OVERPRESSURING AND SEAL STRUCTURE OF PENNSYLVANIAN RED FORK FORMATION IN THE ANADARKO BASIN; OKLAHOMA

By

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DEDICATION

I sincerely dedicate this thesis to my loving parents, to SNH company and to God.

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CHAPTER I

ABSTRACT

Overpressuring, which is a phenomenon common to deep basins, had been detected in the Anadarko basin located in the western Oklahoma and the northern Texas Panhandle for more than a decade. Indeed, the Anadarko basin is the deepest basin in the North American craton. Overpressuring is maintained in deep basins over long geological periods by pressure seals. A pressure seal is a shell-like domain of low permeability sufficient to prevent fluids from escaping from a domain of rocks of relatively good hydraulic conductivity and porosity, called a “compartment”.

The presence of a Megacompartment Complex (MCC) in the Anadarko was first demonstrated by Al-Shaieb et al., 1994. The Megacompartment Complex comprises mainly Pennsylvanian formations from the Morrow through Oswego formation and is enclosed by three types of pressure seals: a basal seal, the Woodford shale, a top seal which cuts across stratigraphy. The lateral seal coincides to the South with the frontal zone of the Wichita Mountain uplift and to the eastern, western and northern boundaries with the convergence of the basal and top seals.

The Red Fork Sandstone is one of the formations cut across by the top planar seal which dips gently southwest. The Red Fork Sandstone is an important producing

reveals that the Red Fork Sandstone is overpressured inside the Megacompartment Complex and normally pressured on the northern shelf. The change of pressure gradients with tectonic setting suggests two distinctive pressure domains: a deep overpressured domain inside the MCC, located in the deep basinal setting, and a near-to-normally pressured domain located on the northern shelf. Moreover, the Red Fork sandstones of the MCC and of the northern shelf present evidence of distinctive and separate, characteristic morphological, textural, mineralogical and diagenetic overprints. The most obvious criterion distinguishing the two is the presence of repetitive small- to medium-scale diagenetic banding patterns that are in the deep overpressured Red Fork Sandstones. These patterns are noticeably absent in sandstones of the near-to-normally pressured Red Fork of the northern shelf. The origin of these bands is attributed to diagenetic alteration of shale host rock, due to deep burial diagenesis (Al-Shaieb et al., 1994). Petrographic examination and x-ray diffraction of these bands reveals that the bands are essentially chloritic in nature (Power, R., 1991; Al-Shaieb et al., 1994).

CHAPTER II

INTRODUCTION

The Anadarko basin is the deepest Paleozoic sedimentary basin of the North American craton (Figure 1). Al Shaieb et al., 1994 distinguished three different levels of compartmentation within the Anadarko basin (Figure 2) based on integrated pore pressure and geologic data. In that study, Al Shaieb et al., (1994) described for the first time the existence of a Megacompartment Complex (MCC) in the Anadarko basin. The basin is enclosed by three pressure seals (Figure 3). The bottom seal coincides with the Woodford Shale whereas the top seal dips gently southwest and cuts across stratigraphy (Al Shaieb et al., 1994). The top seal is found at approximately 7,500-10,000 ft. below surface. The southern lateral seal coincides with the frontal zone of the Wichita Mountain uplift. The eastern, western, and northern boundaries coincide with the convergence of the basal and top seals. The stratigraphy of rocks within the MCC is illustrated on Figure 4 and comprises Siluro-Devonian through Pennsylvanian formations. The Pennsylvanian (Desmoinesian) Red Fork Sandstone, the topic of this study, is a major oil and gas producer in Oklahoma. The Red Fork sandstones display characteristic features related to their depositional environments, tectonic settings, and to their diagenetic history. The Red Fork sandstones reservoirs are overpressured in the deep Anadarko (more than

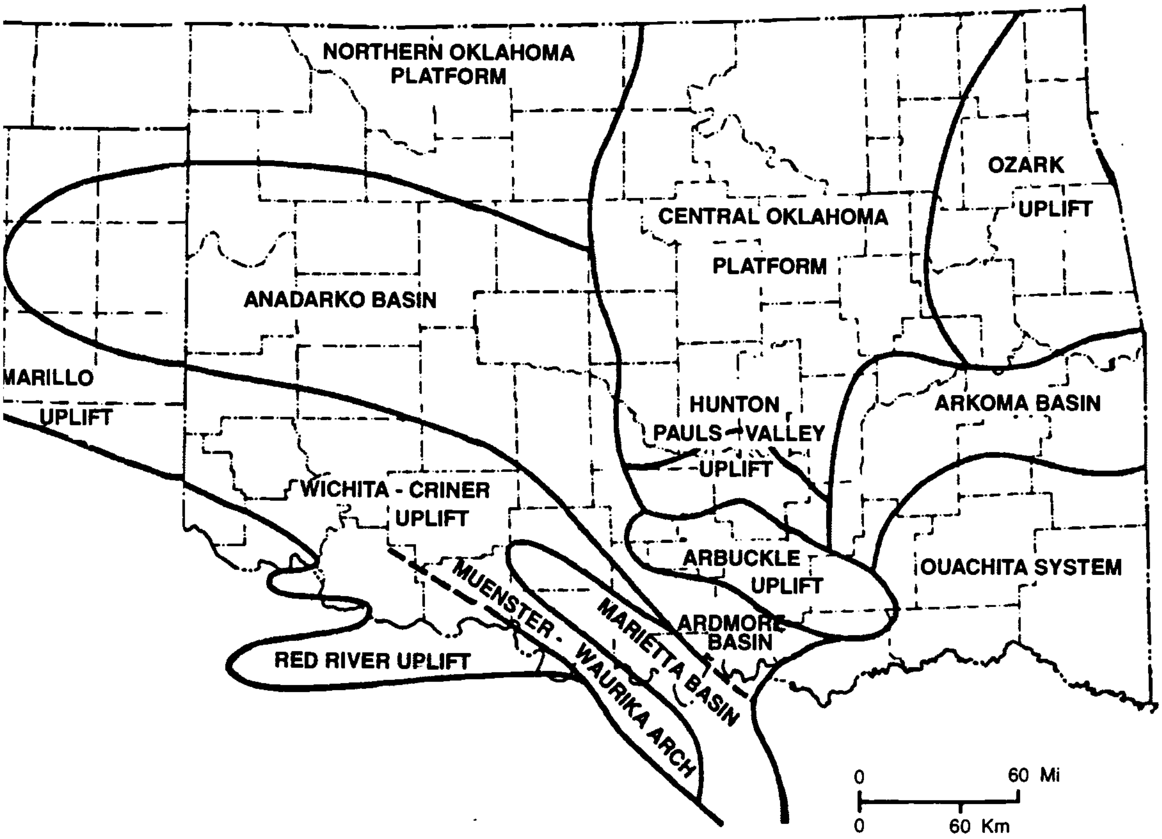


Figure 1. Map showing the location of the Anadarko basin in western Oklahoma, and the major tectonic features of the basin.(After Al-Shaieb and Shelton, 1977.)

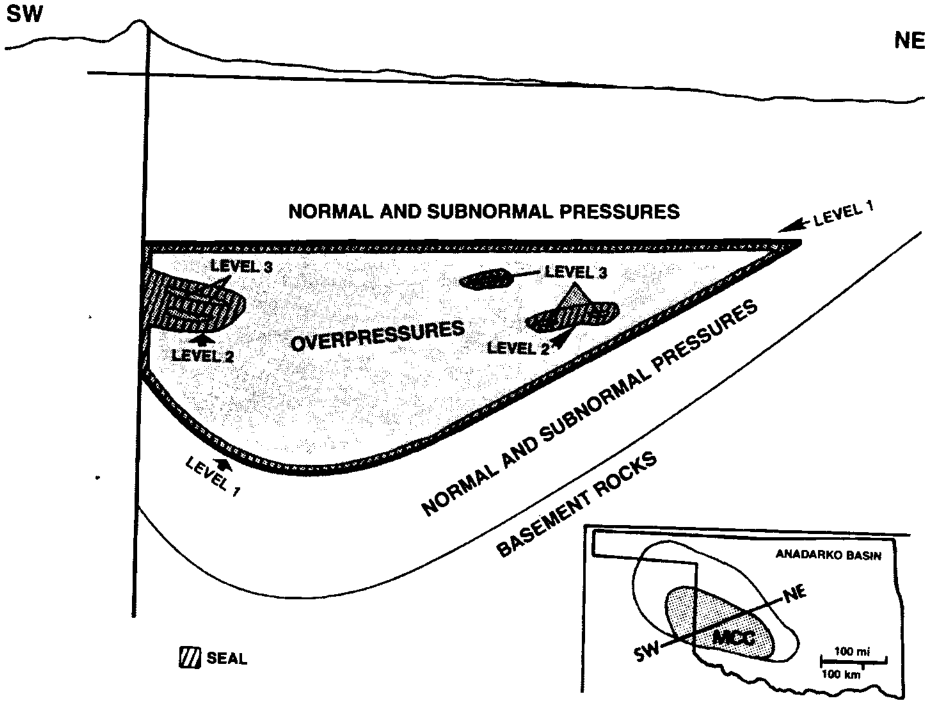


Figure 2. Schematic diagram illustrating the spatial relationship of the three levels of compartmentation in the Anadarko basin.(After Al-Shaieb et al., 1994.)

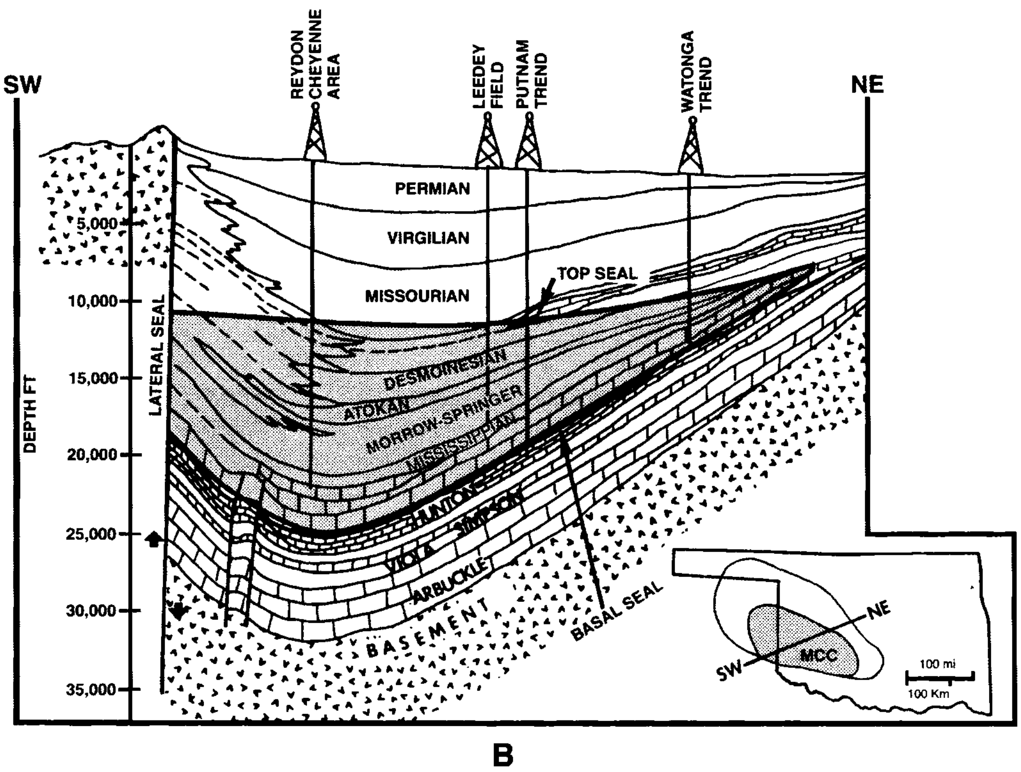


Figure 3. Generalized cross section of the Anadarko showing the spatial position of the MCC within the basin.(After Al-Shaieb et al., 1994.)

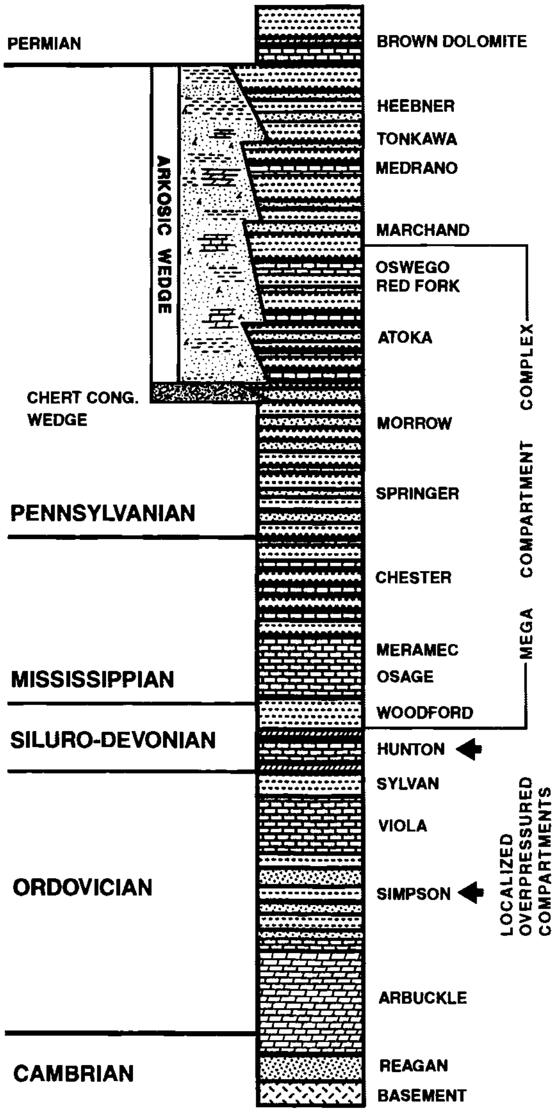


Figure 4. Generalized stratigraphic column of the Anadarko basin showing the intervals contained within the Megacompartment Complex (MCC). (After Al-Shaieb et al., 1994.)

than 11,000 ft.) exhibit repetitive diagenetic bands. These bands are noticeably absent in the Red Fork sandstones of the near- to normally pressured northern shelf. Tiger and Al-Shaieb, (1990), Al Shaieb et al., (1991), and Al Shaieb et al., (1994) indicated the important role these bands play in the sealing mechanism of the deep overpressured sandstones. These studies indicated that the repetition of diagenetic bands enhanced the seal structure in overpressured rocks.

Objectives

The primary objectives of this study are:

1) To verify the presence of compartments in the Red Fork interval within the Anadarko basin;

2) To comparatively analyze the Red Fork rocks of the deep overpressured domain with the Red Fork rocks of the shallow near- to normally pressured northern shelf domain. This analysis will compare: the morphology, the petrology, the mineralogy, and the diagenetic overprints of the Red Fork;

3) To determine the lateral extent of seal rocks and non-seal rocks and;

4) Define a set of criteria that distinguish the Red Fork seal rocks from the non-seal rocks.

Methods of Investigations

The verification of the existence of pressure compartments in the Red Fork gradients was accomplished by examining the pressure-depth profiles from the Anadarko basin. In addition, Red Fork pressure data, mainly bottom hole pressures (BHP), taken from previous investigations were reviewed. The data were plotted on an Oklahoma base map (Figure 5). After reviewing the change from near to normal pressure on the northern shelf to the overpressured deep basin, a stratigraphic cross-section (Figure 6) that extends from the near- to normally pressured area into the overpressured deep basin was prepared. Correlations were done using wire-line signatures. Depositional features and sedimentary structures were studied from five cores (Figure 7) to verify the depositional settings and environments of the Red Fork. The mineralogy and diagenetic overprints of the Red Fork were studied from thin sections, microscopy, and x-ray diffraction.

Petroleum Geology

In the deep overpressured Anadarko basin the Middle Pennsylvanian (Desmoinesian) Red Fork sandstones are thick and constitute excellent reservoirs for natural gas. In the near- to normally pressured northern shelf of the Anadarko basin, the Red Fork sandstones are shallower and thinner and constitute important oil reservoirs.

The Red Fork sandstones produce primarily from stratigraphic traps; such as lenticular sandstone bodies that abruptly terminate against shale. In the deep Anadarko basin, the Red Fork sandstones have lower porosities and permeabilities than their northern shelf counterparts. The Excello black shale and other Cherokee Group black marine shales are considered to be primary hydrocarbon source rocks for Desmoinesian

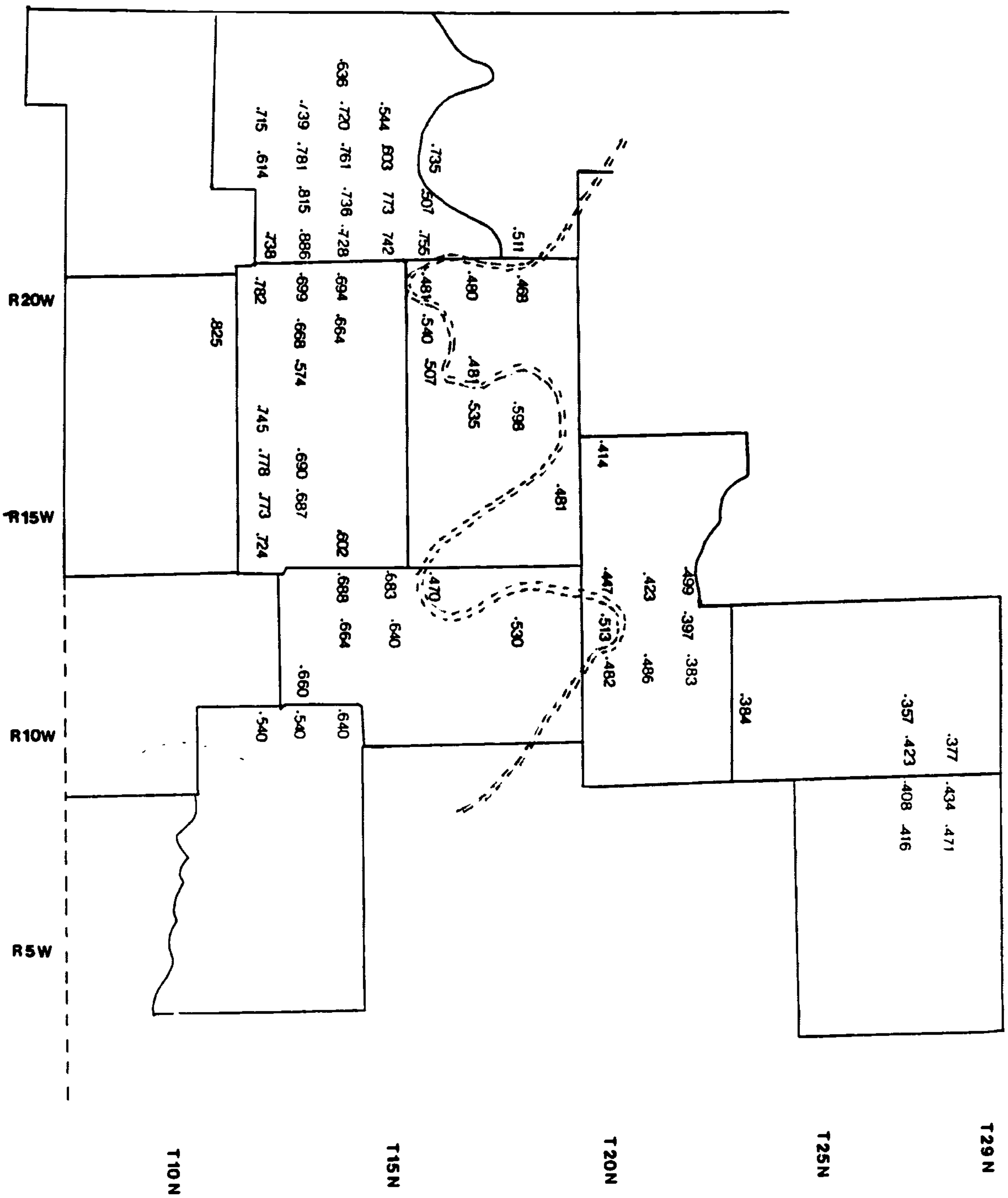


Figure 5. Distribution of the Red Fork pressure-depth gradients and location of the overpressured domain and the near-to-normally pressured northern shelf the dashed line represents the transition zone between the two domains.

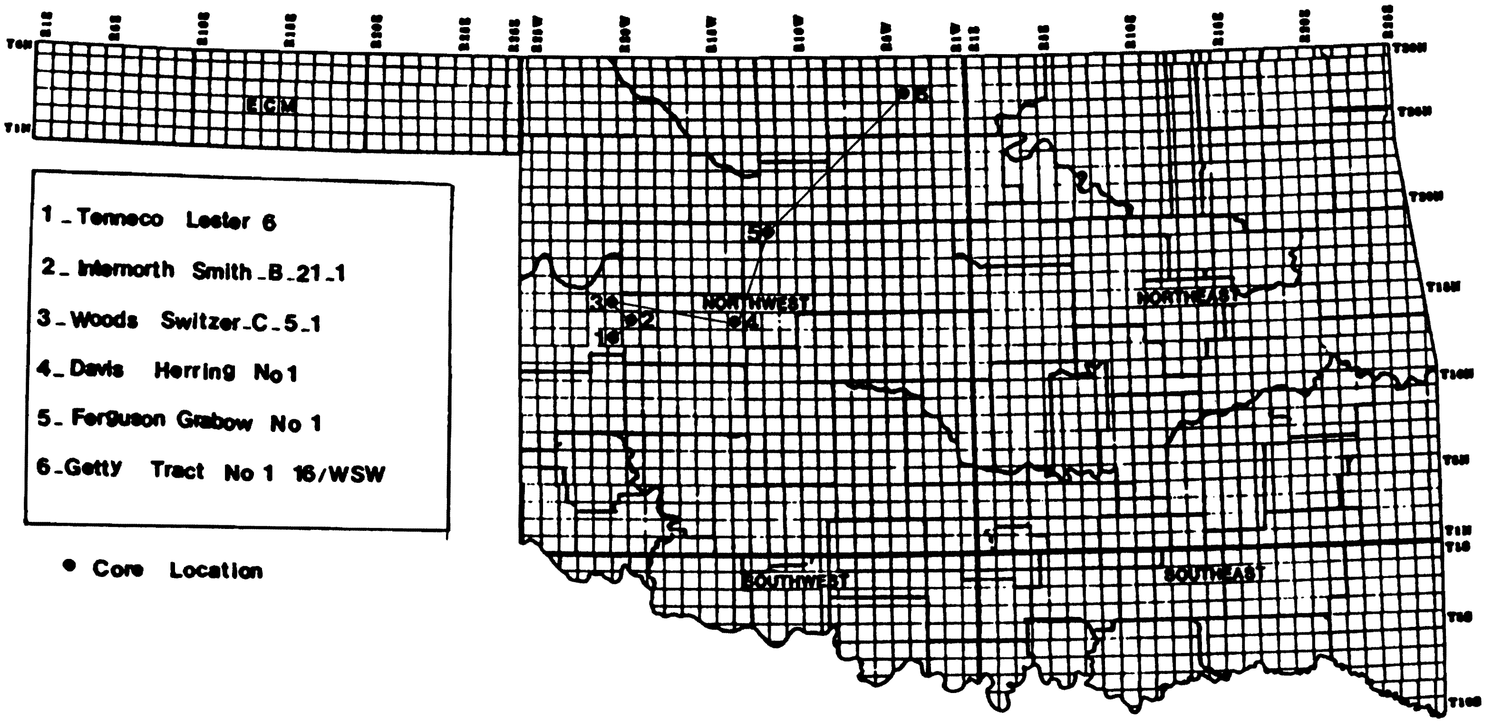


Figure 6. Cross section location map.

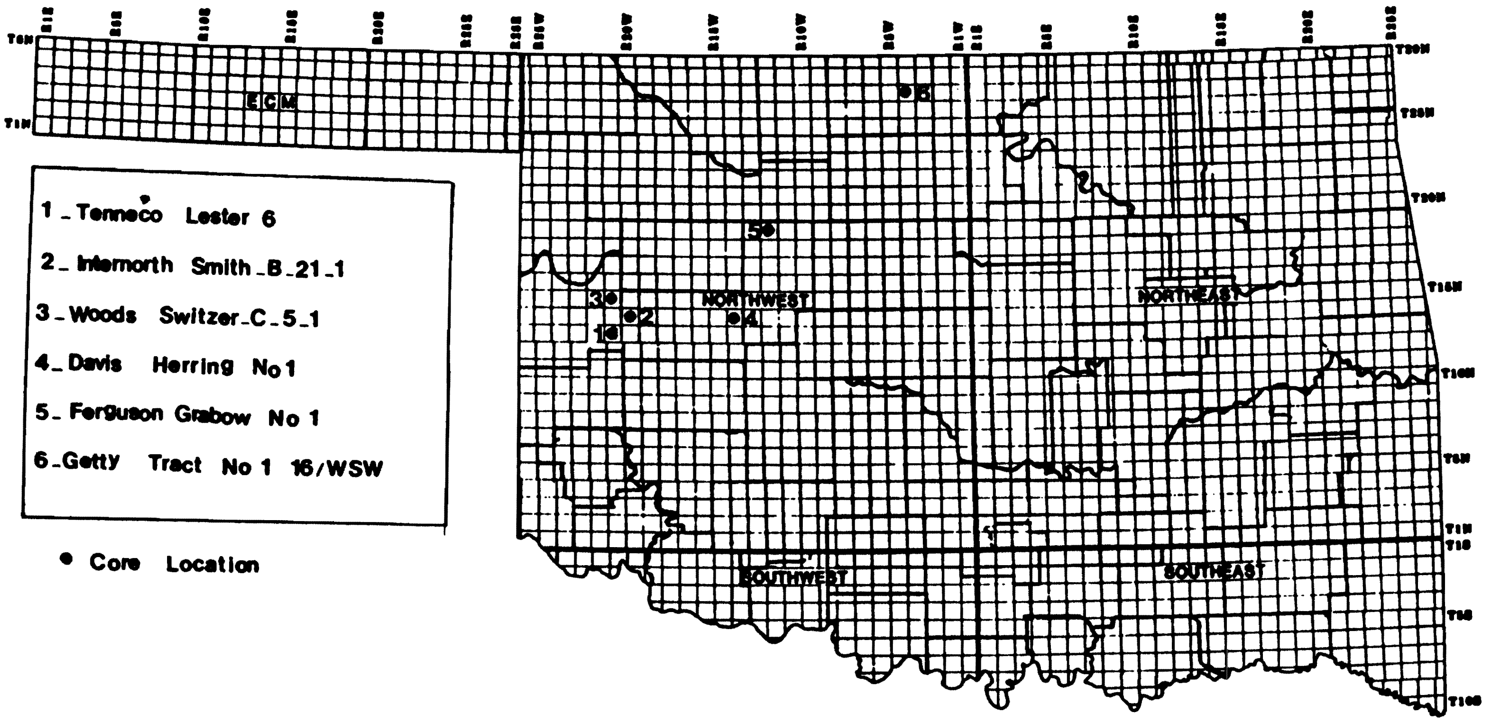


Figure 7. Core location map.

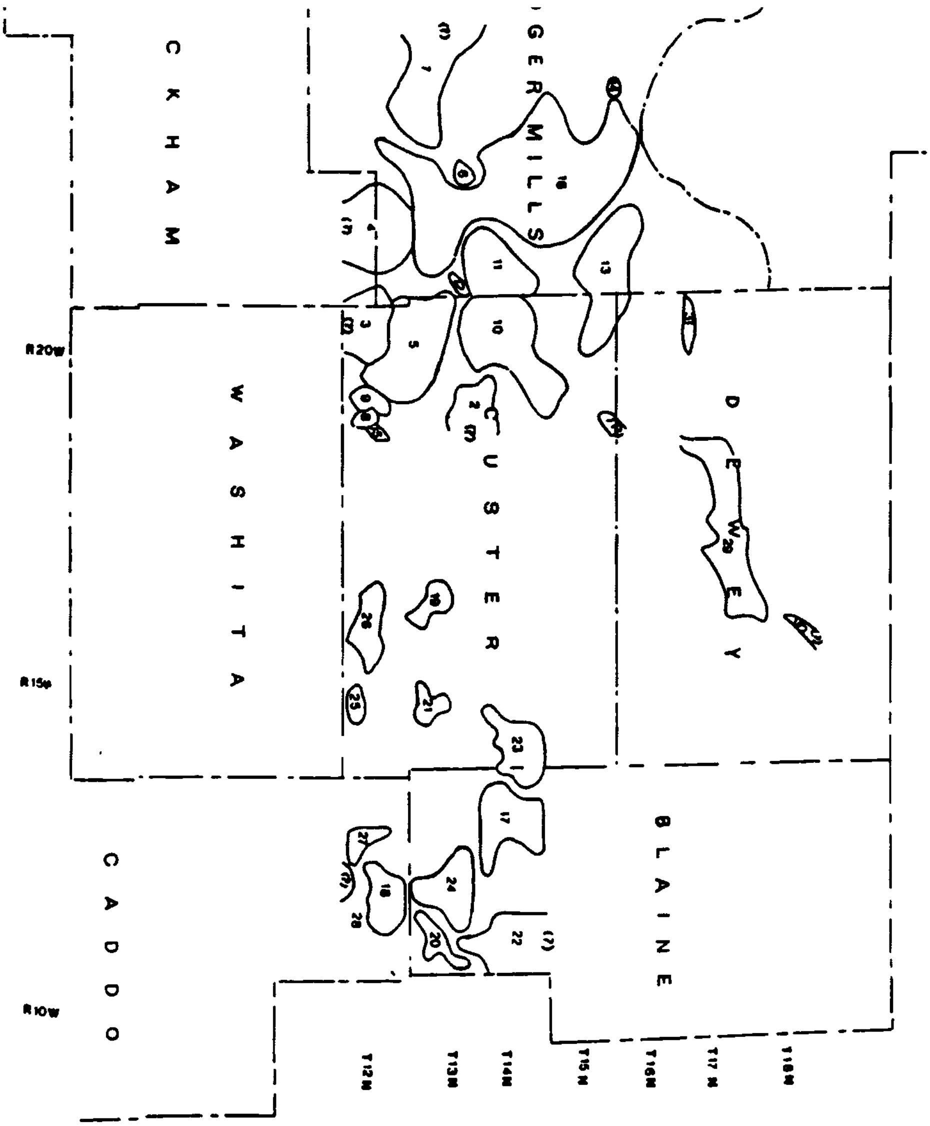
sandstones reservoirs in northeastern Oklahoma (Baker, 1962, James and Baker, 1972). These core shales (Heckel, 1985) contain a mixture of type I and type III kerogens (Ece, 1989; Rice and other, 1989). A number of oil and gas fields have been developed in the Red Fork sandstones of both pressure domains. Table 1 gives a listing of some major Red Fork oil and gas fields and their locations are illustrated on Figure 8.

Table 1 : Total production of Major Red Fork oil and Gas fileds

Field name	Discovery date	Cumulative Oil production (bbl)	Cumulative gas production (MCF)
S. W Aledo	5/72	498,911	18,551,865
West Butler - Custer	2/82	568,096	13,683,896
North Canute	9/62	1,208,189	90,782,329
Carpenter	1/71	641,773	270,664,071
N. E. Carpenter	11/80	858,601	50,292,856
East Cheyenne	4/81	7,259	879,512
West Cheyenne	11/76	41,698	359,198,838
Foss	10/82	18,993	9,803,300
N. W. Foss	10/82	62,862	6,883,120
East Hammon	2/82	748,333	40,879,433
N. W. Hammon	8/81	158,136	13,643,851
S. W.Hammon	8/80	243	932,128
Leedley	8/70	314,057	27,606,553
Stafford	3/82	175,503	12,157,233
Strong City	7/80	3,684,714	343,748,406
Putnam *	2/66	2,788,999	58632
South Trial	2/77	119,623	19,576
Squaw -Creek	10/64	204,671	792,693
Bridgeport- South and West	9/69	47,024	6,089,241
Indianapolis	9/71	22,984	528,797
Geary	10/72	793,624	81,871,309
Watonga - Chickasha Trend	1/75	28,565	1,959,795
South Thomas	4/76	2,983,624	81,871,309
East Clinton	6/80	477,818	42,582,124
Carpenter **	1/82	10,100	459,066

* Total Production as of July, 1990 (After Anderson, 1992)

** After Udayshanker, 1985 and Johnson, 1984



1	S.W Aledo	16	Strong City
2	West Butler - Custer	17	Squaw Creek
3	North Canute	18	Bridgeport-South and West
4	Carpenter	19	Indianapolis
5	N.E. Carpenter	20	Geary
6	East Cheyenne	21	Northwest Weatherford
7	West Cheyenne	22	Watonga- Chickasha trend
8	Foss	23	South Thomas
9	N.W. Foss	24	Elm Grove
10	East Hammon	25	South Weatherford
11	N.W. Hammon	26	East Clinton
12	S.W. Hammon	27	Libbie
13	Leedey	28	Carpenter**
14	N.W. Roll	29	Putnam*
15	Stafford	30	North West Hucmac Field
		31	South Trail

Figure 8 Location of some major Red Fork oil and gas fields in the

CHAPTER III

PREVIOUS INVESTIGATIONS

Depositional Environment of the Red Fork Sandstone

Due to its economic significance, numerous geologic studies have been conducted on the Red Fork. Many of these studies have contributed to the understanding of the Red Fork depositional environments. Some studies also addressed the geometry, petrology, provenance and the diagenesis of the Red Fork Sandstone in the deep Anadarko basin as well as on the northern shelf, and northeastern Oklahoma platform.

McElroy (1961) analyzed the Red Fork in north-central Oklahoma along the Nemaha Ridge and determined that the Red Fork was fluvial and was affected by the positive tectonic feature. Thalman (1967) studied the Red Fork in Oakfield field in Woods and Major Counties, Oklahoma. He found that the Red Fork contained two genetic units: Upper Red Fork and Lower Red Fork. Thalman (1967) interpreted the Lower Red Fork Sandstone as channel-fill "bar finger" or "river bar" deposits. He also concluded that the Upper Red Fork sandstones were delta plain or flood plain deposits. More recent work suggests that the fluvial "river bar" interpretation is the more likely Berg (1969) showed that the Red Fork was deposited in a distributary system in north central north central and northeastern Oklahoma. He suggested that the Nemaha Ridge may have acted as a barrier for sediment sources to the north and east. He based his interpretation on the presence of thicker sandstone deposits on the east side of the Nemaha Ridge. Lyon (1971) who studied the Red Fork in Alfalfa, Major, and Woods Counties, Oklahoma, described the depositional environment as a fluvial system. He divided the Red Fork into an upper, middle and lower intervals. Zeliff (1976) described the Red Fork depositional environment as a fluvial system in Kingfisher County. Albano (1975) and Pulling (1977) suggested that the Red Fork sandstones in central Oklahoma were primarily deposited in deltaic distributary environments. Glass (1981) studied the Wakita trend and determined that the depositional environment of the Red Fork was a fluvial-dominated system

Johnson (1984) interpreted the Lower Red Fork Sandstone in the South Thomas field as submarine type deposits. These lowstand accumulations occur beyond the delta complex above the shelf-slope hinge line. Johnson suggested that the Upper Red Fork was deposited by channels within deltaic environments or associated shallow marine environments. Udayashankar (1985) interpreted the Red Fork in Dewey County, Oklahoma as deltaic distributary channel. He also delineated an Upper and Lower Red Fork based on a calcareous marker bed. Anderson (1992) focused on the distribution of the Upper Red Fork in Beckham, Custer, Dewey, and Roger Mills, Counties, Oklahoma. He showed that the Upper Red Fork sandstones were deposited in a variety of submarine settings including upper, middle, lower parts of submarine fans and in the basin plain.

Seals and Compartmentation in the Anadarko Basin

Abnormal or anomalous formation pressures are defined as pressures that are either higher (overpressure) or lower (underpressure) than the normal hydrostatic pressure (Bradley, 1975). The normal hydrostatic pressure is 0.465 psi/ft. (10.52 kPa/m). According to Ortoleva (1994) a compartment is a domain of rock of relatively good hydraulic conductivity and porosity surrounded by a shell-like domain of sufficiently low permeability that the fluids within the compartment do not have appreciable exchange with the outside environment for long periods of geologic time. This definition implies that a compartment is primarily defined by its hydraulic potential, which is maintained by a three dimensional feature , the seal, that prevents pressure equilibration to normal hydrostatic pressure, by restricting fluids movement.

Compartments are easily recognized on pressure-depth profiles (PDP's) by their departure from the normal hydrostatic gradient to the surface (Figure 9). When a basin subsides and is buried, it becomes a chemical reactor of grand proportions in which sediments and fluids (reactants) are continually being exchanged with the environment. As a result, a variety of diagenetic reactions takes place. They involve strongly coupled reactions, transport, and mechanical processes (RTM) which drive the basin reactor from equilibrium conditions to far-from-equilibrium conditions, which they maintain. Compartments and seals are manifestations of this far-from-equilibrium dynamic (Ortoleva, 1994).

Previous investigations in the deep Anadarko basin by : Powley, (1987), Tigert

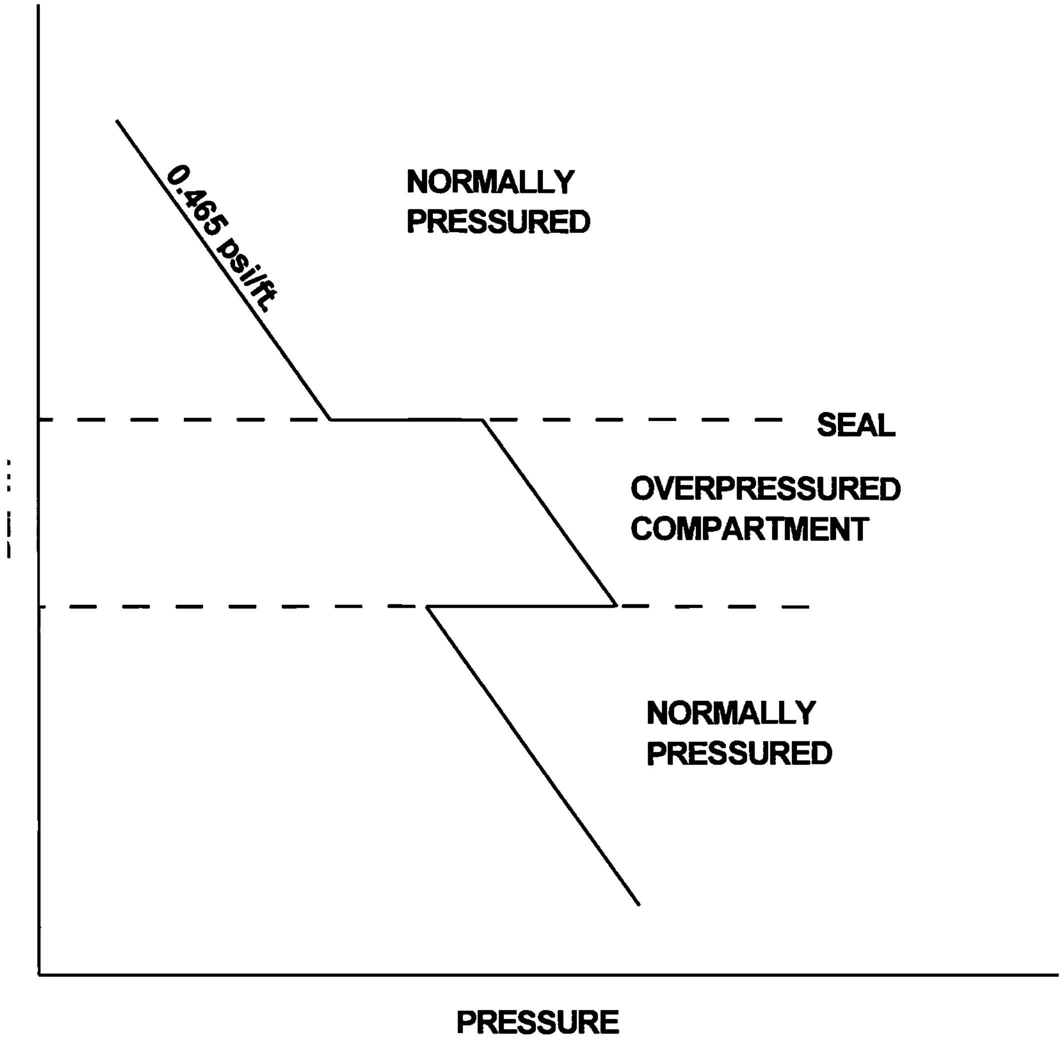


Figure 9. Illustration of an overpressured comparment on a pressure-depth profile.

recognized abnormally pressured zones in the basin. Based on the examination or the study of pressure-depth profiles (Figures 10, 11), cored seal intervals, pressure-depth gradient maps of the Missourian/Virgilian, Red Fork, Morrow, and Hunton intervals, Al-Shaieb et al., (1994) demonstrated the existence of a basinwide, completely sealed overpressured region within the Anadarko basin called the Megacompartment Complex (MCC). That study demonstrated that the near- to normal pressure-depth gradients are characteristic of the Missourian/Virgilian (Figure 12) and that near-to-normal pressure-depth gradients are typical of the Hunton (Figure 13). The same study demonstrated that the Morrow (Figure 14) and the Red Fork (Figure 15) pressure gradients increase significantly from the shelf to basinal settings. Three levels of compartmentation were distinguished in the Anadarko basin (Al Shaieb et al., 1994) (Figure 2). Level 1 is the basinwide overpressured volume of rocks that are completely enclosed by seals called Megacompartment Complex (MCC). Multiple, district-, or field-sized configurations within a particular stratigraphic interval are identified as Level 2 compartments. The last level of compartmentation, Level 3, consists of a single small field or a particular reservoir nested within Level 2.

The Anadarko basin study demonstrated that the top of overpressuring (top seal) is approximately 10,000 to 11,000 ft. (3,000 m) deep in the western and central parts of the basin, but around 7,500 ft. (2,300 m) in the shelf setting. The top seal along the eastern fringe of the basin dips slightly southwestward and coincides with the argillaceous Mississippian carbonates and Pennsylvanian shale/sandstone sequences.

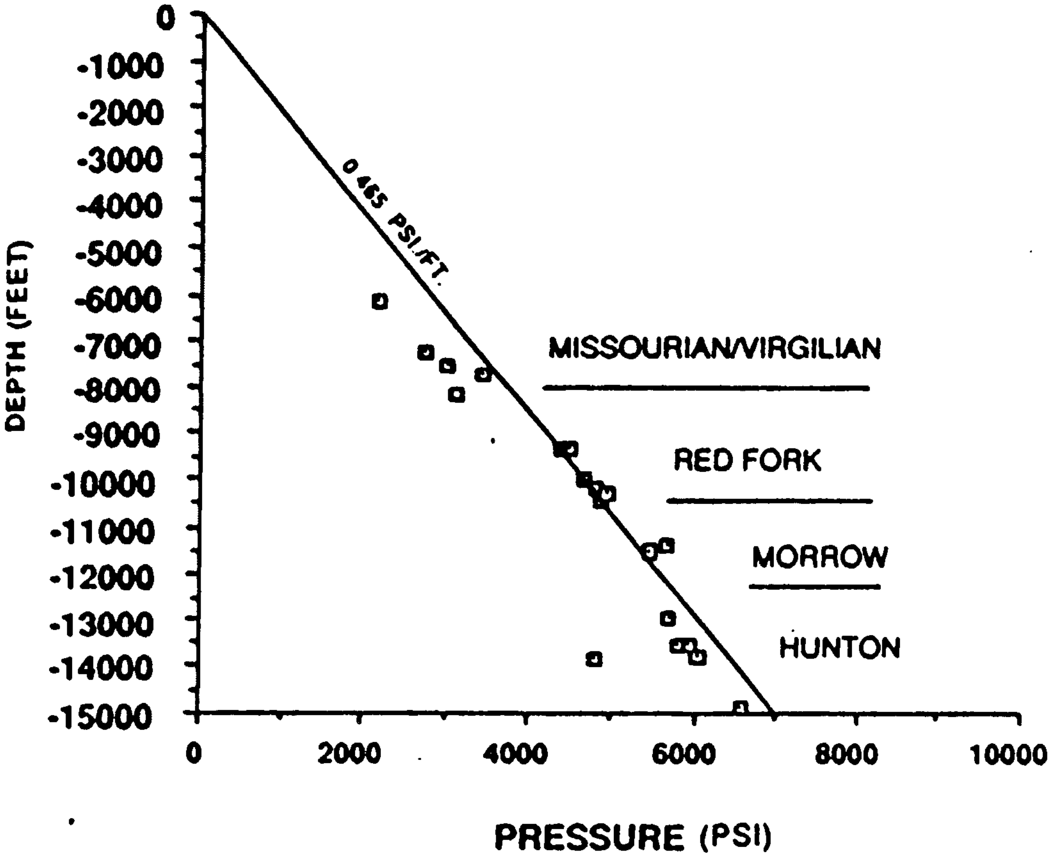


Figure 10. Pressure-depth profile from T. 17 N., R. 18 W. and T. 18 N., R. 18 W. showing normal-pressured Red Fork on the shelf of the Anadarko basin. (After Al-Shaieb et al., 1994.)

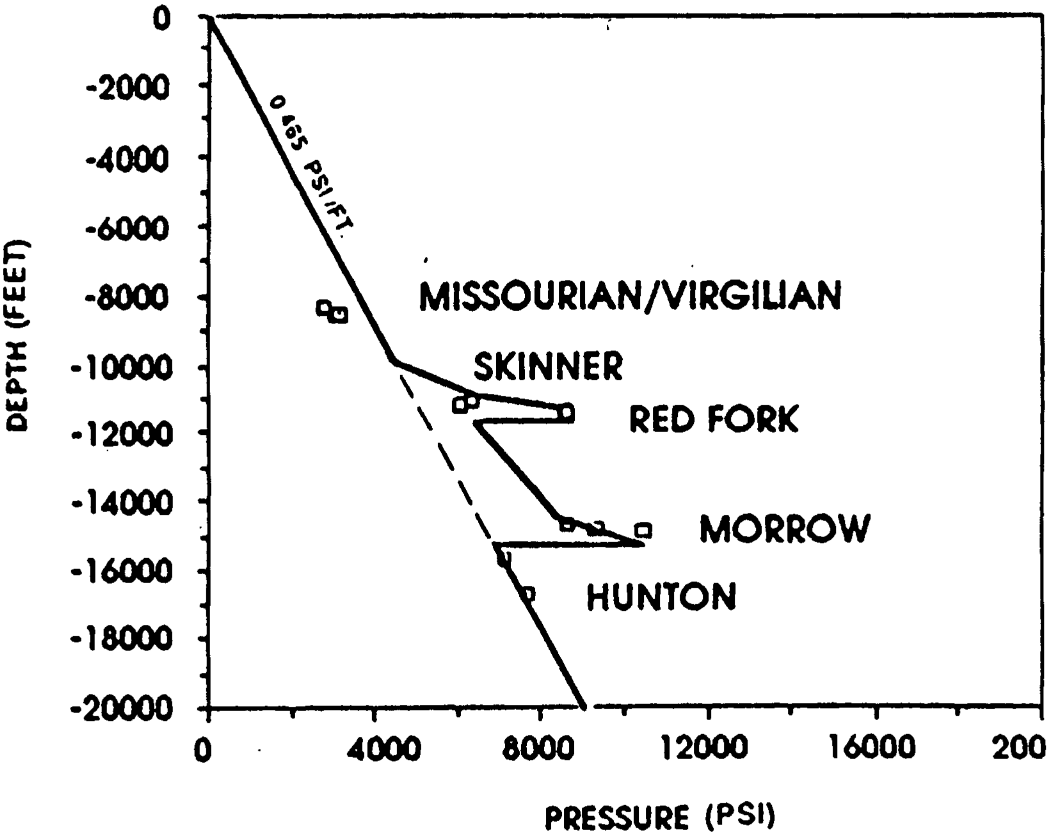


Figure 11. Pressure-depth profile showing overpressured Red Fork in the vicinity of the Woods Switzer "C" in the southwest Leedey field. (After Al-Shaieb et al., 1994.)

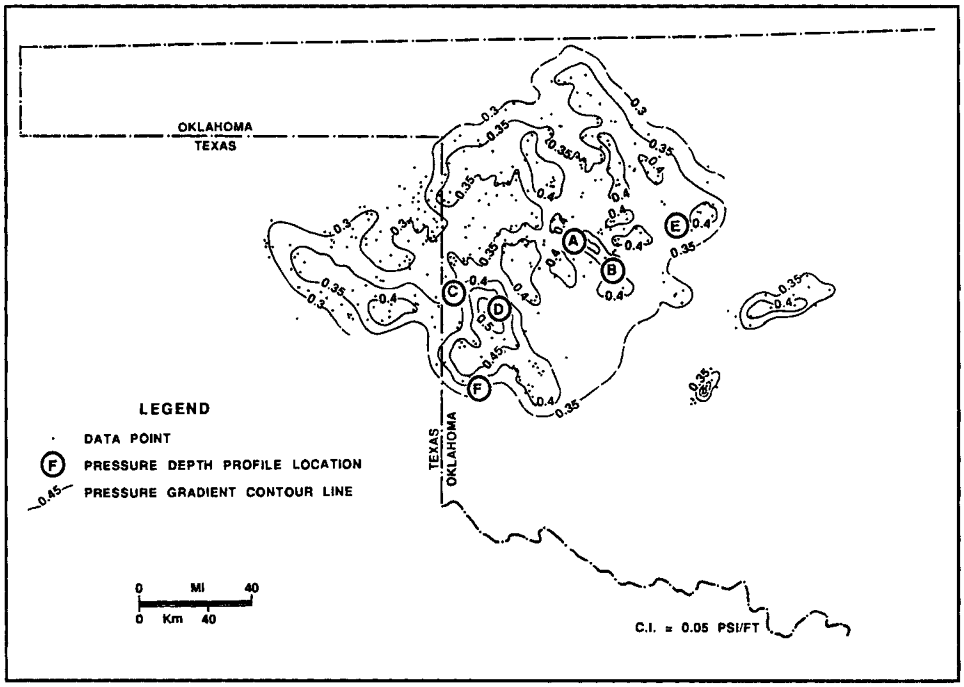


Figure 12. Pressure-depth gradient map of the Missourian/Virgilian sequences. Contour lines indicating predominantly normal pressure regime. (After Al-Shaieb et al., 1994.)

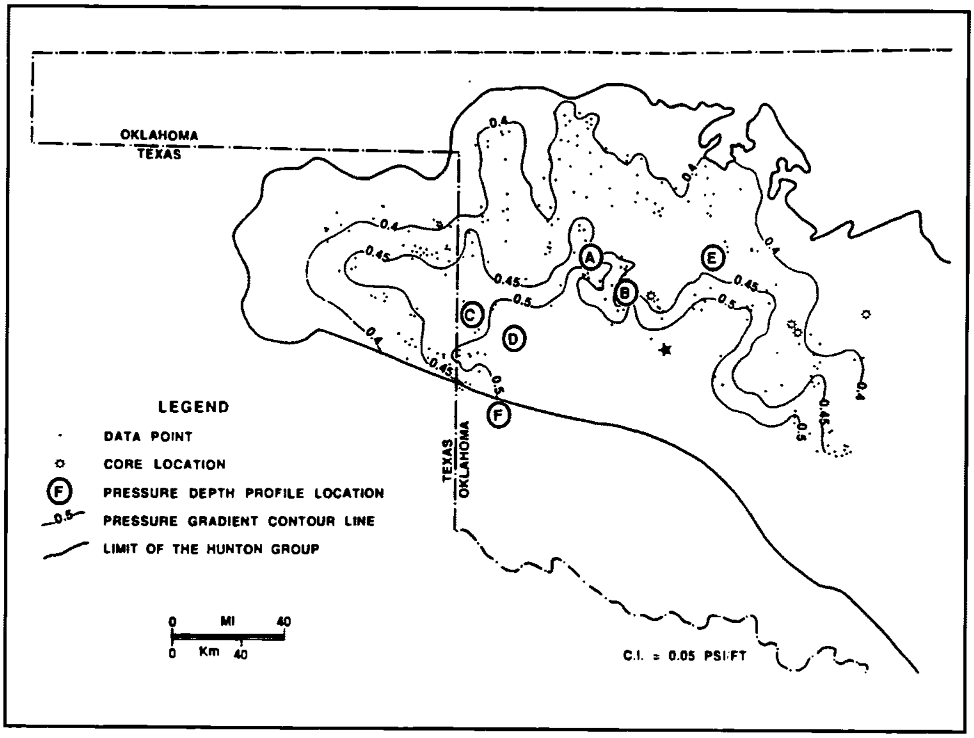


Figure 13. Pressure-depths gradients map of the Hunton Group showing normal pressure regime. (After Al-Shaieb et al., 1994.)

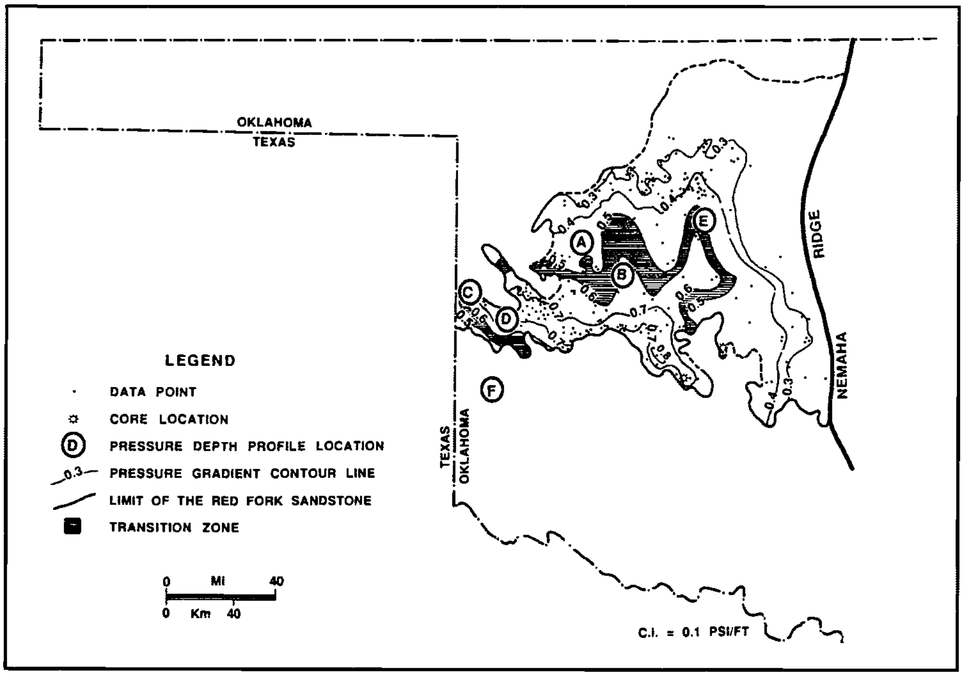


Figure 14. Pressure-depth gradient map of the Morrowan Series. (Modified, after Al-Shaieb et al., 1994.)

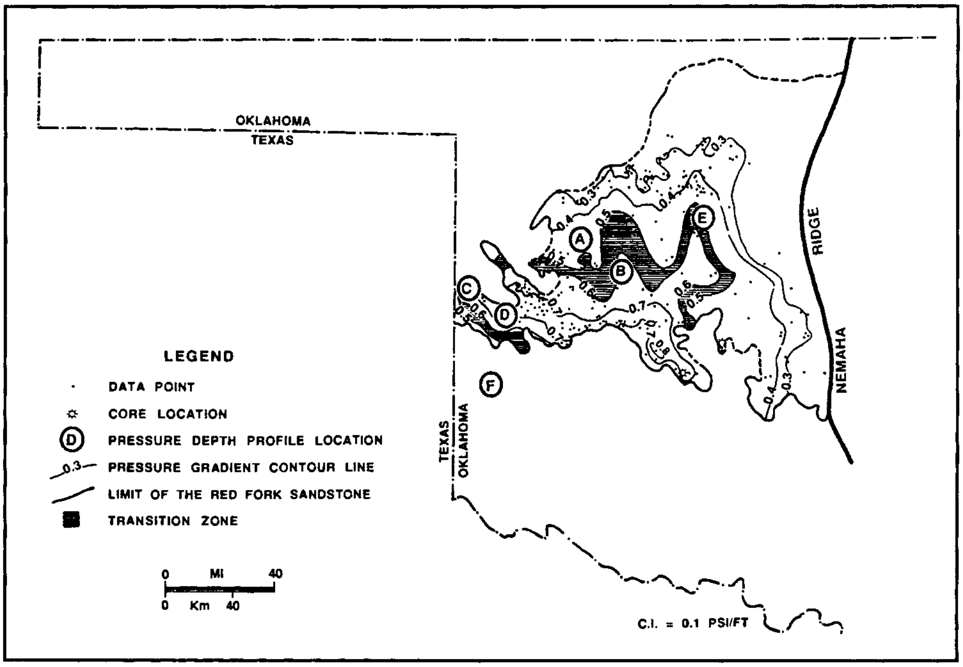


Figure 15. Pressure-depth gradient of the Red Fork indicating an increase of pressure from shelf to basinal setting. (Modified, after Al-Shaieb et al., 1994.)

Westward the top seal becomes flat-lying and cuts across stratigraphic boundaries into younger Missourian-Virgilian rocks. The formation of the top seal is believed to be diagenetically controlled (Tigert and Al-Shaieb, 1990; Al-Shaieb et al., 1994). The basal seal of the MCC is lithologically controlled and coincides with the Woodford Shale in the northern and western parts of the basin, whereas in the southern part the basal seal may coincide with the Mississippian Caney and/or Woodford shales. The nearly vertical frontal fault zone of the Wichita uplift constitutes the southern lateral seal of the MCC. The lateral seal along the northern, western, and eastern boundaries of the MCC is stratigraphically controlled and formed by the convergence of the top and basal seals. Al-Shaieb et al., (1994) and Tigert and Al Shaieb, (1990) studied pressure seals in sand-rich rocks as well as clay rich-rich rocks and indicated that these pressures seals exhibit characteristic banding patterns which have a unique mineralogical and morphological characteristics. Banding patterns are typically observed in rocks that were buried deep enough to be overpressured and are noticeably absent in near to normally pressured rocks that experienced shallow burial and did not enter the "seal window" (Al-Shaieb et al., 1994).

Pressures and Hydrodynamic properties of the Red Fork Interval

Pressure-depth gradient map (Figure 15) of the Red Fork shows that pressure-depth gradients increase significantly from under- to normal gradients on the shelf to overpressured gradients in the deeper basin. A transition zone separates the under-zone tends to mimic the limit of deposition of the Red Fork. The comparison of two pressure-depth profiles: (1) from the northern shelf of the Anadarko basin and (2) from the deep western part of the basin, shows that the Red Fork is normally pressured on the shelf (Figure 10) and overpressured (Figure 11) in the deep Anadarko basin. The potentiometric diagram (Figure 16) of the Red Fork shows two major peaks representing the two major overpressured Red Fork compartments. The two major pressure domains referred to in this study are: (1) a deep overpressured domain located in west central Oklahoma that is characterized by pressure-depth gradients greater than 0.5 psi and (2) a shallow near-to-normally pressured domain located on the northern shelf with pressure-depth gradients less than 0.5 psi.

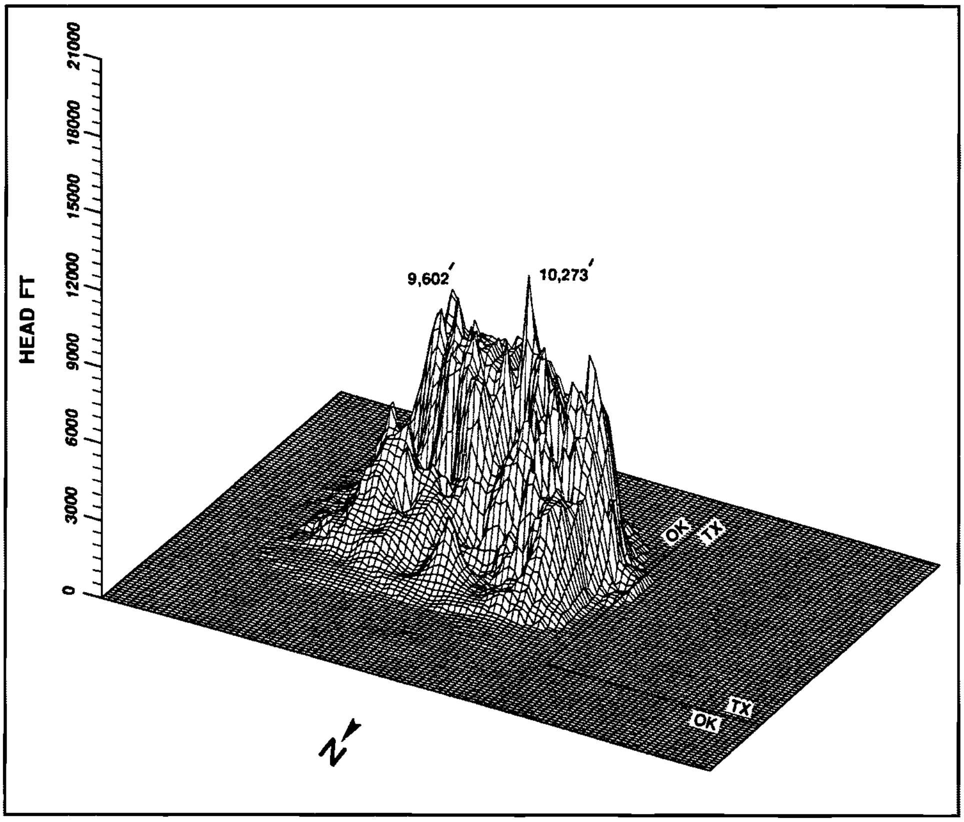


Figure 16. Potentiometric diagram of the Red Fork.(After Al-Shaieb et al., 1994.)

CHAPTER IV

GEOLOGIC SETTING

Regional Structural Geology

The Anadarko basin, located in western Oklahoma and the northern Texas Panhandle, is an elongated, asymmetric, west-northwest trending basin (Figure 1). Its axis is close to the southern margin that separates the basin from the Wichita mountain uplift. The maximum structural separation between the uplift and the basin floor is about 40,000 ft.(13,000 ft.) (Johnson, 1989). The basin covers an area of approximately 90,000 Km^2 (35,000 mi^2). It is bounded to the east by the Nemaha Ridge, to the south by the ancient eroded Amarillo-Wichita mountain front and the Marietta basin, to the southeast by the Ardmore basin and the Arbuckle uplift and to the north and west by the northern shelf (Cardot and Lambert, 1985).

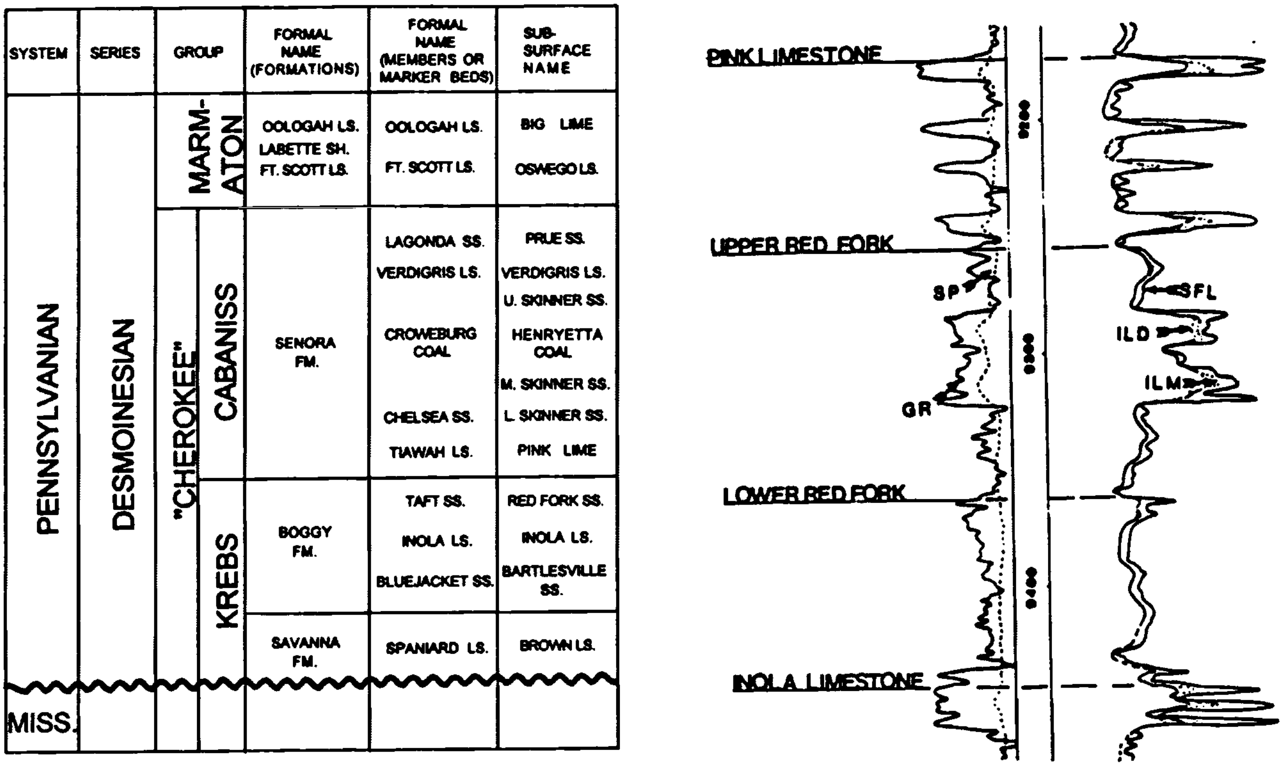
The Anadarko basin is part of the southern Oklahoma aulacogen (Hoffman et al, 1974). The rifting phase of the southern Oklahoma aulacogen began during Cambrian time. The event produced normal faults and igneous rocks were emplaced in the area occupied by the present Anadarko basin and Amarillo-Wichita uplift. Subsidence, ascribed to cooling after a thermal event associated with Cambrian crustal thinning

(Feinstein, 1981; Denison, 1982; Garner and Turcotte, 1984), occurred in the aulacogen in several phases from Late Cambrian through Early Mississippian (Hoffman et al. 1974; Amsden, 1975; Webster, 1977, 1980; Brewer et al., 1983). Relatively rapid rates of subsidence are characteristic of the Cambro-Ordovician. A Late Mississippian to Early Pennsylvalnian subsidence phase, which followed relatively slow rates of subsidence in the Silurian, Devonian, and Early Mississippian, was characterized by an extremely rapid rate of subsidence. This subsident phase coincides with the tectonic development of the Anadarko basin and Wichita mountain uplift. Evans (1974) stated that "maximum rates of subsidence were achieved in Morrowan and Atokan times and the major pulse of vertical uplift occurred in Late Atokan time." Dickinson and Yarborough (1977), and Donovan et al. (1983) illustrated the accelerated subsidence during the Late Mississippian to Early Pennsylvanian using sediment-accumulation plots. By Early Pennsylvanian, the Wichita orogeny raised vertical fault blocks in the Amarillo-Wichita uplift along reactivated zones of weakness produced during the initial graben stage. As the Amarillo-Wichita uplift was elevated, it was eroded. As a result, by Early Pennsylvanian, some 3,000 m (10,000 ft.) of Springer-Morrowan and Atokan rocks were deposited in the Anadarko basin. The rate of subsidence was slowed from the Desmoinesian (Middle Pennsylvanian) through Permian time due to 'thermal contraction' as the lithosphere returned to equilibrium (Garner and Turcotte, 1984).

Red Fork Stratigraphy

The Red Fork Formation is part of the Krebs Group, the lowest group of the Desmoinesian Series of the Pennsylvanian System (Oakes, 1953) (Figure 17). Haworth and Kirk (1984) first used the term "Cherokee" for the sequence of black shales below the Pennsylvanian "Oswego" (Fort Scott) Limestone and the top of the undulating erosional Mississippian strata in Cherokee County, Kansas (Withrow, 1968). The term was applied to same stratigraphic interval in Oklahoma. Oakes (1953) subdivided the Cherokee Group of the northeastern and central Oklahoma into the "Krebs Group" and the "Cabaniss Group". Howe (1956) readopted the term Cherokee Group and divided it into the Krebs and Cabaniss Subgroups. In Oklahoma, the Krebs and the Cabaniss Groups are informally referred to as the "Cherokee Group." The Cherokee Group consists of interbedded sandstone and shale "packages" that are separated by limestone marker beds (Jordan, 1957). These limestone marker beds represent extensive periodic transgressions of the Cherokee Sea onto the platform, whereas interbedded sandstone and shale are records of regressive episodes of the Cherokee Sea.

The Red Fork interval is defined as the interval from the base of the Pink Limestone to the top of the Inola Limestone (Figure 17). The Red Fork Sandstone was named by Hutchinson (1911) to describe a shallow oil-producing sandstone in the Red Fork field near the town of Red Fork, southwest of Tulsa, Oklahoma. The stratigraphic surface equivalent name of the Red Fork is the Taft Sandstone. Subsurface equivalents of the Red Fork are the Earlsboro Sandstone of Pottawatomie County and Chicken Farm



SYSTEM	SERIES	GROUP		FORMAL NAME (FORMATIONS)	FORMAL NAME (MEMBERS OR MARKER BEDS)	SUB-SURFACE NAME
PENNSYLVANIAN	DESMOINESIAN	MARM-ATON		OOLOGAH LS. LABETTE SH. FT. SCOTT LS.	OOLOGAH LS. FT. SCOTT LS.	BIG LIME OSWEGO LS.
		"CHEROKEE"	CABANISS	SENORA FM.	LAGONDA SS. VERDIGRIS LS. CROWEBURG COAL CHELSEA SS. TIAWAH LS.	PRUE SS. VERDIGRIS LS. U. SKINNER SS. HENRYETTA COAL M. SKINNER SS. L. SKINNER SS. PINK LIME
			KREBS	BOGGY FM.	TAFT SS. INOLA LS. BLUEJACKET SS.	RED FORK SS. INOLA LS. BARTLESVILLE SS.
				SAVANNA FM.	SPANIARD LS.	BROWN LS.
MISS.						

A

B

Figure 17. Showing: (A) General stratigraphic column of the Cherokee Group and (B) type log of the two genetic units of the Red Fork. (Modified after Udayashankar, 1985 and Lojeck, 1981.)

Sandstone of Oklahoma County (Jordan, 1957). The Red Fork consists of two genetic units: the Lower Red Fork and the Upper Red Fork (Udayashankar, 1985) (Figure 17). Johnson (1984), using isopach maps of the entire Red Fork interval, showed that the Red Fork thickens markedly from the northern shelf of the Anadarko basin to the deep part of the basin.

CHAPTER V

CORE DESCRIPTION

Introduction

The Red Fork Sandstone was deposited in variety of environments from fluvio-deltaic to submarine fan.

In the shallow near-to-normally pressured northern shelf and transition zone, the Red Fork is interpreted as fluvio-deltaic sandstones and shales (McElroy, 1961; Thalman, 1967; Withrow, 1969; Berg, 1969; Lyon, 1971; Zelif, 1976; Glass, 1981; Udayashankar, 1985).

In the deep overpressured part of the basin (Beckham, Custer, and Roger Mills Counties, Oklahoma) the Red Fork is interpreted as deltaic, shallow marine, and deeper marine including submarine canyon, submarine fan (upper, middle and lower fan) and basin plain sandstone or shale (Johnson, 1984; Anderson, 1992).

The purpose of this chapter is to review the internal features in cores of the Red Fork taken from the deep overpressured basin and from the near to normally pressured northern shelf. Three of the five cores studied in this thesis are from the deep overpressured basin while the remaining cores are from the northern shelf. Locations of wells these cores were taken from are shown on Figure 7. The summary of internal features identified in these cores is shown in Table 2.

Internal Features of the Deep Overpressured Basin

Representative cores from the overpressured domain are the Tenneco Lester 6 (Sec. 6, T. 13 N., R. 21 W., in Roger Mills County, Oklahoma), the Internorth Smith-B-21-1 (Sec. 21, T. 14 N., R. 20 W., in Custer County, Oklahoma), and the Davis Herring No.1 (Sec. 17, T. 14 N., R. 14 W. in Custer County, Oklahoma). The core interval in the Tenneco Lebster 6 is from 12,731 to 12,771 ft. Form the Internorth Smith-B-21-1 the core interval is from 12,210 to 12,531 ft. These two cores were described by Anderson (1992) in his study covering the distribution of Red Fork submarine fans in the Anadarko basin. The cored interval in the Davis Herring No 1 is from 10,857 to 10,916 ft.; and was described by Johnson (1984). Petrologs of the cores are found in Appendix B.

The Red Fork sandstone interval in overpressured domain of the Anadarko basin consists of interbedded sandstone, siltstone and shale. In approximate order of abundance the most commonly observed internal features are: (1) horizontal or parallel laminae and bedding, (2) ripple and wavy laminae, (3) horizontal discontinuous and lenticular bedding, (4) through cross bedding, (5) flaser bedding, (6) soft-sediment deformed bedding (convoluted beds, evidence of flowage, and slump features), (7) burrows and bioturbated rocks, (8) tabular planar cross bedding, (10) massive bedding (11) diagenetic overprints, (12) microfaults, and (13) flame structures.

Table 2: Comparative Table of Sedimentary Structures Occurence in Deep Overpressured and Near to Normal Pressured Domains.

Sedimentary Structures	Deep Overpressured Domain	Near to Normal Pressured Domain
Horizontal or Parallel Laminae Bedding	X	X
Ripple and Wavy Laminae	X	X
Horizontal Streaky and Lenticular Bedding	X	-
Trough Cross-Bedding	X	X
Inclined Laminae and Tabular Planar Cross-Bedding	X	X
Burrowing and Bioturbation	X	X
Graded Bedding	X	X
Soft Sediment Deformation Features	X	X
Microfaults	X	X
Flame Structure	X	-
Diagenetic Bands	X	-
Zones of Intense Diagenetic Cementation	X	X
Scour or Erosional Reactivation Surfaces	-	X
Rip-Up Shale Clasts	-	X

Horizontal or Parallel Laminae and Bedding

Horizontal or parallel lamination and bedding are the most common sedimentary structures observed in the three cores (Figure 18). They are common in siltstone/shale beds and sandstone beds as well.

Ripple and Wavy Laminae

Ripples and wavy laminae (Figure 19) are the second most observed sedimentary structure type of the described cores. They mainly are in interlaminated to interbedded shale, siltstone, and sandstone intervals. They are particularly abundant in the Internorth Smith-B-21-1 Red Fork core.

Horizontal Streaky and Lenticular Bedding

Horizontal streaks and sandstones lenses are in siltstone/shale beds. Sandstones lenses are generally cross bedded (Figure 20). They are in cores from the Internorth Smith-B-21-1, the Davis Herring No. 1, and the lower shale unit of the Tenneco Lester 6.

Trough Cross Bedding

Medium- to small-scale trough cross bedding (Figure 21) are present in all cores. They are mainly observed in sandstone beds but also occur in interbedded sandstone and shale/siltstone beds. They are generally associated with discontinuous wavy and ripple laminae, and flaser bedding.

Figure 18. Horizontal laminae. Getty Tract No. 1, 16/WSW, 4833 ft. (After Glass, 1981.)

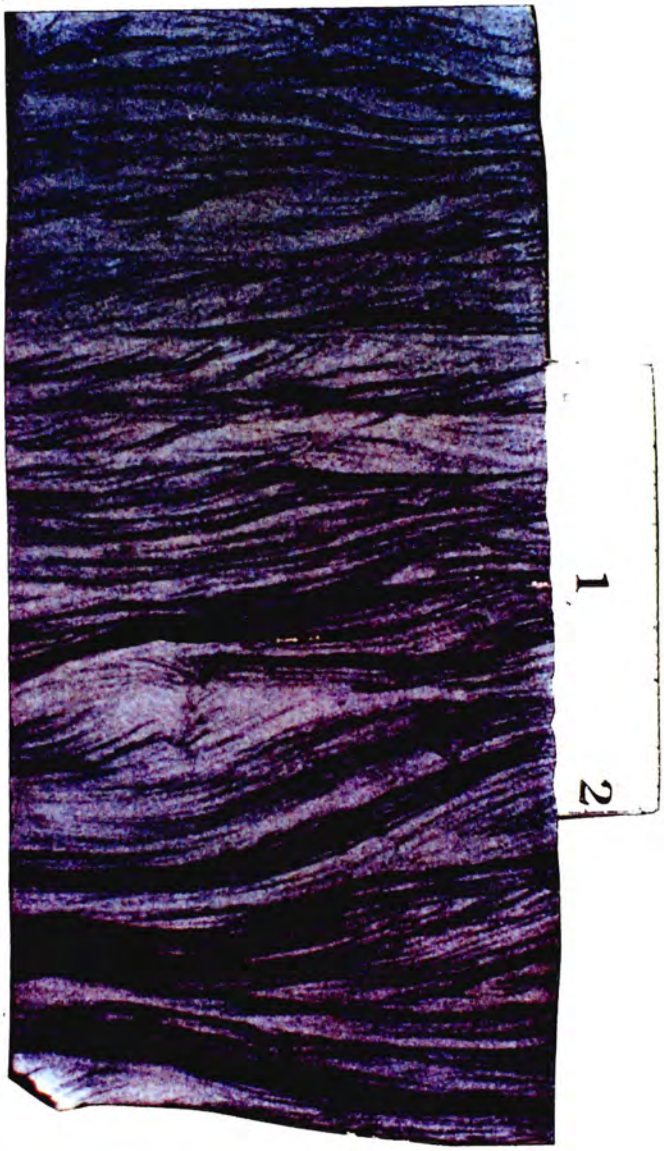


Figure 19. Climbing ripples associated with trough cross bedding. Internorth Smith-B-21-1, 12,228 ft. (After Anderson, 1992.)

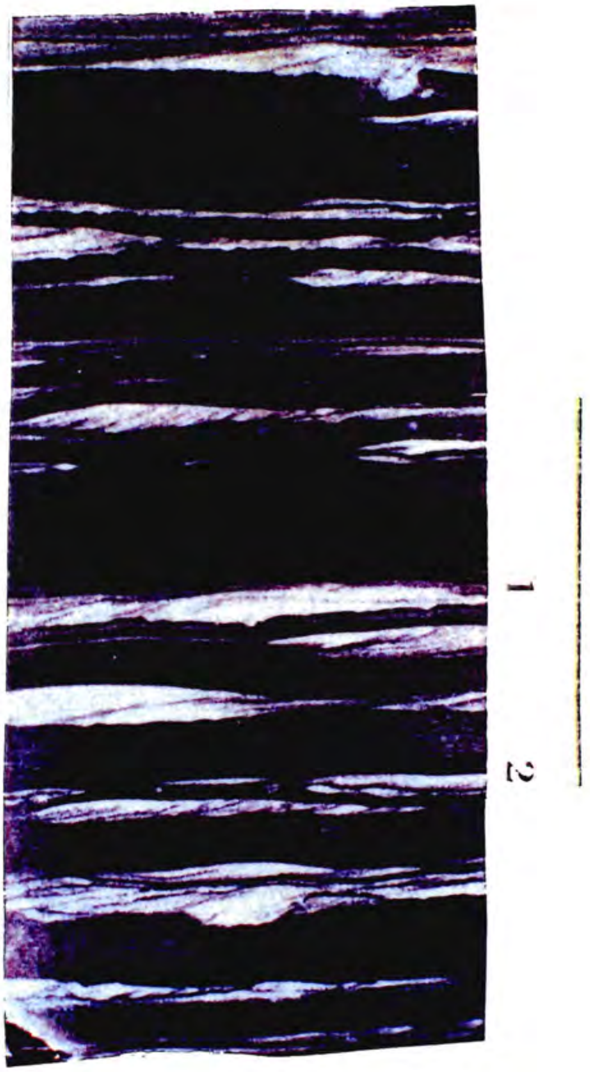


Figure 20. Lenticular bedding associated with small-scale tabular planar cross bedding. Internorth Smith-B-21-1, 12,243'9". (After Anderson 1992.)

Flaser Bedding

Flaser bedding is mainly in sandstone beds of the Internorth Smith-B-21-1 core (Figure 22). This sedimentary structure is generally associated with through cross bedding and/or ripple and wavy laminae.

Soft-Sediment Deformation Features

Soft-sediment deformation features in the described cores included convolute bedding, evidence of flowage, and slump features. All of these features are present in the Internorth Smith-B-21-1 (Figure 23). However, convolute bedding is dominant. In Tenneco Lester 6, the most common soft-sediment deformation is the slump feature.

Burrows and Bioturbated rocks

Burrows and bioturbated rocks were observed in all cores. In the Tenneco Lester 6, burrows are mostly in the fossiliferous upper black shale where they are filled with pyrite (Figure 24A). In the Internorth Smith-B-21-1 (Figure 24B) burrows are present in all types of lithologies: sandstone, siltstone, and shale. A completely bioturbated sandstone bed appears in the Internorth Smith-B-21-1 at 12,249 ft. In the Davis Herring No.1 burrows occur in the upper interlaminated to interbedded sandstone and shale/siltstone interval.

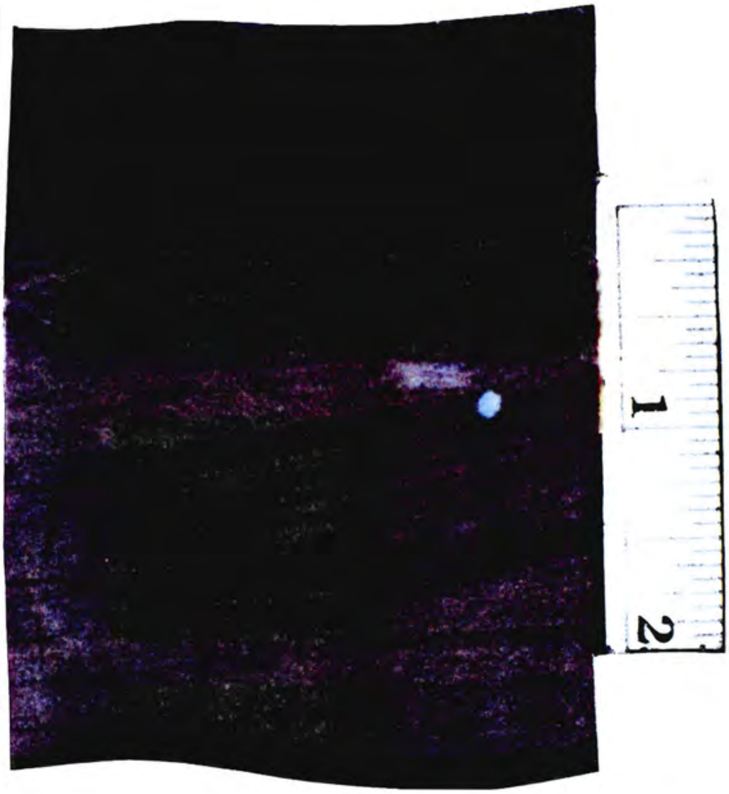


Figure 21. Small-scale through cross bedding. Tenneco Lester 6, 12,576'10". (After Anderson, 1992.)

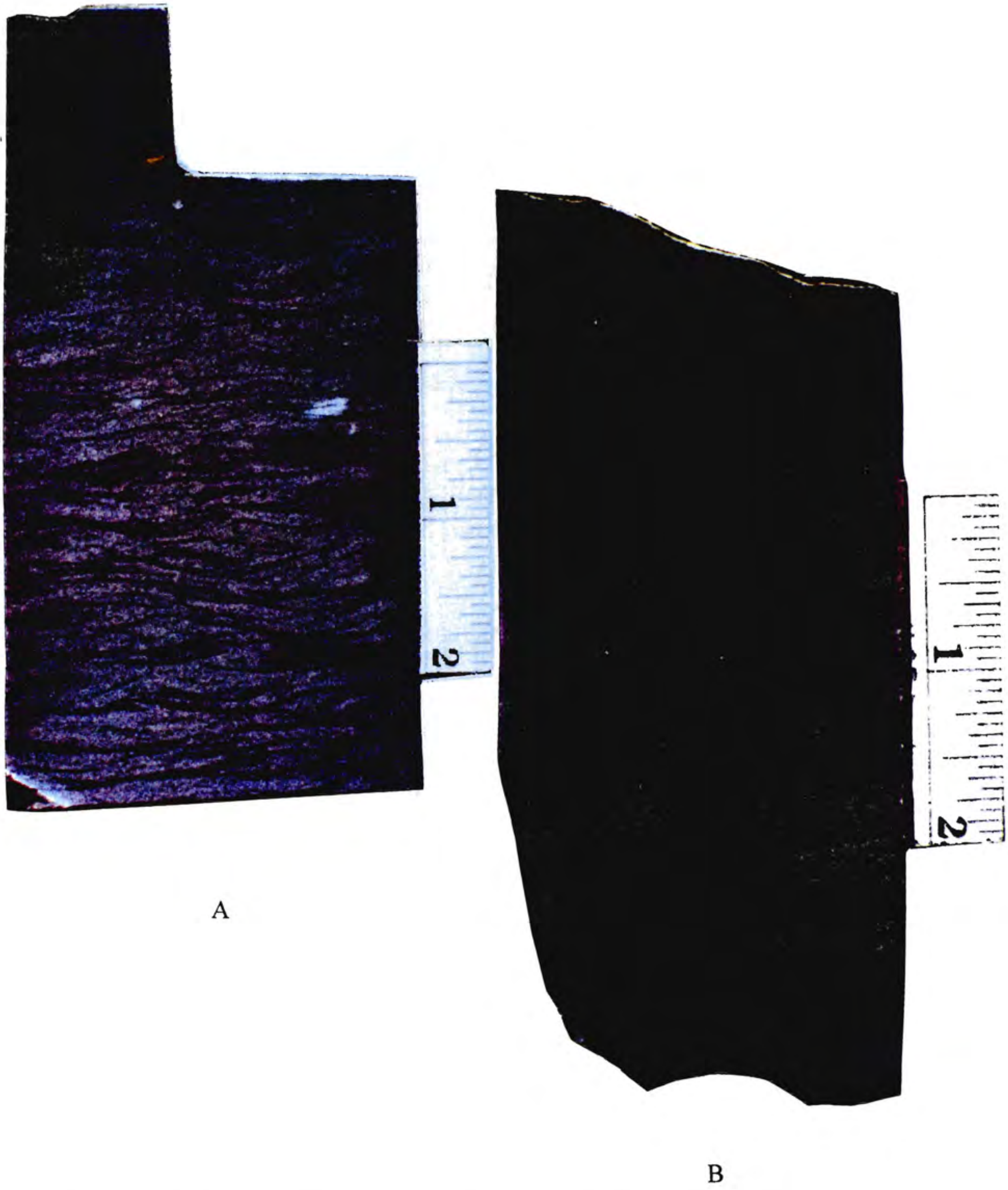


Figure 22. (A) Flaser bedding associated with ripples. Internorth Smith-B-21-1 12,225'10". (B) Tabular planar bedding, possible medium- to large-scale trough cross bedding. Tenneco Lester 6, 12,270'. (After Anderson, 1992.)

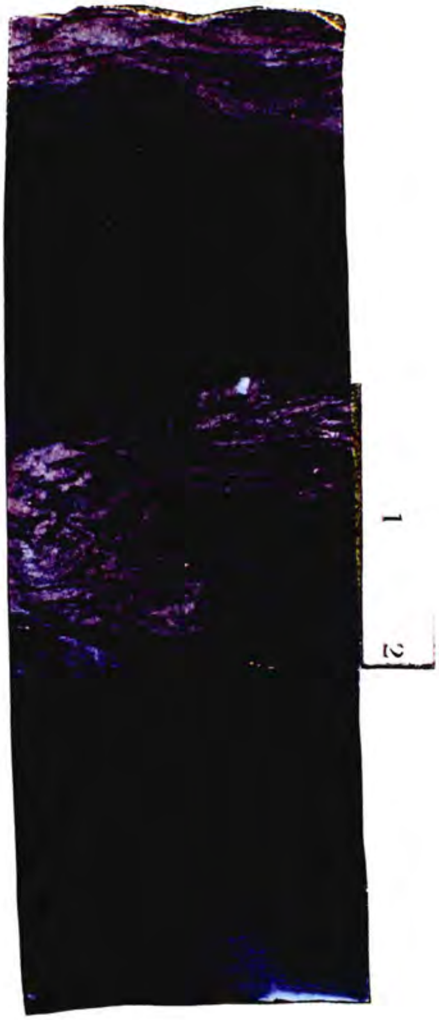


Figure 23. Flowage structure. Internorth Smith-B-21-1, 12,225'10".
(After Anderson, 1992.)

Inclined Laminae and Tabular Planar Cross Bedding

Inclined laminae and tabular planar cross bedding are in all cores. Inclined laminae are numerous in the Internorth Smith-B-21-1 core, whereas tabular planar cross bedding is mostly in sandstone of the Davis Herring No.1 and Tenneco Lester 6.

Massive Bedding

Massive bedding is present in all cores, in sandstone beds (Figure 25) and shale/siltstone beds as well.

Graded Bedding

In the Internorth Smith-B-21-1 core, graded bedding occurs as small-scale fining upward.

Penecontemporaneous Microfaults

Microfaults are minor sedimentary structures observed in interlaminated to interbedded sandstone and shale/siltstone intervals of the Internorth Smith-B-21-1 core. They appear as micro normal faults with offsets that range from 0.5 to 1 cm.

Flame Structures

Flame structures are minor and localized sedimentary structures observed only in the Internorth Smith-B-21-1 core.

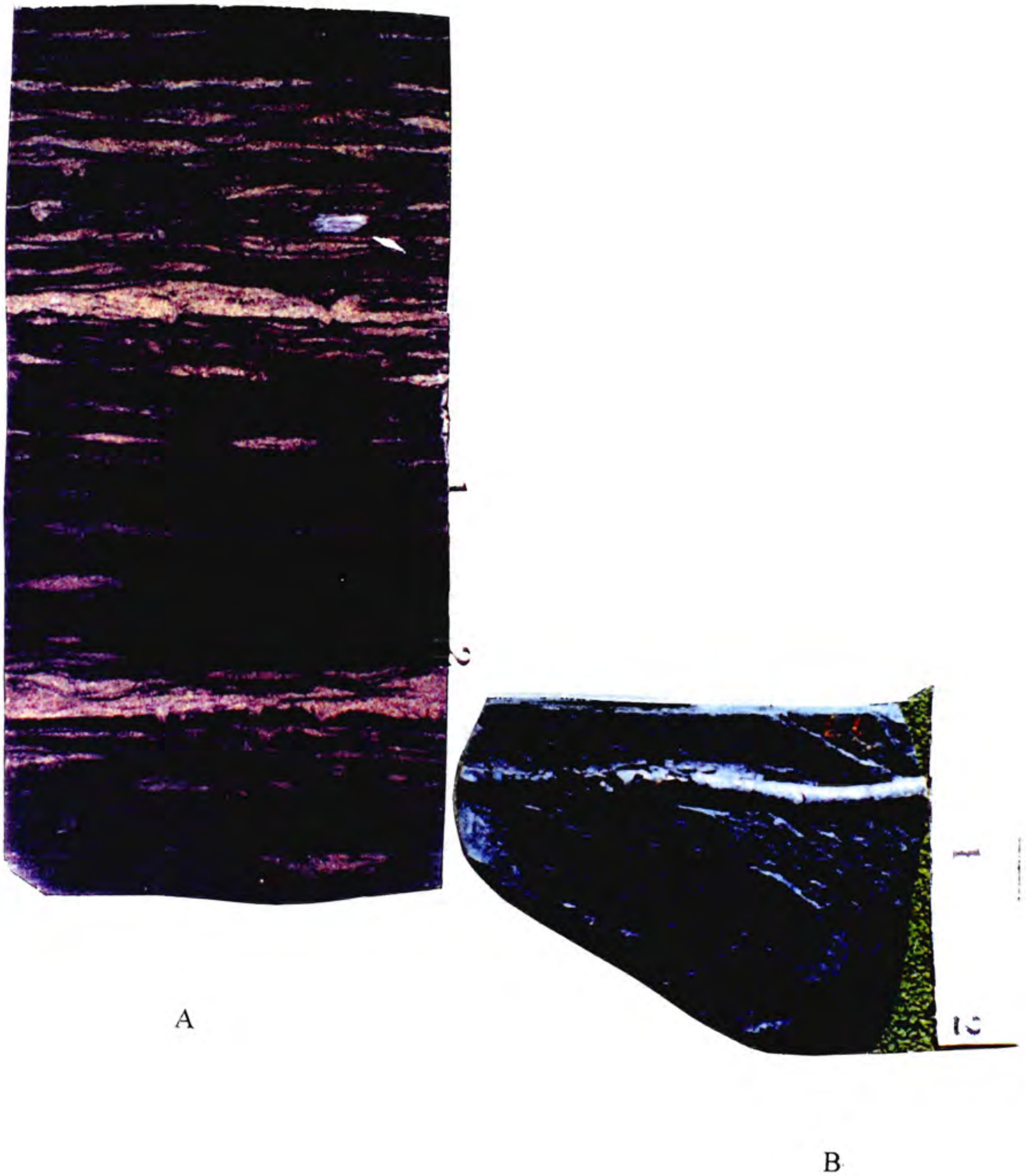


Figure 24. Burrows: (A) Internorth Smith-B-21-1, 12,276 ft.; (B) Pyrite-filled Tenneco Lester 6, 12,732 ft. (After Anderson, 1992 and Glass, 1981.)

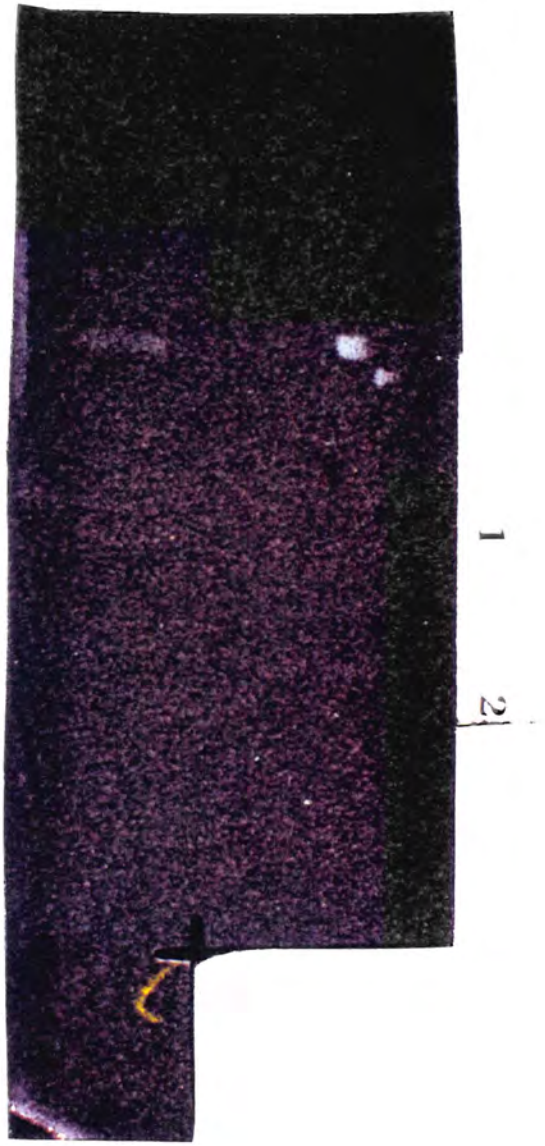


Figure 25. Massive bedding. Internorth Smith-B-21-1, 12,323'6". (Anderson, 1992.)

Diagenetic Overprints: Type 1 and Type 2

Two types of diagenetic overprints are present in the three cores. The first type of diagenetic overprint, type 1 banding, is represented by diagenetic bands that appear to have formed independently of sedimentary features (Al Shaieb et al., 1994). This type of banding occurs mostly in the upper shale/siltstone intervals of the Red Fork cores. In the Tenneco Lester 6, type 1 banding is seen as repetitive small to medium scale (0.5-6 in.) lustrous dark gray to yellowish gray bands. Similarly, repetitive small- to medium-scale reddish dark brown to dark brown diagenetic bands are in the Internorth Smith-B-21-1 core and seem to have occurred independently of sedimentary features (Figure 26).

The second type of diagenetic overprint, type 2, is zones of intense cementation occurring as low-porosity dark gray colored zones. In sandstone intervals, these zones alternate with porous light-colored zones. These cemented zones were observed in sandstone intervals of the Internorth Smith-B-21-1 and Davis Herring No. 1 cores where light gray sandstone zones alternate with highly cemented dark gray ones. In the Tenneco Lester 6, this type of banding occurs as very light gray colored zones.

Internal Features of the Near-to-Normally Pressured Northern Shelf Sandstones

Internal features of the near-to-normally pressured northern shelf and transition zone were studied from the following two cores: the Ferguson Grabow No. 1 located in Sec. 9, T. 19 N., R. 12 W. in Blaine County, Oklahoma, and the Getty Tract No. 1, 16/WSW located in Sec. 21, T. 27 N, R. 4 W. in Grant County, Oklahoma.

Figure 26. Reddish dark brown diagenetic bands. Internorth Smith-B-21-1 12,2468 ft. (After Anderson, 1992.)

The cored interval of the Ferguson Grabow No.1 is from 7,601 to 7,638 ft. The Ferguson Grabow No. 1 was described in the OCGS-OSU core workshop book (1995). On the Getty Tract No 1, 16/WSW the described core interval is from 4,755 to 4,837 ft. Glass (1981) analyzed the Getty Tract No. 1, 16/WSW in his study of the Wakita trend.

The Red Fork sandstone of the near to normal pressured northern shelf commonly consists of two units: a lower sandstone unit, overlain by an upper siltstone/mudstone as in the Getty Tract No. 1,16/WSW, or a lower shale /mudstone unit overlain by a sandstone unit as in the Ferguson Grabow No 1. The common internal features in approximate order of abundance is 1) horizontal or parallel laminae and. bedding, 2) inclined laminae and tabular planar cross bedding, (3) massive bedding, (4) trough cross bedding, (5) ripple and wavy laminae, (6) rip-up shale clasts, (7) flaser bedding, (8) mottled structure, (9) scour or erosional-reactivation surfaces, (10) microfaults, (11) soft deformation features: flowage features, (12) graded bedding, and (13) diagenetic overprints.

Horizontal or Parallel Laminae and Bedding

Horizontal or parallel lamination and bedding are present in both cores. They commonly occur in sandstone intervals and in interlaminated to interbedded shale/mudstone, siltstone, and sandstone intervals as well.

Inclined Laminae and Tabular Planar Cross Bedding

Inclined laminae and tabular planar cross bedding, the second most important sedimentary structures, are present in both cores. They generally next above either massive bedding or horizontal bedding.

Massive Bedding

Massive bedding is in sandstone and shale/siltstone intervals of both cores.

Trough Cross Bedding

Small scale trough cross bedding is in the interlaminated sandstone, siltstone and shale of the Getty Tract No. 1, 16 /WSW core where it is usually associated with ripples and wavy laminae.

Ripple and Wavy Laminae

Ripple and wavy laminae are mostly in the Getty Tract 16/WSW core. They are in interlaminated sandstone, siltstone and shale intervals and are associated with trough cross bedding and/or flaser bedding.

Rip-up Shale Clasts

Rip-up shale clasts (0.25-1.25 in.) are present in the Ferguson Grabow No 1 and Getty Tract No.1, 16/WSW cores. In the Ferguson Grabow No. 1 rip-up shale clasts form a channel lag near the bottom of the sandstone. They are in several places in the Getty Tract No. 1, 16/WSW core.

Flaser Bedding

Flaser bedding is in the Getty Tract 16/WSW core where it is associated with trough cross bedding and some places with ripples.

Mottled Structure

Mottled structure was observed only in the Getty Tract No. 1, 16/WSW core. Mottling presumedly was caused by burrowing.

Microfaults

Microfaults are in the interlaminated sandstone, siltstone and shale section of the Getty Tract No. 1, 16/WSW core (Figure 27).

Graded Bedding

Small-scale graded bedding (fining upward) is in sandstone unit of the Getty Tract No. 1, 16/WSW core (Figure 28).

Scour or erosional-reactivation Surfaces

Scour or erosional-reactivation surfaces are at several positions in the interlaminated sandstone, siltstone and shale section of the Getty Tract No. 1, 16/WSW core (Figure 29).

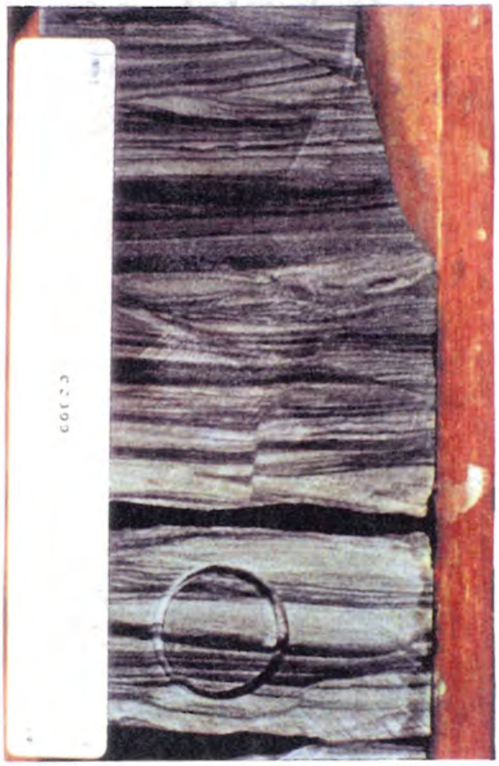


Figure 27. Microfault associated with flaser bedding. Note small-scale trough cross bedding in the lower part of the picture. Getty Tract No. 1, 16/WSW, 4,780 ft. (After Glass, 1981.)

Figure 28. Small-scale upward fining with medium scale tabular planar cross bedding. Getty Tract No. 1, 16/WSW, 4,796 ft. (After Glass, 1981.)

Figure 29. Mottled structure shown in the upper of the picture and erosional-reactivation surfaces near the bottom of the photograph. Getty Tract No. 1, 16/WSW, 4,775 ft. (After Glass, 1981.)

Soft-Sediment Deformation Features

Evidence of soft-sediment deformation features is in the Getty Tract No. 1, 16/WSW core; it and consists mostly of flowage structures.

Diagenetic Overprints: Type 2

Zones of intense cementation are present in the Getty Tract 16/WSW core.

Core Description

Tenneco Lester 6: (Sec. 6, T. 13 N., R. 21 W.)

The cored interval from 12,731-12,771 ft. consists of three major units:

Unit 1: (12,771-12,766 ft.): Dark gray shale/siltstone, parallel laminated, with horizontal sandstone or siltstone streaks and lenses. Other features of this unit include load structures, a reddish dark brown diagenetic band (1.0 cm) of uniform thickness and sharp contacts with the host rock. Contact with the overlying Unit 2 is gradational.

Unit 2: (12,766-12,747 ft.): is sandstone. The upper part (12,747-12751 ft.) is massive and contains slump structures. The middle contains very fine parallel laminae, small-scale trough cross bedding, convolute structures, ripples, a zone of intense cementation (10 cm) with sharp contacts (12,759 ft.), "shale" drapes, and stylolites (12,764 ft.). The lower part of this unit is interlaminated to interbedded with shale. The contact with the overlying unit is sharp.

Unit 3: (12,747-12,731 ft.): Finely laminated banded black shale that contains repetitive small-scale (0.2-1.5 cm) to medium-scale (4.0-15.0 cm) lustrous dark gray and yellowish gray diagenetic bands, abundant pyritized burrows and fossils, and siderite concretions. Lustrous dark gray diagenetic bands have sharp boundaries and regular thicknesses while yellowish gray bands have irregular thicknesses and gradational boundaries. A grayish cement is observed along some bedding laminae. Calcite-cemented fractures are in this unit.

Internorth Smith-B-21-1: (Sec. 21, T. 14 N., R. 20 W.)

The Internorth-B-21-1 core is from 12,209 to 12,531 ft., or a total of 321 ft.; it consists of four major genetic units.

Unit 1: (12400-12,531 ft.): Interlaminated to interbedded sandstone, siltstone, and shale/siltstone. Sandstone is dominant. Sedimentary structures include: horizontal or parallel laminae and bedding, ripple and wavy laminae, horizontal discontinuous sandstone lenses, flaser bedding, small- to medium-scale trough cross bedding, massive bedding, burrows, soft-deformation features (convolute flowage and slump features), inclined laminae, and microfaults. A zone of intense cementation is at 12,367 ft. Small-scale upward fining is present throughout the unit.

Unit 2: 12,265- 12,400 ft.: Interlaminated to interbedded sandstone, siltstone and shale/siltstone, divisible into an upper part (12,265-12,360 ft.), sandstone dominant, and a lower part (12,360-12,400 ft.), shale/siltstone dominant. Sedimentary structures are similar to those in the underlying unit 1. Distinct features of this Unit are :

(1) Alternating light gray and dark gray beds in the upper sandstone interval, results of different episodes of cementation. The dark gray sandstone beds are zones of where cementation intensive.

(2) Abundant burrows; a completely bioturbated sandstone bed is at 12,249 ft.

(3) A number of microfaults between 12,390 and 12,395 ft.

The contact of this unit with the overlying unit is sharp.

Unit 3: (12,227-12,265 ft.): Interlaminated to interbedded sandstone and shale/siltstone. The upper part (12,227 to 12,12243 ft.) moslty is light gray sandstone. The middle zone is dominantly dark gray shale/siltstone. The lower part is banded shale/siltstone. Sedimentary structures include:

(1) Ripple and wavy laminae, cross bedding, flaser bedding, soft sediment deformation (flowage and slump structures), tabular planar cross bedding, and massive bedding which is in sandstones;

(2) Horizontal streaky and lenticular bedding, diagenetic bands occurring mainly in shale/siltstone beds. A zone of intense cementation is present at 12,227 ft.;

(3) Horizontal laminae and burrowing are observed in all lithologies. Contact with the overlying unit 4 is gradational.

Unit 4: (12,209-12,227 ft.): Banded shale/siltstone. This unit consists of repetitive small-scale reddish-dark brown to dark-brown diagenetic bands. Contact of bands with host rock generally is gradational and bands are of uniform thickness and flat. A few bands (at 12,223 and 12,224 ft.) are concretionary in appearance with irregular thickness. The upper part of the unit is mostly shale and grades progressively into thinly interlaminated siltstone at the bottom. Other features of the unit include horizontal laminae, wavy laminae, massive bedding, slump structures, burrows, and mineral-filled vertical fissures.

Davis Herring No. 1: (Sec. 17, T. 14 N., R. 14 W.)

The cored interval (10,857-10,916 ft.) consists of three major genetic units: a shale/siltstone unit at the bottom that is overlain by a sandstone and an upper interlaminated to interbedded sandstone and shale/siltstone unit. The lowermost shale (10,915-10,916 ft.) is massive. Contact with the overlying sandstone unit is sharp. The sandstone (10,878-10,915 ft.) contains: medium-scale tabular planar cross bedding below massive bedding, ripples, small-scale trough cross bedding, flaser bedding, horizontal laminae, flowage structures and wood fragments. A concretionary zone of intense diagenetic cementation is present at 10,887 ft. Contact with the overlying unit is gradational. The interlaminated to interbedded uppermost unit (10,857-10,877 ft.) contains sandstone from 10,864 to 10,871 ft. Sedimentary structures include horizontal laminae, ripples, horizontal sandstone streaks and lenticular bedding, small-scale trough cross bedding and burrows. The sandstone is flaser bedded, and contains small scale cross bedding, and a thin (0.25 in) dark brown hematitic band, and a dark gray zone of intense diagenetic cementation (17 cm) at 10,868 ft.

Ferguson Grabow No. 1: (Sec. 9, T. 19 N., R 12 W.)

The cored interval, from 7,601 to 7,638 ft., consists of two major genetic units: a shale/siltstone unit at the bottom and a sandstone. The shale/siltstone unit (7,637-7,638 ft) is structureless and contains brachiopods. The boundary between the shale/siltstone and sandstone is sharp. The sandstone unit (7,638-7,601 ft.) has two sections: a lower section characterized by abundant rip up shale clasts (0.25-2.5cm) and upper section (7,632-7,632 ft.) of fine-grained sandstone with medium-scale tabular, planar cross bedding, horizontal laminae, thin coal streaks, massive bedding, and inclined laminae.

Getty Tract No. 1, 16/WSW: (Sec. 21, T. 27 N., R 4 W.)

The cored interval (4,755-4,838 ft.) consists of a lower sandstone unit overlain by siltstone /mudstone. The lower unit (4,782-4,838 ft.) is fine grained sandstone that contains medium tabular cross bedding, horizontal bedding, ripples, repeated upward-fining (graded bedding) and massive bedding. Rip-up clasts are at: 4,793, 3,797, 4,801 and 4,817 ft. Concretionary zones of intense cementation (about 15 cm thick) are at 4,814 and 4,828 ft. Hematitic laminae are at 4,790 ft. In its upper part, the sandstone is very fine grained and contains ripples, horizontal lamnae and small-scale cross bedding. Contact with the overlying unit is sharp.

The siltstone/mudstone unit consists of a lower interlaminated sandstone, siltstone, and shale section (4,760-4,789 ft.) that contains: horizontal laminae, ripples, small-scale trough cross laminae, flaser bedding and burrowing. Mottling or intense burrowing is at 4,779 ft. Scour or erosional-reactivation surfaces are at several locations

Figure 30. Calcite concretions. Getty Tract No. 1, 16/WSW, 4,763 ft. (After Glass,1981.)

4,774, 4,779, 4,780, and 4,781 ft. Microfaulting is present at 4,780 ft. shows offset of about 0.25 inch. Hematitic bands (2-4 cm) appear at several depths: 4,769, 4,771, 4,775, and 4,780 ft. The upper section 4,755-4,765 ft. is a laminated shale/mudstone that contains calcite concretions between 4,755-4,765 ft. Contact between this upper section and the underlying section is gradational.

The examination of cores from deep overpressured and shallow near to normal pressured domains shows that:

(1) Sedimentary structures in rocks from the deep overpressured and near to normal pressured domains are similar.

(2) Differences in sedimentary structures between the two domains are evidence of different depositional settings of the Red Fork Sandstone. Sedimentary structures that reflect the basinal setting of some deep overpressured Red Fork reservoirs include flame structures and horizontal streaky and lenticular bedding. Structures that are in channel-fill sandstone of the shallow near-to-normally pressured domain include rip-up shale clasts and scour or erosional-reactivation surfaces.

Two types of diagenetic overprints are observed in rocks of the deep overpressured domain of the Anadarko basin. Repetitive small-to medium-scale diagenetic bands (Type 1) and zones of intense cementation (Type 2) are in the rocks from the overpressured domain. Diagenetic bands are exclusively in shale/siltstone beds whereas zones of intense cementation commonly occur in Red Fork sandstone beds from the overpressured domain. However, Type 2 diagenetic overprint is also in shale/siltstone of the Red Fork from the overpressured domain.

On the shallow near-to-normally pressured area of the Anadarko basin, Type 2 diagenetic overprint, zone of intense cementation, is in sandstone intervals. However, they are less pronounced than in similar zones that occur in rocks from the deep overpressured domain.

The differences in diagenetic overprints occurring in deep overpressured and shallow near-to-normally pressured domains accentuate the importance of depth of burial in the alteration of rocks. Diagenetic bands is well pronounced in overpressured rocks that were buried more than 11,000 ft. deep. Diagenetic bands develop at great depths of burial in shale/siltstone or clay-rich intervals of the Red Fork. Consequently, they are noticeably absent in equivalent lithologies that were buried to less than 11,000 ft. On the other hand, zones of intense cementation are in sandstones that were buried to both shallow and great depths, but they are more abundant in deeply buried rocks. The importance of diagenetic bands as a sealing mechanism has been well demonstrated by Al Shaieb et al., 1991, and Al-Shaieb et al., 1994. Diagenetic bands in shale/siltstone were not observed in the Davis Herring No.1 which is located in the deep overpressured domain, however, zones of intense cementation are present in the Davis Herring No.1. The absence of diagenetic bands and the presence of zones of intense diagenetic cementation in the overpressured Davis Herring No. 1 might suggest these zones of intense diagenetic cementation at the depth of burial of the core (10,850 ft., which is close to 11,000 ft., the seal window for diagenetic bands formation), might be important in keeping the Davis Herring No. 1 pressure gradient (0,602 psi) high. The Davis Herring No. 1 is believed to assure the transition between overpressured diagenetic banded rocks and near-to-normally pressured non banded rocks.

CHAPTER VI

PETROGRAPHY AND DIAGENESIS OF THE RED FORK

Introduction

The purpose of this chapter is to examine the mineralogical constituents, the textural fabric, and diagenetic modifications that characterize the Red Fork from deep overpressured and near-to-normally pressured northern shelf domains and that affect porosity and permeability within the Red Fork reservoirs. Thirty-five thin sections were examined under polarizing microscope to determine the petrography and diagenetic history of the Red Fork.. Of the 35 thin sections, six were from the Tenneco Lester 6, eight from the Woods Switzer-C-5-1 core that is not described in this study but in previous studies (Anderson, 1992), nine from the Davis Herring No. 1, three from the Ferguson Grabow No. 1 and 9 from the Getty Tract No. 1, 16/WSW. Thin sections from wells of the overpressured domain were represented by the Tenneco Lester 6, the Woods Switzer-C-5-1 and the Davis Herring No. 1. Thin sections from near-to-normally pressured rocks were from the Ferguson Grabow No. 1 and the Getty Tract No. 1, 16/WSW. Thin-section examination was supplemented by x-ray diffraction of the diagenetic bands and host shale rocks. QRF (quartz, rock fragments and feldspars) were used to determine to classify rocks. Red Fork of the deep overpressured domain are mostly very fine to fine grained, well sorted sublitharenites to litharenites, whereas sandstones from the near-to-normally pressured northern shelf Red Fork are coarser, and classified as fine to medium grained, moderately to well sorted, sublitharenites to litharenites.

Detrital Constituents

Quartz, rock fragments and feldspar constitute the dominant detrital constituents in rocks from both pressure domains. Quartz, predominantly monocrystalline quartz (Figure 31), average 75 % of the framework grains. Rock fragments, mostly low grade metamorphic, make up about 30 % of the framework grains. Feldspars, mostly orthoclase and plagioclase, average 7.5 % of the framework grain. Some quartz are corroded. Corrosion of quartz is more important in extensive poikilotopic calcite cement and is more evident in thin sections from rocks of the near-to-normally pressured northern shelf (Figure 32). Other quartz grains contain evidence of stress, showing Boehm lamellae or strong undulose extinction. Inclusions of rutile, tourmaline and zircon are common in quartz. An organic matter coating is observed around many quartz grains (Figure 33). Rock fragments are low-grade metamorphic rocks , carbonate rocks , chert, and shale clasts. Low-grade metamorphic rock fragments are the most abundant type. Ductily deformed metamorphic rock fragments and shale clasts form the pseudomatrix (Figure 34) which was observed in all thin sections. Some metamorphic rock fragments are partially replaced by authigenic chlorite (Figure 35) or in rare cases transformed to chlorite by retrograde metamorphism. Micritic carbonate rock fragments are found in organic material seams or in stylolites (Figure 36). Feldspars are usually altered to sericite

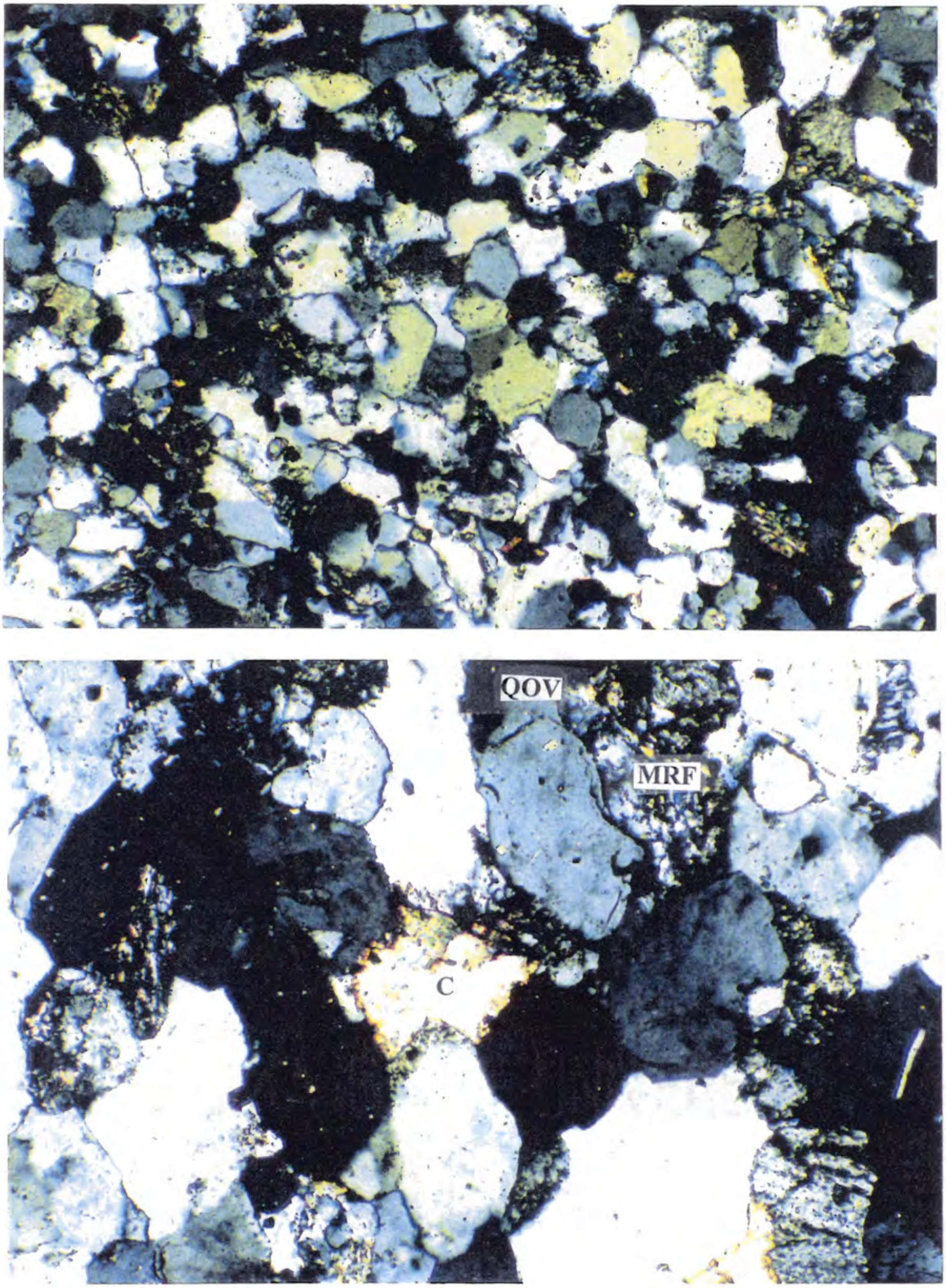


Figure 31. Monocrystalline quartz , syntaxial quartz overgrowths, patchy calcite, MRF. 10X, XN (A): Tenneco Lester 6, 12,763 ft. Note presence of zircon and tourmaline. (B): Getty Tract No. 1, 16/WSW, 4,838 ft.

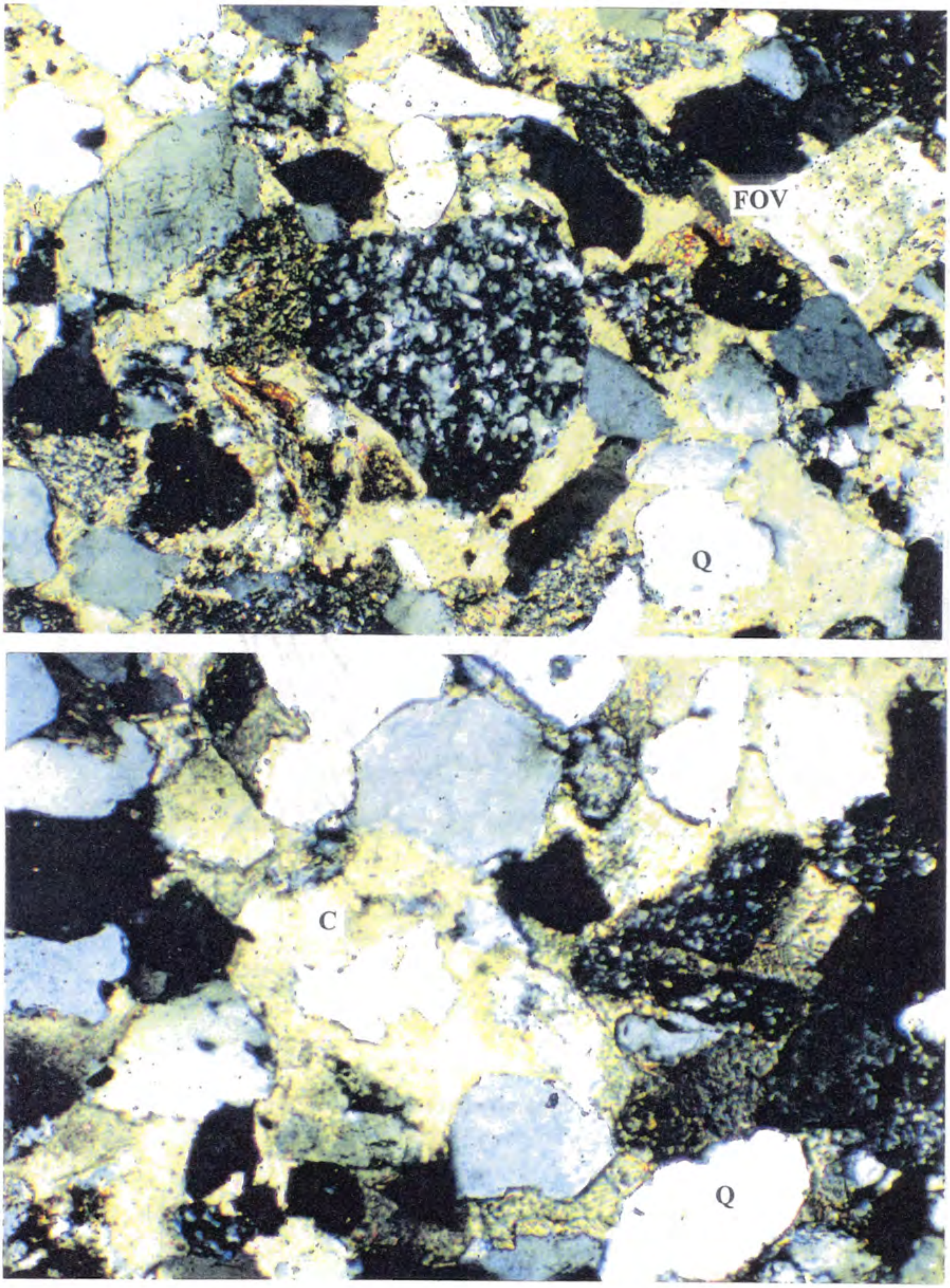


Figure 32. Corroded quartz in extensive poikilotopic calcite cement. 10X, XN. (A): Ferguson Grabow No. 1, 7,635 ft. Note chert fragment in center of picture, abundant pseudomatrix and feldspar overgrowth in the right upper corner. (B): Getty Tract No. 1, 16/WSW, 4,838 ft.

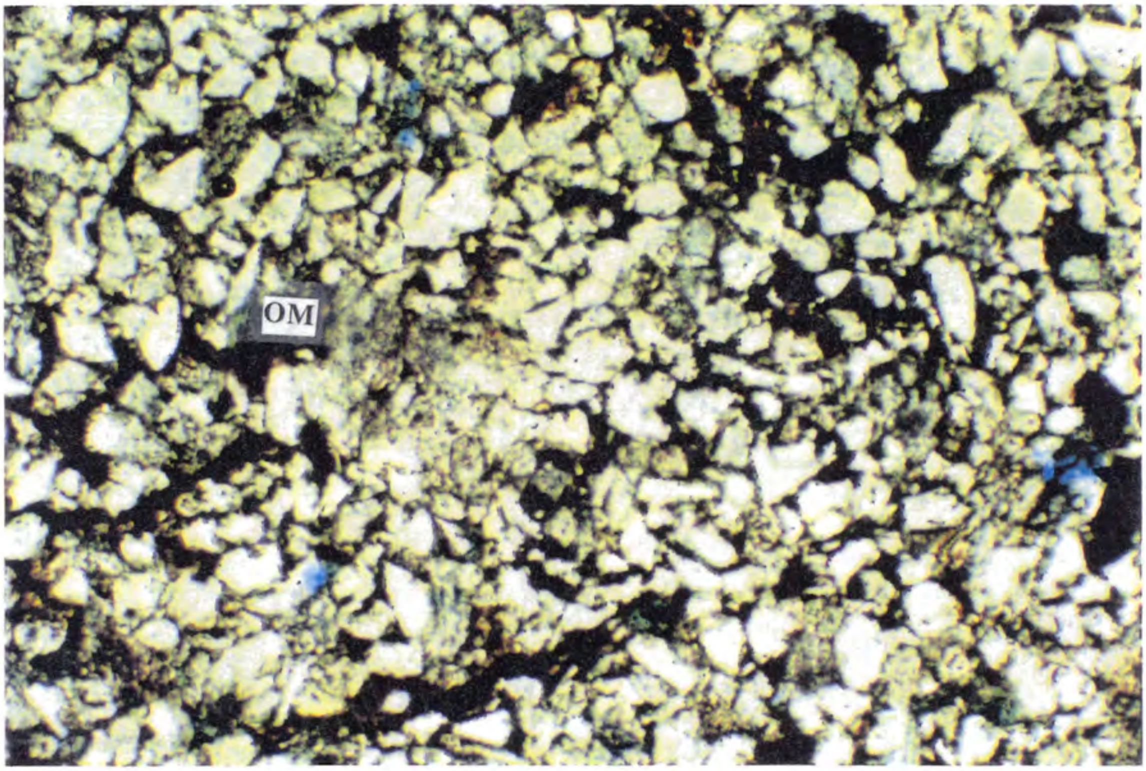


Figure 33. Organic matter coating and cement.
10X, PPL, Tenneco Lester 6, 12,745 ft.

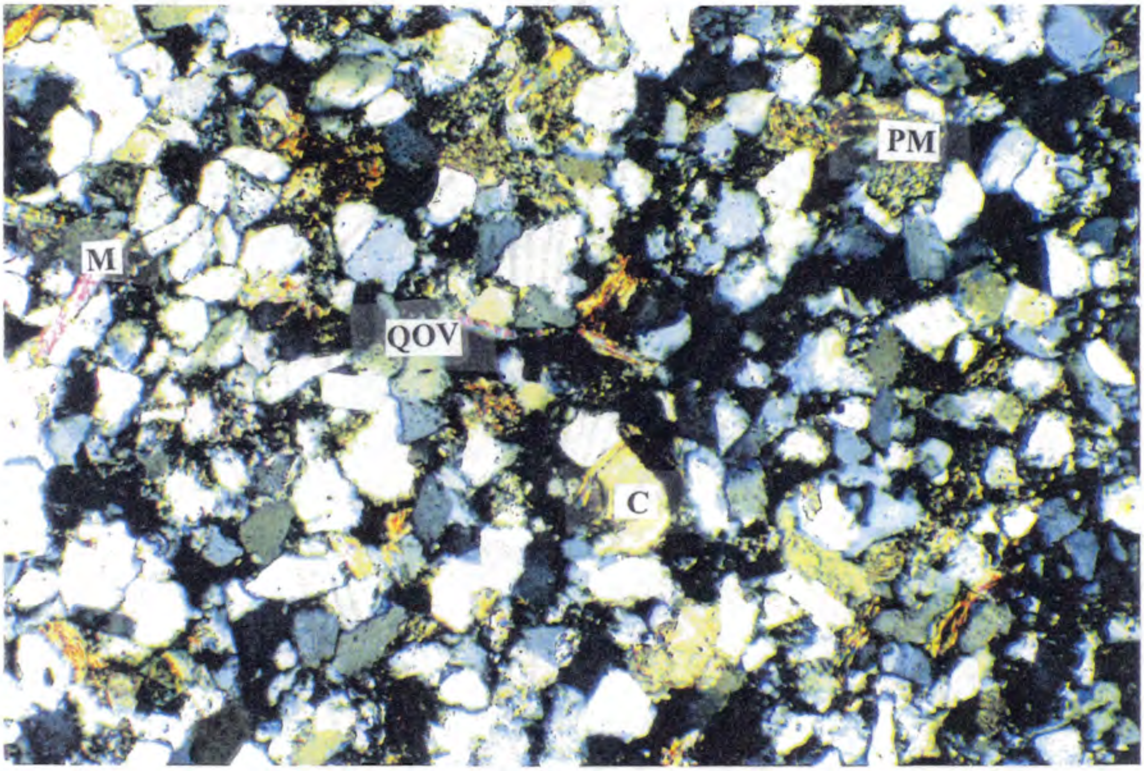


Figure 34. Pseudomatrix. Note syntaxial quartz overgrowths, patchy calcite and the absence of porosity. 10X, XN, Tenneco Lester 6, 12,766 ft.

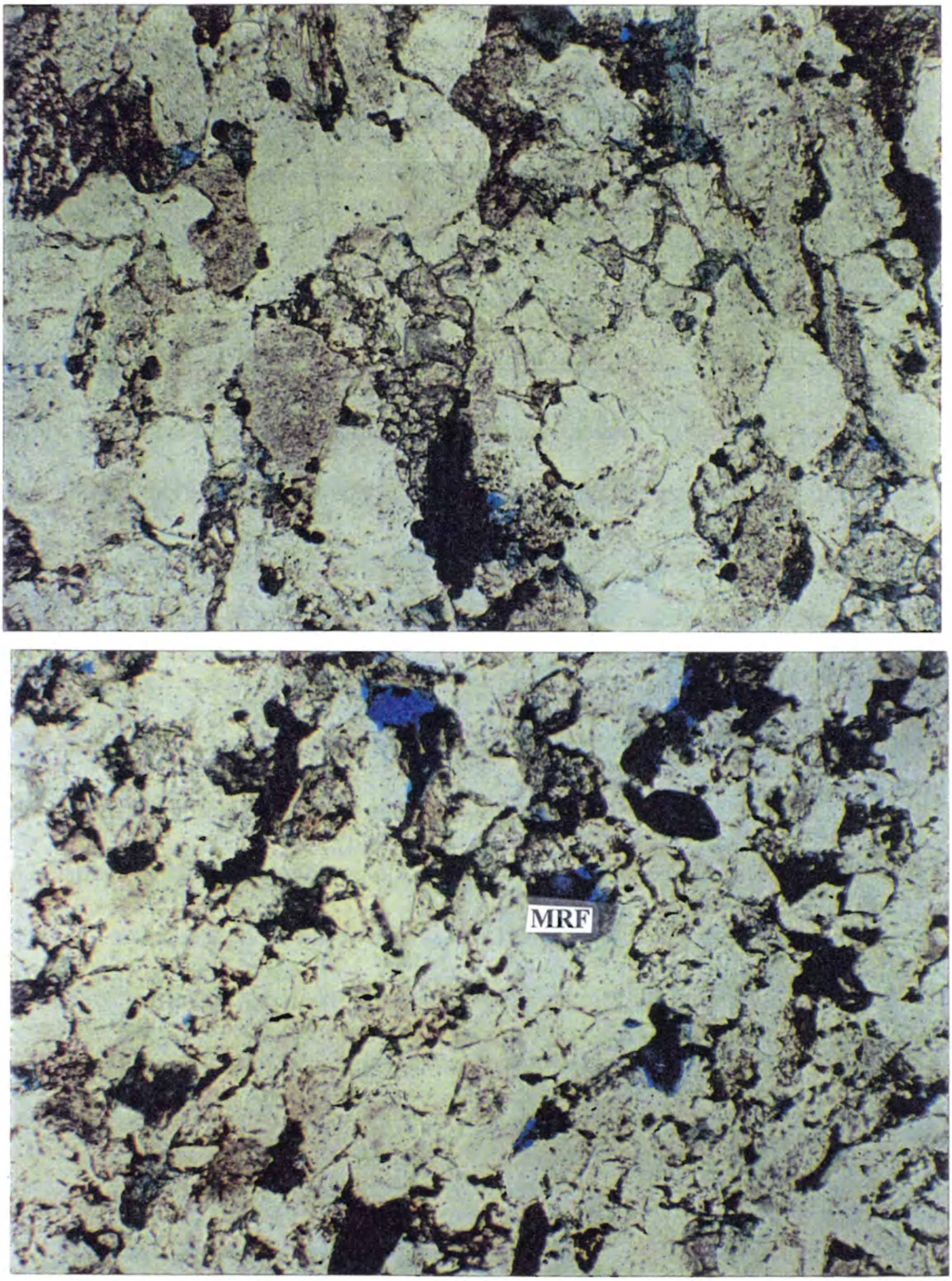


Figure 35. Partially dissolved MRF replaced by authigenic chlorite. 10X, PPL. (A): Davis Herring No. 1, 10,914 ft. (B): Tenneco Lester 6, 12,763 ft.

(Figure 37) or replaced by calcite (Figure 38), dolomite (Figure 37), siderite (Figure 38) or kaolinite (Figure 39). However, other feldspars were found unaltered. Replacement of feldspars by siderite is more common in rocks of the near-to-normally pressured northern shelf. Moreover, dissolution features of feldspars such as honeycomb (Figure 40) are in thin sections of rocks from both domains. Accessory constituents include muscovite, pyrite, detrital chlorite, biotite, polycrystalline quartz and sandstone rock fragments. Locally, muscovite is ductily deformed to form pseudomatrix (Figure 41). Pyrite and micritic fragments are also present in stylolites. Zircon and tourmaline are the most common detrital heavy minerals in these rocks (Figure 31). Glauconite occurs in trace amounts. A detrital matrix (less than 5 %, a mixture of illite, chlorite and micrite) was observed in some rocks. Clayey matrix of more than 5 % is associated with organic-matter seams or stylolites (Figure 36). In the near-to-normal pressured domain some rocks contain fossil fragments that are replaced either by calcite, chert, pyrite or combination of more than one cement. Trace amounts of apatite as replacement of fossils (Figure 42) and a collophane fragment (Figure 43) were observed in the Ferguson Grabow No. 1. Rip-up shale clasts observed in some cores of the near-to-normally pressured terrane consist of large illitic grains (Figure 44).

Diagenetic Constituents

Red Fork sandstones have undergone extensive diagenetic modifications, which have greatly altered their original mineralogic composition, texture, porosity and permeability. Indeed, porosity and permeability reduction is due mainly to diagenetic

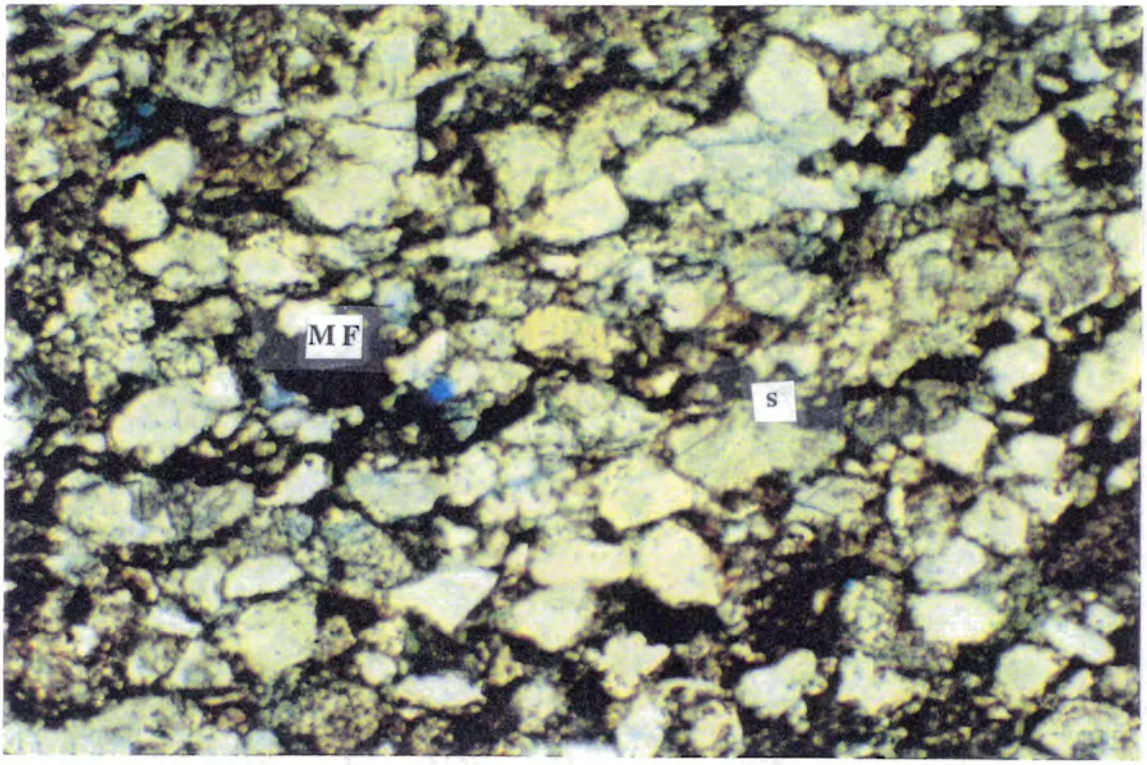


Figure 36. Stylolites. Note micritic fragments associated with stylolites and the presence of abundant detrital clayey matrix. 10X, PPL, Davis Herring No. 1, 10, 868 ft.

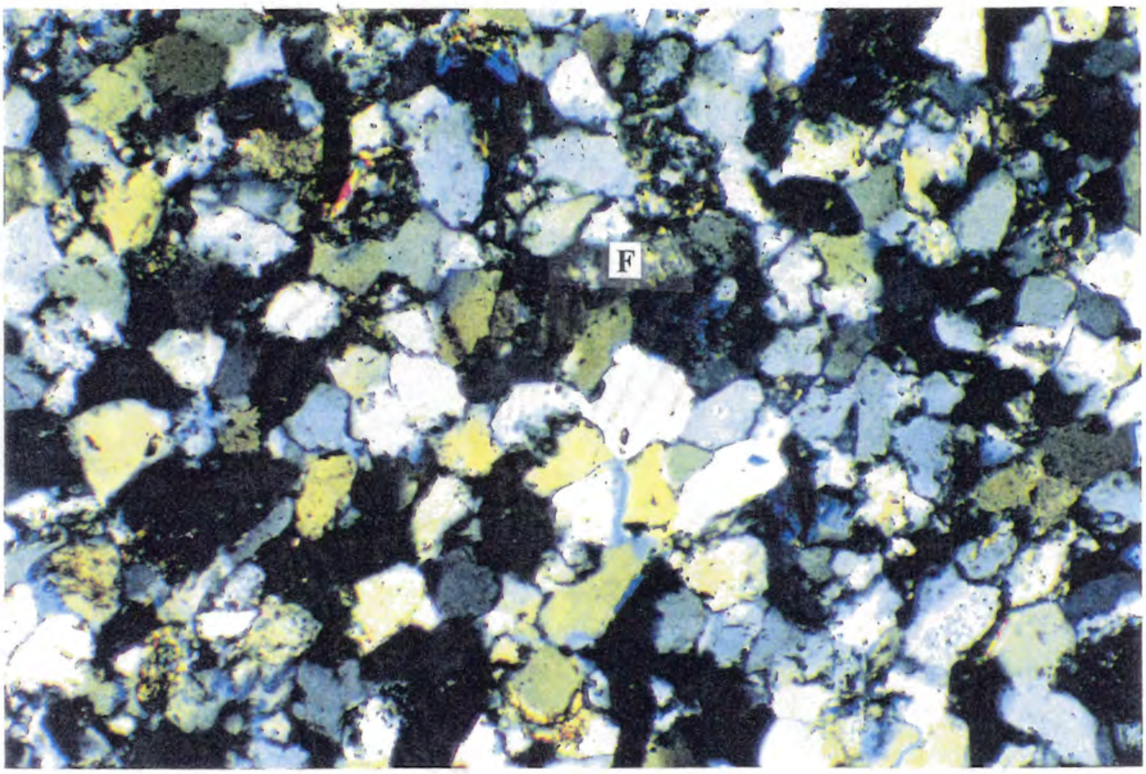


Figure 37. Plagioclase altered to sricite, partially replaced by dolomite.
10X, XN, Tenneco Lester 6, 12,763 ft.

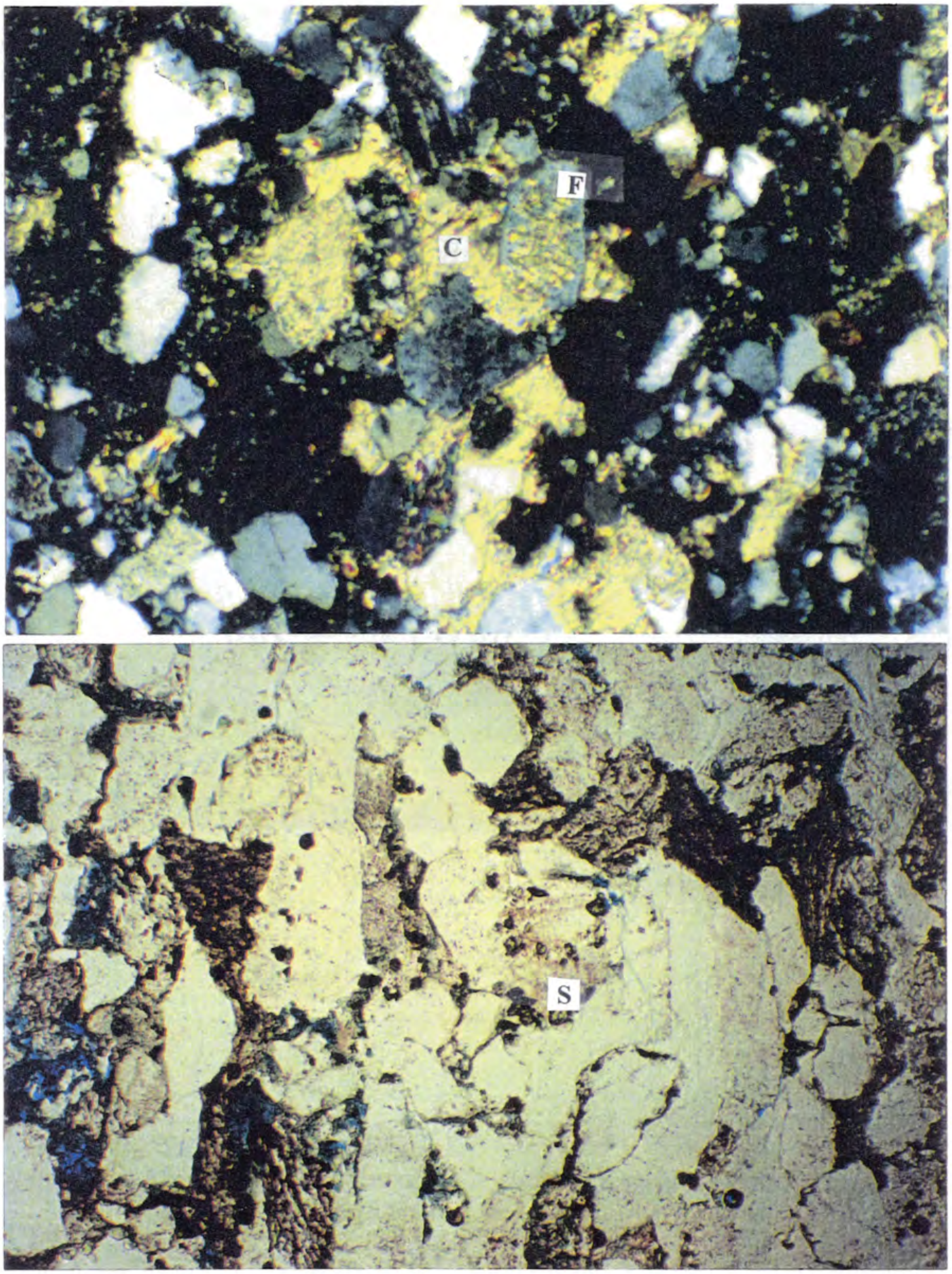


Figure 38. Feldspars replacing cements: (A) Plagioclase partially replaced by calcite. Davis Herring No. 1, 10,883 ft. (B) Plagioclase partially replaced by siderite. Note pore-lining siderite rhombohedra. 10X, PPL, Davis Herring No. 1, 10,914 ft.

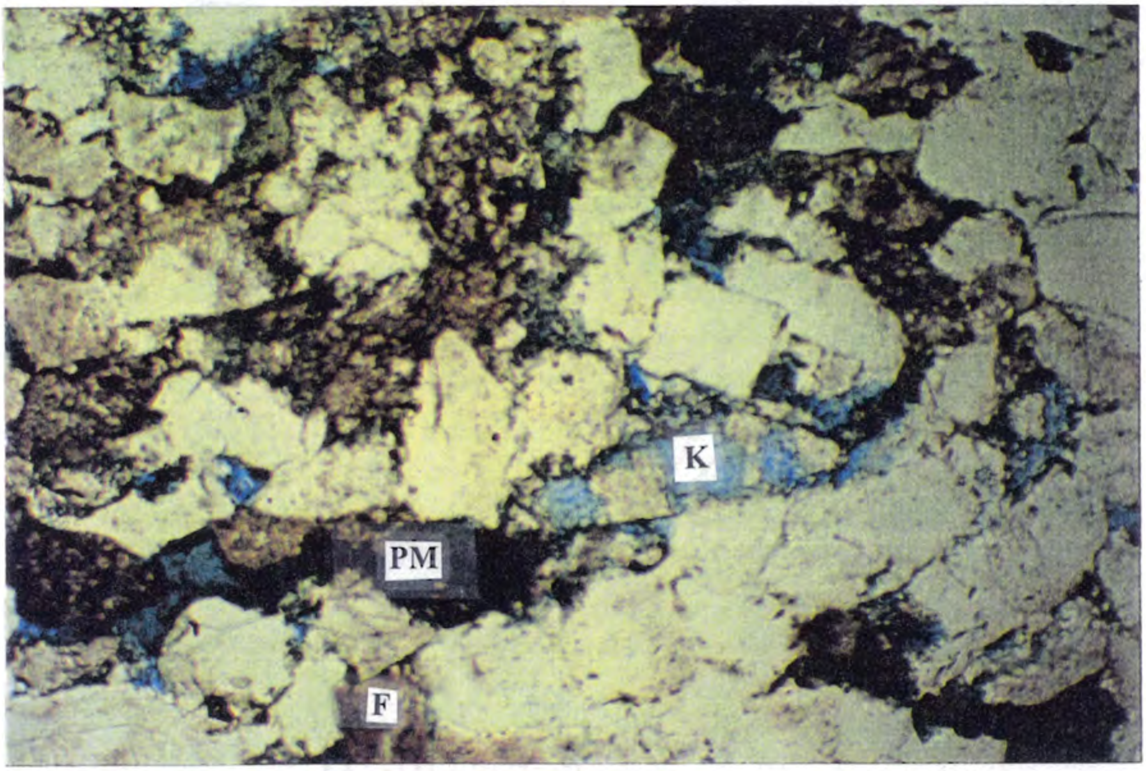


Figure 39. Partially dissolved plagioclase replaced by pore-filling kaolinite booklets 10X, PPL, Davis Herring No.1, 10,914 ft.

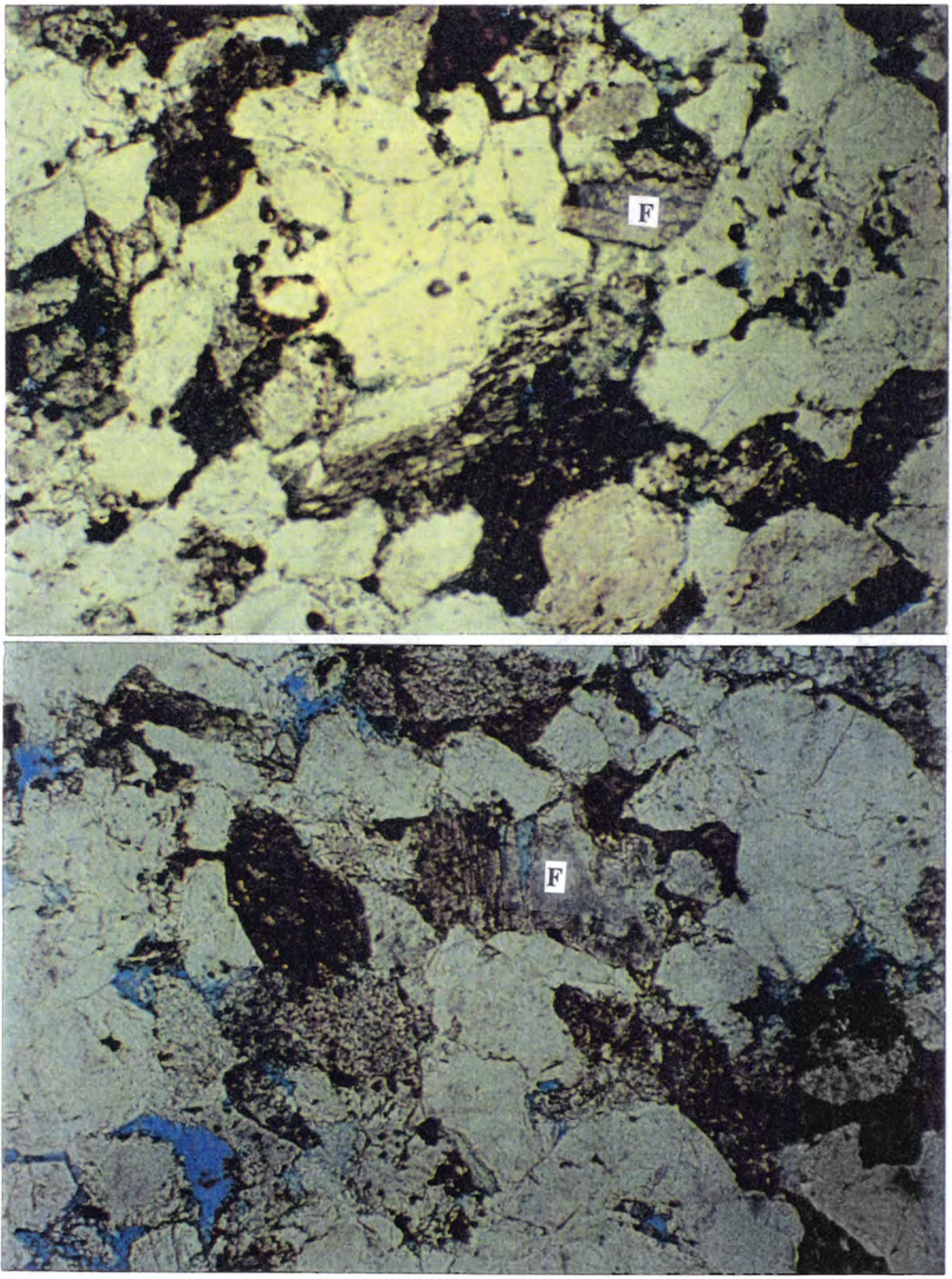


Figure 40. Feldspar dissolved along cleavage planes: initial stage of formation of the honeycomb texture. Note pore-lining chlorite and partially dissolved pseudomatrix. 10X, XN, Davis Herring No.1 , 10,914 ft.

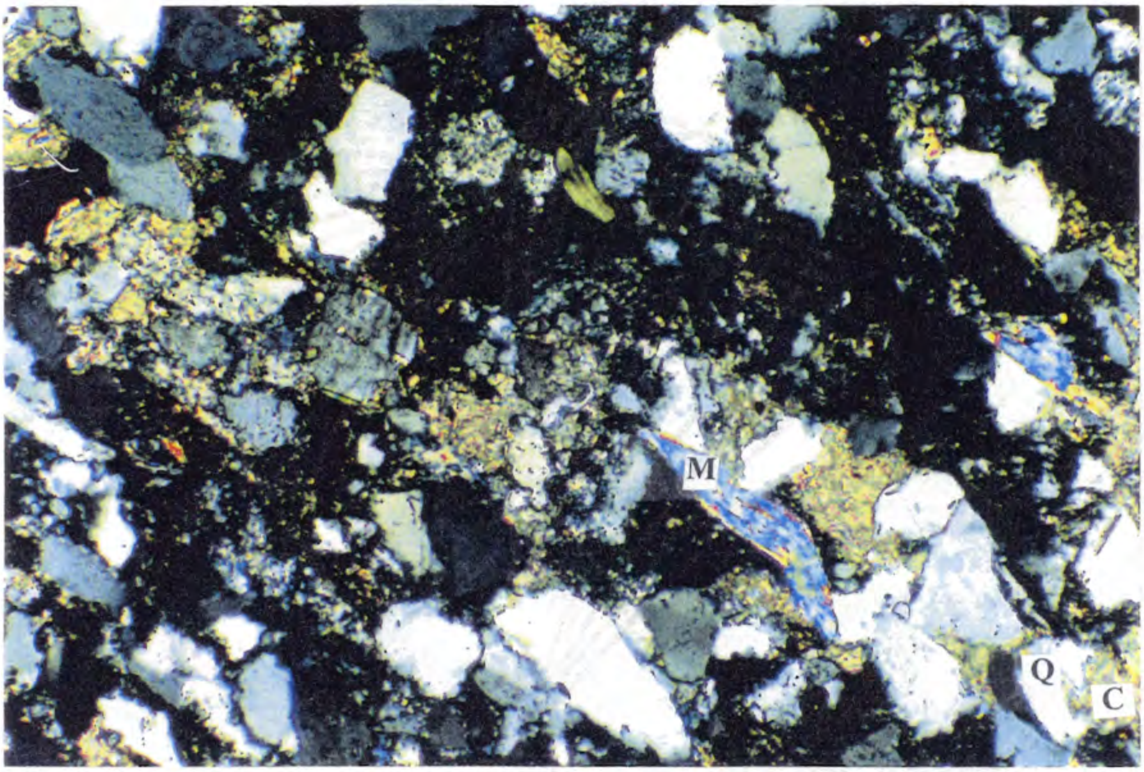


Figure 41. Ductily deformed muscovite. Note presence of detrital chlorite. 10X, XN, Davis Herring No.1, 10,883 ft.

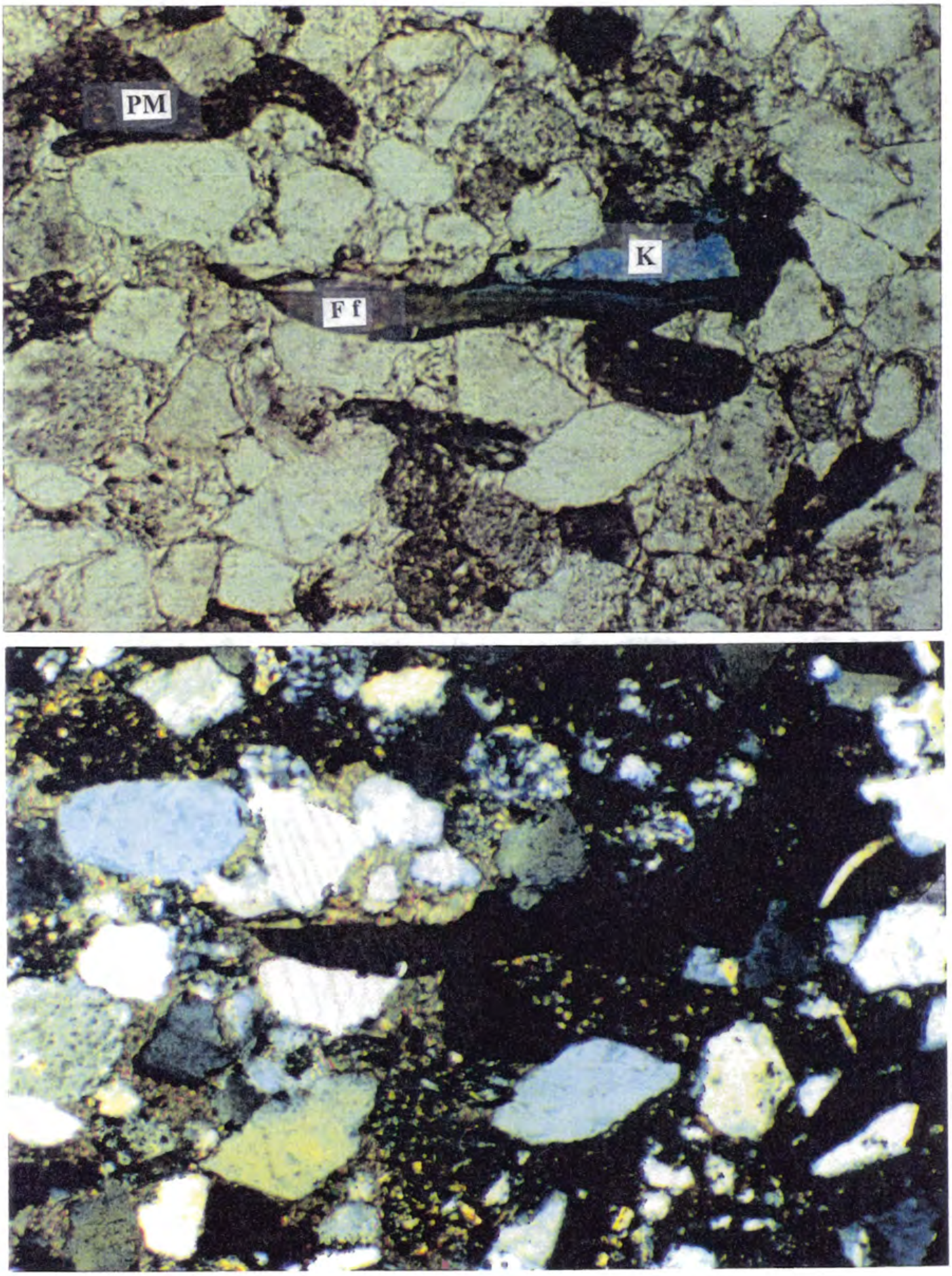


Figure 42. Fossil fragment replaced by apatite. Note pore-filling Kaolinite in adjacent pore space. 10X, Ferguson Grabow No.1, 7,625 ft.
(A) PPL (B) XN

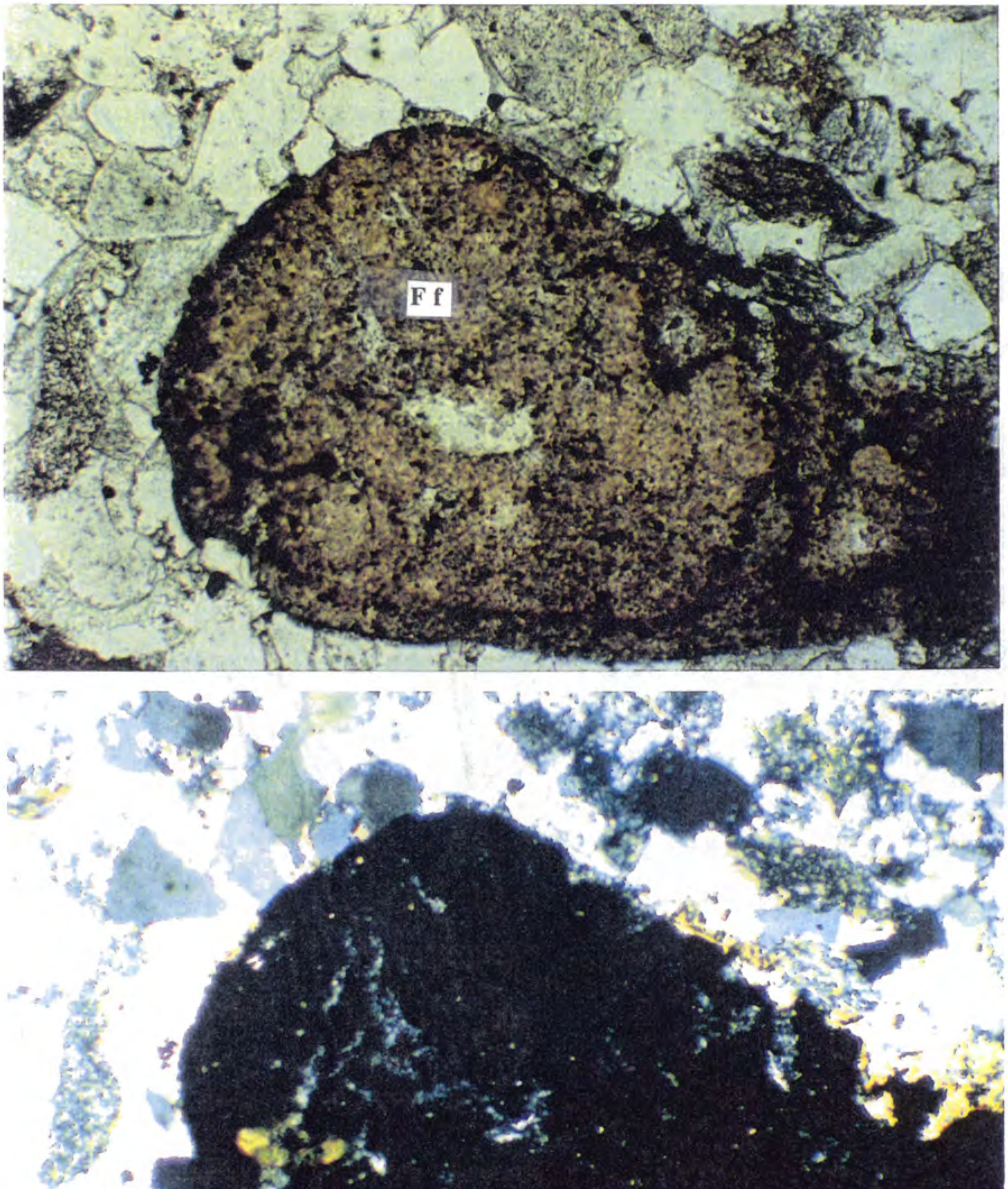


Figure 43. Fossil fragment replaced by collophane. 10X, Ferguson Grabow No.1, 7,635 ft. (A) PPL (B) XN

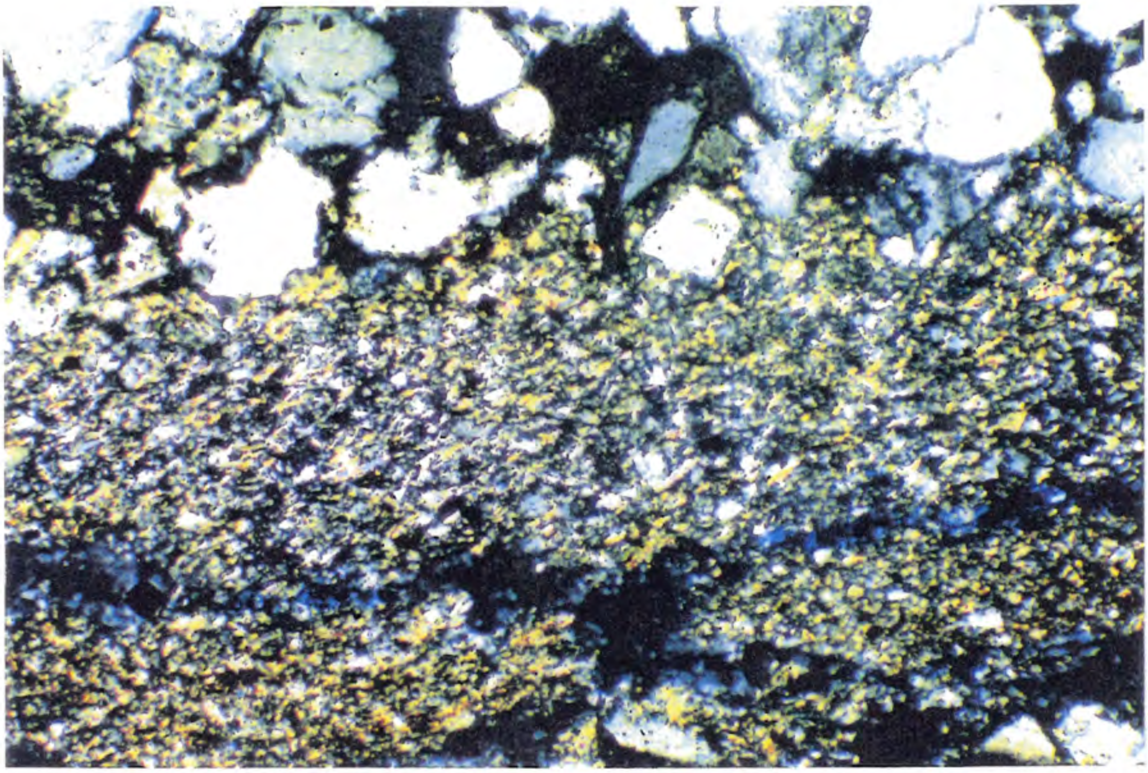


Figure 44. Illitic matrix of a rip-up shale clast. 10X, XN, Getty Tract No.1, 4,787 ft.

constituents such as silica cements, carbonate cements and authigenic clays.

Syntaxial Overgrowth Cements and Silica Cements

Syntaxial overgrowth cements are in two forms. Syntaxial quartz overgrowth, the most common type, comprises about 2 % of the total rock. It is recognized by its optical continuity with of the original quartz grain (the nucleus) that is surrounded by a clay coating (chlorite/illite) called a "dust rim". Quartz with syntaxial overgrowth has straight edges, an important clue in recognizing overgrowth on quartz lacking dust rims. Another form of syntaxial overgrowth cement identified on thin sections is syntaxial feldspar overgrowth (less than 1 %) which occurs on orthoclase and plagioclase as a "cleaner outer rim" around a dirty feldspar nucleus (Figure 45). Microquartz cement as chalcedony is in trace amounts as fibrous rim around detrital grains (Figure 46) or as pore-filling cement. Equigranular microquartz is seen as pore filling cement in the near-to-normally pressured rocks (Figure 47).

Carbonate Cements.

Carbonate cements consist of calcite, dolomite and siderite. Epitaxial sparry calcite forms spots, patches, or where widespread, poikilotopic cement enclosing sand grains. In deep overpressured rocks, calcite cement is not widespread and occurs as patchy cement (Figure 31). In the near-to-normally pressured rocks, calcite is extensive as poikilotopic cement (Figure 32). Zones of intense cementation recognized in cores are

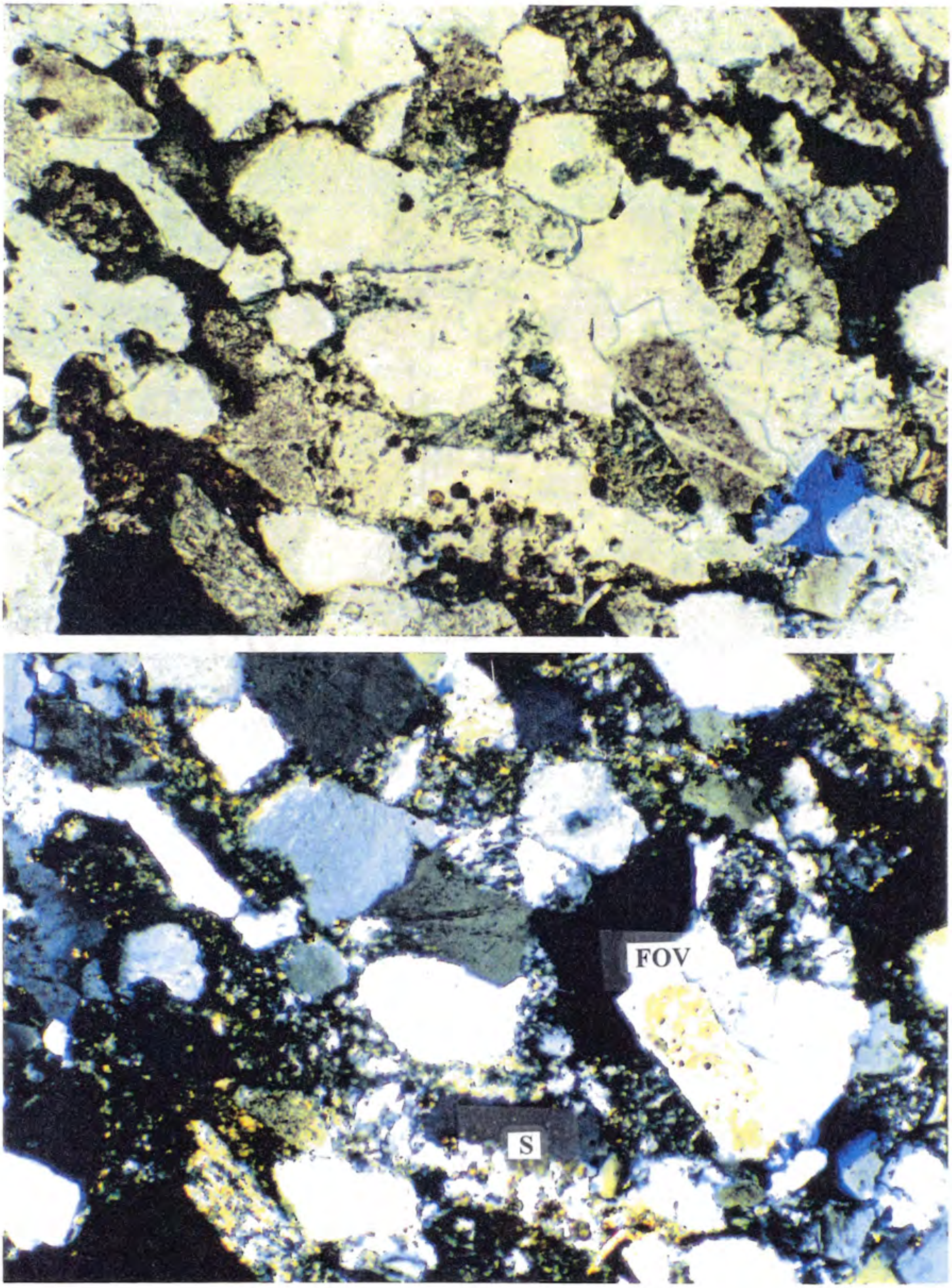


Figure 45. Syntaxial feldspar overgrowth. Note cleaner outer rim around dirtier original grain. Also feldspar replaced by siderite (bottom of the photograph). 10X, PPL, Davis Herring No. 1, 10,914 ft.

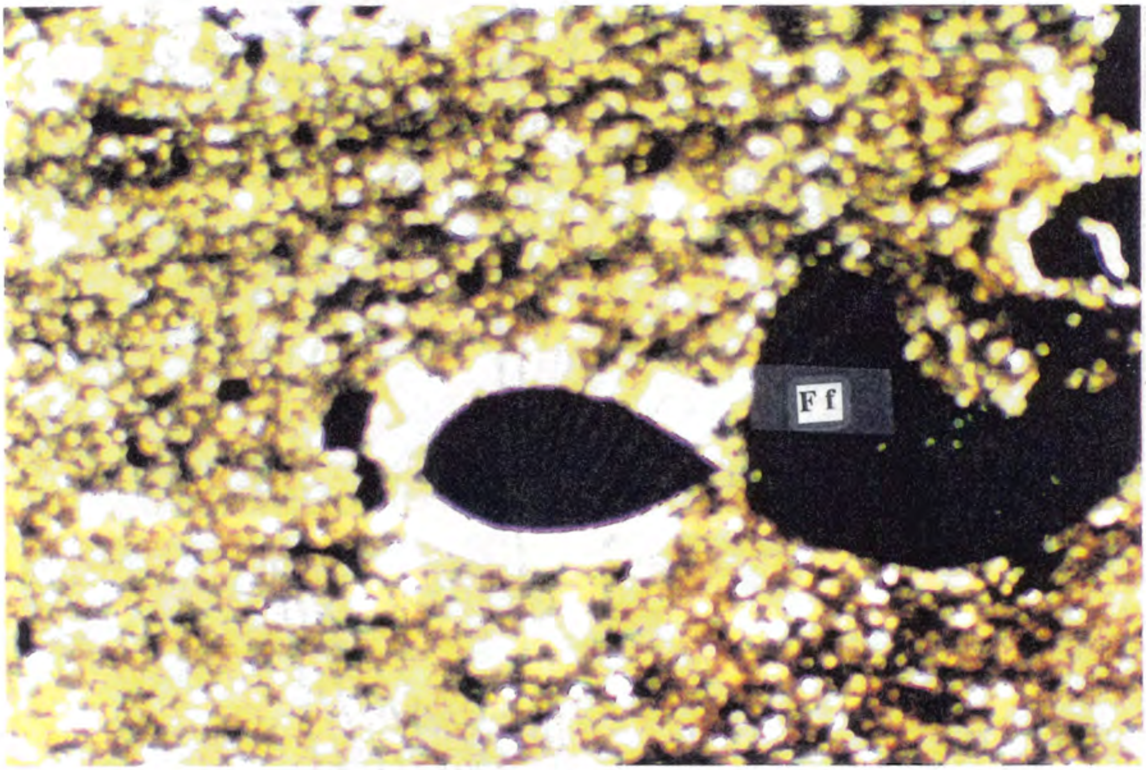


Figure 46. Chalcedony rim around a fossil, in chlorite-rich band.
10X, PPL, Tenneco Lester 6, 12,740 ft.

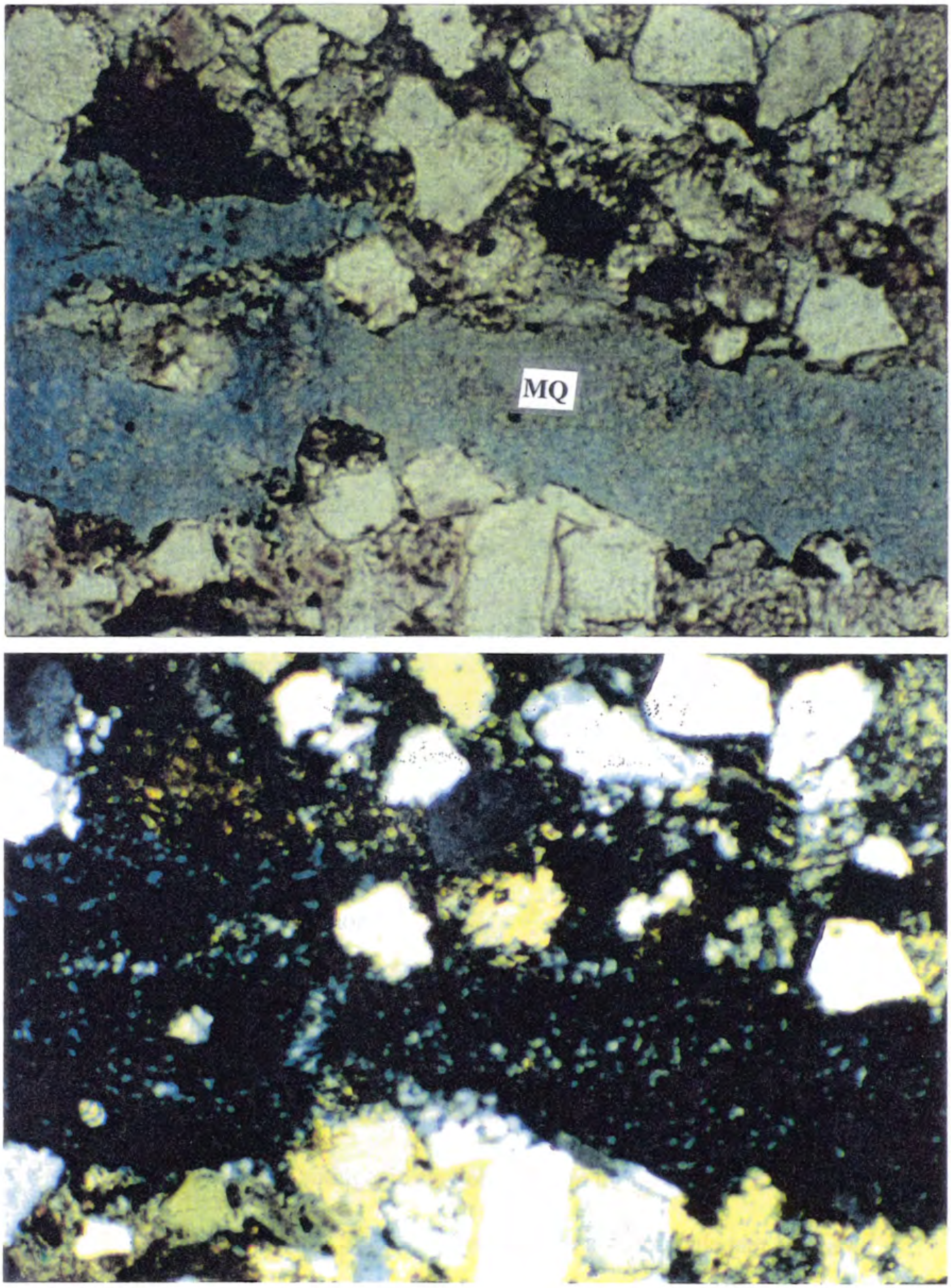


Figure 47. Pore-filling equigranular microquartz. 10X, Ferguson Grabow No.1. 7,635 ft. (A) PPL (B) XN

generally calcite-cement rich in thin sections (Figure 32 B). Cemented vertical fissures recognized in the Tenneco Lester 6 core are calcite filled (Figure 48).

Calcite cements formed in at least two stages: (1) an early microspar or finely crystalline calcite cement, and (2) a late stage that led to the formation of poikilotopic texture. Calcite is the dominant carbonate-type cement in near-to-normally pressured rocks.

Dolomite cements are early small hypidiotopic rhombohedra that lined sand grains or replaced feldspars or calcite cement. Dolomite also is void filling. Dolomite cement formed by at least two episodes: (1) an early pore lining dolomite and (2) late pore filling, feldspar-replacing, and patchy (Figure 49) or poikilotopic calcite-cement replacement (Figure 50). Dolomite is the dominant carbonate-type cement in deep overpressured Red Fork Sandstone.

Siderite cement occurs as isolated or as aggregates of euhedral rhombohedra lining the grains or replacing feldspars (Figure 38), patchy calcite or dolomite(Figure 51). It is commonly associated with micritic fragments. In some rocks of the Davis Herring No. 1, oxidation of siderite is common.

Authigenic Clays

Authigenic chlorite, kaolinite and illite precipitated in place from solutions. Chlorite was the most abundant authigenic clay observed in thin sections. It occurs as pore lining, and pore filling (Figure 52). However, chlorite is more abundant in deep overpressured rocks than in near-to-normally pressured rocks. Kaolinite appears mainly

Figure 48. Fracture filled with calcite/chert in dark organic-rich chloritic band. 10X, PPL, Tenneco Lester, 12,740 ft.

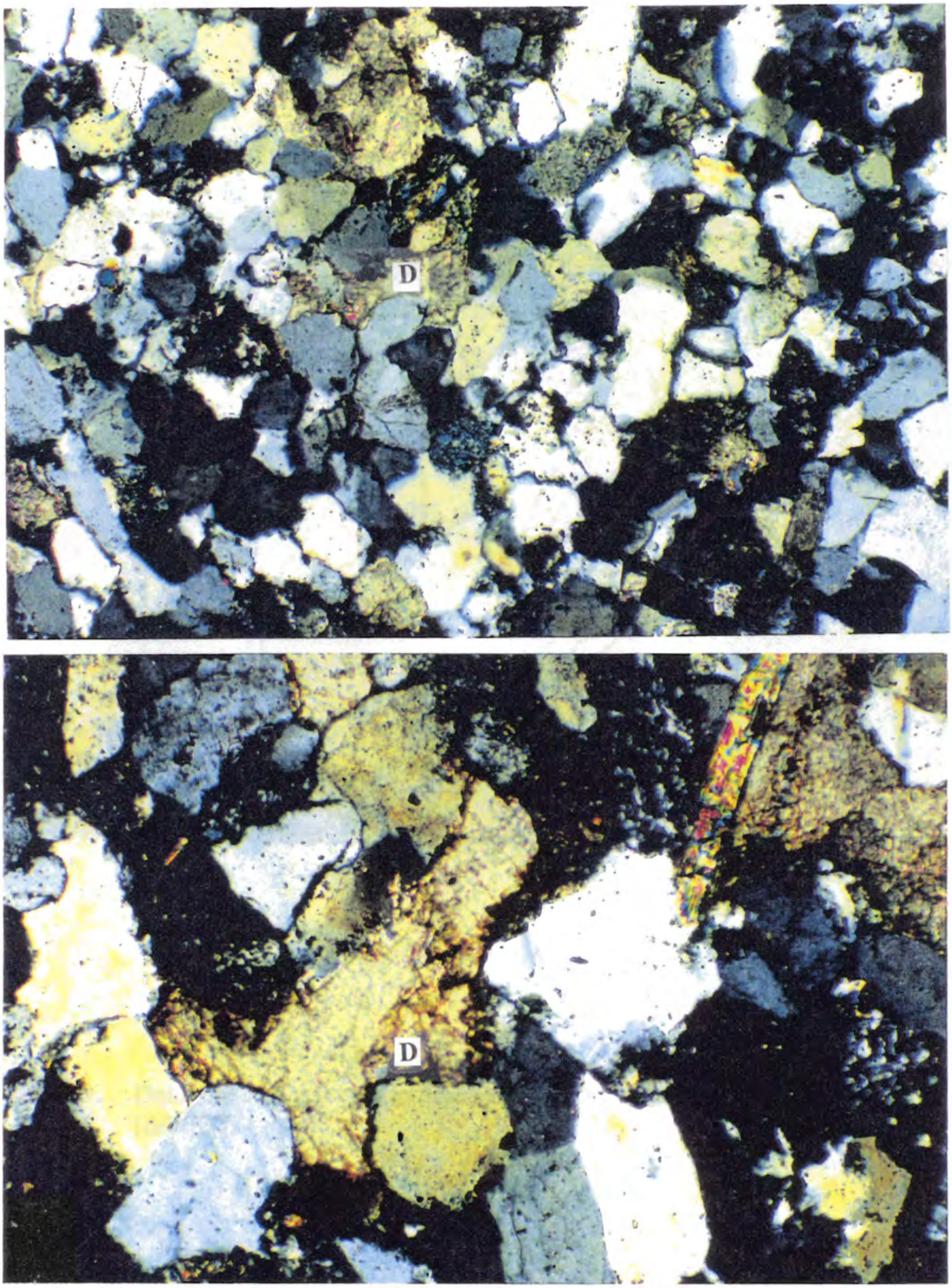


Figure 49. Dolomite that replaced Patchy calcite. 10X, XN (A) Tenneco Lester 6, 12,750 ft. Note glauconite. (B) Getty Tract No. 1, 4,838 ft. Note syntaxial quartz overgrowth.

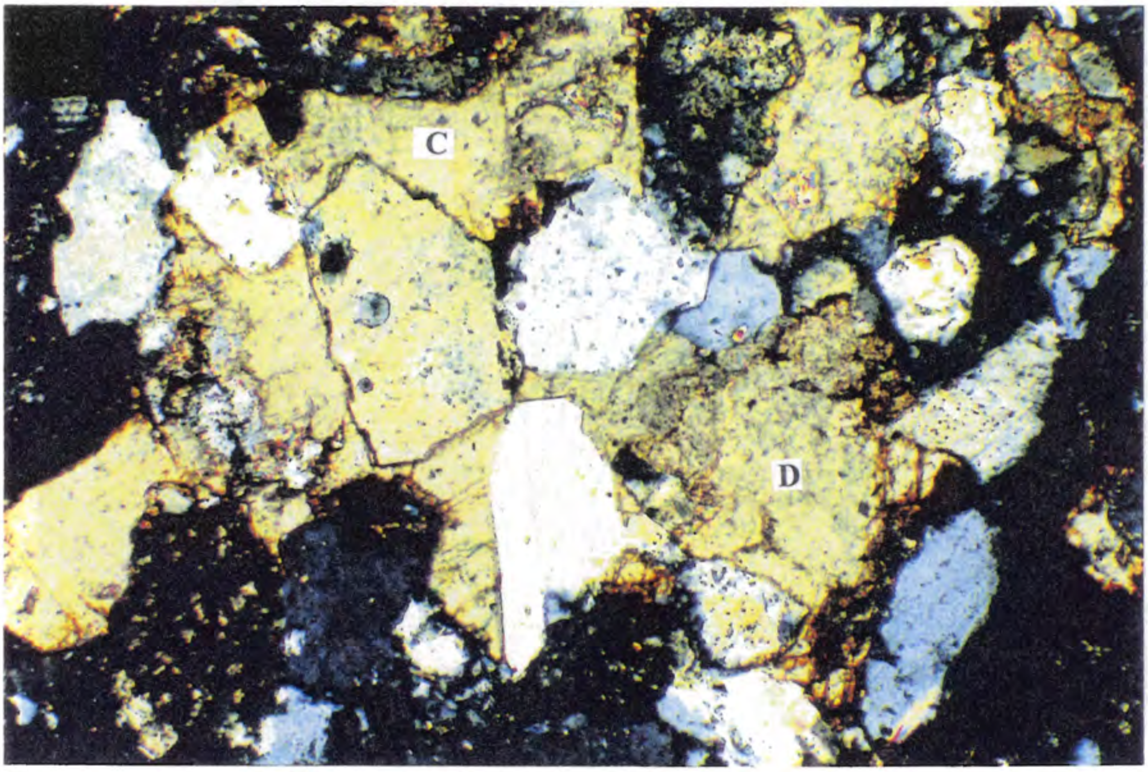


Figure 50. Dolomite replaced poikilotopic calcite. 10X, XN, Getty Tract No. 1, 16/WSW, 4,838 ft.

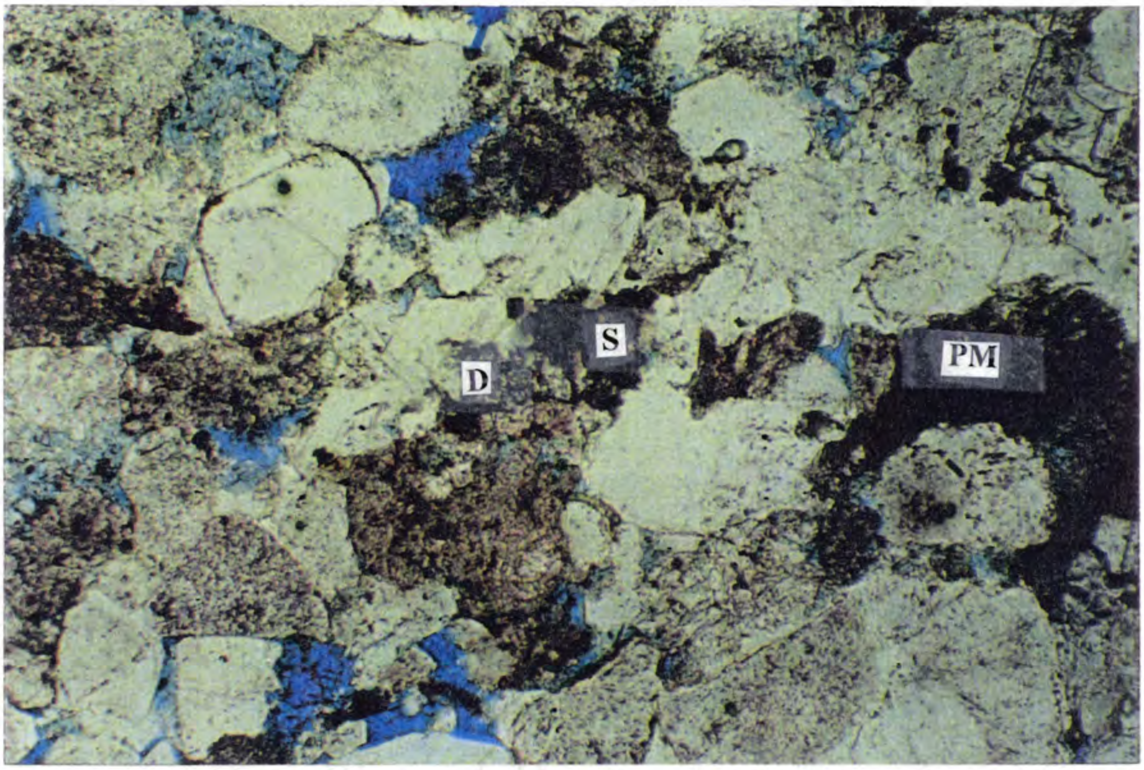


Figure 51. Patchy calcite replaced by dolomite and sericite. 10X, PPL, Ferguson Grabow No. 1, 7,624 ft.

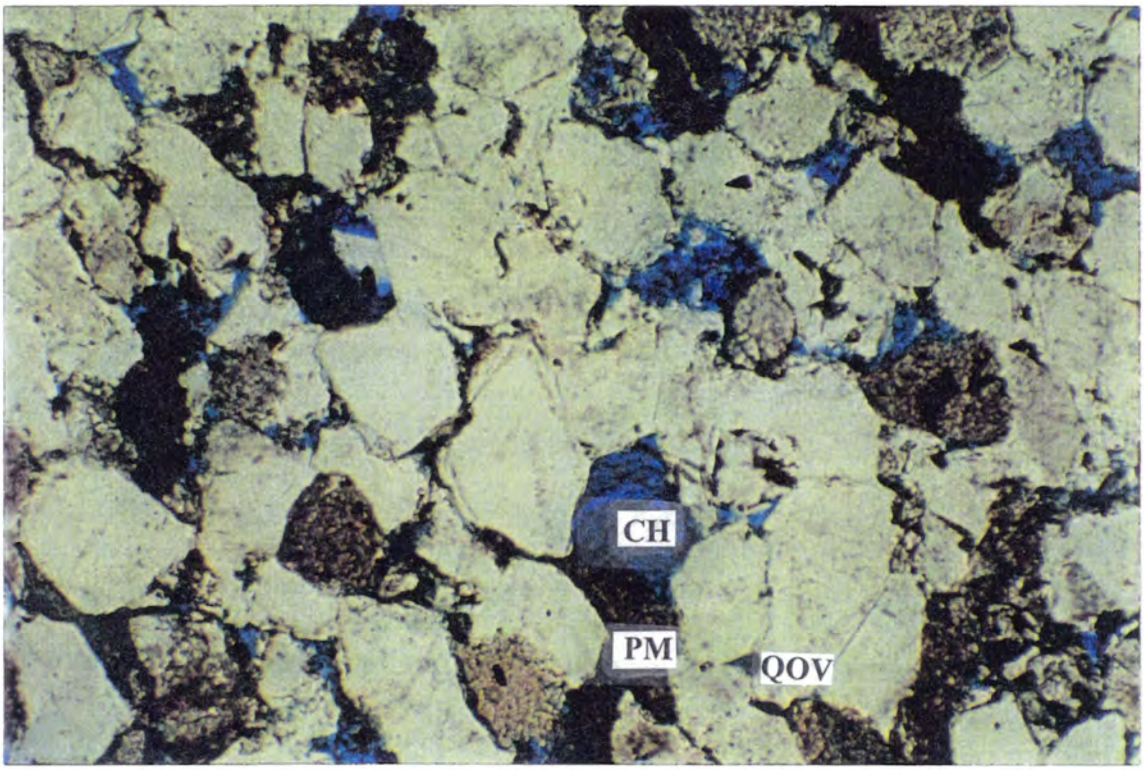
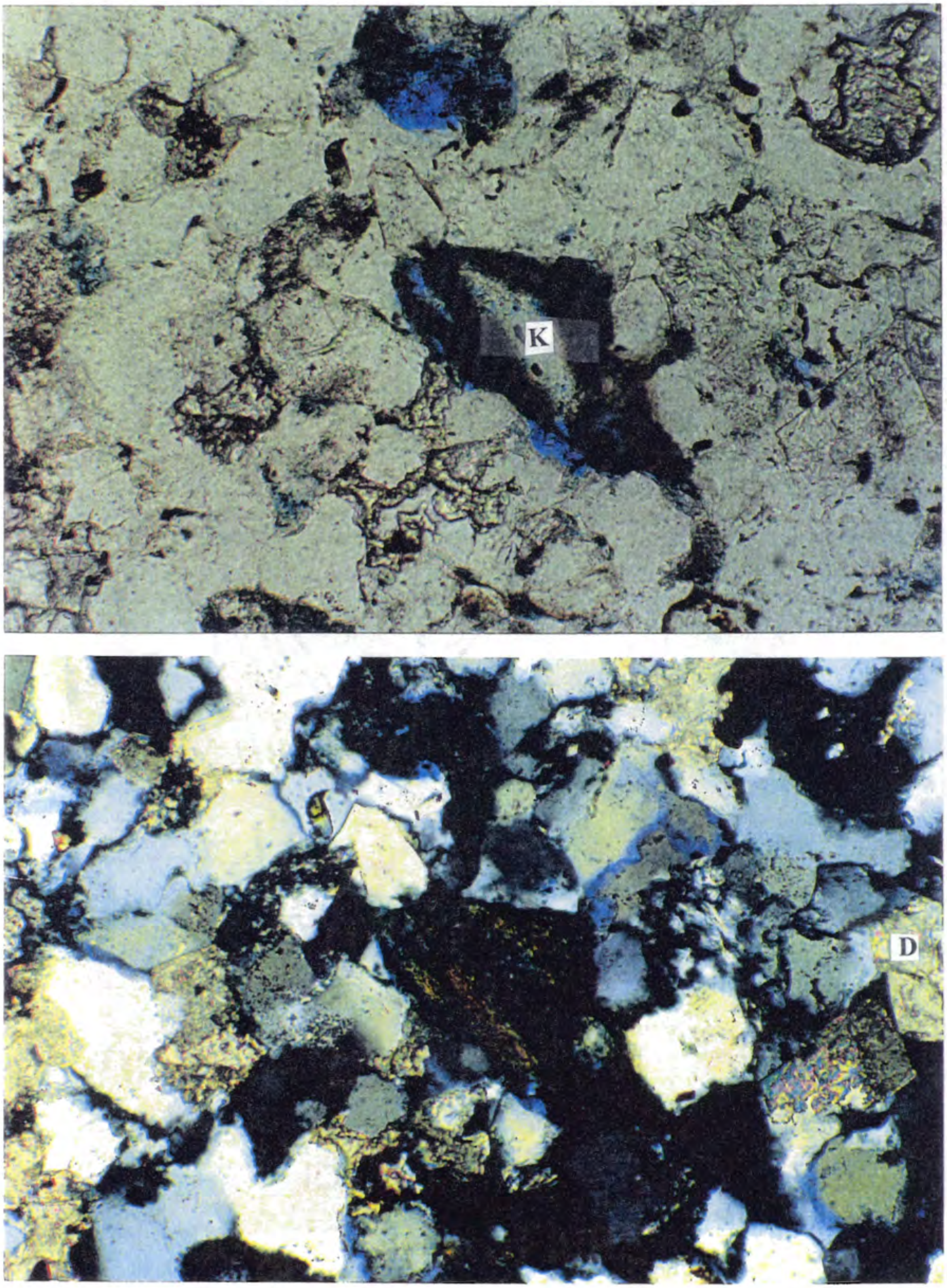


Figure 52. Pore-filling chlorite in moldic porosity. Note syntaxial quartz overgrowth. 10X, Davis Herring No. 1, 10, 908 ft.

as pore filling booklets in enlarged intergranular porosity or in moldic porosity (Figure 53). Kaolinite was found in some samples. It was in trace amounts at very great depths and at very shallow depths. It was more abundant in highly porous rocks of the Davis Herring No. 1 and the Ferguson Grabow No. 1. Illite is in all rocks analyzed as pore lining and pore bridging structure.

Evolution of Porosity

Red Fork porosity is mostly secondary porosity (Figure 54) with trace amounts of remnant primary intergranular porosity (Figure 55). Secondary porosity consists of enlarged intergranular porosity, oversized pores, elongated pores, and moldic porosity. Secondary porosity values range from ? to ? with an average of ?. Secondary porosity appears to increase with grain size. Fine-grained, deep overpressured Red Fork sandstones have much lower porosities than their fine to medium grained near-to-normally pressured, northern-shelf counterparts. In thin sections, zones of high porosity are adjacent to zones with low porosity. Porosity development appears to have been related to the primary mineralogical composition of rocks. Indeed, zones of high porosity (more than 15%) seem to be in rocks originally rich in rock fragments and feldspars (20-30%), whereas strata primarily rich in quartz (70-80%) show low porosity . The early diagenetic stage is dominated by compaction due to burial. In this stage, primary intergranular porosity was virtually destroyed by formation of pseudomatrix, by silica precipitated as syntaxial quartz overgrowths, by syntaxial feldspar overgrowths, and by



igure 53. Pore-filling kaolinite booklets in a partially dissolved MRF. Note replacement of partially dissolved MRF by pore-filling chlorite. 20X, Tenneco Lester 6, 12,750 ft. (A) PPL (B) XN

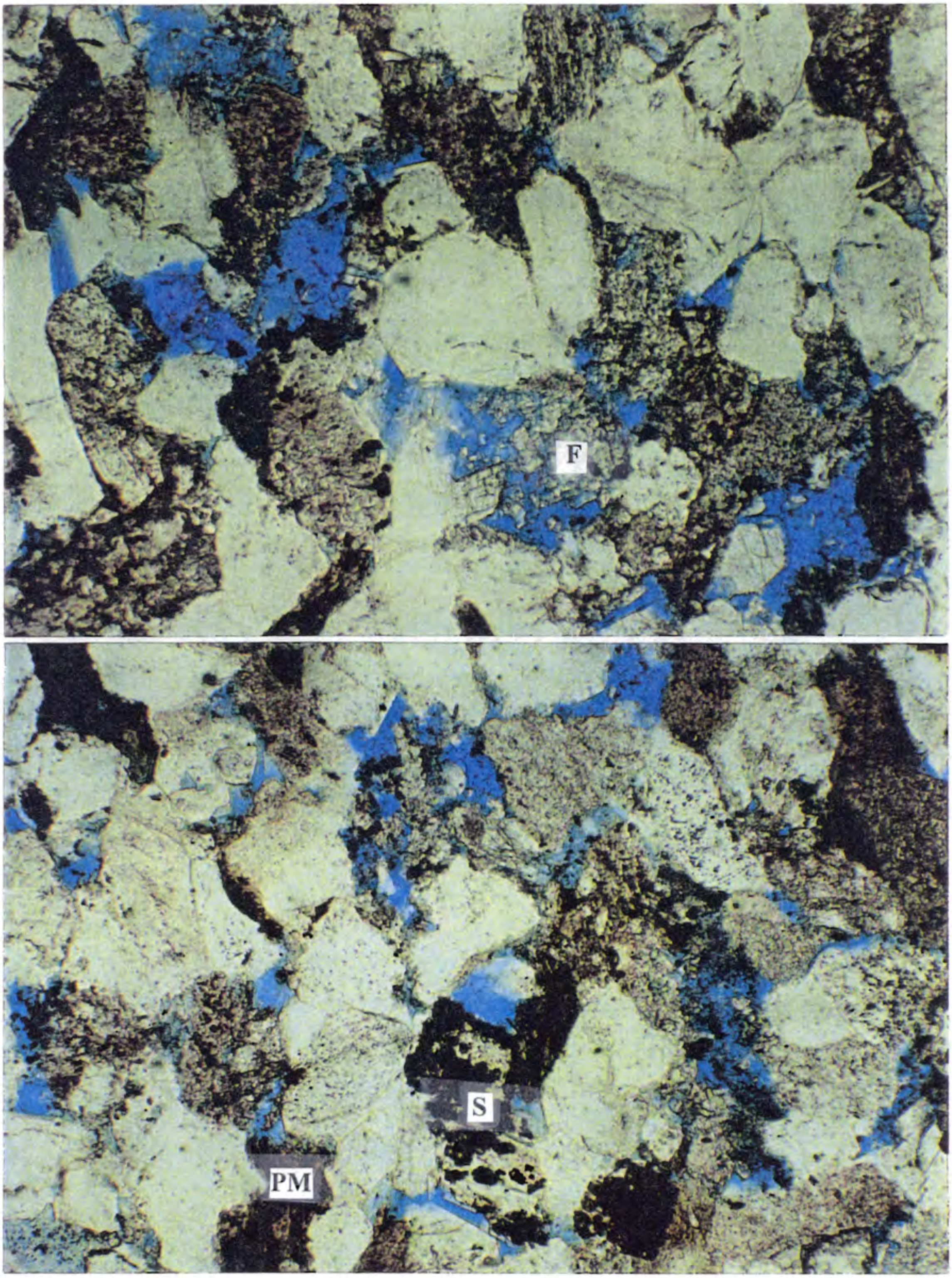


Figure 54. Secondary porosity features: moldic porosity and enlarged intergranular porosity. Note abundant pseudomatrix, and siderite that replaced plagioclase, in the lower part of the picture. 10X, PPL, Ferguson Grabow No. 1, 7,624 ft.

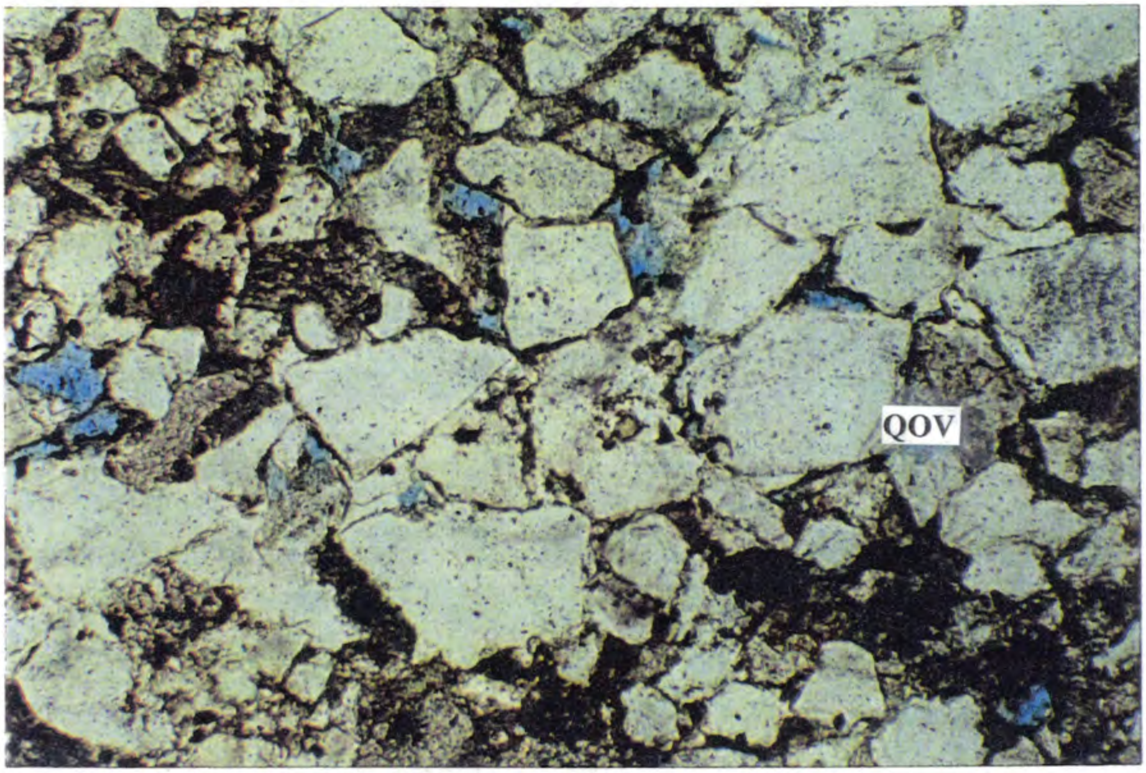


Figure 55. Preserved primary intergranular porosity due to illite-chlorite coating. 10X, PPL, Getty Tract No. 1, 16/WSW, 4,787 ft.

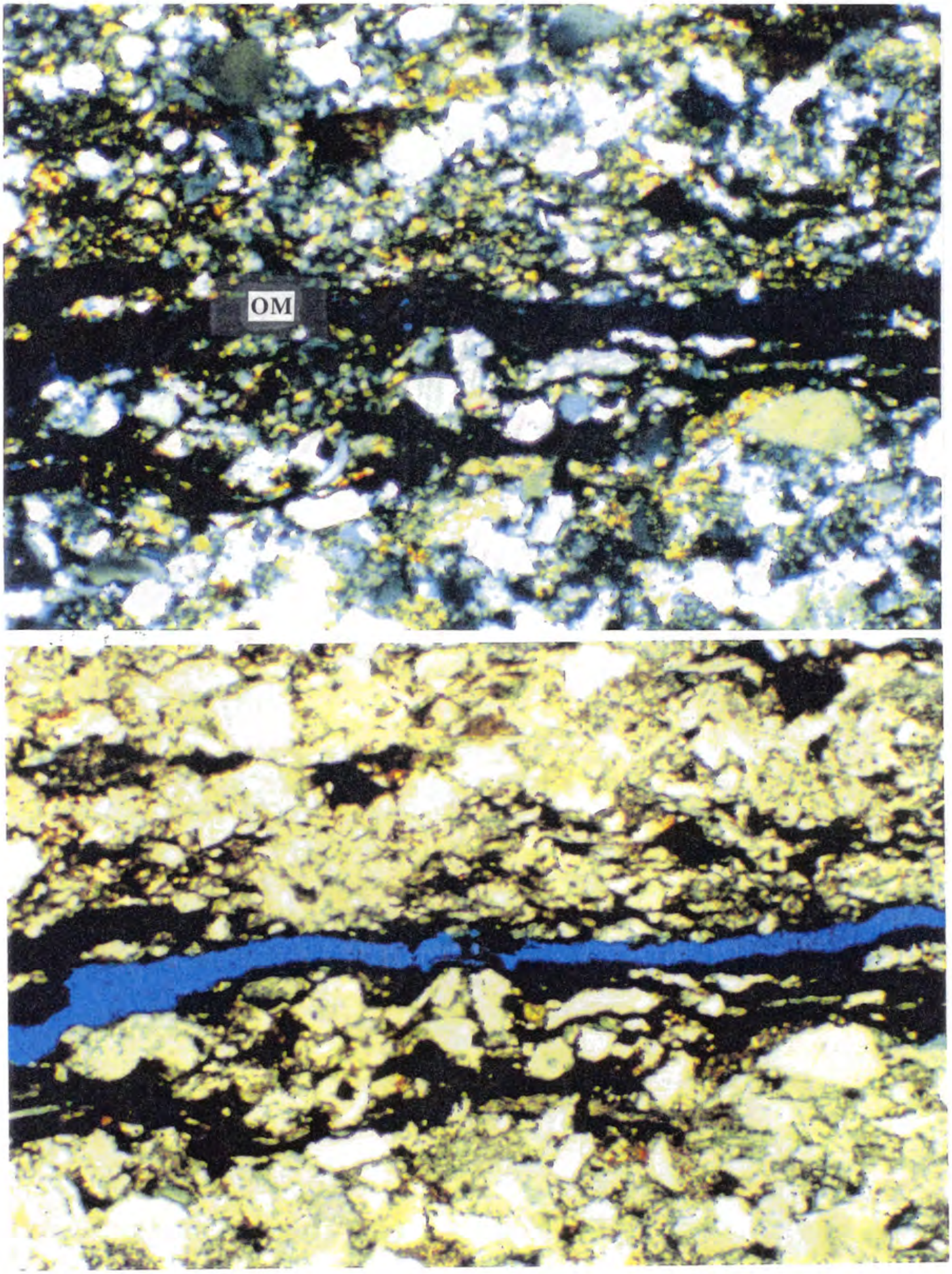


Figure 56. Dissolution of organic-matter seam creating secondary porosity. Note abundant illitic matrix, associated with the seam. 10X, Davis Herring No. 1, 10,873 ft. (A) PPL (B) XN

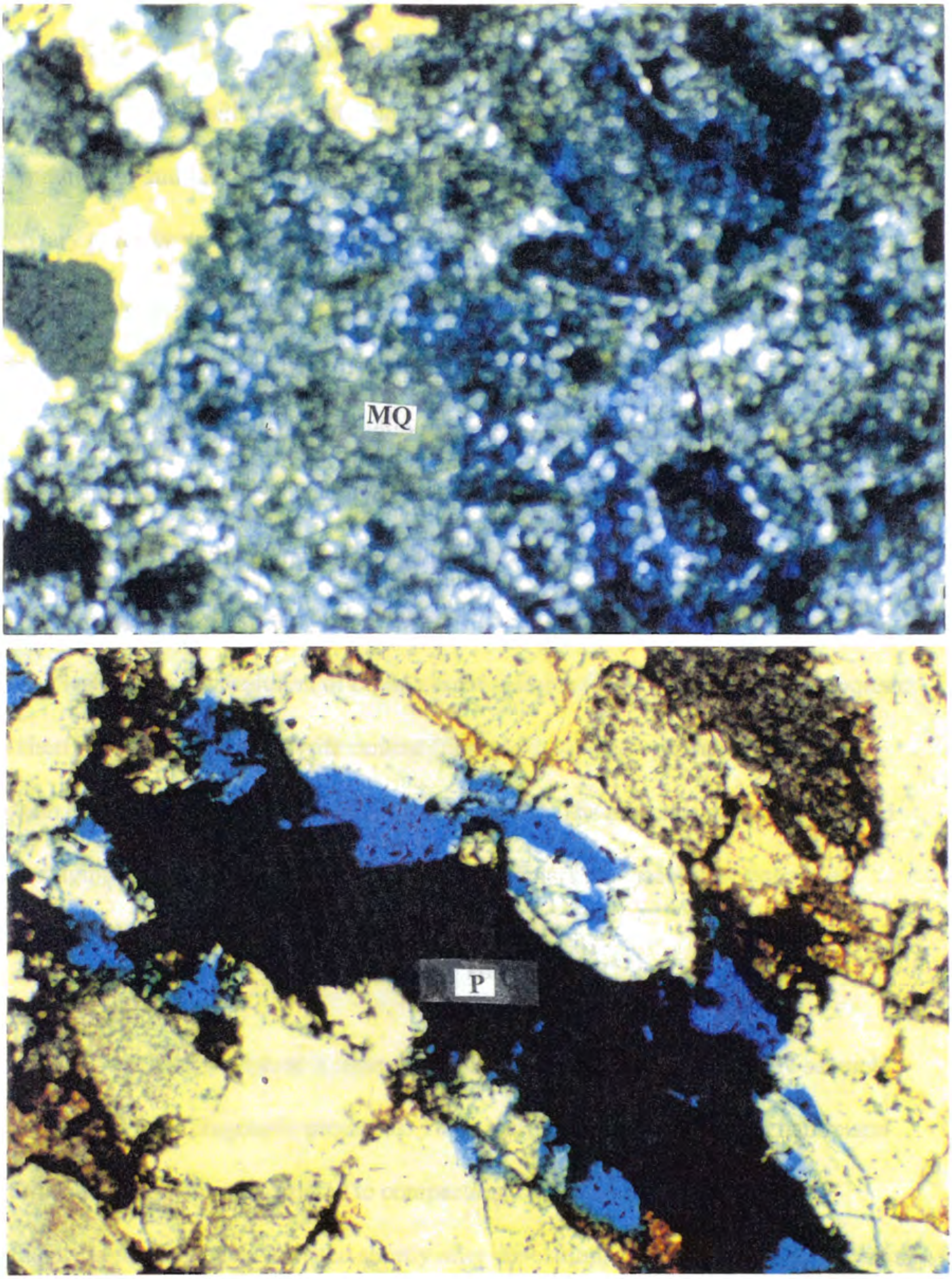


Figure 57. Dissolution features of secondary-porosity development. (A) Dissolution of equigranular microquartz. 10X, XN, Ferguson Grabow No. 1, 7,635 ft. (B) Dissolution of pyrite cement. 10X, PPL, Getty Tract No.1, 16/WSW, 4,838 ft.

early precipitation of clays (chlorite and illite) and hematite. Further porosity-occluding episodes, such as late silica cementation, early and late calcite cementation, or precipitation of authigenic clays accentuated porosity reduction. Development of secondary porosity was initiated when corrosive fluids (carbonic acids, organic acids, and sulfuric acids), most likely derived from hydrocarbon generation and migration, were injected into the system, changing the chemistry of the formation water. Evidence of the first hydrocarbon generation and migration is attested by the presence of thin organic-matter coating between the syntaxial overgrowth of quartz and the original grain. Injection of corrosive fluids triggered multiple dissolution processes of metastable grains such as metamorphic rock fragments, feldspars, shale clasts, pseudomatrix (Figure 54) and to a lesser extent dissolution of organic-matter seams (Figure 56), silica (microquartz and chert) (Figure 57 A) and pyrite cement (Figure 57 B). Microporosity is preserved between authigenic kaolinite booklets (Figures 38, 53). The presence of pore lining and pore bridging authigenic clays also decrease both primary and secondary porosities.

Diagenetic History

The Red Fork sandstone's mineralogical composition and texture were severely modified by various diagenetic processes. These were mechano-chemical in nature and occurred as several episodes related to compaction, cementation, and dissolution. Mechanical processes were initiated shortly after deposition, by sediment-burial. The resulting compaction (vertical stress induced diagenesis) during this early stage ductily deformed low-grade metamorphic rock fragments and shale clasts to form pseudomatrix.

Formation of pseudomatrix reduced primary porosity. With increased burial depth and overburden stress, these feature developed: dust rims (chlorite/illite ?), early pore-lining siderite cement, early silica cement as syntaxial quartz overgrowth and early calcite cement as microspar. At the end of this diagenetic stage primary porosity was nearly obliterated. Further increase in depth of burial and vertical stress increased compaction and resulted in additional cementation and dissolution. Dissolution of feldspars, matrix and pseudomatrix due to generation and migration of corrosive fluids in the system occurred during this stage and changed the water chemistry into a more alkaline solution. Dissolution of feldspars and matrix removed H^+ ions from solution therefore increasing the pH of the solution. The change in water chemistry resulted in precipitation of late poikilotopic and/or patchy calcite, growth of authigenic chlorite, illite, and kaolinite and dissolution of quartz and microquartz. Chlorite although an early constituent of dust rims, was a late-diagenetic cement. Kaolinite is essentially a late-diagenetic pore-filling mineral. Illite was a late-diagenetic pore-lining mineral. Also related to the late-diagenetic stage is the precipitation of pyrite as poikilotopic cement and as replacement of fossils. Pyrite precipitation is probably related to hydrocarbon migration. This is suggested by the frequent association of pyrite with organic matter seams. The sequence of diagenetic events is shown in figure 57 C.

Diagenetic Banding

Petrographic examination of diagenetic bands (dark gray to yellowish gray and reddish dark brown bands) in cores revealed that the bands are fossiliferous and either

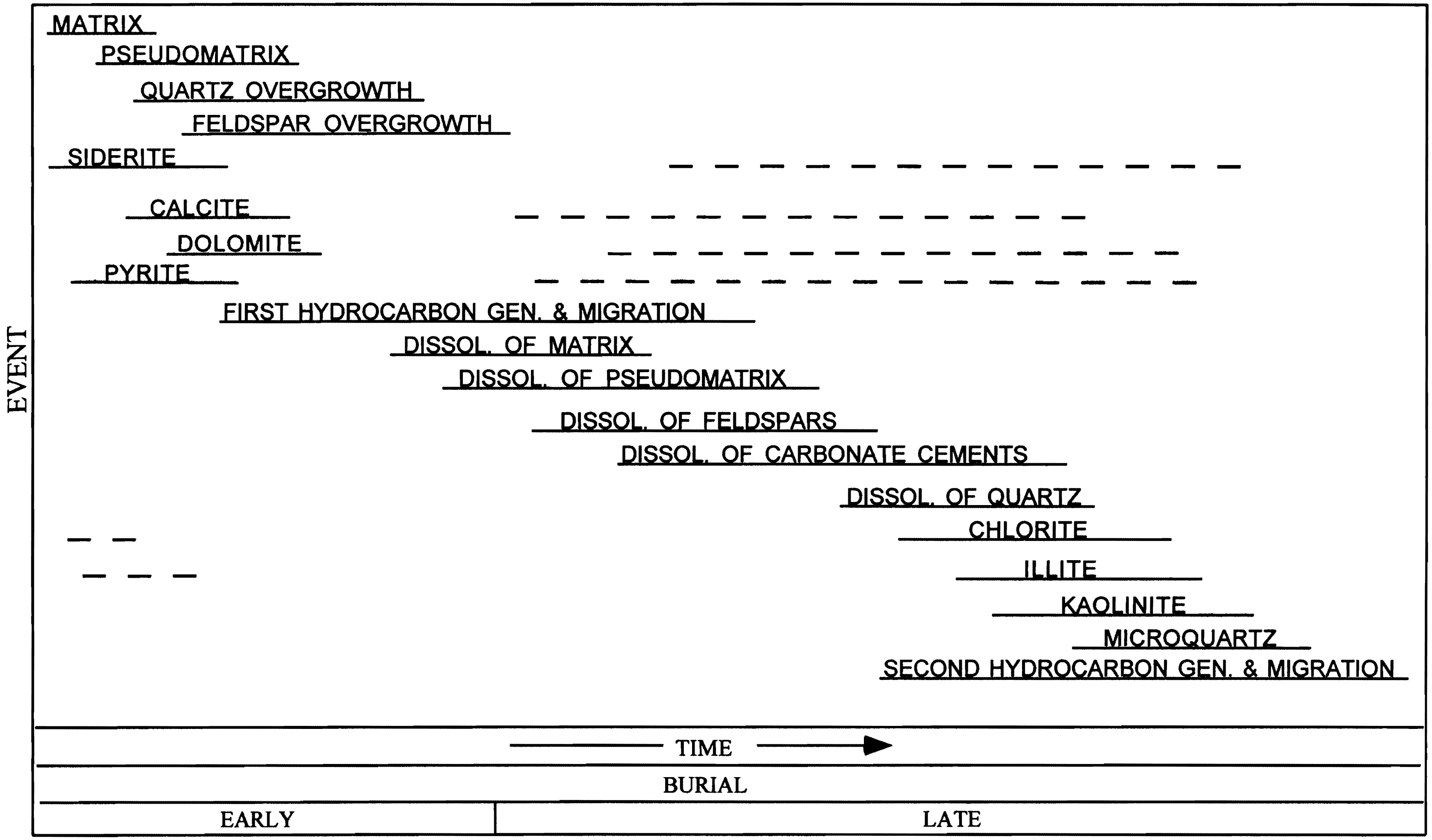


Figure 57 C : Sequence of Diagenetic Events in Red Fork Sandstones

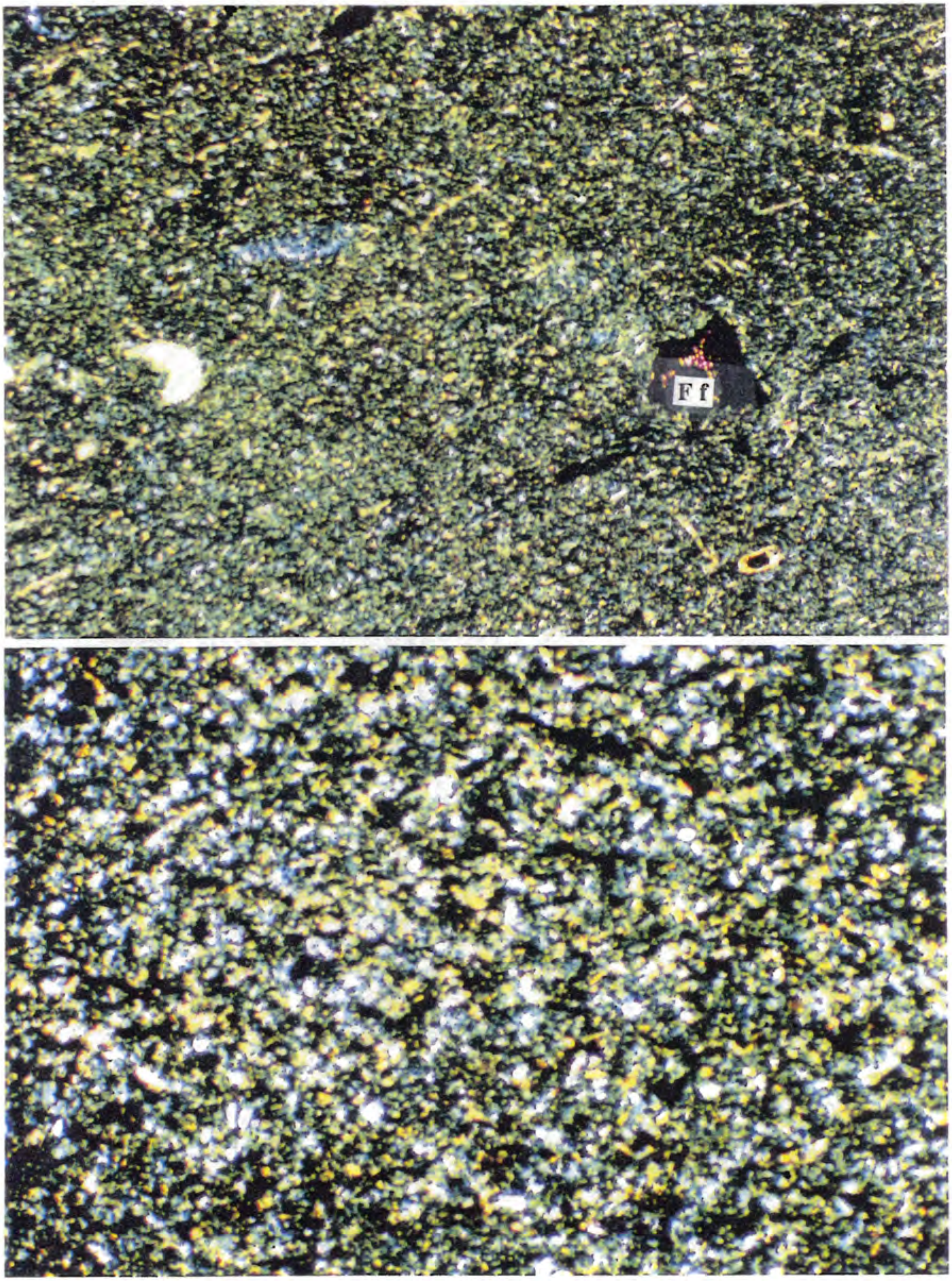


Figure 58. Chlorite-rich band. Note silica cement that replaced clayey matrix. In upper picture, note fossils replaced by calcite, microquartz, and pyrite/calcite. (A) 4X, XN, Tenneco Lester 6, 12,740 ft. (B) 10X, XN, Woods Swtizer "C", 11,407 ft.

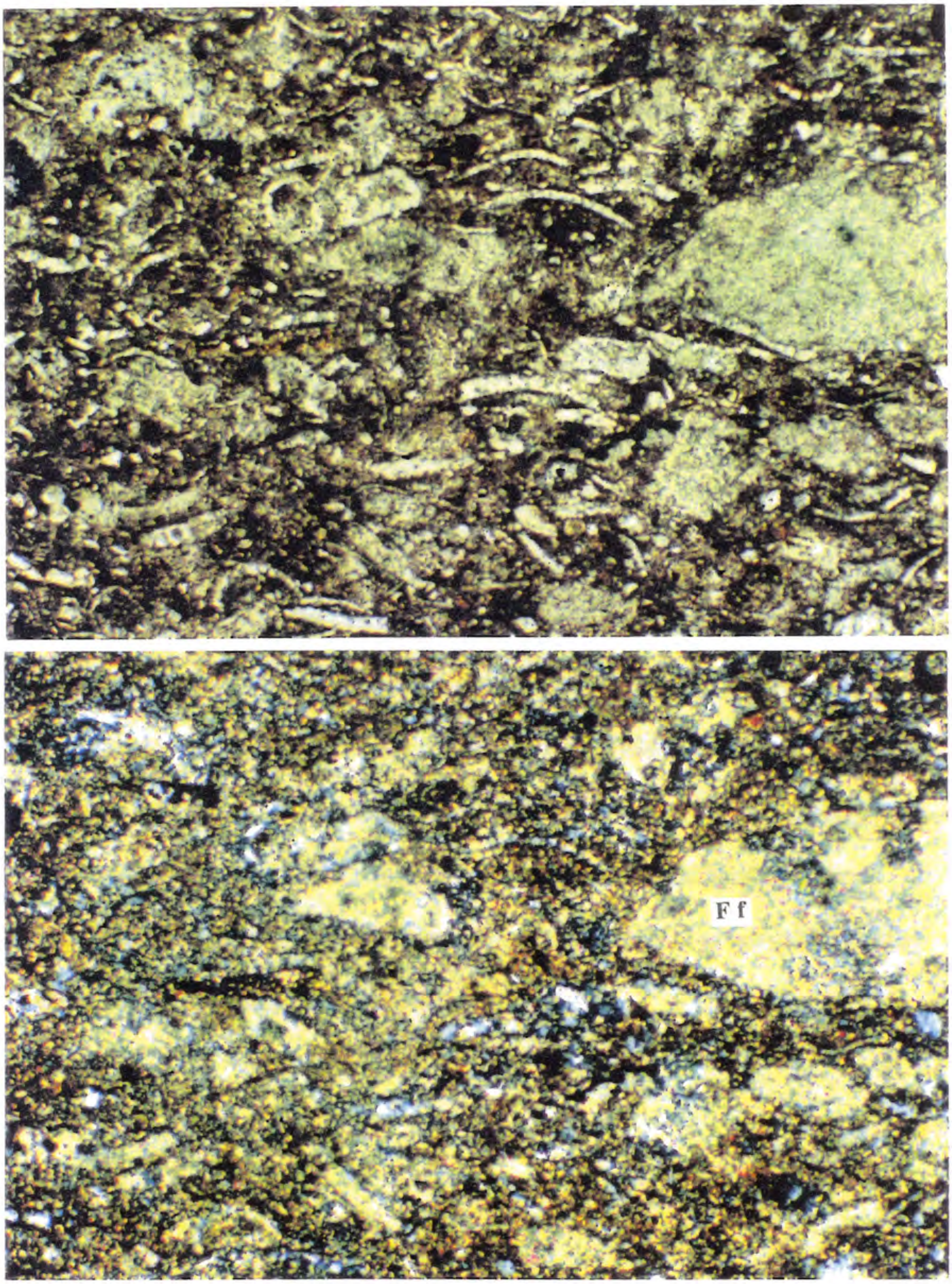


Figure 59. Calcite-rich band. Note abundant fossil fragments replaced by calcite/microquartz. Also note replacement of clayey matrix by silica cement. 10X, Woods Swtizer "C", 11,378 ft.
(A) PPL (B) XN

were replaced by calcite, pyrite, or chert. Combination of two replacing cements such as calcite/pyrite or pyrite/chert in fossils is common. The clayey matrix, more than 90%, is chlorite-rich (Figure 58) or calcite-rich (Figure 59). Chlorite-rich bands commonly are laminated. Fossil shells constitute the main detrital constituents and they commonly composed of chlorite, illite, calcite, and small hypidiotopic dolomite (ankerite) rhombohedra. Silica, as silt-sized quartz, grains is present as replacement cement of the clayey matrix and fossil fragments. Porosity in diagenetic bands is almost nonexistent.

Boundaries between chlorite bands and the host shale rock are sharp to gradational. X-ray diffraction of bulk samples of diagenetic bands taken from the Tenneco Lester 6 and Internorth Smith-B-21-1 cores confirms their mineralogical composition described from thin sections (Figure 60: A, B, C, D, E, F). Previous studies Power, (1991); Al-Shaieb et al., (1994 a); Al-Shaieb et al., (1994 b) related the origin of chloritic bands to the diagenetic alteration of shale host rock by self-reorganization of clay minerals (Orteleva, et al., 1987). In this process, “the diagenetic banding arose through the processes of differentiation from depositionally uniform to less-differentiated sediment through feedback processes” (Orteleva et al., 1987).

Figure 60 A. X-ray diffraction of a dark gray band. Tenneco Lester 6 at 12,744'.

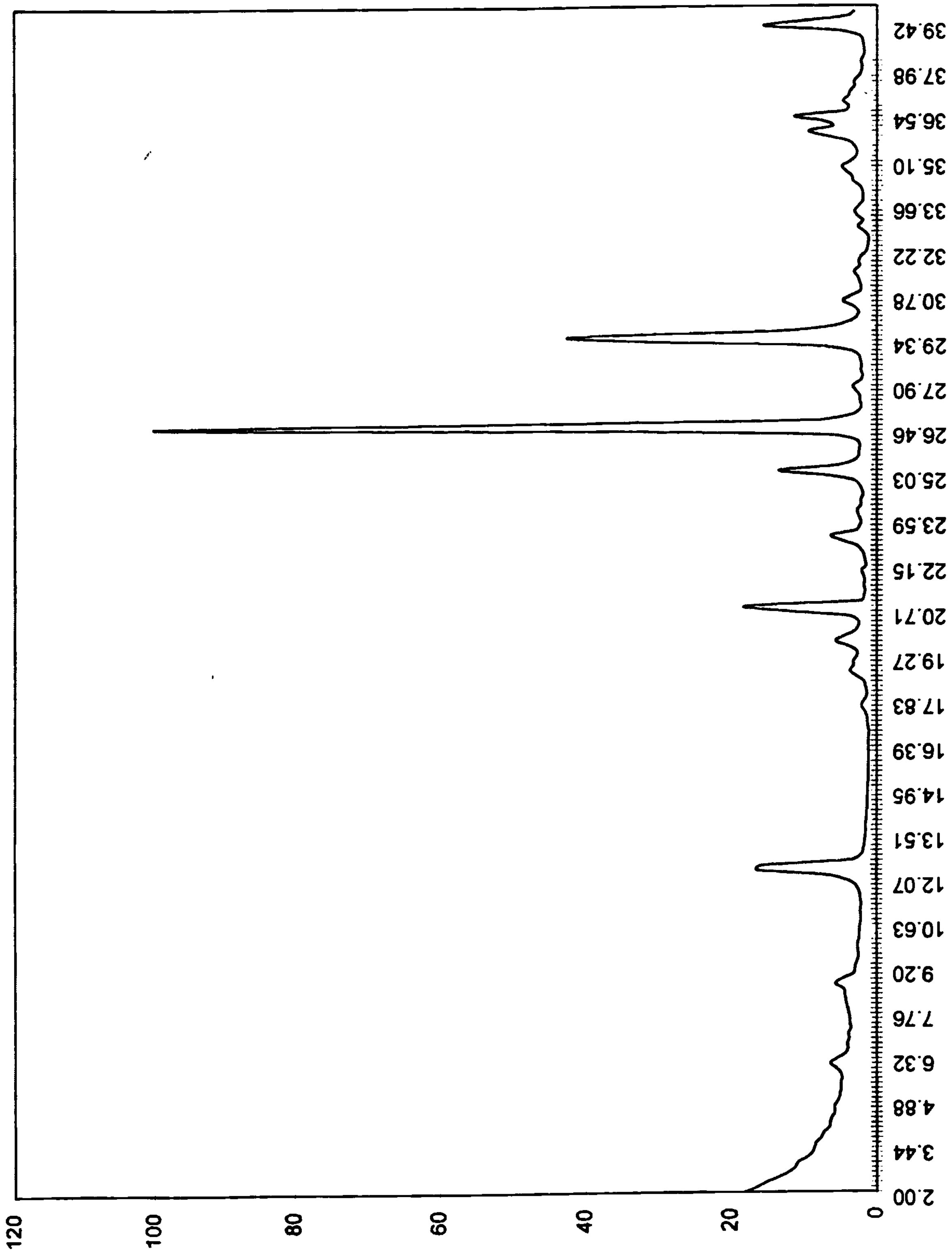


Figure 60 B. X-ray diffraction of a yellowish gray band. Tenneco Lester 6 at 12,733'.

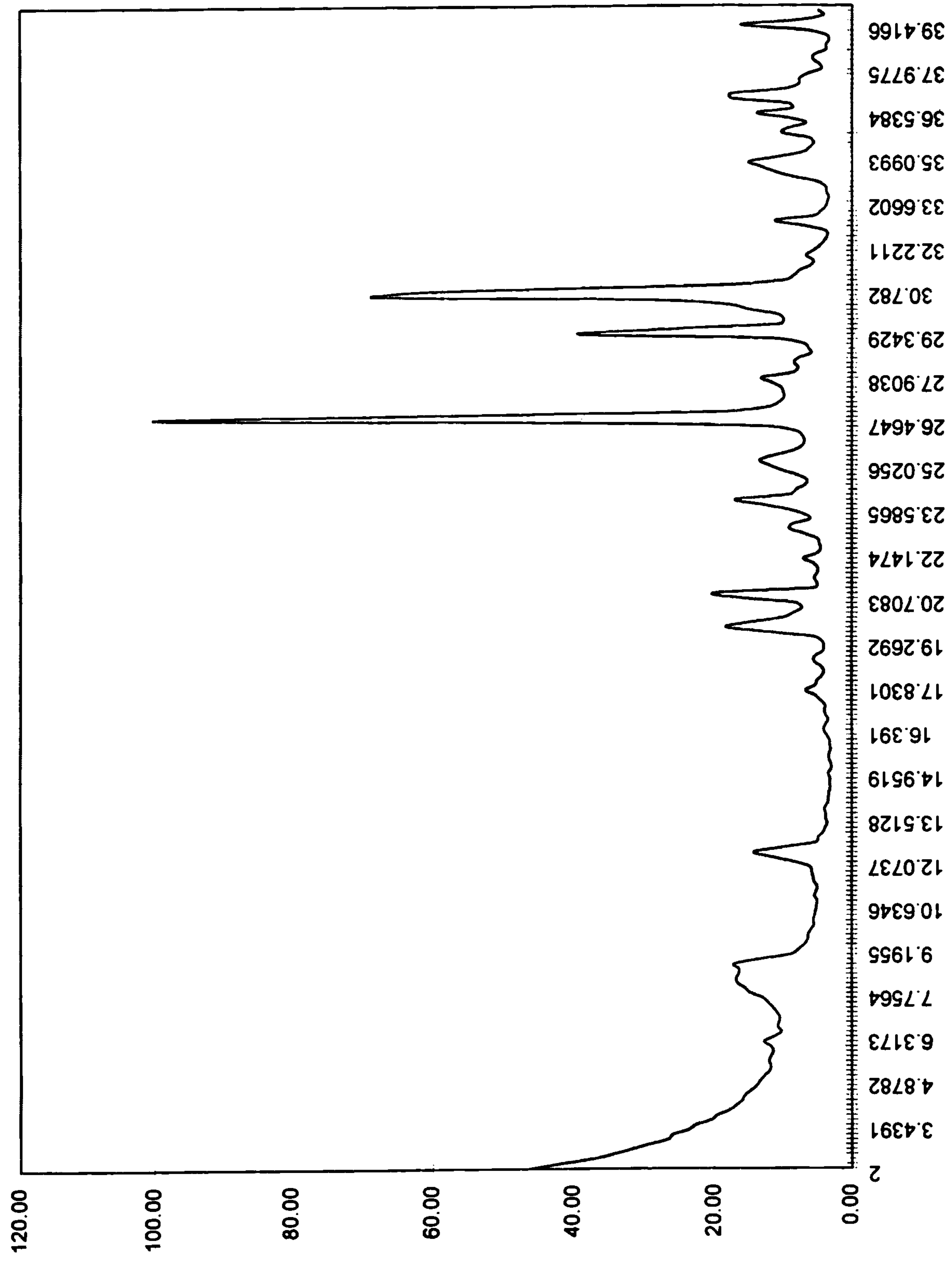


Figure 60 C. X-ray diffraction of the shale host rock. Tenneco Lester 6 at 12,738'.

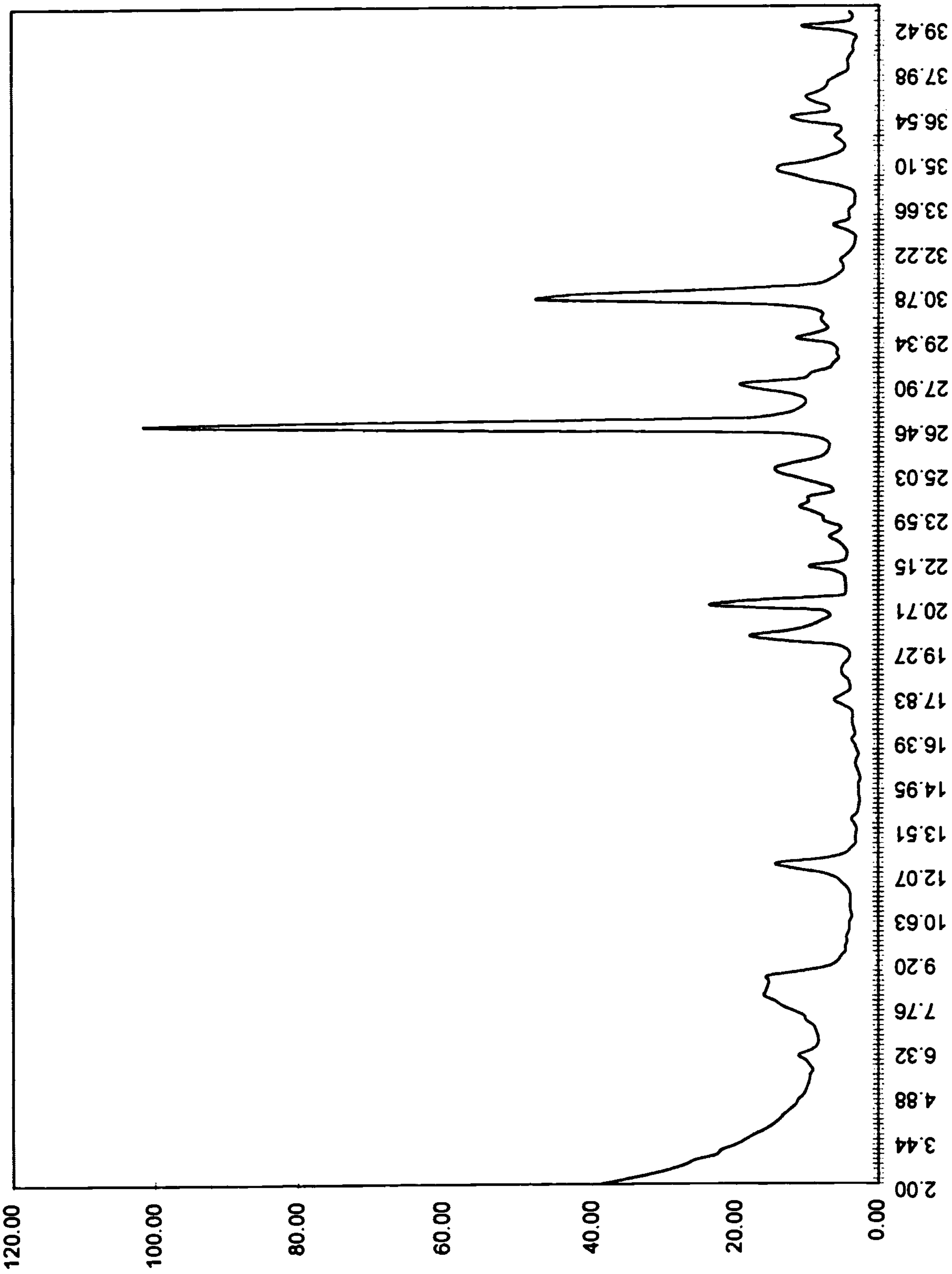


Figure 60 D. X-ray diffraction of an upper reddish dark brown band. Internorth Smith-B-21-1 at 12,223'.

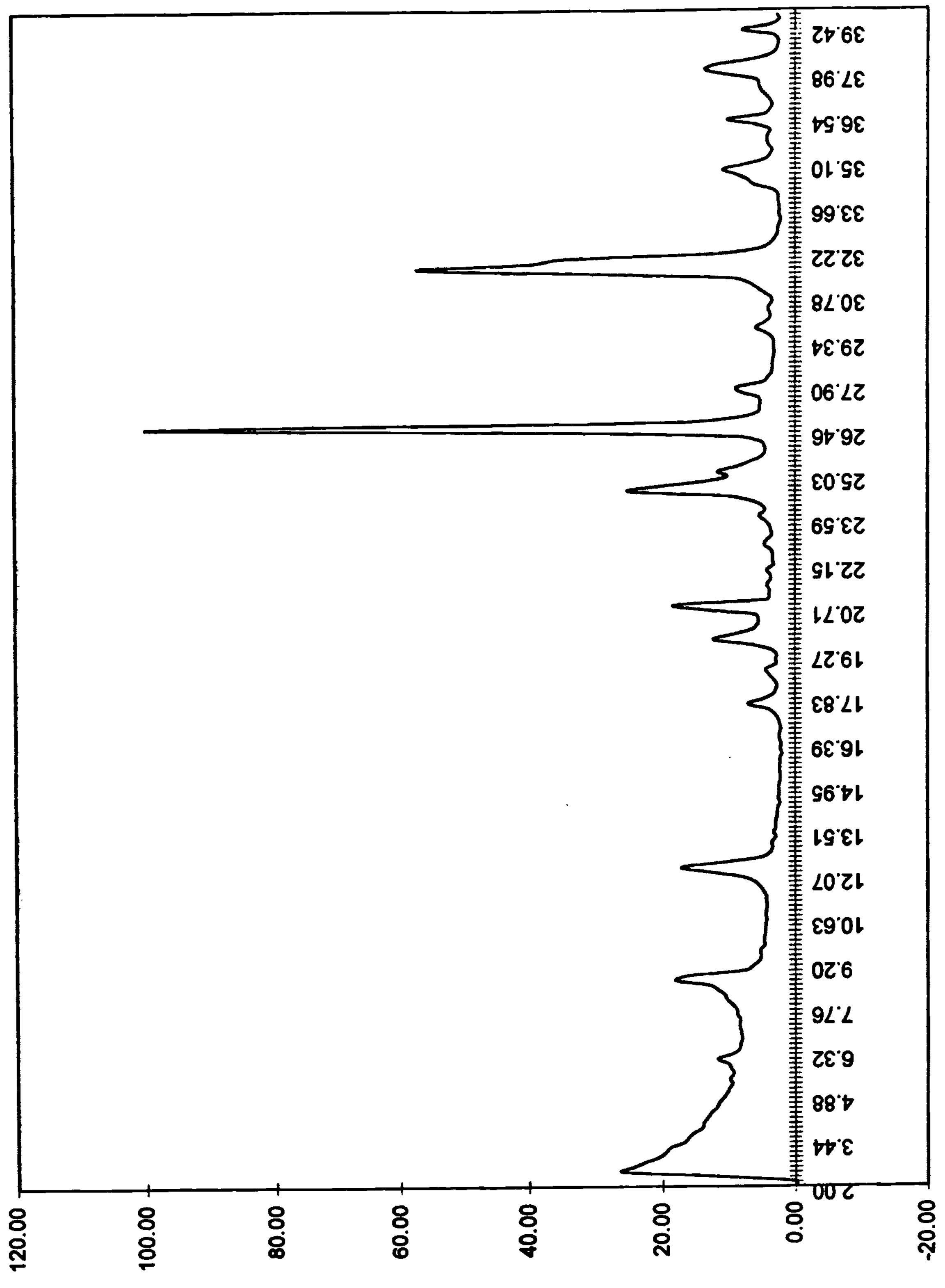


Figure 60 E. X-ray diffraction of a lower reddish dark brown band. Internorth Smith-B-21-1 at 12,260'.

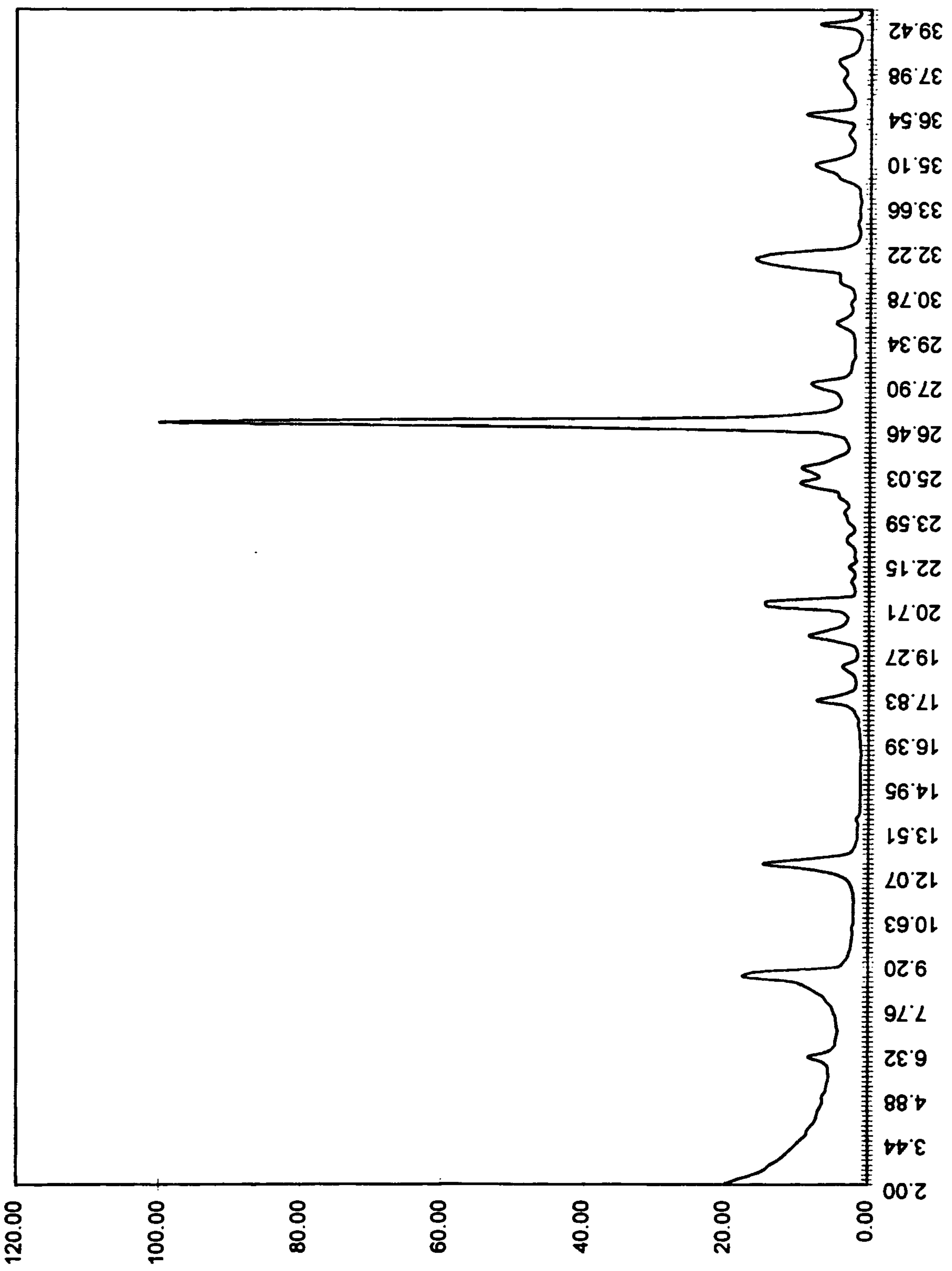
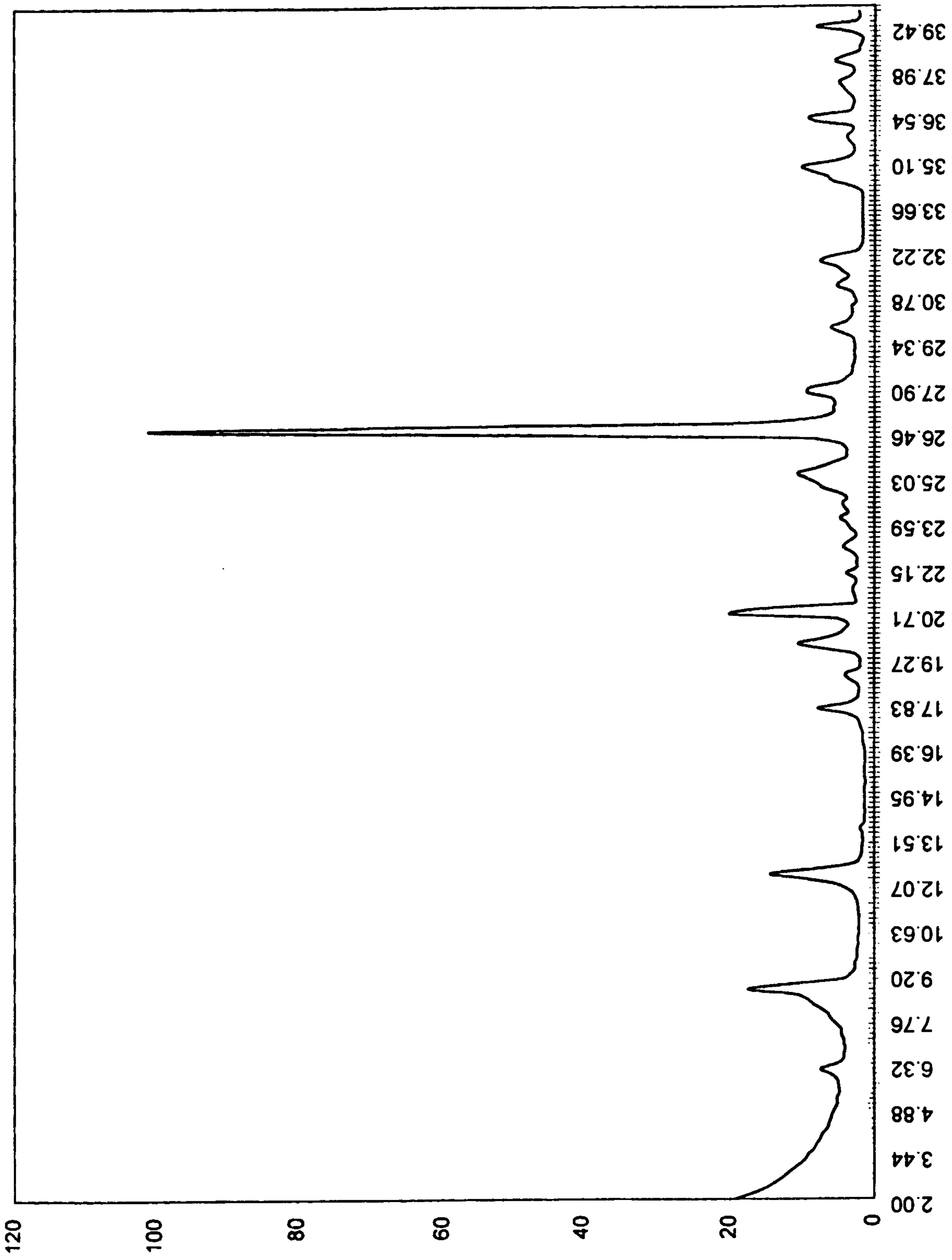


Figure 60 F. X-ray diffraction of the shale host rock. Internorth Smith-B-21-1 at 12,261'.



CHAPTER VII

CONCLUSIONS

The comparative analysis of pressure gradients, morphology, mineralogical composition, and texture of the Red Fork Sandstones yielded the following conclusions:

1- Examination of the pressure-depth gradient maps, pressure-depth profiles and potentiometric diagram of the Red Fork shows that in the Anadarko basin, two distinct pressure domains exist within the Red Fork: (1) a near to normally pressured northern shelf setting, and (2) an overpressured deep basinal setting.

2- Sedimentary structures in deep-overpressured and near-to-normally pressured northern shelf are similar. Minor differences between the sedimentary structures of the two domains reflect the depositional setting of the Red Fork sandstones.

3- Deep overpressured Red Fork sandstones and near-to-normally pressured Red Fork sandstones present distinct diagenetic overprints. Diagenetic bands and zones of intense cementation are in rocks of the deep overpressured domain, whereas the near-to-normally pressured Red Fork show only zones of intense cementation.

4- In thin sections, zones of intense cementation recognized in cores are highly calcite cemented and present no porosity.

5-Thin sections from diagenetic bands have no porosity and are either calcite-rich or chlorite-rich and contain substantial amount of illite, dolomite, very fine-sized muscovite, and silica cement as silt-sized quartz.

6-Silica replacement of the clayey matrix of the diagenetic bands is common and is believed to enhance the sealing properties of diagenetic bands.

7- The noticeable absence of diagenetic bands in the Red Fork of the near-to-normally pressured Red Fork and in the overpressured Davis Herring No. 1 and their presence in certain rocks of the deep overpressured domain suggest that the development of diagenetic bands is a function of the depth of burial to which rocks were subjected.

8 -The Davis Herring No. 1 is believed to be evidence of the diagenetic transition between overpressured banded rocks and near-to-normally pressured non banded Red Fork sandstones.

9- These diagenetic bands form an integral part of the seal structure that confines the high hydraulic pressure of these rocks.

10- The set of criteria distinguishing deep overpressured Red Fork from that of the near-to-normally pressured strata include:

a) In the deep overpressured domain the banded seal rocks are very fine grained, well sorted sublitharenites to litharenites which include repetitive, diagenetic silica cemented chlorite-rich and calcite-rich bands. Extensive syntaxial quartz overgrowth mainly was responsible for occlusion of primary intergranular porosity, with abundant authigenic chlorite. In addition, these rocks contain trace amounts of calcite cement, kaolinite, and microquartz. Overpressured banded rocks have low porosities and

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APPENDIX A

CORE PHOTOGRAPHS

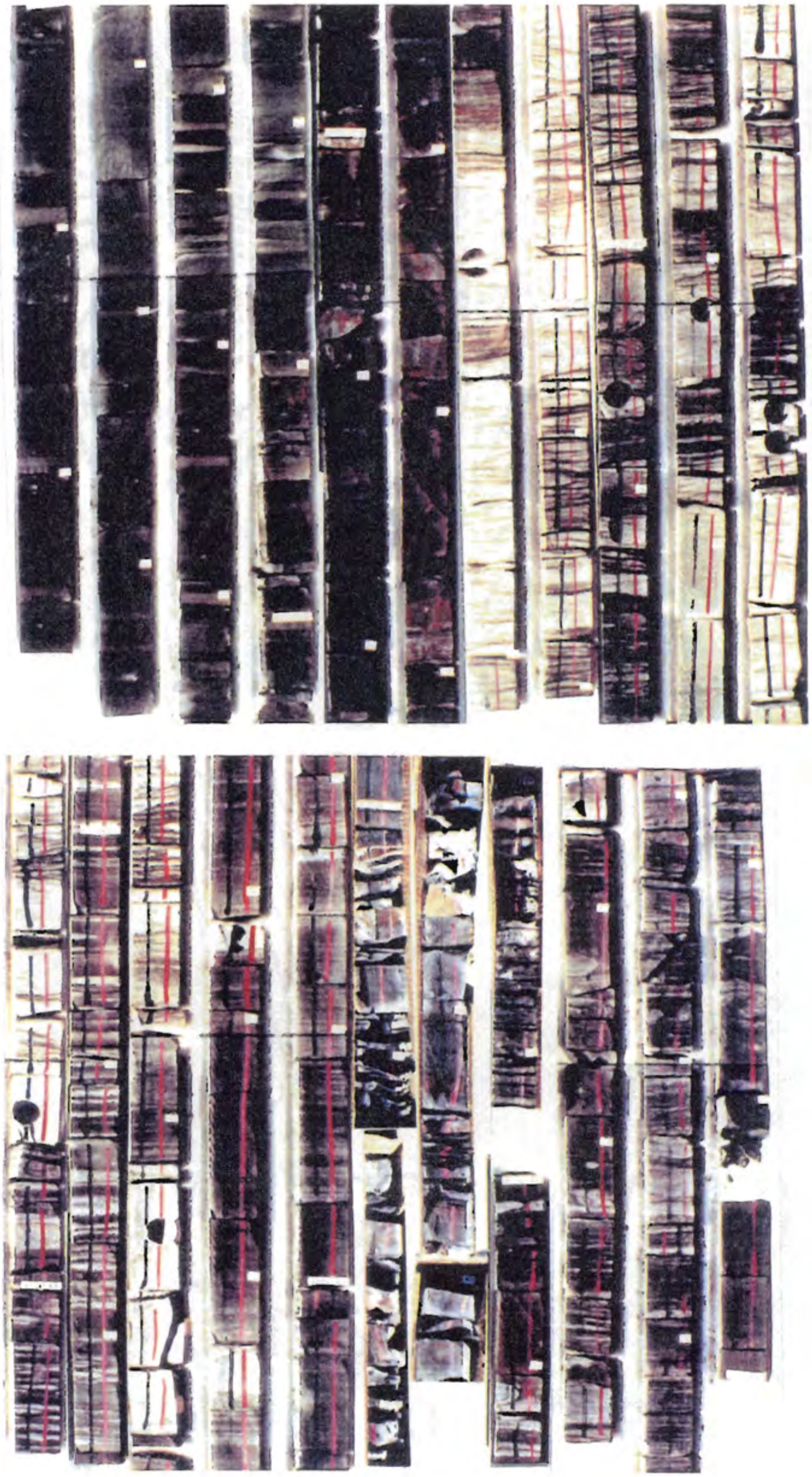


Figure 61. Internorth Smith-B-21-1, (A) 12,209’ to 12,241’ (B) !2,241’to 12,274’. (After Anderson, 1992.)

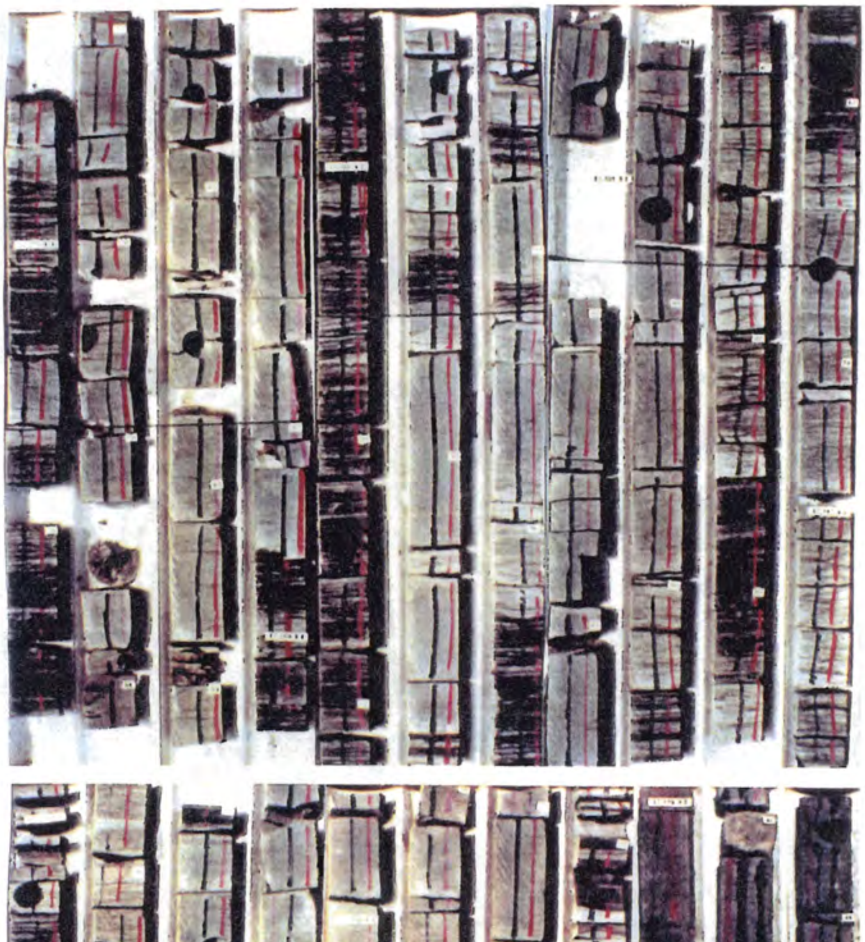


Figure 61 (cont.). Internorth Smith-B-21-1, (A) 12,274' to 12,313' (B) 12,313' to 12,346.8'. (After Anderson, 1992.)

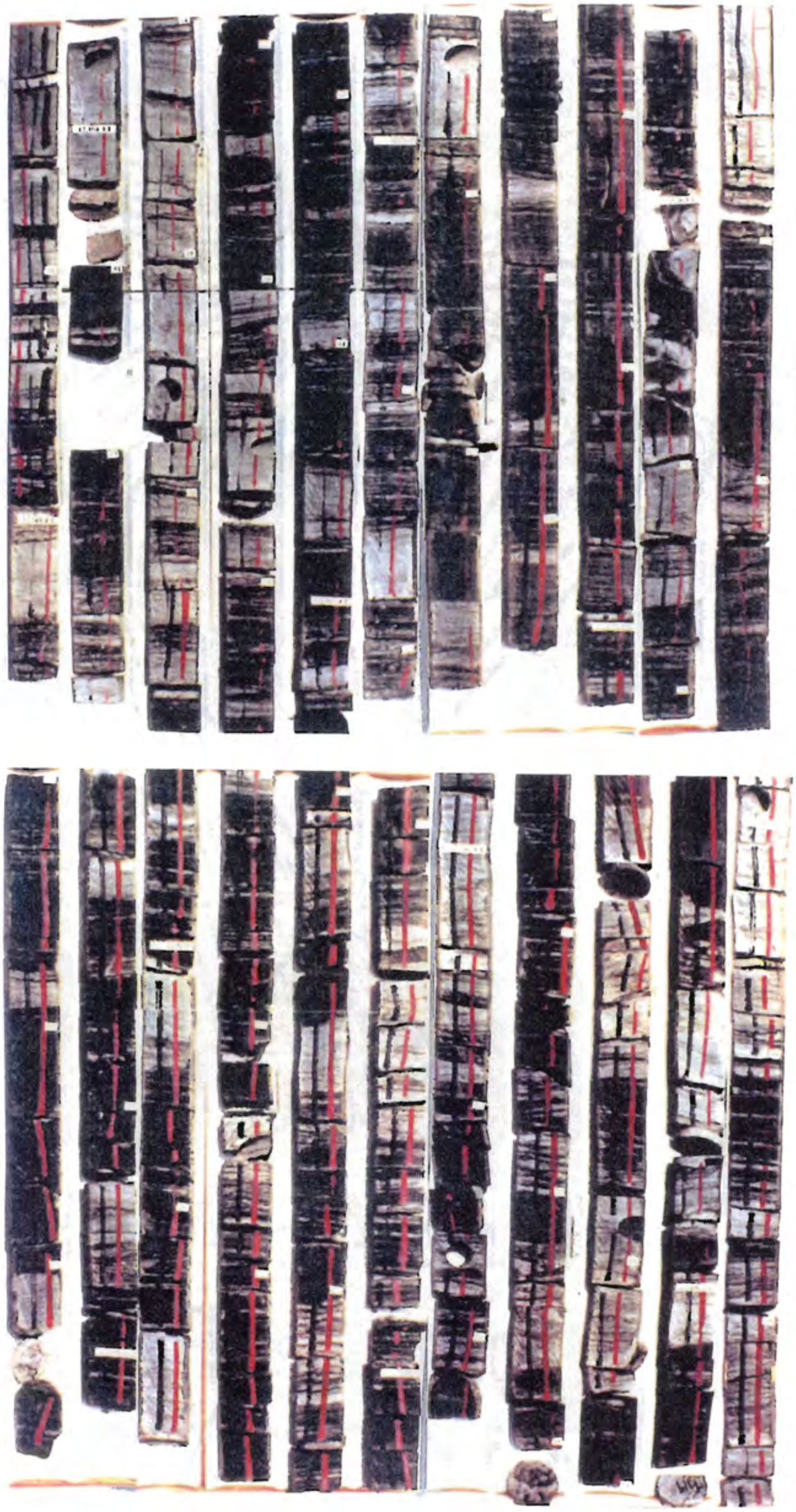


Figure 61 (cont.) Internorth Smith-B-21-1, (A) 12,346.8' to 12,379' (B) 12,379' to 12,409.8'. (After Anderson, 1992.)

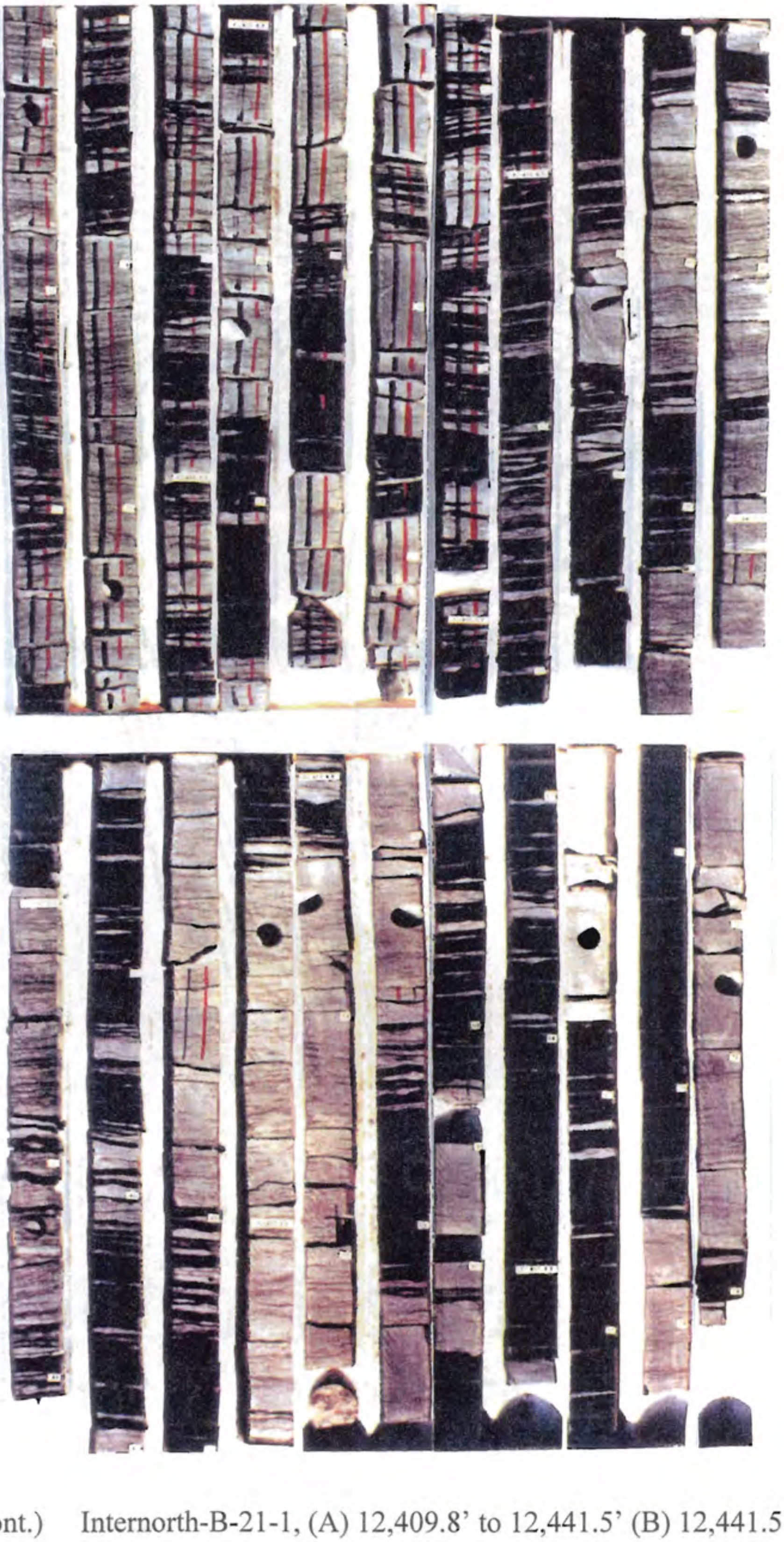


Figure 61 (cont.) Internorth-B-21-1, (A) 12,409.8’ to 12,441.5’ (B) 12,441.5’ to 12,474’. (After Anderson, 1992.)

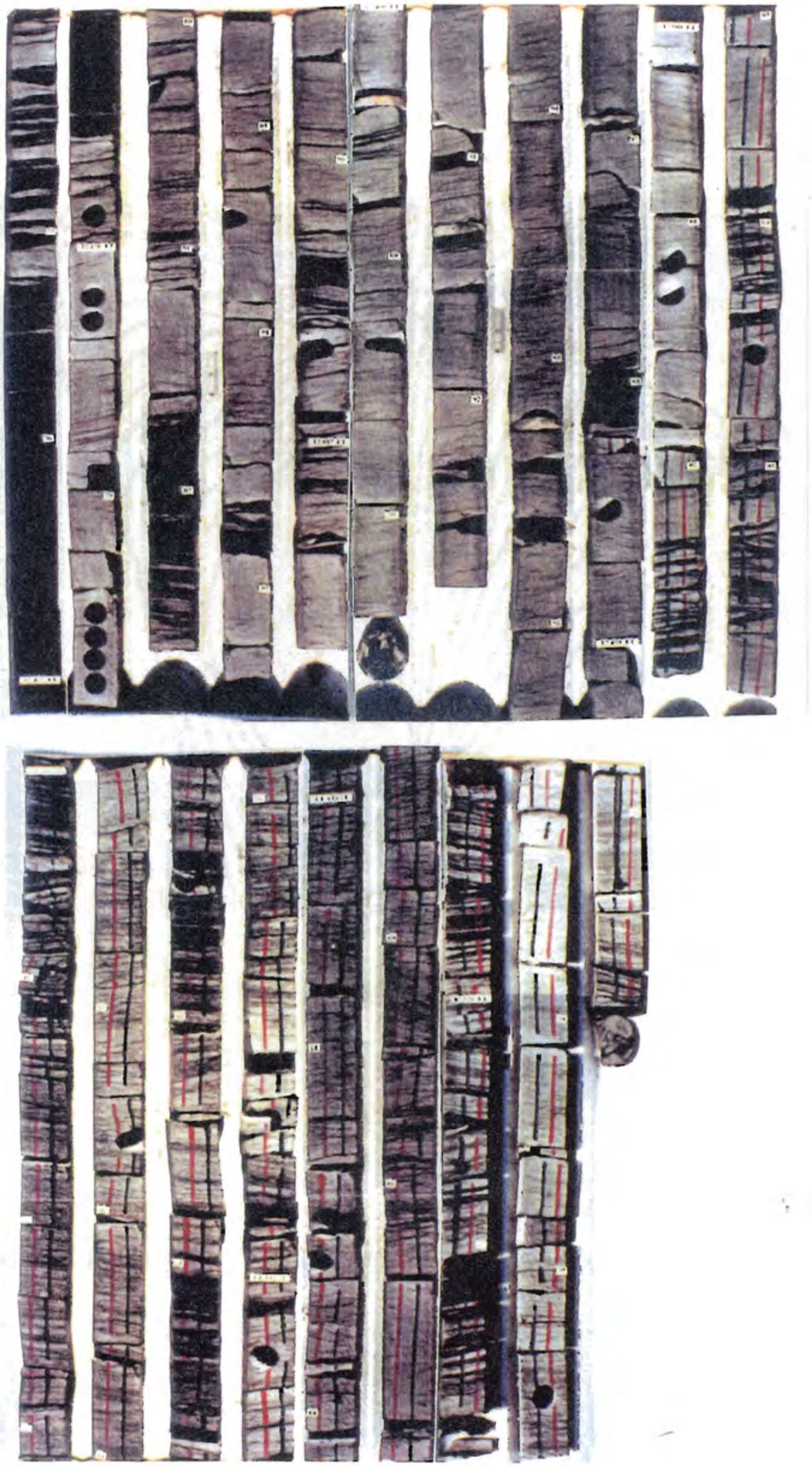


Figure 61 (cont.) Internorth Smith-B-21-1, (A) 12,474’ to 12,506’ (B) 12,506’ to 12,532’.(After Anderson, 1992.)

Figure 62. Davis Herring No. 1, 10,857' to 10,916'. (After Johnson, 1984.)

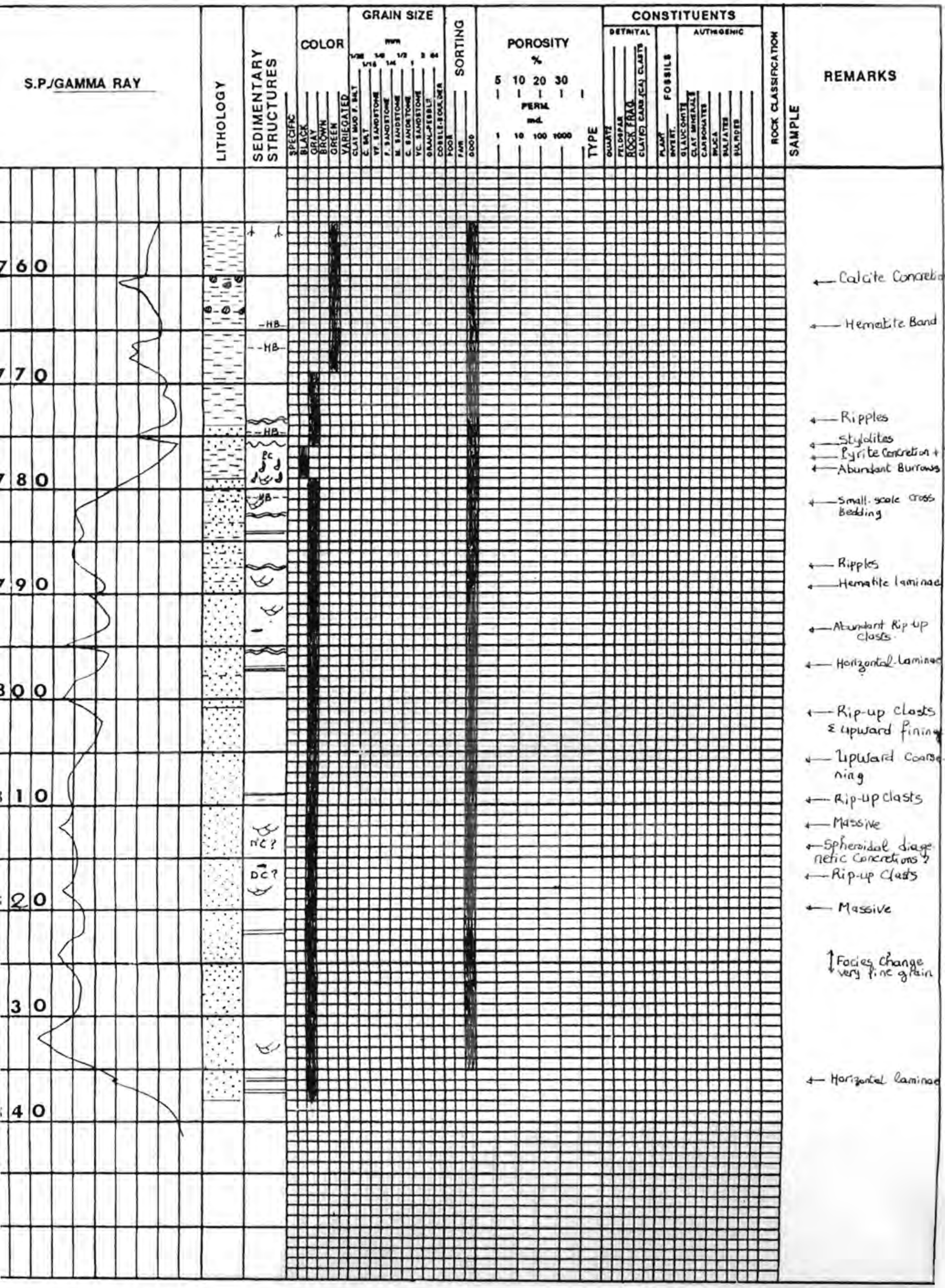
APPENDIX B

CORE PETROLOGS

y GETTY TRACT No 1, 16/WSW

me/Location Sec. 21 - T.27N - R.4W. GRANT Co, OK

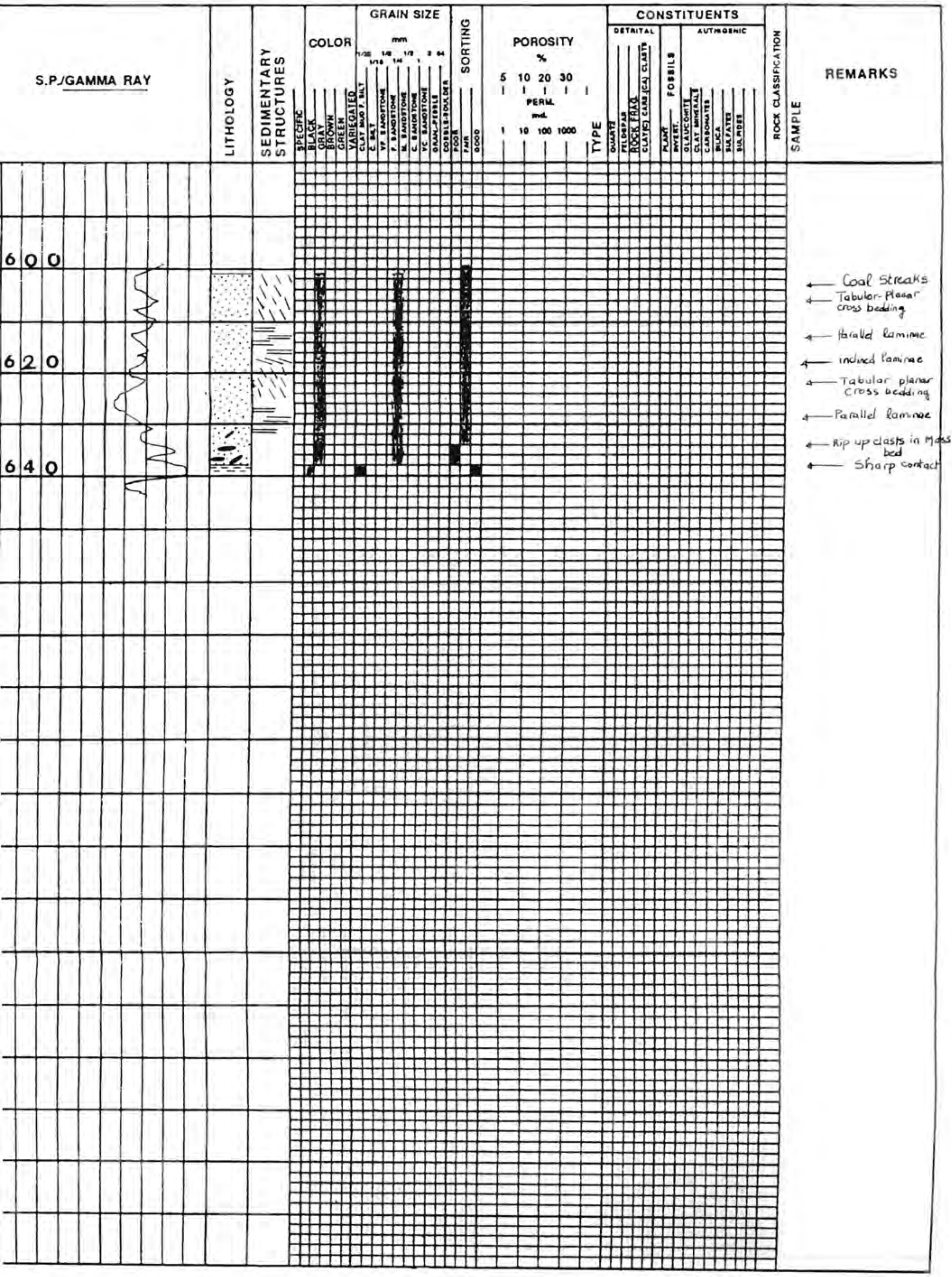
Petrologic Log



ny FERGUSON GRABOW No 1

ame/Location Sec. 9 - T. 19N - R. 12 W.

Petrologic Log



Coal Streaks

Tabular-Planar cross bedding

Parallel laminae

inclined laminae

Tabular planar cross bedding

Parallel laminae

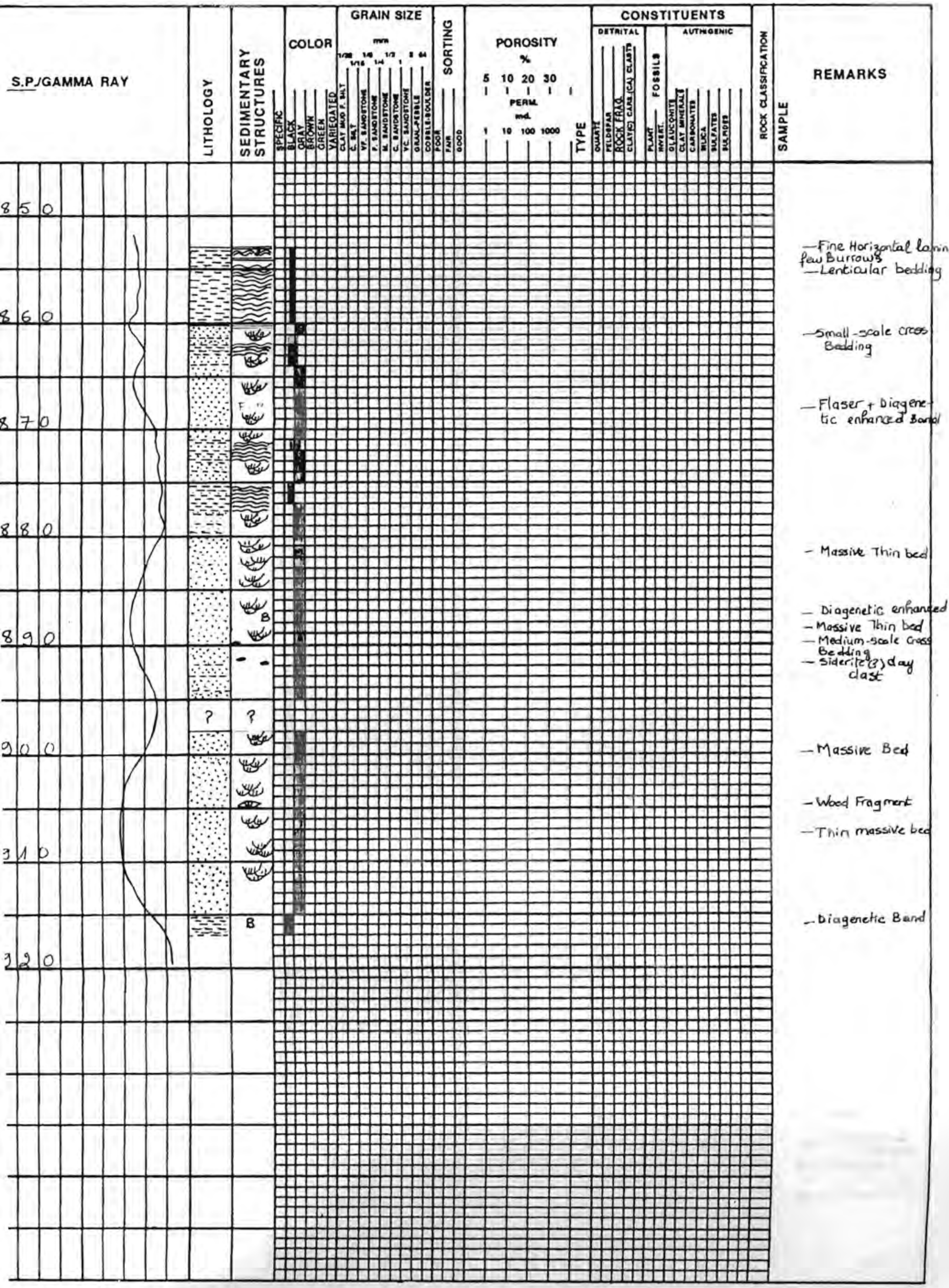
Rip up clasts in Massive bed

Sharp contact

DAVIS OIL COMPANY HERRING No 1-17

e/Location Sec. 17 T.14N - R.14W Custer Co, OK

Petrologic Log



—Fine Horizontal laminae + few Burrows
—Lenticular bedding

—Small-scale cross Bedding

—Flaser + Diagenetic enhanced Band

- Massive Thin bed

— Diagenetic enhanced Band
— Massive Thin bed
— Medium-scale Cross Bedding
— Siderite(?) clay clast

— Massive Bed

— Wood Fragment

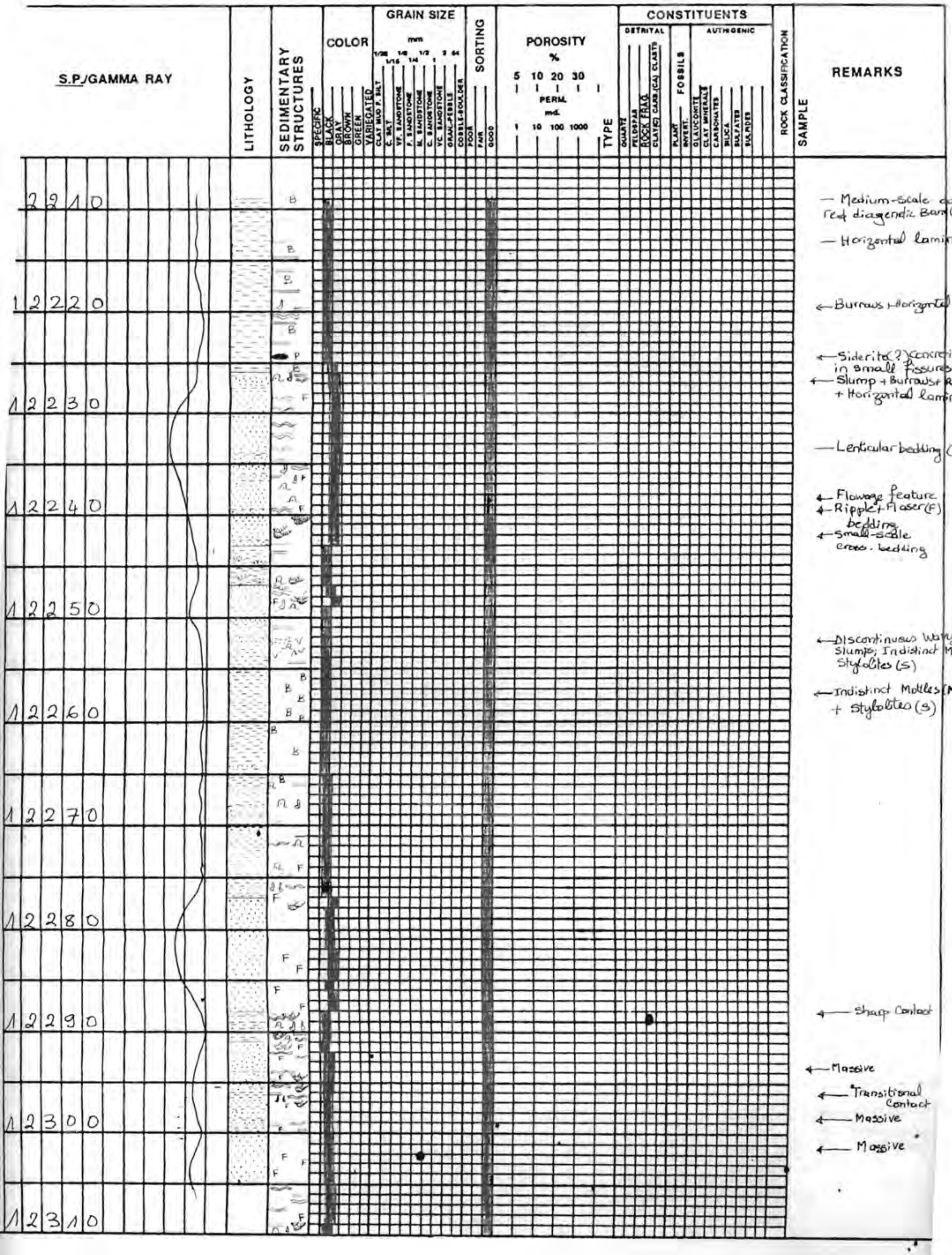
— Thin massive bed

— Diagenetic Band

y INTERNORTH SMITH-B-21-1

ıme/Location Sec.21-T.14N.-R.20W Custer Co. OK

Petrologic Log



— Medium-scale dar
red diagendic Ban(B

— Horizontal lamin

← Burrows + Horizontal l

← Siderite(?) Concretio
in small fissures
← Slump + Burrows + Rip
+ Horizontal lamin

— Lenticular bedding (L

← Flowage feature
← Ripple + Flaser (F)
bedding
← Small-scale
cross-bedding

← Discontinuous Wavy-
Slumps; Indistinct Mo
Stylolites (S)

← Indistinct Mottles (M
+ stylolites (S)

← Sharp Contact

← Massive

← Transitional
Contact

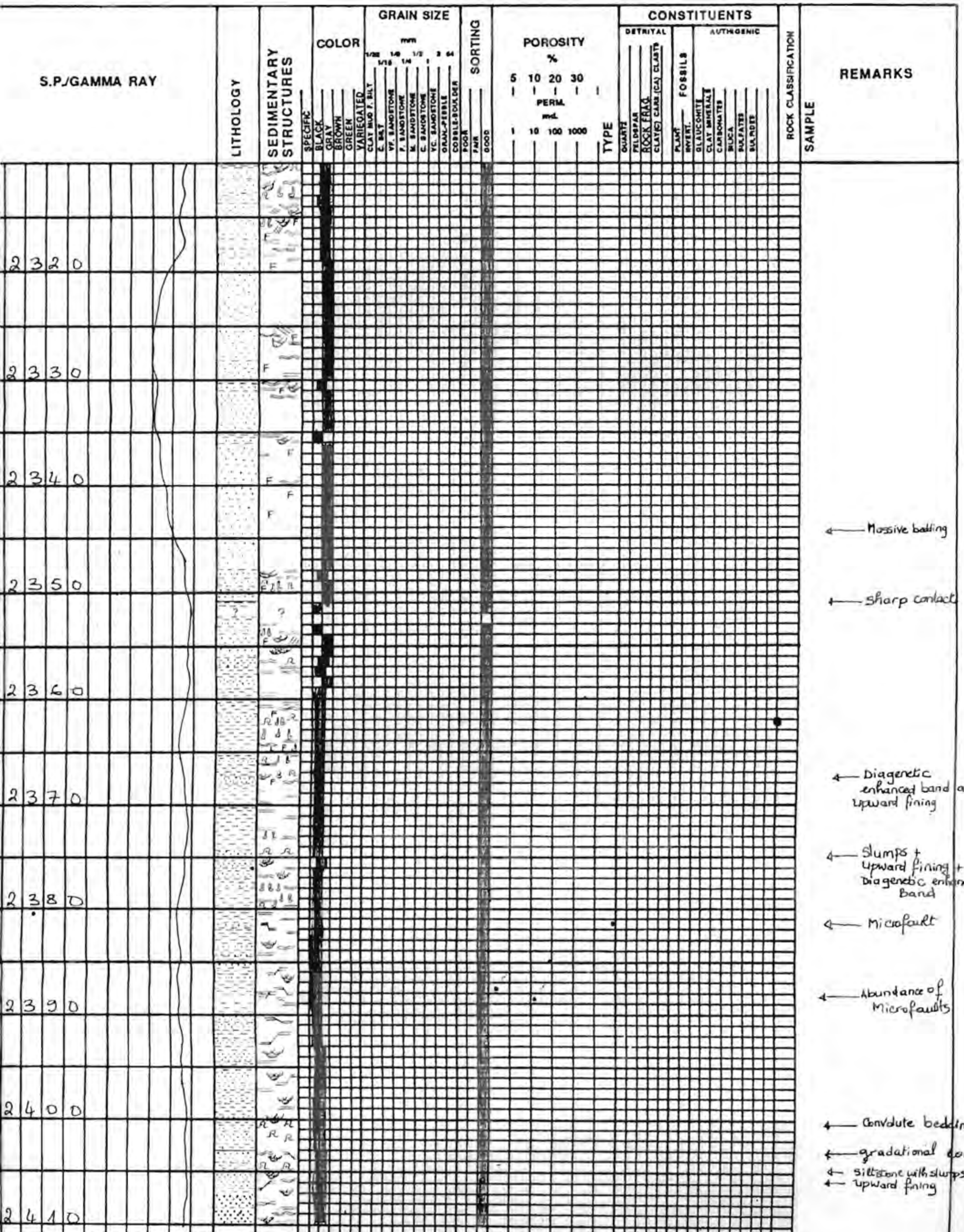
← Massive

← Massive

ny INTERNORTH SMITH-B-21-1

ame/Location Sec.21-T14N-R20W Custer Co. OK

Petrologic Log



Massive bedding

Sharp contact

Diagenetic enhanced band and upward fining

Slumps + upward fining + Diagenetic enhanced Band

Microfault

Abundance of Microfaults

Convolute bedding

gradational contac

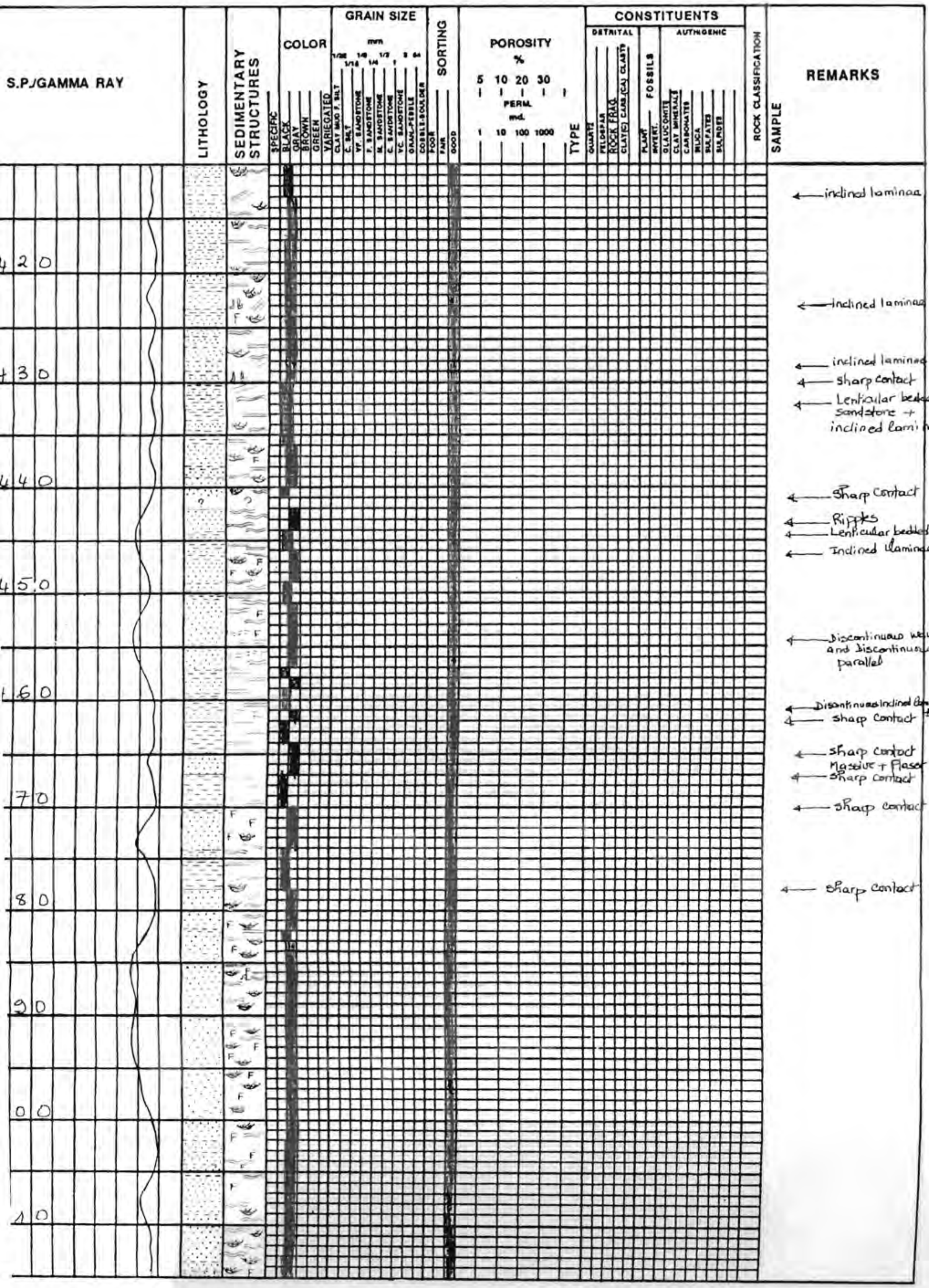
siltstone with slumps

upward fining

INTERNORTH SMITH-B-21-1

e/Location Sec.21-T.14N-R20W Custer Co. OK

Petrologic Log



← inclined laminae

← Inclined laminae

← inclined laminae
← sharp contact
← Lenticular bedded sandstone + inclined laminae

← Sharp Contact
← Ripples
← Lenticular bedded
← Inclined laminae

← Discontinuous wavy and Discontinuous parallel

← Discontinuous Inclined laminae + lentic Bedding
← sharp Contact

← sharp contact
Massive + Flaser
← sharp contact

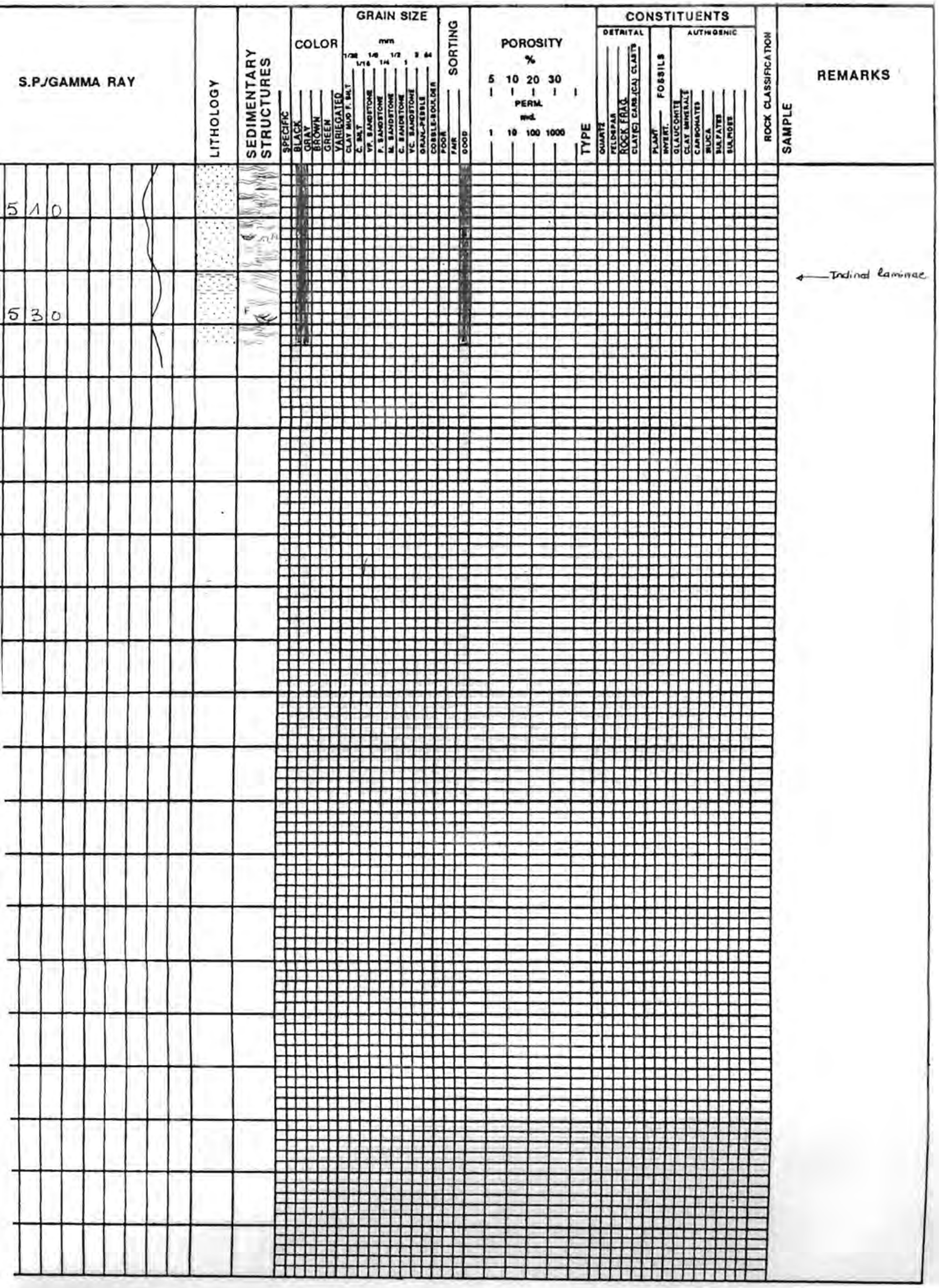
← sharp contact

← sharp contact

INTERNORTH SMITH - B-21-1

me/Location Sec.21 - T.14N - R.20W Custer Co, OK

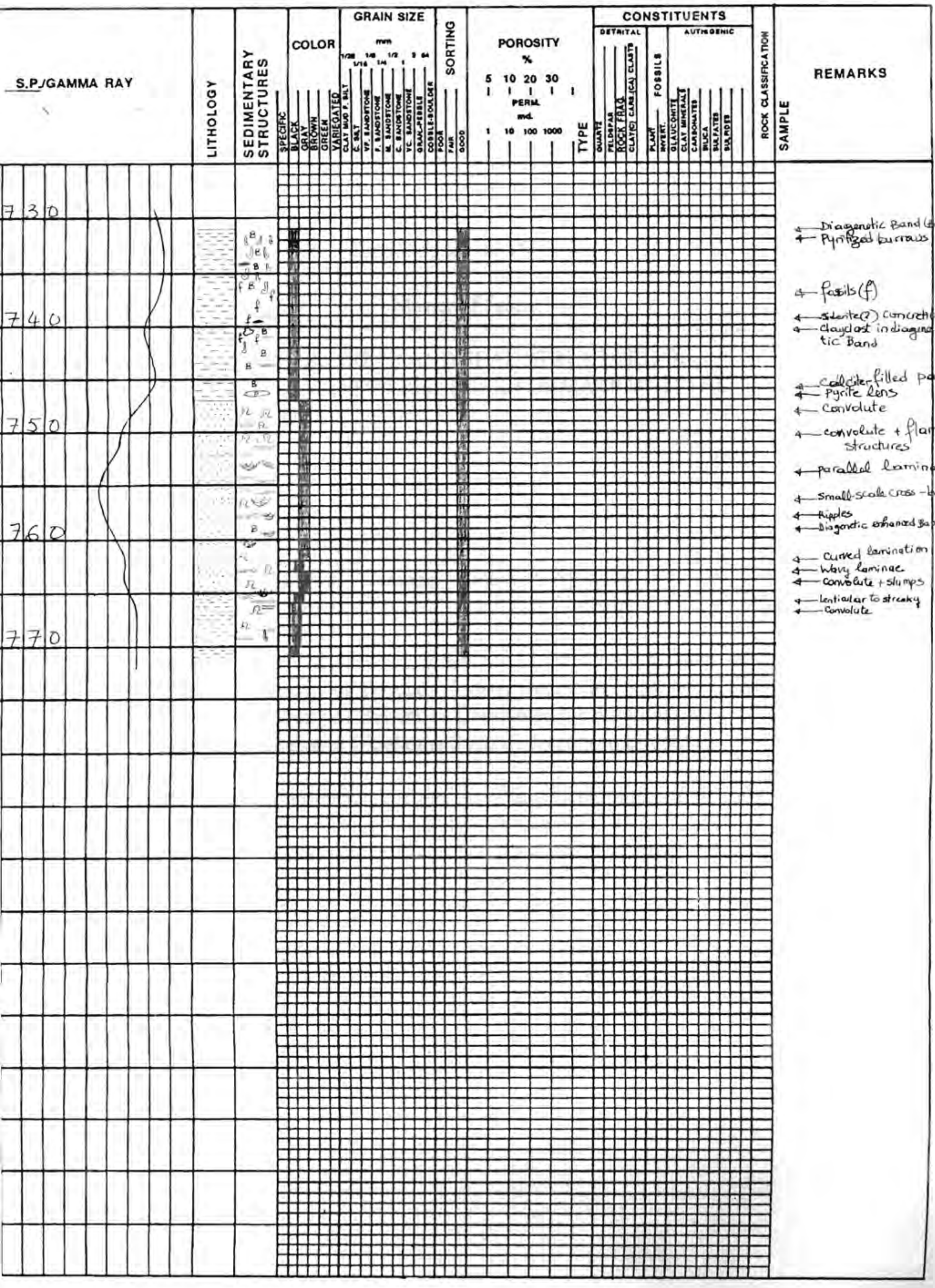
Petrologic Log



TENNECO OIL COMPANY

ne/Location LESTER 6 SEC. 6-T-13N-R-13W Roger Mills Co, OK.

Petrologic Log



Diagenetic Band (B)
Pyritized burrows

fossils (f)

Siderite(?) concretions
Claydast in diagenetic Band

Calcite-filled parallel lar
Pyrite lens
Convolute

convolute + flame structures

parallel laminae

small-scale cross-bedding

Ripples
Diagenetic enhanced Band (B)

Curved lamination
Wavy laminae
Convolute + slumps

Lenticular to streaky
Convolute

VITA

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Professional Experience: Teaching Assistant, Department of Earth Sciences, Faculty of Sciences, University of Yaounde, 1991-1993. Professional Training at National Hydrocarbon Company, Cameroon, December 1992-May 1993.

APPENDIX C -- Plate 1

PLATE I

STRATIGRAPHIC CROSS-SECTION
OF THE STUDIED TREND

ORIENTATION: NORTHEAST-SOUTHWEST

DATUM: TOP OF CHEROKEE BLACK SHALE

VERTICAL SCALE: 100 Feet = 1 INCH

by

Virginie Tchuisseu D., M S, 1995