

LITHOFACIES, DEPOSITIONAL ENVIRONMENTS, AND DIAGENESIS
OF THE MURAL LIMESTONE (LOWER CRETACEOUS),
LEE SIDING AREA, COCHISE COUNTY, ARIZONA

by

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ABSTRACT

In the Lower Cretaceous Mural Limestone of southeastern Arizona, coral-algal-rudist reefs occur as patch reefs. They are analogous to the subsurface reefs of Texas, although in the Mural, corals and stromatolites are the dominant reef builders.

In the small patch reef in which this study was done, the reef core is represented by the coral-stromatolite-rudist boundstone and packstone facies. The reef core facies grades laterally and/or interfingers into the coral-rudist packstone and grainstone facies of the reef flanks which in turn grades into and interfingers with the mollusk-miliolid-Orbitolina facies of the shallow shelf.

Four diagenetic environments acted on the upper Mural limestones to either enhance or occlude porosity: the marine phreatic, the mixing (fresh water phreatic-marine phreatic), the fresh water phreatic, and the deeper subsurface.

INTRODUCTION

Introductory Statements

Reefs are organic build-ups rising above sea floor and are entities and sedimentary systems of their own making. Reefs have the quality to grow and resist turbulent and agitated waters, and because they are built by organisms, fossil reefs are an excellent source of paleontological information. Modern reefs are also an important aid in the study of benthic marine ecology. Furthermore, ancient subsurface reefs contain a large amount of the world's oil and gas reserves.

Corals and algae are the main modern reef builders, although in certain geological times other groups have been more dominant. Rudist reefs of Cretaceous age flourished throughout the Tethyan Sea in shallow tropical and subtropical waters (Coates, 1973; Gordon, 1973). They are widely distributed in the Western and eastern hemispheres; they are common on the surface and in the subsurface of the Caribbean (Kauffman and Sohl, 1974), eastern Mexico (Boyd, 1963; Nigra, 1951; Rose, 1963; Salas, 1949), and central and west Texas (Bebout and Loucks, 1977; Nelson, 1973; Perkins, 1974; Rose, 1972). In Texas and in the Middle East (Henson, 1950), rudist reefs and related facies are important hydrocarbon exploration objectives and reservoirs. Normally, rudists are the primary biotic constituents in east-central

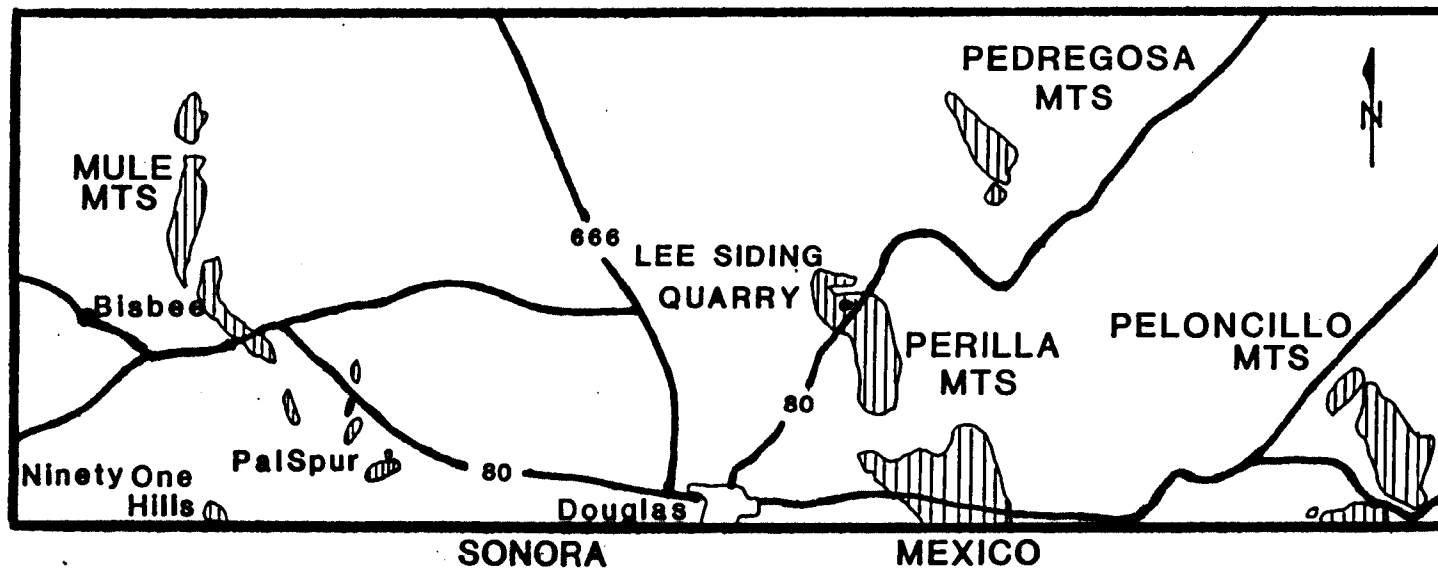
Texas, while corals and algae are of secondary importance. In the Mural Limestone of southeastern Arizona, coral-algal-rudist reefs are analogous to the subsurface reefs of Texas (Scott and Brenckle, 1979; Roybal, 1979, p. 48), although in the Mural, hermatypic corals and associated stromatolites are the dominant reef builders.

The objectives of this study are to define and describe the facies, depositional environments, and related diagenetic environments of a small rudist-algal-coral reef in the upper member of the Mural Limestone located 13 km (8 miles) northeast of Douglas, Arizona, adjacent to U.S. Highway 80 (Fig. 1).

Previous Work

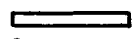
The first description of Cretaceous strata in southeastern Arizona was done by Dumble in 1902 in the Mule Mountains. He described an assemblage of arenaceous and calcareous strata under the name of "Bisbee beds". Later, Ramsome (1904, p. 56) named this set of intercalated marine and non-marine strata the Bisbee Group, which included four conformable formations; Glance Conglomerate, Morita Formation, Mural Limestone, and Cintura Formation. These formation names can adequately be applied to the Lower Cretaceous strata of southeast Arizona and northern Sonora, Mexico (Taliaferro, 1933; Imlay, 1939).

The Mural Limestone, named by Ramsome (1904, p. 56) from the outcrops in the Mule Mountains, records the climax of the Early Cretaceous marine transgression into southeastern Arizona. Ramsome also subdivided the Mural into lower and upper members.



 Lower Cretaceous Outcrops

 Kilometers
0 5 10

 Miles
0 5



ARIZONA
AREA OF STUDY

Figure 1. Location map. Outcrops of Lower Cretaceous rocks are indicated by the stippled areas.

After a time lapse of over 40 years, Stoyanow (1949) restudied the Bisbee Group and assigned an Early Albian age to the Upper Mural based on his palentological study of the ammonites collected. He also recognized the rudist reefs and suggested a shallow marine environment for the upper Mural. G. A. Cooper (1955) studied the brachiopods associated with the rudists, small oysters, and few echinoids in the Mule Mountains. He assumed them to be from the upper Mural. J. R. Cooper (1959) in his reconnaissance geologic map of southeast Cochise County, used the Bisbee divisions of Ramsome. P. T. Hayes and E. R. Landis (1961, p. 127) concluded on their basis of field work in the lower member of the Mural Limestone that facies changes and thickness of Lower Cretaceous rock units are not as extreme as previously thought. Later, Hayes (1970a) made a study on the Mesozoic stratigraphy of the Mule Mountains and Huachuca Mountains. He also interpreted the Cretaceous history and paleogeography of the region (Hayes, 1970b), placing the Aptian-Albian boundary in the upper part of the lower member of the Mural.

Few studies have been done specifically on the upper Mural. Grocock (1975), in his University of Colorado M.S. thesis, described the stratigraphy of the upper Mural, classified the carbonate facies by faunal content, and thus described the environments of deposition. R. W. Scott and P. L. Brenckle (1977) described the biotic zonation of the upper Mural and concluded that the Albian reefs were last built and dominated by corals and algae, which were adapted to a relatively stable and predictable environment.

Scott (1979) continued his studies, and later, proposed a depositional model for the upper Mural in which he recognized five facies which are gradational into one another. He concluded that Mural patch reefs apparently occupied an environmental zone on a carbonate shelf or ramp at the northern end of the Chihuahua Trough (Scott, 1979, p. 1126). Scott also concluded that the Mural reefs are of the two classes: mounds dominated by rudists and patch reefs of coral-algal-rudist. Later, he (Scott, 1981, p. 469) studied the biotic relations of these reefs in which he concluded that they were adapted to a relatively stable and predictable environment. He also made a comparison of the Mural reefs to other reefs described by various authors. Roybal (1979, p. 53), in a study of the facies relationships of a small patch reef near Paul Spur, recognized four major reefs facies. She concluded that the Mural reefs were on a higher angle carbonate platform and developed in a more normal marine environment than the Texas rudist reefs.

Most recently E. R. Warzeski (1983) completed a sedimentologic and diagenetic study (Ph.D. dissertation) of the Mural Limestone in which he made a detailed study of the facies and diagenetic environments of the upper Mural in particular in southeastern Arizona and northeastern Sonora, Mexico. He stated that the deposition of the Mural Limestone began on a low gradient ramp which produced two platforms sloping gently and thickening southeastward.

Purpose of Study

The purpose of this study is to describe the depositional and diagenetic environments in which the upper Mural rocks at Lee Siding quarry were deposited. Although the Mural Limestone has been studied for a number of years, only a few studies have been done on its diagenetic environments. The objective to describe the diagenetic trends that affected the upper Mural rocks, and also to decipher the cement-porosity relationships, is deemed to be equally important as the recognition of the depositional environments.

Methods of Study

Mapping of the lithofacies was done on an enlarged aerial photograph provided by the U.S. Geological Survey. Two stratigraphic sections were measured on the south and southeast sides of the knoll. Samples taken from these sections, and from the top of the hill at the north side of the quarry and in the quarry itself (north wall), were cut for thin sections, acetate peels, and polished slabs. These materials were used for faunal identifications and detailed study of lithology and diagenesis.

STRATIGRAPHIC AND TECTONIC SETTING

Bisbee Group

In southeastern Arizona, rocks of Early Cretaceous age (Aptian-Albian) are exposed in the Winchester, Little Dragoon, Patagonia, Huachuca, Mule, Chiricahua, and Pedregosa mountains. In the Bisbee Group, the marine Mural Limestone records the peak of the Early Cretaceous transgression (Hayes, 1970b).

The thickness of the Bisbee Group varies widely both locally and regionally due to the local relief developed on the underlying formations and to the degree of post-lower Cretaceous erosion. It ranges in thickness from 3000 m to 45000 m (Hayes, 1970a) (Fig. 2).

The Bisbee Group changes markedly in facies from east to west and from south to north. The proportion of limestone decreases westward; the carbonates of the northwestern sections are relatively thin-bedded or platy and are generally silty or argillaceous.

The Glance Conglomerate varies regionally in thickness, composition, contact relationships, and age. It covers the irregular depositional surface of an angular unconformity over rocks of Precambrian to Jurassic age. The Glance is transitional upward interfingering with the Morita Formation or its stratigraphic equivalent. The thickness of this unit is highly variable over short distances, reflecting the relief of

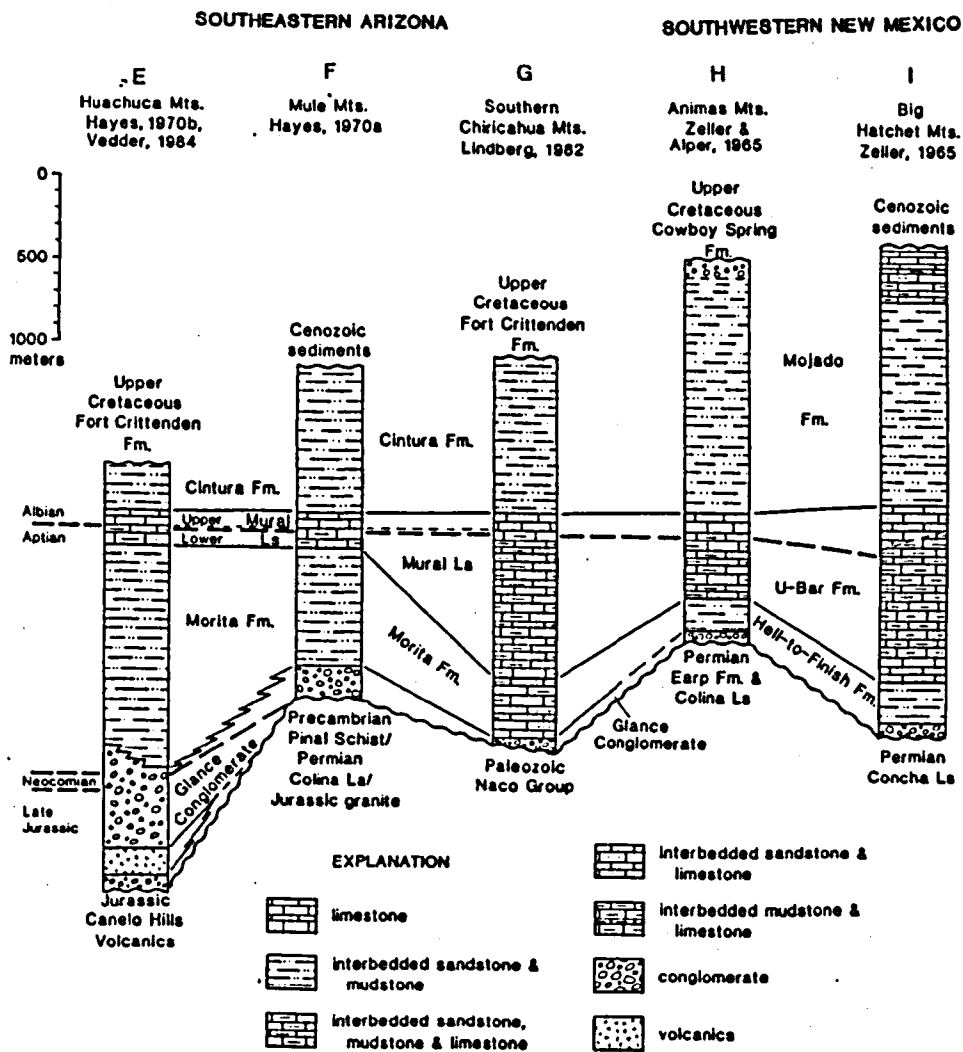


Figure 2. Representative stratigraphic sequences within the Bisbee Group and its correlatives (Dickinson, et al., in press).

the surface on which it was deposited. It ranges from 20 to 2000 m and probably varies considerably in age as well; these local thickness changes reflect the fillings of paleovalleys (Drewes, 1971; Vedder, 1984) and the burial of syndepositional fault scarps by syntectonic Glance sediments (Bilodeau, 1979). The Glance consists of poorly sorted rounded cobbles and pebbles, conglomerates, and breccia. The clasts include Precambrian schist and granite. Paleozoic limestone and quartzite, Jurassic granite, or Mesozoic volcanic rocks embedded in a matrix of reddish-brown sandy and silty mudstone.

Overlying the Glance Conglomerate and often interfingering laterally with it is a series of sandstones, mudstones, and siltstones of the Morita Formation. The Morita Formation ranges in thickness from 500 to 1500 m; the type section in the Mule Mountain is 855 m thick (Hayes, 1970a, p. 17). The Morita is composed mainly of pinkish-gray to pale red feldspathic sandstone and grayish-red siltstones and mudstones with minor pebble conglomerates, greenish-gray claystone, and impure limestone (Hayes, 1970a, p. 16). The contact with the overlying Mural Limestone is gradational, and is placed at the base of the lowest sequence of interbedded mudstone and impure limestone that overlies a series of ledges at the top of the Morita (Hayes, 1970a).

The Mural Limestone occupies a broad carbonate shelf at the northwest end of the Chihuahua Trough. The upper Mural represents the climax of the Aptian-Albian transgression. At the type locality on Mural Hill near Bisbee (Hayes, 1970b), the Mural is divided into lower and upper informal members. The lower member is 91 to 160 m thick and

consists of thin interbeds of shale, mudstone, siltstone, sandstone, and fossiliferous limestone. The upper member is a massive to thin-bedded, cliff-forming limestone 50 to 75 m thick. At many places, lenticular massive limestone buildups occupy the lowermost part of this member.

The characteristic faunas from the upper and lower Mural define the boundary between the Aptian and Albian stages, placing it below the top of the lower member of the Mural (Hayes, 1970b).

The Cintura Formation, overlies the Mural Limestone and contains up to 1000 m of interbedded sandstones and mudstones which are almost identical to the Morita lithologies. When the Mural Limestone is absent, the contact between the Morita and Cintura formations is not readily distinguished (or even impossible) by the field geologist. The conditions of deposition during the formation of the Cintura must have been quite similar to those of the Morita Formation, except that the Bisbee Sea was rapidly retreating rather than slowly advancing toward the head of the Chihuahua Trough.

The Early Cretaceous tectonic setting for southeastern Arizona was characterized by differential vertical movements on northwest and west-north-west-trending normal faults (Bilodeau, 1978, 1979). These movements produced a paleogeography similar to the present Basin and Range Province, i.e., the high relief necessary to develop the alluvial fan environment of the Glance Conglomerate (Bilodeau, 1979). Volcanic flows and breccias present in the Glance Conglomerate in the Huachuca Mountains and in other formations are evidence of backarc

volcanism. The magmatic arc was located far to the west and southwest of southern Arizona (Fig. 3) (Bilodeau and Lindberg, 1983, p. 183).

After the westward displacement of the magmatic arc from southern Arizona, marine waters transgressed northward from the Chihuahua Trough into southeastern Arizona. The Chihuahua Trough was a marine arm of the early opening of the Gulf of Mexico during the Jurassic (Fig. 4). This movement was probably related to larger plate motions throughout the Mesoamerican region. The Chihuahua Trough was formed by backarc rifting, and represents an aulacogen-like basin extending into the continental block from the Gulf of Mexico during mid-Mesozoic time (Bilodeau, 1982).

During the early Cretaceous transgression (late Aptian-Albian time), marine parts of the Bisbee Group were deposited over the Glance Conglomerate. Active deformation ceased and most of the paleotopography was reduced to low relief. By early Aptian, the interbedded sandstones and mudstones of the Morita Formation were deposited onto a slowly subsiding plain as the sea advanced through the Chihuahua Trough (Fig. 5) (Hayes, 1970b).

Later subsidence within the Bisbee basin is thought to be produced by crustal thinning during extensional deformation, followed by lithospheric cooling and associated thermotectonic subsidence (Dickinson et al., in press). In the northwestern part of the Bisbee basin lacustrine sedimentation developed. Bilodeau and Lindberg (1983, p. 186) proposed that the Mural reefs grew on paleostructural highs in the southeastern part of the basin during the maximum highstand of the sea.

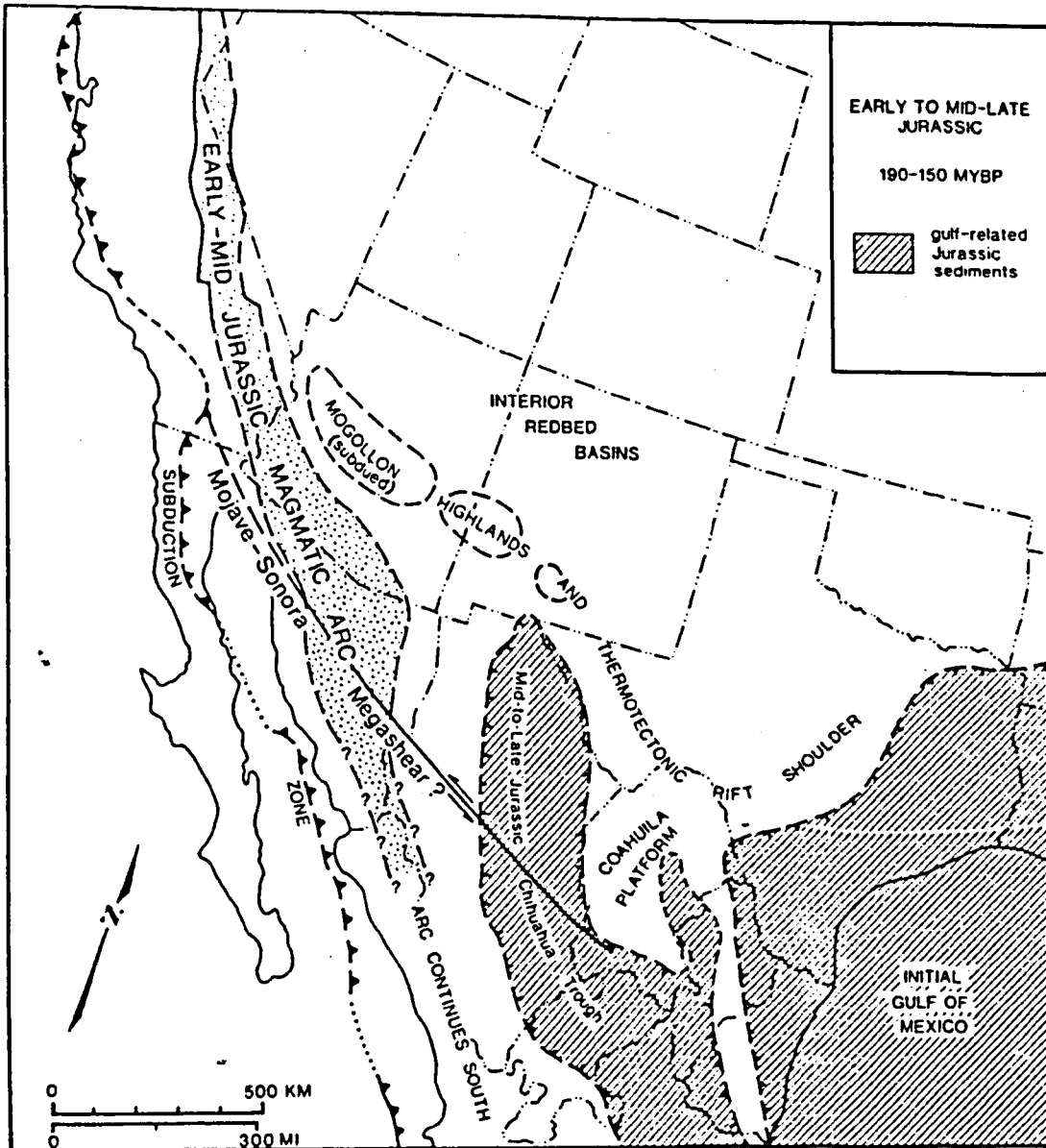


Figure 3. Paleotectonic map of southwestern North America during early to mid-late Jurassic (190-150 m.y.b.p.) (Bilodeau and Lindberg, 1983).

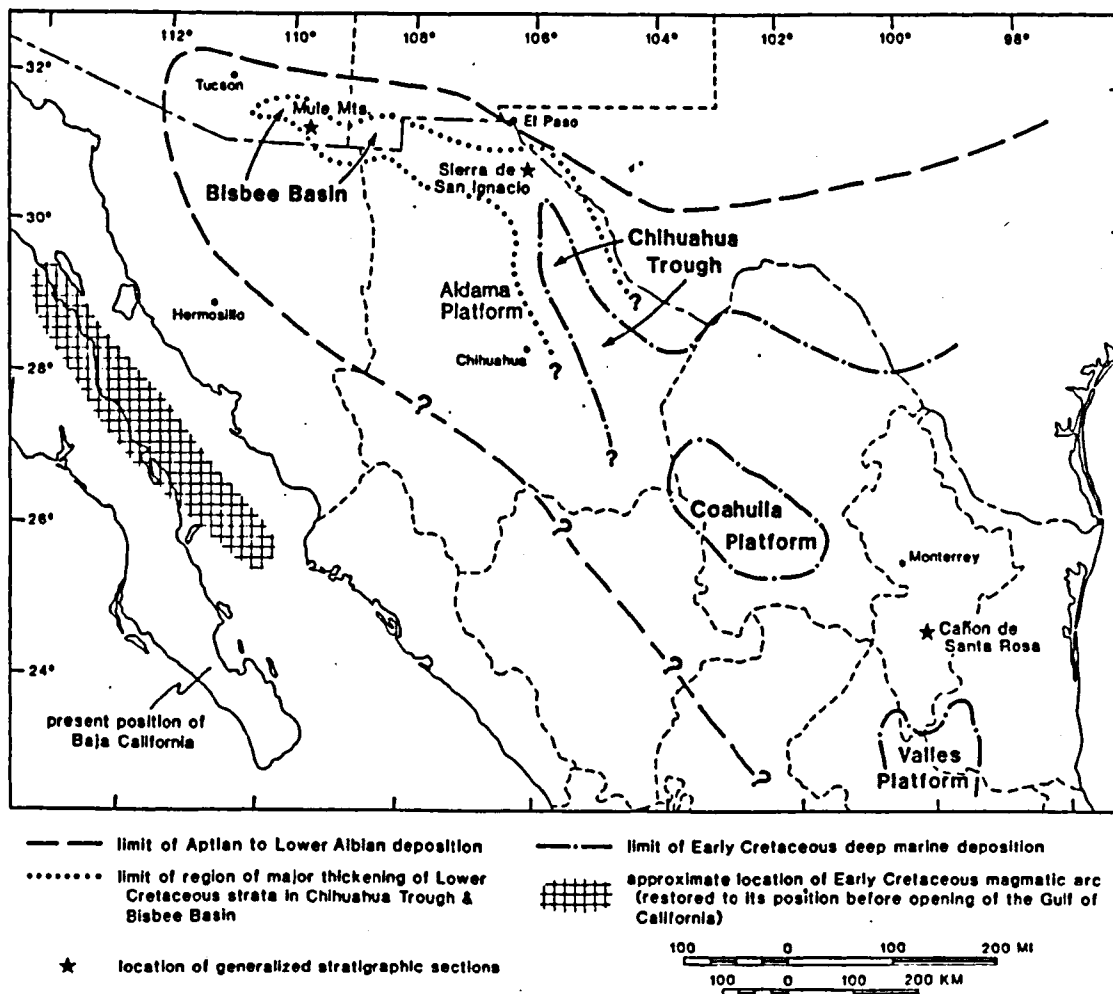
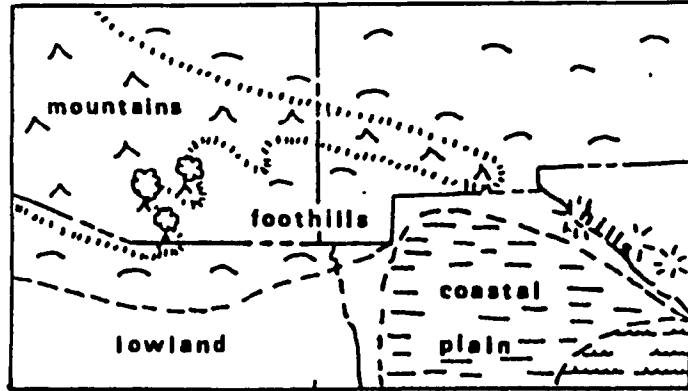
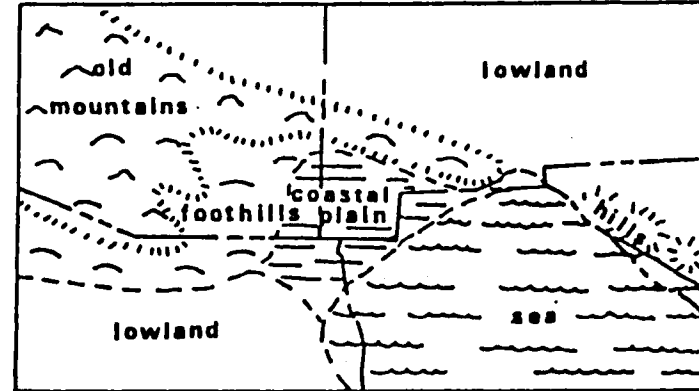


Figure 4. Early Cretaceous Bisbee basin, a northwestern extension of the Chihuahua Trough, a marine arm of the early Gulf of Mexico (Dickinson et al., in press).

Figure 5. Paleogeographic maps of southeastern Arizona (after Hayes, 1970b).

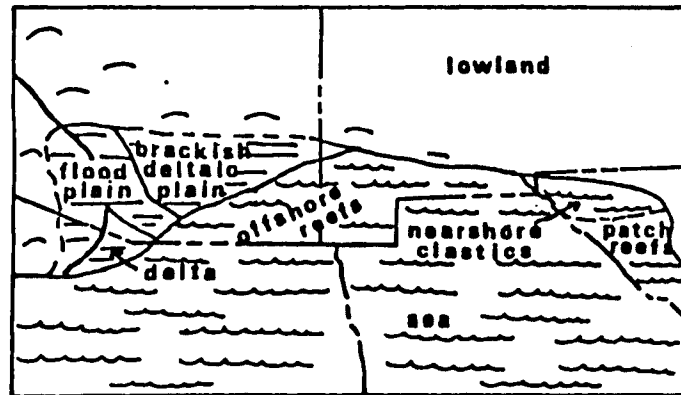


A) LATE NEOCOMIAN. GLANCE DEPOSITION

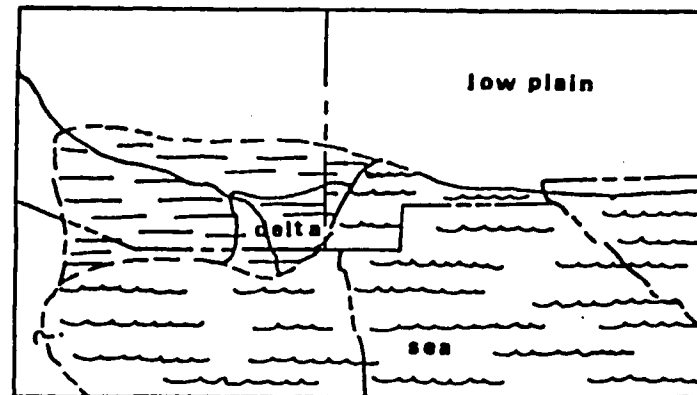


B) EARLY APTIAN. MORITA-MURAL DEPOSITION

Figure 5



C) EARLY ALBIAN. MURAL DEPOSITION



D) MIDDLE ALBIAN. CINTURA DEPOSITION

After the Albian transgression that produced the Mural Limestone, fluvio-deltaic sediments of the Cintura Formation invaded both lacustrine and marine environments from the highlands northwest of the Bisbee basin (Fig. 5). The highlands were produced by the northeastward tilting of the region rather than lowering the sea level (Hayes, 1970b).

These conditions prevailed until the Late Cretaceous Laramide Orogeny uplifted the entire region above sea level, causing the deposition of Upper Cretaceous lacustrine and dominantly fluvial sediments over the Cintura Formation.

Mural Limestone Patch Reefs

In the Lower Cretaceous, patch reefs composed mainly of corals, but also containing stromatolites, rudists, and bivalves, developed on a substrate of the mollusk-miliolid-orbitolinid facies (Scott, 1979, p. 1124) during the maximum transgression into the Chihuahua Trough. The patch reefs of the upper Mural are exposed in block-faulted mountain ranges of the Basin and Range Province of southeastern Arizona, namely on the flanks of the Mule, Perilla, and Peloncillo Mountains, but exposures of the Mural are discontinuous due to faulting.

Reefs of the upper Mural Limestone range from about 300 m to 1.5 km in length and up to 25 m thick. The Mural rocks have been mapped and divided into several facies and microfacies. G. R. Grocock (1975) studied the upper member of the Mural and concluded that three main facies with their lithofacies subdivisions make up the upper Mural. G. H. Roybal (1979), in a study of the biofacies and associated

lithologies of a small patch reef at Paul Spur, concluded that four facies with subsequent transitional areas make up the reef. R. W. Scott (1979, p. 1109) proposed that five main lithofacies, from which he interpreted five depositional environments, are present in the upper Mural patch reefs. E. R. Warzeski (1983), in his doctoral dissertation, noted that seven facies constitute the upper Mural in southeastern Arizona. Table I is a compilation of the facies proposed by the four authors mentioned above and by the present author.

	G. H. Grocock (1975) (Southern Arizona)	G. H. Roybal (1979) (Paul Spur)	R. W. Scott (1979) (Southern Arizona)	E.R. Warzeski (1983) (Southern Arizona)	R. Monreal (this paper) Lee Siding Quarry
Back reef	Interbioherm : Sparry Micritic : Allochem Facies : Limestone Facies : Facies (2 subfacies) (6 subfacies)	Microsolena-Stromatolite Facies Coral Facies Caprinid Subfacies	Ostracod-Mollusk-Skeletal- Algal Wackestone (restricted lagoon or shelf) Peloid-Ooid- Grainstone (lagoon shoals)	Ooid-Pelletoid Grainstone and Packstone Fine-grained well sorted Pelletoid skel. Pack. & Grain Algal-Mollusk- Echinoid Packstone	
Reef flat	Flank Lithofacies	Caprinid Subfacies Rudist Facies Petalodontia Subf.	Coral-Rudist-Fragment Packstone (reef flank)	Coral-Rudist Fragment Rudstone	
Reef crest	Core Lithofacies Base Lithofacies	Microsolena-Stromatolite Facies	Coral-Stromatolite-Rudist Boundstone (reef core)	Coral-Rudist-Algal Boundstone (reef core) Worn-heavily encrusted, C. Coral-Mollusk Packstone (reef base)	Coral-Stromatolite-Rudist Boundstone and Packstone (4 subfacies)
Reef front	Flank Lithofacies	Coral Facies	Coral-Rudist-Fragment Pack stone (reef flank)	Coral-Rudist Fragment Rudstone	Coral-Rudist Packstone and Grainstone
Fore reef		Debris Facies	Mollusk-Miliolid- Orbitolinid Wackestone (shallow shelf to open lagoon)	Mollusk-Miliolid-Orbitolina Wackestone and Packstone	Mollusk-Miliolid-Orbitolina Wackestone and Packstone

Table I. Facies proposed by different authors for the Upper Mural Limestone of southeastern Arizona.

THE LEE SIDING QUARRY MURAL LIMESTONE PATCH REEF

General Topographic and Geologic Setting

The small patch reef in which this study was done is part of a series of north-trending reefs. These reefs appear to be scattered upon a shallow shelf in the Bisbee basin at the northwestern end of the Chihuahua Trough. Reef growth took place upon a substrate of mollusk-miliolid-orbitolinid muds (Scott, 1979, p. 1124). The quarry at Lee Siding is located on a small knoll 13 kilometers northeast of Douglas on the northwest side of U.S. Highway 80 (NW1/4 NE1/4 NW1/4, sec. 11, T.23 S., R.28 E., 15 minute College Peaks Quadrangle) (Fig. 1). Although the area is quite small (74,322 m²), the facies are well exposed on the upper flanks of the knoll and in the quarry itself (Fig. 6). The upper Mural Limestone at Lee Siding is 32 m thick and consists principally of thickly bedded fossiliferous limestone. The reef core itself is a coral-algal-rudist packstone, grainstone, and boundstone and is about 17 m thick. It is underlain comfortably by the lower Mural. The upper beds of the Cintura Formation are not exposed at Lee Siding quarry because of post-lower Cretaceous erosion.

The lower Mural crops out on the lower slopes around the Lee Siding quarry and bedding dips toward the quarry. The cause for this attitude is not known, but a possible explanation is that the overload

Figure 6. Geologic map of Lee Siding area, Cochise County, Arizona.

EXPLANATION

	Alluvium
	Upper Mural
	Lower Mural
	Bedding Contact
	Normal fault
	Syncline
	Bedding attitude
	Joint
	Prospect

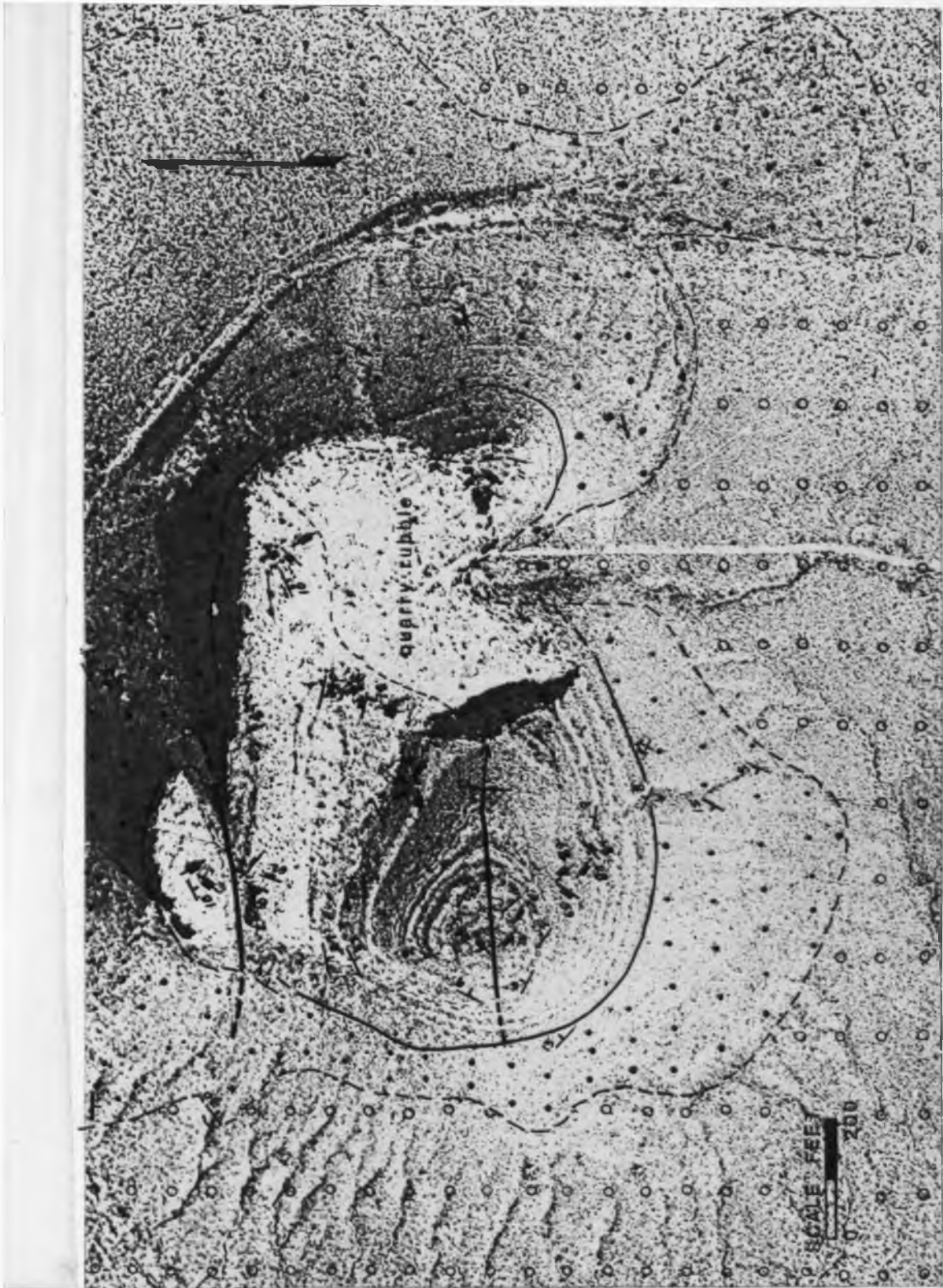


Figure 6.

weight of the patch reef rocks produced a depression on the beds of the Lower Mural. Another explanation is post-Mural Limestone tectonic activity (extension, flexuring, and normal faulting) in the area.

The southwest part of the knoll, a conical hill formed by wackestone and packstone beds, is a gentle east-west trending syncline dipping 4 degrees to the east. The exact causes for the formation of this structure are not clear. It could be a tectonic feature or simply a depositional feature if we assume that at the same time of formation of the Lee Siding patch reef, another patch reef developed close to the southwest.

Fracturing of the rocks at Lee Siding is quite pervasive with two sets of fractures standing out. The first set strikes between N. 25° to 50° W. and dips between 75° and 90° either to the southwest or northeast. The second set strikes between N. 15° and 40° E. and dips between 65° and 90° both to the northwest and to the southeast.

Facies

In this study lithologic descriptions of the facies occurring at Lee Siding quarry are based on Dunham's (1962) classification of carbonate rocks. Dunham's classification emphasizes depositional texture and utilizes five terms for recognizable depositional textures. Where applicable the textural term is prefaced by the principal particle kind. In addition, in the measured section descriptions both Dunham's (1962) and Folk's (1959) terminology are used. Paleontological identifications are based upon species descriptions by Robert W. Scott

(1974, 1979, 1981) and Scott and Brenckle (1977). Lithofacies were defined by field and laboratory studies from observations of texture, minerology, and diversity of fauna.

Three lithofacies and four subfacies are defined in this study on the basis mentioned above. The three lithofacies are the coral-stromatolite-rudist boundstone and packstone (CSRBP, reef core); coral-rudist-packstone and grainstone (CRPG, reef flank); and mollusk-milioid-Orbitolina wackestone and packstone (MMOWP, shallow shelf) (Fig. 7). Four subfacies make up the CSRBP facies: Actinastrea; Microsolena-stromatolite; Coalcomana-Petalodontia; and pelletoid-heavily algal-coated wackestone and packstone.

Coral-Stromatolite-Rudist Boundstone and Packstone

This facies represents the reef core and consists of organically bound, very thick-bedded to massive, lenticular carbonates. Now a cliff, the quarry face outcrop is up to 18 m in height and varies in color from medium light gray to medium gray (Fig. 8). The facies grades laterally into and interfingers with, the coral-rudist-packstone and grainstone facies (CRPG). Shallow shelf and/or lagoon wackestones, mudstones, and packstones of the mollusk-milioid-Orbitolina facies underlie and overlie the CRPG facies.

Paleontologically, the facies mainly consists of the lamellar and coral Microsolena encrusted by laminar stromatolites, the massive coral Actinastrea, the rudist caprinids (Coalcomana) and caprotinids (Monopleura and Petalodontia), and other green algae. Rudists are

Figure 7. Facies map of the Lee Siding quarry Lower Cretaceous rocks.

EXPLANATION

mmo	Mollusk-miliolid- <u>Orbitolina</u> facies
cr	Coral-rudist packstone and grainstone facies.
csr	Coral-stomatolite-rudist boundstone and packstone facies.

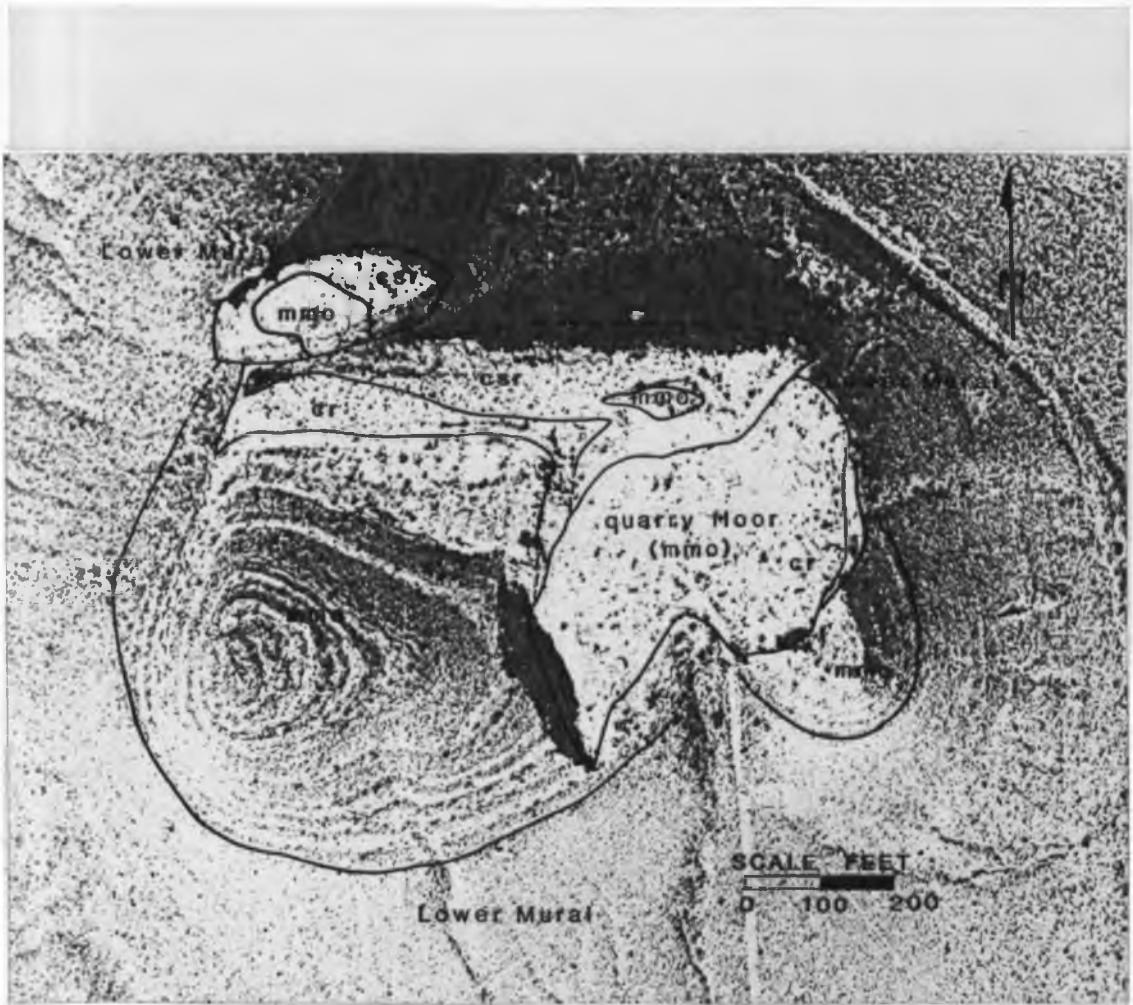


Figure 7.



Figure 8. Coral-stromatolite-rudist boundstone and packstone facies (CSRBP, reef core). Quarry face outcrop, looking north; height of cliff is 18 m.

nestled within and/or under the edges of Microsolena colonies.

Brachiopods and bryozoans are attached to the sides of the Microsolena colonies. Borings by bivalves and other organisms are abundant.

Figure 9 shows a geopetal structure along with blocky calcite filling a rudist cavity. Fine to coarse-grained packstone, with rudist, coral, echinoderm, gastropod, and algae fragments in a matrix of micrite and microspar, fill some spaces between rudists as well as rudist internal cavities (Fig. 10). Pelletoids in a micritic and sparry calcite matrix fill other rudist cavities and spaces between them (Fig. 11).

Other allochems include Orbitolina, ostracodes, bryozoans, boring bivalves, ooids and other coated grains, Coskinolina, milioids, and micritized grains; a few fine sand-size quartz grains also occur.

The taxonomic composition of the CSRBP facies varies vertically, and is the basis of further subdivisions into several subfacies.

The coral Actinastrea, which can display massive, irregular and tabular growth habit, occupies the base of the reef core (Fig. 12). Borings by bivalves are common in this Actinastrea subfacies.

The Microsolena-stromatolite subfacies developed during the climax stage of the reef and comprises the major part of the inner reef core (Fig. 13). Finely laminated stromatolites grew in the platy colonies of the coral Microsolena. Sparse caprinids, bryozoans, and brachiopods also occur. Boring bivalves are also common.

The Microsolena-stromatolite subfacies grades upward into the Coalcomana-Petalodontia subfacies (Fig. 14). This facies consists of irregular branching Actinastrea and laminar Microsolena corals, and

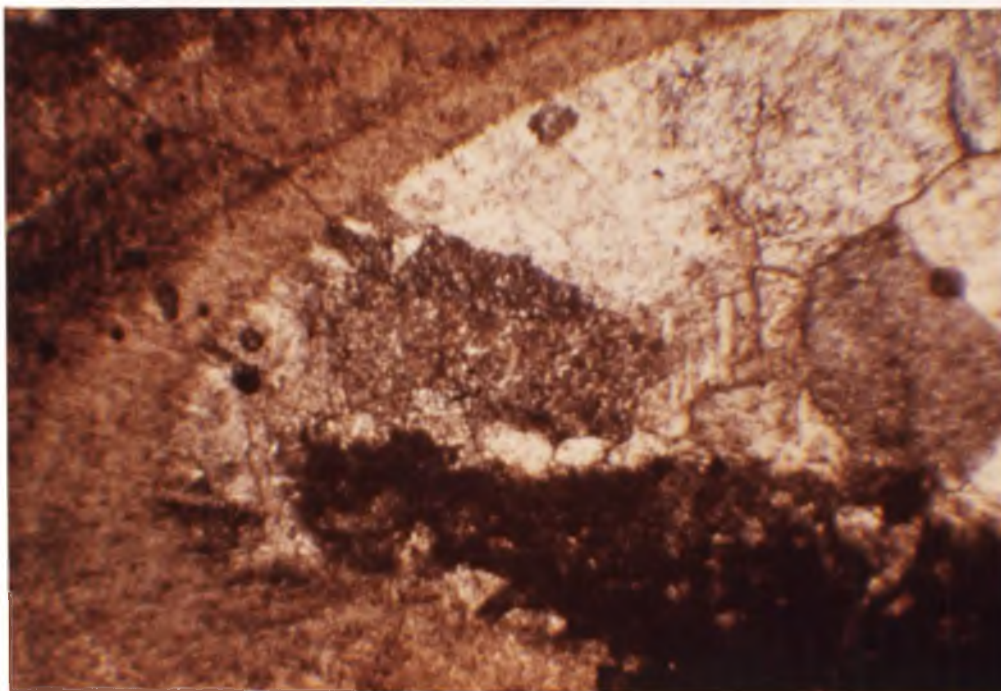


Figure 9. Coral-stromatolite-rudist boundstone and packstone facies. Geopetal structure shows blocky calcite/coarse sparry calcite resting on micrite in a rudist cavity. Thin section, crossed nicols, X 45.

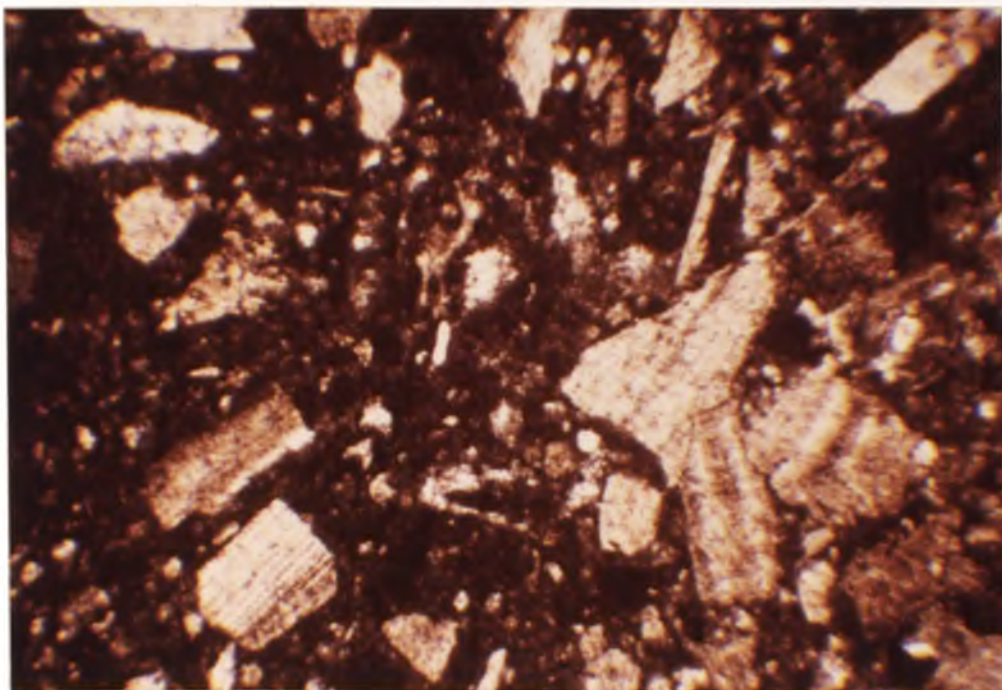


Figure 10. Coral-stromatolite-rudist boundstone and packstone facies. Fine to coarse-grained packstone (mostly rudist fragments in a matrix of micrite and microspar) filling spaces between and in internal cavities of rudists, walls of cavity not shown in photomicrograph. Thin section, plane-polarized light, X 45.

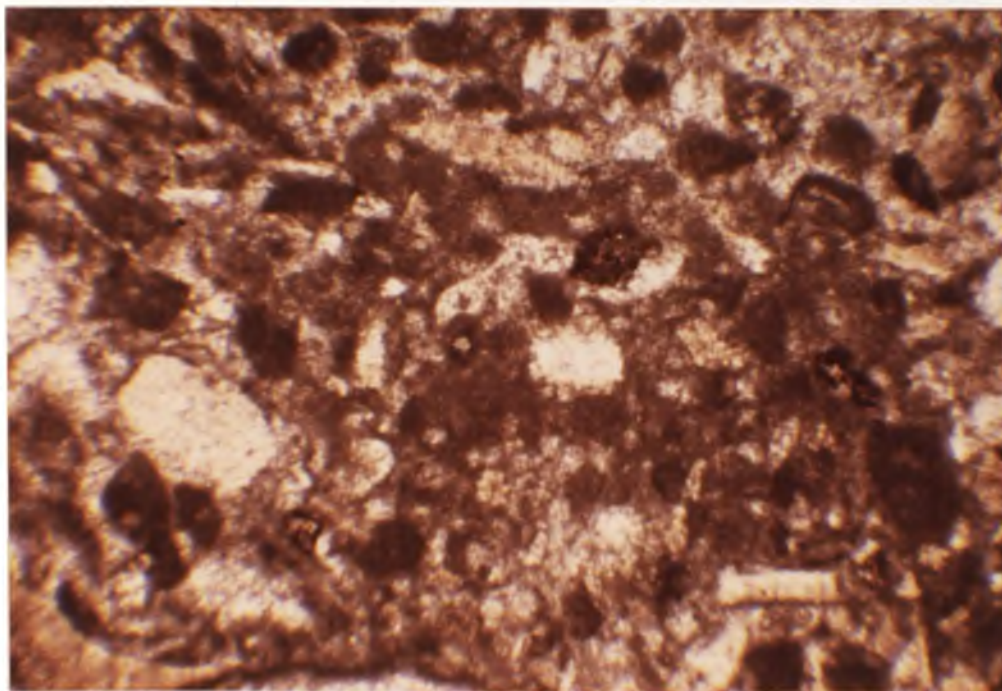


Figure 11. Coral-stromatolite-rudist boundstone and packstone facies. Pelletoids and rudist shell fragments in a micritic and sparry calcite matrix filling rudist cavities and spaces between them, walls of rudist not shown in photomicrograph. Thin section, plane-polarized light, X 45.



Figure 12. Coral Actinastrea in tabular growth (light patches) from base of CSRBP facies. Pencil is 15.5 cm in length.

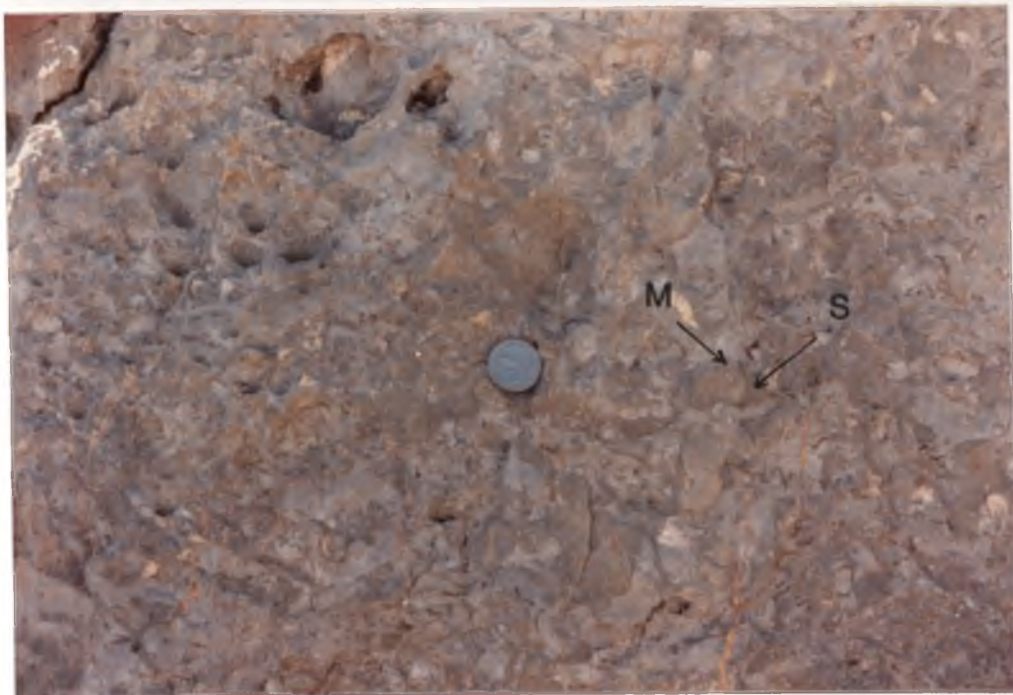


Figure 13. Coral Microsolena (M) interfingering with stromatolitic mud (S) of the CSRBP. Coin is 24 mm in diameter.

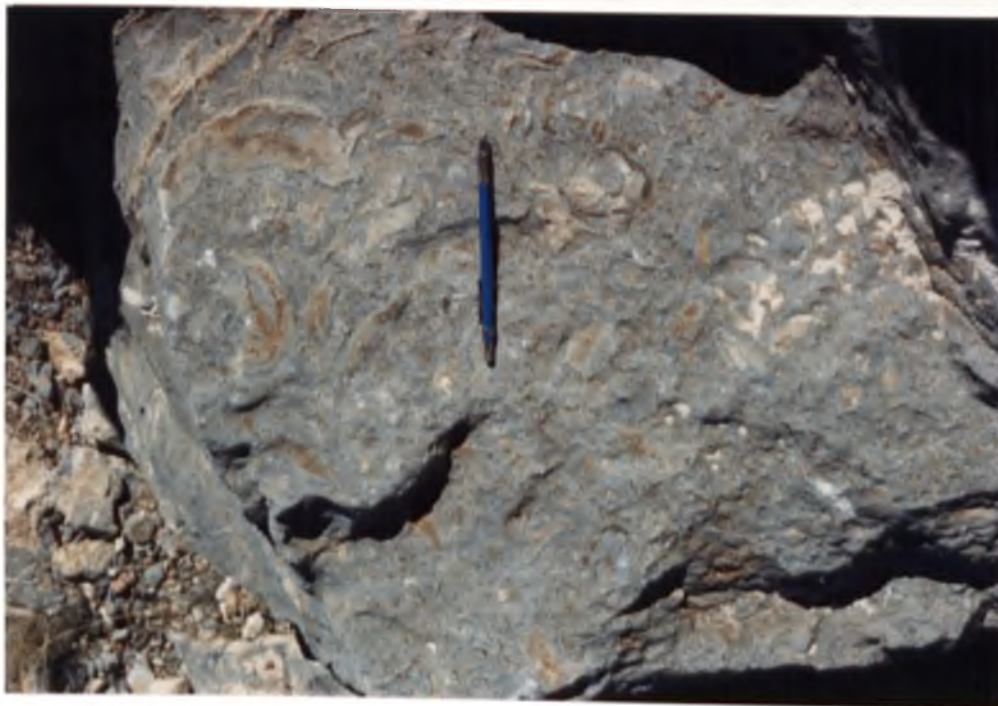


Figure 14. Coalcomana-Petalodontia subfacies (in place).
Pencil is 15.5 cm in length.

abundant in-place caprinids and thick-walled monopleurids, which are bound together and encrusted by algae. The fauna of this facies is dominated by rudists. Other allochems include brachiopods, gastropods, echinoids, pellets, and fine sand-size quartz grains.

The Coalcomana-Petalodontia subfacies grades upwards into the pelletoid heavily algal-coated packstone and wackestone subfacies. This subfacies consists of abundant large rudists, brachiopods, coral and bryozoan fragments, and large Orbitolina, which are heavily coated by algae, in a micrite matrix (Fig. 15). Other common allochems are pelletoids, calcisilt, oyster fragments, Dictyoconus, miliolids, Nautiloculina, other forams, gastropods, and red algae. This facies is generally a well-sorted, thin to thick-bedded, massive packstone, but some wackestones do occur. Borings into the heavily algal-coated shell fragments are also common (Fig. 16).

The most common large whole fossils are monopleurids, toucasids, Chondrodonta, and gastropods (Turritella up to 15 cm in length were recognized). Chondrodonta and Toucasia form thin bisotromes (Figs. 17, 18).

Coral-Rudist Packstone and Grainstone

The coral-Stromatolite-rudist facies grades laterally into and/or interfingers with the coral-rudist-packstone facies which represents the reef flanks (reef front) (Fig. 19). This facies consists of a light to medium gray, thin-bedded to massive grainstones and packstones. The latter consist of abundant rounded, heavily micritized grains of



Figure 15. Pelletoid, heavily algal-coated packstone and grainstone subfacies (in place). Pencil is 15.5 cm in length.

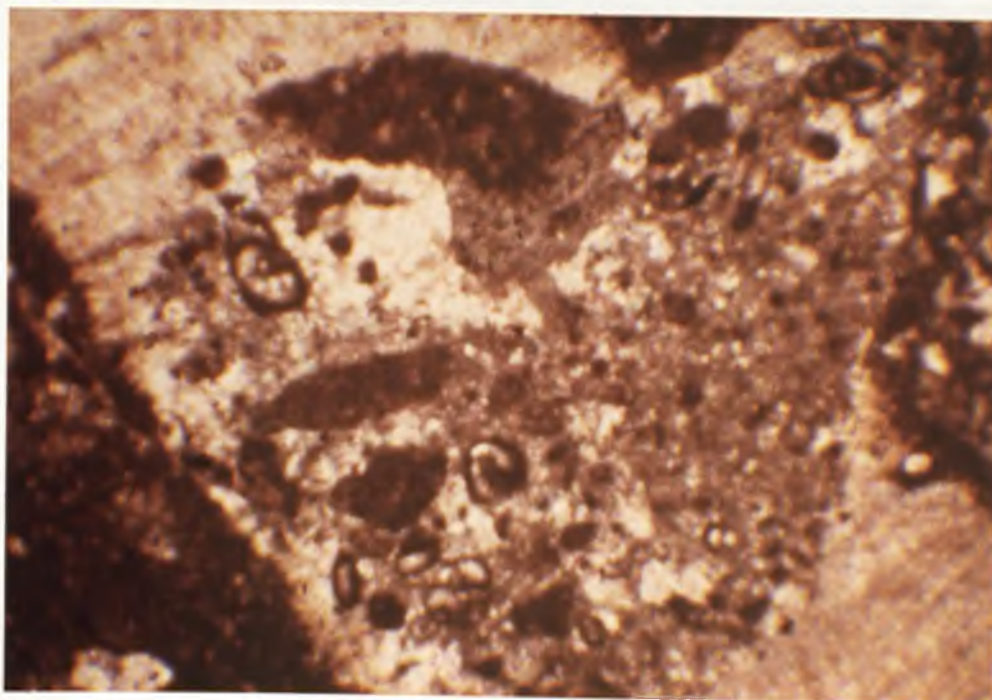


Figure 16. Boring of a rudist shell filled with micrite, forams, and sparry calcite from top of CSRBP facies. Thin section, crossed nicols, X 45.



Figure 17. Toucasia biostrome at top of CSRBP facies (in place). Pocket knife is 10 cm in length.



Figure 18. Chondrodonta biostrome at top of CSRBP facies (in place). Pencil is 15.5 cm in length.

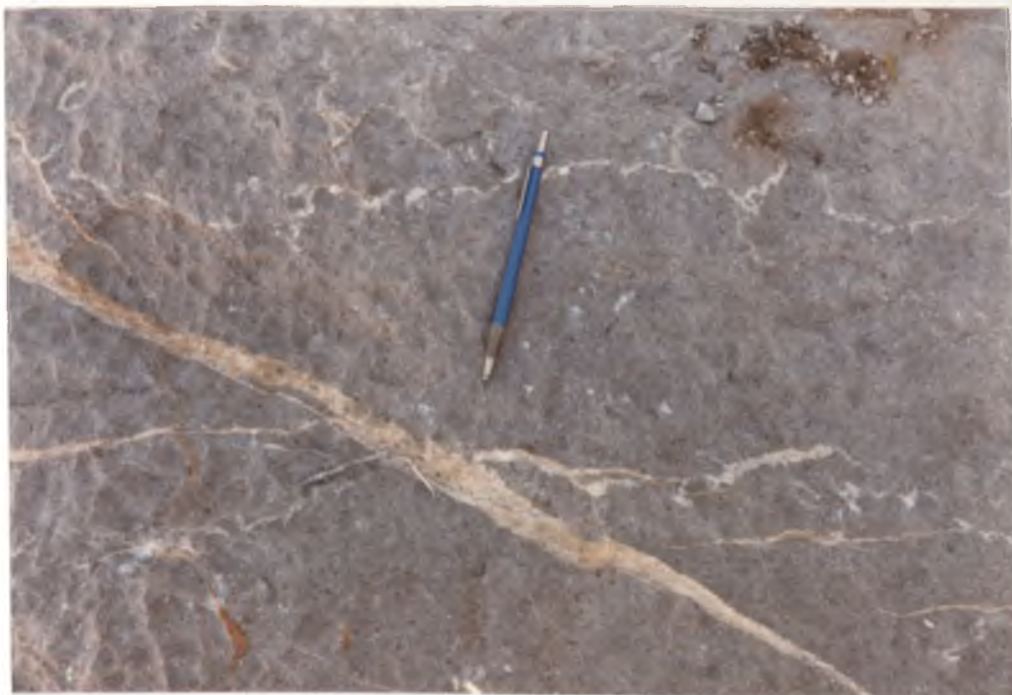


Figure 19. Coral-rudist packstone and grainstone facies (in place). Pencil is 15.5 cm in length.

rudists and corals and minor algae and Orbitolina. These grains range from fine sand to granule size, are subangular to subrounded, and are more or less aligned horizontally in a micrite matrix which also contains some sparry calcite cement (Fig. 20). Other allochems are Nautiloculina, Nummulites(?), echinoid spines, Dictyoconus and fragments of Permocalculus, bryozoans, brachiopods, and ostracodes. This facies also grades into and interfingers laterally with the mollusk-milioid-Orbitolina facies (Fig. 21).

The coral-rudist packstone and grainstone facies crops out on the southwest and west sides of the reef core and in a small lens-like bed to the west-southwest of the quarry floor (Fig. 7).

Mollusk-Miliolid-Orbitolina Wackestone and Packstone

The mollusk-miliolid-Orbitolina facies crops out on the conical hill west of the quarry floor, and to the west of the quarry floor. This facies grades laterally into and overlies and underlies the coral-rudist packstone facies (Fig. 21).

This facies consists of medium dark-gray wackestones and packstones which are thin- to very thick bedded and form ledges and small cliffs (Fig. 22). These rocks are not laminated and are thus assumed to have been extensively bioturbated. Stylolites and "dusky smears", which may be the result of compaction and/or pressure solution, are abundant, especially in the lower 16 m. The "dusky smears" are even more abundant in the lower 6 m (samples LS-1a to LS-3c).



Figure 20. View looking due east at the Lee Siding quarry. CRPG facies interfingers with the MMOWP facies.



Figure 21. Mollusk-miliolid-Orbitolina facies. View looking north showing line of measured section A.

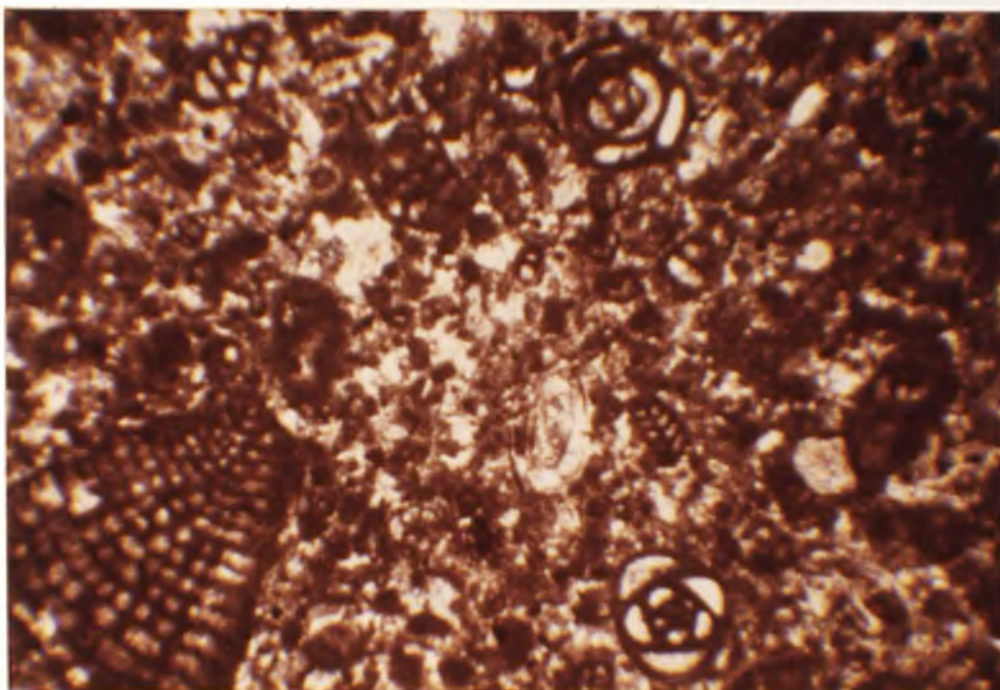


Figure 22. Mollusk-miliolid-Orbitolina facies. Miliolids, Coskinolina (lower left hand corner), Nummuloculina (center), and biserial forams in a matrix of micrite and sparry calcite. Thin section, crossed nicols, X 45.

The mollusk-miliolid-Orbitolina facies rocks are fine- to very coarse grained and poorly sorted, but in some places they are fine-grained and well sorted. Miliolids and/or Orbitolina are abundant; locally the fauna is silicified. Other allochems include pelletoids, pelecypod shell fragments, other unidentified fossil hash, brachiopods, echinoid fragments and spines, gastropods, the red algae (Permocalculus), green algae, rudist fragments, diverse benthic forams (particularly Coskinolina, Nautiloculina, Dictyoconus, Cuneolina, Nummuloculina, Pseudocyclammina, Globigerina, and other unidentified benthic forams), and some fine-grained to silt-size quartz grains (Fig. 23). Locally silicified Toucasia biostromes with abundant silicified Thalassinoides burrows are present (samples LS-7d, LS-9b). Orbitolina becomes more abundant in some intervals throughout the section (Fig. 24; samples LS-3c; LS-11bb, LS-16).

Depositional Environments

The small patch reef located at Lee Siding is one of a series of north-trending reefs, which were scattered upon the shallow shelf at the northwestern end of the Chihuahua Trough. These patch reefs developed on a substrate on mollusk-miliolid-orbitolinid muds (Scott, 1979, p. 1124) in the Bisbee basin during Early Cretaceous (Aptian-Albian) time.

By early Albian time the "Bisbee Sea" had made its maximum transgression into southeastern Arizona, and by this time, the Glance Conglomerate, Morita Formation, and lower upper Mural beds had been



Figure 23. Toucasids in the MMOWP facies. Pencil is 15.5 cm in length.



Figure 24. Orbitolina-rich bed in the MMOWP facies. Pocket knife is 10 cm in length.

deposited. Later tectonic events and higher rates of sedimentation to the west caused the "Bisbee Sea" to retreat from southeastern Arizona, and at this time the rest of the upper Mural along with the overlying Cintura Formation were deposited (Hayes, 1970b).

Reefs may be divided into five zones: (a) reef crest- highest part of the reef- which receives most of the wind and wave energy; (b) reef front, which extends from the surf zone to an intermediate depth, but generally no deeper than 100 m; (3) fore reef, which is an area of skeletal debris accumulation; (d) reef flat, a zone of moderate energy in a protected area behind the reef crest; and (e) the back-reef, in the lee of the reef flat, where tranquil conditions prevail with abundant mud accumulation and prolific growth of sand-producing bottom fauna.

The depositional environments of each of the sedimentary facies described in the previous section are interpreted below.

Coral-Stromatolite-Rudist Boundstone and Packstone Facies

The CSRBP facies represents the reef core (reef crest) and it contains abundant indicators of a rigid in-place binding of organisms primarily by algae. The rock fabrics, facies relations, binding, and laminar encrusting growth morphology of the communities, which can withstand great physical stress, suggest a high energy environment. The Microsolena-stromatolite community which comprises the major part of the reef core is interpreted to represent an upper reef slope, or upper fore-reef stage formed below storm wave base (Warzeski, 1983). The Coalcomana-Petalodontia community represents somewhat quieter waters

but above storm wave base than the Microsolena-stromatolite community. Warzeski (1983) proposes a depth of 10 m or less. Chondrodonta and Toucasia biostromes developed on the uppermost part of the reef on a shallow algal-bound reef flat. Also, the pelletoidal, heavily algal-coated packstones and wackestones top the reef crest. These rocks are interpreted as bank slope sediments prograding over the reef crest.

Coral-Rudist Packstone and Grainstone Facies

The CRPG facies represents the reef flank environment in which coral-rudist rubble was transported by waters with energy capable of moving and abrading shell fragments. Orbitolina is in some places oriented in horizontal clusters. This facies occurs only in the upper part of the reef front.

Mollusk-Miliolid-Orbitolina Wackestone and Packstone Facies

This facies represents shallow to slightly deeper waters on a shallow shelf of normal marine salinity. The presence of Toucasia biostromes indicates that this facies was close to the reef with water agitation not high enough to remove the lime mud but sufficient to produce growth of calcareous organisms. The abundance of Orbitolina and miliolids varies vertically. In some beds where Orbitolina is abundant, miliolids are almost absent, and vice versa. The relative abundance of orbitolinids versus miliolids reflects certain water circulation conditions within the open sea. Miliolids are more abundant in shelf and platform environments and very shallow quiet interior waters with restricted water circulation (Rose and Lidz, 1977); whereas Orbitolina

becomes more abundant in the open interior with shallow waters (Douglass, 1960) and with normal circulation (Rose and Lidz, 1977). Thus it is possible that the Orbitolina-rich beds only accumulated when the water circulation and temperature were favorable for their proliferation since Orbitolina is generally a warm normal circulation water foraminifer (Douglass, 1960).

DIAGENESIS OF THE UPPER MURAL LIMESTONE

Introductory Statement

Diagenetic changes that take place in a carbonate deposit are complex. These changes may be selective in part because of the original mineralogy of a skeletal element or grain. Moreover, the processes are complex because they may take place at time of deposition, at time of burial, or at time of post-uplift. Therefore, diagenesis is often the least understood of the major processes that influence carbonate rocks. Since diagenesis is the most important agent involved in the destruction and creation of porosity, it is of prime importance to the petroleum geologist.

Diagenesis is used in this study to mean the physical and chemical changes that sediments undergo during and after accumulation and burial, as well as those changes that take place after consolidation of the sediments. The purpose of this study is to recognize and interpret the diagenetic environments which the upper Mural underwent during its diagenetic history.

Over 50 thin sections and 50 acetate peels were prepared from the upper Mural limestones in the Lee Siding area. Thin sections and acetate peels were not prepared for every unit and were taken only from measured section A; the rest of the thin sections and acetate peels were prepared from samples taken randomly over the Lee Siding quarry area.

Cements

Blocky (Equant) Calcite Cement

Blocky calcite is the most abundant type of cement, and occurs in most of the thin sections examined. It occurs chiefly in partially leached rudist shells. Grain size varies from 50 to 800 μm in diameter, but in some instances reaches 2500 μm .

Drusy Mosaic Calcite Cement

Drusy mosaic calcite is also abundant in the upper Mural. This type of cement fills primary and secondary cavities inside fossils, voids in matrix, and leached shells. In most instances the drusy mosaic calcite cement consists of at least two generations of emplacement. A fine equant calcite crystal rim first coats the cavity and then the rest of the cavity is filled with larger equant crystals (Fig. 25).

Bathurst (1971) believes this difference in size of cements is a product of waters entering in two generations, that is, the small, finer rim cement forms first. Normally, the first generation crystals vary in size between 5 and 20 μm in length, but in some cases they reach 50 and even 200 μm in length. The second generation crystals are normally 20 to 300 μm and as great as 500 μm in diameter.

Radiaxial Fibrous Calcite Cement

Radiaxial fibrous cement is quite rare in the upper Mural. I found it in but one of the thin sections examined (Fig. 26); the crystals are about 80 μm in width. Radiaxial fibrous calcite has a

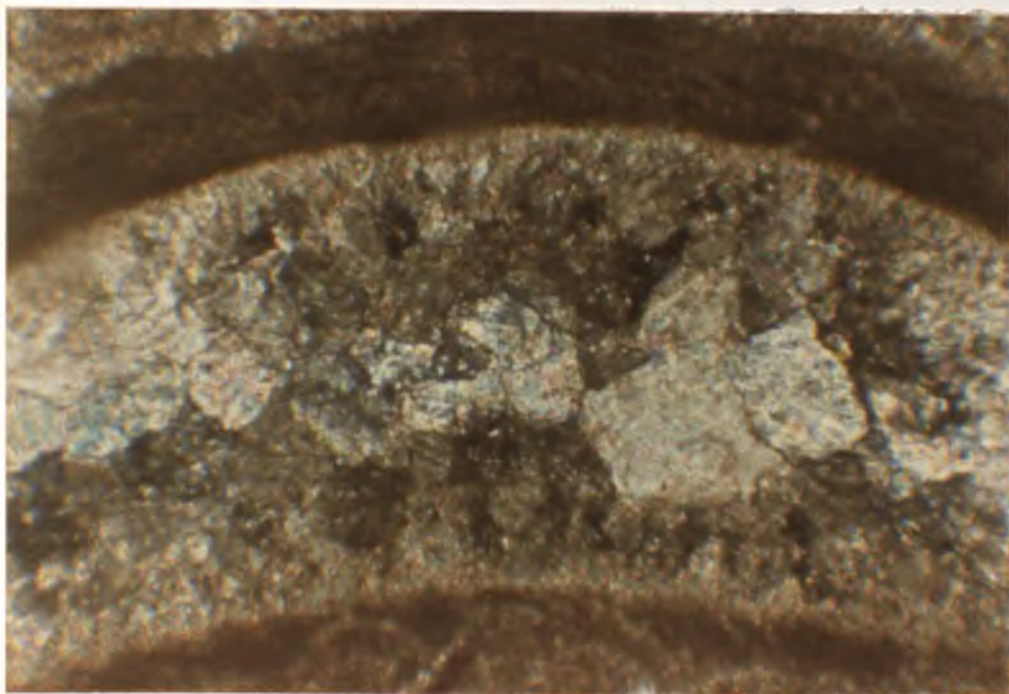


Figure 25. Drusy mosaic calcite filling a worm tube in the CSRBP facies. Two generations of cement are present; the second generation fills the middle area of the tube and consists of the larger crystals. Thin section, crossed nicols, X 150.

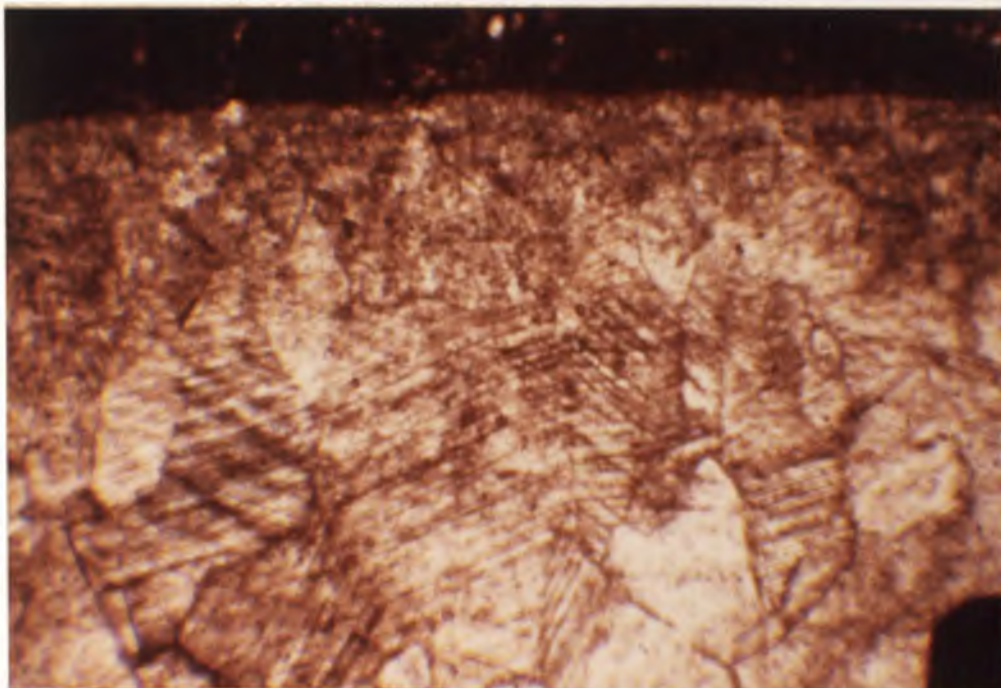


Figure 26. Radiaxial calcite replacing a rudist shell in the CSRBP facies. Thin section, plane-polarized light, X 45.

peculiar fabric; it shows undulatory extinction, curved twins, convergent optic axes, and divergent subcrystals within each cement crystal (Bathurst, 1971). These characteristics distinguish a radiaxial fibrous mosaic fabric from a true radial-fibrous mosaic fabric.

Radiaxial fibrous calcite was found partially replacing rudist shells in the CSR facies.

Bladed Calcite Cement

Bladed calcite is also rare in the upper Mural. Crystal size ranges from 5 to 50 μm in diameter and up to 125 μm in length.

Bladed calcite fills primary pores, cavities inside fossils (ostracodes), and worm tubes (Fig. 27).

Radial-Fibrous Calcite Cement

Radial-fibrous cement is not abundant in the upper Mural. Crystals are brownish in plane light; they grow to lengths of about 120 μm and perpendicular to walls (Fig. 28). As the crystal fabric becomes coarser, it resembles radiaxial fibrous calcite, but lacks curved twins and undulatory extinction. Radial-fibrous cement is found in primary pores in packstones and grainstones of the pelletoid, heavily algal-coated wackestone and packstone subfacies.

Syntaxial (Overgrowth) Rim Cement

Syntaxial cements include monocrystalline overgrowths on echinoderm (Fig. 29) and shell fragments, and multicrystalline overgrowths in rudist shells (Fig. 30).

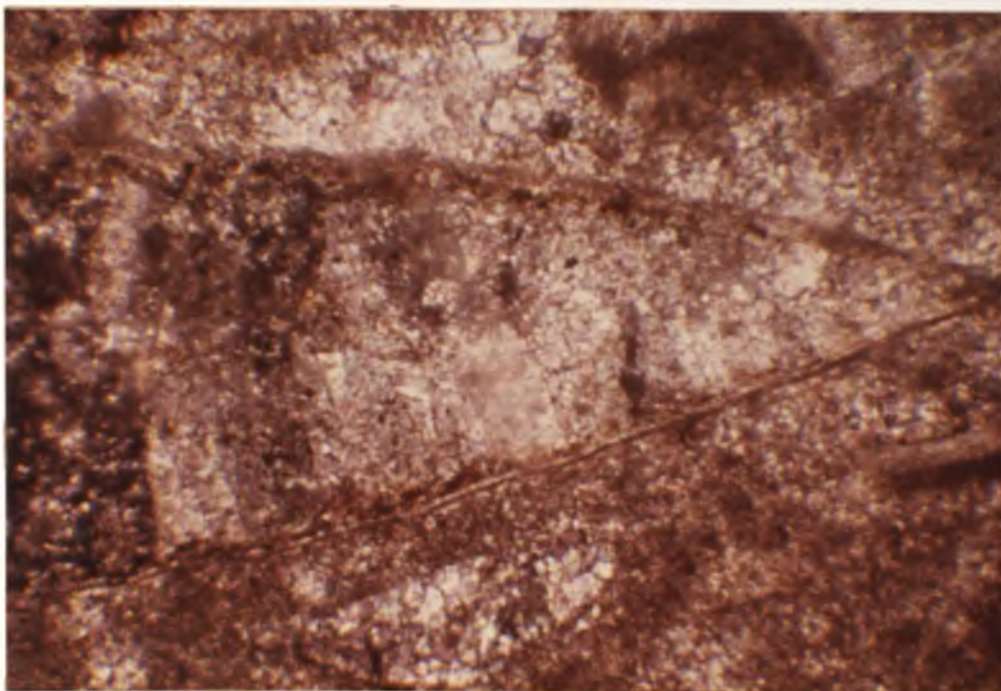


Figure 27. Bladed calcite filling an ostracode shell in the CSRBP facies. This type of cement fills primary pores, cavities inside fossils, and worm tubes in the upper Mural. Thin section, crossed nicols, X 150.

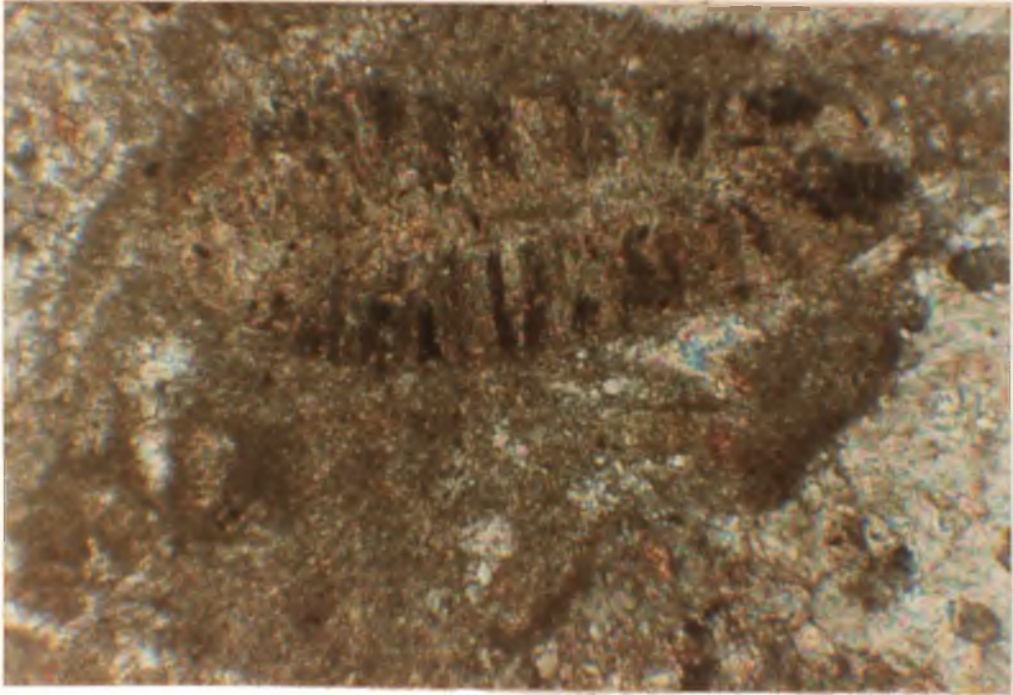


Figure 28. Radial fibrous calcite at top of the CSRBP facies. Coated grain upper center recrystallized coral at lower right hand corner. Thin section, crossed nicols, X 150.

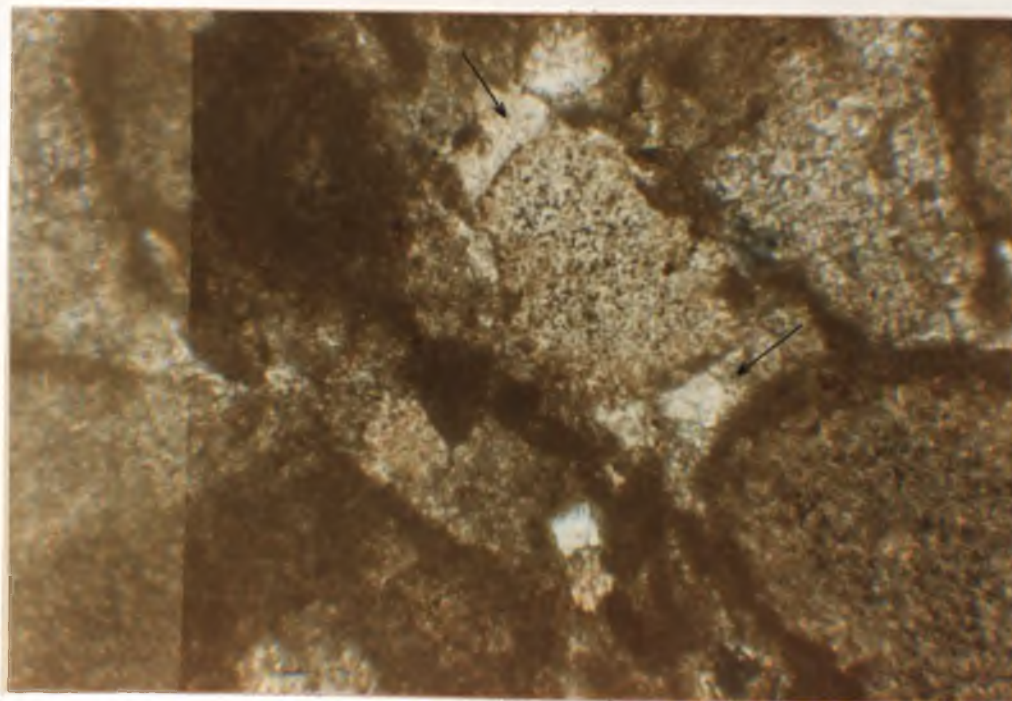


Figure 29. Syntaxial overgrowth rim cement from the MMOWP facies. Monocrystalline syntaxial overgrowth (arrows) on an echinoderm fragment. Thin section, crossed nicols, X 150.

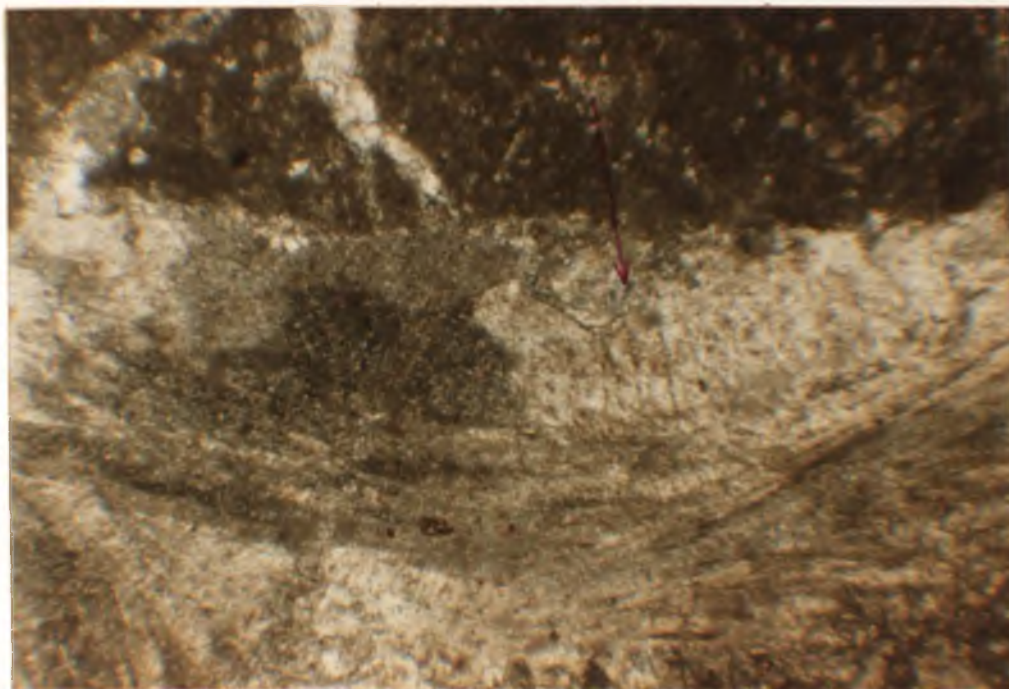


Figure 30. Syntaxial overgrowth rim cement in the CSRBP facies. Multicrystalline syntaxial overgrowth (arrow) on a rudist shell (lower center). Thin section crossed nicols, X 45.

Micrite Cement

Micrite cement, although not very common, rims primary pores of corals, borings in corals, and rudist shells in general. This micrite cement is not meant to be the so-called micrite enveloped (Fig. 31).

Neomorphic Spar and Microspar

Inversion of Aragonite Grains

Most Aragonite fossils underwent inversion to calcite. Many of the rudist and other pelecypod shell fragments still retain the lacy network of their original aragonitic structure. Calcite crystals are from 20 to 300 μm in diameter. Also many of the pelecypod shells underwent recrystallization after their inversion to calcite). Other shell fragments were leached and replaced by calcite cement and/or silica.

Aggrading Neomorphism

Aggrading neomorphism in shell fragments, corals, matrix, and cements is also present. Outer prismatic and fibrous layers of rudist and other pelecypod shells underwent aggrading neomorphism (Fig. 32). Some of the recrystallized shell fragments still retain some of their original structure. Recrystallization of corals after their inversion of aragonite is also common (Figs. 31, 33).

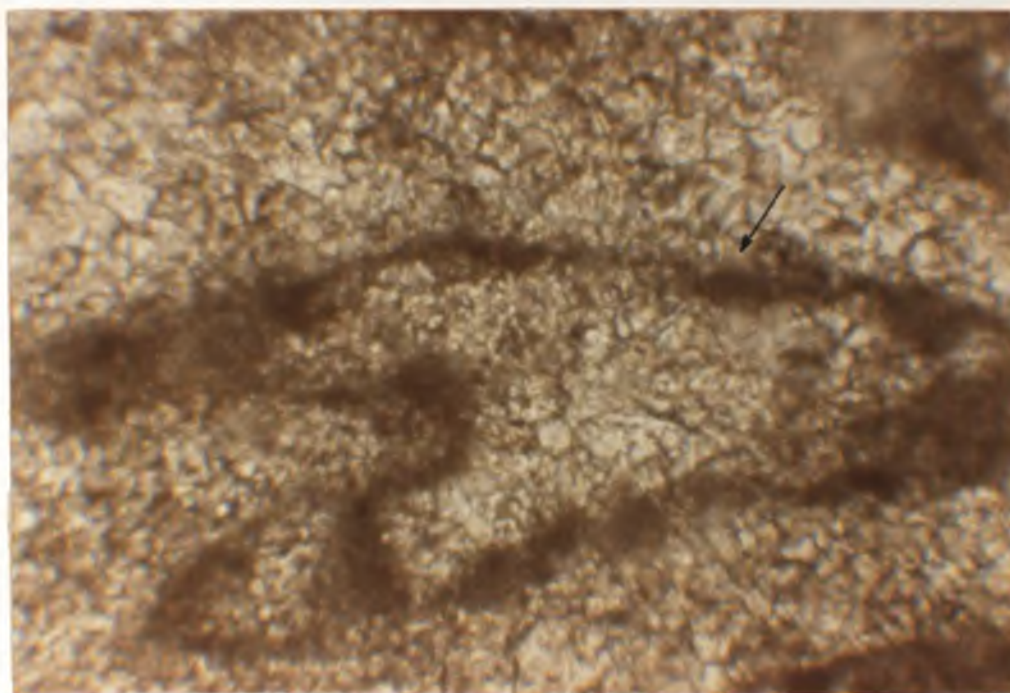


Figure 31. Micrite rim cement (arrow) in the CSRBP facies rimming internal pores in a recrystallized coral. Thin section, plane-polarized light, X 150.

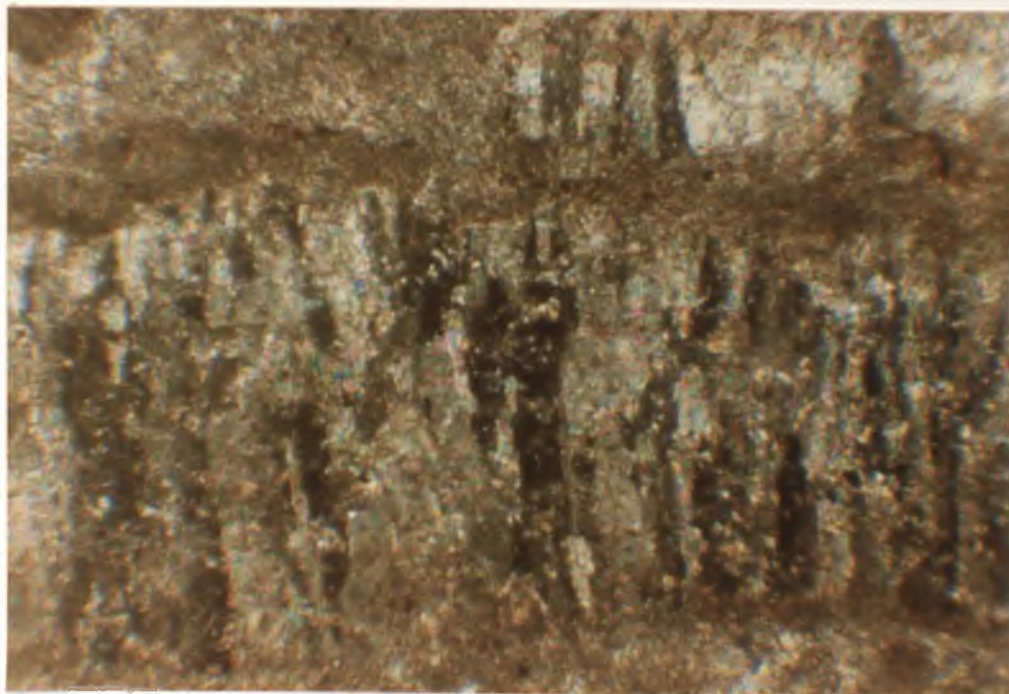


Figure 32. Agraddung neomorphism in a rudist shell fragment top of the CSRBP facies. Recrystallized fibrous layers in a rudist shell. Thin section, crossed nicols, X 150.

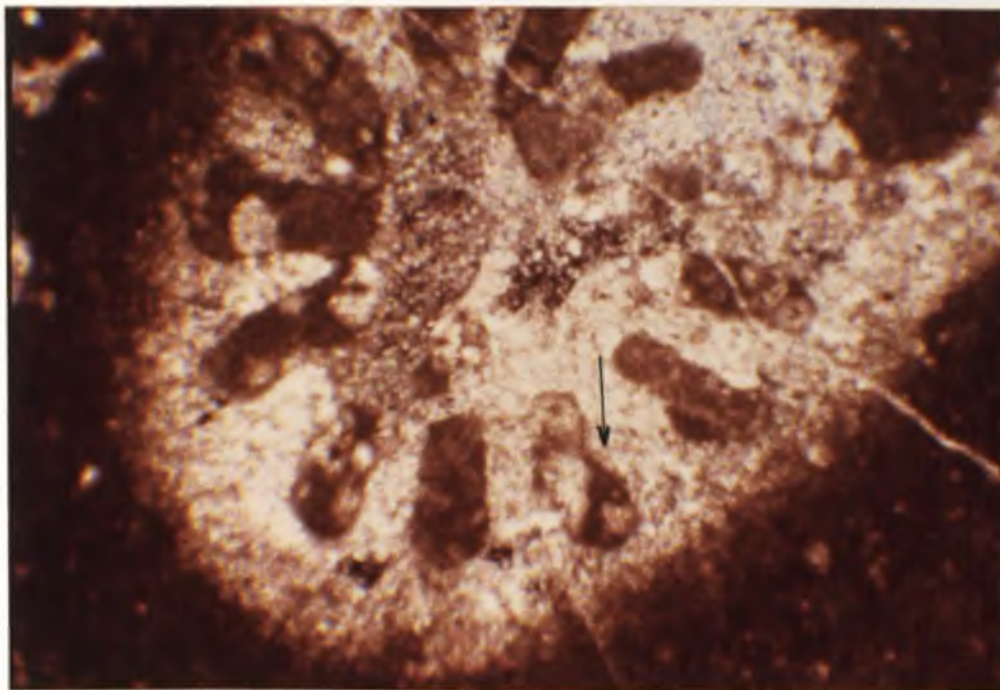


Figure 33. Recrystallized coral, top of the CSRBP facies. Internal pores (arrows) are rimmed with micrite cement and filled with micrite mud and sparry calcite. Thin section, crossed nicols, X 45.

Recrystallization Veins

Recrystallization veins represent aggrading neomorphism or recrystallization of the matrix without the opening and infilling processes (Misik, 1971, p. 453) and are produced by shear stresses. These veins occur mainly in the wackestones and packstones of the MMOWP facies (Fig. 34).

Dolomite and Dedolomite

Dolomite occurs sparingly in the upper Mural Limestone at Lee Siding quarry. The dolomite in some cases replaces the sparry calcite and/or fills original and moldic voids of shell fragments. Crystals vary in size from 70 to 950 μm , but in some samples reach 2 mm (Fig. 35).

Dolomite is also present along sutured or stylolitic and non-sutured pressure solution seams. Crystal size ranges between 70 and 450 μm (Fig. 36). Wanless (1979, p. 439) concluded from his studies that if magnesium is present during the pressure solutioning, dolomite crystals may grow along or in the vicinity of the zone of solution. He also states that dolomite can be a common mineral produced during pressure solution. In most cases the pressure solution seams in which the dolomite occurs are also iron-stained. Wanless also believes that much of the source of magnesium can be quite local in origin. The rest of the magnesium is supplied by local interstitial waters, organic material, or from limestones or dolomites stratigraphically above or below.

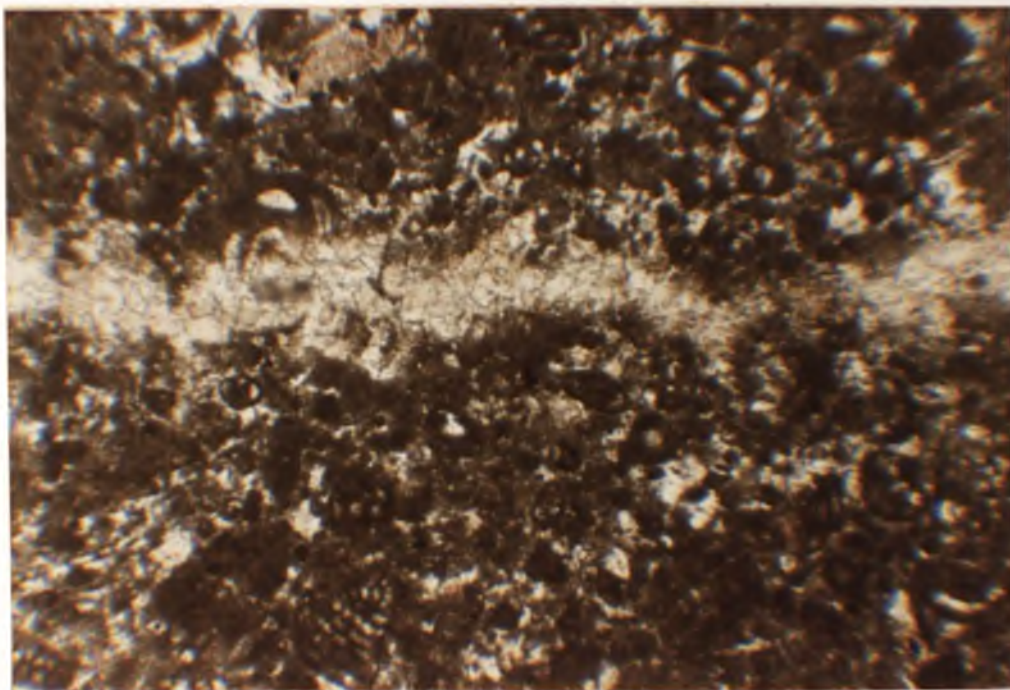


Figure 34. Recrystallization vein in the MMOWP facies. A miliolid at left center of photograph shows that the calcite vein has not cut through the foram (a main recognizing feature for neomorphic veins). Thin section, plane-polarized light, X 45.



Figure 35. Large dolomite crystals in the CSRBP facies. Calcite crystals recognized by Alizarine red-S at the left half of photograph. Thin section, crossed nicols, X 45.

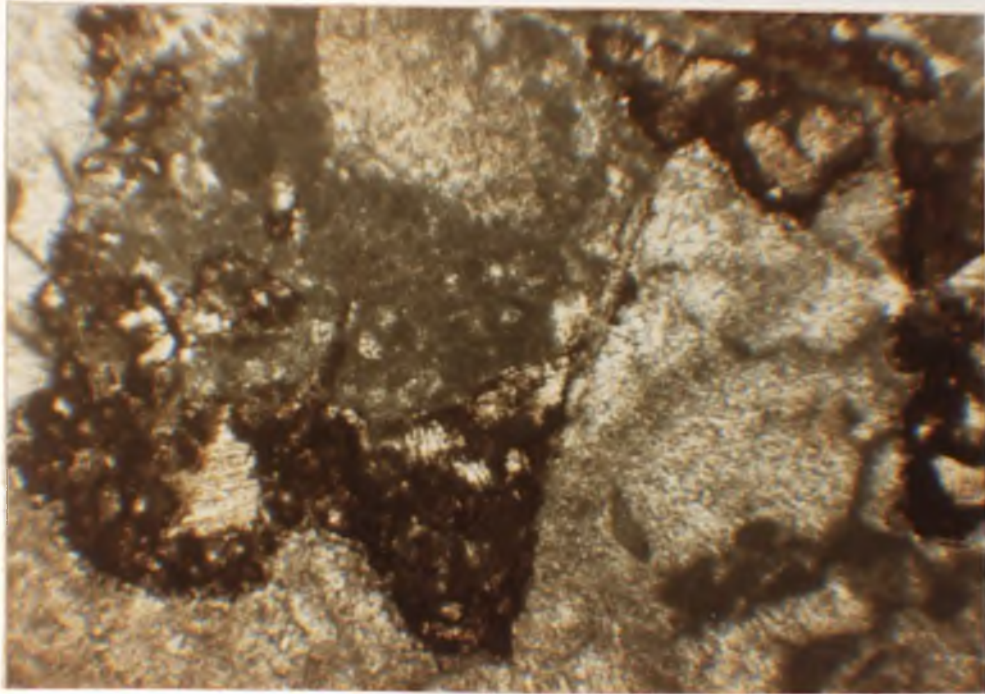


Figure 36. Dolomite crystals along a stylolite in the CSRBP facies. The dolomite crystals are iron-stained. Thin section, plane-polarized light, X 45.

Dedolomitization, or the replacement of dolomite by calcite may be seen in the upper Mural Limestone (Fig. 37). The calcite that replaces dolomite is both multicrystalline and monocrystalline. Most of these crystals are hematite-stained, a product of exsolution and oxidation during dedolomitization.

Pressure Solution

Sutured or stylolitic and non-sutured solution seams are present in the upper Mural Mural (Figs. 36,38,39). Wanless (1971, p. 445) found that limestones containing stylolites have less than 10 percent clay and/or silt content, and that limestones with non-sutured solution seams have more than 10 percent clay and/or silt content.

Silica

Silification in the upper Mural is widespread. Silica in the form of megaquartz, microquartz, and chalcedony is abundant and mostly replaces shell fragments (Fig. 40). Coarse silt-sized quartz grains (50 μm in size) in matrix is a more or less common occurrence (Fig. 37). Most of the chalcedony that replaces the shell fragments is length-slow.

Length-slow chalcedony is unusual in nature. Folk and Pittman (1971) believe that this type of chalcedony occurs almost exclusively in association with sulphates in an evaporitic environment. Also, Folk and Pittman (1971, p. 1057) state that if the stratigraphic section in which the length-slow chalcedony is found contains waters with evaporitic effluent, length-slow chalcedony may precipitate nearby in beds which may have been free of evaporites.

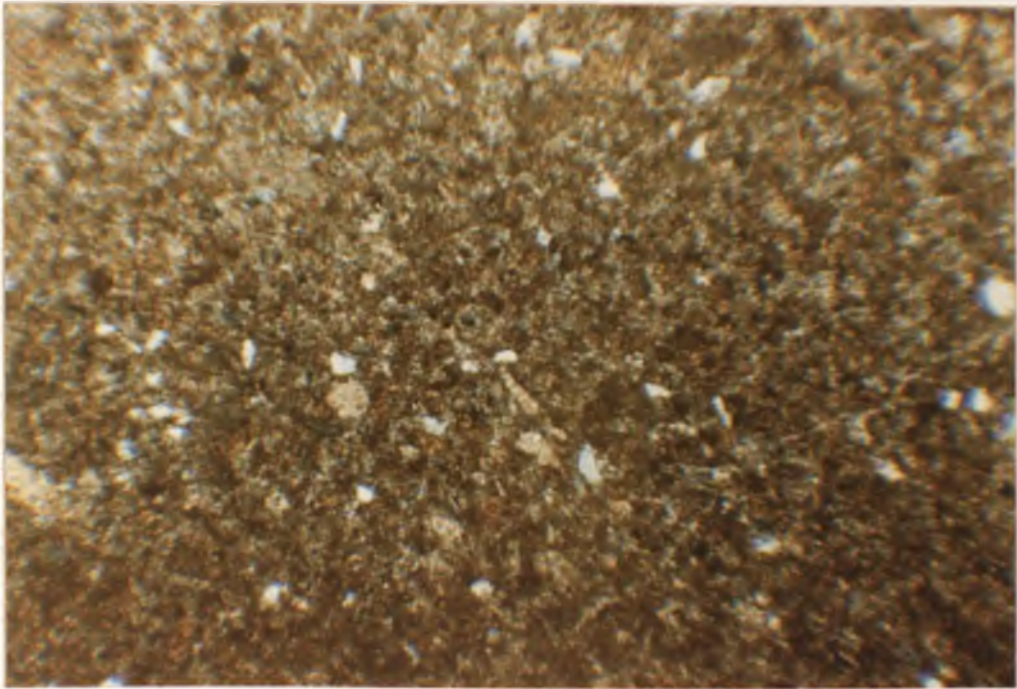


Figure 37. Dedolomitization in the CSRBP facies. Small dolomite crystals are replaced by calcite. White patches are silt-size quartz grains, some of which are being replaced by the carbonate. Thin section, crossed nicols, X 45.



Figure 38. Stylolites: sutured solution seams in the MMOWP facies. The bright white patches are actual porosity produced by the stylolitization. Thin section, plane-polarized light, X 45.

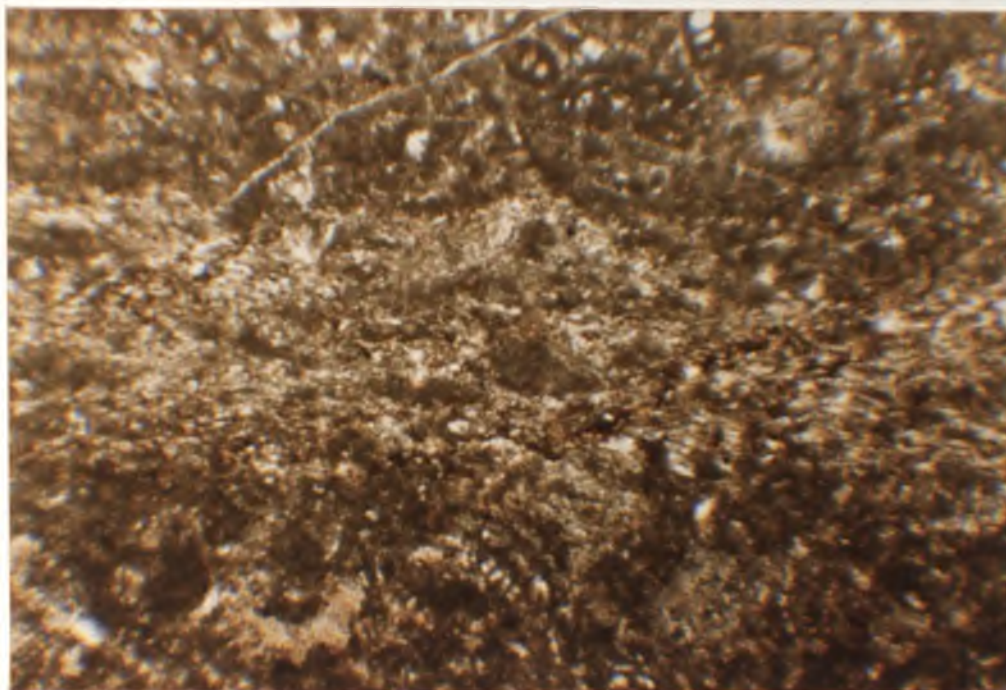
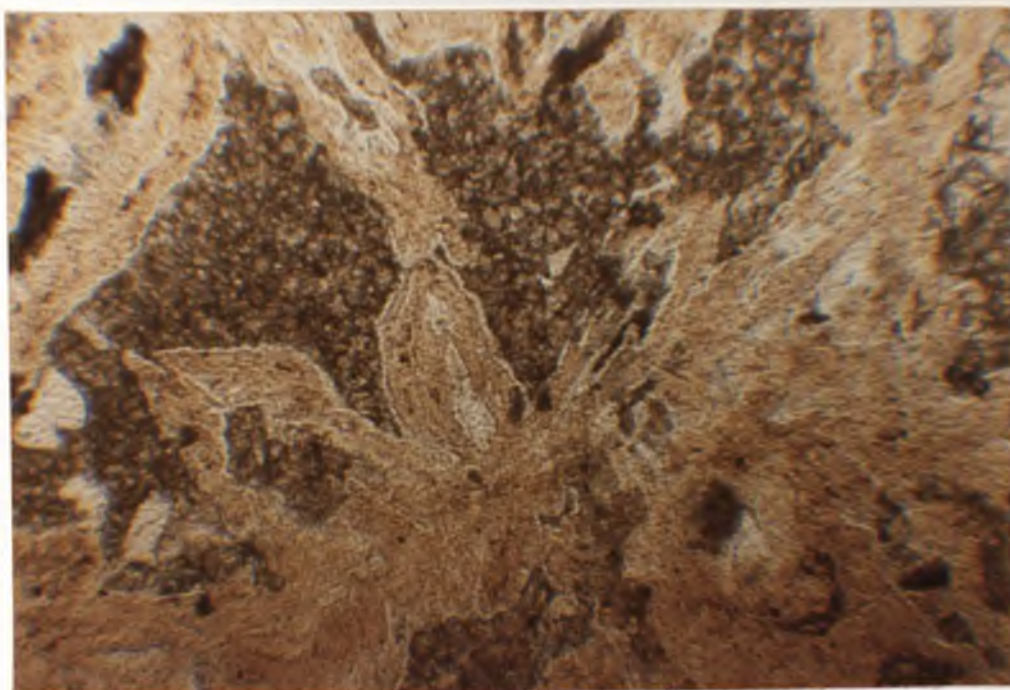
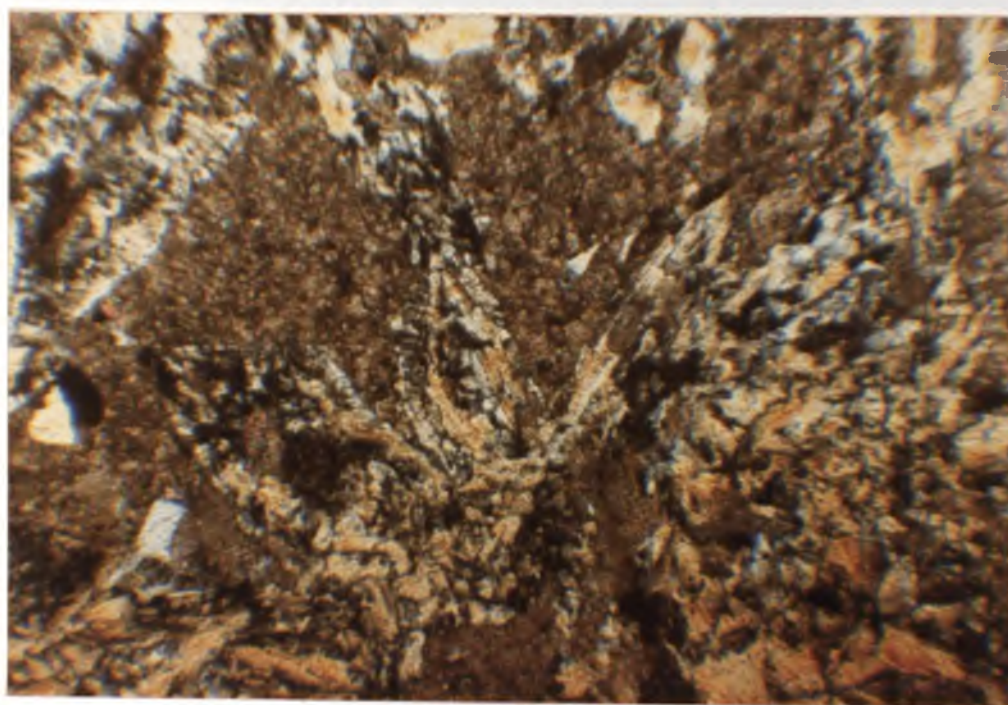


Figure 39. Unsutured solution seam of the MMOWP facies.
Thin section, plane-polarized light, X 45.

Figure 40. Calcite and silica in the MMOWP facies. Recrystallized (?) calcite is intercalated with microquartz and chalc-dony replacing the shell of a toucasid. Thin section; (a) plane-polarized light; (b) crossed nicols; X 45.



(a)



(b)

Figure 40.

Silicified Thalassinoides burrows are also common in the wackestones of the MMOWP facies, especially on top of the Toucasia bioherms. Microcrystalline quartz replaces the micrite and allochems (miliolids) that fill the burrows; it also replaces a halo in the matrix that surrounds the burrow. The outer part of the burrow is not completely silicified, as there are still some patches of calcite. The inner part is completely silicified except for a few calcite patches and has a brownish organic (?) color. These features may be a product of the organic substances which are more abundant inside and in the walls of the tubes than in the mucus sheath lining the tubes during the worm's life (Mason, 1980). Alkalinity (pH) increases inside the burrow from the generation of ammonia due to microbial decomposition of the organic matter present in the burrow itself and burrow linings (Fürsich, 1973), and thus, causes the precipitation of calcite. On the other hand, organic decay may also lower pH leading to dissolution of carbonate in the burrow fill. Finally, if dissolved silica in waters moving through these sediments is concentrated in the burrows, the break-down of organic matter releases the absorbed silica producing local silica supersaturation and precipitation of silica (Bromley et al., 1975).

Diagenetic Environments

Marine Phreatic Zone

In the marine phreatic zone all pore space in the sedimentary rock is filled with normal marine water. Sea water moves freely in the active zone where cementation occurs or moves so slowly in the stagnant

zone that cementation is lacking. Aragonite and high Mg-calcite are the dominant carbonate minerals that precipitate from sea water at shallow depths (Friedman, 1964; Davies, 1977; Longman, 1981). These carbonates may precipitate in the form of fibrous radial and radiaxial cements, which may or may not be isopachous, and micrite cements.

At Lee Siding quarry, radial fibrous, radiaxial calcite, and micrite cements are thought to be formed in this zone. Radial fibrous, and bladed calcite, and interpreted to form after replacement of isopachous magnesian calcite cement (Davies, 1977; Longman, 1981). The fibrous texture may be preserved in spite of neomorphism to calcite; if so, this may be used to distinguish former marine cements (Shinn, 1975). Radiaxial calcite has been interpreted to form in this type of diagenetic environment after a replacement of acicular aragonite (Kendall and Tucker, 1973, p. 372). Kendall and Tucker believe that replacement by radiaxial calcite occurs almost contemporaneously with reef growth and precipitation or acicular cement during early diagenesis. Although Bebout and Loucks (1974, p. 60) in their study of Lower Cretaceous Stuart City Trend rocks concluded that radiaxial calcite was probably deposited by phreatic meteoric waters in the shallow subsurface, acicular cements appear to be restricted to marine, early diagenetic environments. The most recent research by Kendall (1985), based upon Australian occurrences, suggest that radiaxial calcite is a primary cavity fill. Kendall (p. 74) reinterpreted the fabric of convergent fast-vibration directions within each crystal, to have formed as a result of asymmetric growth within the calcite crystals growing in

splitting directions. Therefore, it is concluded that the formation of radiaxial calcite also occurred during early diagenesis of the Mural Limestone.

Micritization, a product of borings by algae and fungi on the carbonate grains, occurs in the submarine diagenetic environment at Lee Siding quarry. In some beds of the MMOWP facies, very thick micrite envelopes developed. Micritic high Mg-calcite, not to be confused with micrite envelopes, occurs as the first cement in small voids, borings, and internal cavities. This form of calcite is also interpreted as early submarine cement. Also, some of the microcrystalline quartz at Lee Siding quarry may have been the product of replacement of calcite microspar by silica during this stage of diagenesis (Milliken, 1979).

Mixing (Fresh Water Phreatic-Marine Phreatic) Zone

Water in pores of sedimentary rocks under the influence of this zone is a combination of fresh water and marine phreatic brackish waters. In the Lee Siding quarry area minor neomorphism of aragonite and Mg-calcite, dolomitization, and slight cementation by micrite high Mg-calcite or bladed calcite took place at this time. Length-slow chalcedony, which partially replaces some shells, may also have developed during this time (Milliken, 1979).

Fresh Water Phreatic Zone

The fresh water phreatic zone lies between the vadose and the mixed phreatic-fresh water zones. Pore spaces in this zone are filled with meteoric water with variable amounts of dissolved carbonate.

This zone is divided into three main subzones (Longman, 1981, p. 99): the zone of solution or undersaturated zone, the active-saturated zone, and the stagnant zone.

At Lee Siding quarry, these subzones are characterized by different diagenetic features. In the undersaturated zone, or zone of solution, meteoric water which pass through the vadose zone without becoming saturated with calcite, dissolves the calcium carbonate until they reach saturation. Both aragonite and high Mg-calcite may be dissolved producing vuggy and moldic porosity; aragonite shells may be completely or only partially leached. During the time of existence of an active saturated zone at Lee Siding quarry, aragonitic solution continued along with calcite precipitation, and aragonitic shells that were not leached were neomorphosed to calcite.

At Lee Siding quarry, both neomorphism and leaching of aragonite shells seem to be equal importance, although Warzeski (1983) concluded in his studies that leaching was dominant over neomorphism of rudist shells in the upper Mural. Neomorphism of matrix, which produced patches of equant calcite, and formation of neomorphic veins are other diagenetic features produced in this subzone. Cements introduced during this diagenetic time include: drusy mosaic, which in some areas was found to have been introduced in two stages; and syntaxial overgrowths, monocrystalline and multicrystalline, on echinoderm and rudist shell fragments.

During the time of the stagnant subzone at Lee Siding quarry area, little or no cementation took place even though generally the waters are already saturated with calcium carbonate, for they are not able to move readily through the sediments. These waters generally reach equilibrium with the surrounding sediments by the time they get into this subzone. Neomorphism of aragonite grains with preservation of some original structures continued slowly during this stage. Also, minor small rims of isopachous equant calcite were precipitated on grains.

Subsurface Diagenetic Environments

Subsurface diagenesis continues to be a factor of controversy in part because it is so difficult to study directly. During this stage any remaining void space in the Lee Siding quarry rocks was gradually filled by calcite cement. Blocky calcite began to precipitate in the shallow subsurface zone and continued through to the deep subsurface zone. After a few hundred to a few thousand feet of burial, dissolution, caused by compaction associated with either subsurface brine migration or decarboxilation, becomes important.

Pressure solution (stylolitization) may have started during compaction of the sediments in the early stages of subsurface diagenesis (Longman, 1981, p. 112) and continued into the late stages. Dolomitization along stylolites is a common feature in the Lee Siding quarry rocks; dolomite crystals form after dissolution in stylolites. Also, dolomite as a cement may have precipitated during this stage.

Cement-Porosity Relationships

If the intermediate and late stages in the diagenesis of a carbonate rock lead to a tight rock, how is porosity preserved? The stages of diagenesis may be interrupted at any point by stagnation of the diagenetic fluids, rapid burial, replacement of fresh water with stagnant marine waters, or even by migration of hydrocarbons into the system (Longman, 1981). The rate of diagenesis generally slows down once a rock passes through the shallow subsurface to the deep subsurface. Thus, porosity has a good chance of being preserved unless stylolitization takes place (this point will be explained later).

Preservation of primary intergranular porosity generally occurs in arid climates or in carbonates unaffected by fresh water because complete cementation of primary porosity in shallow carbonates almost always occurs during subaerial exposure in humid climates. Primary porosity is related to the depositional facies, thus, its relation to secondary porosity usually can be determined. In the case of vugs, fractures, and later dolomitization, the causes of porosity can be determined by other factors.

Porosity in the upper Mural at Lee Siding quarry has been greatly reduced, although some still exists especially in the MMOWP facies. Much of the moldic voids from dissolution of aragonite and intergranular and intragranular pore space are still present at depths appropriate for hydrocarbon entrapment. Primary interparticle porosity was highly reduced and only a few samples show this type of porosity.

Secondary moldic porosity in pelecypod shells has also been almost completely reduced in the boundstones and grainstones, although some moldic porosity was found in the MMOWP facies (Fig. 41). Some primary intraparticle porosity has been preserved particularly inside the cavities of foraminiferal tests. Abundant porosity as voids in the matrix of the MMOWP facies rocks accounts for most of the porosity left in the upper Mural (Fig. 41).

Fracturing at Lee Siding quarry also accounts for some of the porosity. Most fractures are 2 to 3 feet in length, although some are longer, and no more than 5 mm wide. They are 3 m deep, although depth ranges from a few cm to almost 18 m at the reef core. Some fractures are partially filled with blocky calcite cement. Some porosity occurs along stylolites (Fig. 38) where the clay and silt have been removed from the stylolitic surface and no dolomite has been formed.

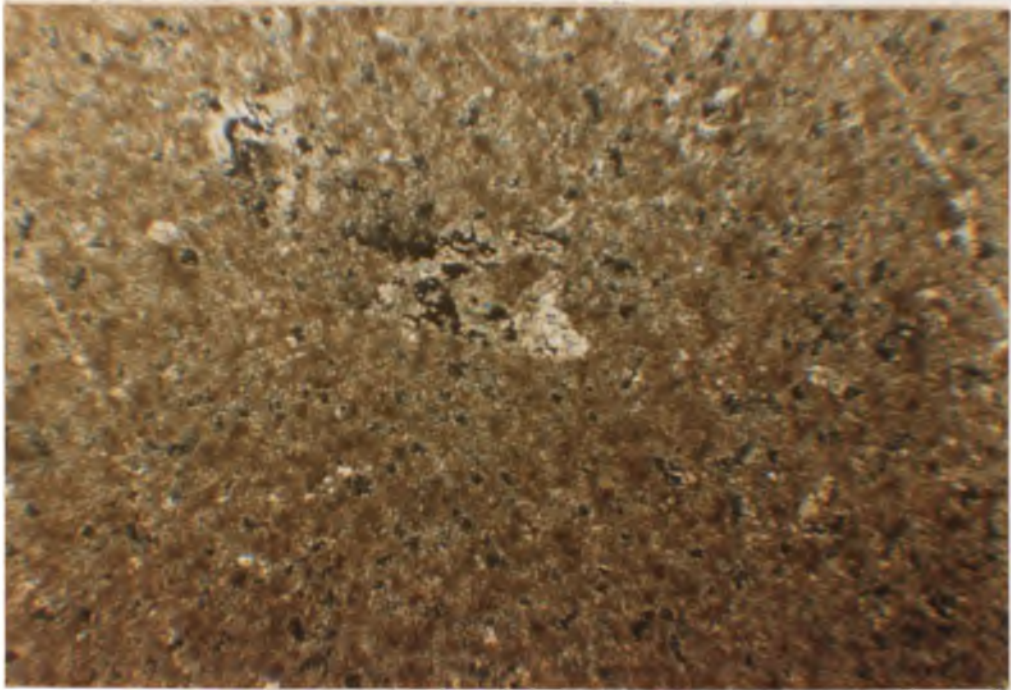


Figure 41. Porosity in the MMOWP facies. Porosity occurs in the matrix and in a partially leached shell fragment. Thin section, crossed nicols, X 45.

COMPARISON WITH TEXAS AND MEXICO CRETACEOUS REEFS

Corals as reef builders reached a peak during the Early Cretaceous Epoch in the Tethyan region, particularly in the area to become the Mediterranean Sea, but also occurred eastward to Japan, southward to east Africa, and westward around the Gulf of Mexico (Wilson, p. 319). Rudist also became major contributors to Cretaceous reefs; they lived in different parts of the reef complexes and ranged from frame builders to unattached sediment contributors (Perkins, 1969). Lower Cretaceous shelf carbonates of Aptian, Albian, and Cenomanian age accumulated in a broad band surrounding the Gulf of Mexico (Fig. 42). These carbonates are well-known from surface outcrops in eastern Mexico and central Texas and in the subsurface of the Yucatan Peninsula in southern Mexico, south and east Texas, central and south Louisiana, south Florida, and the Bahamas (Bebout and Loucks, 1977, p. 234). Biogenic growth climaxed along a narrow band in the basinward edge of this broad shelf and a complex of reefs, banks, bars, and islands developed so as to form an almost continuous belt around the entire Gulf of Mexico (Bebout and Loucks, 1974, p. 2). The limestone making up this shelf margin complex, the Stuart City trend, is composed of reef and bank carbonates constructed primarily of rudist pelecypods and various types of carbonate sand strata (Bebout and Loucks, 1974, p. 6).

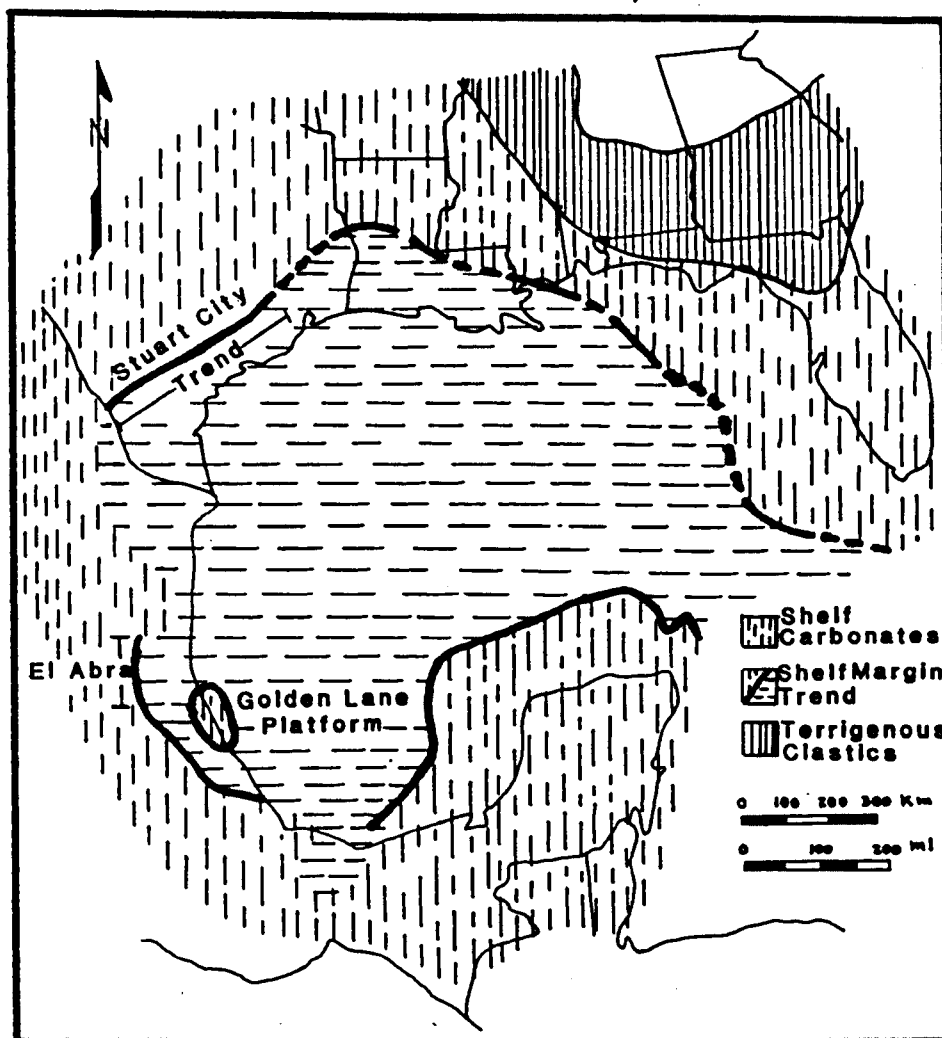


Figure 42. Distribution of Lower Cretaceous shelf-margin facies around the Gulf of Mexico (after Meyerhoff, 1967).

The Edwards group, the Glen Rose Formation, the El Abra Formation and the Mural Limestone (Fig. 43) were deposited mostly on gentle ramps and isolated platforms standing high above the sea floor (Warzesk, 1983, p. 286). Whether the Mural Limestone was deposited on a carbonate shelf or ramp is not known yet, since upper Mural shoreline sediments have not been found. The Glen Rose Formation (Lower Albian) is taken as the best equivalent of the Mural Limestone (Warzeski, 1983, p. 287). The Glen Rose was laid down along the shoreward margin of the broad Cretaceous shelf (Perkins, 1974, p. 144). The low relief bottom was covered by very shallow water no greater than 10 to 20 feet deep (Perkins, 1974, p. 145). Glen Rose reefs and associated deposits prograded gradually seaward and are separated horizontally and vertically. Warzeski (1983, p. 287) suggested that the above model might be applicable to the Mural reef development. Further development of the upper Mural was obliterated by the late Albian regression producing the Cintura Formation (Hayes, 1970b). In contrast the Glen Rose Formation is overlain by the Stuart City Formation which represents a major platform margin build-up (Bebout and Loucks, 1974, p. 6). Also, the lower Glen Rose developed on a shallow platform over an almost flat shelf with a low level of water circulation in intertidal (and in places supratidal) environments (Stricklin et al., 1971, p. 31, 32). Waters apparently retreated from a shelf exposing the sediments to become lithified or semiconsolidated (Stricklin et al., 1971, p. 31). The Glen Rose reefs do not contain abundant organisms since they are dominated by caprinids which act as a trap for sediments (Perkins, 1974,

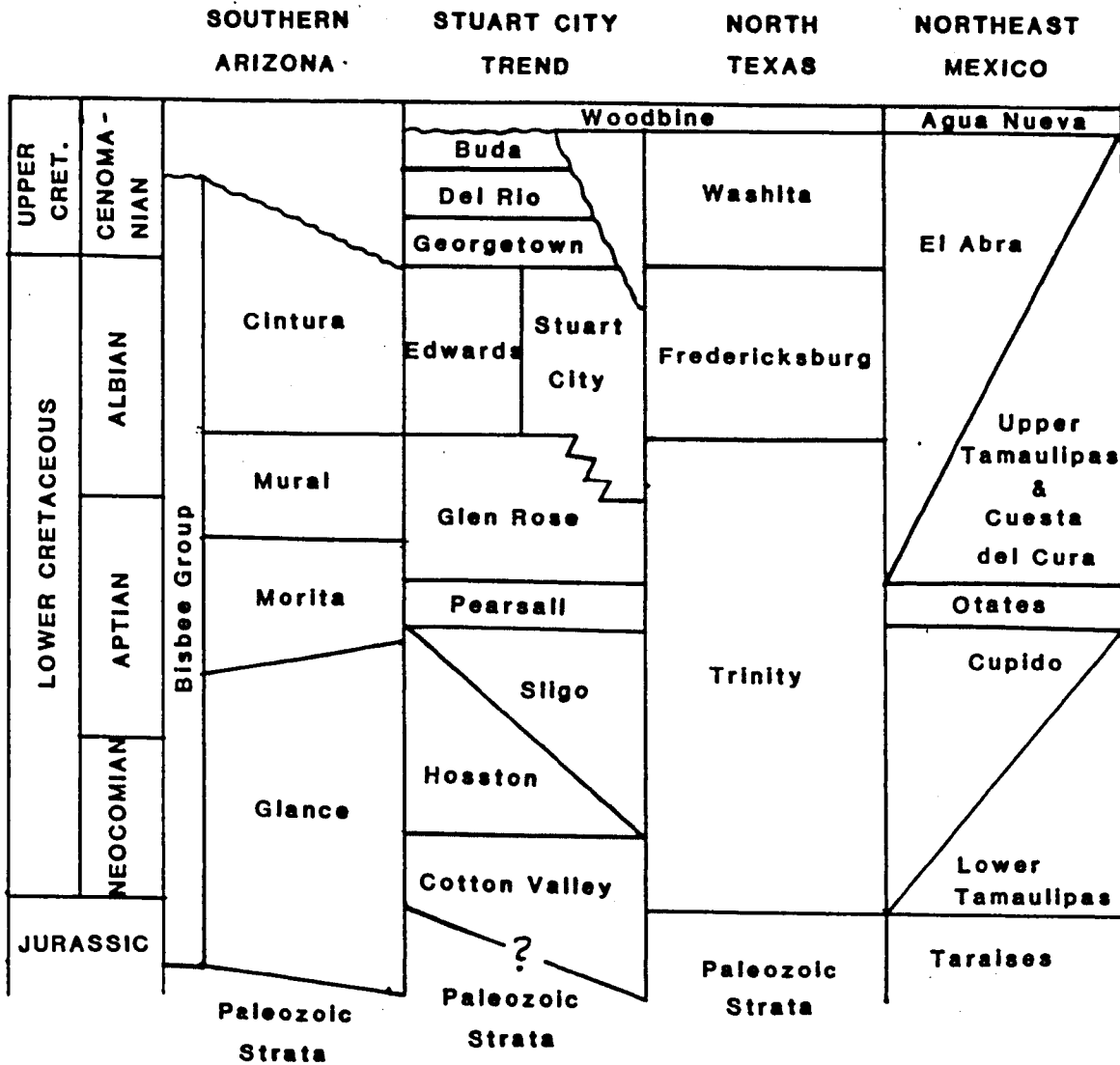


Figure 43. Correlation of Lower Cretaceous rocks in southeastern Arizona with the Gulf of Mexico region. (After Bebout and Loucks, 1974; and Warzeski, 1983).

p. 151). The Mural reefs are dominated by corals and stromatolites, as well as rudists.

The Stuart City Formation of Texas is believed to have been deposited on a broad shelf in which water depths ranged from less than 10 feet to little more than 60 feet (Bebout and Loucks, 1974, p. 14). Warzeski (1983, p. 294) believes that the Stuart City boundstones may have accumulated in slightly deeper waters than Bebout and Loucks estimated.

The El Abra Formation of east-central Mexico formed high banks with steep sides and high relief, which exhibit a variety of small rudist buildups. Here, the dominant binders appear to be submarine cements, although coralline algae and stromatoproids (now known to be the coral Microsolena) are present (Rose, 1963).

The significant rudist development in the Texas reefs in comparison with the coral dominance in the Mural reefs may indicate less than normal marine conditions in the Glen Rose. The Glen Rose was exposed several times to subaerial exposure (Perkins, 1974, p. 131) which is not evident from the Mural reefs. The relative abundance of corals and radiolitids versus caprinids in the Glen Rose reefs are thought to be related to an increase in temperature salinity in a shoreward direction (Perkins, 1974, p. 152). The abundance of binding and encrusting algae in the Mural contrast with the abundant stromatoproids (actually Microsolena) and encrusting the framing organisms in the Stuart City and El Abra formations; although some binding and

encrusting algae to occur in the Stuart City and El Abra (Griffith, et al., 1969, p. 132).

The Glen Rose, Edwards, and El Abra were exposed and re-immersed repeatedly because of sea level changes, and thus allowed the invasion of meteoric water during their development. The extreme product of these subaerial exposures is the Golden Lane Platform bank of the El Abra Formation, which was exposed for long periods of time (Viniegra and Castillo-Tejero, 1970, p. 320). On the other hand, the Mural Limestone was not exposed to widespread invasion of meteoric waters before burial. The Stuart City Trend was also exposed to meteoric waters, but the reef trend was not exposed for a long time and thus the fall of the sea level did not have as much effect as it did on the Golden Lane Platform of Mexico (Warzeski, 1983, p. 300).

Submarine cements are not abundant in the Mural Limestone, Glen Rose, and Stuart City, but they are extremely abundant in the Valles-San Luis Potosi Platform bank of the El Abra Formation (Rose, 1963).

CONCLUSIONS

During Lower Cretaceous patch reefs composed mainly of corals, but also containing stromatolites, rudists and bivalves, developed on a substrate of mollusk-miliolid-orbitolinid muds. The patch reefs occupied a favorable environmental zone on a carbonate shelf or ramp at the northern end of the Chihuahua Trough where the abundance of corals indicates a more normal marine environment than in the equivalent rudist reefs of Texas.

The Mural patch reefs at Lee Siding contains three main lithofacies and four subfacies: (a) the coral-stromatolite-rudist boundstone and packstone facies represent the reef coral which is divided in an upward succession into the Actinastrea, Microsolena-stromatolite, Coalcomana-Petalodontia, and pelletoidal, heavily algal-encrusted wackestone and packstone subfacies; (b) the coral-rudist packstone and grainstone facies represents the reef front at Lee Siding; (c) the mollusk-miliolid-Orbitolina wackestone and packstone facies represents shallow to moderate waters on a shallow shelf of normal marine salinity and close to reef environment.

Two diagenetic environments dominated the diagenetic history of the upper Mural at Lee Siding quarry; the freshwater-phreatic and subsurface zones. In the freshwater phreatic zone, most of the aragonitic





shells were leached; the remaining were neomorphosed. Drusy mosaic calcite cement filled pore spaces, and some syntaxial overgrowths developed. In the subsurface environment the remaining void space was occluded by blocky calcite cement. Also, pressure solution features, dolomitization, and dolomite cements (?) characterizes the environment. The unique exposure of the Mural reefs, especially at Lee Siding quarry, allows a better study of the patch reefs equivalent to the Texas reefs. The outcrop expression of the patch reef reveals the original structural character of the reef itself, thus allowing for its study in great detail. Further study of the Mural reefs will give us a better understanding of the diagenetic environments of the upper Mural Limestone.

APPENDIX



KEY TO MEASURE SECTION SYMBOLS

ORGANISMS

Rudists

	Caprinids
	Petalodontia
	Monopleura
	Toucasia




Other Mollusks

	Gastropods
	Pelecypods

Corals

	General
---	---------





Echinoderms

	Echinoid spines
	Crinoids
	Echinoids











Bryozoans

	General
---	---------







Algae

	Red
	Green
	Blue-green
	Algal-encr. grains



Foraminifera

	Orbitolina
	Coskinolina
	Miliolids
	Nautiloculina
	Pseudocyclamina
	Dictyoconus
	Cuneolina
	Nummuloculina
	Globigerina
	Benthic (general)





Other Organisms

	Brachiopods
	Ostracodes
	Calpionellids/Tintinids
	Burrows
	Burrows (Silicified)
	Fossil hash

Modifiers

	Abundant
	Fragmented, etc.

NONSKELETAL GRAINS

	Pelletoids
	Intraclasts
	Ooids
	Quartz grains

TYPE OF SAMPLE

TYPE OF DATA SHOWN

H Hand specimen

Out. Outcrop

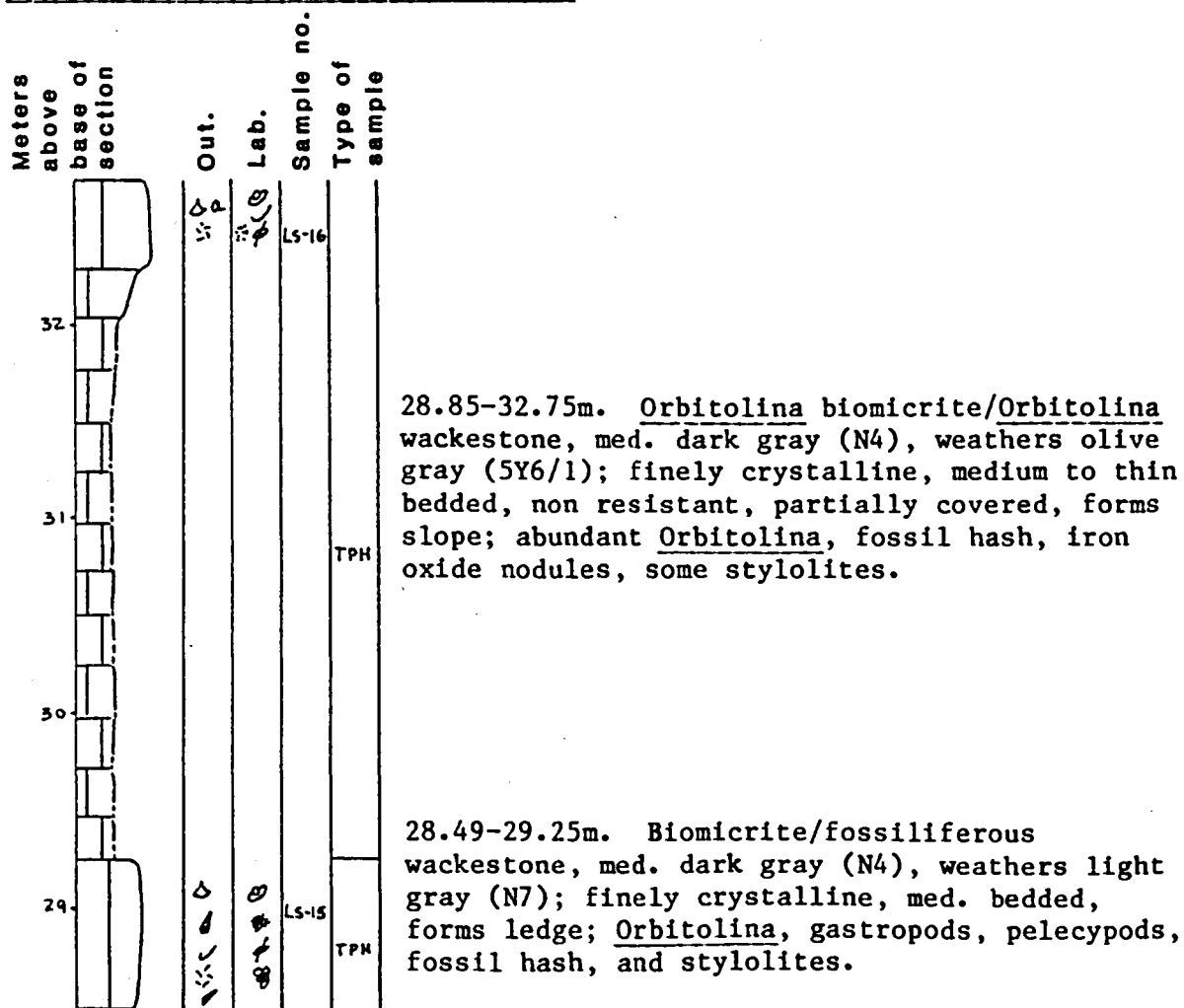
PH Acetate peel & hand
specimen

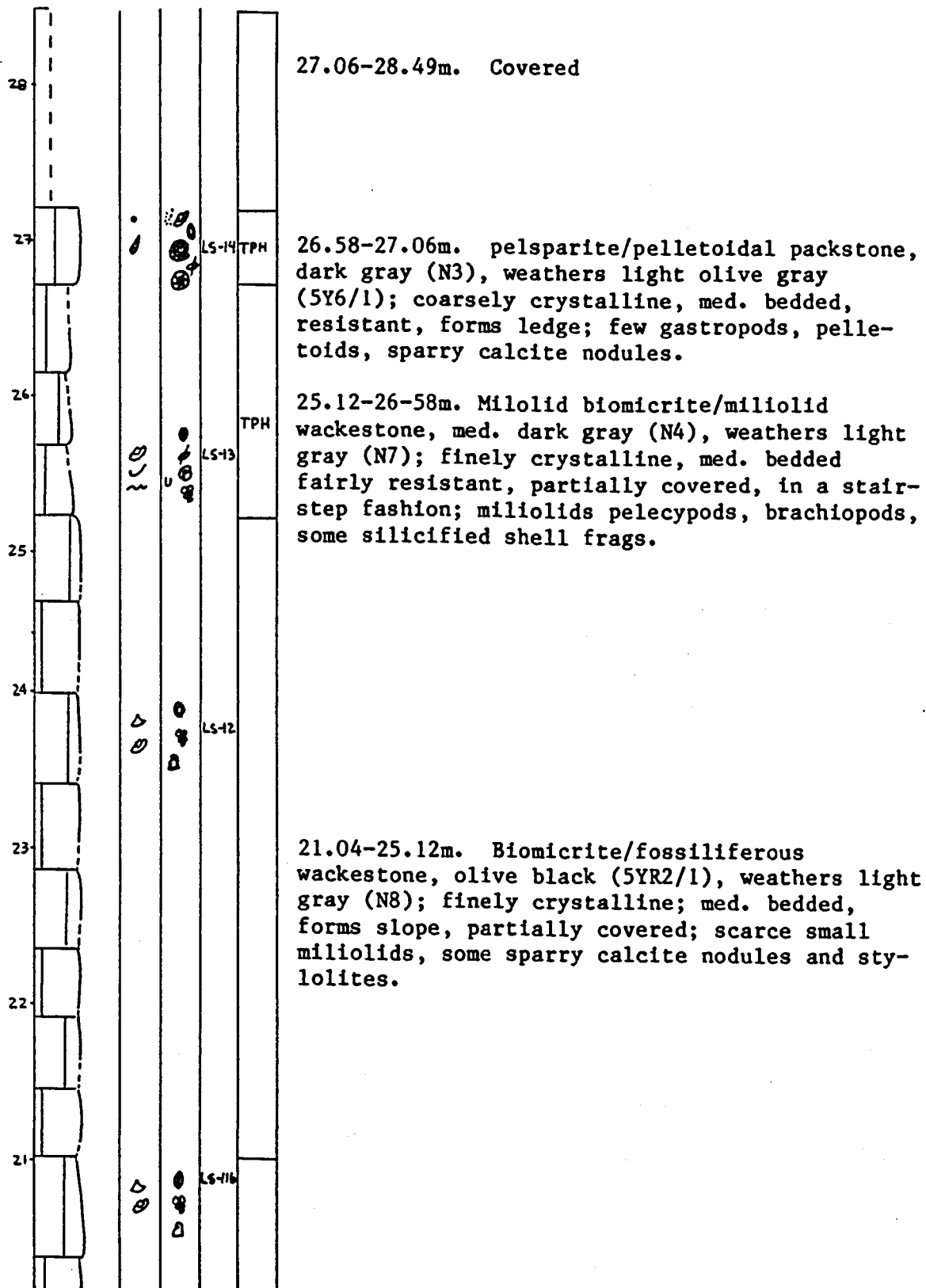
Lab. Laboratory exam of peels
and thin sections.

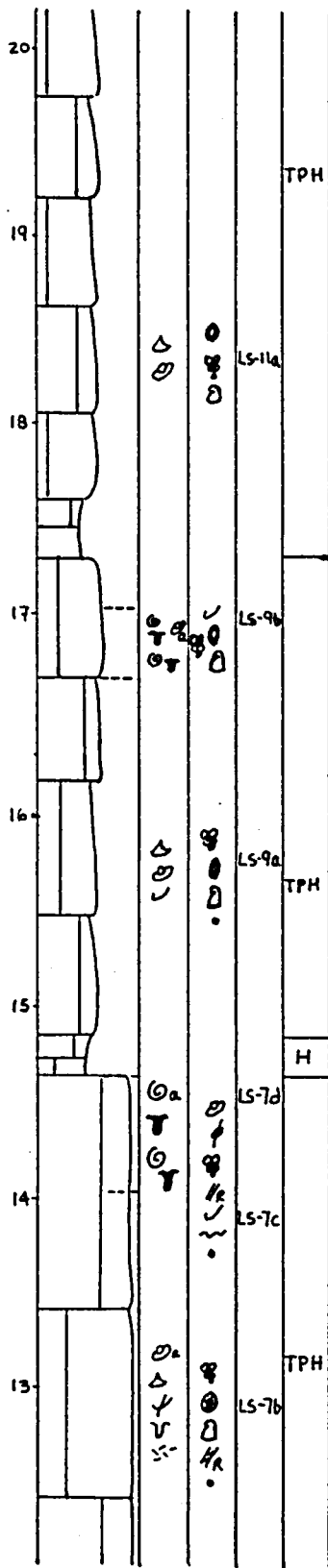
TPH Thin section

MEASURED SECTION LSA

Location: NE $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 11, T. 22S., R.28 E., College Peaks quadrangle. Section was measured in the only stream gully on the south side of the conical hill of the Lee Siding quarry and in the quarry itself (Fig. 21). Measured by Rogelio Monreal, August, 1984, with Brunton compass and Jacob's staff.

Bisbee GroupMural LimestoneUpper member of the Mural Limestone

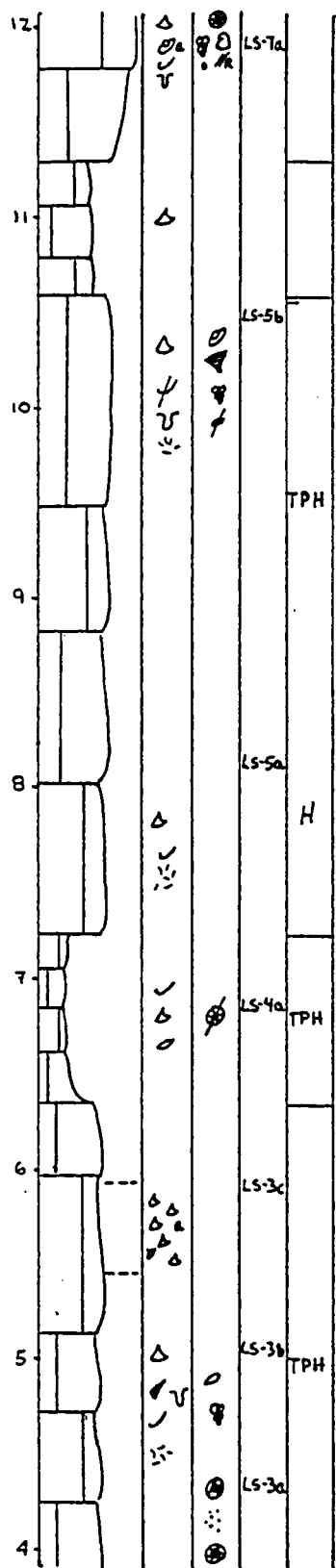




17.29-21.04m. Foraminiferal biomicrite/foraminiferal wackestone, med. dark gray (N4), weathers med. light gray (N6); finely crystalline, med. bedded, resistant, forms ledge in a stair-step fashion; miliolids, some Orbitolina (more abundant at top).

14.66-17.29m. Biomicrite/foraminiferal wackestone, med. dark gray (N4), weathers light gray (N7); finely crystalline, thick to med. bedded, resistant, forms ledge; miliolids, some pelecypods, abundant stylolites and sparry calcite nodules (0.25 mm.), small Toucasia and silicified Thalassinoides burrows at top of unit.

11.31-14.66m. Orbitolina biomicrite/Orbitolina wackestone, med. dark gray (N4), weathers light gray (N7), finely crystalline, very thick bedded, resistant, forms cliff; abundant Orbitolina, shell frags. and some miliolids, some burrowing; abundant stylolites, silicified Thalassinoides and abundant Toucasia at the top of 0.60m; "dusky smears".

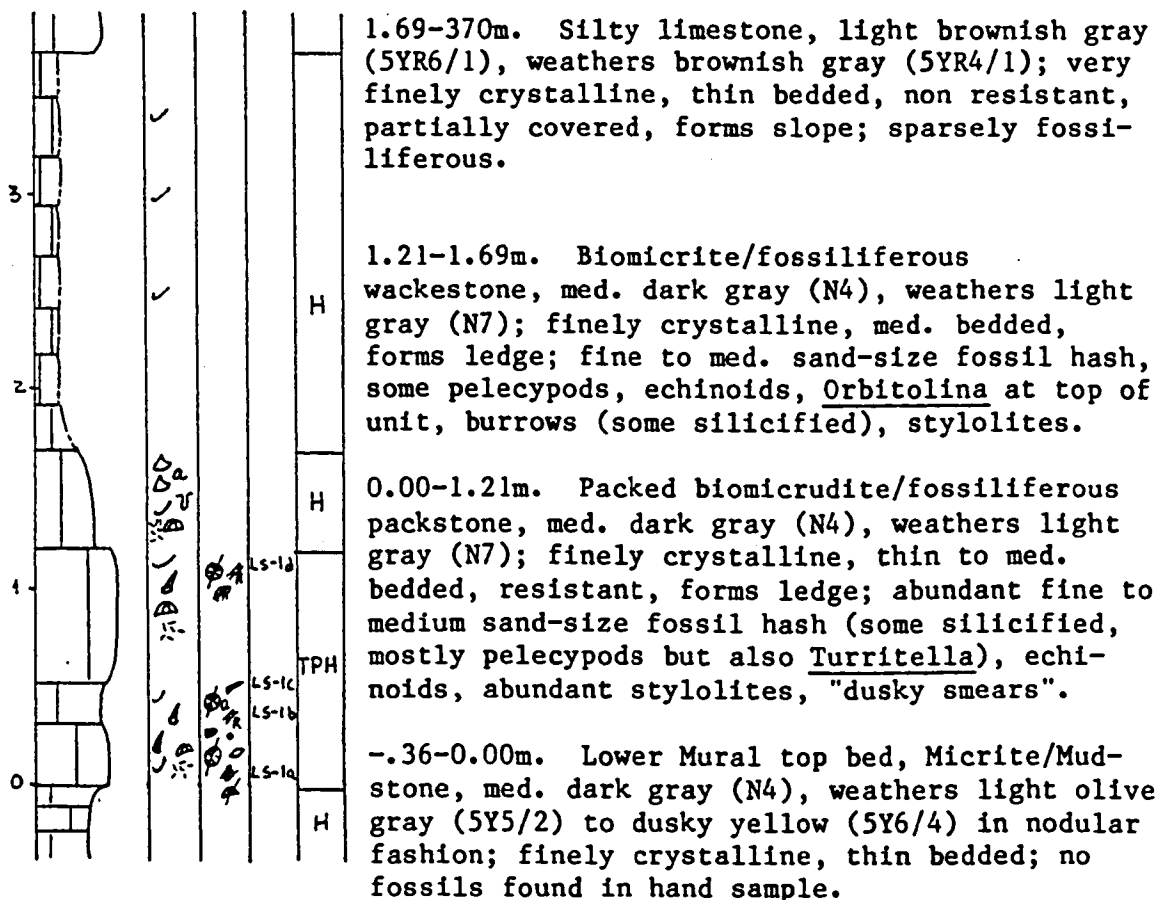


10.61-11.31m. Fossiliferous micrite/fossiliferous mudstone, light brownish gray (5YR6/1), weathers light olive gray (5Y6/1); finely crystalline, thin bedded, clay rich (?), non resistant; some Orbitolina; grades into the unit above.

7.26-10.61m. Orbitolina biomicrite/Orbitolina wackestone, dark gray (N3), weathers light gray (N7); finely crystalline, med. to thick bedded, resistant, forms ledge in a stair-step fashion; Orbitolina pelecypods, shell frags. some small rudists, some burrows, and abundant stylolites.

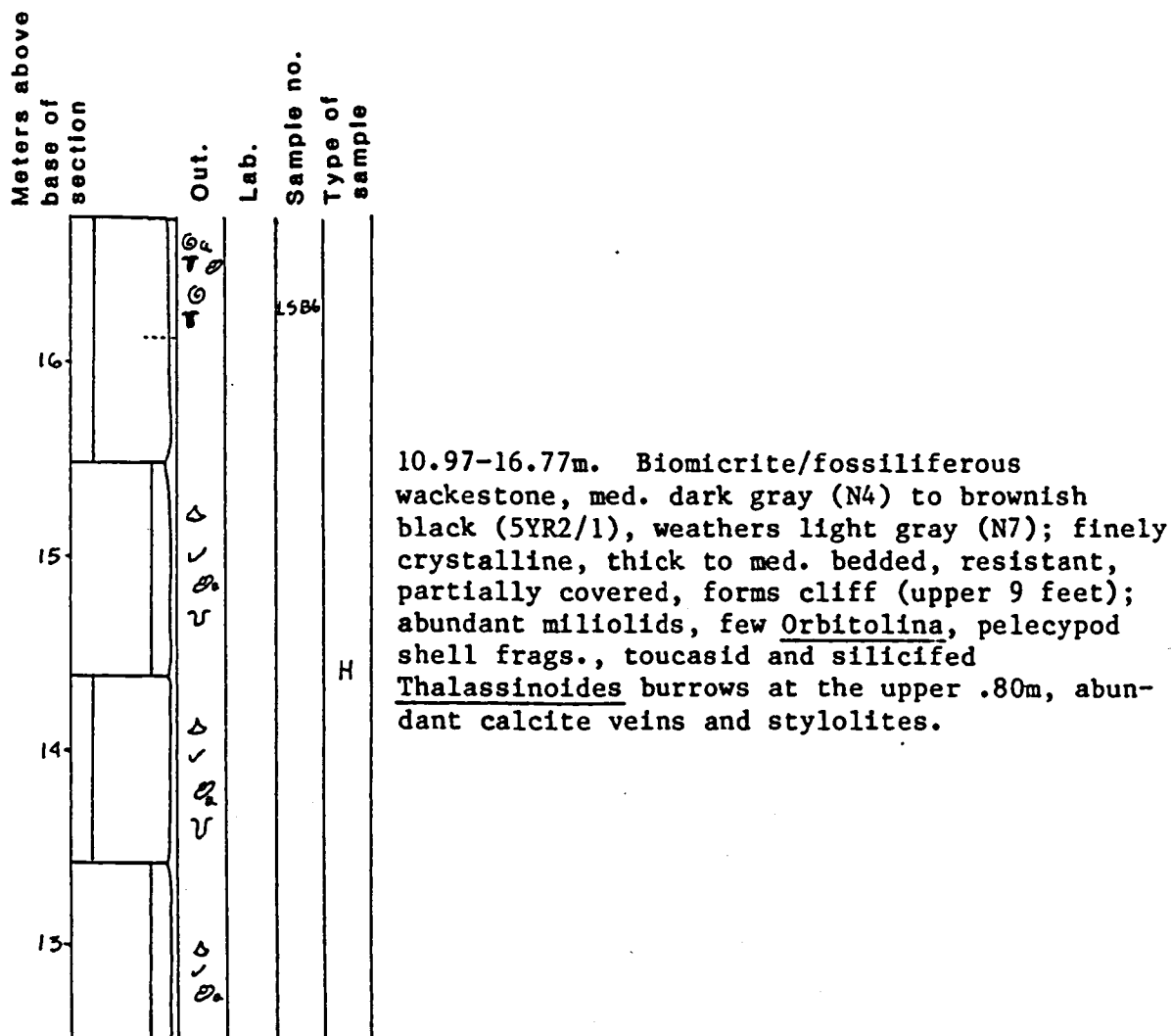
6.35-7.26m. Orbitolina biomicrite/Orbitolina wackestone, olive gray (5Y4/1), weathers light gray (N7) in nodular fashion; finely crystalline, thin bedded, non resistant, forms slope; Orbitolina, some shell frags (pelecypods), ostracodes, stylolites.

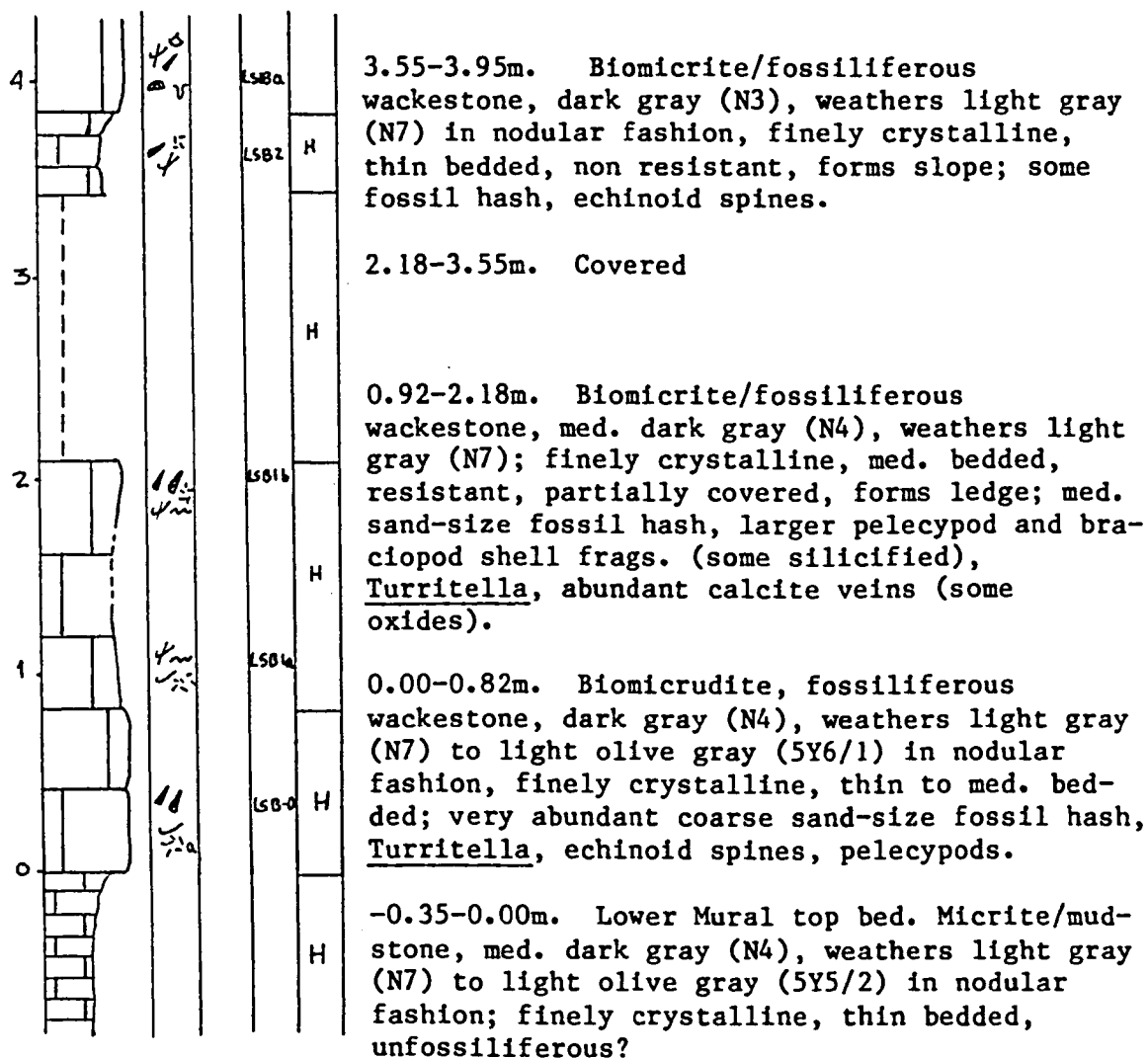
3.70-6.35m. Orbitolina biomicrite/Orbitolina wackestone, brownish gray (N7), weathers light gray (N7); very finely crystalline, medium bedded, resistant, forms ledge in a stair-step fashion; pelecypods, echinoid spines, Orbitolina (abundant near top), fossil hash, burrows with some silicification, dusky smears near top.



MEASURED SECTION LSB

Location: NE1/4NW1/4 sec. 11, T.22 S., R.28 E. College Peaks quadrangle.
 Section was measured in the low hill on the southeast side of the quarry floor. Measured by Rogelio Monreal, September, 1984, with Brunton compass and Jacob's staff.

Bisbee GroupMural LimestoneUpper member of the Mural Limestone



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