unit 2 by silica replacement of fossils, and in Unit 3 where extensive secondary chert replacement has taken place along bedding planes. In relation to the dolomitization model just described, shallowly buried Unit 2 sediments were first subjected to the dolomitizing waters of the mixing zone diagenetic environment where lime mud was replaced by fine grained dolomite. Fossil allochems, consisting of calcite and aragonite, were dissolved and their molds were probably cemented by dolomite spar (fig. 33). Alternatively,
Figure 33: Photomicrograph of coarse, internally zoned dolomite spar which has filled former void space in a brachiopod shell (Unit 2, Dry Mountain). Later stage chalcedony has cemented remaining porosity. Geopetal silt (not shown) occurs at the bottom of the picture. Field of view is 3.5 mm., polarized light.
the dolomitization may have been fabric selective in this unit and have only partly replaced skeletal components. Mattes and Mountjoy (1980) noted that degree of dolomitization decreased away from the source of dolomitizing waters in the Albertan Miette buildup and was fabric selective where dolomitization was less pervasive. This may have been the case in thesis Unit 2 rocks, as dolomitization is less extensive in this unit and Unit 3 than for the overlying rocks. In any case, fossil allochems were then replaced by silica, either concurrent with dolomitization or shortly thereafter.

Chert formation in Unit 3 is clearly secondary, as seen by the preservation of lamination in nodules (fig. 34). The presence of small dolomite euhedra in the chert indicates that chert was able to replace some of the original lime mud before complete dolomitization of the sediment occurred. Dolomite is less soluble than calcium carbonate in most natural solutions and therefore, early-formed rhombs were preserved in the chert while calcium carbonate was dissolved and replaced by silica (Dietrich et al., 1963; Dunham and Olson, 1980). Source for the silica presents a problem in that most secondary silica is believed to have an organic source, such as sponge spicules or radiolaria whose opaline (opal A) composition is more soluble than quartz. As there is no trace of such organisms in Unit 3 sediments, an organic source for the chert cannot be shown conclusively. An inorganic source for silica frequently
Figure 34: Photomicrograph of small dolomite euhedra and relict lamination preserved in secondary chert in Unit 3. Silicification is believed to have taken place prior to extensive dolomitization of original silty carbonate mud. Field of view is 1 mm., polarized light.
listed in the literature is volcanic glass, but there is no evidence of nearby volcanism in this region of the Cordilleran miogeoclone. Peterson and von der Borch (1965) documented inorganic chert deposition in lakes associated with the Coorong Lagoon of South Australia under widely fluctuating pH conditions. The source of silica in this case was believed to have been dissolution of detrital quartz under high pH conditions and precipitation as a colloidal gel during evaporation and a lowering of pH. Quartz sand and silt grains in Unit 3 and 4 have been significantly corroded along grain borders and may have provided silica for chert formation. Problems arise, however, in providing for the volumes needed to account for the abundant chert in Unit 3 unless basinward migration of silica solutions is assumed. Also, it would be necessary to significantly raise intraformational temperatures and widely fluctuate the pH of the intrastratal waters. As such, the silica source for the chert remains unresolved.
DEPOSITIONAL HISTORY AND PALEOGEOGRAPHY

Shallow marine shelf deposition characterized the sedimentation pattern in the main part of the thesis area during Early and Middle Devonian time. In the extreme western part of the area, deposition took place in carbonate slope environments. In earliest Devonian time, Unit 1 intertidal to very shallow subtidal sediments were deposited to the east, whereas a skeletal carbonate bank or reef-complex fringing the platform edge supplied bioclastic material to slope areas at Vaughn Gulch and Sunday Canyon. The continental shelf thus consisted of a broad, inner platform and a narrow outer shelf basin (fig. 7), similar to that envisioned for central Nevada at this time (Matti and McKee, 1977). Circulation of marine waters on the eastern platform was greatly restricted by energy-dissipating platform-edge carbonate banks or reefs to the west, and conditions were inhospitable to benthic organisms. Consequent late Lochkovian regression subaerially exposed extreme southeastern platform areas, such as the Nopah Range, and erosion of the Upper Silurian and lowermost Devonian sediments took place (fig. 8). Farther seaward platform regions in the northern Panamint Range are not believed to have been eroded, but a depositional hiatus marks the top of Unit 1 deposits in this area (fig. 7). At Vaughn Gulch and Sunday Canyon, lowering of sea level caused
the biotope supplying skeletal detritus to prograde seaward in order to sustain a suitable habitat for reef or bank builders.

During the lochkovian-Pragian hiatus, a marked sedimentologic change took place on the outer shelf and slope (Johnson and Sandberg, 1977). A skeletal bank or reef with an adjacent steep slope characterized the Lochkovian setting. However, a depositional ramp typified the Pragian setting.

In early Pragian time, marine transgression covered underlying intertidal-very shallow subtidal sediments and the fossiliferous Unit 2 was deposited in all shelf areas of the Panamint Range and Funeral Mountains (figs. 7 and 8). In the extreme southeast, at the Nopah Range and Bat Mountain, an interbedded sequence of sandy beds and thinly laminated aphanitic dolomite of Sevy character marked the landward extent of Pragian transgression in the thesis area (fig. 8). At Bat Mountain, Sevy-like lithology is directly overlain by deposits of the Unit 2 lithotope. In the Nopah Range, surf-zone reworked Trematospira age fossils document the age equivalence of sandy lithology to Unit 2 deposits, as well as indicate that transgression was a relatively rapid depositional event across the inner shelf region. Shelly marine organisms, corals and brachiopods in particular, quickly entered the shallow subtidal environment. More shoreward biotopes were subjected to moderate current activity and episodic
conditions of storm agitation. Deeper water biotopes, such as at Andy Hills and Red Amphitheater, were characterized by less agitated conditions and a higher diversity of fauna. Increasing amounts of silt and detrital clay entering the Unit 2 lithotope was probably responsible for the gradual decline of habitat suitable for shelly marine benthos. The gradual replacement of the Unit 2 lithotope by silty argillaceous Unit 3 deposits is also marked by proliferation of soft-bodied infaunal deposit feeders which intensively burrowed the substrate. The lower part of Unit 3 was deposited during continued transgression, evidenced by the landward overstepping of Sevy-like rocks by silty, burrowed subtidal lithology at the Nopah Range (fig. 8). The cherty upper part of Unit 3 reflects shallowing-upward conditions and initiation of late Early Devonian regression. Lack of burrowing and presence of current-formed structures, along with overlying very shallow water sandy deposits, indicates a regional sea level drop and westward progradation of the Unit 3 lithotope. Slope areas to the west contain correlative deposits of silty limestones and secondary chert characteristic of upper Unit 3 bed to the east and, thus, also indicate shallowing upward conditions in the thesis area (fig. 7). The outer shelf gradient may have again increased at the carbonate shelf edge by westward progradation and buildup of sediments. Large scale down-slope slumping by oversteepening at Vaughn Gulch and a re-entrance of bioclastic deposits at the Sunday
Canyon section suggest that the carbonate shelf edge had steepened considerably with respect to the preceding configuration.

To the east, the seaward prograding nearshore environment was overstepped by Unit 4 sandy deposits indicative of a beach-barrier bar environment, during continued late Early Devonian regression. Local unconformable contacts, cross-bedding, and abundance of well sorted, well rounded quartz sand point to a system of beaches and submerged offshore bars separating deeper water to the west from landward tidal flat areas. Not only does the sandy lithotype mark regression, it also reflects an increased clastic sediment supply into the thesis area during Dalejan time. Sand was supplied from erosion of older arenaceous deposits exposed on the craton and carried to the coastline by rivers where it was distributed along its length by longshore currents, as suggested by Osmond (1954) and Kendall (1975). Finer grained silt was wind-transported into the nearshore Unit 3 environment and also into landward tidal flat areas. Slope regions to the west received increased amounts of fine silt and argillaceous material brought in by westward progradation of clastic sediments. Formation of a series of barrier islands at the northwest extremity of the thesis area may possibly be indicated by abnormally thick quartz sand deposits at Dry Mountain, and as seen in central Nevada (Kendall, 1975, fig. 38). Alternatively, thick sand accumulations such as
at Dry Mountain may be composed of a lower regressive part and an upper transgressive part.

The seaward-prograding sandy Unit 4 lithotope was followed and progressively overstepped by eastern intertidal-supratidal coarse crystalline dolomite deposits of Unit 5 during regression, in accordance with Walther's Law. The relative thinness and gradational lower contact indicate that the transgressive part of coarse crystalline deposition seen in central Nevada (Kendall, 1975) may not be present in southeast California. The dark gray channel deposit cut into the top of Unit 5 at Ubehebe Peak suggests a period of subaerial exposure and local erosion at this area during latest Unit 5 time.

Deposition of Unit 6 intertidal to shallow subtidal sediments during early Middle Devonian time records a return of more open marine conditions to the inner shelf regions by initial transgression. The paleoslope was a broad and nearly flat carbonate surface. Initial marine transgressive pulses spread over tidal flat areas and deposited thin beds of dark gray organic-rich muds. Lighter colored beds, indicative of intertidal-supratidal deposition, were gradually replaced by the darker subtidal deposits. At the end of Unit 6 time in the early Givetian, conditions were suitable for the proliferation of laterally extensive dendroid stromatoporoid mats. Rocks overlying Unit 6 in the thesis area reflect the larger transgressive pulse of the Taghanic onlap.
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APPENDICES
APPENDIX I:
FOSSIL COLLECTIONS AND LOCALITIES

Collections are from the upper Hidden Valley Dolomite unless otherwise noted. Collections are located as feet below the first quartzite in the Lippincott Member of the Lost Burro Formation.

Bat Mountain: Ryan 15 min. quad., NE 1/4 of SE 1/4 at edge of sheet, prominent ridge 1/2 mile N of Peak 4963, west slope of Funeral Mts.

Collection HBM-1A (200 ft.)

Conodonts:  
Icriodus nevadensis  
Icriodus claudiae  
Pandorinellina sp. indet.  
Panderodus sp.  
Belodella sp.

Corals:  
Breviphrentis invaginatus  
branching favositid

Age: upper part of kindlei Zone

Collection HBM-B1 (205 ft.)

Brachiopods:  
inert. strophoeodontid sp. 1  
Nucleospera sp. 1  
Meristella sp. 1  
Acrospirifer aff. murchisoni? 1

Age: Trematospera Zone; F.I. 6-7?
Red Amphitheater: Ryan 15 min. quad., NW 1/4 approx.
5-1/2 miles due E of "Hole in the Wall", along National
Monument boundary, 9000 ft. NW of Pyramid Peak.
Collection HRA-5 (13 ft.)
  Conodonts: Icriodus trajani
            indet. simple cones
  Age: dehiscens to serotinus Zones
Collection HRA-3 (192 ft.)
  Brachiopods: Euschuchertella sp. 1
               Gypidula? (or Carinagypa) sp. (smooth) 28
               Atrypa sp. (coarse costae) 10
               Nucleospira sp. 1
               Meristella sp. 1
               Acrospirifer kobehana 3
               Platyceras sp. (spiny) 3
  Corals:   Favorites gronbergi?
            Breviprerenis invaginatus
  Age: upper part of Kobehana Zone; F.I. 9
Collection HRA-2 (197 ft.)
  Conodonts: Icriodus claudiae
            Icriodus nevadensis
            Panderodus sp.
  Corals:   Favorites swannii
            Syringopora eurekae
            Cladopora sp.
            Breviprerenis invaginatus
  Age: upper part of kindlei Zone
Mesquite Springs: Tin Mountain 15 min. quad., SE 1/4 of NW 1/4, approx. 4 miles S30°W of Mesquite Springs campground, 1.3 miles due E of Peak 5181, narrow SW-trending canyon.

Collection HMS-1 (217 ft.)

Conodonts: *Icriodus claudiae*

Age: *sulcatus* through *kindlei* Zones

Collection HMS-7 (50 ft.)

Conodonts: *Polygnathus serotinus*

*Icriodus* sp. indet.

*Indet. simple cones*

Age: base of *serotinus* Zone into *costatus* Zone

Cottonwood Mountains: Marble Canyon 15 min. quad., SE 1/4, 2200 ft. due S of Peak 2185.

Collection HCM-13 (134 ft.)

**Brachiopods:** *Eoschuchertella* sp. 3

*Leptocoelia* sp. 1

*Meristella* sp. 11

*Acrospirifer kobehana* 16

Conodonts: *Eognathodus sulcatus kindlei*  

*Icriodus claudiae*  

*Panderodus* sp.

**Corals:** *Favosites kobehensis*  

*Thamnopora* sp.  

*Halliid?*  

*Metriophyllid?*

Age: *Kobehana* Zone; *kindlei* Zone; F.I. 8-9, probably 8
Andy Hills: Marble Canyon 15 min. quad., NW 1/4, 1200 ft. NNE of NE trending ridge.
Collection HAH-4 (127 ft.)
Corals: Breviphruntis invaginatus
massive favositid
Age: probably Kobehana Zone

Collection HAH-2B (137 ft.)
Brachiopods: Gypidula sp. (praeloweryi?) 1
Costistrophonella sp. 1
Parachonetes macrostriatus 25
Meristella robertensis 69
Age: Kobehana Zone, upper part; F.I. 9

Collection HAH-2A (159 ft.)
Brachiopods: Eoschuchertella sp. 1
Coelospira sp. 1
Leptocoelia sp. 3
Meristella sp. 3
Acrospirifer kobehana 19
Megakozlowskiella sp. 3
Corals: Halliid?
Age: Kobehana Zone; F.I. 8-9, probably 8

Collection HAH-1 (164 ft.)
Corals: Favosites cf. F. koryste
Age: probably Kobehana Zone

Lost Burro: Ubehebe Peak 15 min. quad., (type section of Lost Burro Fm.), NE 1/4, 1700 ft. SSE of BM 4682.
Collection HLB-7 (82 ft.)

Corals:  
Favosites cf. F. korsyte  
Favosites cf. F. kobehensis  
Emmonsia bartinensis  
Breviphrrentis invaginatus

Age: probably Kobehana Zone

Collection HLB-5 (95 ft.)

Brachiopods:  
Meristella aff. robertsensis 32  
Acrospirifer aff. murchisoni 8

Corals:  
Halliid?

Age:  
Trematospira Zone (possibly younger); F.I. 6-7

Collection HLB-1 (210 ft.)

Conodonts:  
indet. ramiform elements

Age: none assignable

Ubehebe Peak:  
Ubehebe Peak 15 min. quad., NE 1/4, WNW-trending ridge 100 ft. N of Peak 5208, 1-1/4 miles SSW of Ubehebe Mine, Panamint Range.

Collection HUP-10 (1 ft.)

Conodonts:  
Icriodus trojani  
Panderodus sp.

Age: dehiscens to serotinus Zones

Collection HUP-4A (200 ft.)

Conodonts:  
Icriodus claudiae  
Polygnathus sp. indet.  
Panderodus sp.

Age: sulcatus through kindlei Zones
Collection HUP-4 (201 ft.)

Brachiopods:  
- Eoschuchertella? sp. 1
- Meristella sp. 10
- Acrospirifer aff. murchisoni 6
- Elytha sp. 1
- indet. costellate brachiopod

Conodonts:  
- Icriodus claudiae
- Icriodus sp. indet.
- Panderodus sp.

Age:  
Trematospira Zone; F.I. 6-7

Collection HUP-1 (282 ft.)

Conodonts:  
- Ozarkodina sp. indet. (Pa elements)
- indet. Sc element
- indet. Pa element
- indet. ramiform elements

Age:  none assignable


Collection HKM-2 (104 ft.)

Corals:  indet. rugosan

Age:  none assignable

Vaughn Gulch:  Independence 15 min. quad., (type section for Vaughn Gulch Ls.), SE 1/4, EW-trending ridge, 0.3 mile NNW of Peak 4906, 0.9 mile SSE of Whiteside Mine; Samples located as feet below unconformable contact with overlying
Mississippian Perdido Formation.

Collection HVG-23 (19 ft.)

Conodonts:  
- Icriodus sp. indet.
- Pandorinellina sp. indt.
- Panderodus sp.

Corals:  
- Favosites swanni

Age:  possibly F.I. 10-13

Collection HVG-17 (291 ft.)

Conodonts:  
- Icriodus claudiae
- Icriodus nevadensis?
- Icriodus sp. indet.
- Pandorinellina sp. indet.
- indet. ramiform elements
- Panderodus sp.

Age:  upper part of kindlei Zone

Collection HVG-16 (368 ft.)

Conodonts:  
- Icriodus sp. indet.
- indet. ramiform elements

Age:  none assignable

Collection HVG-12 (494 ft.)

Corals:  
- Favosites cf. F. koryste

Age:  none assignable

Sunday Canyon:  Independence 15 min. quad., (type section for Sunday Canyon Fm.), SW 1/4 of NE 1/4, approx. 1/2 mile NE of Barrel Springs, section occurs in Bonanza Gulch; Sample located as feet below unconformable contact with
overlying Mississippian Perdido Formation.

Collection HSC-10 (40 ft.)

Conodonts:  

Tortodus kockelianus kockelianus  
Polygnathus pseudofoliatus  
Polygnathus eifelius  
Polygnathus parawebbi  
Polygnathus linguiformis linguiformis gamma  
Polygnathus sp. (trigonicus group)  
Polygnathus n. sp. (aff. P. n. sp. N of Klapper)  
Polygnathus angustipennatus  
Icriodus sp.

Age: kockelianus Zone

Supplementary unpublished collections

AH-1 (USNM loc. 13208)


Brachiopods: Dalejina sp. 3  
Dalejina cf. musculosa 2  
Eoschuchertella sp. 3  
Leptocoelia sp. 11  
Leptostrophia? sp. 1  
Trematospira cf. multistriata 3
Pseudoparazyga cf. cooperi 2
Meristella cf. robertsensis 146
indet. spiriferid 1
Acrospirifer kobehana
Dyticspirifer mccolleyensis 1
Megakozlowskiella sp. 1
spiny platycerid 2

Age: Trematospira Zone; F.I. 6-7

68FP-17F (USNM loc. 17419)

Quartz Spring area, lat. 36°15', long. 117°28'30".
Panamint Range, Death Valley 2° sheet, Inyo Co., Calif.;
Collection by F.G. Poole and A.J. Boucot, 1968.

Brachiopods: Dalejina sp. 1
Eoschuchertella? sp. 1
Leptococoelia cf. murphyi 6
Ancillotoechia aptata 1
Leptostrophia? sp. 1
Nucleospira sp. 1
Meristella cf. robertsensis 25
Acrospirifer kobehana 19
Costispirifer sp. 4
Megakozlowskiella cf. raricosta 1

Age: probably Costispirifer Subzone of Trematospira Zone; F.I. 7
APPENDIX II
LOCATION AND DESCRIPTION
OFMeasured SECTIONS

NOPAH RANGE

Stewart Valley 15 min. quad., SE 1/4 of NW 1/4, approx. 0.9 mile due E of Hwy. 52, 0.8 mile S45°E of BM 2878, EW-trending canyon, northern Nopah Range.

0'-114'--medium grained dolomite; (f) medium gray, (w) light gray; thick bedded to massive, rough, pitted weathering surface; rounded benches and small cliffs.

114'--erosional unconformity

114'-143'--interbedded aphanitic dolomite and sandy dolomite; sandy dolomite is (f) medium gray, (w) light pinkish gray, numerous small bits of dolomite spar and probable fossil hash, clasts of underlying lithology in basal beds, faintly laminated to structureless; aphanitic dolomite is (f) variegated medium gray, reddish gray, and pale yellowish brown, (w) light gray and light pinkish gray, finely preserved thin laminae, dessication cracks, fenestrae, and intraclasts, thinly laminated; talus-covered slopes and small steps.

143'-162'--fine grained dolomite; (f) medium gray, (w) light gray; small 2-3" beds, lenses, and thin laminae of quartz silt and sand; subordinate 1 ft. intraclastic dolomite beds.
162'-215'--interbedded sandy dolomite, dolomitic sandstone, and quartzite; (f) light grayish white to medium gray, (w) light gray to pale brown; thin to thick bedded; planar laminated and planar cross-bedded intervals, vertical burrows; rounded dolomite clasts; upper 20 ft. predominantly sandstone and quartzite.

215'-274'--silty and cherty argillaceous dolomite; (f) medium gray, (w) light yellowish gray to light bluish gray, chert is dark grayish brown as nodules and coalescing nodular horizons in upper part; thick bedded; lower part predominantly silty and burrowed; talus-covered slopes and steep benches.

275'-290'--interbedded sandy dolomite and dolomitic sandstone; (f) light gray to medium gray, (w) pale brown to light bluish gray; thin to thick bedded; sandstone is thinly laminated with less common 2" cross-beds, vertical burrows; prominent small cliffs and ledges.

290'-299'--medium to coarse grained dolomite; (f) medium gray, (w) medium gray; thick bedded; faint thin laminae; rare very thin sandy laminae; small bench.

302'-311'--fine grained quartzite; (f) grayish white, (w) pale brown; thin bedded; planar laminated, very fine to fine, rounded and well sorted quartz grains; a few rounded dolomite clasts; prominent bench.

311'-326'--medium to coarse grained dolomite; (f) medium gray, (w) light gray; thinly laminated; wavy laminae and
lenses of fine sand; slope to small benches.
326'-340'--dolomitic sandstone and quartzite; (f) grayish white, (w) light gray; thick bedded to massive; partly affected by brecciation and breakage into 2-4" chunks and blocks; prominent ledge.
340'-424'--medium to coarse grained dolomite; (f) light gray, (w) light gray; thick bedded to massive; faint thin wavy laminae; thin sandy laminae in lower beds; faint intraclastic texture and relict lamination in upper beds; rough pitted to vuggy surfaces; rounded benches and slopes.
424'-464'--interbedded light and dark gray dolomite; medium grained grading upward to fine grained; thick bedded; light gray dolomite dominant in lower part with faint laminae and intraclasts; dark gray dolomite is fine grained, thinly laminated, and fetid; slopes and small steps.
464'-484'--dark gray fossiliferous dolomite; thick bedded; fine to medium grained; coarse white sparry dolomite ghosts of *Amphipora*? and biscuit-shaped, minor silicification of fossil material; possible brachiopod valves and shelly debris; prominent small cliffs and benches.

RED AMPHITHEATER

Ryan 15 min. quad., approx 5-1/2 miles due E of "Hole in the Wall", along National Monument boundary, 9000 ft. NW of Pyramid Peak.
0'-85'--fine to medium grained dolomite; (f) medium pinkish gray, (w) light gray; thin to thick bedded; faintly
laminated; scattered coarse sparry blebs from 1-30 mm; rough pitted and vuggy surface, rounded slopes and small steps.

85'-93'--fine grained fossiliferous dolomite; (f) medium dark gray, (w) medium bluish gray; thick bedded, slightly argillaceous; silicified rugose and tabulate corals on bedding surfaces; small bench.

93'-125'--fine grained fossiliferous dolomite; (f) medium pinkish gray, (w) light pinkish gray to light yellowish gray; thin to thick bedded; argillaceous and somewhat silty at top; silicified corals and brachiopods, disarticulated and articulated, concentrated in thin beds and lenses with fine shelly debris, fossil content decreases upward; slightly burrowed in upper silty part; small steps and talus-covered slopes.

125'-150'--poorly exposed, silty burrowed dolomite talus weathering light yellowish gray.

150'-190'--silty burrowed dolomite; (f) medium gray, (w) light brownish gray to light yellowish and pinkish gray; thick bedded to massive; intensely burrowed horizons 1 to 3 ft. apart, silt-rich burrows weather dark brown in epirelief, 5-10 mm diameter tubular-shaped subparallel to oblique to bedding; talus-covered saddles and small resistant benches.

190'-223'--silty and cherty argilaaceous dolomite; (f) medium gray to bluish gray, (w) light bluish gray; fine
grained; thick bedded, faintly laminated where not extensively burrowed; chert occurs as small olive gray nodules and coalesive horizons parallel to bedding, occasional relict lamination in nodules, burrowing common on lower part, decreases upward; silt content slightly decreases upward; prominent small steps and benches.

223'-265'--cherty argillaceous dolomite; (f) medium gray, (w) light bluish gray; thick bedded to massive; fine grained; chert occurs as irregularly shaped nodules with no preferred orientation; minor burrowing in lower part; prominent benches.

265'-288'--fine grained dolomite with small 1-3" sandy interbeds; (f) medium dark gray, (w) light bluish gray; poorly exposed in upper 5 ft.; thin to thick bedded; notably chert free; small steps and soil-covered saddles.

288'-349'--quartzite and dolomitic sandstone; (f) grayish white, (w) pale brown to light grayish brown; thick bedded, planar laminated and planar cross-bedded in 2-10" sets in lower 35 ft.; a few rounded dolomite clasts; slightly more dolomitic in upper part, thin interbeds of sandy dolomite and dark gray medium grained dolomite with thin wavy sandy laminae; prominent cliffs and steep benches.

349'-440'--interbedded dolomitic sandstone, sandy dolomite, and dark gray dolomite; (f) medium gray, (w) light to medium gray; thin to thick bedded, thin wavy laminae in sandy dolomite; sandstone occurs in 6-12" beds, sandy dolomite in 1 ft. beds; dark gray dolomite in 6-12" beds; prominent
cliffs and benches.
440'-467'--fine to medium grained dolomite; (f) medium gray, (w) light gray to light brownish gray; thick bedded, thin lenses and wavy laminae of sand; rough pitted to vuggy surface, rounded benches and slopes.
467'-544'--medium to coarse grained dolomite; (f) light gray, (w) light gray, massive, relict thin and wavy laminated; possible intraclastic texture, small fine grained pinkish lenses and elongate clasts; rough pitted to vuggy surface, rounded benches and steps.
544'-545'--dark gray dolomite; fine grained; thinly laminated; slightly fetid; small step.
545'--faulting and brecciation; end of section.

ANDY HILLS

Marble Canyon 15 min. quad., NW 1/4, 1200 ft. NNE on NE-trending ridge.
0'-37'--fine grained massive dolomite; (f) medium gray, (w) light gray; undulatory weathering surfaces, blocky ledges and soil-covered slopes.
37'-53'--fine grained fossiliferous dolomite; (f) olive gray to medium gray, (w) medium gray; thick bedded; silicified fossils and small fossil debris concentrated in some beds and on bedding surfaces; small benches and steps.
53'-90'--silty argillaceous fossiliferous dolomite, (f) medium gray, (w) light brownish to yellowish gray; thin to thick bedded; fine grained; lower 10 ft. interbedded
with medium gray fossiliferous dolomite, thin lamination common; silicified fossils on bedding planes and in 6-10" beds; upper beds slightly burrowed, a few small chert nodules and discontinuous cherty horizons; slopes and prominent benches.

140'-202'--cherty argillaceous and silty dolomite; (f) medium gray to brownish gray, (w) light brownish gray to bluish gray; thick bedded, some thin laminae and current formed structures in upper beds, abundantly cherty in middle part; chert occurs nodules and 2-6" nodular horizons parallel to bedding, relict lamination sometimes preserved in nodules; heavily burrowed in lower and middle part decreasing rapidly in uppermost beds; prominent small cliffs and benches, last 15 ft. covered by talus.

202'-212'--quartzite; (f) grayish white, (w) pale brown to brownish gray; thin to thick bedded, planar laminated and planar cross-bedded; fine grained, well sorted and rounded quartz, minor rounded dolomite clasts; slope to prominent small cliff.

212'-242'--interbedded quartzite, dolomitic sandstone, and sandy dolomite; (f) medium gray to light gray, (w) light grayish brown to light gray; thin to thick bedded, sandstone and sandy dolomite commonly contain laminated and rippled sandy layers, quartzite occurs as 1-2 ft. planar laminated beds, minor cross-bedding; rounded and moderately sorted quartz; prominent benches and steep slopes.
242'-336'--interbedded medium to dark gray dolomite and sandy dolomite; thin to thick bedded, planar laminated, minor wavy laminae and discontinuous sandy lenses; thin 2-4" quartzite beds; darker colored dolomite is fine to medium grained, increasing in grain size upward; brecciation in some of the upper beds; steep slopes and small benches.

336'-345'--sandy dolomite; (f) light gray, (w) light gray; medium to coarse grained; thin bedded, thin sandy laminae and lenses; rounded steps and benches.

345'-420'--coarse grained dolomite; (f) light gray, (w) light gray; thick bedded to massive; crudely preserved thin wavy lamination and minor sandy laminae in lower part; brecciation in irregular zones, cementation by coarse dolomite; angular dark dolomite clasts; rounded benches and small cliffs.

420'-475'--alternating light and dark gray dolomite; thick bedded; dark dolomite beds are fine grained, 1-2 ft. thick, occurring on a 15-20 ft. spacing; light gray dolomite is medium to coarse grained and may be laminated; possible intraclastic texture and fenestral structures; small steps and benches.

475'-620'--alternating light and dark gray dolomite; thick bedded, dark dolomite commonly thinly laminated, possible hummocky stromatolitic lamination; occasional light and medium bluish gray mottled dolomite beds; gentle slopes and small ledges.
620'–740'--alternating light and dark gray dolomite; thick bedded, dark dolomite is predominant in upper part, occurs as 2-6 ft. thinly laminated fine grained beds on a 5 ft. spacing; lighter beds give way to light and medium gray mottled dolomite upward; upward grain size decrease; soil-covered slopes and small benches.

740'–770'--dark gray fossiliferous dolomite; thick bedded, horizons of concentrated dendroid stromatoporoids (Amphipora?), upper 10 ft. contains abundant brachiopod valves, free of stromatoporoids; fine grained with clear coarse spar patches and fossil replacments; prominent large benches.

UBEHEBE PEAK

Ubehebe Peak 15 min. quad., NE 1/4, WNW-trending ridge 1000 ft. N. of Peak 5208; 1-1/4 miles SSW of Ubehebe Mine, Panamint Range.

0'–75'--very fine grained dolomite; (f) medium gray, (w) light bluish gray, local light bluish gray and light brownish gray mottled patches; thick bedded to massive; faintly laminated from 25-35 ft.; forms small benches and steps.

75'–125'--very fine grained to fine grained dolomite; (f) light gray to medium gray, (w) light bluish to medium bluish gray; thick bedded, faint thin laminations and 1/4" dolomite clasts; local beds containing 1-2 mm medium grained sparry dolomite bits and blebs; low resistant steps.
125'-150'--fine grained dolomite; (f) light to medium gray, (w) light yellowish gray to light bluish gray; thick bedded to massive; brownish weathering siliceous material along joints and fractures; locally soft sediment deformed beds containing small cream colored dolomite clasts; low slopes and small steps.

150'-170'--fine grained sparsely fossiliferous dolomite; (f) medium dark gray, (w) medium bluish gray; thick bedded, local 2-6" lenses and beds of small crinoid debris, broken and disarticulated brachiopod valves and corals; fossils are silicified and weather out on exposed surfaces; brownish weathering siliceous material on joints and fractures; small resistant benches and steps.

227'-289'--fine grained silty dolomite to dolomitic siltstone; (f) medium bluish gray, (w) light brownish gray; thin bedded, 2-4" abundant silty beds show faint lamination; 1-3 ft. abundantly burrowed beds; silt-rich burrows weather to resistant light brown; occasional small nodules of light gray chert weathering reddish brown; small benches and float-covered saddles.

289'-343'--fine grained cherty argillaceous dolomite; (f) medium bluish gray, (w) light bluish gray to light brownish gray; thick to thin bedded; chert is reddish brown to dark olive green, occurring as 2-3" nodular horizons parallel to bedding in 1-2 ft. intervals; chert becomes slightly less abundant and more irregular in shape and orientation upward; burrowing decreases upward; small ledges and slopes.
343'-352'--very fine grained dolomite; (f) medium to dark bluish gray, (w) medium bluish gray; massive; less silt content than underlying lithology; notable chert-free, no visible sedimentary structures; poorly exposed.

352'-370'--fine to medium grained dolomite sandstone; (f) light gray, (w) light to dark brown; less resistant thin dolomitic laminae weather to a light brownish gray; thin to thick bedded, planar laminated and planar cross-bedded in 2-8" unidirectional and multidirectional sets; bottom 8 ft. is generally planar laminated and contains a few 10-20 mm dolomite clasts and faint vertical burrow traces; rounded ledges and benches.

370'-397'--interbedded fine to medium grained quartzite, dolomitic sandstone, and sandy dolomite; (f) light gray, (w) light brownish gray to medium brown; thick bedded, quartzite in 1-6 ft. beds, sandy dolomite and dolomitic sandstone in 1-3" beds; thinly laminated and minor 2-4" cross-laminated beds; prominent ledges and small cliffs.

397'-420'--fine to medium grained quartzite and subordinate sandy dolomite and dolomitic sandstone; (f) light gray, (w) light brown; thick bedded, quartzite beds display disruption and breakage into small laterally continuous blocks; sandy dolomite is medium grained sparry and occurs as small 2-6" beds and as infilling between disrupted quartzite; rounded benches.

420'-479'--interbedded fine to medium grained quartzite, sandy dolomite and dolomitic sandstone; (f) light gray,
(w) light brownish gray; thick bedded; considerable zones and beds of disruption of quartzite and dolomitic sandstone into large and small angular blocks and chunks; medium to coarse grained dolomite as matrix material; prominent outcrops and bare slopes.

479'-495'--very fine grained dolomite; (f) dark gray, (w) light bluish gray; thick bedded to massive; occasional thin sandy laminae; poorly exposed.

495'-504'--interbedded fine grained sparry dolomite and fine grained quartzite; (f) medium gray, (w) light gray; dolomite dominant as 4-6" thinly laminated beds, quartzite occurs as 2-5 mm laminae and small irregular masses; bare steep slopes.

504'-533'--medium to coarse grained sparry dolomite with large blocks and disrupted wavy laminae of quartzite and siliceous material; (f) medium gray, (w) light gray; massive bedded; disruption of bedding, zones of chaotic blocks, chunks and subangular-subrounded clasts of dark gray fine grained dolomite, light gray dolomite, and light brownish gray quartzite; bare slopes and prominent benches.

533'-555'--coarse crystalline dolomite; (f) medium light gray, (w) light gray, massive; occasional thin wavy laminae; zones of disruption, chaotic blocks and angular clasts of dark gray dolomite and light to medium gray fine grained dolomite; bare slopes and small ledges.

555'-660'--fine grained dolomite with subordinate beds of
coarse grained dolomite and dark gray dolomite; (f) medium gray to light gray, (w) medium gray; thick to thin bedded, dark gray dolomite is thinly laminated and slightly disrupted-brecciated; possible intraclastic texture; prominent benches and steps.

660-738'--alternating light and dark gray dolomite; thin to thick bedded; dark gray dolomite contains discontinuous thin laminae and stringers of coarse sparry white dolomite cement; light gray dolomite occasionally mottled light gray and light bluish gray; dark gray Amphipora? bearing bed at 736 ft.; benches and ledges.

738'-895'--alternating light and dark gray dolomite; thick bedded, light gray dolomite is dominant in 2-4 ft. beds, dark dolomite in 1-2 ft. beds; light dolomite frequently mottled; local beds or zones of disruption; benches and exposed slopes.

895'-915'--dark gray fine grained fossiliferous dolomite; horizons of abundant Amphipora? and biscuit-shaped stromatoporoids; horizons of brachiopods valves preserved as coarse white sparry dolomite ghosts; faint thin laminations; ledges and small cliff.

VAUGHN GULCH

Independence 15 min. quad., (type section for Vaughn Gulch Limestone), SE 1/4, EW-trending ridge, 0.3 mile NNW of Peak 4906, 0.9 mile SSE of Whiteside Mine, just N of Vaughn Gulch.
0'-19'--interbedded argillaceous shaly limestone and bioclastic limestone; (f) medium bluish gray, (w) light gray to light bluish gray; very thin to thin bedded, bioclastic limestone occurring in 2-18" beds, one 6 ft. structureless bed composed of large (up to 1 ft.) and small lithified carbonate blocks, corals, and calcareous algae; thinner bioclastic beds composed of coral and pelmatozoan degris, bryozoans, calcareous algae fragments, and shelly debris; frequently graded and micro cross-laminated at top, local scoured bases and soft sediment deformation; shaly limestone poorly exposed, argillaceous and slightly silty; platy parting; small bioclastic ribs and talus-covered saddles.

19'-76'--laminated shaly limestone; (f) dark bluish gray, (w) light bluish gray; shaly-bioclastic ratio approx. 1:1; bioclastic beds 6-18" thick, commonly graded, sometimes cross-laminated near top; silicified coral, pelmatozoan, bryozoan, algal, and other skeletal debris, soft sediment flowage and deformation of soft underlying carbonate muds; minor silty beds; talus-covered saddles and bioclastic ribs.

116'-148'--laminated shaly limestone to calcareous siltstone; (f) dark gray, (w) medium to light gray; poorly exposed, minor thin laminae of moderately sorted skeletal material; talus-covered slope.

148'-272'--interbedded shaly limestone and bioclastic limestone; (f) medium gray, (w) light bluish gray, thinly
laminated shaly beds; bioclastic beds are 2"-3 ft. thick, several of 3 ft. beds structureless with large skeletal fragments and lithified carbonate blocks; soft sediment flowage of carbonate muds; scour or load structures as base of some graded and structureless bioclastic beds; covered slopes and ribs.

272'-291'--thinly laminated calcareous shale and shaly limestone; (f) medium gray, (w) light bluish gray; thin 1/2" lenses-laminae of fine skeletal debris; poorly exposed.

291'-700'--interbedded bioclastic limestone and thin bedded shaly limestone; shaly-bioclastic ratio approx. 1:1, bioclastic beds 1-2 ft. thick, occasional 5 ft. structureless bed of large lithified carbonate blocks and corals up to 1 ft. diameter; other bioclastic beds overwhelmingly dominated by large fragments of crinoids and crinoidal debris; ribs and intervening saddles.

700'--fault; unknown amount of displacement; no significant change in bedding attitude.

700'-720'--interbedded bioclastic limestone and thin bedded shaly limestone; shaly-bioclastic ratio approx. 2:1, bioclastic beds thinner and less skeletal-rich; ribs and talus-covered slope.

720'-948'--thin bedded shaley limestone, calcareous silty shale and minor bioclastic beds; bioclastic beds only 10% of total lithology; becomes silty upward; poorly exposed; talus-covered slope and small steps.
948'-1084'--silty and platy argillaceous cherty limestone; (f) medium bluish gray, (w) medium gray to light brownish gray; chert occurs as scattered small nodules and rhythmically occurring nodular horizons on a 1-2 ft. spacing in argillaceous and silty limestone; limestone is brittle and platy in upper 50 ft.; large scale soft sediment slumping and flowage, plastic deformation and folding in cherty beds.

1084'--erosional unconformity; considerable relief on erosion surface, limestone-chert conglomerate and siliceous quartzites overlying above lithology.

SUNDAY CANYON

Independence 15 min. quad., (type section for Sunday Canyon Formation), SW 1/4 of NE 1/4; approx. 1/2 mile NE of Barrel Springs, in Bonanza Gulch.

0'-66'--calcareous shale, minor bioclastic beds; (f) medium gray, (w) light gray; very thinly laminated, rare graptolite fragments on bedding planes; bioclastic beds 2-8" thick, less than 5% of total lithology; soil and talus-covered slopes.

66'-96'--interbedded calcareous shale, thin bedded limestone, and minor bioclastic beds; bioclastic beds about 10% of total interval, occurring as medium to fine skeletal debris, sometimes graded; silicified skeletal material; shale and argillaceous limestone poorly exposed.
96'-190'--poorly exposed; talus is shaly and platy calcareous shale.

190'-373'--calcareous shale, siltstone, and thin bedded argillaceous limestone; occasional 2-4" beds of medium to fine grained skeletal debris; graptolite fragments in shaly beds; poorly exposed, small ribs and soil-covered slopes.

373'-468'--thin bedded silty and cherty argillaceous limestone; (f) medium dark gray, (w) light brownish gray to pale brown; dark gray chert occurs as rhythmically occurring nodular horizons parallel to bedding on a 6" to 2 ft. spacing; chert less abundant at bottom of interval; somewhat silty; well exposed in gully floor and walls; chert forms small ribs.

468'-523'--thin bedded argillaceous limestone and minor bioclastic beds; bioclastic beds 6" to 3 ft. thick, about 5-10% of total lithology, last bioclastic bed 40 ft. from tope of formation; soil-covered slopes and small bioclastic ribs.

523'--erosional unconformity; overlain by chert pebble conglomerate and calcareous sandstone.

LOCATION OF OTHER MEASURED SECTIONS

Bat Mountain: Ryan 15 min. quad., NE 1/4 of SE 1/4 at edge of sheet; prominent ridge 1/2 mile N of Peak 4963, west slope of Funeral Mountains.
Cottonwood Mountains: Marble Canyon 15 min. quad., SE 1/4, 2200 ft. due S. of Peak 2185.

Dry Mountain: Dry Mountain 15 min. quad., NW 1/4 of NE 1/4, 2.5 miles due N of Dry Mountain, 2.5 miles SSE of Marble Bath, 1/2 mile NE of Peak 8191, just S of basalt outcrop.


Lost Burro: Ubehebe Peak 15 min. quad., Lost Burro Gap southern end, NE 1/4, 1700 ft. SSE of BM 4682.

Panamint Range: Dry Mountain 15 min. quad., SE 1/4, 2-3/4 miles SSE of Dry Mountain, 1-1/4 miles S of Peak 8433, 3 miles due W of road, EW-trending ridge, E slope of Panamint Range.