THE DEPOSITIONAL HISTORY OF THE

SYCAMORE LIMESTONE

By

KAREN ELIZABETH FRANKLIN

Bachelor of Science

Oklahoma State University

Stillwater, Oklahoma

1997

Submitted to the faculty of the
Graduate College of
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
August, 2002

THE DEPOSITIONAL HISTORY OF THE

SYCAMORE LIMESTONE

Thesis Approved:

Thesis Adviser

Dean of the Graduate College

ACKNOWLEDGEMENTS

I sincerely thank my advisers for all their help and patience with this thesis. Dr. Al Shaieb provided me with confidence and an unending supply of information. Dr. Boardman and Dr. Cemen provided helpful information from their disciplines.

I thank my parents for all their help as well. They supported my family and I both mentally and financially. I especially thank Mom and Dad for watching my sons when I just had to get to school to work.

I cannot express how thankful I am to my husband for all his support while I was working on my thesis. Without him, this wouldn't be possible. He and my sons provided support and love when things didn't seem to be going right.

Finally I would like to thank the professors in the Geology Department and my fellow students for suffering through my constant questions. Many of them provided ideas and answers that helped me continue on those days where it seemed impossible to do so.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Purpose of Study

The purpose of this study is to determine the depositional history of the Sycamore Limestone. The study will attempt to explain the environment in which the carbonates of this formation were deposited.

The limestone of the Sycamore is hard enough that it was commonly used as a building stone. While the formation consists mainly of carbonates – limestones with some chert – it also contains shales.

Location

In the area of study, the Sycamore Formation is bounded by the older Woodford Shale and the younger Caney Shale. The outcrops studied are road cuts along Interstate Highway 35, which runs through the Arbuckle Mountains of southern Oklahoma.

The northern Sycamore road cut is approximately at mile marker 50 on the east side of the north-bound traffic lanes, W1/2, SE1/4, NE1/4, Sec. 30, T. 1 S., R. 2 E., in Murray County, Oklahoma. The southern Sycamore road cut is at mile marker 44 on the west side of the south-bound traffic lanes, C, NW1/4, SE1/4, Sec. 25, T. 2 S., R. 1 E. in Carter County, Oklahoma (see Figure 1).

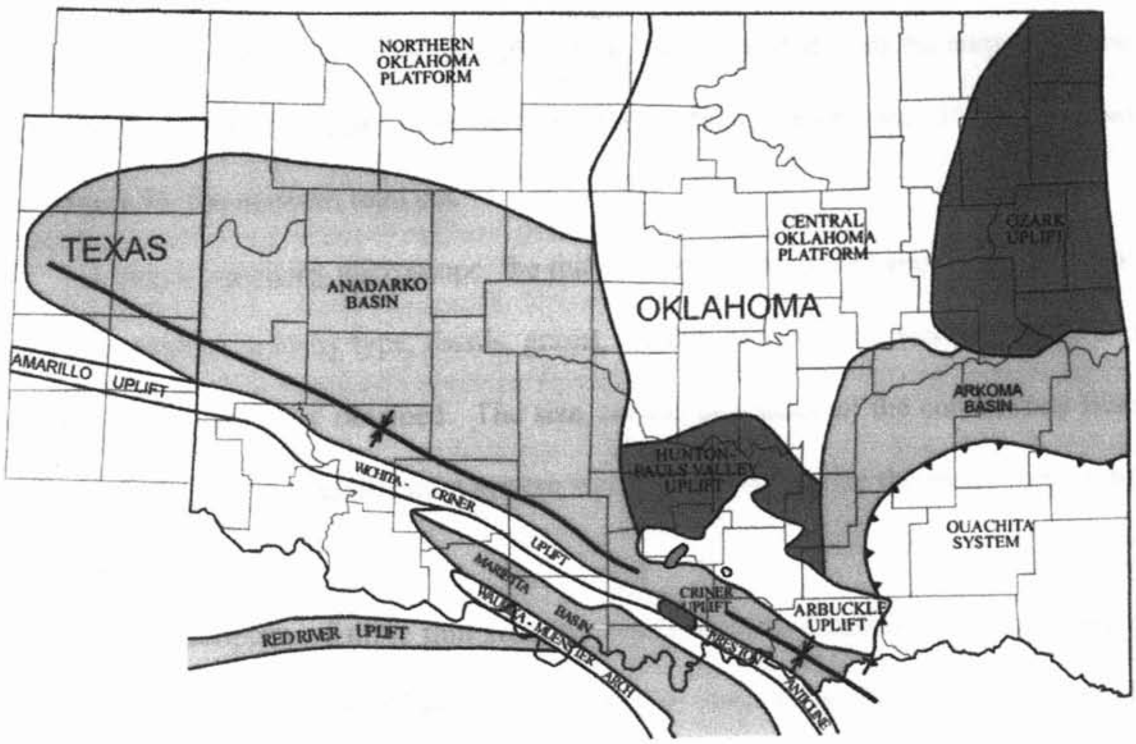


Figure 1. General location of study area, shown in red. Yellow area is Taff's type locality of the Sycamore Limestone (from Taff, 1903). Included in the map are structural regions in Oklahoma, with the Anadarko Basin shown.

Method of Study

Intensive fieldwork began in the late spring of 2000 and continued through autumn of the same year. Measured sections were made. Description of the measured sections included the weathered and unweathered colors of the outcrop, thickness, possible cements, notation of fossils (or lack thereof), lithology, regularity of bedding and bedding characteristics. 80 to 100 samples in all were collected from the sites. Of these field samples, 39 thin sections were made for the southern road cut and 31 thin sections were made for the northern road cut.

Using a polarizing microscope, the thin sections were studied and described in the lab. The porosity, porosity type, fossils, grains, cement, and minerals were described and percentages of each were obtained. The size, sorting and shape of the constituents were also noted. Dunham's classification system was utilized to describe the rock types, using several descriptors.

The description of these thin sections will be used to determine the depositional environment of the Sycamore Formation, as well as notes from fieldwork. A research study was also conducted, but was used more as a comparative study rather than as a descriptive tool.

Formation History

The Sycamore Formation is known to have formed during the Mississippian Period. When during this period has been a subject of dispute from the time the formation was discovered.

In the European view, the Mississippian is actually a sub-period of the Carboniferous Period, which contains the Tournaisian, Visean and Serpukhovian Epochs, in ascending order. In the United States however, the Mississippian and Pennsylvania Periods more often replace the Carboniferous Period, with the Mississippian being the older of the two. The Mississippian Period is divided into the Kinderhookian, Osagean, Meramecian and Chesterian Epochs, with the Kinderhookian being the oldest.

The Mississippian period is believed to have begun around 363mya. It lasted about 40 million years and ended around 323mya. The best estimates say that the Kinderhookian lasted about 9 million years (from 363mya to 354mya), the Osagean lasted 9 million years (from 354mya to 345mya), the Meramecian lasted 4 million years (from 345mya to 341mya) and the Chesterian, being the longest of the Epochs in the Mississippian, lasted about 18 million years (from 341mya to 323mya) (see figure 2). (Harland et al, 1989)

On the southern half of the North American continent, the Mississippian was a very busy time, geologically speaking. As the Sycamore Formation was beginning its deposition there were three major mountain building events occurring.

On the eastern margin of the craton the convergence of the African continent was causing the Acadian orogeny. An oceanic plate colliding on the western margin of the craton was causing the Antler orogeny. Also, on the southern margin of the craton another continent-to-continent collision was occurring. The South American continent converging on the North American Craton was causing the Proto-Ouachita orogenic event.

Paleozoic	Pennsylvanian	Morrowan 323mya
	Mississippian	Chesterian 341mya
		Meramecian 345mya
		Osagean 354mya
		Kinderhookian 363mya
	Devonian	Famennian

Figure 2. A simplified geologic time scale showing the Mississippian Period, it's Epochs and their approximate ages. Modified from Harland et al, 1989.

Due to these multiple compressions the Transcontinental Arch formed on the stable cratonic platform. A few structural troughs and depositional basins occurred around this platform. The Anadarko Basin was one of these and is the basin in which the Sycamore was deposited. The descent into this basin from the shelf edge was gradual, with the foreslope being from 1 to 5 degrees from the horizontal.

At the time the Sycamore formation was starting to be deposited, the eustatic rise of sea level reached highstand. Gutschick and Sandberg (1983) believe the greatest depth of the Anadarko Basin at this time was 200m, the shallowest depth being 50m. They also believed this depth kept the basin within the neritic zone.

Because the Anadarko Basin was south of the equator at this time, surface sea currents, according to the counter-clockwise coriolis effect of the southern hemisphere, flowed from east to west across the Anadarko Basin. Upwelling along some of the shelf edges was also a major factor at this time, creating nourishing environments for many different faunas.

Previous Investigations

Sporadic work has been done on the Sycamore Formation since its original description and documentation in 1903 by J.A. Taff. In his work on the Tishomingo Folio, Taff states that the Sycamore Limestone "is spoken of as a wedge", indicating the possibility of even earlier work on the formation (Taff, 1903). After an intensive search for any information on the Sycamore, nothing earlier than 1903 has been revealed. It is possible that this "previous work" may have been only word-of-mouth speculation between colleagues.

Taff named the Sycamore Limestone after Sycamore Creek. The creek crosses the type locality of the Sycamore Limestone at NE1/4, NE1/4, Sec. 34, T.3S., R.4E (see Figure 1). Taff also gave a basic description of the Sycamore Formation in a 1904 publication. In both publications the formation is described as earliest Carboniferous, a lentil or wedge, and having no fossils.

The next author to note the Sycamore was Reeds in 1910. He described places where the formation crops out and directly quoted Taff's description.

In 1924, Morgan did a more in depth study of the Sycamore. He described its areal extent in the Stonewall Quadrangle and goes on to describe its thickness, character, fauna, age and correlation. He appears to be the first one to attempt a more accurate description of the Sycamore's age. Using faunal data and correlation with other formations, he believes the Sycamore is Kinderhookian in age, a slightly better description than that given by Taff in 1903.

In 1926, Cooper published a 26 page circular exclusively on the Sycamore. He states that, given its lithologic characteristics, it makes an excellent key horizon. "The Sycamore formation is a lentil and is the result of continuous deposition from the Woodford Shale all the way through to the Caney Shale." (Cooper, 1926) Cooper was unable to come up with a better age for the Sycamore than Kinderhookian.

In 1927, Buchanan published a paper correlating the Sycamore limestone to the Kinderhookian Group, although he was more specific in a chart in which he placed the Sycamore in latest Kinderhookian. Buchanan gives a very basic description of the formation. The age of the Sycamore was previously studied using a collection of fossils from the formation. Buchanan agreed with the previously studied age.

Reeds published in 1927 as well – a circular on the Arbuckle Mountains. He barely mentions the Sycamore, giving only a sparse quote from his 1910 work.

There was nothing published on the Sycamore for almost 21 years until 1948. It was a collaborative work correlating all the Mississippian formations of North America, headed by J. Marvin Weller. A basic description of the Sycamore is given but it is not assigned any age other than Mississippian. It is noted that it may correlate with the Osagean "Mayes" formation.

In 1950, Huffman and Barker studied the Lawrence Uplift in Pontotoc County, Oklahoma. What was previously considered to be Sycamore Limestone in the Uplift was reevaluated and reclassified as the Weldon Limestone.

Bennison, in 1956, wrote a paper for the Tulsa Geological Society, studying the Springer and its related formations in Oklahoma. He gives a general lithologic description of the Sycamore and then attempts to put an age to it. Using the current research of the time, Bennison states that the Sycamore is probably Kinderhookian and Osagean, with the possibility that it could even be younger (Meramecian).

Also in 1956, Harlton published a work on the Harrisburg Trough. He gives a general description of the Sycamore and dates the formation as lower Meramecian. What is previously thought of as the Sycamore of Osagean age Harlton calls Pre-Sycamore.

Rutledge gives an account of the stratigraphy of the Velma Oil Field in 1956. The Sycamore is given a basic description and he places it in Osagean time. The upper portion that was in the Meramecian time he refers to as "Mayes".

In the first thesis done on the Sycamore Formation, Prestridge does the most in-depth study up to 1957. However, his study deals more with a lithologic study of the Sycamore in the Ardmore Basin than a time stratigraphic correlation. He holds with the Sycamore being Osagean in age. In his study, Prestridge separated the Sycamore into three members, the Estate member (oldest), the Quarry member and the Worthy member (youngest). Later authors have referred to his member names, but they are not taken as fact. Prestridge feels that the lower Sycamore was deposited in a shelf or outer shelf environment. The middle section of the Sycamore is most likely transgressive clastic limestone while the upper Sycamore is probably from a shallow shelf environment.

The next thesis to cover the Sycamore was published by Braun in 1959. He places the Sycamore in Meramecian time, calling anything previous to it Weldon Limestone. He calls the Sycamore a transgressive clastic limestone formed in stable conditions with an environment not conducive to life. Both Braun and Prestridge believe there could have been a clastic source to the southwest of the formation.

Champlin sites the lack of fossils from the Sycamore as part of the problem with obtaining an accurate age for the formation in his 1959 masters thesis. Despite this lack and using research, both lithologic and literature, Champlin places the Sycamore in the lower Meramecian Epoch. Champlin feels that the formation was deposited in relatively shallow water during stable depositional conditions.

Culp continues the general trend in 1961 and also places the Sycamore in the Meramecian Epoch. He indicates the formation was probably deposited in a "shallow shelf environment not favorable to abundant life" (Culp, 1961). Culp is unsure as to the source area for the clastics in the limestone. He feels that the southeast may be a possible direction due to an "early pulse of the Ouachita movement." (Culp, 1961)

Between 1967 and 1969 the road cuts examined in this study were created due to a federally funded road project. Dr. Robert O. Fay was responsible for studying the many road cuts along the new route for Interstate Highway 35. Among these road cuts was the Sycamore Formation. Fay does an in-depth outcrop study that includes fossil collections from both Sycamore road cuts. Included in these collections were corals, bryozoans, brachiopods, trilobites and echinoderms. Due to the immense scale of the study, no attempt was made to determine the age of the Sycamore. It is simply noted as being Mississippian. The field information obtained by Fay was used extensively in this author's field studies.

Between 1969 and 1988 there were a few publications that featured the Sycamore Formation, but they were mainly guidebooks and publications where the formation was simply mentioned in passing. No physical research had actually been done.

In 1988, Cole published his master's thesis on the Sycamore Limestone. He took a slightly different approach to the study in that he divided the formation into six different facies types based on their lithology. He uses four different environments to explain the deposition of these facies, although these environments are basically lagoonal or slightly deeper marine. None of these depositional environments are below storm wave base. Based on previous research, Cole believes the Sycamore is Osagean in age.

In 1990, Schwartzapfel published his doctoral dissertation. While it was more of a paleontological study of radiolaria, it did include short lithostratigraphic studies of particular formations which include the Sycamore. Using conodont zonation data, Schwartzapfel feels the Sycamore could be no lower than middle Meramecian in age. He also uses sedimentary and bedding data to point out that the Sycamore could be partially to entirely turbiditic in origin. An interesting note to his work is that Schwartzapfel believes he found a partial Bouma Sequence (an indicator of turbidity currents) in the upper Sycamore.

Schwartzapfel published again in 1996 with Holdsworth, however the part of the work containing information on the Sycamore was simply condensed from the author's 1990 dissertation.

Finally, in the year 2000, Coffey published his dissertation on the Carter-Knox oil field. The Sycamore was studied in great detail in this publication.

Like Cole, Coffey also divided the Sycamore into stratigraphic units, although he used four instead of six. He gives detailed descriptions of each.

Coffey agrees with the chronostratigraphic position of the Sycamore that was proposed by Schwartzapfel. This position has the lower Sycamore being no older than middle Meramecian. These conclusions are all based on very extensive faunal studies done by several different workers. The author of this study agrees with both Schwartzapfel and Coffey on this chronostratigraphic position for the Sycamore Formation.

After a lithologic study, Coffey's findings tended to agree with Schwartzapfel's depositional setting. Both the authors felt the Sycamore was deposited by means of gravity flows and/or turbidity currents.

In recent decades, the number of researchers working on the Sycamore and the detail of the studies has increased. This author is simply one in a long line extending back almost one hundred years. The complexity of this formation is surprising considering the fact that in outcrop it looks deceptively simple. It is hoped that studies on the Sycamore formation will continue for another hundred years, or until all the complexities are worked through – whichever comes first.

CHAPTER II

GEOLOGICAL SETTING

Regional Structure

During the Late Precambrian to Early Cambrian time (about 600mya to 550mya) southeastern Oklahoma was the site of what may have been a triple junction. It is hypothesized that a triple junction occurs as the result of a localized deep mantle convective plume. As the plume heats up the overlying continental crust, a bulge in the crust forms and eventually splits into three radial rifting arms, or a triple junction. Often two of these arms will join and begin a continental rift zone while the third arm fails, becoming an Aulacogen (see Figure 3). An aulacogen is a structurally weak zone that subsides and collects a thick sequence of sediments. This is what happened in southeastern Oklahoma. The region is known as the Southern Oklahoma Aulacogen.

The development of an aulacogen follows three stages, all of which are represented in the Southern Oklahoma Aulacogen. The first stage is the rifting stage, characterized by uplift, extensional rifting and the formation of grabens or small rift valleys. Both extrusive and shallow intrusive igneous activity is associated with this stage. The 500 to 550 million year old Colbert Rhyolite, found in the core of the Arbuckle Anticline, is evidence for the rifting stage of the Southern Oklahoma Aulacogen.

The second stage of aulacogen formation is the subsidence stage. The rapid subsidence of this stage is accompanied by the development of a passive continental margin, marine transgression and the development of a very thick sedimentary sequence.

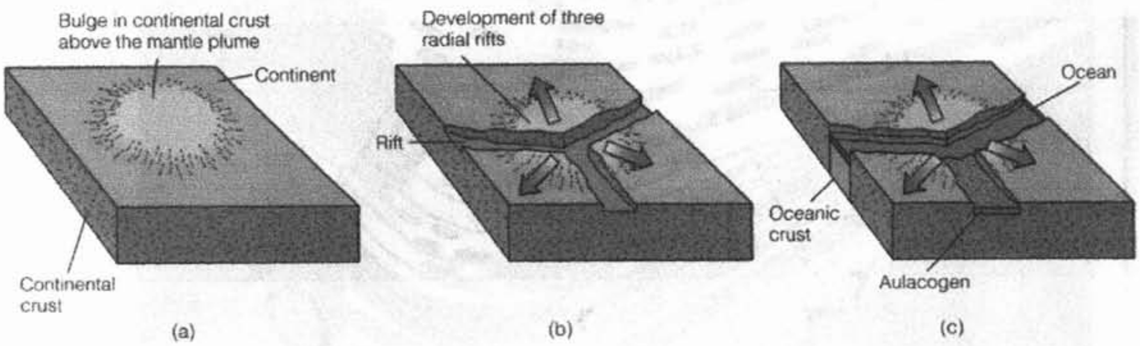


Figure 3. Formation of (a) bulge, (b) triple junction and (c) an aulacogen. From Wicander and Monroe, 1993.

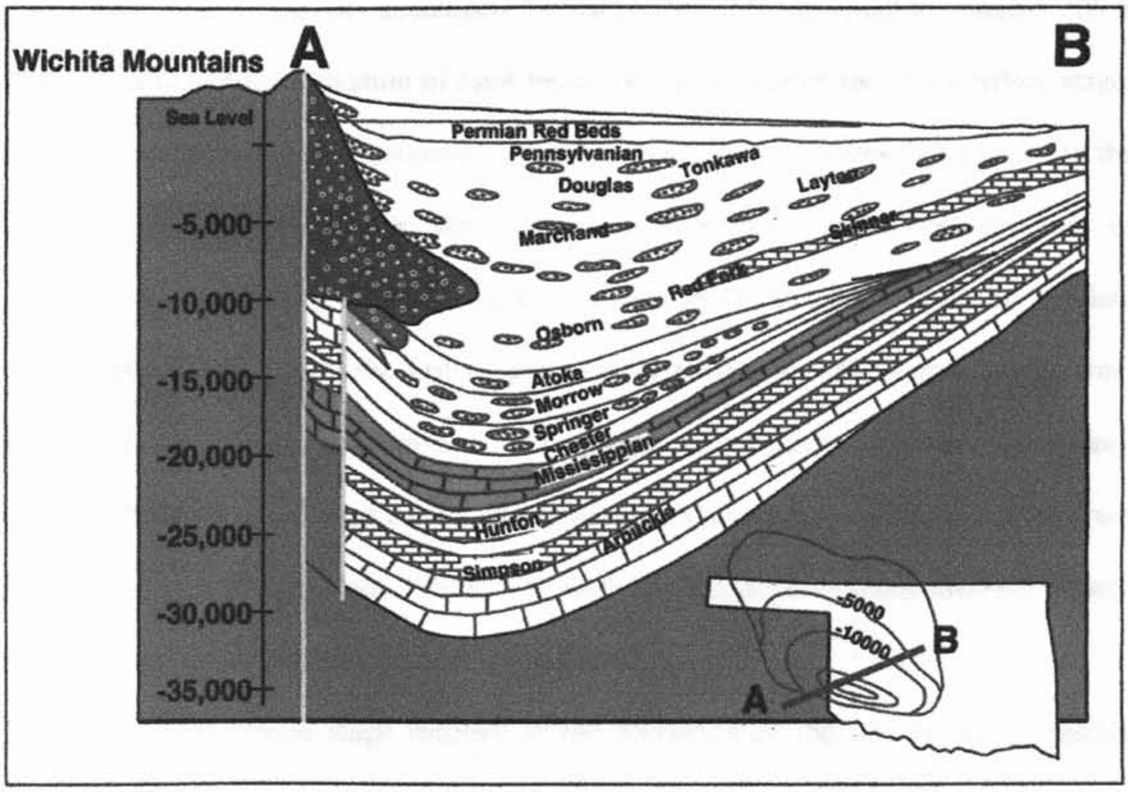


Figure 4. Illustration of the formations included in the subsidence stage of the Anadarko Basin/Southern Oklahoma Aulacogen. Mississippian aged strata is shown in red.

In the Southern Oklahoma Aulacogen, this stage was the longest, lasting from the late Cambrian to Mississippian time (about 500mya to 330mya) (see Figure 4). Sediments that accumulated in the Anadarko Basin are evidence for the subsidence stage. By the time the final aulacogen stage was finished, it is estimated that about 30,000 feet of sediments had accumulated in the Southern Oklahoma Aulacogen (Palladino, 1985).

The final stage of aulacogen formation is the deformation stage. It is characterized by the reactivation of fault trends (produced during the initial rifting stage) along with the production of orogenic conglomerates and local basins and uplifts. In the Southern Oklahoma Aulacogen this stage was developed by different orogenic or mountain building events. The earliest of these events may have begun in the late Mississippian Period, with the last orogenic event ending in Late Pennsylvanian time (approximately 330mya to 300mya). Four uplifts, the Arbuckle, Munster, Wichita and Criner Hills Uplifts, and three basins, the Anadarko, Marietta and Ardmore Basins, were formed during this stage (Cole, 1988). The Wichita and Arbuckle Orogenies contributed to the deformation of the Southern Oklahoma Aulacogen.

This deformation stage resulted in the formation of the present day Arbuckle Mountains. What are seen of those mountains today are only the deep roots of what were once very high mountains – possibly higher than today's Rocky Mountains.

Regional Stratigraphy

The stratigraphy of this region reflects the activity of the Southern Oklahoma Aulacogen, beginning with the Colbert Rhyolite. This formation is characterized mainly by volcanic flows and is estimated to be about 7500 feet thick. Although there is no contact at the surface, the Colbert Rhyolite would lie above the Tishomingo and Troy Granites, estimated to be 1.3 billion years old (Hart, 1994).

The first sedimentary deposit above the Colbert Rhyolite (and the first known sedimentary deposit of the subsiding aulacogen) is the Reagan Sandstone, which has an unconformable contact with the rhyolite. The Reagan Sandstone is the first unit in the Timbered Hills Group, followed by the Honey Creek Limestone. The sandstone is a terrigenous clastic unit and represents the initial marine transgression over the subsiding aulacogen. The Timbered Hills Group, as well as the Lower Arbuckle Group, is Cambrian in age. In ascending order, the Lower Arbuckle Group consists of the Fort Sill Limestone, the Royer Dolomite and the Signal Mountain Formation (see Fig. 5).

The rest of the Arbuckle Group is Lower Ordovician in age. In ascending order, the members of the Upper Arbuckle Group are the Butterly Dolomite, the McKenzie Hill Formation, the Cool Creek Formation, the Kindblade Formation and the West Spring Creek Formation (see Fig. 5). Despite the wide range in age between the first and last members of the Arbuckle Group (a difference of approximately 30 million years), the sediments of the group are all mainly characterized by tidal flat and shallow subtidal lithologies (Palladino, 1985).

The Middle Ordovician Simpson Group overlies the Arbuckle Group. Its oldest member is the Joins Formation, followed by the Oil Creek Formation, the McLish Formation, the Tulip Creek Formation and the Bromide Formation. The Bromide Formation consists of two members, the Mountain Lake Member and the Poolville Limestone Member, with the Mountain Lake Member being the oldest (see Fig. 5). The sediments of the Simpson Group are similar to those of the Arbuckle Group, however,

STRATIGRAPHIC SECTION EXPOSED ON I-35 THROUGH THE ARBUCKLE ANTICLINE AND MAPPED AREA

SYSTEM	GROUP	GROUP, FORMATION AND MEMBER	MAP SYMBOL	THICKNESS (ft) SOUTH FLANK	THICKNESS (ft) NORTH FLANK
QUATERNARY		Alluvium and Terrace deposits	Qat		
		UNCONFORMITY			
PERMIAN - PENNSYLVANIAN		Pontotoc Group *undifferentiated*	Po IPp		
		UNCONFORMITY			
PENNSYLVANIAN		Collings Ranch Conglomerate	IPcr		3000 estimated
		UNCONFORMITY			
MISSISSIPPIAN		Goddard Shale	Mg	2500	
		Delaware Creek Shale (formerly "Caney" Shale)	Md	425	
		Sycamore Limestone	Ms	358	221
DEVONIAN		Woodford Shale	MDw	290	274
	Hunton Group (DSOh)	Bois d'Arc Limestone	*	9	19
	Hunton Group (DSOh)	Haragan Formation	*	25	16
SILURIAN	Hunton Group (DSOh)	Henryhouse Formation	*	191	72
	Hunton Group (DSOh); Chimneyhill Subgroup	Clarita Limestone	*	12	16
	Hunton Group (DSOh); Chimneyhill Subgroup	Cochrane Limestone	*	13	4+
ORDOVICIAN	Hunton Group (DSOh); Chimneyhill Subgroup	Keel Limestone	*		7
		Sylvan Shale	Os	305	275
		Viola Group	Ov	684	710
	Simpson Group	Bromide Formation	Obr	420	346
	Simpson Group	Poolville Limestone Member	*	120	80
	Simpson Group	Mountain Lake Member	*	300	266
	Simpson Group	Tulip Creek Formation	Otc	395	297
	Simpson Group	McLish Formation	Oml	475	397
	Simpson Group	Oil Creek Formation	Ooc	747	
	Simpson Group	Joins Formation	Oj	294	
	Upper Arbuckle Gp	West Spring Creek Formation	Ow	1515	
	Upper Arbuckle Gp	Kindblade Formation	Ok	1410	
	Upper Arbuckle Gp	Cool Creek Formation	Occ	1300	
	Upper Arbuckle Gp	McKenzie Hill Formation	Omh	900	
	Upper Arbuckle Gp	Butterly Dolomite	Ob	297	
CAMBRIAN	Lower Arbuckle Group	Signal Mountain Formation	€sm	415	
	Lower Arbuckle Group	Royer Dolomite	€ry	717	
	Lower Arbuckle Group	Fort Sill Limestone	€fs	155	
	Timbered Hills Group	Honey Creek Limestone	€hc	105	
	Timbered Hills Group	Reagan Sandstone	€r	240	
		Colbert Rhyolite	€c	4500 drilled	7500 estimated

* Formation or member shown only on cross section

Figure 5. Stratigraphic section of the Arbuckle Mountains along highway I-35, Carter and Murray Counties, Oklahoma. From Fay, 1969.

they contain a greater percentage of terrigenous clastics. During the deposition of these two groups the subsidence rate of the aulacogen was approximately equal to the sedimentation rate (Palladino, 1985).

The Middle to Upper Ordovician Viola Group consists mainly of deep marine carbonates. The nature of these carbonates indicates an increased rate of subsidence in the aulacogen. The Sylvan Shale comes next, followed by the Keel Limestone, both Upper Ordovician in age. The Keel Limestone is the oldest member of the Hunton Group and is the last unit of Ordovician age in this region (see Fig. 5).

The Hunton Group, which is characterized by marly limestones, extends from Upper Ordovician time through the Silurian Period to the Devonian Period. After the Keel Limestone comes, in ascending order, the Cochrane Limestone, the Clarita Limestone and the Henryhouse Formation, all Silurian in age. The last two members of the Hunton Group are the Lower Devonian Haragan Formation and the Middle Devonian Bois d'Arc Limestone (see Fig. 5).

The Upper Devonian to Lower Mississippian Woodford Shale and the Lower to Middle Mississippian Sycamore Limestone represent another period of increased subsidence in the aulacogen. Palladino (1985) characterizes the Sycamore Limestone as "a micritic limestone with varying amounts of clay and silt sized terrigenous debris."

The Delaware Creek Shale, also known as the Caney Shale, follows the Sycamore Limestone and represents a continued high subsidence rate. It is followed in turn by the Upper Mississippian Goddard Shale that appears to be the last unit deposited in the subsiding aulacogen before the deformation stage began.

The Pennsylvanian Collings Ranch Conglomerate rests unconformably on the Goddard Shale and represents uplift that occurred during the deformation stage (see Fig. 5). It contains pebbles and debris from the Reagan Sandstone upward (Fay, 1969). After another unconformity comes the Pontotoc Group which is Upper Pennsylvanian to Permian in age. It is also representative of the uplift that occurred during the deformation of the aulacogen. Quaternary alluvium and terrace deposits complete the stratigraphy of this geological region.

Sequence Stratigraphy

Sequence Stratigraphy is used to place specific formations within a context of stratigraphic cyclicity. Because sequence stratigraphy is a relatively new science, W.S. Coffey is the only other author attempting to place the Sycamore Limestone within some sort of cyclicity.

The smallest unit of measure in sequence stratigraphy is the parasequence. A parasequence is defined as "a relatively conformable succession of genetically related beds or bed sets bounded by marine flooding surfaces and their correlative surfaces". (Van Wagoner et al, 1987) This measurement therefore is not based on any certain amount of time or even a particular lithology but, as Coffey states, is "based on stratal relationships." The Sycamore Limestone is made up of only a few or more parasequences, which may or may not form a parasequence set.

One formation is usually not enough to find a pattern of cyclicity. It often requires several formations to even begin finding a pattern. The formations mentioned in the Regional Stratigraphy section of this chapter may be enough to find a pattern of cyclicity.

The sequence stratigraphic analysis of the Sycamore Limestone done by W.S. Coffey was quite interesting. He first divided the Sycamore into 3 distinct lithologies. These were the basal shale facies, the lower and upper bench silty peloidal packstone facies and the middle shale facies (Coffey, 2000).

Coffey stated that the basal shale facies represented the initial flooding surface over the Woodford Shale. The development of the middle shale facies over the lower bench silty peloidal packstone facies represented another flooding surface and created a transgressive systems tract (Coffey, 2000).

The way Coffey described the depositional history of the lower and upper bench silty peloidal packstone facies affected his sequence stratigraphic analysis of those facies. Coffey believed that the facies were deposited mainly by gravity flow deposits. Because of this interpretation he placed the facies in a lowstand sea level cyclicity.

CHAPTER III

PETROLOGY AND PETROGRAPHY

Procedures

In order to conduct a study on the deposition of the Sycamore Limestone there must first be an examination of the physical data. The petrologic composition of the Sycamore is considered here. Classification of the carbonates in the Sycamore is done using the system proposed by Dunham.

Random samples were collected from two outcrops of the Sycamore Limestone. 31 samples were collected from the northern flank outcrop and 39 samples were collected from the southern flank outcrop. Measured sections of the outcrops can be found in the appendix.

Thin sections were made from each rock sample and studied using a polarizing microscope. Analysis of each of the thin sections was done at 100 times magnification and percentages of each of the components were obtained.

Thin Section Analysis

Although field studies are valuable for the information they gather, there is only so much that can be known about a carbonate in the field. A more in depth study must be conducted in a laboratory setting in order to obtain more specific information on the composition and origin of a carbonate.

When studying thin sections under a microscope, there are five general categories in which to group what is being seen. The allochemical particles, orthochemical particles, additional constituents, porosity and the grain size, sorting and rounding of the constituents.

Allochemical Particles

Allochemical particles are defined as "the coarse silt-, sand-, and gravel-size carbonate particles that form the framework in mechanically deposited limestones" (Ehlers and Blatt, 1982). These particles are divided into four general categories, which consist of fossils, peloids, ooliths and limeclasts. Ooliths and limeclasts will not be covered here because of their absence in the Sycamore Limestone.

Ehlers and Blatt (1982) define fossils as "the solid carbonate remains of living organisms." Field identification of fossils is often made easy by their recognizable shapes and characteristics. Sharks teeth, for example, are roughly triangular shaped, while trilobites have a recognizable ridged body following a generally arc-shaped head. The more that fossils are broken up and reworked though, the harder it is to identify them.

Often when studying thin sections, only a fragment of a fossil is left for identification. In these cases, there are certain characteristics of the hard parts that are left which help in the identification of a fossil. For example, crinoids are often characterized by a single large, porous-looking calcite crystal that goes to extinction every 90°. (When the nichols are crossed on a polarizing microscope, calcite goes to extinction, or turns black, every 90° that the microscope stage is rotated.) Most brachiopod shell fragments appear fibrous under the microscope and the extinction runs in waves along the shell fragment when the stage of the microscope is rotated.

Figure 6A. Brachiopod fragment, plain polarized light, x100.

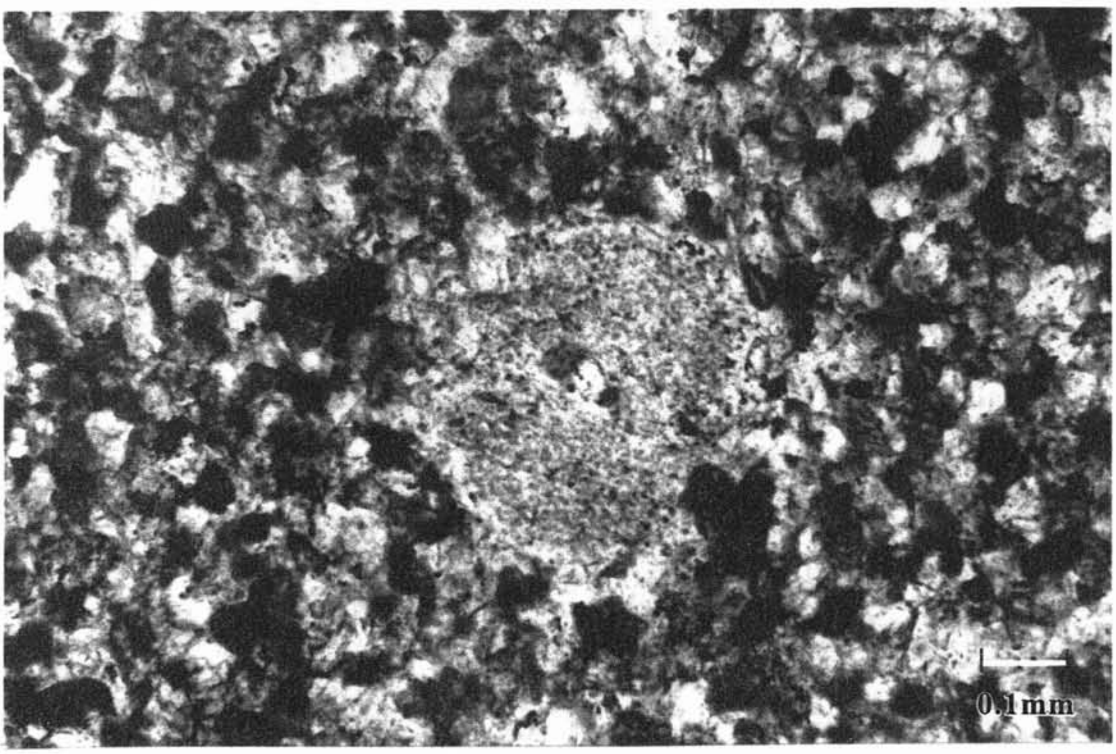


Figure 6B. Crinoid fragment, plain polarized light, x100.

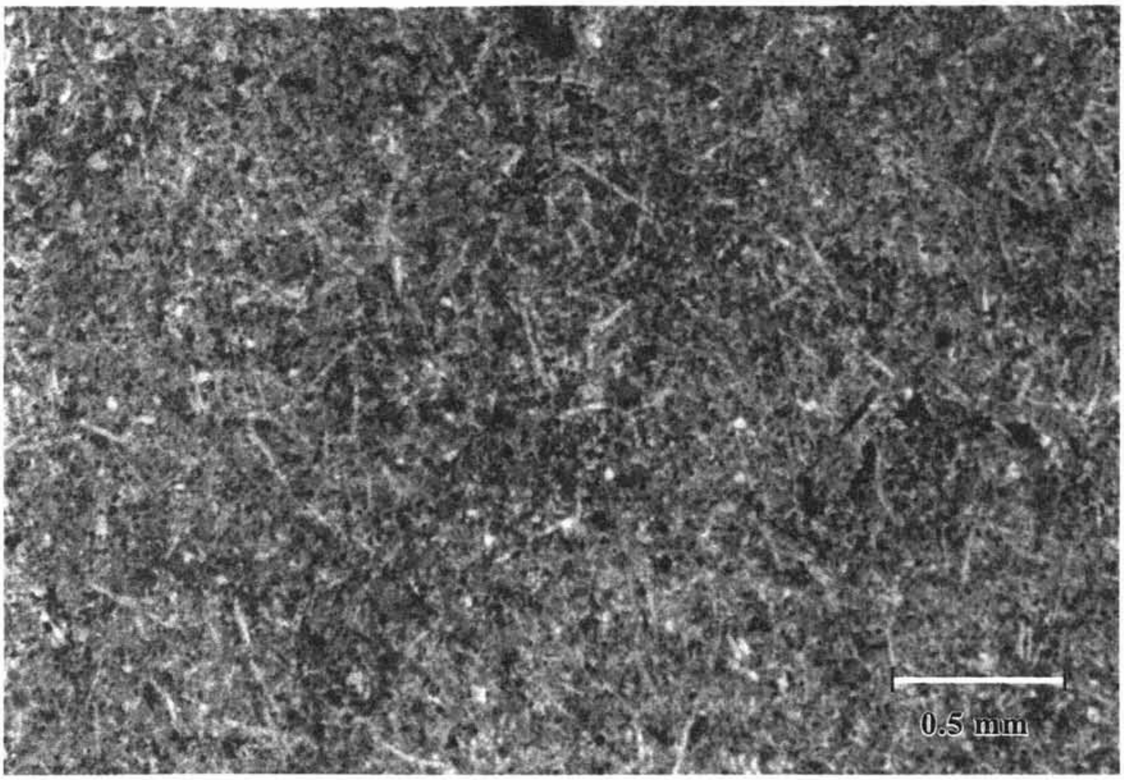


Figure 7. Sponge spicules in chert with porosity, plain polarized light, x40.

This is especially significant because when sponges die and decompose, the spicules are scattered and can be found anywhere from shallow lagoons to deep marine environments (see Figure 7).

A few foraminifera were found in the thin sections. They were difficult to identify due to micritization, a process where micrite replaces original material. Foraminifera are very tiny organisms, usually smaller than 1mm. Those found in the samples were 0.1 to 0.2mm in size. These organisms have shells that are either excreted of calcium carbonate or built using available materials such as sand grains, sponge spicules or whatever else can be found (Boardman et al, 1987). During the Mississippian, foraminifera were all benthic marine organisms. Presently there are both benthic and planktonic varieties of foraminifera (see Figure 8).

Only three examples of bryozoans were found in the analysis. Bryozoans are colonizing organisms that often look like corals or even some types of algae. The colonies are commonly found attached to hard surfaces on the sea floor and can either be encrusting or massive growths (Boardman et al, 1987) (see Figure 9A).

One fragment each was found of an ostracode and a trilobite. Ostracodes are small crustaceans (like a tiny crab between two shells), no larger than 1cm, but commonly are less than 1mm long. They have two shells that can be opened for the ostracode to feed and move around.

Trilobites were not too common in the Mississippian. They were most abundant between the Cambrian and Ordovician Periods, and then began dying out. They finally became extinct at the Permo-Triassic Boundary. Trilobites were benthic organisms, generally found in shallow marine environments (see Figure 9B).

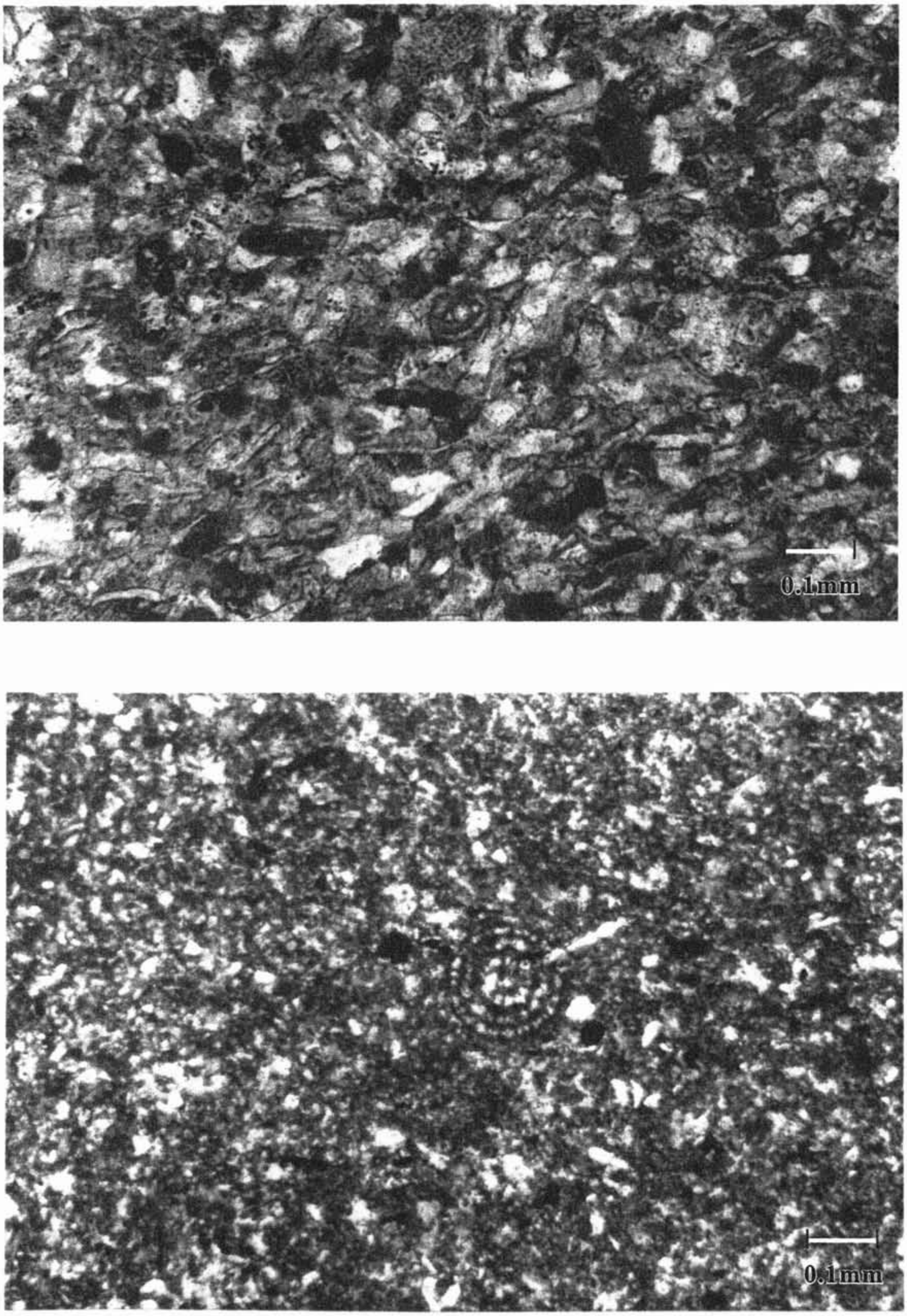


Figure 8. Two examples of foraminifera, plain polarized light, x100.

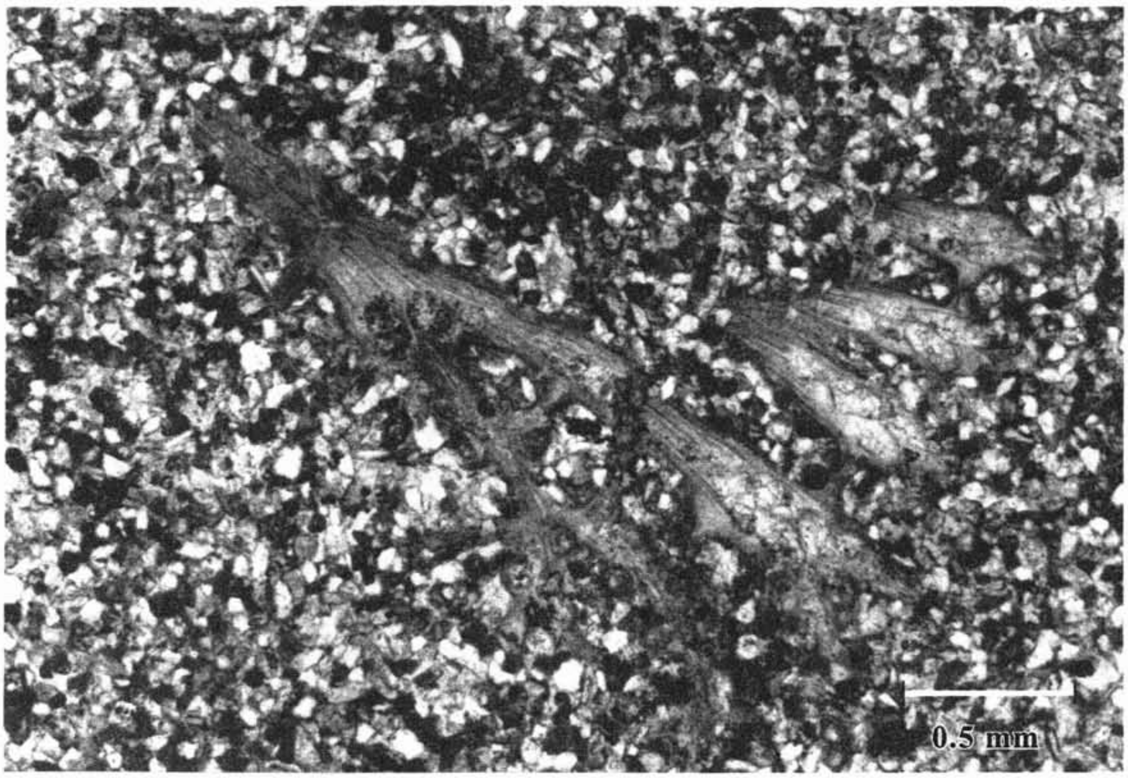


Figure 9A. Bryozoan, plain polarized light, x40.

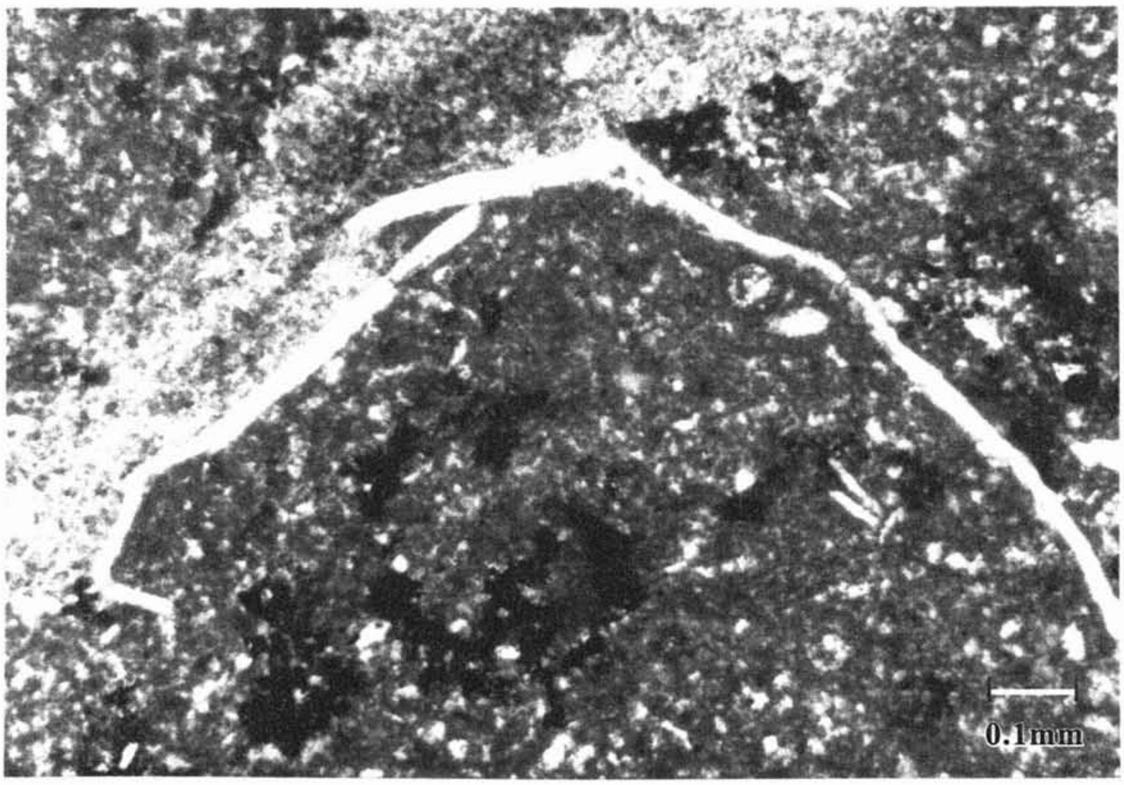


Figure 9B. Trilobite cross section, plain polarized light, x100.

The final fossil type to be noted in the thin section analysis was a conodont fragment, about which little is known. These fossils are theorized to be skeletal elements of mostly soft-bodied organisms and have a tooth-like appearance (see Figure 10). They range in age from the Late Proterozoic Era through the Triassic Period. An important note about these fossils is that they are highly indicative of the ocean depth in their environment of deposition.

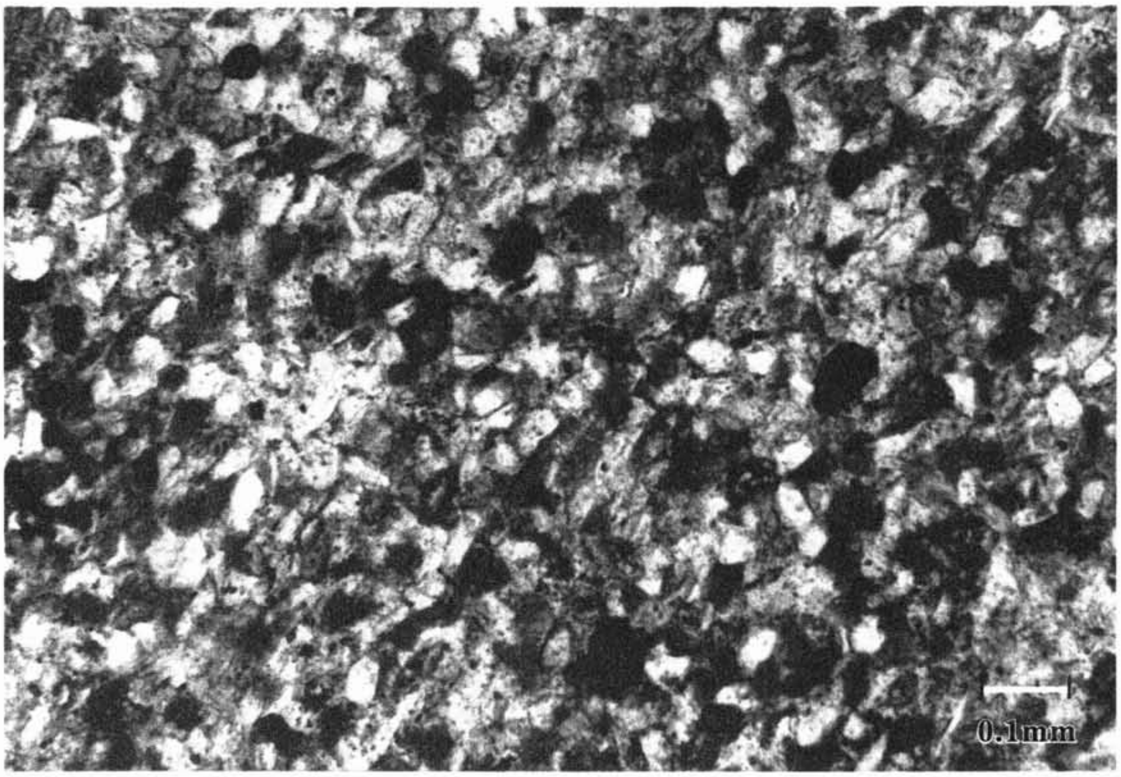
The other allochemical particles found in the thin sections were peloids, or more specifically, pellets. A pellet is defined as "a small rounded aggregate of sedimentary material, such as a fecal pellet, which is typically made up of clay sized calcareous material that is devoid of internal structure and is contained in a well-sorted phosphatic or carbonate rock." (Bates and Jackson, 1984) The average size of the pellets found in this analysis was 0.1mm in diameter. They were most likely fecal in origin, coming from various burrowing organisms that ingested the muddy sediments on the sea floor for nutrients and dispelled the waste as fecal pellets (see Figure 11).

Orthochemical Particles

Orthochemical particles are the calcareous matrix and cements that bind the allochemical particles to lithify the sediment (Ehlers and Blatt, 1982). The two types of orthochemical particles are micrite and sparite. Micrite is microcrystalline calcite and sparite is coarsely crystalline calcite. The Sycamore Limestone can generally be called a micritic limestone although there are occasional occurrences of sparry calcite.

Almost all micrite is formed from calcareous algae. When the algae dies it decomposes and the tiny aragonitic pieces that formed the hard parts of the algae drop to the sea floor, eventually recrystallizing into calcareous cement.

Figure 10. Conodont, plain polarized light, x100 (Glauconite in lower right corner).



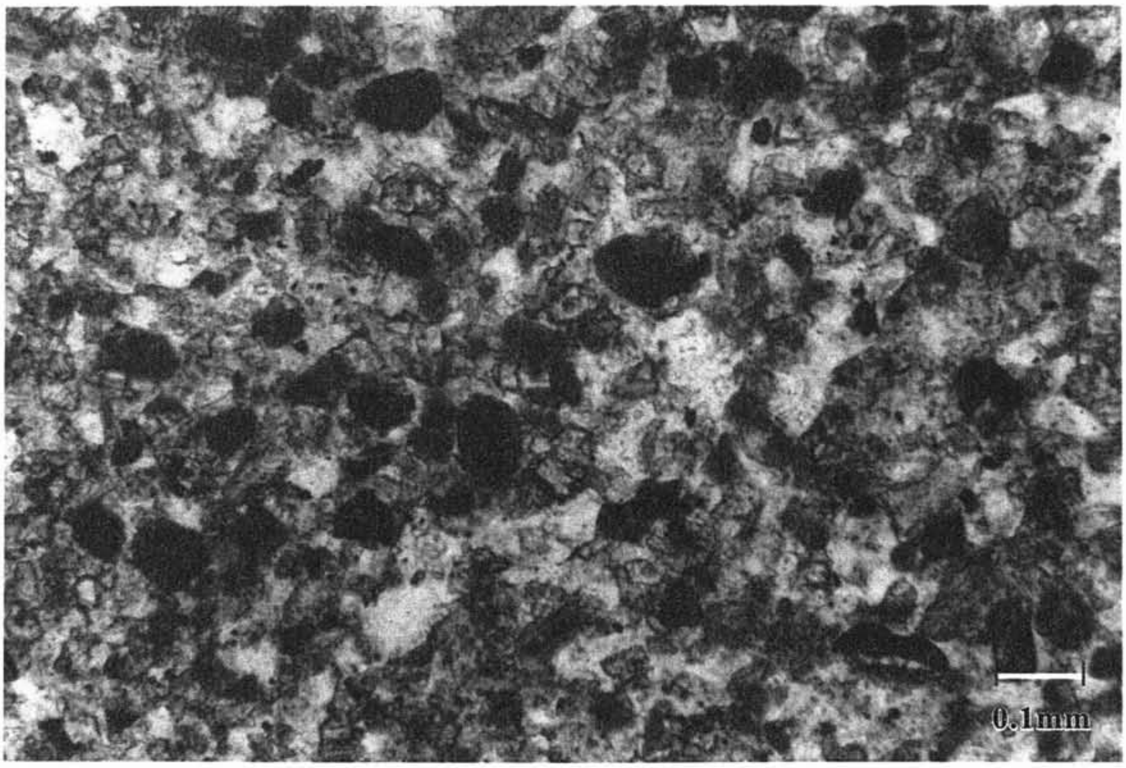


Figure 11. Peloids (dark constituents) plain polarized light, x100.

Additional Constituents

Aside from the porosity, the additional constituents cover the non-organic components of a carbonate. This includes both primary and secondary constituents.

Of the primary constituents (those constituents that were deposited or precipitated in the carbonate before lithification and burial) there were siliceous silt- and fine sand-sized grains and glauconite. The Sycamore Limestone is unusual for the amount of siliceous grains it contains. It ranges from 1.4% of one sample to 39.2% of another sample. This makes the Sycamore very silty and very hard. In the field, rocks with high silt content can be identified by a "soily" or "earthy" odor and are termed argillaceous.

Silt is known to be transported from other sources because carbonates don't form in heavily silted water. Silt is considered terrigenous material, therefore its presence often indicates an influx of fresh water (see Figure 12). If there were many more sample sites in this study a source direction might be found. Discovering the source of this silt, however, is not the purpose of this study.

Glauconite is a greenish mineral of marine origin. It is often indicative of deeper water and slower sedimentation rates. Only a small amount was found in the thin sections (see Figure 13).

Chert, found in a few of the samples, is a secondary constituent, meaning it was not deposited or precipitated before the lithification and burial of the Sycamore Limestone. Because the chert is not in nodular form, it appears that the silica for the chert was already in the limestone, probably in the form of diatoms and radiolarians. These organisms' shells (commonly made of opaline silica) dissolved when fluid moved

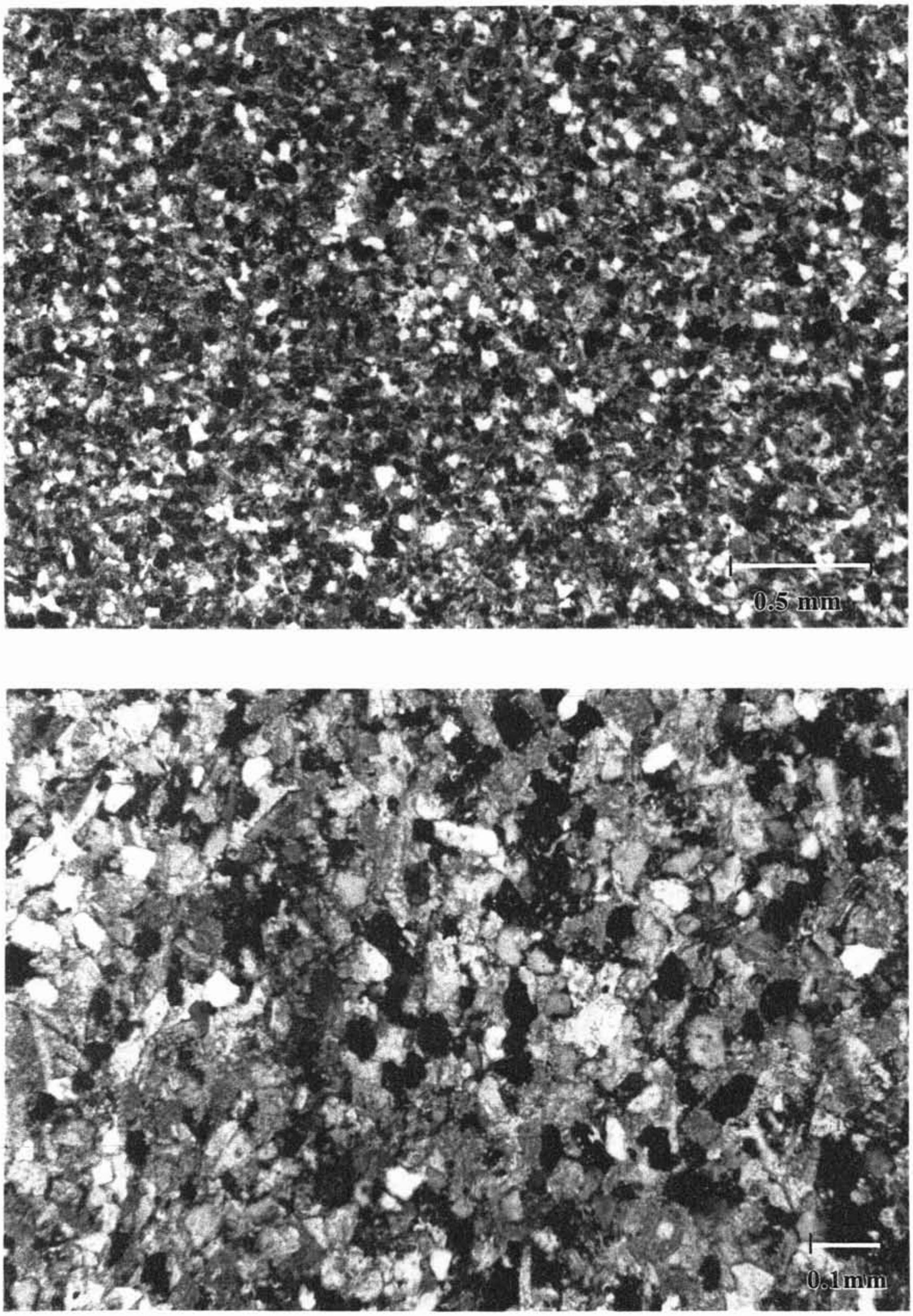


Figure 12. Siliceous grains (dark and light mottled areas), cross polarized light.

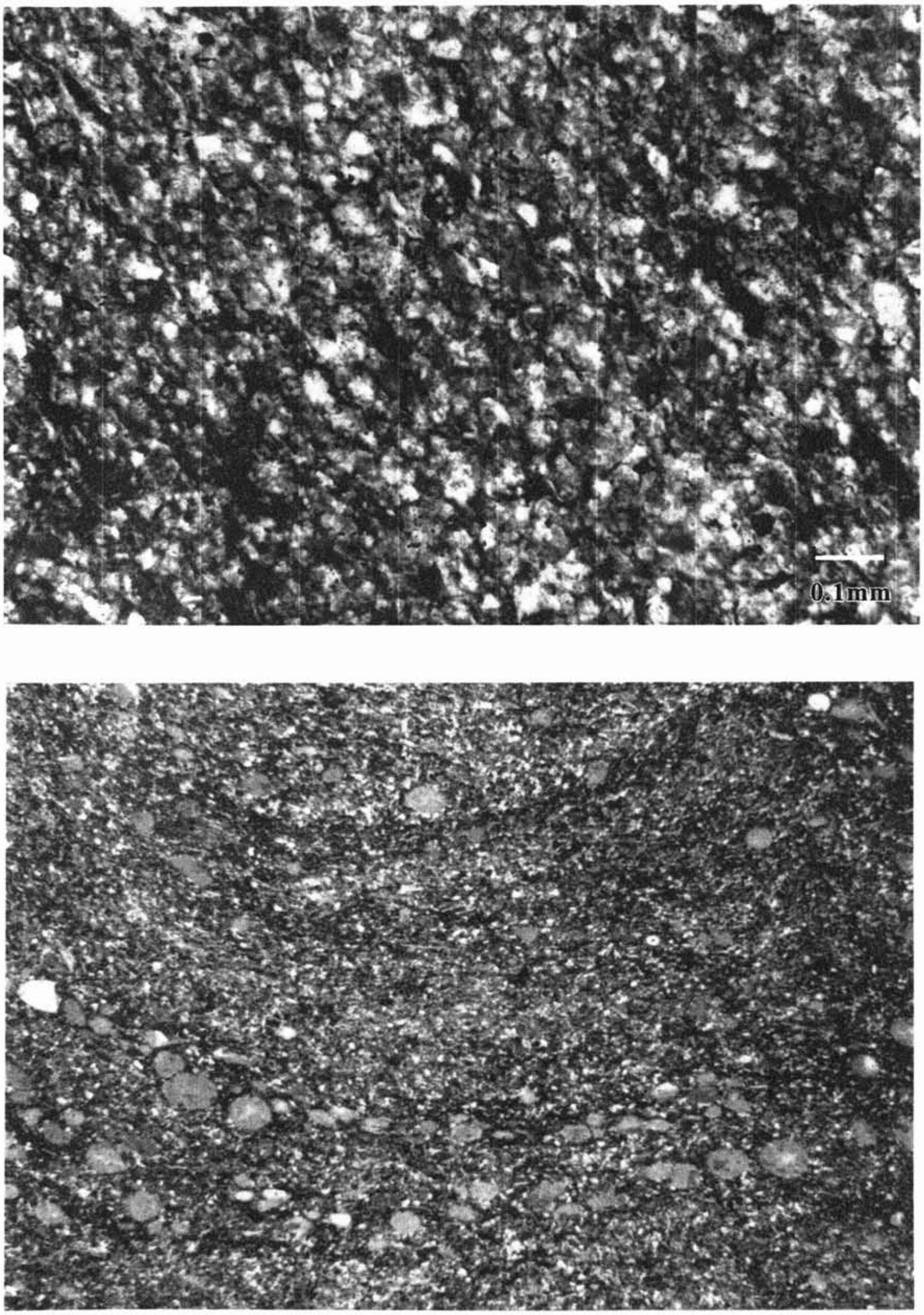


Figure 13. Glauconite (greenish constituents), plain polarized light, magnification of lower photomicrograph x20.

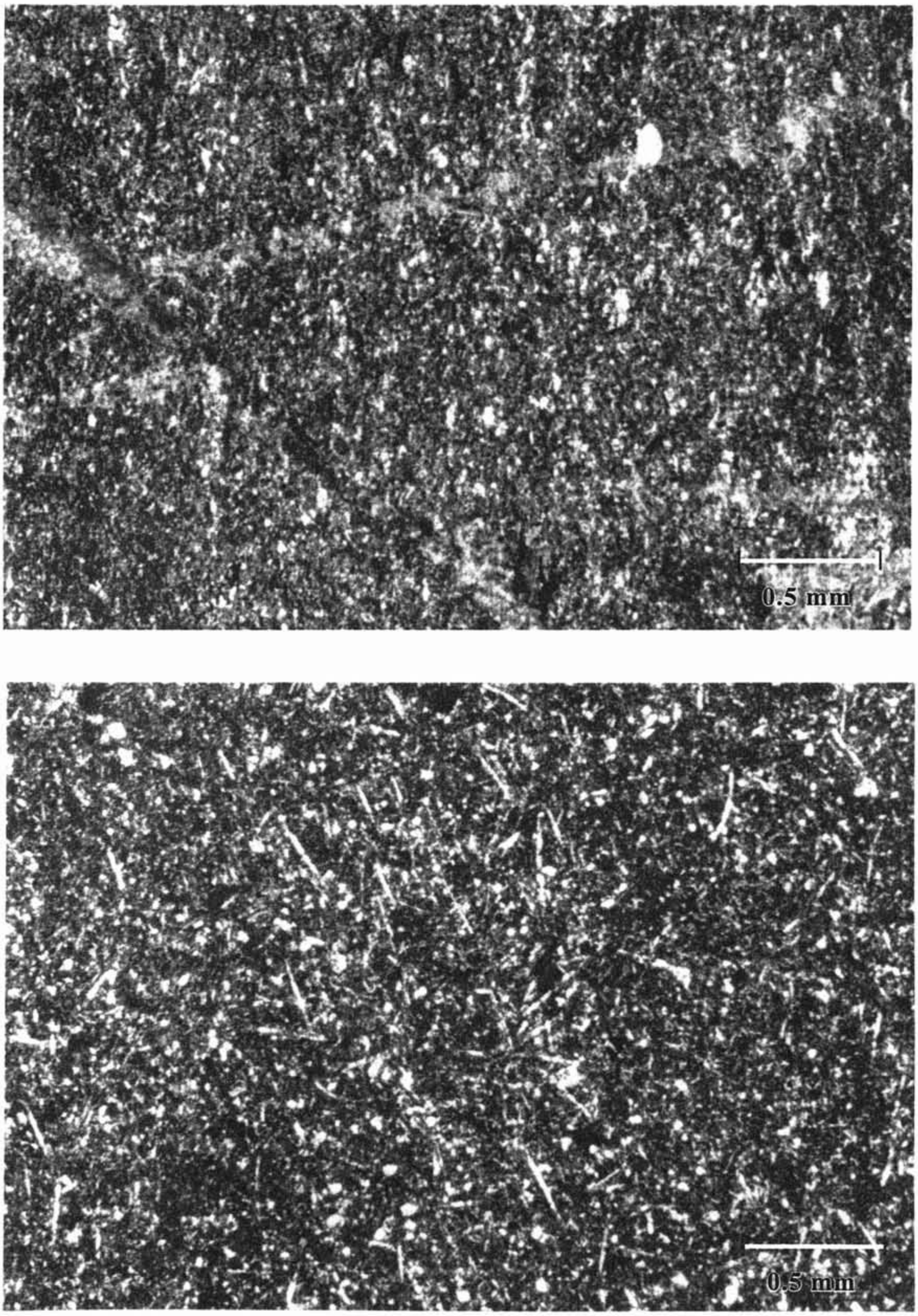


Figure 14. Chert (black mottled areas), cross polarized light, x40. Blue stain in lower photomicrograph is porosity.

through the lithified rock, and then recrystallized again, replacing the original calcite cement with microcrystalline quartz or chert (see Figure 14).

Porosity

Porosity is the ratio of the volume of pore spaces in a rock to its total volume and is usually stated as a percentage (Bates and Jackson, 1984). The porosity of the Sycamore Limestone averages 1-2%. This number is based strictly on the study of the thin sections and does not include fracture porosity.

The Sycamore Limestone is not a very porous formation. It will produce some hydrocarbons at depth but most of its porosity comes from fracture porosity (pore space created by the fracturing of the rock). A slight amount of pore space comes from water dissolving portions of the rock. This makes the porosity secondary, rather than having been formed at the time of deposition (see Figure 15).

Grain Size, Sorting and Rounding

In sandstones, the size, sorting and rounding of the grains can be highly indicative of their environment of deposition. With carbonates however, most of the grains are biologic. There may be very well sorted pellets in a limestone but the sorting is sometimes biologically determined rather than being winnowed by currents.

As a carbonate, the Sycamore is somewhat different. The characteristics of the biologic grains, along with the characteristics of the inorganic grains, provide valuable information as to the possible depositional environment of the Sycamore limestones.

Almost all of the fossils found in the thin section study were broken and somewhat rounded. They all ranged in size from 0.1mm to 0.9mm in diameter. This is tolerably good sorting, running the gamut of very fine sand sized grains to coarse sand-

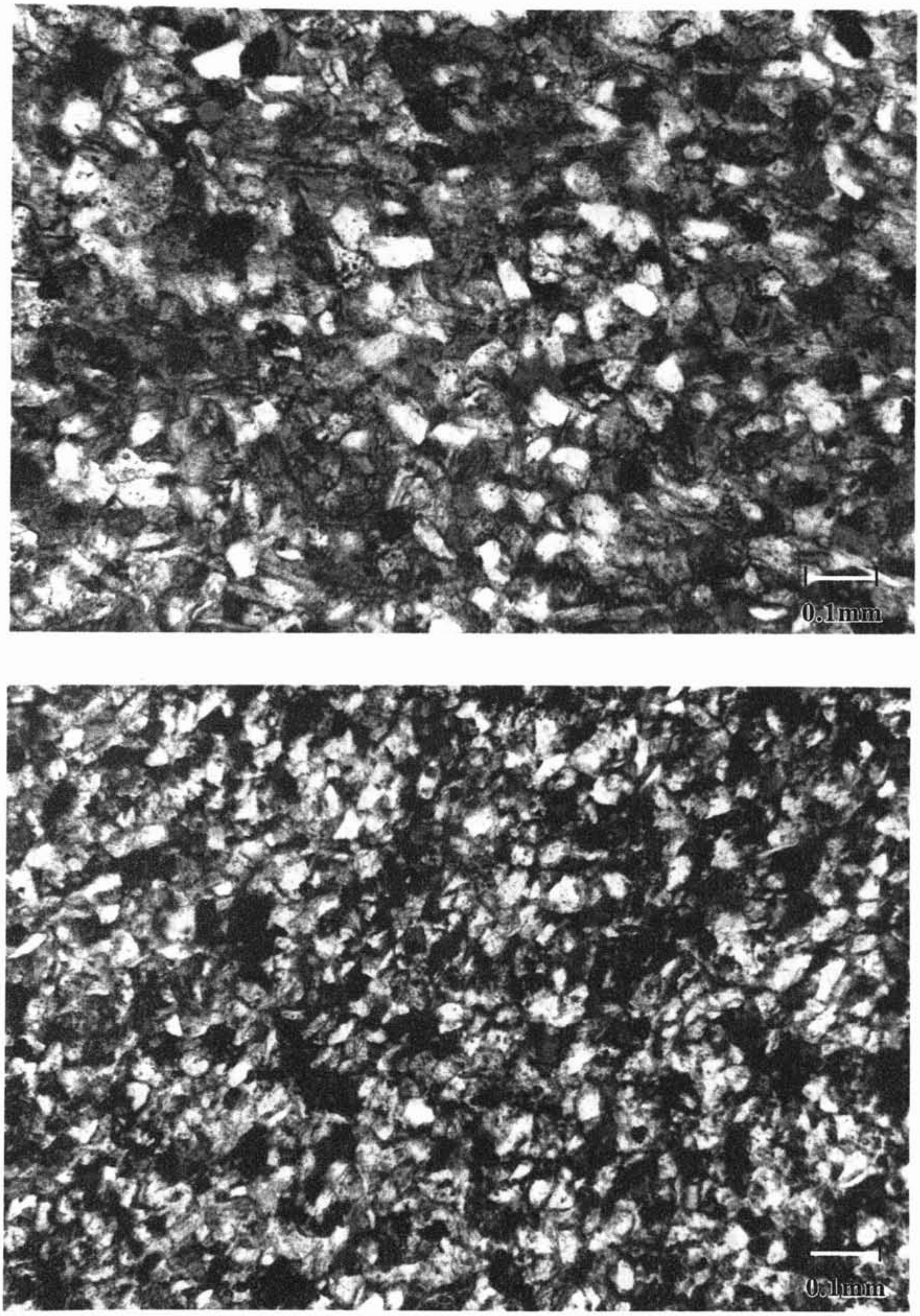


Figure 15. Porosity (blue stain), plain polarized light, x100. Highly weathered samples.

sized grains. The silt included in the carbonates was smaller. This author has been calling the siliceous grains silt, when according to the Udden-Wentworth grain size scale they are actually large enough to be called sands (Prothero, 1990). The grains range in size from 0.05mm (coarse silt sized) to about 0.2mm (fine sand sized). The siliceous grains appear to be sub-angular to sub-rounded and tolerably well sorted.

Stratigraphic Distribution

The lithology of the Sycamore carbonates is, using Dunham's classification system, mostly silty peloidal wackestone. The other carbonates are either silty mudstones or cherty mudstones. In Dunham's classification system, wackestones contain greater than 10% grains and mudstones contain less than 10% grains. Grains are considered to be the allochemical constituents of the carbonate (see Fig. 16).

There was a consistent pattern of allochem occurrence in the Sycamore Limestone, some of which coincided with Dr. Robert Fay's division of the formation. In both the north and south flank outcrops Dr. Fay divided the formation into upper and lower limestones and shales and a transition zone. The transition zone was found in both outcrops and was located in the lower part of the Sycamore, just above the Woodford Shale (see Plates 1 and 2 (fig. 17 & 18)).

One thing that is noticeable about Plates 1 and 2 is that the outcrops are not close to being equal in length. The south flank is at least 100 feet thicker than the north. Also, there are many more shales in the south flank than the north. It was discovered during research that there is consistently more silt and larger constituents in

Dunham's (1962) classification of carbonate rocks

<table>
<tr><th colspan="5">DEPOSITIONAL TEXTURE RECOGNIZABLE</th><th rowspan="2">DEPOSITIONAL TEXTURE NOT RECOGNIZABLE</th></tr>
<tr><td colspan="4">Original Components Not Bound Together During Deposition</td><td rowspan="5">Original components were bound together during deposition... as shown by intergrown skeletal matter, lamination contrary to gravity, or sediment-floored cavities that are roofed over by organic or questionably organic matter and are too large to be interstices.

Boundstone</td></tr>
<tr><td colspan="3">Contains mud (particles of clay and fine silt size)</td><td rowspan="4">Lacks mud and is grain-supported

Grainstone</td><td rowspan="4">Crystalline Carbonate

(Subdivide according to classifications designed to bear on physical texture or diagenesis.)</td></tr>
<tr><td colspan="2">Mud-supported</td><td rowspan="3">Grain-supported

Packstone</td></tr>
<tr><td>Less than 10 percent grains</td><td>More than 10 percent grains</td></tr>
<tr><td>Mudstone</td><td>Wackestone</td></tr>
</table>

Figure 16. Dunham's classification system for carbonate rocks. From Scholle, 1978.

the north outcrop while the south outcrop is consistently slightly deeper than the north. How could there be such a change in the same formation in only six miles? An explanation of this is the fact that as the Southern Oklahoma Aulacogen/Anadarko Basin was deformed, the two outcrop sites were displaced. An immediately apparent aspect of that displacement is in the anticline itself. If the Arbuckle anticline were stretched out, the outcrops would be about 10 miles apart. This still isn't quite enough distance to explain the changes seen. It is the opinion of this author that there is also a strike-slip component to the displacement. This could result in at least an extra 30 miles being added to the displacement. It is possible for the changes seen between the two outcrops to occur over ~35 miles.

The transition zone, so called because it appears to be the transition between the Sycamore and the Woodford, is considered to be of greater depth than the rest of the Sycamore Limestone. Whether the contact of the transition zone with the Woodford Shale is conformable or not is still being debated. Other authors have found phosphatic nodules (an indication of slowed or non-deposition) in the lower part of the transition zone. This would mean that there was at least a brief hiatus between the two, however the shales of the transition zone and the upper Woodford are quite similar, indicating continuous deposition. To further complicate matters, Over (1992) found that the boundary between the Sycamore and the Woodford Shale was unconformable using conodont zonation data.

In both outcrops, pellets occurred throughout the Sycamore except for the transition zone. The only exceptions to this are samples S29 and S30-B from the south flank. There were a few pellets found in both of these samples. Sample S29 contained

2.7% pellets while sample S30-B contained 0.2% pellets. Because pellets of the size found (0.1-0.2mm in diameter) are likely made by burrowing organisms, the occurrence of pellets in these samples may indicate a momentary shallowing of sea level.

As stated earlier, brachiopods and echinoderms were the most abundant fossils (other than the pellets) found in the Sycamore. They were so common that it was unusual to find a sample containing one of the fossil types and not the other. Brachiopods and echinoderms were found throughout the Sycamore, except in the transition zone. The one exception was sample S30-A from the south flank. Both fossil types were found in this sample, brachiopods comprising 0.8% and echinoids comprising 0.7%. The reason for this, as in samples S29 and S30-B, is a possible shallowing of sea level.

This author believes the abundance of fossils found in the Sycamore, and the percentages of each related to the others reflected the abundance of each fossil type of that time. Therefore, brachiopods and echinoderms were the most common invertebrate organisms of the time. Foraminifers, being benthic organisms at the time, were the next most common. Foraminifers were found mainly at the top of the Sycamore and just above the transition zone.

One exception to the abundance of a particular fossil may occur with the sponges. The siliceous spicules of sponges were found mainly in the transition zones of both of the outcrops. There may have been many more sponges than there appeared to be represented by spicules. Some varieties of sponges are made up of calcareous spicules, which, like the hard parts of calcareous algae, may dissolve and recrystallize, helping to form the limestone.

There were only a few examples of bryozoans. These were found with some of the same samples that contained the foraminifers, in the upper part of the Sycamore and just above the transition zone.

One conodont fossil fragment was found, as mentioned earlier. It was found in sample N18 from the north flank. Knowing that conodonts are indicators of deep water and also having found glauconite in the same sample, it can be inferred that the water depth at this point in time was deeper than usual for the Sycamore carbonates. This is significant because this sample was taken from just above the transition zone.

One trilobite and one ostracode were found in the same sample, S22, from the south flank. Also found in this sample were pellets, brachiopods, foraminifers, echinoderms and sponge spicules. The reason for this sudden abundance of different fossil types together in one sample could be a shallowing of sea level, making it easier than usual to find less common organisms of the time.

The siliceous silt that characterizes the Sycamore Limestone was found consistently throughout the formation's carbonates, although not always of the same amount. While the amount of silt in the carbonates averages about 22%, in the transition zone the average amount of silt is approximately 2%. This indicates that throughout the entire deposition of the Sycamore formation the source of the silt continued to produce, although not always at the same rate. The rate of silt deposition appears to have fluctuated with sea level.

The porosity of the Sycamore carbonates extends almost throughout the formation, except for in the transition zone. Most of the porosity is secondary and fracture porosity. The possible explanation for lack of porosity in the transition zone is it extensive recrystallization. The crystallization of microcrystalline quartz in this zone may have taken up any possible pore spaces that could have previously formed.

The simple explanations and interpretations given in this chapter were meant to serve as a general guide for analysis of the thin section data. The information presented here will be valuable in the interpretation of the depositional history of the Sycamore Limestone, which is presented in the following chapter.

CHAPTER IV

LITHOFACIES AND DEPOSITIONAL HISTORY

Previous authors have divided the Sycamore Formation into different lithofacies in an attempt to better understand and interpret its depositional history. Because this study deals mainly with the carbonates of this formation, such subdivisions will be done among them. After a description of the lithofacies, and using information obtained through literature research, field study, laboratory study, etc., this author will present a description of the depositional history of the Sycamore Limestone.

Before getting into the lithofacies and an interpretation of the depositional history of this formation, there will be a review of the two most recent investigations of the Sycamore. The purpose of this review is not to try to prove or disprove the work of other authors, but simply to keep in mind the purpose and scope of a study such as this.

Recent Investigations

The two most recent investigations reviewed here will be J.A. Schwartzapfel's 1990 dissertation "*Biostratigraphic Investigations of Late Paleozoic (Upper Devonian to Mississippian) Radiolaria within Arbuckle Mountains and Ardmore Basin of South-Central Oklahoma*", and W.S. Coffey's 2000 dissertation "*The Diagenetic History and Depositional System of the Sycamore Formation (Mississippian), Carter-Knox Field, Grady and Stephens Counties, Oklahoma*".

Schwartzapfel's study was mostly paleontologic in nature. For the purpose of his study, Schwartzapfel described the base of the Sycamore as being "the first appearance of laterally persistent, traceable carbonate beds above the chert/shale strata of the Upper Woodford." (Schwartzapfel, 1990) Although this completely disregarded the transition zone, it helped him to more accurately describe where particular samples were taken within the formation.

Schwartzapfel concluded that the Sycamore Formation was "partially, if not entirely, turbiditic in origin." (Schwartzapfel, 1990) Part of the information that led him to this conclusion was the initial appearance of a lack of correlation between Fay's subdivisions of the Sycamore Formation. In Fay's 1969 Guidebook, he divided the north flank into (in ascending order) a transition zone, lower limestone, middle shale, and an upper limestone (see Plate 1). He divided the south flank of the Sycamore into (in ascending order) a lower transition zone, lower limestone, middle shale, middle limestone, upper shale and an upper limestone (see Plate 2). Due to Fay's labeling, it sounds as if the middle limestone and upper shale are missing in the north flank of the Sycamore. Because of this, Schwartzapfel lithostratigraphically correlated most of the north and south flank beds of the Sycamore Formation, except for the lower beds (see Figure 19).

While trying to correlate these lower beds, Schwartzapfel found that "(1) individual beds (from both sections) are well sorted and bear sharp, planar contacts; (2) few north limb beds posses chert lag at their bases; and (3) the north limb (landward) beds are predominantly coarser grained whereas the south limb (seaward) beds are mostly finer grained." (Schwartzapfel, 1990)

Work on the chronostratigraphic position of the Sycamore Formation using a radiolarian study revealed, in addition to conodont data both observed and obtained

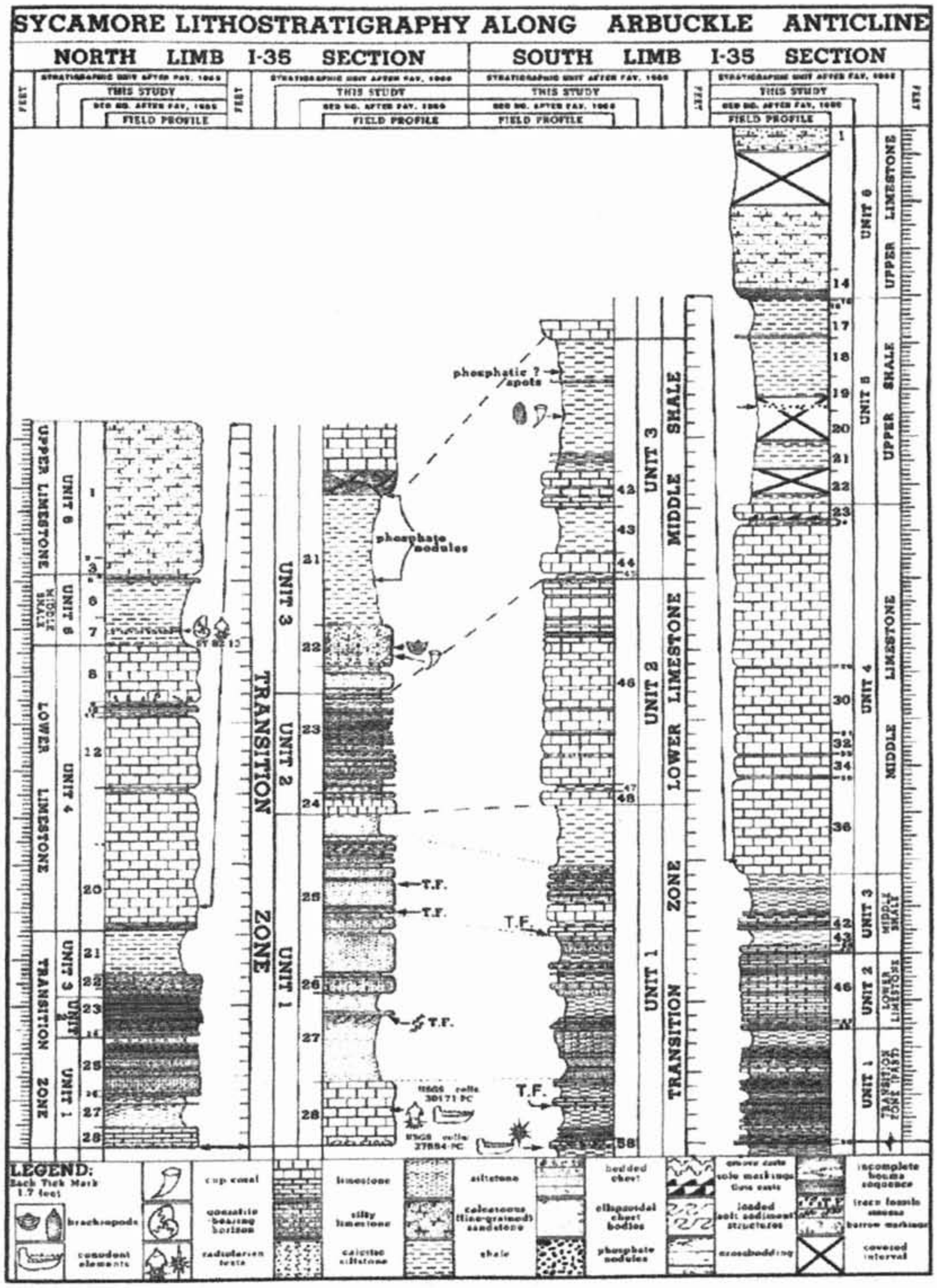


Figure 17. Correlation of units from Sycamore north and south flank outcrops. From Schwartzapfel, 1996.

through literature (Ormiston and Lane, 1976), "(1) the occurrence of an Upper Meramecian goniatite; (2) the presence of an incomplete Bouma (B,C,D,(?)E) Sequence; (3) the occurrence of groove casts, flute casts, and contorted sedimentary structures; (4) the occurrence of intraclasts; (5) the presence of aligned chert (ellipsoidal) bodies; (6) direct, sharp contact between the uppermost Woodford chert bed and the overlying basal Sycamore limestone bed and the south flank section; (7) a possible genetic relationship between the cherty units of observations (5) and (6) above; (8) general coarsening and thickening upward trend; (9) reported limited geographical extent (restricted deposition (?)) and wedge-like profile of the Sycamore; and (10) the presence of mixed conodont faunas (indicating reworking)." (Schwartzapfel, 1990)

The previous observations mentioned aided Schwartzapfel in concluding that the Sycamore was at least partially deposited through turbidite or mass-gravity flow processes. He also felt that the "well sorted bedding, variably developed Bouma sequences, and coarsening and thickening upward successions" contributed to this hypothesis. (Schwartzapfel, 1990) Finally, the paleontologic data Schwartzapfel collected in the chronostratigraphy study led to the most accurately dated position of Upper Meramecian for the Sycamore Formation.

W.S. Coffey's 2000 dissertation is more concerned with the hydrocarbon potential of the Sycamore, although the author does offer good information for the depositional history of this formation.

Coffey divides the Sycamore into four different lithofacies based on field observations, cores and thin section studies. These are (1) the basal shale facies, (2) the lower bench silty peloidal packstone facies, (3) the middle shale facies, and (4) the upper bench silty peloidal packstone facies.

Coffey stated that the basal shale facies represented the initial sea level rise over the Woodford Formation. He felt that the contact between the Sycamore and Woodford Formations was unconformable due to evidence including weathered and broken phosphate nodules at the base of the Sycamore. Coffey also stated that "in sequence stratigraphic terms, this basal shale facies was deposited when the rate of accommodation gain (sea level) is greater than the rate of sedimentation," resulting in transgressive systems tract (TST) facies. (Coffey, 2000)

Coffey grouped the lower and upper bench silty peloidal packstone facies together because they represented similar sequence stratigraphic origins. Using previous works (including those done by Schwartzapfel (1990) and Ormiston and Lane (1976)) and his own research, Coffey states that these facies have "truly unique genetic origins." Coffey came to the same conclusion as Schwartzapfel considering the depositional mechanism of the Sycamore. He felt that the formation was deposited through gravity flows and/or turbidity currents. Within a sequence stratigraphic framework, Coffey concluded that these facies represented lowstand systems tract (LST) facies.

The final facies type Coffey covered was the middle shale facies. These facies were between the lower and upper bench silty peloidal packstone facies. The middle shale facies were created by a quick rise in sea level that produced "condensed section-like deposits consisting of shaley, micritic, thin-bedded bioturbated mudstones to wackestones." (Coffey, 2000) He felt these facies were transgressive systems tract (TST) facies.

Lithofacies

There are two basic lithofacies types among the carbonates of the Sycamore. These are the silty peloidal wackestones, found above Fay's transition zone, and the cherty mudstones, found within the transition zone. Slight differences occur in each lithofacies type, but not enough to alter the entire facies description.

One thing that was interesting about these carbonates was the seeming relationship between the amount of peloids and siliceous grains in the samples. It appeared as if the peloids did not occur unless a particular amount of siliceous grains were present. This could very well be a relationship caused by the transportation of these constituents (see Tables 1 and 2). What is also obvious in these tables is the difference in silt and peloid amounts between the two facies types. The cherty mudstone facies have very little silt and almost no peloids, while the silty peloidal wackestone facies have very high counts of each.

Silty Peloidal Wackestones

According to Dunham's classification system for carbonate rocks, a wackestone is a mud-supported carbonate with more than 10% grains (see Fig. 16). Grains include the allochemical constituents of the rock – fossils, peloids, ooliths and limeclasts. The Sycamore Limestone contains fossils and peloids, but no ooliths or limeclasts (although Schwartzapfel seems to have found a few limeclasts). Silt and sand sized siliceous grains are part of the additional constituents (the non-organic components of the carbonate). Because silt and peloids make up a large part of their constituent groups, they are used as modifiers before the word Wackestone (see Figure 18).

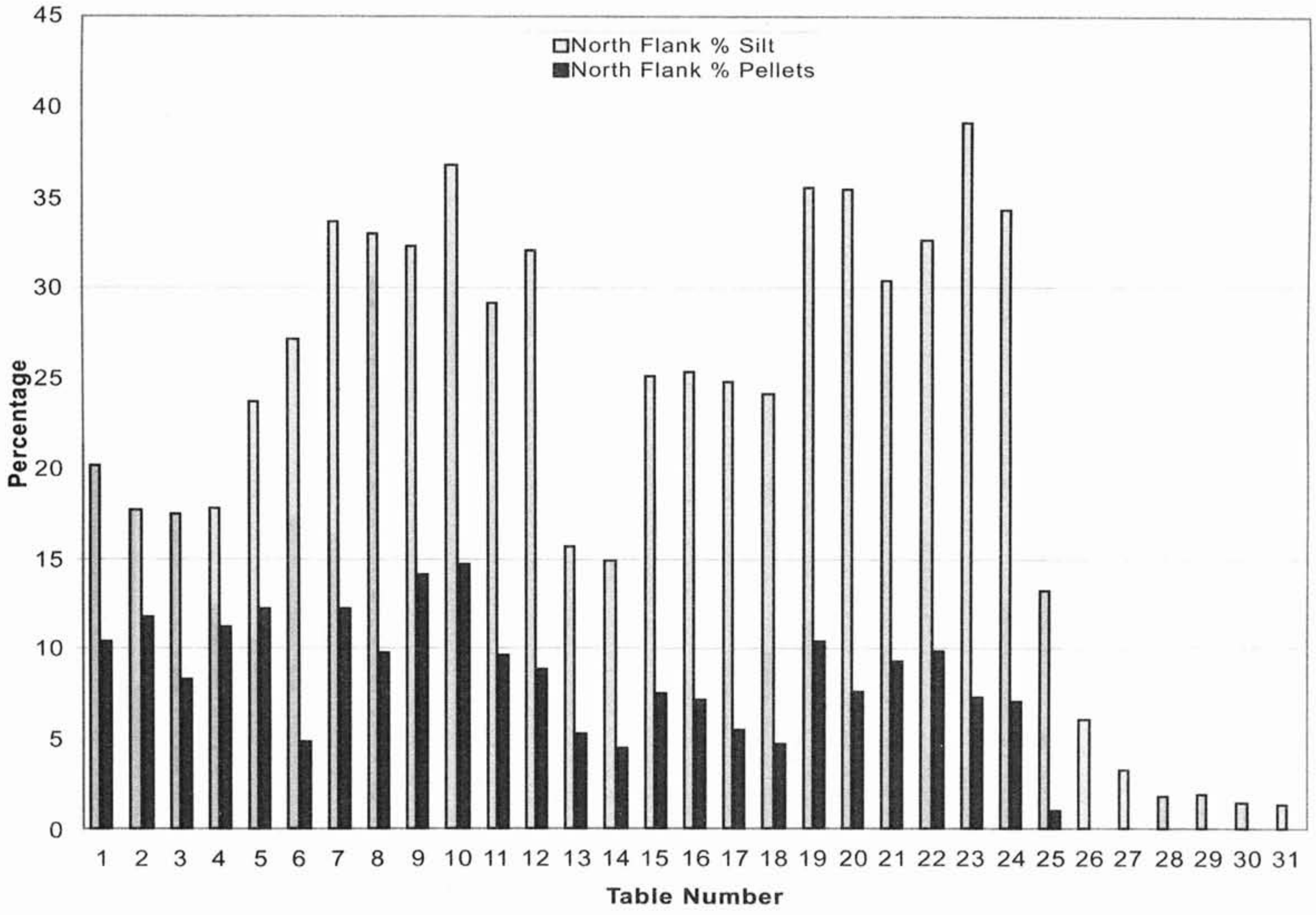


Table 1. North flank silt counts vs. pellet counts.

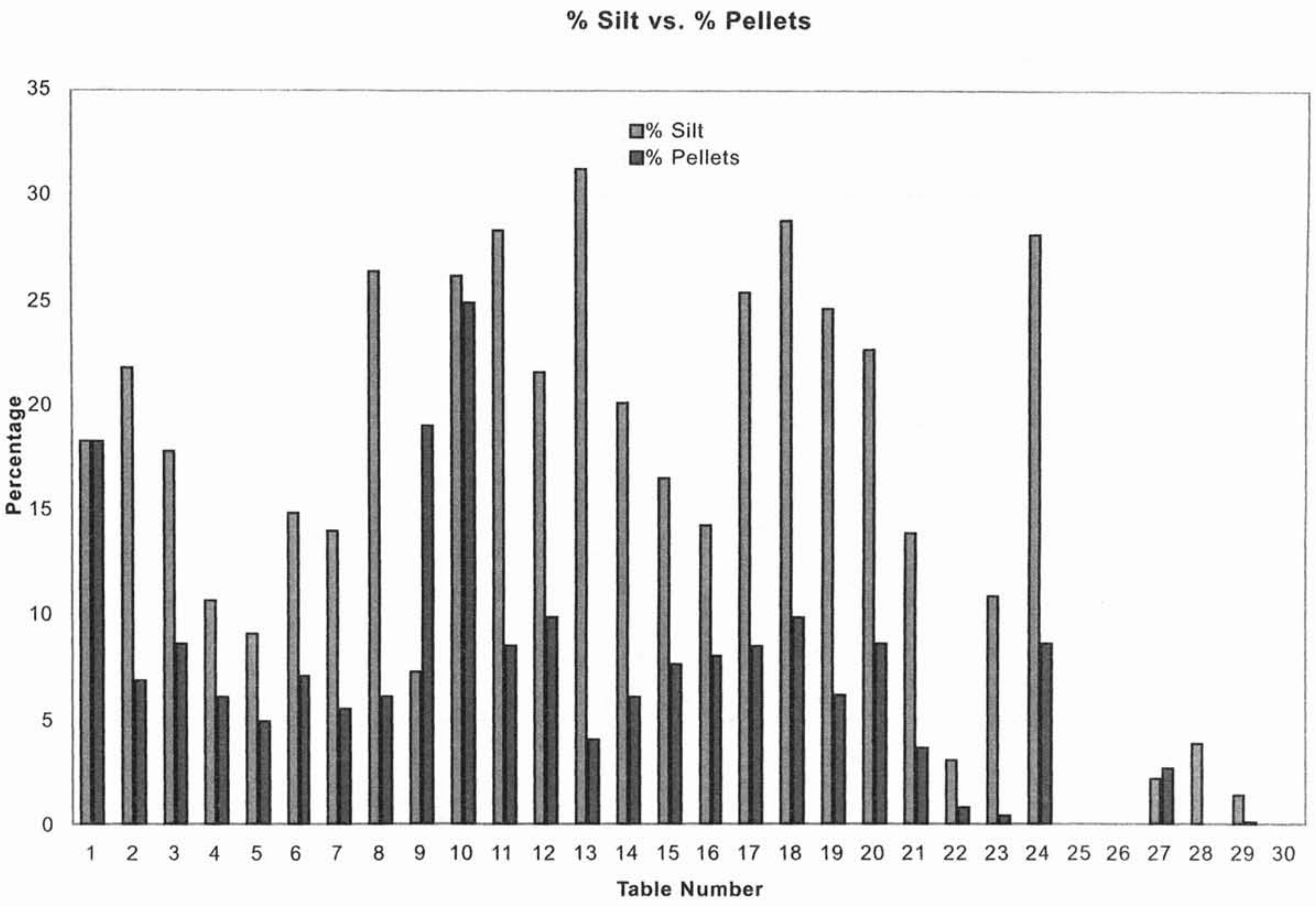


Table 2. South flank silt counts vs. pellet counts.

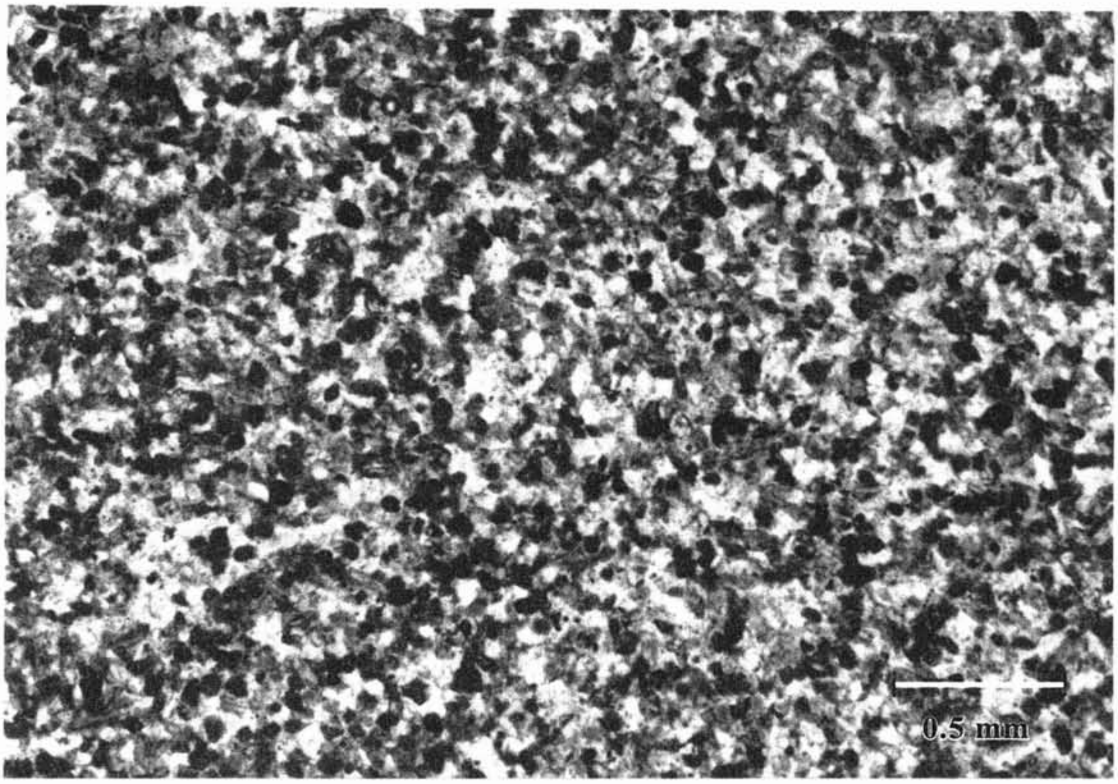


Figure 18. Example of typical silty peloidal wackestone, plain polarized light, x40.

This lithofacies comprises all of the carbonates above the transition zone. It is characterized by high silt counts (ranging between 10 and 35 percent), abundant peloids and assorted fossils. All of the varieties of fossils noted earlier in this study were found in this lithofacies. Almost all of the fossils found were broken. Only the smallest fossils were found whole, such as the ostracode and most of the sponge spicules. The sizes of the whole fossils though were comparable to the size of the fossil fragments.

The siliceous grains in this lithofacies are coarse silt sized to fine sand sized. W.S. Coffey stated in a personal communication that silt counts were consistent throughout the Sycamore meaning the amounts noted by this author were not localized. After a study of the siliceous grains was conducted it was found that the grains are present in a 1:2 ratio of coarse silts to fine sands. It should be noted that the presence of terrigenous debris (the siliceous grains) indicates an influx of water from elsewhere (not necessarily fresh water).

The peloids in this lithofacies are similar in size to the siliceous grains and appear to be well sorted. They were fecal in origin and most likely created by burrowing organisms. While the sorting of fecal pellets present in a carbonate is not always determined by winnowing of currents (biologic sorting is sometimes likely) this author feels that this is the case with the Sycamore. There is no evidence in the outcrop sections that the fecal pellets were originally formed at the site of Sycamore deposition. If this were true, preserved burrowing organisms would probably be present in the outcrop. Because evidence of burrowing organisms is not present this author feels that the peloids were transported.

Fossils found in this facies were brachiopods, echinoderms, foraminifers, bryozoans, sponge spicules, a conodont, a trilobite, and an ostracode. As mentioned earlier, few of these fossils were found whole. The average size of a fragment was 0.2mm. The only fossils found whole were the ostracode and most of the sponge spicules. While initially this would indicate a high energy environment, it must be considered that there are often whole fossils found in such environments along with other characteristics. These would include much more abundant fossils, possible ooids and a greater variety of fossils. The fossils present in the Sycamore indicate that they came from a high-energy environment (where they were broken up) and transported to the Sycamore, a very low energy environment. During transportation they were sorted and winnowed by size, along with the peloids and siliceous grains.

Cherty Mudstones

The second lithofacies type among the carbonates of the Sycamore Formation is the Cherty Mudstones. The chert was not originally present during deposition but was diagenetically formed after lithification. Counts of fossils, peloids and siliceous grains are all greatly decreased (see Figure 19).

Siliceous grain counts range between 0 and 6 percent of the samples. While the presence of these grains still indicates their transportation, the amount of silt possibly indicates a greater water depth than that of the previous lithofacies. Peloids also have much lower counts throughout this lithofacies. They are almost nonexistent in fact. Because they are also transported, this too would be a good indicator of an increase in water depth.

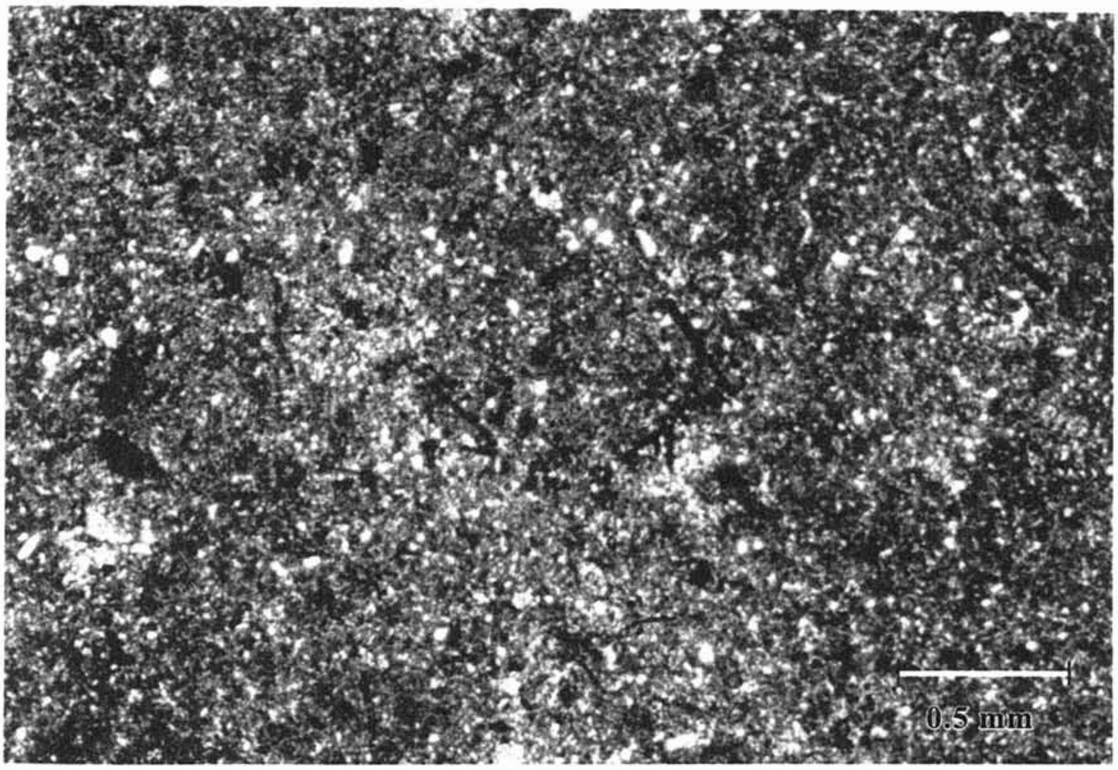


Figure 19. Example of cherty mudstone, cross polarized light, x40.

While fossils are present in this lithofacies, like the siliceous grains and the peloids their counts are also much lower. The types of fossils present are less varied as well. Sponge spicules have the highest occurrence. There was an occasional appearance of an echinoderm or brachiopod fragment but no major counts among the samples.

Much of the original micrite in this lithofacies has been replaced by siliceous material or chert. While the presence of chert in the outcrop was not immediately apparent, testing for cement using dilute hydrochloric acid indicated that it was not calcite cemented. It was assumed at the outcrop that the cement was siliceous. This assumption was later confirmed during the thin section analysis. Because of the presence of the sponge spicules and knowing from previous investigations that the lower Sycamore contains radiolarian tests, the source of the diagenetic chert was probably the silica from these fossils, and may include some silica from the ever-present siliceous grains.

Depositional History

Throughout this study, this author has been collecting data on the Sycamore Limestone, organizing this data and studying it intensely. To say the least, the Sycamore Limestone is a challenge. In outcrop, it looks simple – like a very clean, deep marine mudstone. Once samples were taken and thin sections were studied, the Sycamore took on a mind of its own. Even previous research was a challenge to study. Publications going back almost 100 years reflected the various geologic ideas and styles that have changed through time and with the addition of new technologies. What was originally thought of as a shallow marine, high-energy lagoonal facies is now considered to be a deep marine, low energy facies. This is not to say that any particular author is wrong, just that styles of thinking have changed through time. Recently, changes in thinking are occurring even faster with more and more access to advanced technology and research. The point of this is that this study will be unique among studies of the Sycamore Limestone concerning what is presented. The conclusions presented are merely the opinion of this author, who came to these conclusions through much research and many agonizing days of study.

The Sycamore Limestone began to form about 345 million years ago in the Meramecian Age. Through research and study it has been determined that the carbonates of the Sycamore formed in an outer ramp to basin setting at 150 to 200m depth (492 to 656ft.). This puts the formation below storm wave base.

During the Mississippian, the Anadarko basin, found SW of the Burlington Shelf, was surrounded on three sides (NE to NW to SW) by a shallow foreslope, which led up to a platform on the Transcontinental Arch (see Figures 20 & 21). The water depth on the platform was usually no greater than 30m (98ft.). Platform lithology consisted of limestones toward the deeper edges of the platform (10 to 30m) and dolomites in the shallower areas of the platform (<10m). The foreslope consisted of carbonates and ranged in depth from 30-50m (98-164ft.) down to 50-100m (164-328ft.). The angle of the foreslope was no greater than 5°. The angle of slope within the Anadarko Basin itself was very low to no slope at all (Gutschick and Sandberg, 1983).

The Anadarko Basin is considered to have been a sink for sediments during the Carboniferous Period (Mississippian and Pennsylvanian Periods) and not considered to be a major conduit for sediment transport (Bouma and Stone, 2000). Another indication that this basin was relatively quiet and low energy during the Mississippian is that there

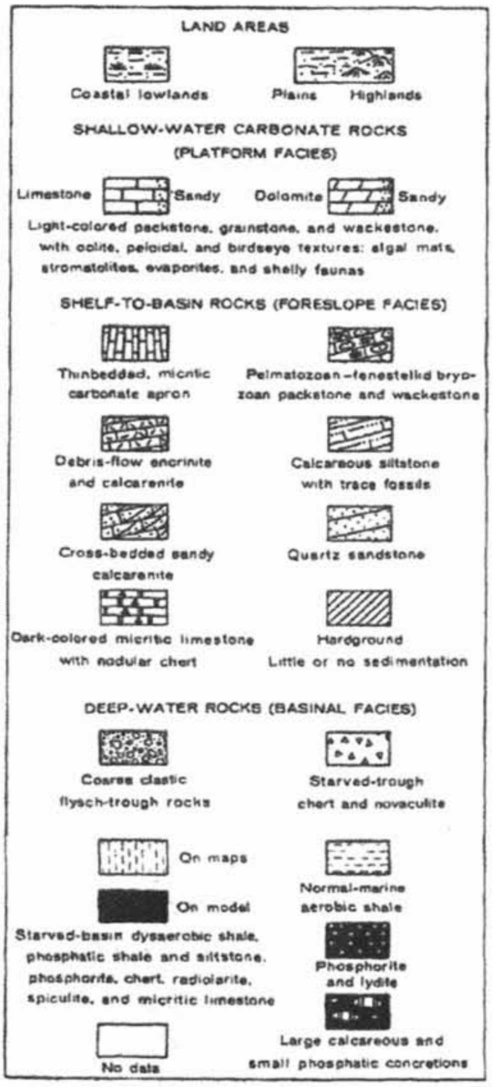


Figure 20. Lithologic key for Figure 21. From Gutschick and Sandberg, 1983.

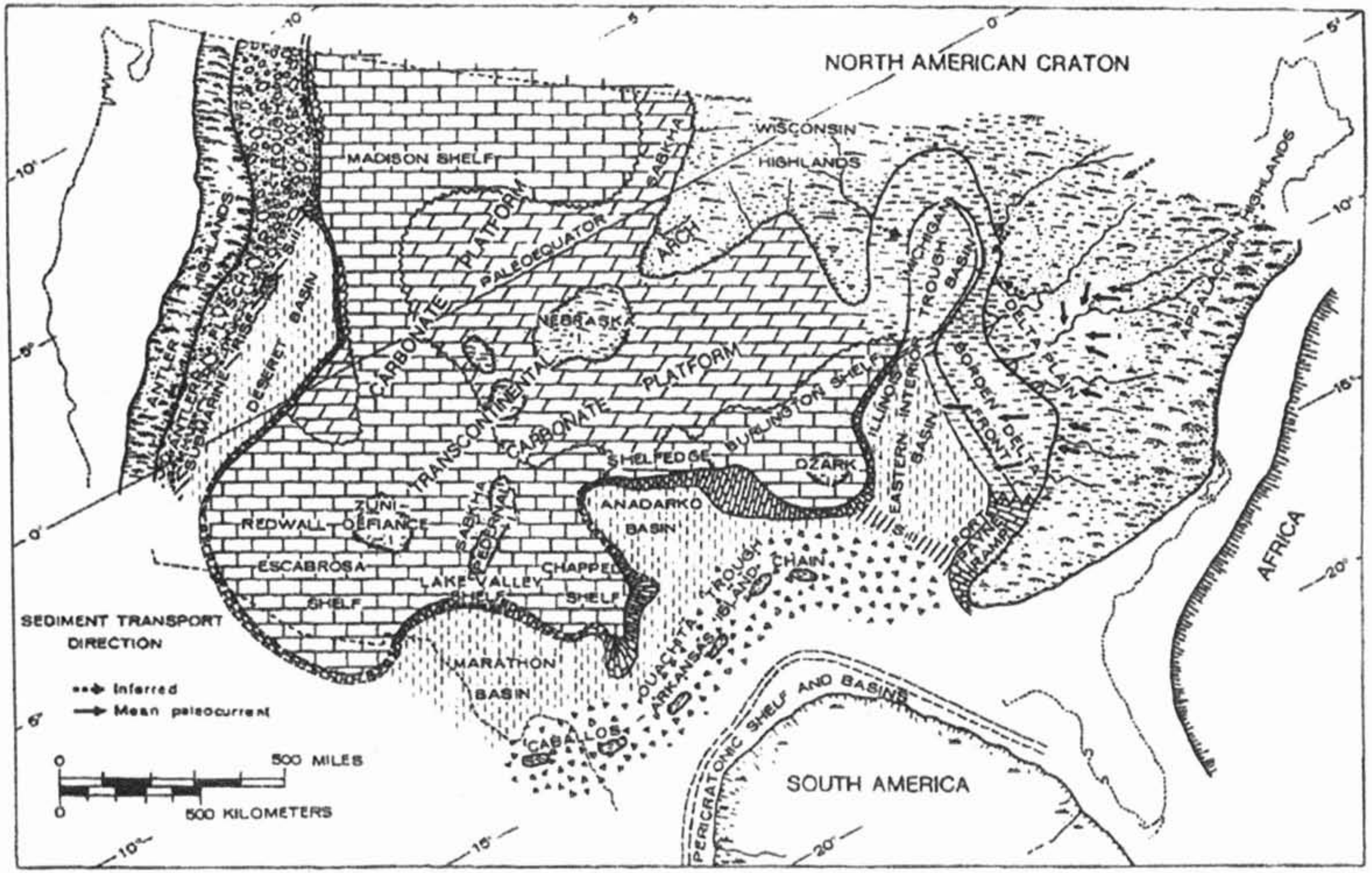


Figure 21. Mississippian lithology of the conterminous United States, ~345mya. From Gutschick and Sandberg, 1983.

are no turbidites or conduits for such preserved in the surrounding slope at the corresponding time of Sycamore deposition.

It is common for basins to collect high amounts of silt and fine sands through time, usually showing these high silt amounts in marine condensed sections. Condensed sections are thin lithologic beds that have taken great amounts of time to form because of their extreme depth. The materials usually found in condensed sections are, in addition to the silt grains, volcanic ash and minerals including glauconite. Condensed section bedding is usually thin and interspersed with shales. While the Sycamore Limestone formed at about 200m (656ft.), has high silt counts and does include some glauconite, it is the opinion of this author that it is not entirely composed of condensed sections. The bedding of the Sycamore is medium to massive and while shales are included in the Sycamore, they make up their own zones in the formation, meaning they generally aren't mixed up with the carbonates but form their own lithofacies. Also, the lower carbonate beds of the Sycamore (the cherty mudstone lithofacies) have much lower silt counts in them although they are considered to have formed at greater depths than the silty peloidal wackestone lithofacies. Another aspect to consider is that higher silt counts do not consistently occur in the thinner Sycamore carbonate beds. Equally high silt counts can be found in much thicker beds (high silt counts in thin beds is one characteristic of condensed section facies).

It has been established that the Sycamore Limestone formed in a low energy, relatively deep water environment and that it is not pelagic in origin, meaning it is not composed of condensed sections or other characteristics of very deep marine facies. What is known about the constituents is that they are all very small (average size of all

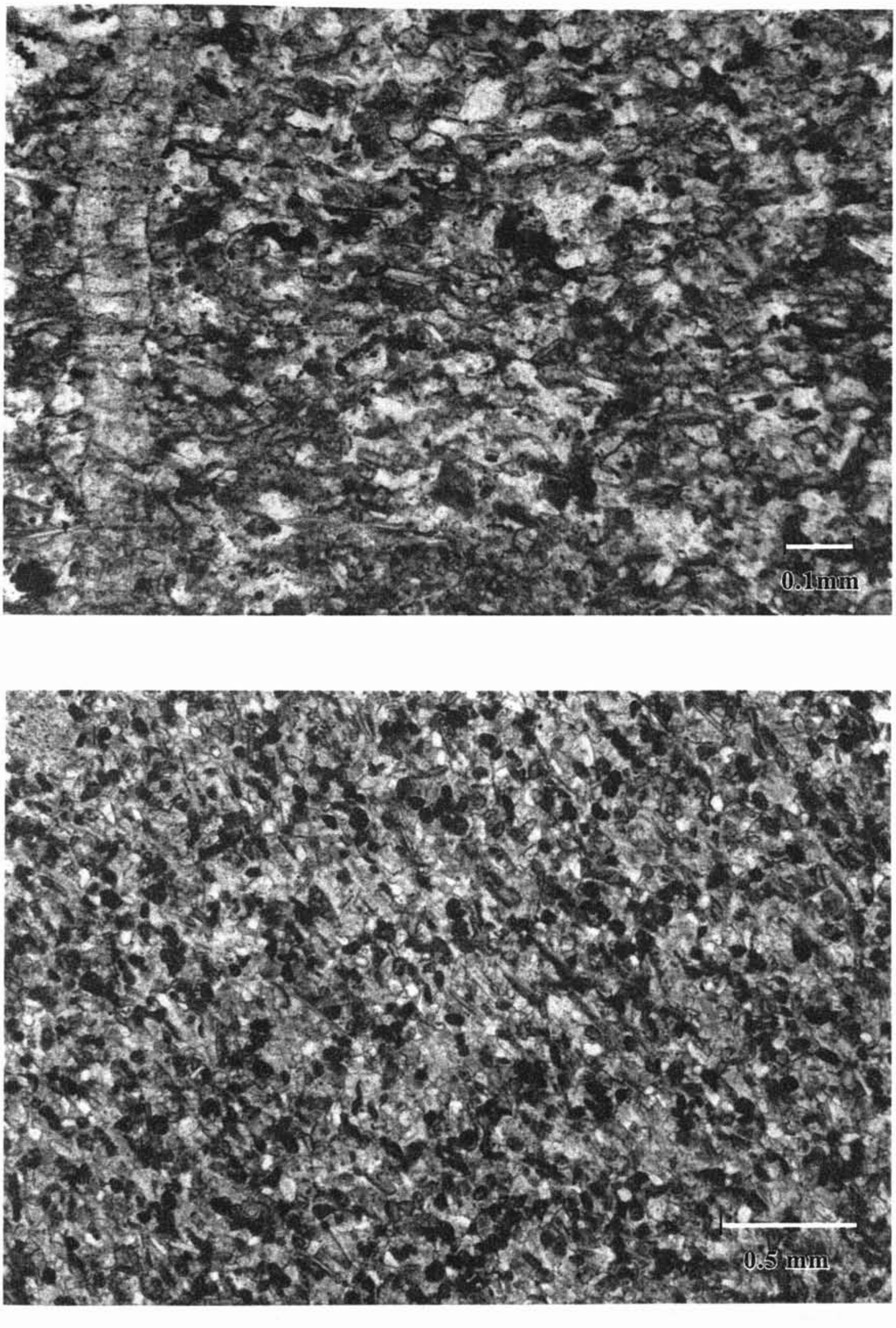


Figure 22. Aligned grains, plain polarized light, x40.

constituents is 0.15mm), most of the fossils are broken fragments, sorting is good among and between all the constituents and they all appear to have been transported to the site of deposition. Also, many samples display aligned grains, an indication of a slight current at the time of deposition (see Figure 22). The problem with the Sycamore now is figuring out how all these constituents were transported into such a low energy environment.

The two most recent studies on the Sycamore were really the only ones to acknowledge that the constituents in the carbonates were transported, therefore they are the only two studies to have presented a possible mechanism for deposition. These studies were reviewed earlier in this chapter. Both Schwartzapfel and Coffey presented the same idea for a depositional mechanism – turbidity currents or gravity flows.

A turbidity current is a dilute suspension of sediment that occurs in the deep sea. They require a slope of 0.5° or less and can travel from 10s to 100s of kilometers, lasting from a few hours to several days. Preserved evidence for turbidity currents is quite often evident in outcrop. Turbidites commonly show graded bedding, have wedge shaped or lenticular beds and beds are laid down in a fan-shaped geometry. Another characteristic of turbidites is the Bouma Sequence – a set of sedimentary layers and structures that follows a particular sequence (see Figure 23). Turbidites can commonly be found at the lower end of deep-sea canyons, which act as conduits for gravity flows and turbidity currents. Sedimentation from turbidity currents is not constant and it can provide anywhere from <5cm to >5m of sediments every 1000 years. (Stow, 1994)

While turbidity currents are a plausible explanation for the deposition of outside components in the Sycamore, this author feels that there may be another explanation.

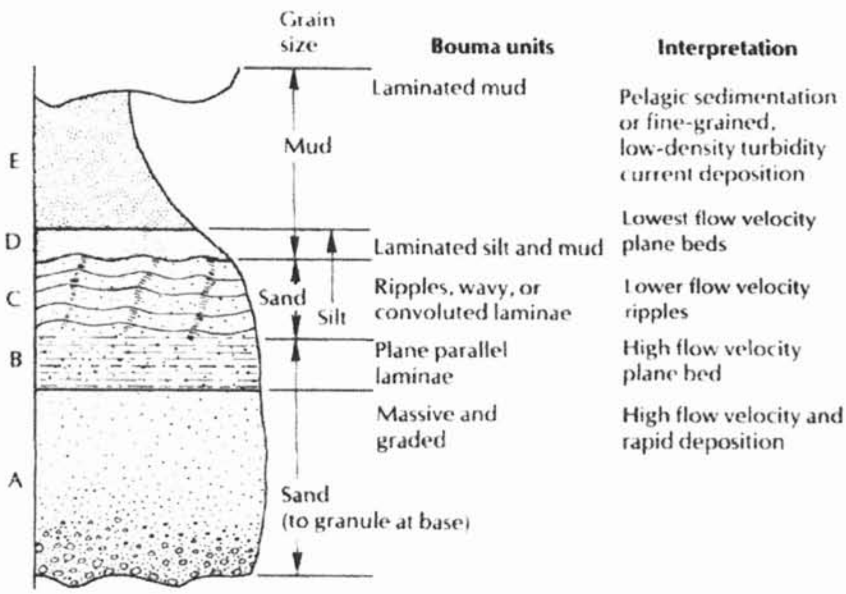


Figure 23. Illustration of classic Bouma Sequence. Sedimentary structures, grain sizes and depositional conditions are shown. From Prothero, 1990.

Bottom currents or deep surface currents appear to provide a better, simpler explanation for the transported constituents in this formation. Bottom currents are active in deep-sea settings (200m and deeper) and are the result of "thermohaline circulation" (Stow, 1994). This essentially means that the difference in temperature and pressure between different bodies of water provides the energy to activate and sustain these currents. Deep surface currents are the "deep parts of surface wind-driven ocean currents." (Stow, 1994) In shallower seas (200m) these currents reach deep enough to affect the entire water column. Both types of currents are deep, slow, "clear-water" flows that require little or no slope and have lengths up to several 1000s of kilometers. Some bottom currents are called contourites because they flow parallel to ocean floor contours. Bottom currents and deep surface currents flow almost continuously with some marked periodicities, have widths up to 10s of kilometers and depths of 100s of meters. (Stow, 1994) The implications of these characteristics are that the sedimentation rates are almost continuous, graded bedding is rare and beds are not wedge shaped (lenticular), nor do they form fan-shaped geometries. Stow (1994) states that the sedimentation rate of these currents is almost consistently <10cm of deposition for every 1000 years.

Looking at the paleobathymetric map created by Gutschick and Sandberg (1983) it can be seen that bottom or deep surface currents are a plausible explanation for the depositional mechanism of the Sycamore Limestone (see Figure 24). The dashed arrows show the direction of inferred sea surface currents. These currents are sourced from the east and move towards the west. Comparing this map with the lithology map (Figure 21) it can be seen that some of these currents flow into the Anadarko Basin from the east,

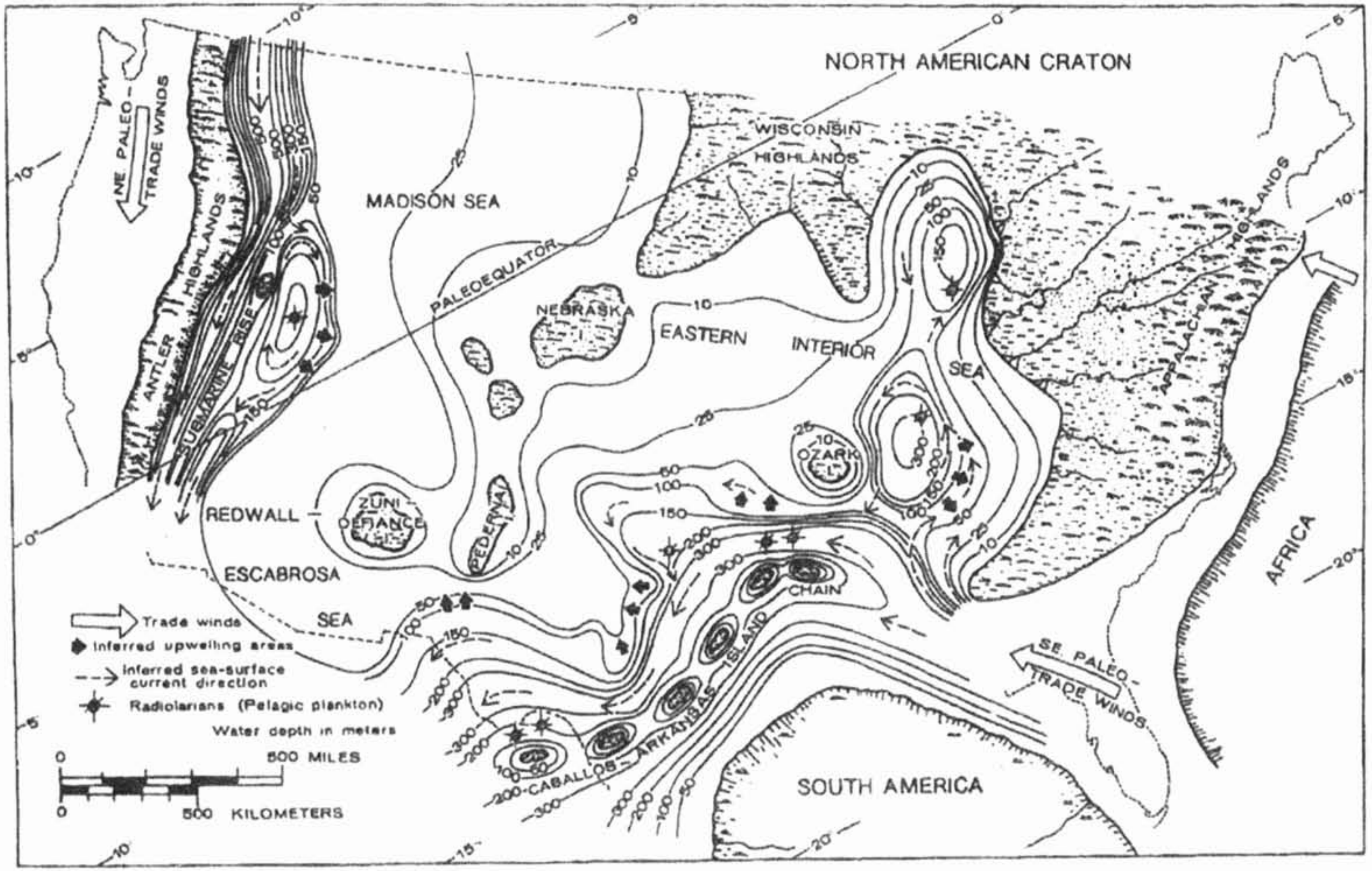


Figure 24. Mississippian paleobathymetric map of the conterminous United States, ~345mya. From Gutschick and Sandberg, 1983.

move around the basin along the foreslope and exit the basin in the southwest. It is the opinion of this author that because of the location of the equator (almost along the Transcontinental Arch) the shallow waters on the platform are so warm that they become less dense than the surrounding cooler basin waters. This temperature and pressure difference prevents major exchanges of water between the basins and the platform so that the area above the foreslope is essentially a barrier to cooler waters, effectively helping to move surface and bottom currents along.

It should be noted at this time that the location of this author's Sycamore outcrops on the paleobathymetric map are right where the radiolarian symbol (from the map key in Figure 24) is found in the Anadarko Basin (very convenient for this author). Moving currents would not normally drop a sediment load unless they were interrupted in some way. It is the opinion of this author that the Anadarko Basin itself creates the interruption in current flow. The fact that the basin is surrounded on three sides by the foreslope and somewhat blocked on the southeastern side by the Caballos-Arkansas Island Chain creates an opportunity for the surface or bottom current to form a slow whirl into the center of the basin (compare Figures 21 and 24). This would effectively slow the currents, causing them to drop their sediment load. Also, simply entering the basin and moving around the foreslope would be enough to slow the currents. This method of deposition may also help explain previous authors' difficulty in finding a source for terrigenous debris. Source directions have been given ranging from NW to SW. While it is beyond to scope of this study to say exactly where the material came from, the assumption was made that most of it probably comes from the area east of the basin.

One problem to resolve with this explanation is the occasional appearance of small shale beds among the carbonate lithofacies. Because these bottom and deep surface currents are known to have marked periodicities, these breaks in current flow could explain small shale intervals between large carbonate beds. Without the influx of outside constituents, the only thing left to deposit in the basin is shale. The larger shale intervals in the Sycamore Formation (those large enough to form their own lithofacies) are most likely the cause of a change in sea level from somewhat deep to deeper marine depths. A greater water depth would essentially stop the currents from affecting deposition.

Bottom currents or deep surface currents provide a more simplistic explanation for the consistent appearance of the Sycamore formation. This author found no graded bedding, Bouma Sequences or anything else that would indicate a more turbulent method of deposition. The deceptively simplistic look of the Sycamore Limestone in outcrop may even be a result of the presented mechanism for deposition.

Previous Hypotheses

There are two other hypotheses presented for the depositional history of the Sycamore Limestone in addition to the one presented here. The first hypothesis to be presented was that the Sycamore was deposited in a shallow marine/lagoonal setting. It is easy to see why this would have been originally presented. The variety of fossils in these carbonates would indicate a shallow environment that was conducive to life. Also, the lack of a great amount of mud might indicate a higher energy environment, thus the assumption of a lagoonal setting. However, there are a few reasons why this hypothesis is not plausible.

First, while the fossils might initially indicate a shallow, high-energy environment, it should be noted that there are other indicators of such an area. Even in high energy environments large and whole fossils can still be found and there may even be ooids. Radiolarians are generally not found in such environments (the premise of Schwartzapfel's study), but in much deeper, quieter water. Also, the silt amounts noted in the samples would effectively shut off the "carbonate factory" in this type of environment.

The second hypothesis, somewhat more plausible than the first, was that presented by both Schwartzapfel (1990) and Coffey (2000). This was the hypothesis that the Sycamore was deposited in a quiet, deep marine environment by turbidity currents or gravity flow deposits. This hypothesis is more plausible than the first simply because of the presented environment of deposition. It is most likely that the Sycamore carbonates were deposited in a quiet, deep marine setting. In geology, simplicity is generally the key when explanations are required. This second hypothesis has too many requirements to be plausible. Table 3 is a comparison of the characteristics of turbidity currents to those of bottom or deep surface currents.

One of the first characteristics of turbidity currents that can be found without intense study is graded bedding or Bouma Sequences. While there may be a case of general shallowing upward in the Sycamore, no graded bedding or evidence of any Bouma Sequences was found in either outcrop, even by a full class of graduate students with two professors. Turbidity currents also deposit inconsistent amounts of sediment. One of the characteristics of the Sycamore is its consistency in outcrop. The carbonate beds are generally all medium bedded and have the same look throughout the formation.

Turbidity Currents	Bottom or Deep Surface Currents
• Dilute suspension of sediments • Occur in deep to very deep ocean • Travel 10s to 100s of kilometers • 0.5° slope or less • Duration from hours to days • Flow lofting can create "hemiturbidites" • Bouma Sequences • Graded bedding • Wedge-shaped (lenticular) beds • Fan-shaped geometry • Usually found at lower end of canyons • <5cm to >5m deposition for every 1000 years	• Deep, slow, "clear-water" flows • Movement initiated by thermohaline circulation or surface winds • No or gentle slope (<1°) required • Semi-continuous with marked periodicities • Travels up to several 1000s of kilometers • 10s of kilometers wide by 100s of meters deep • <10cm deposited for every 1000 years

Table 3. Listing and comparison of characteristics of turbidity currents and bottom or deep surface currents. Modified from Stow, 1994.

This is a better indicator of nearly constant deposition rather than sudden bursts of sedimentation. The transported constituents could be a characteristic of either depositional type, however, the samples in this study displayed constituents that were all well sorted both between and among their groups. This would not be indicative of chaotic flows. Aligned grains in the sample are also not characteristic of these flows. In gravity flow bedding, the constituents are more likely to point in every which direction rather than one direction.

As mentioned earlier, the Anadarko Basin was (during the Mississippian) considered to be a quiet, low energy basin that was a sink for sediments. This means that little sediment moved into or out of the basin. In order to form, turbidity or gravity flows usually use a channel to move along during flow. Even if the Sycamore consisted of the very tips of gravity flows, where the smallest bits of debris would be, there would still be evidence around the basin from the same time period of turbidites and/or gravity flows, possibly even canyons or valleys to act as conduits. At this time, there is no such evidence. Also, as mentioned earlier, there was probably not a great exchange of water between the platform and basin because of the temperature and lower density of the platform waters.

While this newest hypothesis presented may not be the most accurate explanation of the depositional history of the Sycamore Limestone, it is the opinion of this author that it is the most plausible explanation to date.

CHAPTER V

CONCLUSION

The Sycamore Limestone has been studied for about the last one hundred years. The first publication concerning the Sycamore Limestone was done by J.A. Taff in 1903. He named the limestone after Sycamore Creek, which crosses the Sycamore Limestone at its type locality. Other authors followed Taff. It wasn't until the last quarter of the twentieth century that there were any in-depth studies done on the Sycamore Limestone, with the most detailed studies being published in the last three years.

The Sycamore Limestone has gone through some drastic changes since it's beginning about 345 million years ago. After deposition and burial, the limestone suffered an intense period of mountain building during the construction of the Arbuckle Mountains. At that time it was uplifted, folded, faulted, tilted, and in some places, overturned. After the period of deformation stopped, the Arbuckle Mountains eventually eroded into their present form. Highway I-35 was cut through the mountains between 1967 & 1969 and revealed the Sycamore road cuts that we see today.

A thin section analysis revealed that the Sycamore Limestone is not very fossiliferous, but it does contain a high amount of silt in the silty peloidal wackestone lithofacies. Using research and literature it was determined that an outer ramp to basin environment is most indicative of the Sycamore Limestone's depositional environment.

There are noticeable differences between the north and south flank outcrops, which are attributed to displacement between the two during deformation. This author found that the constituents in the Sycamore Limestone were transported.

Finally, after noting and dismissing previous hypotheses and using all the data accumulated during this study, it has been concluded that the depositional mechanism for the Sycamore Limestone was deep surface or bottom currents, thus explaining the depositional history of the carbonates in this formation.

BIBLIOGRAPHY

Bates, R.L. and Jackson, J.A., 1984, Dictionary of Geological Terms, Third Edition, Prepared by the American Geological Institute, Published by Doubleday, New York, New York.

Bennison, A.P., 1956, Springer and Related Rocks of Oklahoma, Tulsa Geological Society Digest, Vol. 24, p. 112.

Boardman, R.S., Cheetham, A.H. and Rowell, A.J., 1987, Fossil Invertebrates, Blackwell Scientific Publications, Cambridge, Massachusetts.

Bouma, A.H. and Stone, C.G., 2000, Fine-Grained Turbidite Systems, AAPG Memoir 72, SEPM Special Publication No. 68, pp. 22-23.

Braun, J.C., 1959, A Stratigraphic Study of the Sycamore and Related Formations in the Southeastern Anadarko Basin, Shale Shaker, Vol. 10, No. 1, pp. 6-22.

Buchanan, G.S., 1927, The Distribution and Correlation of the Mississippian of Oklahoma, Bulletin of the American Association of Petroleum Geologists, Vol. 11, pp. 1307-1320.

Burchette, T.P. and Wright, V.P., 1992, Carbonate Ramp Depositional Systems, *in* Sedimentary Geology, Vol. 79, Nos. 1-4, pp. 3-57.

Champlin, S.C., 1959, A Stratigraphic Study of the Sycamore and Related Formations in the Eastern Arbuckle Mountains, University of Oklahoma, Masters Thesis.

Coffey, W.S., 2000, The Diagenetic History and Depositional System of the Sycamore Formation (Mississippian), Carter-Knox Field, Grady and Stephens Counties, Oklahoma, Oklahoma State University, Dissertation.

Cole, T., 1988, A surface to Subsurface Study of the Sycamore Limestone (Mississippian) along the North Flank of the Arbuckle Anticline, University of Oklahoma, Masters Thesis.

Cooper, C.L., 1926, The Sycamore Limestone, Oklahoma Geological Survey, Circular No. 9.

Culp, C.K., 1961, Stratigraphic Relations of the Sycamore Limestone (Mississippian) in Southern Oklahoma, Shale Shaker, Vol. 11, No. 10, pp. 7-18.

Ehlers, E.G., and Blatt, H., 1982, PETROLOGY; Igneous, Sedimentary and Metamorphic, W.H. Freeman and Company, New York, pp. 423-470.

Fay, R.O., 1969, Geology of the Arbuckle Mountains along Interstate 35, Carter and Murray Counties, Oklahoma, Ardmore Geological Society Guidebook, pp.1-9, 44-46.

Gutschick, R.C. and Sandberg, C.A., 1983, Mississippian Continental Margins of the Conterminous United States, SEPM Special Publication No. 33, pp. 79-96.

Hart, D.L. Jr., 1994, Reconnaissance of the Water Resources of the Ardmore and Sherman Quadrangles, Southern Oklahoma, U.S. Geological Survey, Map HA-3, Sheet 1 of 4.

Harland, W.B. et al, 1989, A Geologic Time Scale 1989, Cambridge University Press, Cambridge, pp. 44-45.

Harlton, B.H., 1956, The Harrisburg Trough, Stephens and Carter Counties, Oklahoma *in* Petroleum Geology of Southern Oklahoma, Ardmore Geological Society, Vol.1, p. 137.

Huffman, G.C. and Barker, J.C., 1950, Mississippian Problems in the Lawrence Uplift, Pontotoc County, Oklahoma, *in* Proceedings of the Oklahoma Academy of Science, University of Oklahoma, pp. 78-80.

Morgan, G.D., 1924, Geology of the Stonewall Quadrangle, Oklahoma, Bureau of Geology, Bulletin No. 2, pp. 48-50.

Ormiston, A.R. and Lane, H.R., 1976, A Unique Radiolarian Fauna from the Sycamore Limestone (Mississippian) and its Biostratigraphic Significance, Paleontographica, Abteilung A, vol. 154, pp. 158-170.

Over, D.J., 1992, Conodonts and the Devonian-Carboniferous Boundary in the Upper Woodford Shale, Arbuckle Mountains, South-Central Oklahoma, Journal of Paleontology, V. 66, No. 22, pp. 293-311.

Palladino, D.L., et al, 1985, Tectonism and Sedimentation in the Arbuckle Mountain Region, Southern Oklahoma Aulacogen, Baylor University, Waco, Texas.

Prestridge, J.D., 1957, A subsurface Stratigraphic Study of the Sycamore Formation in the Ardmore Basin, University of Oklahoma, Masters Thesis.

Prothero, D.R., 1990, Interpreting the Stratigraphic Record, W.H. Freeman and Company, New York, p.26.

Reeds, C.A., 1910, A Report on the Geological and Mineral Resources of the Arbuckle Mountains, Oklahoma, Oklahoma Geological Survey, Bulletin No. 3, p. 41.

Reeds, C.A., 1927, The Arbuckle Mountains, Oklahoma, The Fossil Collector's Happy

Hunting Grounds, Oklahoma Geological Survey, Circular No. 14, pp. 13-14.

Rutledge, R.B., 1956, The Velma Oil Field, Stephens County, Oklahoma, *in* Petroleum Geology of Southern Oklahoma, Ardmore Geological Society, Vol. 1, p. 267.

Scholle, P.A., 1978, A Color Illustrated Guide to Carbonate Rock Constituents, Textures, Cements and Porosities, American Association of Petroleum Geologists, Tulsa, Oklahoma, Memoir 27, p.171.

Schwartzapfel, J.A., 1990, Biostratigraphic Investigations of Late Paleozoic (Upper Devonian to Mississippian) Radiolaria within the Arbuckle Mountains and Ardmore Basin of South-Central Oklahoma, University of Texas at Dallas, Dissertation, pp. 11-23, 333-336.

Schwartzapfel, J.A. and Holdsworth, 1996, Upper Devonian and Mississippian Radiolarian Zonation and Biostratigraphy of the Woodford, Sycamore, Caney and Goddard Formations, Oklahoma, Cushman Foundation for Foraminiferal Research, Special Publication No. 33.

Stow, D.A.V., 1994, Deep Sea Processes of Sediment Transport and Deposition *in* Sediment Transport and Depositional Processes, Pye, K. (ed), Blackwell Scientific Publications, Oxford, pp. 257-287.

Taff, J.A., 1903, Geologic Atlas of the United States, Tishomingo Folio, Indian Territory, No. 98, p. 5.

Taff, J.A., 1904, Preliminary Report on the Geology of the Arbuckle and Wichita Mountains in Indian Territory and Oklahoma, United States Geological Survey, Professional Paper No. 31, p. 33.

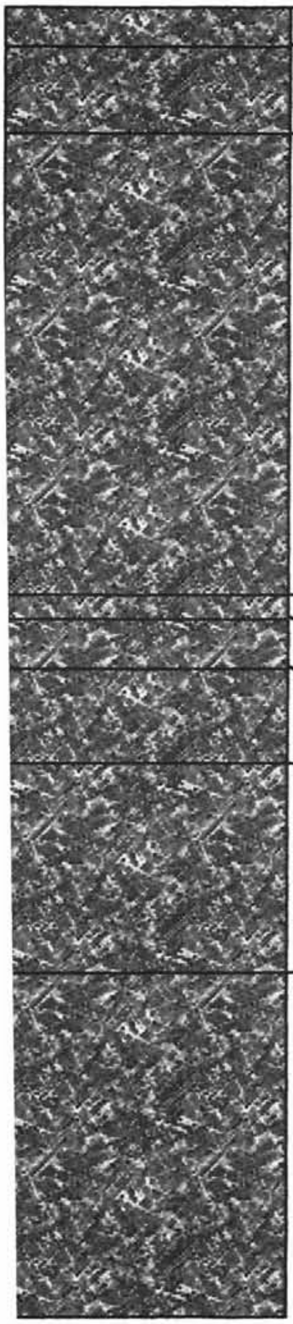
Van Wagoner, J.C. et al, 1987, Seismic Stratigraphy Interpretation using Sequence Stratigraphy, Part 2: Key Definitions of Sequence Stratigraphy, *in* Bally A.W. (ed), Atlas of Seismic Stratigraphy, Amer Assoc Pet Geol Stud Geol, 27(1): 11-14.

Weller, J.M., et al, 1948, Correlation of the Mississippian Formations of North America, Bulletin of the Geological Society of America, Vol. 59, p. 144.

Wicander, R. and Monroe, J.S., 1993, HISTORICAL GEOLOGY; Evolution of the Earth and Life through Time, West Publishing Company, Minneapolis/Saint Paul, p. 404.

APPENDIX 1

North flank stratigraphic column. One inch equals 4 feet.



N1 - Silty limestone, tan, siliceous veins, weathers to grayish tan, medium bedded, calcareous cement.

N2 - Silty limestone, tan, weathers to grayish tan, medium bedded, calcareous cement.

N3 - 3 samples gathered. Silty limestone, calcareous cement, medium bedded, tan, weathers to grayish tan. Samples taken from top, middle and bottom.

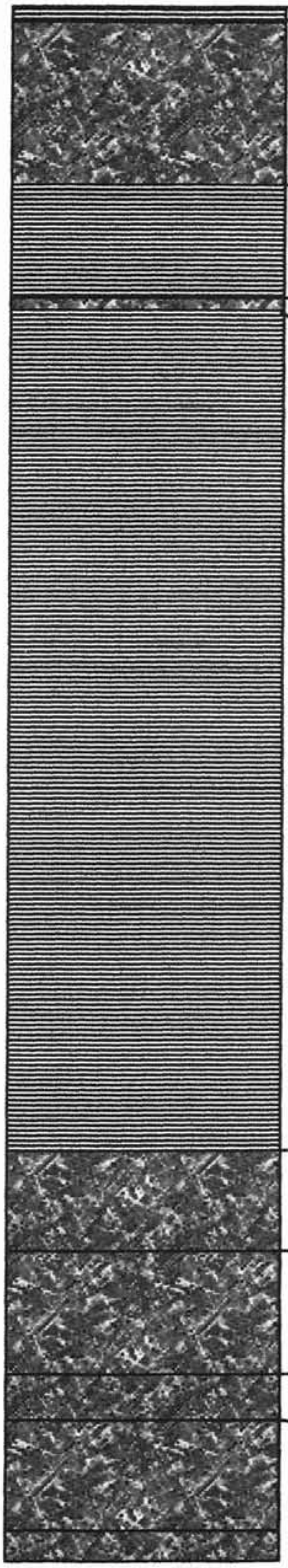
N4 - Shale? Fissile Limestone? Light gray, weathers to gray, thin bedded to fissile, calcareous cement.

N5 - Silty limestone, light gray, weathers to gray, calcareous cement, medium bedded, argillaceous.

N6 - Silty limestone, light gray, weathers to gray, argillaceous, medium bedded, calcareous cement.

N7 - Silty limestone, light gray, weathers to gray, calcareous cement, argillaceous, medium bedded.

N8 - Silty limestone, light gray, weathers to gray, argillaceous, calcareous cement, medium bedded.



Shale, mostly covered, weathers to gray

N9 - Silty limestone, light gray, weathers to gray, argillaceous, medium bedded, calcareous cement.

Shale, dark gray, weathers to light gray, thin bedded fissile.

N10 - Silty limestone, light gray, weathers gray argillaceous.

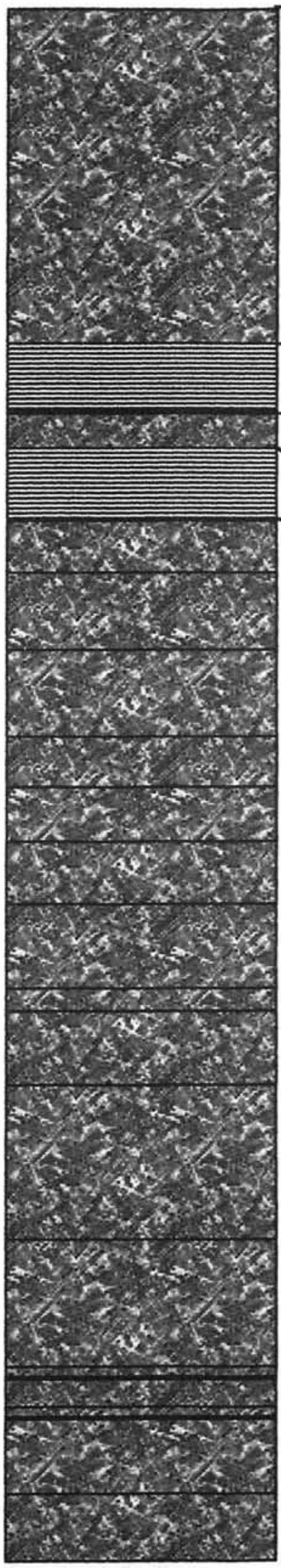
Shale, dark gray, weathers to light grays and tans, thin bedded, fissile. This is Fay's upper shale unit.

N11 - Limestone, bioturbated, light gray, weathers to orangy tan, calcareous cement, argillaceous, medium bedded.

N12, Limestone, light gray, weathers to orangy tan, medium bedded, calcareous cement, argillaceous.

N13 - Silty limestone, light gray, weathers to gray, argillaceous, calcareous cement, medium bedded.

N14 - Silty limestone, calcareous cement, light gray, weathers to gray, medium bedded, argillaceous, measurements taken at bedding planes.



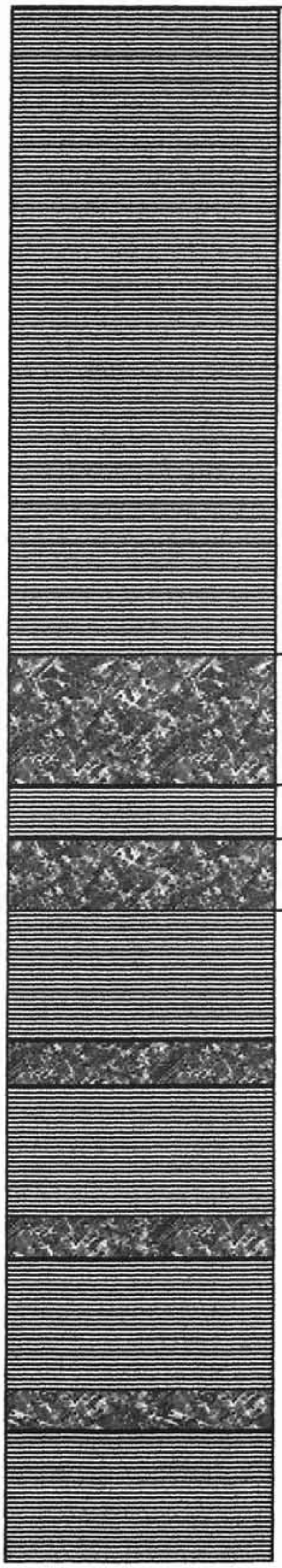
N15 - Silty limestone, light gray, weathers to gray, very blocky, argillaceous, massive bedded, calcareous cement.

Shale, dark gray, weathers to light gray, thin bedded, fissile

N16 -Silty limestone, light gray, weathers to reddish gray calcareous cement, argillaceous, medium bedded, very blocky.

Shale, dark gray, weathers to light gray, thin bedded, fissile

N17 - Silty limestone, six samples taken, very large unit. Argillaceous, calcareous cement, light gray, weathering to reddish gray, medium bedded, very blocky.



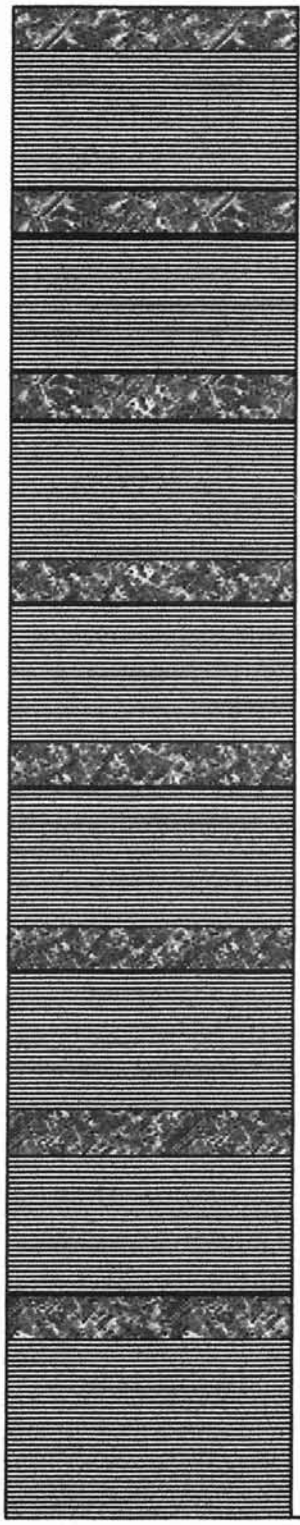
Shale, tan, mostly covered.

N18 - Limetone, light gray, weathers to orangy tan, calcareous cement, medium bedded, very blocky making sampling difficult.

Shale, weathers to tan, thin bedded, fissile.

N19/E1 (E for "end") - Limestone, gray, weathers to tan thin bedded, siliceous cement, cherty.

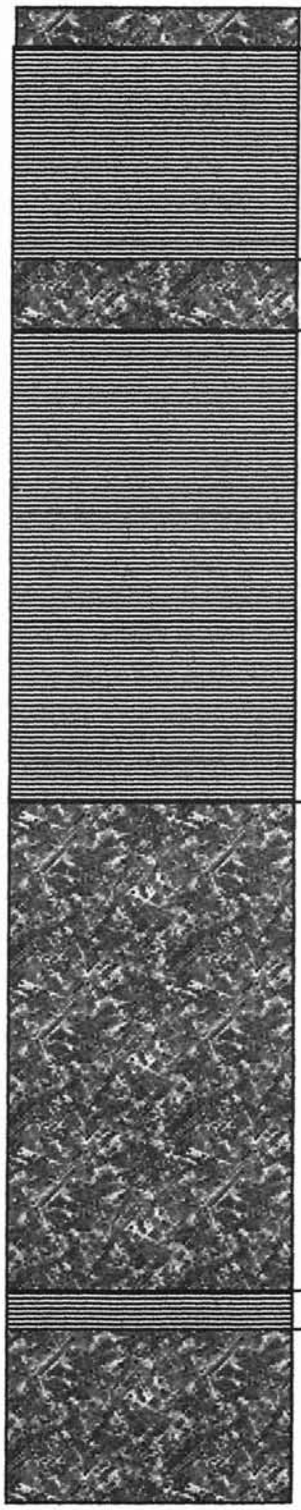
Transition zone. All limestone are gray, weathering to orangy tan. The thin limestones average 1 foot while the shales average 3 feet. Sampling extremely difficule due to blockiness and severe weathering. Samples E2 through E5 were chosen randomly down this section.



Transition zone continued to end. Top of Woodford Shale beneath transition zone.

APPENDIX 2

South flank stratigraphic column. One inch equals 4 feet.



S1 - Silty limestone, calcareous cement, medium bedded, grayish tan, weathers to gray-brown.

Shale, covered.

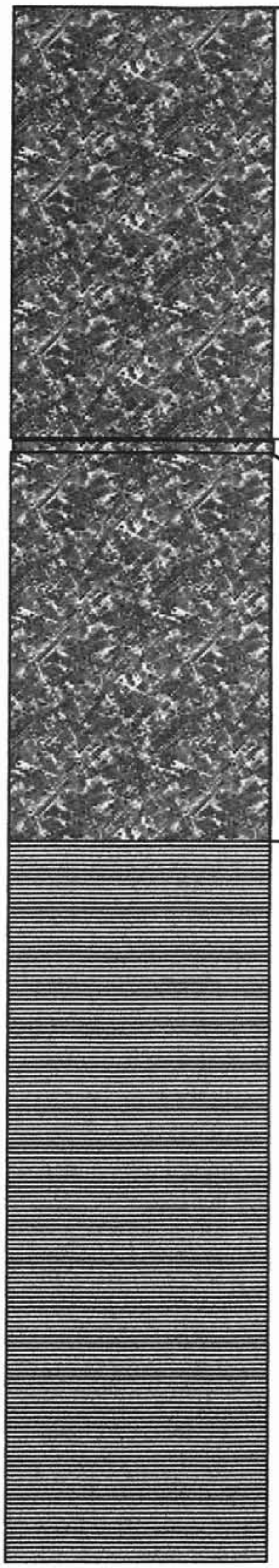
S2 - Silty limestone, calcareous cement, massive bedded, tan, weathers to dark tan.

Shale, covered.

S3 - Silty limestone, calcareous cement, massive bedded, light gray, weathers grayish tan.

Shale, weathers dark tan, calcareous cement, fissile.

S4 - Limestone, calcareous cement, massive bedded, light gray, weathers tan.

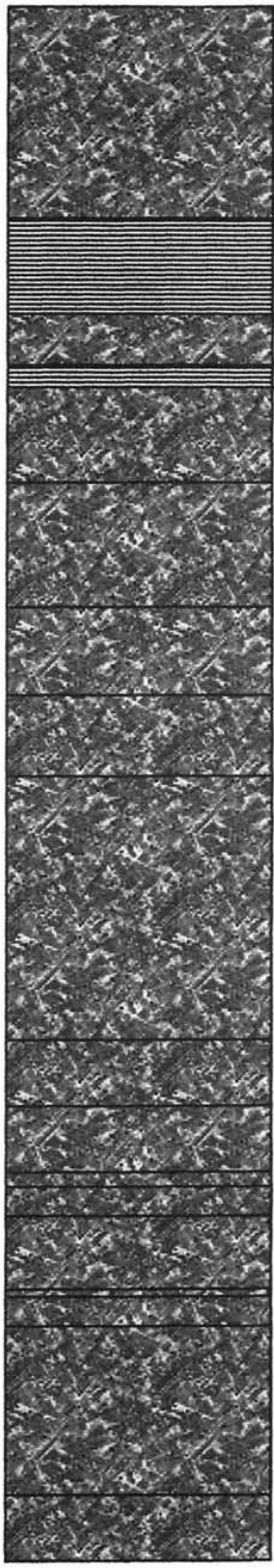


S5 - Limestone, calcareous cement, massive bedded, light gray, weathers dark gray.

S6 - Silty limestone, poorly indurated, calcareous cement, argillaceous, light gray, weathers dark gray.

S7 - Limestone, clacaeous cement, massive bedded, light gray, weathers dark gray-tan.

Shale, completely covered. This is Fay's upper shale zone. It has been condensed here, but in outcrop is 72' thick.



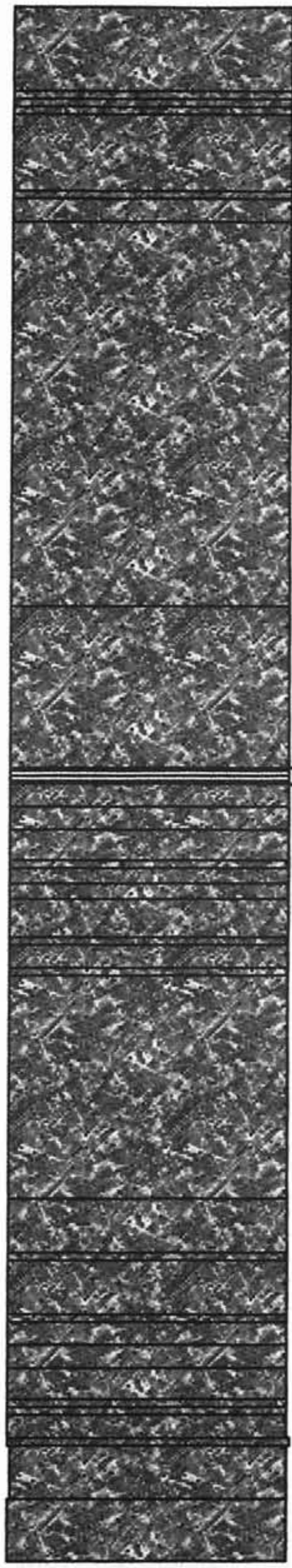
S8 - Limestone, calcareous cement, massive bedded, well indurated, light gray, weathers dark gray.

Shale, dark gray, weathers gray, fissile

S9 - Limestone, calcareous cement, massive bedded, light gray, weathers dark gray.

Shale, weathers light gray, fissile.

S10 - limestone, calcareous cement, medium bedded, blocky. light gray, weathers dark gray. Measurements taken at bedding planes. Three samples taken (S10.1, S10.2, S10.3).



S10 continued.

Shale, dark gray, weathers light gray

S11 - Limestone, three samples taken, calcareous cement, light gray, weathers dark gray, medium bedded, blocky. Measurements taken at bedding planes.

S11 continued.

Shale, thin and fissile.

S12 - Limestone, calcareous cement, thin bedded, blocky

Shale, thin and fissile.

S13 - Limestone, calcareous cement, medium bedded, light gray, weathers dark gray, took two samples, left one on outcrop.

Shale, weathers light gray, thin and fissile.

S14 - Limestone, calcareous cement, thin bedded, blocky, light gray, weathers dark gray.

Shale, dark gray, weathers light gray

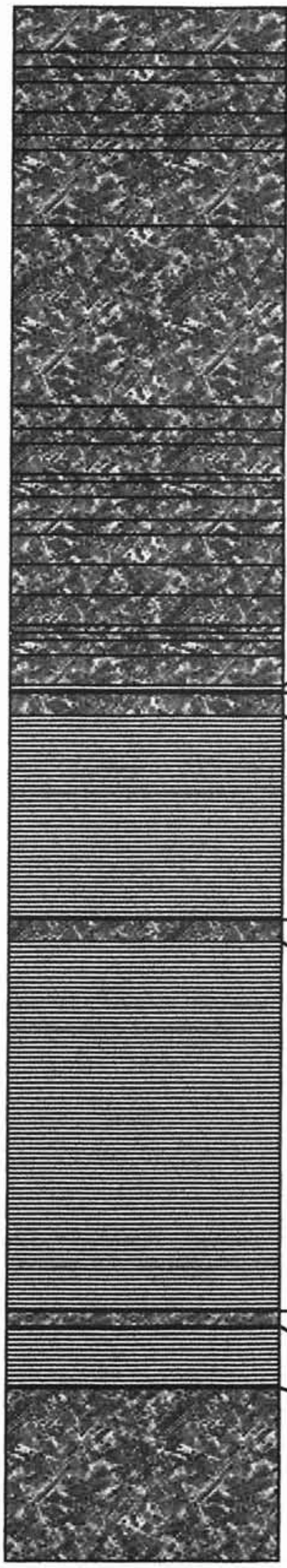
S15 - Limestone, calcareous cement, medium bedded, light gray, weathers dark gray.

Shale, dark gray, weathers light gray, thin bedded.

S16 - Limestone, calcareous cement, medium bedded, blocky light gray, weathers to dark gray.

Shale, dark gray, weathers light gray

S17 - Limestone, calcareous cement, medium bedded, light gray, weathers dark gray, measurements taken at bedding planes.



S17 continued.

Shale, dark gray, weathers light gray, fissile.

S18 - Limestone, calcareous cement, medium bedded, light gray, weathers dark reddish gray.

Shale, weathers to dark tans and grays, fissile.

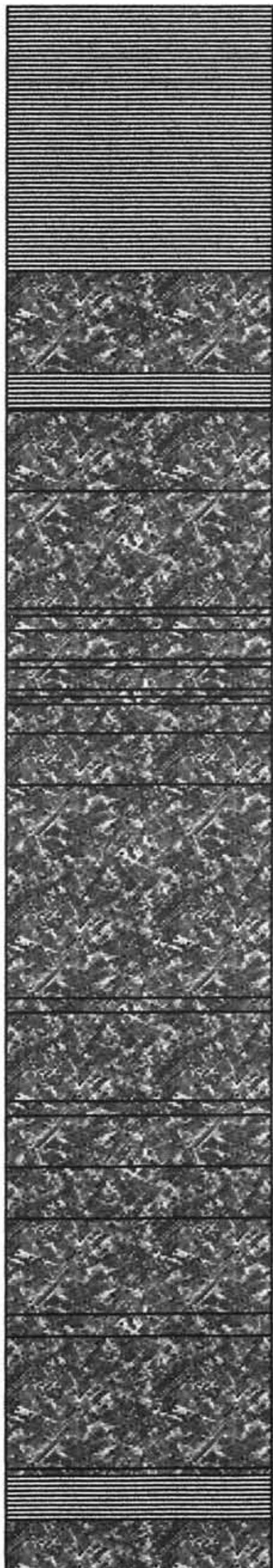
S19 - Limestone, calcareous cement, medium bedded, gray, weathers reddish gray.

Shale, weathers to grays, tans and reds, thin bedded, fissile.

S20 - Limestone, calcareous cement, medium bedded, light gray, weathers dark gray.

Shale, weathers in to grays, thin bedded, fissile.

S21 - Limestone, calcareous cement, medium bedded, light gray, weathers gray.



Shale, weathers to grays, thin bedded, fissile

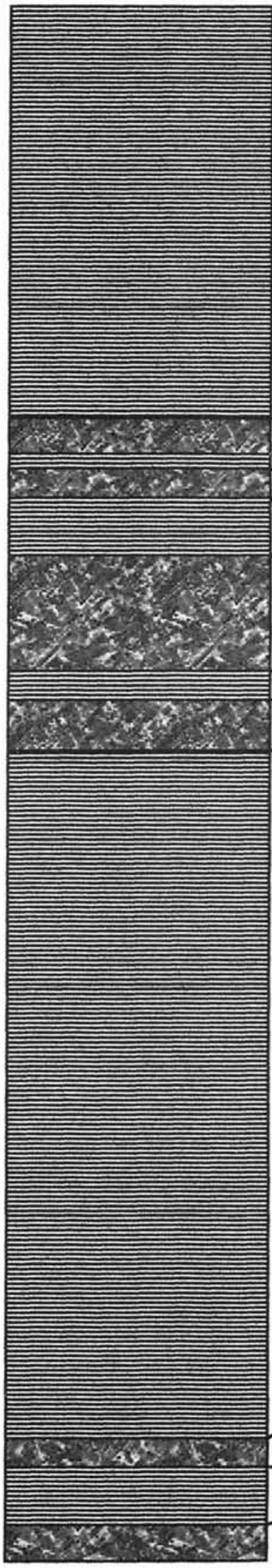
S22 - Limestone, calcareous cement, masive bedded, light gray, weathers to grays and tans, blocky.

Shale, weathers to grays, thin bedded, fissile.

S23 - Limestone, calcareous cement, medium to massive bedded, light gray, weathers to grays and reddish tans, blocky. Measurements taken at bedding planes.

Shale, dark gray, weathers to gray, thin bedded, fissile

S24 - Limestone, calcareous cement, thin bedded, blocky light gray, weathers to gray, reddish tans and tans.



Shale, weathers to grays, thin bedded, fissile

S25 - Limestone, siliceous cement, thin bedded, blocky dark gray, weathers to dark reddish gray.

Shale, weathers dark gray, thin bedded, fissile.

S26 - Limestone, siliceous cement, thin bedded, blocky, dark gray, weathers to dark reddish gray.

Shale, weathers to grays, reds and tans, thin bedded, fissile.

S27 - Limestone, siliceous cement, medium bedded, silica-filled fractures, dark gray, weathers to reddish gray.

Shale, weathers to grays, thin bedded, fissile.

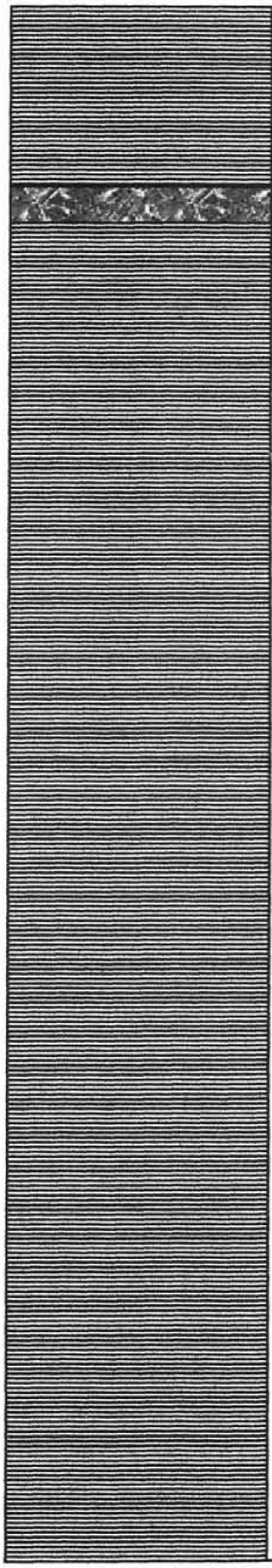
S28 - Limestone, as above, siliceous cement, blocky

Shale, dark gray, weathers to grays and reddish tans, thin bedded, fissile.

S29 - Limestone, siliceous cement, medium bedded, dark gray, weathers to dark reddish gray.

Shale, weathers to grays, thin bedded, fissile.

S30 - Limestone, siliceous cement, medium bedded, dark gray, weathers to grays and reddish tans.



Shale, weathers to grays, thin bedded, fissile

S31 - Limestone, siliceous cement, medium bedded, dark gray, weathers to grays and reddish tans, almost chert-like

Shale, final interval above Woodford, weathers to grays and reddish tans, mostly covered. 30 to 40 feet represented here

VITA

Karen Elizabeth Franklin

Candidate for the Degree of

Master of Science

Thesis: THE DEPOSITIONAL HISTORY OF THE SYCAMORE LIMESTONE

Major Field: Geology

Biographical:

Personal Data: Born in San Diego, California, on June 26, 1974, daughter of Dennis and Judy Ferrell, wife to Michael Franklin and mother of Gus and Austin Franklin.

Education: Graduated from Lackey High School, Indian Head, Maryland in June, 1992; received Bachelor of Science degree in Geology from Oklahoma State University, Stillwater, Oklahoma in May, 1997. Completed the requirements for the Master of Science degree with a major in Geology at Oklahoma State University in August, 2002.

Experience: Raised near various cities around the United States and in the country of Japan. Employed in various food service and menial labor jobs as an undergraduate. Worked as a research assistant during various semesters as a graduate student in the Department of Geology, Oklahoma State University.

Professional Memberships: American Association of Petroleum Geologists.