DEPOSITIONAL ENVIRONMENT, DIAGENESIS, AND UNCONFORMITY IDENTIFICATION OF THE CHIMNEYHILL SUBGROUP, IN THE WESTERN ANADARKO BASIN AND NORTHERN SHELF, OKLAHOMA

By

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PREFACE

The subjects of this study are the Keel, Cochrane, and Clarita Formations of the Upper Ordovician to Middle Silurian Chimneyhill Subgroup. The purpose of the investigation was to determine depositional environment, diagenesis and unconformity identification of the Chimneyhill.

I wish to express my appreciation to my major advisor, Dr. Zuhair Al-Shaieb, for proposing the study and for his help and guidance through its completion. I am grateful to Drs. Gary Stewart and Mateu Esteban for their assistance. Rick Fritz is also acknowledged for his helpful suggestions on depositional environment interpretation. I would like to thank ERICO for providing information which aided this study. Eldon Cox and his assistants are acknowledged for their help at the Oklahoma Geological Survey Core Library, where all the cores used in this study are stored.

Thanks are extended to my friends in the Geology Department who made working in the Dairy Building bearable, especially Jennifer Richardson, Mary Rafalowski and Scott McBride for their unending encouragement. Special thanks are due to my office mate, Kath McBride, who put up with my endless complaining while providing unremitting support.

Finally, I wish to thank my mother and sister for their patience, support and encouragement, without which I could not have completed this study. I dedicate this thesis to my father for instilling in me the dream to become a scientist.

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CHAPTER I

INTRODUCTION

Location

The subjects of this study are the Keel, Cochrane, and Clarita Formations of the Chimneyhill Subgroup (Hunton Group, Upper Ordovician to Middle Silurian) in the western Anadarko Basin and on the northern shelf of the Anadarko Basin in western Oklahoma (Figure 1).

Statement of Purpose

The purpose of this study is to determine the depositional environment and diagenesis of the Chimneyhill Subgroup. These models are proposed, based on evidence from depositional facies and diagenesis recorded in samples from 11 cores of the Chimneyhill. Evidence gathered to determine depositional environment and diagenesis are then evaluated to find criteria useful to identify unconformities in the Chimneyhill of the subsurface.

Geologic History

The Anadarko Basin is highly asymmetric and bounded to the south by the frontal fault zone of the Wichita Mountain uplift (Figure 2). The dip of the northern shelf is gentle. The Anadarko Basin is located within the southern Oklahoma Aulocogen. The basin could not have been identified as an individual entity until after the deposition of the

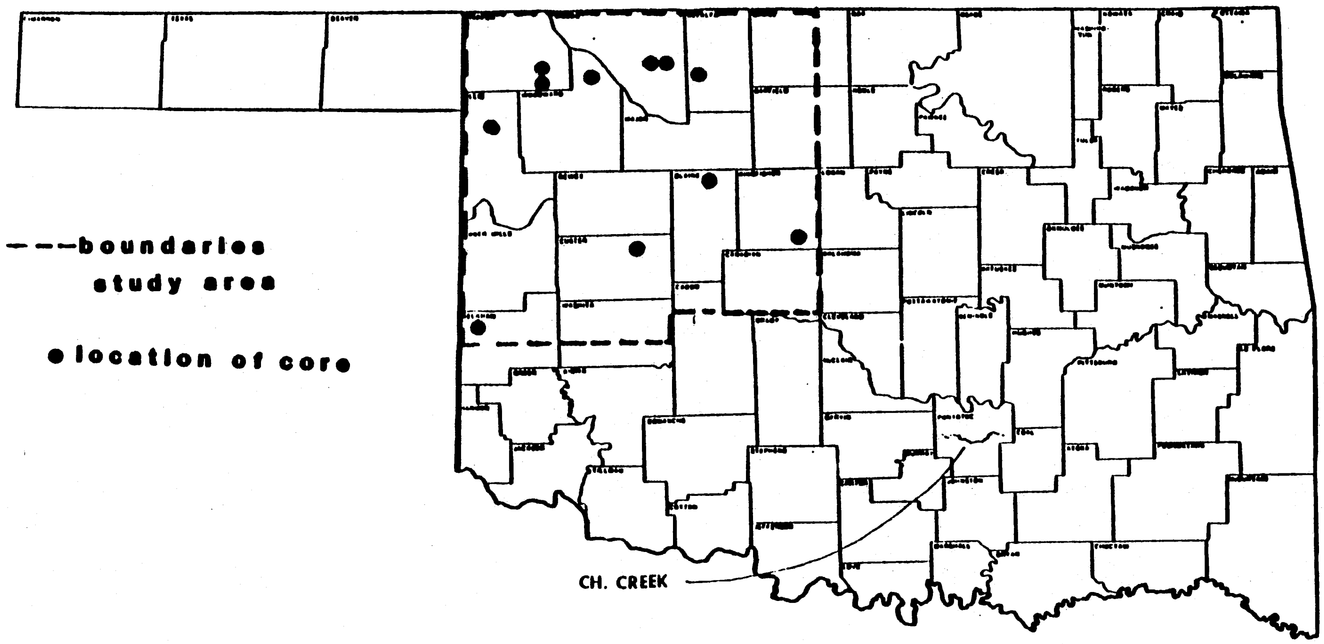


Figure 1. Area of Study and Location of Cored Wells

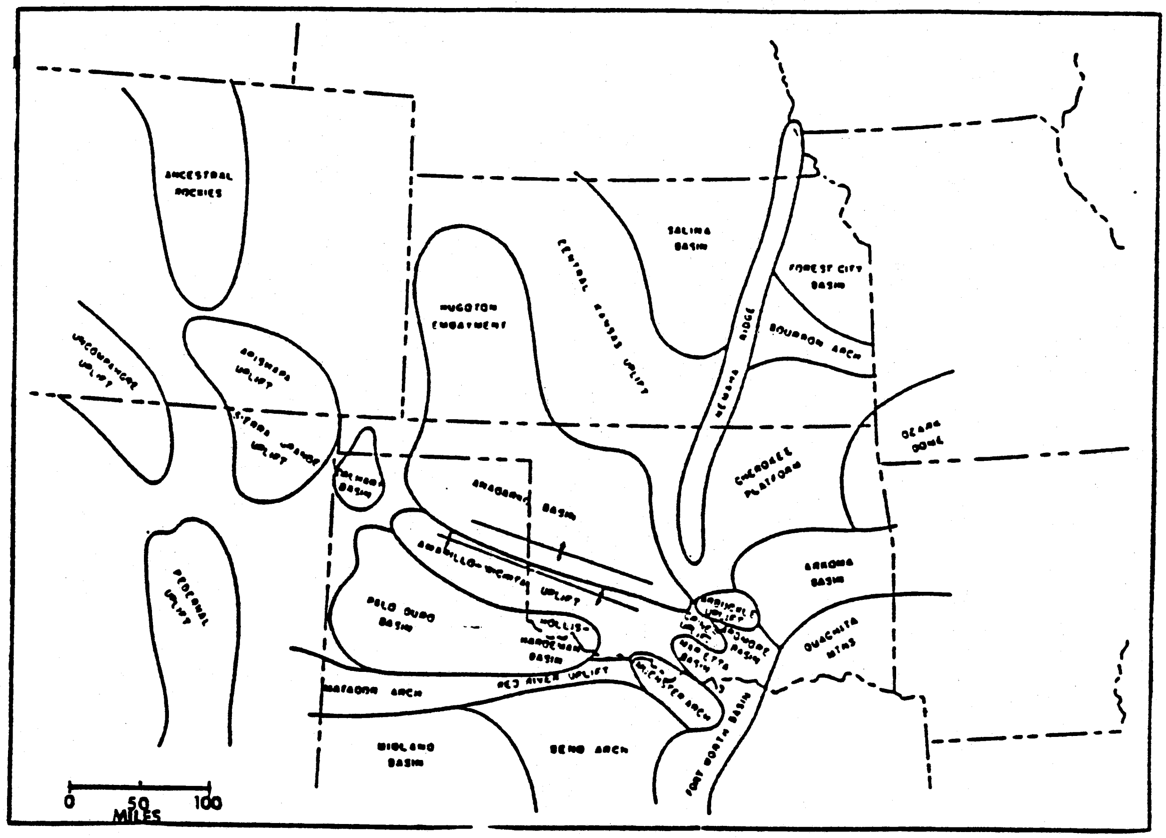


Figure 2. Major Structural Features of the Midcontinent (after Moore, 1979)

Hunton Group. Deformation that followed deposition of the Hunton resulted in isolation of the Anadarko Basin within the Aulocogen. Initiation of the Anadarko Basin is recorded by intrusion of rocks of the Middle Cambrian Wichita Province during the rifting stage of formation. Deposition and rapid subsidence followed throughout the Ordovician, during which mostly carbonate sediments and some siliciclastic sediments were deposited. Deposition of the Silurian to Devonian Hunton Group marks the end of the subsident stage of the southern Oklahoma Aulocogen.

Several unconformities are present within the Hunton Group. These unconformities are due to nondeposition and erosion. The rate of subsidence from the Silurian to Devonian was extremely slow compared to that of the Ordovician (Adler, 1971). Because of this slow, average rate of deposition, there were episodes of nondeposition and erosion. Uplift and erosion followed by the deformation of the Aulocogen occurred after deposition of the Hunton. This period of deformation broke the aulocogen into different basins, one being the Anadarko Basin. The unconformity above the Hunton resulted from partial erosion of the Group where stream channels cut into the Hunton as much as 300 feet (Amsden, 1975). The Woodford Shale was deposited on this uneven surface. The final stage of development of the Anadarko Basin was the deposition of Mississippian to Permian carbonate and clastic sediments, some of which were derived from the Wichita Mountains.

Methods of Investigation

Unconformities may be identified by features that are results either of depositional processes, diagenetic processes, erosion, or some combination of these events. To define the parameters necessary to identify unconformities in the Chimneyhill of the subsurface, it is necessary to compile evidence that allows development of a depositional model and paragenetic sequence. The methods used in this investigation included:

1. Description of 11 cores from the Chimneyhill from west-central Oklahoma. Sedimentary structures and fauna were observed in order to interpret the depositional environemnts

2. Examination of thin sections yielded evidence used to support and expand upon inferences about depositional environments, and determination of paragenetic sequences

3. Stratigraphic cross sections were constructed to assist in definition of local and regional unconformities

4. X-ray diffraction was used for quantitative mineralogical and petrographic description

CHAPTER II

PREVIOUS WORKS

Stratigraphy

The Chimneyhill was first recognized within the Hunton Group by Taff (1902). It was named by Reeds (1911) as the Chimneyhill Formation, for exposures at Chimneyhill Creek, Oklahoma (Figure 1). It was composed of three members: a basal oolitic member, a glauconitic limestone member, and a crinoidal limestone member. Reeds confirmed his conclusions in another publication in 1927 (Figure 3). Maxwell (1936) supported definition of the Chimneyhill Formation, but gave formal geographic names to Reeds' members, adding a fourth at the bottom:

1. Dillard Limestone Member
2. Cochrane Limestone Member
3. Keel Limestone Member
4. Hawkins Limestone Member

Amsden (1957) recognized Maxwell's divisions but gave new names to two members, Ideal Quarry (=Hawkins) and Clarita (=Dillard), because the old names were already in use when Maxwell proposed them. In 1962, Shannon stated that the Hunton could be divided into four units that are lithologically distinctive in well samples and that can be easily identified on electric logs. After further study of the Chimneyhill, Amsden (1967) proposed that the Chimneyhill Limestone be changed to a Subgroup. He also suggested that the Keel, Cochrane, and Clarita be designated as

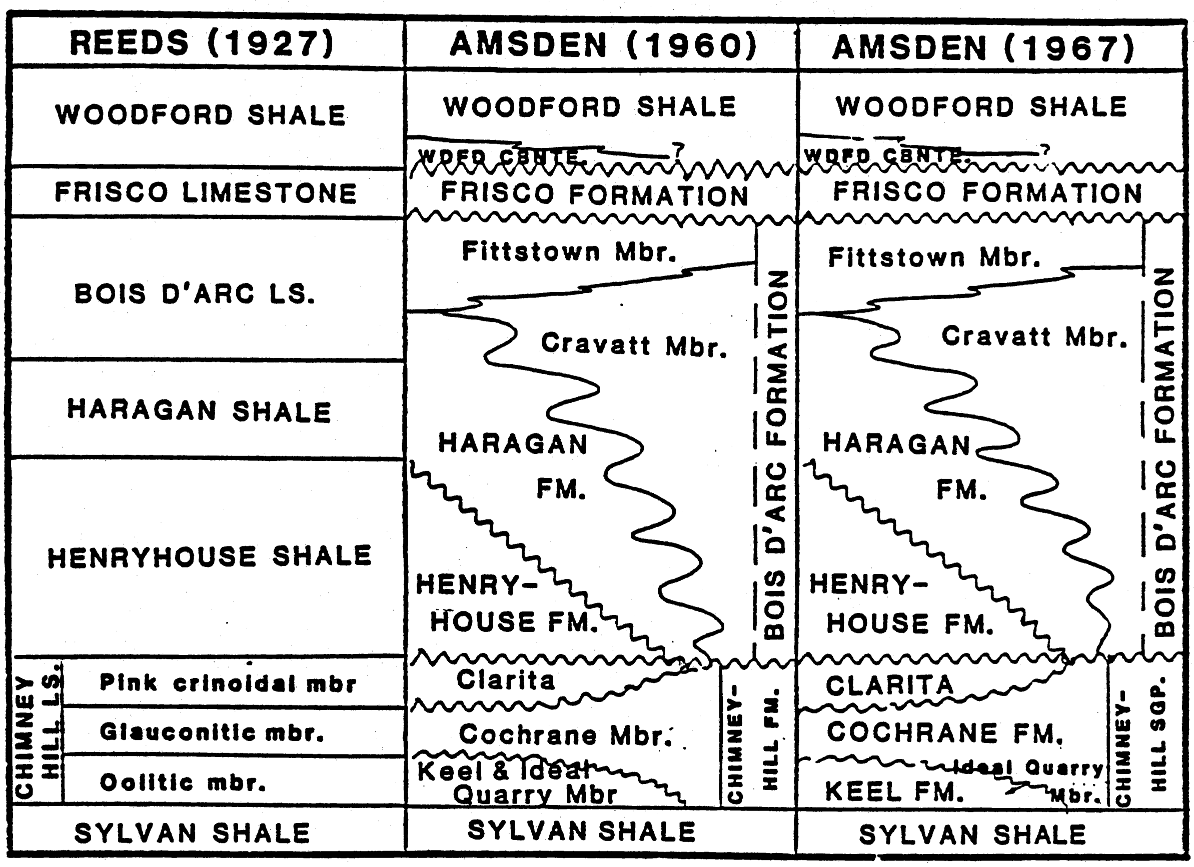


Figure 3. Stratigraphy of the Hunton. Bois D'Arc Members are Limestones. Chimneyhill Members are Limestones

formations. The Ideal Quarry Limestone Member was included as a member of the Keel Formation. The Clarita Formation was divided into two members:

1. the upper Fitzhugh Limestone Member
2. the lower Price Falls Shale Member

Amsden (1967) also determined the age of the Clarita to be Llandoverian to earliest Wenlockian, that of the Cochrane to be early-late Llandoverian, and the age of the Keel to be some part of the early Llandoverian.

Unconformities

Unconformities between the Chimneyhill Subgroup and the subjacent Sylvan Shale, and that between the Chimneyhill and the overlying Henryhouse Formation were identified first by Reeds (1911, 1927). He made no mention of the presence of unconformities between members of the Chimneyhill. Maxwell (1936) confirmed the presence of the unconformities identified by Reeds and described one between the Cochrane and the Clarita. In 1960, Amsden presented the idea that all the above unconformities were present as well as one between the Keel and the Cochrane. Shannon (1962) discounted all previous evidence for any of the unconformities and stated that all contacts, those within the Chimneyhill and those between the Subgroup and adjacent formations, are all gradational. Work by Amsden (1967, 1975) has refuted Shannon's proposal with the exception of the unconformity below the Keel. Amsden no longer finds enough evidence to call this contact unconformable (Amsden, 1975).

Depositional Environment

Very little work has been done to determine the depositional environments of the Chimneyhill. Amsden (1960) described the depositional environment of the Keel as a ramp with carbonate saturated water which was agitated by waves or current action. The Cochrane was described as a warm, quiet-water deposit on an offshore shelf lacking land-derived clastics. The Clarita was interpreted as a quiet-water shelf-type deposit with some input of land-derived material. After continued research, Amsden (1975) summarized the depositional environment of the Keel as shallow water of reasonably high energy. The Cochrane and Clarita were believed to have been deposited in relatively quiet water, possibly in the outer neritic zone.

Petrography

Results of very few petrographic studies of the Hunton Group have been published. Isom (1973) studied cores and well cuttings from the Chimneyhill in Major, Woodward, and Woods Counties, Oklahoma. Amsden (1975) completed a detailed study of the Hunton Group of the Anadarko Basin. Lithofacies and biofacies of the Chimneyhill Subgroup were described.

Porosity

Porosity in the Hunton has been related to the presence of dolomite (Harvey, 1968a; Isom, 1973; Amsden, 1975). Amsden (1975) completed the most thorough study of porosity in the Chimneyhill Subgroup. Most of the porosity within the Chimneyhill is in a crystalline dolomite facies. Porosity within the dolomites tends to be greatest in the central and northern parts of Western Oklahoma, extending into the Panhandle. Amsden (1975) also found significant porosity to be present in low-magnesium Silurian limestones within the Chimneyhill. This porosity is intergranular and is owing to incomplete cementation, enhanced by solution. Numerous vugs in these limestones suggest solution along fractures.

Dolomite and Dedolomitization

Amsden and Rowland (1967) demonstrated that the Silurian part of the Hunton shows a well-marked differentiation between a limestone and dolomite facies. Amsden (1967) noted that the limestone facies is largely restricted to south-central Oklahoma and that the dolomite facies is very common in the northeastern, central and western portions of Oklahoma.

Two types of dolomitization in the Hunton were proposed by Isom (1973). The first is "stratigraphic dolomite" which was interpreted as having resulted from early replacement of calcareous sediments. He believed that this type of dolomitization occurred by seepage reflux or the fluctuation of magnesium concentration in sea water during deposition. The second type of dolomitization is "late-replacement dolomite," which is related to tectonic and erosional features. This type of dolomite apparently forms from circulation of high-magnesium water along fractures and unconformities.

In 1975, Amsden stated that "there is no indication that dolomite in the Hunton is related to tectonic features, nor does it appear to be related to any considerable extent to the overlying and underlying strata." For the most part, Amsden believed that Silurian dolomite represents regional dolomitization that was unrelated to any internal features such as crinoid-rich beds, or any external factors, such as faults. He stated that most Silurian dolomite is due to near-surface or depositional-interface replacement. Amsden (1980) summarized dolomitization of the Chimneyhill as a process wherein dolomite was introduced as scattered euhedral crystals in the matrix of organo-detrital limestones. Crystals increased in quantity and began to corrode clasts of fossils. Finally, complete obliteration of the organic material produced crystalline dolomite.

No evidence of dedolomitization has been published by workers who studied the Hunton Group.

CHAPTER III

DEPOSITIONAL MODELS

Introduction

The Anadarko Basin subsided only slightly during deposition of the Chimneyhill from Late Ordovician to Silurian time (Adler, 1971), resulting in a very shallow carbonate ramp environment. Fluctuations of sea level could alter the environments. Deposition of the Chimneyhill Subgroup was interrupted by periods of nondeposition and erosion which are manifest as unconformities.

The typical carbonate ramp model (Figure 4) presented in the literature (Shaw, 1965) shows supratidal, intertidal, and subtidal environments in a broad, shallow, low-energy epicontinental sea. The environments parallel each other and the paleoshoreline (Irwin, 1965). Irwin divided the carbonate ramp into three energy belts which helped control the type of sediment (Figure 5). The outermost energy belt is a low-energy zone below wave base where fine-grained, laminated muds settle out of suspension. Irwin termed this, zone "X." The fauna is swept in from other zones. This environment may cover hundreds of square miles. The intermediate energy belt, called zone "Y," is a high-energy zone beginning where the wave base first directly affects the sea floor. Carbonate mud is winnowed and sparry calcite is the most common cement. Skeletal material is abundant due to the proliferation of life. Under certain conditions, oolites may form. These constituents often form

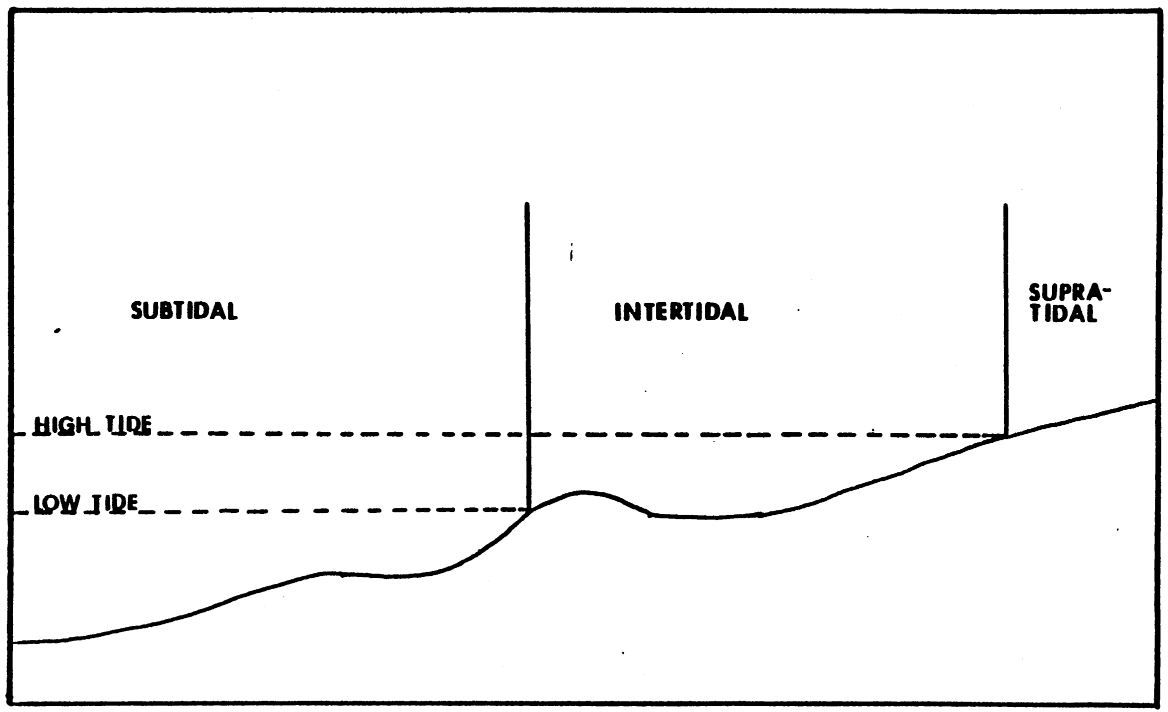


Figure 4. Generalized Model of a Carbonate Ramp (after Shaw, 1961)

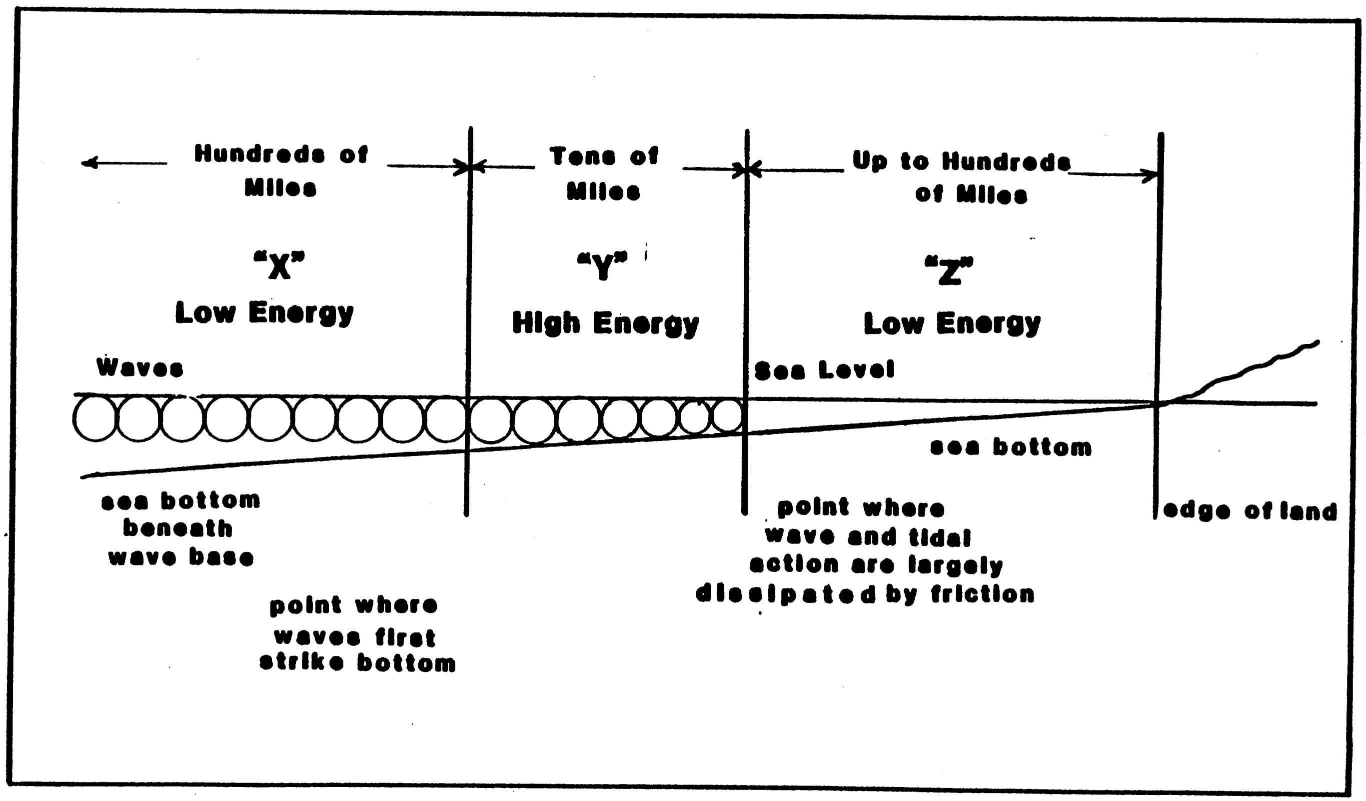


Figure 5. Section Showing Irwin's Energy Zones in Eipeiric Seas. Not to Scale (after Irwin, 1965)

shoals and bars. This zone is usually tens of miles wide and ends at the landward limit of tidal action. Zone "Z," the innermost energy belt, is the extremely shallow, low-energy area landward of zone "Y". Very little circulation of water results in the deposition of sediments of chemical origin. Lime muds and evaporites form in this area, which may be up to hundreds of miles wide.

Although the Chimneyhill does show facies characteristic of the supratidal, intertidal and subtidal environments of Irwin's model, it varies somewhat from the general ramp system. Localization of the facies occurred, so that the facies did not form bands parallel to the paleo-shoreline as in Irwin's depositional model.

Keel Formation

The Keel Formation is characterized by oolites and a paucity of fossils. Together, these features indicate supersaturation of the sea water with respect to calcium carbonate to allow the precipitation of oolites, coupled with a higher-than-average salinity resulting in the general paucity of fauna. Agitation of sea water was likely for oolites to form. This combination of conditions most likely occurred because of the shallowness of the epicontinental sea. This type of environment has been called a transitional marine environment (Heckel, 1972). Oolites characteristically formed shoals in the shallow subtidal-intertidal waters when the Keel was deposited. The Keel covers hundreds of square miles as a thin, oolite blanket, generally thinner than ten feet. This blanket most likely formed by shoreward migration of the oolitic shoals in transgression. Migration of the oolitic shoals is made evident by the presence of crossbeds (Figure 6).

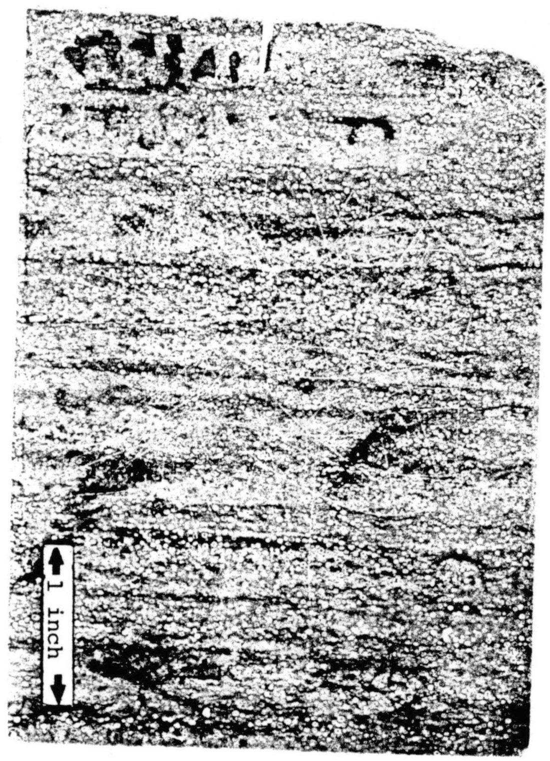


Figure 6. Bedded Oolites
Found in the
Keel Formation

Oolitic shoals were the only facies observed during the study. This observation does not imply that this was the only facies to form. The absence of other depositional facies is most likely due to erosion after deposition of the Keel that resulted in an unconformity between the Keel and the cochrane. This period of erosion formed an uneven surface upon which the Cochrane was deposited.

Cochrane Formation

The Cochrane Formation was deposited above the Keel after a period of nondeposition, which appears to have resulted in the partial or in some places complete removal of the Keel. The presence of this unconformity has been evidenced by Amsden (1960) who observed truncation of oolites in the Keel along the contact.

The Cochrane Formation is believed to have been deposited on a ridge-and-swale topography on a carbonate ramp with a very gentle slope. The ridges and swales varied in height and depth with respect to sea level, thus controlling the types of facies present. The varying dimensions of components of this topography resulted in the localization of facies, such that the individual facies did not form wide bands of similar carbonate types over broad areas that paralleled the paleoshoreline. Subtidal, intertidal and supratidal facies are present within the Cochrane. The subtidal-intertidal facies are most common.

The subtidal facies is characterized by two dominant carbonate rock types, crinoidal grainstones and lime mudstones/wackestones. Crinoidal grainstones represent crinoidal shoals which formed on tops of ridges. The shoals are characterized by pinkish-gray limestone containing abundant crinoid fragments, which are very well preserved (Figure 7).

Figure 7. Crinoidal Shoal in the Cochrane Formation. Crossed Polars

These fossil fragments are cemented by syntaxial calcite overgrowths and sparry calcite cement (Figure 8). The presence of abundant sparry calcite cement and the lack of micrite is indicative of deposition in an area of moderate to highly agitated water. Crinoids also indicate water agitation. Crinoids need water movement to survive because they are filter feeders.

The subtidal lime mudstone/wackestones most likely formed along the flanks of the ridges and in the swales. Mud and fossil fragments were washed from ridges and settled in the deeper areas. Many fossil fragments are broken and corroded, indicating transportation. Glauconite, a characteristic constituent of the Cochrane Formation, is common in these mudstone/wackestones. Glauconite is indicative of a quiet environment, very slow deposition, and locally oxidizing and reducing conditions. Since glauconite is present only in the Cochrane, the source of iron was effective only during the deposition of the Cochrane. (A detailed discussion of glauconite formation is given under the diagenesis of glauconite.) Clay wisps, horizontal burrows and chert are the sedimentary features typical of these subtidal mudstones/wackestones.

The intertidal facies is typified by dolowackestones/packstones and lime wackestones/packstones. Dolomite is absent in some areas but may be locally abundant (Figure 9). The presence of dolomite is a result of a decrease in water depth and may be associated with unconformities. The formation of dolomite was probably concentrated on the slopes and tops of ridges. These are areas which would have been most affected by a change in water depth. The fossils in this zone include crinoids, brachiopods, trilobites and ostracods. Vertical burrows and burrow mottling are common (Figure 10). Dolomitized rock is greatest in the burrowed zones. Chert nodules and vugs are present as well as algal laminations, which

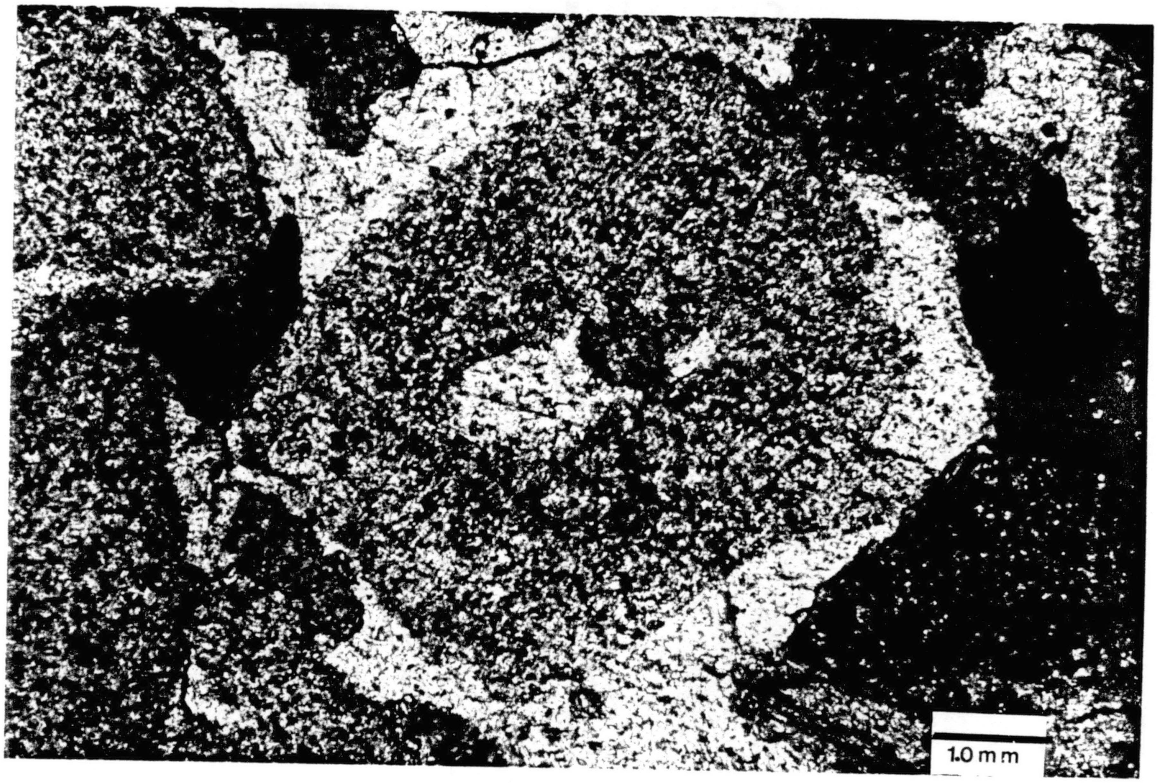


Figure 8. Sparry Calcite Cement and Syntaxial Overgrowths Common in Crinoidal Shoals. Plane Polarized Light

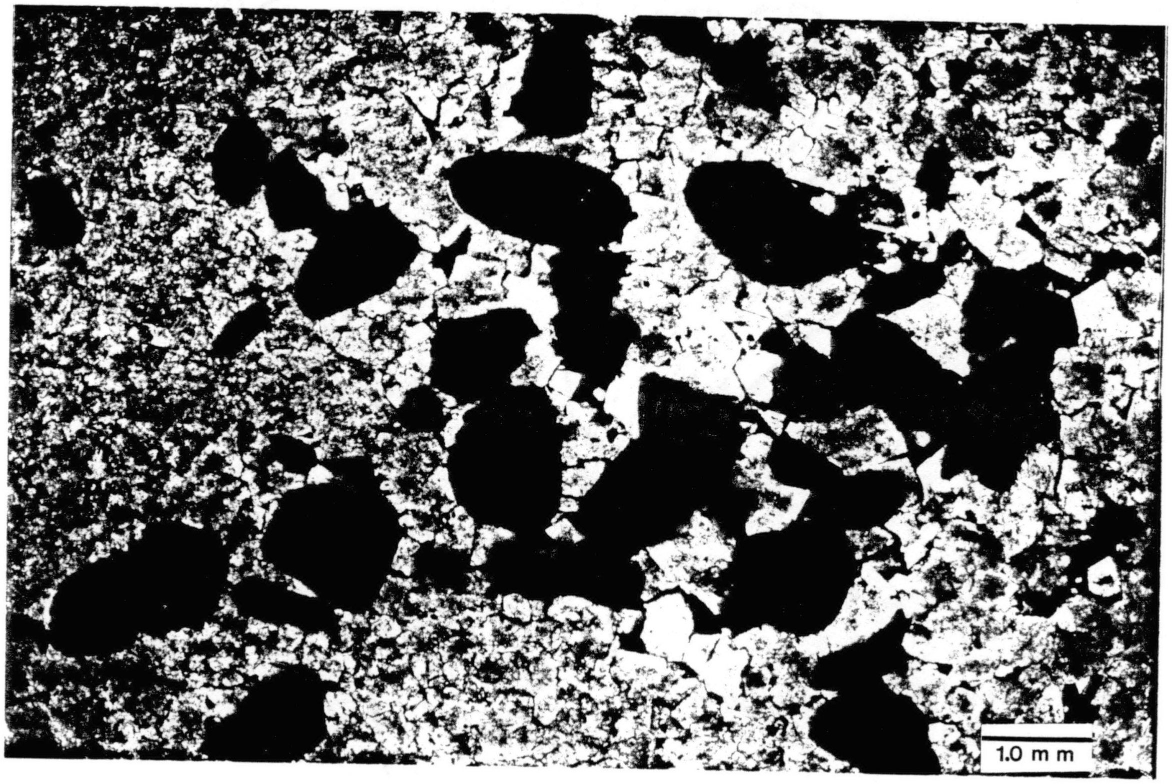


Figure 9. Extensive Dolomitization Present in the Cochrane Formation. Plane Polarized Light

Figure 10. Burrow Mottling Seen in the Cochrane Formation

are common in the upper portion of the intertidal facies.

The supratidal facies has a restricted occurrence within the Cochrane Formation. It is characterized by algal laminations, fenestral fabrics, paucity of fossils and lack of burrowing. Glauconite, which was probably brought in by storm action, and calcitized anhydrite nodules (Figure 11) also are in this facies. Dolomitized parts of this can be seen. In some cores, collapse breccias, usually found overlying the algal laminations (Figure 12), indicate supratidal conditions.

These facies in the Cochrane do not occur as bands paralleling each other and the paleoshoreline, but as localized patches. This is due to the localized ridge-and-swale topography that resulted in varying water depth over the entire area. Fluctuations in the sea level result in aggradations which are only locally consistent. Because of this, the Cochrane cannot be labeled as a dominantly prograding or regressing depositional sequence.

Clarita Formation

The Clarita Formation was deposited above the eroded Cochrane. The depositional model of the Clarita is very similar to that of the Cochrane. The distinguishing features between the two formations are that glauconite, which is present in the Cochrane, is absent in the Clarita, and although crinoidal shoals are present within the Cochrane, they are much more common in the Clarita.

The most common facies within the Clarita is the subtidal shoals as previously mentioned, but distal subtidal, upper subtidal and intertidal to shallow intertidal facies are also present. The subtidal crinoidal shoals were discussed in detail in the previous section so they will not

Figure 11. Calcitized Anhydrite Nodules

Figure 12. Collapse Breccia and Algal Laminations

be discussed here. The distal-subtidal facies is characterized by mudstones and wackestones, and probably formed in the deeper swales. The fossils, typically brachiopods, crinoids and corals, are broken-up and often corroded. Deformed clay laminae and wisps are common, as are clay-filled irregular fractures. Sparry calcite-filled vugs and nodules are also present (Figure 13). The upper subtidal facies is also characterized by mudstones and wackestones, but packstones are present as well. This facies probably formed in the shallower swales. Stylonodular bedding can be seen near the bottom of the facies (Figure 14) whereas some burrowing, mostly horizontal, and irregular fractures are present throughout.

The intertidal facies is typified by packstones and grainstones. The facies most likely formed on the flanks and tops of the ridges, or possibly in the shallower swales. Crinoid fragments are the most common fossils, but brachiopods and trilobites can also be found. Syntaxial calcite overgrowths are common, but low-amplitude stylolites are rare. The upper intertidal facies is made up of mudstones and wackestones which contain abundant crinoids, and some trilobites and bryozoans. Laminae are abundant, especially toward the shallowest part of the facies. Burrows are rare.

Chimneyhill Subgroup

The Chimneyhill Subgroup was deposited on a carbonate ramp with a very gentle depositional slope. The slope was so gentle that a very small change in sea level, which may have been due to a tectonic event, seasonal change, or eustatic sea level change, would have exposed large expanses of the sea floor to subareal erosion. The sea floor surface represents a ridge-and-swale topography. The ridges and swales were scattered

Figure 13. Sparry Calcite
Filled Vugs
and Nodules

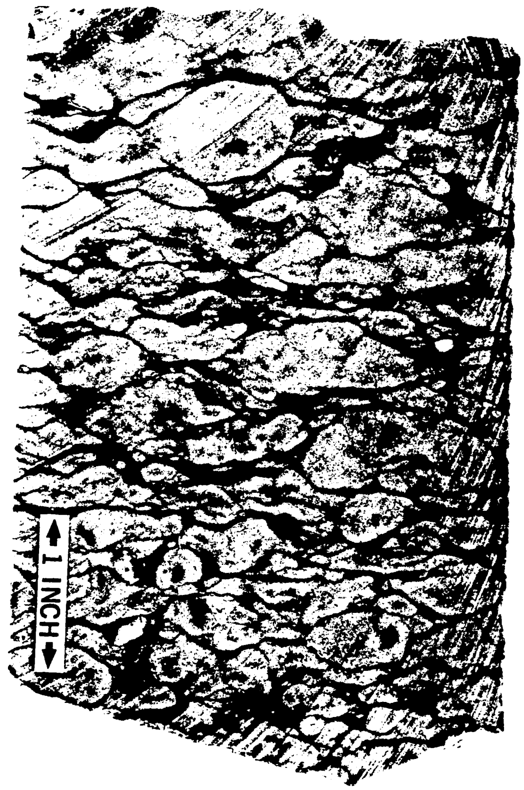


Figure 14. Stylonodular Bedding Near the Bottom of the Clarita Formation

throughout the area and exhibited different lateral and vertical dimensions with respect to each other. These differing dimensions resulted in some ridges being lower than some swales as well as the ridges (and swales) being different depths below sea level. This phenomenon helps explain the localized occurrence of different facies (Figure 15) as opposed to the facies occurring in parallel bands, typically seen in carbonate ramp environments.

Although the depositional slope during the deposition of the Keel was much like that of the rest of the Chimneyhill Subgroup, conditions varied so that fossils were scarce and oolitic shoals formed. Water depth seems to have been more uniform and the migrating nature of the shoals indicates a basically transgressive sequence.

The onset of the deposition of the Cochrane marked the beginning of an environment much more suitable for the survival of fauna. This continued throughout the deposition of the Clarita. The water was quite shallow, most likely less than 100 meters in depth, and clear enough to stimulate the proliferation of fauna which are present throughout the Cochrane and Clarita Formations. Pelmatazoan colonies appeared to be the most abundant. They tended to grow in clusters on top of the ridges which resulted in the formation of crinoidal packstones and grainstones. Some pelmatazoan fragments were washed down along the ridge flanks and into the swales by storms or wave action. These fragments are found with brachiopod, ostracod, trilobite, and bryozoan fragments in the mudstone, wackestones and packstones which formed along the ridge flanks and in the swales. The packstones tended to occur farther up along the flanks while the mudstones appear to represent flatter, deeper areas in the swales. Glauconite, which is found only in the Cochrane Formation, indicates the

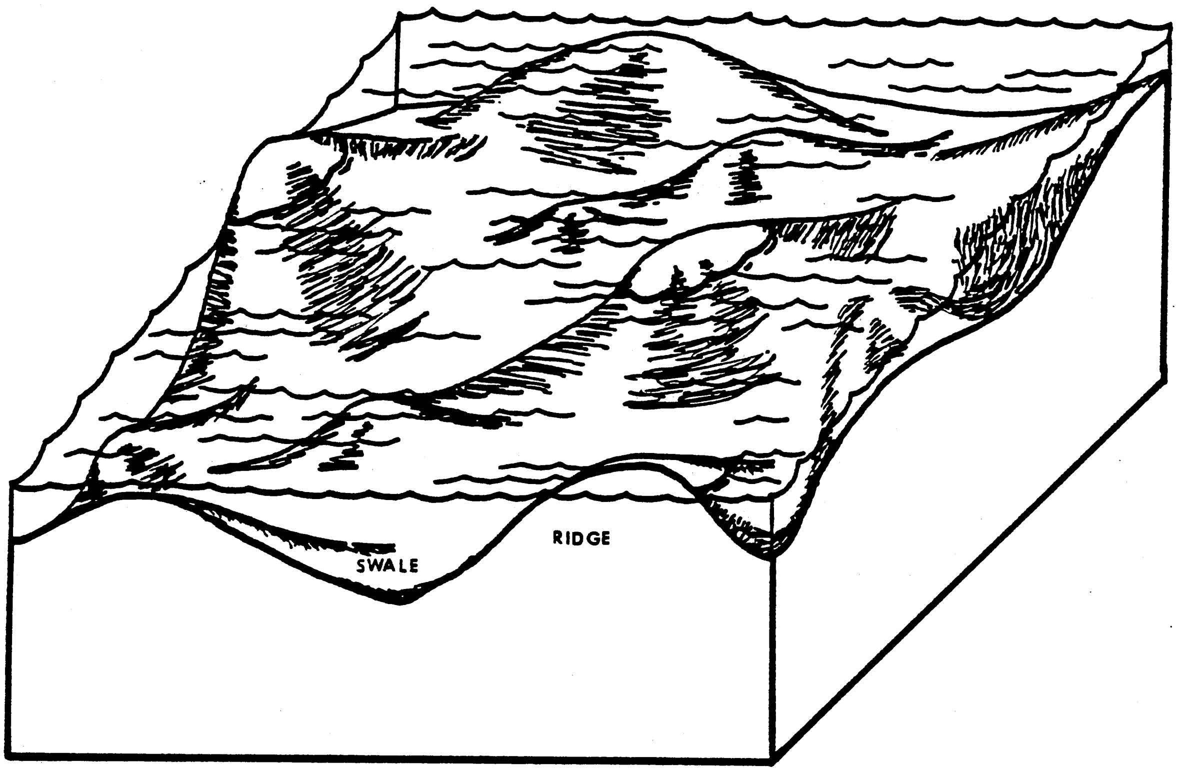


Figure 15. Block Diagram of the Chimneyhill Depositional Environment Showing the Localization of Facies.

presence of a source of iron and a slow rate of deposition. The iron source is not known, but the iron may have come from a terrigenous source which was obliterated by continued deposition, followed by erosion after the deposition of the Cochrane and before the deposition of the Clarita. Intertidal and some supratidal conditions were also present in the Cochrane and the Clarita, but distinguishing these two facies is often difficult. The presence of these facies is due to the fluctuation of sea level throughout the area.

Dolomitization in the Chimneyhill Subgroup also appears to be related to the fluctuation of sea level. Dolomitization most likely occurred when drops in sea level, either exposed parts of the sea floor subareally or decreased water depth enough to allow dolomitization, resulting in either evaporation of sea water or mixing of meteoric and sea waters.

These drops in sea level also resulted in the formation of minor, local unconformities within the Cochrane as well as the major unconformity located between the Cochrane and the Clarita Formations. The unconformity between these two formations reflects erosional activity as well as a period of nondeposition. The minor disconformities may have been due to erosion, short periods of nondeposition or the destruction of carbonate deposits by a drop in the wave base.

Although the Cochrane has dominated the above discussion, all the information holds true for the Clarita except where noted.

CHAPTER IV

PETROLOGY AND PETROGRAPHY

Introduction

The sedimentary rocks in the Chimneyhill Subgroup can best be named according to the classification cited by Dunham (1961), although the classification created by Folk (1959) can be used as well. All types of carbonates, ranging from mudstones to grainstones, are present within the Subgroup, although some are more prevalent in one formation than in the others. The types and amounts of constituents present in each Chimneyhill formation varies from one to another as well. The petrography of each formation will be discussed individually and then comparisons will be made.

Keel Formation

The Keel was cored in very few of the available wells, so that, unfortunately, petrographic evidence for the formation is very limited. The dominant constituent in the Keel is oolites. The oolites range in abundance from 25 to 85% and in size from 0.2 to 2.0 mm. The oolites are seen in both their original calcitic form and as dolomitized ooids. The dolomitized ooids (Figure 16) are most common in the cores studied in this investigation. These oolites retained their original ovoid shape, but are composed of small, 0.01 to 0.1 mm, dolomite rhombs which obliterate the original calcitic structure of the oolites. Both radial

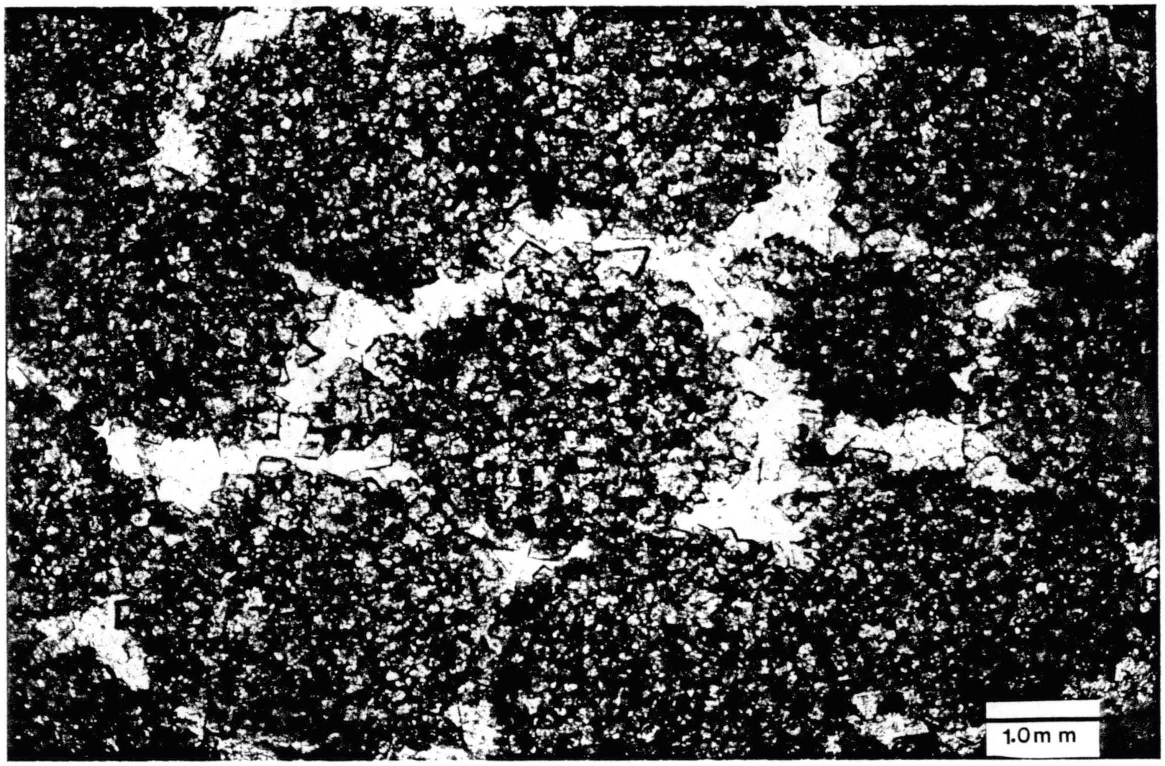


Figure 16. Dolomitized Ooids. Plane Polarized Light

and concentric structures are seen in the calcitic oolites (Figure 17). Most of the oolites are round although some deformed ooids are present as well.

The oolites, whether calcitic or dolomitized, are always cemented by sparry calcite (see Figure 16). This calcite cement makes up the remaining bulk of the rock.

Cochrane Formation

The Cochrane Formation contains a variety of constituents, the most diagnostic of which is glauconite (Figure 18). This constituent is present only within the Cochrane, and can be readily identified in thin section. It is present as bright green, rounded pellets. Glauconite varies from trace amounts to 10% in abundance and ranges in size from 0.08 to 0.15 mm.

Fossil fragments make up anywhere from trace amounts to 40% of the constituents (Figure 19). The fossils present include pelmatazoans, brachiopods, ostracods, trilobites and bryozoans. Pelmatazoans are by far the most common, ranging in abundance from 0 to 40% and varying in size from 0.2 to 2.0 mm. Both whole and broken fragments are found. Ostracods are the next most abundant fossil fragment, ranging from 0 to 7% in abundance and ranging in size from 0.1 to 0.7 mm. Some ostracods act as geopetal structures, reflecting the paleoslope of the environment. Brachiopods, trilobites and bryozoans all occur in trace amounts. In most samples they are present only in trace amounts and never exceed 5% in abundance. These fossils are always seen as broken fragments.

Micrite and sparry calcite cements are both present in the Cochrane, but micrite is more common. It makes up from 0 to 90% of the rock and

Figure 17. Calcite Ooids. Plane Polarized Light

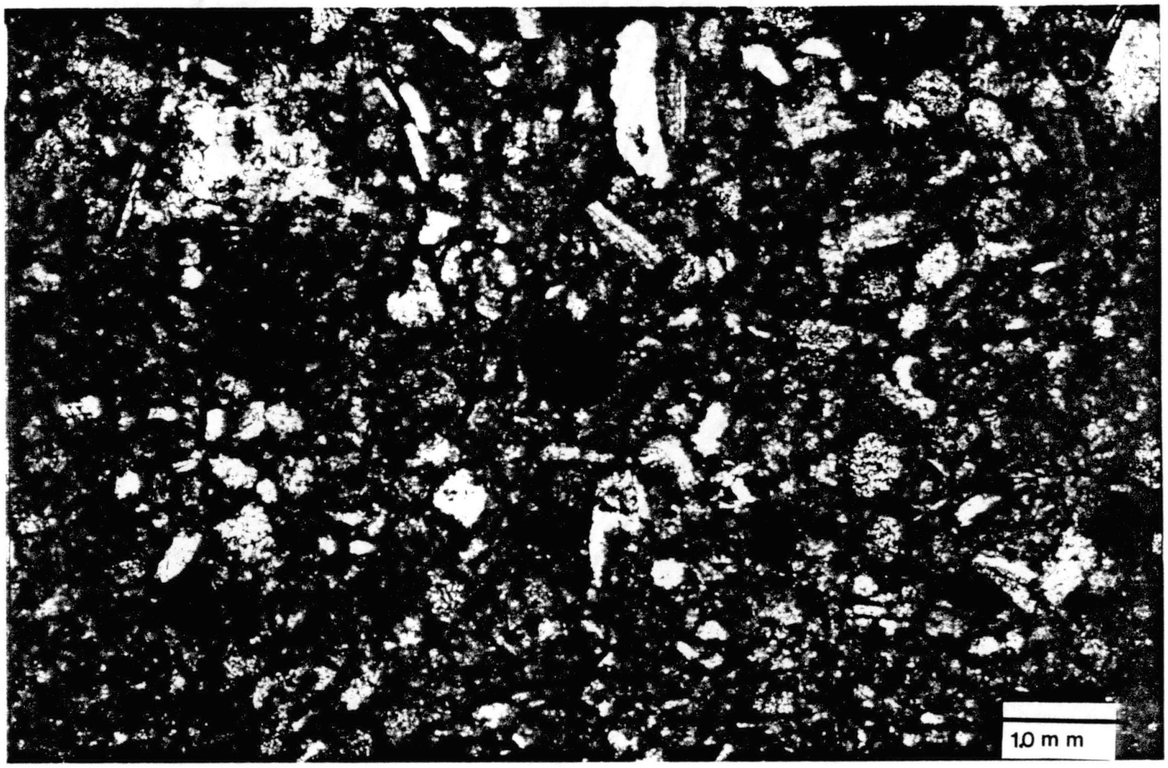


Figure 18. Glauconite Pellets. Plane Polarized Light

Figure 19. Fossil Assemblage in the Cochrane Formation. Plane Polarized Light

can be seen filling voids in fossils as well as cementing the constituents. Sparry calcite cement ranges from 0 to 55% in abundance and is often seen as a syntaxial overgrowth around echinoderms and as a vug filling cement. Dolomite is present in some Cochrane cores. It ranges from 0 to 90% in abundance, and the rhombs vary from 0.01 to 0.25 mm in size. Where the amount of dolomite is high, the original texture of the rock may be completely obliterated. The rhombs can be seen as an interlocking mosaic (Figure 20), as scattered rhombs (Figure 20), and as concentrations of rhombs within micrite or sparrycalcite, probably representing burrows (Figure 20).

Silica is not abundant in any Cochrane cores, but it is present in many of them, ranging from 0 to 2% in abundance. It is most often seen as chert or chalcedony replacing fossils, especially crinoid fragments, although silica is also present as megaquartz veins and vug filling chalcedony.

Pyrite is present in parts of the Cochrane, most commonly in trace amounts, but it may be seen varying in abundance up to 2%. Pyrite is usually scattered as tiny crystals throughout the rock, but in a few areas it is present as isolated concentrations.

Anhydrite, detrital phosphate and detrital quartz are present in small amounts and are very restricted in their occurrences. Anhydrite appears as elongated crystals and nodules which are now being replaced by calcite, dolomite and silica. Detrital phosphate grains are seen in only one core, where they make up 6% of the constituents. Detrital quartz is present in the same core as the phosphate grains and ranges from 3 to 8% in abundance. They vary from 0.02 to 0.04 mm in size.

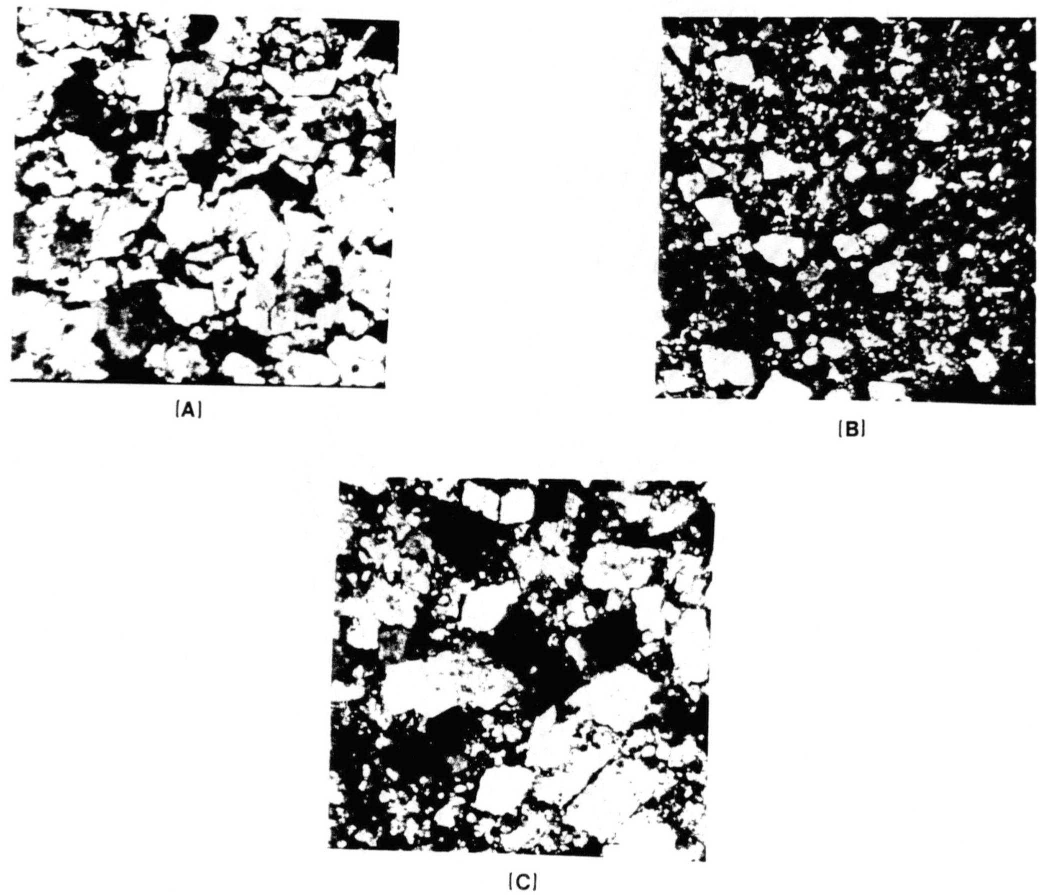


Figure 20. Dolomite Types Present in the Chimneyhill. (A) Interlocking Dolomite Mosaic; (B) Scattered Dolomite Rhombs; (C) Concentration of Dolomite Rhombs. All are Crossed Polars

Clarita Formation

The Clarita Formation is characterized by the presence of pink crinoidal shoals, thus making an abundance of crinoid fragments and a relative paucity of other fossils its diagnostic feature. The echinoid fragments range in abundance from 5 to 38% and vary in size from 0.2 to 2.0 mm. They appear both as whole and broken fragments. Some of the fragments show evidence of micritization that is noted by the presence of micrite envelopes (Figure 21).

Other fossil fragments present in the Clarita are ostracods, brachiopods, bryozoans and trilobites. Ostracods vary in abundance from 0 to 6% and range in size from 0.15 to 0.16 mm. Brachiopod fragments range from 0 to 4% in abundance and vary in size from 0.4 to 1.0 mm. Bryozoans vary from 0 to 2% in abundance and the trilobites occur only in trace amounts. Most of the fossils are preserved as broken fragments.

Both micrite and sparry calcite are present as cements in the Clarita. Sparry calcite is the most common of the two, ranging from 2 to 40% of the rock. The amount of sparry calcite is lower where dolomitization has taken place and it is most often present as syntaxial overgrowths on the echinoid fragments. It is also seen as vug filling, fracture filling and fossil void filling cement. Micrite tends to be most common in rocks which contain other fossil fragments besides crinoids and ranges in abundance from 0 to 60%.

Dolomite occurs in the same ways in the Clarita as it does in the Cochrane. The abundance of all other constituents is reduced due to the replacement by dolomite. The rhombs range in size from 0.01 to 0.15 mm and vary in abundance from 0 to 46%.

The only accessory mineral in the Clarita is pyrite. It is absent

Figure 21. Micrite Envelopes and Calcite Overgrowths in Clarita Shoals. Plane Polarized Light

from most samples but can be seen in trace amounts, scattered through the more micritic sections.

Nomenclature and Classification

After concluding the petrographic study, the rocks in the Chimneyhill Subgroup were named according to Dunham's classification. All the rock types listed in the classification are present within the Chimneyhill. Modifiers were added to the names to give a better definition of the rock constituents.

The lithology of the Chimneyhill varies from mudstone to grainstone. Mudstones are the least common of all the rock types due to the abundance of fossils in the Chimneyhill. Packstones and grainstones are the most abundant.

Although different rock types may be present, each formation within the Chimneyhill Subgroup is characerized by a certain lithology. The Keel can be characterized by oolitic grainstones because of the abundance of oolites and sparry calcite cement. The Cochrane is best represented by fossiliferous wackestones to packstones, reflecting the abundance of micrite and fossils. The Clarita is dominantly packstones to grainstones, indicating an abundance of sparry calcite cement and the almost exclusive presence of crinoid fossil fragments.

CHAPTER V

DIAGENESIS

Introduction

The Chimneyhill Subgroup has undergone a significant amount of diagenesis since its deposition. The diagenetic events began syndepositionally and continued through time. Paragenetic sequences have been constructed for each of the formations within the Chimneyhill. Each formation will be discussed separately. Porosity, dolomitization and dedolomitization models will be discussed in separate sections in this chapter.

Paragenesis

Keel Formation

The diagenesis of the Keel is simpler than that of the other formations (Figure 22). This is because cementation by sparry calcite occurred relatively early in the diagenetic history of the rocks. The precipitation of sparry calcite cement prohibited the further migration of waters through the formation so that no other diagenesis could occur. The spar is seen as poikilitic cement, which indicates slow precipitation of the cement and as drusy spar which reflects more rapid precipitation.

In some localities, dolomitization of the ooids occurred. Dolomitization appears to have occurred after cementation by sparry calcite.

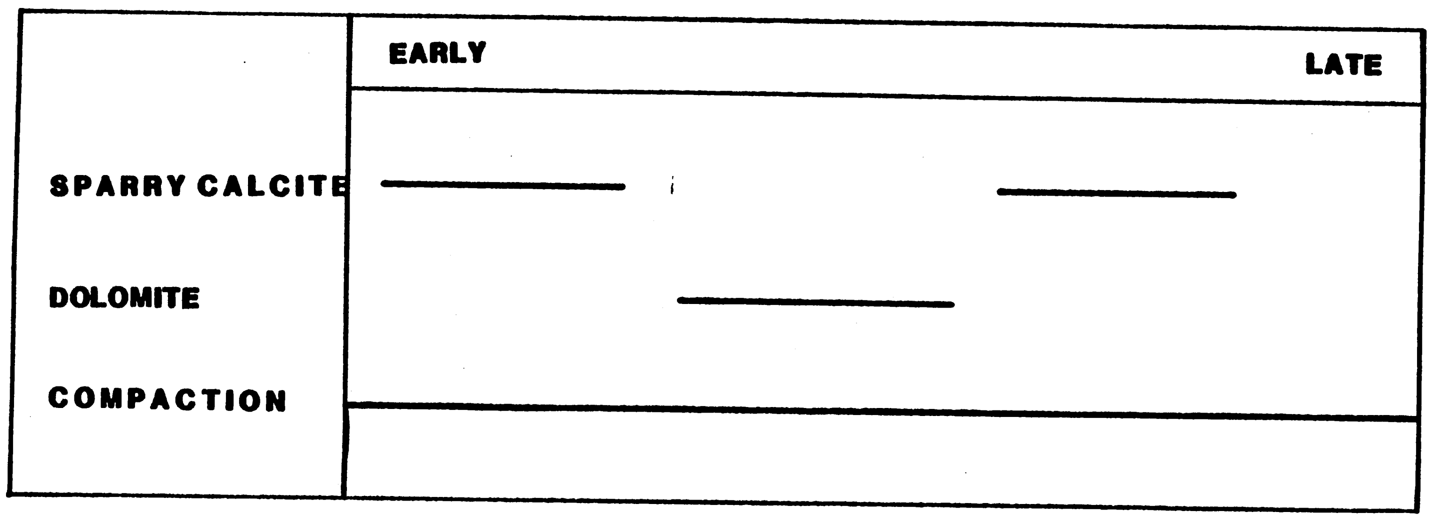


Figure 22. Paragenetic Sequence for the Keel Formation

Selective dolomitization of the oolites probably occurred by diffusion of magnesium ions through the sediments. The selective replacement of oolites by dolomite probably happened because the oolites may still have been composed of aragonite which is less stable than calcite, or because the oolites were composed of finer grained carbonate than the cement, therefore were more easily replaced than the sparry calcite. The ooids are completely recrystallized by dolomite and show no relict features. These dolomitized oolites are still well rounded, indicating that dolomitization occurred before compaction, therefore early in the diagenetic history of the rock.

Calcitic ooids are present within the Keel, as well as dolomitized oolites. The presence of calcitic ooids indicates that conditions were not right for the formation of dolomite, probably due to a lack of magnesium, therefore resulting in the direct precipitation of sparry calcite.

Cochrane Formation

The Cochrane Formation has the most complex diagenesis in the Chimneyhill Subgroup. Chemical diagenetic processes include:

1. secondary authigenic precipitation
2. alteration, dissolution and replacement

These processes, along with physical processes, are summarized in the paragenetic sequence in Figure 23.

Secondary Authigenic Precipitation. Minerals recognized as secondary authigenic precipitants include anhydrite, glauconite, calcite and pyrite.

Anhydrite most likely formed syndepositionally. It indicates a more arid, evaporitic, upper intertidal to supratidal environment. Its

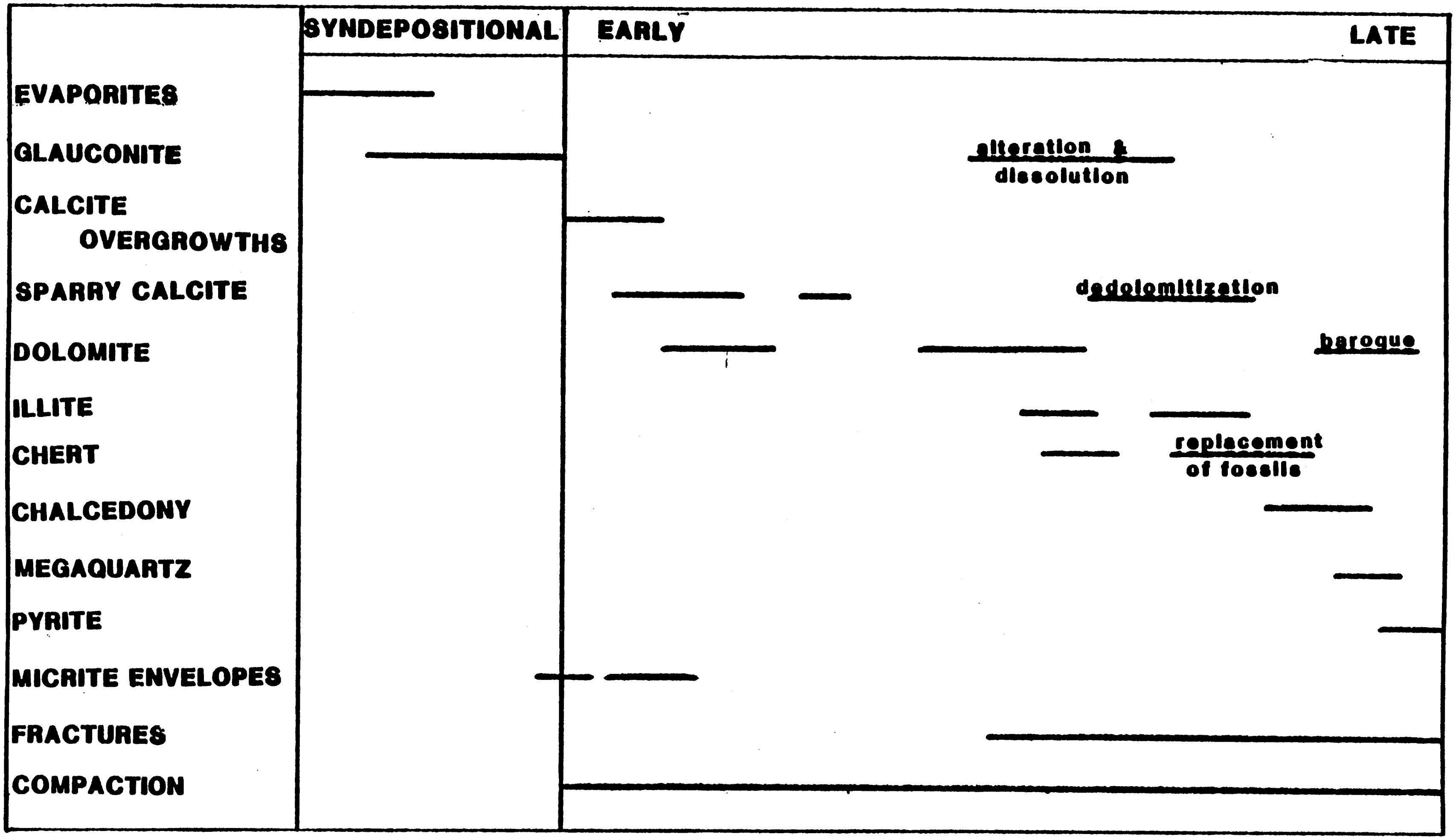


Figure 23. Paragenetic Sequence for the Cochrane Formation

appearance is limited, but collapse breccias and calcitized nodules remain as evidence for the presence of anhydrite.

Glauconite is also a syndepositional precipitate. It is present as pellets and as a pore filling precipitate in the Cochrane. Glauconite needs a very specific environment to form. It has been suggested that the precipitation of glauconite requires a semi-confined microenvironment. This microenvironment needs to be slightly reducing to oxidizing ($Eh<0$), have chemically stable water (pH 7-8) and low sedimentation rates.

Calcite is the most common secondary authigenic precipitant in the Cochrane Formation. The types of calcite cement include syntaxial overgrowths and sparry calcite cement. Syntaxial overgrowths occur predominantly on crinoid fragments. These overgrowths characteristically occur as an early phase of cementation in the active phreatic environment (Longman, 1980). Active circulation of sea water allows rapid and equal precipitation around the crinoid grains (Flügel, 1982). Sparry calcite precipitation occurred sporadically from early to late diagenesis. This cement forms in the freshwater phreatic zone (Longman, 1980) which lies between the meteoric vadose and mixed-marine and fresh water zones (Figure 24). Early spar is seen as a drusy or equant pore filling cement in dolomites, where it is resulting in dedolomitization. In thin section examination, the individual episodes of sparry calcite cementation appear to be constant. But, examination by cathodoluminescence indicates otherwise. Figures 25 and 26 show multiple periods of cementation resulting in alternating bands of bright and dull luminescence. These bands may occur because precipitation of spar results in the localized depletion of $CaCo_3$ in the pore filling solution adjacent to the grain. Whenever this undersaturation occurs, there is a period of nonprecipitation

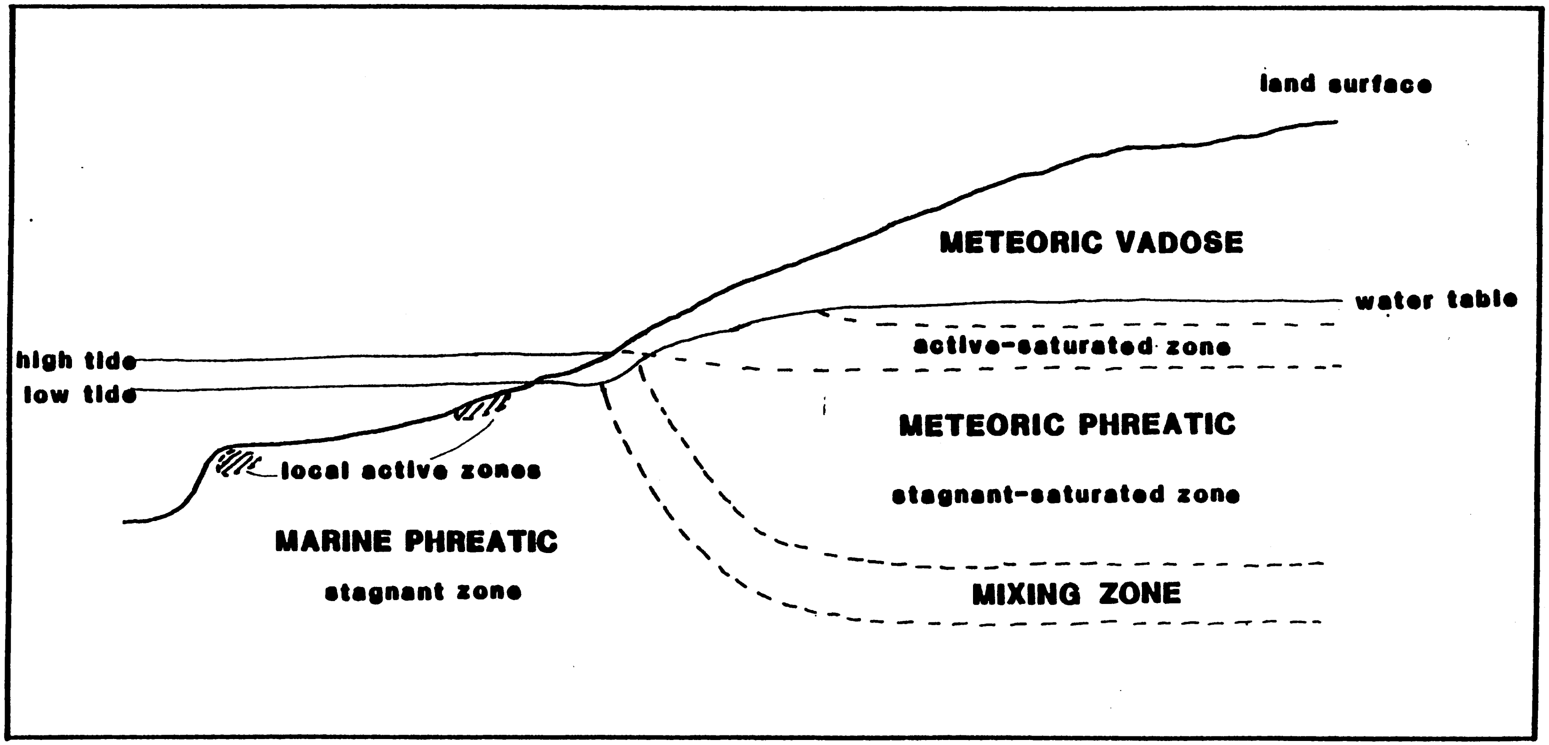
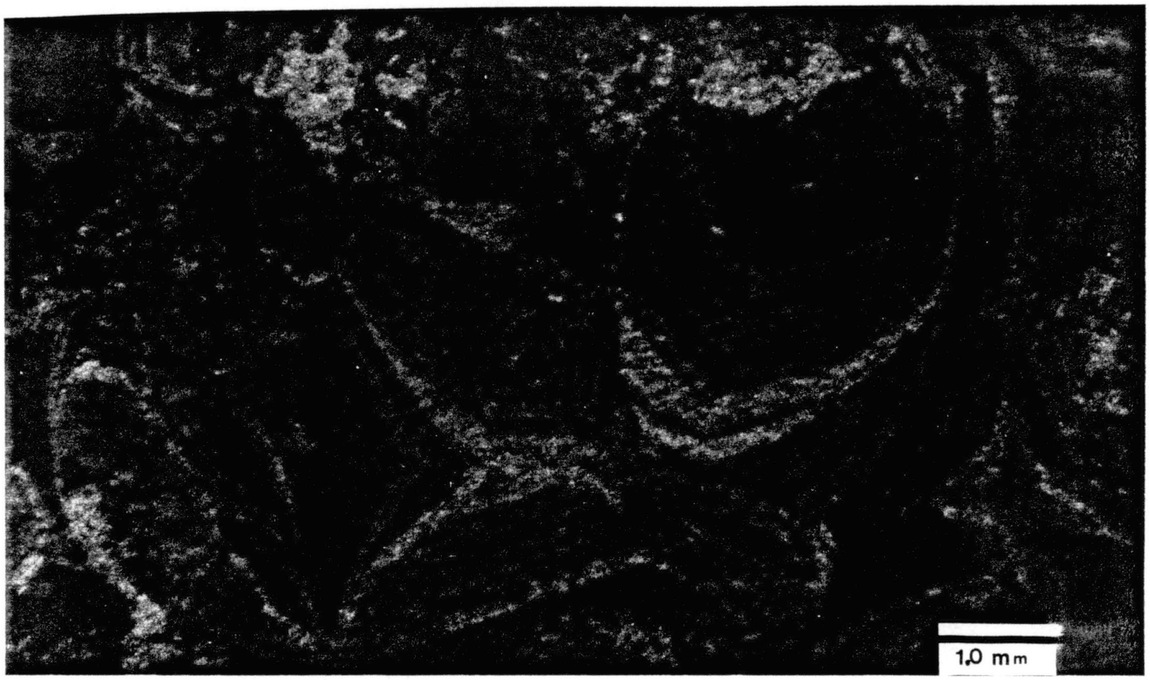
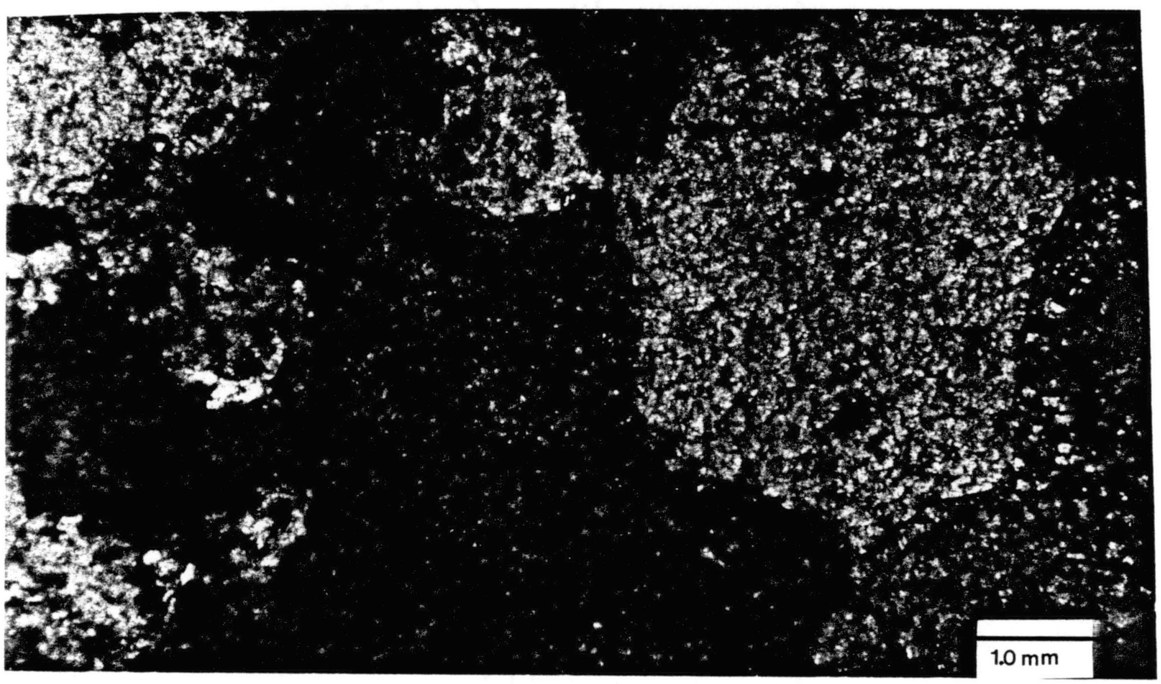


Figure 24. Generalized Diagram of Diagenetic Environments (after Longman, 1980, Figs. 1, 3, 7, 14)



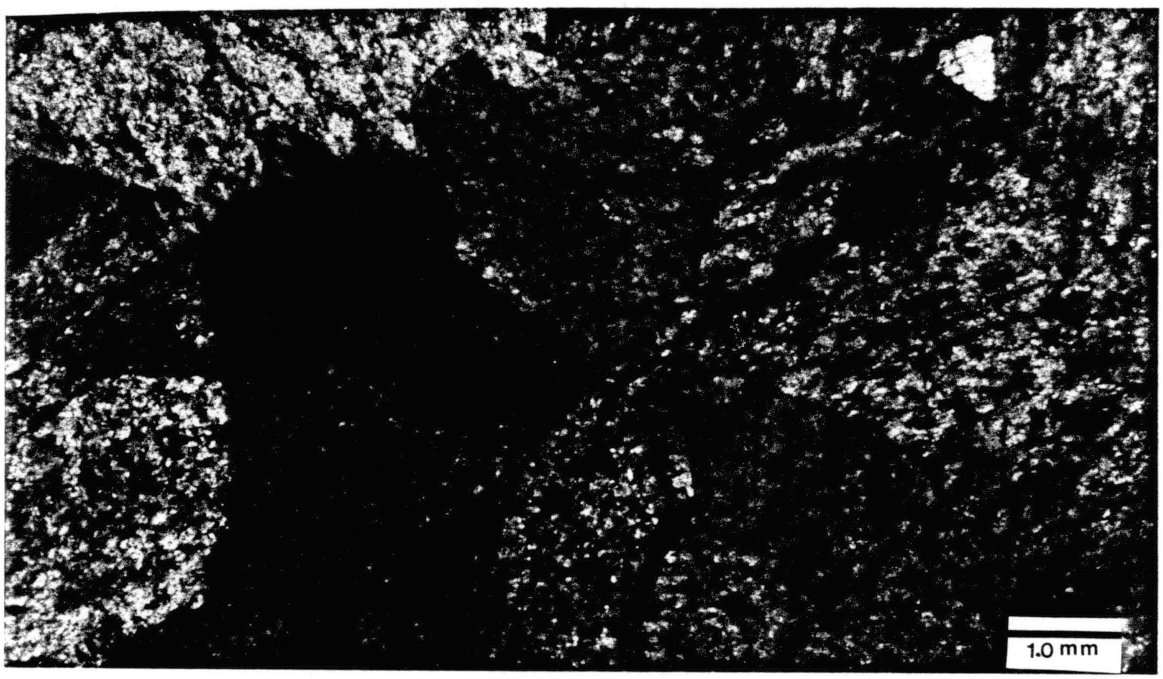
[A]



[B]

Figure 25. (A) Cathodoluminescence of Calcite Cement. Alternating Bands of Brightness Indicate Multiple Periods of Cementation; (B) Plane Polarized Light of the Same Thin-Section Shows Large Calcite Crystals

[A]



[B]

Figure 26. (A) Cathodoluminescence of Calcite Cement; (B) Plane Polarized Light of the Same Thin Section

for the fluid to replenish itself with the necessary ions. When local supersaturation once again occurs, precipitation of a new band begins.

Pyrite is present as a minor precipitant in the Cochrane Formation and is a late occurrence. It forms when the sediments are placed in reducing conditions with increasing depths.

Alteration, Dissolution and Replacement. The constituents which are affected by one or more of these processes are glauconite, clay, dolomite, calcite, silica and fossil fragments.

Both alteration and dissolution of glauconite are seen in the Cochrane. Some of the glauconite was removed from its stable microenvironment and brought into oxidizing conditions soon after its formation. The oxidizing conditions altered the glauconite to smectite (Figure 27). In some cases, alteration continued to where the pellets were dissolved. This is evidenced by brown rims lining the pores from where the altered glauconite was dissolved (Figure 28). In other instances, the smectite resulting from the alteration of glauconite was brought to reducing conditions by burial and was altered to illite (Figure 29).

Dolomite is present as a moderately early diagenetic feature which formed by reflux or fresh-sea water mixing. A detailed discussion of this dolomite formation follows later in the chapter. This dolomite, as well as the late diagenetic dolomite is seen replacing calcite (Figure 30). The late diagenetic dolomite present in this formation is known as baroque dolomite. It is a deep burial hydrothermal constituent. Dissolution of the early diagenetic dolomite takes place when the rocks are brought back up to or near the surface due to erosion. This dissolution takes place during dedolomitization.

Silica replaces calcite, fossil fragments, and dolomite. Silica

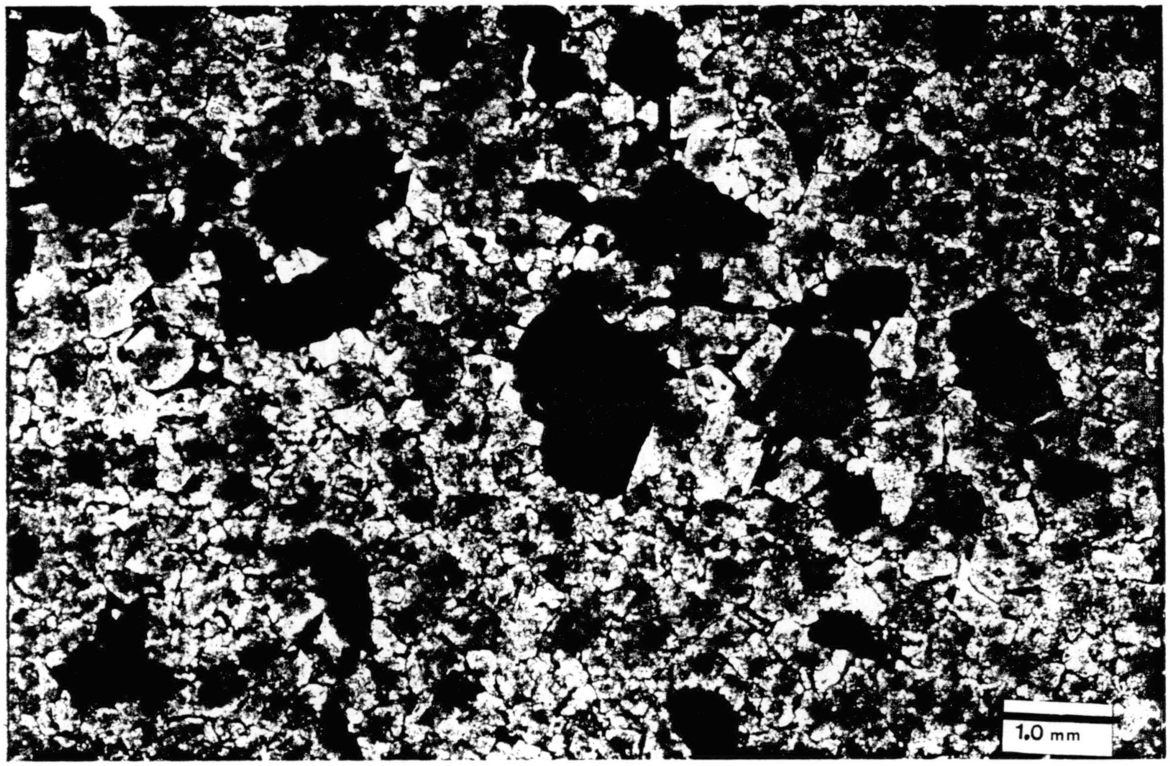


Figure 27. Alteration of Glauconite to Smectite Due to Oxidation. Plane Polarized Light

Figure 28. Dissolution of Glauconite. Results from Continued Alteration.
Plane Polarized Light

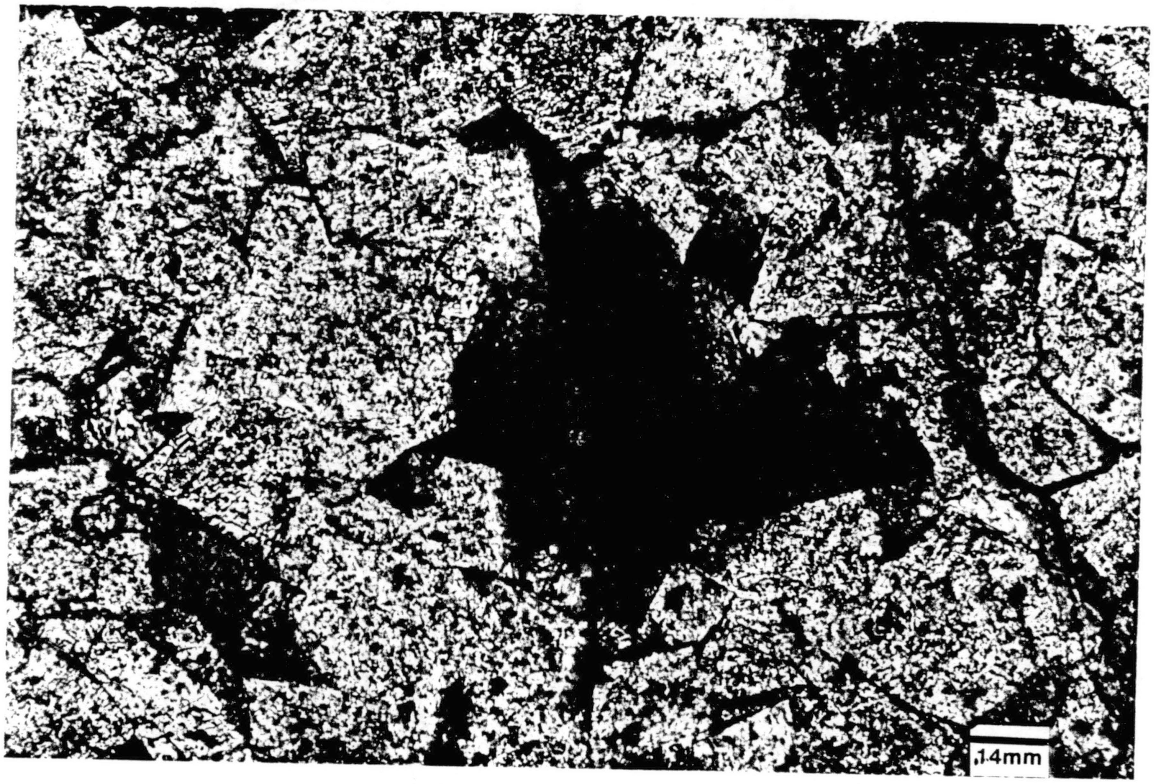


Figure 29. Alteration of Glauconite to Illite Due to Reduction. Plane Polarized Light

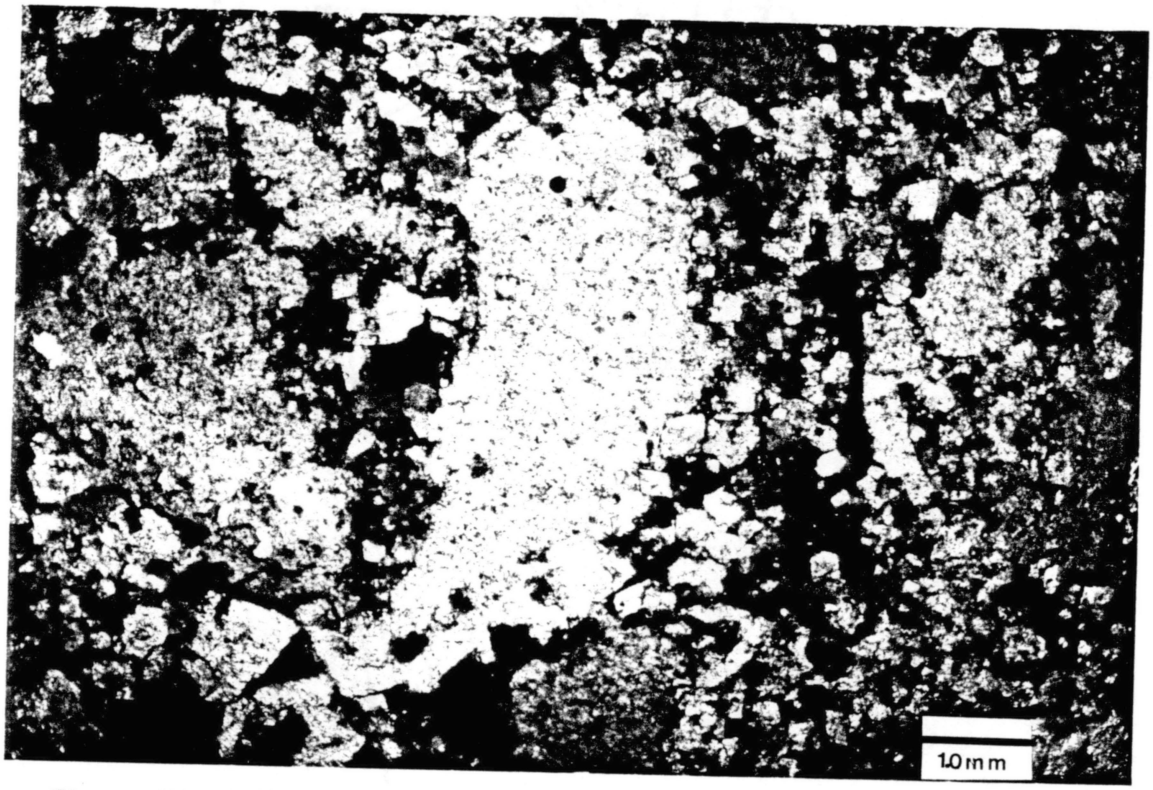


Figure 30. Dolomite Seen Replacing Calcite. Crossed Polars

replaces calcite in the forms of chert, chalcedony and megaquartz. This replacement is a function of pH and silica concentration of the formation waters. When pH drops below approximately 7.5, silica will become stable and precipitate while calcite dissolves. When the pH allows for silica precipitation, the type of silica which forms is then a function of silica concentration in solution. The precipitants, in order of decreasing silica concentration, are chert, chalcedony and megaquartz (Folk and Pittman, 1971). This relationship can be seen in Figure 31, where chert replaced the matrix first, lined the fracture with chalcedony next, and finally filled in the remaining voids with megaquartz. Fossil fragments are rarely replaced, but when they are, chert is the most common type of silica to do so. Dolomitization interrupted by silicification by chert can also be seen in some areas.

Clarita Formation

The diagenesis of the Clarita Formation also includes:

1. Secondary authigenic precipitants
2. Alteration, dissolution and replacement

much like the Cochrane Formation. The paragenesis for these features and physical effects are summarized in Figure 32.

All minerals present as secondary authigenic precipitants and those due to alteration, dissolution and replacement found in the Clarita Formation are formed by the same mechanisms as those found in the Cochrane.

The formation of neomorphic spar is the only diagenetic feature in the Clarita which is not found in the Cochrane. Neomorphism of fossil grains occurs in the active freshwater phreatic environment (Longman,

Figure 31. Vug Filling Silica Reflects a Decrease in Silica Concentration. Crossed Polars

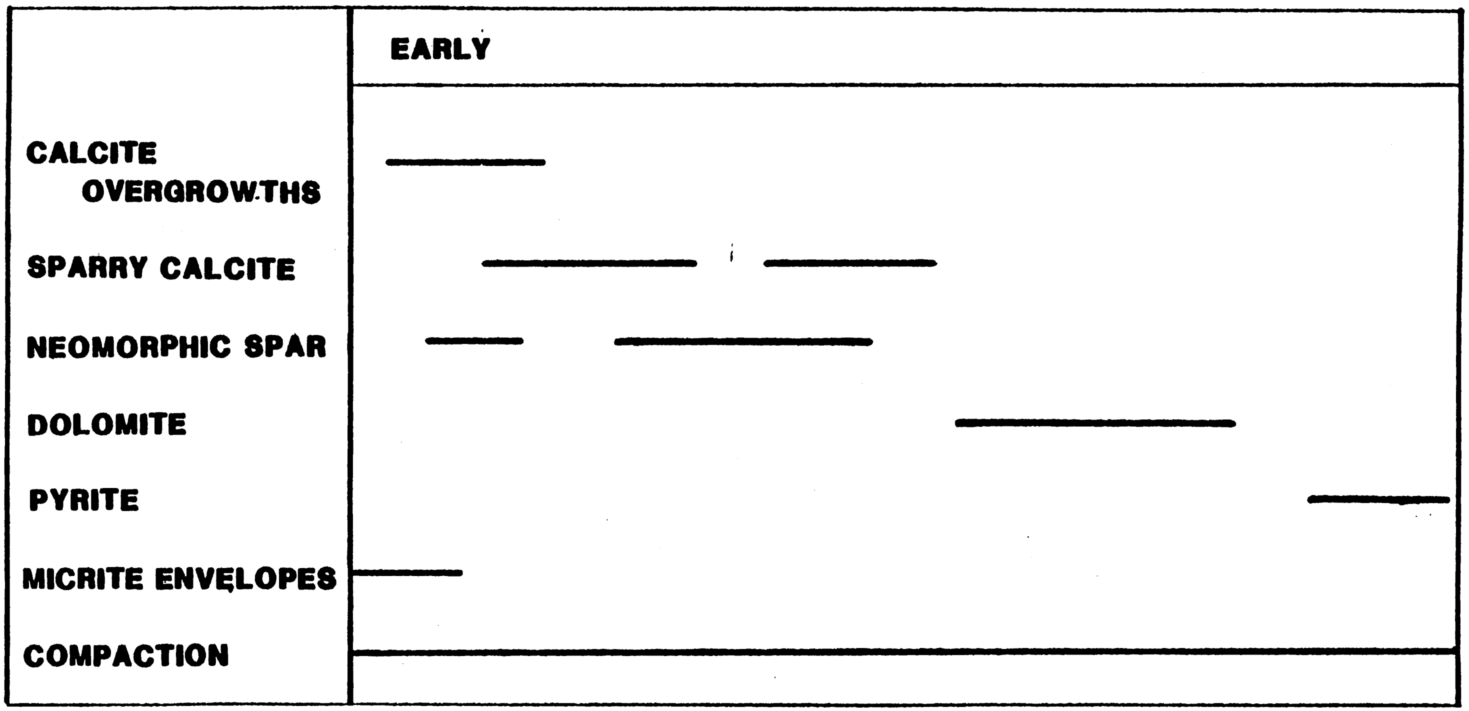


Figure 32. Paragenetic Sequence for the Clarita Formation

1980). This tends to occur because the water flowing through aragonite rich sediments is undersaturated with repsect to aragonite, resulting in solution. However, the water is saturated with respect to calcite, therefore precipitating calcite in the place of dissolved aragonite (Longman, 1980).

Porosity

Porosity Types

Porosity within the Chimneyhill Subgroup can be defined according to the classification by Choquette and Pray (1970). According to this classification, porosity can be fabric selective or not fabric selective. Fabric selective porosity is by far the most abundant within the subgroup.

The porosity types present within each Chimneyhill formation will be discussed separately for each formation.

Keel Formation. Porosity in the Keel Formation is present in the dolomitized zones. Interparticle porosity, which resulted from the dolomitization of the ooids, is the only type of porosity present within the Keel. No porosity is found in the limestones.

Cochrane Formation. Porosity in the Cochrane is present in the dolomitized zones and in the limestones. The dolomites show interparticle, moldic, and intraparticle porosity, all of which are fabric selective. The limestones exhibit moldic porosity, which is fabric selective, and fracture porosity, which is not fabric selective.

Interparticle porosity (Figure 33) is the most common type of porosity in the Cochrane dolomite. It is due to the replacement of limestones by dolomites which results in an increase in porosity. This

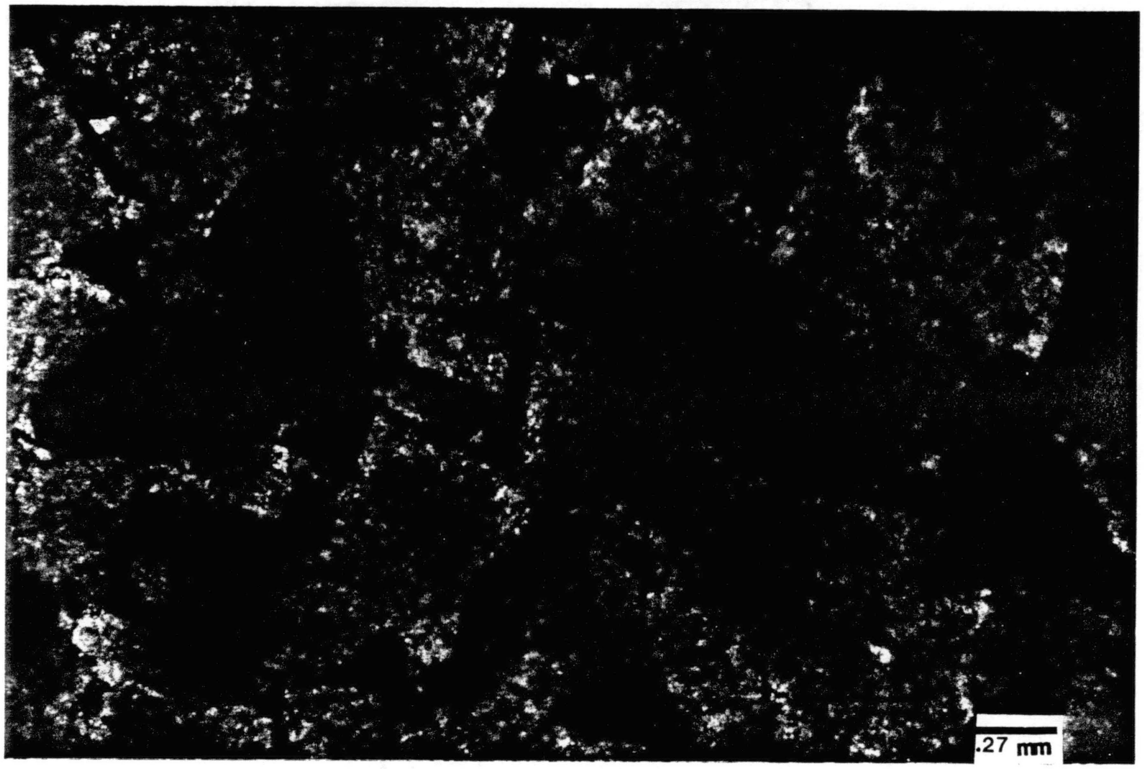


Figure 33. Interparticle Porosity in the Cochrane Dolomite. Plane Polarized Light

type of porosity may also be a result of dissolution of calcite and dolomite, where the mold is no longer visible.

Moldic porosity (Figure 34), which is also present in the dolomites, is due to the dissolution of dolomite, fossil fragments (mostly crinoids), glauconite and remnant sparry calcite cement. The type of grain whose dissolution resulted in these pores can most often be identified by the shape of the mold. Occasionally, remnants of the grains are seen in the molds, confirming the origin of the pore. The dissolution of glauconite can be confirmed by the presence of brown rims around the pores which are a result of the alteration of glauconite to smectite/illite.

Intraparticle porosity (Figure 35) is the least common porosity type present in the Cochrane Formation. Its presence is due to the partial dissolution of dolomite rhombs and glauconite pellets.

Moldic porosity (Figure 36) is the most common porosity type in Cochrane limestones. It results from the dissolution of fossil fragments. Crinoid fragments are most commonly dissolved, but in cases of extensive dissolution, other fossil grains such as brachiopod fragments are also dissolved.

Fracture and vuggy porosity are present in the limestones, but not common. Neither are fabric selective and tend to occur late in the diagenesis of the rocks. They can be seen cutting across many other diagenetic features. In some areas, the vugs are present along the fractures indicating that they are associated with each other.

<u>Clarita Formation</u>. Porosity in the Clarita is present in the dolomitized zones and in the limestones, as in the Cochrane. Interparticle porosity is present in the dolomitized zones, while moldic, interparticle and intraparticle porosity are found in the limestones.

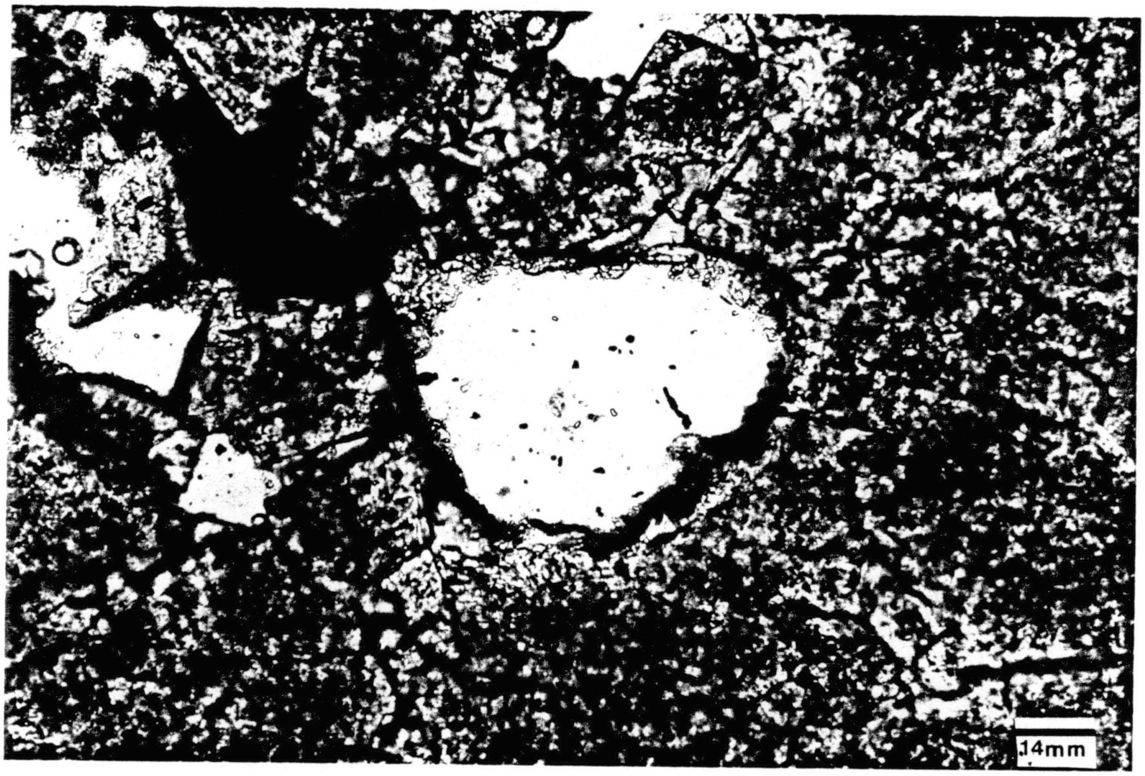


Figure 34. Moldic Porosity in the Cochrane Dolomite. The Dissolved Grain Can Be Identified by the Pore Shape. Plane Polarized Light

Figure 35. Intraparticle Porosity in the Cochrane Dolomite. Plane Polarized Light

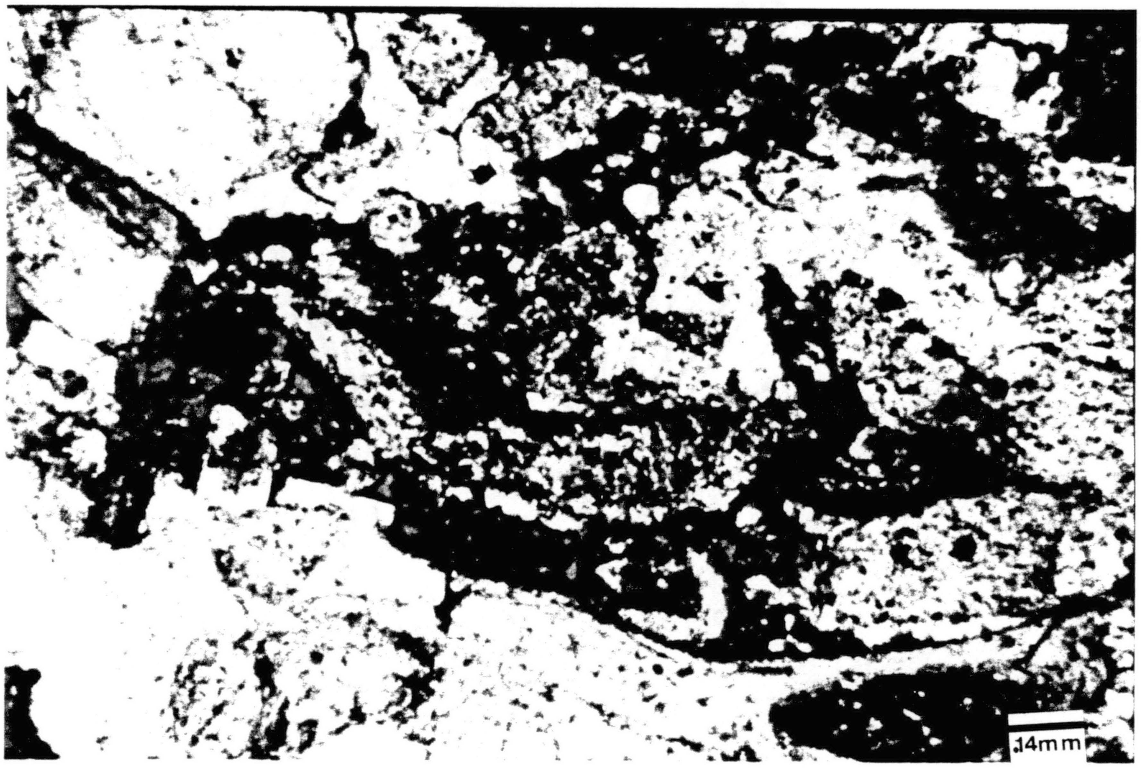


Figure 36. Moldic Porosity in the Cochrane Limestone. Plane Polarized Light

Interparticle porosity in the dolomites is present between the rhombs. The porosity is a result of the replacement of calcite by dolomite rhombs. Isolated patches of greater porosity most likely indicate burrows in the sediment.

Moldic porosity in the limestones is due to the dissolution of fossil fragments, predominantly crinoid grains. It is the most common porosity in the Clarita limestones.

Intraparticle and interparticle porosity are present but not common. Intraparticle porosity is a result of the partial dissolution of fossil fragments. Interparticle porosity is due to the dissolution of micrite and incomplete cementation. This is the least common porosity type.

Porosity Controls

Porosity in the Chimneyhill Subgroup is found in the dolomitized zones and in the limestones. Production occurs from both these rock types in the Chimneyhill (Amsden, 1975).

Porosity appears to be greatest in the dolomitized zones. Samples with the greatest porosity show evidence of solution. Fossil fragments, dolomite rhombs and glauconite pellets are all constituents which dissolved to form porosity. Some of the porosity in the dolomites is a result of the development of crystalline texture. Solution along veins, stylolites and fractures may also contribute to the presence of porosity. However, solution of the above mentioned grains appears to be the greatest contributor to dolomite porosity. This solution is directly related to dolomitization because calcite fossil fragments would become unstable with the influx of magnesium-rich waters conducive to dolomite formation.

Some low-magnesium limestones in the Chimneyhill also exhibit good porosity. Some of the porosity in these zones appears to be interparticle. Incomplete cementation, possibly followed by solution, may have resulted in this type of porosity. Although interparticle porosity is seen in these limestones, moldic porosity is most common, resulting from the dissolution of fossil fragments, primarily crinoids. Small amounts of dolomite are present in these limestones indicating that the solution of these fossil grains is a result of the influx of magnesium-rich waters through the limestones.

Dolomitization

The most accepted theories for dolomitization are diagenesis by eogenetic hypersaline brines (Adams and Rhodes, 1960; Hsü and Siegenthaler, 1969; Deffeyes, Lucia, and Weyl, 1965; Beales and Hardy, 1980; and others), marine water-freshwater mixing (Hanshaw, Back, and Deike, 1971; Badiozamani, 1973; Land, 1973; Folk and Land, 1975; Dunham and Olson, 1980; and others), or both (Folk and Siedlacka, 1974; Sears and Lucia, 1980). Evidence to be presented in this section supports dolomitization of the Chimneyhill Subgroup to be a result of both hypersaline brines and marine-freshwater mixing.

A paleogeographic reconstruction by Habicht (1979) places the Anadarko Basin between 20 to 25° south of the equator during Late Ordovician time, and between 15 to 20° south of the equator during Early to Middle Silurian time. This geographic location indicates the possibility of a semiarid to arid environment during Chimneyhill time. This type of environment would be conducive to hypersalinity in shallow eiperic seas if evaporation exceeded precipitation. For this to be true, there must be some evidence of the presence of evaporites.

It is possible for mixing to occur in a semiarid to arid environment as well. It is, therefore, plausible to assume that dolomite, which formed by early hypersaline methods, may later be affected by mixing type dolomite. A feasible mode of dolomite formation in the Chimneyhill is where early hypersaline dolomite formed, followed by the modification and/or addition of a second species of dolomite. This has been noted by Folk and Siedlacka (1974). Petrographic evidence will be cited to confirm this type of dolomitization. Because the dolomitization models discussed here pertain to all the formations in the Chimneyhill Subgroup, dolomitization will be discussed for the subgroup as a whole, and not for each formation.

Dolomitization Model

Dolomitization in the Chimneyhill Subgroup can be divided into two phases:

1. Penecontemporaneous hypersaline dolomitization
2. Eogenetic mixed water dolomitization

Phase I - Hypersaline Dolomitization. Hypersaline dolomitization is evidenced by the features summarized in Table I. These features are characteristic of the supratidal depositional facies which has been noted in the formations of the Chimneyhill Subgroup. The presence of this environment indicates arid to semiarid conditions which may have resulted in a drop in sea level, exposing isolated areas on the depositional slope (see Chapter III). This arid environment resulted in the evaporation of sea water which caused the precipitation of gypsum and/or anhydrite. Some anhydrite laths are still seen (Figure 37) although silica has replaced

TABLE I

SUMMARIZATION OF EVIDENCE FOR HYPERSALINE DOLOMITIZATION

Observations	Inferences
Paleogeography Algal Structures Sparse Fauna Fenestral Fabric	--Sabkha-type Environment
Anhydrite Laths Replaced Anhydrite Nodules	--Result in Increased $\frac{Mg^{2+}}{Ca^{2+}}$ Ratio
Cloudy Brown Rhomb Centers	--Typical of Hypersalinity
Dolomite Decreases With Depth	--Dolomitizing Fluids Percolate Down from Above

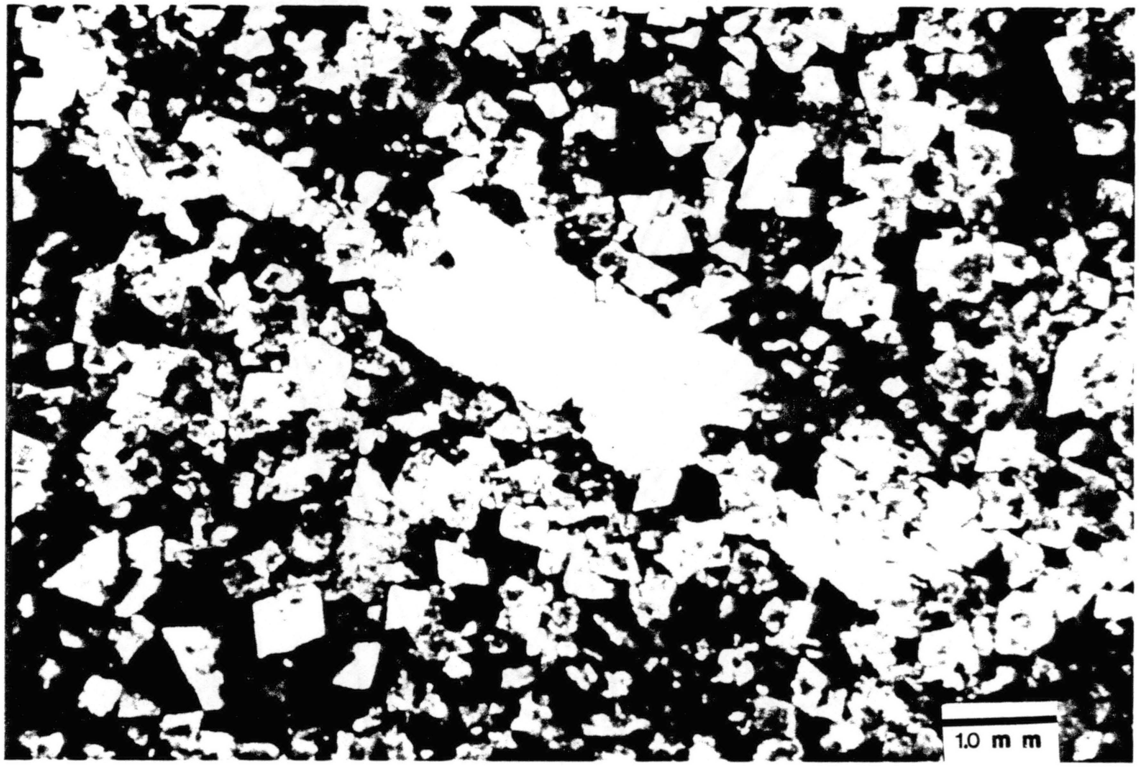


Figure 37. Anhydrite Lath in Dolomite Indicating the Possibility of an Evaporitic Environment. Crossed Polars

some evaporites in some cases. The precipitation of $CaSO_4$ results in an increase in the Mg^{2+}/Ca^{2+} ratio of the brines. This precipitation of $CaSO_4$ is a major contributor to the formation of dolomite.

Hypersaline dolomitization occurs when these Mg^{2+} rich brines, which formed by evaporation of sea water, sink down through the underlying sediment. They pass through the most porous limestones, dolomitizing the rocks they pass through. Figure 38 is a diagram depicting the localized dolomitization resulting from the migration of these refluxing brines. Changes in compositional character of the brines and of the invaded limestones, limit the downward extent of dolomitization (Adams and Rhoades, 1960).

The dolomite formed by hypersaline brines is typically anhedral, and has irregular boundaries. The rhombs appear "dirty" due to the presence of inclusions which give the rock and thin sections a brownish color. Phase I dolomite, which forms near the surface, does not allow Fe^{2+} to be incorporated into its lattice. This results in rhombs with very low electron-induced luminescence (Figure 39).

Phase II - Mixed Water Dolomitization. Evidence for mixed water dolomitization (Table II) is not as clearcut as that for Phase I dolomitization.

Mixed water dolomitization takes place when a zone of fresh water comes into contact with ocean water. The fresh water which caused this dolomitization in the Chimneyhill, was most likely derived from rainfall which accumulated as a freshwater lens in exposed ridges in the ridge and swale Chimneyhill topography. This fresh water migrated downward until it met the sea water. A brackishwater zone (Figure 40) formed due to the mixing of these two waters (Hanshaw and others, 1971). Mg^{2+} is supplied

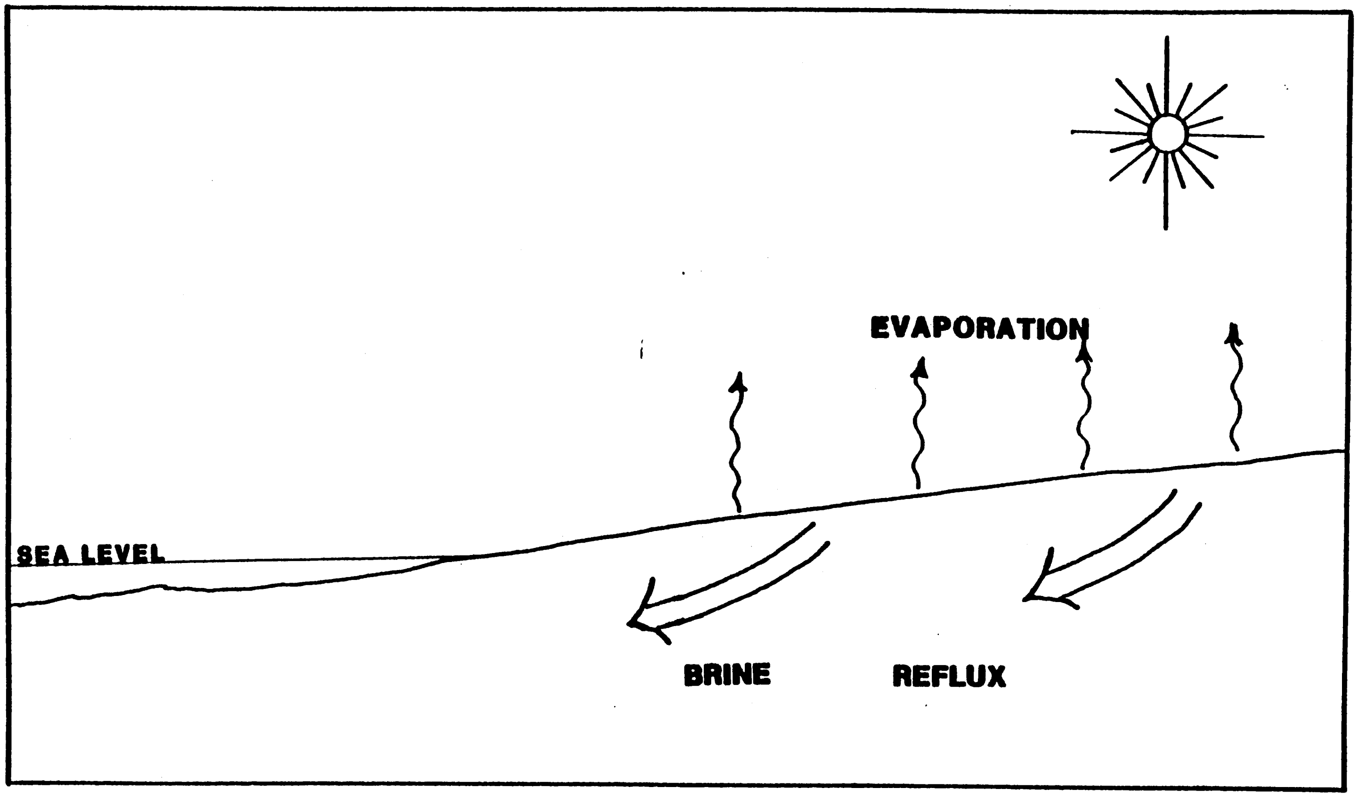


Figure 38. Illustration Depicting Hypersaline Dolomitization (after Beardall, 1983)

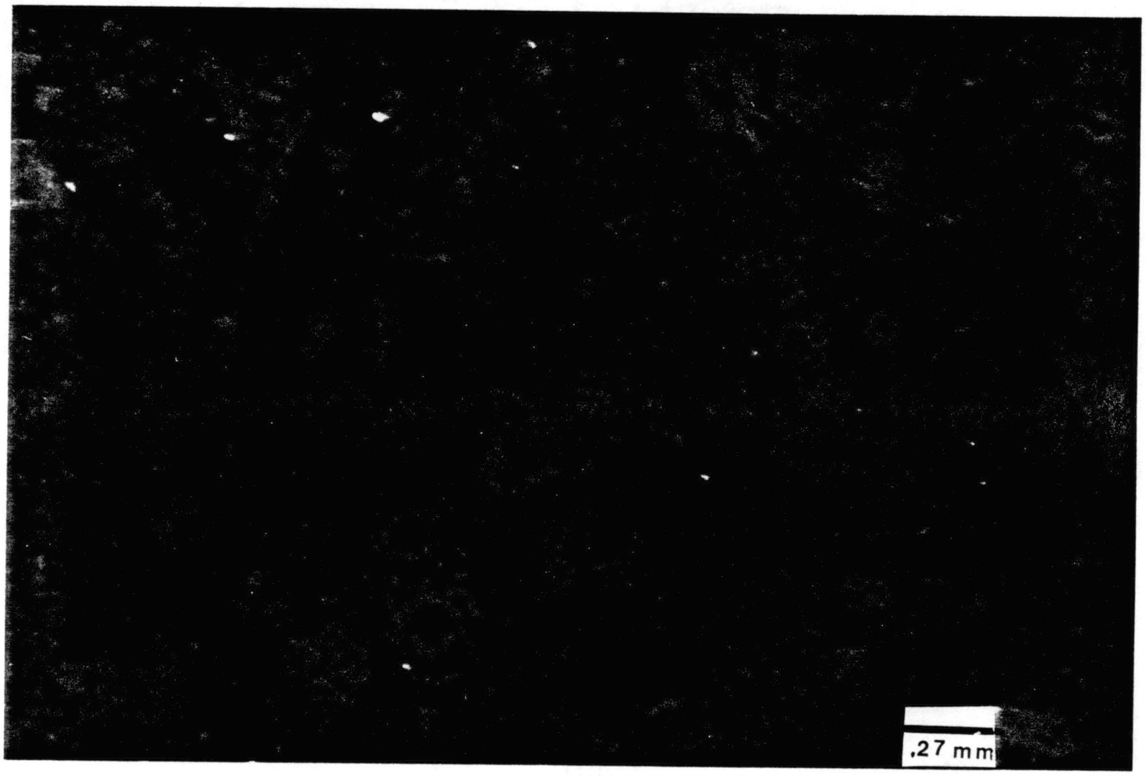


Figure 39. Cathodoluminescence of Phase I Dolomite

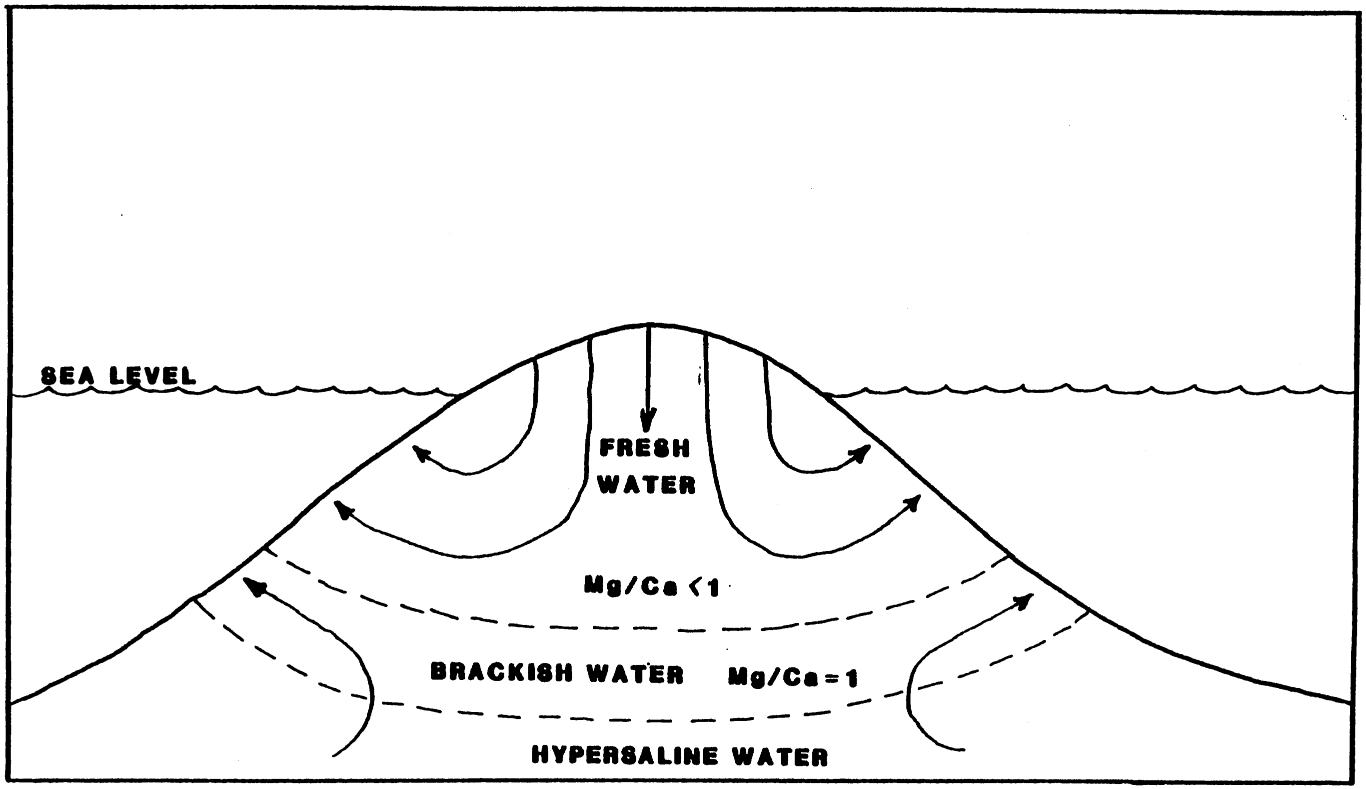


Figure 40. Illustration Depicting Mixed-Water Dolomitization (after Hanshaw, Back and Deike, 1971)

TABLE II

SUMMARIZATION OF EVIDENCE FOR MIXED WATER DOLOMITIZATION

Observations	Inferences
Prograding Shoreline	--Advancing Freshwater Lenses
Clean Rhomb Overgrowths	--Characteristic of Fresher Water
Cathodoluminescence	--Suggests a Late Anaerobic, Phreatic Influence

to this zone by the sea water, while $CaCO_3$ dissolution is due to the mixing of the two waters. The mixing of these waters drastically reduces the salinity, while the Mg^{2+}/Ca^{2+} ratio remains high because the amounts of Mg^{2+} and Ca^{2+} from the fresh water are very small compared to the large amounts found in sea water. This decrease in salinity results in the formation of dolomite (Folk and Land, 1975).

The dolomite formed by mixed water dolomitization is limpid, or has a cloudy center and a limpid rim (Figure 41) and lacks inclusions. This type of dolomite forms because dilution by fresh water results in slow crystallization. This Phase II dolomite is much more resistant to dissolution than Phase I dolomite.

Luminescence can be important to distinguish Phase II dolomite. This dolomite exhibits distinct bands of variations in luminescent intensity (Choquette and Steinen, 1980). This variation is due to different concentrations of the activator (Mn^{2+}) and quencher (Fe^{2+}) ions within the dolomite rhombs. The zonation occurs because initially, the oxidized Fe^{3+} and Mn^{3+} ions are too large to be incorporated in the rhombs, resulting in dull luminescence. This is indicative of dolomite initiated as Phase I dolomite. As reducing conditions take over, the Mn^{2+} ion will enter the lattice, resulting in bright luminescence. This bright zone often coincides with the limpid rims which indicate fresh-saline water mixing (Figure 42). Fe^{2+} may be incorporated with increasingly reducing conditions and result in nonluminescence.

Dedolomitization

The occurrence of dedolomitization is restricted to the Cochrane Formation. The presence of dedolomitization is believed to indicate the

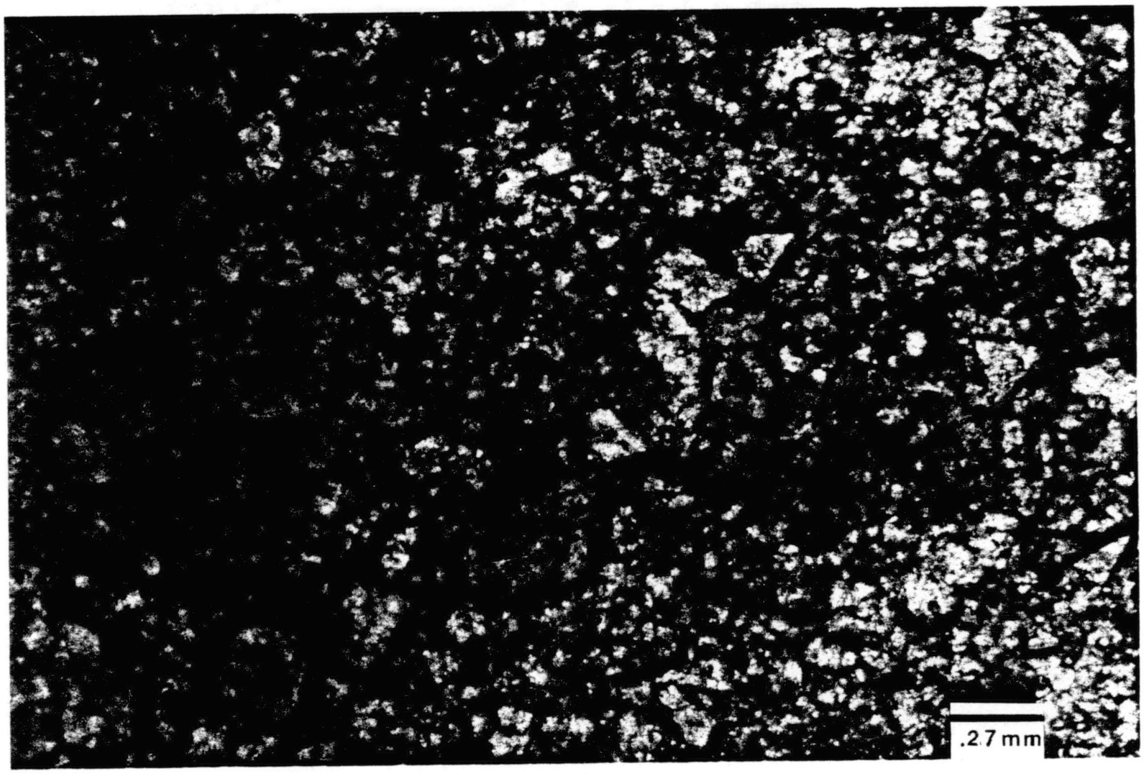


Figure 41. Phase II Dolomite with Limpid Rims and Cloudy Centers. Plane Polarized Light

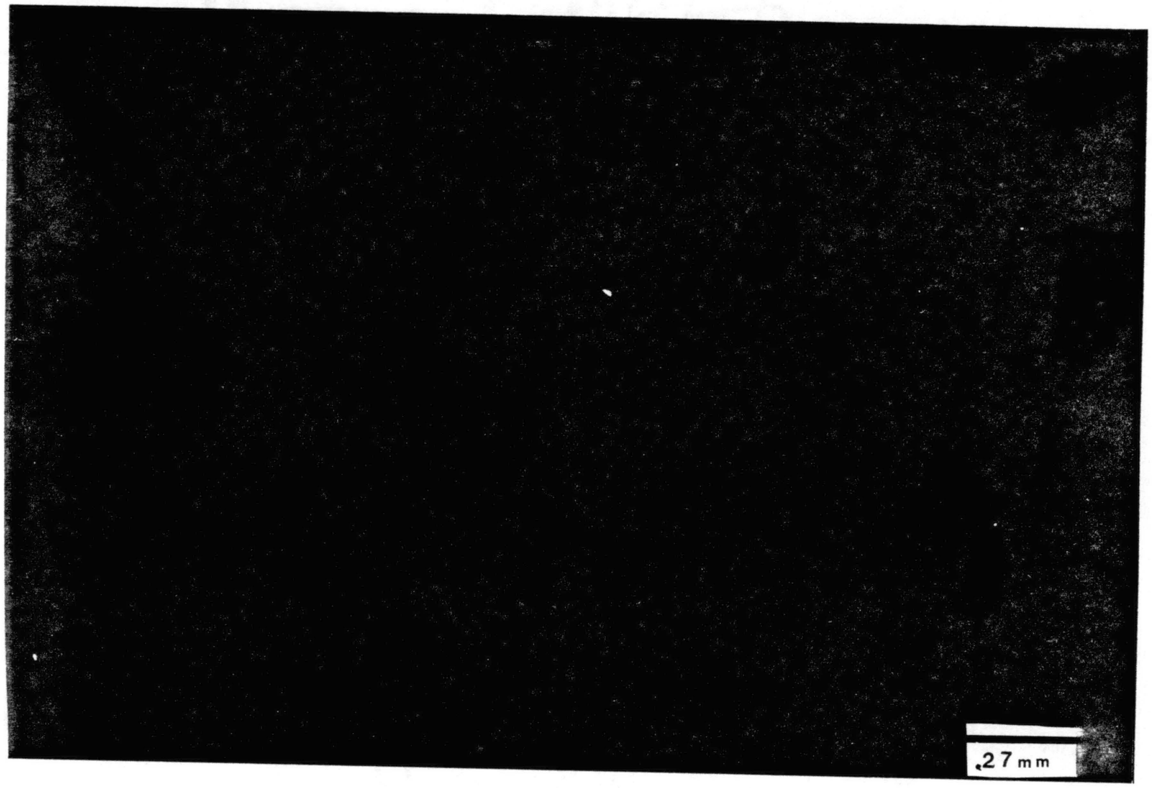


Figure 42. Cathodoluminescence of Limpid Rim Dolomite

presence of an unconformity (Schmidt, 1965; Goldberg, 1967; Braun and Friedman, 1970; Chafetz, 1972; and others). In the case of the Cochrane Foramtion, dedolomitization may indicate the regional unconformity between the Cochrane and the Clarita formations, or small, local unconformities found within the Cochrane. This will be discussed in detail in Chapter VI.

Braddock and Bowles (1963), Evamy (1963) and Folkman (1969) suggested that dedolomitization occurs as a result of the introduction of excess calcium and sulfate ions from gypsum and anhydrite:

$$CaSO_4 + CaMg(CO_3)_2 \rightleftharpoons 2CaCO_3 + MgSO_4$$

Katz (1971) believed that dedolomitization is the product of early diagenesis due to the dilution of interstitial dolomitizing brines. But deGroot (1967) concluded from experimental work that the process of dedolomitization requires solutions with a high Ca^{2+}/Mg^{2+} ratio, rapid flow rate of solutions, temperatures below $50^{o}C$ and pressure below 0.5 atm. These conditions indicate near surface processes. This coincides with the fact that nearly all reported dedolomitization is associated with subareal weathering, either at ancient unconformities, or at the Earth's surface (Munn and Jackson, 1980).

Process of Dedolomitization

Dedolomitization occurs when carbonate rich waters with a high Ca^{2+}/Mg^{2+} ratio flow through dolomitized rocks. The migration of these fluids results in the dissolution of dolomite and the precipitation of calcite. Where gypsum and/or anhydrite are present, the dissolution of dolomite is enhanced. This occurs because the dissolution of gypsum/anhydrite releases Ca^{2+} into the system. This increases the Ca^{2+}/Mg^{2+}

ratio for the migrating fluid and results in continued calcite precipitation and dolomite dissolution.

Dedolomitization is believed to initiate in various ways resulting in different textures. Dolomite will often retain tiny, relict calcite inclusions of the original limestone as it grows. These inclusions are thought to occur in most dolomite that has replaced calcite, although they may be too small to observe under a microscope (Evamy, 1967). These inclusions are thought to have a fairly even distribution throughout the rhombs, except in cloudy-centered, clear-rimmed dolomite, where the inclusions are concentrated in the middle. When the Ca^{2+} rich waters flow through the rock, the dolomite will become unstable and the calcite inclusions will take over.

Another way for dedolomitization to initiate is when calcite precipitates in the pores of the dolostones and attacks the rhombs adjacent to it. The dolomite will initially be attacked at its edges, producing centripital corrosion (Munn and Jackson, 1980). With continued corrosion, dedolomitization moves toward the center resulting in corroded rhomb boundaries (Figure 43).

When the rhombs are zoned, the outer, cleaner rims tend to be more stable than the cores, due to their lack of inclusions. In this case, the Ca^{2+} rich waters will begin to corrode the core and precipitate calcite there, while leaving a rim of dolomite (Figure 44). Cathodoluminescence confirms the presence of dedolomitization where parts of a corroded rhomb show the same luminescence as the surrounding sparry calcite cement (Figure 45).

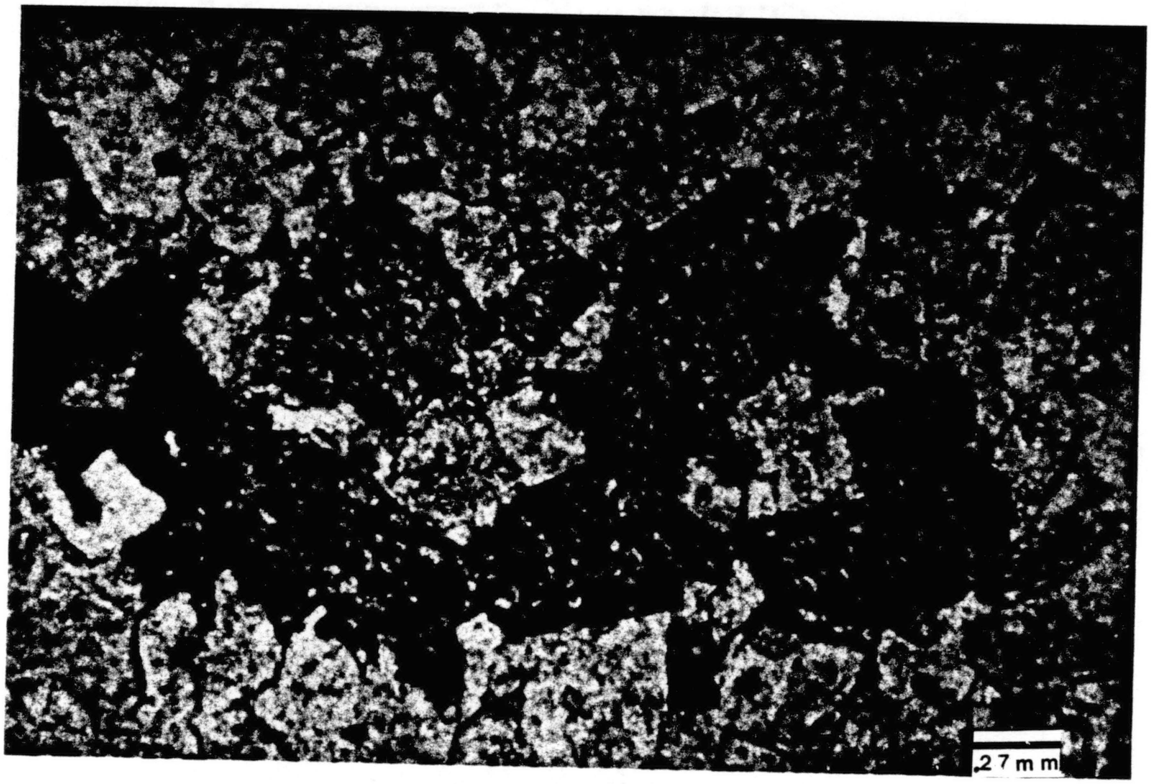


Figure 43. Corroded Dolomite Rhomb Boundaries Resulting from Dedolomitization. Plane Polarized Light

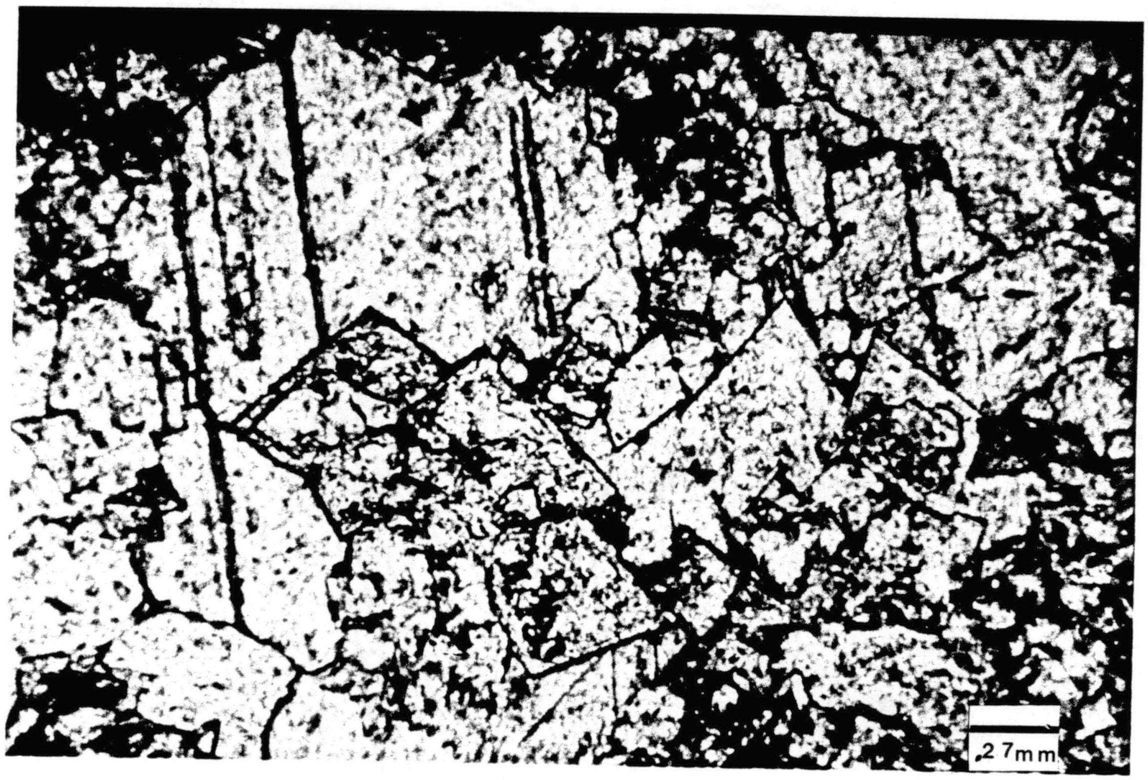


Figure 44. Dolomite Rhomb with Stable Limpid Rim and Unstable Core Which Has Been Replaced by Calcite. Plane Polarized Light

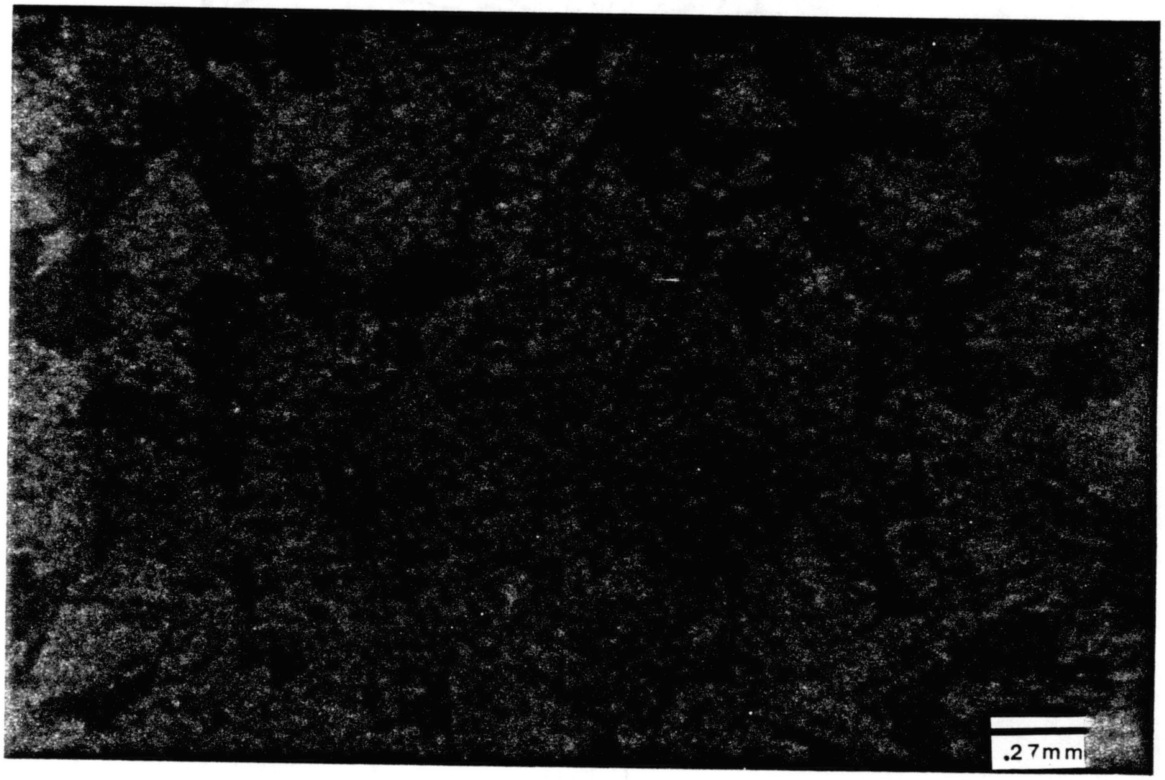


Figure 45. Cathodoluminescence of Corroded Dolomite Rhombs Shows Different Brightnesses for Dedolomitization

CHAPTER VI

RECOGNITION OF UNCONFORMITIES

Introduction

The presence of a regional unconformity associated with the Chimneyhill Subgroup has been confirmed by Amsden (1960) and Shannon (1962). This unconformity is located between the Chimneyhill and the overlying Woodford Shale where the rest of the Hunton Group has been removed by erosion. Features which were used to identify this unconformity will be discussed and examples presented.

The study of this regional unconformity, which in most cases has been found directly above the Cochrane Formation in most cores, has led to the discovery of possible local unconformities within the Cochrane. These unconformities may be considered paraconformities which are situations where no apparent erosional break exists, but a hiatus is present (Chenowith, 1967). Evidence used to identify the regional unconformity will be adapted to propose possible sights for local unconformities within the Cochrane which may have formed due to erosion or periods of nondeposition.

Regional Unconformity

The presence of a regional unconformity identified above the Chimneyhill Subgroup is confirmed in three cores used in the study: ARCO Marcum U-1, Calvert Mid-America Bloyd 2, and E. L. Cox Annis A-1. These cores all penetrated the Chimneyhill and the Lower Woodford. This unconformity is evidenced by changes in lithology, electric log kick-backs, dedolomitization and karstification.

Lithology Changes

An abrupt facies change is used as the most obvious criteri identify unconformities. In the case of the regional unconformity above the Chimneyhill, the lithology change is obvious. The Woodford Shale is underlain by either limestone or dolomite. No facies gradation is seen in any of the cores, although the ARCO Marcum U-1 does exhibit a thin sandstone stringer at the base of the Woodford directly above the Chimneyhill. This general lack of facies gradation indicates that strata are missing.

Electric Logs

Electric logs were also used to help confirm the presence of a regional unconformity. Lithology changes seen in the cores were confirmed by electric logs showing the Woodford/Chimneyhill contact at the same depth. This contact is very easily identified using gamma ray and resistivity curves (Figure 46). Cross-sections constructed in both east-west and north-south directions confirmed the lateral extent of the unconformity (Figure 46).

Dedolomitization

Dedolomitization has been used as petrographic evidence to identify unconformities associated with carbonates in published literature (Schmidt, 1965; Goldberg, 1967; Braun and Friedman, 1970; Chafetz, 1972;

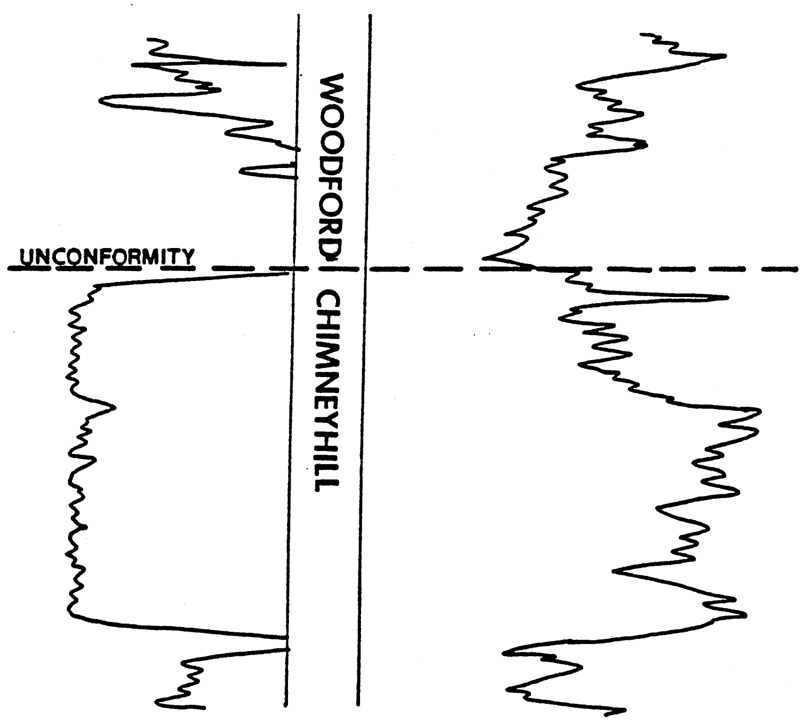


Figure 46. Electric-Log Signature of the Woodford/ Chimneyhill Unconformity

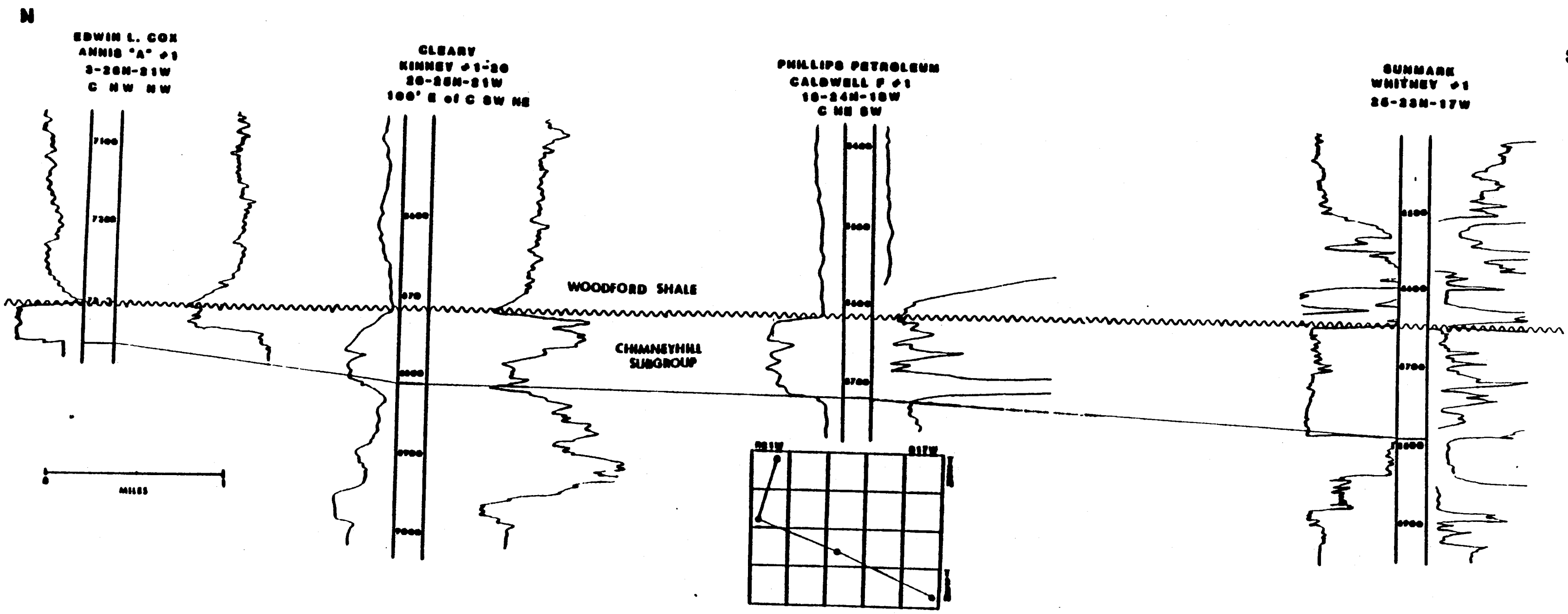


Figure 47. Stratigraphic Cross Section Showing the Extent of the Woodford/Chimneyhill Unconformity

Munn and Jackson, 1980; Frank, 1981; and others). Experimental work by deGroot (1967) concluded that dedolomitization is most likely a near-surface phenomenon. This aids in the confirmation that dedolomitization is associated with unconformities.

Dedolomitization is the process which results in corrosion, dissolution, and/or calcitization of dolomite rhombs. This occurs when Ca^{2+} rich waters flow through the dolomite, rendering it unstable and resulting in its dissolution or replacement. A detailed discussion of this process can be found in Chapter V, and therefore will not be repeated here.

Several cores exhibit extensive dedolomitization for some depth below the known regional unconformity. This is especially visible in the ARCO Marcum U-1 core (Figure 48). Dedolomitization was only seen in cores where it appeared to be associated with an unconformity and tended to decrease with depth away from the unconformity.

Karstification

Karst and collapse breccia features are believed to represent unconformity surfaces (Esteban and Klappe, 1983). Karstification occurs in limestones and in dolomites. The Chimneyhill exhibits karstification in the dolomites and in the pink crinoidal shoal packstones/grainstones.

Karstification is the result of carbonate dissolution by calcium carbonate undersaturated waters. Most caves and vugs result from dissolution by cold meteoric water (Thrailkill, 1968). This phreatic water may be undersaturated with respect to calcium carbonate due to either a change in temperature, floods in surface streams, or mixing of dissimilar waters. The mixing of dissimilar waters usually occurs when saturated or supersaturated vadose water mixes with ground water and

Figure 48. Dedolomitization Believed to be Associated with the Regional Unconformity. Plane Polarized Light

results in carbonate solution. Circulation of the undersaturated water is important to remove dissolved material to allow continued carbonate dissolution. This water circulation is dependent on discharge and groundwater recharge (Legrand and Stringfield, 1973).

The karstification process occurs through three zones which include infiltration, percolation and lenticular zones (Esteban and Klappa, 1983). The upper infiltration zone is found in the upper vadose, surface landforms, vertical caves and collapse breccias are characteristic of karstification here. The percolation zone occurs next and is found in the lower vadose. Vertical movement of water through pre-existing paths occurs here. Because this zone is dominated by vadose water seepage, there is little dissolution. Only localized vadose flows show active dissolution. The lowermost area of karstification is the lenticular zone which is present in the upper phreatic. Subhorizontal caves are the dominant feature, while subvertical caves, although present, are minor. Most solution caves occur here and most abundant just below the water table. Collapse breccias which are related to the occurrence of caverns are locally abundant.

The Cleary Kinney No. 1-20 is an excellent example of karstified carbonates. This core shows the most complete set of features, whereas other Chimneyhill cores show only some of the karst characteristics. The cored interval immediately below the unconformity is a collapse breccia (Figure 49). The clasts are very angular, very poorly sorted and show no evidence of transport. The breccia is underlain by limestone which has undergone solution, but is still in place. Solution vugs, both horizontal and vertical (Figure 50), are present throughout this interval. The vugs decrease in abundance downward, indicating an association with

Figure 49. Core Slab Showing Brecciation Located Immediately Below the Unconformity

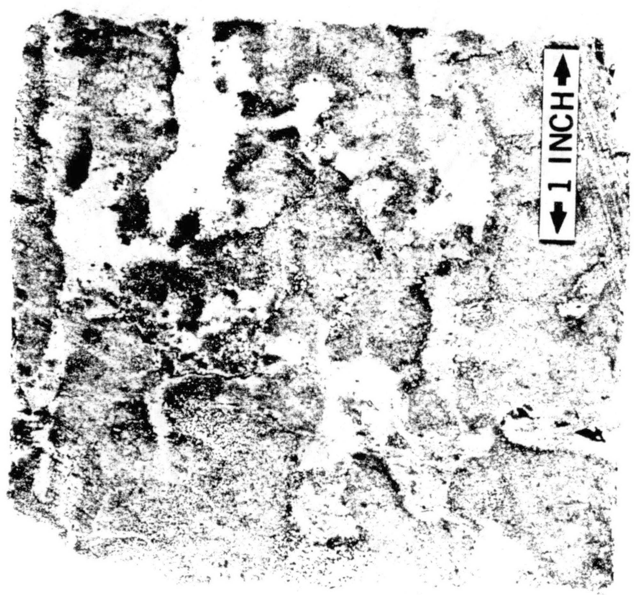


Figure 50. Core Slab of Solution Vugs Present Beneath the Unconformity

the overlying unconformity. The shape of the vugs is related to the movement of the water through the formation. Infiltration of waters results in vertical vugs, while deeper, phreatic water migration forms horizontal vugs. There are zones where all the solution vugs are horizontal, indicating horizontal water flow for a period of time. The horizontal vugs are more common in the section. Below the horizontal vugs is a zone of vertical solution cavities which reflect vertical movement of the water table. Another horizontal dissolution zone occurs beneath the vertical solution cavities. In one horizon, vugs show both horizontal and vertical elongation components (Figure 51). These indicate a change in water-flow direction from horizontal or vertical or vice versa. Most of the cavities, both horizontal and vertical, are filled by calcite mud. In some areas of the core, vugs are only partially filled and contain some larger crystals (Figure 52). These incompletely filled vugs may be due to a second solution period after cementation of the cavities or to incomplete cementation after solution. Fractures are also in this core, especially in the upper portion of the limestone. They are most commonly vertical and appear to have been enlarged by solution (Figure 53). It is plausible to believe that these fractures aided the downward percolation of carbonate-undersaturated waters. Some of the fractures exhibit incomplete cementation of both carbonate mud and calcite crystals which may be due to partial dissolution of the crystals during karstification, or to incomplete cementation at the time of precipitation.

Local Unconformities

Examination of cores led to the identification of evidence of unconformities in rocks in which the regional unconformity was not

Figure 51. Solution Vug Which Reflects Both Horizontal and Vertical Water Migration

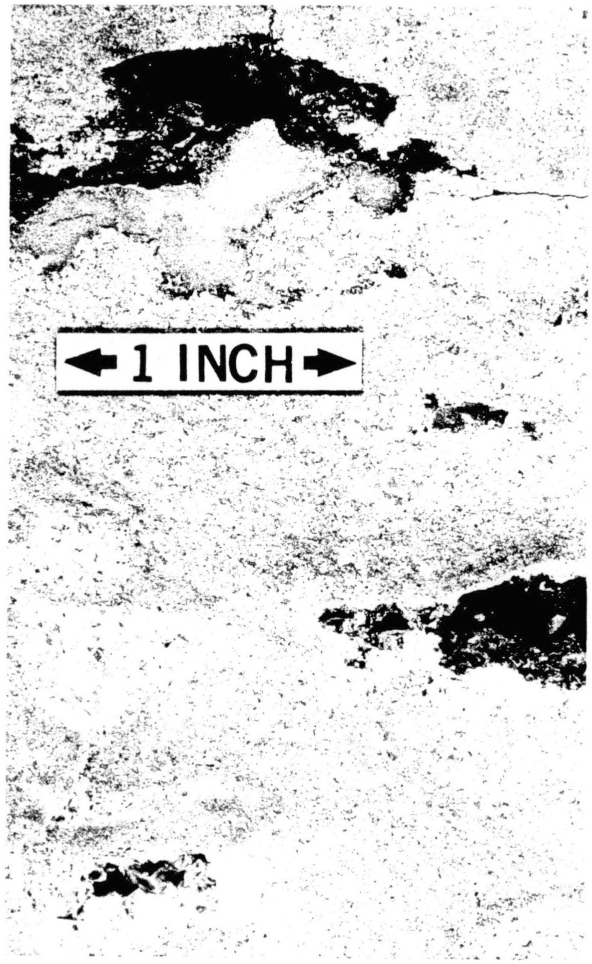


Figure 52. Vug Filling
Calcite Mud
and Calcite
Crystals

Figure 53. Fractures Associated with Dissolution Appear Enlarged

associated. It is proposed that these areas may represent local unconformities which resulted from fluctuations in sea level during Cochrane deposition and their localized nature is related to the ridge and swale topography occurring in the formation.

The features used to identify unconformities, already discussed in the previous section, were found in the C. M. Bloyd and Texaco Wheeler cores in rocks not adjacent to the regional unconformity. Changes in lithology (Figure 54) were observed in the cores, with limestones above the proposed unconformity and dolomite below. Dedolomitization (Figure 55) was found associated with the dolomitized zones, and decreases in abundance with increasing depth away from the limestone/dolomite contact. Solution vugs (Figure 56) were seen in the limestones in areas where limestones are located below the possible unconformity. Electric log cross sections were constructed over two to four sections incorporating the cored wells. The gamma ray curve for the Chimneyhill tends to indicate very clean rock, but occasional kickbacks can be seen (Figure 57). The kicks in the gamma ray curve are not due to an influx of insoluble residues because no shale occurs at these locations. These variations in the gamma ray curve are associated with a change in lithology from limestone to dolomite. The variations are due to an increase in porosity, resulting from the formation of solution vugs and to the incorporation of radioactive material in the dolomite lattice. The radioactive material comes from fluids responsible for the formation of dolomite. No sources in literature mention the composition of the radioactive material. The corresponding kicks in the resistivity curve do not show the expected increase of the invasion profile of the formation. This is probably because, although porosity increased by

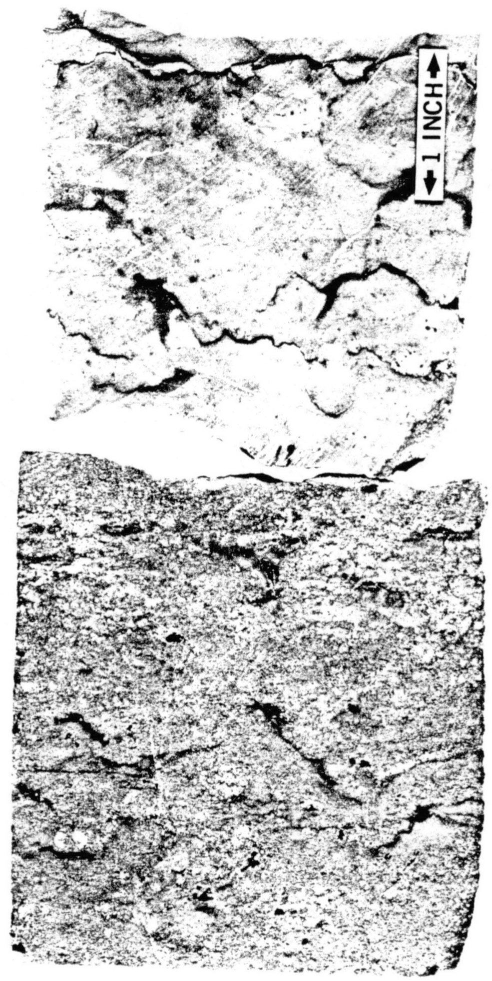


Figure 54. Dolomite Overlain by Limestone is an Easily Identifiable Change in Lithology Which May Indicate the Presence of a Local Unconformity

Figure 55. Dedolomitization Associated with a Local Unconformity.
Plane Polarized Light

Figure 56. Solution Vugs in Limestone Which Underlie the Dolomite Adjacent to the Unconformity

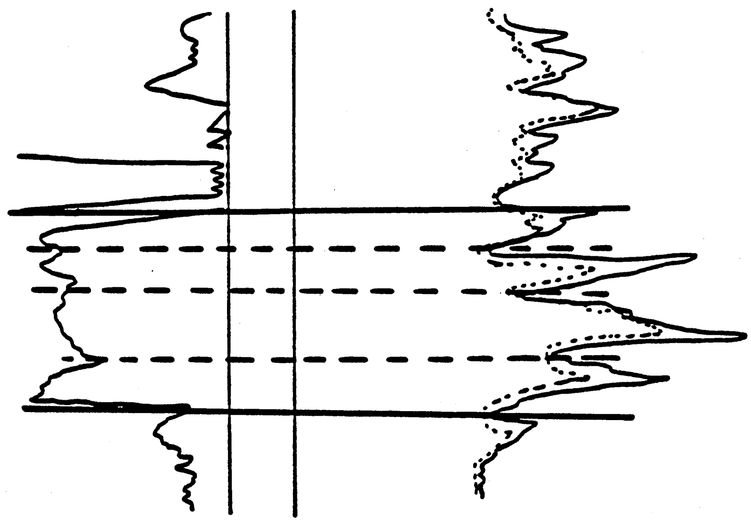


Figure 57. Electric-Log Signature of the Chimneyhill Showing Kickbacks in the Gamma Ray Curve That May Indicate Local Unconformities. Solid Lines Denote Boundaries of the Chimneyhill and Dashed Lines are Locations for Suspected Unconformities. Log Shown is from Calvert Mid-America Bloyd No. 2

dissolution, permeability of the rocks did not. Points at which these kickbacks corresponded with kickbacks in the resistivity curves were used as localities for possible unconformities. These locality depths from the cross sections were then compared to those in the core where unconformities were suspected. In all cases, there was a kickback in gamma ray/resistivity curves where an unconformity was predicted.

Although the author believes that sufficient evidence has been presented for the presence of local unconformities in the Chimneyhill, alternate hypotheses for the presence of these features should be discussed. It may be possible that diagenetic fluids which resulted in dedolomitization and calcite dissolution, could not alter all the rocks because of differing porosities and permeabilities. For example, the limestone above the proposed unconformity may have been impermeable to the fluids and therefore remained unaltered, while the dolomite below, having greater permeability than the limestone, allowed the migration of the undersaturated waters and therefore was diagenetically changed. This could account for discrepancies, but all the facies changes associated with the proposed unconformities are very sharp, there are no gradation contacts. This indicates the possibility of a period of erosion or nondeposition before the deposition of the overlying sediments. Another explanation for the presence of the criteria for unconformities in the Cochrane is that each horizon may not represent one unconformity, but actually several diagenetic horizons associated with one unconformity located at the top of these zones. If dedolomitization occurred at four depths within the formation, all the horizons may be associated with one unconformity, but reflect different horizons where the dedolomitizing fluids passed.

The fact that all the evidence associated with the regional unconformity is found in rocks not associated with it, and that in all cases, more than one feature is present, leads the author to believe that these horizons may actually represent unconformities.

CHAPTER VII

CONCLUSIONS

The following conclusions have been made from this study:

1. Sedimentary constituents and structures recognized in the Chimneyhill Subgroup can be used to construct a depositional model containing subtidal, intertidal and supratidal depositional facies.

2. The depositional facies are localized in their occurrences due to fluctuations in sea level and the presence of ridges and swales scattered on the depositional slope.

3. Diagenetic processes within the Chimneyhill include: 1) secondary authigenic precipitation; 2) alteration, dissolution and replacement of minerals and grains.

4. Dolomitization can be divided into two phases: 1) penecontemporaneous hypersaline dolomitization; 2) eogenetic mixed-water dolomitization.

5. Porosity is greatest in the dolomitized zones where it is present as interparticle, moldic and intraparticle porosity. Moldic and interparticle porosity are the most common porosity types found to occur in the limestones.

6. Porosity is directly related to depositional environment. It is best developed in the intertidal facies. Burrowing and abundant pelmatozoan fragments are features that caused preferential development of porosity.

7. The regional unconformity, located above the Chimneyhill Subgroup can be identified in cores and thin sections by changes in lithology, electric-log patterns, location of dedolomitization and by evidence of karstification of rocks.

8. The criteria used to identify the regional unconformity can be applied within the Cochrane Formation to find possible local unconformities which resulted from erosion or nondeposition due to fluctuations in sea level.

REFERENCES CITED

Adams, J. E. and M. L. Rhodes, 1960, Dolomitization by seepage refluxion: AAPG Bull., Vol. 44, No. 12, pp. 1912-1920.

Adler, F. J., 1971, Future petroleum provinces of the Mid-Continent; Future petroleum provinces of the United States, their geology and potentials: AAPG Memoir, No. 15, pp. 985-1120.

Amsden, T. W., 1957, Stratigraphy of the Hunton Group: Oklahoma Geological Survey Circular, 44, pp. 57.

Amsden, T. W., 1960, Hunton stratigraphy: Oklahoma Geological Survey Bulletin, 84, pp. 311.

Amsden, T. W., 1967, Chimneyhill limestone sequence (Silurian), Hunton Group, Oklahoma: AAPG Bull., Vol. 51, No. 6, Pt. 1, pp. 942-945.

Amsden, T. W., 1975, Hunton Group (Late Ordovician, Silurian, and Early Devonian) in the Anadarko Basin of Oklahoma: Oklahoma Geological Survey Bulletin, 121, pp. 214.

Amsden, T. W. and T. L. Rowland, 1967, Geologic maps and stratigraphic cross sections of Silurian strata and Lower Devonian formation in Oklahoma, Oklahoma Geological Survey Map GM-14.

Back, W., B. B. Hanshaw, L. N. Plunmer, P. H. Rahn, C. T. Rightmire, and M. Rubin, 1983, Process and rate of dedolomitization: mass transfer and ^{14}C dating in a regional carbonate aquifer: GSA Bull., Vol. 94, pp. 1415-1429.

Badiozamani, K., 1973, The Doray Dolomitization Model - application to the Middle Ordovician of Wisconsin: Jour. Sed. Pet., Vol. 43, pp. 965-984.

Beales, F. W. and J. W. Hardy, 1980, Criteria for the recognition of diverse dolomite types with an emphasis on studies of host rocks for Mississippi Valley-type ore deposits: in Concepts and Models of Dolomitization, SEPM Spec. Publ., No. 20, pp. 197-215.

Braddock, W. A. and G. C. Bowles, 1963, Calcitization of dolomite by calcium sulphate solutions in the Minnelusa Formation, Black Hills, South Dakota and Wyoming, U.S. Geol. Surv. Prof. Pap. 475-C, pp. 96-99.

Braun, M. and G. M. Friedman, 1970, Dedolomitization fabric in peels: a possible clue to unconformity surfaces: Jour. Sed. Pet., Vol. 40, pp. 417-419.

Chafetz, H. S., 1972, Surface diagenesis of limestone: Jour. Sed. Pet., Vol. 42, No. 2, pp. 325-329.

Chenowith, P. A., 1968, Early Paleozoic (Arbuckle) overlap, southern Mid-Continent, U.S.: AAPG Bull., Vol. 52, pp. 1670-1688.

Choquette, P. W. and L. C. Pray, 1970, Geologic nomenclature and classification of porosity in sedimentary carbonates: AAPG Bull., Vol. 54, pp. 207-250.

Choquette, P. W. and R. Steinen, 1980, Mississippian non-supratidal dolomitization, Ste. Genevieve Limestone, Illinois Basin: evidence for mixed water dolomitization: SEPM Spec. Publ., 28, pp. 163-196.

Curhs, D. M. and S. C. Champlin, 1959, Depositional environments of Mississippian limestones of Oklahoma: Tulsa Geological Society Digest, Vol. 27, pp. 90-103.

Deffeyes, K. S., F. J. Lucia, and P. R. Weyl, 1965, Dolomitization of recent and Plio-Pleistocene sediments by marine evaporitive waters on Bonnaire, Netherlands Antilles: in Dolomitization and limestone diagenesis: SEPM Spec. Publ., 13, pp. 71-87.

Dietrich, R. V., C. R. B. Hobbs, Jr., and W. D. Lowny, 1963, Dolomitization interrupted by silicification: Jour. Sed. Pet., Vol. 33, No. 3, pp. 646-663.

Dunham, R. J., 1961, Classification of carbonate rocks according to depositional texture: in W. E. Ham (ed.), Classification of Carbonate Rocks, AAPG Mem., No. 1, pp. 108-121.

Dunham, J. B. and E. R. Olson, 1980, Shallow subsurface dolomitization of subtidally deposited carbonate sediments in the Hanson Creek Formation (Ordovician-Silurian) of Central Nevada: SEPM Spec. Publ., 28, pp. 139-161.

Esteban, M. and C. F. Klappa, 1983, Subaerial exposure environment: in P. A. Scholle, D. B. Bebout, and C. H. Moore (eds.), Carbonate Depositional Environments: AAPG Memoir, 33, pp. 1-54.

Evamy, B. D., 1963, The application of chemical staining techniques to the study of dedolomitization: Sedimentology, Vol. 2, pp. 164-170.

Evamy, B. D., 1967, Dedolomitization and the development of rhombohedral pores in limestones: Jour. Sed. Pet., Vol. 37, No. 4, pp. 1204-1215.

Evans, J. L., 1979, Major structural and stratigraphic features of the Anadarko Basin: in Pennsylvanian Sandstones of the Mid-Continent: Tulsa Geological Society Spec. Publ., No. 1, pp. 97-114.

Flügel, E., 1982, Microfacies Analysis of Limestones: Springer-Verlag, New York, pp. 633.

Folk, R. L. and L. S. Land, 1975, Mg/Ca ratio and salinity: two controls over crystallization of dolomite: AAPG Bull., Vol. 59, pp. 60-68.

Folk, R. L. and Pittman, J. S., 1971, Length slow chalcedony: a new testament for vanished evaporites: Jour. of Sed. Pet., Vol. 41, pp. 1045-1058.

Folk, R. L. and A. Siedlecka, 1974, The "schizohaline" environment: its sedimentary and diagenetic fabrics as exemplified by Late Paleozoic rocks of Bear Island, Svalboard: Sedimentary Geology, Vol. II, pp. 1-15.

Folkman, Y., 1969, Diagenetic dedolomitization in the Albaman-Cenon-Aman Yagur dolomite on Mount Carmel (Northern Israel): Jour. Sed. Pet., Vol. 39, pp. 380-384.

Frank, J. R., 1981, Dedolomitization in the Taum Sauk Limestone (Upper Cambrian), southeast Missouri: Jour. Sed. Pet., Vol. 51, No. 1, pp. 7-18.

Goldberg, M., 1967, Supratidal dolomitization in Jurassic rocks of Hamakhtesh Hagatan, Israel: Jour. Sed. Pet., Vol. 37, pp. 760-773.

Groot, K. de, 1967, Experimental dedolomitization: Jour. Sed. Pet., Vol. 37, pp. 1216-1220.

Habicht, J. K. A., 1979, Paleōclimate, paleomagnetism, and continental drift: AAPG Studies in Geology, No. 9, pp. 31.

Ham, W. E., R. E. Denison, and C. A. Merkitt, 1964, Basement rocks and structural evolution of southern Oklahoma: Oklahoma Geological Survey Bulletin, No. 95, pp. 302.

Hanshaw, B. B., W. Back, and R. G. Deike, 1971, A geochemical hypothesis for dolomitization by groundwater: Economic Geology, Vol. 66, pp. 710-724.

Harlton, B. H., 1972, Faulted fold belts of southern Anadarko Basin adjacent to frontal Wichitas: AAPG Bull., Vol. 56, No. 8, pp. 1544-1551.

Harvey, R. L., 1968a, West Campbell - key to unlock the Hunton, Pt. 1: Oil and Gas Jour., Vol. 66, pp. 124-132.

Harvey, R. L., 1968b, Subsurface only scratched in Hunton search, Pt. 2: Oil and Gas Jour., Vol. 66, pp. 142-143.

Heckel, R. H., 1972, Recognition of ancient shallow marine environments: SEPM Spec. Publ., No. 16, pp. 340.

Hsü, K. S. and C. Siegenthaler, 1969, Preliminary experiments on hydrodynamic movement induced by evaporation and their bearing on the dolomite problem: Sedimentology, Vol. 12, pp. 11-25.

Ireland, B. J., C. D. Curtis, and J. A. Whiteman, 1983, Compositional variation within some glauconites and illites and implication for their stability and origins: International Association of Sedimentologists.

Irwin, M. L., 1965, General theory of clear water sedimentation: AAPG Bull., Vol. 49, No. 4, pp. 445-459.

Isom, J. W., 1973, Subsurface stratigraphic analysis, Late Ordovician to Early Mississippian, Oakdale-Campbell Trend, Woods, Major, and Woodward Counties, Oklahoma: Shale Shaker, Vol. 24, Pts. 1 & 2, pp. 32-42, 52-57.

Katz, A., 1971, Zoned dolomite crystals: Jour. of Geology, Vol. 79, pp. 38-52.

Land, L. S., 1973, Contemporaneous dolomitization of Pleistocene limestones, North Jamaica: Sedimentology, Vol. 20, pp. 411-424.

Legrand, H. E. and V. T. Stringfield, 1973, Karst hydrology - a review: Jour. Hydrology, Vol. 20, pp. 97-120.

Longman, M. W., 1980, Carbonate textures from nearsurface diagenetic environments: AAPG Bull., Vol. 64, No. 4, pp. 461-487.

Maxwell, R. A., 1936, The stratigraphy and areal distribution of the Hunton Formation, Oklahoma: Unpublished doctoral thesis, Northwestern University, pp. 114.

Morgan, W. A., 1983, Productive upward-shoaling sequences within the Hunton Group (Silurian): Mt. Everette and southwest Reeding fields, Kingfisher Co., Oklahoma: Unpublished article.

Munn, D. and D. E. Jackson, 1980, Dedolomitization of Lower Carboniferous dolostone in the Wirksworth area, Derbyshire, England: Geology Magazine, Vol. 117, No. 6, pp. 607-612.

Oden, G. S. and A. Matter, 1981, De glauconiarum origine: Sedimentology, Vol. 28, pp. 611-641.

Reeds, C. A., 1911, The Hunton Formation of Oklahoma: Amer. Jour. of Science, Vol. 182, pp. 256-269.

Reeds, C. A., 1914, Oolites of the Chimneyhill Formation, Oklahoma: GSA Bull., Vol. 25, pp. 75-76.

Reeds, C. A., 1927, The Arbuckle Mountains: Oklahoma Geological Survey Circular, 14, pp. 256-267.

Schmidt, V., 1965, Facies, diagenesis and related reservoir properties in the Gigas beds (U. Jurassic), northwest Germany: in Dolomitization and limestone diagenesis--a symposium: SEPM Spec. Publ., No. 13, pp. 124-168.

Sears, S. O. and F. J. Lucia, 1980, Dolomitization of northern Michigan Niagara reefs by brine refluxion and freshwater/seawater mixing: SEPM Spec. Publ., 28, pp. 215-235.

Shannon, Jr., J. P., 1962, Hunton Group (Silurian-Devonian) and related strata in Oklahoma: AAPG Bull., Vol. 46, No. 1, pp. 1-29.

Shaw, A. B., 1965, Time in Stratigraphy: New York, McGraw-Hill, p. 353.

Sloss, L. L., 1984, Comparative anatomy of cratonic unconformities: in J. S. Schlee (ed.), Interregional unconformities and hydrocarbon accumulation: AAPG Memoir, 36, pp. 1-6.

Taff, J. A., 1902, Atoka Folio, pp. 30.

Thrailkill, J., 1968, Chemical and hydrologic factors in the excavation of limestone caves: GSA Bull., Vol. 79, pp. 19-46.

Weimer, R. J., 1984, Relation of unconformities, tectonics, and sea-level changes, Cretacious of Western Interior, U.S.A.: in J. S. Schlee (ed.), Interregional unconformities and hydrocarbon accumulation: AAPG Memoir, 36, pp. 7-36.

Wilson, J. L., 1975, Carbonate Facies in Geologic History: Springer-Verlag, New York, pp. 471.

Wilson, J. L. and C. Jordan, 1983, Middle shelf environment: in P. A. Scholle, D. G. Bebout, C. H. Moore (eds.), Carbonate depositional environments: AAPG Memoir, 33, pp. 298-343.

APPENDIX

CORE DESCRIPTIONS

HUNTON GROUP

PETROLOG

Well ______________________

Location __________ Sec. ____ T. ____ N., R. ____ W.

__________ Co., __________ OKLAHOMA

Lithology

- CLAY/CLAYSTONE
- SILTY CLAYSTONE/MUDSTONE
- SILT/SILTSTONE
- SAND/SANDSTONE
- INTERBEDDED SANDSTONE/MUDSTONE
- MUDDY SANDSTONE
- CONGLOMERATE
- BRECCIA
- COAL/LIGNITE
- LIMESTONE
- DOLOMITE
- GYPSUM/ANHYDRITE
- HALITE
- CHERT
- MARL
- DOLOMITIC ROCKS
- CHERTY ROCKS
- GYPSIFEROUS/ANHYDRITIC ROCKS

Sedimentary Structures

- HORIZONTAL BEDDING
- HORIZONTAL LAMINAE
- TROUGH CROSSBEDS
- TABULAR CROSSBEDS
- DISTURBED BEDDING
- GRADED BEDDING
- NODULAR OR KNOBBY/HUMMOCKY BEDDING
- MASSIVE BEDDING
- RIPPLE CROSS-LAMINAE
- FLASER LAMINAE
- ALGAL LAMINATION
- LINEATION
- CURRENT SOLE MARKS
- LOW-ANGLE INCLINED STRATIFICATION
- BURROWS
- LOADCASTS
- MUDCRACKS
- BURROW MOTTLED
- ROOTLETS
- CONCRETIONS

Fracture

- OPEN
- CLOSED
- FILLED

Stylolites

- COARSE
- FINE

Miscellaneous

- o DOMINANT GRAIN OR RHOMB SIZE
- • SECONDARY MODE FOR GRAIN OR RHOMB SIZE
- ◄ THIN SECTION
- ■ X RAY DIFFRACTION SAMPLE
- ✱ GLAUCONITE
- P PYRITE
- C CARBONACEOUS DETRITUS
- r RARE c COMMON a ABUNDANT

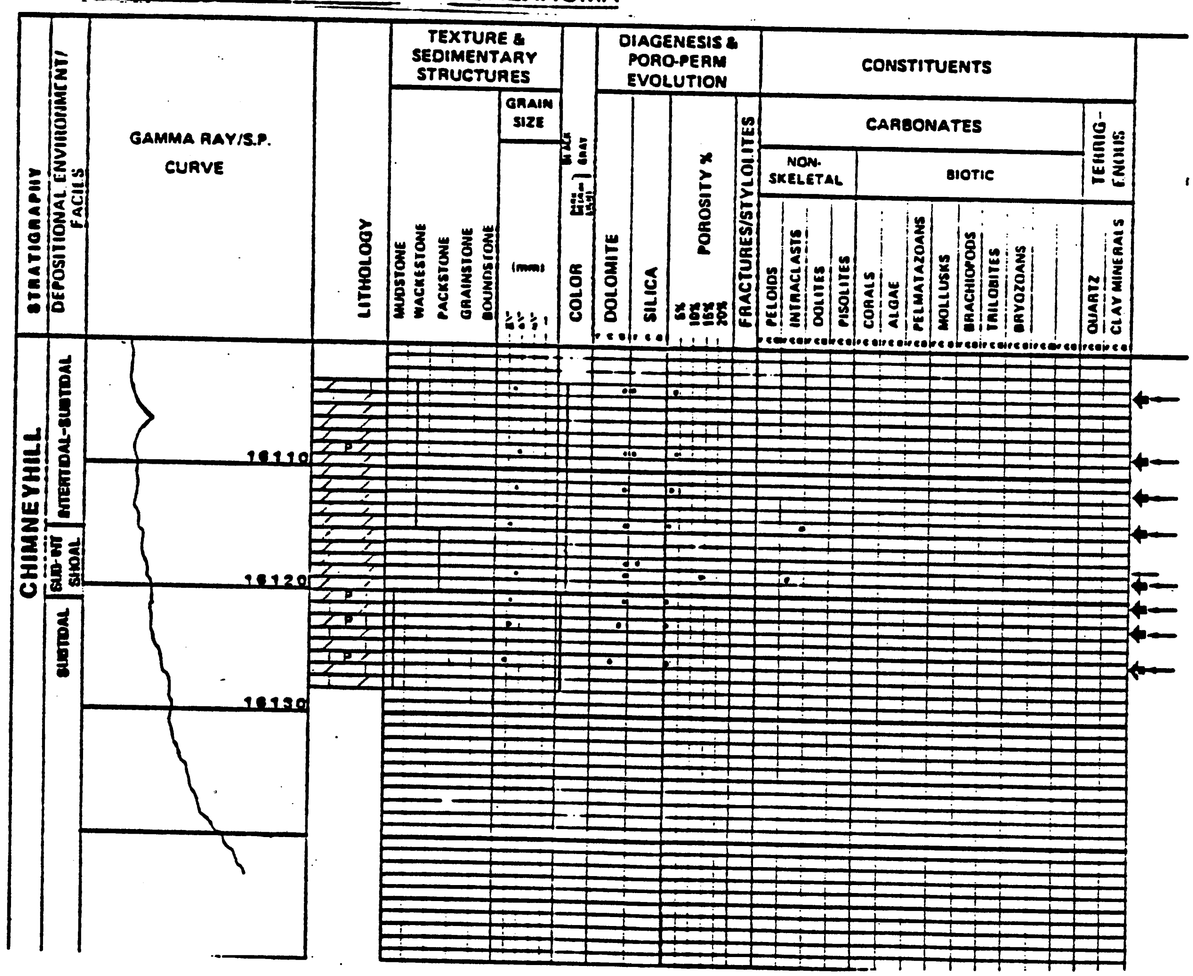
WELL: Helmerich and Payne Adkerson No. 1
LOCATION: 28-10N-26W
CORED DEPTH; 16103-16128 ft
STRATIGRAPHIC INTERVAL: Keel, Chimneyhill

The cored interval contains three facies. The lowermost unit (16121-16128) is a dolomudstone with some calcite and scattered fossils present. This zone is thought to represent a subtidal environment.

The middle interval (16116-16121) is an oolitic dolopackstone which was deposited as a subtidal to lower intertidal shoal.

The uppermost unit (16103-16116) is a bioturbated dolowackestone. Clay and sparry dolomite cement are present in this interval. This wackestone is believed to have been deposited in an intertidal to subtidal environment.

Well **Helmerich and Payne Adkerson No. 1**
Location Sec. 28 T. 10 N., R. 26 W.
Beckham Co., OKLAHOMA



WELL: Calvert-Mid-America Bloyd No. 2
LOCATION: 21-27N-15W
CORED DEPTH: 6189-6242 ft
STRATIGRAPHIC INTERVAL: Cochrane, Keel

The cored Hunton is made up of dolomite, packstone, mudstone and wackestone facies.

The lowermost unit (6239-6242 ft) is a greenish dolomudstone. It is laminated and contains clay and pyrite. This was probably deposited in a reducing environment, either a lagoon or an offshore area.

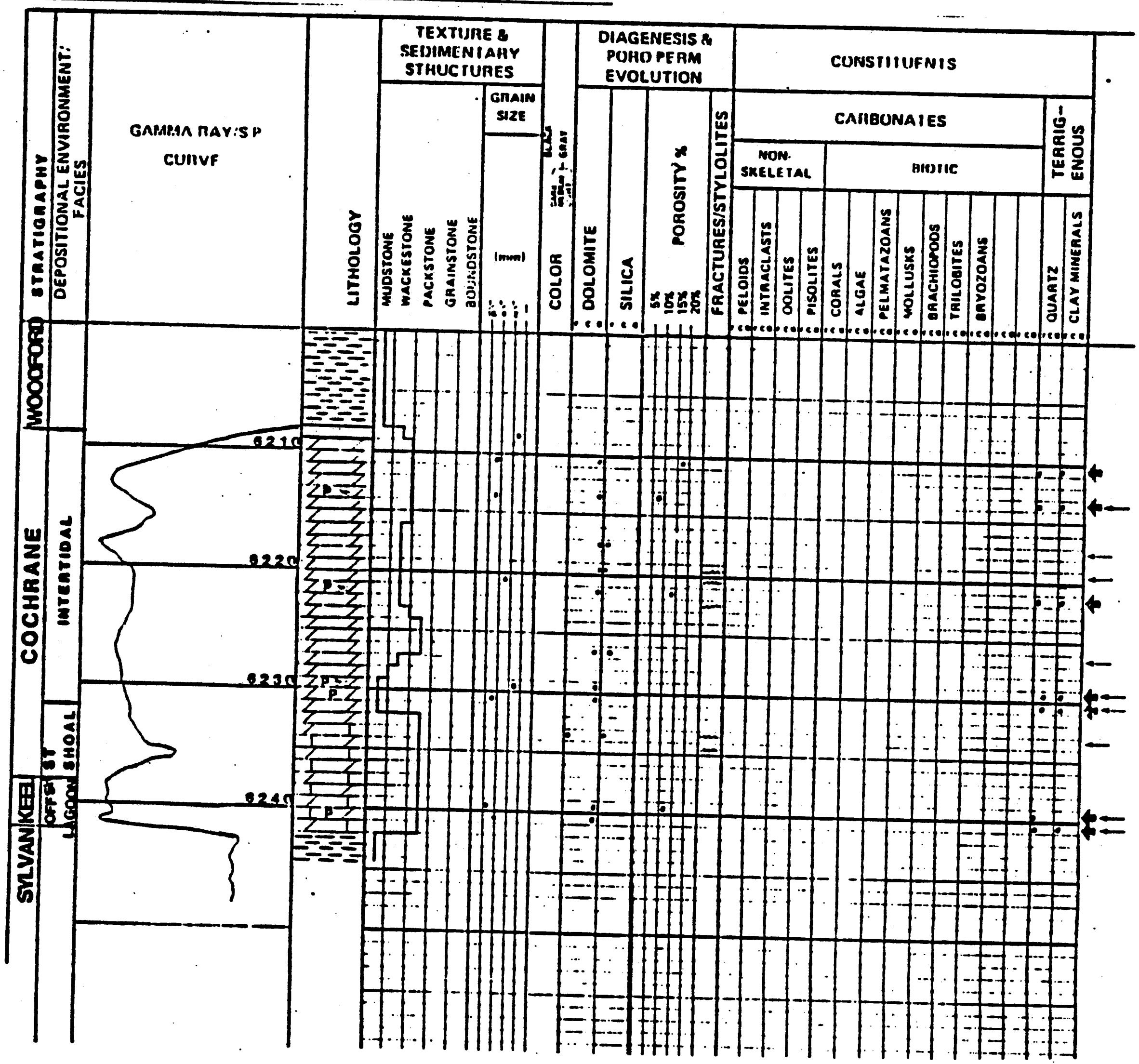
The next unit (6233-6238 ft) is a pink crinoidal packstone. It was deposited in a subtidal shoal.

The packstone is overlain by a mudstone (6230-6232 ft). It has highly contorted laminae and was probably deposited in an intertidal to subtidal environment.

The uppermost unit (6209-6230 ft) is a fossiliferous wackestone. Burrows and laminations are common. This was believed to have been deposited in an intertidal to upper intertidal environment.

The Hunton section is overlain by the Woodford shale (6189-6209 ft).

Well Calvert Mid America - Bloyd No. 2
Location Sec. 21 T. 27 N., R. 15 W.
Woods Co., OKLAHOMA



WELL: ARCO Marcum Gas Unit No. 3
LOCATION: 20-27N-15W
CORED DEPTH: 6225-6266 ft
STRATIGRAPHIC POSITION: Cochrane

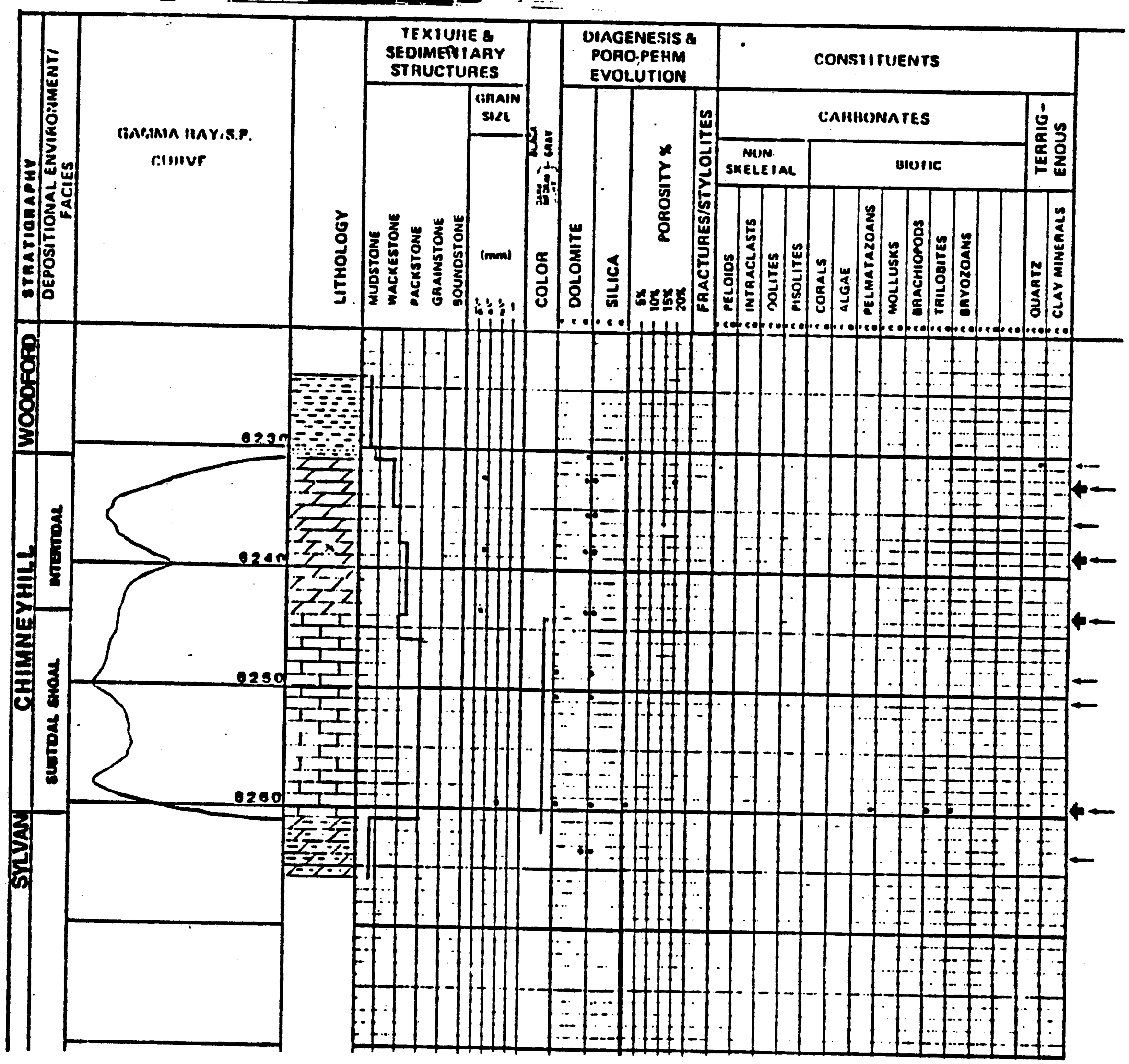
The cored Hunton interval contains a lower limestone and upper dolomite facies.

The Hunton is underlain by the Sylvan shale (6262-6266 ft). This shale contains pyrite, distorted bedding and a thin dolograinstone stringer.

The lower Hunton facies (6245-6262 ft) is a crinoidal packstone/grainstone. Crossbedding and scattered vugs, some of which are filled with sparry calcite, are present in this unit. This represents a subtidal shoal environment.

The upper unit (6231-6244 ft) is a peloidal dolowackestone/packstone. Algal laminations, glauconite, chert nodules and vertical burrows are present in the interval which is believed to have been deposited in an intertidal environment.

Well ARCO Marcum Gas Unit No. 3
Location Sec. 20 T. 27 N., R. 15 W.
Woods Co., OKLAHOMA



WELL: E. L. Cox Annis A No. 1
LOCATION: 3-26N-21W
CORED DEPTH: 7280-7365 ft
STRATIGRAPHIC INTERVAL: Chimneyhill

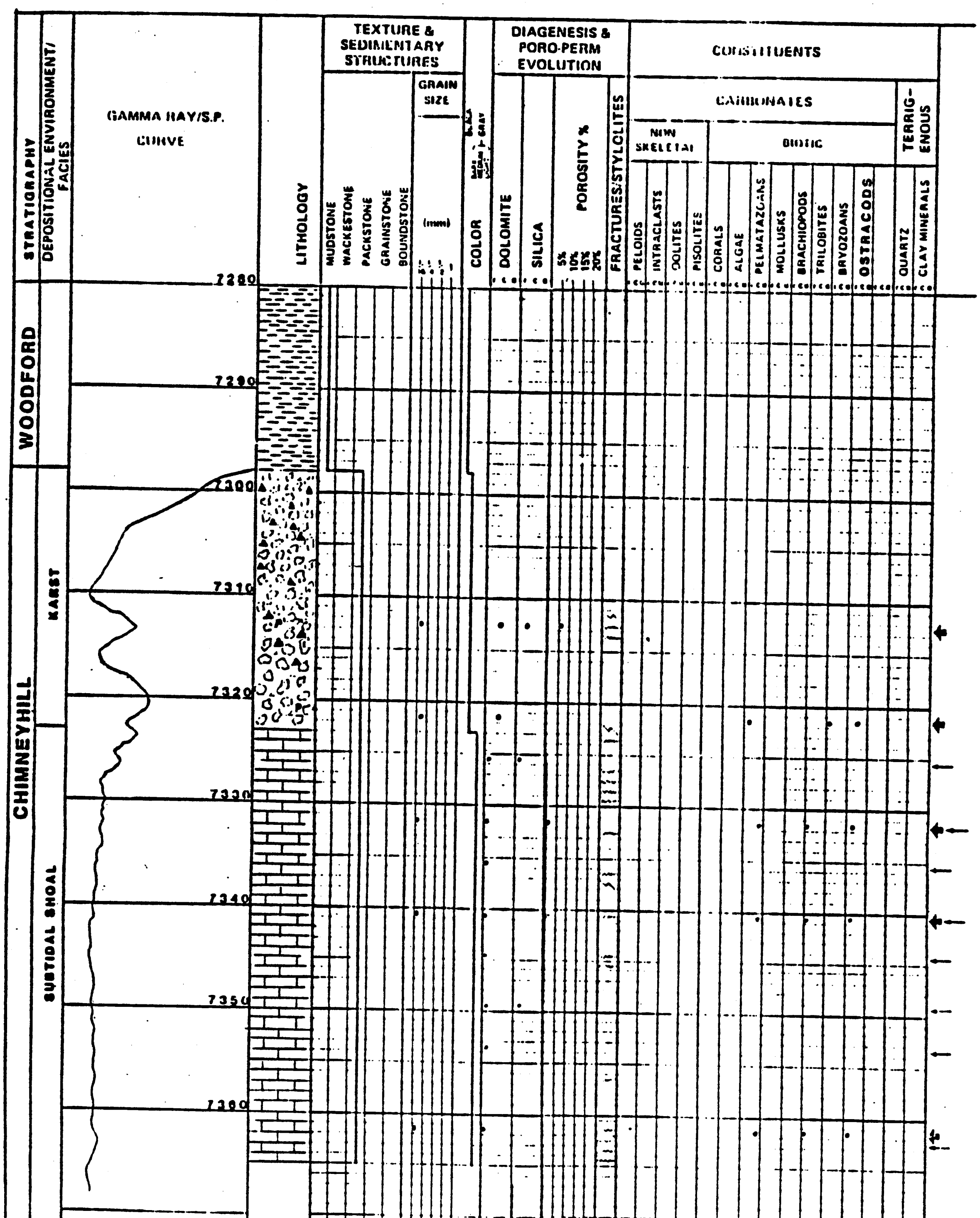
The cored interval is made up of a packstone and a breccia.

The lower unit (7323-7365 ft) is a pink, skeletal packstone. It contains sparry calcite cement and solution cavities filled with dolomite and/or calcite. Some stylolites are also present. This was probably deposited as a subtidal shoal.

The upper unit (7298-7323 ft) is a dolomite, chert breccia. Thin beds exhibiting a steep dip are present in this interval. This breccia is believed to be a collapse breccia where chertification occurred before brecciation. Dolomite then cemented the breccia.

The Hunton is overlain by the Woodford shale (7280-7298 ft). The shale contains glauconite, pyrite and laminae with steep dip.

Well Edwin L. Cox Annis -A No.3
Location Sec. T. N., R. W.
Harper Co., OKLAHOMA



WELL: Anadarko Production Hawkins No. B-1
LOCATION: 26-26N-11W
CORED DEPTH: 6135-6160 ft
STRATIGRAPHIC INTERVAL: Cochrane

The Hunton in the cored interval contains two dolomite units separated by a grainstone.

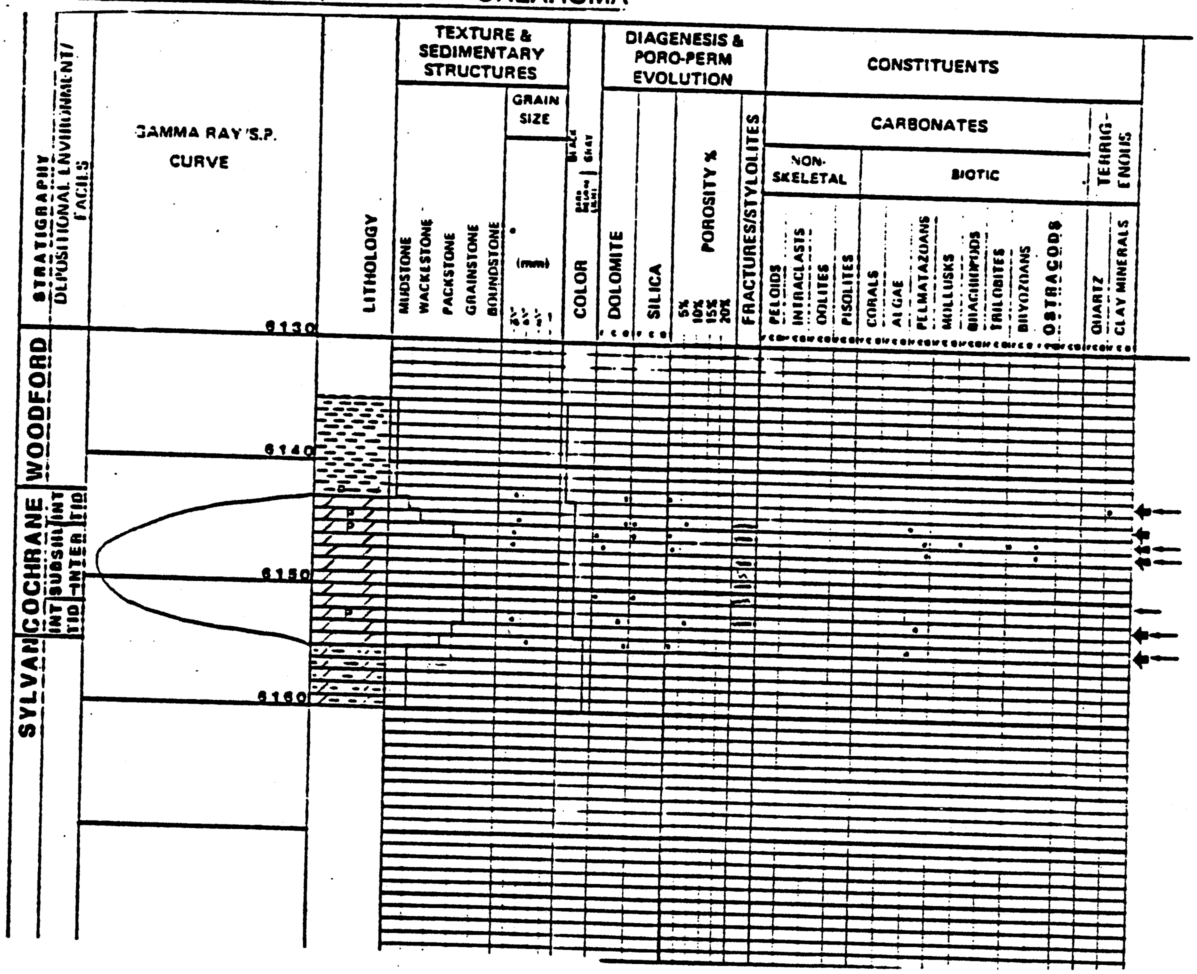
The lower dolopackstone (6152-6160 ft) is burrowed and contains algal laminae. It was probably deposited in an intertidal environment.

The middle crinoidal grainstone (6146-6152 ft) is pinkish-gray in color. Isolated vugs, burrows, laminations and cross-laminations are present in this unit. The depositional environment is a subtidal shoal to intertidal environment.

The upper dolowackestone (6144-6146 ft) contains glauconite and pyrite. Burrows and vugs are also present in this unit as well as a one inch pyritic, conglomeratic sandstone, present at the very top which represents the sharp contact between the Hunton and the Woodford. The depositional environment for this unit is intertidal.

The Hunton is overlain by the Woodford shale (6135-6146 ft).

Well Anadarko Production Hawkins B No. 1
Location Sec. 26 T. 26 N., R. 11 W.
Alfalfa Co., OKLAHOMA



WELL: Cleary Kinney No. 1-20
LOCATION: 20-25N-21W
CORED DEPTH: 8721-8760 ft
STRATIGRAPHIC INTERVAL: Cochrane

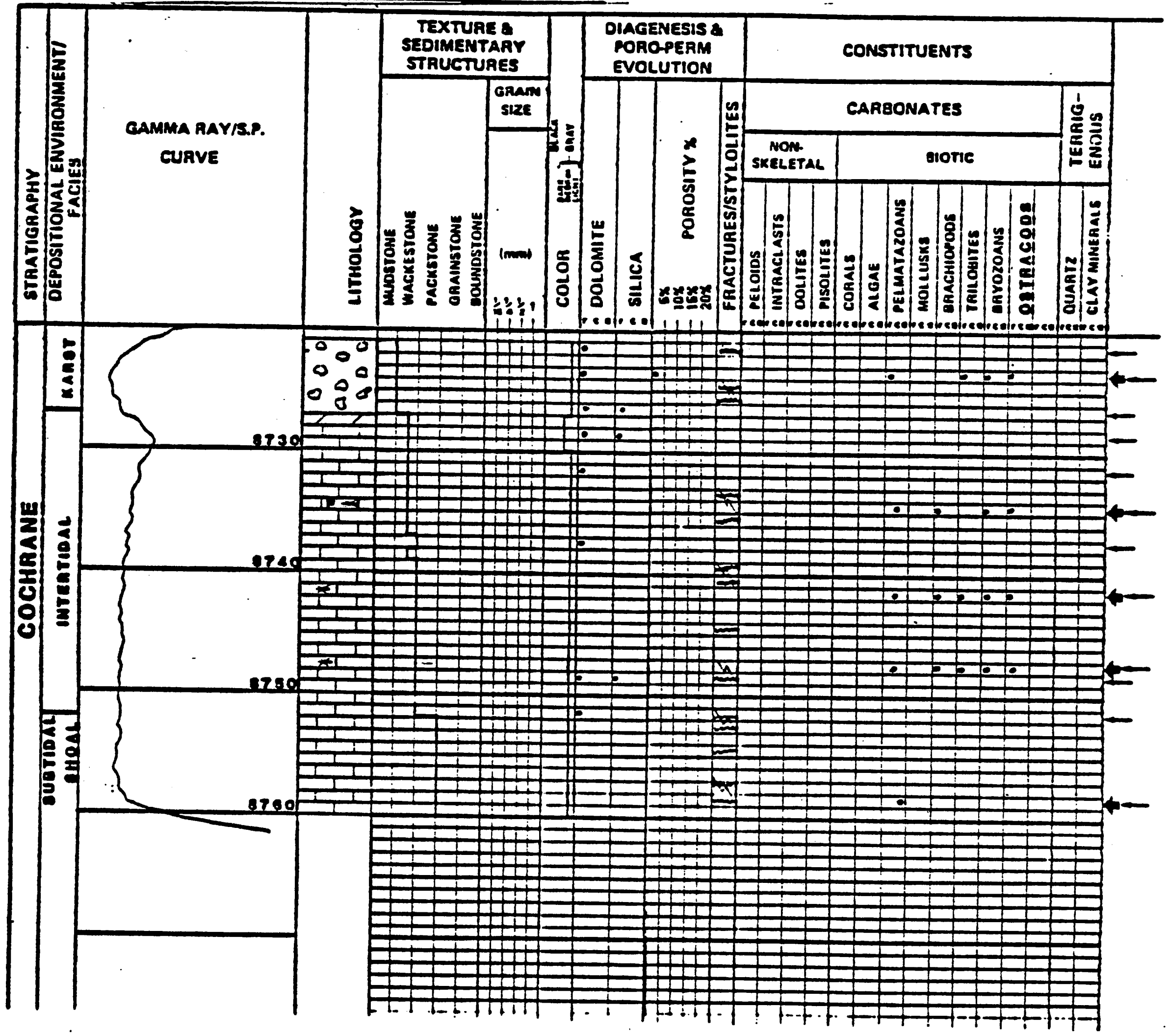
This core is made up of two packstone intervals, a dolomitic zone and a breccia. The lowermost unit (8752-8760) is a pink, crinoidal packstone. Sparry calcite cement and fractures are present. This is thought to represent a subtidal shoal.

The next unit (8729-8752 ft) is a pinkish gray packstone which is separated from the lower packstone by a sharp contact. This packstone contains fossils, glauconite and sparry calcite cement. Fractures, stylolites and stylobrecciations affect this interval which is believed to have been deposited in an intertidal environment.

The interval from 8728 to 8729 ft is a dolomitic unit which overlies the packestone with a sharp contact. It contains glauconite, pyrite and calcitized nodules, and is laminated. This unit may have been deposited in a supratidal environment.

The uppermost unit (8721-8728) is a limestone breccia. It probably resulted from the collapse of overlying strata due to dissolution.

Well Cleary Kinney
Location Sec. 20 T. 25 N., R. 21 W.
Harper Co., OKLAHOMA



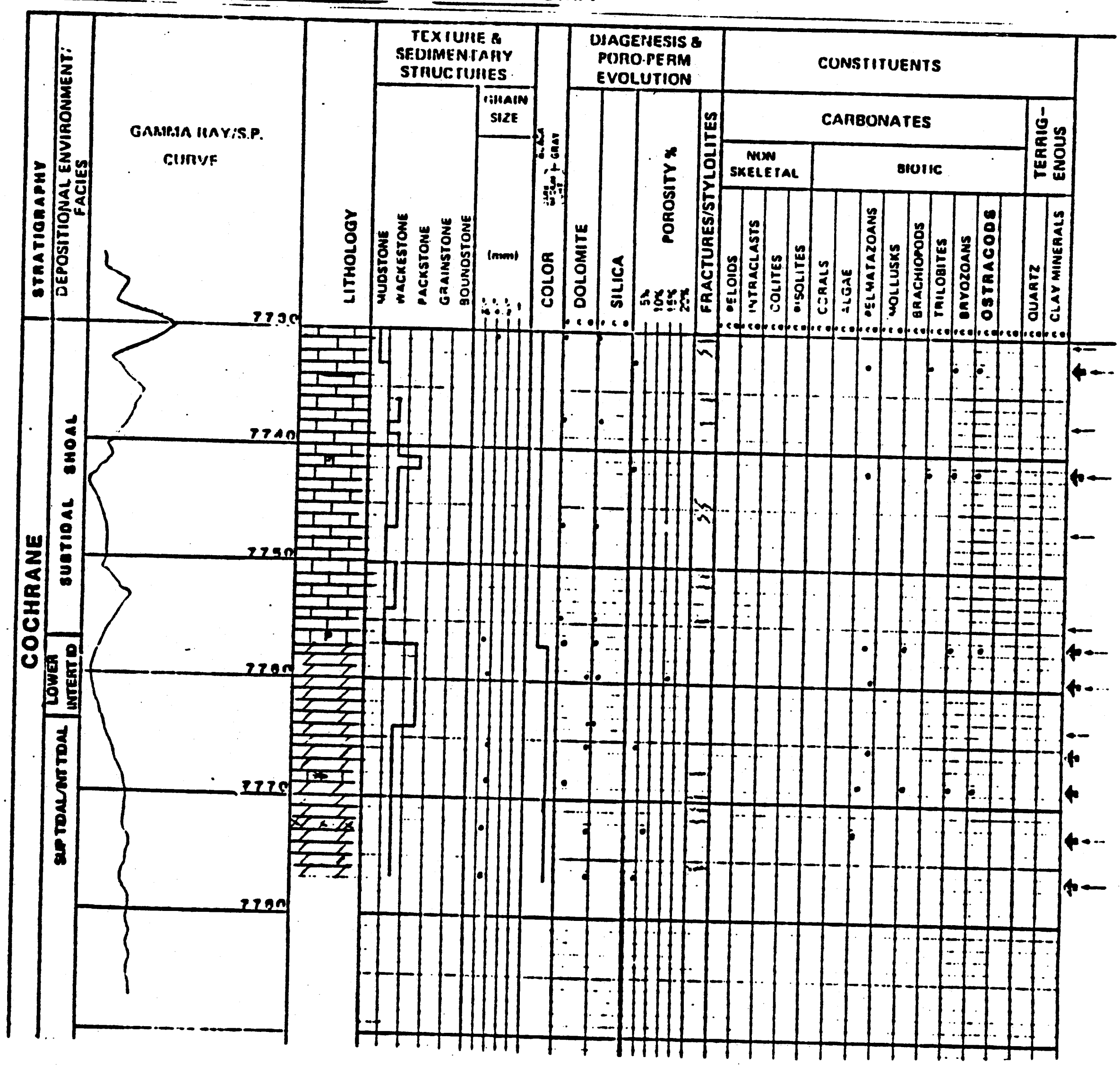
WELL: Texaco Wheeler No. 1
LOCATION: 25-25N-18W
CORED DEPTH: 7730-7777 ft
STRATIGRAPHIC INTERVAL: Cochrane

The cored interval consists of dolowackestone, dolopackstone and mudstone/wackestone facies. The lowermost unit (7764-7777 ft) is a bioturbated dolowackestone. Some vertical burrows and laminae are present. This unit contains glauconite, chert and pyrite and is thought to represent an intertidal environment.

The next unit (7757-7764 ft) is a dolopackstone which contains fossil fragments, glauconite and pyrite. Bioturbation and laminations are present in some areas. This unit probably represents an intertidal environment.

The uppermost unit (7730-7757 ft) is a mudstone/wackestone which contains fossil fragments, pyrite and chert. Horizontal burrows, clay wisps and clay laminae are also present. This was probably deposited in a subtidal environment. A pinkish gray crinoidal packstone (7741-7742 ft) is present within this interval. It is separated from the dolowackestones by sharp contacts, and was deposited as a subtidal shoal.

Well Texaco Wheeler No. 1
Location Sec. 25 T. 25 N., R. 18 W.
Woodward Co., OKLAHOMA



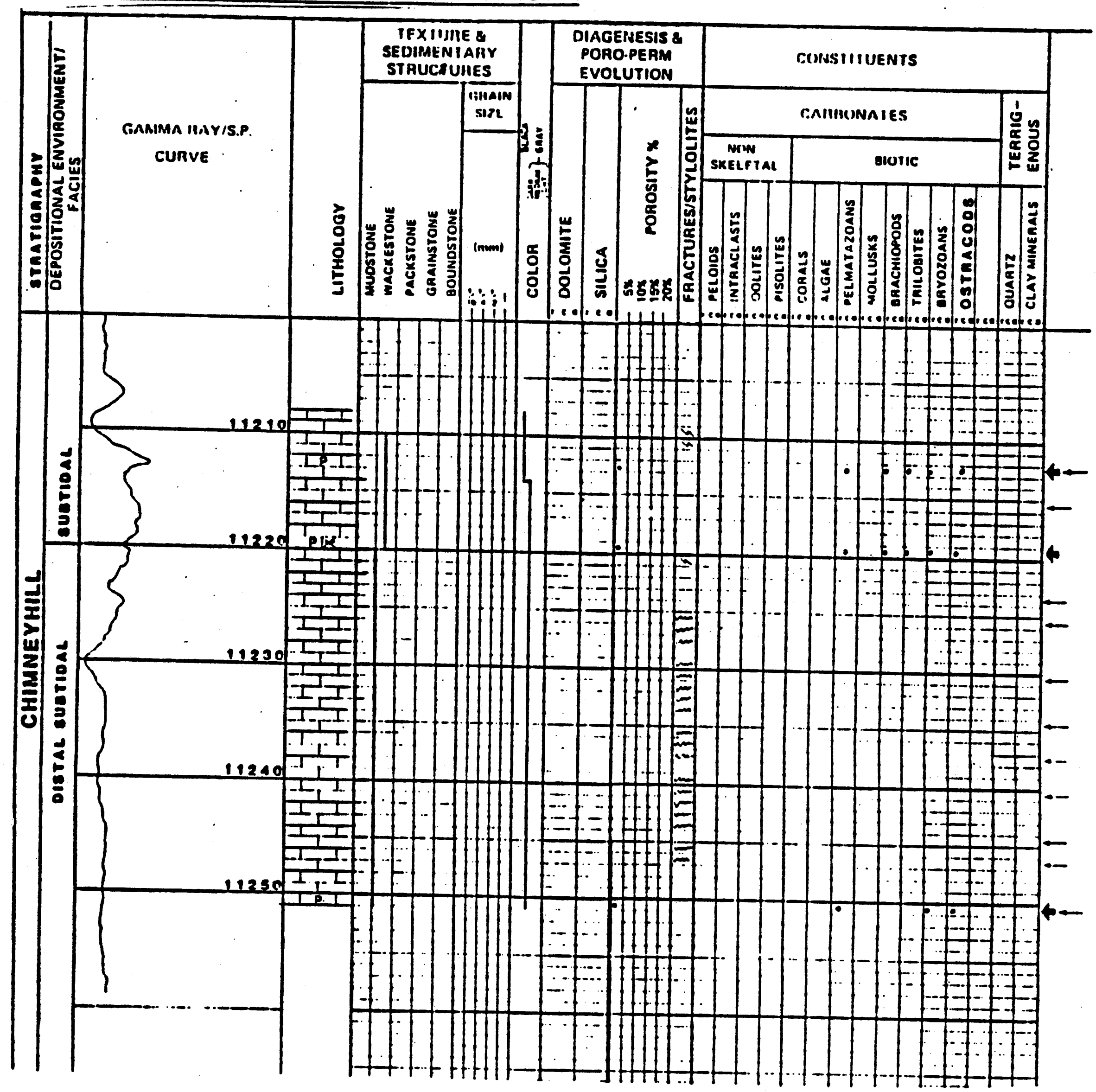
WELL: Getty Coffman No. B-1
LOCATION: 4-22N-24W
CORED DEPTH: 11209-11251 ft
STRATIGRAPHIC INTERVAL: Chimneyhill

The cored interval contains a wackestone/mudstone and wackestone/packstone facies.

The lower unit (11221-11251 ft) is a fossiliferous wackestone/mudstone. It contains deformed clay laminae and wisps, and sparry calcite filled vugs and nodules. It was probably deposited in a deeper or distal subtidal environment.

The upper unit (11209-11220 ft) is a fossiliferous wackestone/packstone. Irregular fractures filled with sparry calcite are present. An interval at 11209 to 11210 exhibits inclined crystalline fabric and inclined laminations. This may indicate the calcitization of evaporites. The depositional environment is thought to be upper subtidal with locally restricted intertidal to supratidal conditions in the upper part of the unit.

Well Getty Coffman No. B-1
Location Sec. 22 T. 4 N., R. 24 W.
Ellis Co., OKLAHOMA



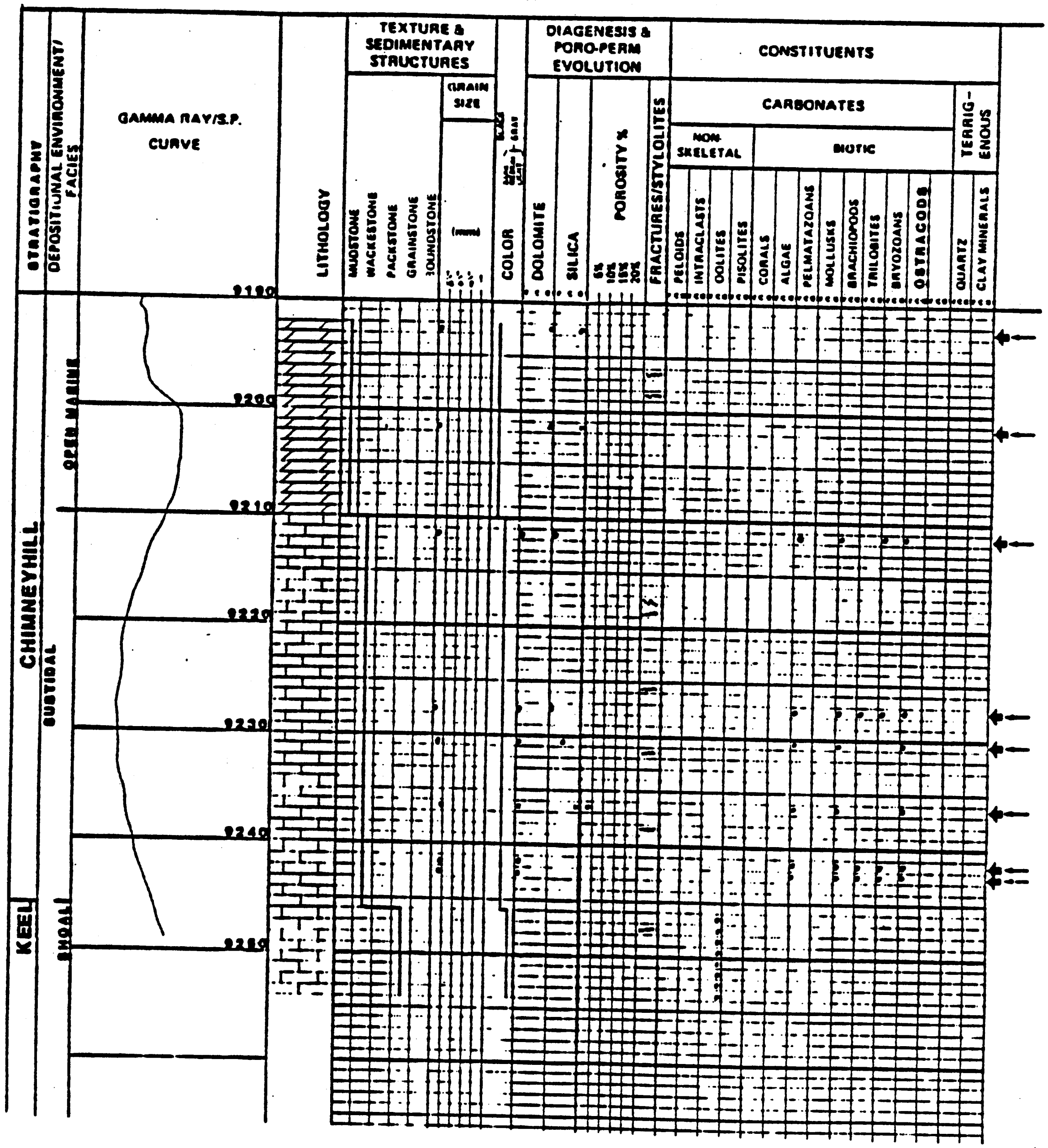
WELL: Getty Leutkemeyer
LOCATION: 24-19N-11W
CORED DEPTH: 9192-9152
STRATIGRAPHIC INTERVAL: Keel, Chimneyhill

The cored interval contains grainstone, a wackestone and a dolomudstone. The lowermost unit is a crossbedded oolitic grainstone (9146-54 ft). It represents a subtidal shoal.

The middle zone (9210-9246 ft) is a lime wackestone which contains fossil fragments and abundant tripoli chert nodules. It exhibits knobby, hummocky bedding and represents a subtidal environment.

The uppermost unit (9192-9210 ft) is a dolomudstone which exhibits clay laminae and chert nodules. This unit is thought to be open-marine subtidal.

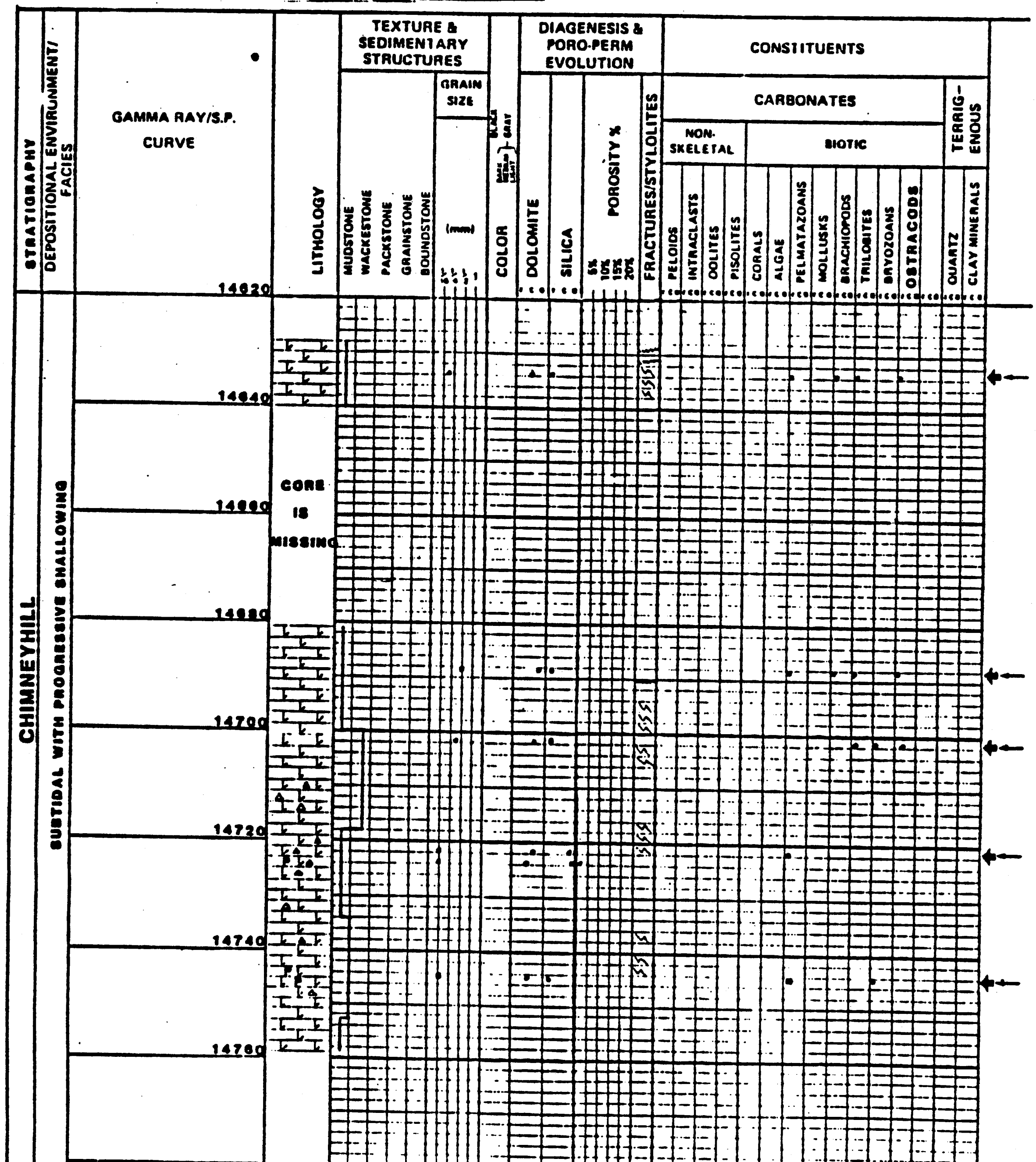
Well Getty Leutkemeyer No. 1
Location Sec. 24 T. 19 N., R. 11 W.
Blaine Co., OKLAHOMA



WELL: Mobil Horton No. 1
LOCATION: 14-15N-15W
CORED DEPTH: 14628-14759

The cored interval consists of dolomudstone/wackestone, dolowackestone and an upper dolomudstone facies. The lowermost unit (14718-14759 ft) is a dolomudstone/wackestone. It is cherty, knobby bedded and contains some pyrite. The next unit (14700-14718 ft) is a dolowackestone. It is similar to the lower unit, but has more dolomite and less silica. The uppermost unit (14628-14718 ft) is a dolomudstone which is similar to the underlying units but contains fewer fossils. The amount of dolomite tends to decrease downward throughout the section. The entire unit is probably subtidal with progressive shallowing through time.

Well Mobil Horton No.1
Location Sec.14 T.15 N., R.15 W.
Custer Co., OKLAHOMA



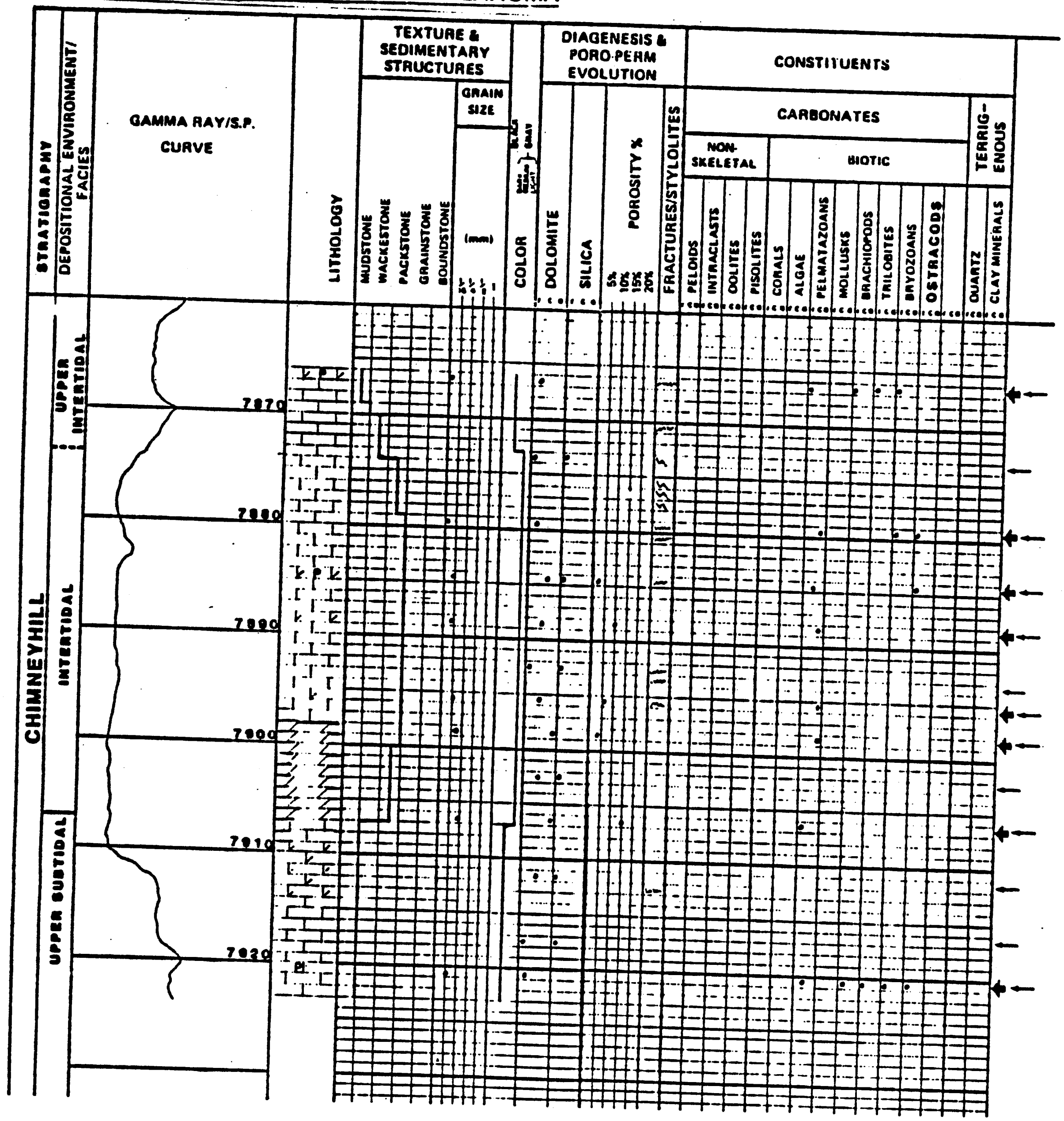
WELL: Jones and Pellow Reherman No. 1
LOCATION: 25-15N-6W
CORED DEPTH: 7867-7923
STRATIGRAPHIC INTERVAL:

The cored interval contains a pack/grainstone in between two mud/wackestone units. The lowermost interval (7908-7923 ft) is a gray mudstone/wackestone with prominent burrowing visible throughout and some hummocky bedding present at the base. This unit was probably deposited in an upper subtidal environment.

The middle unit (7874-7907 ft) is a pinkish gray packstone/grainstone. Crinoid fragments are the most common fossil present. Minor amounts of dolomite and pyrite are found in the middle of this section which is believed to have been deposited in an intertidal environment.

The uppermost interval (7867-7874 ft) is a gray, laminated mudstone/wackestone. It was probably deposited in an upper intertidal environment.

Well Jones and Pellow Reherman No. 1
Location Sec. 25 T.15 N., R. 6 W.
Kingfisher Co., OKLAHOMA



VITA 2

Federica Maria Manni

Candidate for the Degree of

Master of Science

Thesis: DEPOSITIONAL ENVIRONMENT, DIAGENESIS, AND UNCONFORMITY IDENTIFICATION OF THE CHIMNEYHILL SUBGROUP, IN THE WESTERN ANADARKO BASIN AND NORTHERN SHELF, OKLAHOMA

Major Field: Geology

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