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Depositional environments and paleogeographic setting of the middle Mississippian section in eastern California

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DEPOSITIONAL ENVIRONMENTS AND PALEOGEOGRAPHIC SETTING OF THE MIDDLE MISSISSIPPIAN SECTION IN EASTERN CALIFORNIA

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ABSTRACT

Field study of the middle Mississippian section in eastern California indicates that during this time a carbonate platform in this area evolved from a ramp to a rimmed shelf. The platform evolution is reflected in lithologic changes in both platform and basinal settings within the study area that can be correlated with similar lithologic changes in age-equivalent sections in the Monte Cristo Group of southern Nevada and the Redwall Limestone of northern Arizona. The units specifically studied in eastern California include the informally named Stone Canyon limestone and Mexican Spring formation, which comprise the Perdido group (informally elevated from formational status), and the Santa Rosa Hills Limestone.

During the early Osagean, the western portions of the shallow-water, Early Mississippian shelf were drowned and an initial homoclinal ramp developed, which extended from northern Arizona to the study area. This homoclinal ramp deepened to the northwest with the shallow-water facies represented by the Thunder Springs Member of the Redwall Limestone in northern Arizona and the deeper, basinal rocks composed of radiolarian-bearing mudstone in eastern California.

In the late Osagean, a thick sequence of cherty lime

mudstone and wackestone accumulated in the southeastern portion of the study area, and the morphology of the carbonate ramp was altered to that of a distally steepened ramp. Submarine slides, chert, and argillaceous limestone were deposited to the northwest at the base of the carbonate slope. A well defined inner ramp was present in northern Arizona and southern Nevada and the outer ramp, ramp slope, and basin were developed in eastern California.

During the Meramecian, inner ramp carbonate sands prograded northwestward over the outer ramp deposits. These shallow-water, high-energy, carbonate sands prograded to the carbonate slope (situated near the Santa Rosa Hills) and the carbonate platform became a rimmed shelf with cross-bedded carbonate sand shoals and coral buildups at the platform margin. The shoal-rimmed shelf was fully developed by the middle Meramecian with inner and middle shelf (northern Arizona and southern Nevada), outer shelf (Santa Rosa Hills Limestone in eastern California), slope, base-of-slope, and basin (Mexican Spring formation) environments clearly delineated. Abundant turbidites and debris flows were deposited in a base-of-slope setting to form a carbonate base-of-slope apron. The shelf extended through northern Arizona into eastern California, where, in the study area, the shelf-to-basin transition is located.

INTRODUCTION

Within the thick accumulations of Paleozoic strata in the Basin and Range Province are sedimentary patterns and structural features that record the complex tectonic evolution of the Paleozoic western margin of North America. Excellent exposures of Paleozoic sedimentary rocks are present in the Inyo Mountains-Death Valley region of California. This area is of particular significance because it represents the westernmost extension of the Basin and Range Province and is the southwesternmost area in the Cordillera that may be unaffected by post-Paleozoic tectonic erosion and/or accretion processes (Coney and others, 1980; Blake and others, 1982).

The present investigation is a detailed study of the vertical and lateral depositional patterns present in the shallow- to deep-water facies of the middle Mississippian section in eastern California. The purpose of this research is:

(1) to study the evolution of the carbonate platform in this region during the middle Mississippian,

(2) to better determine mass transport sedimentation styles on the slope of this carbonate platform,

(3) to interpret the origin and paleoenvironmental

significance of the siltstone facies present from northern Death Valley to the Inyo Mountains, and

(4) to determine whether or not the Antler orogenic belt influenced sedimentation patterns in the study area.

The combined results from this research should lead to a better understanding of the Mississippian paleogeography in southwestern United States and provide detailed information regarding the sedimentary characteristics, styles, and processes that are directly associated with carbonate shelf-to-basin transitions.

Area of Investigation

The area of study is located in the westernmost part of the Basin and Range Province from northern Death Valley National Monument to the southeastern Inyo Mountains (fig. 1). Within this region six localities were selected for study (fig. 2) based on geographic location, outcrop exposure, and accessibility. Geographically, the investigation sites were chosen in order to cross the shelf-to-basin transition approximately perpendicular to the trend of the Mississippian platform margin. The six localities are:

(1) Quartz Spring area (type locality for the Perdido Formation) - northern Death Valley National

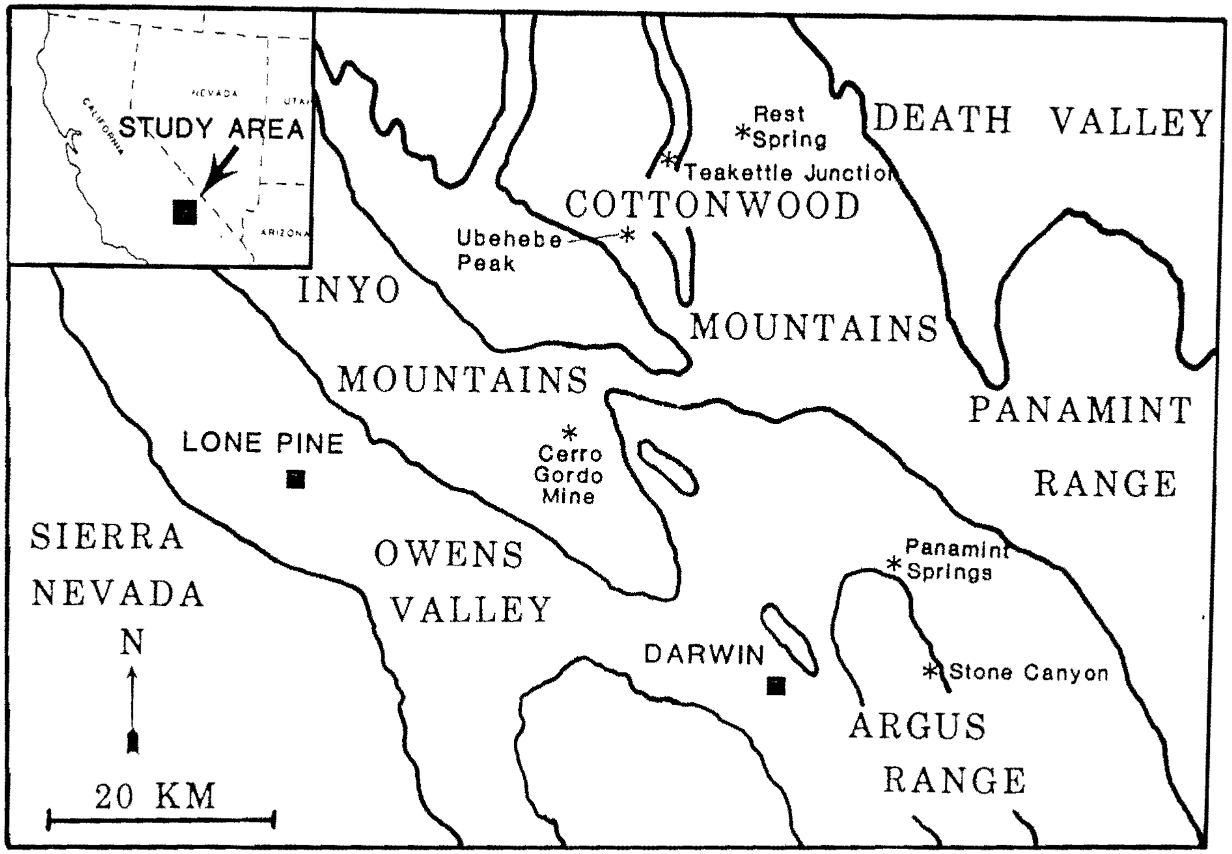


Figure 1. Location of study area in eastern California.

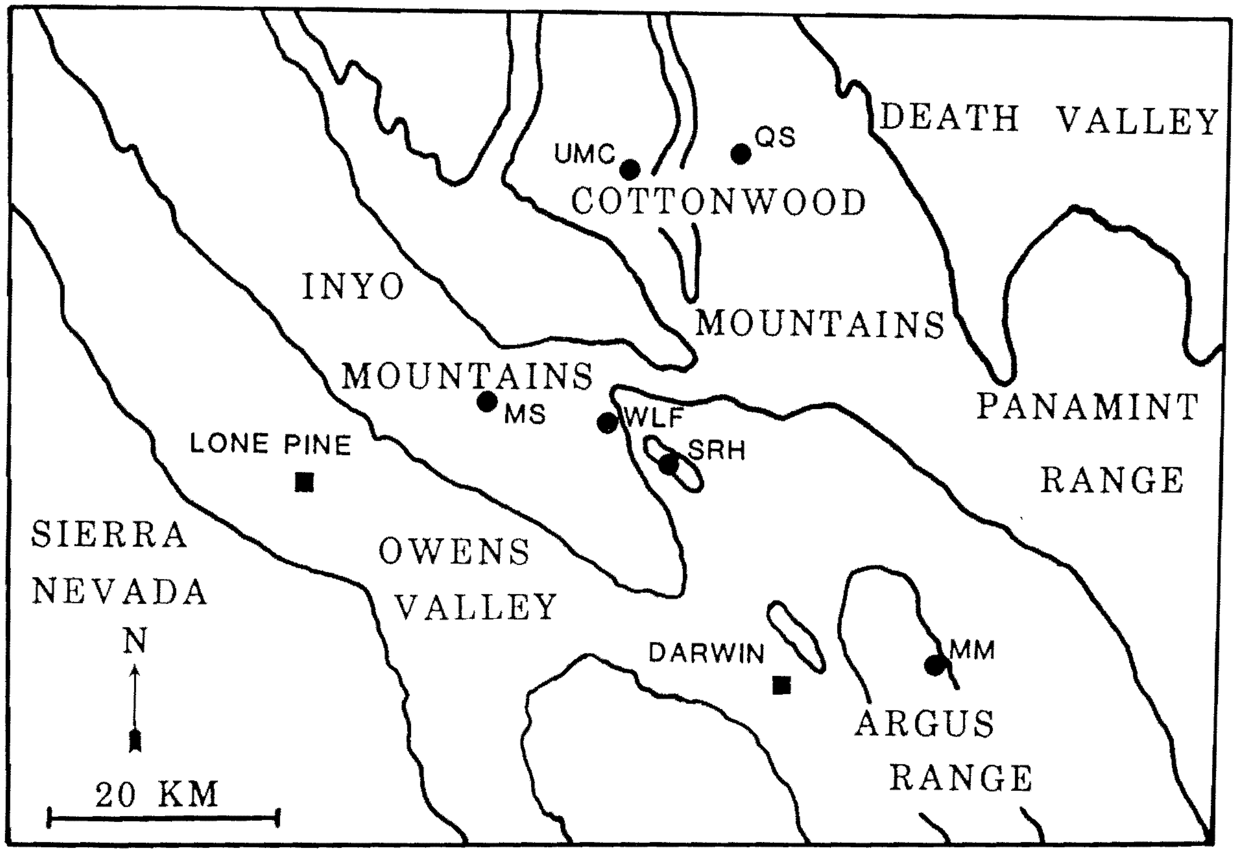


Figure 2. Measured section localities (QS - Quartz Spring area, UMC - Ubehebe Mine Canyon area, WLF - western Lee Flat area, SRH - Santa Rosa Hills, MS - Mexican Spring area, MM -Minnietta Mine area).

Monument, Tin Mountain quadrangle, T13S, R42E, 36°45'30"N lat, 117°26'27"W long, approximately 9 km east of Teakettle Junction.

(2) Ubehebe Mine Canyon - northern Death Valley National Monument, Dry Mountain quadrangle, T14S, R42E, 36°45'20"N lat, 117°36'3"W long, approximately 7 km north of Ubehebe Peak.

(3) western Lee Flat area - Ubehebe Peak quadrangle, T15S, R39E, 36°31'10"N lat, 117°42'10"W long, on the east side of the Inyo Mountains.

(4) Santa Rosa Hills (type locality for the Santa Rosa Hills Limestone) - Darwin quadrangle, T17S, R40E, 36°27' to 36°28'N lat, 117°38'W long.

(5) Mexican Spring area - southeastern Inyo Mountains, New York Butte quadrangle, T15S, R38E, 36°35'48"N lat, 117°26'34"W long, approximately 7 km northwest of Cerro Gordo Mine.

(6) Minnietta Mine area - northern Argus Range, Panamint Butte quadrangle, T19S, R42E, 36°15'13"N lat, 117°26'28"W long, approximately 9.5 km south of Panamint Springs.

Methods of Investigation

Sixty-eight days were spent doing field work during the three-year period from 1982 to 1984. Field work took place in two phases. Reconnaissance was undertaken during 1982 and was designed to determine the accessibility of each proposed investigation site and to note the completeness of each section to be measured and described. Actual field work took place during 1983 and 1984. Each section was measured with a Jacob's staff and described in detail. Section description included both vertical and lateral observations in order to note lithologic changes, sedimentary structures, paleocurrent indicators, local facies geometries, and lateral facies variations. Particular emphasis was placed on the recognition and delineation of facies sequences for their subsequent environmental interpretation in terms of facies associations.

Samples for petrographic and paleontologic study were collected from each measured section. Petrographic samples were collected of all major lithologies for subsequent thin-section analysis to better define the nature of the constituents and fabric, and to classify the rocks. Classification schemes of Dunham (1962) and Folk (1980) were utilized. Clasts from limestone conglomerates also were sampled for thin-section analysis in order to determine their origin. This resulted in the preparation and examination of 126 thin sections.

Paleontologic samples (conodont, foraminifera, and coral) were collected primarily for the purpose of dating in order to establish relative sedimentation rates and time-stratigraphic correlations. Thin sections that contained foraminifera were sent to Paul Brenckle (Amoco) for identification and dating. Conodont samples were collected from most major limestone lithologies. Each conodont sample constituted 3 to 4 kg of rock, which was crushed to 2- to 5-cm pieces and placed in a solution of 10 percent acetic acid. The resulting insoluble residues were dried and separated into light and heavy fractions with bromoform. Conodonts were picked from the heavy fraction and sent to Charles Sandberg (U.S. Geological Survey) for identification and dating. Colonial rugose corals were thin sectioned and identified by Calvin Stevens (San Jose State University).

Geologic Setting

The Inyo Mountains-Death Valley region in eastern California lies near the western margin of the Basin and Range Province, at the eastern edge of the Sierra Nevada Province, and extends almost completely across the Cordilleran miogeocline. Because interpretation of the Mississippian geologic history depends, in part, on an understanding of the prior and subsequent tectonic development of western North America, this history is briefly outlined in the following paragraphs.

Roberts (1964) divided the upper Proterozoic and lower Paleozoic rocks in the Basin and Range Province into three sedimentary assemblages: an eastern carbonate (miogeosynclinal) assemblage, a western siliceous (eugeosynclinal) assemblage, and an intermediate transitional assemblage. The carbonate assemblage is essentially equivalent to the shallow-marine sedimentary rocks and consists primarily of carbonates and orthoquartzites. These rocks occur in eastern Nevada and extend through southern Nevada into eastern California. The siliceous assemblage represents the sedimentary rocks deposited in base-of-slope and basin-plain settings and consists predominantly of impure sandstone, chert, and shale. These rocks occur primarily in central and western Nevada. The transitional assemblage appears between the carbonate assemblage and siliceous assemblage and consists of a mixture of both rock assemblages. This scheme has generally been applied to the Precambrian through Mississippian rocks of eastern California.

The Antler orogeny occurred during the late Devonian to Early Mississippian. This major tectonic event resulted in the emplacement of lower Paleozoic, deep-water siliceous-assemblage rocks over age-equivalent carbonate-assemblage rocks along the complex Roberts Mountain thrust in central Nevada (Roberts and others, 1958; Stewart and Poole, 1974; Smith and Ketner, 1977). The emplacement of the allochthon resulted in the formation of an orogenic highland and led to the development of a foreland basin situated to the east (fig. 3).

Poole (1974) and Poole and Sandberg (1977) showed the Antler orogenic belt extending from near the United States-Canada border to southern California (fig. 4). Evidence used for extending the Antler belt into regions beyond central Nevada is based on the presence of late Paleozoic siliciclastics and chert-bearing conglomerates (Pelton, 1966; Poole, 1974; Dover, 1977; Skipp and Hall, 1977; Nilsen, 1977; Burchfiel and Davis, 1981), because thrust faults of Mississippian age have not been found in the Basin and Range Province outside of Nevada (Stevens and Ridley, 1974; Dover, 1977; Skipp and Hall, 1977). Because of the lack of structural data, this extension of the Antler orogenic belt has remained a point of contention.

Although the structural record of the Antler orogeny appears to be restricted to central Nevada, the event is believed to have affected sedimentation patterns on the adjacent continental shelf. Rose (1976), Gutschick and others (1980), Sandberg and Gutschick (1980), and Gutschick and Sandberg (1983) studied the Mississippian stratigraphy throughout much of the Basin and Range Province and

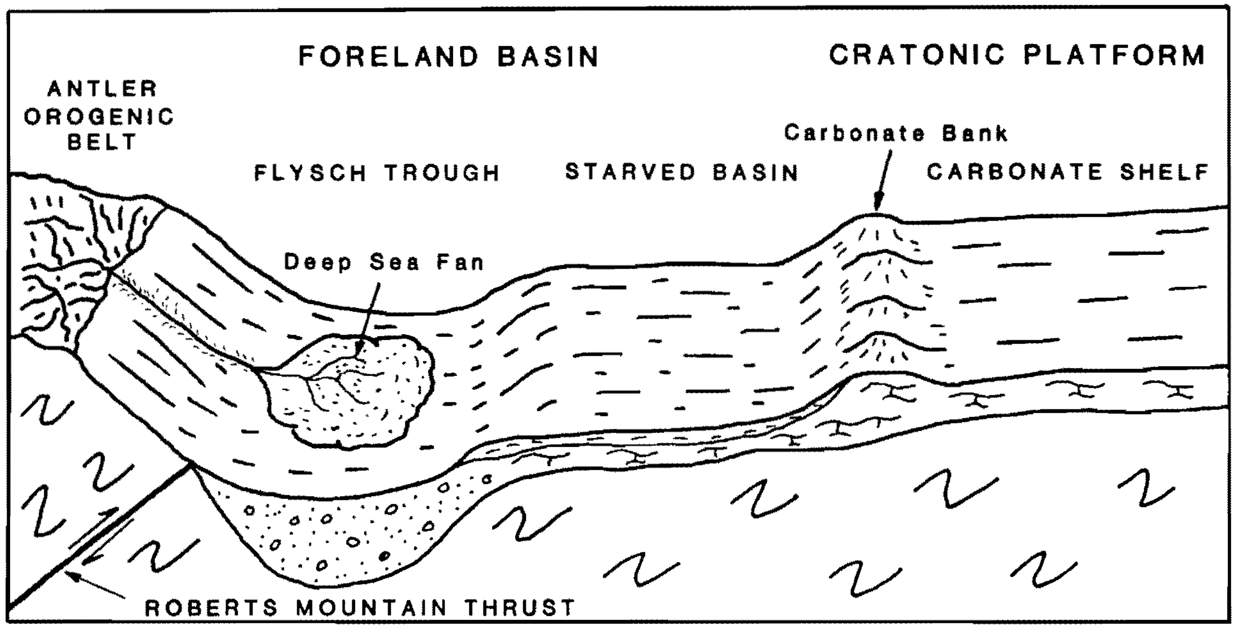


Figure 3. Depositional settings of the foreland basin and cratonic platform during early Mississippian time (modified from Nilsen, 1977).

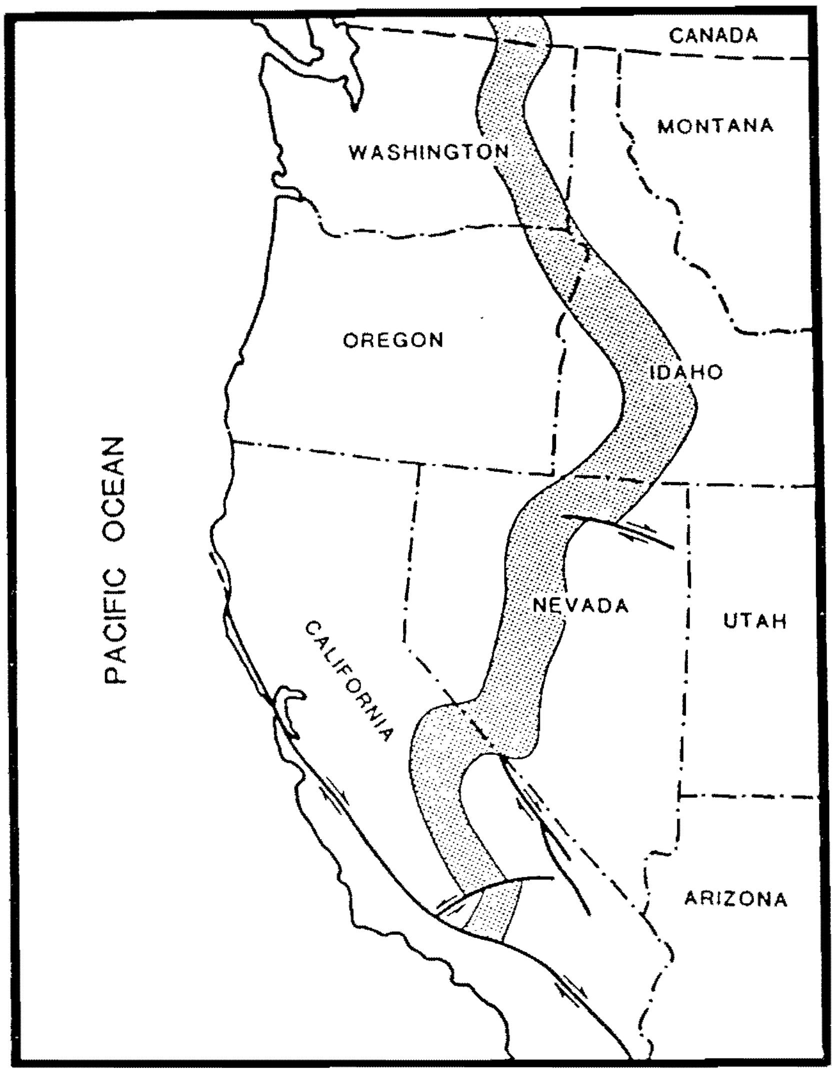


Figure 4. Regional extent of the Antler orogenic belt as interpreted by Poole (1974) and Poole and Sandberg (1977).

identified several eustatic sea level changes that may be attributable to the Antler orogeny. Of particular significance to the present study is a major sea level rise (transgression) which occurred during the middle Osagean S. anchoralis - D. latus conodont zone (latest Tournaisian, Mamet foraminiferal zone 9) (Gutschick and others, 1980; Gutschick and Sandberg, 1983), and a possible drop in eustatic sea level during middle Meramecian time (Rose, 1976; Gutschick and others, 1980).

Thrust faults of Late Paleozoic and Mesozoic age have been identified in the area of study. These thrust faults generally involved west to east movement that has resulted in the telescoping and juxtaposition of very different sedimentary facies on adjacent structural blocks (Stevens and Stone, 1985). For instance, the measured sections at Mexican Spring and western Lee Flat, that are presumably within a single structural block, have been telescoped against profoundly different facies in the Santa Rosa Hills. In the northern portion of the study area, the Racetrack Thrust has telescoped the sedimentary facies between Ubehebe Mine Canyon and the Quartz Spring area. The amount of west to east displacement on this fault is unknown, but it may be as great as several tens of kilometers. The identification of these thrust faults is important in interpreting the spatial relations of major sedimentary facies in the study area.

The Late Mesozoic was a time of pronounced tectonic changes in the study area and throughout much of the Cordillera. Andean-type subduction was responsible for the magmatic Nevadan orogeny and numerous thrust faults that telescoped sedimentary facies throughout the back-arc region of the Basin and Range Province. In the Inyo Mountains- Death Valley region, Mesozoic intrusive bodies penetrate the Paleozoic sedimentary section in many locations and are interpreted to underlie much of the western portion of the region (Ross, 1966). These plutonic rocks locally have complicated the interpretation of the Paleozoic depositional history.

Low-angle extensional faults (Stewart, 1983) and voluminous silicic volcanics (Cook, 1960; Mackin, 1960; Cook, 1968) reflect the tectonic change from compression to extension in the Tertiary. Northwest-trending, large-scale dextral faults, including the Las Vegas and Death Valley-Furnace Creek shear zones, resulted in the separation of sedimentary facies on the order of 40 to 100 km. Extensional tectonics continued into the Quaternary with movement along normal faults and extrusion of young felsic and basaltic volcanic rocks.

Previous Work

McAllister (1952) completed the earliest systematic work on Mississippian stratigraphy in the region of study. Three Mississippian units (Tin Mountain Limestone, Perdido Formation, and Rest Spring Shale) were named, described, and mapped in the area immediately surrounding Quartz Spring of northern Death Valley National Monument. The stratigraphic scheme of McAllister (1952) has been applied in most subsequent investigations in the Inyo Mountains-Death Valley region with only minor revisions due to the recognition of additional formations. One is the Santa Rosa Hills Limestone, which occurs in the southeastern portion of the study area and was named for exposures in the Santa Rosa Hills of the Darwin quadrangle (Dunne and others, 1981). This unit was previously mapped as Lee Flat Limestone of Hall and MacKevett (1962) and subsequently by Stadler (1968), Hall (1971), Johnson (1971), Randall (1975), and Holden (1976) throughout much of the region. Recently, the Indian Springs Formation has been recognized in the Darwin quadrangle (Stevens, 1986). This unit was originally named for exposures in the Spring Mountains of Nevada. The Indian Springs Formation previously had been mapped as Rest Spring Shale in the study area (Hall and MacKevett, 1962; Dunne and others, 1981).

Stevens and others (1979) summarized the sedimentologic and paleontologic data available on four Mississippian units present in eastern California. The Indian Springs Formation was not recognized as a distinct unit and was included as part of the Rest Spring Shale. Two conclusions from Stevens and others (1979) are particularly pertinent to this investigation and represent the foundation upon which this present investigation was constructed.

(1) The Perdido Formation can easily be divided into a clastic facies and a carbonate facies that differ greatly in lithologic character. This division is desirable because the two facies are envisioned to have been deposited in much different depositional environments.

(2) A Mississippian shelf-to-basin transition is present in eastern California. Shallow-shelf carbonates are present to the southeast and the deeper water rocks occur to the northwest.

REGIONAL MISSISSIPPIAN STRATIGRAPHY

The formational boundaries mapped in eastern California are based on major lithologic changes in the stratigraphic section. These lithologic changes, in turn, are sedimentary facies boundaries crucial to the understanding of the paleogeography of the region.

The Perdido Formation and the Santa Rosa Hills Limestone are the two primary middle Mississippian units studied in this investigation. Within the study area, the Perdido Formation consists of two major facies: a carbonate facies, which is present in the southeastern portion of the area, and a clastic facies, which is present to the northwest. Only in the central portion of the study area are these two facies coincident. Because of this, the Perdido Formation is informally designated the Perdido group and subdivided into two formations. The carbonate facies is informally named the Stone Canyon limestone and the clastic facies is informally named the Mexican Spring formation. Throughout the study area the Perdido group is underlain by the Tin Mountain Limestone, and it is overlain by the Rest Spring Shale in the northwest portion of the region and the Santa Rosa Hills Limestone to the southeast. The Rest Spring Shale everywhere overlies the Mexican

Spring formation within the study area and is nowhere present in the same stratigraphic section as the Santa Rosa Hills Limestone. The Indian Springs Formation overlies the Santa Rosa Hills Limestone in the Darwin quadrangle and also may be present in the Argus and Panamint ranges (Calvin Stevens, pers. comm., 1985). These units correlate with the Monte Cristo Group, Battleship Wash Formation, and the Indian Springs Formation of southern Nevada (Pierce and Langenheim, 1972; Brenckle, 1973; Poole and Sandberg, 1977) and the Redwall Limestone of northern Arizona (McKee and Gutschick, 1969; Rawson and Kent, 1979). Figure 5 shows correlations of the units in eastern California, southern Nevada, and northern Arizona.

Tin Mountain Limestone

General Description and Occurrence

The Tin Mountain Limestone was named by McAllister (1952) for exposures on Tin Mountain in the northern Panamint Range, but because the area is so inaccessable, the type locality was designated as a southern slope of hills approximately 4 km southeast of Quartz Spring. This unit is the lowest Mississippian formation in the region and consists predominantly of fossiliferous, medium- to dark-gray limestone that locally contains dark-gray chert nodules. Limestone beds typically are 5 to 50 cm thick and

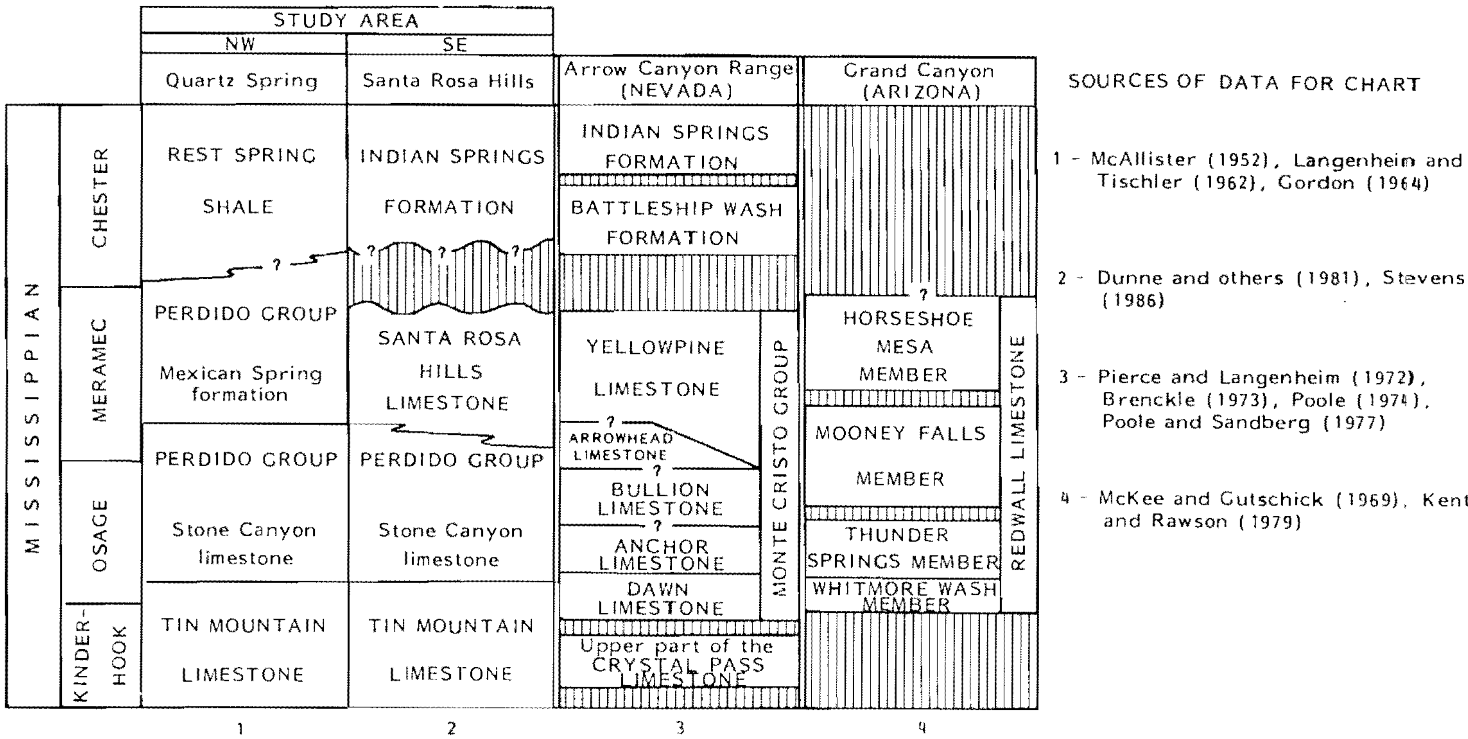


Figure 5. Correlation of Mississippian units in eastern California, southern Nevada, and northern Arizona.

are separated by thin partings of bluish-gray to pale-red shale (McAllister, 1952).

The Tin Mountain Limestone is present throughout much of the Inyo Mountains-Death Valley region. McAllister (1956) mapped the Tin Mountain Limestone in the Ubehebe Peak quadrangle, and it subsequently was recognized in the Darwin quadrangle (Hall and MacKevett, 1962), the Dry Mountain quadrangle (Burchfiel, 1969), and the Panamint Butte quadrangle (Hall, 1971). The unit is 105 to 175 m thick throughout most of eastern California but thins abruptly to the northwest (Stevens and others, 1979). In the Cerro Gordo Mining District, where the Tin Mountain Limestone is much finer grained and more thin bedded than usual, it is only 105 m thick and it pinches out only a short distance to the northwest, just outside of the study area (Merriam, 1963; Ross, 1965).

Age

The Tin Mountain Limestone is the most fossiliferous Mississippian unit in the region. McAllister (1952) and Langenheim and Tischler (1960) collected numerous corals, brachiopods, and gastropods from the Quartz Spring area and dated the unit as Early Mississippian. Similarly, Hall (1971) arrived at an Early Mississippian age for the Tin Mountain Limestone in the Panamint Butte quadrangle based on an extensive collection of corals, brachiopods, gastropods, and several other invertebrate groups. At Cerro Gordo, in the southeastern Inyo Mountains, Merriam (1963) collected several species of corals and brachiopods and also determined that the unit is Early Mississippian in age. McAllister (1974) studied the Tin Mountain Limestone in the Funeral Mountains (just east of the Death Valley-Furnace Creek shear zone) and was the first to date the unit at epochal level. Based upon an exhaustive collection of both macrofossils (corals, brachiopods, and gastropods) and microfossils, McAllister (1974) determined that the base of the Tin Mountain Limestone is Kinderhookian and the top is Osagean. Throughout the study area the Tin Mountain Limestone is considered Early Mississippian in age.

Perdido Group

General Description and Occurrence

The Perdido Formation was named by McAllister (1952) for a heterogenous sequence of strata which crops out in Perdido Canyon, approximately 3 km southeast of Quartz Spring. Because the uppermost portion of the Perdido Formation is faulted in Perdido Canyon, the type locality is supplemented by a second locality, about 1 km south of Rest Spring.

The type section of the Perdido Formation includes a diverse assemblage of carbonate and clastic rocks.

McAllister (1952, p. 22) stated that "the Perdido Formation lithologically is greatly diversified within one section and also from place to place, so that its heterogeneity is an outstanding characteristic." In the Quartz Spring area the Perdido Formation has been divided into two lithologically distinct facies: a lower carbonate facies, which is predominantly composed of fine-grained limestone and chert, and an upper clastic facies, composed of siltstone, limestone, conglomerate, shale, and sandstone (McAllister, 1952; Langenheim and Tischler, 1960). In the Quartz Spring area, Ubehebe Mine Canyon, and the western Lee Flat area, both the carbonate and clastic facies of the Perdido Formation are present. Elsewhere, only one facies is present in any given area, except locally where the two facies may be been juxtaposed by thrust faulting (e.g., Talc City Hills). Figure 6 shows the distribution of the carbonate and clastic facies of the Perdido Formation in the area of study.

The very different lithologic character and areal distribution of the two facies of the Perdido Formation has been the source of much confusion in discussions pertaining to regional Mississippian depositional environments and paleogeography (Stevens and others, 1979; Klingman, 1984; Stevens, 1986). Because of this confusion, the Perdido Formation is herein informally designated the Perdido group

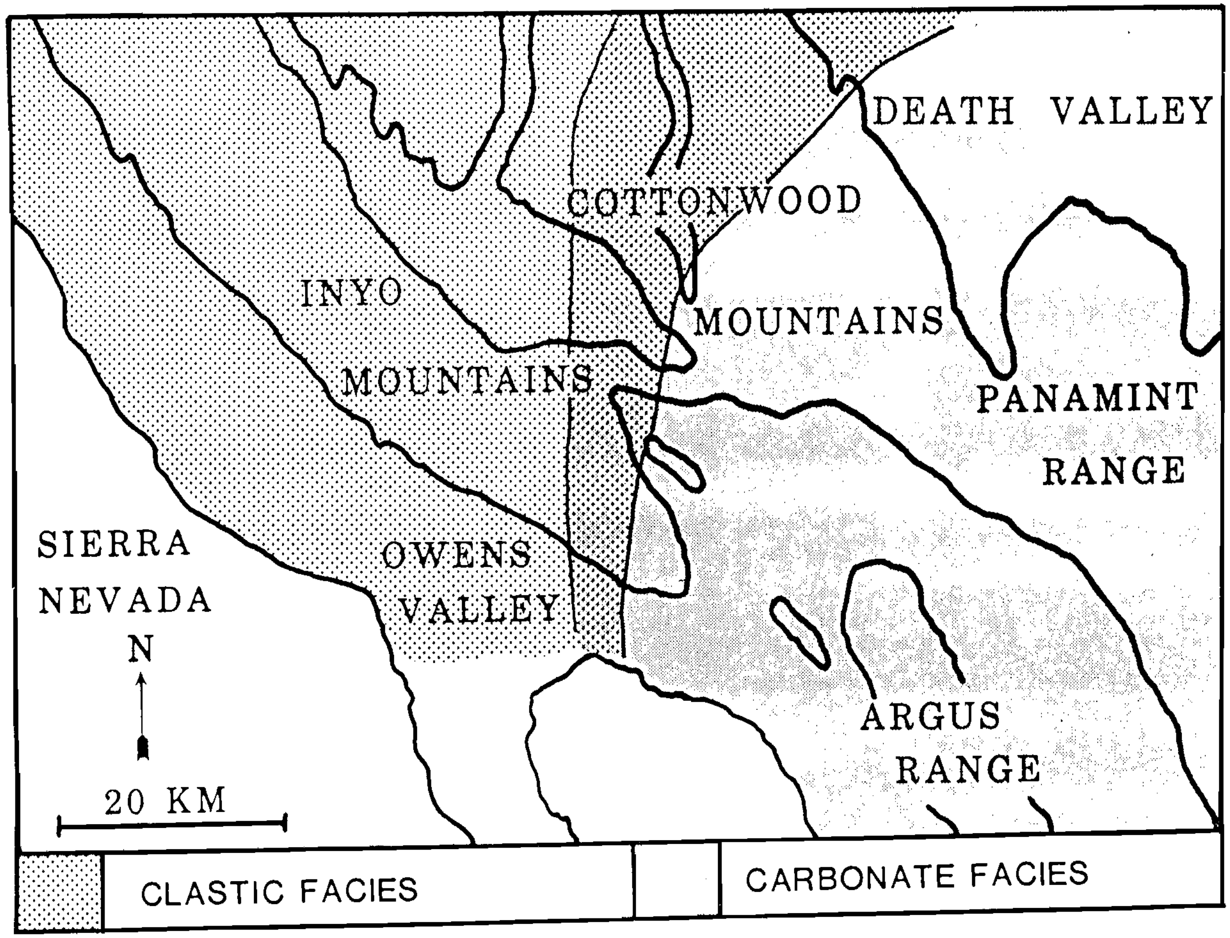


Figure 6. Distribution of the carbonate and clastic facies of the Perdido Formation.

and divided into two distinct formations. The carbonate facies of the Perdido Formation is informally designated the Stone Canyon limestone for the slightly metamorphosed but excellent exposures present near the mouth of Stone Canyon in the northern Argus Range of the Panamint Butte quadrangle (fig. 7). The upper clastic facies is informally named the Mexican Spring formation for a section mapped by Merriam (1963) at Mexican Spring in the southeastern Inyo Mountains. In the Quartz Spring area, and to the south and east of Quartz Spring, the Stone Canyon limestone lies conformably upon the Tin Mountain Limestone. The contact is placed between the lower thick-bedded, fossiliferous limestone and the upper thin-bedded, fine-grained, cherty, argillaceous limestone (McAllister, 1952; Langenheim and Tischler, 1960). Elsewhere in the study region, the contact between the Tin Mountain Limestone and the Stone Canyon limestone is less distinct. The basal contact of the Stone Canyon limestone commonly is placed at the base of the lowest occurrence of thick-bedded chert (Hall, 1971; Dunne and others, 1981).

The abundance of siltstone is the diagnostic characteristic of the Mexican Spring formation. At the type locality, the Mexican Spring formation consists entirely of siltstone. Elsewhere, it commonly occurs interbedded with limestone, chert, and limestone

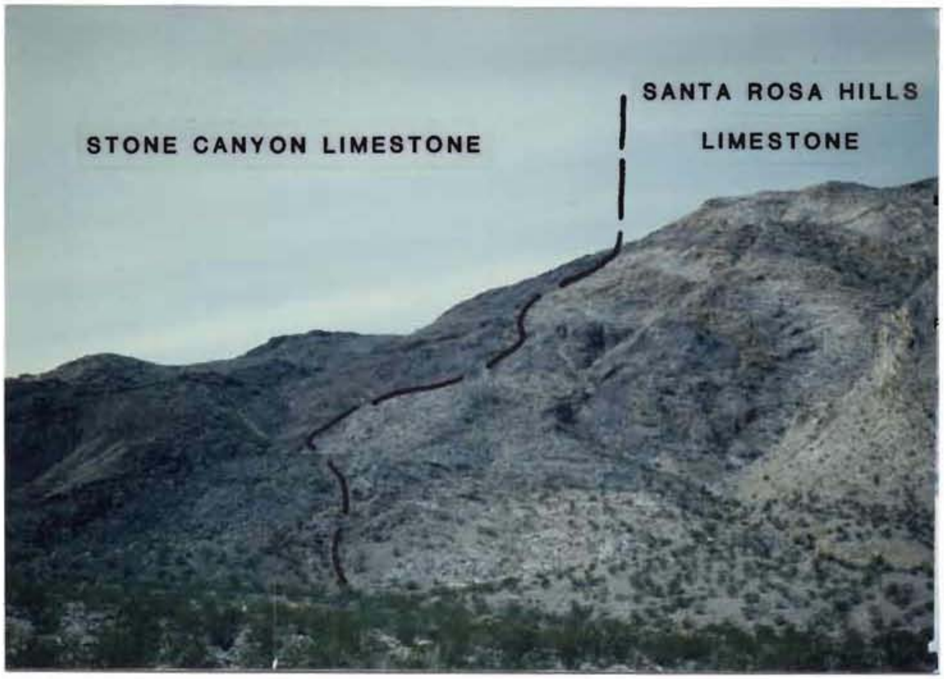


Figure 7. Stone Canyon limestone near the mouth of Stone Canyon in the Argus Range.

conglomerate. It is 163 m thick in the Quartz Spring area and thins to 37 m in the southern Inyo Mountains.

In the Quartz Spring area, where the lithologic transition between the informally designated formations is somewhat gradational, the base of the Mexican Spring formation is placed at the base of the lowest sequence of siltstone beds. The Mexican Spring formation commonly underlies smooth, rounded slopes covered with siltstone rubble (fig. 8) and, as a result, care must be taken in mapping the lower contact because uppermost limestones of the Stone Canyon limestone are commonly concealed by siltstone talus. The upper contact of the Mexican Spring formation is placed at the top of the uppermost limestone or siltstone bed that underlies the thick sequence of dark-gray, carbonaceous shale of the Rest Spring Shale. Everywhere in the study area the Mexican Spring formation is overlain by the Rest Spring Shale; where the Mexican Spring formation is not present, the unit overlying the Stone Canyon limestone is the Santa Rosa Hills Limestone.

Age

Age-diagnostic macrofossils are relatively scarce in both the Stone Canyon limestone and the Mexican Spring formation. In the Quartz Spring area collections of corals, brachiopods, and gastropods made by McAllister (1952) and Langenheim and Tischler (1960) date both of the

Figure 8. Mexican Spring formation in the Quartz Spring area. Note the smooth, rounded slopes covered with siltstone rubble.

formations as Late Mississippian. The presence of *Cravenoceras* in an ammonoid-bearing limestone at the base of the Rest Spring Shale, immediately overlying the Mexican Spring formation, indicates that the top of the Mexican Spring formation probably is Chesterian in age (i.e., latest Mississippian). A brachiopod collected from the uppermost limestone bed of the Mexican Spring formation reinforces a Chesterian age for the top of the unit (Calvin Stevens, pers. comm., 1983).

The Mexican Spring formation has not been dated outside of the Quartz Spring area and age-diagnostic fossils have been identified in the Stone Canyon limestone in only a few localities. Dunne and others (1981) recovered probable Meramecian conodonts from the Stone Canyon limestone in the Santa Rosa Hills. McAllister (1974) collected brachiopods, conodonts, foraminifera, and calcareous algae from the formation in the Funeral Mountains. The fossils obtained from the base of the unit were inadequate to distinguish an Osagean from Meramecian age. The top of the Stone Canyon limestone in the Funeral Mountains is middle Meramecian based on foraminifera and conodonts.

Santa Rosa Hills Limestone

General Description and Occurrence

The Santa Rosa Hills Limestone was named by Dunne and others (1981) for exposures of light- to medium-gray, massive limestone that overlies the Stone Canyon limestone in the northern Santa Rosa Hills. This limestone unit is rich in pelmatozoan debris and contains minor amounts of interbedded chert. The transition between the Stone Canyon limestone and Santa Rosa Hills Limestone is somewhat gradational; the lower contact of the Santa Rosa Hills Limestone is placed at the lowest light-gray, massive limestone that lacks chert (Dunne and others, 1981; Stevens, 1986). The upper contact is abrupt and is placed at the base of the lowest siliciclastic bed of the overlying Indian Springs Formation.

Throughout most of the Argus and Panamint ranges, the Santa Rosa Hills Limestone is a light-gray, medium- to coarse-grained marble with subordinate calc-hornfels formed from chert. Within the study area, the Santa Rosa Hills Limestone was previously mapped as Lee Flat Limestone (Stadler, 1968; Hall, 1971; Johnson, 1971; Randall, 1975; Holden, 1976).

At the type locality, the Santa Rosa Hills Limestone is 83 m thick, but it thickens to more than 200 m to the southeast (Stevens and others, 1979; Dunne and others, 1981). The formation is not present at any locality north or west of the Santa Rosa Hills, where the approximately coeval strata are represented by the Mexican Spring formation.

Age

Except in the type locality, few age-diagnostic fossils have been recovered from the Santa Rosa Hills Limestone. In the Santa Rosa Hills, Dunne and others (1981) collected colonial rugose corals, conodonts, foraminifera, and calcareous algae that indicate the unit is Meramecian in age.

Rest Spring Shale

General Description and Occurrence

The Rest Spring Shale overlies the Mexican Spring formation and was named by McAllister (1952) for exposures about 0.6 km south of Rest Spring in the Quartz Spring area. The Rest Spring Shale consists of dark-gray, carbonaceous shale with subordinate amounts of siltstone, sandstone, and conglomerate (McAllister, 1952). The lower contact is placed at the lowest occurrence of dark-gray shale overlying the siltstone of the Mexican Spring formation. In the Quartz Spring area, McAllister (1952) placed the lower contact of the Rest Spring Shale at the base of the dark shale immediately overlying an ammonoid-bearing limestone, which he assigned to the Perdido Formation. However, during this study the ammonoid-bearing limestone was considered more appropriately placed within the Rest Spring Shale because dark-gray shale occurs both below and above the limestone. Therefore, in all areas, the base of the Rest Spring Shale is placed at the lowest occurrence of dark-gray shale.

The actual thickness of the Rest Spring Shale is not known in most areas because of the numerous complex structures within the formation. McAllister (1952, p. 25) stated that "no complete stratigraphic section of the Rest Spring Shale has been measured in the Quartz Spring area. Complex structures, generally covered by finely broken shale in slope rubble, could not be mapped and precluded the measurement of the true stratigraphic thickness." Estimates of thickness generally have ranged from 120 m to more than 305 m in the region of study (McAllister, 1952; Merriam, 1963). The Rest Spring Shale thickens to the northwest and pinches out to the southeast, west of the Santa Rosa Hills (Stevens and others, 1979; Stevens, 1986).

Age

Fossils are scarce in the Rest Spring Shale. McAllister (1952) provisionally dated the formation as Early Pennsylvanian based on Chesterian ammonoids present near the base of the Rest Spring Shale and Middle

Pennsylvanian fossils found near the base of the overlying Tihvipah Limestone. However, Gordon (1964) reported the occurrence of the Mississippian ammonoid *Cravenoceras* above the ammonoid-bearing limestone in the Quartz Spring area and Merriam (1963) collected ammonoids, including *Cravenoceras*, from this unit in the Cerro Gordo Mining District. Recently George Dunne collected brachiopods within 10 m of the top of the unit in the western Lee Flat area that have been dated by Thomas Dutro, Jr. as Late Mississippian (Calvin Stevens, pers. commun., 1986). Thus, the unit is considered to be mostly, if not entirely, Chesterian in age.

Indian Springs Formation

General Description and Occurrence

In the southern and eastern portions of the study area, Stevens (1986) recently recognized the Indian Springs Formation overlying the Santa Rosa Hills Limestone. This unit was originally named the Indian Springs member of the Bird Spring Formation by Longwell and Dunbar (1936) for outcrops in the hills southwest of Indian Springs, Nevada. Gordon and Poole (1968) studied the unit and suggested that it might be more appropriately elevated to formation status. In the study area, the Indian Springs Formation was previously mapped as Rest Spring Shale in the Darwin quadrangle (Hall and MacKevett, 1962; Dunne and others, 1981); however, it consists predominantly of quartzite and siltstone with minor amounts of shale. The Indian Springs Formation generally is less than 20 m thick and in many localities, such as the Argus Range, siliciclastic beds that occur at the same stratigraphic position are extremely thin and have not been mapped separately (Dunne and others, 1981; Stevens, 1986).

Age

Brachiopods collected from the Indian Springs Formation in the Santa Rosa Hills indicate a Chesterian age for the unit (Stevens, 1986). Morrowan (Early Pennsylvanian) conodonts were obtained from a limestone immediately overlying the formation in the southeastern Darwin Hills (Stevens, 1986); hence, the unit is considered Chesterian to perhaps earliest Pennsylvanian in age (Stevens, 1986).

MINNIETTA MINE AREA

Introduction

The Stone Canyon limestone and the Santa Rosa Hills Limestone were studied in a section on the eastern flank of the Argus Range located approximately 0.5 km north of the mouth of Stone Canyon (fig. 9). The Stone Canyon limestone section was measured, sampled, and described in detail. The overlying Santa Rosa Hills Limestone has been recrystallized by regional metamorphism to a medium- to coarse-grained marble, and most primary sedimentary structures have been obliterated. Because of this, only the thickness and general character of the Santa Rosa Hills Limestone could be ascertained.

In the Minnietta Mine area, the thickness of the Stone Canyon limestone and Santa Rosa Hills Limestone are 107 m and 199 m, respectively. The Stone Canyon limestone crops out as thin-bedded, dark-gray limestone containing beds and nodules of chert. The lower part of the Stone Canyon limestone is gradational with the underlying Tin Mountain Limestone; the contact is placed at the lowest occurrence of bedded chert. The massive, light-gray marble of the Santa Rosa Hills Limestone rests conformably on the Stone Canyon limestone in this area. The transition is gradational over several meters and the contact is placed

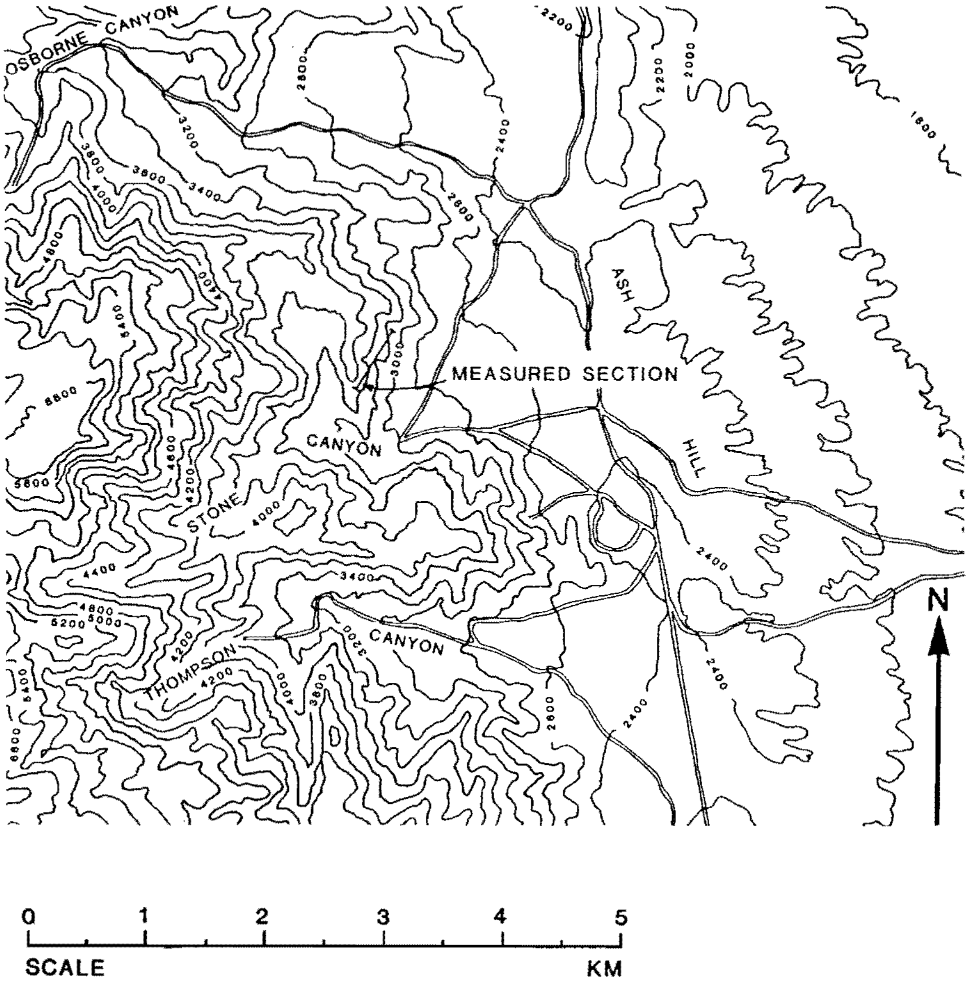


Figure 9. Location of the Minnietta Mine area measured section plotted on a portion of the USGS 15-minute Maturango Peak and Panamint Butte quadrangles, California (contour interval = 200 feet).

at the point where the limestone becomes much lighter gray in color, more massive, coarser grained, and more pelmatozoan-rich with much less abundant chert. The limestone has been mostly recrystallized to marble. The thin-bedded, dark-gray limestone of the Pennsylvanian Tihvipah Limestone overlies the Santa Rosa Hills Limestone in apparent disconformity. Strata of known Chesterian age (e.g., the Indian Springs Formation) were not observed at this specific locality.

Section Description

Stone Canyon Limestone

The Stone Canyon limestone in the Minnietta Mine area is easily subdivided into three lithologically distinct units: a lower unit of bedded chert and dark-gray limestone, a middle unit of dark-gray limestone with nodular chert, and an upper unit of dark-gray limestone and nodular chert with interbedded pelmatozoan-rich, bioclastic limestone beds. The measured section of the Stone Canyon limestone is shown diagrammatically in figure 10 with the three units designated. See Appendix A-1 for a more detailed description of the measured section.

The lower unit is 16 m thick and the lower contact is placed at the base of the lowest occurrence of bedded chert overlying the Tin Mountain Limestone. Although the

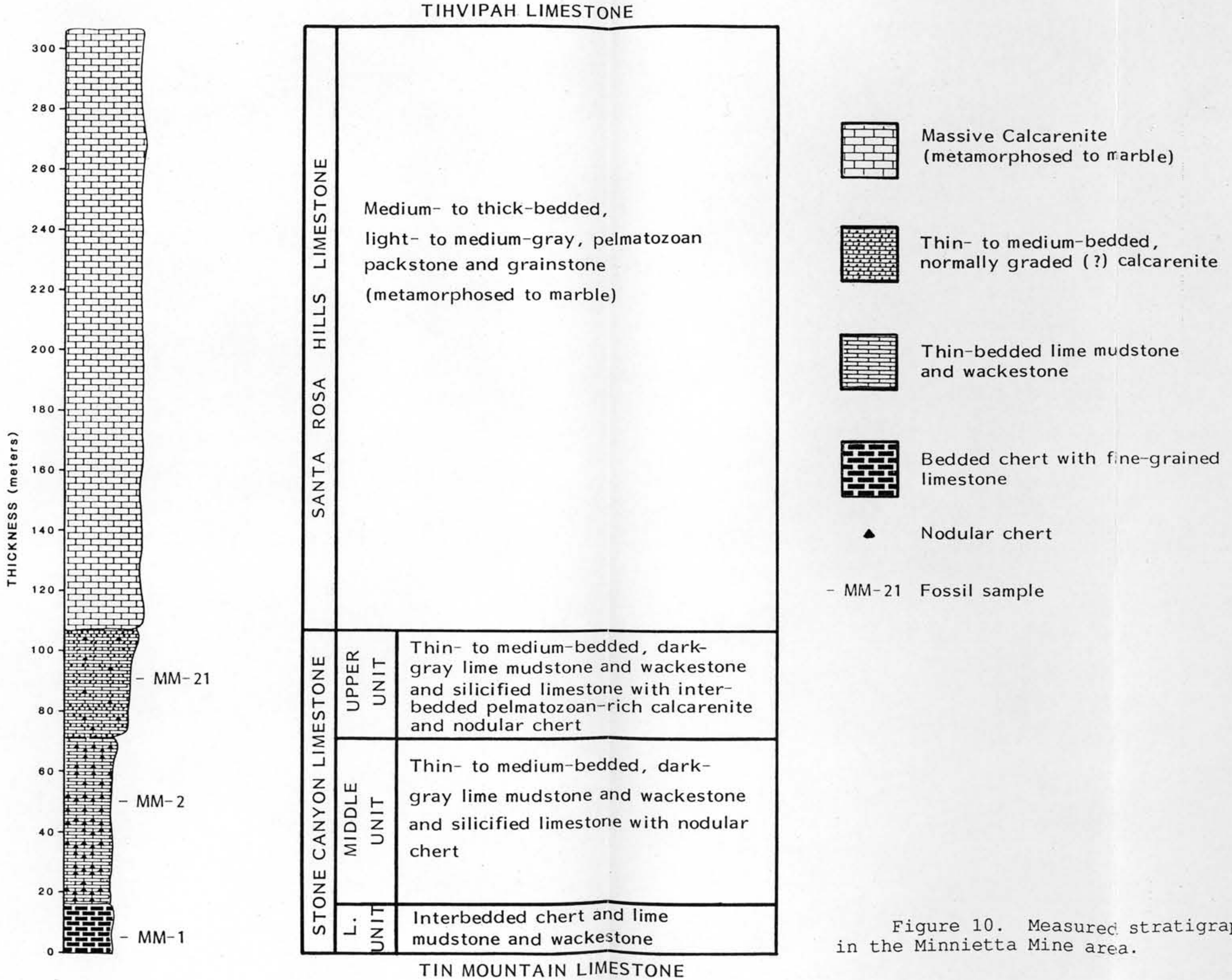


Figure 10. Measured stratigraphic section in the Minnietta Mine area.

transition is somewhat gradational over a thickness of 3 to 5 m, the lower unit of the Stone Canyon limestone is easily distinguished from the underlying Tin Mountain Limestone by a general change in color from dark-gray to brown (fig. 11).

This unit consists of approximately 40% thin- to medium-bedded, dark-gray, lime mudstone and wackestone; 45% brown-weathering, dark-gray, spiculiferous chert (occurring as irregular beds 1 to 15 cm thick and as nodules); and 15% orangish-brown-weathering, thin- to medium-bedded, dark-gray, sponge-spicule-rich, silicified lime mudstone and wackestone. Macrofossils, other than scattered pelmatozoan debris, and bioturbation features are rare to absent in these rocks. Neither normal grading nor other sedimentary features indicative of sediment-gravity-flow deposition were observed.

The silicified limestone beds of this unit have been described in previous investigations as "silty limestone"; however, thin-section analysis of these rocks revealed that the orangish-brown-weathering and the more resistant nature of this limestone lithology is due to the moderately high percentage of siliceous sponge spicules and incomplete chert diagenesis (fig. 12). Siliciclastic grains (sand or silt) were not observed in any of the nine thin sections studied.

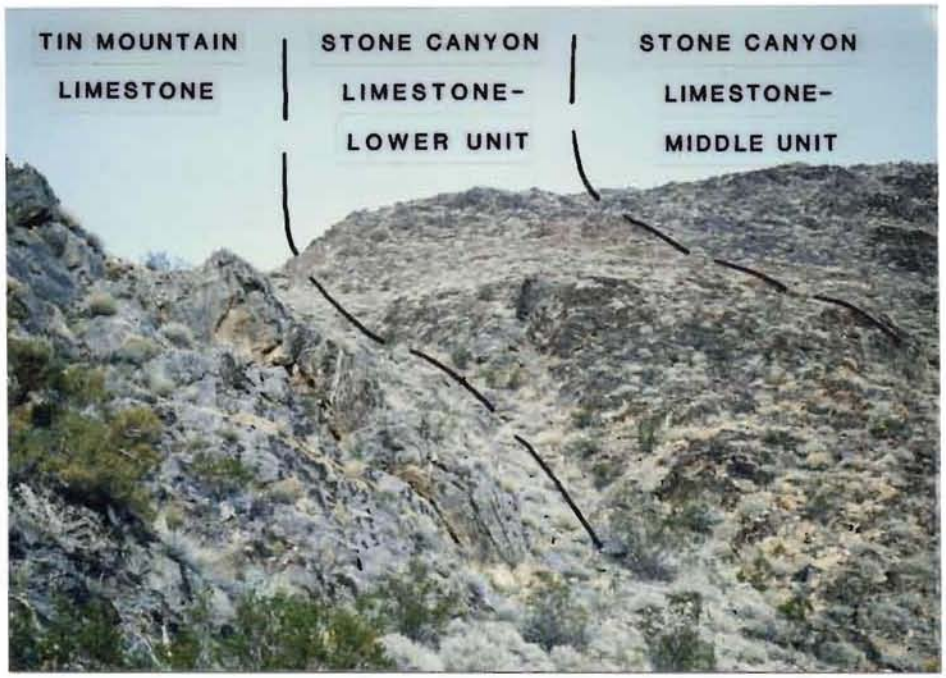


Figure 11. Contact between the Tin Mountain Limestone (left) and the Stone Canyon limestone (right) in the Minnietta Mine area. The chert-rich lower unit of the Stone Canyon limestone is easily distinguished from the Tin Mountain Limestone by its dark brown color.

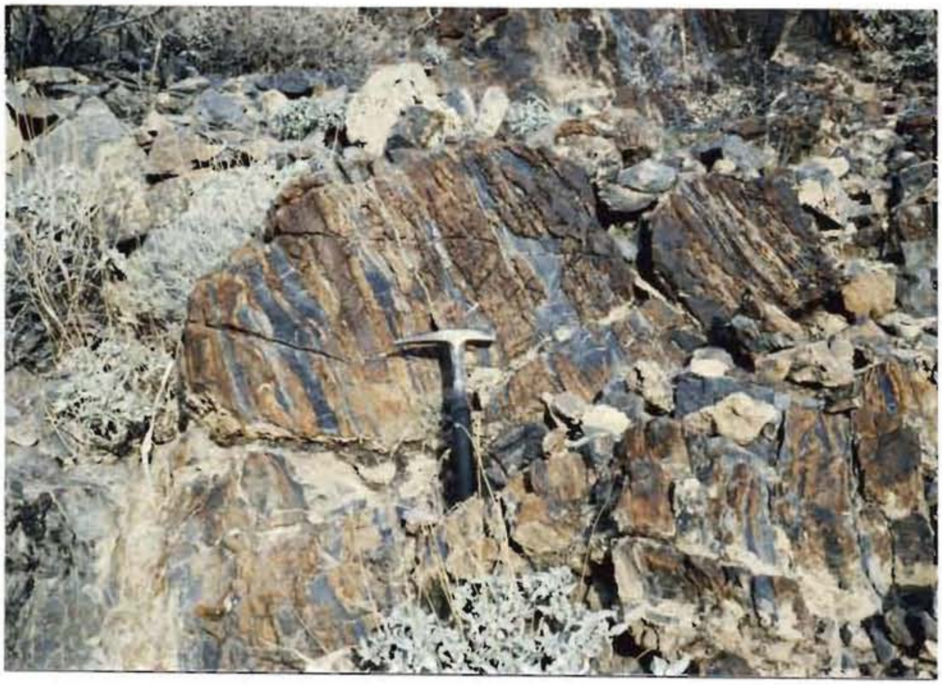


Figure 12. Lower unit of the Stone Canyon limestone in the Minnietta Mine area. The orangish-brown-weathering beds are sponge-spicule-rich lime mudstone. The dark-brown-weathering beds are chert and the bluish-gray beds are lime mudstone and wackestone. Rock hammer is 30 cm in length.

The middle unit is gradational with the lower unit and consists of the same lithologies; chert, however, is proportionally less abundant and only occurs as discontinuous lenses and irregular nodules. The limestones are thin- to medium-bedded and the chert lenses and nodules range from less than 1 cm to 10 cm in thickness. Macrofossils, other than scattered pelmatozoan debris, and bioturbation features are rare to absent, and sediment-gravity-flow features were not observed.

The upper unit, which begins at 71 m above the base of the section, consists of dark-gray lime mudstone and wackestone of similar composition to the lower unit, silicified limestone, and discontinuous lenses and nodules of chert. Light- to medium-gray-weathering, pelmatozoan-rich, bioclastic limestone beds and lenses differentiate this unit from the underlying middle unit. The pelmatozoan-rich, bioclastic limestone occurs as both diffuse, lenticular accumulations and as continuous beds with sharply defined bases and gradational tops. Crudely developed normal grading of bioclastic grains (some with internal parallel laminations) was noted in a few of these beds. The pelmatozoan-rich, bioclastic beds become more numerous toward the top of the unit at the expense of the other limestone lithologies and chert. Bioturbation features also are more numerous in this unit; however, on the whole, the unit was not intensely reworked.

In general, the Stone Canyon limestone in the Minnietta Mine area is dominated by dark-gray, fine-grained limestone and chert. The overall dark-gray to brownish-gray color and the thin-bedded nature easily distinguish the Stone Canyon limestone from the overlying Santa Rosa Hills Limestone.

Santa Rosa Hills Limestone

Detailed measurements and description of the Santa Rosa Hills Limestone were not undertaken in the Minnietta Mine area because of the effect of regional metamorphism on the unit. The Santa Rosa Hills Limestone is 199 m thick and consists predominantly of thick-bedded, massive, fairly well sorted, light- to medium-gray, medium-to coarse-grained marble with a minor amount (less than 1 to 2%) of nodular chert (fig. 13). Other than the abundant pelmatozoan columnals and traces of brachiopod(?) debris, no macrofossils were observed. The bedding, where preserved, is commonly 5 cm to 20 cm thick. The lack of sedimentary structures may indicate extensive bioturbation. These rocks are lithologically similar to the pelmatozoan-rich, bioclastic limestone beds in the upper unit of the Stone Canyon limestone.

Approximately 100 m east (downslope) from the top of the measured section in the Stone Canyon limestone is a

Figure 13. Santa Rosa Hills Limestone in the Minnietta Mine area. This unit is metamorphosed to a light-gray, massive marble with minor chert.

"tongue" of Santa Rosa Hills Limestone enveloped above and below by rocks of the upper unit of the Stone Canyon limestone (Fig. 14). This "tongue" of Santa Rosa Hills Limestone reaches a maximum thickness of approximately 25 m at the base of the slope and pinches out approximately 120 m to the west.

Biostratigraphy

Age-diagnostic conodont assemblages were recovered from three levels in the Stone Canyon limestone (samples MM-1, MM-2, and MM-21 (fig. 10). The conodonts identified and dated by Charles Sandberg (pers. commun., 1985) and the author are:

Sample MM-1 (5 m above base of Stone Canyon limestone; lower unit)

Gnathodus cuneiformis

Gnathodus typicus

Pseudopolygnathus nudus

Bispathodus utahensis Pa

Sample MM-2 (50 m above base of Stone Canyon limestone; middle unit)

Pseudopolygnathus nudus

Polygnathus communis communis

Hindeodus penescitulus

Gnathodus typicus

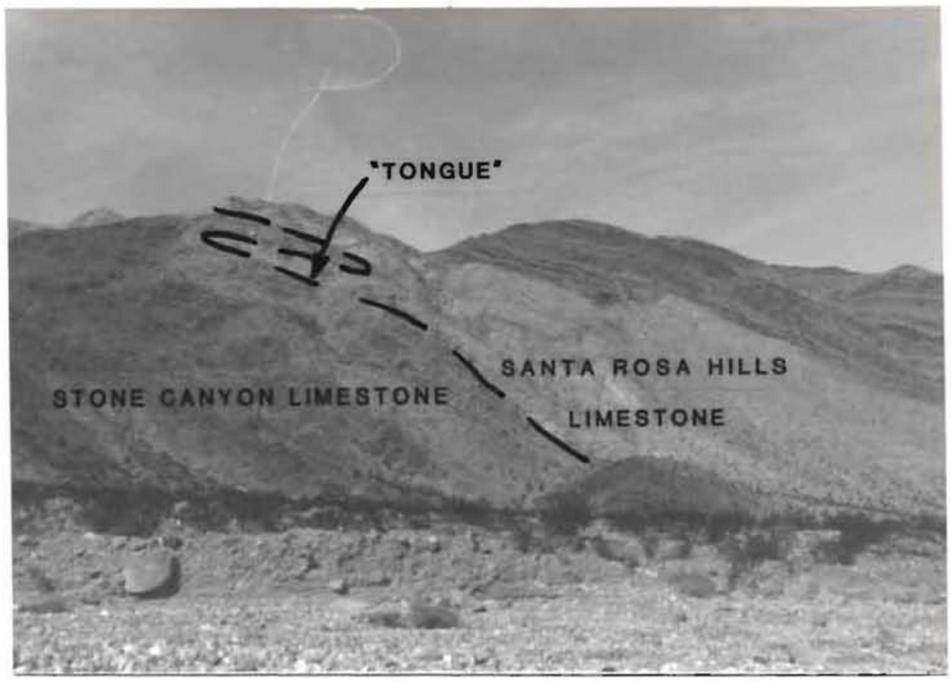


Figure 14. Tongue of Santa Rosa Hills Limestone (outlined) within the Stone Canyon limestone in the Minnietta Mine area.

Sample MM-21 (90 m above base of Stone Canyon limestone; upper unit)

Polygnathus communis communis

Bispathodus utahensis Pa

Polygnathus sp.

Sandberg determined samples MM-1 and MM-2 to be Osagean (upper Gnathodus typicus Zone) in age and assigned the conodonts of both samples to the gnathodid-pseudopolygnathid conodont biofacies of Sandberg and Gutschick (1984). Sample MM-21 is either Osagean or Meramecian in age. Unequivocal Meramecian fossils were not recovered from either the Stone Canyon limestone or the Santa Rosa Hills Limestone at this locality.

Environmental Interpretations

The lower unit of the Stone Canyon limestone, consisting of dark-gray lime mudstone, lime wackestone, and spiculiferous chert, most likely was deposited in a quiet-water setting. The lack of unequivocal shallow-water macrofossils and the presence of conodonts of the gnathodid-pseudopolygnathid biofacies suggest these rocks were deposited in a moderately deep-water environment (Sandberg and Gutschick, 1984). The dark-gray color of these rocks and the virtual absence of bioturbation suggest that dysaerobic conditions prevailed (Byers, 1977; Sandberg and Gutschick, 1984).

The middle unit contains lithologies and sedimentary features very similar to those in the lower unit, which suggests that these rocks also were deposited in a quiet, dysaerobic, and moderately deep-water environment. The less abundant bedded chert in this unit may reflect an environment that contributed fewer siliceous sponge spicules to the sediment. The depositional environment indicated for the lower and middle units is consistent with earlier interpretations of Stevens and others (1979), Klingman (1984), and Stevens (1986).

The Santa Rosa Hills Limestone was most likely deposited in shallow water. This light-gray unit is characterized by abundant pelmatozoan debris in a moderately well-sorted, massive limestone (marble), which suggests that these rocks were deposited as mobile, skeletal sand sheets in an active, agitated environment, perhaps similar to the mobile grain flats depicted by Wilson and Jordan (1983, figure 64). Colonial rugose corals recovered from this unit and correlative units at other localities further substantiate a shallow-water environment of deposition (Stevens and others, 1979; Webster and Langenheim, 1979). The tongue of Santa Rosa Hills Limestone that is exposed in the Minnietta Mine area is believed to represent the initial progradation of this shallow marine unit over the deeper-water Stone Canyon limestone.

The transitional upper unit of the Stone Canyon limestone contains rock lithologies similar to both the lower portion of the Stone Canyon limestone (that is, dark-gray lime mudstone, lime wackestone, and chert) and to the Santa Rosa Hills Limestone (the pelmatozoan-rich, bioclastic limestone beds). The dark-gray lime mudstone, lime wackestone, and nodular chert, like that in the lower and middle units, indicates that these rocks were deposited in a quiet-water environment. The proximity of these beds to the overlying shallow marine Santa Rosa Hills Limestone coupled with the increase in bioturbation suggests that this quiet-water setting was in shallower, more oxygenated water. The crudely graded pelmatozoan-rich, lime packstone beds with sharp bases, gradational tops, and rare internal laminations correspond to the S_a and S_b divisions observed in storm deposits (tempestites) by Aigner (1982a, 1982b) and Nelson (1982). Although texturally similar to carbonate turbidites, these beds display less well developed normal grading and internal lamination, and do not contain material of unequivocal deep-water origin. The lack of hummocky stratification may be due to the coarse-grained nature of these rocks. The absence of observed escape burrows remains problematical, but it also may be a function of the well-sorted, coarse-grained nature of these beds. This sequence of interbedded tempestites and lime mudstone-wackestone with nodular chert is interpreted as representing the transition from the moderately deep marine rocks of the lower and middle units of the Stone Canyon limestone to the shallow marine pelmatozoan packstones and grainstones of the Santa Rosa Hills Limestone.

SANTA ROSA HILLS

Introduction

The Stone Canyon limestone and the Santa Rosa Hills Limestone were studied in the Santa Rosa Hills located approximately 12 km north of the Saline Valley Road - State Route 190 junction (fig. 15). Two sections, which collectively traverse the Stone Canyon limestone and the Santa Rosa Hills Limestone, were measured, sampled, and described. Because of Cenozoic faulting and cover by younger deposits, the two sections were deemed necessary in order to construct a complete stratigraphic section.

The thickness of the Stone Canyon limestone and the Santa Rosa Hills Limestone at the measured sections are 532 m and 91 m, respectively. Here, the Stone Canyon limestone is very similar in lithologic appearance to the same unit in the Minnietta Mine area. The Stone Canyon limestone crops out as thin-bedded, dark-gray limestone containing beds and nodules of chert. The lower part of the Stone Canyon limestone is gradational with the underlying Tin Mountain Limestone and the contact is placed at the lowest occurrence of bedded chert. The Santa Rosa Hills Limestone rests conformably on the Stone Canyon limestone and, as in the Minnietta Mine area, the contact is placed at the point where the limestone becomes lighter

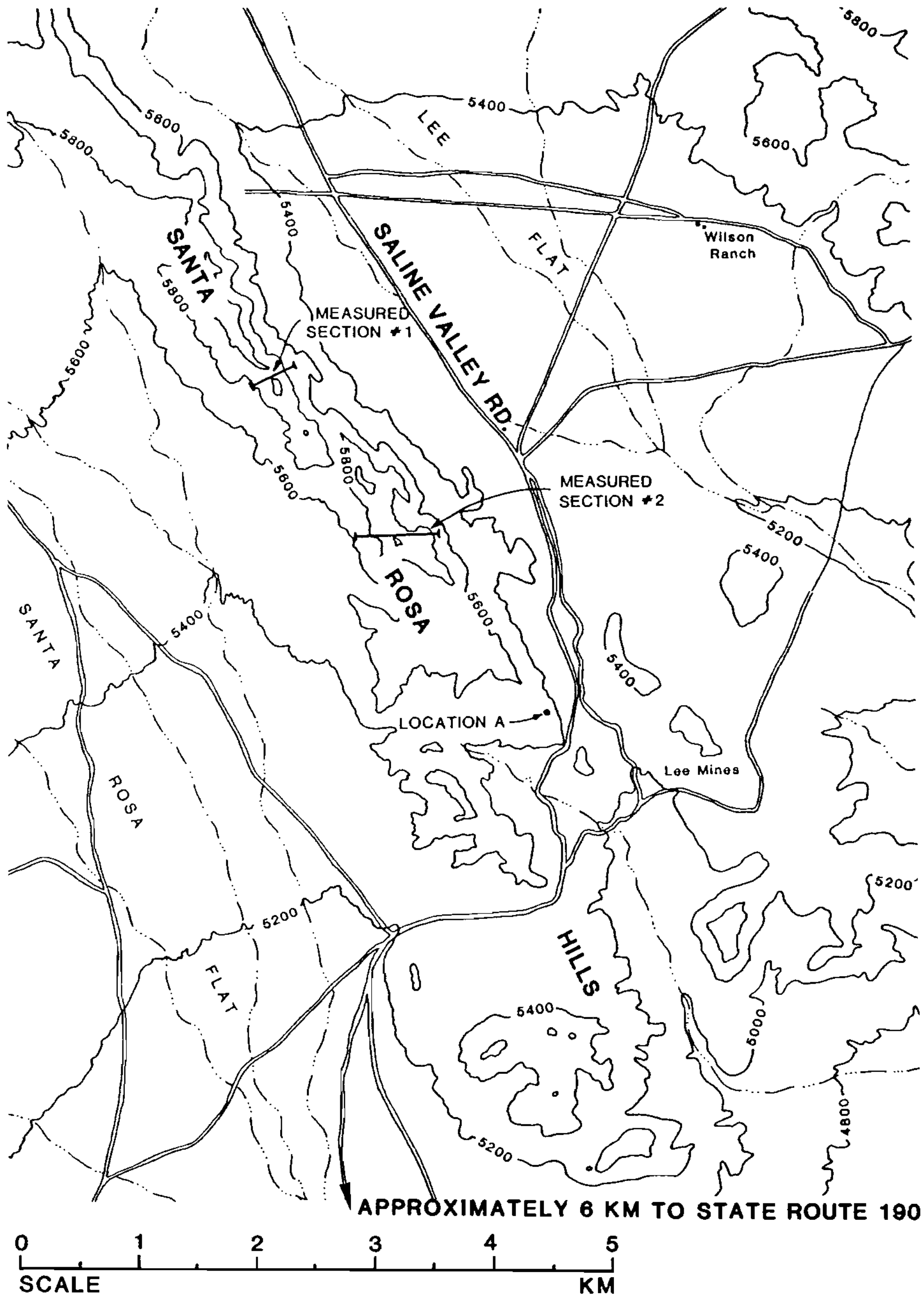


Figure 15. Location of the Santa Rosa Hills measured sections plotted on a portion of the USGS 15-minute Darwin quadrangle, California (contour interval = 200 feet).

gray, more massive, coarser grained, and more pelmatozoan-rich with much less abundant chert. Approximately 20 m of reddish-brown-weathering quartzite and grayish-orange-weathering siltstone and shale of the Indian Springs Formation lie disconformably on the Santa Rosa Hills Limestone in the area (Stevens, 1986).

Section Description

Stone Canyon Limestone

The Stone Canyon limestone in the Santa Rosa Hills is subdivided into three lithologic units that correspond to those recognized in the Minnietta Mine area: a lower unit of bedded chert and dark-gray limestone, a middle unit of dark-gray limestone and nodular chert, and an upper unit of dark-gray limestone and nodular chert with interbedded pelmatozoan-rich bioclastic limestone beds. The composite measured section of the Stone Canyon limestone is shown diagrammatically in figure 16 with the three units designated. See Appendix A-2 for a more detailed description of the measured section.

The lower unit is 25 m thick and consists predominantly of thin- to medium-bedded, dark-gray lime mudstone and lime wackestone interbedded with brown-weathering, dark-gray, spiculiferous chert, which occurs both in irregular beds, 1 cm to 20 cm thick, and as nodules

Continued on Fig. 16B

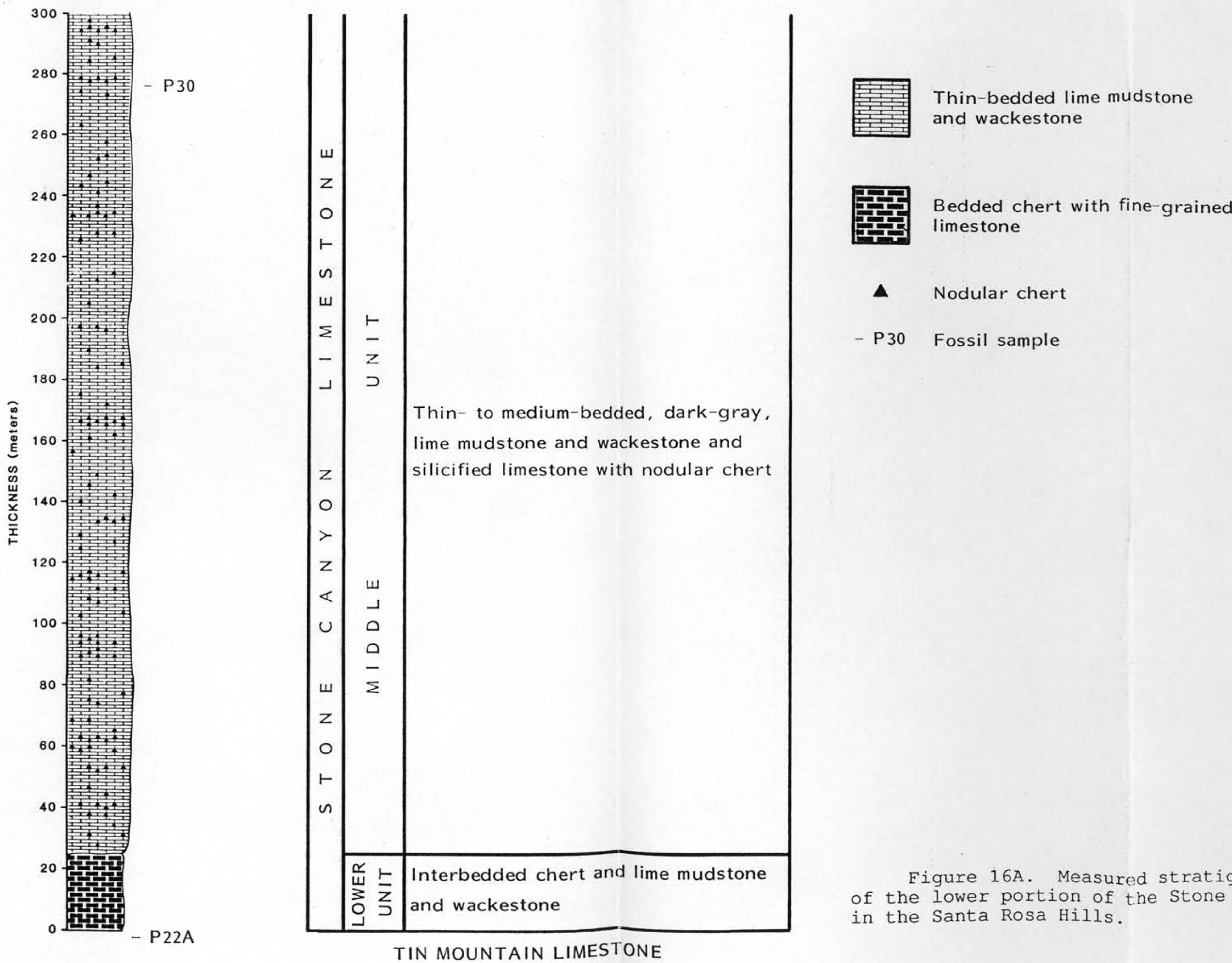
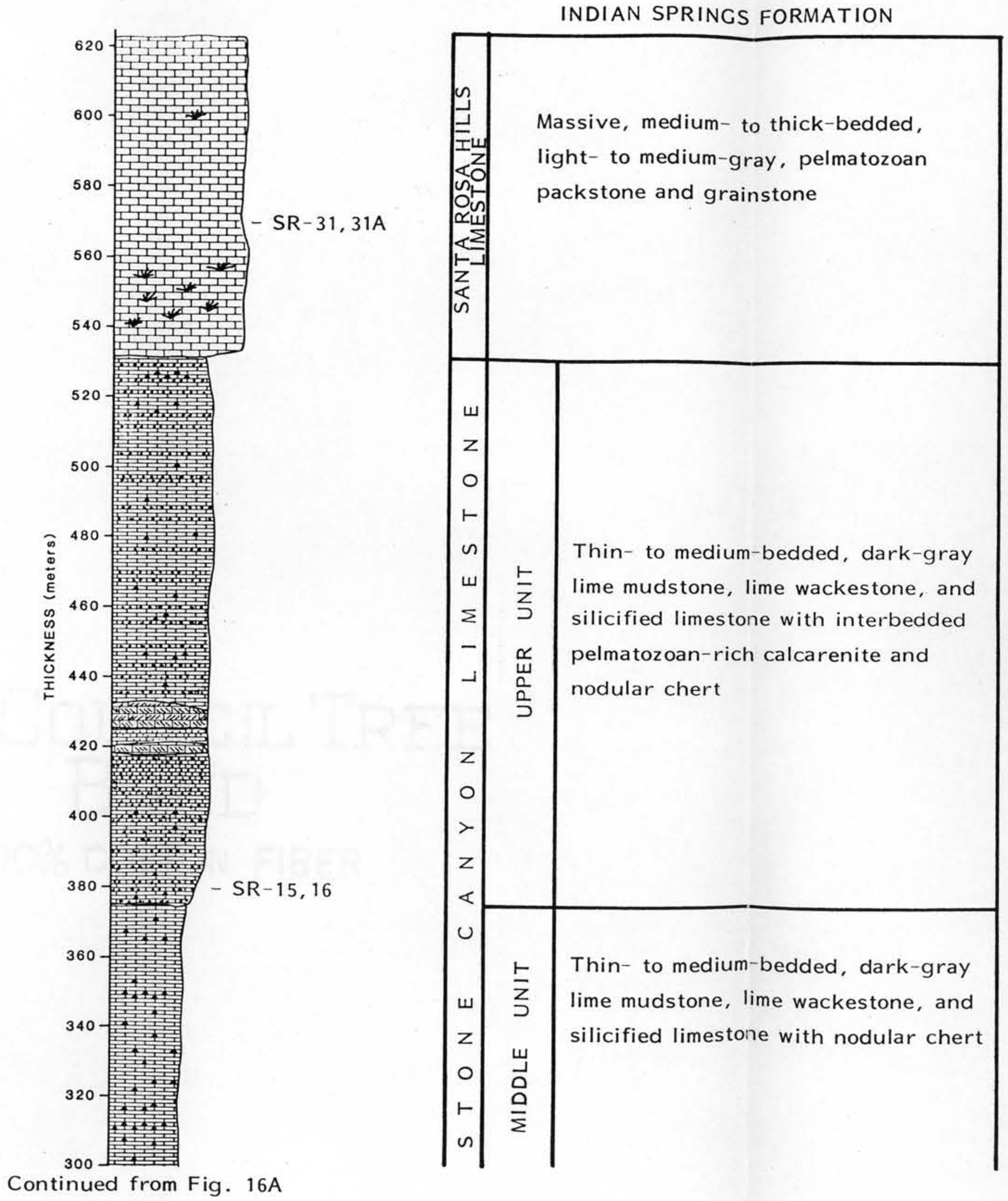


Figure 16A. Measured stratigraphic section of the lower portion of the Stone Canyon limestone in the Santa Rosa Hills.



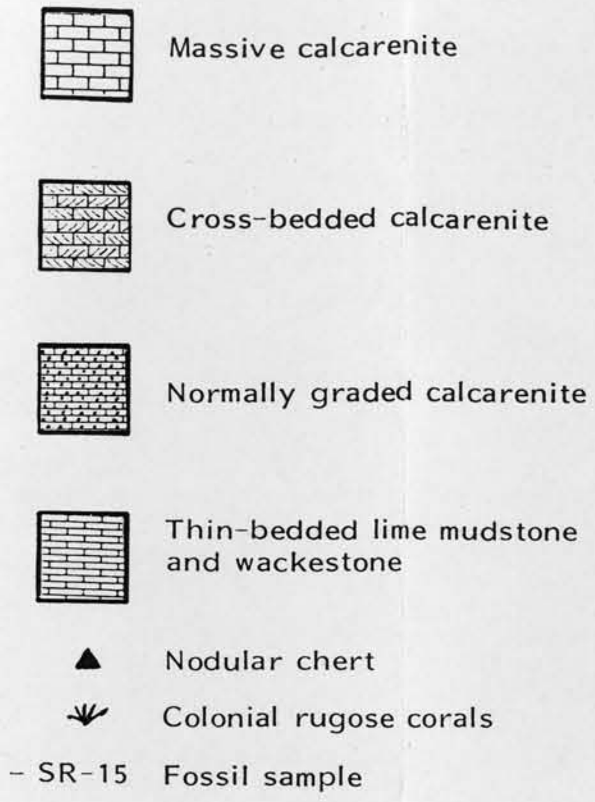


Figure 16B. Measured stratigraphic section of the upper portion of the Stone Canyon limestone and the Santa Rosa Hills Limestone in the Santa Rosa Hills.

(figs. 17 and 18). These irregular beds and nodules of chert locally show disrupted bedding features and comprise 50 to 60 percent of the unit. Orange-brown-weathering, dark-gray, sponge-spicule-rich, silicified limestone is rare in this unit in the Santa Rosa Hills. Macrofossils, other than scattered pelmatozoan debris, and bioturbation features are rare to absent in these rocks.

The middle unit is approximately 350 m thick in the Santa Rosa Hills and, as in the Minnietta Mine area, is gradational with the lower unit. It consists of the same lithologies as the lower unit, but chert is less abundant and occurs in discontinuous lenses and nodules (fig. 19). The orange-brown-weathering, thin- to medium-bedded, silicified limestone locally is more abundant than in the lower unit. Bioturbation features are rare throughout this unit.

A sequence of turbidites and debris flows occurs very near the base of the middle unit (Stevens, 1986) (fig. 20). The turbidites are normally graded, with both coarse-tail and distribution grading, have erosive bases and planar tops, and range in thickness from 3 cm to 1 m. Only thin-bedded turbidites occur along the measured section traverse; the thick-bedded turbidites and debris flows crop out at location A, approximately 2 km to the southeast of measured section #2 (fig. 15). The thick-bedded turbidites

Figure 17. Lower unit of the Stone Canyon limestone in the Santa Rosa Hills. Note the abundance of chert beds (dark beds). Jacob's staff is about 1.5 m in length.

Figure 18. Lower unit of the Stone Canyon limestone in the Santa Rosa Hills, where it crops out as a dark brown-weathering unit situated between the overlying gray-weathering middle unit of the Stone Canyon limestone (left) and the underlying Tin Mountain Limestone (right).

Figure 19. Typical exposure of the middle unit of the Stone Canyon limestone in the Santa Rosa Hills. This unit consists of lime mudstone with discontinuous lenses and nodules of dark brown-weathering chert. Rock hammer is 30 cm in length.

Figure 20. Coarse-grained T_{ab} turbidite exposed near the base of the middle unit of the Stone Canyon limestone in the Santa Rosa Hills. Pencil is 14 cm in length.

(greater than 15 cm) are T_{ab} calcarenites and calcirudites composed of dark-gray lime mudstone, lime wackestone, and chert clasts and pelmatozoan debris in a lime-mudstone matrix. The clasts commonly are 2 cm to 8 cm in diameter, although a few clasts up to 25 cm in diameter also are present. A 1.5-m-thick debris flow, which also is composed of clasts of fine-grained limestone and chert suspended in a dark-gray, lime-mudstone matrix, occurs interbedded with the thick-bedded turbidites.

The thin-bedded turbidites are primarily base-cut-out T_b turbidites composed of lime mud and very fine-grained fossil debris (fig. 21). At location A these beds immediately overlie the sequence of thick-bedded turbidites. Debris of unequivocal shallow-water origin has not been identified in any of the sediment-gravity-flow deposits in this sequence. Paleocurrent indicators were not seen in these deposits.

The upper unit begins at about 375 m above the base of the Stone Canyon limestone. It consists of dark-gray lime mudstone and wackestone, similar to that of the lower unit; silicified limestone; and discontinuous lenses and nodules of chert. The limestone in this upper unit is more fossiliferous than that in the middle unit and includes crinoids, brachiopods, gastropods, and solitary rugose corals. Although these beds are not extensively

Figure 21. Sequence of base-cut-out T_b turbidites exposed near the base of the Stone Canyon limestone in the Santa Rosa Hills. Pencil is 14 cm in length.

bioturbated, some vertical burrows are evident. Lime mud and siliceous sponge spicules remain the most abundant constituents in these rocks.

The presence of light- to medium-gray-weathering, coarse-grained, pelmatozoan-rich, bioclastic calcarenite beds is used to separate this upper unit from the rocks below. These calcarenites are packstones and grainstones with little or no interparticle lime mud and are divided into two types of deposits based on sedimentary features. The first type commonly displays crudely to moderately developed normal grading above a sharp, erosive base; some beds also contain internal laminations (fig. 22). The beds range in thickness from 5 to 70 cm and the thicker beds commonly are amalgamated (fig. 23). Coarse sand- to gravel-size pelmatozoan debris constitutes the vast majority of the rock. Brachiopods, foraminifera, horn corals, and intraclasts of lime mudstone and chert also are present but are relatively rare. Brachiopods, where present, are disarticulated and commonly oriented concave-side down. These bioclastic beds are very similar to the pelmatozoan-rich, bioclastic limestone beds present within the same unit in the Minnietta Mine area, but in the Santa Rosa Hills the sequence is thicker and the sedimentary features are more fully developed and easily recognized. These calcarenite beds generally thicken,

Figure 22. Pelmatozoan-rich, bioclastic calcarenite of the upper unit of the Stone Canyon limestone, displaying moderately developed normal grading (A) and internal laminations (B). Photograph taken in the Santa Rosa Hills. Pencil is 14 cm in length.

Figure 23. Sequence of amalgamated pelmatozoan-rich, bioclastic calcarenite beds of the upper unit of the Stone Canyon limestone in the Santa Rosa Hills. Jacob's staff is approximately 1.5 m in length.

coarsen, and increase in frequency immediately below the second type of pelmatozoan calcarenite deposit described below. Cross-bedding, bioturbation (including escape burrows), and well developed hummocky stratification were not observed in these beds.

The second type of pelmatozoan calcarenite, which consists of packstones and grainstones showing well developed cross-bedding, occurs in two intervals in the upper unit of the Stone Canyon limestone. The lower interval attains 3 m and the upper bed 7 m in thickness. These beds are lenticular and pinch out into the surrounding lime mudstone and wackestone over a distance of 500 m. Generally north-south-trending, bimodal, trough and planar cross-bedding is present in sets that average 8 cm in thickness with foreset bed inclinations ranging from 14 to 23 degrees (fig. 24). Although the cross-bedding is bimodal, approximately 90 percent of the foreset beds dip N15W to N20E with an average about due north (fig. 25). A third cross-bedded calcarenite, also with bimodal foreset dips with a dominant northward paleocurrent direction, is present at the base of the Santa Rosa Hills Limestone, approximately 1 km northwest of measured section #2.

The normally graded pelmatozoan calcarenite beds occur above the cross-bedded calcarenite beds within the upper unit of the Stone Canyon limestone. These beds show an

Figure 24. Cross-bedded calcarenite of the upper unit of the Stone Canyon limestone in the Santa Rosa Hills. Most foresets dip due north. Rock hammer is 30 cm in length.

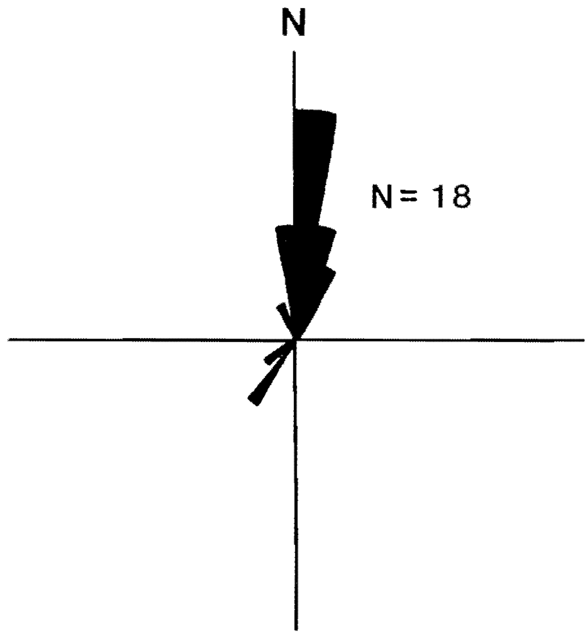


Figure 25. Rose diagram of paleocurrent measurements taken in the cross-bedded calcarenite of the upper unit of the Stone Canyon limestone in the Santa Rosa Hills.

abrupt and dramatic decrease in grain size, bed thickness, and bed frequency immediately above the cross-bedded calcarenites. The dark-gray lime mudstone and wackestone, silicified limestone, lenticular and nodular chert, and pelmatozoan packstone and grainstone are interbedded up to the base of the Santa Rosa Hills Limestone.

Santa Rosa Hills Limestone

The Santa Rosa Hills Limestone was studied along the western half of measured section #1 and is not subdivided into major lithologic units. The measured section is shown diagrammatically in figure 16, and Appendix A-2 contains a more detailed description of the measured section.

The Santa Rosa Hills Limestone is 91 m thick and consists primarily of medium- to light-gray, thin- to thick-bedded, massive, medium- to coarse-grained, pelmatozoan calcarenite with minor amounts (less than 1 percent) of nodular chert (fig. 26). The calcarenite is a moderately well sorted, pelmatozoan packstone and grainstone, which locally contains solitary rugose corals, calcareous foraminifera, calcareous algae, and brachiopods. In addition, colonial rugose corals are present at several horizons but are most concentrated in the lower portion of the formation (fig. 27). Stevens (1986) noted a 20-m-thick buildup of colonial corals north of measured section #1.

A cross-bedded calcarenite is present at the base of

Figure 26. Contact between the Santa Rosa Hills Limestone and the underlying Stone Canyon limestone at measured section #1 in the Santa Rosa Hills. The light gray-weathering Santa Rosa Hills Limestone crops out as massive, pelmatozoan-rich calcarenite with only minor chert. View to the south.

Figure 27. Colonial rugose coral present near the base of the Santa Rosa Hills Limestone in the Santa Rosa Hills. Pencil is 14 cm in length.

the Santa Rosa Hills Limestone, approximately 1 km northwest of measured section #2. This cross-bedded unit, which contains bimodally dipping foreset beds with a dominant dip to the north, is of similar texture and composition to the cross-bedded calcarenite beds present in the upper unit of the Stone Canyon limestone.

Biostratigraphy

Stone Canyon Limestone

Two age-diagnostic conodont assemblages were recovered from the samples collected in the Santa Rosa Hills: sample P22A from the top of the Tin Mountain Limestone and sample P30 from near the middle of the Stone Canyon limestone (see figure 16 for the sample locations in the stratigraphic section). The conodonts were identified and dated by Charles Sandberg (pers. commun., 1985) as follows:

Sample P22A (Tin Mountain Limestone; 1.5 m below the base of Stone Canyon limestone)

Gnathodus cuneiformis

Gnathodus punctatus

Gnathodus typicus

Sample P30 (274 m above base of Stone Canyon limestone; middle unit)

Gnathodus pseudosemiglaber

Gnathodus texanus (form?)

Sample P22A is early Osagean (lower *Gnathodus typicus* Zone) in age and contains conodonts of the gnathodid conodont biofacies (Sandberg and Gutschick, 1984). Sample P30 is either latest Osagean or earliest Meramecian (*Gnathodus texanus* Zone) in age and also contains conodonts of the gnathodid biofacies (Sandberg and Gutschick, 1984).

Samples SR-15 and SR-16 (fig. 16), collected from near the base of the upper unit in the Stone Canyon limestone, contain calcareous foraminifera. The following taxa were identified by Paul Brenckle (pers. commun., 1984).

Earlandia elegans gp.
Earlandia moderata? gp.
Earlandia claratula gp.
Earlandia vulgaris gp.
Endothyra? sp.
Eoendothyranopsis? sp.
Endothyridae indeterminate

Although the samples are poorly preserved, Brenckle believed them to be late Osagean or Meramecian in age.

The age of the lower portion of the Stone Canyon limestone in the Santa Rosa Hills, therefore, is Osagean and probably early Osagean in age. The upper half of the formation may extend into the early Meramecian. Dunne and others (1981) listed conodont assemblages from samples collected from the Stone Canyon limestone in the Santa Rosa

Hills that are of Visean age (i.e., late Osagean or Meramecian in age). The uppermost 140 m of this unit has not been dated.

Santa Rosa Hills Limestone

The Santa Rosa Hills Limestone contains age-diagnostic foraminifera and corals. Samples SR-31 and SR-31A (fig. 16), collected during the course of this study from near the middle of the unit, contained foraminifera that were identified by Paul Brenckle (pers. commun., 1984) as:

Earlandia clavatula gp.
Earlandia moderata gp.
Earlandia vulgaris gp.
Eoendothyranopsis ermakiensis
Eoendothyranopsis scitula
Eoendothyranopsis sp.
Endothyra sp.
Priscella prisca
Tetrataxis sp.
Mametella?

Brenckle reported that the foraminiferal fauna listed above indicates a middle Meramecian age, or equivalent to the St. Louis fauna of Missouri. This is consistent with a foraminiferal sample from about the same stratigraphic interval in the Santa Rosa Hills Limestone reported by Dunne and others (1981) as middle Visean, or approximately equivalent in age to Mamet foraminiferal zone 12 - 13 (Mamet and Skipp, 1970).

The colonial rugose corals present near the base of the Santa Rosa Hills Limestone include Lithostrotionella sp. aff. L. birdi and Lithostrotion (Siphonodendron) warreni(?). In addition, Lithostrotion (Siphonodendron) sp. A (Armstrong, 1970) was collected from float believed to be derived from the lower portion of the formation (Dunne and others, 1981). Lithostrotion warreni and Lithostrotion (Siphonodendron) sp. A are reported as middle Visean corals (Dunne and others, 1981) and therefore suggest the same age as the foraminifera. The Santa Rosa Hills Limestone, therefore, is largely middle to late(?) Meramecian in age, although the upper 25 m of this unit have not been dated.

Environmental Interpretations

The lower and middle units of the Stone Canyon limestone consist largely of lime mudstone, lime wackestone, and spiculiferous chert. These rocks resemble the rocks of the same units in the Minnietta Mine area and probably were deposited in a similar quiet-water setting. The lack of unequivocal shallow-water fossils and the presence of conodonts of the gnathodid biofacies imply a moderately deep-water environment of deposition (Sandberg and Gutschick, 1984). The dark-gray color of these rocks and the virtual absence of bioturbation features suggest that dysaerobic conditions prevailed (Byers, 1977; Sandberg and Gutschick, 1980). An offshore, moderately deep, dysaerobic, quiescent depositional setting is inferred and is consistent with earlier interpretations of Stevens and others (1979), Klingman (1984), and Stevens (1986).

The sequence of turbidites and debris flows that occurs near the base of the middle unit of the Stone Canyon limestone indicates instability of the depositional slope in this deep-water depositional setting.

The Santa Rosa Hills Limestone most likely was deposited in shallow water. The light-gray, massive, pelmatozoan-rich, well-sorted nature of the limestones of this formation suggests that these rocks were deposited as mobile, skeletal sand sheets in an active, fairly well agitated environment. The presence of colonial rugose corals, especially the buildup reported by Stevens (1986), and calcareous algae and foraminifera further support a shallow marine environment of deposition on a carbonate platform (Stevens and others, 1979; Dunne and others, 1981; Sando, 1981; Gutschick and Sandberg, 1983). These rocks are interpreted to have been deposited at or near the platform margin.

The upper unit of the Stone Canyon limestone contains rock lithologies similar to those in both the lower and middle units and to the overlying Santa Rosa Hills Limestone. The dark-gray, fine-grained limestone and chert, like the lower and middle units of the Stone Canyon limestone, indicate a quiet-water depositional environment. However, the vertical proximity of these beds to the shallow marine Santa Rosa Hills Limestone and the increase in bioturbation in the fine-grained limestone of this unit suggest a shallower, more aerobic depositional setting.

The crudely to moderately graded, bioclastic calcarenite beds with sharp bases, gradational tops, and occasional internal laminations correspond to the S_a and S_b divisions observed in storm deposits (tempestites) (Aigner, 1982a, 1982b; Nelson, 1982). Although texturally similar to carbonate turbidites, these beds contain much less lime mud matrix, display less well developed normal grading and internal laminations, and do not contain material of unequivocal deep water origin. The lack of S_c deposition and hummocky stratification may be due to the coarse-grained nature of these pelmatozoan-rich rocks. The absence of observed escape burrows and other bioturbation features may similarly, be a function of the coarseness of the grains.

The cross-bedded, pelmatozoan-rich, calcarenite beds represent skeletal, carbonate sand shoals as indicated by the lenticular morphology, medium to coarse grain size, and the bimodality of the cross-bedding (Halley and others, 1983). These sand shoals were situated in fairly shallow, well agitated water and influenced by shallow marine (tidal?) currents. The close vertical relationship of the cross-bedded sand shoals and the tempestites suggests that the sand shoals were within the influence of storm-generated flows.

QUARTZ SPRING AREA

Introduction

The Stone Canyon limestone and the Mexican Spring formation were studied at a section in the northern Panamint Range located approximately 3.5 km east of Perdido Canyon (fig. 28). The measured section of the Mexican Spring formation is incomplete due to faulting. Although stratigraphic correlation was not possible across the faults, the author believes that fault displacement is minimal and that the measured thickness of the Mexican Spring formation is a close approximation of its true thickness. Here, the thicknesses of the Stone Canyon limestone and the Mexican Spring formation along the measured section traverse are 83 m and 163 m, respectively. Thickness of the units is reported to be quite variable throughout the area (McAllister, 1952; Langenheim and Tischler, 1960).

The Stone Canyon limestone conformably overlies the Tin Mountain Limestone; the contact is placed at the change from dark-gray lime mudstone with nodular chert to yellow-brown-weathering, thin- to medium-bedded, silicified lime mudstone and wackestone with interbedded argillaceous lime mudstone and chert. The Mexican Spring formation conformably overlies the Stone Canyon limestone, and the

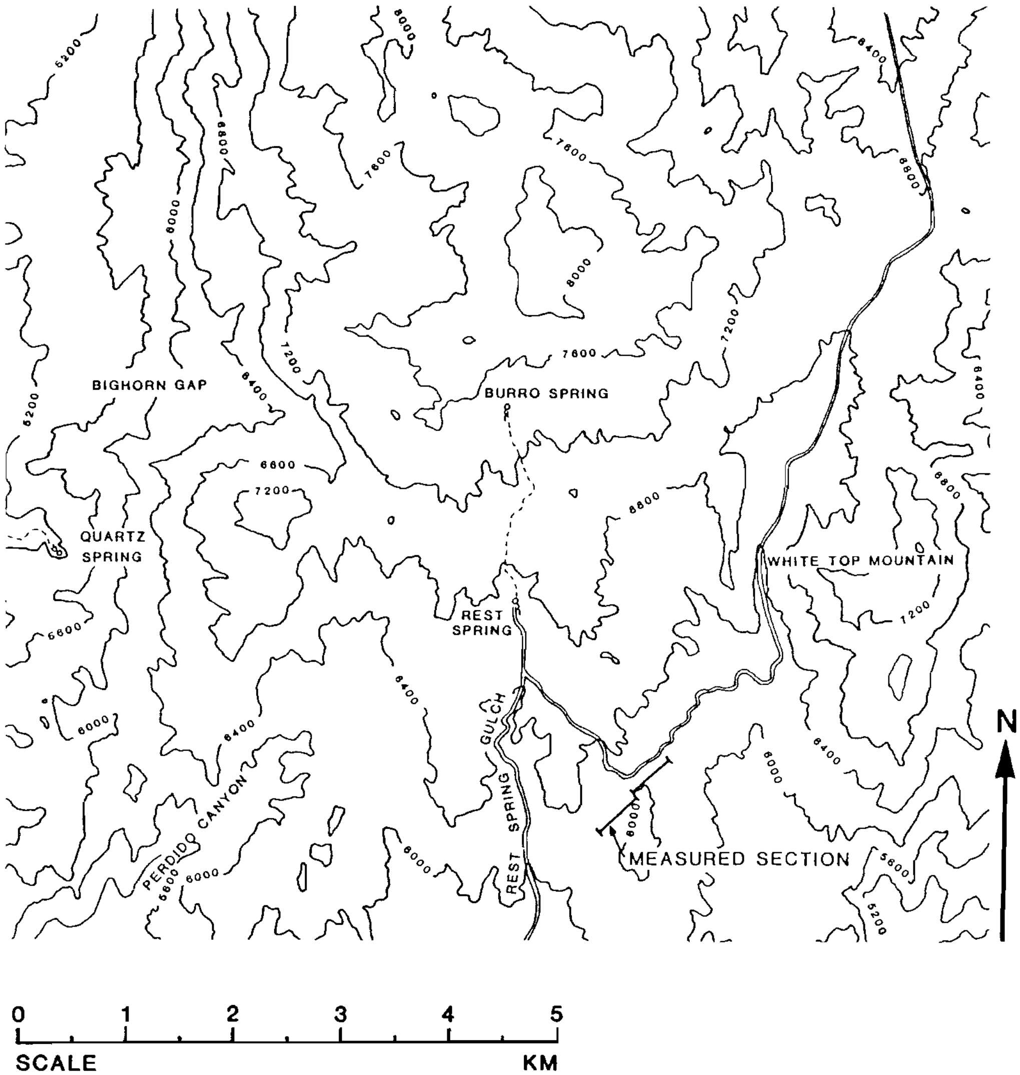


Figure 28. Location of Quartz Spring area measured section plotted on a portion of the USGS 15-minute Tin Mountain quadrangle, California (contour interval = 400 feet). Also note the location of Rest Spring Gulch and Bighorn Gap.

contact is placed at the lowest occurrence of siltstone. The Rest Spring Shale overlies the Mexican Spring formation in apparent conformity; the contact is placed below the lowest occurrence of dark-gray, carbonaceous shale.

Section Description

Stone Canyon Limestone

The Stone Canyon limestone in the Quartz Spring area is subdivided into three lithologic units; a lower unit of interbedded limestone, silicified limestone, and chert; a middle unit of mudstone, chert, and synsedimentary-folded submarine-slide masses; and an upper unit of interbedded limestone, silicified limestone, and chert. Limestone turbidites and debris-flow conglomerates are present in the middle and upper units. The measured section of the Stone Canyon limestone is shown diagrammatically in figure 29 with the three units designated. See Appendix A-3 for a more detailed description of the measured section.

The lower unit is 7 m thick and consists predominantly of thin- to medium-bedded, yellow-brown-weathering, siliceous sponge-spicule-rich, silicified lime mudstone and wackestone interbedded with medium- to dark-gray-weathering, argillaceous lime mudstone and chert. The dark-gray chert occurs in 4-cm- to 10-cm-thick beds and as irregularly shaped nodules. The chert nodules are most

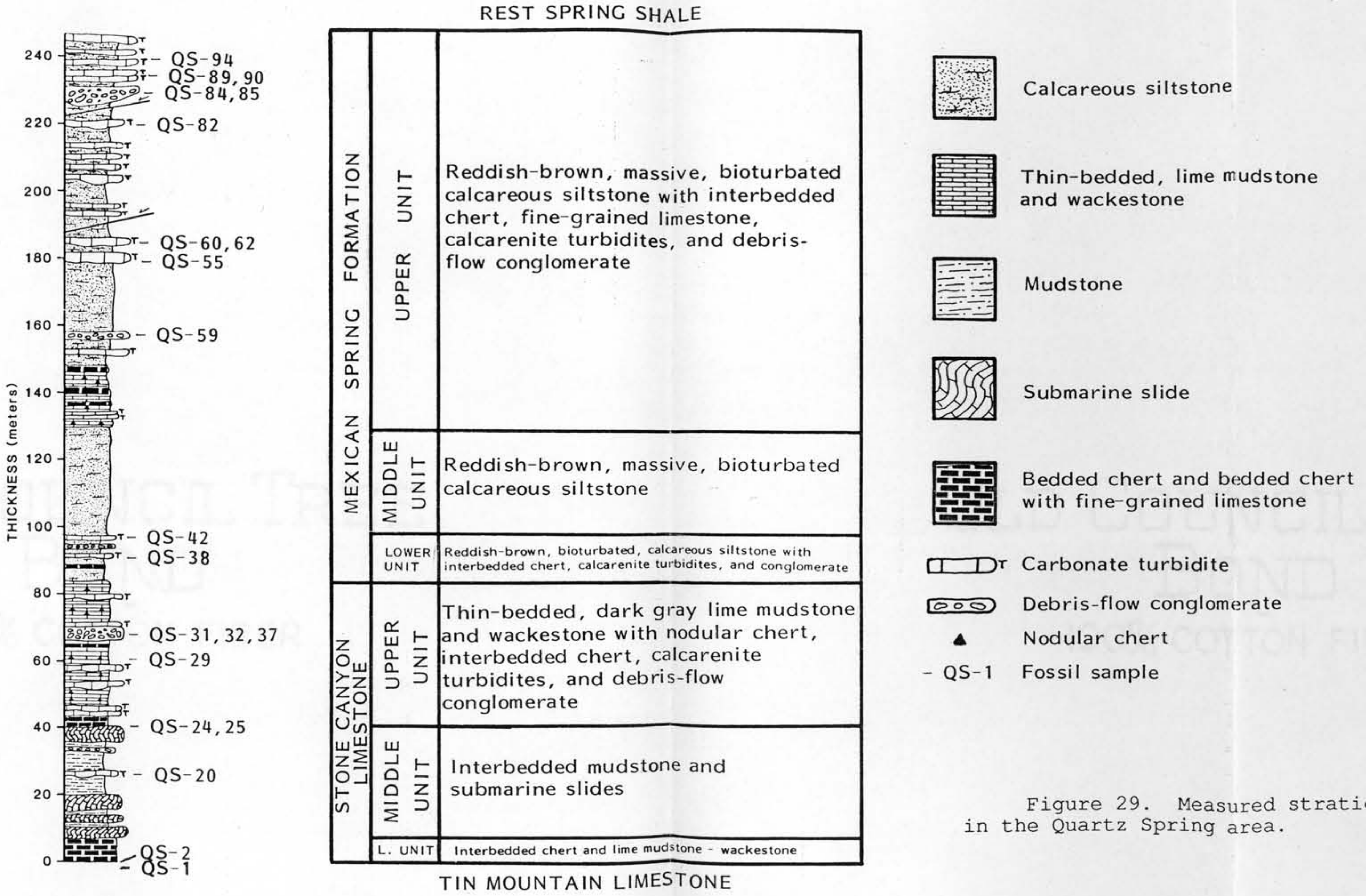


Figure 29. Measured stratigraphic section in the Quartz Spring area.

numerous near the top of the unit. Macrofossils, other than minute pelmatozoan debris, are absent. Bioturbation features are rare and are limited to horizontal burrows.

The middle unit is 33 m thick and consists of reddish-brown-weathering, flaggy mudstone; thin- to medium-bedded, dark-gray, spiculiferous chert; and deformed submarine-slide masses of fine-grained limestone and chert. The submarine slides distinguish this middle unit from the adjacent units and define its lower and upper boundaries.

Rotation was not observed in any of the slide masses, and hence, they are classified as translational slides or glides (Cook, 1979). All of the submarine slides are broadly lenticular in shape but are quite variable in thickness, lateral extent, and degree of deformation. Thicknesses range from less than 1 m to 4 m and several slides are more than 100 m in lateral extent. The degree of deformation is variable both within slide masses and between subsequent slides. The internal deformation does not show the well-developed, predictable pattern described by Cook and Taylor (1977), Cook (1979), and Cook and Mullins (1983) from the Cambrian submarine slides of central Nevada (fig. 30). Overfolds are common in the thinner slides (fig. 31), but the slides only seldom show the continued deformation and development of conglomeratic texture along the basal shear plane or the lateral margins

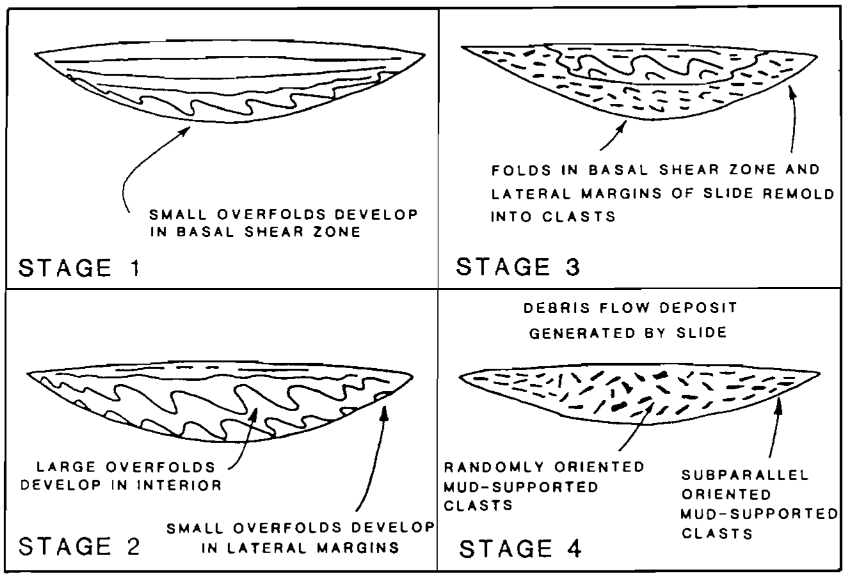


Figure 30. Four-stage model for the progressive deformation of a semiconsolidated, submarine slide moving downslope. By stage 4 the slide material has been completely remolded into clasts and lime mud, and behaves as a debris flow (modified from Cook and Mullins, 1983).

Figure 31. An approximately 1-m-thick overfolded submarine-slide mass from the middle unit of the Stone Canyon limestone in the Quartz Spring area. Submarine slide displacement direction is to the right. Rock hammer is 30 cm in length.

(fig. 32). Internal deformation in the thicker slides commonly is slight. The thicker slide masses are recognized as translational slides based on the lenticular morphology and the presence of a basal shear plane that is concordant with the underlying, undisturbed beds. Overfolds, where present in the thicker slides, typically are restricted to the lower portion of the slide mass and are of very limited extent. A mean paleoslope direction of N32W was determined by measuring the direction of overfolding within the slides (fig. 33).

A 30-cm-thick T_{ab} turbidite and a 25-cm-thick debris-flow conglomerate are the only sediment-gravity-flow deposits present in the middle unit. The turbidite has an erosional base and fills scours up to 10 cm deep in the underlying mudstone. The turbidite consists primarily of pelmatozoan debris and mudstone rip-up clasts. Measurement of groove lineations and clast imbrication indicate an average transport direction of N41W. The debris-flow deposit consists of dark-gray, lime mudstone and chert clasts in a dark-gray lime mudstone matrix. Paleocurrent directional features were not observed in this deposit.

The upper unit of the Stone Canyon limestone is 43 m thick and consists largely of thin- to medium-bedded, dark-gray, fine-grained, argillaceous limestone, silicified limestone, and spiculiferous chert. Unlike the chert in

Figure 32. Submarine slide in the middle unit of the Stone Canyon limestone showing the rarely developed continued deformation transitional to a debris-flow, conglomerate-like texture. Many of the overfolds are broken and remobilized as individual clasts. Photograph taken in the Quartz Spring area. Rock hammer is 30 cm in length.

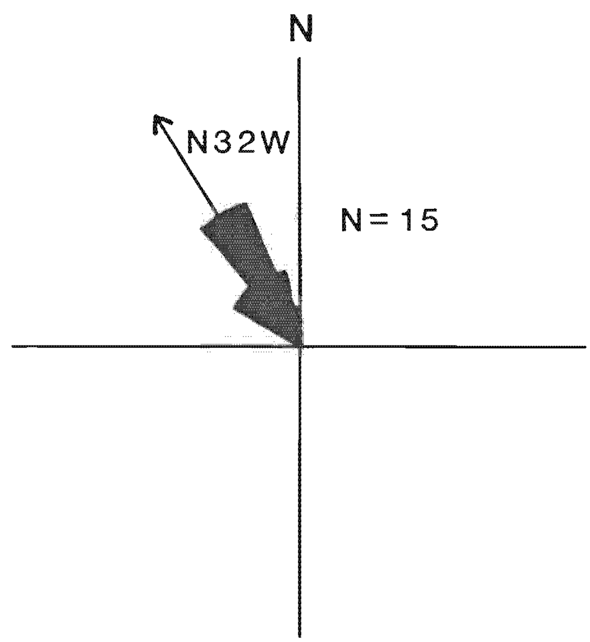


Figure 33. Rose diagram showing mean paleoslope direction of the middle unit of the Stone Canyon limestone in the Quartz Spring area. Measurements made of overfolds within the submarine slides.

the lower and middle units, which is present as individual beds and nodules, the chert in the upper unit commonly occurs in bedded sequences up to 4 m thick. Each 5-cm- to 20-cm-thick chert bed is separated by a very thin parting of argillaceous lime mudstone. Macrofossils are rare throughout the fine-grained limestones in this upper unit and include pelmatozoan debris, scattered horn corals, and brachiopod fragments. Bioturbation features are common throughout the sequence and include both horizontal and vertical burrows.

Sediment-gravity-flow deposits are common in the upper unit and include T_a and T_{ab} turbidites and one debris-flow deposit. The turbidites, which range in thickness from 10 cm to 50 cm, are normally graded with erosive bases and planar tops. These lime packstone beds consist primarily of pelmatozoan debris with fragments of bryozoans, brachiopods, and horn corals.

A 2.5-m-thick debris-flow conglomerate occurs within the upper unit of the Stone Canyon limestone. This deposit contains clasts of lime mudstone, chert, colonial rugose coral fragments, and fossiliferous wackestone and packstone, which are up to 40 cm across (fig. 34). The matrix of this deposit consists of a mixture of dark-gray lime mudstone, abundant pelmatozoan debris, and other fossil debris. Locally, the clasts in this conglomerate

Figure 34. Coarse-textured, debris-flow conglomerate in the upper unit of the Stone Canyon limestone, Quartz Spring area. This debris flow contains clasts of lime mudstone, chert, fossiliferous lime wackestone and packstone, and colonial rugose coral fragments in a fossiliferous matrix. Rock hammer is 30 cm in length.

appear crudely coarse-tail graded; however, the majority of the deposit is disorganized. The upper surface of this debris flow is irregular; clasts commonly project above the matrix of the deposit. The basal surface is slightly erosional and this deposit fills scours up to 10 cm deep into the underlying beds.

This debris flow serves as a marker bed throughout the Quartz Spring area and is easily identified by the occurrence of colonial rugose coral fragments. The conglomerate is well exposed 1 km west of the measured section in Rest Spring Gulch where it is only 1 m thick (figs. 35 and 36). There, the top is fairly planar and the base is slightly erosional. The debris-flow conglomerate was also identified during reconnaissance at Bighorn Gap, approximately 4.3 km to the northwest of the measured section. At Bighorn Gap the deposit is about 1 m thick, contains numerous clasts of colonial rugose coral fragments, displays well developed coarse-tail grading, and has a fairly planar top and an erosive base. A much thinner, very similar appearing, normally graded conglomerate occurs at approximately the same stratigraphic level in Ubehebe Mine Canyon (about 14 km west of the measured section). However, colonial rugose coral fragments were not identified in this deposit, and, therefore, the correlation remains speculative.

Figure 35. Debris-flow deposit (arrow) in the upper unit of the Stone Canyon limestone at Rest Spring Gulch. This is the same debris flow that is shown in figure 34. Here this deposit is only 1 m thick. The Jacob's staff is about 1.5 m in length.

Figure 36. The coralline, debris-flow conglomerate exposed in Rest Spring Gulch. Here this bed is about 1 m thick; it is the same debris flow shown in figure 34. Clasts of a colonial rugose coral are designated with the letter "C". The rock hammer is about 30 cm in length.

Submarine-slide masses were not identified in the upper unit along the measured section traverse and only one small-scale (1-m-thick) slide mass was noted in Rest Spring Gulch. This submarine slide contains a bioclastic limestone turbidite and measurement of the overfolding indicates a S78W direction of movement.

Several paleocurrent measurements were obtained from sole markings (flute and groove casts) exposed on the bases of turbidites in this upper unit of the Stone Canyon limestone. The rose diagram in figure 37 summarizes the measurements and shows that the directional mean for the turbidites is N51W.

Mexican Spring Formation

The base of the Mexican Spring formation occurs at 83 m above the base of the measured section. This formation is subdivided into three units. The lower and upper units consist of interbedded calcareous siltstone; fine-grained, argillaceous and silicified limestone; spiculiferous chert; bioclastic, carbonate turbidites; and carbonate debris-flow conglomerate. The middle unit consists solely of calcareous siltstone. The measured section of the Mexican Spring formation is shown diagrammatically in figure 29. The more detailed description of the measured section is included in Appendix A-3.

The lower unit of the Mexican Spring formation is 14 m

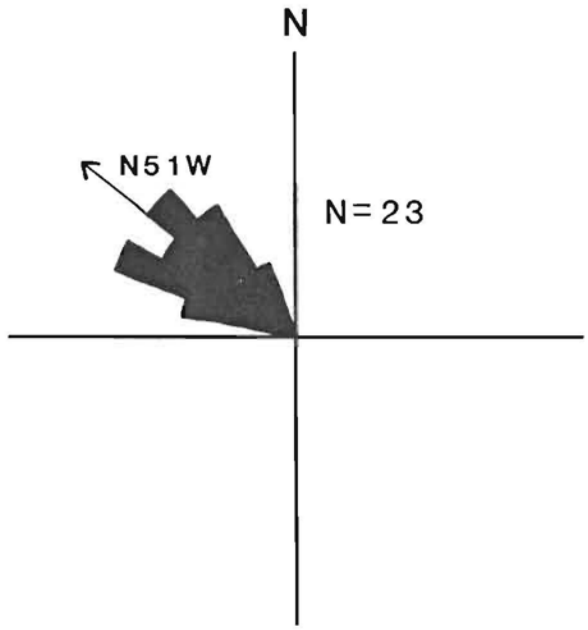


Figure 37. Rose diagram of paleocurrent measurements obtained from the turbidites in the upper unit of the Stone Canyon limestone at the Quartz Spring area. The directional mean for the turbidites is N51W.

thick and consists primarily of calcareous siltstone; thin- to medium-bedded, dark-gray, spiculiferous chert; and 4-cm- to 30-cm-thick, bioclastic, carbonate turbidites. Argillaceous lime mudstone and limestone conglomerate are minor constituents of this unit.

The reddish-brown-weathering, calcareous siltstone most commonly occurs as slope rubble; exposures are very rare. The siltstone is intensely bioturbated with both vertical and horizontal (e.g., Nereites) burrows that leave the rock virtually devoid of primary sedimentary structures (fig. 38). Thin-section analysis revealed that these rocks are composed predominantly of silt-size grains of quartz and feldspar(?) with approximately 15 percent carbonate cement and clay matrix. The siltstone is quite uniform throughout the Mexican Spring formation, and, hence, this description applies to the siltstone present in the middle and upper units, as well.

The T_a and T_{ab}, bioclastic turbidites in this unit contain abundant pelmatozoan debris and other fossils of presumed shallow-water origin (including calcareous foraminifera). All of the turbidites are normally graded with erosive bases and planar tops (fig. 39). No paleocurrent indicators or organized vertical sequences were observed in these beds.

No submarine slides are present within the lower unit

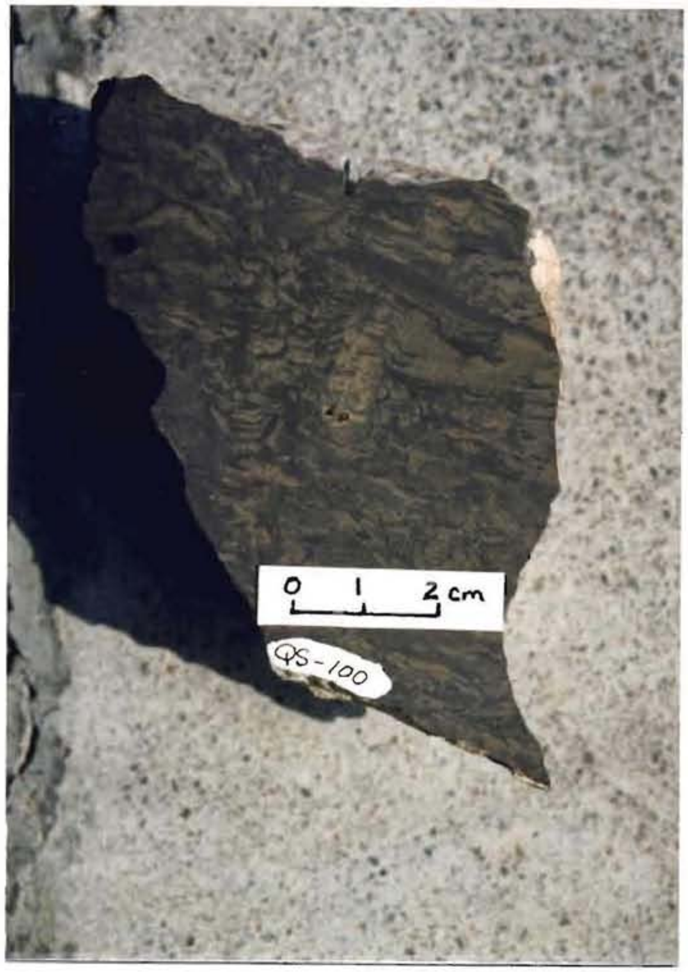


Figure 38. Polished slab of the calcareous siltstone of the Mexican Spring formation from the Quartz Spring area. Note the extensive bioturbation, which has left this rock devoid of primary sedimentary structures. Note 2-cm scale.

Figure 39. A typical T_{ab}, carbonate turbidite in the lower unit of the Mexican Spring formation in the Quartz Spring area. Rock hammer is 30 cm in length.

along the measured section traverse; however, a conspicuous 5-m-thick slide of dark-gray, lime mudstone and wackestone was identified during reconnaissance at Bighorn Gap (fig. 40). A normally graded, thin-bedded turbidite was used to determine the stratigraphic top within the slide mass and the overfolding indicates a due west direction of displacement.

The middle unit is 32 m thick and consists entirely of bioturbated, calcareous siltstone. Outcrops of this unit are very scarce. Figure 41 shows the massive, blocky character of the siltstone in one of the rare exposures.

The upper unit of the Mexican Spring formation is 117 m thick and, like the lower unit, consists of siltstone, fine-grained limestone, chert, bioclastic turbidites, and limestone conglomerate. The siltstone, fine-grained limestone, and chert are very similar to those present in the lower units of the Mexican Spring formation and Stone Canyon limestone. Chert occurs both as solitary beds and in bedded sequences a few meters thick.

Bioclastic turbidites are very conspicuous in this upper unit, as these resistant beds stand out in strong contrast to the siltstone rubble. These turbidites are mainly thick- to very thick-bedded (up to 1.3 m) T_a and T_{ab} calcarenites composed largely of shoal-water grains (fig. 42). Calcareous foraminifera and ooids, although seldom

Figure 40. Five-meter-thick submarine slide in the Mexican Spring formation exposed at Bighorn Gap. Displacement direction is due west (to the left). Jacob's staff is approximately 1.5 m in length.

Figure 41. Massive, bioturbated, calcareous siltstone in the middle unit of the Mexican Spring formation in the Quartz Spring area. Pencil is 14 cm in length.

Figure 42. A typical T_a, carbonate turbidite in the upper unit of the Mexican Spring formation in the Quartz Spring area. Pencil is 14 cm in length.

abundant within a single turbidite, are present in nearly all of these beds. Intraclasts of dark-gray lime mudstone, radiolarian-bearing, spiculiferous chert, and rare phosphatic material attest to the mixture of shallow-water and deep-water grains (fig. 43).

The turbidites are normally graded with erosional, commonly cobble-bearing bases and planar tops (figs. 44 and 45). These cobble-bearing, sediment-gravity flows may have been deposited from gravelly, high-density turbidity currents as described by Lowe (1982). Although inversely graded, R2 gravels are rare or absent in these beds, figures 44 and 45 show that normally graded, R3 gravels are readily identified. High-density, turbidity-current deposition is further supported by the presence of deposits of surging turbidity currents (Lowe, 1982) as shown in figure 46.

Debris-flow conglomerates also are present within the upper unit. At 155 m, a 75-cm-thick debris-flow deposit contains clasts of lime mudstone and chert suspended in a lime mudstone matrix (fig. 47). Fossils derived from shallow-water were not identified in this deposit; only conodonts of deep-water biofacies are present (sample QS-59).

A 6.5-m-thick, channel-form, debris-flow conglomerate is well exposed in Rest Spring Gulch and in a small gulley

Figure 43. Polished slab of a T_a turbidite in the upper unit of the Mexican Spring formation in the Quartz Spring area. Dark clasts are chert and lime mudstone and wackestone. A majority of the material is fossil debris. Note the 1-cm scale.

Figure 44. Cobble-bearing turbidite in the upper unit of the Mexican Spring formation in the Quartz Spring area. Note the crude normally graded R3 gravels near the base of the bed. Jacob's staff is about 1.5 m in length.

Figure 45. Cobble-bearing turbidite in the upper unit of the Mexican Spring formation in the Quartz Spring area. The R3 gravels in this bed show fairly well developed coarse-tail grading. Rock hammer is 30 cm in length.

Figure 46. Deposit inferred to have formed from a surging (or pulsating) turbidity current in the upper unit of the Mexican Spring formation in the Quartz Spring area. At least 7 high density/low density surge (or pulse) couplets are noted in this outcrop. Pencil is 14 cm in length.

Figure 47. Debris-flow conglomerate in the upper unit of the Mexican Spring formation in the Quartz Spring area. Clasts consist of dark-gray, fine-grained limestone and chert in an argillaceous lime mud matrix. Rock hammer is 30 cm in length.

along the measured section traverse (fig. 48). Although the lateral extent of the channel is unknown, it does not extend 200 m to the south because the debris flow is not present there at the same stratigraphic horizon. Clasts collected from the conglomerate include fossiliferous packstone and grainstone, lime mudstone and wackestone, and calcareous siltstone. The packstone and grainstone clasts contain calcareous algae, foraminifera, bryozoans, brachiopods, ooids, and intraclasts of pelleted lime mud (fig. 49). The matrix of this deposit consists of a mixture of fossil debris, lime mud, and silt grains.

The interbedded sequence of limestone turbidites and siltstone continues to the top of the Mexican Spring formation. No vertically-organized sediment-gravity-flow sequences (e.g., thickening-upward sequences) were noted in this unit.

Paleocurrent indicators are rare in spite of the numerous turbidites in this unit. Five measurements of sole markings and a possible T_c rippled division yielded transport directions ranging from due west to N20W with an arithmetic mean of N52W.

Biostratigraphy

Many samples were collected for fossils from the Stone Canyon limestone and Mexican Spring formation along the

Figure 48. A 6.5-m-thick, channel-form, debris-flow conglomerate in the upper unit of the Mexican Spring formation at Rest Spring Gulch. This debris flow contains clasts up to 1.5 m across. Notebook case is about 20 cm in length.

Figure 49. Polished slab of debris-flow conglomerate in the upper unit of the Mexican Spring formation in the Quartz Spring area. Clasts include a mixture of fossiliferous packstone and grainstone and dark-gray lime mudstone and wackestone. Matrix is a mixture of fossil debris, lime mud, and terrigenous silt grains. Note the scale near the bottom of the photograph.

measured section in the Quartz Spring area. Only those samples most crucial for stratigraphic control are listed.

Stone Canyon Limestone

The Stone Canyon limestone contains age-diagnostic conodonts, foraminifera, and corals. An age-diagnostic conodont assemblage was collected just below the base of the Stone Canyon limestone (the top of the Tin Mountain Limestone) and five age-diagnostic conodont samples were recovered from the Stone Canyon limestone (see figure 29 for the sample locations in the stratigraphic section). The conodonts were identified and dated by Charles Sandberg (pers. commun., 1985) as follows:

Sample QS-1 (Tin Mountain Limestone; 1 m below base of Stone Canyon limestone)

Gnathodus punctatus
Gnathodus cuneiformis
Bipathodus utahensis
Polygnathus communis communis

Sample QS-2 (base of Stone Canyon limestone; lower unit)

Gnathodus punctatus
Gnathodus cuneiformis
Pseudopolygnathus multistratus Morphotype 1
Pseudopolygnathus multistratus Morphotype 2
Polygnathus communis communis

Sample QS-20 (27 m above base of Stone Canyon limestone; middle unit)

Doliognathus latus Morphotype 1

Doliognathus latus Morphotype 3

Eotaphrus burlingtonensis Late Morphotype

Bactrognathus n.sp. Pa (Lane, Sandberg, and Ziegler)

Gnathodus n.sp.

Gnathodus semiglaber

Gnathodus sp.

Geniculatus sp.

Hindeodella segaformis

Hindeodella sp.

Polygnathus communis communis

Bispathodus utahensis Pa

Synprioniodus sp.

Neoprioniodus sp.

Ozarkodina sp.

Metalochotina sp.

Ligonodina sp.

Sample QS-25 (41 m above base of Stone Canyon limestone; upper unit)

Cloghergnathus sp. Early Form

"Gnathodus" deflexus

Gnathodus pseudosemiglaber

Gnathodus texanus Early Form

Bispathodus utahensis Pa

Hindeodus cf. H. cristulus

Sample QS-29 (60 m above base of Stone Canyon limestone; upper unit)

Bispathodus utahensis Pa

Bispathodus utahensis Pb

Sample QS-37 (68 m above base of Stone Canyon limestone; upper unit)

Cloghergnathus sp.

Taphrognathus varians

Bispathodus utahensis Pa

Samples QS-1 and QS-2 are both early Osagean (lower Gnathodus typicus Zone) in age and contain conodonts of the gnathodid-pseudopolygnathid biofacies (Sandberg and Gutschick, 1984). The contact between the Tin Mountain Limestone and the Stone Canyon limestone therefore does not represent a significant disconformity. Sample QS-20 was the richest conodont sample collected during this study, yielding over 400 conodonts per kilogram. This sample is middle Osagean (S. anchoralis - D. latus Zone) in age and contains conodonts of the bispathodid biofacies (Sandberg and Gutschick, 1984). Sample QS-25 is late Osagean (lower G. texanus Zone) in age, and the conodont assemblages recovered from samples QS-29 and QS-37 indicate either a late Osagean or early Meramecian age.

Three foraminiferal samples (QS-24, QS-31, QS-32; fig. 29) were collected from a turbidite in the upper unit of the Stone Canyon limestone and were identified by Paul Brenckle (pers. commun., 1984). The following taxa were recognized:

Sample QS-24 (40 m above base of Stone Canyon limestone; upper unit)

Earlandia elegans gp.
Earlandia moderata gp.
Earlandia claratula gp.
Tetrataxis sp.
Priscella prisca?
Endothyridae indeterminate
Aoujgaliaceae? indeterminate

Samples QS-31, 32 (68 m above base of Stone Canyon limestone; upper unit)

Earlandia elegans gp.
Earlandia moderata gp.
Earlandia claratula gp.
Tetrataxis sp.
Priscella prisca?
Endothyridae indeterminate
Endothyra sp.

Brenckle interpreted sample QS-24 to be late Osagean in age. This fits quite well with the late Osagean age obtained from the conodont assemblage in sample QS-25. Samples QS-31 and QS-32 are considered to be of late Osagean or early Meramecian age.

Fragments of colonial rugose corals were collected from the debris flow deposit located 68 m above the base of the Stone Canyon limestone (fig. 29). The coral fragments were identified by Calvin Stevens (pers. commun., 1984) as *Lithostrotion warreni*, which indicates a Meramecian age for this deposit. Therefore, conodont sample QS-37 and foraminiferal samples QS-31 and QS-32, which were collected from the same bed, also are considered early Meramecian in age.

The Stone Canyon limestone ranges in age from early Osagean to early, or perhaps middle(?), Meramecian. This concurs with the dates reported by McAllister (1974) for the Stone Canyon limestone exposed in the Funeral Mountains of California. The Osage-Meramec boundary occurs below the debris-flow deposit (68 m) and above sample QS-25 (41 m) that contains a late Osagean conodont assemblage. The upper 15 m of the formation have not been dated.

Mexican Spring Formation

Age-diagnostic conodonts and calcareous foraminifera were collected from several beds within the Mexican Spring formation. Two conodont samples were collected from the

Mexican Spring formation (QS-59 and QS-94; fig. 29). The conodonts were identified by Charles Sandberg (pers. commun., 1985) as follows:

Sample QS-59 (72 m above base of Mexican Spring formation; upper unit)

Gnathodus texanus Late Form

Sample QS-94 (155 m above base of Mexican Spring formation; upper unit)

Cavusgnathus unicornis

Paragnathodus commutatus

Gnathodus homopunctatus

Gnathodus texanus Late Form

Gnathodus girtyi collinsoni?

Sandberg believed that sample QS-59 is Meramecian (upper *Gnathodus texanus* Zone) in age. Sample QS-94 contains a conodont assemblage of either latest Meramecian or early Chesterian (*Cavusgnathus* Zone) age. The conodonts in this sample are equivalent to the St. Genevieve fauna in Missouri.

Several foraminiferal samples were collected from turbidites within the lower and upper units of the Mexican Spring formation (fig. 29). Paul Brenckle identified the fauna in these samples and considered the entire suite to be middle Meramecian in age (that is, equivalent to the St. Louis fauna in Missouri). The following is a list of the taxa present in the combined samples.

Earlandia vulgaris gp.

Earlandia elegans gp.

Earlandia moderata gp.

Earlandia claratula gp.

Tetrataxis sp.

Priscella prisca?

Endothyridae indeterminate

Aoujgaliaceae indeterminate

Globoendothyra sp.

Fourstonella sp.

Eoendothyranopsis utahensis?

Eoendothyranopsis ermakiensis gp.?

Eoendothyranopsis sp.

Endothyra bowmani gp.

Endothyra sp.

Mametella chautauquae

Eoforschia sp.

Planoarchaediscus spirillinoides

Planoarchaediscus sp.

Stacheoides meandriformis

Stacheoides tenuis

Stacheoides sp.

Endostaffella cf. *E. discoidea*

Pseudoammodiscus sp.

Nodosarchaediscus sp.

Diplosphaerina maequalis

Septabruniina sp.

Calcisphaera laevis

Archaediscus sp.

Pseudoglomospira sp.

Palaeotextulariidae indeterminate

Brunsia lenensis

Valvulinella sp.?

Archaediscus chernousoveris gp.

Archaediscus stilus gp.

A Chesterian brachiopod collected from the uppermost turbidite in the sequence (Stevens, 1986) suggests that the Mexican Spring formation is mostly Meramecian in age but that the upper part of the formation extends into the Chesterian.

Environmental Interpretations

The lower unit of the Stone Canyon limestone in the Quartz Spring area is lithologically similar to the lower unit in the Minnietta Mine area and in the Santa Rosa Hills. An offshore, deep, quiescent depositional environment is interpreted for these rocks. Although these rocks probably were deposited in a dysaerobic environment, occasional trace fossils indicate that the depositional setting in the Quartz Spring area may have been situated under a slightly more oxygenated water mass than the equivalent rocks to the southeast.

The middle unit differs substantially from equivalent rocks to the southeast because it contains submarine-slide masses and mudstone of inferred hemipelagic origin. Within some of the submarine slides, however, are rocks lithologically similar to the rocks of the middle unit identified at the Santa Rosa Hills and Minnietta Mine localities. The occurrence of submarine-slide masses indicates the presence of an unstable slope (Cook and Mullins, 1983). The submarine slides consist of material obviously displaced from this slope and, because these slide masses are enveloped by mudstone, a lower slope or base-of-slope setting is inferred for these deposits. The turbidite and debris flow present in the sequence do not contain material of unequivocal shallow-water origin; therefore, it seems reasonable to suggest that the slope break was in fairly deep water (that is, well below wave or current influence). It should be noted that although conodonts of the bispathodid biofacies were recovered from the turbidite in this sequence, which indicates basinal conditions, the presence of submarine slides in the unit make an interpretation favoring deposition on a basin plain unlikely.

The predominant fine-grained limestone and chert present in the upper unit of the Stone Canyon limestone indicate that these rocks were deposited in a quiescent environment. The interbedded sediment-gravity-flow deposits suggest that this quiescent depositional setting was either situated on, or more likely near the base of an unstable slope. The submarine slide identified within this unit at Rest Spring Gulch makes a basin plain interpretation improbable. These sediment-gravity-flow deposits contain material of both shallow-water origin (e.g., calcareous foraminifera and colonial rugose coral fragments) and deep-water origin (conodonts of deeper water biofacies). Consequently, the author believes that the slope break was located at shallow depth, within or near the influence of shallow-water sedimentary processes.

The fine-grained limestone and chert of the Mexican Spring formation are, likewise, interpreted as slope deposits. This interpretation is further supported by the presence of cobble-bearing turbidites and deposits of surging turbidity currents (Lowe, 1982), and a submarine-slide mass, composed of fine-grained limestone and chert, which was identified at Bighorn Gap. The majority of the interbedded sediment-gravity-flow deposits contain material derived from shallow water, which suggests that the slope break remained within the influence of shallow-water sedimentary processes.

WESTERN LEE FLAT AREA

Introduction

The Stone Canyon limestone and the Mexican Spring formation were studied at a section exposed on the eastern flank of the Inyo Mountains. The measured section traverse is on a hill located approximately 3.5 km southeast of San Lucas Canyon and 4 km northeast of Conglomerate Mesa (figs. 50 and 51). At this location, the base of the Stone Canyon limestone is missing due to faulting. The Rest Spring Shale overlies the Mexican Spring formation in apparent conformity; the contact is placed at the lowest occurrence of carbonaceous shale. The measured thicknesses of the Stone Canyon limestone and the Mexican Spring formation are 28 m (incomplete) and 101 m, respectively.

Section Description

Stone Canyon Limestone

The measured section of the Stone Canyon limestone begins at the base of the lowest exposed limestone and extends along the gully located immediately west of the hill shown in figure 51. Near the top of the formation, the traverse is offset approximately 100 m to the east onto the north-facing slope of the hill. The measured section of the Stone Canyon limestone is shown diagrammatically in

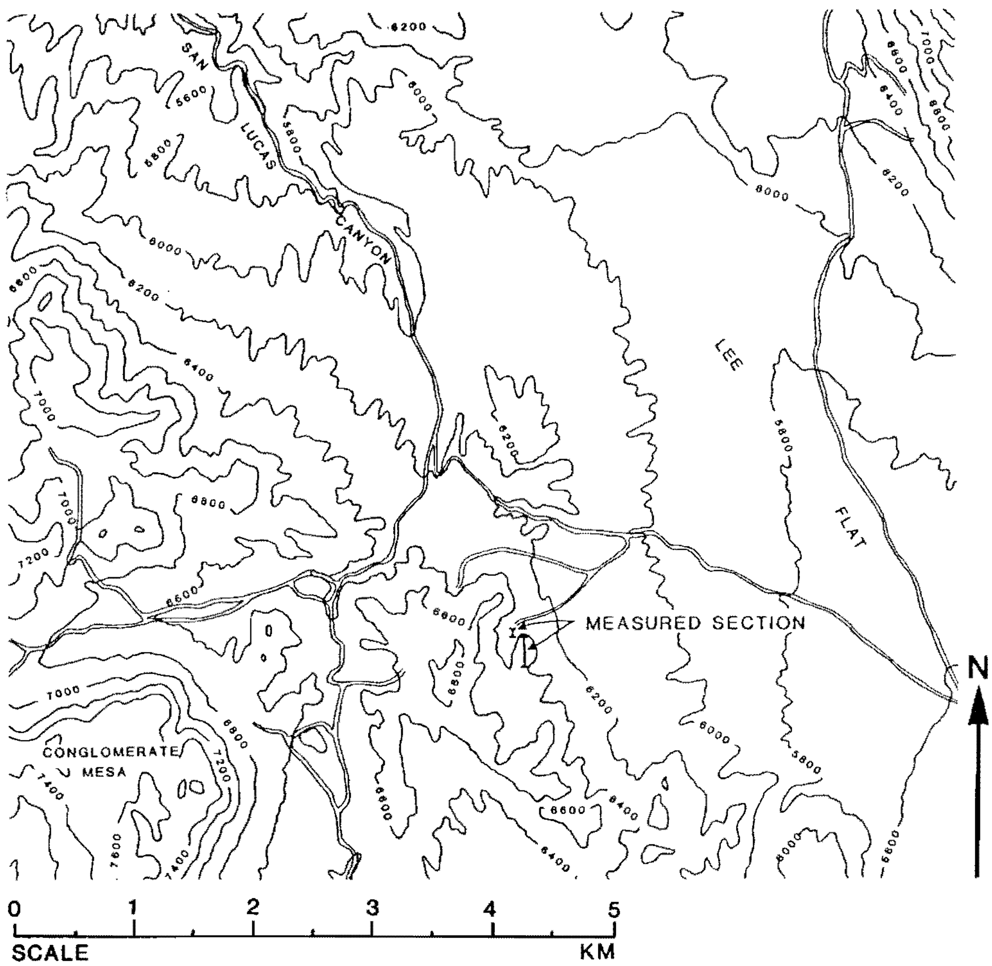


Figure 50. Location of the western Lee Flat measured section plotted on a portion of the USGS 15-minute Ubehebe Peak quadrangle, California (contour interval = 400 feet).

Figure 51. View looking southwest at the western Lee Flat measured section traverse, which extends across the hill in the foreground (from right to left).

figure 52. A more detailed description of the measured section is included in Appendix A-4.

The partial section of the Stone Canyon limestone in the western Lee Flat area is 28 m thick and consists primarily of thin- to medium-bedded, dark-gray, lime mudstone and wackestone and spiculiferous chert; it is not subdivided into lithologic units. The chert occurs in bedded sequences up to 5 m thick and as individual beds and nodules. Macrofossils, other than scattered pelmatozoan debris, and bioturbation features (horizontal and vertical burrows) are rare.

Turbidites and a debris-flow conglomerate are interbedded in this unit. The turbidites are mainly medium-bedded, T_a and T_{ab} calcarenites with sharp, erosive bases and planar tops. These turbidites crop out in strong contrast to the fine-grained limestone and chert. The debris-flow conglomerate is 1.5 m thick and contains clasts of lime mudstone and wackestone and chert suspended in a lime mudstone matrix with pelmatozoan fragments. Channeling was not observed at the base of this deposit. No submarine slides were identified in the Stone Canyon limestone. Paleocurrent indicators and vertically-organized sequences were not observed in the sediment-gravity-flow deposits.

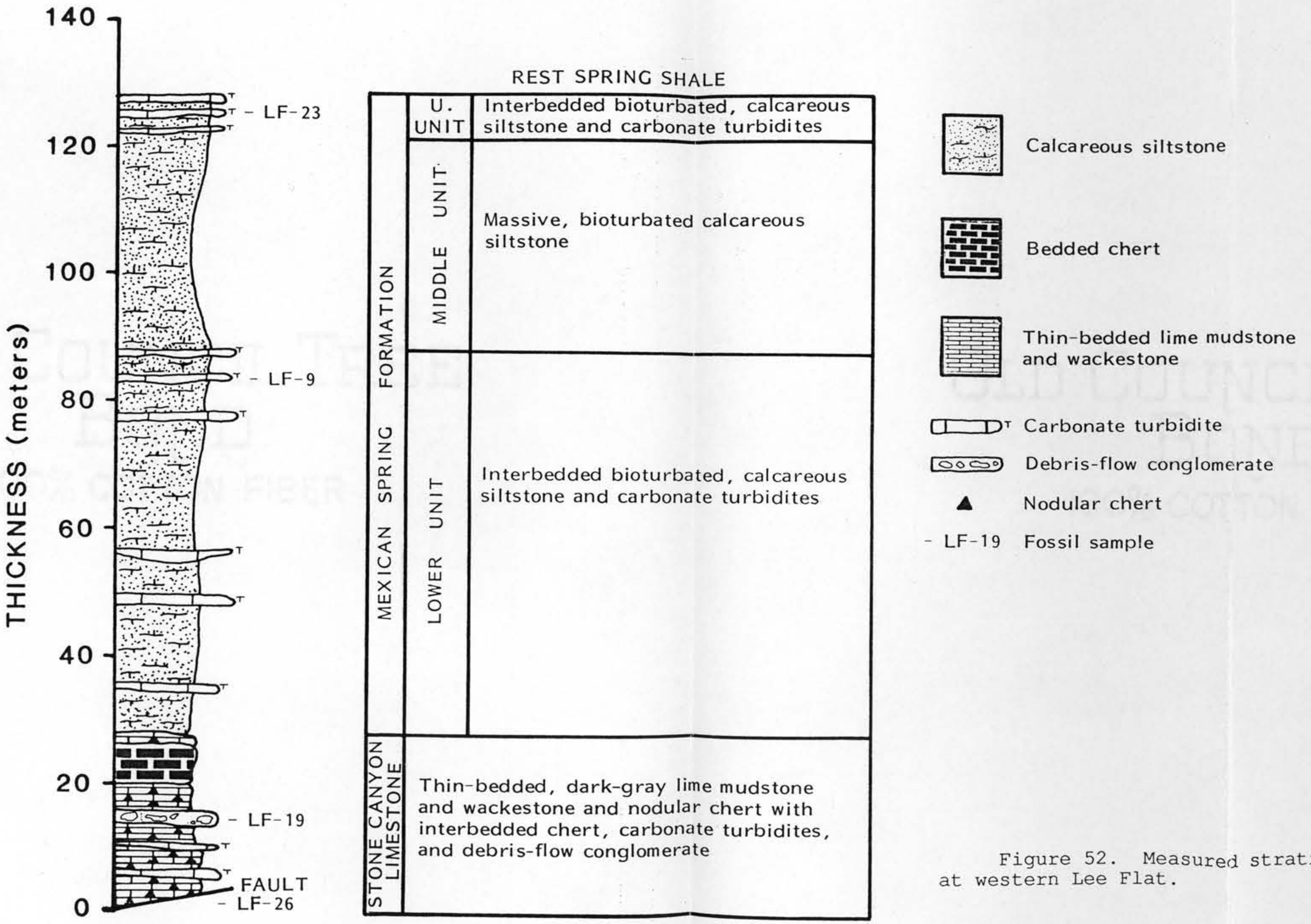


Figure 52. Measured stratigraphic section at western Lee Flat.

Mexican Spring Formation

The base of the Mexican Spring formation occurs at 28 m above the base of the section. This formation is subdivided into three units. The lower and upper units consist of interbedded calcareous siltstone and bioclastic, carbonate turbidites. The middle unit consists solely of calcareous siltstone. The measured section of the Mexican Spring formation is shown diagrammatically in figure 52. A more detailed description of the measured section is included in Appendix A-4.

As in the Quartz Spring area, the reddish-brown-weathering, mostly massive, calcareous siltstone occurs as slope rubble; outcrops of this lithology are extremely rare. The siltstone has been intensely disturbed by both vertical and horizontal (e.g., Nereites) burrows, which leave the rock virtually devoid of primary sedimentary structures. A sample collected from an exposure in the middle unit did, however, reveal very thin, planar laminations. A thin section of this sample showed that the beds are internally laminated with a tighter packing of silt grains near the base of the beds and progressively more clay matrix towards the top. The siltstone is composed predominantly of moderately well sorted, silt-size grains of quartz and feldspar(?) in a clay matrix. Normal grading of the silt grains was not noted in the sample, but the increase in clay matrix towards the top of the beds suggests that the siltstone beds represent dilute turbidity-current deposits. One such bed contains T_b and T_c divisions in which the rippled division is deformed into small flame structures.

Medium- to thick-bedded, T_a and T_{ab} calcarenite turbidites occur within the lower and upper units (fig. 53). The turbidites have erosive bases and planar tops, and they contain badly recrystallized calcareous foraminifera. Paleocurrent indicators are rare in these beds. A turbidite in the lower unit contains siltstone rip-up clasts that are elongate and weakly imbricated in a N37W direction. A N42W-trending groove cast from the same turbidite was the only other paleocurrent feature observed at this locality. Vertically-organized sequences of sediment-gravity-flow deposits were not identified in the Mexican Spring formation at this location.

Biostratigraphy

Stone Canyon Limestone

Two age-diagnostic conodont assemblages from samples LF-19 and LF-26 (fig. 52) were recovered from the Stone Canyon limestone. Foraminifera are present in the bioclastic turbidites, but the samples were too recrystallized for identification. The conodont

Figure 53. A typical T_{ab}, carbonate turbidite in the Mexican Spring formation at the western Lee Flat area. Pencil is 14 cm in length.

assemblages were identified and dated by Charles Sandberg (pers. commun., 1985) and the author.

Sample LF-26 (base of the measured section in the Stone Canyon limestone)

Polygnathus communis communis

Bispathodus utahensis Pa

Sample LF-19 (16 m above the base of the measured section in the Stone Canyon limestone)

Cloghergnathus sp.

Taphrognathus varians

Hindeodus minutus Pa

Gnathodus semiglaber

Gnathodus punctatus?

Gnathodus texanus

Bispathodus stabilis Pa

Hindeodus cristulus Pa

Sample LF-26 contains conodonts of either Osagean or Meramecian age. Sample LF-19 is Meramecian (upper *Gnathodus texanus* Zone) in age.

The portion of the Stone Canyon limestone exposed at this locality ranges from Osagean(?) to Meramecian in age. The Osage-Meramec boundary, if present in these rocks, occurs between the base of the section and the rocks at 16 m. An alternative interpretation is that the entire Stone Canyon limestone section at this locality is

Meramecian in age.

Mexican Spring Formation

As in the Stone Canyon limestone, the foraminifera present in the bioclastic, carbonate turbidites were too recrystallized for identification. Conodont samples LF-9 and LF-23 (fig. 52) were collected from the Mexican Spring formation. The conodonts were identified and dated by Charles Sandberg (pers. commun., 1985) as follows:

> Sample LF-9 (52 m above base of Mexican Spring formation; lower unit)
>
> > *Gnathodus texanus* Late Form
>
> Sample LF-23 (99 m above base of Mexican Spring formation; upper unit)
>
> > *Cavusgnathus* or *Cloghergnathus* fragments
> >
> > *Gnathodus homopunctatus*

Sample LF-9 is Meramecian in age. Sample LF-23, although poorly preserved, contains conodonts of either late Meramecian or early Chesterian age. The top of this unit, as in the Quartz Spring area, may extend into the lower Chesterian.

Environmental Interpretations

The age dates and lithologic character of the Stone Canyon limestone in the western Lee Flat area most closely resemble those in the rocks of the upper unit of the same formation in the Quartz Spring area. The predominant fine-grained, dark-gray limestone and chert with few bioturbation features indicate that these rocks were deposited in a quiescent environment under low oxygen conditions. The interbedded sediment-gravity-flow deposits suggest that this depositional setting was situated either on, or at the base of, an unstable slope. The turbidites are thinner-bedded and less numerous than the turbidites present in this unit at Quartz Spring, which is suggestive of a more distal environment of deposition.

As in the Quartz Spring area, the interbedded carbonate turbidites and calcareous siltstone of the Mexican Spring formation are interpreted to have been deposited in a slope or base-of-slope setting. Here, however, the turbidites are less numerous, thinner-bedded, and do not contain the cobble-bearing R3 gravel division. Also, debris-flow conglomerates and submarine-slide masses were not recognized in the Mexican Spring formation at this locality. Therefore, the author believes that these rocks were deposited in a more distal slope or base-of-slope (basinal?) environment than the correlative section in the Quartz Spring area.

UBEHEBE MINE CANYON AREA

Introduction

The Stone Canyon limestone and Mexican Spring formation were studied in a section in the northern Panamint Range. The section is in Ubehebe Mine Canyon, located approximately 6 km north of Ubehebe Peak (fig. 54). The measured section of the Mexican Spring formation is incomplete due to faulting at the contact between the Mexican Spring formation and the Rest Spring Shale. Displacement is considered minimal (McAllister, 1952, 1956; Burchfiel, 1969); therefore, the measured thickness of the Mexican Spring formation is believed to be a close approximation of its true thickness in this area. Here, the thicknesses of the Stone Canyon limestone and the Mexican Spring formation are 25 m and 64 m, respectively.

The Stone Canyon limestone conformably overlies the Tin Mountain Limestone. The contact is sharp and placed at the change from the dark-gray lime mudstone with nodular chert of the Tin Mountain Limestone to the very dark-gray mudstone of the Stone Canyon limestone. The Mexican Spring formation conformably overlies the Stone Canyon limestone. The contact is placed at the base of the lowest siltstone bed.

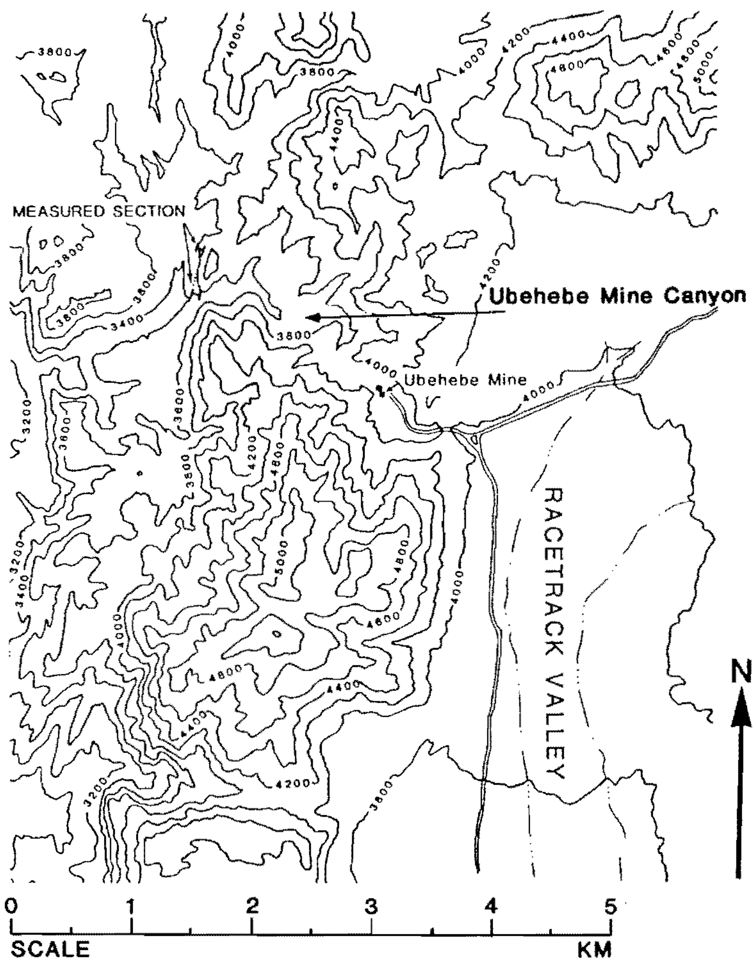


Figure 54. Location of the Ubehebe Mine Canyon area measured section plotted on a portion of the USGS 15-minute Ubehebe Peak and Dry Mountain quadrangles, California (contour interval = 200 feet).

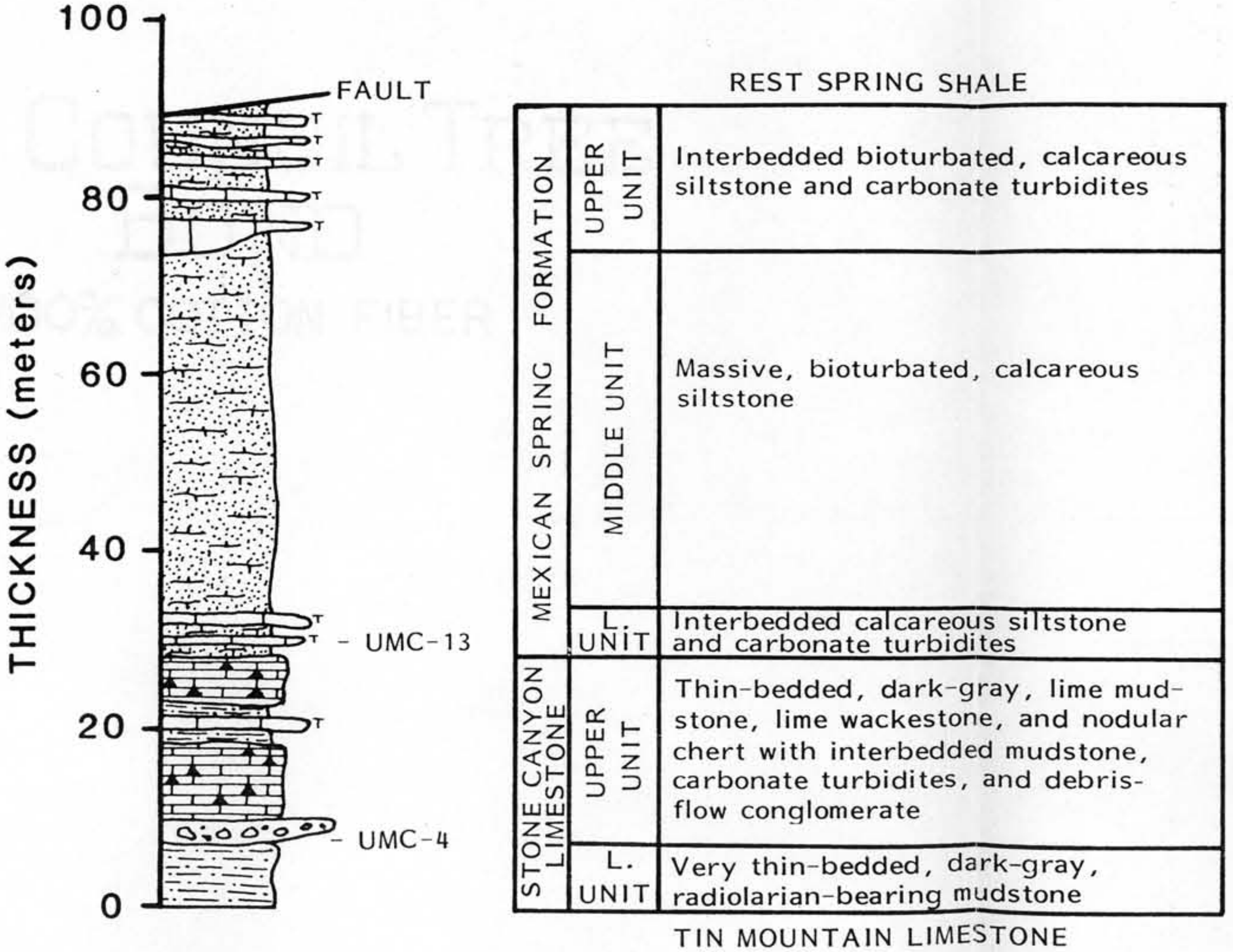
Section Description

Stone Canyon Limestone

The Stone Canyon limestone in Ubehebe Mine Canyon is subdivided into two lithologic units; a lower unit of terrigenous mudstone and an upper unit of interbedded limestone, silicified limestone, mudstone, a limestone turbidite, and a debris-flow conglomerate. The measured section of the Stone Canyon limestone is shown diagrammatically in figure 55. See Appendix A-5 for a more detailed description of the measured section.

The lower unit is approximately 7 m thick and consists exclusively of very thin-bedded, very dark-gray, radiolarian-bearing mudstone with rare chert nodules (fig. 56). Siliceous sponge spicules are present in these rocks, but they are not abundant. The mudstone is organic-rich and contains some silt-size grains of quartz and feldspar(?). Macrofossils and bioturbation features are absent and sedimentary structures characteristic of sediment-gravity-flow deposition were not observed.

The upper unit is 18 m thick and consists primarily of thin-bedded, dark-gray, argillaceous and sponge-spicule-rich, silicified lime mudstone and wackestone with interbedded mudstone, limestone conglomerate, and a bioclastic, carbonate turbidite. The fine-grained limestone is lithologically similar to the limestone



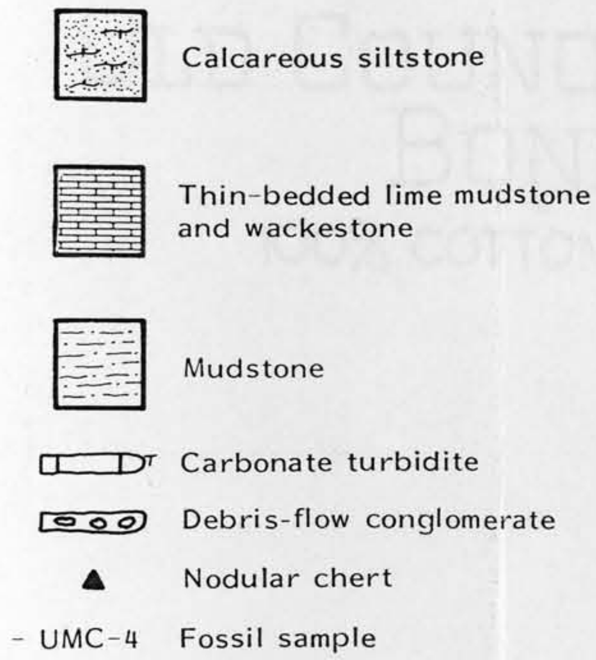


Figure 55. Measured stratigraphic section in the Ubehebe Mine Canyon area.

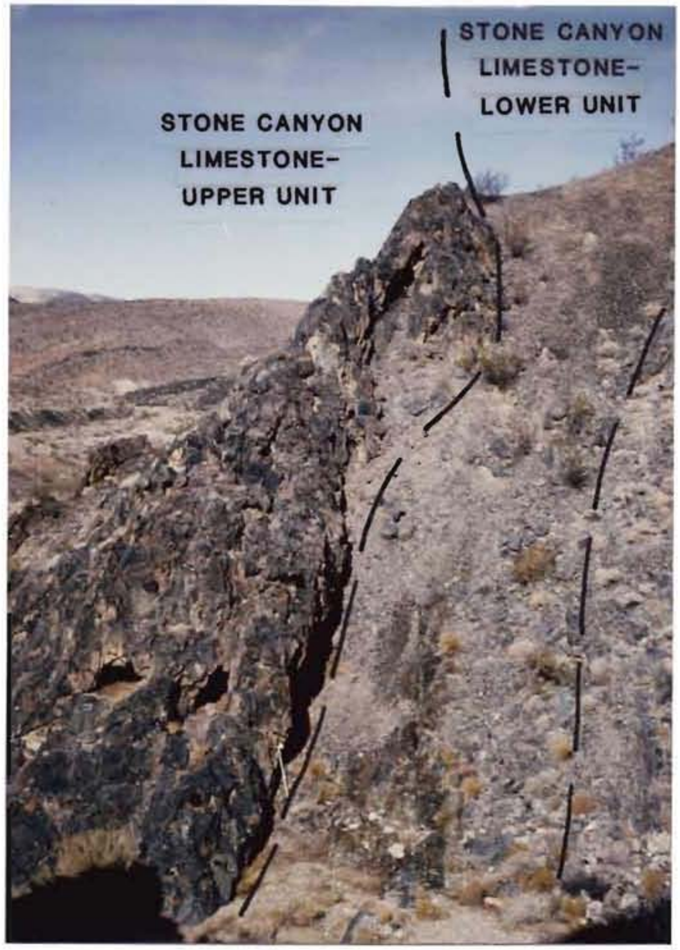


Figure 56. Lower unit of the Stone Canyon limestone consisting predominantly of thin-bedded, radiolarian-bearing mudstone. Photograph taken in the Ubehebe Mine Canyon area. Jacob's staff is approximately 1.5 m in length.

present in the submarine-slide masses at Quartz Spring and show some evidence of soft-sediment deformation (fig. 57); however, these limestones do not occur in lenticular bodies. The dark-gray mudstone of this unit does not contain radiolarians and is commonly bioturbated with horizontal burrows.

Sediment-gravity-flow deposits present in the upper unit of the Stone Canyon limestone include a bioclastic, carbonate turbidite and a debris-flow conglomerate. The 2-m-thick debris-flow deposit is channelized over a distance of 100 m and occurs at the base of the upper unit (fig. 58). Clasts in this deposit are up to 60 cm in diameter and consist of argillaceous limestone, silicified limestone, chert, and pelmatozoan wackestone and packstone. The matrix consists of dark-gray lime mudstone and pelmatozoan debris. No fossils or other allochems of unequivocal shallow-water origin were noted in this deposit. A medium-bedded, T_a, calcarenite turbidite, which contains calcareous foraminifera of shallow-water origin, occurs 20 m above the base of the section. Paleocurrent data were not obtained from either sediment-gravity-flow deposit.

Mexican Spring Formation

The base of the Mexican Spring formation occurs 25 m above the base of the section. This formation is

Figure 57. Thin-bedded, dark-gray, fine-grained limestone of the upper unit of the Stone Canyon limestone in the Ubehebe Mine Canyon area. The arrows point to areas that show evidence of soft-sediment deformation. The Jacob's staff is about 1.5 m in length.

Figure 58. A channelized, 2-meter-thick, debris-flow conglomerate exposed at the base of the upper unit of the Stone Canyon limestone in the Ubehebe Mine Canyon area. Clasts consist predominantly of argillaceous limestone, silicified limestone, chert, and pelmatozoan wackestone and packstone. Jacob's staff is placed at the base of the bed; the dashed black line is drawn along the top of the bed. Jacob's staff is about 1.5 m in length.

subdivided into three units. The lower and upper units consist of interbedded calcareous siltstone and carbonate turbidites. The middle unit consists solely of calcareous siltstone. The measured section of the Mexican Spring formation is shown diagrammatically in figure 55. A more detailed description of the measured section is included in Appendix A-5.

The reddish-brown-weathering, mostly massive, calcareous siltstone occurs mostly as slope rubble; outcrops of this lithology are rare. Intense bioturbation (fig. 59) commonly has left the rock devoid of primary sedimentary structures, although locally, thin, planar beds were noted in these rocks. Thin sections of the bioturbated siltstone revealed that it consists of silt-size grains of quartz and feldspar(?) with approximately 15 percent carbonate cement and clay matrix. The bioturbated siltstone is quite uniform in all three units of the Mexican Spring formation.

Medium- to thick-bedded, T_a and T_{ab}, calcarenite turbidites occur within the lower and upper units (fig. 60). The turbidites have erosive bases and planar tops, and they contain shallow-water calcareous foraminifera (Paul Brenckle, pers. commun., 1984). Paleocurrent data obtained from clast imbrication, clast elongation, and sole markings (groove and flute(?) casts) yielded an average

Figure 59. Polished slab of bioturbated, calcareous siltstone of the Mexican Spring formation from the Ubehebe Mine Canyon area. White circle is approximately 2 cm in diameter.

Figure 60. Thick-bedded, T_{ab}, carbonate turbidite in the upper unit of the Mexican Spring formation in the Ubehebe Mine Canyon area. Rock hammer is 30 cm in length.

transport direction of N40W (fig. 61). Vertically-organized sequences of the sediment-gravity-flow deposits were not observed.

Biostratigraphy

Numerous paleontologic samples were collected from the Ubehebe Mine Canyon section, but the only age-diagnostic fossils are conodonts recovered from the debris-flow deposit at 7.5 m (UMC-4) and calcareous foraminifera collected from a turbidite 25 m (UMC-13) above the base of the section. Figure 55 shows the location of these samples in the stratigraphic section. Although calcareous foraminifera are present in most of the carbonate turbidites of the Mexican Spring formation, preservation generally is too poor for identification. Charles Sandberg (pers. commun., 1985) identified and dated the conodont assemblage in sample UMC-4 and Paul Brenckle (pers. commun., 1984) identified and dated the foraminifera in sample UMC-13.

Sample UMC-4 (7.5 m above base of Stone Canyon limestone; upper unit)

- *Cloghergnathus* or *Clydagnathus* sp. fragment
- *Polygnathus* sp. fragment
- *Bispathodus utahensis* Pa
- *"Gnathodus" deflexus*?

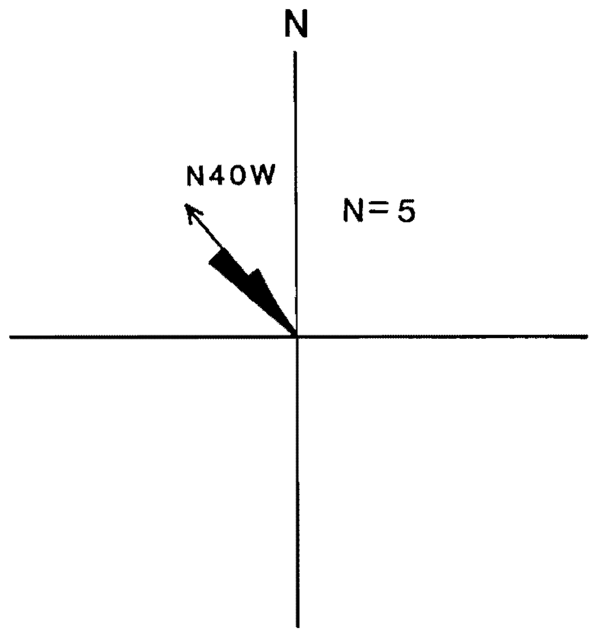


Figure 61. Rose diagram of paleocurrent measurements obtained from turbidites in the Mexican Spring formation in the Ubehebe Mine Canyon area.

Sample UMC-13 (base of Mexican Spring formation; lower unit)

Tetrataxis sp.

Eoendothyranopsis sp.

Stacheoides sp.

Sandberg believed that sample UMC-4 is Osagean in age, but added that an early Meramecian age for this deposit also is possible. Brenckle interpreted the taxa present in sample UMC-13 to be either late Osagean or Meramecian in age. As a result, the Osage-Meramec boundary can not be identified with confidence in the Ubehebe Mine Canyon section based on the fossils collected during the course of this study.

Environmental Interpretations

The lower unit of the Stone Canyon limestone, consisting of very dark-gray, organic-rich, radiolarian-bearing mudstone, most likely was deposited in a quiet-water setting. Sediment-gravity-flow deposits were not noted in this unit and, paleogeographically, this section is situated seaward (to the west) of the slope and base-of-slope rocks present in the Quartz Spring area. Consequently, these mudstones are interpreted to have been deposited in a basinal environment. The high proportion of radiolarians to sponge spicules further supports a basinal environment of deposition (Bonnie Murchey, pers. commun., 1984). The high organic content, very dark-gray color, and absence of bioturbation features indicate that these rocks were deposited under anaerobic conditions (Byers, 1977; Sandberg and Gutschick, 1984).

The lithologic character of the upper unit of the Stone Canyon limestone at Ubehebe Mine Canyon most closely resembles the rocks of the upper unit of the same formation in the Quartz Spring area. The fine-grained limestone and mudstone suggest that the rocks of the upper unit were deposited in a quiescent setting. The debris-flow conglomerate and bioclastic turbidite suggest that the depositional environment was situated near the base of an unstable slope. Although submarine slides are not present at this section, the fine-grained limestone sequences show evidence of soft-sediment movement.

As in the Quartz Spring area, the interbedded carbonate turbidites and calcareous siltstone of the Mexican Spring formation are interpreted to have been deposited in a slope or base-of-slope setting. The presence of a channelized turbidite at 72 m makes a basin plain interpretation for the depositional environment unlikely. The turbidites in Ubehebe Mine Canyon are less numerous and are more thinly bedded than the turbidites in the Quartz Spring area. Also, debris-flow conglomerates and submarine slides are not present in the Mexican Spring formation at this locality. Therefore, the author interprets a more distal slope or base-of-slope depositional environment for these rocks than the correlative section at the Quartz Spring area.

MEXICAN SPRING AREA

Introduction

The Mexican Spring formation was studied at a section in the southern Inyo Mountains, located approximately 7.2 km northwest of Cerro Gordo Mine (fig. 62). The Mexican Spring formation disconformably(?) overlies the Tin Mountain Limestone and is conformably overlain by the Rest Spring Shale, mapped as Chainman Shale by Merriam (1963). In the Mexican Spring area, the Mexican Spring formation is 37 m thick. The Stone Canyon limestone is not present in the southern Inyo Mountains (Merriam, 1963; Stevens and others, 1979; Stevens, 1986).

Section Description

The measured section of the Mexican Spring formation is shown diagrammatically in figure 63. A more detailed description of the measured section is included in Appendix A-6.

In the Mexican Spring area, the Mexican Spring formation consists exclusively of brown-weathering, massive, highly bioturbated, calcareous siltstone (fig. 64). Primary sedimentary structures were not noted in any of the siltstone at this locality. Thin-section analysis revealed that these rocks consist of silt-size grains of

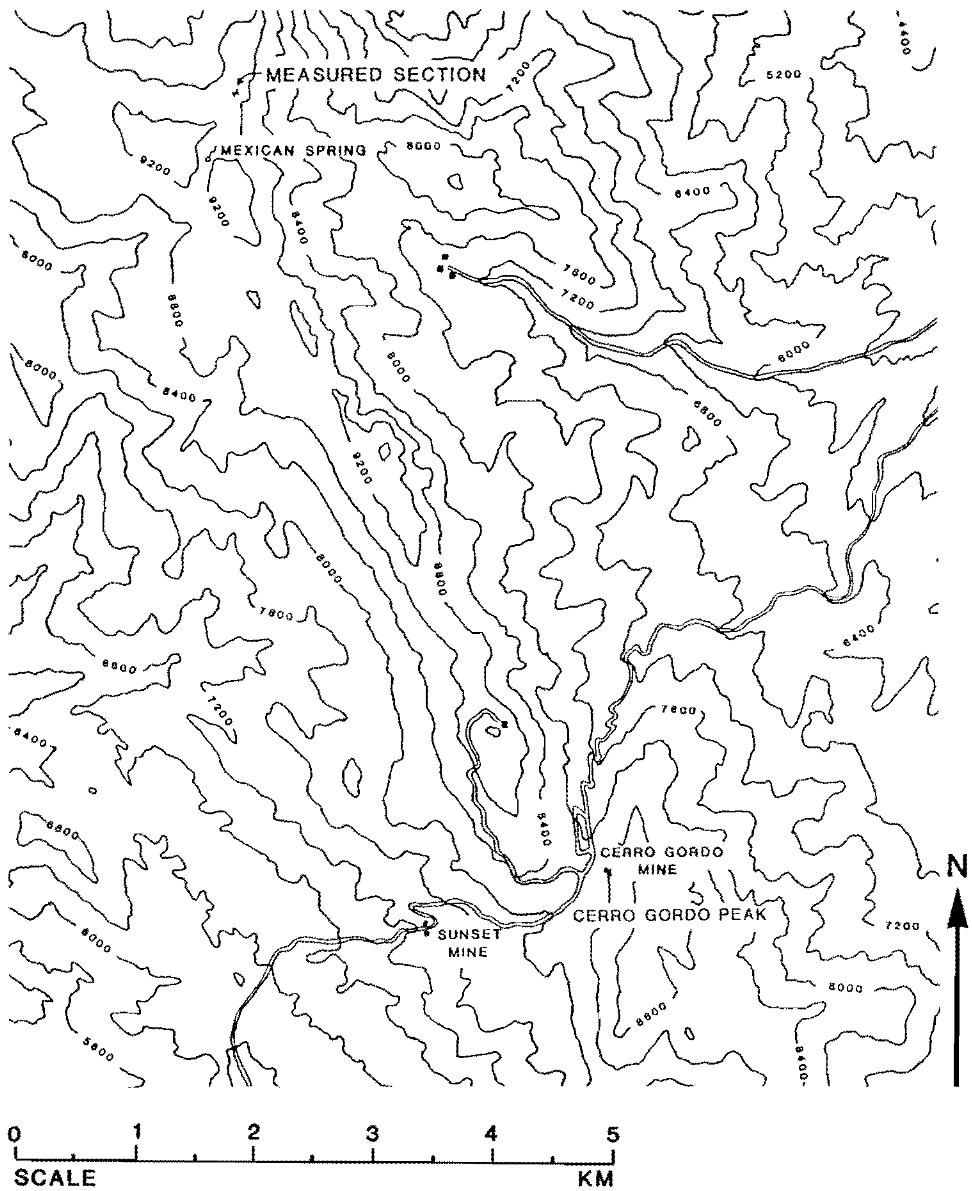


Figure 62. Location of Mexican Spring area measured section plotted on a portion of the USGS 15-minute New York Butte quadrangle, California (contour interval = 400 feet).

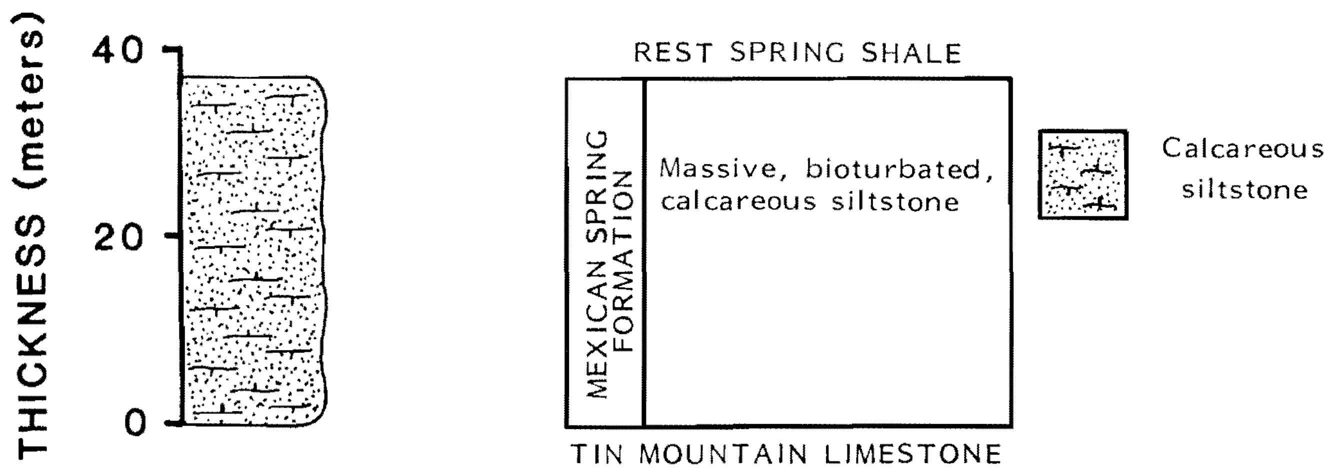


Figure 63. Measured stratigraphic section in the Mexican Spring area.

Figure 64. Bioturbated, calcareous siltstone of the Mexican Spring formation in the Mexican Spring area. Pencil is 14 cm in length.

quartz and feldpar(?) with about 15 percent carbonate cement and clay matrix. Carbonate sediment-gravity-flow deposits and submarine slides were not recognized in this formation in the Mexican Spring area.

Biostratigraphy

No fossils were collected from the Mexican Spring formation at Mexican Spring. The Tin Mountain Limestone contains fossils of early Mississippian age (Merriam, 1963), and a Chesterian ammonoid, Cravenoceras, has been collected from near the base of the Rest Spring Shale (Merriam, 1963; Gordon, 1964). Consequently, the Mexican Spring formation is Mississippian in age, but the epoch can not be assigned with certainty.

Environmental Interpretations

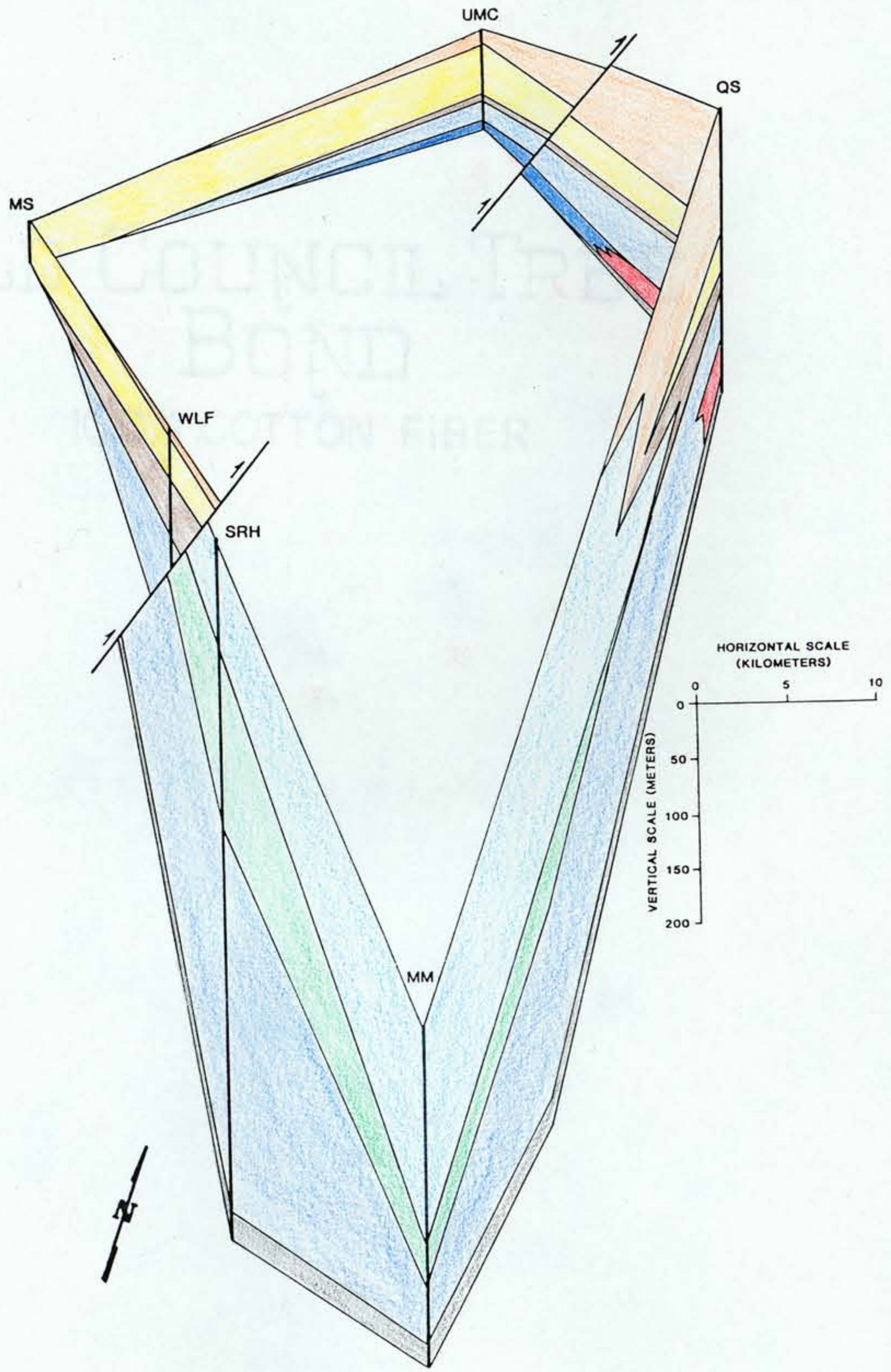
The siltstone is believed to have been deposited in a basinal environment. Paleogeographically, this area is situated the farthest seaward of all six investigation sites. The absence of carbonate sediment-gravity-flow deposits and submarine slides is consistent with the paleogeographic position of this section. The high degree of bioturbation indicates that this depositional setting was situated beneath a well oxygenated water mass.

STRATIGRAPHIC CORRELATION

Lithostratigraphic and biostratigraphic correlations are made between measured sections as an aid in developing depositional and paleogeographic models. At most localities, the Stone Canyon limestone and the Mexican Spring formation were subdivided into several units, some of which are present in more than one measured section. Biostratigraphic correlations are based on the fossils collected during the course of this study and age-diagnostic fossil collections made by previous workers. In spite of the extensive fossil collection made during this study, there are major deficiencies in the age data.

Lithostratigraphic Correlation

Figure 65 shows the lithostratigraphic correlations made during this study. The chert-rich lower unit of the Stone Canyon limestone is present in the Minnietta Mine, Santa Rosa Hills, and Quartz Spring areas. This unit, which is about the same thickness at Minnietta Mine and Santa Rosa Hills, thins to the north at Quartz Spring. The chert and spiculiferous limestone of the lower unit are not present at Ubehebe Mine Canyon, where radiolarian-bearing mudstone occurs at the base of the section. In the western Lee Flat area, this portion of the Stone Canyon limestone



EXPLANATION

MEXICAN SPRING FORMATION

- CALCAREOUS SILTSTONE AND LIMESTONE
- CALCAREOUS SILTSTONE
- CALCAREOUS SILTSTONE AND LIMESTONE

SANTA ROSA HILLS LIMESTONE

- THICK-BEDDED, MASSIVE, PELMATOZOAN-RICH, BIOCLASTIC CALCARENITE

STONE CANYON LIMESTONE

- FINE-GRAINED LIMESTONE AND NODULAR CHERT WITH BIOCLASTIC CALCARENITE
- MUDSTONE AND SUBMARINE SLIDES WITH A FEW SEDIMENT-GRAVITY-FLOW DEPOSITS
- FINE-GRAINED LIMESTONE AND NODULAR CHERT
- RADIOLARIAN-BEARING MUDSTONE
- BEDDED CHERT AND INTERBEDDED CHERT AND LIMESTONE

Figure 65. Fence diagram showing lithostratigraphic correlations in the study area (MM - Minnietta Mine area, SRH - Santa Rosa Hills, WLF - western Lee Flat area, MS - Mexican Spring area, UMC - Ubehebe Mine Canyon area, QS - Quartz Spring area). Thrust faults are indicated by fault symbols. Top of section lines indicate the geographic position of the section.

is not exposed and at Mexican Spring the Stone Canyon limestone is not present.

The middle unit of the Stone Canyon limestone, consisting of monotonously interbedded silicified limestone and lime mudstone and wackestone, was defined in the Minnietta Mine area and identified as a much thicker section in the Santa Rosa Hills. In the Quartz Spring area, a sequence of submarine-slide masses that are composed of a similar lithology occurs above the chert-rich lower unit of the Stone Canyon limestone. The submarine slides, however, are enveloped by terrigenous mudstone and are considered to be a separate lithostratigraphic unit. The upper portion of the radiolarian-bearing mudstone at Ubehebe Mine Canyon is considered separate from, but correlative with, the mudstones at Quartz Spring. In the Mexican Spring area, the Stone Canyon limestone is not present and in the western Lee Flat area, this portion of the Stone Canyon limestone is not exposed.

The upper unit of the Stone Canyon limestone at Minnietta Mine, consisting of interbedded fine-grained limestone and pelmatozoan-rich tempestites, is correlative with a similar unit at the Santa Rosa Hills, where the rocks also contain cross-bedded, carbonate, sand-shoal deposits. In the Quartz Spring, western Lee Flat, and Ubehebe Mine Canyon areas, the upper unit of the Stone

Canyon limestone consists primarily of fine-grained limestone with interbedded sediment-gravity-flow deposits.

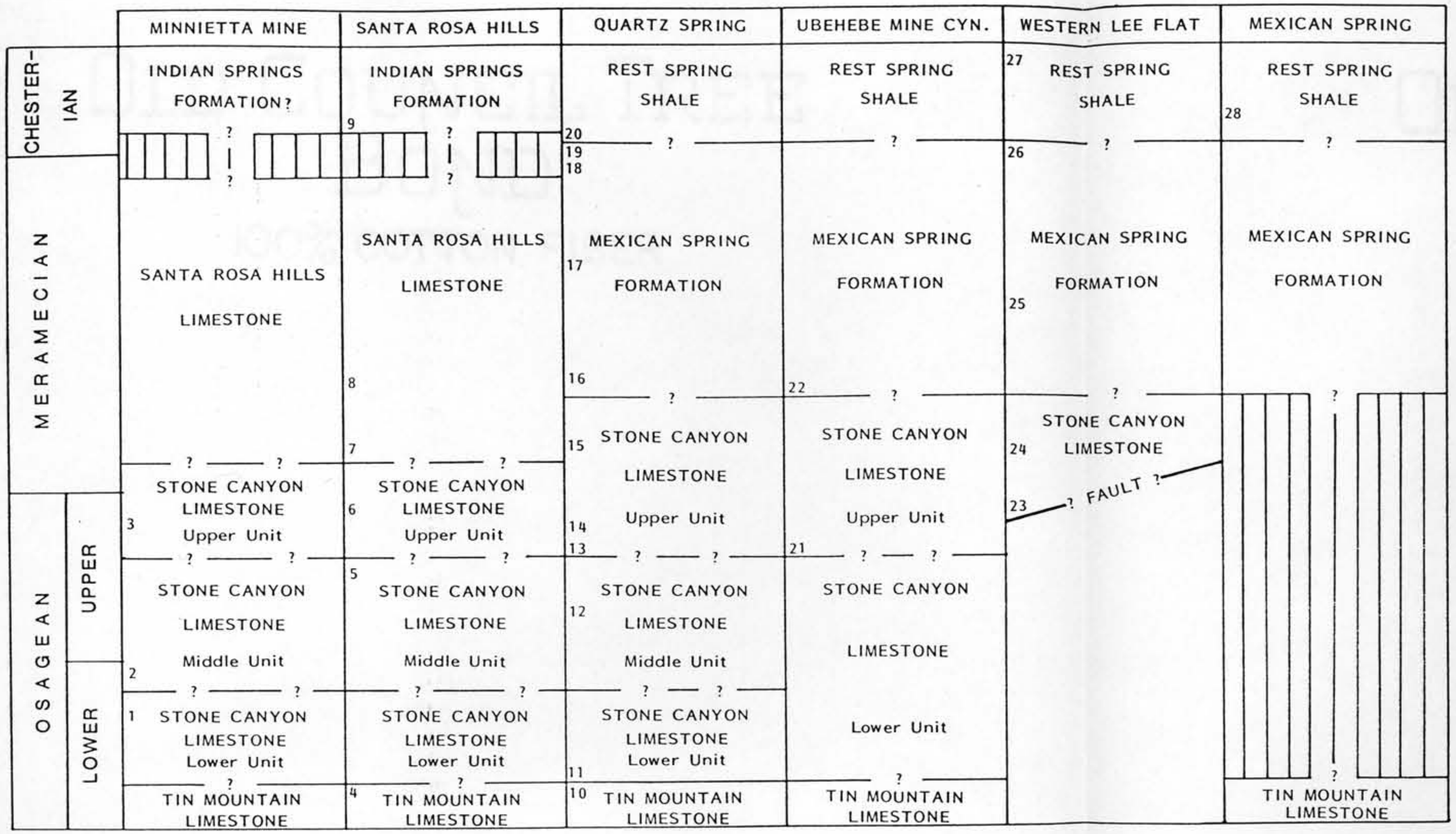
The Santa Rosa Hills Limestone is present in the Minnetta Mine area and in the Santa Rosa Hills but is not present at the other measured sections. In the Minnietta Mine area, the Santa Rosa Hills Limestone is about twice as thick as the correlative section in the Santa Rosa Hills.

The Mexican Spring formation occurs in the Quartz Spring, western Lee Flat, Ubehebe Mine Canyon, and Mexican Spring areas, and it has been subdivided into three units in each area, except Mexican Spring. The upper and lower units contain calcareous siltstone and limestone. The middle unit consists exclusively of calcareous siltstone and is lithostratigraphically correlative with the entire Mexican Spring formation in the Mexican Spring area.

Biostratigraphic Correlation

Figures 66 and 67 show two possible biostratigraphic correlations based on fossils recovered during this study and those collected by previous workers. Both correlations are consistent with the biostratigraphic data collected during this investigation.

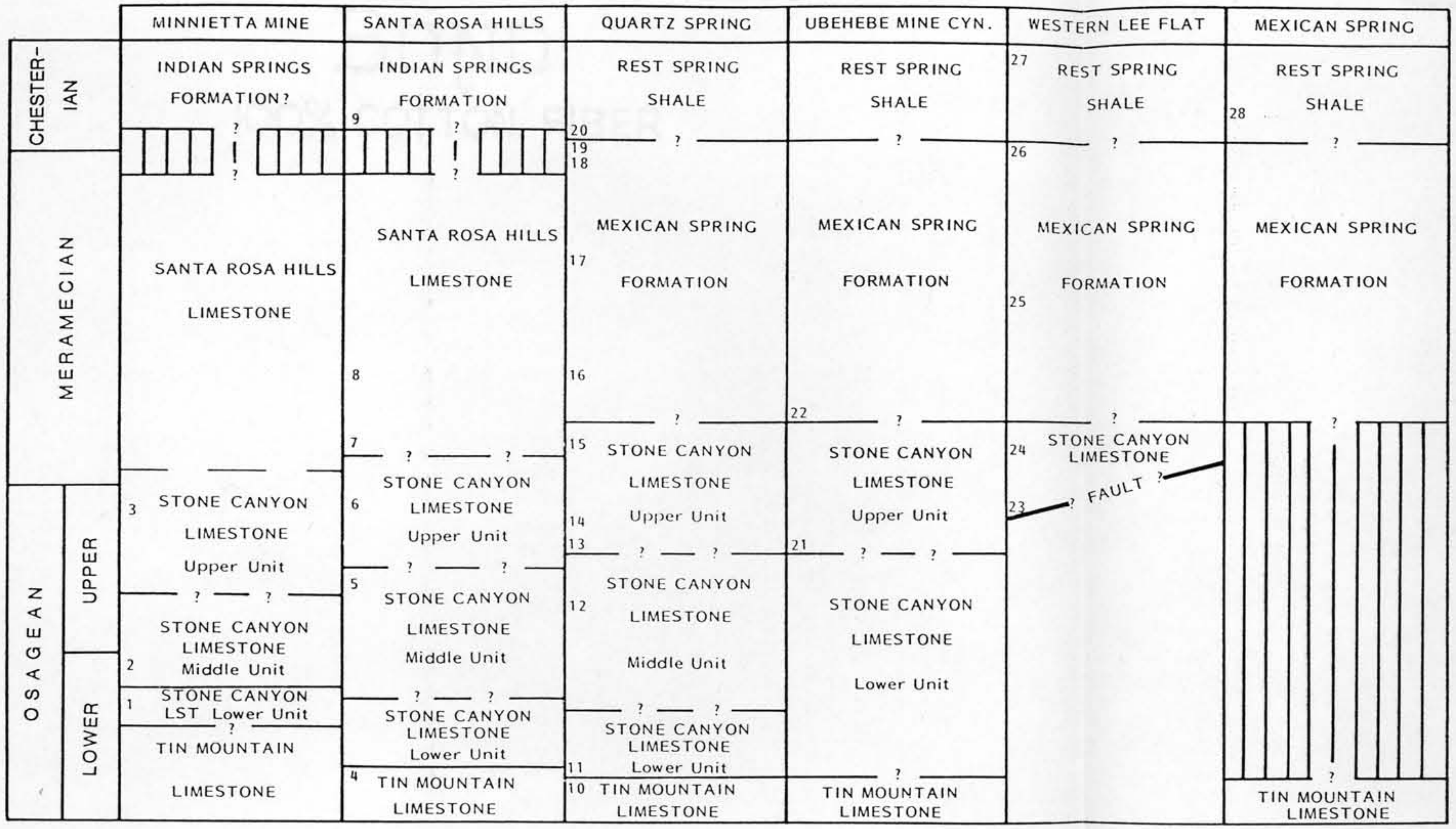
The Osagean is subdivided into the early and late Osagean. Early Osagean, as used here, is equivalent to the lower and upper *Gnathodus typicus* conodont zones and



INDEX OF FOSSIL SAMPLES

1- Conodonts, early Osagean, upper Gnathodus typicus Zone
2- Conodonts, early Osagean, upper Gnathodus typicus Zone
3- Conodonts, Osagean - Meramecian indeterminate
4- Conodonts, early Osagean, lower Gnathodus typicus Zone
5- Conodonts, late Osagean to early Meramecian, Gnathodus texanus Zone
6- Foraminifera, late Osagean to early Meramecian
7- Colonial rugose corals, early Meramecian
8- Foraminifera, middle Meramecian
9- Brachiopods, Chesterian (C. Stevens, pers. commun., 1985)
10- Conodonts, early Osagean, lower Gnathodus typicus Zone
11- Conodonts, early Osagean, lower Gnathodus typicus Zone
12- Conodonts, late Osagean, S. anchoralis - D. latus Zone
13- Foraminifera, late Osagean
14- Conodonts, late Osagean, lower Gnathodus texanus Zone
15- Colonial rugose corals, early Meramecian
16- Conodonts, Meramecian, upper Gnathodus texanus Zone
17- Foraminifera, middle Meramecian
18- Conodonts, latest Meramecian to earliest Chesterian, Cavusgnathus Zone
19- Brachiopods, early Chesterian (Stevens, 1986)
20- Ammonoids, Chesterian (Gordon, 1964)
21- Conodonts, Osagean to early Meramecian
22- Foraminifera, late Osagean to Meramecian
23- Conodonts, Osagean to Meramecian
24- Conodonts, Meramecian, upper Gnathodus texanus Zone
25- Conodonts, Meramecian, upper Gnathodus texanus Zone
26- Conodonts, Meramecian to early Chesterian
27- Brachiopods, Chesterian (C. Stevens, pers. commun., 1985)
28- Ammonoids, Chesterian (Merriam, 1963)

Figure 66. Correlations consistent with fossil data assuming major lithologic units to be about the same age throughout the study area.



INDEX OF FOSSIL SAMPLES

1- Conodonts, early Osagean, upper Gnathodus typicus Zone
2- Conodonts, early Osagean, upper Gnathodus typicus Zone
3- Conodonts, Osagean - Meramecian indeterminate
4- Conodonts, early Osagean, lower Gnathodus typicus Zone
5- Conodonts, late Osagean to early Meramecian, Gnathodus texanus Zone
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16- Conodonts, Meramecian, upper Gnathodus texanus Zone
17- Foraminifera, middle Meramecian
18- Conodonts, latest Meramecian to earliest Chesterian, Cavusgnathus Zone
19- Brachiopods, early Chesterian (Stevens, 1986)
20- Ammonoids, Chesterian (Gordon, 1964)
21- Conodonts, Osagean to early Meramecian
22- Foraminifera, late Osagean to Meramecian
23- Conodonts, Osagean to Meramecian
24- Conodonts, Meramecian, upper Gnathodus texanus Zone
25- Conodonts, Meramecian, upper Gnathodus texanus Zone
26- Conodonts, Meramecian to early Chesterian
27- Brachiopods, Chesterian (C. Stevens, pers. commun., 1985)
28- Ammonoids, Chesterian (Merriam, 1963)

Figure 67. Correlations consistent with fossil data assuming an early Osagean transgression followed by a late Osagean regression.

approximately equivalent to Mamet's foraminiferal zones 7 and 8. Late Osagean includes the Scaliognathus anchoralis - Doliognathus latus and lower Gnathodus texanus conodont zones and is approximately equivalent to Mamet's foraminiferal zones 9 and 10 (Gutschick and others, 1980).

The lower unit of the Stone Canyon limestone is early Osagean in age (fig. 66, 67). A lower Gnathodus typicus Zone conodont assemblage was recovered from the base of the lower unit at Quartz Spring. A sample collected from about 5 m above the base of this unit in the Minnietta Mine area contains condonts of the Gnathodus typicus Zone.

Age-diagnostic fossils are relatively scarce in the middle and upper units of the Stone Canyon limetone. An upper Gnathodus typicus Zone conodont assemblage was collected from the middle unit of the Stone Canyon limestone in the Minnietta Mine area (fig. 66, 67). All other fossil samples collected from the middle and upper units of the Stone Canyon limestone in the Minnietta Mine area and the Santa Rosa Hills have been dated as Osagean-Meramecian indeterminate; however, those recovered near the top of the unit in the Santa Rosa Hills are believed to be no older than late Osagean. In the Quartz Spring area a Scaliognathus anchoralis - Doliognathus latus Zone conodont assemblage was recovered from the middle unit of the Stone Canyon limestone, which indicates a late Osagean age. The

Osagean-Meramecian boundary occurs within the upper unit of the Stone Canyon limestone at Quartz Spring. A late Osagean (lower *Gnathodus texanus* Zone) conodont assemblage was recovered from near the base of the unit. Fragments of the coral *Lithostrotion warreni*, which is Meramecian in age, were collected from a debris-flow conglomerate in the upper portion of this unit. In the western Lee Flat area, two conodont assemblages were recovered from the Stone Canyon limestone. A sample collected from the base of the section yielded conodonts of Osagean-Meramecian indeterminate age. The other sample was collected from 16 m above the base of the section. This sample contained a conodont assemblage dated as Meramecian (upper *Gnathodus texanus* Zone) in age. In the Ubehebe Mine area, a probable Osagean conodont assemblage was recovered from near the base of the upper unit of the Stone Canyon limestone.

In the Santa Rosa Hills, a Meramecian age is indicated for the base of the Santa Rosa Hills Limestone based on the corals and foraminifera collected from near the base and the middle of this unit. No fossils were collected from this unit in the Minnietta Mine area. An Osagean-Meramecian indeterminate conodont assemblage was collected, however, 16 m below the base of the Santa Rosa Hills Limestone at this location.

At all localities where fossils have been recovered from the Mexican Spring formation, the base of the unit is Meramecian in age. A fauna of probable early Chesterian age has been recovered from the uppermost beds of the Mexican Spring formation in the Quartz Spring and western Lee Flat areas. Thus, much of the Mexican Spring formation throughout the study area is approximately the same age as the Santa Rosa Hills Limestone.

STRATIGRAPHIC INTERPRETATIONS

The results of the lithostratigraphic and biostratigraphic correlations have been combined with the sedimentologic data collected at each measured section. It is not clear whether or not the lower unit of the Stone Canyon limestone is the same age at each of the measured sections (fig. 66) or if it becomes younger southeastward (fig. 67). If the unit is time-transgressive, it may reflect an increase in the subsidence rate in the area. Either way, however, a steepening of the depositional slope is suggested by the occurrence of sediment-gravity-flow deposits near the base of the middle unit of the Stone Canyon limestone in the Santa Rosa Hills. The appearance of massive chert in the lower unit of the Stone Canyon limestone also suggests substantial deepening in this area of eastern California.

Fossils are relatively scarce in the Santa Rosa Hills Limestone at most localities, except in the Santa Rosa Hills where it is shown to be Meramecian in age. However, these carbonate sands are believed to have prograded toward the northwest (Stevens and others, 1979; Klingman, 1984; Stevens, 1986). This interpretation was based on the decrease in thickness of the formation from the southeast to the northwest and on the lithologic correlation with the

Bullion Limestone and Yellowpine Limestone of the Monte Cristo Group in southern Nevada, which are late Osagean to Meramecian in age (thus, apparently older than the Santa Rosa Hills Limestone). A tongue of rocks lithologically similar to the Santa Rosa Hills Limestone, which was identified in the Minnietta Mine area (see fig. 14), appears to substantiate the interpretation of westward progradation of the Santa Rosa Hills Limestone because this tongue pinches out in a westerly direction.

The upper unit of the Stone Canyon limestone at the Minnietta Mine and Santa Rosa Hills areas also is interpreted as a progradational unit based on its gradational association with the Santa Rosa Hills Limestone. Thus, the Santa Rosa Hills Limestone is presumed to have followed the upper member of the Stone Canyon limestone as they both prograded across the shelf.

The Osagean-Meramecian boundary, which occurs within the upper unit of the Stone Canyon limestone in the Quartz Spring area, contains numerous pelmatozoan-rich turbidites. These turbidites probably reflect the approach (progradation) of the storm deposits of the upper unit of the Stone Canyon limestone and the shallow-shelf sediments of the Santa Rosa Hills Limestone onto the outer part of the platform. This interpretation is supported by the presence of transported Meramecian colonial rugose corals, which are similar to those that are in place in the Santa Rosa Hills Limestone, in a debris-flow deposit in the upper unit of the Stone Canyon limestone in the Quartz Spring area.

Where fossils have been collected from the Mexican Spring formation, the base of the unit is Meramecian in age; the top of the unit may extend into the Chesterian. The Mexican Spring formation has not been dated in the Mexican Spring area; however, there are no apparent sedimentologic or regional stratigraphic reasons to believe that these siltstones are significantly different in age from those at other localities. The Mexican Spring formation in the Mexican Spring area is interpreted to be largely, if not entirely, Meramecian in age.

Because the Mexican Spring formation is approximately coeval with the Santa Rosa Hills Limestone, and the sediment-gravity-flow deposits contain a large proportion of material derived from shallow water, the turbidites and debris flows in the Mexican Spring formation are considered to be genetically related to the progradation of the Santa Rosa Hills Limestone to the platform margin. This interpretation also is supported by the presence of the Meramecian colonial rugose coral fragments in a debris-flow deposit from the uppermost portion of the Stone Canyon limestone (immediately below the Mexican Spring formation) in the Quartz Spring area.

In summary, the correlations shown on figure 67 are favored based on the sedimentologic evidence, the inferred sedimentary relationships between facies, and the ages of these rocks in eastern California and southern Nevada. The lower unit of the Stone Canyon limestone is believed to be time-transgressive, which may reflect an increase in the subsidence rate of the Early Mississippian platform. During late Osagean(?) to Meramecian time, shallow marine, carbonate sands prograded into the study area from the southeast. The siltstones and limestones of the Mexican Spring formation were deposited in a deeper-water setting during the Meramecian to earliest Chesterian as the shelf, upon which the Santa Rosa Hills Limestone was deposited, became established in the southeastern portion of the study area.

ORIGIN OF THE SILTSTONE

The Mexican Spring formation consists mostly of reddish-brown-weathering, bioturbated, calcareous siltstone. At the Quartz Spring, western Lee Flat, and Ubehebe Mine Canyon localities, the siltstone comprises more than 60 percent of the Mexican Spring formation. In the Mexican Spring area, this formation consists entirely of siltstone. These rocks contain only about 15 percent carbonate cement and clay matrix; shale interbeds are very rare. Overall, the siltstone is massive with few primary sedimentary structures preserved.

This siltstone is not unique to the study area. A sequence of calcareous siltstone of late Osagean(?) to Meramecian age is present throughout much of Lincoln County, Nevada (Tschanz and Pampeyan, 1970), western Utah, and Idaho (Sandberg and Gutschick, 1984). Calcareous siltstone also is present in central Utah, where it is associated with the Humbug delta, and in western Montana and Wyoming (Rose, 1976; Sando, 1976; Sandberg and others, 1983).

The siltstone belt is consistently bordered by a Meramecian carbonate facies on the east and a shale facies of similar age on the west. Figure 68 shows the areal distribution of the major lithologic facies in the western

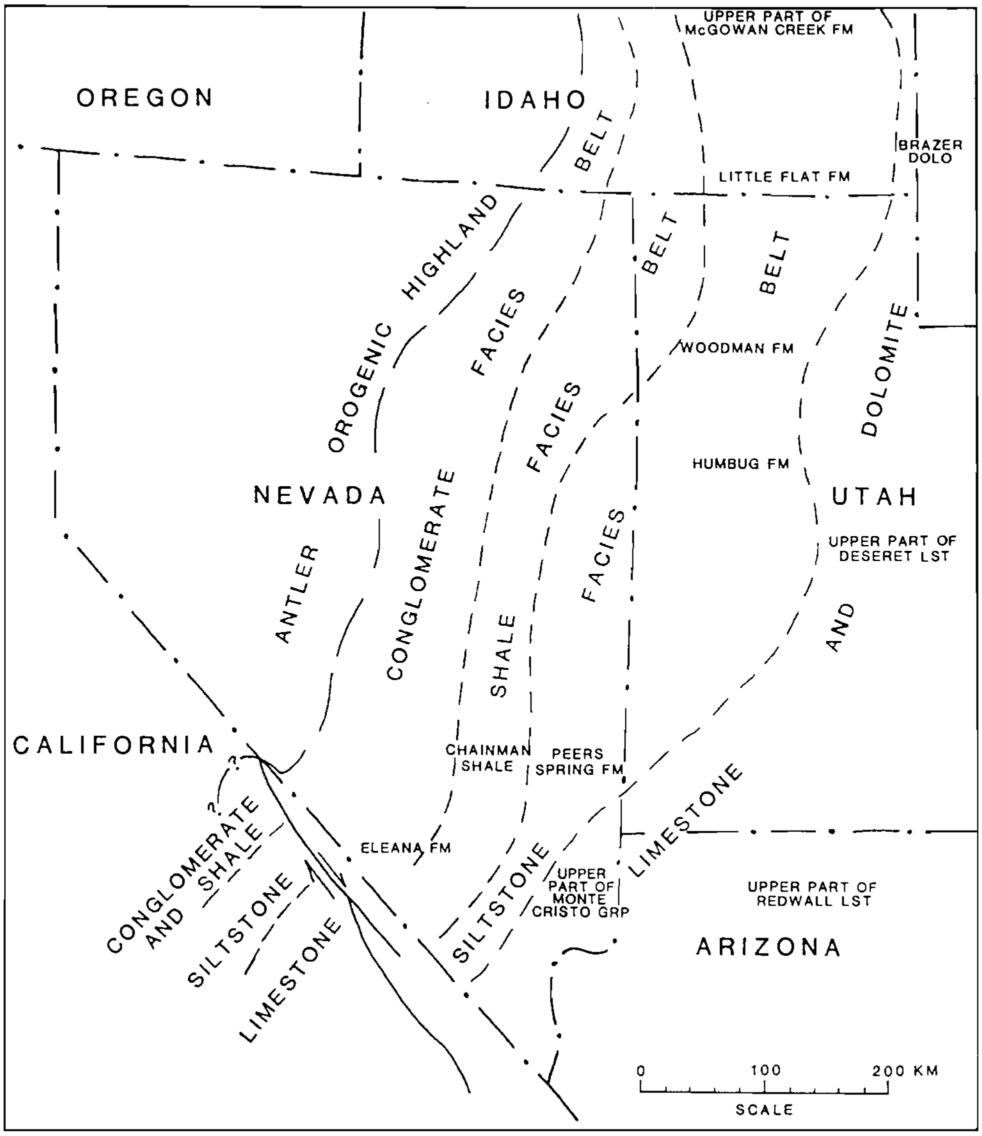


Figure 68. Map showing the areal distribution of the major lithofacies in the western United States during the Meramecian. Note that the facies in eastern California are offset to the northwest due to movement on the Death Valley-Furnace Creek fault. Sources of data: Tchanz and Pampeyan (1970), Rose (1976), Sando (1976), Poole and Sandberg (1977), Sandberg and others (1983).

United States during the Meramecian.

Three possible scenarios were considered for the origin of the siltstone of the Mexican Spring formation:

(1) the siltstone was derived from nearshore sand accumulations, transported northwestward across the carbonate platform, and deposited at the base of the slope;

(2) the siltstone represents Antler-derived detritus and is part of the foreland basin succession;

(3) the siltstone was derived from a cratonic source (perhaps the Humbug delta in Utah or the shelf in western Montana and Wyoming) and was transported southwestward along the base of the slope to the study area by deep-sea currents.

Hand-sample and thin-section petrographic analysis was undertaken of the Santa Rosa Hills Limestone in the Minnietta Mine area and the Santa Rosa Hills. A few samples also were studied from the Monte Cristo Group in the Arrow Canyon Range and the southern Spring Mountains of southern Nevada. This was done in order to determine whether or not the silt-size siliciclastic grains typical of the Mexican Spring formation were present, and thus, consistent with their transport across the shallow carbonate platform to the southeast. Siliciclastic grains are very rare to absent in these rocks, and channels filled with silt were not identified in any of the shallow, carbonate-platform sections. McAllister (1952, 1974) and Dunne and others (1981) mentioned the presence of "silty" limestone in the Stone Canyon limestone, but thin-section study of these rocks has revealed that siliceous sponge-spicules are abundant but siliciclastic grains are virtually absent. The lack of siliciclastic grains in the shallow, carbonate-platform rocks apparently eliminates the southeastern platform as a source for the silt.

Poole and Sandberg (1977) suggested that the calcareous siltstone belt shown in figure 68 represents detritus derived from the Antler highland situated to the west and northwest. The siltstones were interpreted by Poole and Sandberg (1977) as westward-derived turbidites deposited on submarine fans during the infilling of the foreland basin. This interpretation for the origin of the siltstone has been followed by most subsequent workers. Sandberg and others (1983) interpreted the siltstone to be of deltaic origin, but still invoked an Antler source.

Figure 68 shows that the siltstone belt is situated outboard (to the east) of a shale belt if one assumes an Antler source for both facies. This is exactly opposite of what would be anticipated. Therefore, if the calcareous siltstone facies is Antler-derived, some method of sediment bypass must be invented to account for this facies pattern.

Because of the laterally extensive nature of the siltstone belt, the author feels that this interpretation is unlikely.

The third interpretation is that the silt was derived from a cratonic source, perhaps the Humbug delta in Utah, or from the shelf in western Montana and Wyoming. This interpretation requires that the silt was transported southward along the base of the slope either by bottom currents or turbidity currents. In this scenario, the presence of the siltstone belt situated east of the shale belt does not present a problem.

In order to test this hypothesis, the author carried out a reconnaissance-level, comparative, thin-section analysis of siltstone and sandstone from the Chainman Shale collected from the Devil's Gate area, Nevada (Antler source), Humbug Formation in the Lakeside Mountains, Utah (cratonic source), and Mexican Spring formation. The percentage of chert grains was determined, based on a count of 300 grains in thin sections from five siltstone samples from the Mexican Spring formation (at least one thin section from each of the four measured sections), two siltstone samples from the Humbug Formation, and two very fine- to medium-grained sandstone samples from the Chainman Shale.

Identification of the chert grains in the siltstone was not difficult. The crystallites of the chert are smaller than the grains. In the few cases where it proved difficult to identify a silt grain as chert, the grain was counted as chert.

Figure 69 shows the results of the point counts. The sandstone samples from the Chainman Shale contain approximately 40% chert grains, whereas the siltstone samples from the Humbug Formation contain only 8% chert grains. Chert grains in the five siltstone samples of the Mexican Spring formation range from 2% to 9%.

The interpretation that the siltstone of the Mexican Spring formation was derived from a cratonic source is preferred on the basis of both the areal distribution of the lithofacies and the composition of the siltstone, although further work in this area is needed.

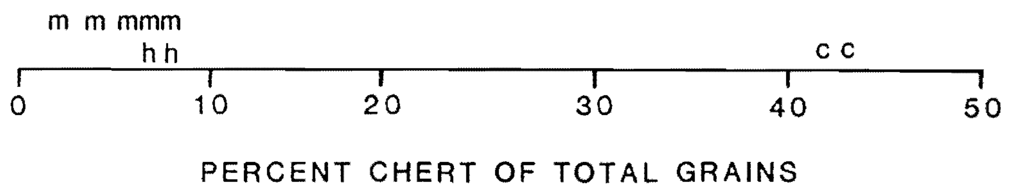


Figure 69. Results of comparative thin-section analysis (c = Chainman Shale data points, h = Humbug Formation data points, and m = Mexican Spring formation data points).

REGIONAL DEPOSITIONAL INTERPRETATION

Data obtained from this study have resulted in the development of regional depositional interpretations that characterize the evolution of the carbonate platform in this portion of the Cordilleran miogeocline. The terminology used in this study is that of Read (1982, 1985).

Carbonate Platform: This is a general term used to include both carbonate shelves and ramps.

Rimmed Carbonate Shelf: A shallow carbonate platform that has a shallow rim (carbonate sand and/or reef) at its outer edge. The slope from the rim to the basin (commonly 2 to 4 degrees) is steeper than that of the carbonate ramp (fig. 70).

Carbonate Ramp: A carbonate platform with a gentle slope (usually less than 1 degree). Homoclinal ramps extend into deeper-water without a marked break in slope (fig. 71A). Distally steepened ramps have a major break in slope that occurs in relatively deep water (fig. 71B). The carbonate ramp can be divided into a shallow, inner ramp dominated by carbonate sand and a deeper, outer ramp dominated by carbonate mud. The transition commonly occurs at wavebase (Read, 1985).

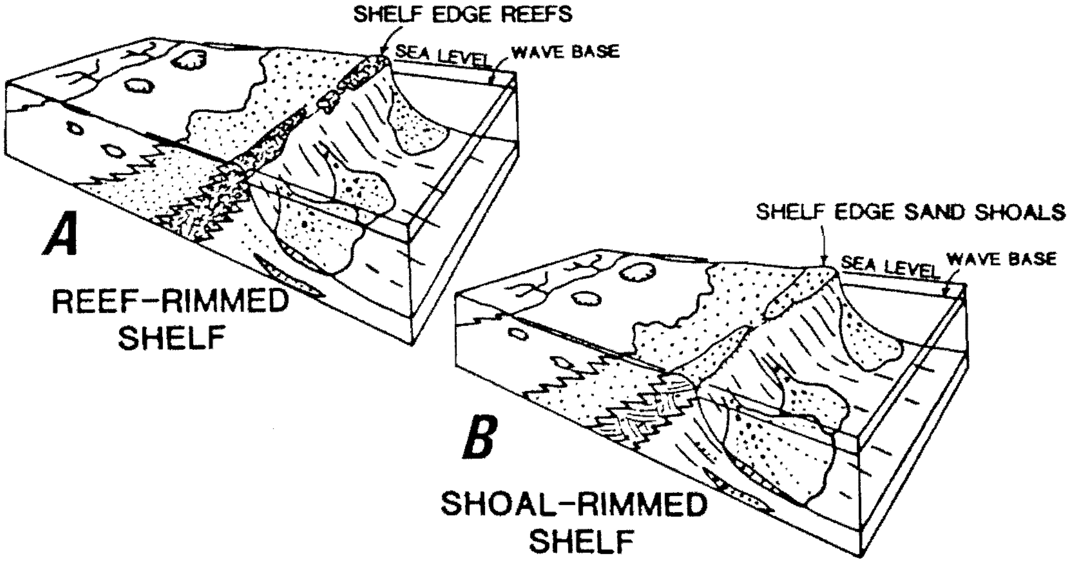


Figure 70. Features of rimmed, carbonate shelves. Notice the relatively flat top of the carbonate shelf and the much steeper slope located just seaward of the shallow rim. The shallow, shelf-edge rim may consist of reefs (A), sand shoals (B), or a combination of the two (modified from Read, 1985).

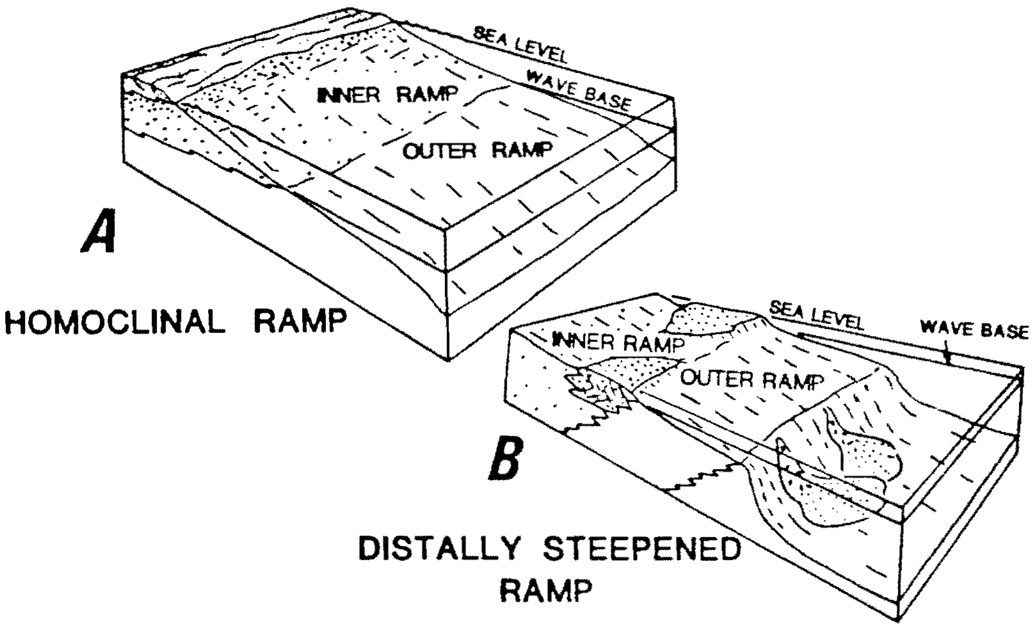


Figure 71. Features of carbonate ramps.
A. Homoclinal ramps slope gently (<1°) into deeper water without a major break in slope. Redeposited sediment is uncommon in the deep water settings.
B. Distally steepened ramps have a major break in slope in relatively deep water. Redeposited sediment, mostly derived from the slope, can be common (modified from Read, 1985).

The Mississippian carbonate platform studied in eastern California extends through southern Nevada and into northern Arizona. Because the regional depositional patterns reflect the evolution of a carbonate platform that changed in character through time, the following discussion addresses three specific time slices during which a particular carbonate platform-type was prevalent. Collectively, the interpretations of these time slices illustrate the evolution of a carbonate platform from the initial development of an Osagean homoclinal ramp (fig. 72A, table 1), through a late Osagean to early Meramecian distally steepened ramp (fig. 72B, table 2), to the final development of a Meramecian shoal-rimmed shelf (fig. 72C, table 3).

During Kinderhookian and earliest Osagean time, prior to the time of deposition of the formations represented in this study, a shallow carbonate shelf was present from northern Arizona to eastern California (Stevens, 1986). The rocks that comprise this Early Mississippian carbonate shelf include the oolitic rocks of the Whitmore Wash Member of the Redwall Limestone in northern Arizona and the fossilferous limestones of the Dawn Limestone in southern Nevada and the Tin Mountain Limestone in eastern California. The edge of this Early Mississippian carbonate shelf is marked by the presence of colonial rugose corals

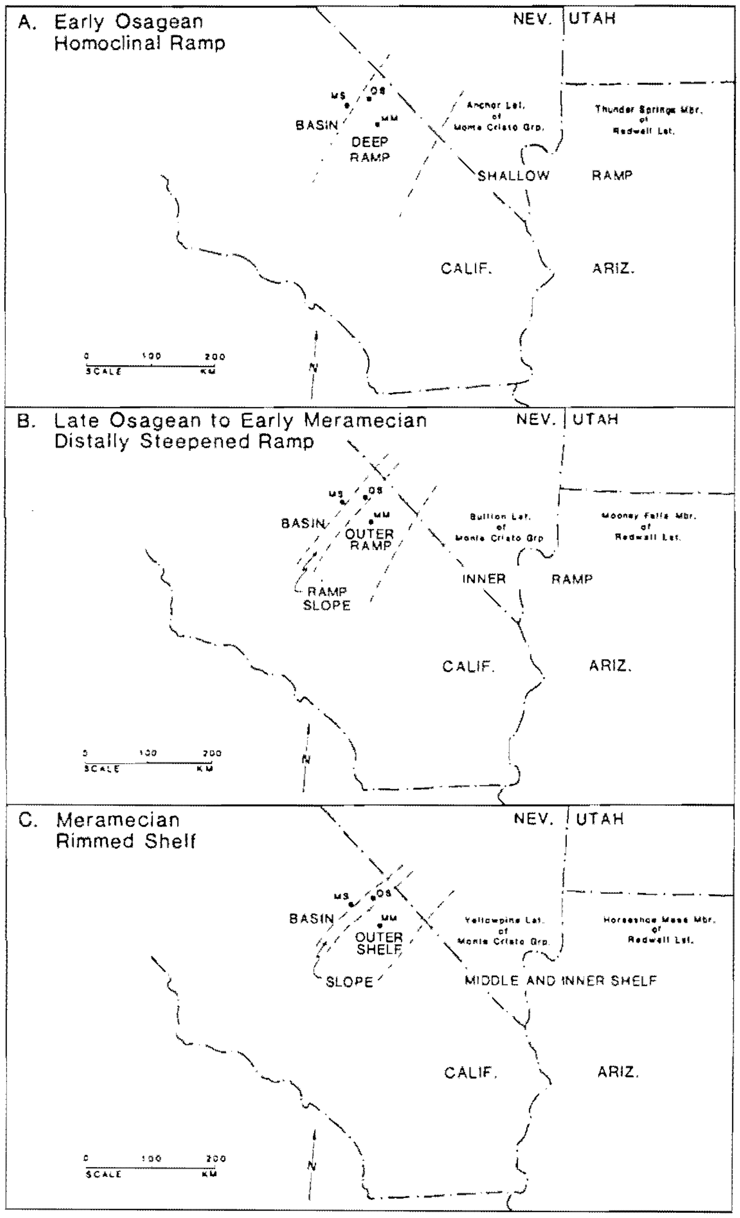


Figure 72. Paleogeographic maps showing the distribution of the major features during the evolution of the carbonate platform from an early Osagean homoclinal ramp (A), through a late Osagean to early Meramecian distally steepened ramp (B), to the development of a Meramecian rimmed shelf (C). The locations of three measured sections (MM - Minnietta Mine area, MS - Mexican Spring area, and QS - Quartz Spring area) are shown for reference.

TABLE 1. EARLY OSAGEAN HOMOCLINAL RAMP

SOUTHEAST — NORTHWEST

	SHALLOW RAMP[1]	DEEP RAMP[2]	BASIN[2]
FORMATIONS	THUNDER SPRINGS MEMBER OF REDWALL LIMESTONE, NORTHERN ARIZONA AND ANCHOR LIMESTONE OF MONTE CRISTO GROUP, SOUTHERN NEVADA	LOWER UNIT OF THE STONE CANYON LIMESTONE AT MINNIETTA MINE, SANTA ROSA HILLS, AND QUARTZ SPRING	LOWER PORTION OF THE LOWER UNIT OF THE STONE CANYON LIMESTONE AT UBEHEBE MINE CANYON
FEATURES	LIGHT- TO DARK-GRAY LIME MUDSTONE THROUGH PACKSTONE WITH DISCONTINUOUS LENSES AND NODULES OF CHERT FOSSILS: PELMATOZOAN DEBRIS, BRACHIOPODS, BRYOZOANS, GASTROPODS, SOLITARY RUGOSE CORALS	THIN-BEDDED, DARK-GRAY LIME MUDSTONE AND WACKESTONE WITH NODULAR CHERT VERY FEW MACROFOSSILS, CONODONTS ARE RARE	RADIOLARIAN-BEARING MUDSTONE (EROSION OR HIATUS? AT MEXICAN SPRING)

REFERENCES:

1- McKee and Gutschick (1969), Brenckle (1973), Poole and Sandberg (1977), Kent and Rawson (1980), and this study.

2- This study.

TABLE 2. LATE OSAGEAN TO EARLY MERAMECIAN DISTALLY STEEPENED RAMP

SOUTHEAST — NORTHWEST

	INNER RAMP[1]	OUTER RAMP[2]	RAMP SLOPE[2]	BASIN[2]
FORMATIONS	MOONEY FALLS MEMBER OF REDWALL LIMESTONE, NORTHERN ARIZONA AND BULLION LIMESTONE OF MONTE CRISTO GROUP, SOUTHERN NEVADA	MIDDLE AND UPPER UNITS OF THE STONE CANYON LIMESTONE AT MINNIETTA MINE AND SANTA ROSA HILLS	MIDDLE UNIT AND LOWER PORTION OF UPPER UNIT OF THE STONE CANYON LIMESTONE AT QUARTZ SPRING AND UPPER UNIT OF THE STONE CANYON LIMESTONE AT UBEHEBE MINE CANYON AND WESTERN LEE FLAT (?)	UPPER PORTION OF THE LOWER UNIT OF THE STONE CANYON LIMESTONE AT UBEHEBE MINE CANYON
FEATURES	THICK-BEDDED, LIGHT- TO MEDIUM-GRAY LIME WACKESTONE TO GRAIN-STONE AND DOLOMITE FOSSILS: FORAMINIFERA, CALCAREOUS ALGAE, COLONIAL AND SOLITARY RUGOSE CORALS, BRACHI-OPODS, CRINOIDS, ETC.	THIN-BEDDED, DARK-GRAY LIME MUDSTONE AND WACKE-STONE AND NODULAR CHERT TEMPESTITES IN UPPER UNIT AT MINNIETTA MINE AND SANTA ROSA HILLS. CROSS-BEDDED SAND SHOALS IN UPPER UNIT IN SANTA ROSA HILLS. BECOMES MORE FOSSILIFEROUS NEAR TOP.	DARK-GRAY LIME MUD-STONE AND WACKESTONE AND CHERT. PRESENCE OF SUBMARINE SLIDES AND A FEW CARBONATE TURBIDITES AND DEBRIS FLOWS. FOSSILS: MAINLY DEEPER WATER CONODONTS AND PELMATOZOAN DEBRIS	RADIOLARIAN-BEARING MUDSTONE (EROSION OR HIATUS? AT MEXICAN SPRING)

REFERENCES:

1- McKee and Gutschick (1969), Brenckle (1973), Poole and Sandberg (1977), Kent and Rawson (1980), and this study.

2- This study.

TABLE 3. MERAMECIAN RIMMED SHELF

SOUTHEAST — NORTHWEST

	MIDDLE SHELF[1]	OUTER SHELF[2]	SLOPE AND BASE-OF-SLOPE[2]	BASIN[2]
FORMATIONS	HORSESHOE MESA MEMBER OF REDWALL LIMESTONE, NORTHERN ARIZONA AND YELLOWPINE LIMESTONE OF MONTE CRISTO GROUP, SOUTHERN NEVADA	SANTA ROSA HILLS LIMESTONE AT MINNIETTA MINE AND SANTA ROSA HILLS	UPPER PORTION OF THE UPPER UNIT OF THE STONE CANYON LIMESTONE AND MEXICAN SPRING FORMATION AT QUARTZ SPRING, WESTERN LEE FLAT, AND UBEHEBE MINE CANYON	MEXICAN SPRING FORMATION AT MEXICAN SPRING
FEATURES	MEDIUM- TO THICK-BEDDED, MEDIUM- TO DARK-GRAY, LIME MUDSTONE TO GRAIN-STONE FOSSILS: FORAMINIFERA, BRYOZOANS, BRACHIOPODS, CRINOIDS, AND COLONIAL TABULATE AND RUGOSE CORALS	THICK-BEDDED, LIGHT-TO MEDIUM-GRAY, MASSIVE PELMATOZOAN LIMESTONE. CROSS-BEDDED SAND SHOALS AT BASE OF SANTA ROSA HILLS SECTION. FOSSILS: FORAMINIFERA, SOLITARY AND COLONIAL RUGOSE CORALS, AND BRACHIOPODS	NUMEROUS SHEET-LIKE SEDIMENT-GRAVITY-FLOW DEPOSITS, A FEW SUBMARINE SLIDES, AND CALCAREOUS SILTSTONE FOSSILS: DEEPER-WATER CONODONTS, REDEPOSITED SHALLOW-WATER FAUNA	BIOTURBATED, CALCAREOUS SILTSTONE

REFERENCES:

1- McKee and Gutschick (1969), Brenckle (1973), Poole and Sandberg (1977), Kent and Rawson (1980), and this study.

2- This study.

in the Tin Mountain Limestone in the Panamint Butte Quadrangle (Hall, 1971).

Early Osagean Homoclinal Ramp

In the early Osagean, major portions of the Early Mississippian platform in the study area were drowned (Klingman, 1984; Stevens, 1986). This is indicated by the abrupt transition from the Early Mississippian shallow shelf rocks to the dark-gray, fine-grained, cherty limestone of Osagean age. This transition is present in the Mississippian sections in northern Arizona (Beus, 1979), southern Nevada (Poole and Sandberg, 1977; Langenheim and Webster, 1979), and eastern California.

An initial homoclinal ramp (fig. 72A), which extended from at least northern Arizona to the study area, developed in response to the drowning of the Early Mississippian shelf. The ramp deepened to the northwest with deposition on the shallower portion of the ramp represented by the Thunder Springs Member of the Redwall Limestone in Arizona and the Anchor Limestone in southern Nevada. The deeper ramp and basin environments are represented by the lower unit of the Stone Canyon limestone in the area of this study. To aid in discussion of the facies associations, the homoclinal ramp is subdivided into shallow ramp, deep ramp, and basin environments. The terms inner ramp and outer ramp (Read, 1985) are not used in this discussion because of the lack of carbonate sand. No precise boundary can be drawn between the shallow ramp and deep ramp deposits; however, the author feels that the rocks show enough dissimilarity to warrant the division. The shallow ramp rocks consist of lime mudstone through packstone and generally are fossiliferous; whereas, the deep ramp rocks consist predominantly of lime mudstone and wackestone with few fossils. Regional relationships play an important role in the general environmental interpretation.

Shallow Ramp

The Thunder Springs Member of the Redwall Limestone in northern Arizona and the Anchor Limestone of the Monte Cristo Group (Spring Mountains) are both fossiliferous and bioturbated (McKee and Gutschick, 1969; Brenckle, 1973), and are interpreted to have been deposited in a shallow ramp environment.

The Thunder Springs Member of the Redwall Limestone is approximately 30 m thick and consists of thin, discontinuous and irregular lenses of chert interbedded with limestone and dolomite. The medium-gray limestone is predominantly lime mudstone, wackestone, and packstone in texture, and consists of fossil fragments, peloids, and lime mud; sparry calcite cement is rare in these rocks. Macrofossils in the Thunder Springs Member include bryozoans, pelmatozoan debris, brachiopods, and gastropods (McKee and Gutschick, 1969). The fine-grained texture of these rocks and lack of sparry calcite cement indicates that these rocks were deposited in a calm-water setting. Facies analysis of the Redwall Limestone suggests that the Thunder Springs Member was deposited in a fairly shallow, open marine environment (Kent and Rawson, 1980).

The Anchor Limestone was visited during the course of this study at Mountain Springs Pass in the Spring Mountains of southern Nevada. At this locality, the Anchor Limestone is 67 m thick and consists largely of medium- to dark-gray lime wackestone interbedded with brown-weathering, irregular lenses of chert. The limestone beds are locally fossiliferous and commonly bioturbated. Fossils in this unit include pelmatozoan debris, brachiopods, solitary rugose corals, and bryozoans.

Like the Thunder Springs Member of the Redwall Limestone, the predominantly fine-grained nature of the Anchor Limestone and the absence of sparry calcite cement suggest that these rocks were deposited in a calm-water setting. The extensive bioturbation and presence of a normal marine fauna indicate a fairly shallow, normal marine environment.

Deep Ramp

The deep ramp deposits within the study area

(Minnietta Mine, Santa Rosa Hills, and Quartz Spring areas) are represented by the lower unit of the Stone Canyon limestone. This sequence of interbedded dark-gray lime mudstone, wackestone, and chert virtually lacks fossils and bioturbation features. It is envisioned to have been deposited in a relatively deep, calm-water setting under dysaerobic conditions. The lack of abundant sediment-gravity-flow deposits indicates that the paleoslope was low.

Basin

Deposits believed to be basinal are represented by the lower portion of the lower unit of the Stone Canyon limestone at Ubehebe Mine Canyon. These very thin-bedded, very dark-gray, radiolarian-bearing mudstones are interpreted to be a basin plain equivalent of the deep ramp rocks to the southeast; however, due to the lack of good age control, this conclusion remains speculative. The abundance of radiolarians (not seen in any of the other locations), fine-grained nature, high organic content, relative lack of carbonate mud, and absence of bioturbation features in these rocks suggest that they were deposited in a very deep environment that was situated seaward of carbonate influence or possibly below the carbonate compensation depth. The lack of sediment-gravity-flow deposits in this sequence indicates that the paleoslope was low.

The Stone Canyon limestone is not present in the Mexican Spring area, although one would predict by the regional paleogeography that this area should contain basinal rocks of this age. Merriam (1963) observed erosional features at the contact between the Tin Mountain Limestone and the Mexican Spring formation in the Cerro Gordo Mining District suggesting that rocks of this age may have been removed by middle Mississippian erosion.

Discussion

A homoclinal ramp is envisioned to have developed during the early Osagean following the drowning of the Early Mississippian carbonate platform. The drowning of the platform is believed to have been primarily due to an increase in the rate of differential subsidence, with the higher rates of subsidence in the northwest portion of the study area. Although the accompanying sea level rise apparently did not reach its maximum extent during this time period (Kent and Rawson, 1980; Gutschick and Sandberg, 1983), it is believed that the combined effects of subsidence and sea level change led to the initial development of the ramp. Because the base of the Stone Canyon limestone is slightly older than the base of the Anchor Limestone (Poole and Sandberg, 1977) and Thunder Springs Member of the Redwall Limestone (McKee and

Gutschick, 1969; Kent and Rawson, 1979), and the base of the lower unit of the Stone Canyon limestone at Quartz Spring and Santa Rosa Hills may be slightly older than the same unit at the Minnietta Mine area (fig. 67), deposition on the homoclinal ramp is interpreted to represent an eastward transgression.

In order to test this hypothesis of increased differential subsidence, estimates of the average subsidence rates for the Tin Mountain Limestone and the Stone Canyon limestone in the Minnietta Mine area and the Santa Rosa Hills were made (table 4) using the thicknesses of the formations, as measured in this study or reported in Stevens and others (1979), and the length of time during which these formations accumulated (Sandberg and others, 1983). The effects of sediment compaction were not considered. In these two locations, the base and the top of the Tin Mountain Limestone (Stevens, 1986) and the top of the Stone Canyon limestone were deposited in fairly shallow water.

Table 4. Estimates of Average Subsidence Rates for the Tin Mountain Limestone and Stone Canyon Limestone at Selected Localities

	Minnietta Mine Area	Santa Rosa Hills
Tin Mountain Limestone	13m/my	18m/my
Stone Canyon Limestone	12m/my	59m/my

Comparisons of the average subsidence rates for these formations in the Minnietta Mine area and the Santa Rosa Hills show: (1) the average subsidence rate of the Tin Mountain Limestone was about 40 percent greater in the Santa Rosa Hills than in the Minnietta Mine area, (2) in the Minnietta Mine area, the average subsidence rates of the Tin Mountain Limestone and the Stone Canyon limestone were about the same, and (3) the average subsidence rate of the Stone Canyon limestone was about 4 to 5 times greater in the Santa Rosa Hills than in the Minnietta Mine area. Differential subsidence occurred in the study area during the deposition of the Tin Mountain Limestone; however, the rate of differential subsidence was substantially accelerated during the time the Stone Canyon limestone was deposited.

The timing of this period of increased differential subsidence is well constrained; it is early Osagean. The cause of this change, however, is not well known. The timing of this event suggests that it may be attributed to the Antler orogeny, and as such, implies that the effects of "Antler-type" tectonics extended into eastern California. An alternative interpretation is that the accelerated rate of differential subsidence was the result of normal faulting on a passive margin and, perhaps, completely unrelated to the Antler orogeny. Additional work in this area is needed.

Late Osagean to Early Meramecian Distally Steepened Ramp

During the late Osagean, the Early Mississippian platform evolved into a distally steepened ramp with a well defined inner ramp, outer ramp, ramp slope and basin plain (fig. 72B).

Inner Ramp

The Mooney Falls Member of the Redwall Limestone in northern Arizona and the Bullion Limestone of the Monte Cristo Group in southern Nevada represent the inner ramp sediment deposited in shallow water. The Mooney Falls Member is approximately 61 m thick in the eastern Grand Canyon and thickens to 125 m in northwestern Arizona (McKee and Gutschick, 1969; Beus, 1979). The unit consists largely of thick- to very thick-bedded, massive, light- to medium-gray lime wackestone, packstone, grainstone, and dolomite. Fossils in the Mooney Falls Member include calcareous algae and foraminifera, pelmatozoan debris, colonial and solitary rugose corals, brachiopods, gastropods, and bryozoans. Pellets, intraclasts, and ooids also are common in the limestone (McKee and Gutschick, 1969).

At Mountain Springs Pass in southern Nevada, the Bullion Limestone (117 m thick) is dolomitized and is easily recognized by the characteristic thick, massive, light-colored beds overlying the Anchor Limestone. Chert is present but rare and occurs as irregular nodules that weather medium brown. In the Arrow Canyon Range of southern Nevada, the Bullion Limestone is not extensively dolomitized and consists predominantly of thick-bedded, light-gray, well-sorted lime packstone and grainstone (Hanson and Carozzi, 1974). Pelmatozoan debris, bryozoans, and brachiopods are abundant in these rocks with lesser amounts of fossils of other groups (Hanson and Carozzi, 1974).

Both the Mooney Falls Member of the Redwall Limestone and the Bullion Limestone contain thick-bedded, massive, coarse-grained, bioclastic limestone that is light gray in color. Microfacies analysis of the Bullion Limestone in the Arrow Canyon Range revealed that the limestone is dominantly grain-supported with very little or no lime mud; evidently it was largely deposited in a fairly high energy, well oxygenated environment (Hanson and Carozzi, 1974). The presence of ooid grainstones in the Mooney Falls Member (McKee and Gutschick, 1969) suggests that these rocks also were deposited in a high energy, inner ramp environment.

The lowermost portion of the Santa Rosa Hills Limestone at Minnietta Mine is lithologically similar to the Mooney Falls and Bullion Limestone and is likewise interpreted as inner ramp rocks deposited during the northwestward progradation. A late Osagean or early Meramecian age for these rocks can not be assigned with certainty, so this interpretation remains speculative.

Outer Ramp

The progradational middle and upper units of the Stone Canyon limestone at Minnietta Mine and Santa Rosa Hills represent the outer ramp sediments deposited at progressively shallower depths through time. The middle unit of the Stone Canyon limestone, which consists predominantly of medium- to dark-gray lime mudstone and wackestone with interbedded silicified limestone and chert, generally lacks macrofossils and bioturbation features. These rocks were deposited in fairly deep water as indicated by the presence of a few sediment-gravity-flow deposits, without material of unequivocal shallow-water origin, near the base of the middle unit in the Santa Rosa Hills. The extreme thickness of this unit in the Santa Rosa Hills suggests that much of the lime mud generated in the inner ramp was winnowed and deposited on the outer ramp resulting in relatively high sedimentation rates.

The upper unit of the Stone Canyon limestone represents the shallower portion of the outer ramp. This sequence of interbedded fine-grained limestone, pelmatozoan-rich tempestites, and cross-bedded sand shoals is transitional to the development of the Meramecian shoal-rimmed shelf. The increased occurrence of macrofossils and bioturbation features suggest that this unit was deposited in a shallower, more open marine, outer ramp environment.

Ramp Slope

The middle unit of the Stone Canyon limestone in the Quartz Spring area is largely late Osagean in age and contains several synsedimentary-folded submarine-slide masses of fine-grained limestone and chert. These submarine slides indicate an unstable depositional slope. The few sediment-gravity-flow deposits and the submarine-slide masses do not contain material of unequivocal shallow-water origin, which suggests that the break in slope occurred within relatively deep water.

The lower portion of the upper unit of the Stone Canyon limestone at Quartz Spring is approximately the same age as the upper unit of the Stone Canyon limestone in the Santa Rosa Hills. The presence of carbonate turbidites and a submarine slide (located in Rest Spring Gulch) in the Quartz Spring area suggests that these rocks also were deposited on, or at the base of, a depositional slope. Again, the lack of material of shallow-water origin implies that the slope break on the distally steepened ramp occurred in fairly deep water.

As the slope prograded toward the northwest, carbonate slope sediment was deposited upon older basin plain sediment. This situation is recorded in Ubehebe Mine Canyon, where the upper unit of the Stone Canyon limestone, consisting of lime mudstone and wackestone with a few sediment-gravity-flow deposits (ramp-slope deposits), overlies the lower unit which consists of radiolarian-bearing mudstone (basin-plain deposits). These ramp-slope deposits are thin and most likely were deposited at the base of the slope. A basin plain interpretation for these rocks is considered unlikely because of a channelized debris-flow conglomerate that occurs at the base of the upper unit and because of the presence of soft-sediment deformational features in the fine-grained limestone.

Basin

The upper portion of the lower unit of the Stone Canyon limestone in Ubehebe Mine Canyon contains dark-gray, organic-rich, radiolarian-bearing mudstone. These rocks are interpreted as the basinal equivalent to the ramp-slope section present in the Quartz Spring area which is dominated by submarine slides. This correlation remains equivocal, however, due to the lack of good biostratigraphic control. The abundance of radiolarians, the fine size of the grains, high organic content, relative lack of carbonate mud, and absence of bioturbation features are suggestive of a very deep-water depositional environment which was situated seaward of carbonate influence or perhaps close to the carbonate compensation depth.

The Stone Canyon limestone is not present in the Mexican Spring area. It is unclear whether or not the lack of these rocks represents a depositional hiatus or an erosional unconformity.

Discussion

As carbonate sedimentation continued in the study area, the early Osagean homoclinal ramp evolved into a distally steepened ramp (fig. 72A, 72B). Submarine-slide masses record the development of a slope on the ramp, although this was not a site of extensive sediment-gravity-flow deposition. During the later stages of development of the distally steepened ramp, inner ramp sands prograded onto the outer ramp as far north as the Santa Rosa Hills. The carbonate platform is still classified as a ramp during this time because the slope break was situated in fairly deep water. The inner ramp, outer ramp, and ramp-slope deposits are all progradational, demonstrating the evolutionary trend towards the development of a rimmed shelf.

The author believes that differential subsidence was still pronounced during the early part of this time period. This interpretation is supported by the occurrence of sediment-graivity-flow deposits near the base of the middle unit of the Stone Canyon limestone in the Santa Rosa Hills. By late Osagean time, however, sedimentation exceeded subsidence and the platform changed morphology from a homoclinal ramp to a distally steepened ramp. The increase in the rate of sedimentation relative to subsidence is recorded in the Stone Canyon limestone with the transition from the deeper-water rocks in the middle unit (for example, the sediment-gravity-flow deposits in the Santa Rosa Hills) to the shallow-water, sand-shoal deposits and tempestites in the upper unit.

Meramecian Rimmed Shelf

During the Meramecian, inner ramp sands prograded northwestward over the outer ramp deposits. When these shallow, high energy, carbonate sands prograded to the edge of the carbonate slope, the carbonate platform became a rimmed shelf with cross-bedded sand shoals and coral buildups situated at the platform margin. The shoal-rimmed shelf was fully developed by the middle Meramecian with inner and middle shelf, outer shelf, slope and base-of-slope, and basinal environments clearly delineated (fig. 72C). The shelf extended through northern Arizona into eastern California where, in the study area, the shelf-to-basin transition is located.

Inner and Middle Shelf

Inner and middle shelf carbonate rocks are present in northern Arizona and southern Nevada, and are represented by the Horseshoe Mesa Member of the Redwall Limestone and the Yellowpine Limestone of the Monte Cristo Group (fig. 72C). In southern Nevada, these rocks are slightly darker in color and contain a somewhat higher percentage of lime mud than the inner ramp rocks deposited during the late Osagean. The limestones range from mudstone to grainstone and commonly are highly bioturbated. Calcareous foraminifera, bryozoans, brachiopods, crinoids, pellets, and colonial tabulate and rugose corals are common in these rocks (McKee and Gutschick, 1969; Hanson and Carozzi, 1974).

The abundance of normal-marine fossils in the limestone with a noticeable amount of lime mud suggests that these rocks were deposited in a shallow, fairly calm-water setting. Colonial rugose corals were exclusively platform-top dwellers (Sando, 1981; Gutschick and Sandberg, 1983), and, hence, a shelf environment is inferred for these rocks. The relatively high percentage of lime mud in these rocks is believed to be the result of the presence of very shallow, carbonate sand shoals situated at the platform margin which restricted the effective off-shelf transport of lime mud.

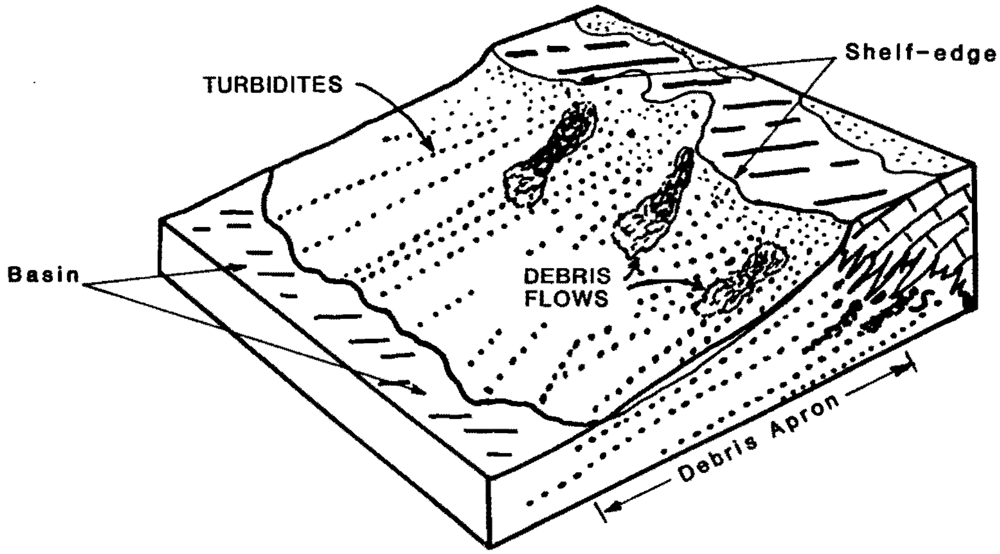
Outer Shelf

Outer shelf rocks are represented in eastern California by the Santa Rosa Hills Limestone. These rocks are predominantly thick-bedded, massive, medium- to light-gray, pelmatozoan-rich, bioclastic calcarenites, and they locally contain patches of colonial rugose corals. The moderately well-sorted character of these rocks attests to deposition in a fairly high energy, platform-top environment. This interpretation is further supported by the cross-bedded, carbonate sand shoal present at the base of the Santa Rosa Hills Limestone approximately 1 km northwest of the Santa Rosa Hills measured section #2. Because rocks showing characteristics of carbonate slope deposition are present at the measured sections to the north and west of the Santa Rosa Hills, the Santa Rosa Hills Limestone is interpreted as having been deposited on an outer shelf, platform margin setting.

Slope and Base of Slope

The Mexican Spring formation and the uppermost portion of the upper unit of the Stone Canyon limestone at the Quartz Spring, western Lee Flat, and Ubehebe Mine Canyon areas are largely Meramecian in age and contain carbonate turbidites, debris flows, and submarine slides indicative of deposition either on, or at the base of, a carbonate slope. Although channelized turbidites and debris flows are present, they are rare. The numerous unchannelized, sheet-like deposits that do not occur in the vertically organized sequences typical of submarine fan deposition, suggest a "line source" origin and redeposition on a debris apron (Cook and Mullins, 1983). Two types of carbonate aprons may develop along a shelf margin. Along gentle (less than 4 degrees) platform-margin slopes, sediment-gravity-flow deposits extend up to the adjacent shelf/slope break without an upper slope by-pass zone. This type of debris apron is called a carbonate slope apron (Cook and others, 1984; Mullins and Cook, 1986) and is shown graphically in figure 73A. Along relatively steep (greater than 4 degrees) platform-margin slopes, the redeposited carbonate sediments accumulate in a base-of-slope setting and largely by-pass the upper slope. This type of debris apron is referred to as a carbonate base-of-slope apron (Cook and others, 1984; Mullins and Cook, 1986) and is shown in figure 73B. The presence of submarine slides suggests that the slope was probably relatively steep and therefore, the carbonate debris is proposed to represent a base-of-slope apron. Because the sediment-gravity-flow deposits contain a mixture of shoal-water and deep-water material, the "line source" for this material is believed to have been the shelf margin. The submarine slides and debris flows generally are restricted to the upper portions

A. SLOPE APRON



B. BASE-OF-SLOPE APRON

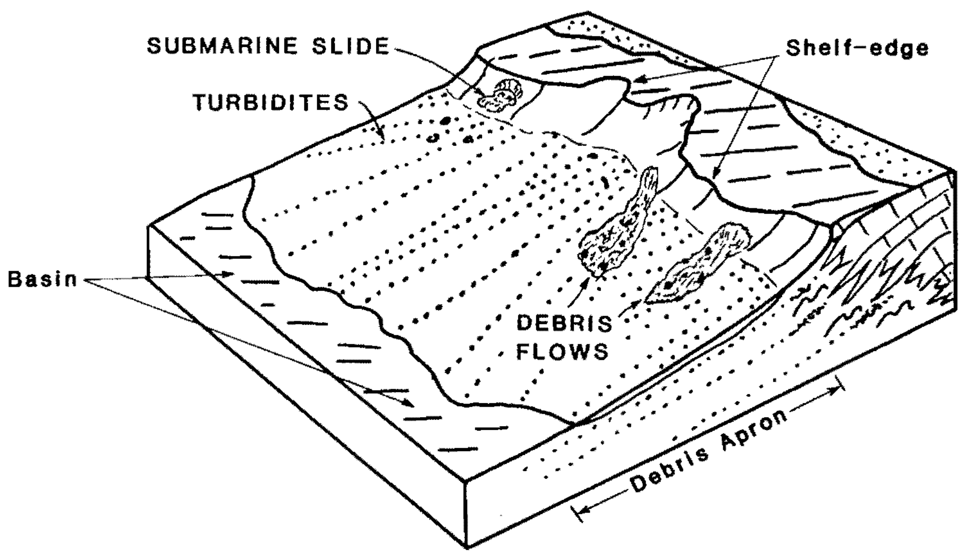


Figure 73. Morphology of (A) a carbonate slope apron and (B) a carbonate base-of-slope apron (modified from Cook and others, 1984).

of the debris apron, whereas the turbidites are common on the lower debris apron and can extend into the basin plain environment (Cook and Mullins, 1983). The interbedded siltstone in the Mexican Spring formation is believed to have had a cratonic source to the northeast (perhaps Utah) and to have been transported along the base of the slope by either contour currents or southwestward-directed turbidity currents.

Basin

The siltstone of the Mexican Spring formation in the Mexican Spring area does not contain interbedded carbonate sediment-gravity-flow deposits and so it is believed to have been deposited in a basinal environment which was situated seaward of the influence of carbonate sediment-gravity flows. The silt had the same source as that in the base-of-slope deposits.

Discussion

During the Meramecian, the subsidence rate appears to have slowed and played less of a role in controlling sedimentation patterns throughout the southwestern United States. The average subsidence rate of the Santa Rosa Hills Limestone in the Santa Rosa Hills was about the same as the average subsidence rate of the Tin Mountain Limestone in the Minnietta Mine area. The author believes that it was primarily this decrease in the rate of differential subsidence that allowed carbonate sands to prograde northwestward into eastern California and form a Meramecian shoal-rimmed shelf.

SUMMARY

The Mississippian units represented in this study formed during and after during a period of accelerated subsidence in the Early Mississippian. Drowning of the previous carbonate platform probably was accompanied by a sea level rise, and an initial homoclinal ramp developed in response to the tectonic and sea level changes. The homoclinal ramp, which deepened to the northwest, extended from northern Arizona, through southern Nevada, and into eastern California (Langenheim, and others, 1962; McKee and Gutschick, 1969; Hanson and Carozzi, 1974).

During the late Osagean, subsidence may have continued to affect the carbonate platform; however, the continued subsidence was accompanied by accelerated sedimentation rates as indicated by the thick section of late Osagean sediments that accumulated in the Santa Rosa Hills. The homoclinal ramp evolved into a distally steepened ramp with a well developed inner ramp (northern Arizona and southern Nevada), outer ramp (southeastern portion of the study area), and ramp slope and basin plain (northwestern portion of the study area). Northwest transport of submarine slides and carbonate turbidites confirms the southeast to northwest trend of the platform-to-basin transition.

During Meramecian time, the subsidence rate slowed and the carbonate sands of the inner ramp prograded northwestward into the study area. As these sands reached the platform margin, the distally steepened ramp evolved into a shoal-rimmed shelf. Numerous sheet-like sediment-gravity flows were generated from the shallow platform margin and redeposited as a base-of-slope apron in deeper water. Paleocurrent data obtained from the carbonate turbidites attest to the southeast to northwest trend of the shelf-to-basin transition. Figure 74 is a generalized representation of the carbonate platform in southern Nevada and eastern California during Meramecian time.

Accompanying the development of the base-of-slope apron, siliciclastic silt of probable cratonic origin was deposited in base-of-slope and basin settings in the study area by either southward-directed contour currents or turbidity currents. The siltstone is extensively bioturbated, which suggests that the deeper water settings were situated within a fairly well oxygenated water mass.

Material of unequivocal Antler origin was not identified at any of the measured sections in the study area. Furthermore, there is no firm sedimentary evidence in the study area to support the extension of the Antler orogenic highland into eastern California. However, the timing of the period of accelerated subsidence in the study area may indicate that the effects of the Antler orogeny

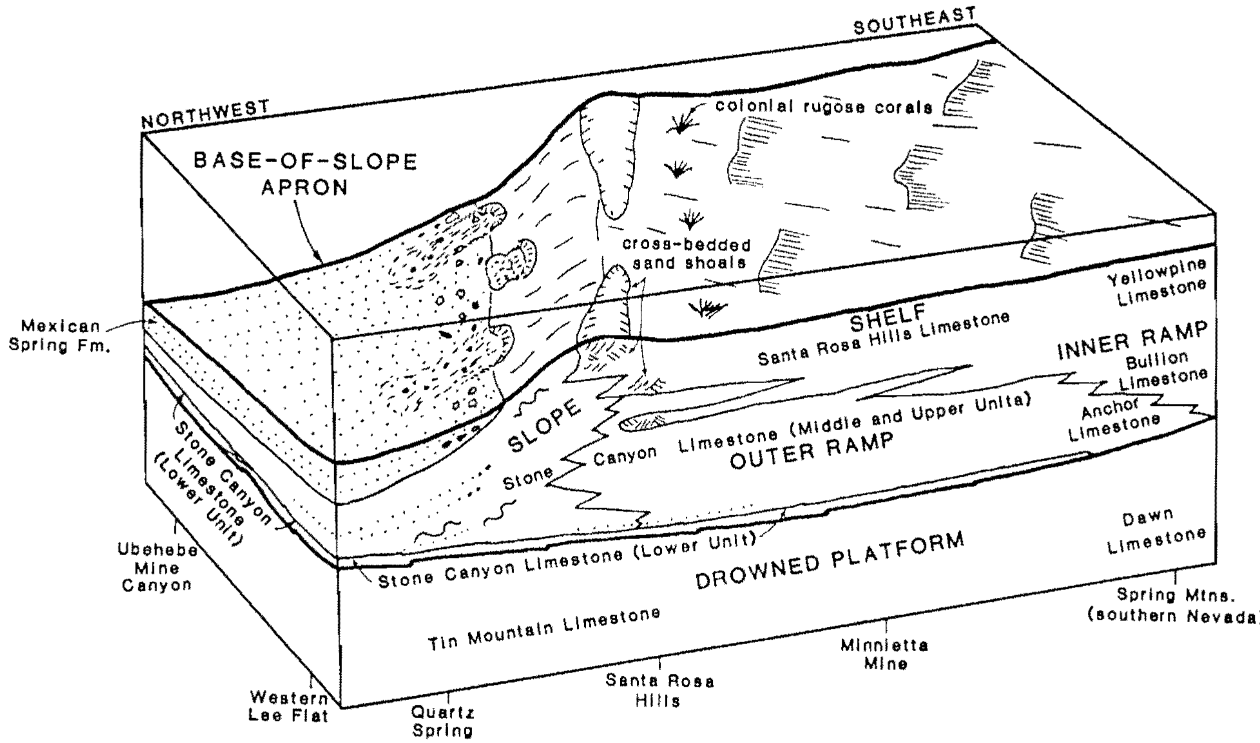


Figure 74. Generalized representation of the Meramecian carbonate platform in southern Nevada and eastern California. Sections located according to place in depositional model and not by geographic location. Not to scale.

extended into eastern California. Alternatively, the increase in the subsidence rate may have been due to normal faulting on a passive margin which was unrelated to the Antler orogeny.

Read (1982, 1985) proposed and ideal model of carbonate platform evolution suggesting that, following the drowning of a platform, a carbonate ramp can develop and evolve into a rimmed shelf. Few documented examples, however, have been described to support the model (Klingman, 1984; Cook and Taylor, 1987). These middle Mississippian rocks of eastern California support this model and show that carbonate ramp to rimmed shelf evolution can be observed in both the platform and slope-to-basin environments.

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APPENDIX A-1

Section of Stone Canyon limestone, Minnietta Mine Area

Section measured along the east flank of the Argus Range, approximately 500 m north of Stone Canyon, from an elevation of about 3440 ft to an elevation of approximately 3120 ft, T 19 S, R 42 E, 36°15'13" lat, 117°26'28" long, Panamint Butte 15-minute quadrangle, Inyo County, California.

Santa Rosa Hills Limestone

Conformable Contact

Stone Canyon limestone

Thickness (m)

5. Limestone (lime mudstone and wackestone), medium blue-gray, thin- to medium-bedded, massive to faintly laminated, some vertical burrows present. Sparse chert nodules up to 8 cm thick. Pelmatozoan calcarenite, medium- to light-gray, beds to 25 cm thick with sharp bases and gradational tops, crude normal grading of pelmatozoan ossicles, some beds display internal parallel laminations. . . 9

4. Limestone (lime mudstone to wackestone), medium blue-gray, mostly medium-bedded, mostly massive, occasional laminations, vertical burrows present but rare. Approximately 25% of beds are silicified and weather medium-brown to reddish-brown. Sparse chert nodules to 10 cm thick. Pelmatozoan calcarenite, medium- to light-gray, beds to 25 cm thick, occur as both diffuse, lenticular accumulations up to 15 cm thick and as beds with sharp bases and gradational tops with crude normal grading of pelmatozoan ossicles. 27

Thickness (m)

3. Limestone (lime mudstone to wackestone), medium blue-gray, thin- to medium-bedded, mostly massive, with scattered pelmatozoan debris; approximately 10% of limestone is silicified and weathers orangish-brown. Chert in nodules and discontinuous lenses to 10 cm thick and 1.5 m across; approximately 20% of unit. 34

2. Limestone (lime mudstone and wackestone), medium to dark blue-gray, thin-bedded, a few beds faintly laminated with minute pelmatozoan debris; approximately 30% of limestone is silicified and weathers medium-brown to orangish-brown. Chert in nodules and discontinuous lenses to 15 cm thick and 5 m across; weathers dark brown to nearly black; constitutes 30% of unit. 21

1. Chert, dark-gray, weathers dark brown to nearly black, in irregular beds and nodules to 15 cm thick; approximately 45% of unit. Limestone (lime mudstone and wackestone), dark blue-gray, thin- to medium-bedded, massive, with occasional pelmatozoan debris; constitutes about 40% of unit. Silicified limestone, dark-gray, weathers orangish-brown, thin- to medium-bedded, sponge spicule-rich; about 15% of unit. 16

Total thickness of Stone Canyon limestone measured at Minnietta Mine area 107

Contact Conformable

Tin Mountain Limestone

APPENDIX A-2

<u>Section #1 of the Santa Rosa Hills Limestone and the upper portion of the Stone Canyon limestone, Santa Rosa Hills</u>

Section measured approximately 1 km south of hill 6170 in Santa Rosa Hills from an elevation of about 5680 ft on the east side of the Santa Rosa Hills, across a saddle to an elevation of approximately 5800 ft on the west side of the Santa Rosa Hills. T 17 S, R 40 E (not sectioned); 36°28′27" lat, 117°38′52" long, Darwin 15-minute quadrangle, Inyo County, California.

Indian Springs Formation

Disconformable Contact

Santa Rosa Hills Limestone

Thickness (m)

8. Limestone (pelmatozoan lime packstone and grainstone), light-gray to medium-gray, medium- to thick-bedded, mostly massive, occasionally finely laminated; with horn corals and disarticulated brachiopod debris. Sparse chert nodules constitute less than 2% of unit. <u>Lithostrotionella</u> colony present near base of unit. 23

7. Limestone (pelmatozoan lime packstone), light-gray, medium-bedded, constitutes about 60% of unit. Chert, medium- to dark-gray, in discontinuous beds and nodules up to 15 cm thick; approximately 40% of unit. 4

6. Covered 8.5

5. Limestone (lime wackestone and packstone) (90%), light- to medium-gray, calcarenite is fine- to medium-grained with horn corals (up to 4 cm across), brachiopods, and calcareous foraminifera. Chert nodules and irregular lenses (10%), dark-gray, weather dark brownish-gray to nearly black, up to 10 cm thick. Unit pinches out 35 m to the north. 3.5

Thickness (m)

4. Limestone (lime packstone and grainstone), light- to medium-gray, medium- to thick-bedded, mostly massive, occasionally finely laminated; constitutes about 99% of unit. Chert nodules, dark-gray, up to 10 cm thick; approximately 1% of unit. 11

3. Limestone (pelmatozoan lime packstone and grainstone), light- to medium-gray, fine- to medium-grained calcarenite, medium- to thick-bedded, mostly massive, occasionally finely laminated. 15

2. Limestone (pelmatozoan lime packstone and grainstone), medium- to dark-gray, medium- to thick-bedded, mostly massive, with patches of *Siphonodendron* and *Lithostrotionella* colonies and scattered horn corals and brachiopods. Chert nodules (1%), medium- to dark-gray, up to 10 cm thick. 17

1. Limestone (pelmatozoan lime packstone and grainstone), medium-gray, medium- to thick-bedded, massive, medium-grained calcarenite. Chert nodules (1%), dark-gray, up to 10 cm thick. 9

Total thickness of Santa Rosa Hills Limestone measured in Santa Rosa Hills 91

Contact Conformable

Stone Canyon limestone

10. Limestone (lime mudstone and wackestone), dark-gray, occasionally silicified, thin- to medium-bedded, mostly massive, with fine-grained pelmatozoan debris and minor brachiopods, gastropods, and solitary rugose corals; rare vertical burrows. Chert lenses and nodules, dark brown- to black-weathering, 5 cm average thickness, more abundant in upper 15 m of unit. Interbedded pelmatozoan calcarenite (lime packstone and grainstone),

Thickness (m)

light- to medium-gray, thin- to medium-bedded, sharp bases and gradational tops, crude to moderate normal grading of pelmatozoan debris, some display internal laminations; contain disarticulated brachiopods, commonly oriented concave-side down, and horn corals. 102

9. Limestone (pelmatozoan lime packstone and grainstone), medium-gray to medium bluish-gray, cross-bedded in sets averaging 8 cm to 10 cm in thickness with foreset bed inclinations ranging from 14 to 23 degrees, bimodal, dominant cross-bed trend to the north (90%); pelmatozoan debris is fine sand to gravel size. Unit pinches out 0.5 km to south. . . . 7

8. Limestone (lime mudstone and wackestone), dark-gray, thin- to medium-bedded, massive. Interbedded pelmatozoan calcarenite (lime packstone and grainstone), dominantly medium-bedded, sharp bases and gradational tops, crude to moderate normal grading of pelmatozoan debris; fine sand to gravel size bioclastic debris with occasional faint internal laminations, some amalgamation of beds. 4

7. Limestone (pelmatozoan lime packstone and grainstone), medium-gray to medium bluish-gray, cross-bedded in sets averaging 8 cm to 10 cm in thickness with foreset bed inclinations ranging from 14 to 20 degrees, bimodal with dominant cross-bed trend to north (90%), pelmatozoan debris is fine sand to gravel size. Unit pinches out 0.5 km to south. . . . 3

6. Limestone (lime mudstone and wackestone), dark-gray, thin- to medium-bedded, some beds silicified and weather orangish-brown, mostly massive, occasionally finely laminated. Chert lenses and nodules, dark-gray, weather dark brown to nearly black, up to 10 cm thick. Interbedded pelmatozoan calcarenite (lime packstone and grainstone), light- to medium-gray, in diffuse lenticular accumulations and

Thickness (m)

crudely to moderately developed normally graded beds. Graded beds display sharp, erosive bases and gradational tops with rare internal laminations, become coarser grained and thick-bedded towards top of unit; amalgamation of beds common in upper 15 m. Normally graded, pelmatozoan calcarenite beds contain pelmatozoan ossicles, calcareous foraminifera, solitary rugose corals, and disarticulated brachiopods commonly oriented concave-side down. 41

5. Limestone (lime mudstone and wackestone), dark-gray, thin- to medium-bedded, mostly massive, occasionally finely laminated, constitutes about 80% of unit. Interbedded silicified, fine-grained limestone (15%), dark-gray, weathers orangish-brown to medium brown, predominantly thin-bedded, often in discontinuous beds. Chert nodules and lenses (5%), dark-gray, up to 15 cm thick 10.5

Partial thickness of Stone Canyon limestone at Santa Rosa Hills section #1. . . . . 167.5

Base of section: underlying units of Stone Canyon limestone are covered by Cenozoic volcanic rocks and Quaternary alluvium.

<u>Section #2 of the lower and middle portion of the Stone Canyon limestone, Santa Rosa Hills</u>

Section measured approximately 1/2 km south of hill 6061 in Santa Rosa Hills from an elevation of about 5720 ft on the east side of the Santa Rosa Hills, across the crest, to an elevation of approximately 5640 on the west side of the Santa Rosa Hills. T 17 S, R 40 E (not sectioned); 36° 27'38" lat, 117°38'5" long, Darwin 15-minute quadrangle, Inyo County, California.

Top of section: overlying units of Stone Canyon limestone are faulted and covered by Quaternary alluvium.

Thickness (m)

6. Limestone (lime mudstone and wackestone), dark-gray, thin- to medium-bedded, some beds silicified and weather orangish-brown, mostly massive, occasionally finely laminated. Chert lenses and nodules, dark-gray, weather dark brown to nearly black, up to 10 cm thick. Interbedded pelmatozoan calcarenite (lime packstone and grainstone), light- to medium-gray, in diffuse lenticular accumulations and crudely to moderately developed normally graded beds. Graded beds display sharp, erosive bases and gradational tops with rare internal laminations, become coarser grained and thick-bedded towards top of unit; amalgamation of beds common in upper 15 m. Normally graded, pelmatozoan calcarenite beds contain pelmatozoan ossicles, calcareous foraminifera, solitary rugose corals, and disarticulated brachiopods, commonly oriented concave-side down. 19

5. Limestone (lime mudstone and wackestone), dark-gray, thin- to medium-bedded, mostly massive, occasionally finely laminated; constitutes about 80% of unit. Interbedded silicified, fine-grained limestone (15%), dark-gray, weathers orangish-brown to medium brown, predominantly thin-bedded, often in discontinuous beds. Chert nodules and lenses (5%), dark-gray, up to 15 cm thick 12

4. Limestone (lime mudstone and wackestone), dark-gray, thin- to medium-bedded, massive; constitutes about 60% of unit; interbedded with silicified, fine-grained limestone (40%), dark-gray, weathers orangish-brown, sponge spicule-rich. 5.5

3. Limestone (lime mudstone and wackestone), dark-gray, thin- to medium-bedded, mostly massive, contains very fine-grained pelmatozoan debris. 6.5

Thickness (m)

2. Limestone (lime mudstone and wackestone), dark-gray, thin- to medium-bedded, mostly massive, occasionally finely laminated; constitutes about 65% of unit. Interbedded silicified, fine-grained limestone (15%), weathers orangish-brown to medium brown, dominantly thinly bedded, sponge spicule-rich. Chert nodules and lenses (20%), dark-gray, to 20 cm thick. Chert and silicified limestone most abundant in lower 100 m of unit. Thin-bedded, fine-grained carbonate turbidites present in lower 10 m of unit. 326

1. Chert (50 to 60%), dark-gray, weathers brown, occurs in irregular (disrupted?) beds and nodules, up to 20 cm thick. Interbedded lime mudstone and wackestone, dark-gray, thin- to medium-bedded, massive; constitutes about 30% of unit. Silicified limestone, fine-grained, weathers orangish-brown, thin-bedded, irregular beds, sponge-spicule-rich; about 10-20% of unit 25

Partial thickness of Stone Canyon limestone at Santa Rosa Hills section #2. 394

Contact Conformable

Tin Mountain Limestone

APPENDIX A-3

Section of Stone Canyon limestone and Mexican Spring formation, Quartz Spring Area

Section measured in Cottonwood Mountains, approximately 4 km east of the mouth of Perdido Canyon, from an elevation of 6240 ft to an elevation of 6160 ft. T 13 S, R 42 E, 36°45'30" lat, 117°26'27" long, Tin Mountain 15-minute quadrangle, Inyo County, California.

Rest Spring Shale

Conformable Contact

Mexican Spring formation

Thickness (m)

11. Siltstone (70%), reddish-brown, calcareous, fairly massive, highly bioturbated, Nereites trace fossils. Interbedded limestone (fossiliferous lime packstone), thin- to thick-bedded; T_a, T_{ab}, and T_b carbonate turbidites; sharp, erosive bases and planar to slightly undulose tops, normal grading of fossil debris and intraclasts, some amalgamation of beds; contains pelmatozoan, brachiopod, and gastropod debris, calcareous foraminifera, minor ooids and intraclasts of lime mudstone and wackestone, chert, and siltstone. 16

10. Conglomerate, pinkish-gray, massive, predominantly matrix-supported, channelized, with clasts of lime packstone and grainstone, siltstone, and lime mudstone and wackestone to 1.3 m across; clasts mostly subrounded, some are tabular in shape; matrix consists of fossil debris and siliciclastic silt grains in lime mud. 6.5

9. Siltstone, reddish-brown, calcareous, massive, highly bioturbated. 4

Fault (minor displacement?)

8. Siltstone (70%), reddish-brown, calcareous, fairly massive, highly bioturbated, Nereites

Thickness (m)

trace fossils. Interbedded limestone (fossiliferous lime packstone), medium- to thick-bedded; T_a, T_{ab}, and T_b carbonate turbidites; sharp, erosive bases and planar to slightly undulose tops, normal grading of fossil debris and intraclasts, some cobble-bearing with R3 gravels and deposits of surging turbidity currents, no amalgamation of beds; contains pelmatozoan, brachiopod, and gastropod debris, calcareous foraminifera, minor ooids and intraclasts of lime mudstone and wackestone, chert, and siltstone. 34.5

Fault (minor displacement?)

7. Siltstone (70%), reddish-brown, calcareous, fairly massive, highly bioturbated, Nereites trace fossils. Interbedded limestone (fossiliferous lime packstone), medium- to thick-bedded; T_a, T_{ab}, and T_b carbonate turbidites; sharp, erosive bases and planar to slightly undulose tops, normal grading of fossil debris and intraclasts, some cobble-bearing with R3 gravels and deposits of surging turbidity currents, no amalgamation of beds; contains pelmatozoan, brachiopod, and gastropod debris, calcareous foraminifera, minor ooids and intraclasts of lime mudstone and wackestone, chert, and siltstone. 5.3

6. Siltstone, reddish-brown, calcareous, massive, highly bioturbated. 22

Section offset approximately 100 m to the northwest

5. Conglomerate, bluish-gray, massive, predominantly matrix-supported, clasts of lime mudstone and chert; matrix is argillaceous lime mudstone; clasts to 15 cm across. 0.75

4. Siltstone (70%), reddish-brown, calcareous, fairly massive, highly bioturbated, Nereites trace fossils. Interbedded limestone (fossiliferous lime packstone), medium- to thick-bedded; T_a, T_{ab}, and T_b carbonate turbidites; sharp, erosive bases and planar to slightly undulose tops, normal grading

Thickness (m)

of fossil debris and intraclasts, some cobble-bearing with R3 gravels and deposits of surging turbidity currents, no amalgamation of beds; contains pelmatozoan, brachiopod, and gastropod debris, calcareous foraminifera, minor ooids and intraclasts of lime mudstone and wackestone, chert, and siltstone. 8

3. Limestone (lime mudstone and wackestone) (70%), dark-gray to bluish-gray, argillaceous, thin- to medium-bedded, some minor internal laminations, some beds silicified and weather orangish-brown. Interbedded chert (20%) in bedded sequences to 3 m thick, dark-gray to nearly black; individual beds 5 cm to 15 cm thick, separated by very thin beds of fine-grained limestone. Chert nodules to 10 cm across, constitute approximately 5% of unit. Interbedded T_a, T_{ab}, and T_b carbonate turbidites to 20 cm thick, sharp bases, fairly planar tops, normally graded; contains fossil debris (mostly pelmatozoan ossicles) and intraclasts of lime mudstone, wackestone, and packstone, and chert; about 5% of unit. 19.7

2. Siltstone, reddish-brown, calcareous, massive, highly bioturbated. 32

1. Siltstone, reddish-brown, calcareous, massive, highly bioturbated. Interbedded T_a and T_{ab} carbonate turbidites and debris-flow conglomerate. Turbidites to 40 cm thick; have sharp bases, fairly planar tops, normal grading; some beds internally laminated, contain abundant fossil debris. Interbedded chert in sequences to 2 m thick, dark-gray to black; individual beds to 20 cm thick, separated by very thin beds of argillaceous lime mudstone. 14

Total thickness of Mexican Spring formation measured in Quartz Spring area. 163

Contact Conformable

Stone Canyon limestone

7. Limestone (lime mudstone and wackestone), dark-gray, thin- to medium bedded, argillaceous, some

Thickness (m)

beds silicified and weather orangish-brown, mostly massive, occasionally finely laminated. Chert lenses and nodules 10 cm thick. Interbedded T_a and T_{ab} carbonate turbidites, 10 cm to 30 cm thick, sharp erosive bases, fairly planar tops, normally graded, some with internal laminations; contain fossil debris (mostly pelmatozoan ossicles) and intraclasts of lime mudstone and wackestone and chert. 14

6. Conglomerate, medium-gray, weathers brownish-gray, both matrix-supported and clast-supported; contains clasts of lime mudstone, chert, fossiliferous wackestone, packstone, and Lithostrotionella to 40 cm across; local crudely developed coarse-tail grading, slightly erosive base and irregular top with clasts projecting above the matrix. Matrix is dark-gray lime mud and fossil debris. 2.5

5. Limestone (lime mudstone and wackestone), dark-gray, thin- to medium-bedded, argillaceous, some beds silicified and weather orangish-brown, mostly massive, bioturbated with vertical and horizontal burrows; contains minor pelmatozoan debris, horn corals, and brachiopod debris. Interbedded chert, dark-gray, weathers dark brownish-gray to nearly black, in bedded sequences to 4 m thick; individual beds 5 cm to 20 cm thick, separated by thin partings of argillaceous limestone. Chert lenses and nodules, dark-gray, weather dark brown to nearly black, up to 10 cm thick. Interbedded T_a and T_{ab} carbonate turbidites to 50 cm thick, some amalgamated, sharp, erosive bases, fairly planar tops, normally graded, some with internal laminations. 26.5

4. Limestone (lime mudstone to wackestone), dark-gray; beds folded and contorted, to 10 cm thick, some silicified; minor chert nodules to 8 cm thick. . . 3

3. Mudstone, reddish-brown-weathering, flaggy, bioturbated; T_{ab} carbonate turbidite, 30 cm thick, sharp, erosive base (scours to 10 cm), fairly planar

Thickness (m)

top, normally graded with pelmatozoan debris and intraclasts, imbricated N41W, groove lineations on base. Debris-flow conglomerate, 25 cm thick, dark-gray; lime mudstone and chert clasts, matrix-supported, planar base and top. 14

2. Limestone (lime mudstone to wackestone), dark-gray, three masses with folded and contorted beds; individual beds to 10 cm thick, some silicified; minor chert to 15 cm thick. Mudstone, reddish-gray, reddish-brown-weathering, flaggy, bioturbated, slightly calcareous. 16

1. Limestone (lime mudstone and wackestone), dark-gray, weathers yellowish-brown, thin- to medium-bedded, commonly silicified, sponge-spicule-rich; interbedded argillaceous lime mudstone, medium- to dark-gray-weathering, thin- to medium-bedded. Chert, dark-gray, thin- to medium-bedded, to 10 cm thick, also chert nodules (most common in upper 3 m of unit). . 7

Total thickness of Stone Canyon limestone measured in the Quartz Spring area. 83

Contact Conformable

Tin Mountain Limestone

APPENDIX A-4

Section of Stone Canyon limestone and Mexican Spring formation, western Lee Flat Area

Section measured in eastern Inyo Mountains, approximately 4 km northeast of Conglomerate Mesa, from an elevation of 6320 ft to an elevation of 6400 ft. T 15 S, R 39 E, 36°31'10" lat, 117°42'10" long, Ubehebe Peak 15-minute quadrangle, Inyo County, California.

Rest Spring Shale

Conformable Contact

Mexican Spring formation

Thickness (m)

8. Siltstone (60%), reddish-brown, calcareous, fairly massive, highly bioturbated, Nereites trace fossils. Interbedded limestone (fossiliferous lime packstone), medium- to thick-bedded, T_a and T_{ab} carbonate turbidites; sharp, erosive bases and planar to slightly undulose tops, normal grading of fossil debris and intraclasts, no amalgamation of beds; contains pelmatozoan, brachiopod, and solitary rugose coral debris, calcareous foraminifera, silt-size siliciclastic grains, and intraclasts of lime mudstone and wackestone, chert, and siltstone; fossils recrystallized 7

7. Siltstone, reddish-brown, calcareous, mostly massive, some beds are internally laminated, highly bioturbated, Nereites trace fossils 34

6. Siltstone (90%), reddish-brown, calcareous, fairly massive, highly bioturbated, Nereites trace fossils. Interbedded limestone (fossiliferous lime packstone), medium- to thick-bedded, T_a and T_{ab} carbonate turbidites; sharp, erosive bases and planar to slightly undulose tops, normal grading of fossil debris and intraclasts, no amalgamation of beds; contains pelmatozoan, brachiopod, and solitary rugose coral debris, calcareous foraminifera, silt-size siliciclastic grains, and intraclasts of lime mudstone and wackestone, chert, and siltstone; fossils recrystallized 60

Thickness (m)

Total thickness of the Mexican Spring formation measured in the western Lee Flat area 101

Conformable Contact

Stone Canyon limestone

5. Limestone (lime mudstone and wackestone), dark-gray, thin- to medium-bedded, argillaceous, some beds silicified and weather orangish-brown, rare horizontal and vertical burrows, mostly massive, rarely finely laminated. Chert lenses and nodules, dark-gray, weather dark brown to nearly black, to 15 cm thick . 2

4. Chert, dark-gray, weathers dark brownish-gray to nearly black, sponge-spicule-rich, individual beds range from 2 cm to 25 cm thick, separated by thin partings of argillaceous limestone 5

Section offset approximately 100 m to the east

3. Limestone (lime mudstone and wackestone), dark-gray, thin- to medium-bedded, argillaceous, some beds silicified and weather orangish-brown, rare horizontal and vertical burrows, mostly massive, rarely finely laminated. Chert lenses and nodules, dark-gray, weather dark brown to nearly black, to 10 cm thick . 4

2. Conglomerate, bluish-gray, massive, predominantly matrix-supported, fairly planar top and base, with clasts of lime mudstone, lime wackestone, and chert; matrix is fine-grained limestone and pelmatozoan debris, clasts to 50 cm across 1.5

1. Limestone (lime mudstone and wackestone), dark-gray, thin- to medium-bedded, argillaceous, some beds silicified and weather orangish-brown, rare horizontal and vertical burrows, mostly massive, occasionally finely laminated. Chert lenses and nodules, dark-gray, weather dark brown to nearly black, to 15 cm thick. Interbedded T_a and T_{ab} carbonate turbidites to 30 cm thick, sharp, erosive bases, fairly planar tops, normal grading of pelmatozoan debris 15.5

Total thickness of partial section of Stone Canyon limestone measured in the western Lee Flat area 28

Fault Contact

APPENDIX A-5

Section of Stone Canyon limestone and Mexican Spring Formation, Ubehebe Mine Canyon

Section measured in the Panamint Range, approximately 6 km north of Ubehebe Peak, from an elevation of 3600 ft to an elevation of 3600 ft. T 14 S, R 42 E, 36°45'20" lat, 117°36'3" long, Dry Mountain 15-minute quadrangle, Inyo County, California.

Rest Spring Shale

Fault Contact

Mexican Spring formation

Thickness (m)

9. Siltstone (75%), grayish-brown, reddish-brown-weathering, calcareous, fairly massive, highly bioturbated, Nereites trace fossils. Interbedded limestone (fossiliferous lime packstone), medium- to thick-bedded; T_a and T_{ab} carbonate turbidites with sharp, erosive bases and planar tops, normal grading of fossil debris and intraclasts, no amalgamation of beds. Contains pelmatozoan, brachiopod, and solitary rugose coral debris, calcareous foraminifera, silt-size siliciclastic grains, and intraclasts of fine-grained limestone, chert, and siltstone; fossils recrystallized 9

Section offset approximately 400 m to the north

8. Siltstone (75%), grayish-brown, reddish-brown-weathering, calcareous, fairly massive, highly bioturbated, Nereites trace fossils. Interbedded limestone (fossiliferous lime packstone), medium- to thick-bedded; T_a and T_{ab} carbonate turbidites with sharp, erosive bases and planar tops, normal grading of fossil debris and intraclasts, no amalgamation of beds, lower turbidite fills a 3.5-m-thick scour channel. Contains pelmatozoan, brachiopod, and solitary rugose coral debris, calcareous foraminifera, silt-size siliciclastic grains, and intraclasts of fine-grained limestone, chert, and siltstone; fossils recrystallized 7

Thickness (m)

7. Siltstone, grayish-brown, weathers reddish-brown to brown, calcareous, massive, highly bioturbated, Nereites trace fossils 42.5

6. Siltstone (80%), grayish-brown, reddish-brown-weathering, calcareous, fairly massive, highly bioturbated, Nereites trace fossils. Interbedded limestone (fossiliferous lime packstone), medium-bedded; T_a and T_{ab} carbonate turbidites with sharp, erosive bases and planar tops, normal grading of fossil debris and intraclasts, no amalgamation of beds. Contains pelmatozoan, brachiopod, and solitary rugose coral debris, calcareous foraminifera, silt-size siliciclastic grains, and intraclasts of fine-grained limestone, chert, and siltstone; fossils recrystallized 5.5

Total thickness of Mexican Spring formation measured in Ubehebe Mine Canyon area 64

Conformable Contact

Stone Canyon limestone

5. Limestone (lime mudstone and wackestone), dark-gray, argillaceous, thin-bedded, some beds are silicified and weather orangish-brown. Chert lenses and nodules, dark-gray, weather dark brown to nearly black, up to 15 cm thick 4

4. Mudstone, dark-gray, weathers pinkish-brown, mostly massive, bioturbated with horizontal and vertical burrows; T_a carbonate turbidite, 15 cm thick with sharp, erosive base, fairly planar top, normally graded; contains calcareous foraminifera, pelmatozoan and solitary rugose coral debris, and intraclasts of fine-grained limestone and chert 3.5

3. Limestone (lime mudstone and wackestone), dark-gray, argillaceous, thin-bedded, some beds are silicified and weather orangish-brown. Chert lenses and nodules, dark-gray, weather dark brown to nearly black, up to 15 cm thick. Contains some soft-sediment deformational features 8.5

Thickness (m)

2. Conglomerate, dark-gray, massive, predominantly matrix-supported, channelized (pinches out 100 m to the north), with clasts of lime mudstone and wackestone, silicified limestone, pelmatozoan wacketone and packstone, and chert, to 60 cm in diameter. Clasts commonly are subrounded, some are tabular to irregular in shape. Matrix consists of dark-gray, lime mudstone and pelmatozoan debris . . 2

1. Mudstone, dark-gray, very thin-bedded, radiolarian-bearing, some siliceous sponge spicules, organic-rich, few burrows, with occasional chert nodules to 8 cm across 7.25

Total thickness of Stone Canyon limestone measured in Ubehebe Mine Canyon 25.25

Conformable Contact

Tin Mountain Limestone

APPENDIX A-6

Section of Mexican Spring formation, Mexican Spring Area

Section measured in the southern Inyo Mountains, approximately 7.2 km northwest of Cerro Gordo Mine, from an elevation of about 8920 ft to an elevation of about 8970 ft. T 15 S, R 38 E, 36°35'48" lat, 117°26'34" long, New York Butte 15-minute quadrangle, Inyo County, California.

Rest Spring Shale

Conformable Contact

Mexican Spring formation

Thickness (m)

1. Siltstone, grayish-brown, weathers light brown, massive, calcareous, highly bioturbated, abundant trace fossils 37

Total thickness of Mexican Spring formation measured in the Mexican Spring area 37

Disconformable(?) Contact

Tin Mountain Limestone