PALEOKARST CHARACTERISTICS OF THE SURFACE AND SUBSURFACE IN THE VIOLA LIMESTONE(ORDOVICIAN), ARBUCKLE MOUNTAINS, OKLAHOMA

By

MICHAEL SYKES

Bachelor of Science

Western Kentucky University

Bowling Green, Kentucky

1993

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment
of the requirements for
the Degree of
MASTER OF SCIENCE
DECEMBER, 1995

OKLAHOMA STATE UNIVERSITY

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Thesis Approved:

Thesis Adviser

Dean of the Graduate College

ACKNOWLEDGMENTS

First and foremost, I would like to express thanks to my parents Laythe and Frances Sykes for their encouragement and guidance, without it I would not be who I am today. I've always admired my parents because they have been such wonderful role models for my brother, Evan, and my sisters; Anne and Lara. Thank you Mom and Dad.

I would also like to thank Kristin for putting up with a rock nerd and listening to my geology jargon when she really didn't want to hear it.

Thank you Dr. Al for making my stay in Oklahoma a true learning experience. I will always remember your words: "If you listen to the rocks, they will tell you everything". Having concluded my graduate career, I am one step closer to understanding what the rocks are telling me.

Next, I would like to thank my committee members, Dr. Vitek and Dr. Cemen for short, but enlightening office chats and greatly improving this thesis.

This person needs little or no introduction: "Captain Jim Puckette" deserves tremendous recognition. Thank you ever so much for your proofreading! I know it was a hard job and your assistance was greatly appreciated. I hope that someday, I might aspire to the level of commitment and dedication that I see in you.

I would like to thank the Oklahoma City Geological Society for their financial support, without it this thesis would not have been possible.

Next, thanks goes to two great friends, Roberto Milburn and Charlie Lingerfelt, for their wealth of computer knowledge that they have so generously donated.

Last, but not least, I would like to thank all of my undergraduate professors for their contribution in my education.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figures Page

LIST OF PLATES

PLATE

CHAPTER I

INTRODUCTION

The paleokarstic features found in the Viola Group display a distinct diagenetic pattern. This thesis develops a systematic approach to the interpretation of the development of the paleokarstic features. Paleokarst features are of increasing interest to the oil/gas industry, because of potential hydrocarbon reservoirs. Some paleokarstic induced reservoirs will have a greater lateral extent, whereas other paleokarstic features have low porosity and are small. Specific reservoir characteristics and parameters can be identified in karsted Viola reservoirs. These characteristics may be applied to other paleokarstic reservoirs.

It is important that one keep an open mind about the origin and diagenesis of the features documented in this thesis. The cores that were studied for evidence of Viola paleokarst features can be correlated between the outcrops and the subsurface.

Purpose of Study

This investigation assesses the paleokarstic and karstic features in outcrop and subsurface, and classifies and interprets the origins. In analyzing these features, I will determine if the karstic features found in the Viola Limestone impact the location or migration and trapping of oil within the structures. The area of study was restricted to the Arbuckle Mountain region, where extensive outcrops are located (Figure 1). Some past investigations have suggested that the only paleokarstic features are fracture related. Fractured zones within the Viola have previously been studied as the reservoir rock, but little has been published about the karstified grainstone intervals. This thesis investigates the possibility that zones of karst are instrumental in trapping and transmitting fluids, or causing reservoirs to form in areas adjacent to the zones of karst in the Viola.

Area of Study

The Arbuckle Mountain Uplift was chosen as the area of study because of the extensive outcrops of the Viola Group and adjacent formations in the region. The subsurface study area was based on the number and footage of cores located in oil fields adjacent to the Arbuckle Mountains. Figure 1 shows subcrop and outcrop areas of investigation; a more detailed map showing the exact locations of the outcrops is located in plate 1.

Methods of Study

The outcrops examined were located on a geologic map of the Arbuckle Uplift prepared by Ham, McKinley et. al, (1954). All accessible outcrops on the map were examined in the field. Twelve outcrops having key karstic features were located using a Trimble Navigational GPS (Global Positioning System) for relocation purposes. Next, each karstic feature was given a preliminary label as either karstic or paleokarstic based on the field observations and features. If the features supported paleokarst origin, they

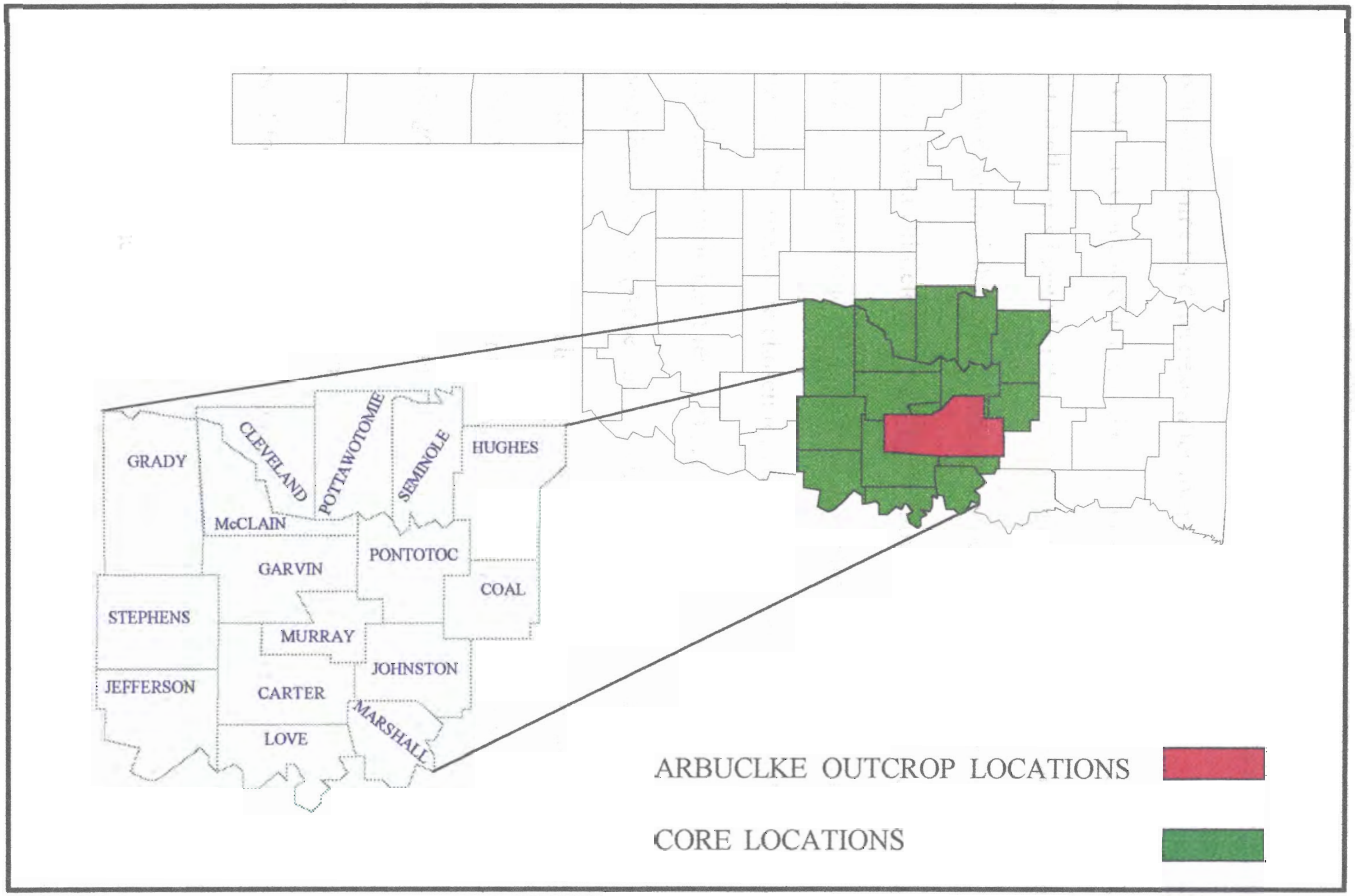


Figure 1. Thesis area location.

were thoroughly examined to explain:

1) morphology of passage displayed based on type,
2) origin of the feature, such as collapse passage or infill,
3) origin related to phreatic or vadose dissolution.

In addition to the megascopic features, samples were collected in conduits and examined by thin sections to determine its diagenesis after formation.

All the Viola cores located in the Oklahoma Geological Survey Core Library were complied. A list of all cores located in the vicinity of the Arbuckle Mountains were then plotted on a map to determine the spatial relationship between core to core and core to outcrop (Figure 2). Viola Oil fields reported by Chenoweth (1966) were added to the map and chosen for additional study based on the proximity to oil production zones (Figure 3). A total of 25 cores were chosen for additional examination (Table I) and only 7 cores displayed characteristic karst features (Table II). Cores having paleokarstic features were described, logged (Appendix A), photographed (Appendix B) and thin sections were made in selected intervals. Selected thin sectioned intervals were crushed and analyzed using X-ray powder diffraction to asses composition and provide some insight into the diagenetic changes within the interval.

A model was formulated using the field observations and core data to explain the actual processes of formation of the paleokarstic features. The model shows that multi-episodic karst processes occurred in the Viola Limestone. The approximate timing of the event was postulated using the relationships of karstic features (cavern filled breccia and cements included within the karsted zones) and potential exposure surfaces.

TOWNSHIP-RANGE	LOCATION	COUNTY	WELL NAME AND #
05S-03W-20	N/A	CARTER	WADE 1-20
09N-02W-16	SWNWNE	CLEVELAND	COOLBAUGH 1-16
09N-01W-03		CLEVELAND	WALTERS 2
09N-01W-03		CLEVELAND	WALTERS 2
10N-03W-12	SWSE	CLEVELAND	KUCHYNKA 1
03N-10E-30	SESENW	COAL	HILL 3-A
01N-02W-31	SWSWNE	GARVIN	J CANADA 1
03N-02W-22		GARVIN	KING 1
03N-02W-22		GARVIN	KING 1
03N-02W-22		GARVIN	KING 1
03N-02W-22		GARVIN	KING 1
01N-03W-12	SENESE	GARVIN	HARRELL B-1
03N-02W-22		GARVIN	KING 1
01N-02W-31	SWSWNE	GARVIN	J CANADA 1
01N-02W-31	SWSWNE	GARVIN	J CANADA 1
01N-02W-18		GARVIN	STORY UN 1
01N-02W-17	NWSW	GARVIN	BALL UN 1
01N-02W-17	SENENW	GARVIN	PEASE 1
01N-02W-07	SENWSE	GARVIN	HETHORNE 1
01N-02W-07	E2SWSE	GARVIN	FREEMAN 1
02N-02W-08	E2NENW	GARVIN	A NEAL 1-8
04N-02W-22	N/A	GARVIN	J.M. MCDANIEL 2
03N-02W-22		GARVIN	KING 1
04N-01W-22	NWNW	GARVIN	J.M. MCDANIEL 1
04N-06W-04	NWSWNE	GRADY	CHITWOOD-HARRIS 1
05N-05W-36	N2SWNW	GRADY	JADE 1
28N-04W-32	SWSWNE	HUGHES	HAMMOND 1-4
06S-06E-10	NWNESW	MARSHALL	BEARD NORVELL 1
05N-03E-21	W2SESE	MCCLAIN	MCAFEE 1
05N-01E-09	SESW	MCCLAIN	NEWBERN 1-9
05N-03W-35	W2NW	MCCLAIN	WATKINS1
05N-03E-21	W2SESE	MCCLAIN	MCAFEE 1
09N-03W-31	NWNE	MCCLAIN	KUNNEL 2
07N-02W-18		MCCLAIN	SUSAN 1-18
07N-02W-21		MCCLAIN	DOLL 1-21
05N-02W-04	SWSW	MCCLAIN	LOVE, GLADYS 1
01N-02E-29	SESE	MURRAY	CRAWFORD 1
01S-02E-20	S2NESW	MURRAY	JOYCE 1
04N-05E-04	SESESW	PONTOTOC	HATHCER 1-A
04N-05E-04	SESESW	PONTOTOC	HATCHER 1-A
04N-05E-04	SESESW	PONTOTOC	HATCHER 1-A
04N-05E-04	NWSESW	PONTOTOC	HATHCER2-A
04N-07E-25	SENWNE	PONTOTOC	SLEDGE 1
02N-07E-26	NENENW	PONTOTOC	BATES 2
05N-04E-36	N/A	PONTOTOC	PHOENIX 1
05N-08E-20	NWSWNW	PONTOTOC	PERRY 23
05N-08E-17	NESWSW	PONTOTOC	HARJO 10
05N-08E-20	NWNENW	PONTOTOC	PERRY 24
02N-07E-27	NWNENE	PONTOTOC	E. FITT'S UN 9-41
02N-07E-27	SWNWNW	PONTOTOC	E. FITT'S UN 21-19
02N-06E-29	E2NWNW	PONTOTOC	SIMPSON JR 1
05N-08E-20	NWNENW	PONTOTOC	PERRY 24
02S-06W-32	SWSE	STEPHENS	COMANCHE 322-14
02S-06W-32	SWSE	STEPHENS	COMANCHE 322-14

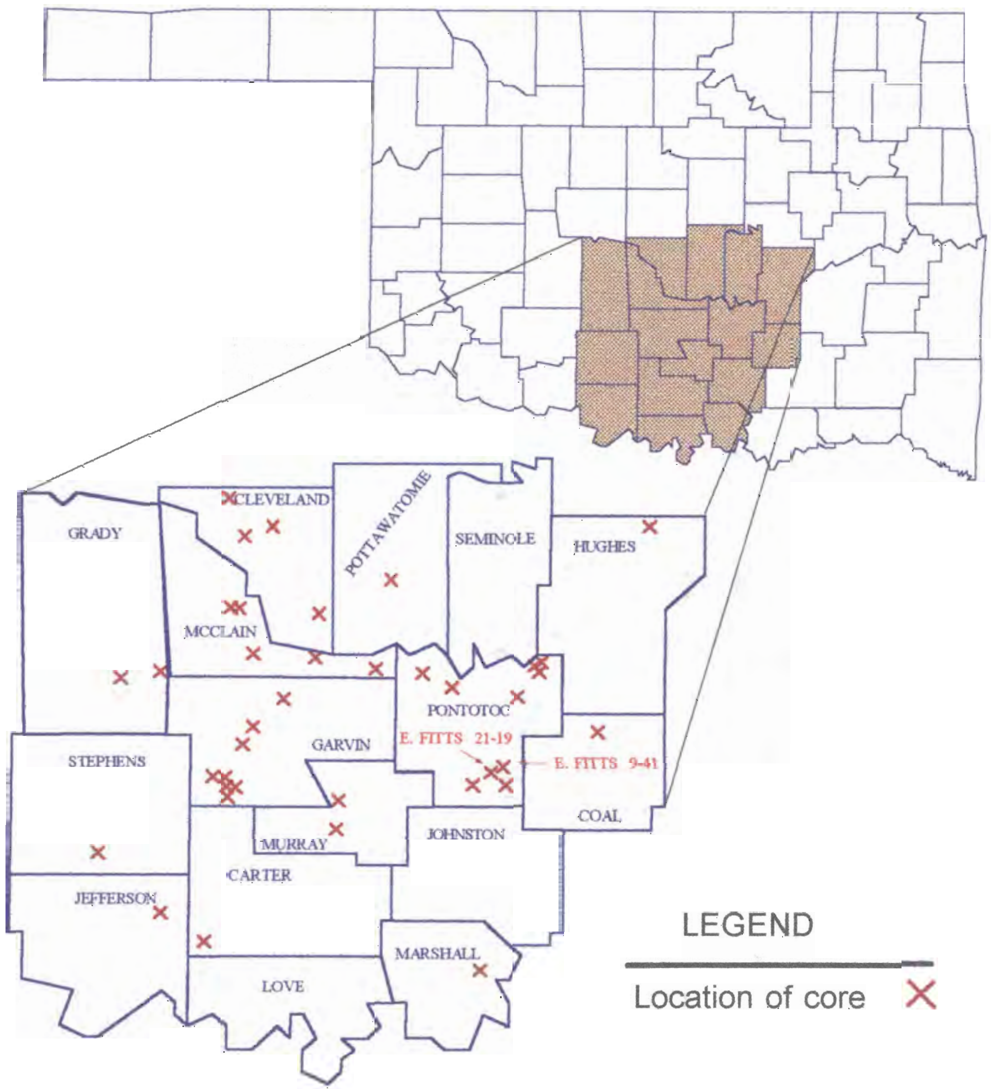


Figure 2. Location of Viola cores in proximity to Arbuckle Mountains.

FIELD NO.	COUNTY	FIELD DISCOVERY
	CARTER COUNTY	
1	Hewitt	1919
2	Simon, N	May 58
3	Springer	Nov-65
	GARVIN COUNTY	
4	Antioch District, E	Oct-47
5	Antioch District, N	Dec-5
6	Antioch District, NE	Oct-47
7	Antioch District, SW	Mar-46
8	Maysville, NE	Aug-56
9	Pauls Valley, NE "A"	Oct-58
10	Pauls Valley, W	1944
	Harper County	
11	Selman	Jun-60
	Love County	
12	Marietta, N	Oct-37
	McClain County	
13	Payn	Sept-58
	Murray County	
14	Davis, E	1960
15	Hoover, SE	Nov-55
16	Sandy Creek, SE	Nov-61
	Pontatoc County	
17	Fitts	Dec-32
18	Fitts, S	Dec-37
19	Allen District	May-62
	Stephens County	
20	Commanche	

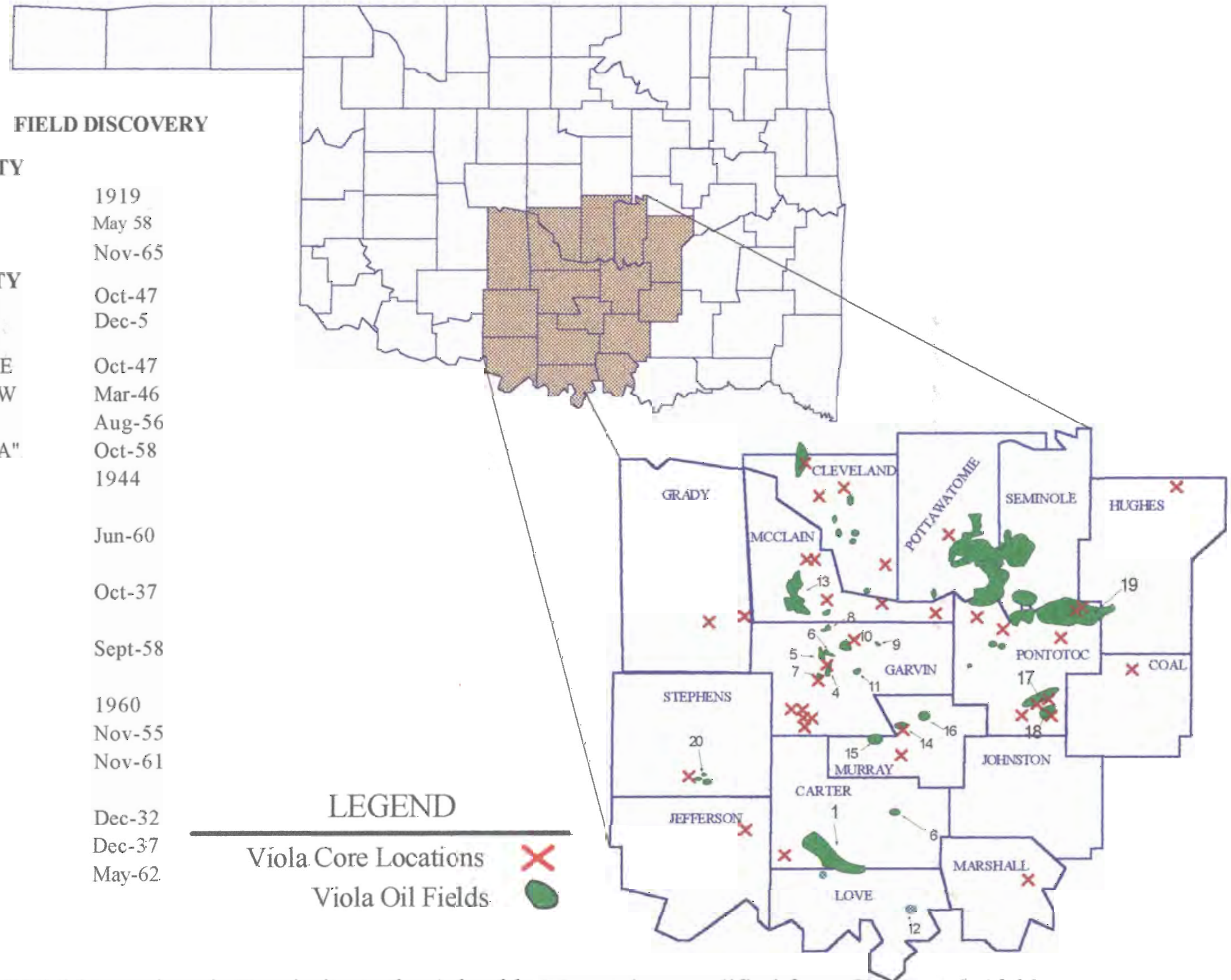


Figure 3. Viola Oil Field Locations in Proximity to the Arbuckle Mountains, modified from Chenoweth 1966.

TABLE I
VIOLA CORE EXAMINED

WELL NAME	KARSTIC FEATURES	NON-KARSTIC FEATURES
WADE 1-20		X
STATE 1-22		X
HILL 3-A		X
A NEAL 1-8		X
HETHORNE 1		X
MCAFEE 1		X
MCAFEE 1		X
CRAWFORD #1	X	
ZEMP 2		X
MOYER 1		X
BENNETT 1		X
HATCHER 1-A	X	X
HATCHER 1-A	X	X
PHOENIX 1	X	
EAST FITTS 21-19	X	
SIMPSON JR. 1		X
PERRY 23	X	
HARJO 10		X
PERRY 24		X
PERRY 24		X
EAST FITTS UN 9-41	X	
BATES 2		X
WILLIAMS 1		X
NEWBERN1-9		X

TABLE II
INTERVAL AND THIN SECTION INFORMATION

TOWNSHIP-RANGE-SECTION	LOCATION	COUNTY	CORE NAME	INTERVAL CORED	No. OF THIN SECITONS
05S-03W-20	N/A	CARTER	WADE 1-20	11298-11320	
07N-01E-22	W2NESW	CLEVLAND	STATE 1-22	6420-6466	
03N-10E-30	SESENW	COAL	HILL 3-A	5524-5534	
02N-02W-08	E2NENW	GARVIN	A NEAL 1-8	8010-8041	
01N-02W-07	SENWSE	GARVIN	HETHORNE 1	6122-8880	
05N-03E-21	W2SESE	MCCLAIN	MCAFEE 1	3600-3621	
05N-03E-21	W2SESE	MCCLAIN	MCAFEE 1	3460-3484	
01N-02E-29	SESE	MURRAY	CRAWFORD 1	5474-5499	
21N-01E-33	SENENW	NOBLE	ZEMP 2		
14N-02W-15	NWNWNE	OKLAHOMA	MOYER 1	6081-6119	
19N-04E-31	SESENW	PAYNE	BENNETT 1		
04N-05E-04	SESESW	PONTOTOC	HATHCER 1-A	1925-1983	7
04N-05E-04	SESESW	PONTOTOC	HATCHER 1-A	2010-2048	6
05N-04E-36	N/A	PONTOTOC	PHOENIX 1	2947-2968	7
02N-07E-26	N/A	PONTOTOC	EAST FITTS 21-19	3802-3977	79
02N-06E-29	E2NWNW	PONTOTOC	SIMPSON JR 1	3382-3394	
05N-08E-20	NWSWNW	PONTOTOC	PERRY 23	4037-4060	
05N-08E-17	NESWSW	PONTOTOC	HARJO 10	3860-3898	
05N-08E-20	NWNENW	PONTOTOC	PERRY 24	3886-3899	
05N-08E-20	NWNENW	PONTOTOC	PERRY 24	3907-3928	
02N-07E-27	NWNENE	PONTOTOC	E. FITT'S UN 9-41	4000-4185	
02N-07E-26	NENENW	PONTOTOC	BATES 2	4069-4099	
08N-03E-23	NWSENE	POTTAWATOMIE	WILLIAMS1		
05N-01E-09	SESW	POTTAWATOMIE	NEWBERN1-9	6330-6389	

Previous Investigations of Paleokarstification

Paleokarstic features in the Viola have mostly been classified as fractured structures with porosity related to tectonic origin. Until recently, no published works were devoted entirely to paleokarst recognized within the Viola Limestone. Becker (1988) recognized a few paleokarstic features within the Viola, but concluded that the features only occurred within the upper 4.2m. He attributed the origin of the features to submarine processes described in Flugel, (1982). Becker also described collapse features by Esteban et al. (1983) as being altered by subaerial exposure.

Al-Shaieb, Puckette, Abdalla, Rice (1994) have performed the most detailed work to date on the paleokarstic features in the Viola Limestone. They described the paleokarst features as multi-episodic, including deposition of the Viola, burial, fracturing, uplifting, and telegenetic alteration prior to the deposition of the Sylvan Shale.

Areas of Outcrop Exposure

The Viola Limestone outcrops in southern Oklahoma are the direct result of uplift associated with the Pennsylvanian Orogeny. Viola outcrops are found primarily in the Arbuckle Mountains, the Criner Hills south of the Arbuckle Mountains, and the Wichita Mountains. The outcrop areas of the Viola Limestone and Sylvan Shale studied in the Arbuckle Mountain region are represented on the map in Plate 1; also included are the faults that structurally influenced the outcrop patterns. The aerial extent of the Viola Limestone in Oklahoma is shown in the isopach map in figure 4.

Figure 4. Isopach map of the Víola Group and equivalent rocks, Oklahoma, Kansas, Colorado and Texas (modified, after Huffman and Merriam, 1966).

Topography of the Viola Limestone in the Arbuckle Mountains

The Viola Limestone is observed mostly on the surface by topographic highs or ridges (Figure 5). The ridges are steeply dipping rocks that trend to the northwest. The three units of the Viola (Glaser, 1965) have specific weathering patterns that differ from the other units within the Viola Group. The upper and lower units appear more resistive to weathering, whereas the middle unit shows evidence of more rapid weathering and produces topographic lows between the more resistive units. The different weathering patterns of each unit can be attributed to the change in rock type, such as grainstone to packstones, and compositional changes from the top to bottom of the formation.

CHAPTER II

GENERAL GEOLOGY

Geologic Setting of The Viola

The Viola Limestone was deposited in a shallow ramp type environment (Glaser, 1965) in an eperic Ordovician sea that occupied Oklahoma about 425 million years ago (Figure 6). The primary control of regional deposition for the Viola Group was the Southern Oklahoma Aulacogen (Wengerd, 1948). Grammer (1983) described Hoffmans (1974) interpretation of an aulacogen as a deeply subsiding trough, often bounded by high angle faults, that extends at an high angle from a geocline far into the interior of the foreland platform. The aulacogen formed as a result of a three armed radial rift system with the third arm trending to the northwest and southeast. The third arm in the rift system extended into the stable craton to the north (Figure 6, location A) and the remaining two arms formed the Ouachita/Marathon Miogeocline (Figure 6, location B) to the south.

The aulacogen was formed in three main stages. In the first stage, during early to middle Cambrian the failed arm of the triple junction was filled by extrusive and shallow intrusive rocks. In the second stage (subsidence stage), a passive continental margin formed and was accompanied by marine transgression and relatively rapid subsidence

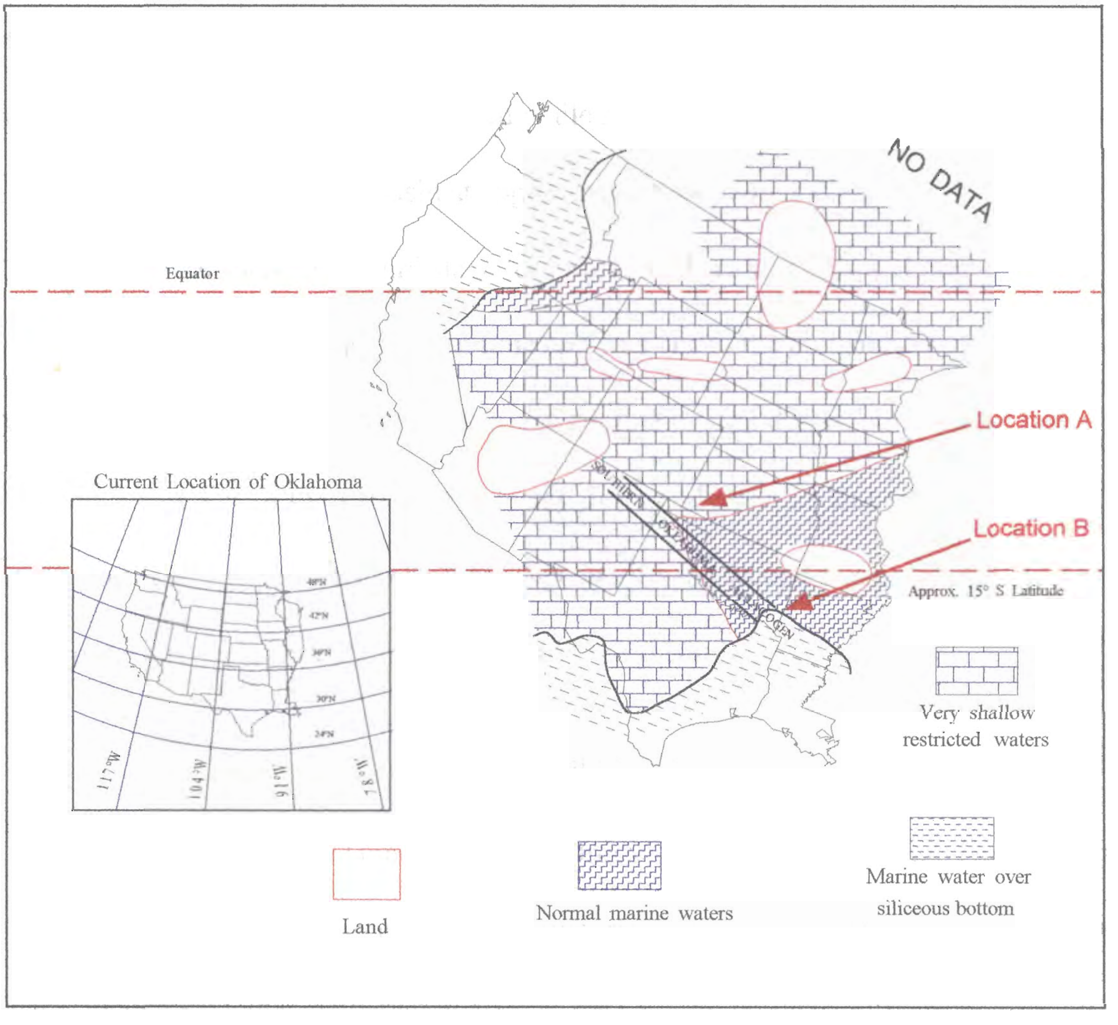


Figure 6. Location of Oklahoma during Early Cincinnatian and location of the Southern Oklahoma Aulacogen and carbonate depostional paleo-environment (Grammer, 1980 after Ross, 1975).

(Palladino and Jamieson, 1985). During the second stage there was a massive deposition of a thick sedimentary sequence(approximately 10,000m, Ham, 1973). The sequence included both carbonate sequences, such as the Simpson Group, Viola Group and the Hunton Group and other terrigenous clastic influxes, such as the Reagan Sandstone. The sediments in the geocline were deposited while subsidence (Webster, 1980 and Grammer, 1983) was taking place in the basin at approximately four times (Glaser, 1965) the rate of deposition on the shelf. The third stage (deformational stage) began in Late Mississippian to Early Pennsylvanian time and was due to the collision of the South American continent and the North American continent. The deformational state lasted until the occurrence of the Arbuckle Orogeny in Late Missourian and early Virgilian time. During this time all the sediments deposited in the second stage were being folded to form the Arbuckle Mountains and the Ardmore Basin.

Viola Stratigraphy

The Viola Group is Upper to Middle Ordovician (Black Riverian to Richmondian Age). The Viola Group in southern Oklahoma, represented by several different limestone facies, includes nodular chert-rich mudstone, packstones, porous grainstones , wackestones and dolomitized wackestones. Classification of the Viola facies have been presented by Glaser (1965), Alberstadt (1967), Reid (1980), and Grammer (1983) (Figure 7).

The Viola Limestone is found as far north as Kansas and Eastern Colorado. In areas of northeastern Oklahoma, the Viola is truncated in locations by the Pre-Woodford unconformity. In these locations, the Viola is overlain by the Woodford Shale which acts

Figure 7. Comparative stratigraphic subdivisions of the Viola Limestone (after Glaser, 1966; Reid,1980; Grammer,1983).

as a unconformity trap for the migration of hydrocarbons. In southern Oklahoma the Viola thickens greatly in the Anadarko and Ardmore Basins. South of the basin on the Wichita Uplift (Figure 4), the Viola is eroded and only Cambrian and Precambrian rocks remain.

The Viola Limestone was first documentation by J.A. Taff in 1902 when he described and named the limestone at an outcrop near a small village located 5 miles west of Wapanucka in Johnson County, Oklahoma (Grammer, 1983). Taff (1902) proposed that the contact between the Viola and Bromide was transitional, not unconformable. Taff (1902) did not recognize that the contact between the Viola and Sylvan Shale was unconformable. Taff (1902) placed the age of the Viola as Blackriverian to Richmondian, an age that is still being used today.

Depositional Facies of the Viola

The deposition of the Viola Group is depicted as a shallowing upward cycle (Becker, 1980). Within this cycle, fluctuations in the sea level are represented by smaller-scale regressive and transgressive cycles in the Viola sediments.

The lower part of the Viola Group, the Viola Springs Formation, was proposed as a relatively deeper water environment (Grammer, 1983). This part of the Viola, is the 1L/1C unit of Glaser (1965) and Alberstadt (1967). Grammer (1983) also based his conclusion of the deeper water environment on the presence of phosphate and pyrite mineralization, which he attributed to an anaerobic environment. The deposition of this facies is primarily seen as deep water sediments with the inclusion of minor amounts of fauna from shallower water deposited by 1) current action, 2) small scale slope failures or turbidites (Grammer, 1983), or 3) storm events (Reid, 1980). The core samples of this section are seen as a uniform lithology with intervals of dolomitized zones and few fossils (Figure 8). Few occurrences of silicification are seen within this facies because of later fluid migration through the formation after deposition (Appendix C, depth 3975). The lower facies in the Viola can be classified as subtidal and are found in the deepest portions of the ramp facies described by Wilson (1975) and deepest portion of the aulacogen formed basin (Glaser, 1965).

After the deposition of the deeper water sediments, the sequence of sediments record definite shallowing upward trend. The next facies, a grainstone facies (Figure 9), is high in porosity and was likely formed in an intertidal to lower intertidal setting. This grainstone facies is well composed of sorted bryozoa, brachiopods and echinoderm bioclastic debris. This grain-rich sediment developed in a shallow water environment when wave and current energy could remove the sediments and entrain carbonate mud.

Following the deposition of the grainstone facies, a moderate increase in the water depth produced muddier sediments (Figure 10). The next facies represented in the section documents a gradual decrease in water depth and is represented by intervals of alternating wackestone, packstone and grainstones. The thicknesses of the grainstones found in this facies are on the scale of 10 to 15 centimeters. The wackestone portion of these facies can be one to two meters in thickness. The remainder of the section is mostly lower intertidal sediments with no evidence of significant depth change. Within this

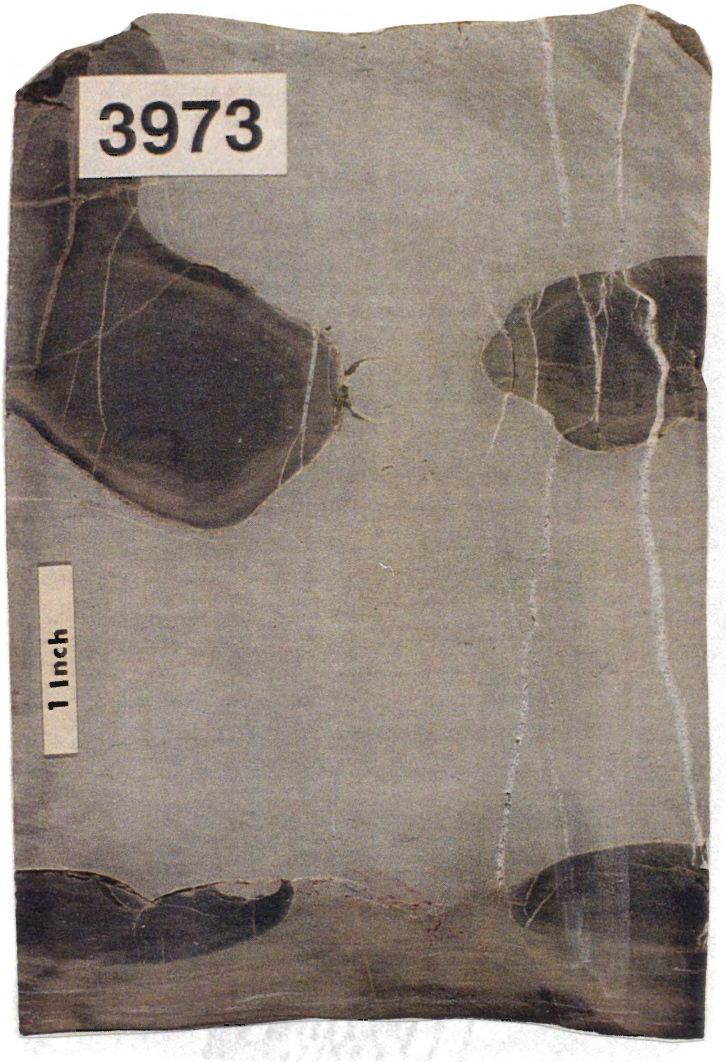


Figure 8. Core photo of ViolaGroups Viola Springs Formation. Mudstone with chert nodules and calcite cement filled fractures. Notice the color change, due to dolomitization, at the bottom of the core sample.

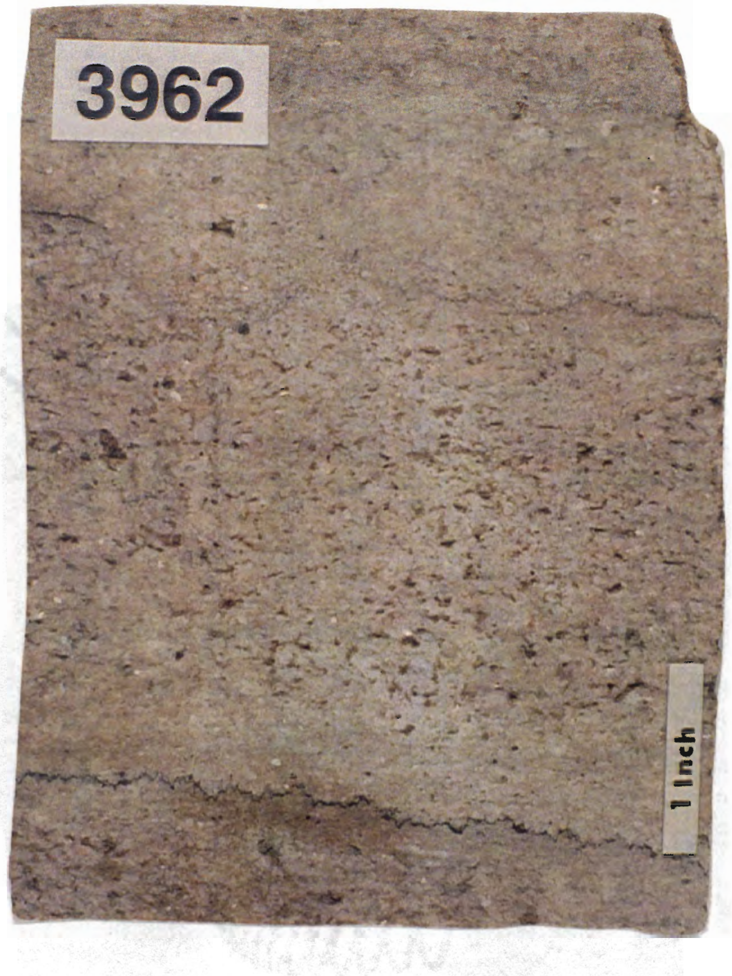


Figure 9. Viola Springs grainstone depth interval 3962 with high porosity. Abundant fossils of bryozoan, brachiopod and echinoderms.

Figure 10. Viola Springs wackstone to packstone facies from East Fitts Core 21-19 inteval 3910. Fossil fragments of trilobites, bryozoan, brachiopods and echinoderms. Matrix is mostly dolomitized.

section, zones of increased bryozoan debris may represent small mound type deposits (Figure 11).

The uppermost facies in the Viola Group, the Fernvale Limestone is dominated by echinoderm grainstone lithology and suggests a shallow water environment. The Fernvale Limestone depositional setting is most likely an intertidal zone where wave action could winnow mud from grain-rich sediment.

Figure 11. Viola Springs wackstone facies from East Fitts Core 21-19 inteval 3808. Fossil fragments of trilobites, bryozoan,brachiopods and echinoderms. Matrix is partially dolomitized around clay seams. Notice large echinoderm fragments and calcite filled fractures.

CHAPTER III

KARST

Introduction

Karst is a process that produces characteristic landforms and surface features. The term karst generally applies to carbonate and or evaporitic type rocks in which weathering and erosion of the underlying bedrock produces unique surface topography and also impacts the subsurface. Erosion and dissolution of the rock is generally caused by the interaction between the rock and the groundwater that moves through the fractures and pore spaces. The water acts like a sculptor on the soluble rock exposed on or below the surface. According to White (1988) the most characteristic landforms in karst regions are:

Closed depressions of various size and arrangement,
Disrupted surface drainage, and
Caves and underground drainage systems.

The combinations of different lithologies and dissolution can generate many types of karstic terrains. Karst terrains have numerous landforms (White, 1988) whose names describe the results of the dissolutional reaction between rock and water. These include:

doline karst,
cockpit karst,
cone and tower karst,
fluviokarst,
pavement karst,

polje karst,
labyrinth karst, and
cave karst.

Each type of these karstic landforms have individualized controlling factors that produce characteristic landscapes. The landforms are primarily large-scale structures whose size is usually on the order of 10's to 1000's of meters. Karst morphologies also exist in smaller scale varieties. Karren is a small scale feature that is studied quite often for the intricate patterns it produces. It is described as a smaller scaled morphologic pattern produced by the water-rock interaction. Karren is an important factor in the karst process because it is a dissolutional process that changes the karstic landscape.

Karst Formation Process

In a karst system, the chemical balance between the lithology and the water are in disequilibrium. This system ultimately wants to reach equilibrium status and attempts to obtain it by the reaction between the lithology and the groundwater. As groundwater flows through the fractures above (vadose zone) or below (phreatic zone) the watertable in limestone ($CaCO_3$), the limestone dissolves because of its reaction with the acidic groundwater. The principle sources of carbon dioxide in groundwater are (1) soil gas-CO_2 produced through microbial respiration and decomposition of organic debris, (2) atmospheric CO_2 (White 1988, Lynch 1990). Carbon dioxide (CO_2) is one of the dominant controlling factors of the dissolution of limestone. The interaction between the CO_2 and the groundwater increases the CO_2 concentration in the groundwater. The groundwater reacts with the increased levels of CO_2 represented in equation (1) and produces a weak acid called carbonic acid (H_2CO_3). The presence of the acid inturn reacts with the limestone (equation 2), to release Ca++ ions into solution and is carried away by the movement of groundwater.

Equation 1.) $$CaCO_3 + H_2O \leftrightarrow H_2CO_3 + Ca^{++}$$
$$\uparrow\downarrow$$
Equation 2) $$CO_2 + H_2O \leftrightarrow H^+ + HCO_3^-$$

If the concentration of CO_2 is high, dissolution of the limestone will continue as long as sufficient amounts of water exist in the system. Because of the constant contact between the CO_2 and the groundwater, a ready supply of acid exist for dissolution of the soluble rock. The CO_2 is just as important as water and sediment to the development of karst (White 1988).

Distinctive Characteristics of Karst

Within karst regions, numerous features can be seen with simple observation, such as sinkholes (doline), caves, karren (topographic shapes produced by the weathering of limestone) and disappearing streams. The landforms are not always seen just on the surface. Many landforms exist in the subsurface as well as on the surface(Table III). These unique features make karst landscapes so interesting.

Subsurface Karst

Caves are usually the most dominant feature studied in any karst system. The formation of caves initially starts with the dissolution of soluble host-rock by the

TABLE III

CHARACTERISTIC FEATURES OF KARST

Stratigraphic

- Karstic Landforms
- Unconformities Truncated shallowing-upward cycles

Macroscopic

Surface Karst

Karren
- Paleosoils
- Caliches
- Non-sedimentary channels
- Lichen structures
- Boxwork structure
- Mantling non-sedimentary breccias

Subsurface

- Caves and dissolution channels
- Stratiform breccias
- Collapse structures
- Solution-enlarged fractures
- Sediment in non-depositional cavities
- Breccias in irregular bodies
- Spelothems

Microscopic

- Eluviated soil in small pores
- Etched carbonate cements
- Reddened and micritized grains
- Meniscus, pendant, and needle-fiber vadose cements
- Subisopachous columnar-calcite phreatic cement
- Extensive dissolution, or enlargement of fabric-selective pores

Lynch, 1990(modified after Choquette and James, 1988)

- Features discernible in core.

chemical reactions previously explained. Two of the most important factors in cave production in karst regions are the lithology and the orientation of fractures within the lithology. The type of lithology will determine how the rock weathers and influences the path water follows in the underground labyrinths. For example, an extreme difference in lithologies (such as limestone and gypsum) will result in two different types of cave morphologies.

Cave passages are subdivided into two basic types: branchwork and mazework. Branchwork caves form in a tubular or canyon passage where a downward gradient exist for water motion. A dominate or main passages exist with smaller tributaries off to the sides, much like a tree trunk and its limbs. The smaller tributary passages of a branchwork cave are similar to feeder streams in a river, usually represented by a dendritic pattern. Mazework caves which can be subdivided into 3 different types (Figure 12):

1)anastomosing,
2)network, and
3)sponge work.

Mazework caves are basically developed because of specific drainage patterns and structural controls. Palmer (1991) suggests the primary occurrence in two situations: (1) by aggressive recharge over the whole system and not in one specific passage, and by highly recharge over the whole system and not in one specific passage, (2) by highly variable floodwater recharge where no stable passage is allowed to form.

In a karst system, fractures are usually the path of least resistance that is taken by the groundwater. This path would become the common flow route and be enlarged by the dissolution process. Another important feature that can determine how caves form is the

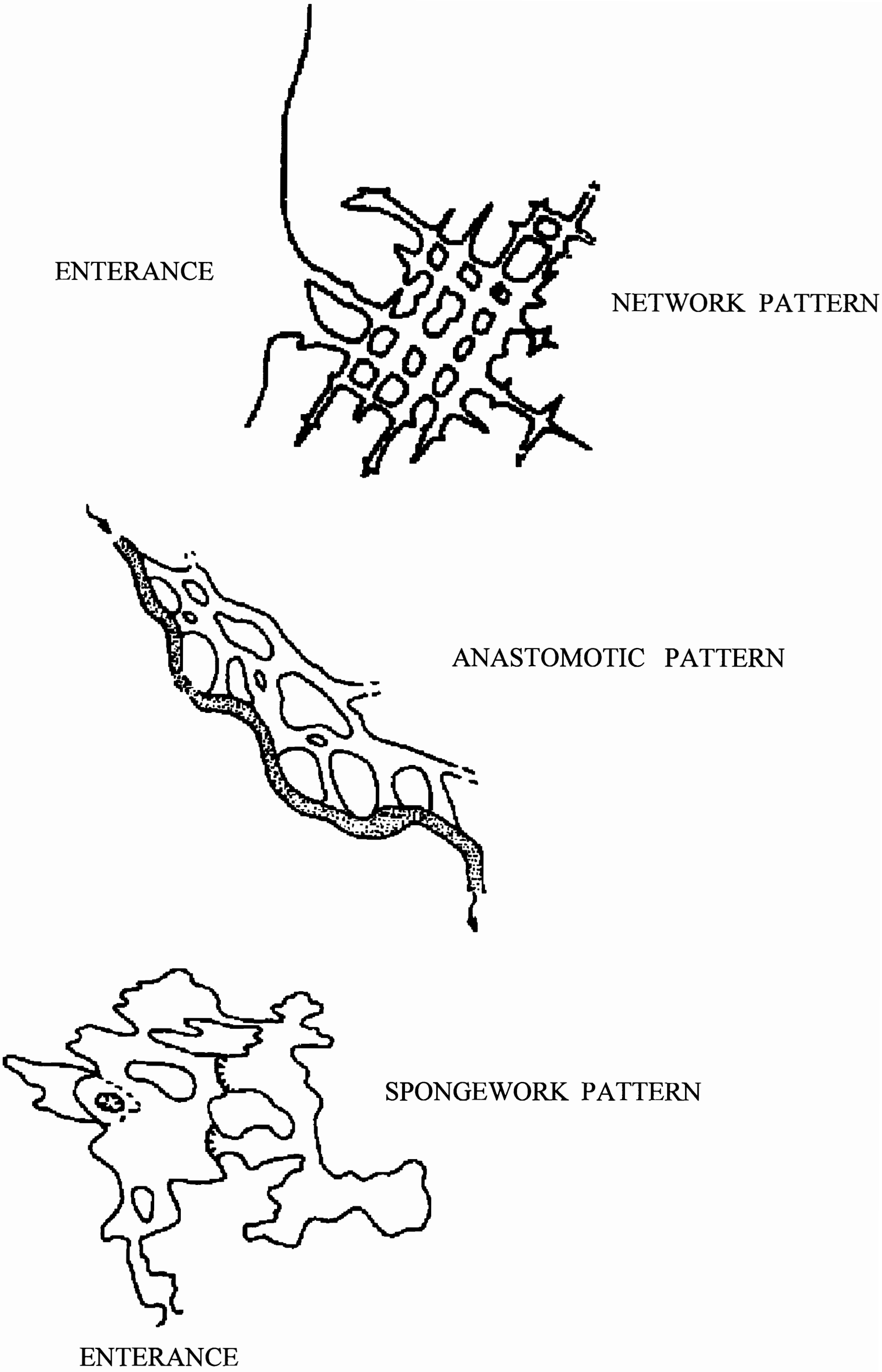


Figure 12. Sketch maps showing plan view of maze-type cave passsages (White 1988).

structure. Structure defines the attitude or direction of dip and orientation of strata. Many caves have passages oriented along bedding planes because of the low resistance in these areas.

Surface Landforms

Surface landforms (Table III) in karst regions include sinkholes, disappearing streams (swallets), and collapse valleys. They result from the dissolution of the underlying bedrock. For example, sinkholes are formed by the collapse of a single section of a cave passage. In the collapse area, the geometry of the passage is no longer stable enough to support the overlying weight of rock. At the surface, large holes form as a result of the collapse. Collapse valleys are created in a similar fashion as sinkholes. If a series of collapses occur close together or the complete section of a passage collapses, a long trough the width of the passage forms. In karst areas, the surface hydrology and hydrogeology are difficult subjects to master because of the numerous flow routes the water may travel. Surface runoff in advanced karst regions readily finds its way to the subsurface because hundreds of small drainage basins form as a result of sinkholes. Of the few streams that form on karst surface, all inevitably end up running directly into the subsurface and are known as a disappearing stream or swallet.

Karst Model

In order for the formation of karst to occur, the ideal climatic condition must prevail for subaerial exposure to occur. An ideal climate has warm temperatures and sufficient amounts of water. If conditions exist, the karstification process begins by dissolution and precipitation reactions in the vadose and phreatic zones. An ideal karst profile described by Esteban and Klappa (1983) is shown in (Figure 13). Within the ideal conditions, the formation of karst should progress through three stages of development: 1) initial, 2) second or main and 3) final or late stage. The description of each stage suggests how the morphology is derived and what landforms should be present.

Initial Stage

The initialization of karst (Figure 14) occurs when the first drop of water encounters soluble rock. The development of fractures in the rock allows water to make its way into the subsurface. As more water is diverted through the fractured vadose zone, the fracture widths gradually increase, thereby allowing more water into the subsurface. At a stable location of the water table, conduits begin to form because of the amount of water present at this datum below the surface. In time fractures begin to widen even more and create passages of various types in response to the lithology and the structure of the rock. Multiple conduits may splay off of the main route of hydrologic flow because structural influences or changes in rock type. The initialization stage of karstification is primarily controlled by phreatic processes.

Main Stage

The second stage (Figure 15) in karst formation depicts a mature karst morphology of well developed single conduits with possible multi-level conduits, both abandoned and active. Within the second stage phreatic and vadose processes control the development of the underground network. As the watertable drops, the downward cutting action deepens

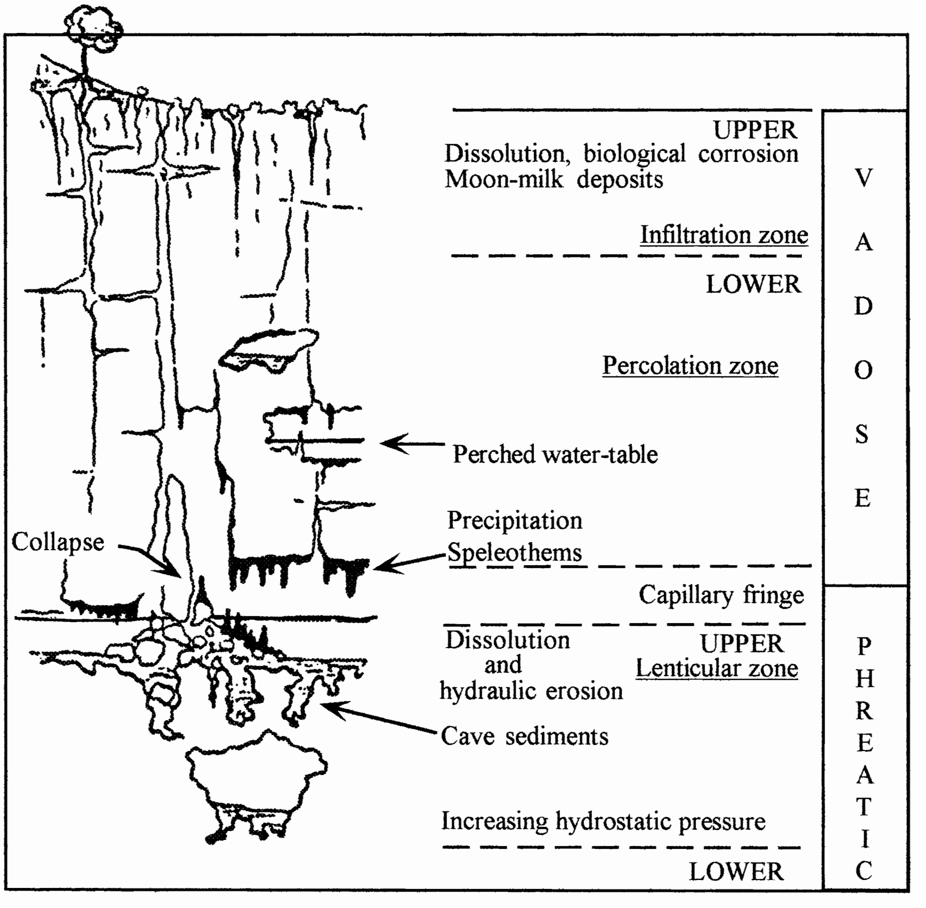


Figure 13. Idealized karst profile (Lynch 1990 from Esteban and Klappa, 1983).

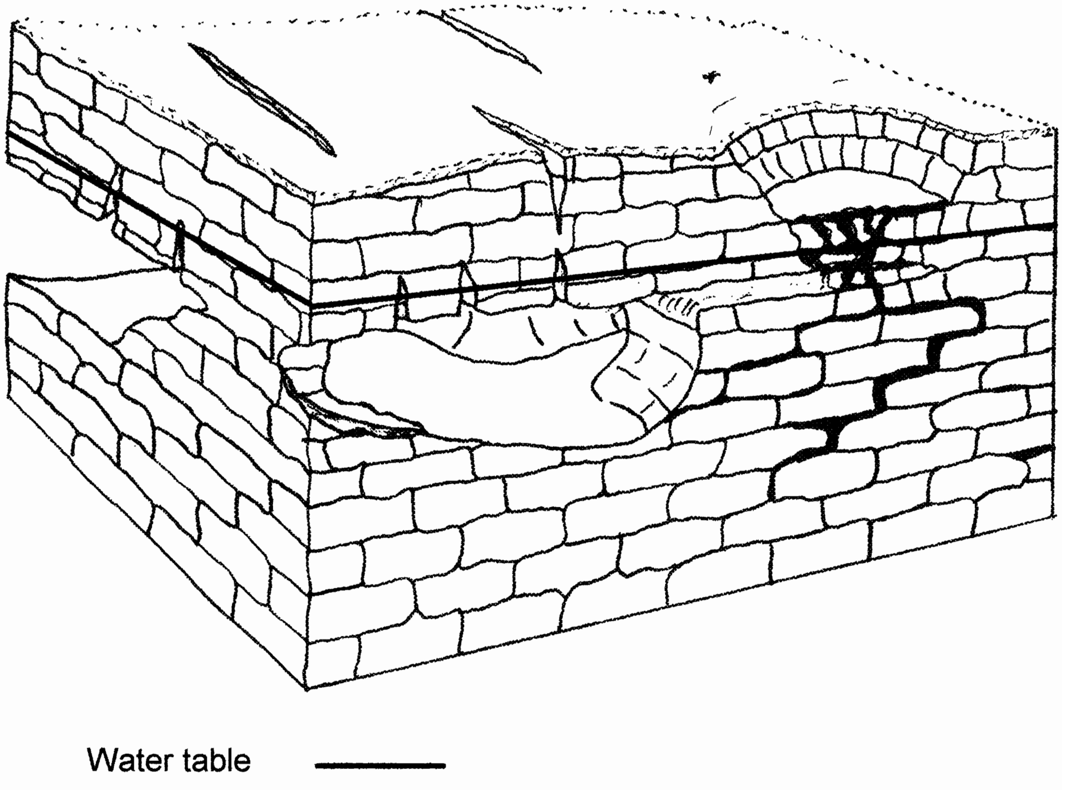


Figure 14. Initial stage of karstification (Lynch 1990). Cave passage growth at the water table, phreatic dissolution of fractures and vadose precipitation.

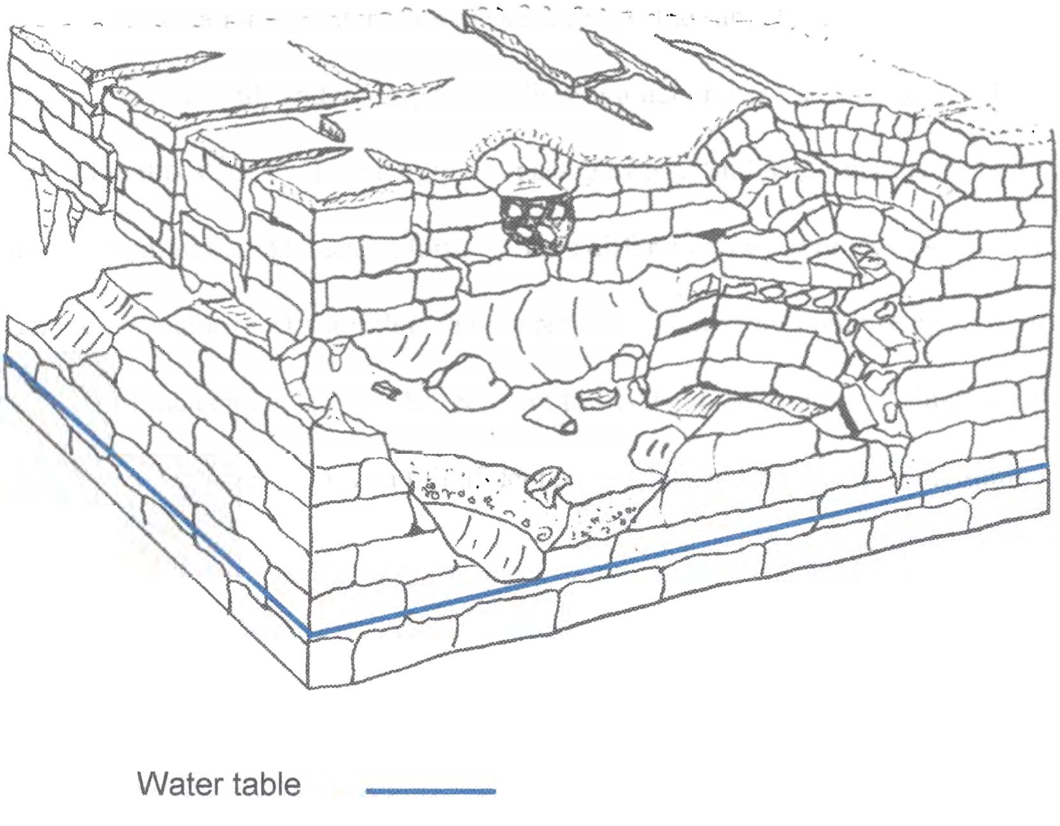


Figure 15. Second stage of karstification. Well developed passageways with cave formations and some passage collapse (modified from Lynch, 1990).

the passages and enlarges the vertical dimension of the passages. The physical factor controlling the growth of passageways and conduits is the location of the watertable. In general, the slower the watertable drops, the more evenly the passageways form. If the watertable drops quickly, a variety of features may form including shafts and deeper levels. When this occurs, the upper passages are left dormant and well developed speleothems such as stalactites and stalagmites may occur in the upper vadose passages because of percolation of water from the surface. At the same time the lowest passages (phreatic zone) are still undergoing active dissolutional processes. Subsurface drainage is advanced in this stage by the enlarging of passageways. Sinkholes, another karstic feature present in the main stage, form by three different types of processes, 1) lateral widening of fractures, 2) regolith arch collapse and 3) cave roof collapse because of instability of the conduit shape. As sediment infills the depressions and sinkholes form, the landscape becomes a horizon full of depressions brought on by the undermining of the subsurface.

Final Stage

The final stage of karst (Figure 16) formation is the destructional stage. Denudation of the landscape has reached a plateau in the dissolution process. The hydrologic gradient has little or no slope and water migration within the system is minimal. The passages and conduits within the cave system have reached an unstable geometry and collapse. Collapsed passages are recognized by features called collapse valleys. After the collapse of passageways and conduits, the landscape is left covered with outlier remnants of what used to be the supporting structures of the cave system.

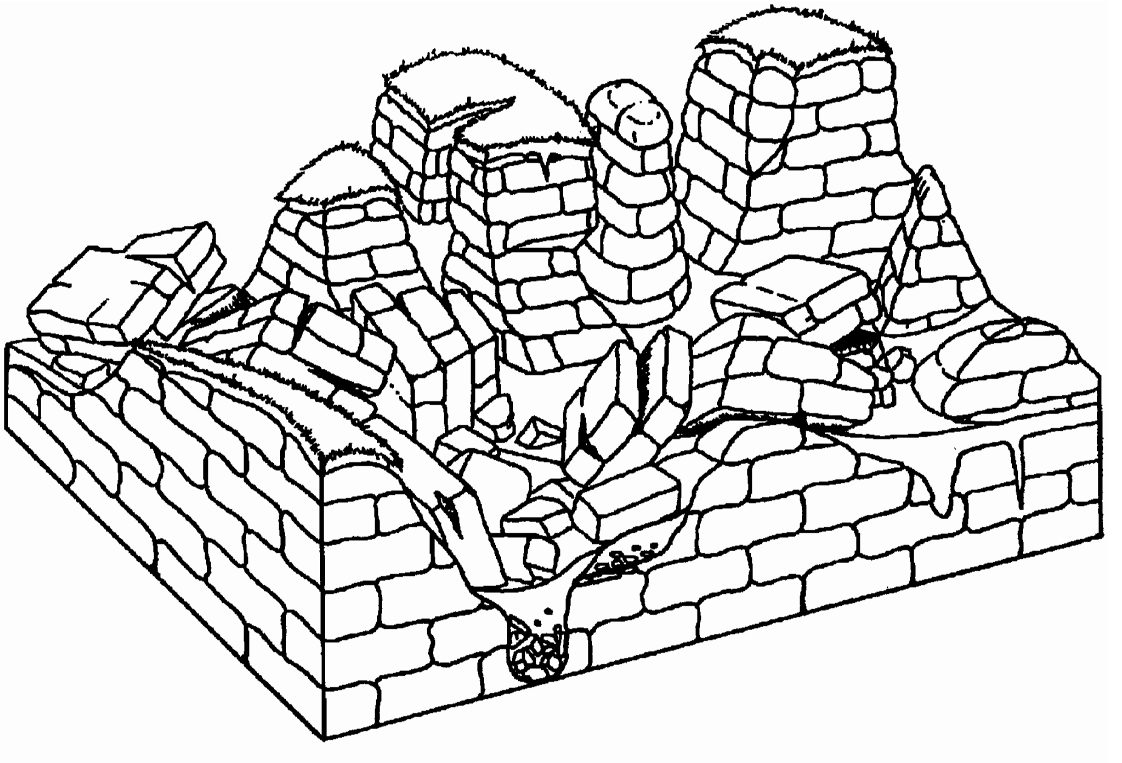


Figure 16. 3-D sketch of the final stage of karst, the destructional stage (Lynch 1990)

The old and decayed surface is ready for the next episode of karstification if the area is rejuvenated by uplift.

CHAPTER IV

PALEOKARST

Introduction

Paleokarst is defined as, "a rock or area that has been karstified and subsequently buried under sediments" (AGI, 1987). Paleokarst studies have shown that these structures have economic value and contain deposits of minerals and hydrocarbons. Many areas, including the states of Tennessee, Kansas, Texas, Missouri, and Oklahoma have benefited economically from paleokarst deposits (Bosak, Ford, Glazzek, Horacek, 1989; Kerans, 1989). Secondary porosity in paleokarst permits the migration of mineralizing or petroleum bearing fluids. By examining paleokarstic features, a better understanding of porosity evolution may be developed.

Paleokarstic features formed by two basic processes. The first process involves the direct confined flow of meteoric fluid through structural cracks and other small conduits such as vugs. The second process involves diffused or dispersion flow of meteoric fluid through the rock. This typically occurs in grain-rich rocks. Both processes depend on the amount of meteoric fluids moving through the host-rock and the extent of secondary porosity features present.

Paleokarst Formation

For paleokarstic terrain to be preserved, the conditions must exist for the development of karst. The geologic setting must be maintained so that subsequent erosional processes do not disturb the karstic terrain. If the karst process ceases at any moment in time, then the environment changes direction toward the formation of paleokarst. Paleokarst is recognized by several different types of structures recorded in the strata after the karstification process has ceased. Paleokarst identification can be described as, "looking for mineral records of precipitated cements or replacive minerals from fine-scaled process of dissolution-precipitation" (Lohmann, 1988).

Karst and as paleokarst undergoes diagenesis based on intrinsic and extrinsic factors (James, 1974). The most important intrinsic factor is the mineralogy of the sediments which are mainly $CaCO_3$ minerals. James (1974) describes these minerals as being metastable in a freshwater environment. He also states that the grain size controls the rate at which the sediments are meteorically altered. Grain sizes within the system influence porosity and permeability by allowing fluids to flow at specific rates based on the grain size. The second controlling factor is climate. Areas with warm dry climate (arid region) show little alteration, whereas carbonates in warm humid climates, such as Florida and the southeastern U.S., undergo rapid dissolution. James (1974) also states that the time the system is exposed to controlling factors is critical for the alteration process. Other conditions critical to the development of a karst terrain are water chemistry and volume of fluid flow. Fluids must be undersaturated with respect to the country rock and adequate fluid flow must be available to transport products of dissolution away from the site of reaction (Lohmann, 1988). In addition to the intrinsic and extrinsic factors, the concentrations of dissolved CO_2 and the resultant carbonic acid tremendously influence the reaction times needed to form the karst landscape and paleokarst.

Breccia and Conglomerates

Breccias and conglomerates are paleokarst features that are formed by two similar processes. Both are initially formed by the systematic breakdown of a karst system. In paleokarst several types of breccias are related to karst systems. Breccia form by rockfall or collapse of an ancient passageways or conduits. Active karst passage rock debris or rockfall is called breakdown. In paleokarst, collapse debris is given the term breccia because of the angularity of the fragments. As a passageway begins to fill with clasts, the fill shows an upward fining in clast size. This is attributed to the transition from larger clasts at initialization of the collapse and smaller clast at the end of the collapse, when the passage/conduit has reached a more stable geometry. Many exceptions to this rule occur because of multiple episodes of collapse and dissolution. The clasts maintain an angular morphology because of the lack of transport from the site of collapse. Upward through the collapse, the type of breccia changes because of the spatial orientation of the clasts. Near the bottom of the collapse, the clasts are more chaotically deposited and the breccia is called rubble breccia. Where the outer and uppermost edges of the passage/conduits are foundering, the clasts have a more compact orientation, because they have not been significantly displaced much from the original position. This type of breccia is called crackle breccia. Through time, the interstices between the breakdown are filled up with 1) sediment, 2) other smaller fragments washed in from fluvial action in the active karst system, or 3) cements from later fluids that migrate through the host-rock.

Cements found in the matrix of breccias can be highly variable and may include large blocky calcite, fine microspar, sulfide minerals or dolomite depending on the geological setting.

Sediment Infills

Sediment infills are created by the accretion of sediment transported into a cave system by either direct flow of water into a swallet or by sediment falling through cracks or sinkholes. Large quantities of sediment are deposited in cave systems during storm events. These high energy events entrain a large amount of sediment and transport it into the cave system. After the cave system fills with water, the sediment is forced into and deposited in areas where it would not normally be deposited. With several storm events, the accumulation of sediment can be rather thick. Sediments in caves contain sedimentary structures, such as crossbedding and stratification (poorly to well sorted), and disconformities (scour and fill structures) within the deposited sediment.

Meteoric Cements

Dissolution in karst regions generate solute enriched waters that ultimately result in cement precipitation in phreatic and vadose zones. The phreatic flow of pore fluids in a karst system allows for the precipitation of intergranular cements such as blocky calcite and isopachous cements, only when fluids are supersaturated with respect to calcite or other minerals. In the vadose zone, cements are gravity influenced types of dripstone. They occur as rimming meniscus cements around grains and clast. Vadose and phreatic cements are important indicators of the meteoric diagenesis that accompanies karstification.

Paleokarst In The Viola

Lynch (1990) suggested paleokarst in core samples of the Arbuckle Group are not credible because of the uncertainty of not knowing what could be adjacent to the core sample. In an outcrop study, the "whole truth is before you", because you can observe the complete structure in two dimensions and observe its setting. The only constituent missing is the third dimension, the depth to which the features penetrate the outcrop face and the morphology of the of the feature. In viewing an outcrop the third dimension can be postulated by the observed structures. Just as Lynch (1990) said about core observation, "the interpretation of these features relies on inference and imagination", and outcrops have to be approached in the same manner. Whereas some observations indicate actual trends of paleokarst passages/conduits, the genesis of these features can spawn multiple hypotheses on formation and passage types.

Viola Paleokarst Facies

The Viola limestones contain three distinct paleokarst facies, 1) an unconformity facies related to early vadose meteoric diagenesis, 2) a porous grainstone facies related to phreatic meteoric diagenesis and 3) the burial dolomitization of the limestones. These facies are separated by stages of time and in the durations of alteration.

Episodic Karstification

Where and when was the Viola was subjected to the environmental conditions that formed the paleokarstic features observed today? The alteration of the Viola has left the limestone scarred with clues to its geologic history. These scars identify distinctive karst episodes. The episodes of uplift and dissolution are summed up in the following chronological sequence (Al-Shaieb et al., 1993):

- ⇨ Intra-Viola
- ⇨ Post-Viola (Pre-Sylvan)
- ⇨ Pre-Woodford where the Sylvan is eroded
- ⇨ Peri-Orogenic (Pennsylvanian Orogenies)
- ⇨ Post Arbuckle Orogeny
- ⇨ Active Karst

Intra-Viola Karstification

During the deposition of the Viola Limestone, exposure surfaces were created by fluctuations in sea level. During the times of subaerial exposure, the limestone was subjected to meteoric diagenesis. The primary evidence of this episode is seen in abandoned breccia filled conduits and crackle breccia seen feet below the Sylvan/Viola contact. These breccias filled cavities and passages, suggest no connection with the Pre-Sylvan surface.

Post-Viola (Pre-Sylvan)

The disconformable contact between the Fernvale Limestone and Sylvan Shale represents another stage of karstification. Karstic features along or near this contact include clast filled solution channels, small conduits filled with sediments, and blocky calcite cements rimming fractures and conduits. These features represent the majority of karstic evidence found in the Viola.

Pre-Woodford Karstification

In areas where the Hunton Group and the Sylvan Shale was removed by erosion, the Woodford directly overlies the Viola. Though this contact was not cored, it is expected that karst developed during this erosional episode.

Peri-Orogenic Karstification (Pennsylvanian Orogenies)

During the Criner, Wichita and Arbuckle Orogenies, the Viola was modified by multiple episodes of uplift, deformation, and exposure. In southern Oklahoma, eroded Viola Group carbonates are eroded by Pennsylvanian and Permian rocks. It is probable that the surface was karstified. Though the carbonates have not been cored, limited oil and gas production suggest they developed a porosity network.

Post-Arbuckle Karstification

The post orogenic stage is represented by karstic features that formed between the Arbuckle Orogeny and the present. Post-Arbuckle dissolution is seen in the outcrops where steeply dipping rocks contain caves with nearly horizontal stratified fill.

Active Karst

This stage, the active ongoing dissolution of the Viola, is represented by solution-enlarged joints, karren, small caves, and soil genesis, all of which can be found throughout the Arbuckle Mountains. In areas along the Arbuckle Mountains, travertine is being deposited on the Viola limestone forming flowstones, caverns and other karstic features.

CHAPTER V

PALEOKARST FEATURES IN CORE

Focused Flow Features

Focused flow features are produced by the channeling of the main flow of meteoric fluids into areas of least resistance. In these areas, the dissolution of the host-rock is concentrated through elevation-induced hydrologic conditions (potientiometeric heads). This focused dissolution initially produces solution enlarged fractures or vugs that enlarge to conduits or passages.

Paleokarstic features of focused flow have been recognized in the cores. These features are typical in karst terrains and include:

1. cavern-fill parabreccia,
2. crackle breccia,
3. solution enlarged fractures (SEF),
4. sediment infill, and
5. conduits and channels.

Cavern-fill Parabreccia

Cavern-fill parabreccias represent a chaotic deposition of angular to subrounded clasts with matrix support. These parabreccias are initially formed by the calving and transportation of lithoclast derived from local collapse or upstream breakdowns. Breakdown is a generalized karst term used to define clasts that are from the calving of walls and roofs of caves. The clasts may be deposited insitu or transported through the system until deposition occurs within the passageway/conduit network. If the clasts are transported a sufficient distance and become rounded, they are typically called sedimentary breccia or cavern-fill conglomerates. The clasts are deposited in a matrix derived from the weathering of the host-rock or transported in from the surface. The depositional setting of parabreccias may be 1) stable conduit/passages or 2) areas of complete collapse. Cavern-filled brecciation suggests a episodes of turbulent flow through the passage/conduit network.

Cavern-fill parabreccia observed in the East Fitts 21-19 core (EFU 21-19) contains clasts that range from gravel to cobble size (Figure 17). They are primarily composed of the slightly dolomitized mudstone host-rock. The matrix in the EFU 21-19 is carbonate mud that contains a few fossils (Figure 18 and 19). Secondary mineralization within the breccia is minor pyrite that was noticed in thin section examination (Figure 18, 19). In the Delaney Phoenix core, the parabreccia clasts were derived from a grainstone (Figure 20). In the Delaney Phoenix, the parabreccia has matrix of mud, blocky calcite, and fossil fragments (Figure 21).

Collapse breccia

Collapse breccias are produced by the in-situ collapse of a passage/conduit because of structural weaknesses in the host-rock. Collapse breccias are not transported and clast supported. After collapse, the damming effect of the collapse slows the flow of fluids and the finer grained matrix of the breccia may be deposited. The collapse

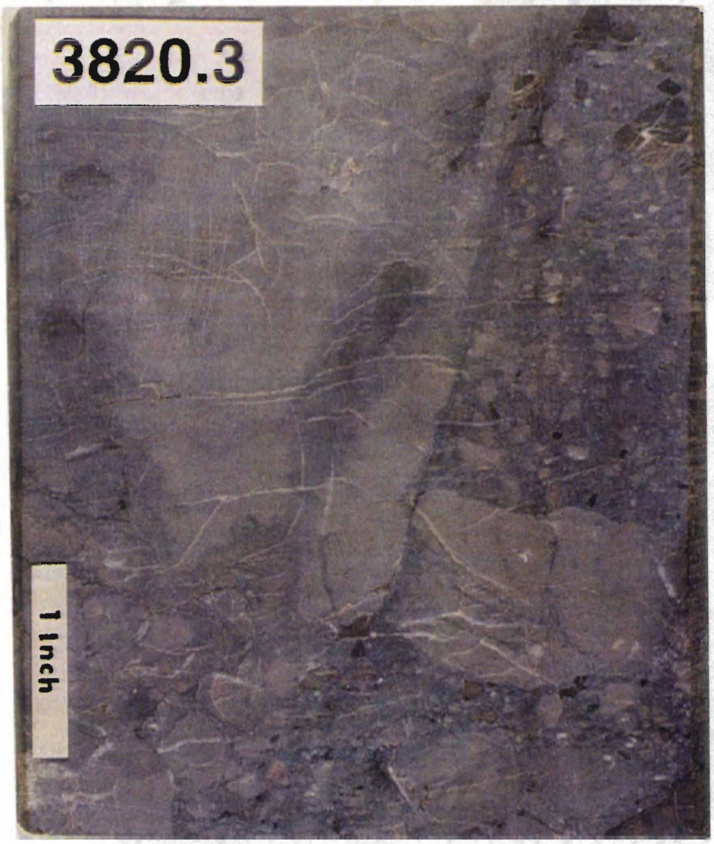
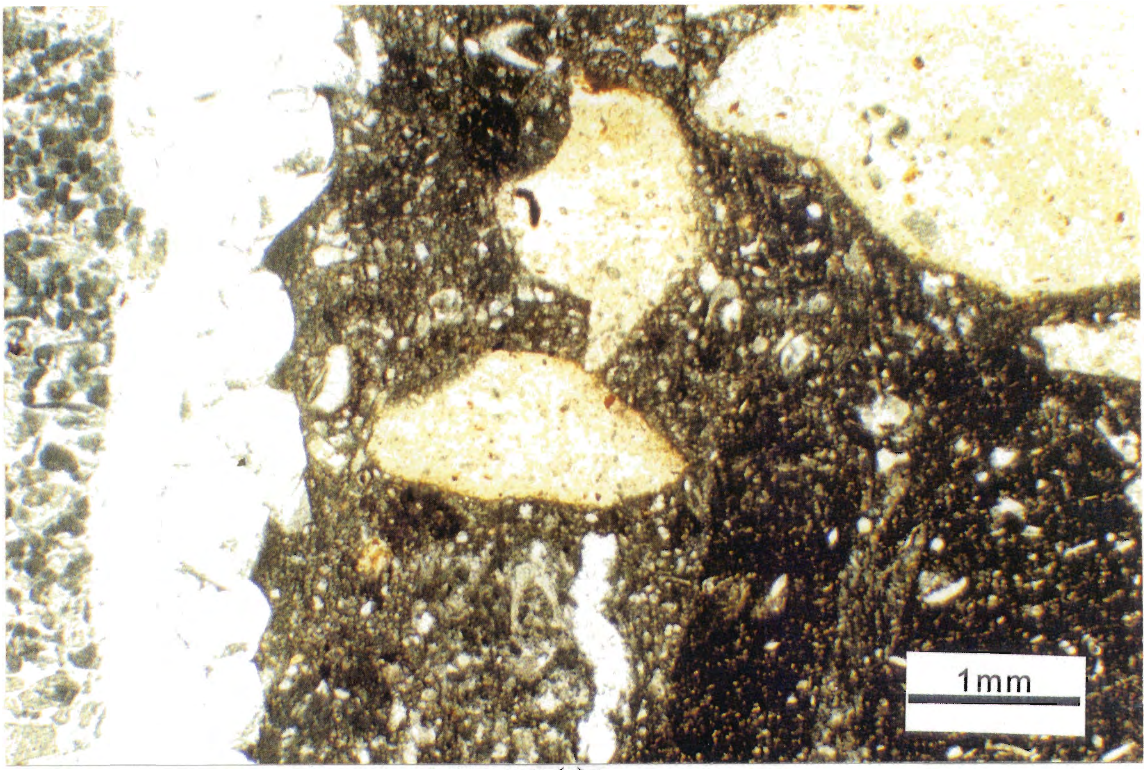
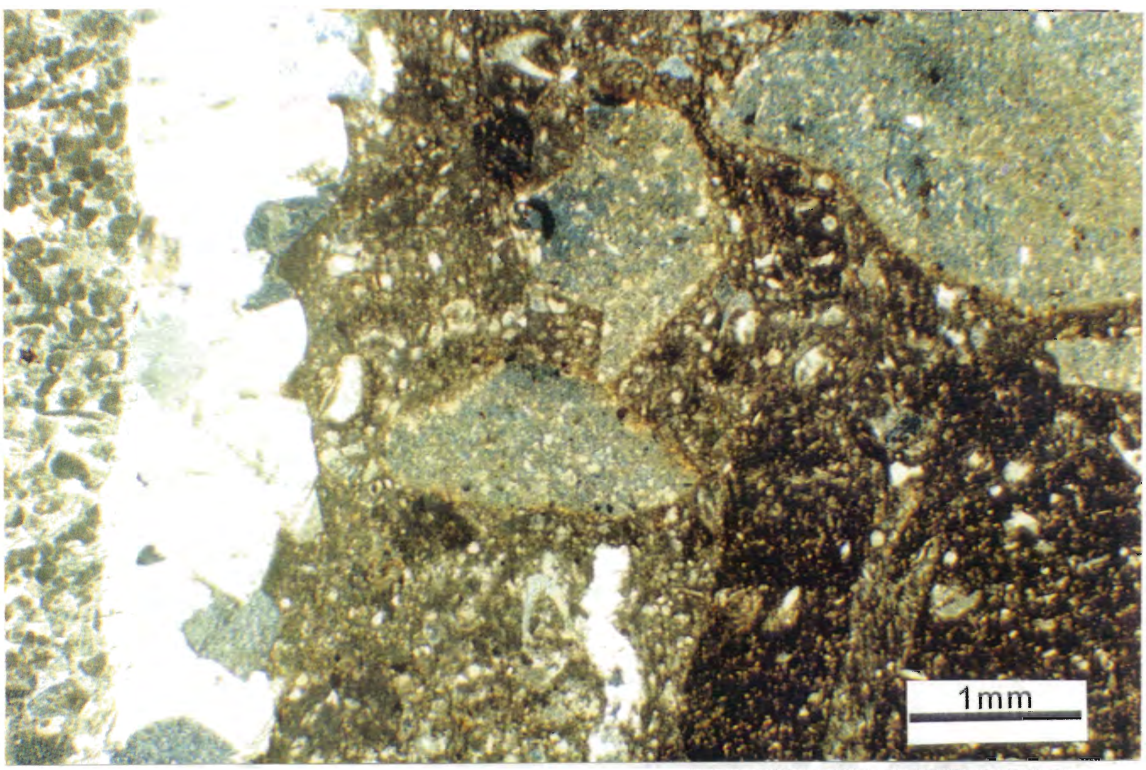


Figure 17. Cavern fill parabreccia from East Fitts Core 21-19, depth 3820.5 ft. Clast fractured before deposition of the collapse.

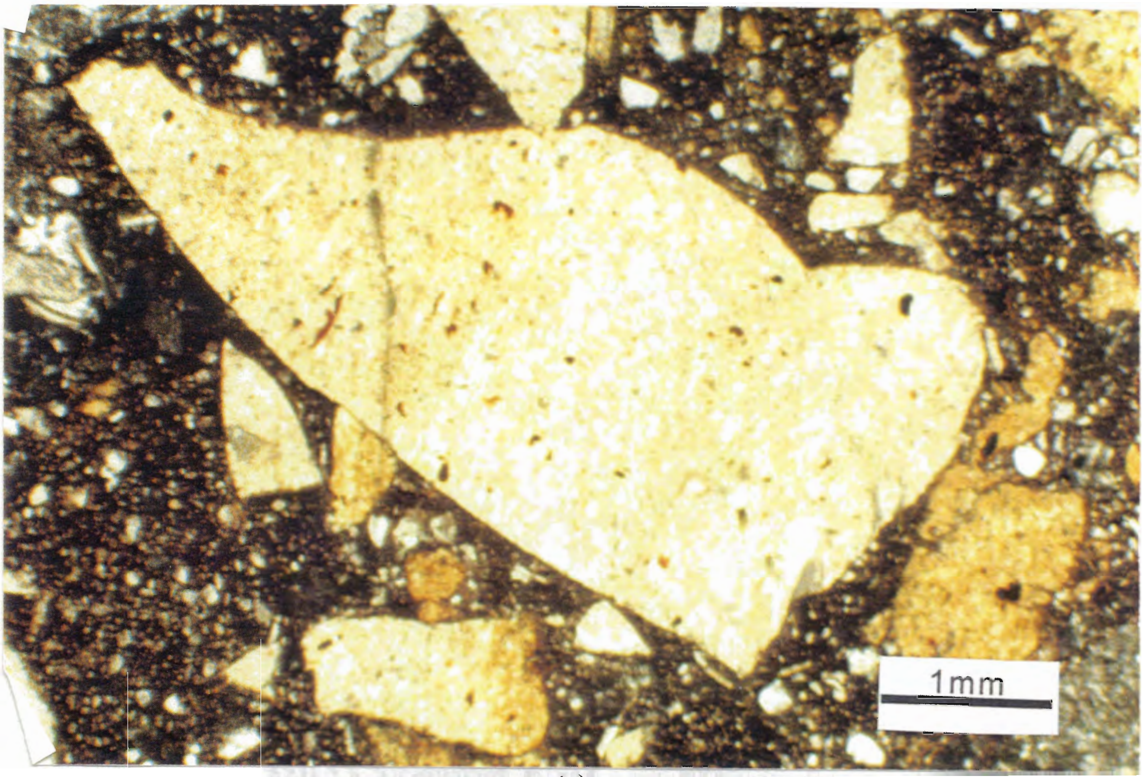


(a)

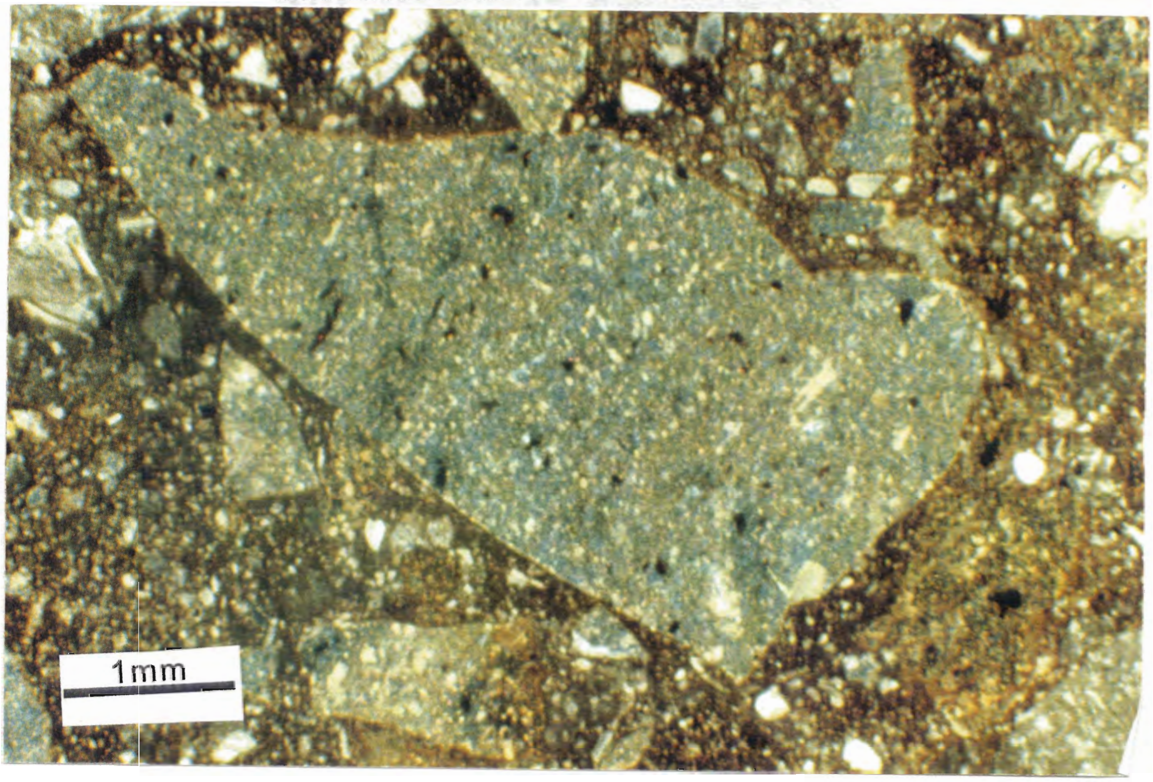


(b)

Figure 18. Photomicrographs of East Fitts core breccia zone (3820-3827 ft.), depth 3824 ft.. Mud matrix with quartz grains. (a) PPL. (b) XN.



(a)



(b)

Figure 19. Photomicrographs of East Fitts core breccia zone (3820-3827 ft.), depth 3825 ft.. Mud matrix with a few quartz grains. (a) PPL. (b) XN.

Figure 20. Cavern fill parabreccia from Delaney Phoenix core, depth 2950 ft., Pontotoc Co., Oklahoma. Grainstone clast with matrix of mixed weathered fossils fragments and blocky calcite cement.

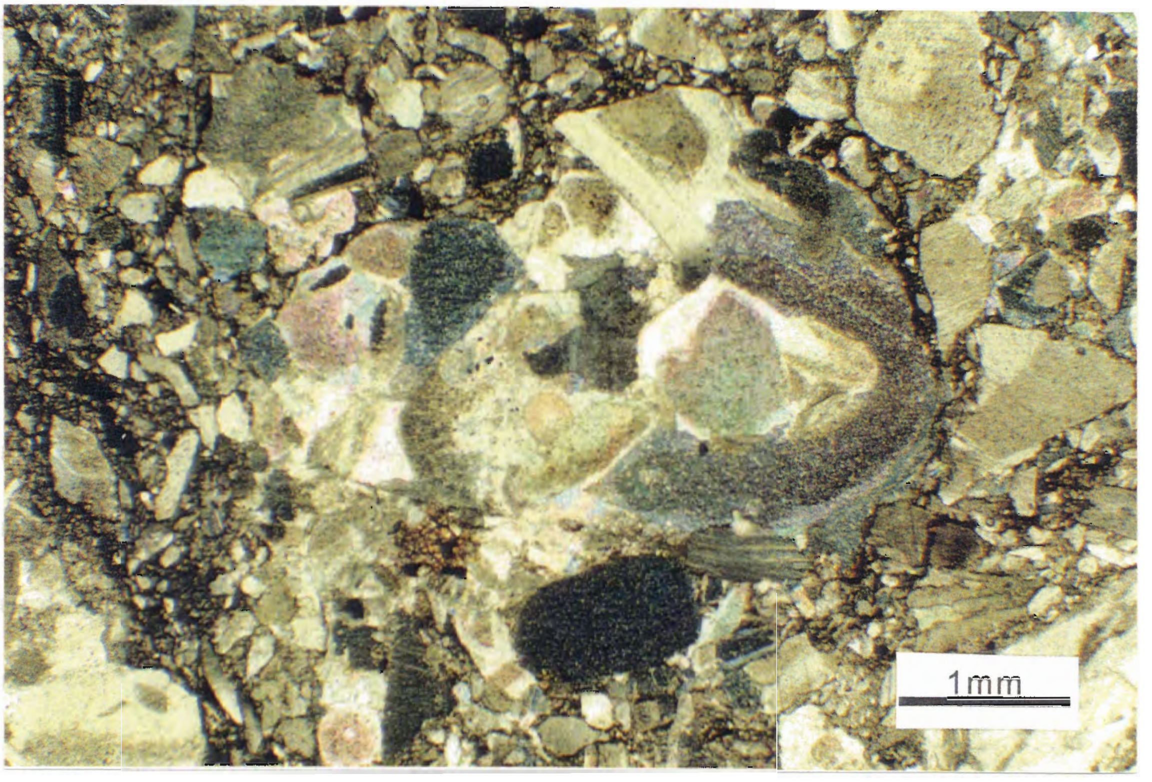


Figure 21. Photomicrographs of Delaney Phoenix core para-breccia, depth 2950, breccia. Grainstone clast in a matrix of weathered fossil fragments, micritic mud and secondary pyrite. (a) XN.

structure is recognized by large angular lithoclasts that support the rock fabric. Angular lithoclasts and clast supported architecture are the dominant features of collapse breccia.

Collapse breccia observed is present in several cores. In the EFU 21-19 core, collapse breccia occurs in the interval from 3903-3907 ft. The breccia is composed of clasts of the overlying beds (Figure 22). The matrix between the lithoclasts, primarily carbonate mud matrix (Figure 23), is derived from the weathering of the host-rock. They are slightly rotated but show little displacement from the original position.

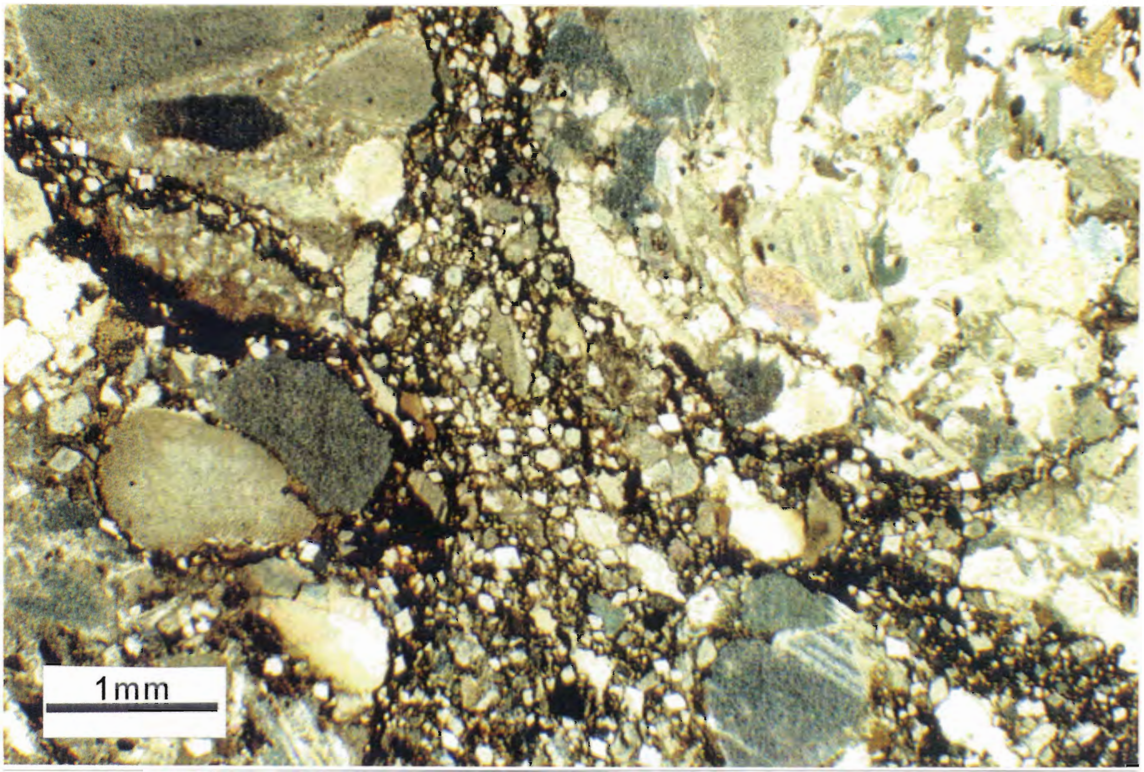
Crackle Breccia

Crackle breccias form in the roof or wall of a passage/conduit as it founders and breaks. The chaotic stacking of breakdown to form parabreccia or collapse breccia is a product of displacement. Crackle breccia may contain rotated clast, but they are not completely dislodged from the host-rock (Figure 24). Within a filled conduit, the breakdown may be a upward transition from parabreccia to collapse to crackle breccia. Crackle breccia may also form adjacent to faults. In this case the clast are often rotated from the original position from movement along the fault.

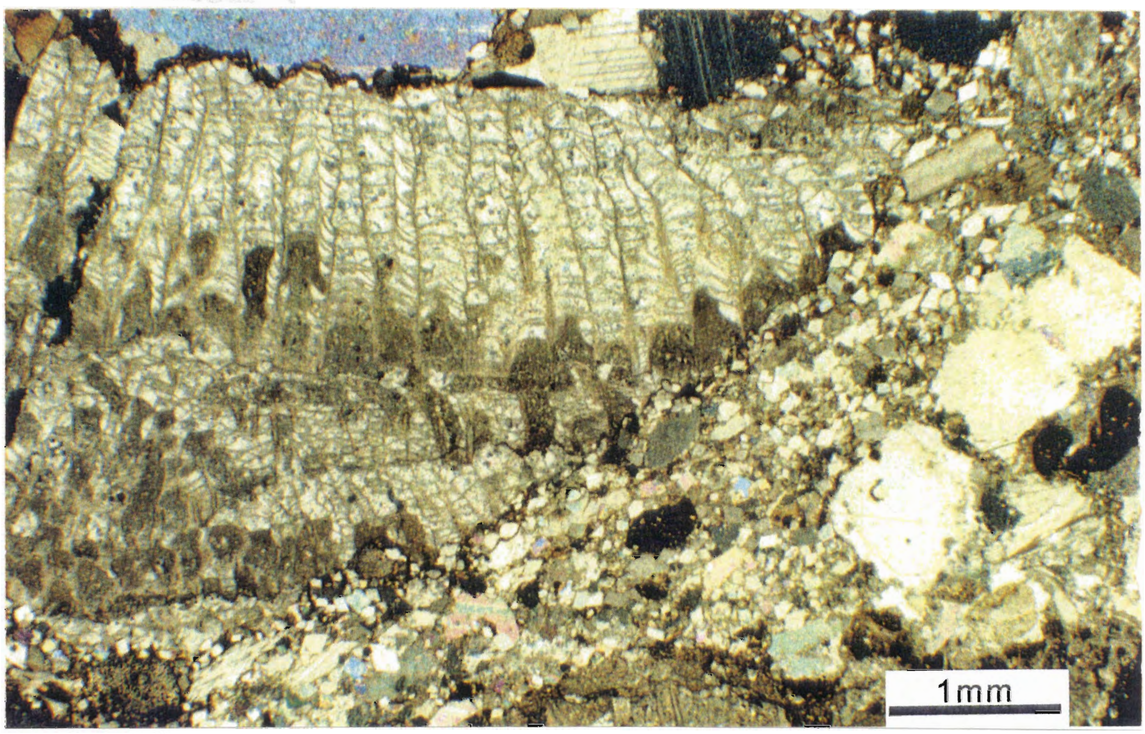
In both cases, crackle breccias are clast supported breccia with little or no matrix. Interclast space may be filled later with sediment weathered from the host-rock or by the precipitation of cements.

Crackle breccias were found in two of the cores examined; East Fitts 21-19 and East Fitts 9-41. EFU 21-19 contains one interval of crackle breccia (Figure 25). This feature is located above a parabreccia and may represent the roof of the parabreccia filled

Figure 22. Collapse breccia from East Fitts Core 21-19, depth 3906 ft., collapse zone 3903-3907 ft.



(a)



(b)

Figure 23. Photomicrographs of lower East Fitts core collapse breccia (3903-3907 ft.) clast and matrix, depths: (a) 3905 ft. (b) 3906 ft. Notice dolomite rhombs in matrix. (both photographs XN).

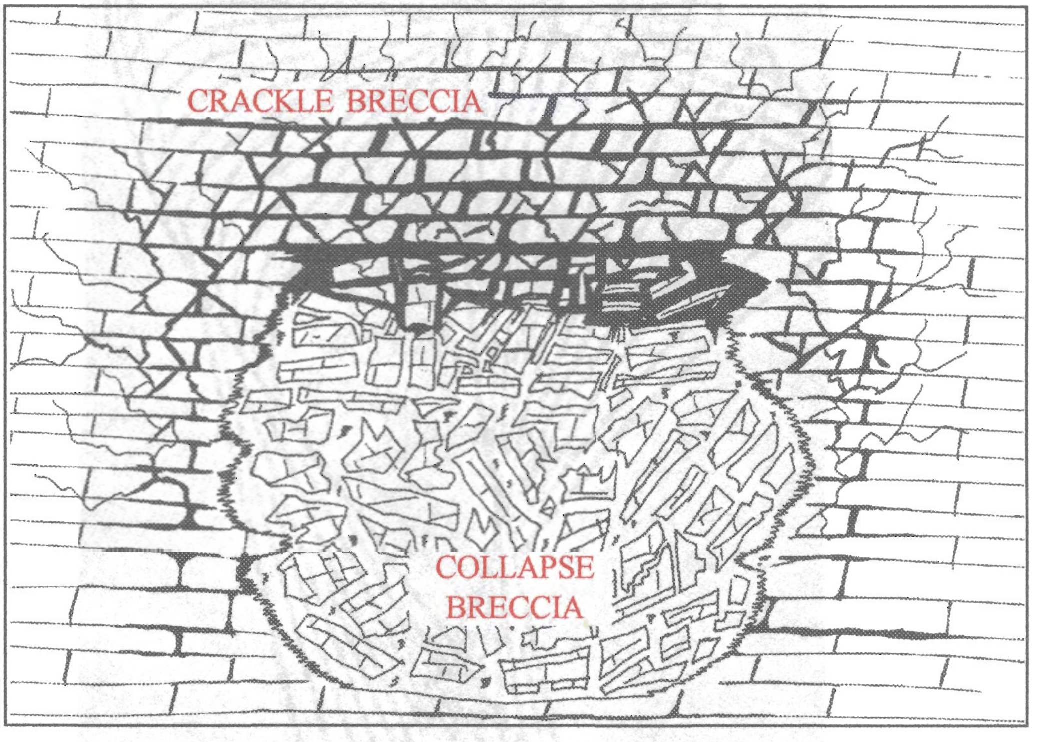


Figure 24. Viola specific: Location of crackle breccia and collapse breccia.

Figure 25. Crackle breccia from East Fitts Core 21-19, depth 3820 ft., Pontotoc Co., Oklahoma. Fractures are cemented with blocky calcite cement.

conduit. The clasts in this breccia were only transported a few centimeters from their original location. In the EFU 9-41 core (Figure 26), the crackle breccia is believed to be located on the outer fringe of a collapse structure. This can only be postulated because there is no apparent collapse structures are present within the core. This crackle breccia appears to be the same zone as the one in EFU 21-19. This interval suggests aerially widespread zones of karstification. In both cores the matrix is primarily calcite cement precipitated after the collapse.

Solution Enlarged Fractures (SEF)

Fractures in the host-rock are the primary sites of the dissolution. Meteoric water is diverted into small joints and faults soon after carbonate is subaerially exposed. Within the subsurface water may be forced through fractures by hydrologic flow (path of least resistance). Acidic water widen the fractures, creating larger conduits for flow or localities for infilling by cements that precipitated as water chemistry changed. Most solution enlarged fractures (SEF) in the cores are small-scale features that are partially infilled by cements. In Sohio Hatcher A-1 core (Figure 27), the fractures are open and enlarged.

Sediment Infill Features

Sediment infill occurs as a result of influx of material into the passage. Infill occurred primarily during high watertable episodes and flooding events or through weathering of the host-rock and deposition in a lower velocity zone within the system. Infill is seen as laminated sediments with definite orientation. Sediment compositions

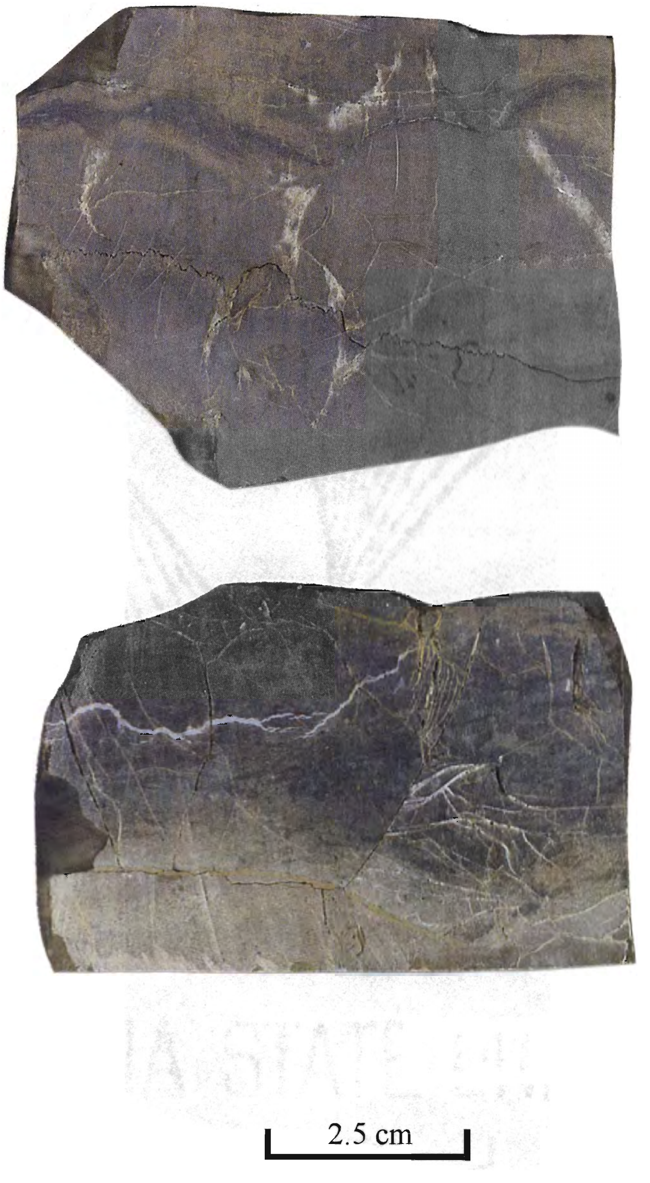


Figure 26. Crackle breccia from East Fitts Core 9-41, depth 4030 ft., Pontotoc Co. Fractures are cemented with blocky calcite cement.

Figure 27. Photograph of Sohio Hatcher A-1 core, depth 1941 ft.. Solution enlarged fracture and small vug.

typically range from clay to silt size grains and may contain plant and other organic material, if the sediment is transported from the surface.

In the Sohio Hatcher A-1 core, a small vug is filled with carbonate mud, clay and silt (Figure 28). These sediments were apparently derived from the weathering of the host-rock. This fill contains laminated depositonal structure (Figure 28). A SEF that cross-cuts the fill has been cemented by blocky calcite cement (Figure 29) indicating that multiple stages of dissolution, deposition, and cementation have affected these rocks.

Diffuse Flow Features

Diffuse flow in the Viola occurs when the groundwater flow is primarily through the grainstone facies, first by the help of primary porosity in the grainstone and secondly by less permeable mudstone and wackestone facies. As the flow moves through the small interparticle interstices, the pore spaces enlarge through diagenetic meteoric dissolution and greater porosity is produced. Mud in grain-rich rocks was partially dissolved and replaced by blocky calcite cement.

Diffuse flow features are common in the grain-rich facies. The principal grains are echinoderms with brachiopods, trilobites and bryozoa. In EFU 21-19 (Figure 30) reservoirs have developed in grainstone facies by the dissolution of grains and cement. Porosity types with the grainstone facies have been restricted to two types, interparticle and moldic (Figure 31) and have produced porosities values from 15-20%.

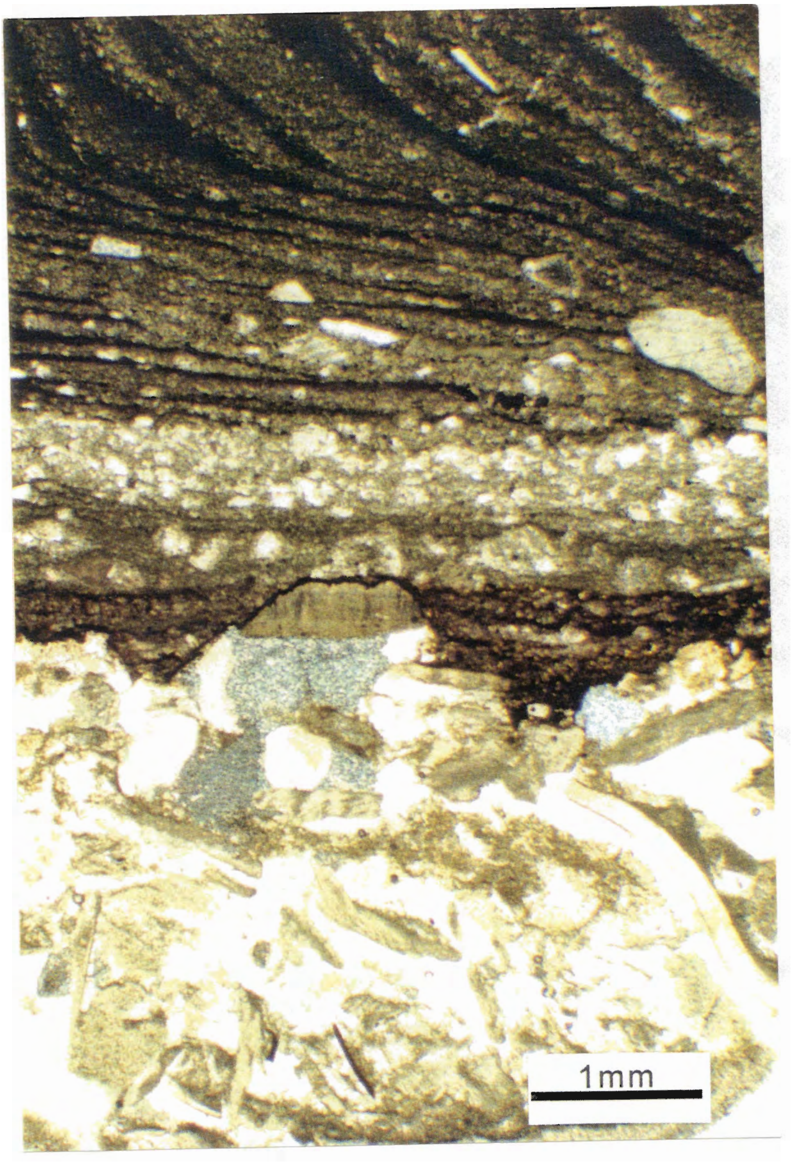


Figure 28. Photomicrograph of Sohio Hatcher A-1 core, depth 1966 ft. Solution enlarged vug infilled with micritic mud. (XN)

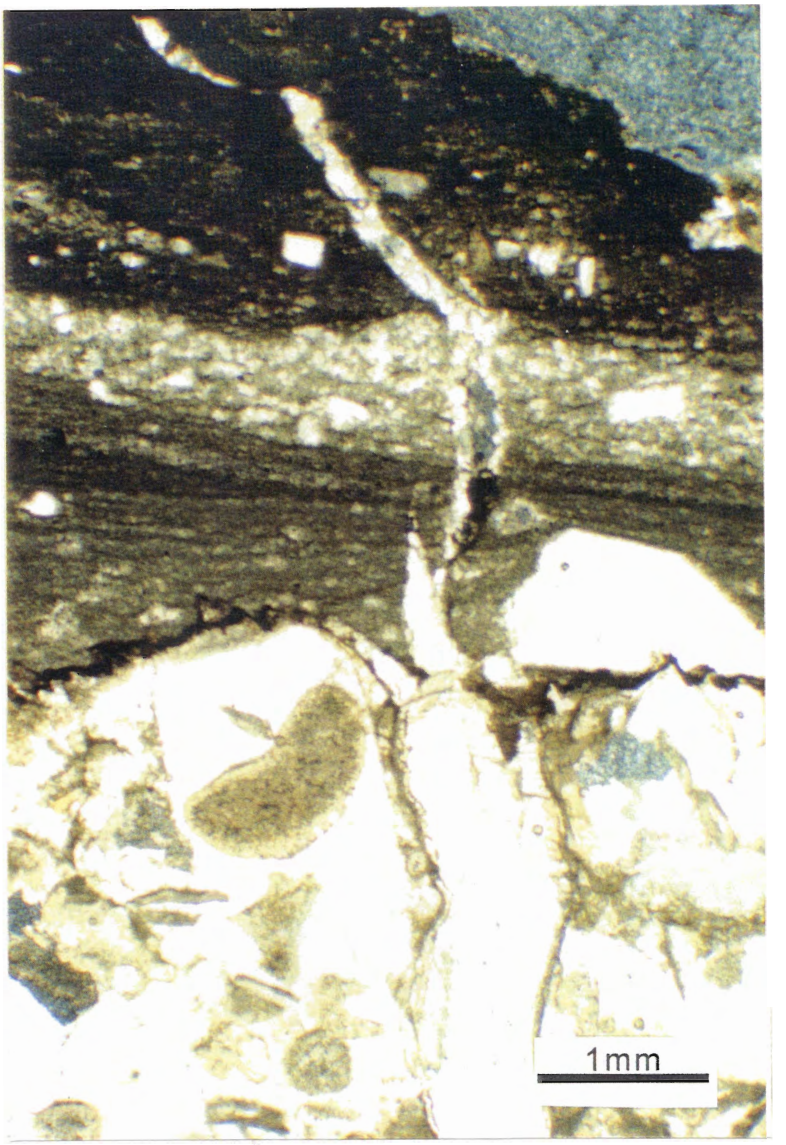


Figure 29. Photomicrograph of Sohio Hatcher core, depth 1940 ft. Solution enlarged vug infilled with micritic mud and SEF infilled with blocky calcite cement. (XN)

Figure 30. Core photo of EFU 21-19, depth 3965 ft. Viola grainstone facies, site of diffused flow paleokarstic features. High porosity found throughtout the grainstone facies.

Figure 31. Photomicrograph of typical Viola grainstone facies with moldic and interparticle porosity. (XN)

CHAPTER VI

PALEOKARST AND KARST OUTCROP DESCRIPTIONS

The outcrops were located on a geologic map of the Arbuckle Uplift prepared by Ham, McKinley et. al, (1954). All accessible outcrops on the map were field examined and screened for detailed examination. Outcrops were screened on the basis of the number of paleokarst and karst features present. The location of each feature was given a convenient road side location and a specific longitude and latitude location using a Trimble Navigational Global Positioning System (GPS) (Appendix C). Twelve outcrops were selected for detailed investigation (Plate 1).

The outcrops contain a variety of paleokarst features such as sediment infills, collapse breccias and parabreccias. The karst features include solution enlarged fractures, active conduits, caves and vugs. Each feature was described and postulated so that evolution could be related to the tectonics and fluids in the area. Data gathered concerning the origin of the features included outcrop settings, clast arrangement, clast type, matrix, mineralization and proposed host passage/conduit type.

Outcrops present a much larger "picture" and allowed better understanding of karstic features than cores. Outcrops allow the viewer to observe karst on a much broader scale, where individual features can be observed in the context of the outcrop face.

The following descriptions only include outcrops with specific paleokarstic features, because this is the main focus of the thesis. Descriptions of all karst features have been included in Appendix C. The generalized formation of the features are referenced in Chapter 4 and are not included in the outcrop listings.

Outcrops with Sediment Infill

Outcrop #7 (Figure 32), classified as a sediment filled conduit, is located on the northern limb of the Doughtery anticline (for detailed location, see Appendix C). The conduit has been completely filled with sediment. The sediment is well compacted and contains small amounts of weathered pyrite. No apparent stratification was observed in the matrix. The walls of the conduit showed no precipitation or mineralization. The trend of the conduit is in the down dip direction along the bedding plane. Only one conduit was observed at this outcrop location. This feature has recently been infilled with sediments derived from the soil cover.

Outcrop #8d (Figure 33) is a sediment filled conduit with angular .5 cm to 1 cm limestone clast within the sediment. Conduit size is approximately 30 cm by 20 cm. No observable stratification was present within the fill material. The area surrounding the filled conduit is mineralized with pyrite that weathered to hematite. Large areas on the outcrop face are stained with iron oxide (Figure 34). Euhedral pyrite crystals occur within the blocky calcite cement on the outcrop face.

Outcrop #8b, a collapse feature (Figure 35), found on the west side of the north-bound lane of I-35. This collapse is dominated by sediment fill with large blocks of

Figure 32. Photograph of sediment infill from Highway 77d, outcrop #7.

Figure 34. Photograph of iron staining in the limestone from I-35.

(a)

(b)

Figure 35. Photograph of collapse feature on I-35, outcrop #8b. (a) close-up of sediment. (b) photograph of complete collapse.

strata incorporated into the matrix. Matrix stratification is near horizontal, whereas the dip of the host-rock is approximately 45°. The clasts range from 1 cm to 2m. The structure appears to be a mega-fracture infilled with sediment from its rim. The staining of the limestone from sediment contact of soil can be seen in figure 35. This structure could be a direct connection with the large calcite-filled fractures on the south bound lane of the outcrop.

Outcrop 10 is a sediment filled feature located on the west side of the south bound lane of I-35 (Appendix C for detailed location). The feature is a single conduit found 3 meters up the face of the outcrop. The sediment contains angular limestone and chert clasts and root fragments. Clasts range from .5 cm to 2.5 cm and are found in the bottom portion of the conduit (Figure 36). This would indicate stratification of the sediments deposited within the conduit. The trend of the conduit is along the present strike. The walls of the conduit are coated by a thin veneer of blocky calcite cement which can be traced to a joining calcite cemented fracture on the face of the outcrop. This calcite veneer is approximately 1 cm to 2 cm in thickness.

Breccia Filled Conduits/Passages

Outcrop #6 is a cavern-fill parabreccia in a conduit located on highway 77d (Figure 37, detailed location in Appendix C). The feature is located in the center of the NW to SE trending Doughtery Anticline. The conduit is filled with angular to subrounded limestone clasts that have an average clast size of 10 cm and a range of 1 cm to approximately 17 cm. The fill is clast supported and the matrix is predominately

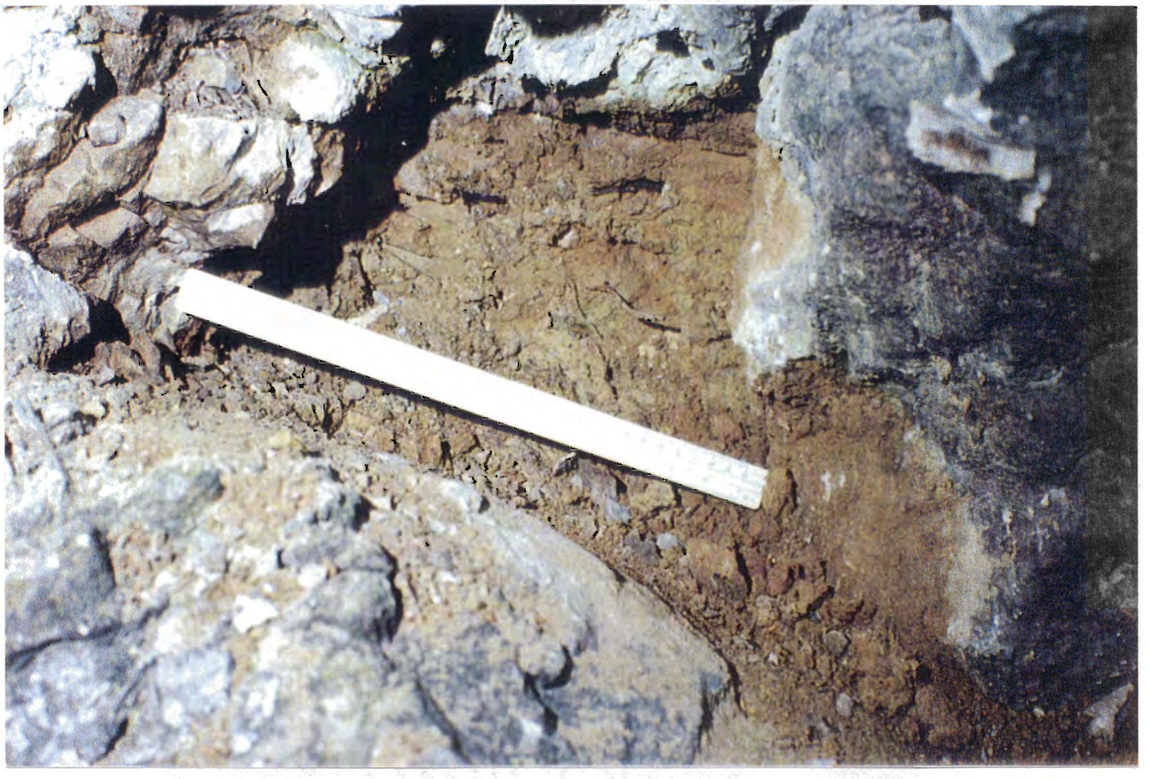


Figure 36. Photograph of sediment infill on I-35, outcrop #10.

Figure 37. Photograph of cavern fill breccia on 77d, outcrop #6.

smaller clasts with little or no carbonate mud between the clasts. No apparent mineralization was found within the conduit. The folding in the area has masked the trend of the conduit, but appears to trend 90° into the surface. No evidence for the continuation of the breccia filled conduit was found.

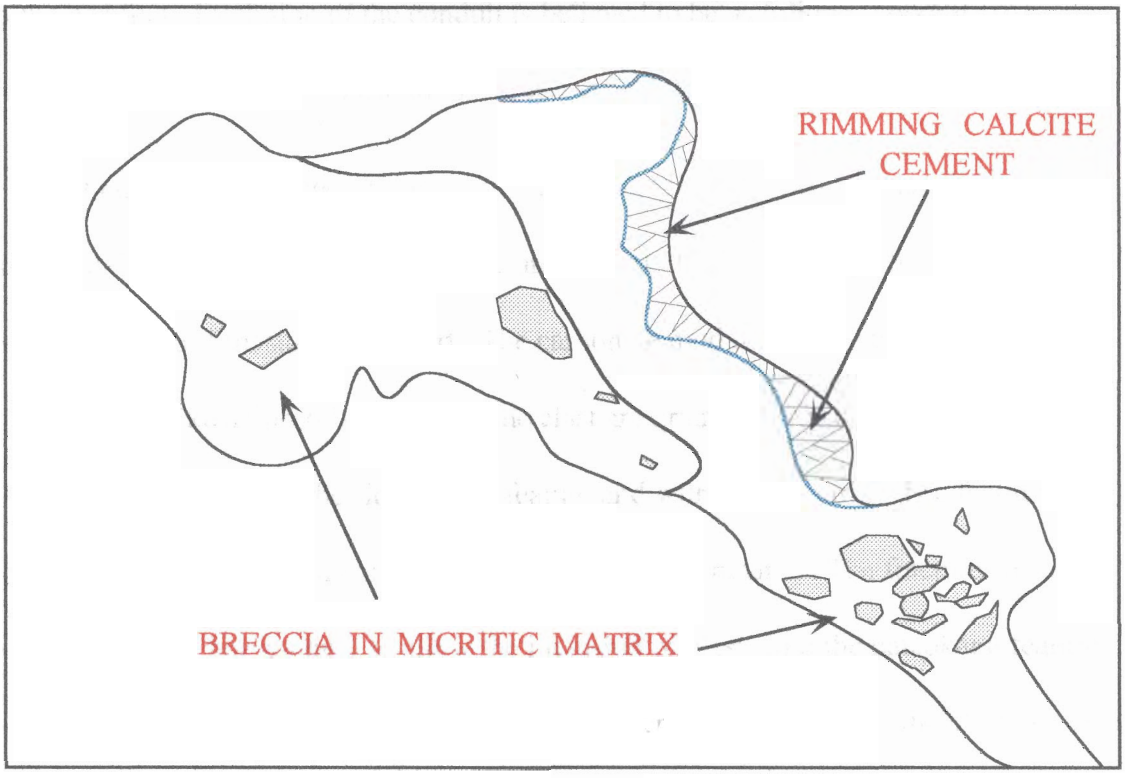
Outcrop #8c is a breccia filled conduit, approximately 2.5m tall and 2m wide (Figure 38). No evidence of structural failure is seen in all directions surrounding the breccia. Clasts are composed primarily of limestone and chert. The average clast size is approximately 10 cm and range from .2 cm to 30 cm. The breccia is grain supported and of larger and smaller clasts. The smaller clasts are lightly cemented with carbonate in locations within the breccia. Also several locations of pyrite mineralization were located on the conduit walls. The conduit shows minor stratification throughout the thickness of the conduit. The lower portion of the conduit contains stratification that dips to the south at approximately 15-20°. The upper portion of the breccia has a dip closer to horizontal. This would suggest two separate distinct depositional stages of conduit filling.

Outcrop #11 contains a combination of parabreccia and conduit filling sediment in an enlarged fracture(Figure 39). The breccia matrix is composed of carbonate mud weathered from the host-rock. In figure 39, the lower right-hand corner of the feature is filled with angular clasts that are cemented with micritic sediment. The upper right-hand corner of the conduit is rimmed with blocky calcite cement that ranges from 2 to 5 cm from the conduit wall. Clast size ranges from .2 cm to 8 cm. No stratification was observed in the conduit fill. The orientation of the trend of the conduit was difficult to plot, but appeared to follow the strike of the beds. The fracture is oriented perpendicular

(a)

(b)

Figure 38. Photograph of cavern fill breccia on I-35, outcrop #8c. (a) close-up. (b) complete feature.



(a)

(b)

Figure 39. Photograph of a combination: parabreccia and conduit filled with breccia on I-35, outcrop #11. (a) sketch of outcrop. (b) photograph of feature.

to the bedding. Evolution of the conduit is believed to be as follows: conduit dissolutioning, fracturing, dissolutioning, and sediment infill with included clasts.

Outcrop #12 is a tectonically widened fracture (Figure 40) with small breccia filled conduits found throughout the fractures extent. Clast size range from 1 to 9 cm and are composed of limestone and chert. The carbonate mud matrix contains small angular clasts, almost like a micro-breccia, and the clast are grain supported. Blocky calcite cement is found on both the sides of the feature and within the matrix. The feature appears to be several small conduits interconnected by fractures. The fractures have widened enough horizontally to allow the inclusion of clasts into the paleokarst feature. No orientation was found in the conduit and no orderly arrangement of the clast was seen in the matrix. Dead oil was found in upper most portion of the feature.

Figure 40. Photograph of a tectonically widened fracture with small breccia filled conduits on I-35, outcrop #12.

CHAPTER VII

CONCLUSIONS AND IMPLICATIONS

Surface and subsurface evidence indicate that the Viola Group has been modified by several episodes of uplift and meteoric diagenesis. The primary episodes of karstification are:

1) Intra-Viola,
2) Sylvan/Viola unconformity,
3) Pre-Woodford unconformity (postulated),
4). Peri-orogenic (Pennsylvanian Orogenies),
5) Post Arbuckle Orogeny and,
6) Active Karst.

The karstic episodes within the Viola Group are manifested as distinct karstic features included as:

1) solutionally enlarged fractures (SEF),
2) conduits filled with breccia, created during periods of instability in the ancient karst system,
3) sediment infills produced when dissolution in the karst system was at peak performance,
4) grainstone facies that have been modified by diffuse flow and now accommodate valuable petroleum reservoirs and
5) erosional surfaces produced during times of non-deposition, such as the one along the Viola/Sylvan contact.

Evidence from cores and outcrops indicate that, 1)the Viola has been altered by meteoric fluids and periods of erosion, 2) the petroleum accumulations in the Fitts Pool Field primarily occur in the grainstone facies and not in the collapse passages/conduits, 3) primary porosity within conduit features have been decreased by later infilling of weathered host-rock material, and 4) presence of multiple grainstone facies within the Viola Group generates the potential for valuable reservoirs.

The once active karst processes of the Viola Group in Southern Oklahoma are now only hardened clues of past geologic episodes. In time these features may be recycled and perhaps, once again found in actively thriving karst system in the future.

BIBLIOGRAPHY

Al-Shaieb, Z., Puckette, J.O., Abdalla, A., Rice, A., 1994. Facies and Karst development in the Viola Limestone *in* Simpson and Viola Groups in the Southern Midcontinent, A Workshop.

Alberstadt, L.P., 1967. Brachiopod biostratigraphy of the Viola and "Fernvale" Formation (Ordovician), Arbuckle Mountains, south-central Oklahoma. University of Oklahoma, Ph.D. dissertation.

Bates, R.L., Jackson J.A., 1987. Glossary of Geology. American Geological Institute 3rd edition, p.788.

Becker, R.D., 1988. Stratigraphy and Depositional Characteristics of the Bromide "Dense" Unit and Viola Limestone (Middle and Upper Ordovician), Subsurface Central Oklahoma unpublished M.S. Thesis. University of Tulsa.

Bosak, P., Ford, D.C., Glazzek, J., Horacek I.,1989. Paleokarst, Elsevier, 725p.

Chenoweth, P.A., 1966. Viola oil and gas fields of the mid-continent. Tulsa Geological Society Digest, Symposium on the Viola, Fernvale and Sylvan, vol. 34, pp. 110-118.

Esteban, M., and Klappa, C.F., 1983, Subaerial exposure environment in carbonate depositional environments, Scholle, P.A., Debout, D.G., and Moore, C.H., eds., American Association of Petroleum Geologist Memoir 33, 708p.

Flugel, E., 1982, Microfacies analysis of limestones , Spring-Verlag, New York, 633p.

Gentile, L.F., 1984, Sedimentology and graptolite biostratigraphy of the Viola Group (Ordovician), Arbuckle Mountains and Criner Hills, Oklahoma: unpublished M.S. thesis, Oklahoma State University, 104 pp.

Glaser, G., 1965. Lithostratigraphy and Carbonate Petrology of the Viola Group. University of Oklahoma., Ph.D. dissertation.

Grammer, G.M., 1983. Diagenesis of the Viola Limestone (Middle Ordovician Bromide Formation, Arbuckle Mountains, Oklahoma, U.S.A. Southern Methodist University, Unpublished M.T. 151p.

Grammer, G.M., 1985, Diagenetic destruction of primary reservoir porosity in Viola limestone, south-central Oklahoma, (abs.) American Association of Petroleum Geologist Bulletin v. 69, pp. 658-659.

Hoffman, P., Dewey, J. and K. Burke, 1974. Aulacogens and their genetic relation to geosynclines, with a Phanerozoic example from Great Slave Lake, Canada. In Soc. Econ. Paleon. Mineral. Spec. Publ., n. 19, P. 38-55.

James, N.P., 1974. Limestones the meteoric diagenetic environment. Geoscience Canada, v. 11 no. 4, p. 161-194.

Jennings, J.N., 1985, Karst geomorphology: Oxford, Basil Blackwell, 293 p.

Kerans, C., 1989. Karst-Controlled reservoir heterogeneity and an example from the Ellenburger Group (Lower Ordovician) of West Texas, 40p.

Lohmann, K.C., 1988. Geochemical patterns of meteoric diagenetic systems and their applications to studies of paleokarst *in* N.P. James and P.W. Choquette, Paleokarst, Springer-Verlag, New York, p.58-80.

Lynch, M.T., 1990. Evidence of paleokarstification and burial diagenesis in the Arbuckle Group of Oklahoma, Oklahoma State University, unpublished M.T., p. 163

Palladino, L.D., Jamieson, W.H., 1985. Tectonism and sedimentation in the Arbuckle Mountain region, Southern Oklahoma Aulacogen. Baylor University. p.43.

Palmer, A.N., 1975. The origin of maze caves. Natl. Seleol. Soc. Bull. 37, 56-76.

Webster, R.E., Evolution of Southern Oklahoma aulacogen: Oil and Gas Journal, v. 78, pp. 150-172.

White, William B., 1988. Geomorphology and Hydrology of Karst Terrians, Oxford Press, 464p.

Wickman, J.S., 1978, The Southern Oklahoma aulacogen: Geological Society of America South Central Section Field Trip Guide Book no. 3, pp. 8-41.

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

_______, J.L., and Jordan, C., 1983, Middle shelf environment, in Carbonate Depositional Environments, Scholle, P.A., Bebout, D.G., and Moore, C.H., eds., Amer. Assoc. Pet. Geol. Mem. 33, 708p.

APPENDICES

APPENDIX A

CORE DESCRIPTIONS AND PETROLOGS

EAST FITTS CORE 21-19 GENERAL CORE DESCRIPTION

3802-3810

Nodular (boudinage) dolomite/limestone with very few chert nodules and with the occasional stylolite. Dolomitization is intense in zones where the stylolites are present. Few fractures are present within the this interval. Abundant fossils exist including echinoderms, trilobites , brachiopods, bryozoa and occasional ostrocodes. The carbonate is predominantly fossiliferous peloid dolo-wackestone with little or no porosity.

3811-17

This interval contains more dolomitization and stylolites around clay seams. It is nodular bedded. Within the interval, there are healed, filled, and solutionally enlarged near-vertical fractures. The carbonate in this section is fossiliferous dolo-wackestone with approximately 8 to 10% porosity.

3817-3826- Breccia Zone

Crackle breccia found in the zone from 3817 to 3819. The fracture between the clast are filled with blocky calcite cement. Just below the crackle zone is a zone of cavern filling clasts, from 3820 to 3826. The clast compositions are peloidal wackestones, grainstones, and chert fragments. The clast are cobble size and angular. Smaller subrounded pebble size clasts are found in the cavern-fill zone as well. The matrix of the breccia zone consists of micritic lime mud with abundant fossil fragments, include crinoids, bryozoans, and trilobites. Stylolites are very abundant throughout the cavern-fill. Along the stylolite boundaries, intense dolomitization has occurred and produced euhedral dolomite rhombs.

3827-3838

This interval has abundant nodular bedding and contains increased amount of dolomite within the clay seams. Silicification in the upper portion of this interval is represent by chalcedony within the zones of dolomicrospar. Sections of the interval are less fossiliferous than others, but do contain abundant ostrocodes. The interval is highly fractured and cemented with calcite. Styolites are common throughout the interval and show intense dolomitization around clay boundaries. The dominant lithology is a fossiliferous peloidal dolo-wackestone that has porosity around 8-10%.

3839-3860

This interval is less nodular than the uppermost section in the core. Fewer fossils are present in this section. Fossil-rich zones are filled with large bryozoan fragments, trilobites and brachiopods. Dolomitization within the interval has changed the color to a light brown. This interval has very few stylolites and fractures. Chert nodules are present in two areas.

3860-3879

Nodular bedding decreases in this interval. Increasing amount of dolomitization is present around clay seams and stylolite boundaries. Rock color is dark brown as the result of the increased amount of dolomite. Fossils and peloids are present throughout the interval. Rock types found within the interval are peloidal dolo-wackestones and few dolo-packstones. Minor amounts of calcite-filled fractures are present.

PETROLOG DESCRIPTIONS

LITHOLOGY

- SANDSTONE
- SHALE
- LIMESTONE
- DOLOMITIC LS
- DOLOMITE
- CLAYEY DOLOMITE
- BRECCIA
- CRACKLE BRECCIA
- CHERT

SEDIMENTARY STRUCTURES & CONSTITUENTS

- UNCONFORMITY
- NODULAR BEDDING
- PELOIDS
- INTRACLASTS
- TRILOBITE
- GASTROPODS
- ALGAE
- VUGS, CHANNELS
- CEMENT VIEN
- G GLAUCONITE
- P PHOSPHATE
- PYRITE
- CHALCEDONY
- BRACHIOPODS
- ECHINODERMS
- BURROWS
- OSTRACODS
- BRYOZOAN

POROSITY TYPES

F	FRACTURE
SEF	SOLUTION-ENLARGED FRACTURE
V	VUGULAR
M	MOLDIC
IG	INTERGRANULAR
IX	INTERCRYSTALLINE

CLAST SHAPES

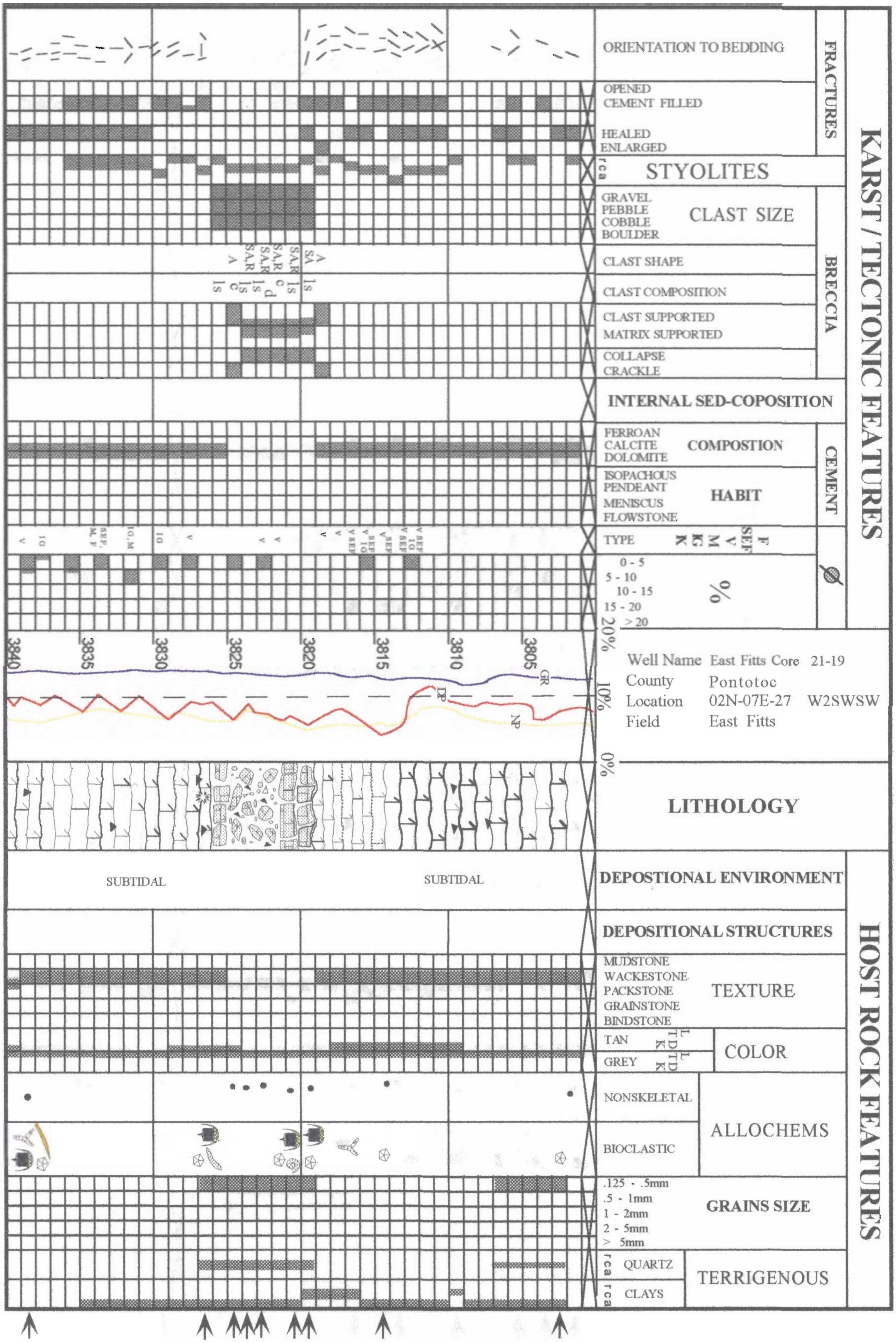
A	ANGULAR
SA	SUBANGULAR
SR	SUBROUNDED
R	ROUNDED

MISCELLANEOUS

▮	DOMINANT FEATURE, TEXTURE
¦	LESS COMMONLY OCCURING
cmt	CEMENT
⊠	MISSING CORE
SI	SILICA REPLACEMENT
LI	LOWER INTERTIDAL
S	SUBTIDAL

← THIN SECTION

r	RARE
c	COMMON
a	ABUNDANT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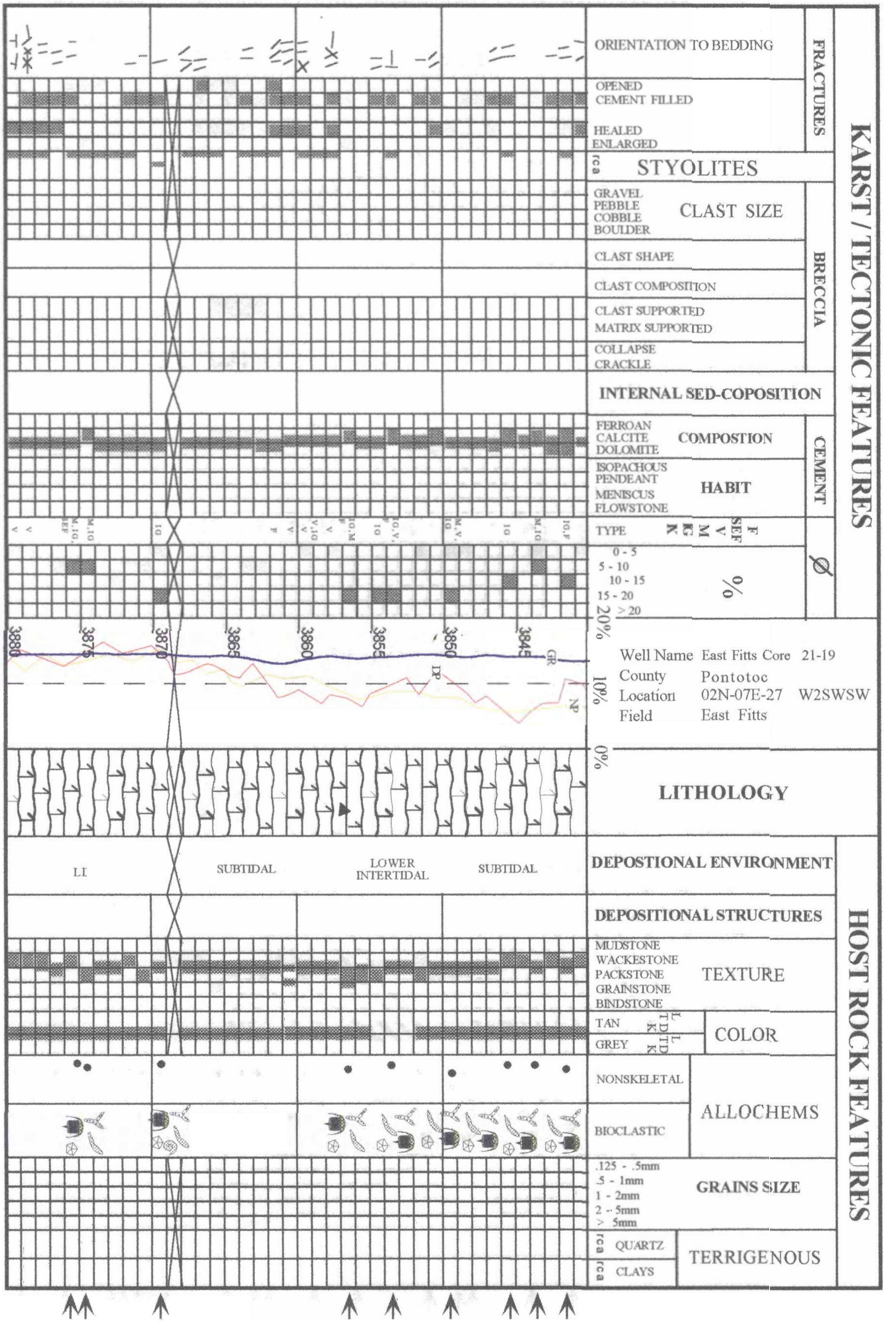
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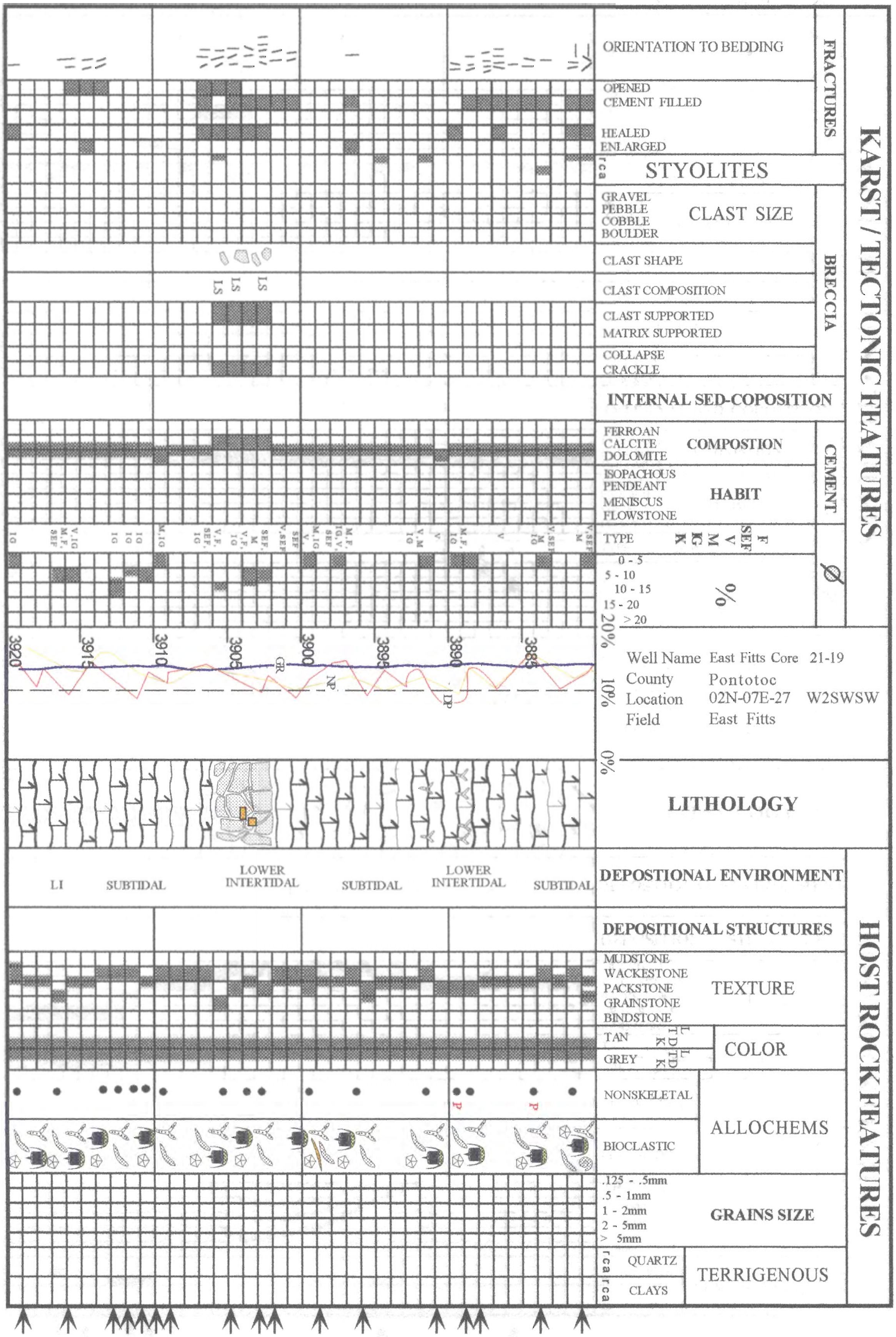
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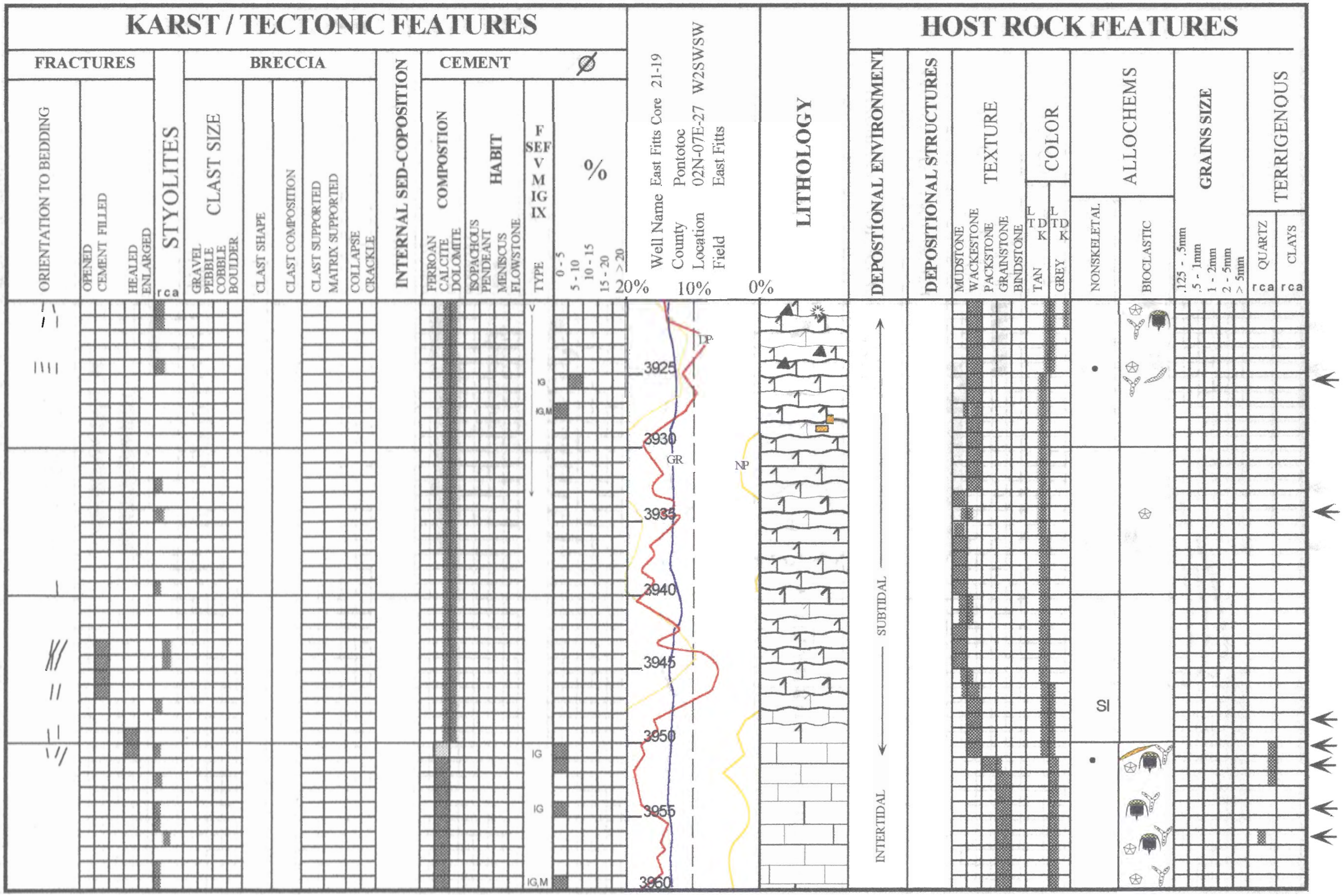
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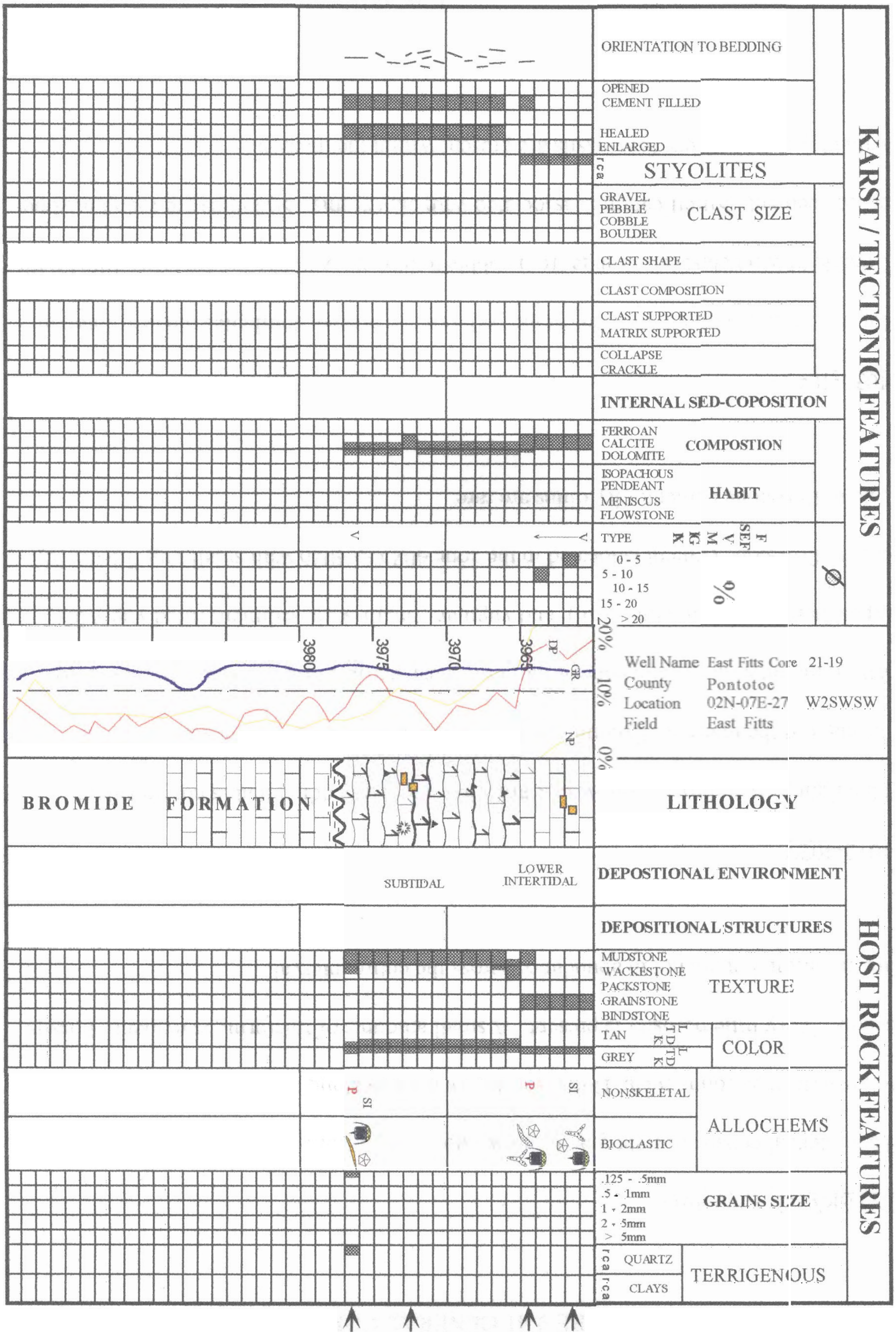
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CALCITE
DOLOMITE
COMPOSTION
ISOPACHOUS
PENDEANT
MENISCUS
FLOWSTONE
HABIT
TYPE
0 - 5
5 - 10
10 - 15
15 - 20
> 20
%
KARST / TECTONIC FEATURES
3980
3975
3970
3965
DP
GR
NP
20%
10%
0%
Well Name East Fitts Core 21-19
County Pontotoc
Location 02N-07E-27 W2SWSW
Field East Fitts
BROMIDE FORMATION
LITHOLOGY
SUBTIDAL
LOWER INTERTIDAL
DEPOSTIONAL ENVIRONMENT
DEPOSITIONAL STRUCTURES
MUDSTONE
WACKESTONE
PACKSTONE
GRAINSTONE
BINDSTONE
TEXTURE
TAN
GREY
COLOR
P
SI
NONSKELETAL
BIOCLASTIC
ALLOCHEMS
.125 - .5mm
.5 - 1mm
1 - 2mm
2 - 5mm
> 5mm
GRAINS SIZE
QUARTZ
CLAYS
TERRIGENOUS
HOST ROCK FEATURES

EAST FITTS CORE 9-41 GENERAL CORE DESCRIPTION

INTERVAL 4000-4011

This interval consist of light gray to brown dolo-wackestone with nodular bedding. Little to no stylolitization is seen. Dolomitization increases along the areas of insoluble clay seams. Very little porosity is present. A small amounts of fracturing is evident. Fossils are common, but are not in abundance across the entire interval.

4012-4029

This light gray to brown dolo-wackestone has nodular bedding that is not prevalent throughout the interval. Dolomite is found around the insoluble clay seams. Some zones within the interval contain concentrations of near-vertical oriented fractures. Porosity types include open fractures, SEF and vugular. Small-scale sediment filled vug with calcite flowstone cement is located in the zone 4025 to 4026 with small vug filled with calcite flowstone cement. Stylolites are rare.

4030-4040

Light gray mudstone/dolo-wackestone with crackle breccia dominates the next interval. Crackle breccia clasts size range from cobble to gravel size. The fractures are filled with calcite cement. Silicification is associated with clay seams. Stylolites are found in zones with clay seams. Very few fossils are present within the interval.

4041-4060

This interval is light gray dolo-wackestone with nodular bedding and a few zones of silicification in the form of chert nodules. Fractures are not common. Those that are present are mostly healed or cemented with calcite. Few stylolites within the interval. Dolomitization has occurred adjacent to fractures and the clay seams present.

4061-4078

Dolo-wackestone, packstone, and few zones of mudstone form the next interval. Occasional chert nodules are also present. Alternating bands of dolomite occur throughout the interval. Nodular bedding is not continuous. Increased porosity occurs in the form of vugs and intergranular porosity generated by dolomitization. Very few fractures are present.

4079-4141

Light gray to brown dolo-wackestone, packstone and grainstone present in the interval with little or no chert nodules present. Few zone within the interval are grainstone with the with sections of predominately dolo-wackestone to packstone with scarce nodular bedding Dolomitization is seen throughout the entire interval. Porosity within the interval is restricted to vugular and intergranular types. Cemented fractures found in a few zones along with healed fractures common in the interval. Large bryozoan are seen in section

4142-4153

This interval consists of brown dolo-wackestone that contain abundant fossils. Lower portion of the interval has alternating beds of dolo-wackestone that are slightly stylolitzed. Open fractures are found within the matrix and chert nodules. The matrix is composed of mainly calcite and replacement dolomite.

4154-4167

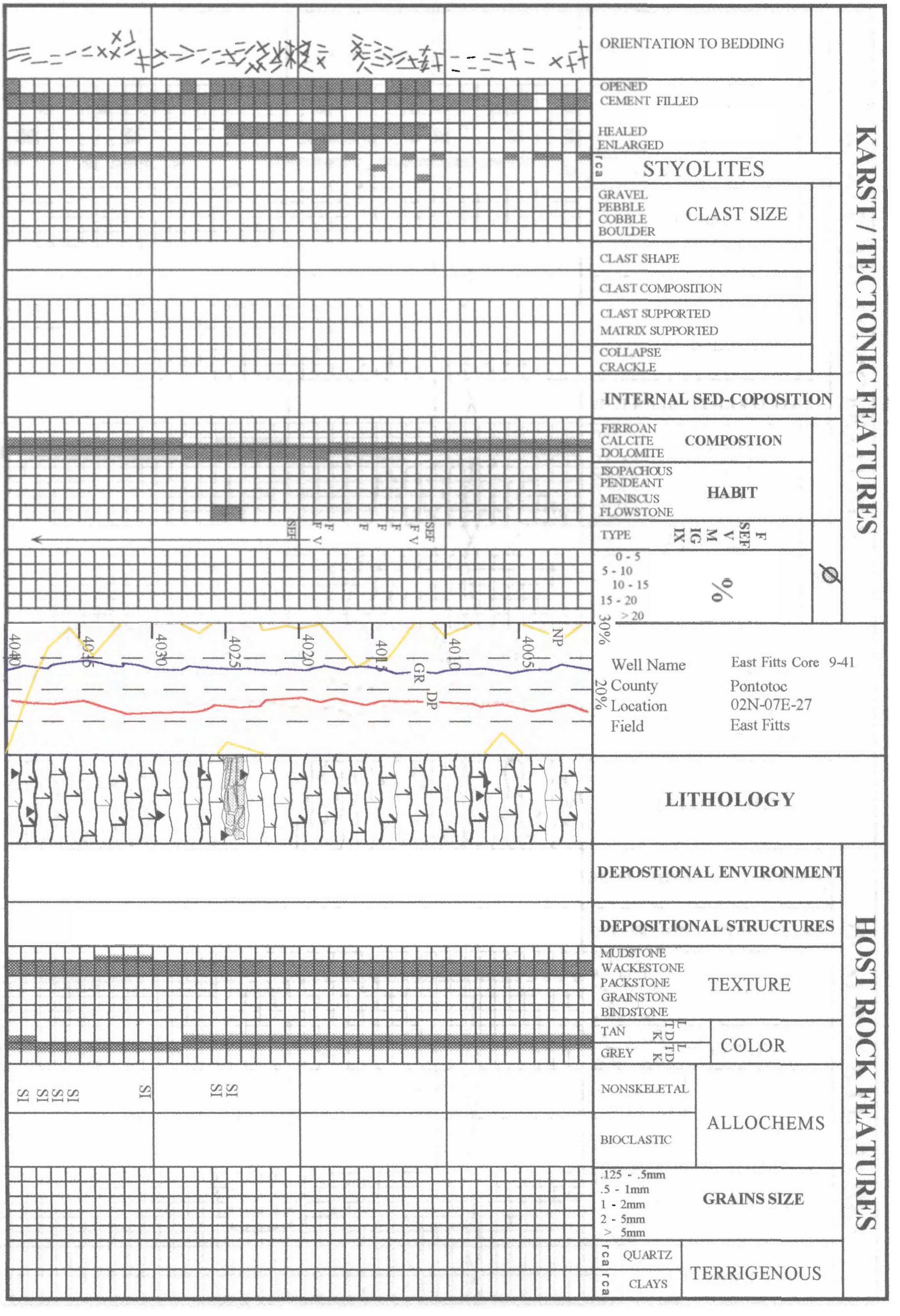
Brown dolo-mudstone with little or no fossils dominate this interval. Chert nodules are found throughout the interval and contain open fractures. Few stylolites are seen. Porosity is primarily intergranular.

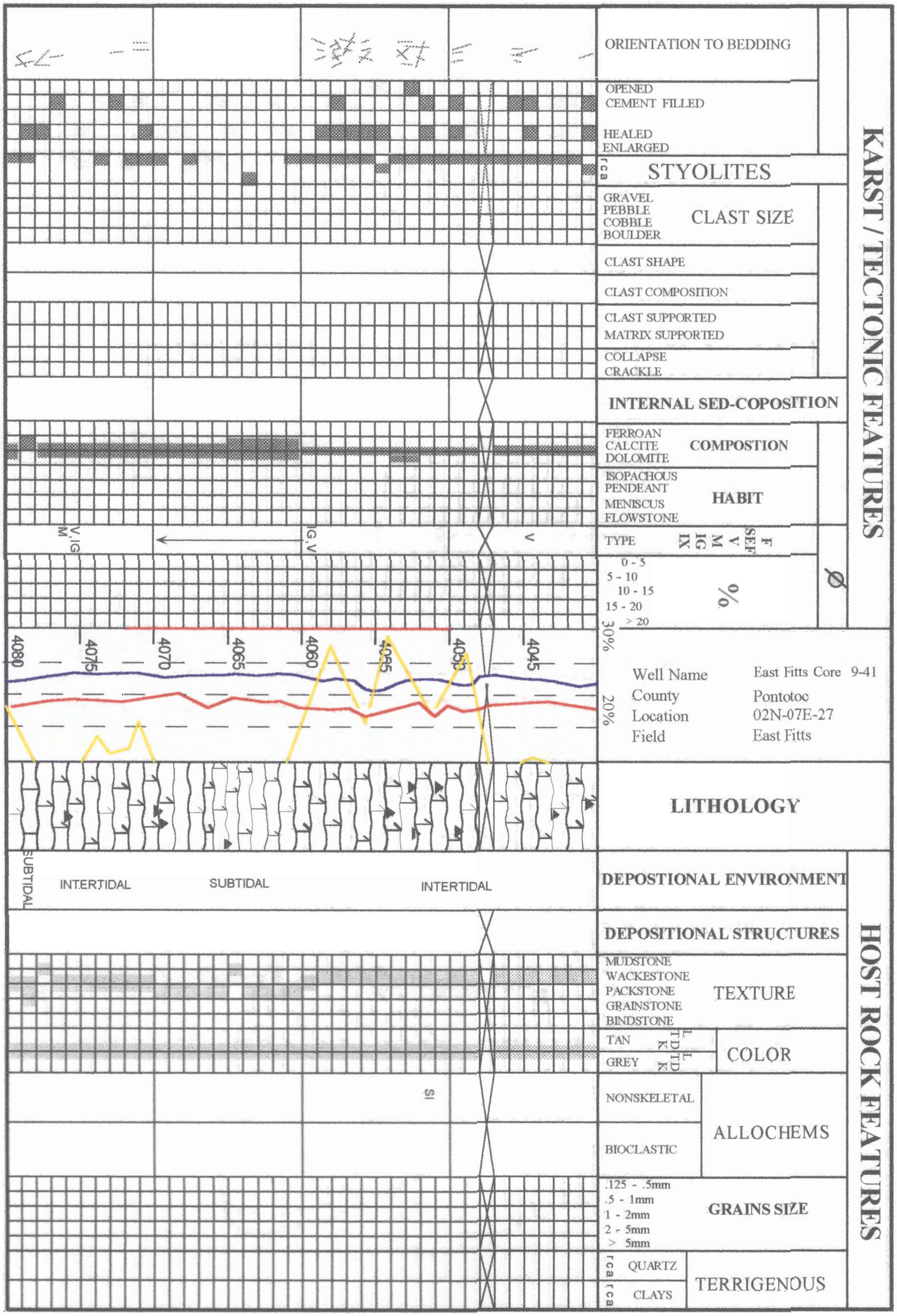
4168-4176

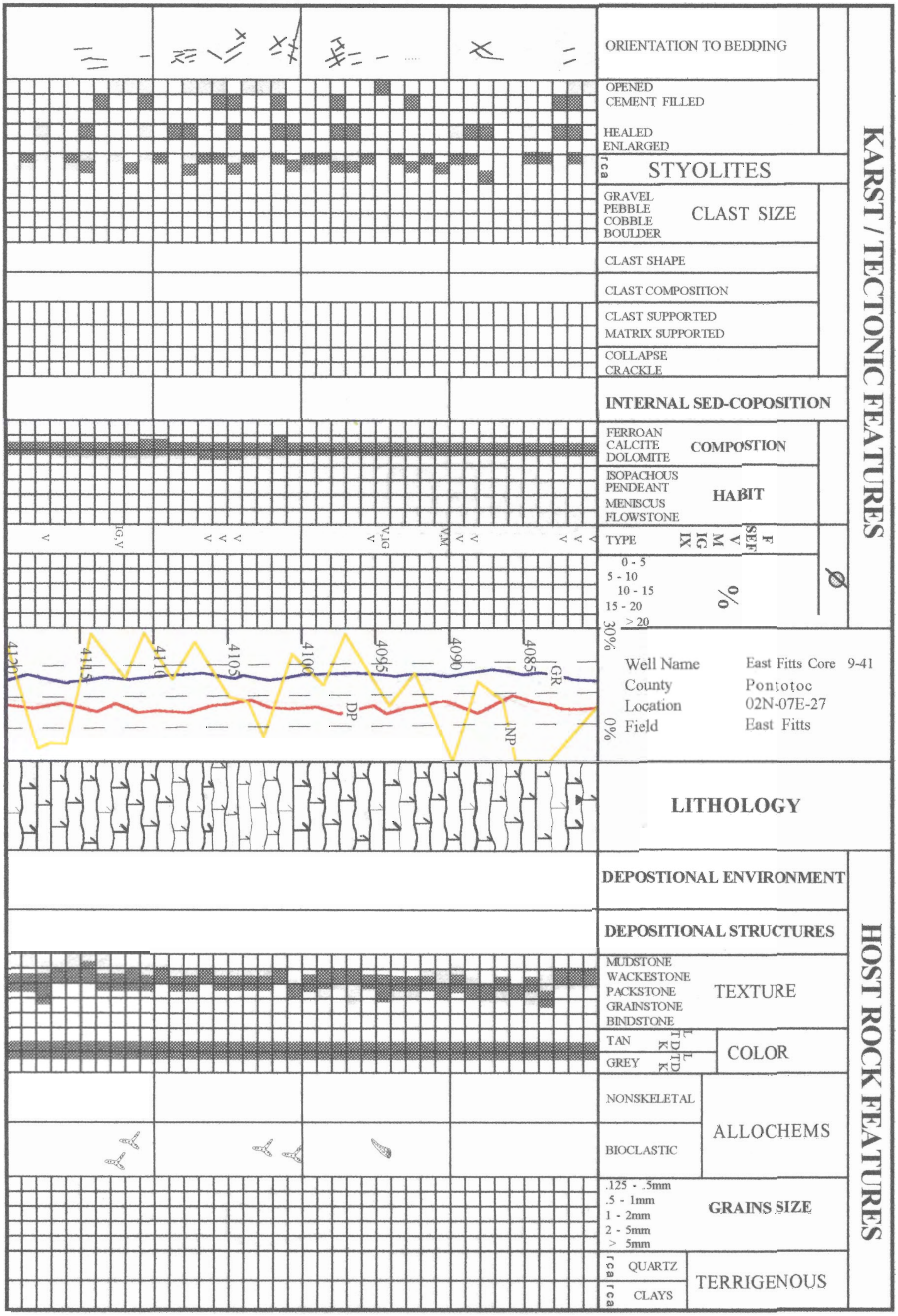
This interval contains light gray to brown dolo-wackestone to dolo-packstone with calcite and dolomite matrix. Vugular porosity is found in the dolo-packstone. Few fractures and stylolites are present within the interval.

4173-4185.5

Light gray bioclastic grainstone is calcite cemented. Porosity within the grainstone zone is vuggy and intergranular. The interval has calcite-filled fractures that decrease in abundance down section. Dolomite is rare.


ORIENTATION TO BEDDING
OPENED
CEMENT FILLED
HEALED
ENLARGED
STYOLITES
GRAVEL
PEBBLE
COBBLE
BOULDER
CLAST SIZE
CLAST SHAPE
CLAST COMPOSITION
CLAST SUPPORTED
MATRIX SUPPORTED
COLLAPSE
CRACKLE
INTERNAL SED-COPOSITION
FERROAN
CALCITE
DOLOMITE
COMPOSTION
ISOPACHOUS
PENDEANT
MENISCUS
FLOWSTONE
HABIT
TYPE
IX IG M V SEF F
0 - 5
5 - 10
10 - 15
15 - 20
> 20
%
Ø
KARST / TECTONIC FEATURES
4040
4035
4030
4025
4020
4015
4010
4005
NP
GR
DP
30%
20%
Well Name
East Fitts Core 9-41
County
Pontotoc
Location
02N-07E-27
Field
East Fitts
LITHOLOGY
DEPOSTIONAL ENVIRONMENT
DEPOSITIONAL STRUCTURES
MUDSTONE
WACKESTONE
PACKSTONE
GRAINSTONE
BINDSTONE
TEXTURE
TAN
GREY
COLOR
SI
NONSKELETAL
BIOCLASTIC
ALLOCHEMS
.125 - .5mm
.5 - 1mm
1 - 2mm
2 - 5mm
> 5mm
GRAINS SIZE
QUARTZ
CLAYS
TERRIGENOUS
HOST ROCK FEATURES


KARST / TECTONIC FEATURES
ORIENTATION TO BEDDING
OPENED
CEMENT FILLED
HEALED
ENLARGED
STYOLITES
GRAVEL
PEBBLE
COBBLE
BOULDER
CLAST SIZE
CLAST SHAPE
CLAST COMPOSITION
CLAST SUPPORTED
MATRIX SUPPORTED
COLLAPSE
CRACKLE
INTERNAL SED-COPOSITION
FERROAN
CALCITE
DOLOMITE
COMPOSTION
ISOPACHOUS
PENDEANT
MENISCUS
FLOWSTONE
HABIT
TYPE
0 - 5
5 - 10
10 - 15
15 - 20
> 20
%
Ø
30%
20%
4080
4075
4070
4065
4060
4055
4050
4045
Well Name
East Fitts Core 9-41
County
Pontotoc
Location
02N-07E-27
Field
East Fitts
LITHOLOGY
SUBTIDAL
INTERTIDAL
SUBTIDAL
INTERTIDAL
DEPOSTIONAL ENVIRONMENT
DEPOSITIONAL STRUCTURES
MUDSTONE
WACKESTONE
PACKSTONE
GRAINSTONE
BINDSTONE
TEXTURE
TAN
GREY
COLOR
NONSKELETAL
BIOCLASTIC
ALLOCHEMS
.125 - .5mm
.5 - 1mm
1 - 2mm
2 - 5mm
> 5mm
GRAINS SIZE
QUARTZ
CLAYS
TERRIGENOUS
HOST ROCK FEATURES


ORIENTATION TO BEDDING
OPENED
CEMENT FILLED
HEALED
ENLARGED
STYOLITES
GRAVEL
PEBBLE
COBBLE
BOULDER
CLAST SIZE
CLAST SHAPE
CLAST COMPOSITION
CLAST SUPPORTED
MATRIX SUPPORTED
COLLAPSE
CRACKLE
INTERNAL SED-COPOSITION
FERROAN
CALCITE
DOLOMITE
COMPOSTION
ISOPACHOUS
PENDEANT
MENISCUS
FLOWSTONE
HABIT
TYPE
0 - 5
5 - 10
10 - 15
15 - 20
> 20
%
KARST / TECTONIC FEATURES
30%
0%
4120
4115
4110
4105
4100
4095
4090
4085
GR
DP
NP
Well Name
East Fitts Core 9-41
County
Pontotoc
Location
02N-07E-27
Field
East Fitts
LITHOLOGY
DEPOSTIONAL ENVIRONMENT
DEPOSITIONAL STRUCTURES
MUDSTONE
WACKESTONE
PACKSTONE
GRAINSTONE
BINDSTONE
TEXTURE
TAN
GREY
COLOR
NONSKELETAL
BIOCLASTIC
ALLOCHEMS
.125 - .5mm
.5 - 1mm
1 - 2mm
2 - 5mm
> 5mm
GRAINS SIZE
QUARTZ
CLAYS
TERRIGENOUS
HOST ROCK FEATURES

KARST / TECTONIC FEATURES

ORIENTATION TO BEDDING

OPENED
CEMENT FILLED
HEALED
ENLARGED

r c a STYOLITES

GRAVEL
PEBBLE
COBBLE
BOULDER
CLAST SIZE

CLAST SHAPE

CLAST COMPOSITION

CLAST SUPPORTED
MATRIX SUPPORTED

COLLAPSE
CRACKLE

INTERNAL SED-COPOSITION

FERROAN
CALCITE
DOLOMITE
COMPOSTION

ISOPACHOUS
PENDEANT
MENISCUS
FLOWSTONE
HABIT

TYPE IX IG M V SEF F

Ø

0 - 5
5 - 10
10 - 15
15 - 20
> 20
%

4160 4155 4150 4145 4140 4135 4130 4125

GR DP NP

20% 0%

Well Name	East Fitts Core 9-41
County	Pontotoc
Location	02N-07E-27
Field	East Fitts

LITHOLOGY

HOST ROCK FEATURES

DEPOSTIONAL ENVIRONMENT

DEPOSITIONAL STRUCTURES

MUDSTONE
WACKESTONE
PACKSTONE
GRAINSTONE
BINDSTONE
TEXTURE

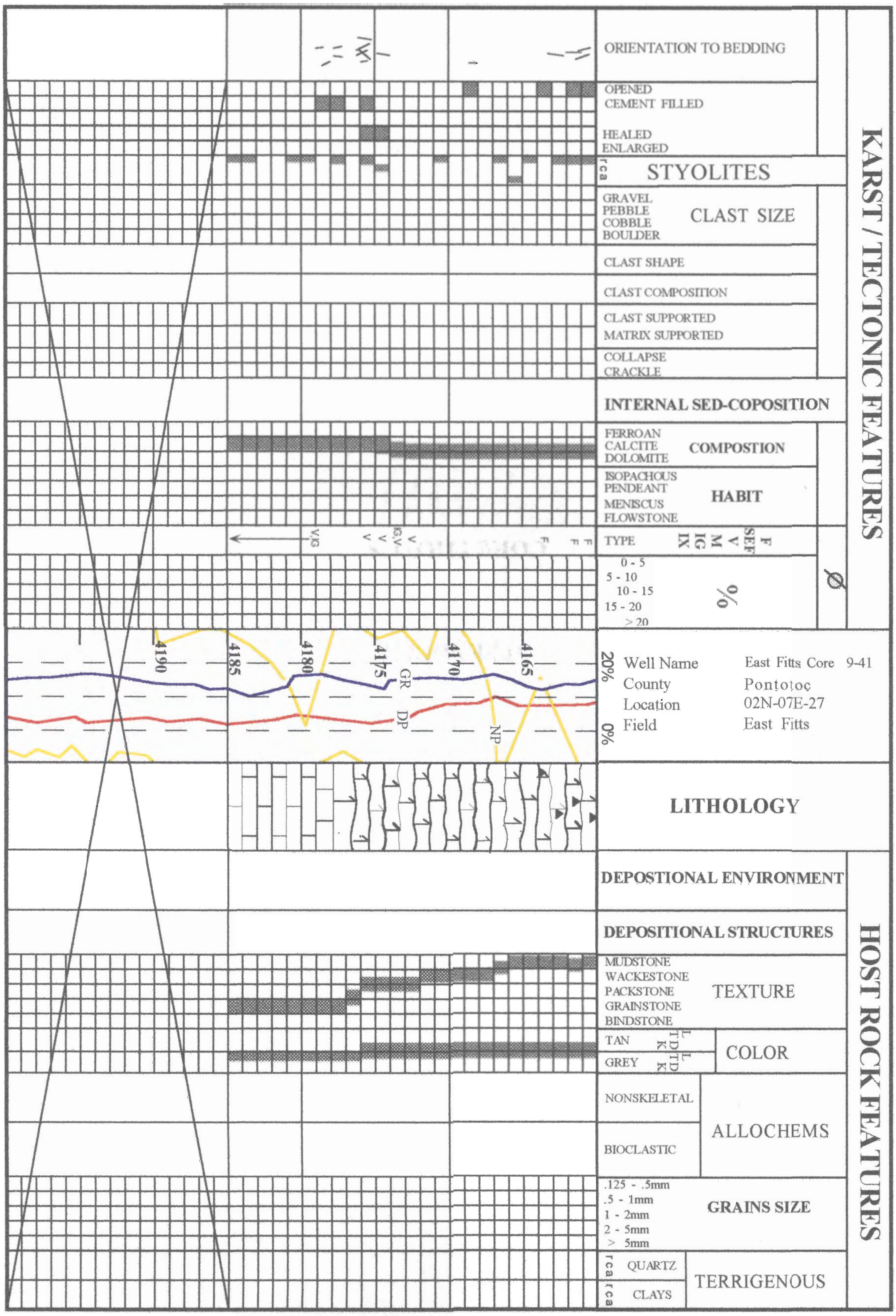
TAN L TD K
GREY L TD K
COLOR

SI

NONSKELETAL
BIOCLASTIC
ALLOCHEMS

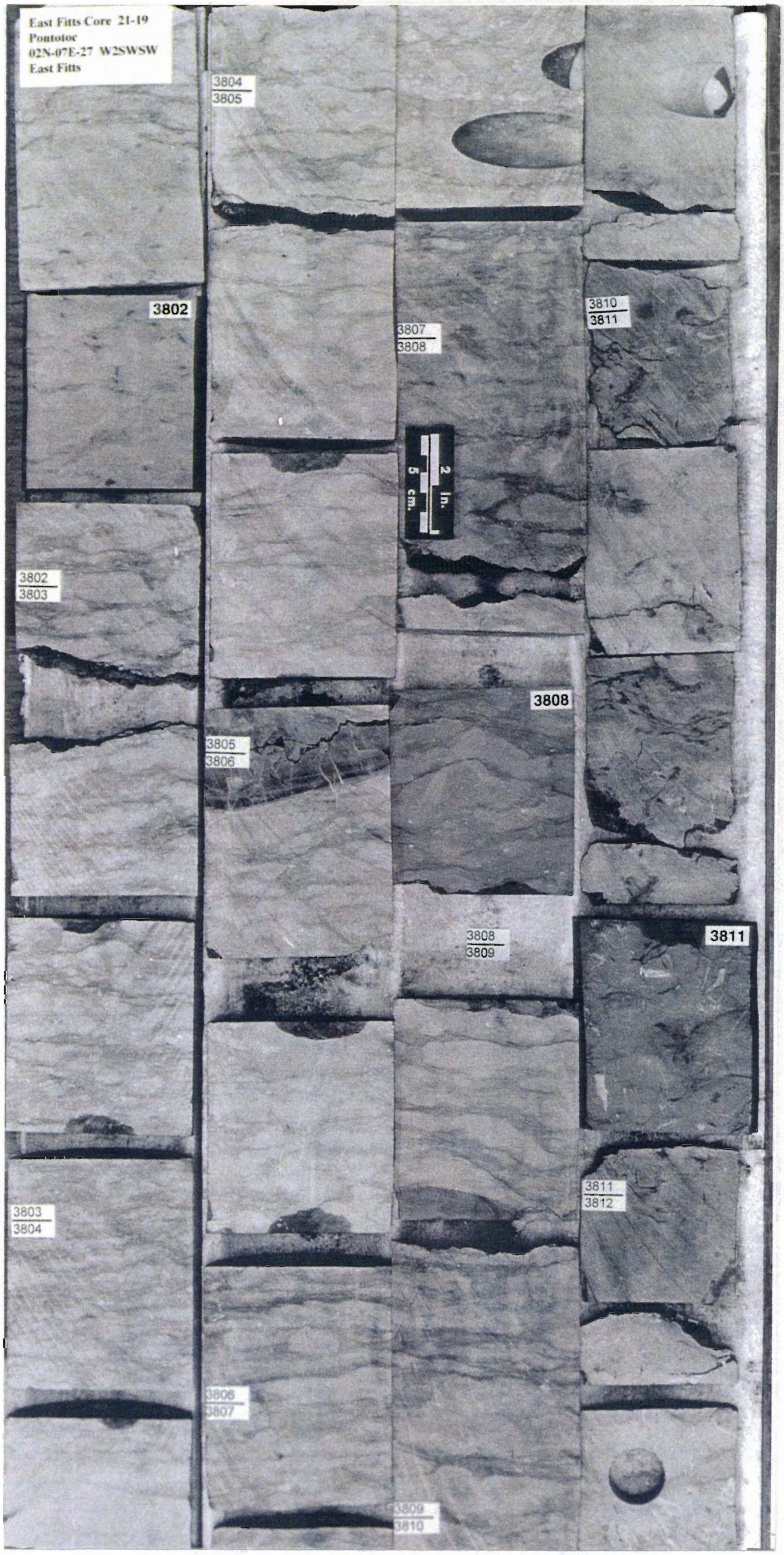
.125 - .5mm
.5 - 1mm
1 - 2mm
2 - 5mm
> 5mm
GRAINS SIZE

r c a QUARTZ
r c a CLAYS
TERRIGENOUS


KARST / TECTONIC FEATURES
ORIENTATION TO BEDDING
OPENED
CEMENT FILLED
HEALED
ENLARGED
rca
STYOLITES
GRAVEL
PEBBLE
COBBLE
BOULDER
CLAST SIZE
CLAST SHAPE
CLAST COMPOSITION
CLAST SUPPORTED
MATRIX SUPPORTED
COLLAPSE
CRACKLE
INTERNAL SED-COPOSITION
FERROAN
CALCITE
DOLOMITE
COMPOSTION
ISOPACHOUS
PENDEANT
MENISCUS
FLOWSTONE
HABIT
TYPE
IX
IG
M
V
SEF
F
0 - 5
5 - 10
10 - 15
15 - 20
> 20
%
Ø
4190
4185
4180
4175
4170
4165
GR
DP
NP
20%
0%
Well Name
East Fitts Core 9-41
County
Pontotoc
Location
02N-07E-27
Field
East Fitts
LITHOLOGY
DEPOSTIONAL ENVIRONMENT
DEPOSITIONAL STRUCTURES
MUDSTONE
WACKESTONE
PACKSTONE
GRAINSTONE
BINDSTONE
TEXTURE
TAN
GREY
COLOR
NONSKELETAL
BIOCLASTIC
ALLOCHEMS
.125 - .5mm
.5 - 1mm
1 - 2mm
2 - 5mm
> 5mm
GRAINS SIZE
QUARTZ
CLAYS
TERRIGENOUS
HOST ROCK FEATURES

APPENDIX B

CORE PHOTOS


East Fitts Core 21-19
Pontotoc
02N-07E-27 W2SWSW
East Fitts
3802
3802
3803
3803
3804
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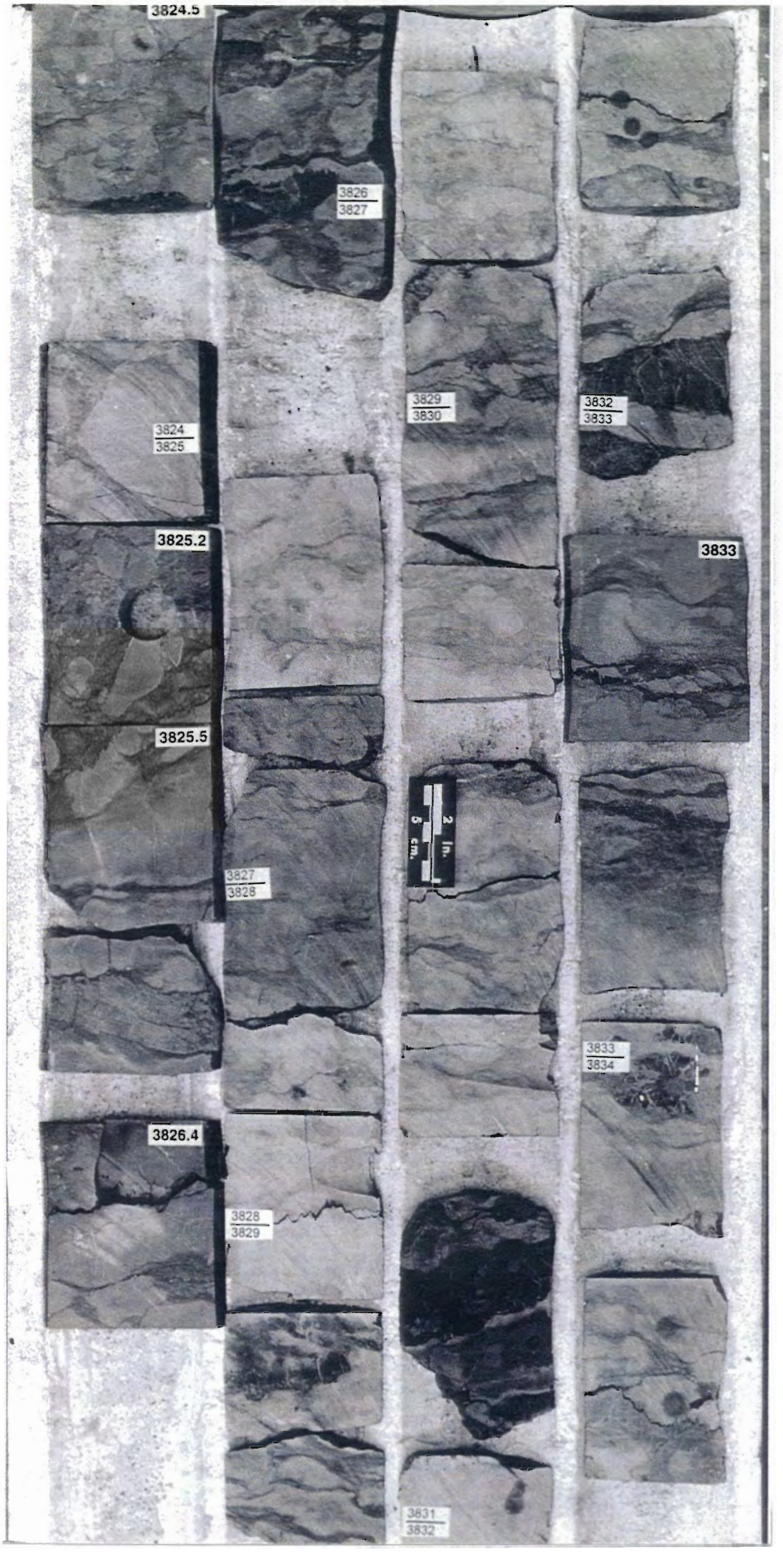
3805
3806
3806
3807
3807
3808
3808
3808
3809
3809
3810
3810
3811
3811
3811
3812
2 in.
5 cm.


3812/3813
3813/3814
3814
3814/3815
3815/3816
3816/3817
3817/3818
3819
3818/3819
3819/3820
3820
2 in.
5 cm.
3820.3
3820.7
3820/3821
3821
3821.5
3821/3822
3822.3
3822.6
3822/3823
3823.7
3824
3823/3824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3829
3830
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2 in.
5 cm.
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3826.4
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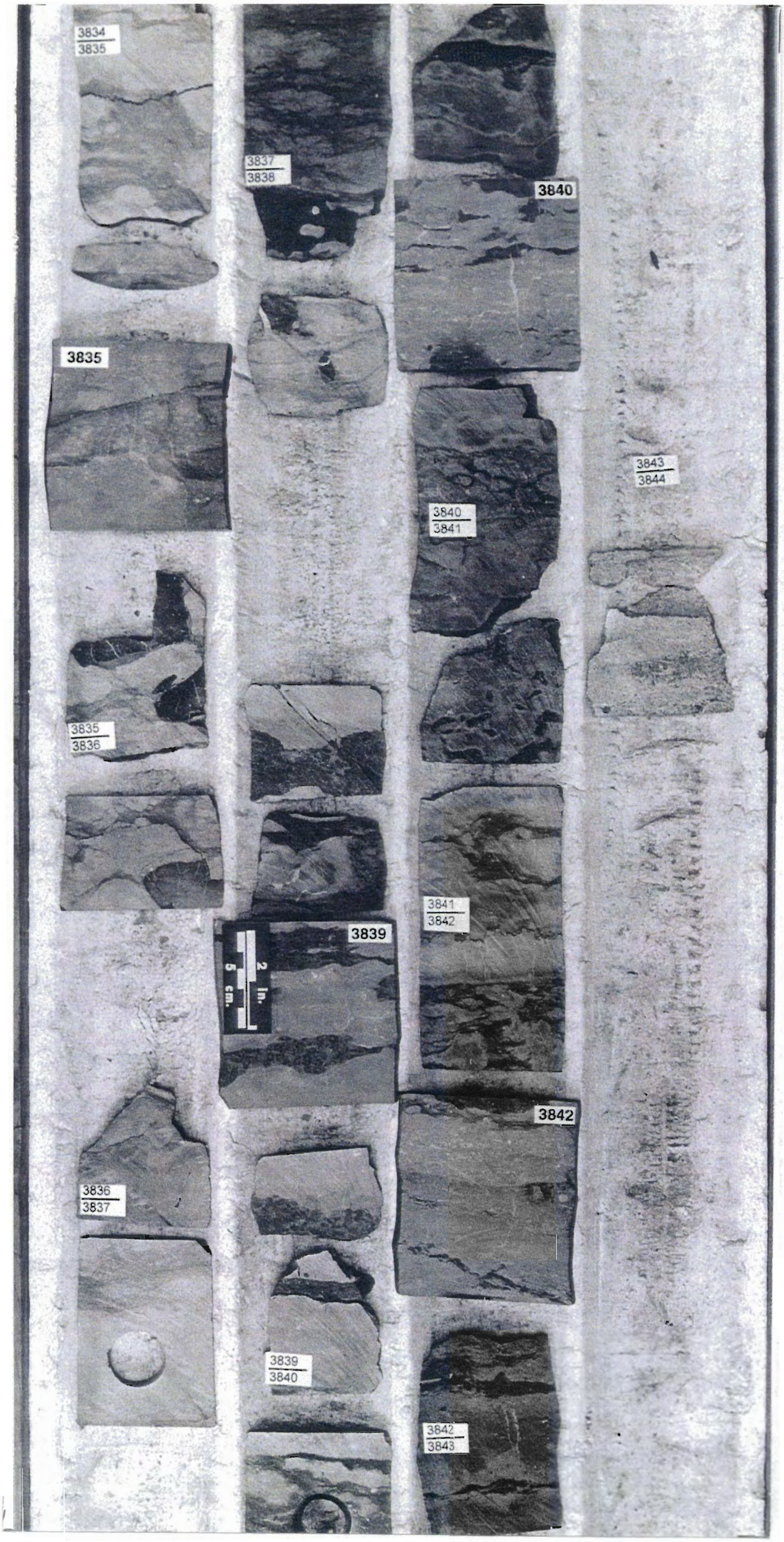
3831
3832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5 cm.
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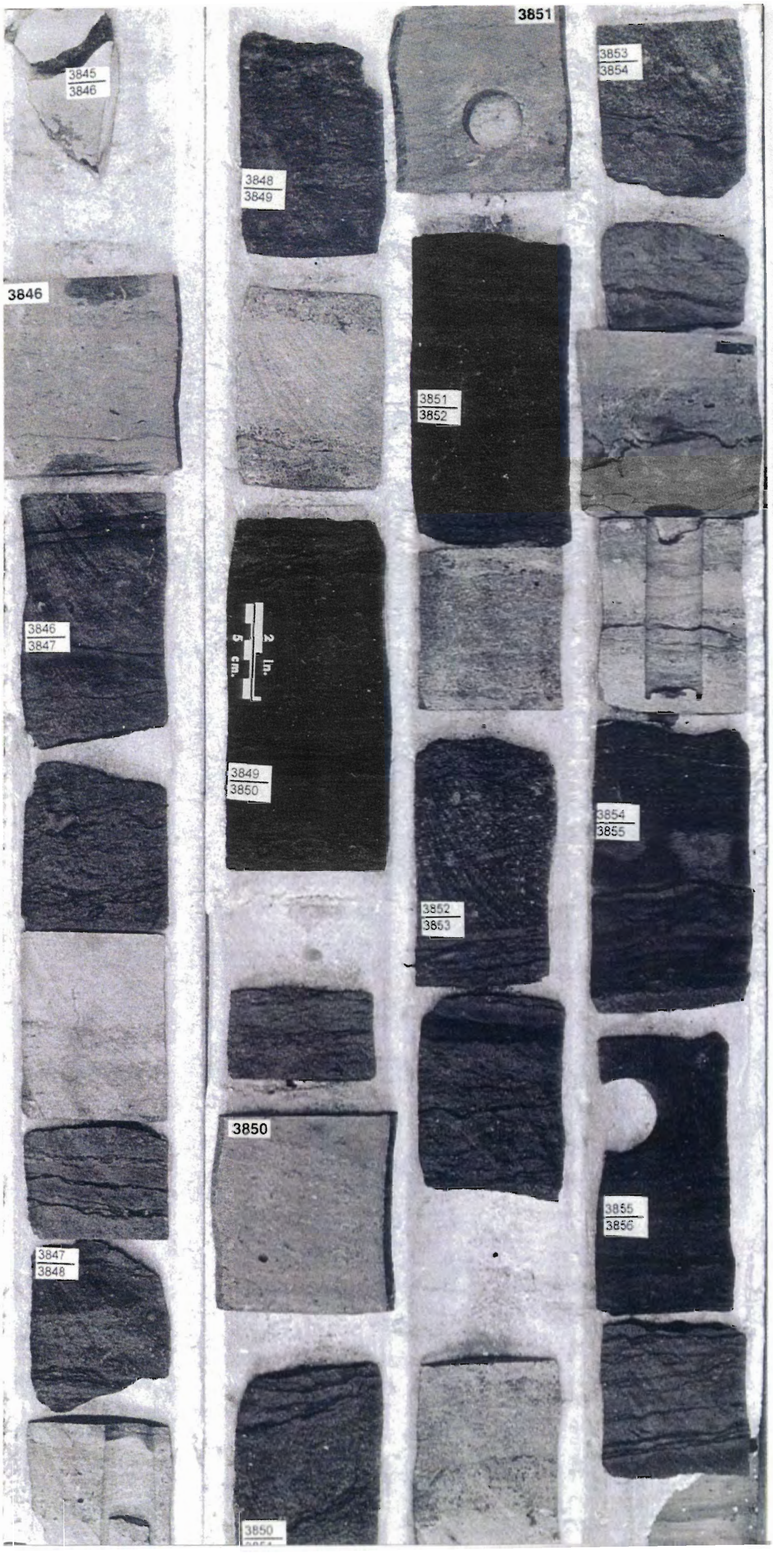
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3849
2 in.
5 cm.
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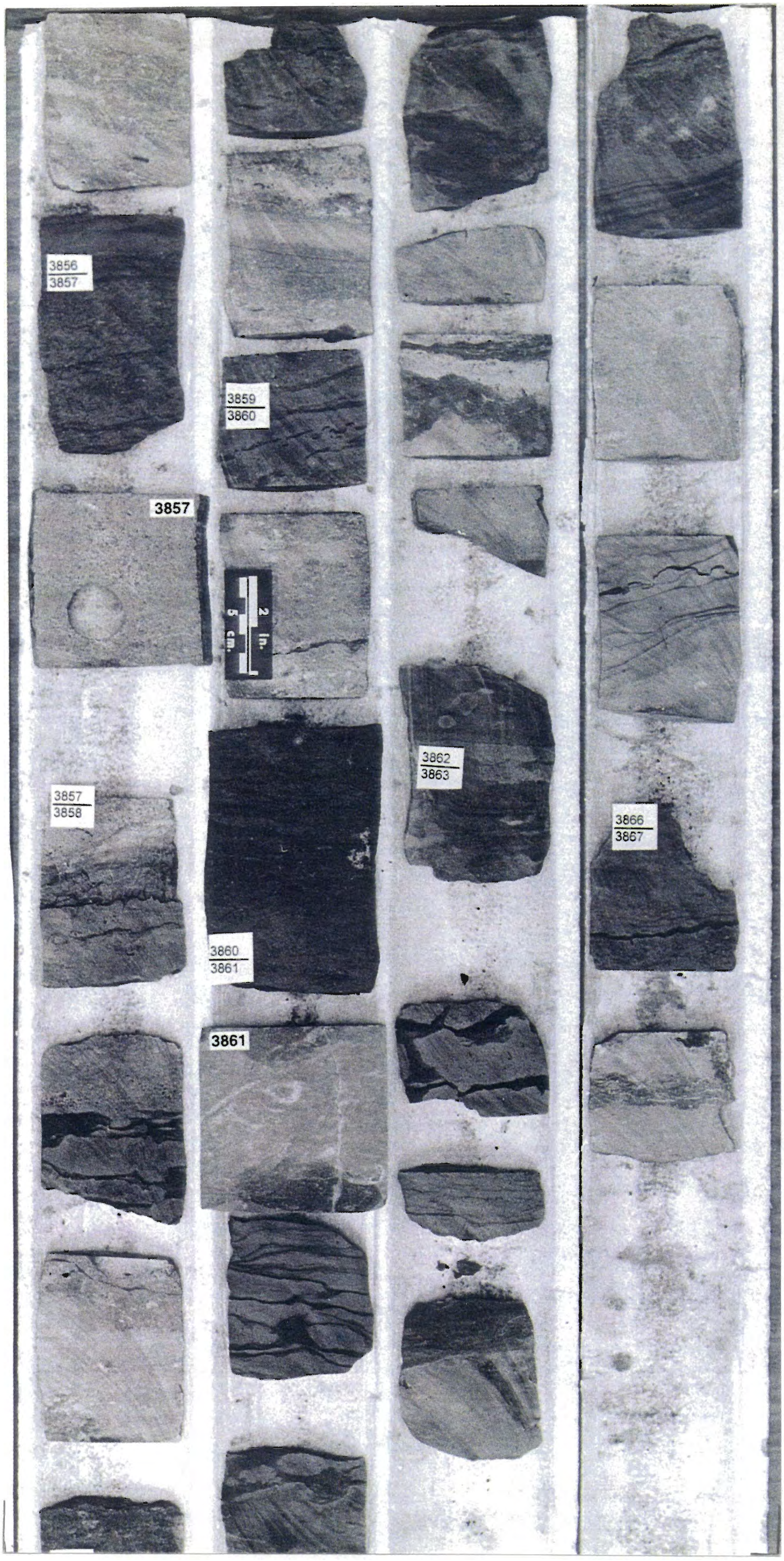
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2 in.
5 cm.
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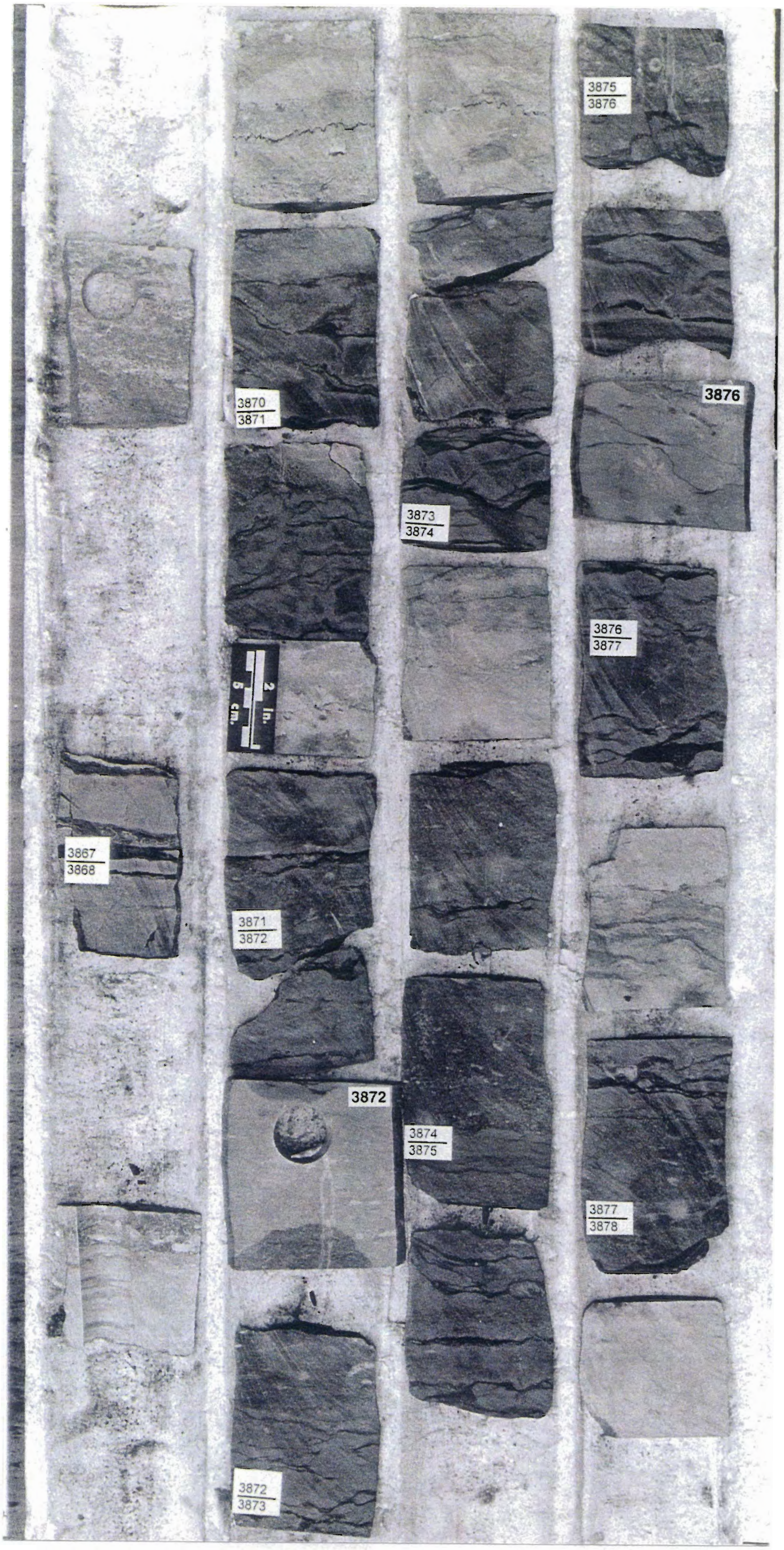
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2 in.
5 cm.
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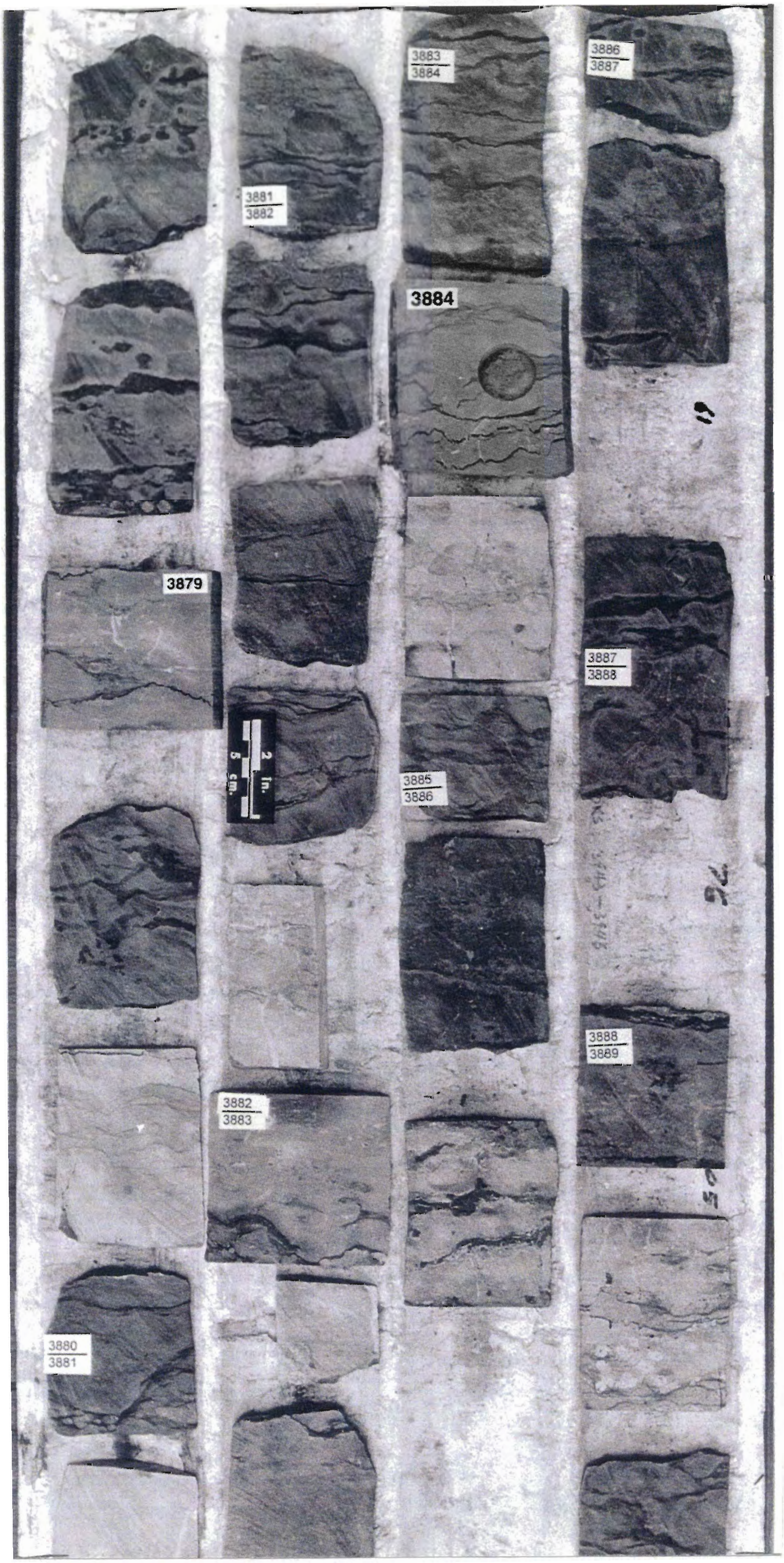
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2 in.
5 cm.
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3889
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2 in.
5 cm.
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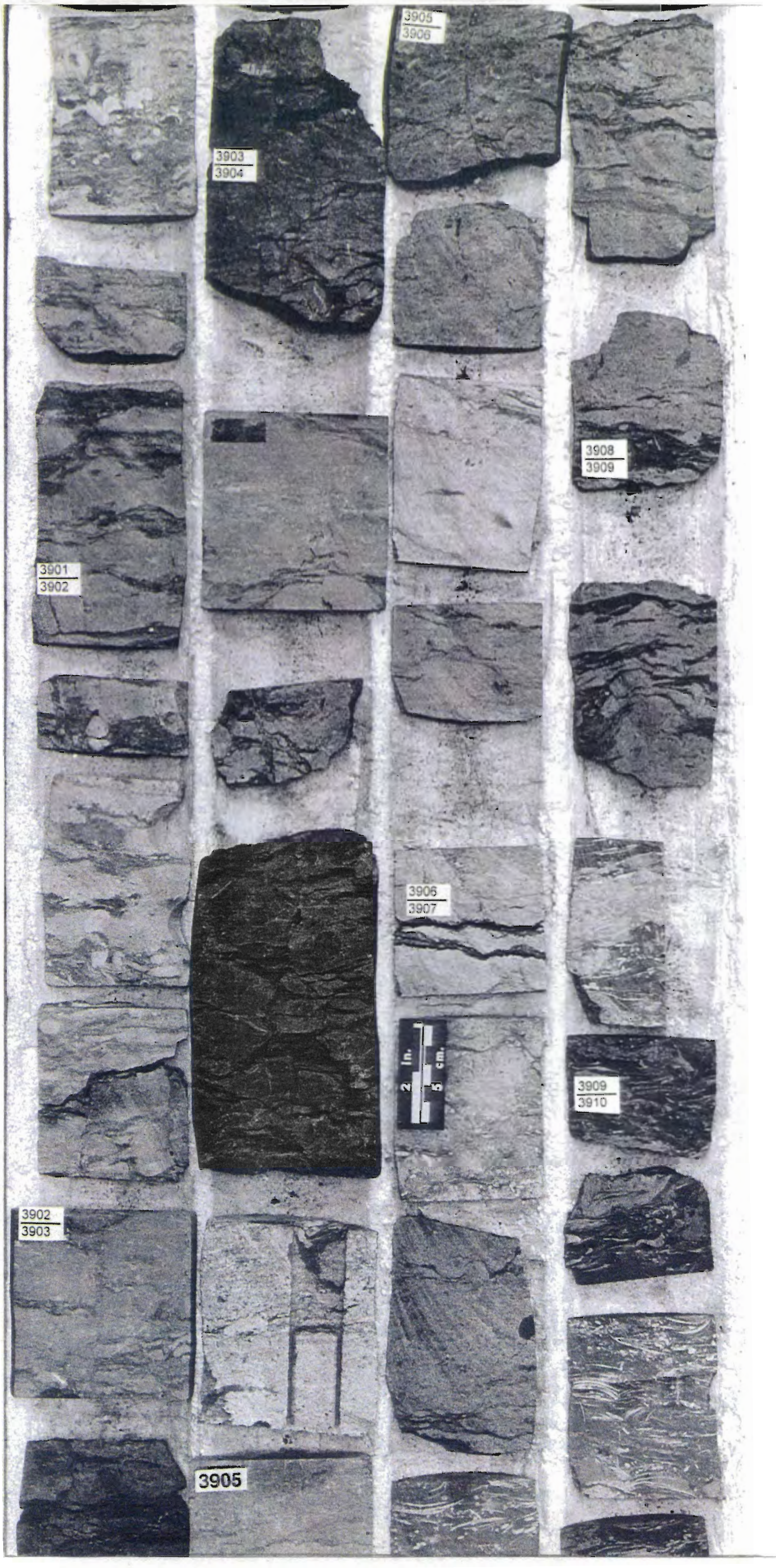
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2 in.
5 cm.
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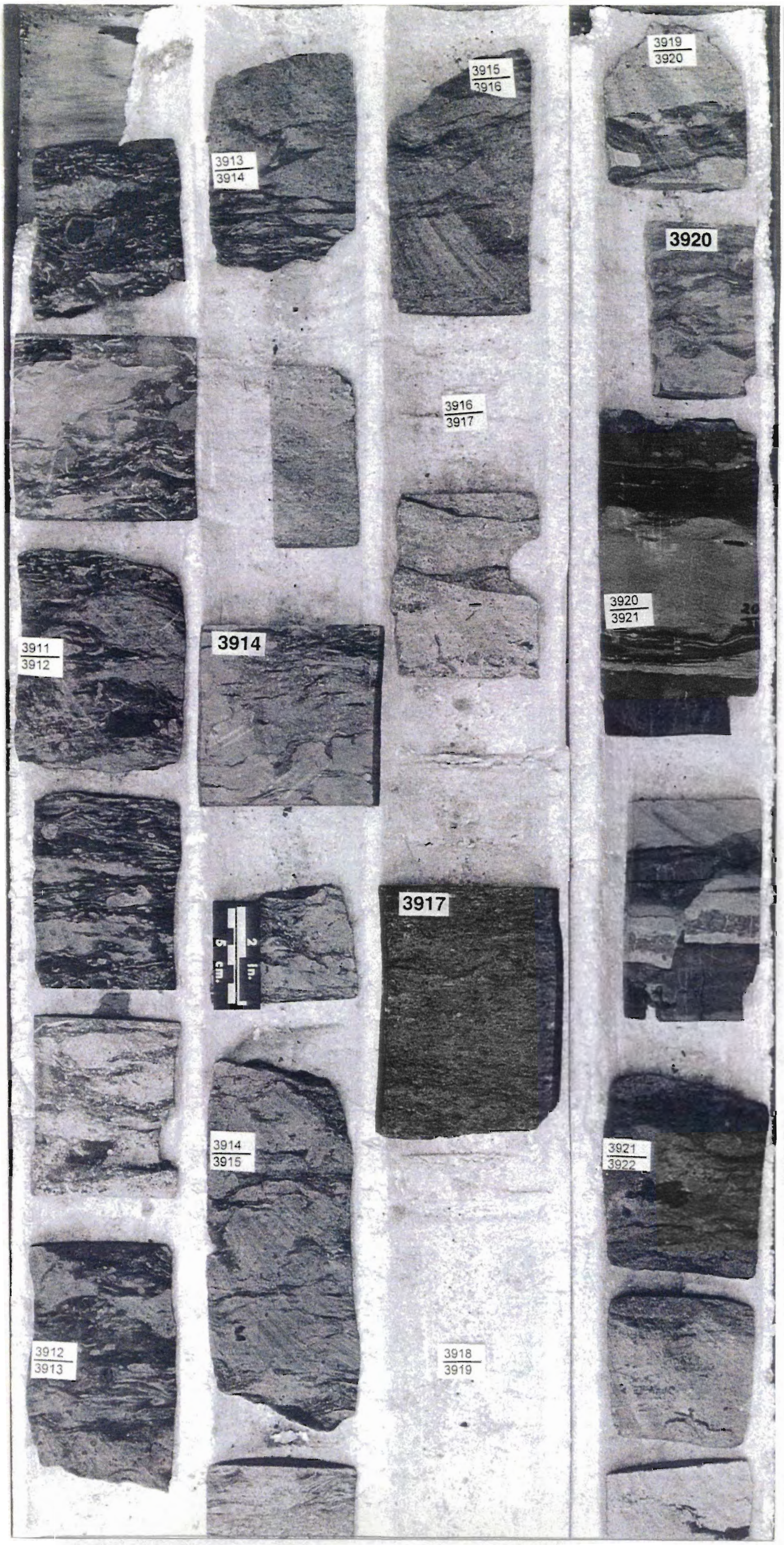
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In.
5 cm.
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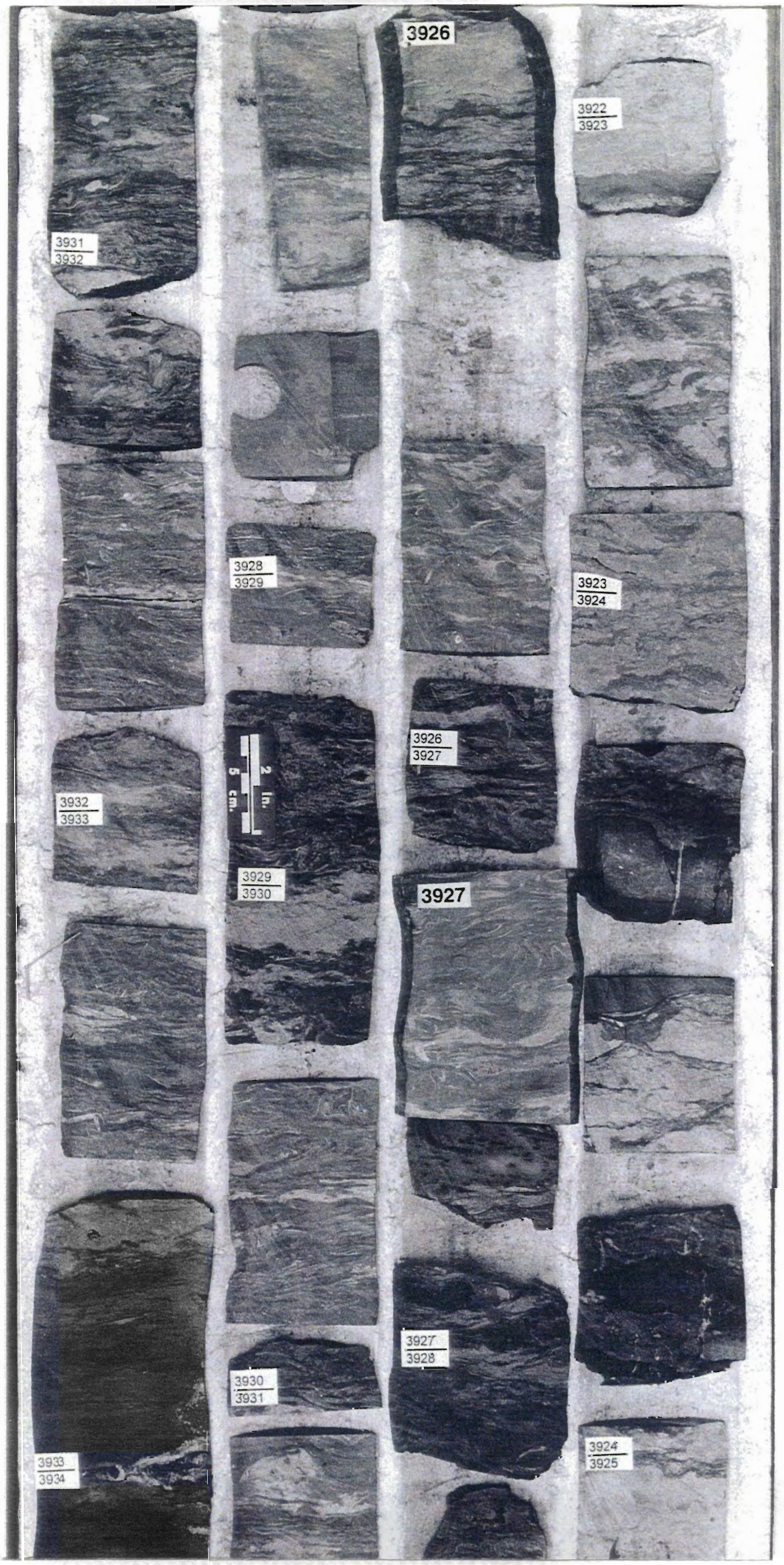
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2 in.
5 cm.
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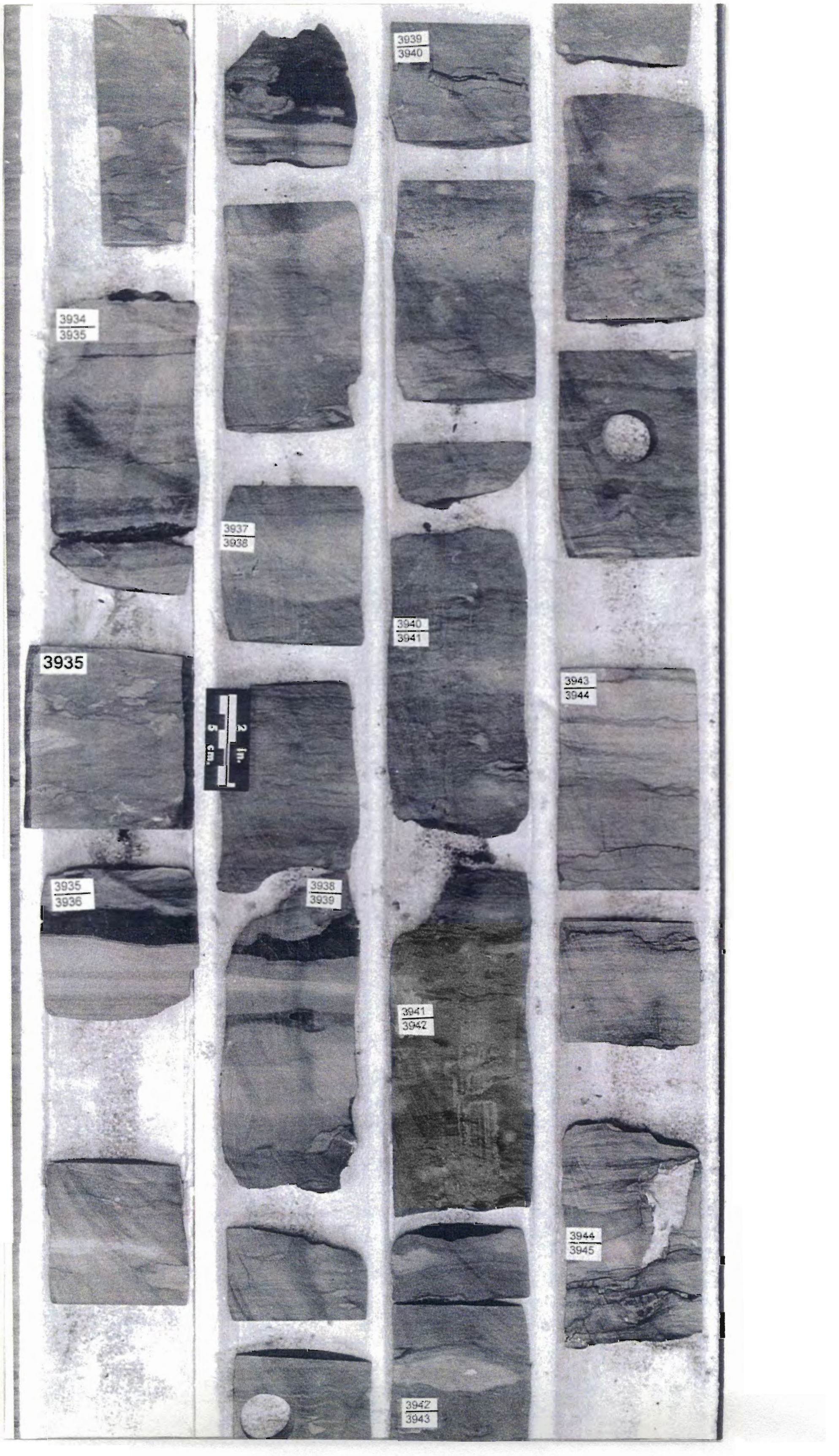
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2 in.
5 cm.
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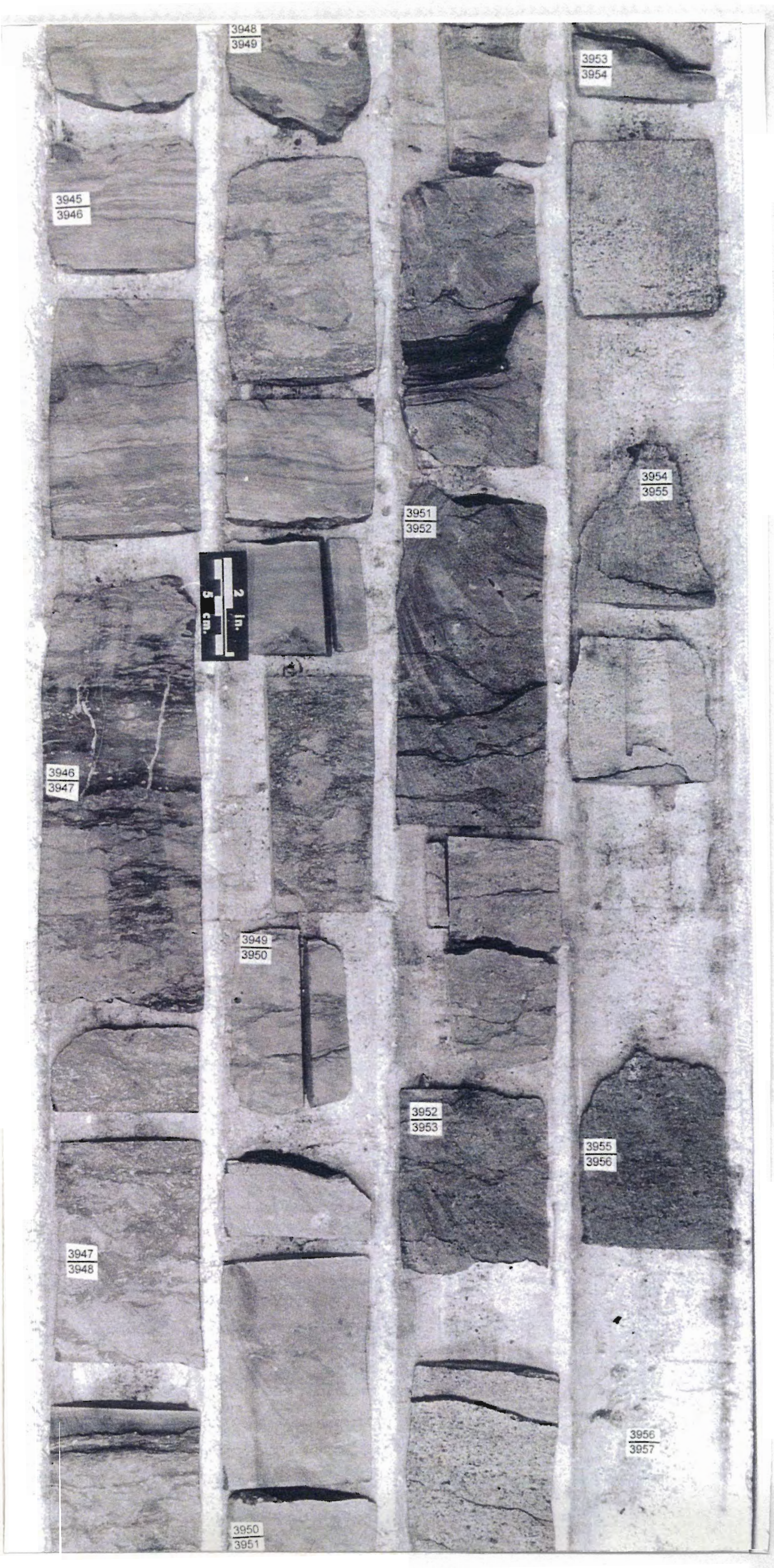
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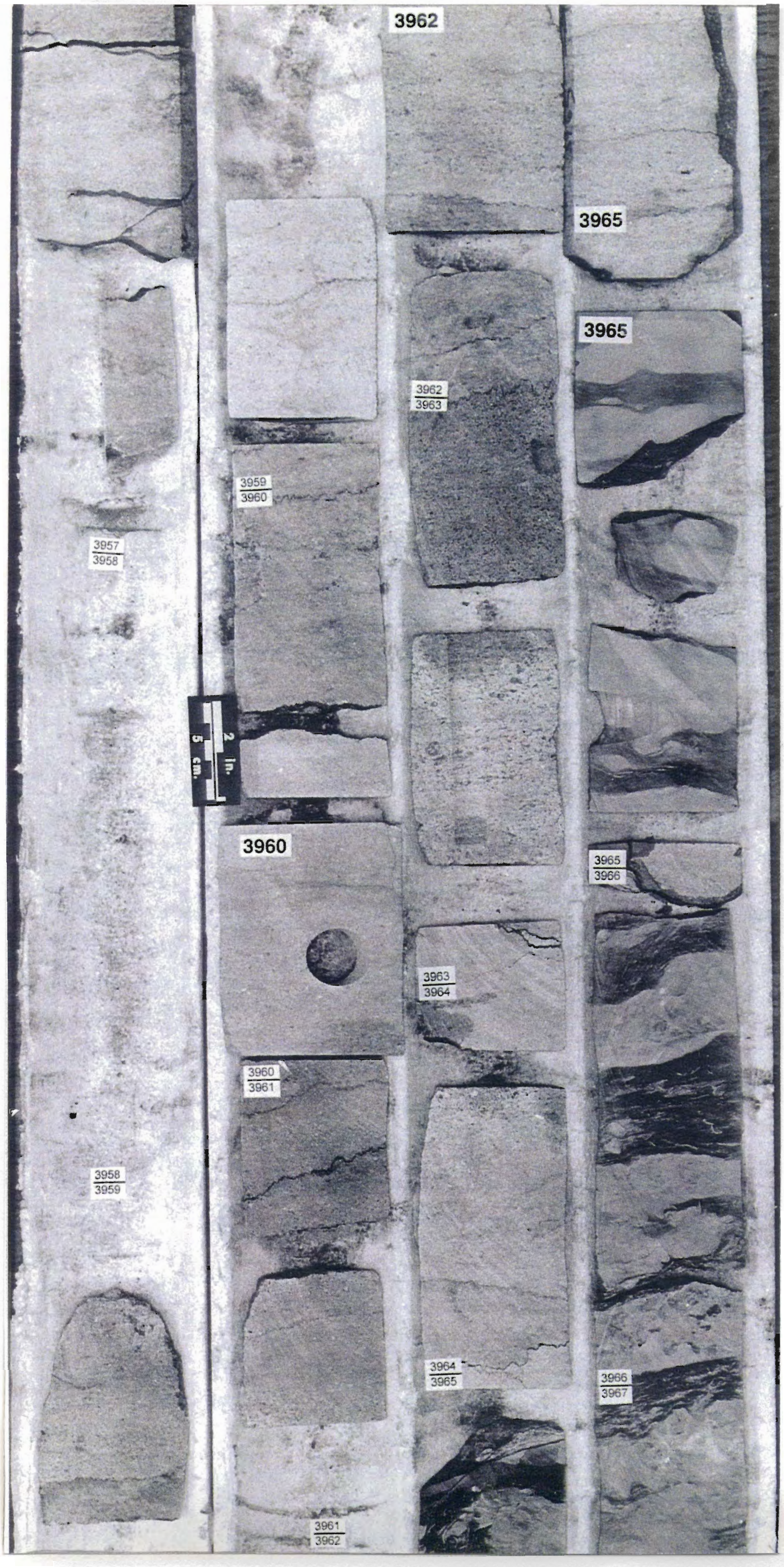
2 in.
5 cm.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3960
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3958
2 in.
5 cm.
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2 in.
5 cm.
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APPENDIX C

DETAILED KARST AND PALEOKARSTIC OUTCROP DESCRIPTIONS

VIOLA KARSTIC AND PALEOKARSTIC OUTCROP DESCRIPTIONS

#	Outcrop Location	Outcrop Description	Stratigraphic Location of outcrop features	Karstic/Paleokarstic Features
1.	N 34° 34' 08.9" W 97° 37' 04.4" Fittstown location Highway 377 West side of roadcut.	• Seepage from outcrop in several locations. Must be active channel for fluid movement. • Vugular porosity dominates outcrop where seepage is occurring. • Interconnection between porosity. • A solutional channel .5 meters in diameter runs along strike and in bedding plane, some sediment infill, penetrates rock about 1.5 meters. • Another channel was found and must connect through some type of passage work.	Middle of the Viola.	Active Karstic
2.	N 34° 34' 08.9" W 96° 37' 51.5" Fittstown location Highway 377 West side of roadcut.	• Fault with several solutional conduits stacked up the fault. • Numerous chert nodules in this section. • Fracture with popcorn forming on the sides , which indicates a time of active karstic precipitation of calcite. • Chert nodules in bedding plane show rimmed dissolution around nodules. • Solutional fracture also seen in outcrop and extents from top of outcrop down approximately 3 meters.	N\A	Active Karst

3.	N 34° 34' 10.6" W 96° 37' 51.0" Fittstown outcrop location. Highway 377 West side of roadcut on top of the ridge.	• Possibly a collapse solutional conduit that trends N85E. • Approximately 7 meters in length with a depth of 1.5 meters (This is possibly a result of the mining in the area.)	N\A	Active Karst
4.	N 34° 40' 47.4" W 96° 45' 26.1" Off Highway to the east approximately .5 miles. West side of water tower.	• Solutional fractures with high amount of vugular porosity, ranging from 3 to 5 cm vugs. • Some dissolution along bedding planes. • Poor outcrop exposure due to mining in the area.	N\A	Active Karst
5.	N 34° 26' 20.5" W 97° 07' 25.3" Hwy. 77D Northern Arbuckle mountains North side of roadcut	• Single conduit runs down dip to the SW. • No evidence of cement on the walls of the conduit. • Conduit was clean with little regolith infill form surface some rip-rap rubble have calcite popcorn.	N/A	Karst
6.	N 34° 26' 29.5" W 97° 07' 8.1" Highway 77D East side of road cut on the north side of unimproved road.	• Crackle breccia formed by a collapse of a large cavernous conduit, possibly part of a cave system that one might have covered this region. • Clast range from pebble to cobble and with no evidence of dead oil in the matrix of the breccia. • Orientation and direction of the conduit is unknown.	N\A	Paleokarst

7.	N 34° 26' 16.6" W 97° 07' 24.9" Hwy. 77D West side of road cut	Sediment Infill • Conduit that trends in the down dip direction. • Complete infill of sediments. • Sediments have large nodules of hematite weathered from pyrite. • Sediment is light brown to tan hard and compact	N\A	Paleokarst
8.	N 34° 21' 14.9" W 97° 08' 54.3" I-35 outcrop Southern Arbuckles on the East side of roadcut.	SEF Filled Fracture • Calcite spar cement precipitation on sides of cavernous solutional fractures. • Small conduits were observed and vugular porosity. • Conduits do not have sediment infill. • One conduit cross-cuts a fracture that has been filled with spar and indicates that the conduit is younger than the spar precipitation. •	Upper Viola	Paleokarst
8b	N 34° 21' 14.9" W 97° 08' 54.3" I-35 outcrop Southern Arbuckles on the West side of the roadcut.	Fracture Filled with Sediment • Fracture infilled with sediment and clast. • Large blocks of the overlying strata have fallen into a fracture and infilled with sediment. The result is a large breccia with a matrix of sediment. Clast range from boulder to cobble.	Upper Viola	Paleokarst
8c	N 34° 21' 14.9" W 97° 08' 54.3" I-35 outcrop Southern Arbuckles on the West side of the roadcut.	Breccia Filled Conduit • Conduit filled with clast. No evidence of collapse. • Conduit trends in a WNW direction. • The passage can be traced to the east outcrop. • Infill of conduit is due to cavernous material carried through the passage when active. • Conduit dimensions are ft. wide by 2 meters tall.	Upper Viola	Paleokarst

8d	N 34° 21' 14.9" W 97° 08' 54.3" I-35 outcrop Southern Arbuckles on the west side of north bound lane.	Sediment infill conduit • Clast found within sediment. • Areas of mineralization, calcite, pyrite and hematite found surround the feature. • Clast range from .5cm to 1cm. • No noticeable passage trend	Upper Viola	Paleokarst
9.	N 34° 21' 17.8" W 97° 08' 57.2" I-35 outcrop Southern Arbuckles on the East side of the roadcut.	• Small single conduit with some breccia. • Appears orientation is along strike. • No evidence of dead oil in this feature. • This could be a section of the passage work from the large conduit located to the south.	Upper Viola	Paleokarst
10.	N 34° 21' 23.2" W 97° 08' 56.7" I-35 outcrop West side of South bound lane.	• Small single sediment filled conduit approximately 25 cm in diameter. • Clast in the sediment matrix range from .2 cm to 4cm, clast are predominately chert. • Walls of conduit have calcite cement, approximately 1cm thick. • Conduit orientation appears to trend in the direction along strike.	Upper Viola	Paleokarst
11.	N 34° 21' 19.9" W 97° 08' 55.3" I-35 outcrop West side of South bound lane.	• Sediment and breccia filled conduit. • No orientation of conduit. • Cement rimmed the side of the conduit (clear to white). • Clast size range .2cm to 8 cm. • No stratification in the sediment(gray). • Matrix of breccia is calcite cement very angular clast.	Upper Viola	Paleokarst

12.	N 34° 21' 22.4" W 97° 08 58.9" I-35 outcrop West side of South bound lane	• Conduit filled with breccia, clast range form 1 to 9 cm. • Matrix is filled with small clast almost a micro breccia. • Appears to be a widened conduit with adjacent fractures fracture and not a single vertical fracture conduit. • Dead oil found higher up on the outcrop.	Upper Viola	Paleokarst

VITA

Michael Patton Sykes

Candidate for the Degree of

Master of Science

Thesis: Paleokarst Characteristics of the Surface and Subsurface in the Viola Limestone(Ordovician), Arbuckle Mountains, Oklahoma

Major Field: Geology

Biographical:

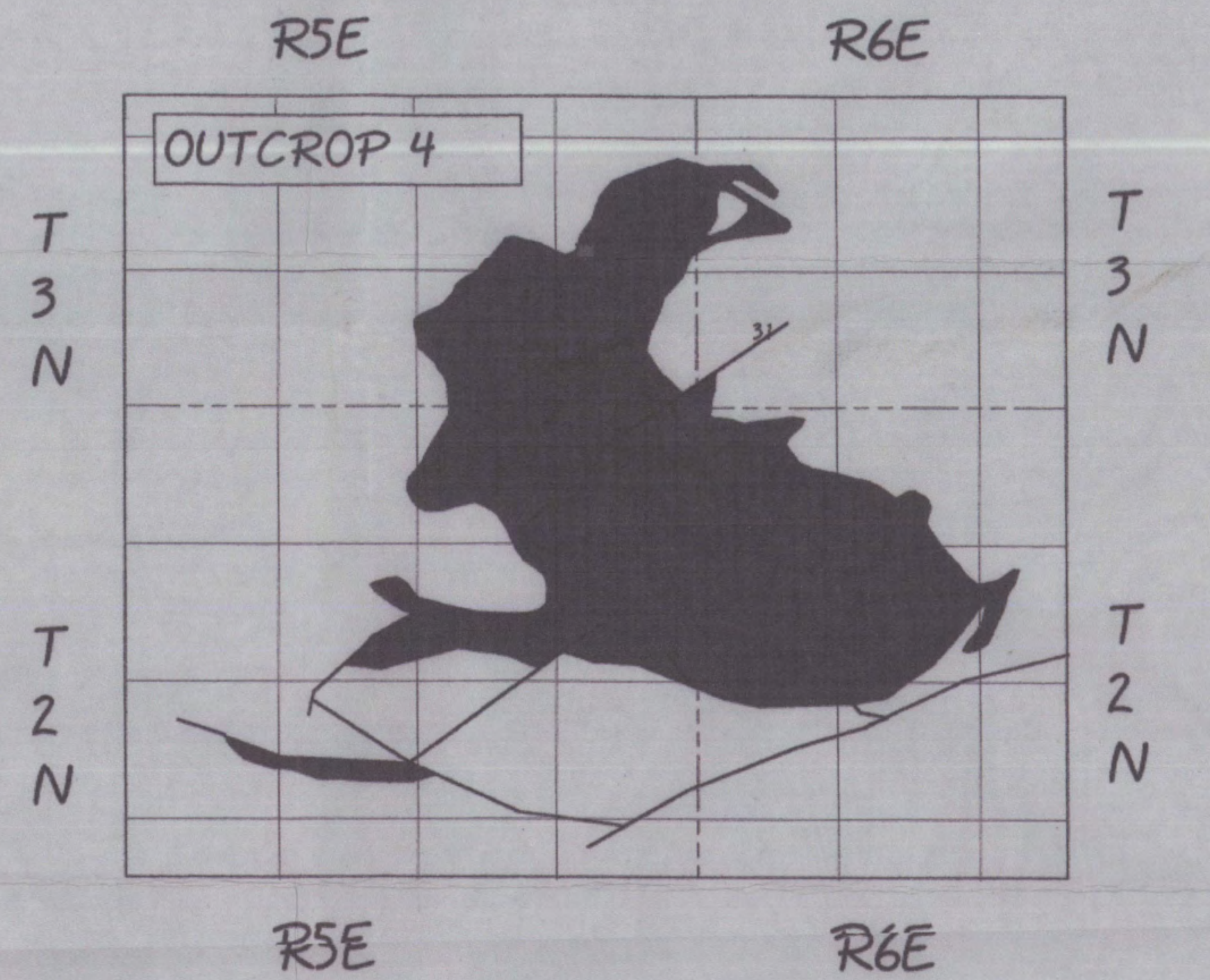
Personal Data: Born in Elkhorn City, Kentucky, the son of Laythe and Frances Sykes.

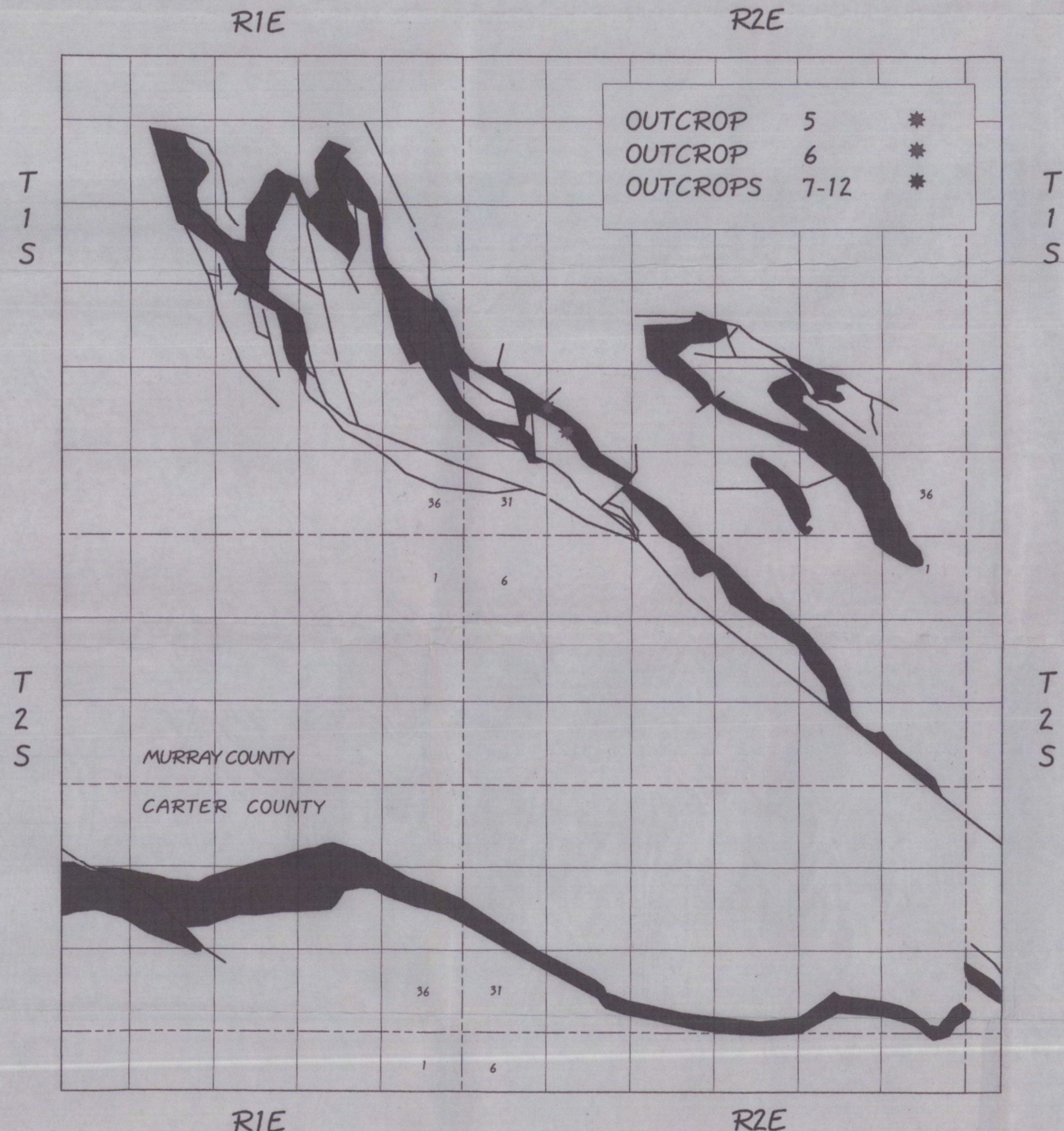
Education: Graduate of Elkhorn City High School, May 1988; received Bachelor of Science from Western Kentucky University, Bowling Green, Kentucky in May 1993; completed requirements for Master of Science in Geology at Oklahoma State University, Stillwater, Oklahoma, December 1995.

Professional Experience: Teaching and Research Assistant: Department of Geology, Oklahoma State University. Teaching Assistant: Department of Geography and Geology, Western Kentucky University.

Plate 1.

PLATE 1





OUTCROP LOCATIONS

1. N 34° 34' 08.9" W 97° 37' 04.4"
2. N 34° 34' 08.9" W 96° 37' 51.5"
3. N 34° 34' 10.6" W 96° 37' 51.0"
4. N 34° 40' 47.4" W 96° 45' 26.1"
5. N 34° 26' 20.5" W 97° 07' 25.3"
6. N 34° 26' 29.5" W 97° 07' 08.1"
7. N 34° 26' 16.6" W 97° 07' 24.9"
8. N 34° 21' 14.9" W 97° 08' 54.3"
9. N 34 ° 21' 17.8" W 97° 08' 57.2"
10. N 34° 21' 23.2" W 97° 08' 56.7"
11. N 34° 21' 19.9" W 97° 08' 55.3"
12. W 34° 21' 22.4" N 97° 08' 59.9"

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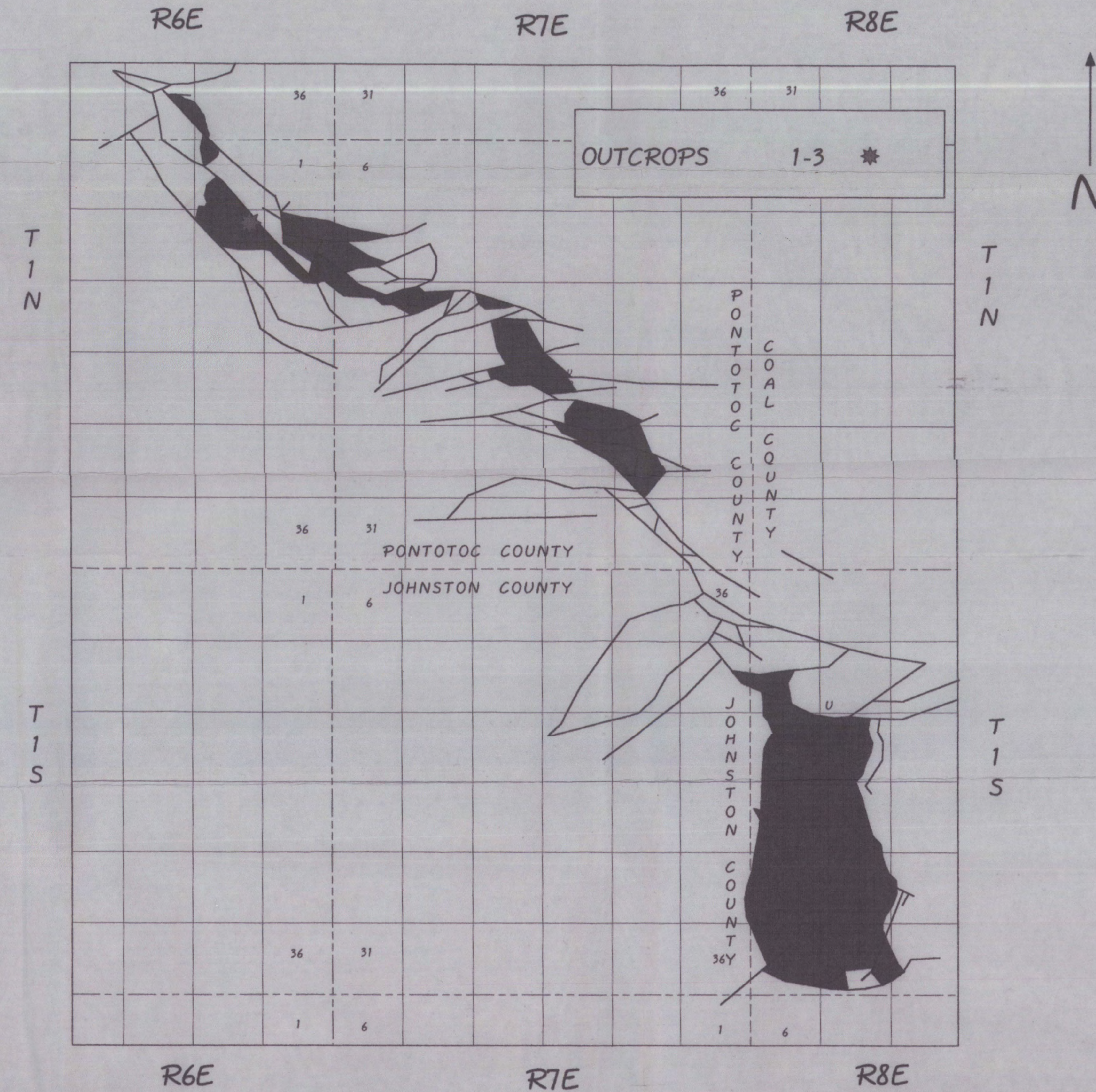

OUTCROP LOCATIONS IN THE ARBUCKLE MOUNTAINS

MICHAEL SYKES OKLAHOMA STATE UNIVERSITY M.S. THESIS DECEMBER 1995

VIOLA/SYLVAN OUTCROPS FROM HAM, MYRON, MCKINLEY AND OTHERS 1954.