IDENTIFICATION AND CHARACTERIZATION
OF A PRESSURE SEAL
IN SOUTH-CENTRAL
OKLAHOMA

By

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TABLE OF CONTENTS

Chapter Page

APPENDICES

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

CHAPTER I

INTRODUCTION

General Statement

Pressure compartments and pressure seals have recently been recognized as a significant concept in exploration of hydrocarbons in deep basins. In the Anadarko Basin of Oklahoma, and as in most deep sedimentary basins (Powley, 1987), abnormally pressured zones are enclosed by pressure seals. Compartments are generally encountered in sedimentary rocks which, at some time, were buried greater than 10,000 feet. Compartments are a two-component system consisting of an internal volume and a surrounding impermeable seal. The internal volume displays hydraulic continuity. Compartments are separated from each other as well as from normally pressured fluids by pressure seals. Pressure seals are a unique vertical and/or horizontal body of rock which contains unconnected pore throats. This pore-throat geometry maintains no single- or multi-phase fluid movement. A diagenetic pressure seal consist of a rock body which maintains no single- or multi-phase fluid movement due to occlusion of the pore throat network by chemical and mechanical processes. Provided the seal is not broken, once deeply buried overpressured compartments may be converted to underpressured compartments as overburden rock is removed (Barker, 1972).

Pressure seals are significant geological phenomena since they may form a major trapping mechanism for hydrocarbons. Oil or gas can occur abutting a seal and/or trapped in permeable layers within a seal. Seals are known to be present in rocks of many lithologies including shales, evaporites, limestones, and more uncommonly, sandstones. However, they are generally reported in the literature as being dominantly in shale or evaporite (Perrodon, 1983). Three types of seals can occur in deep sedimentary basins (Figure 1). Basal seals outline the lower extent of a pressured compartment; this type tends to follow stratigraphic units. Lateral seals usually parallel vertical or high angle faults; they occur in highly fractured and faulted zones (Powley, 1987). The fractures and faults are extensively cemented with calcite and/or silica (Powley, 1987). Top seals occur as essentially horizontal or gently dipping surfaces. They may parallel bedding, or they may cut across strata and structures.

Objectives

The purpose of this investigation is to: 1)determine the existence of pressure seals in the study area; 2)determine the corresponding strata of the pressure

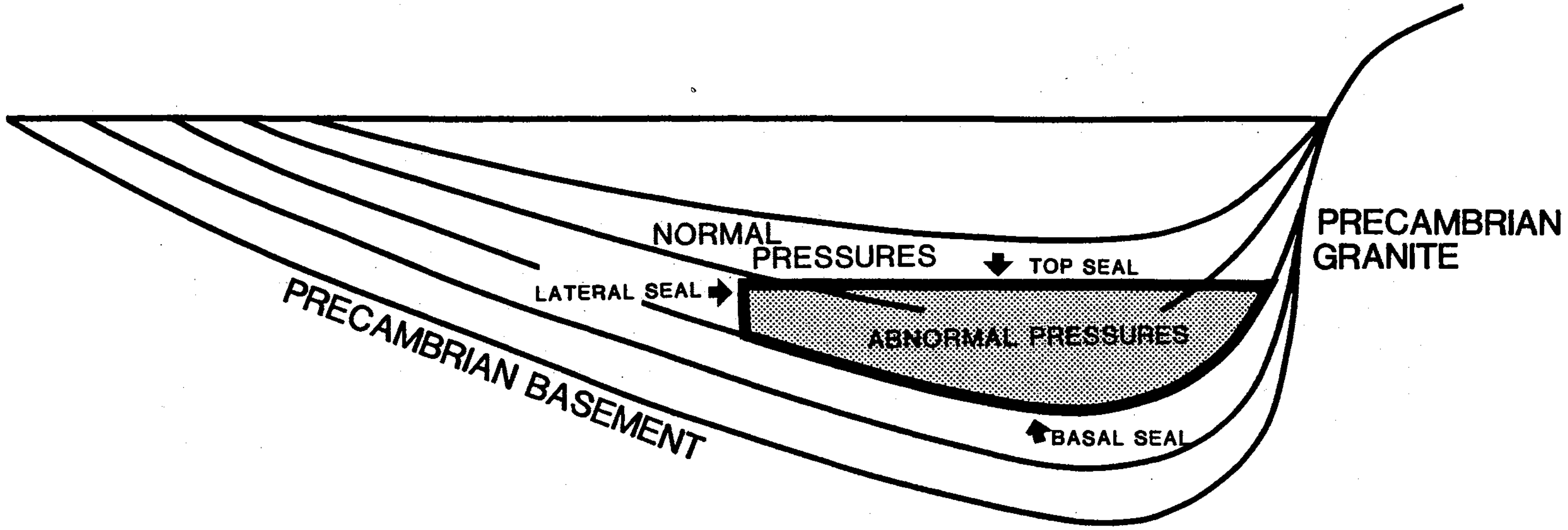


Figure 1. Basal, lateral and top pressure seals enclose an abnormal pressure compartment (modified after Powley, 1987).

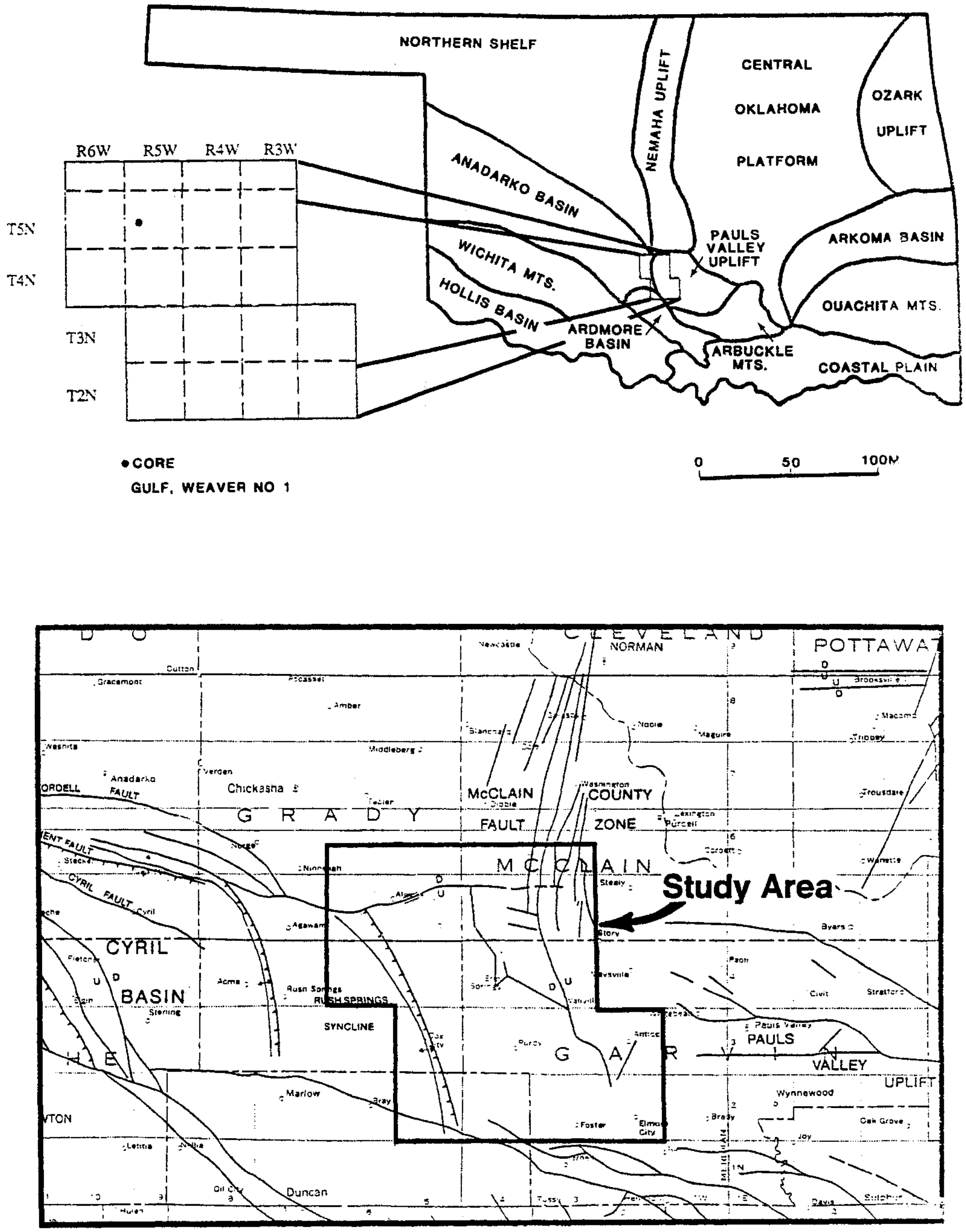


Figure 2. Location of study area, core and tectonic features in Oklahoma.

seal; 3) determine the diagenetic overprints in the seal interval; and 4)relate the petrology and diagenesis of the seal lithology to seal structure and evolution.

Location of Study Area

The area of this investigation includes 18 townships in the southeastern portion of the Anadarko Basin (Figure 2). In this area, the pressure compartment is confined to the northern sector. The top pressure seal in T.5 N. R.4 W. corresponds to units of the Simpson Group.

Pressure data indicate the presence of abnormally pressured compartments and a pressure seal between 3,000 feet and 13,500 feet.

Structural Setting

This study is located in the Golden Trend of south-central Oklahoma in the Southeastern embayment of the Anadarko basin (Swesnik, 1950). This area is bounded to the north by the Nemaha Ridge, to the east by the Pauls Valley uplift, to the south by the Arbuckle Mountains and Ardmore Basin and to the west by the Anadarko Basin.

A large-scale north-south fault zone, the McClain County fault zone, separates the structurally high central Oklahoma platform from the Anadarko Basin in the eastern extent of the study area (Jacobsen, 1949).

Geological History

The southern Oklahoma aulacogen began rifting during the Late Precambrian or Early Cambrian time. The rifting stage was followed by basin subsidence during which time sediments, ranging in age from Cambrian through Mississippian, were deposited. A shallow sea transgressed northward during Lower to Middle Ordovician time depositing the Simpson Group. Five sequences of shale coarsening up to sandstone were deposited (Esslinger, 1983). Slight emergence may have occurred at the end of Simpson deposition (Johnson, 1958).

Deposition of the Viola Formation resulted from an advancing sea. The Sylvan Shale was deposited in Late Ordovician time in a shoaling sea (Anderson, 1930). The Hunton Group was deposited by Silurian and Lower Devonian seas and consists of limestone, dolomite and marly shale (Webster, 1980). In Early Mississippian, Woodford seas advanced, depositing Woodford shales in euxinic conditions. The Mississippi Limestone and the Caney Shale rest conformably upon the Woodford Formation. There were two major intervals of deformation in Pennsylvanian time, the Wichita orogeny and the Arbuckle orogeny. The Wichita orogeny extended from Late Morrowan to Desmoinesian time (Huffman, 1959; Webster, 1980). The formation of separate basins in the Southern Oklahoma Aulacogen occurred during this period. The Arbuckle orogeny affected southern Oklahoma. The Arbuckle

Mountain system in the southeast was formed; the Wichita uplift and Criner Hill arch were faulted and folded and the strata of the Ardmore and Marietta basins were compressed and folded (Huffman, 1959; Webster, 1980).

In the Golden Trend area, faulting occurred in two major pulses during the Wichita Orogeny. The first faulting event occurred in Morrowan time (Swesnik, 1950, Jacobsen, 1949); and the second event in early Desmoinian time.

Methods of Investigation

Final shut-in pressure measurements from drill stem test were utilized to construct pressure versus depth profiles. These profiles were used to identify and interpret subsurface pressure patterns. Pressure measurements were used to determine the extent of the abnormal pressure compartment and identification of a local pressure seal.

Internal features of the pressure seal were investigated through detailed examination of the cored Simpson Group interval in the Gulf Oil Co., Weaver No. 1 which consisted of petrological logging of 480 feet of Oil Creek, McLish, Tulip Creek and Bromide Formations combined. Petrography consisted of examining 85 thin sections, x-ray diffraction of selective samples, scanning electron microscopy, and cathodolumincense petrography (Table I). Interpretation of the seal structure and formation was made from these investigations.

TABLE I

LIST OF CORE SAMPLES, WITH CORRESPONDING FORMATION AND ANALYSIS

Depth (ft)	X-ray diffraction	SEM	Compositional Analysis
First Bromide Sandstone			
-11014		X	X
-11020	X		X
-11023			X
-11029			X
-11030			X
-11033			X
-11048	X		X
-11052	X	X	X
-11059			X
-11060	X	X	X
-11065	X		X
-11099			X
-11100			X
Second Bromide Sandstone			
-11139.2	X		X
-11139.3			X
-11139.4			X
-11139.5			X
-11139.6			X
-11139.7			X
-11140			X
-11144	X	X	X
-11145			X
-11172.1			X
-11181			X
-11185	X		X
-11189	X	X	X
-11203	X		X
Tulip Creek Formation			
-11273			X
-11280			X
-11314			X
-11315			X
-11316			X

TABLE I (continued)

Depth (ft)	X-ray diffraction	SEM	Compositional Analysis
-11317			X
-11318			X
-11320.1			X
-11320.2			X
-11320.3			X
-11322			X
-11325			X
-11328.1			X
-11328.2			X
-11329			X
-11332			X
-11335	X		X
-11337			X
-11339.1	X		X
-11339.2			X
-11346			X
-11351	X		X
-11357			X
-11360.1			X
-11360.2			X
-11377		X	X
-11378	X	X	X
McLish Formation			
-11393.2	X		X
-11396			X
-11410.1	X		X
-11410.2	X		X
-11423			X
-11424	X		X
-11440	X		X
-11449	X	X	X
-11459			X
-11523			X
-11524			X
-11530.1			X
-11530.2			X
-11534.1			X
-11534.2			X
-11548.2			X
-11555	X		X
-11606			X
-11609			X
-11621			X
-11627.5	X		X
-11629.5			X
-11632			X

TABLE I (continued)

Depth (ft)	X-ray diffraction	SEM	Compositional Analysis
-11635.5			X
-11649.9			X
-11650	X		X
-11670	X		X

CHAPTER II

PREVIOUS INVESTIGATIONS

Abnormal Pressures

Prior to 1960 relatively few explorationists had documented abnormal pressures patterns. Most of the literature concerning abnormal pressures, including early documentation, is based upon data from the Texas and Louisiana Gulf Coast region. Since abnormally high formation pressures presented an expensive hazard to drilling, recognition of overpressures and the transition into overpressures became increasingly important as drilling frequency into these zones increased in the Gulf Coast. Cannon and Craze (1938) first discussed the occurrence of abnormal pressures in the Gulf Coast area. Burst (1969) proposed that overburden pressures which caused clay dewatering contributed to abnormally high pressures. Bradley (1975) summarized the numerous factors which contribute to the origin of abnormal pressures as well as their preservation. These factors include epeirogenic movements, temperature fluxes, osmosis, pore water interaction, carbonization and hydrocarbon column buoyancy. Barker (1972) suggested aquathermal pressuring, the process of an isolated volume of water-filled rock being moved up or down a geothermal gradient, as a possible mechanism for generating abnormal subsurface pressures. Gold and Soter (1984/85) proposed an ascending stream of fluid that percolates upward from a deep source through a column of rock domains generates abnormal pressures.

Pressure Seals and Compartments

Dickinson (1953) first recognized the abrupt increase in pressure above the normal pressure gradient occurred over a rather short vertical interval in the Gulf Coast sediments. Stuart (1970) defined a pressure seal as a mutation zone. Perrodon (1983) defined a seal as a lithological bed which provides a barrier for hydrocarbon movement. He also maintained that a seal could be effective source rocks. Dickey (1972) stated that differences in fluid potential in different aquifers indicates a lack of hydraulic water connection rather than the generally accepted idea of water flow between two aquifers. Bradley (1975) recognized that for abnormal pressures to exist there must be an "effective" seal (no water fluid migration) or pressures would equalize to hydrostatic (normal). Chiarelli and Duffand (1980) documented the concept of pressure "compartments" in the Jurassic strata of the Viking Basin in the North Sea. They define a series of compartments in the basin as bodies of rock with their own distinct hydrodynamic environments. The work on the validation of pressure compartments was generated by Powley (1985) where he documented the existence of pressure compartments in 180 basins worldwide and quantified reoccurring characteristics of pressure seals in these basins. Most recently Dewers and Orteleva (1988) have proposed mathematical reaction-transport models which join theoretical treatments of grain size, clay formation, intergranular pressure solution textures with structures found in pressure seals.

Both Breeze (1970) and Masroua (1973) described the differentiating reservoir pressure patterns found in the Morrow Formation in the Anadarko Basin. In Blaine County, the Morrow sands have abnormally high pressures; whereas, in Woodward County, the pressures are normal, and in the Oklahoma Panhandle, they are subnormal (Masroua, 1973). Breeze (1970) noted that the pressure distribution in Morrowan reservoirs in northwestern Oklahoma did not coincide with any easily recognizable geological phenomena such as structure, stratigraphy or petroleum trapping.

Simpson Group

In this study, the pressure seal correlates to the cored interval of the Simpson Group in the Gulf Oil Co. Weaver No. 1. Much of the literature which pertains to the Simpson Group concentrates on regional correlation, paleontology and regional and local geologic mapping.

Stratigraphy

In 1902 Taff was the first to recognize and describe the Simpson as a formation in the Arbuckle Mountains (Schramm, 1964). Ulrich (1911) named five of the accepted formations of the Simpson Group which included the Joins, Oil Creek, McLish, Tulip Creek, and Bromide (Schramm, 1964). Harris (1964) used Simpson ostracods to name the Corbin Ranch Formation which is more commonly known as the Simpson or Bromide "Dense" in the subsurface.

Deitrich (1933) addressed the problem of thinning of the Simpson Group in the northern flank of the Anadarko Basin. Cronenwett (1956) correlated Simpson subsurface strata of east-central Oklahoma with Simpson exposures in the Arbuckle and Wichita mountains and the Ozark uplift in Cherokee and Adair counties in northeastern Oklahoma. Dapples (1955) suggested a genetic relationship between the St. Peter sandstone and the Simpson Group. Disney (1952), Wheeler (1950) and Swesnik (1950), all addressed the stratigraphy of pre-Pennsylvanian strata in the Golden Trend area of south-central Oklahoma.

Diagenesis

Heald (1955) compared the cements of the Simpson Group to those in the equivalent St. Peters Sandstone in Arkansas. Pittman (1981) discussed the porosity reduction in the Simpson Group caused by cataclasis generating granulation textures. The Bromide Formation has been studied the most extensively of the formations within the Simpson Group. Houseknecht (1988) described some of the intergranular pressure solution characteristics seen the the Bromide sandstones.

CHAPTER III

PRESSURE COMPARTMENT AND SEAL IDENTIFICATION

Hydraulic Systems

Basins may be subdivided into two separate hydraulic regimes, each of which may be identified by its own unique pressure gradient. Normally pressured systems are basin wide and can be found at any depth, but they generally occur above abnormally pressured compartments. In some areas they are known also to be present below abnormally pressured compartments. Abnormally pressured systems are bounded by effectively impermeable seals. Pressure compartments can be individually sealed, creating a box-like geometry (Powley, 1987).

Methods of Identification

Pressure Data

Pressure measurements versus depth of measurements taken were plotted to construct pressure-depth profiles (Appendix B). These measurements were taken from drill stem tests. Pressure-depth profiles are used to directly identify abnormally pressured fluid compartments by comparing the pressure gradients of individual well tests to the normal pressure gradients. The procedure is to construct a straight line through pressure measurements that parallels the normal pressure gradient line of .465 psi/ft. (Figure 3). Deviation of values from this line suggest the presence of abnormal pressured compartments. Abnormal pressure is either greater or less than normal hydrostatic pressure (Bradley, 1975).

Documentation of pressure seals in terms of lithologic features is almost nonexistent. Essentially, the only reported property known is extreme low permeability. Seals are directly identified from final shut-in pressure measurements. The top and basal pressure seals generally exhibit a characteristic linear pressure change with increasing depth across the seal zone (Powley, 1987).

Identification of underpressured conditions is more tenuous than identification of overpressures since production of gas, oil, or water may result in subsequent reduction of pore pressure. Also, when final shut-in pressure test measurements were taken, duration of the test may have been too short for pressures to have built up to capacity. Consideration must also be given to the quality of pressure test measurements taken in overpressured zones. In these intervals some pressure measurements are too low because of inadequate test times, or in other cases the test measurements may be

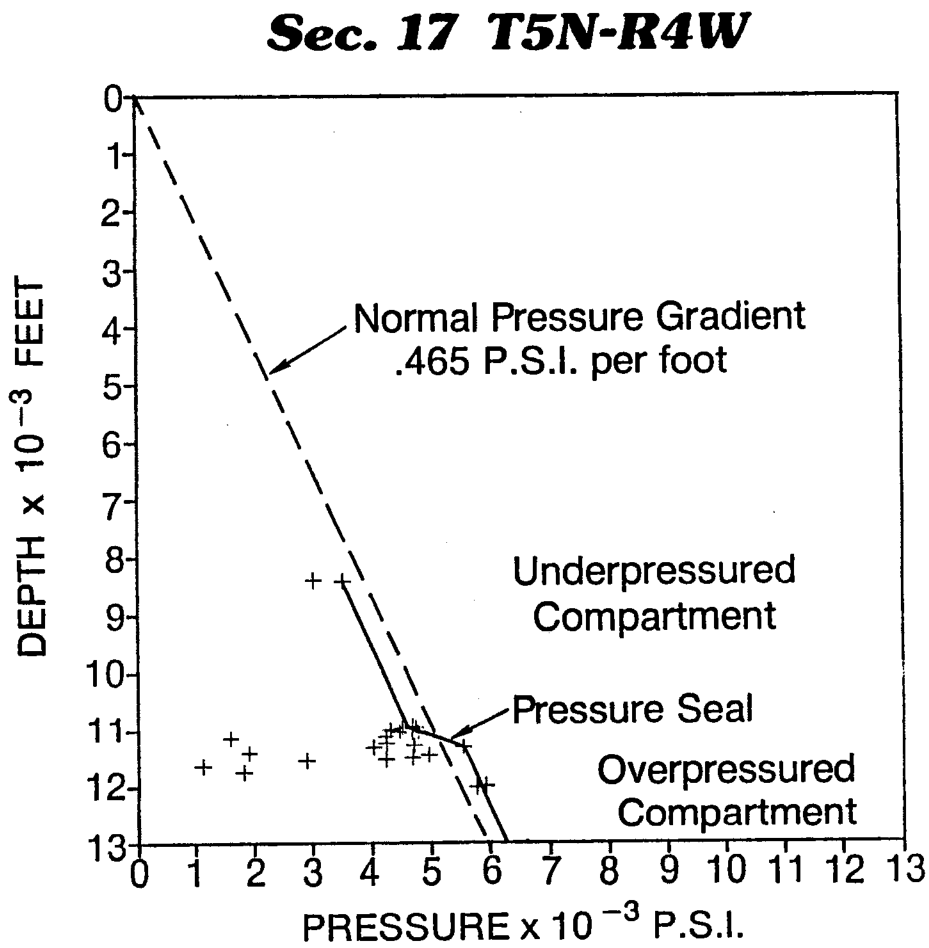


Figure 3. Pressure-depth profiles can directly identify abnormal pressures. From pressure measurements located in the southwestern corner of McClain Co., Okla., three types of pressure gradients identify three distinct pressure regimes. Normal pressures exhibit a .465 psi/ft. gradient, abnormal pressures exhibit a higher or lower than normal gradient.

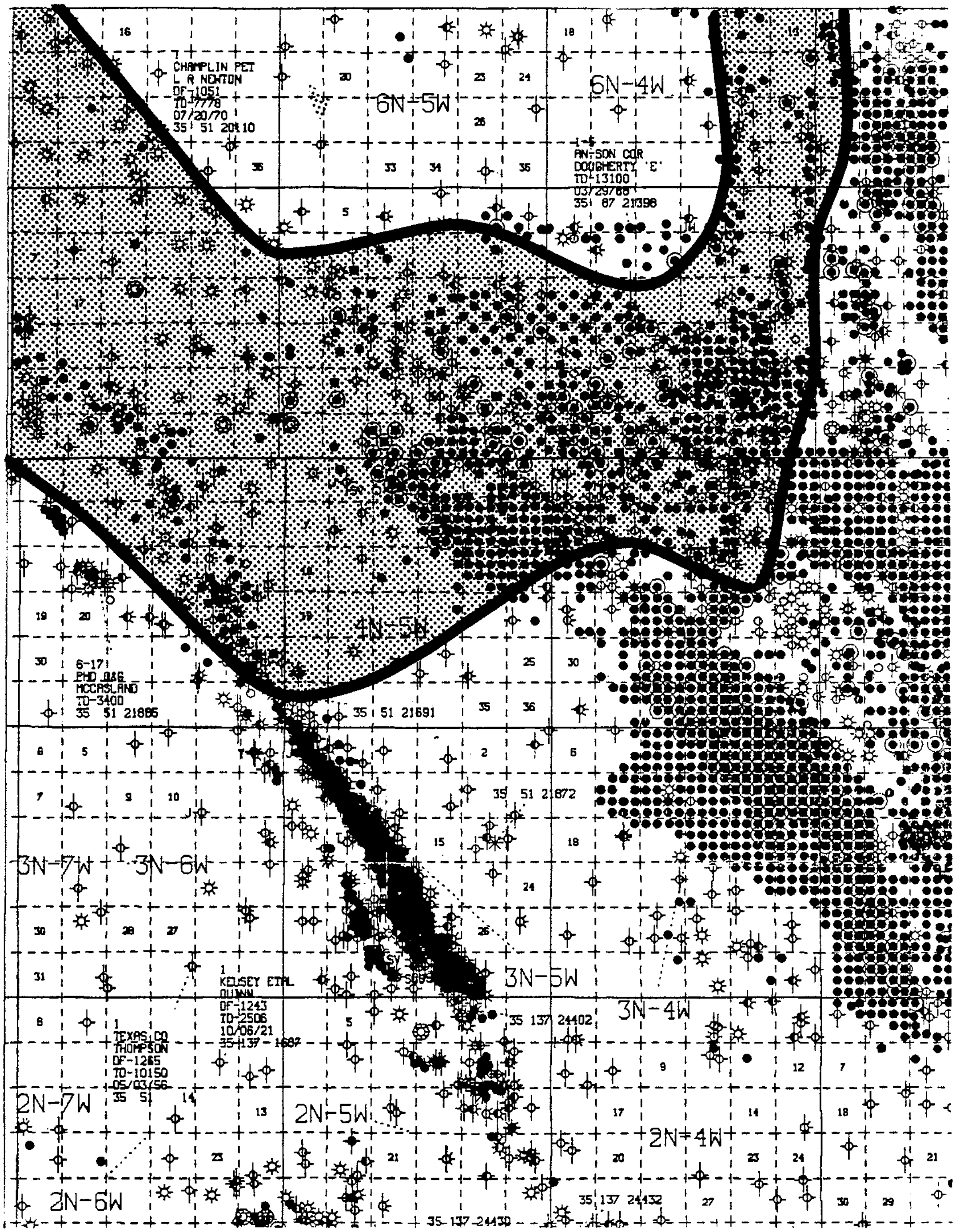
erroneously high due to instrument problems.

Compartment and Seal Location

The south-central portion of the Anadarko basin in Oklahoma displays a locally layered sequence of pressure compartments. An underpressured fluid compartment exists between approximately 3,000 feet and 10,000 feet, corresponding to stratigraphic units between the Middle Pennsylvanian and the Upper Ordovician strata (Powley, 1987). Although the top seal in this area has yet to be adequately identified, it is located approximately within the Marmaton Group. In the northern half of the study area overpressured conditions exist between 10,000 feet and 13,500 feet (Figure 4). The pressure interval gradient in the overpressured compartment averages 0.50 psi/ft.

Pressure Data

A distinct overpressured seal has been identified throughout the northern sector of the study area (Plate I). This seal intersects the Lower Pennsylvanian in the western half and Lower to Middle Pennsylvanian strata in the central and eastern half of the study area (Plate II). This zone is present predominantly at depths from 10,000 feet to 12,000 feet. A linear increase in pressure build-up is common within the Ordovician Simpson Group. Pressures across the seal in the upper Bromide



SCALE 1 IN. = 15,840 FT.

Figure 4. Shaded area shows extent of overpressured conditions below -10,000 feet in the study area.

Sandstone in T5N R4W, are usually less than 3450 psi (underpressures), whereas the lower Bromide and the Tulip Creek have pressures ranging between 3450 psi and 5290 psi (under-to-normal pressures). The McLish Formation, when tested, has normal pressures averaging 5350 psi, and the Oil Creek is overpressured with values ranging from 5660 psi to 6000 psi. A 'best fit' straight line from the first Bromide Sandstone pressure tests through succeeding pressure tests in the second Bromide Sandstone, Mclish Formation, and finally the Oil Creek Sandstone shows transition from underpressures to overpressures (Figure 3).

The top of the pressure seal interval gradient averages less than .40 psi/ft., whereas the bottom of the pressure seal interval gradient averages more than 0.50 psi/ft. The average pressure gradient across the pressure seal interval zone is 2.2 psi/ft. This slope is controlled by the thickness of the seal and the pressure differential across it.

Salinity

The fluid in the pressure compartment displays a pressure increase with depth. This increase is controlled by the density of the fluids in the rock column which is in turn dependent upon the temperature, pressure, and the dissolved solids content (Bradley, 1975).

Salinity of formation waters in McClain Co., Oklahoma, in the normally pressured system varies significantly from the pressure seal interval and the abnormally pressured compartment (Figure 5). These measurements were taken from drill stem tests. Salinity in the overpressured compartment below 10,700 feet is 150,000 mg/liter total dissolved solids (TDS) content. This measurement is noticeably lower than those taken from waters in the overlying pressure seal between 10,000 and 10,700 feet which is very high as well as those measurements in the underpressured and normally pressured areas. The TDS content in the pressure seal ranges from 260,000 to 240,000 mg/liter. The TDS in the underpressured and normally pressured sections average 210,000 mg/liter. This salinity profile agrees with other profiles presented from the Gulf Coast (Schmidt, 1973), which showed lower salinity waters found in areas corresponding to high pressures.

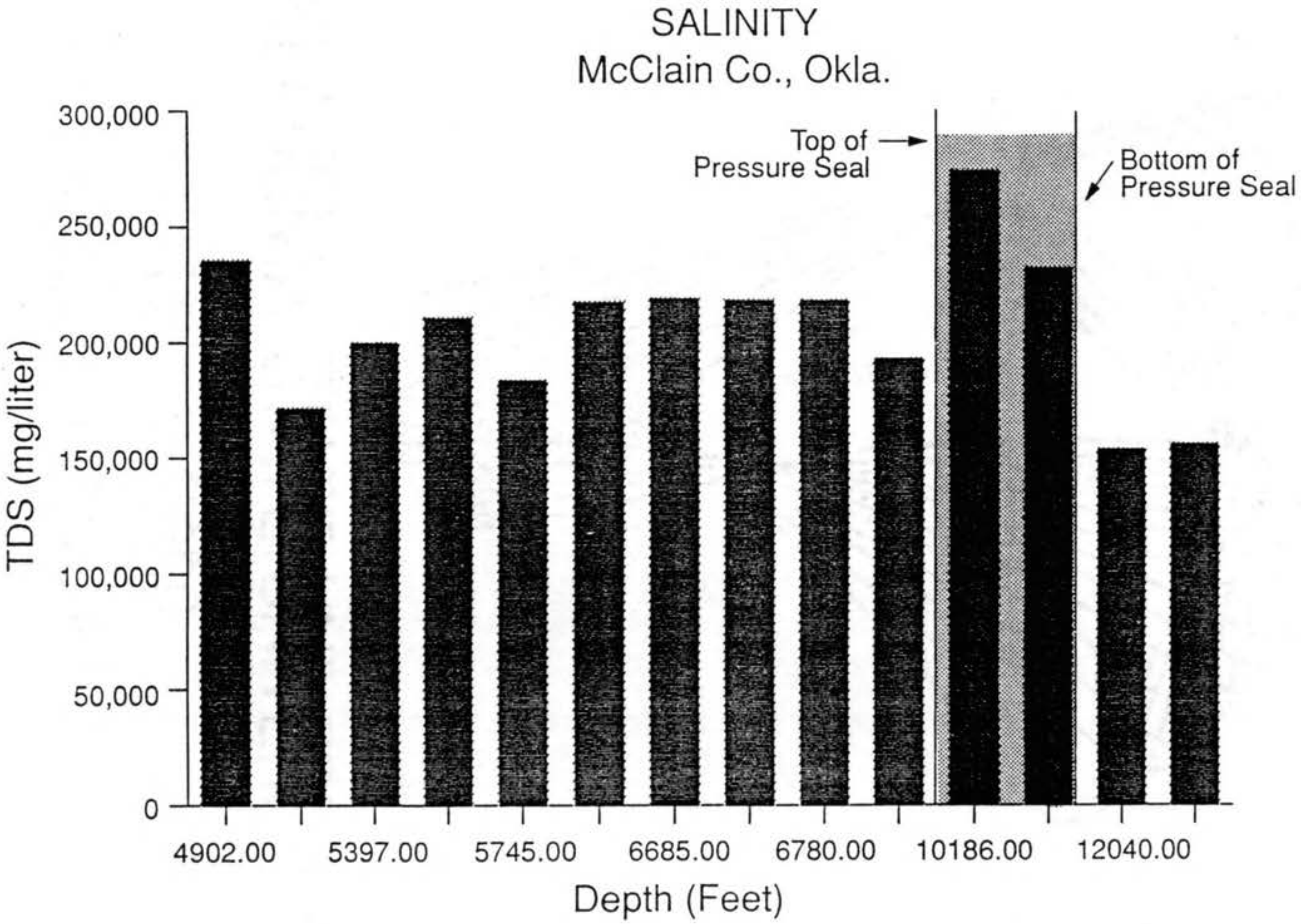


Figure 5. Salinity measurements from McClain Co., Okla.

CHAPTER IV

PRESSURE SEAL CHARACTERISTICS

Petrography and Depositional Environments

Pressure data from the Gulf Oil Co. Weaver No. 1, McClain County, show the cored Simpson Group interval (Plates III - IV) in the Weaver No. 1 to be a part of a pressure seal zone. The Simpson Group (Figure 6) consists of five formations which are in ascending order: Joins, Oil Creek, McLish, Tulip Creek, and Bromide. The average thickness of the Simpson Group in McClain County is approximately 1,250 feet.

The cyclicity of limestones, shales and sandstones in the Oil Creek, McLish, Tulip Creek and Bromide Formations is evidence for alternating transgressive and regressive depositional conditions. Subsidence occurred in four pulses during submergence of the Southern Oklahoma Aulacogen during deposition of the Middle Ordovician Simpson Group (Longman, 1981). The three oldest formations - Oil Creek, McLish and Tulip Creek respectively - were deposited during the first three of these pulses while the fourth pulse produced Bromide Formation deposits (Longman, 1981). Simpson sands originated from quartz-rich sand dunes bordering epeiric

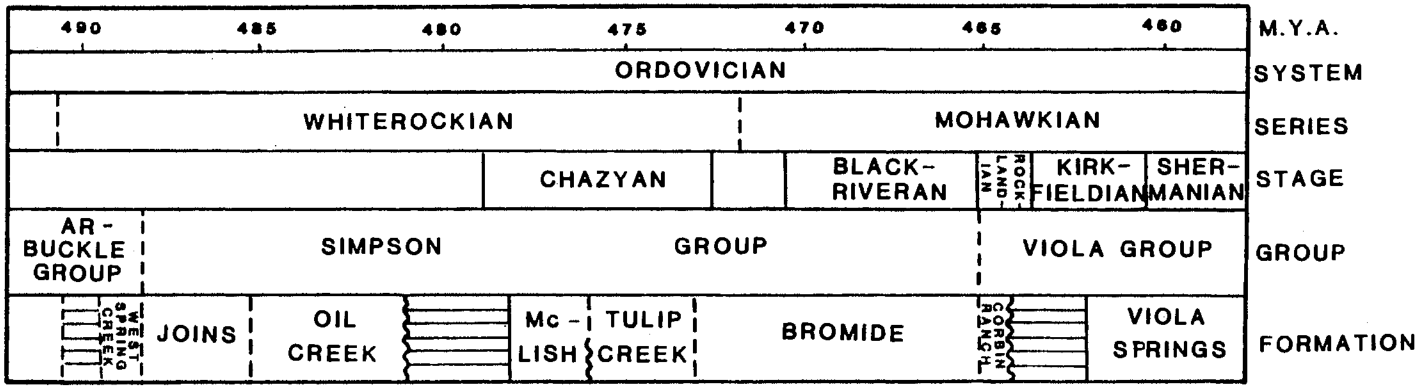


Figure 6. Stratigraphy of Simpson Group (after Ross, 1982).

seas and were deposited in upper and lower shoreface environments (Longman, 1981).

The Second Bromide sand and the Tulip Creek sand are the most important oil-bearing units in the Weaver Unit No. 1. These units together flowed 376 BO and 4200 MCFGD in a seven hour period.

Oil Creek Formation

The Oil Creek Formation is Chazyan in age and is 828 feet thick in the Weaver Unit No. 1. It is made up of a basal sandstone which is 90 feet thick. This sandstone bed is overlain by 280 feet of alternating shale and limestones (Bell, 1961) . These shales and limestones define the lower boundary of the seal and the upper boundary of the overpressured Oil Creek Formation. An unconformity is present at the top of the Oil Creek Formation and base of the McLish Formation.

McLish Formation

The McLish Formation is Middle Chazyan in age and is 222 feet thick. It can be divided lithologically into two units. The basal McLish sandstone consists of 50 feet of white to light gray, fine to very fine-grained bioturbated quartzarenites. The upper 272 feet of the McLish Formation is dominated by alternating wackestone and packstone beds grading upward into bioturbated sublitharenites, siltstones, and fossiliferous mudstones.

Tulip Creek Formation

The Mohawkian age Tulip Creek formation is referred to as the "Third Bromide" sand in the subsurface. In the Weaver No. 1 the Tulip Creek formation is 136 feet thick. The Tulip Creek Sandstone is predominantly a coarse to medium-grained, black and tan quartzarenite with abundant stylolites and bioturbation features.

Bromide Formation

The Bromide Formation in the study area is made up of sandstones, shales and dense limestone in almost equal proportions. It is Mohawkain in age. The Bromide is divided into three units in the subsurface of southern Oklahoma. In descending order, they are Corbin Ranch, (Harris, 1964) the First Bromide sandstone and the Second Bromide sandstone.

The Second Bromide sandstone is 60 feet thick in the Weaver Unit No. 1. It is composed of white to tan alternating with oil stain, fine to medium-grained quartzarenites with abundant pyrite nodules, stylolites and bioturbation features. Clay laminae and clay nodules are present.

The First Bromide sandstone is 106 feet thick. It is composed of alternating tan and oil-stained, medium-grained quartzarenites. Some green clay laminae is present towards the top of the first Bromide sandstone.

Detrital clay, which occurs in both of these sands, was either deposited with the sand-sized sediments, or infiltrated into the sands shortly after deposition.

The Corbin Ranch is a light gray to buff, hard, dense, lithographic limestone (Bell, 1961, Jacobsen, 1949).

Diagenesis

Diagenetic and Lithologic Banding Patterns

The compositionally homogeneous Simpson Group sandstones exhibit textural heterogeneity due essentially to diagenetic processes. The diagenetic processes are cementation, intergranular pressure-solution, and mechanical brecciation. A paragenetic sequence (Figure 7) for the Simpson Group in the Weaver No. 1 is based upon the textural and morphological relationships observed and described below. The textural heterogeneity in the Gulf Weaver No. 1 core is manifested as chemical and mechanical banding.

Silica-cemented sandstone are predominant in all the Simpson sandstones. Upon burial, precipitation of silica cement was one of the first diagenetic events to develop. Sandstones cemented by either calcite or dolomite are second in abundance. Areas with relatively high clay content have generally lower than average silica and/or carbonate cement.

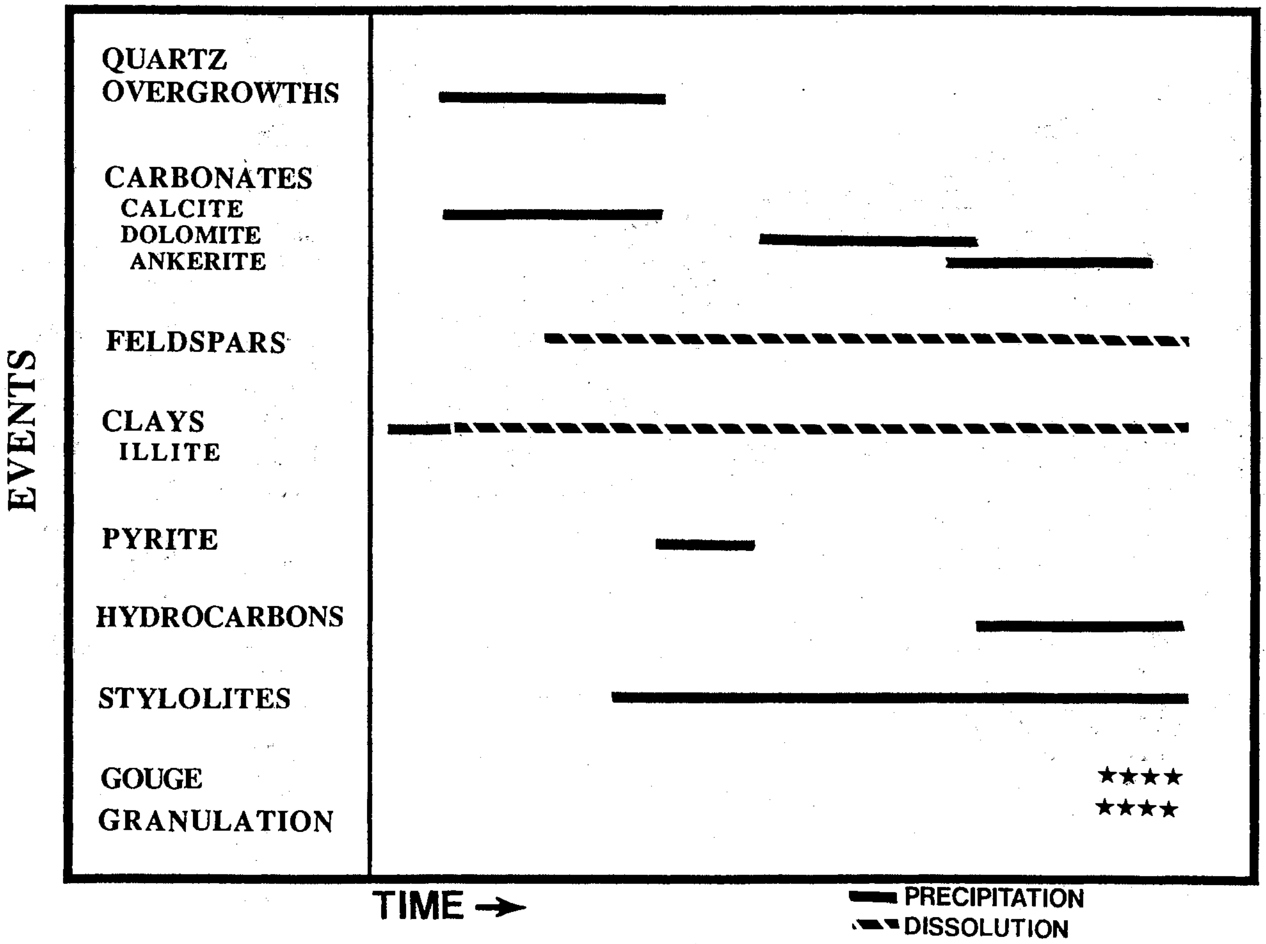


Figure 7. Paragenetic sequence of the Simpson Group.

<u>Silica-Cemented Sandstones</u> Quartz as syntaxial overgrowths is the most abundant authigenic mineral present. Quartzarenites with little detrital clays and no detrital carbonate grains exhibit maximum development of quartz overgrowths. In these sandstones, quartz overgrowths account for an average of 16% of the rock volume and values ranging from 6 to 30% (Figure 8a).

Quartz overgrowths were initiated during early burial conditions from interstitial waters which were saturated with respect to silica and were slightly acidic. They are distinguished from detrital quartz grains by the presence of illitic dust rims which formed a thin coating on the detrital grain.

Thin-section microscopy reveals that quartz overgrowths developed in various stages. The earliest stage formed blob-like growths (Pittman, 1972) which lacked crystal faces. Subsequently, small euhedral crystals developed from these incipient overgrowths. When sufficient pore space was available, the overgrowths formed large euhedral crystal faces.

Dissolution of detrital clays and plagioclase feldspars proceeded as temperatures increased during burial. Hydrolysis is the major reaction responsible for generation of secondary porosity which averages approximately 7% with values ranging from 1 to 14%. Hydrogen ion consumption caused an increase in alkalinity as the formation waters precipitated minor amounts of

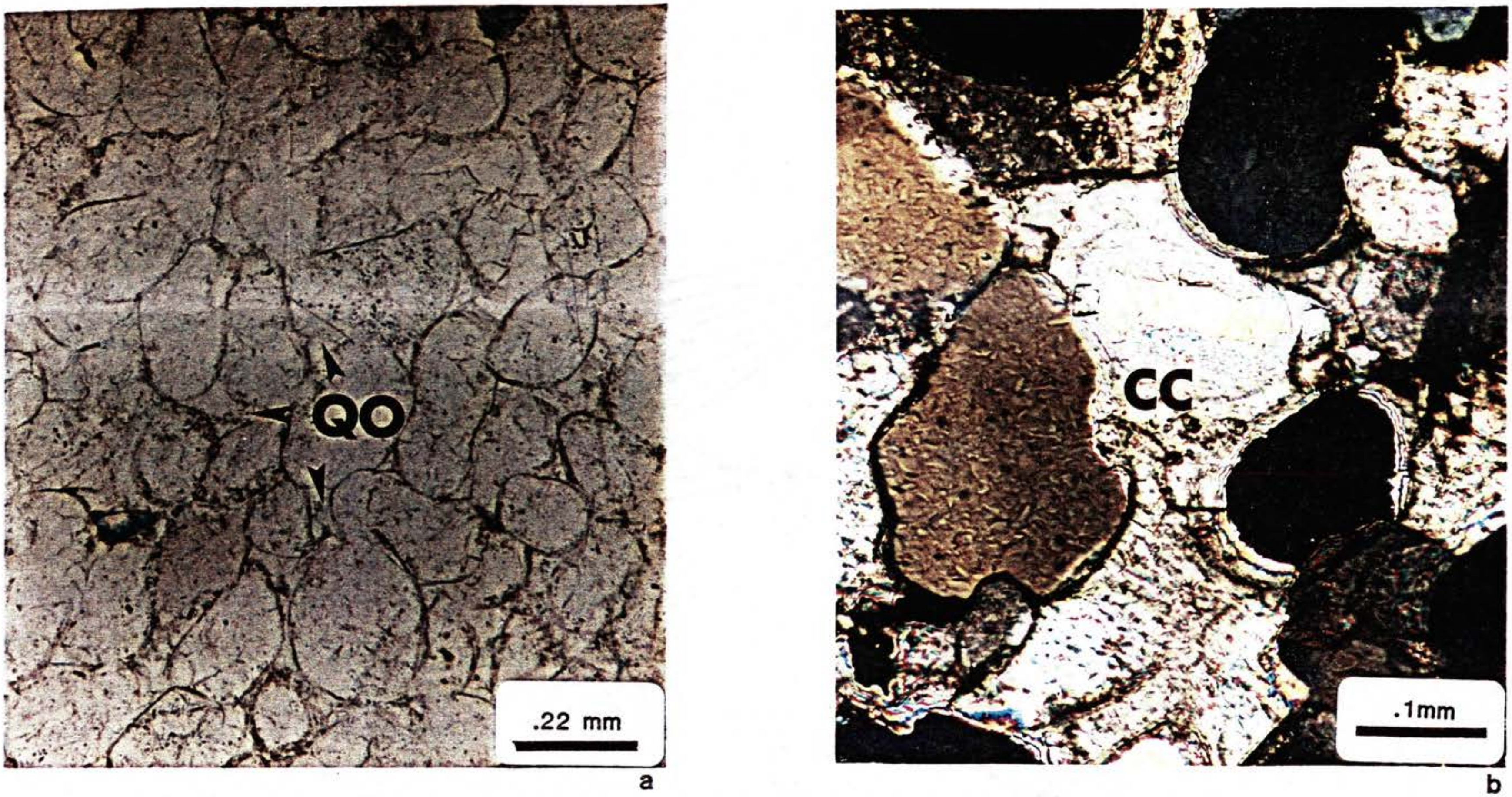


Figure 8. a) Complete occlusion of primary porosity by precipitation of quartz overgrowths (QO) (ppl). b) Quartzarenite cemented with poikilotopic calcite cement (CC) (cpl).

dolomite. As feldspar dissolution proceeded, fluids became saturated again with respect to silica. Webber (1987), presented evidence of a second stage of silica cement in the form of chalcedony replacing fossil fragments and as chert rimming dolomite grains.

Petrographic evidence suggests the presence of two episodes of hydrocarbon migration in the Simpson sandstones. The first episode coincided with the precipitation of quartz overgrowths. The second episode preceded secondary porosity generation.

<u>Carbonate-Cemented Sandstones</u> Carbonate-cemented sandstones contain large volumes of calcite and/or dolomite. The mean value of calcite cements is 31%, with values ranging from 26 to 41% of the total rock volume (Figure 8b). High carbonate percentages are due to the displacing and replacing nature of calcite cement. By comparison, quartz overgrowths compose only 2 to 6% of these sandstones.

Poikilotopic sparry calcite occurs as pore-filling cement that enclosed floating quartz grains. Local precipitation of silica cement as quartz overgrowths preceded precipitation of calcite cement.

Dolomite-cemented Simpson sandstones occur in zones with higher detrital clay content. Detrital illite and chlorite were replaced by dolomite, which in turn was replaced by ankerite. Dolomite and ankerite are late diagenetic events that form under deeper burial conditions.

As pore fluids became more acidic due to decarboxylation (Al-Shaieb, et al., 1981) the precipitation of carbonates ceased and dolomite and ankerite began to corrode. A late episode of pore filling kaolinite was precipitated. The presence of residual hydrocarbons indicates that oil migration may have halted the late dissolution process.

Clay-Dominated Sandstones Clay-dominated sandstones are those which contain significant amounts of neomorphic clays. This class can be divided into clay-dominated quartzarenites exhibiting granulation textures and those without granulation textures. Granulated zones have a mean clay content of 16% with values ranging from 3 to 28%. Mean porosity is 7.3%, with a range of 4 to 12%. This texturally significant rock type is discussed under a subsequent heading. Samples with no observable granulation textures have a mean porosity of 7%, ranging from a trace to 12%; clay content averages 16.5%, with a range of 5 to 44%.

Quartz overgrowth nucleation in these sandstones was absent due to the thick clay coats on detrital grains (Figure 9). Where dissolution of metastable grains occurred the resultant rock was highly porous, permeable and poorly-indurated.

In summary there are three distinct horizontal banding and lamination types observed in these

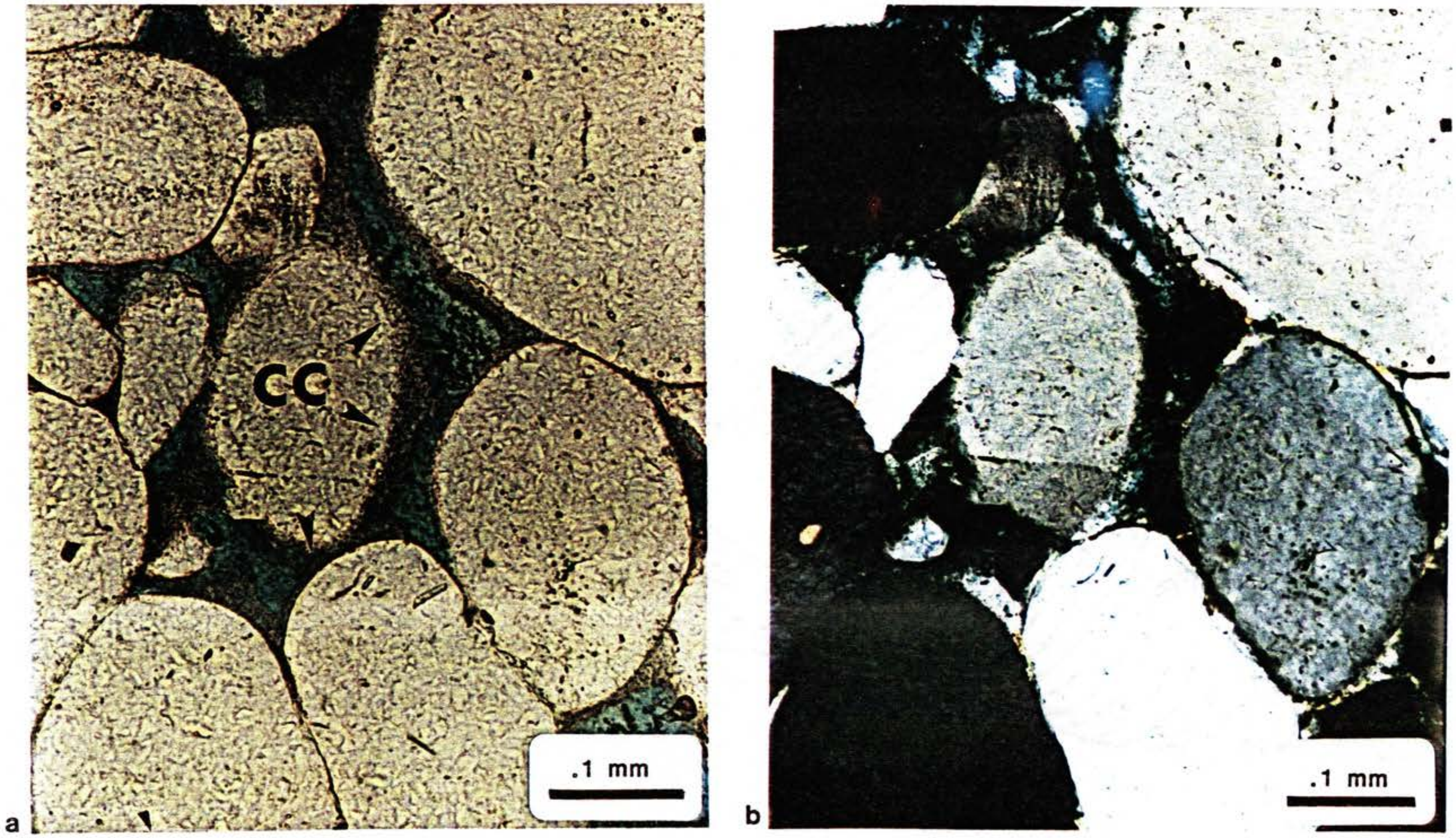


Figure 9. a) Illitic clay coatings inhibited precipitation of quartz overgrowths (ppl). b) (cpl).

sandstones. Poorly-indurated sandstones alternate with well indurated silica-cemented sandstones (Plate VII, Figure 10). Silica-cemented sandstones abruptly change to carbonate-cemented sandstones. The boundary is locally associated with stylolites (Plate VIII). Oil-stained sandstones alternate with non-oil-stained sandstones and exhibit black to tan bands (Plate VIII).

Pressure-Solution and Gouge Features

Pressure-solution and formation of stylolites is related to rock compaction processes. Gouge and granulation textures are formed by deformational processes associated with faulting and chemical processes to a lesser extent.

Pressure-Solution and Stylolites Pittman and Larese (1988) indicated that "pressure-solution involves the interpenetration of adjacent grains in contact under the influence of directed pressure and in the presence of interstitial solutions." In the Weaver Unit No. 1 core sutured, long concavo-convex, and straight grain contacts were observed. Dissolution of the quartz grains occurs at the stressed contacts (Weyl, 1959; de Boer, 1977). Silica liberated at the contact is removed by migrating pore fluids.

Simpson sandstones subjected to pressure-solution have 11% quartz overgrowths, 2.1% authigenic clays and 1% porosity. It is interesting to note that quartz

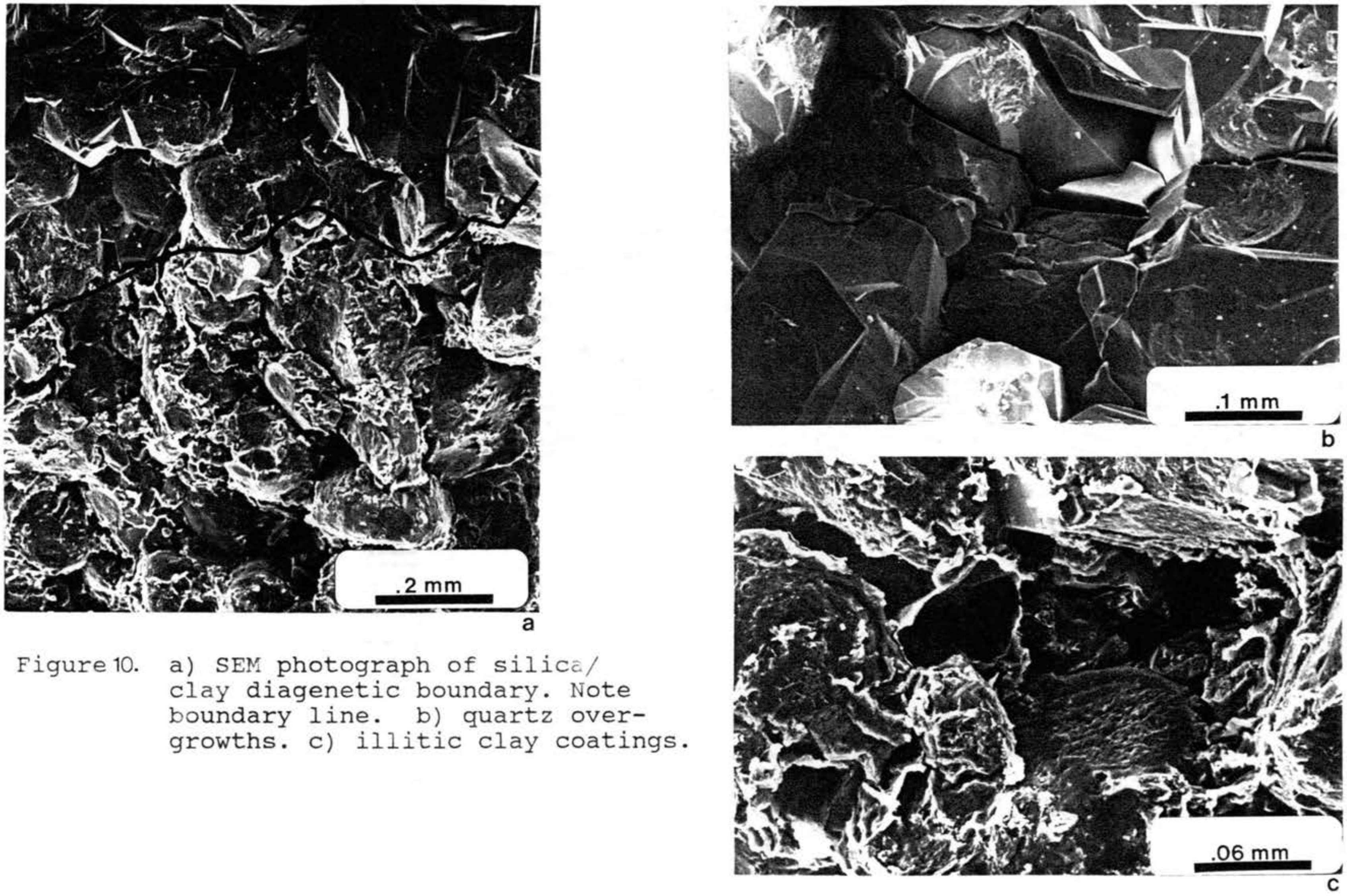


Figure 10. a) SEM photograph of silica/ clay diagenetic boundary. Note boundary line. b) quartz overgrowths. c) illitic clay coatings.

overgrowths in sandstones with minimal pressure-solution features constitute up to 16% of the rock, which indicates early quartz precipitation predates pressure-solution processes (Table II).

Pittman and Lumsden (1968) suggested that pressure-solution occurs where clay coatings are thin and non-pervasive. In addition, Houseknecht (1984) indicated that pressure-solution increases with increasing temperature and decreasing grain size. This is evidenced in the Tulip Creek Formation where pressure-solution features are associated with fine-grained sandstones. Banding and laminations are preferentially developed in these zones. However, pressure-solution features are not confined to only finer grained sediments. The medium-grained First and Second Bromide Sandstones also exhibit pressure-solution features.

Pressure-solution is commonly associated with zones containing minor amounts of clay. This suggests that as pressure-solution began to develop, interstitial fluids were squeezed along quartz-clay boundaries, allowing ions to migrate and precipitate in areas experiencing less stress.

Stylolites developed after quartz overgrowths and continued throughout the burial of the Simpson sandstones (Figure 11). Stylolite surfaces contain insoluble residues, including residual hydrocarbons, dolomite, calcite, pyrite, clay, and feldspar. However, some

TABLE II

CLAY AND POROSITY PERCENTS IN BANDED ZONES

	Clay Present	Porosity Present
Granulated Zones	16 (3-28 range)	7 (4-12 range)
Non-granulated Zones	13 (5-44 range)	7 (0-12 range)

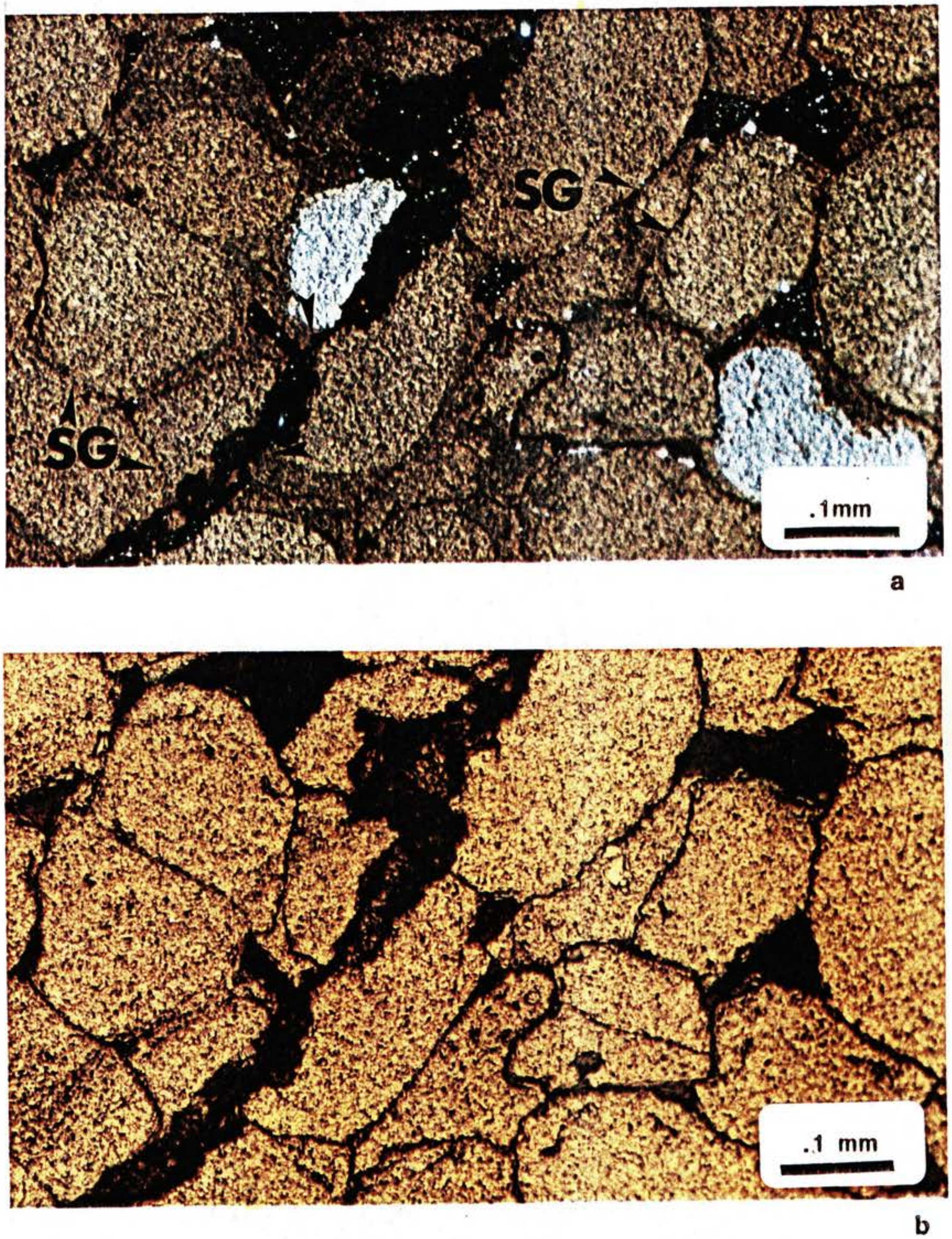


Figure 11. Cathodoluminescence photomicrographs show the effect of pressure solution on quartz overgrowths and stylolite development. Arrows delineate cross-cutting relationships. Sutured grain contacts (SG) are also visible.
a)(ppl) b)(cpl)

stylolitic seams which formed prior to hydrocarbon migration contain only clay residues. This particular stylolite type is usually localized at the boundary between silica-cemented and carbonate-cemented sandstones.

<u>Granulation/Gouge</u> Deformation bands ranging from few micrometers to 15 cm thick are present in the Weaver Unit No. 1 core. These white veins exhibit granulation and fault gouge features. Granulated sandstones contain slightly fractured original grains which can still be recognized (Engelder, 1974). Gouge textures result from severe deformation leaving few distinguishable detrital grains (Engelder, 1974). Heald (1955) first noted granulation textures as hard white veins in Simpson Group outcrops. Pittman (1981) showed that the sandstones between the deformation seams are undisturbed and contain good intergranular porosity. Several formation stages of granulation and gouge textures ranging from slightly fractured quartz grains to a crushed fine-grained matrix were observed.

Minimum granulation is represented by slightly rotated quartz grains. With minimal fracturing of the grains, faint light-colored fractures and cracks developed (Figure 12a). A major increase in rotation results in distinct crushing of grains into smaller fine-grained fragments (Figure 12b). This process generates a bimodal grain size texture (Pittman, 1981). Intensive

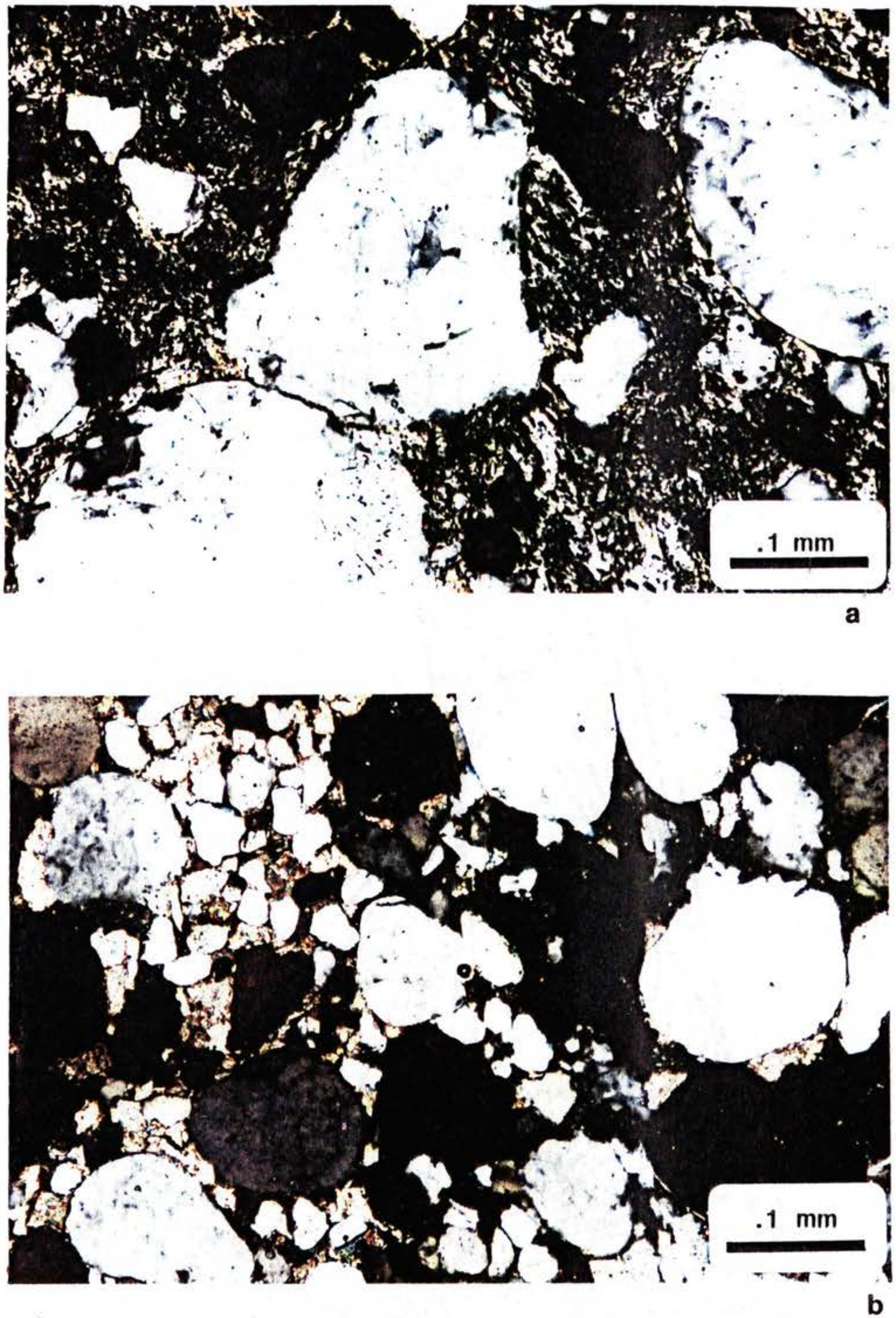


Figure 12. Evidence of granulation. a) A slightly rotated quartz grain is fractured and pulled apart (cpl). b) Bimodal grain-size fabric resulting from rotation and crushing of quartz grains (cpl).

fracturing of grains is very evident at this stage. As quartz grains are fractured and crushed, diagenetic clays coat the grains and fill the open fractures (Figure 13a). The final granulation stage is the complete replacement of the crushed grain by clay minerals (Figure 13b).

Granulated sandstones develop secondary porosity where authigenic clays have been dissolved. Fine-grained, shattered sandstones with initially low clay content weld together forming a white chert-like matrix. Unlike the granulated sandstones where clay percentages average 13%, the 'gouge' sandstones contain no clay (Figure 14). This would indicate clean well cemented sandstones readily undergo cataclasis (Engelder, 1974), while sandstones exhibiting a significant amount of clay form granulation textures.

Relationship between Petrography and Log Signatures

Wireline logging methods are used to detect abnormal formation pressures as well as estimating formation pressures. Electric surveys, acoustic, bulk density, neutron and pulsed neutron log signatures can detect overpressured zones. With the exception of the spontaneous potential log, all other log measurements are taken from shales. Spontaneous potential measurements are taken from sandstone (Sahay, et al., 1988). Under normal hydrodynamic conditions porosity decreases at an

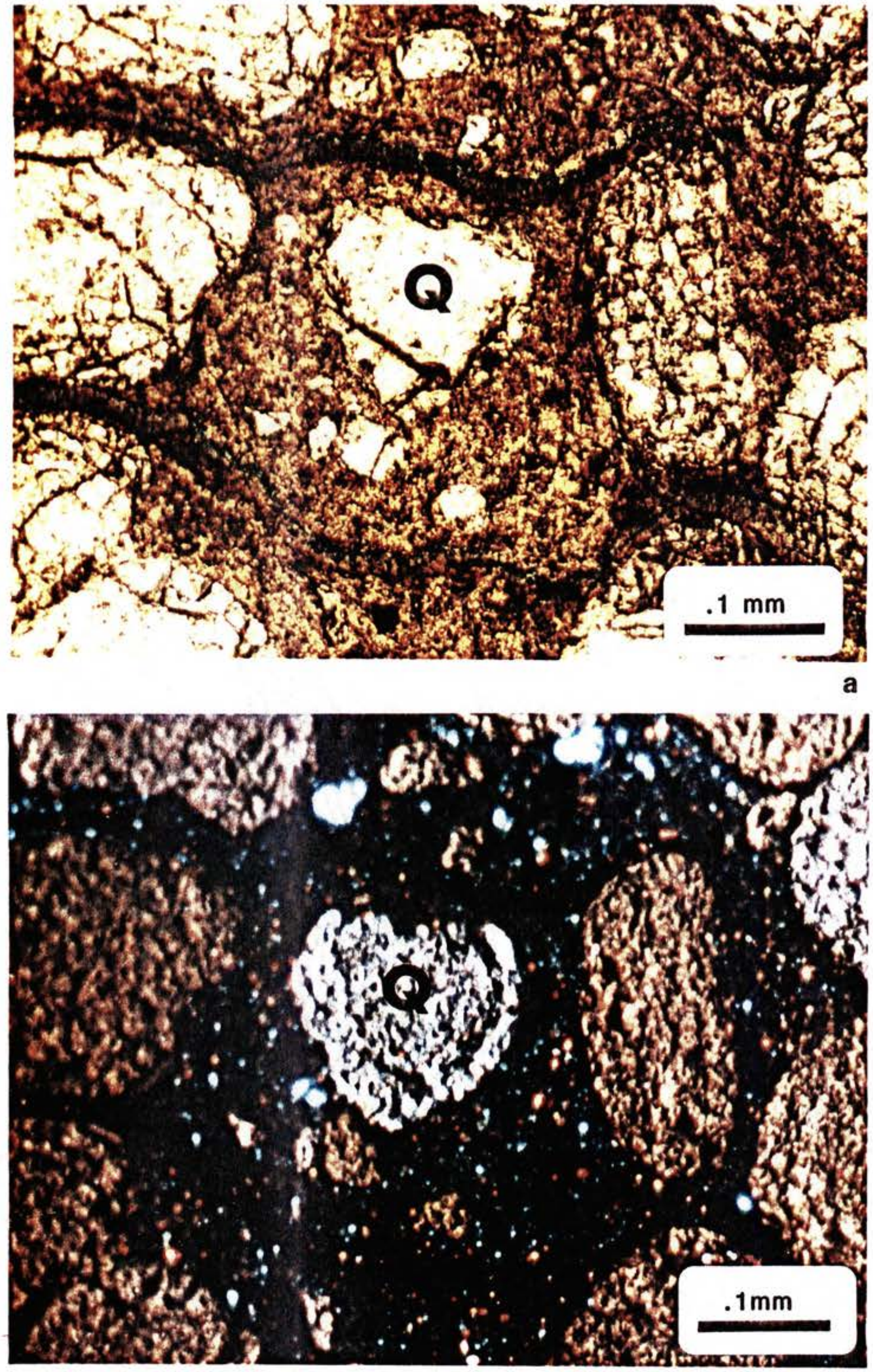


Figure 13. a) Cathodoluminescence photomicrographs show evidence of minerals replacing quartz grains (Q) during granulation (ppl). b) (cpl).

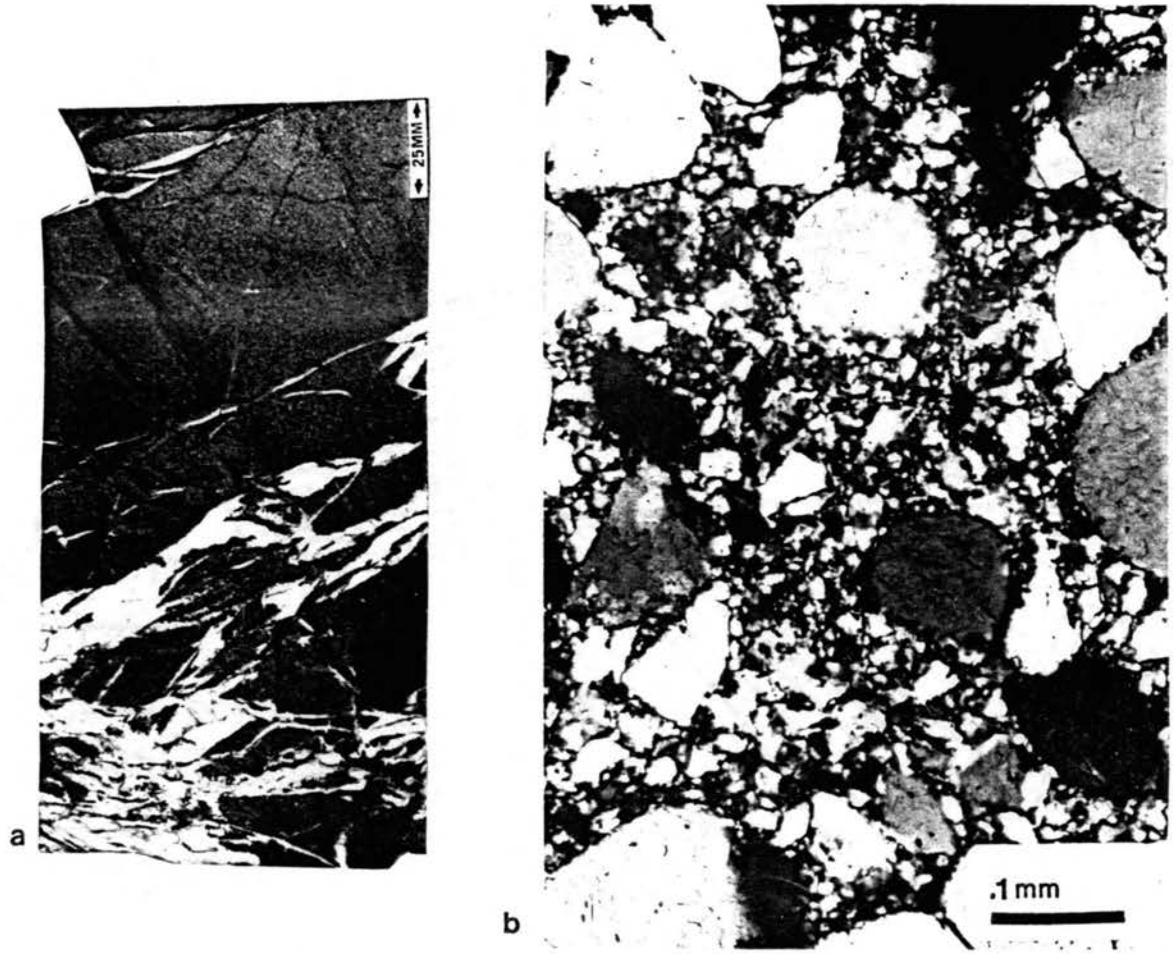


Figure 14. a) Core photograph of gouge sandstones.
b) Photomicrograph of gouge zone. Note abscence of clays (cpl).

exponential rate with depth as water is squeezed from shales due to the increase of overburden stress (Sahay, et al., 1988). When hydrostatic conditions are encountered, water cannot escape and porosity increases. Normal trends in shale resistivities can be established by plotting measurements on semilog paper. Departure from these trends indicate abnormally high pressured conditions (Figure 15) (Sahay, et al., 1988).

Detection of overpressure using electric logs is dependent upon the existence of a pressure depth ratio of.61 psi/foot pressure gradient. Shale resistivity log signatures decrease when the .61 psi/ft. pressure gradient is encountered (Powley, 1987).

The acoustic log may be a more informative tool to use for identification of the top and bottom extent of abnormal pressures. Unlike the electric log, the acoustic log responds to the first onset of abnormal pressures whether they be abnormally high or abnormally low (Powley, 1987).

Pore pressures can be calculated from the density log which reads true bulk density. Bulk density is dependent upon the rock matrix density, formation porosity and fluid density of the pore space. The neutron log measures formation porosity.

Electric Log Response

The short normal electric log curve is considered to

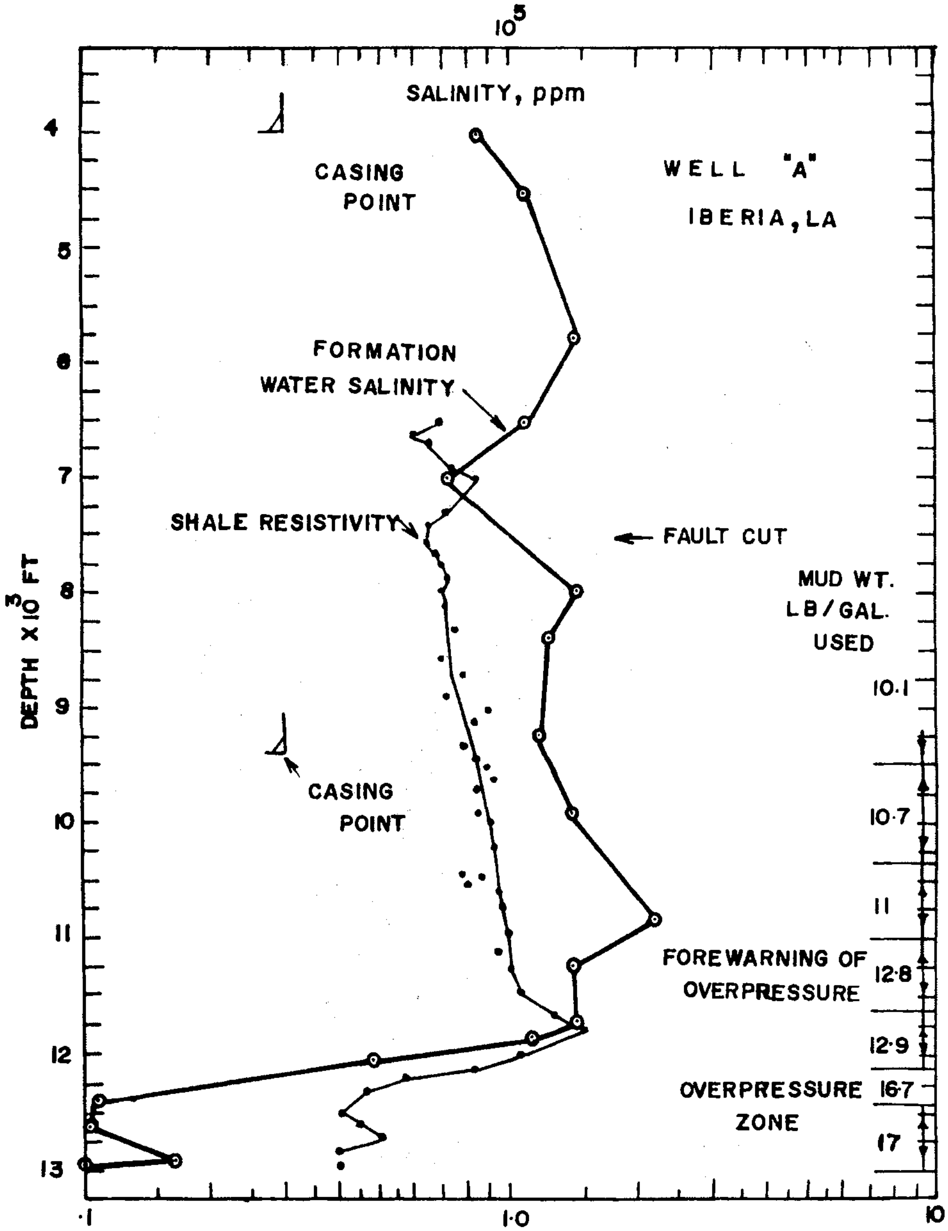


Figure 15. Log response to abnormal pressures (after Sayhay, et al., 1988).

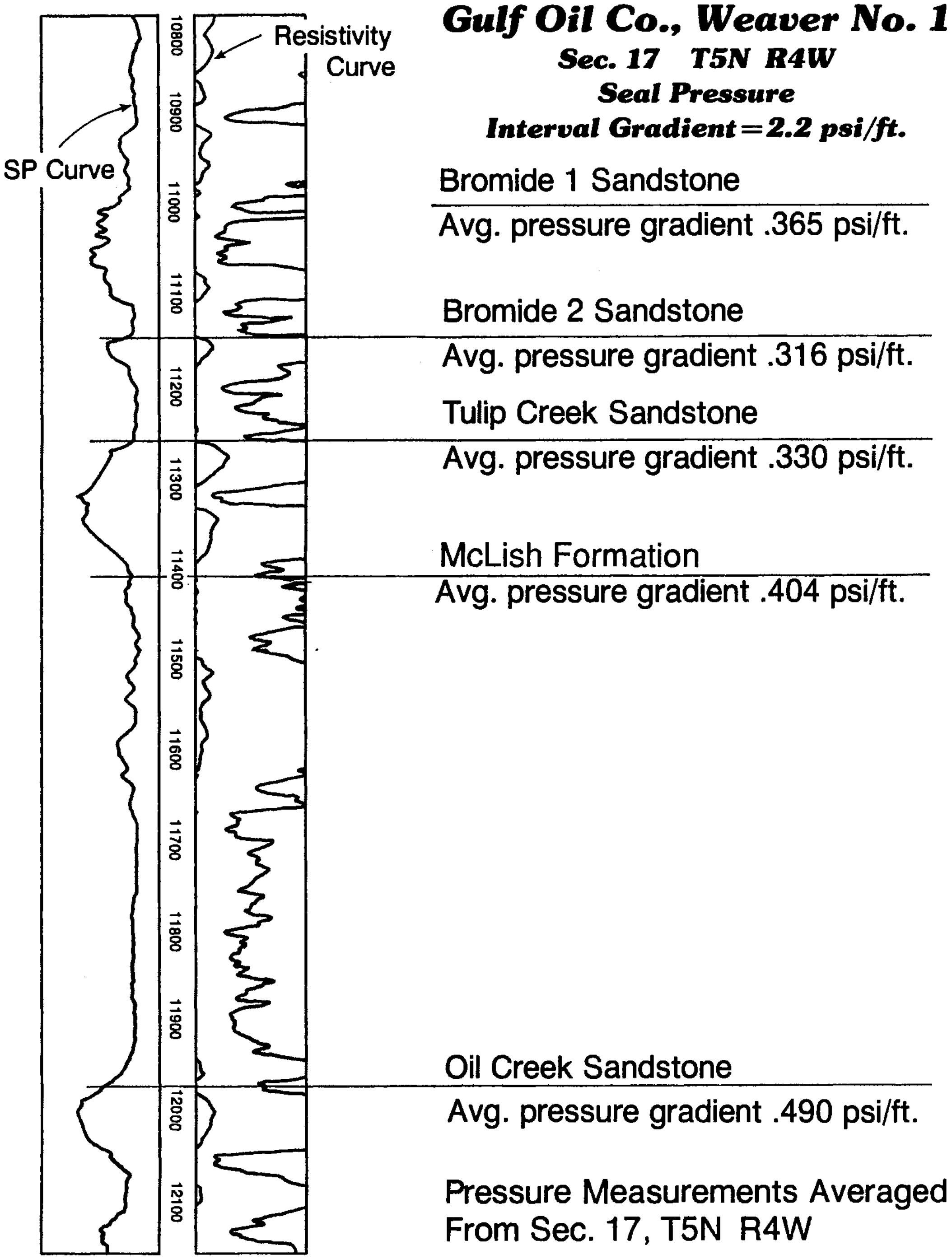


Figure 16. Resisitivity and spontaneous potential well logs of the Weaver Unit No. 1.

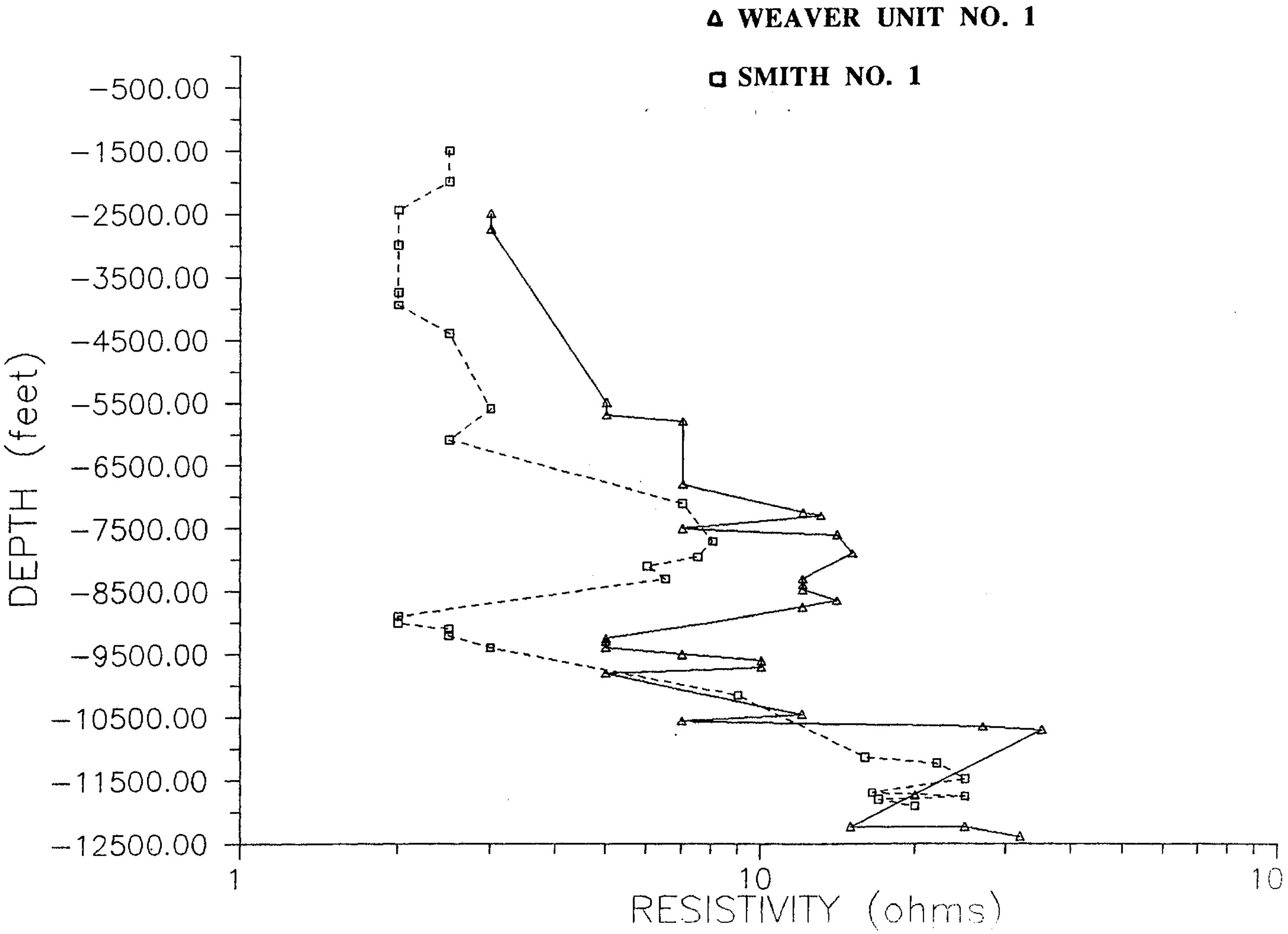


Figure 17. Short-normal shale resisitivity log response of the Weaver Unit No. 1.

be the most reliable electric logging device (Sahay, et al., 1988). Hottman and Johnson (1965) wrote the classic paper on methods of pressure detection using electric log signatures. The short normal curve will break from the normal shale resistivity to lower resistivity readings when a .61 psi/foot pressure gradient is encountered in the shales. Data points taken from normally pressured zones will plot along a trend line. Departure from this trend line to lower resistivity indicates abnormally high pressures. This method was employed to plot shale resistivities in the Weaver Unit No. 1 (Figure 16) and surrounding wells to see if abnormalities in the pressure seal and compartment could be detected (Figure 17). Shale resistivity measurements plotted logrithmiclly versus depth on a linear scale was plotted.

Some procedures for evaluating abnormal pressure zones from shale resistivities (Sahay, et al., 1988) which directly apply to the Weaver No. 1 are listed below:

> For selecting the proper shales for such studies care should be taken to see that they are pure and consistent. Siltyness, limyness, sandiness and carbonaceous nature of shales will be detrimental and should be avoided. For example calcareous shales show higher resistivity and thus could give erroneous pressure readings. Hence, it is necessary to carry out laboratory analysis of core and cuttings to quantify "lithology" effects before considering them for pressure detection techniques.

This last statement is extremely important. In the study area there is no way to detect the existence of a pure shale except from sporadic notations made on the log. Most shales which were examined in the Weaver Unit No. 1 contained calcite. The presence of calcite might account for abnormally high resistivity values obtained from the log signatures located in the pressure compartment.

Microlog Response to Banding Boundaries

The boundaries of different banding types which were composed of either a change in cement or clay content could be detected on the micro normal device on the microlog (Figure 18).

The microlog detects mudcake. The micro normal device on the microlog investigates three to four inches into the formation, measuring R_{xo}. Positive separation between the micro inverse and the micro normal indicates permeability present in the formation (Asquith, 1982).

Carbonate and silica resistivity values averaged 9.5 ohms microlog resistivity (Table III). Microlog resistivity value ranges for carbonate and silica cement are from 2-20 and 1-20 respectively. Clay values were considerably lower averaging 3.1 with ranges from 4.2 - 2.5. The number of clay samples were considerably lower which affected this value. Half of the boundaries showed transitions from permeable to impermeable zones while the remainder showed transitions from different cements

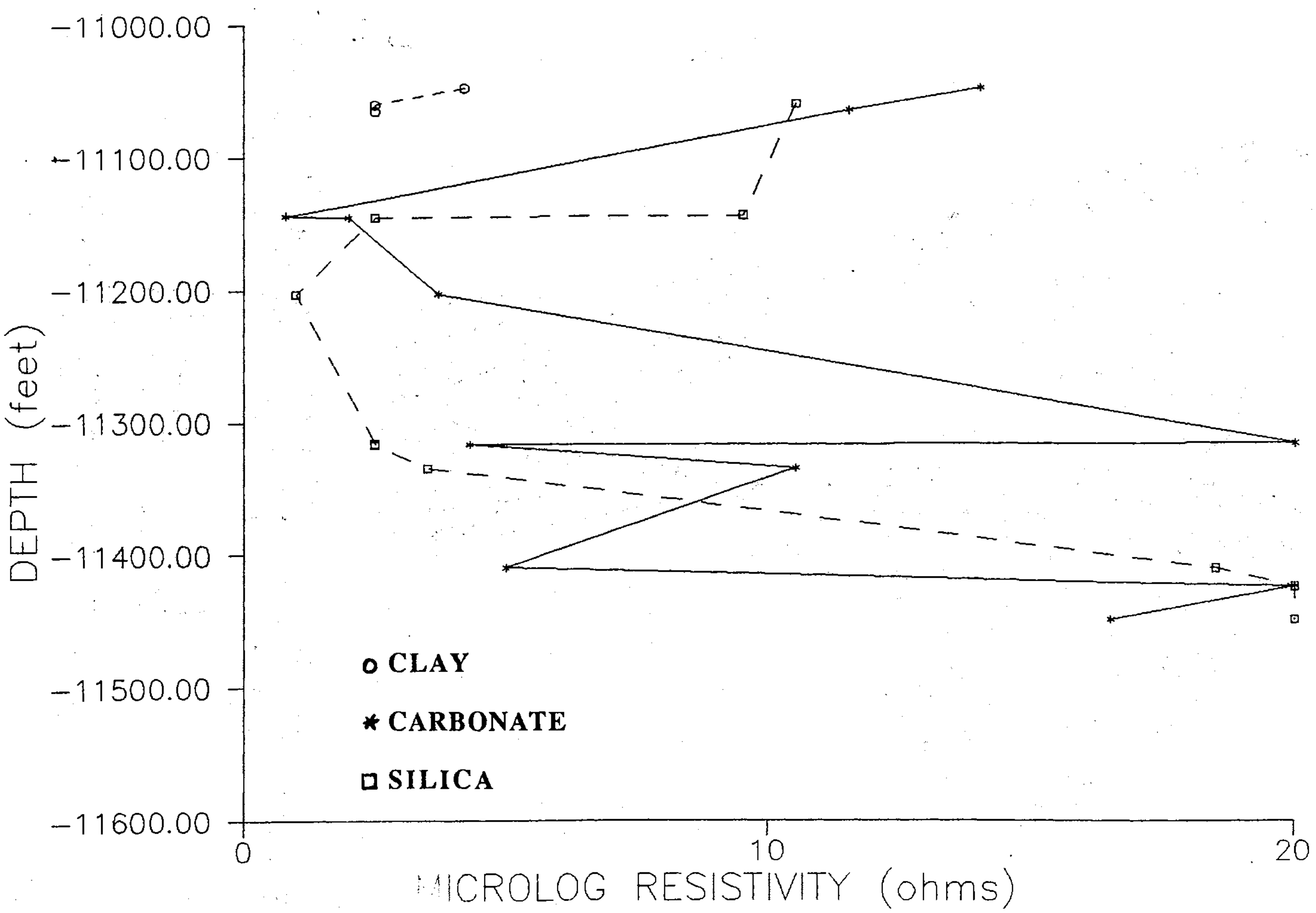


Figure 18. Microlog resistivity versus depth of cements and clays within the pressure seal interval.

TABLE III

MICROLOG RESISTIVITIES

Boundary Core	Depth Log	Resisitivity	Cement/Clay
-11048	-11048	14	carbonate
-11048	-11048	4.2	clay
-11060	-11056	10.5	silica
-11060	-11056	2.5	clay
-11065	-11060	11.25	carbonate
-11065	-11060	2.5	clay
-11144	-11144	9.5	silica
-11144	-11144	8	carbonate
-11145	-11145	2	carbonate
-11145	-11145	2.5	silica
-11203	-11203	3.7	carbonate
-11203	-11203	1	silica
-11316	-11315	off scale	carbonate
-11316	-11315	2.5	silica
-11317	-11318	2.5	silica
-11317	-11318	4.3	carbonate
-11335	-11335	3.5	silica
-11335	-11335	10.5	carbonate
-11410	-11409	5	carbonate
-11410	-11409	18.5	silica
-11424	-11424	off scale	carbonate
-11424	-11424	off scale	silica
-11449	-11449	off scale	silica
-11449	-11449	16.5	carbonate

allowed for no permeability change.

Cement and clay transitions can be detected by changes in separation of the micro normal and micro inverse devices. This repeated occurrence within a sandstone may indicate diagenetic banding of different cement types and clays with interspersed permeable beds.

CHAPTER V

BURIAL HISTORY AND SEAL EVOLUTION

Methods developed by Lopatin in 1971 were used to develop a reconstruction of the burial history of the Simpson Group. This reconstruction was generated in order to compare the diagenetic features of the pressure seal to depth of burial and seal evolution. The relationship between the paragenetic sequence and burial history is much more useful than just the paragenetic sequence because it not only establishes the relative time between diagenetic events, but depths and temperatures at which those events occurred.

Proving this relationship however is extremely tenuous. Very little evidence and information are available that can establish the absolute time of diagenetic events in relation to burial events that affected the Simpson Group. Perhaps the best direct line of evidence for establishing this relationship is fluid inclusion analysis of the different cements. Conjectural relationships are established however which relate the burial history curve and paragenetic sequence constructed for the Weaver Unit No. 1 to the scenario for the pressure seal evolution.

Burial History Curve

The Simpson Group was deposited at the sedimentary surface (depth = 0) 488 mybp. The Simpson Group is 1250 feet thick in the Weaver No. 1. Since that time the strata have undergone burial histories illustrated by the curve in Figure 19.

The major burial and tectonic events that have affected the Simpson Group regionally include the uplift at the end of the Hunton deposition, the Wichita orogeny that occurred from Late Morrowan to Desmoinesian time, the Arbuckle orogeny which occurred in late Missourian to Virgilian time and the deep and rapid burial in Pennsylvanian and Permian time.

After deposition of the Simpson Group, there was continual deposition until 367 mybp, the end of the Hunton deposition when the area was uplifted (Jacobsen, 1949). Although the unconformity produced from this uplift is widespread, the actual amount of section eroded is believed to be the same (Swesnik and Green, 1950). Deposition then continued until the Wichita orogeny occurred, 305 mybp. This regional uplift lasted for 5my from Late Morrowan to Desmoinesian time, eroding Atoka, Springer, Goddard, Caney, Mississippi, and Woodford strata in the areas of greatest uplift (Thomas, 1965). Deposition resumed at an increased rate, forming a thick

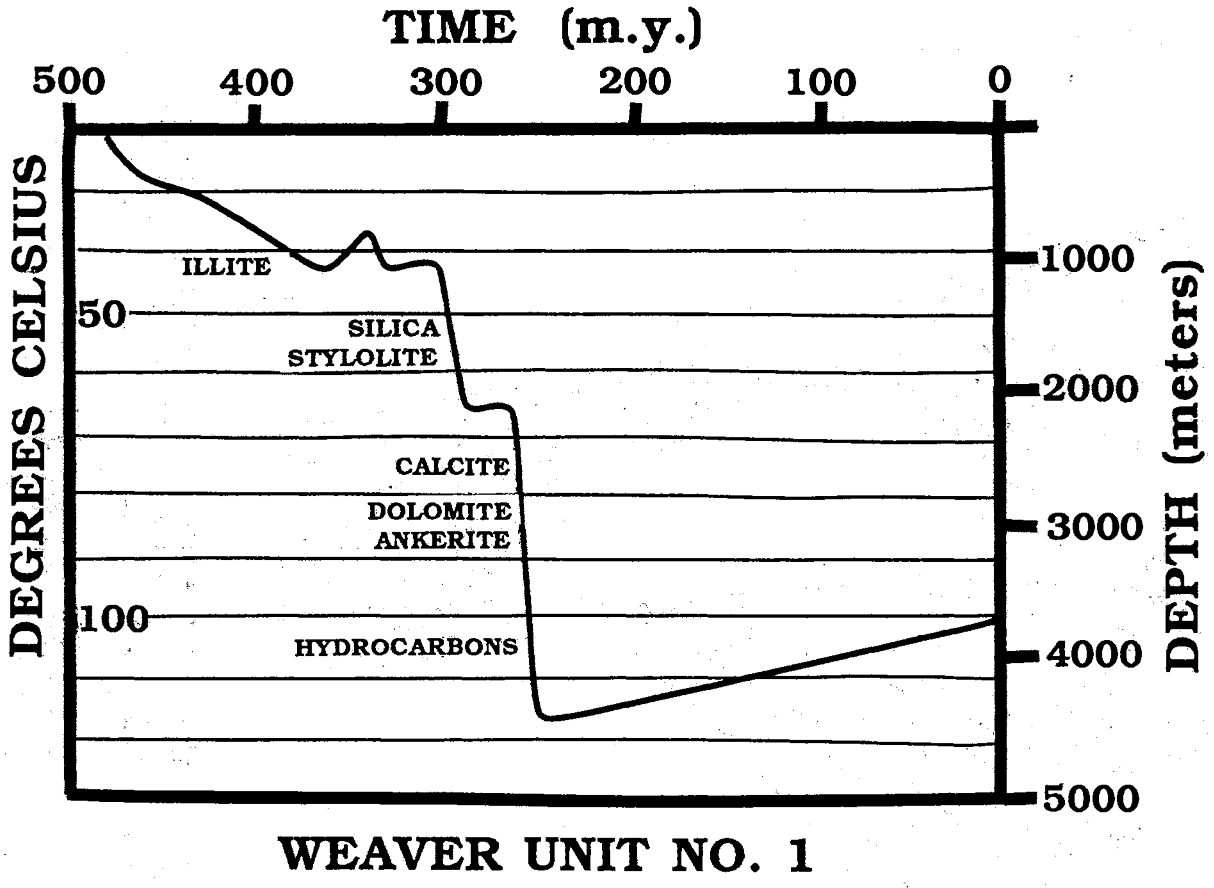


Figure 19. Burial history curve of the Weaver Unit No. 1.

stratigraphic sequence of Pennsylvanian and Permian strata. Approximately 3459 feet of Pennsylvanian and Permian strata are present in the Weaver Unit No. 1 well. The Arbuckle orogeny occurred in Late Missourian-Virgilian time, 287 - 280 mybp, resulting in major uplift in southern Oklahoma and rejuvenation of some pre-existing faults. Approximately 251 mybp, deposition of the Permian essentially ceased with erosion occurring since that time to the present.

The information used in the reconstruction of the depositional and tectonic history came from scout tickets of the Weaver No. 1 and surrounding wells; articles on the area's geological history and stratigraphic sections published for areas near the wells. Minor unconformities within formations and between them were not included because the thickness of the strata eroded would be minimal relative to the strata column.

Table IV list the thicknesses of the groups and formations that were identified from the electric log of the Weaver Unit No. 1. Cumulative thicknesses for each major time interval beginning with the Arbuckle Formation were calculated. Each subsequent thickness since the time of the Simpson deposition event represents the amount of burial of the Simpson Group. This is represented in the depths plotted on the burial history diagram (Figure 19). A temperature grid was constructed on the burial history diagram (Figure 19). The present-

TABLE IV

BURIAL CURVE DATA FOR WEAVER UNIT NO. 1

DATE (mybp)	SYSTEM	SERIES	FORMATION/ MEMBER	REFERENCE	THICKNESS (meters)
250	Permian			Anderson, 1930 Jacobsen, 1949	2068
280	(ARBUCKLE OROGENY)				
287	Pennsylvanian	Virgilian	Cisco	Disney, 1952	1094
			LeCompton		
			Tonkawa		
		Missourian	Layton		
			Checkerboard		
300		Desmoinesian	Gibson		
			Hart		
305	(WICHITA OROGENY)		Goddard (eroded)		-809
309	Mississippian	Springeran	Springer	Disney, 1952	614
		Chesterian	Caney		
		Meramecian	Mayes		
357		Osagean	Sycamore		
	Upper Devonian	Kinderhookian	Woodford		
367			Frisco (eroded)	Disney, 1952	
387	(PRE-WOODFORD UNCONFORMITY)				-307
435	Lower Dev/Silurian		Hunton Group		560
464	Ordovician	Cincinnatian	Sylvan		
		Mohawkian/	Viola		
492		Whiterockian	Simpson		409
	Cambrian		Arbuckle		365

day geothermal gradient which was estimated as $2.19^{0}C/100$ meters by Schmoker (1986) was used. The surface temperature was assumed to be 20 degrees Celsius (Waples, 1980, Schmoker, 1986). The geothermal gradient and surface temperatures were assumed to have been constant throughout the time interval being constructed.
Observed heterogeneity in the sandstones of the Simpson Group is directly linked to mechanical and chemical diagenetic processes which occurred during seal evolution. Carbonate- and/or silica-cemented zones alternating with porous and permeable zones generate unique banded "diagenetic lithologies" that are not related to any depositional facies. These differential cementation patterns are develop into bands of varying thicknesses and porosities (Figure 20). This structure is accentuated by porous and permeable units generated by secondary porosity development. It is important to note that both permeable and impermeable strata were originally composed of the same material. These bands of permeable rock are actually reservoirs within the seal zone. Multiple bands of permeable and impermeable strata act collectively as a pressure seal. The extensively cemented zones play a similar sealing role as do the more traditional shale and evaporites seals.

The characteristic banding structure of the seal zone (Figure 19) may be genetically related to mechanical processes as well as the changing of formation fluids

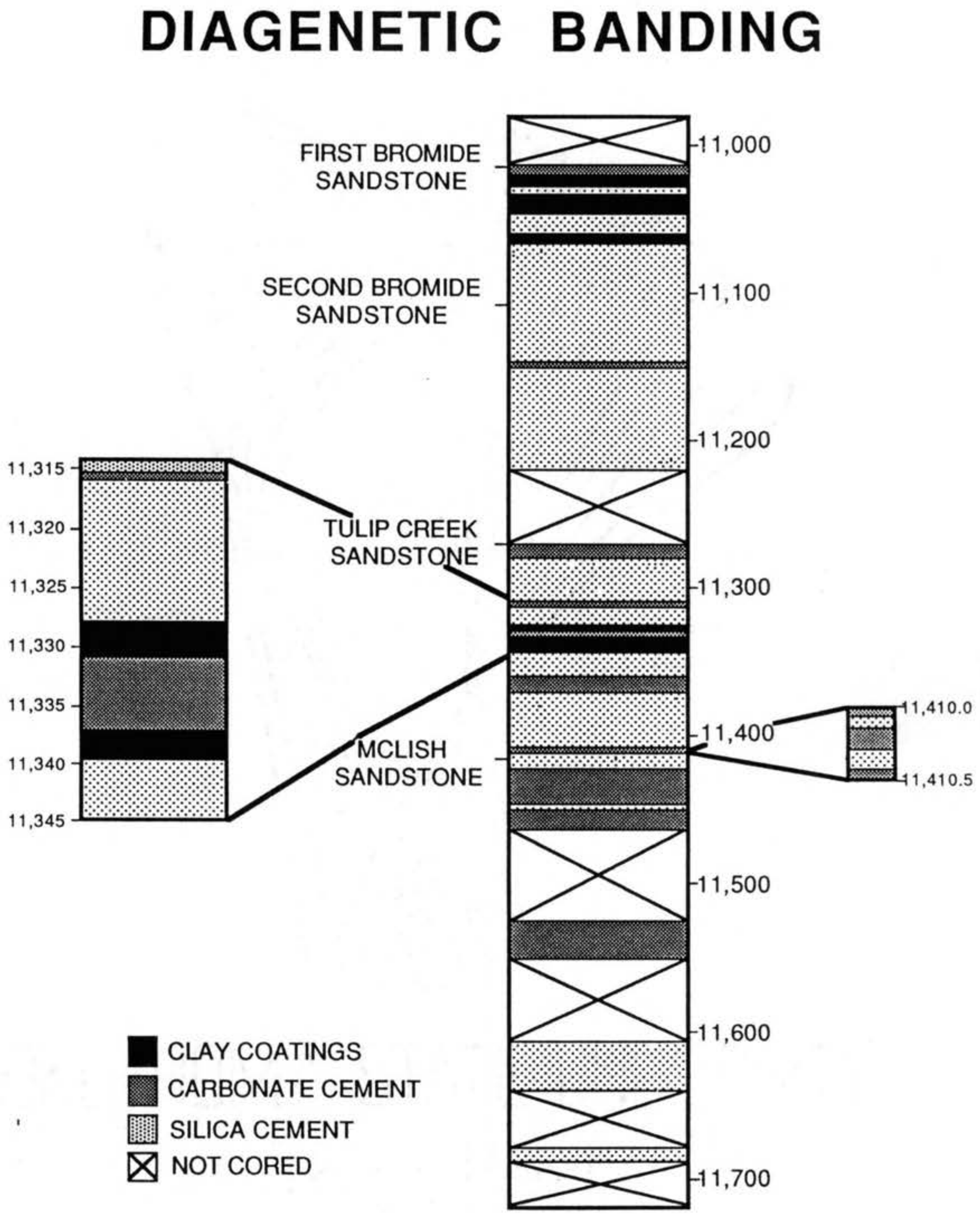


Figure 20. Schematic diagram of the diagenetic bands of the pressure seal present in the Weaver Unit No. 1.

during burial of the sandstones. Early hydrodynamic fluids, which precipitated early cements, were replaced by more corrosive fluids during burial (with concomitant increasing temperature with depth). Stylolites development and other pressure solution processes may have played an important role in the initiation of early banding structures. Fluids, enriched in H^+ ions, were more corrosive and usually resulted in the removal of metastable constituents, thus increasing the porosity and permeability of the affected rock. These fluids may have become "constructive" upon complete consumption of the H^+ ions. Hydrocarbon-maturation reactions is the obvious source for the H^+ ions. The fluctuation of H^+ ions in the formation fluids may have been repeated several times during the history of the basin, resulting in the generations of a diagenetically laminated pressure seal.

CHAPTER VII

CONCLUSIONS

In south-central Oklahoma, both underpressured and overpressured compartments are identified. Two adjacent overpressured fluid compartment exists between 3,000 and 13,500 feet. Pressure gradients average 0.50 psi/ft in the overpressured compartment. Pressure tests in the study area show a linear transitional change in pressure gradient from 10,000 to 12,500 feet above an overpressured compartment and below a underpressured compartment. This pressure transition is identified as the pressure seal. Core data from this seal zone within the Simpson Group indicates the transitional pressure changes correspond to alternating cemented and porous sandstones. These diagenetically banded sandstones may be genetically related to hydrocarbon-maturation reactions. The pressure seals consist of diagenetically banded sandstones and/or interbedded impermeable lithologies such as limestone and shale beds. Because of the permeability contrasts, the pressure seal with diagenetic fabric can serve as both the trap and reservoir rock in deep sedimentary basins.

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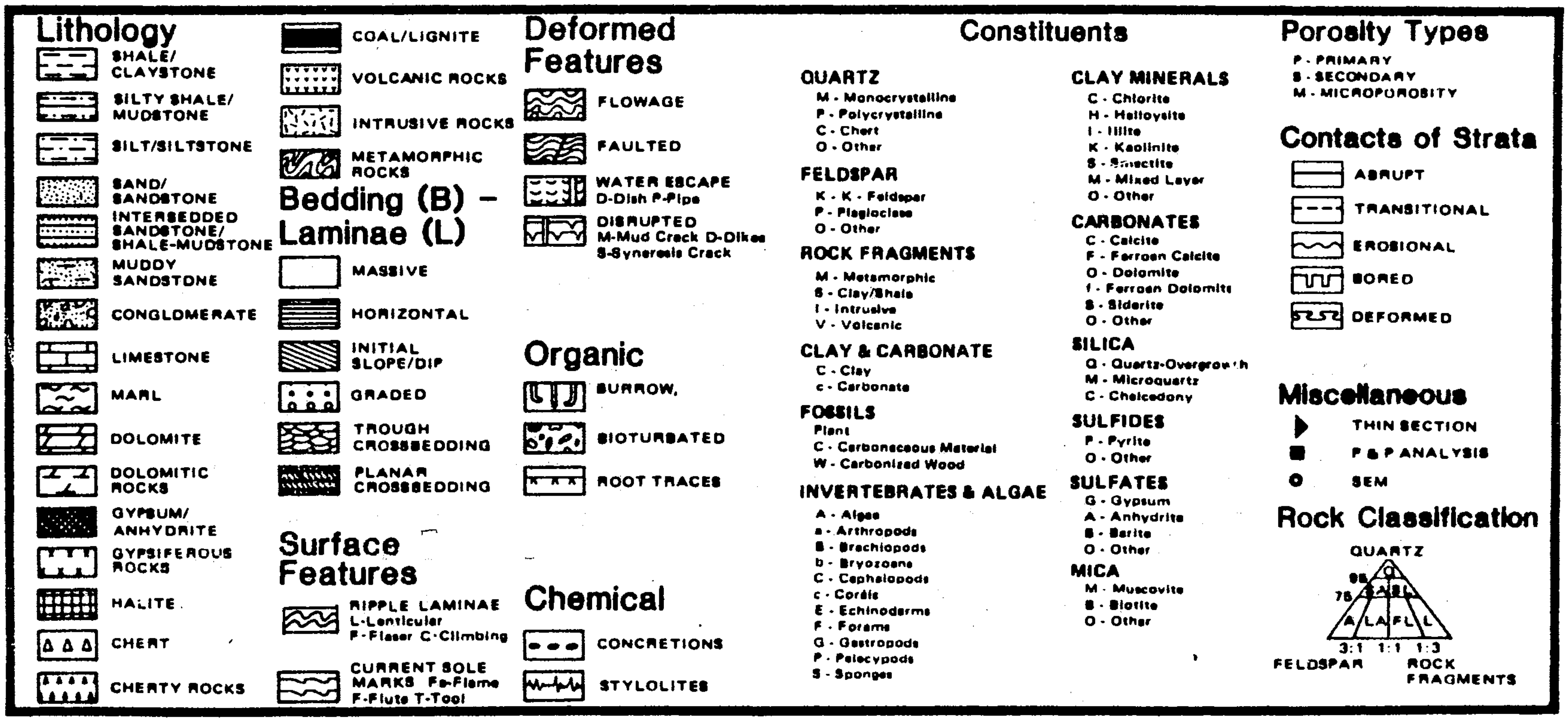
APPENDIX A

CORE DESCRIPTIONS; SUMMARIES



Lithology

- SHALE/ CLAYSTONE
- SILTY SHALE/ MUDSTONE
- SILT/SILTSTONE
- SAND/ SANDSTONE
- INTERBEDDED SANDSTONE/ SHALE-MUDSTONE
- MUDDY SANDSTONE
- CONGLOMERATE
- LIMESTONE
- MARL
- DOLOMITE
- DOLOMITIC ROCKS
- GYPSUM/ ANHYDRITE
- GYPSIFEROUS ROCKS
- HALITE
- CHERT
- CHERTY ROCKS
- COAL/LIGNITE
- VOLCANIC ROCKS
- INTRUSIVE ROCKS
- METAMORPHIC ROCKS

Bedding (B) – Laminae (L)

- MASSIVE
- HORIZONTAL
- INITIAL SLOPE/DIP
- GRADED
- TROUGH CROSSBEDDING
- PLANAR CROSSBEDDING

Surface Features

- RIPPLE LAMINAE L-Lenticular F-Flaser C-Climbing
- CURRENT SOLE MARKS Fa-Flame F-Flute T-Tool

Deformed Features

- FLOWAGE
- FAULTED
- WATER ESCAPE D-Dish P-Pipe
- DISRUPTED M-Mud Crack D-Dikes S-Syneresis Crack

Organic

- BURROW,
- BIOTURBATED
- ROOT TRACES

Chemical

- CONCRETIONS
- STYLOLITES

Constituents

QUARTZ
M - Monocrystalline
P - Polycrystalline
C - Chert
O - Other

FELDSPAR
K - K - Feldspar
P - Plagioclase
O - Other

ROCK FRAGMENTS
M - Metamorphic
S - Clay/Shale
I - Intrusive
V - Volcanic

CLAY & CARBONATE
C - Clay
c - Carbonate

FOSSILS
Plant
C - Carbonaceous Material
W - Carbonized Wood

INVERTEBRATES & ALGAE
A - Algae
a - Arthropods
B - Brachiopods
b - Bryozoans
C - Cephalopods
c - Corals
E - Echinoderms
F - Forams
G - Gastropods
P - Pelecypods
S - Sponges

CLAY MINERALS
C - Chlorite
H - Halloysite
I - Illite
K - Kaolinite
S - Smectite
M - Mixed Layer
O - Other

CARBONATES
C - Calcite
F - Ferroan Calcite
O - Dolomite
f - Ferroan Dolomite
S - Siderite
O - Other

SILICA
Q - Quartz-Overgrowth
M - Microquartz
C - Chalcedony

SULFIDES
P - Pyrite
O - Other

SULFATES
G - Gypsum
A - Anhydrite
B - Barite
O - Other

MICA
M - Muscovite
B - Biotite
O - Other

Porosity Types

P - PRIMARY
S - SECONDARY
M - MICROPOROSITY

Contacts of Strata

- ABRUPT
- TRANSITIONAL
- EROSIONAL
- BORED
- DEFORMED

Miscellaneous

▶ THIN SECTION
■ P & P ANALYSIS
● SEM

Rock Classification

Core description of the Gulf Oil Co., Weaver No. 1, S.W.1/4, Section 17, T5N, R4W, in the Golden Trend Field, (Lindsay Northwest); First Bromide Sandstone interval from 11,014 - 11,103 feet.

The First Bromide Sandstone is described from bottom to top. The sandstone bed can be partitioned into five units based upon lithologic sequences.

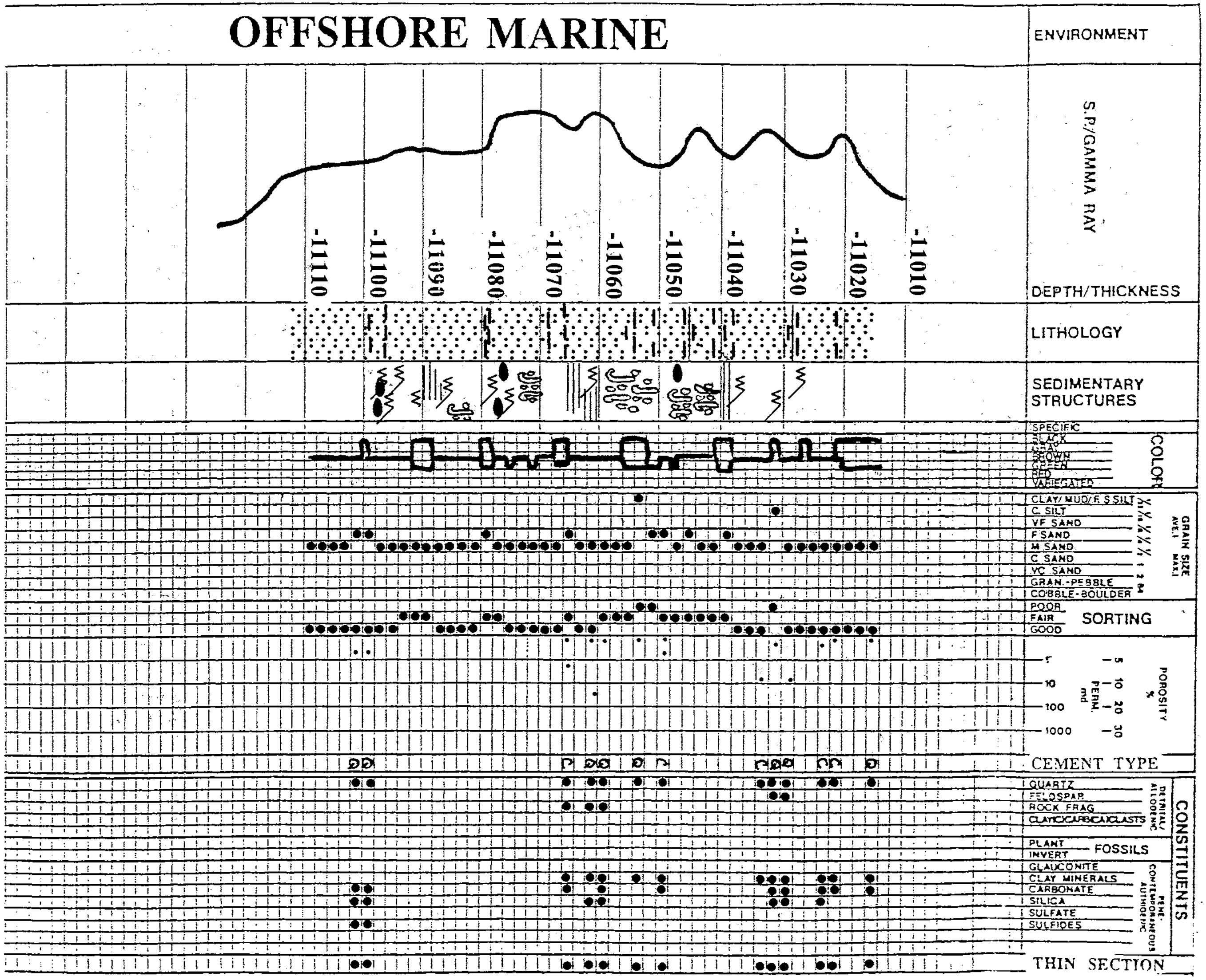
1. From 11,103 to 11,080 feet, medium-grained, tan and black sandstones. Horizontal laminae are the dominant sedimentary structures. Pyrite concretions and stylolites are present. Green shale laminae and deformed shale clasts increase in content in the top five feet of this interval.

2. From 11,088 to 11,077 feet, medium-grained, tan and black sandstones. Green shale laminae increasing towards the top. Bioturbation is the most common feature. Stylolites and pyrite concretions are present.

3. From 11,077 to 11,066 feet, medium-grained, poorly to moderately indurated tan sandstones. Very-thin to thin green shale beds increase at the top. Clay laminae are abundant. Stylolites and pyrite concretions are present.

4. From 11,066 - 11,050 feet, medium-grained, moderately to poorly indurated, black and tan sandstones. Green shale laminae increase towards the top. Ripple laminae and bioturbation are the predominant sedimentary features.

5. From 11,050 - 11014 feet, medium- to fine-grained, moderately indurated, black and tan sandstones. Green shale and shale laminae are present throughout. Bioturbation and stylolites are common features.


OFFSHORE MARINE
ENVIRONMENT
S.P./GAMMA RAY
-11110
-11100
-11090
-11080
-11070
-11060
-11050
-11040
-11030
-11020
-11010
DEPTH/THICKNESS
LITHOLOGY
SEDIMENTARY STRUCTURES
SPECIFIC
BLACK
GRAY
BROWN
GREEN
RED
VARIEGATED
COLOR
CLAY/MUD/F.S.SILT
C. SILT
VF SAND
F SAND
M SAND
C SAND
VC SAND
GRAN.-PEBBLE
COBBLE-BOULDER
GRAIN SIZE
AVE.) MAX.)
POOR
FAIR
GOOD
SORTING
1
10
100
1000
PERM. md
5
10
20
30
POROSITY %
CEMENT TYPE
QUARTZ
FELDSPAR
ROCK FRAG.
CLAY/CARB/CA.CLASTS
DETRITAL/ALLOGENIC
PLANT
INVERT
FOSSILS
GLAUCONITE
CLAY MINERALS
CARBONATE
SILICA
SULFATE
SULFIDES
PENE-CONTEMPORANEOUS AUTHIGENIC
CONSTITUENTS
THIN SECTION

Core description of the Gulf Oil Co., Weaver No. 1, S.W.1/4, Section 17, T5N, R4W, in the Golden Trend Field (Lindsay Northwest): Second Bromide Sandstone interval from 11,104 - 11,210 feet.

The Second Bromide Sandstone is described from bottom to top. The sandstone bed can be partitioned into five units based upon lithologic sequences.

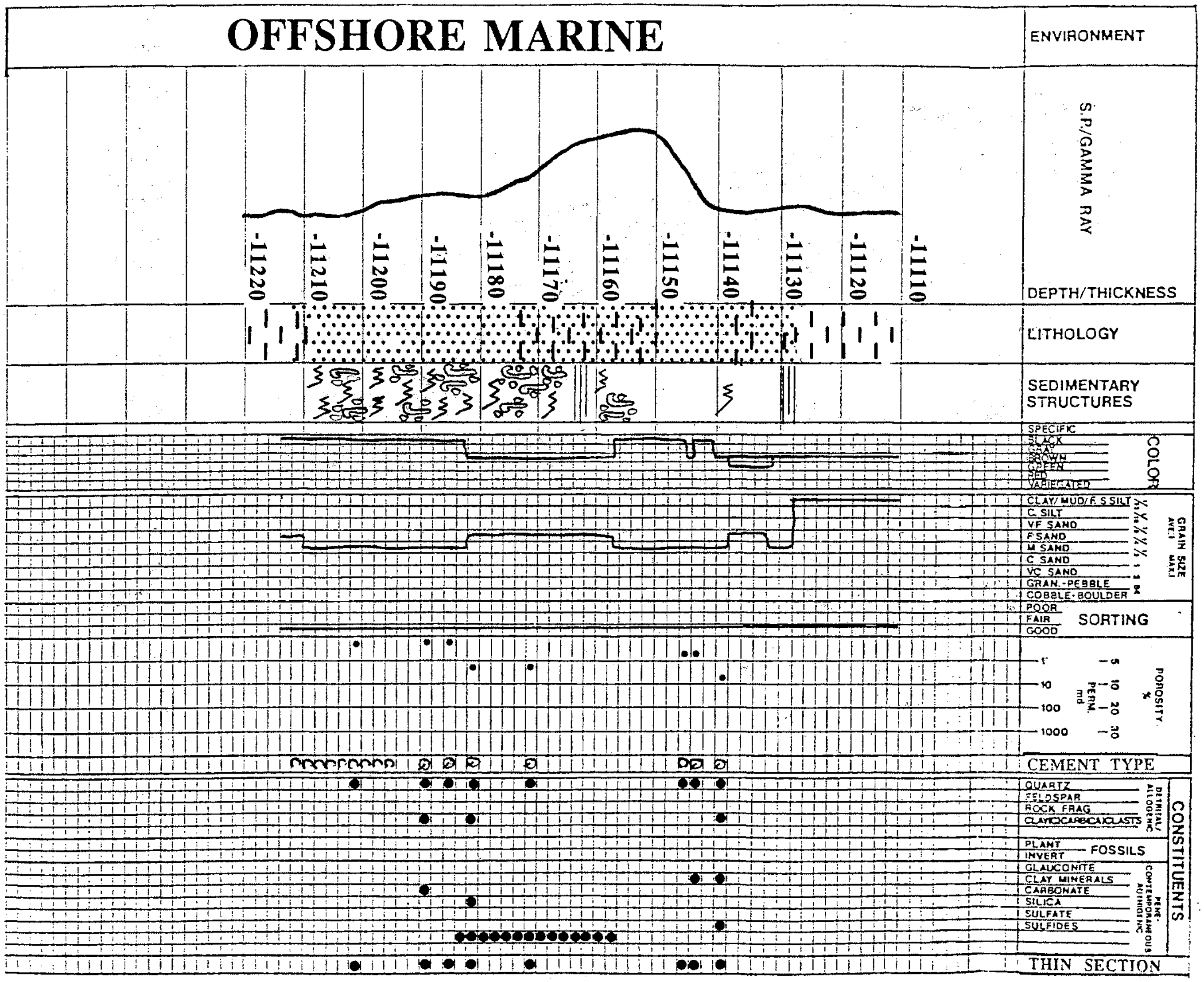
1. From 11,213 to 11,208 feet, oil stained, fine-grain sandstone interbedded with very thinly bedded to thin bedded shales.

2. From 11,208 to 11,176 feet, medium-grained, black and brown sandstone. Stylolites and bioturbation are the most common feature.

3. From 11,175 - 11,152 feet, fine-grained, tan sandstone with abundant clay laminae and clay rip up clasts. Stylolites, pyrite nodules and bioturbation are common.

4. From 11,151 - 11,138 feet, medium-grained, tan and black sandstone. Massive bedding is abundant.

5. From 11,138 - 11,110 feet, a transitional unit of interlaminated siltstone and shale. Sedimentary features include very thinly bedded green shale.


OFFSHORE MARINE
ENVIRONMENT
S.P./GAMMA RAY
-11220
-11210
-11200
-11190
-11180
-11170
-11160
-11150
-11140
-11130
-11120
-11110
DEPTH/THICKNESS
LITHOLOGY
SEDIMENTARY STRUCTURES
SPECIFIC
BLACK
GRAY
BROWN
GREEN
RED
VARIEGATED
COLOR
CLAY/MUD/F.S.SILT
C. SILT
VF SAND
F SAND
M SAND
C SAND
VC SAND
GRAN.-PEBBLE
COBBLE-BOULDER
GRAIN SIZE
AVE.)
MAX.)
POOR
FAIR
GOOD
SORTING
1
10
100
1000
PERM. md
5
10
20
30
POROSITY %
CEMENT TYPE
QUARTZ
FELDSPAR
ROCK FRAG
CLAY/CO/CARB/CA/CLASTS
DETRITAL/ALLOGENIC
PLANT
INVERT
FOSSILS
GLAUCONITE
CLAY MINERALS
CARBONATE
SILICA
SULFATE
SULFIDES
PENE-CONTEMPORANEOUS AUTHIGENIC
CONSTITUENTS
THIN SECTION

Core description of the Gulf Oil Co., Weaver No. 1, S.W. 1/4, Section 17, T5N R4W in the Golden Trend Field, (Lindsay, Northwest), Tulip Creek Formation interval from 11,270 - 11,410.

The Tulip Creek Formation is described from bottom to top. The sandstone bed can be partitioned into five units based upon lithologic sequences.

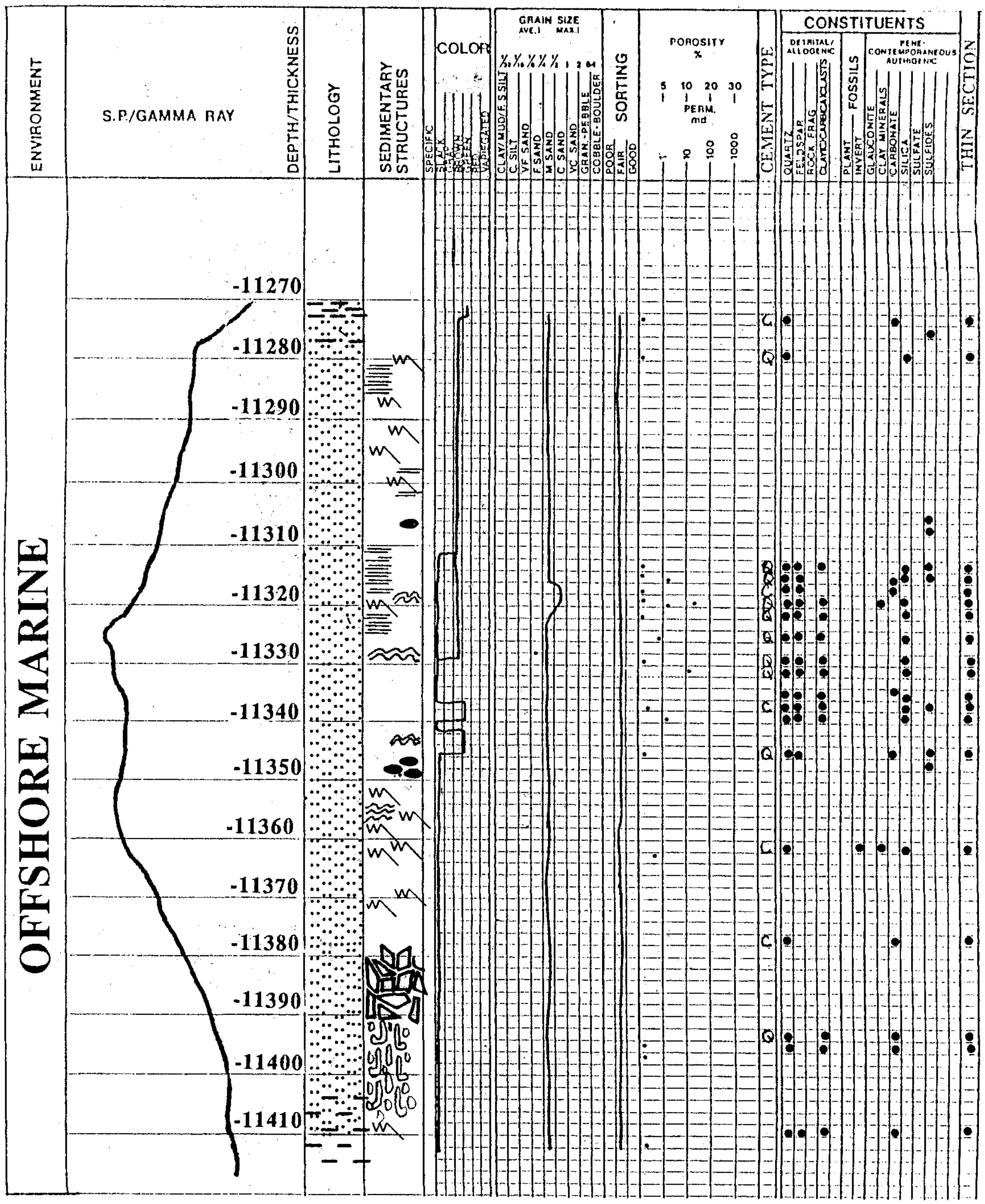
1. From 11,272 - 11,311, medium-grained, well indurated, brown sandstone. Massive bedding predominates. Shale laminae increases towards the top. Stylolites are abundant.

2. From 11,346 - 11,273 coarse- to medium-grained, moderately indurated, tan and black sandstone. Ripple laminae and massive bedding predominates at the top of this interval.

3. From 11,380 - 11,347 feet, medium-grained, black, well-indurated sandstone with abundant stylolites. Some ripple laminae and pyrite nodules are present.

4. From 11,390 - 11380 feet, medium-grained, black and white, very well indurated sandstone displaying brecciation and fractures.

5. From 11,410 to 11,390 feet, medium-grained, black sandstone. Bioturbation is abundant. This interval displays a coarsening upwards sequence into a very fine-grained sandstone and shale.


ENVIRONMENT
OFFSHORE MARINE
S.P./GAMMA RAY
DEPTH/THICKNESS
-11270
-11280
-11290
-11300
-11310
-11320
-11330
-11340
-11350
-11360
-11370
-11380
-11390
-11400
-11410
LITHOLOGY
SEDIMENTARY STRUCTURES
COLOR
SPECIFIC
BLACK
GRAY
BROWN
GREEN
RED
VARIEGATED
GRAIN SIZE
AVE.) MAX.)
CLAY/MUD/F.S.SILT
C. SILT
VF SAND
F SAND
M SAND
C SAND
VC SAND
GRAN.-PEBBLE
COBBLE-BOULDER
SORTING
POOR
FAIR
GOOD
POROSITY
%
5 10 20 30
PERM.
md
1
10
100
1000
CEMENT TYPE
CONSTITUENTS
DETRITAL/ALLOGENIC
QUARTZ
FELDSPAR
ROCK FRAG.
CLAY/CARB/CA CLASTS
FOSSILS
PLANT
INVERT.
PENE-CONTEMPORANEOUS AUTHIGENIC
GLAUCONITE
CLAY MINERALS
CARBONATE
SILICA
SULFATE
SULFIDES
THIN SECTION

Core description of the Gulf Oil Co., Weaver No. 1, S.W.1/4, Section 17, T5N R4W in the Golden Trend Field (Lindsay Northwest); McLish Formation interval from 11,678 to 11,670 and from 11,650 to 11,620 feet.

The McLish Formation is described from bottom to top. The sandstone bed can be partitioned into two units based upon lithologic sequences.

1. From 11,620 to 11,650 feet, fine-grained, black and tan sandstones interbedded with very thin laminae of shale. Bioturbation and ripple laminae are abundant. Some fractures are present which are filled with silica cement.

2. From 11,678 to 11,670 feet, very fine-grained, white, well indurated sandstone. Bioturbation is abundant.

3. From 11,560 - 11,554 feet, very fine-grained oil-stained sandstone to siltstone. Bioturbation and stylolites are apparent.

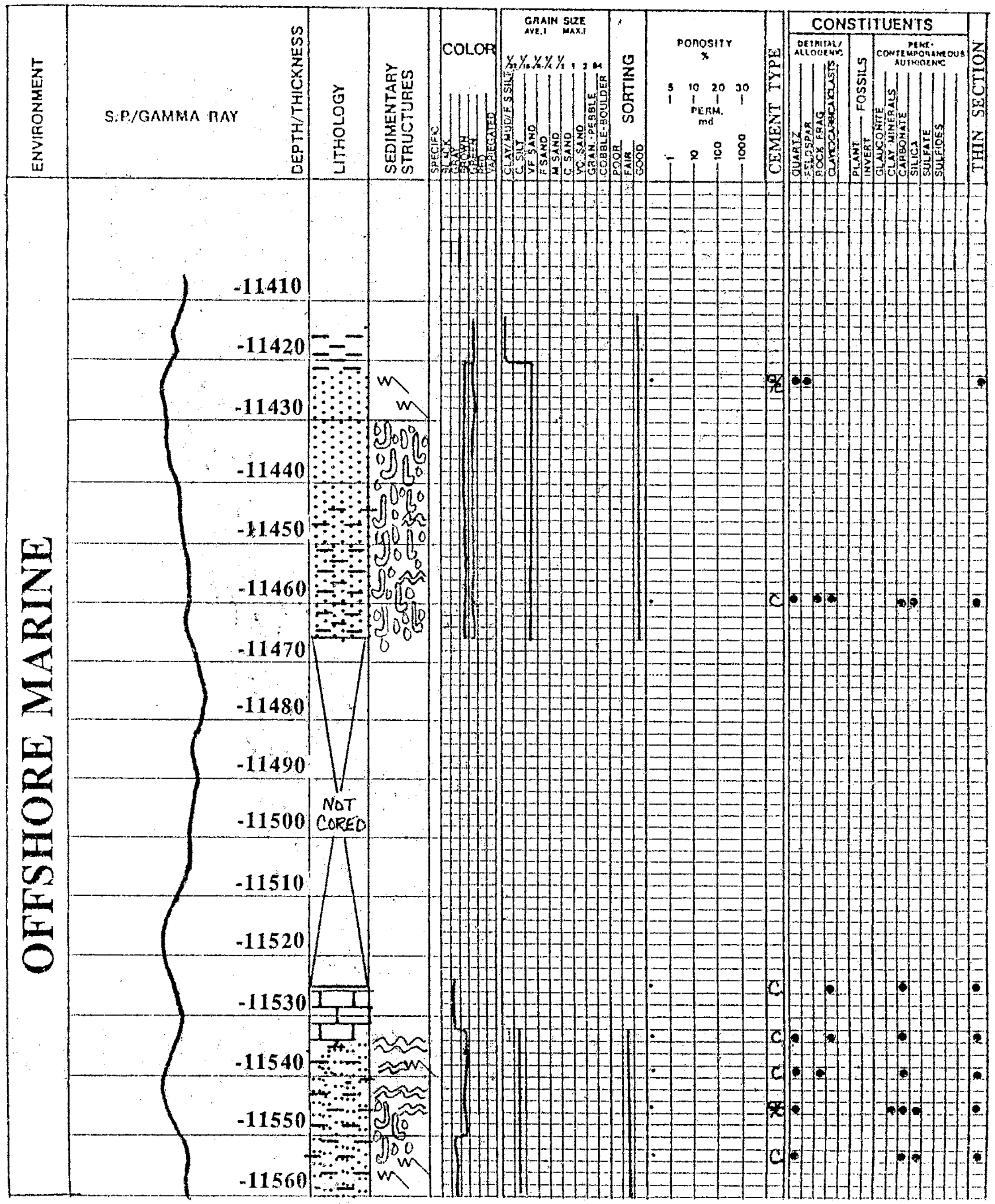
4. From 11,553 - 11,548 feet, light gray fossiliferous grainstone.

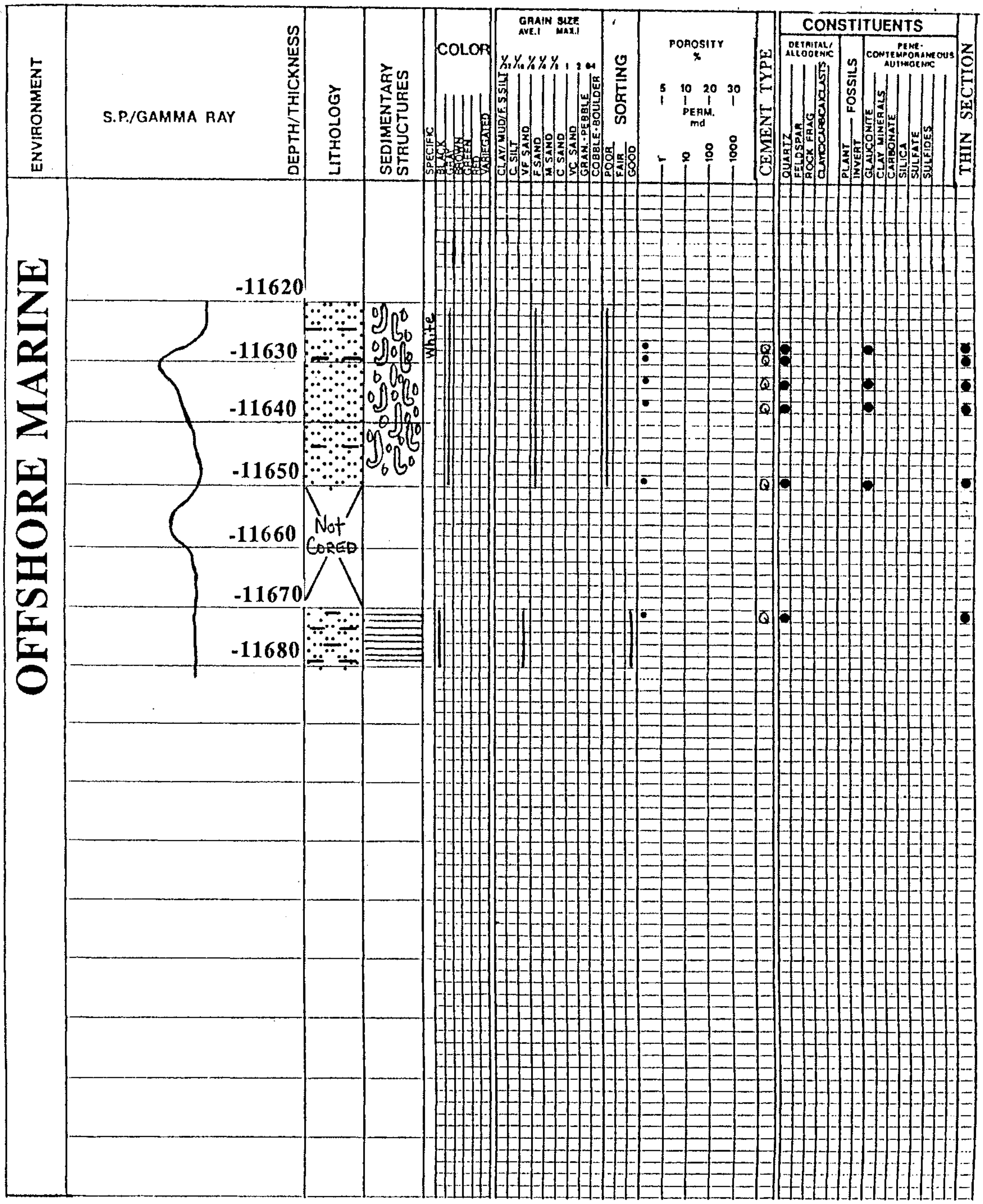
5. From 11,548 - 11,524 feet, fine-grained siltstone and mudstone . Bioturbation and ripple laminae are abundant.

6. From 11,466 - 11,444 feet, very fined grained, tan and black sandstone with interbedded green shale laminae. Bioturbation is abundant.

7. From 11,444 - 11,421 feet, fine-grained, green and tan sandstone with some massive bedding, stylolites and bioturbation.

8. From 11421 - 11412 feet, green siltstone and mudstone.

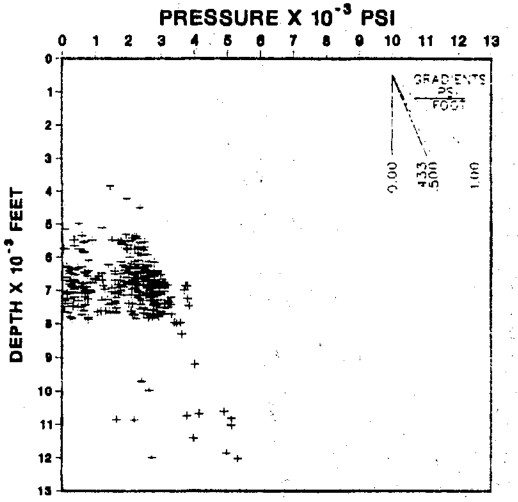

ENVIRONMENT
S.P./GAMMA RAY
DEPTH/THICKNESS
LITHOLOGY
SEDIMENTARY STRUCTURES
COLOR
SPECIFIC
BLACK
GRAY
BROWN
GREEN
RED
VARIEGATED
GRAIN SIZE
AVE.! MAX.!
CLAY/MUD/F.S.SILT
C. SILT
VF SAND
F SAND
M SAND
C SAND
VC SAND
GRAN.-PEBBLE
COBBLE-BOULDER
SORTING
POOR
FAIR
GOOD
POROSITY
%
5
10
20
30
PERM.
md
1
10
100
1000
CEMENT TYPE
CONSTITUENTS
DETRITAL/ALLOGENIC
QUARTZ
FELDSPAR
ROCK FRAG.
CLAY/CARBONATE CLASTS
FOSSILS
PLANT
INVERT
PENE-CONTEMPORANEOUS AUTHIGENIC
GLAUCONITE
CLAY MINERALS
CARBONATE
SILICA
SULFATE
SULFIDES
THIN SECTION
OFFSHORE MARINE
-11410
-11420
-11430
-11440
-11450
-11460
-11470
-11480
-11490
-11500
-11510
-11520
-11530
-11540
-11550
-11560
NOT CORED
C
C
C
C
C
C


ENVIRONMENT
OFFSHORE MARINE
S.P./GAMMA RAY
DEPTH/THICKNESS
-11620
-11630
-11640
-11650
-11660
-11670
-11680
LITHOLOGY
Not Cored
SEDIMENTARY STRUCTURES
COLOR
SPECIFIC
BLACK
GRAY
BROWN
GREEN
RED
VARIEGATED
White
GRAIN SIZE
AVE.I MAX.I
CLAY/MUD/F.S.SILT
C. SILT
VF SAND
F SAND
M SAND
C SAND
VC SAND
GRAN.-PEBBLE
COBBLE-BOULDER
SORTING
POOR
FAIR
GOOD
POROSITY %
5 10 20 30
PERM. md
1 10 100 1000
CEMENT TYPE
Q
CONSTITUENTS
DETRITAL/ALLOGENIC
QUARTZ
FELDSPAR
ROCK FRAG.
CLAY/CARB/CALCICLASTS
FOSSILS
PLANT
INVERT.
PENE-CONTEMPORANEOUS AUTHIGENIC
GLAUCONITE
CLAY MINERALS
CARBONATE
SILICA
SULFATE
SULFIDES
THIN SECTION

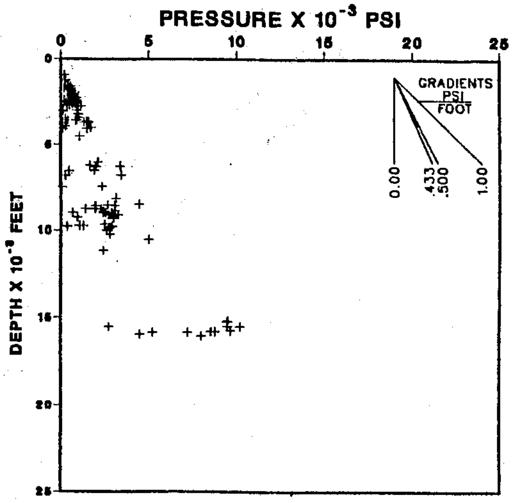
APPENDIX B

PRESSURE DATA PROFILES

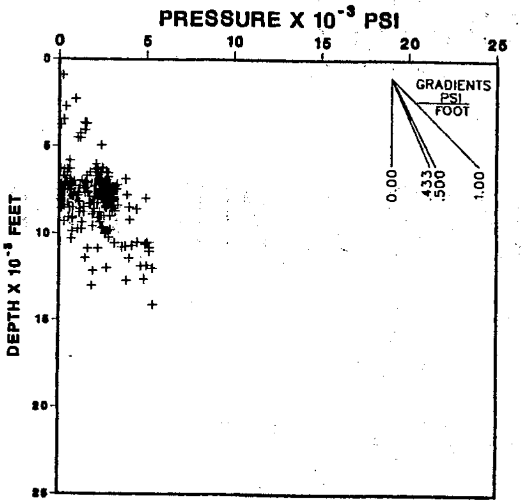
MILL CREEK, T 2N R2W



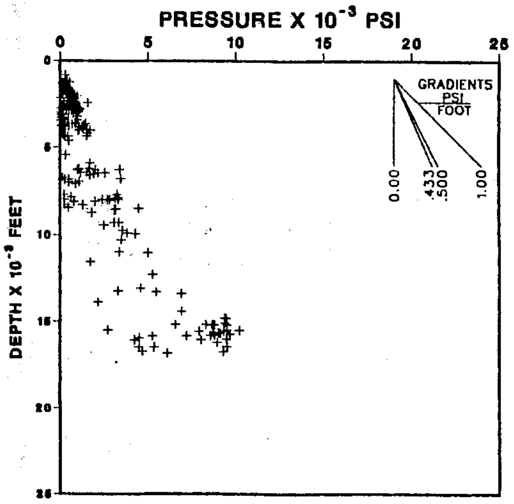
MILL CREEK, T2N R4W



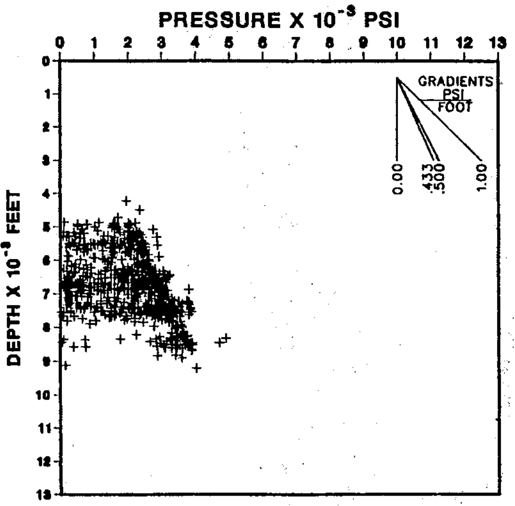
MILL CREEK T2N R3W



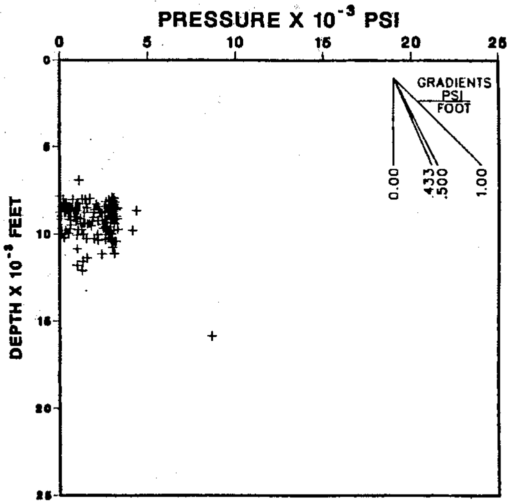
MILL CREEK T2N R5W



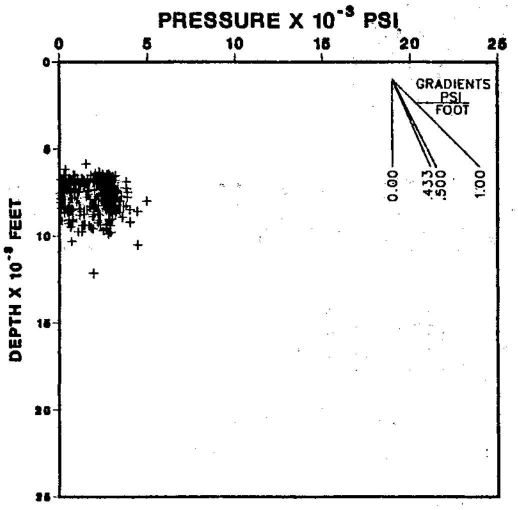
MILL CREEK T3N R2W



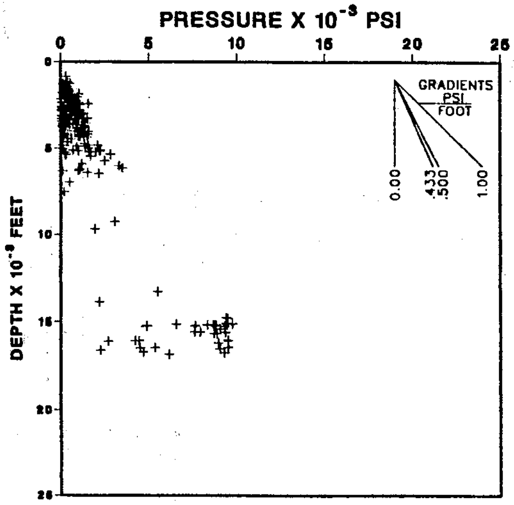
MILL CREEK T3N R4W



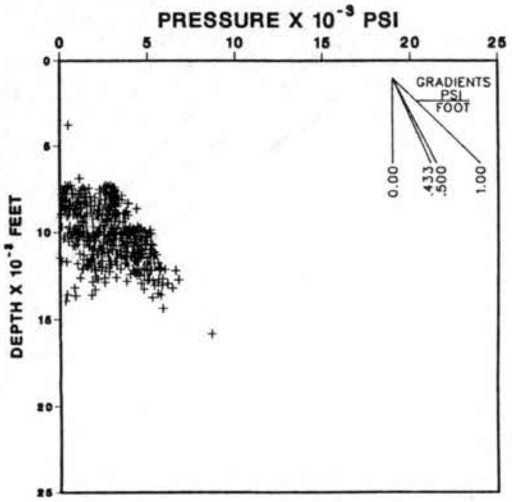
MILL CREEK T3N R3W



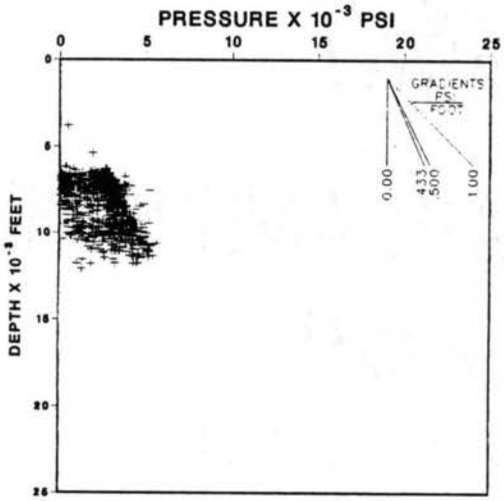
MILL CREEK T3N R5W



MILL CREEK T4N R4W



MILL CREEK, T 4N R3W



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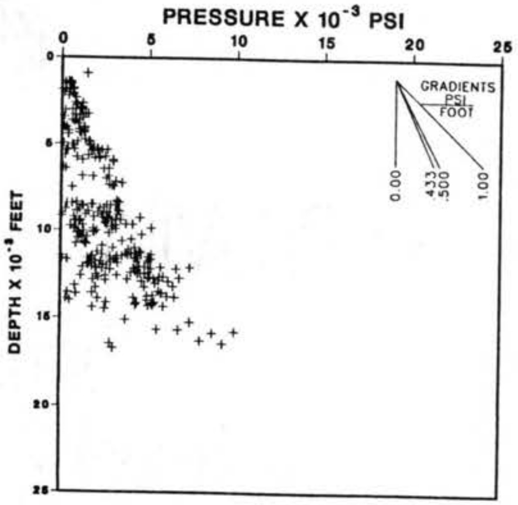
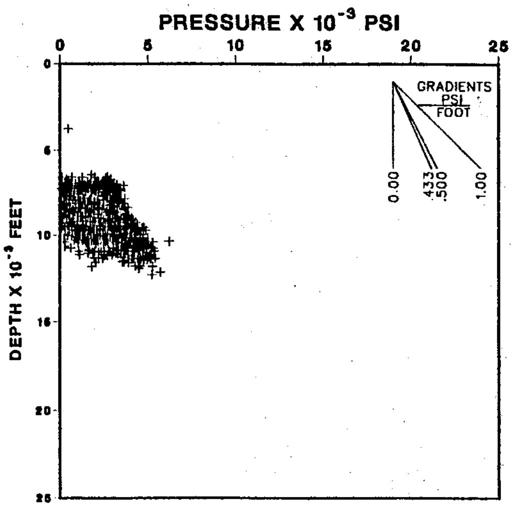
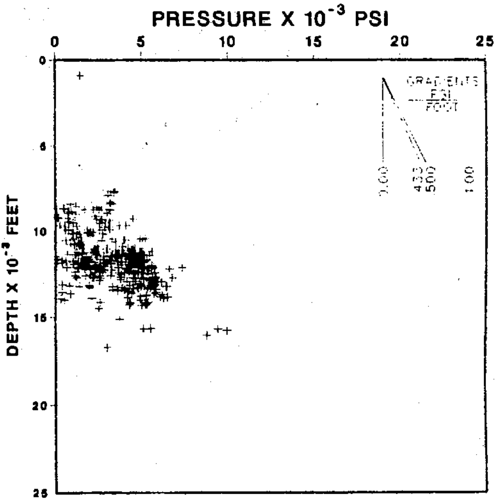
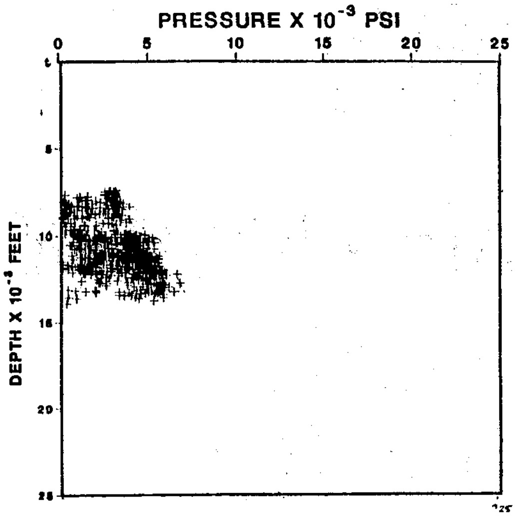
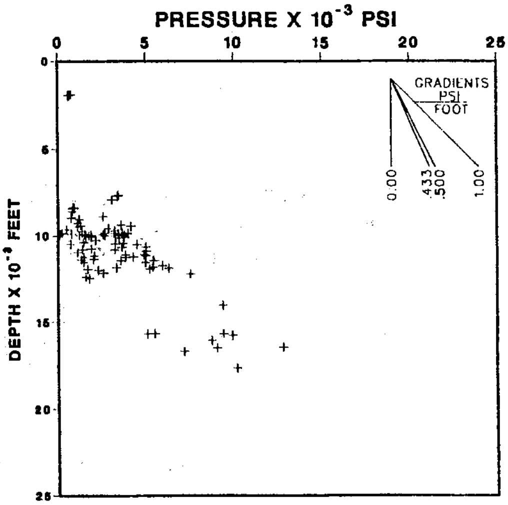


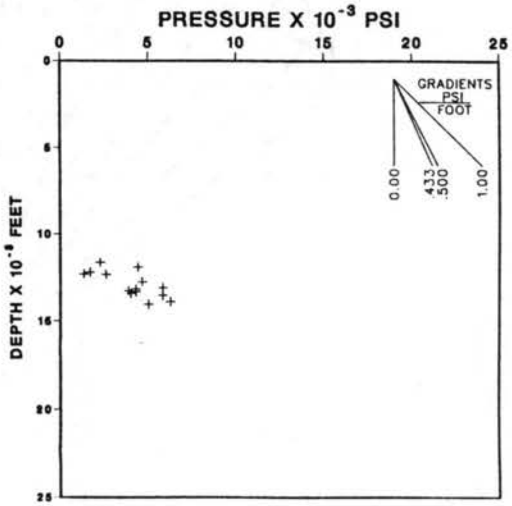

MILL CREEK T5N R3W


MILL CREEK, T 5N R5W

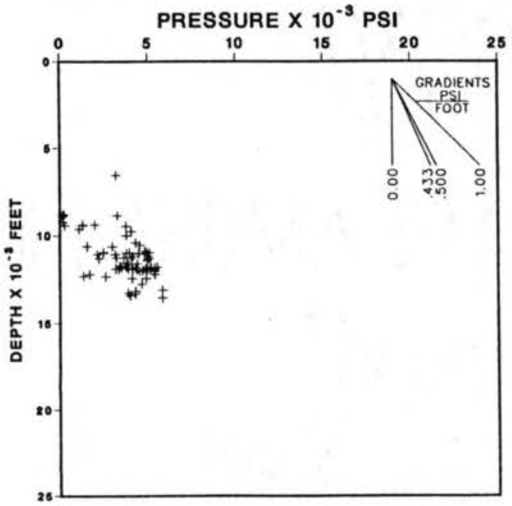

MILL CREEK T5N R4W


MILL CREEK T5N R6W

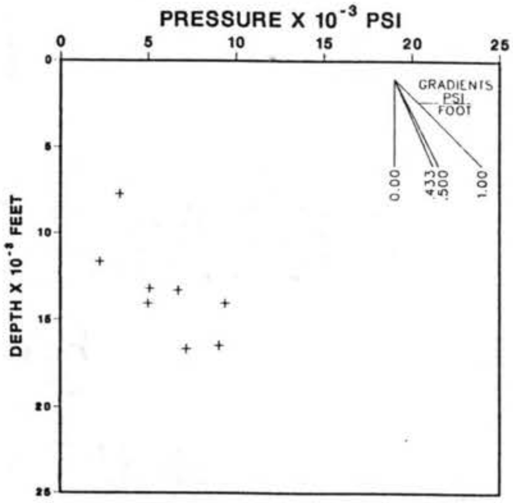
MILL CREEK, T6N R5W



MILL CREEK T6N R4W



MILL CREEK T6N R6W



VITA

Vanessa A. Tigert

Candidate for the Degree of

Master of Science

Thesis: IDENTIFICATION AND CHARACTERIZATION OF A PRESSURE SEAL IN SOUTH-CENTRAL OKLAHOMA

Major Field: Geology

Biographical:

Personal Data: Born in Duncan, Oklahoma, August 9, 1959, the daughter of Charles and Virginia Tigert.

Education: Graduated from Farmington High School, Farmington, New Mexico, in May, 1977; received a Bachelor of Science Degree in Communications from University of Tulsa, Oklahoma in May, 1981; received a Bachelor of Science Degree in Geology from University of Tulsa, Oklahoma in August, 1986; completed requirements for the Master of Science degree at Oklahoma State University in December, 1989.

Professional Experience: Research and Teaching Assistant, School of Geology, Oklahoma State University, January, 1988 to December, 1989. Petroleum Geologist, Indian Wells Oil Company, Tulsa, Oklahoma, September 1984 to November, 1987. Associate Editor, PennWell Publishing Company, Tulsa, Oklahoma, June, 1981 to August, 1984. Staff News Writer, American Association of Petroleum Geologists, Tulsa, Oklahoma, September, 1980 to May, 1981.

PLATE I.
PRESSURE-DEPTH PROFILE CROSS SECTIONS

T5N R4W
PRESSURE PROFILE CROSS SECTION

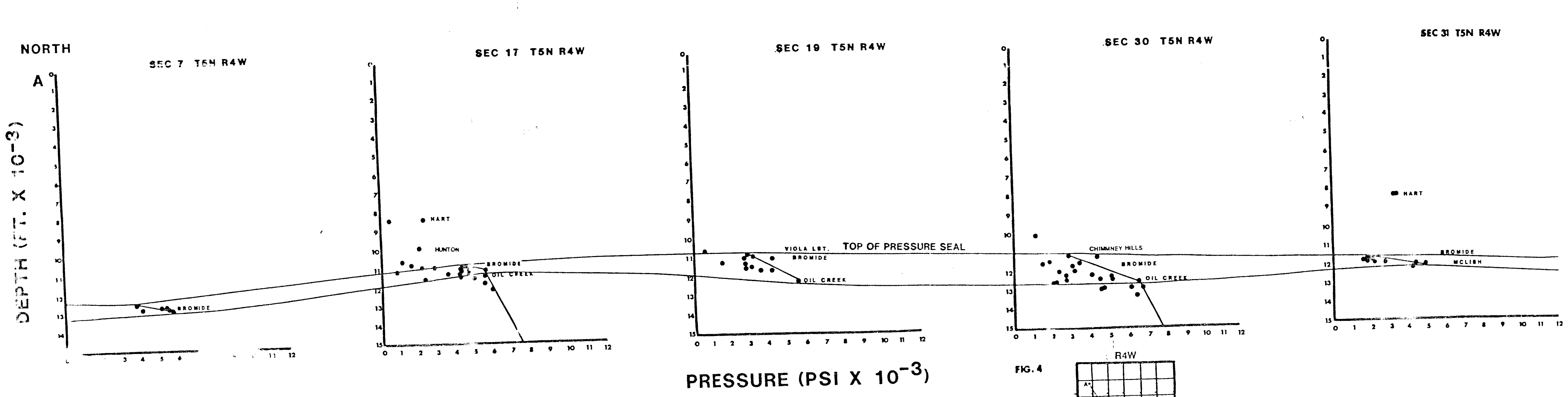
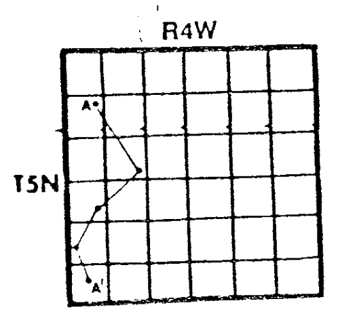
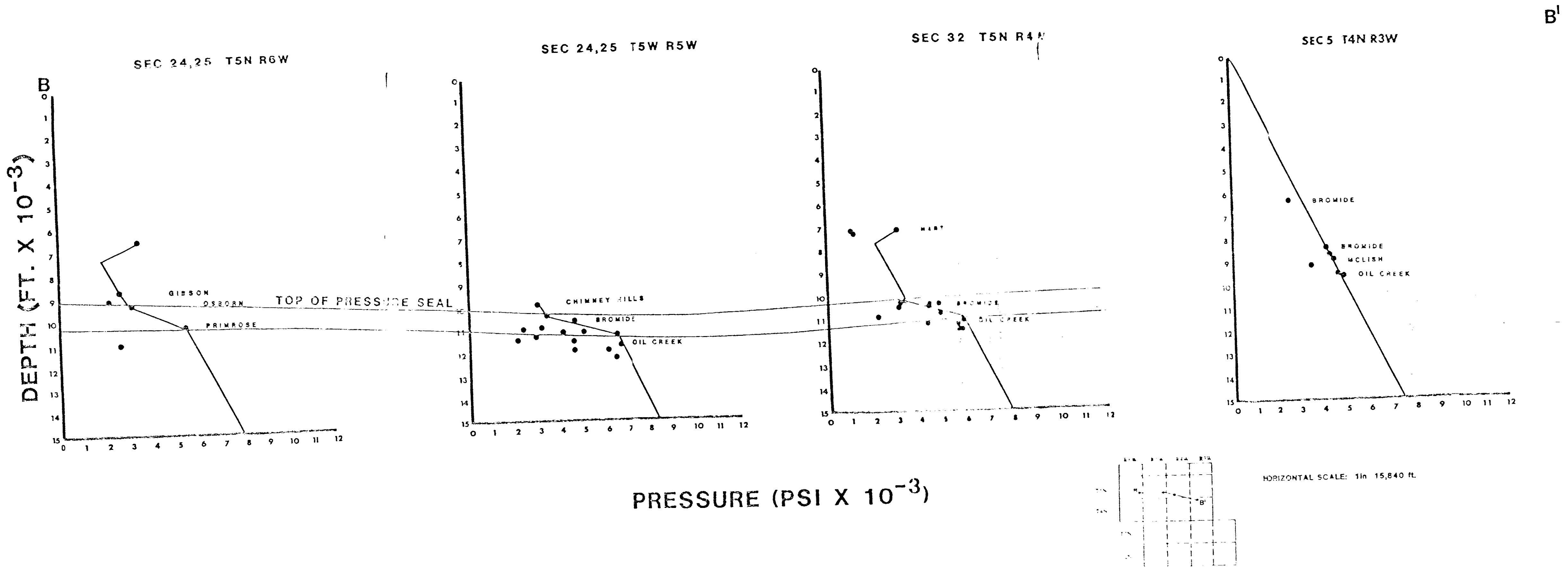


FIG. 4

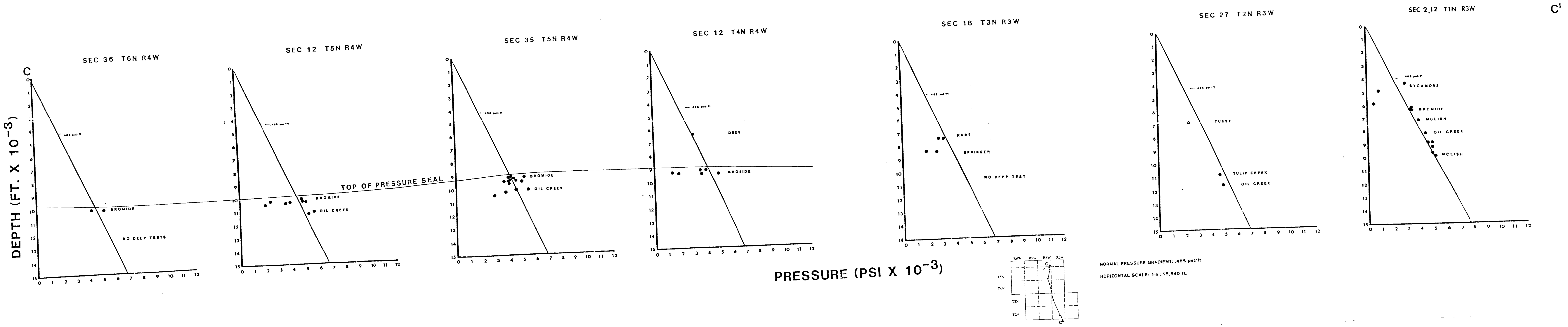


WEST EAST REGIONAL
PRESSURE PROFILE CROSS SECTION



HORIZONTAL SCALE: 1in 15,840 ft.

NORTH SOUTH REGIONAL
PRESSURE PROFILE CROSS SECTION



NORMAL PRESSURE GRADIENT: .465 psi/ft

HORIZONTAL SCALE: 1in=15,840 ft.

PLATE II. STRUCTURAL CROSS SECTION PRESSURE-PROFILE CROSS SECTION

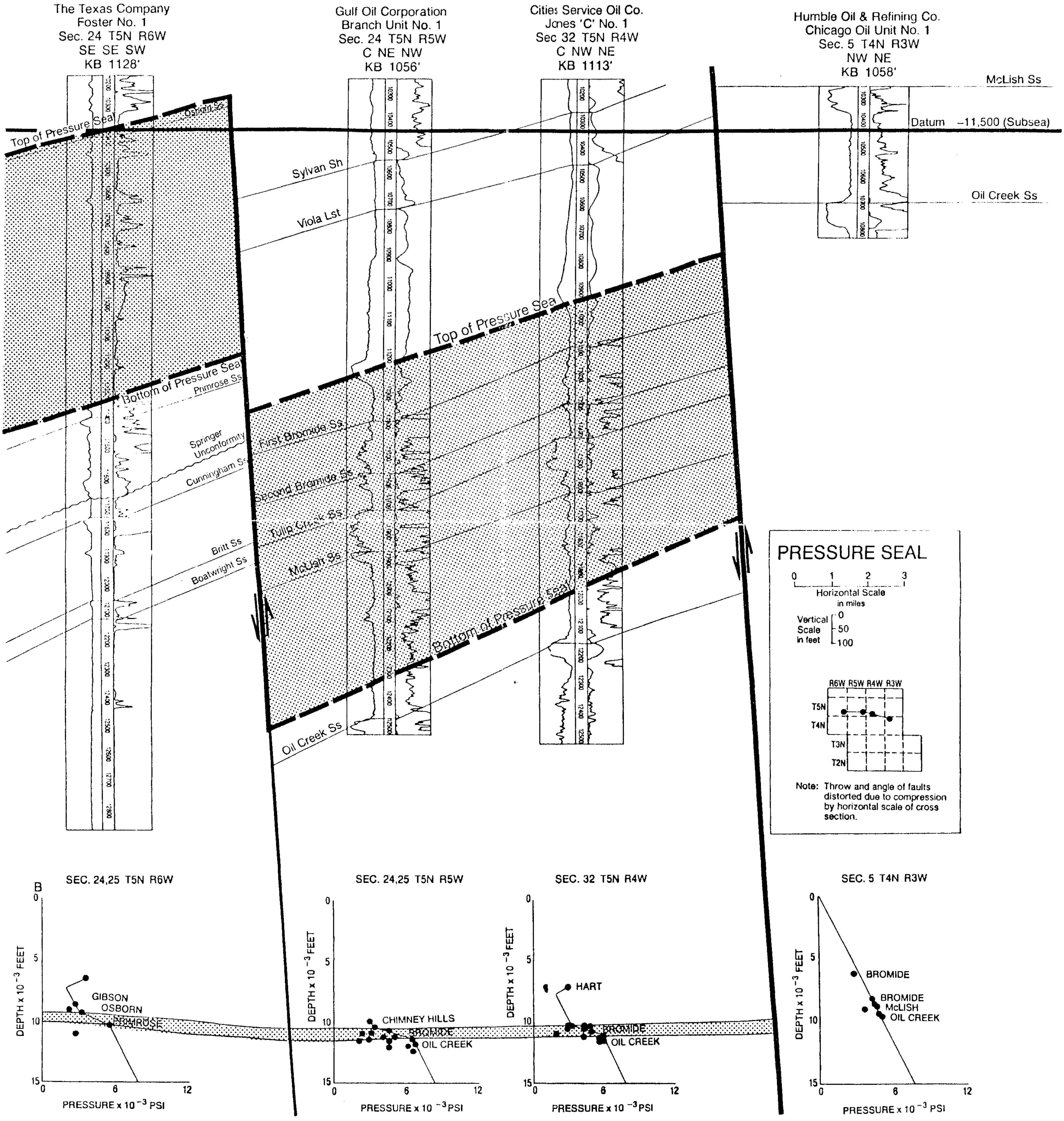


PLATE III. FIRST BROMIDE SANDSTONE

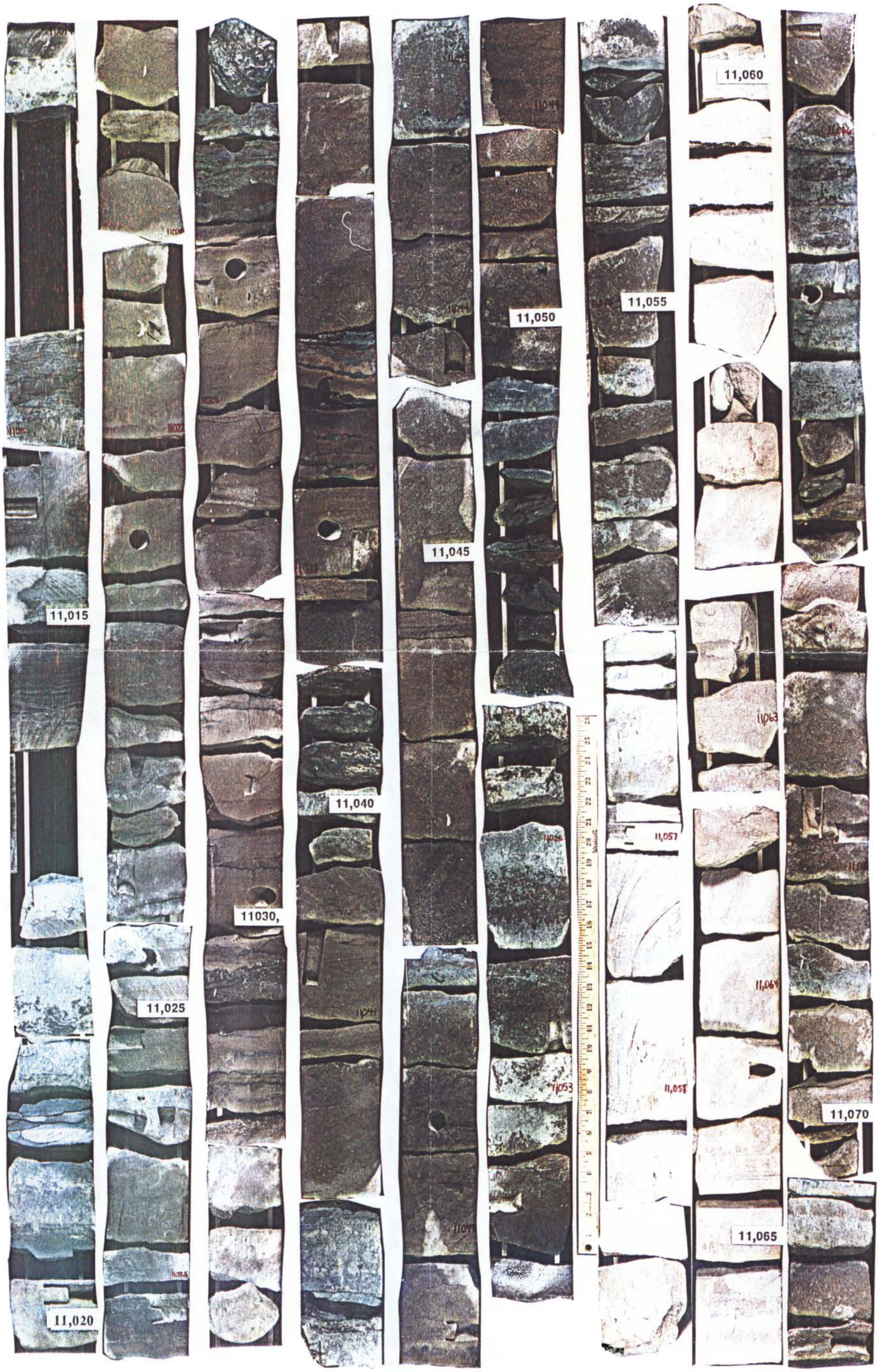


PLATE IV. FIRST BROMIDE SANDSTONE

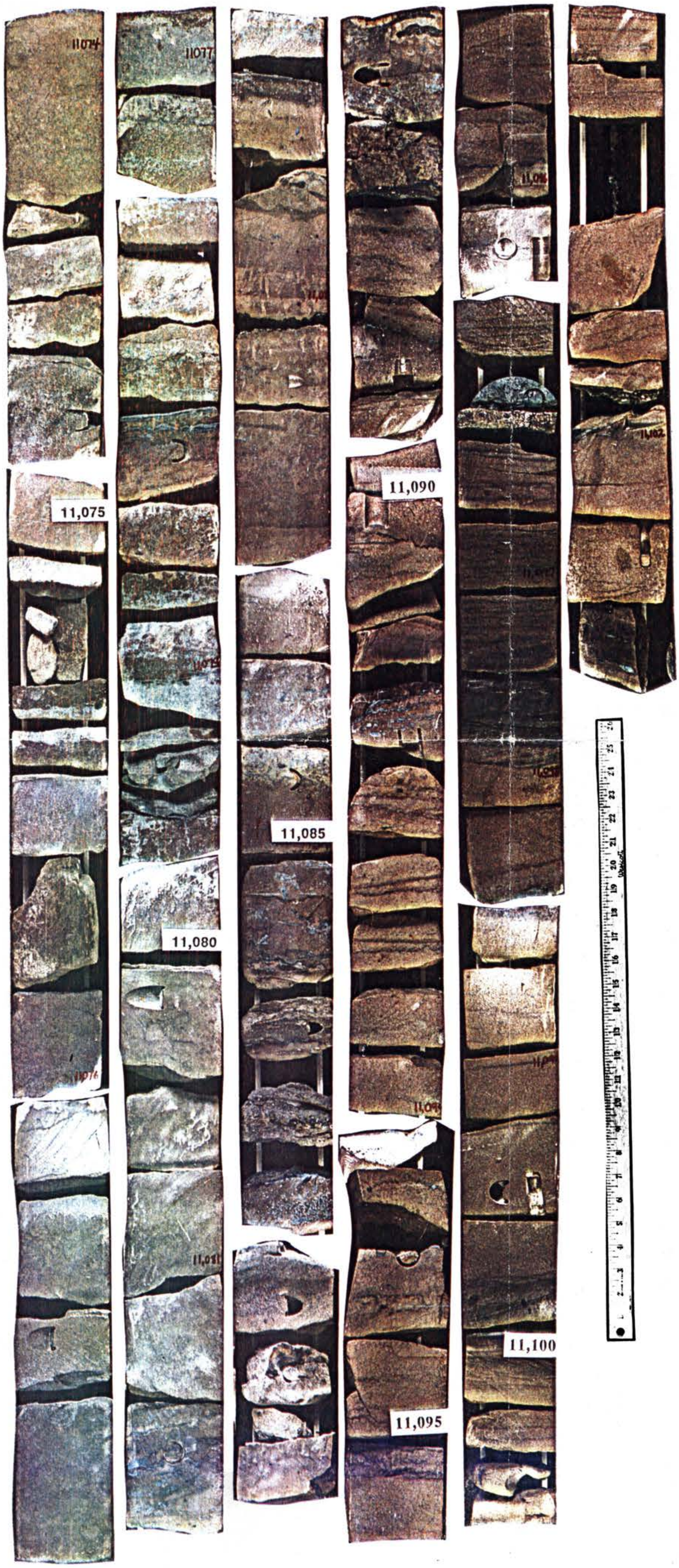


PLATE V. SECOND BROMIDE SANDSTONE

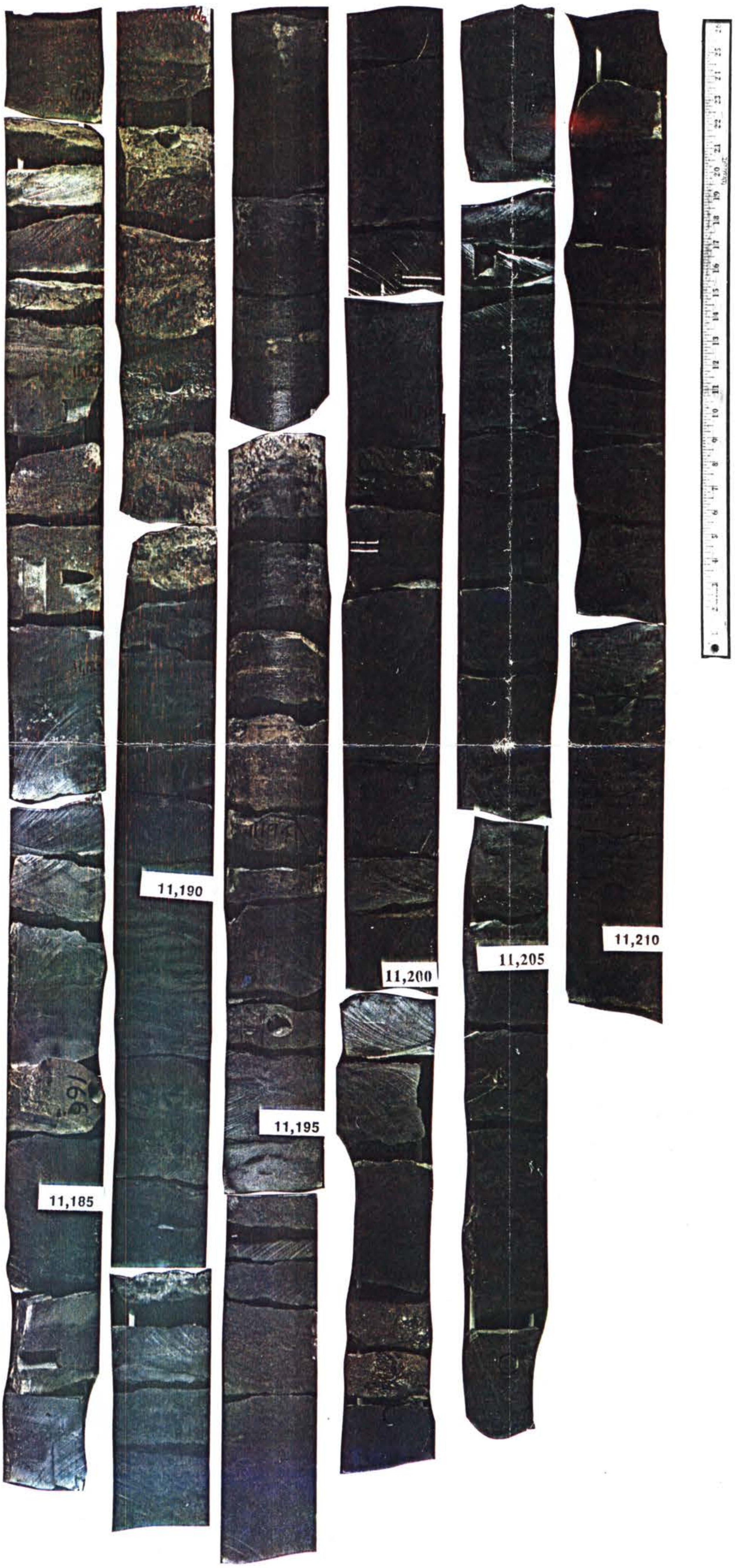


PLATE VI. SECOND BROMIDE SANDSTONE

PLATE VII. TULIP CREEK FORMATION

PLATE VIII. TULIP CREEK FORMATION

PLATE IX. TULIP CREEK FORMATION

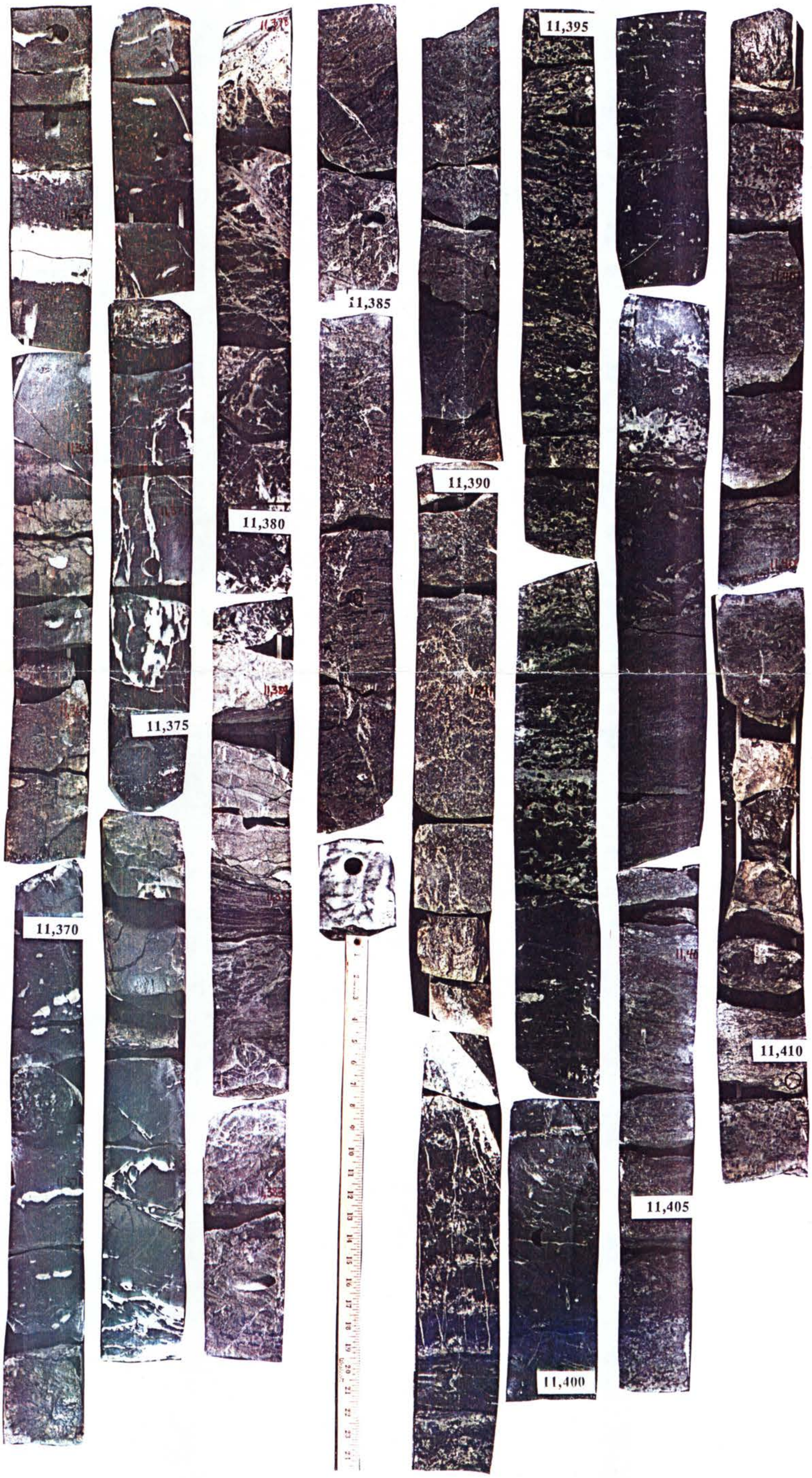


PLATE X. TULIP CREEK FORMATION

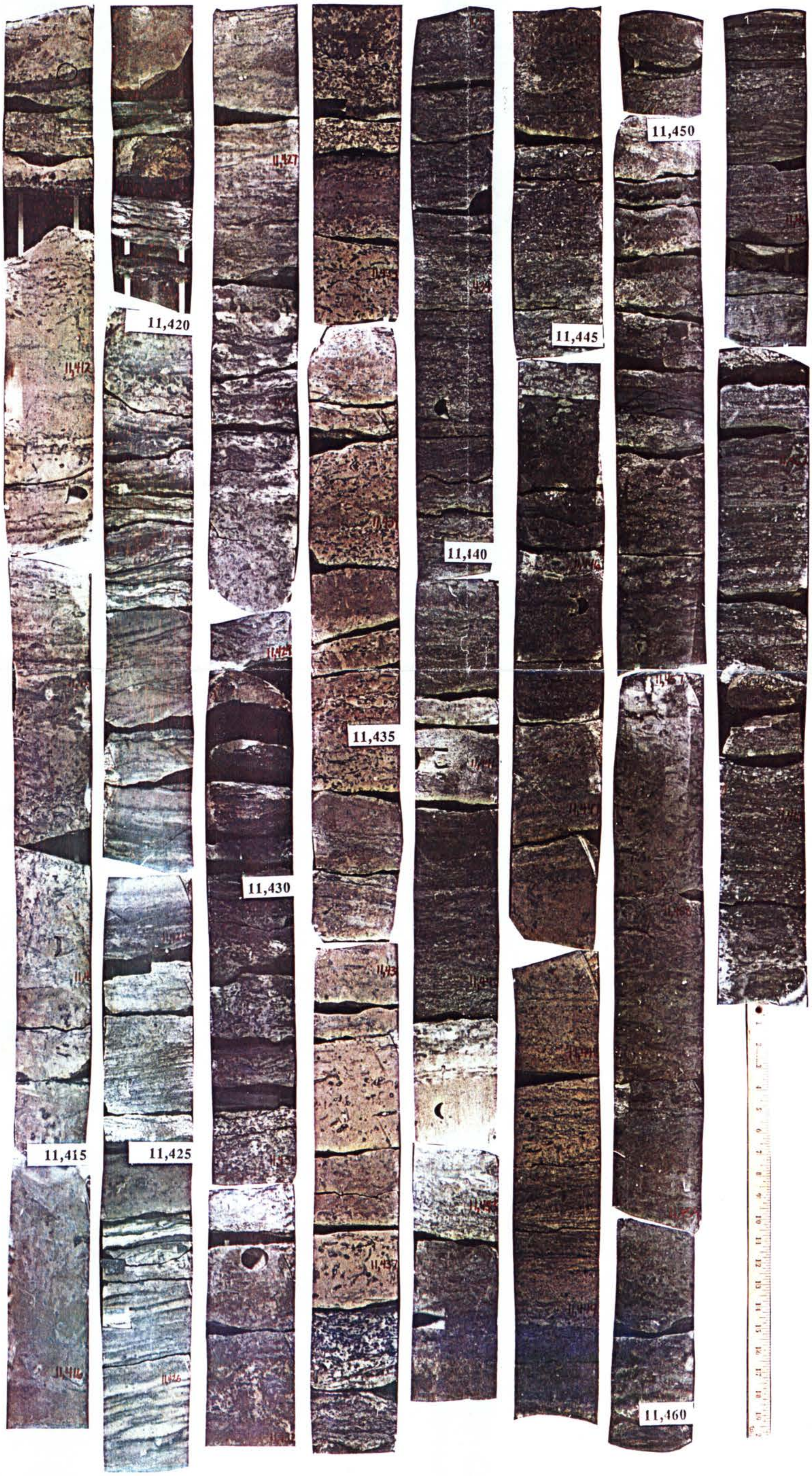


PLATE XII. MCLISH FORMATION

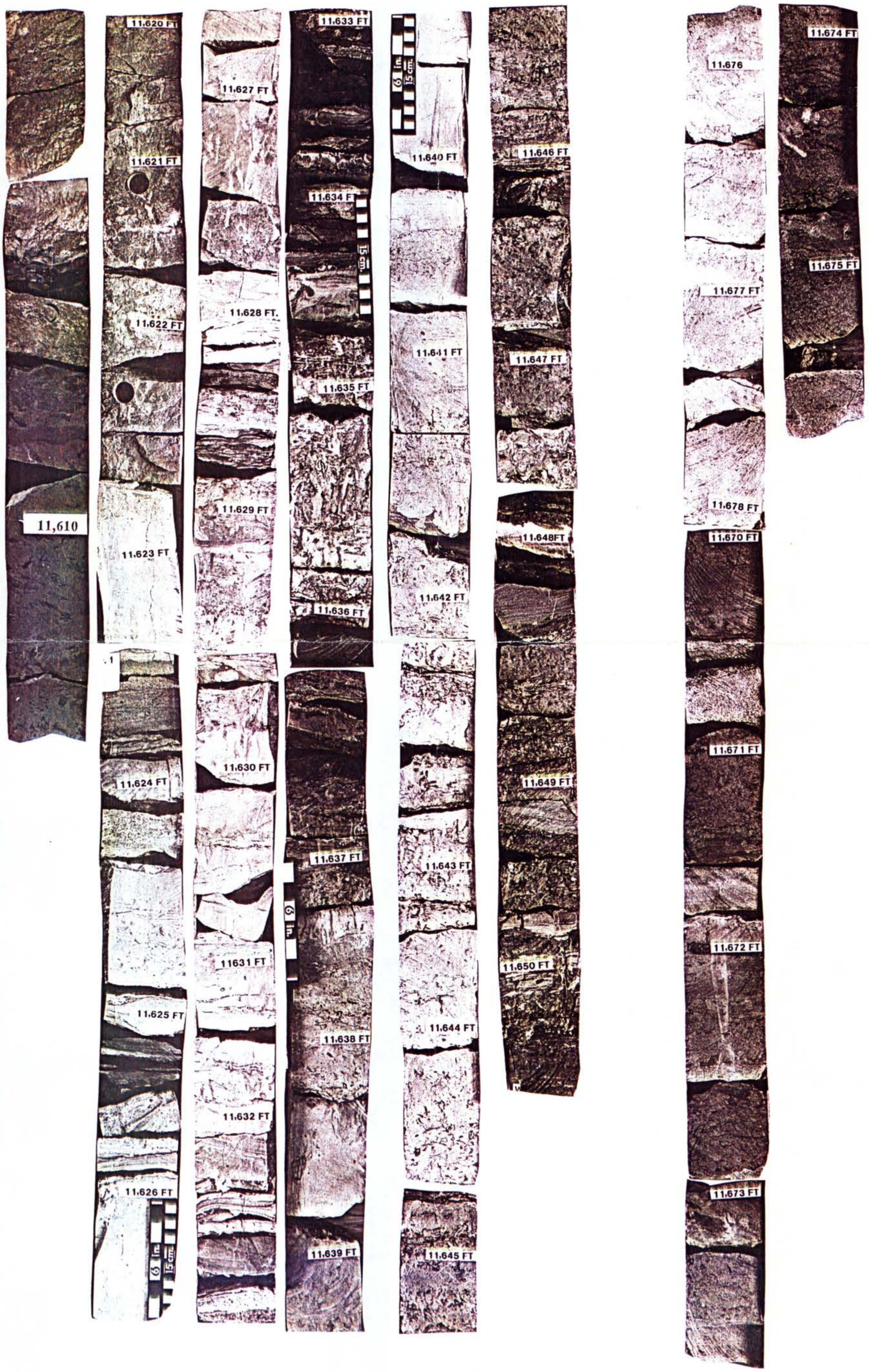
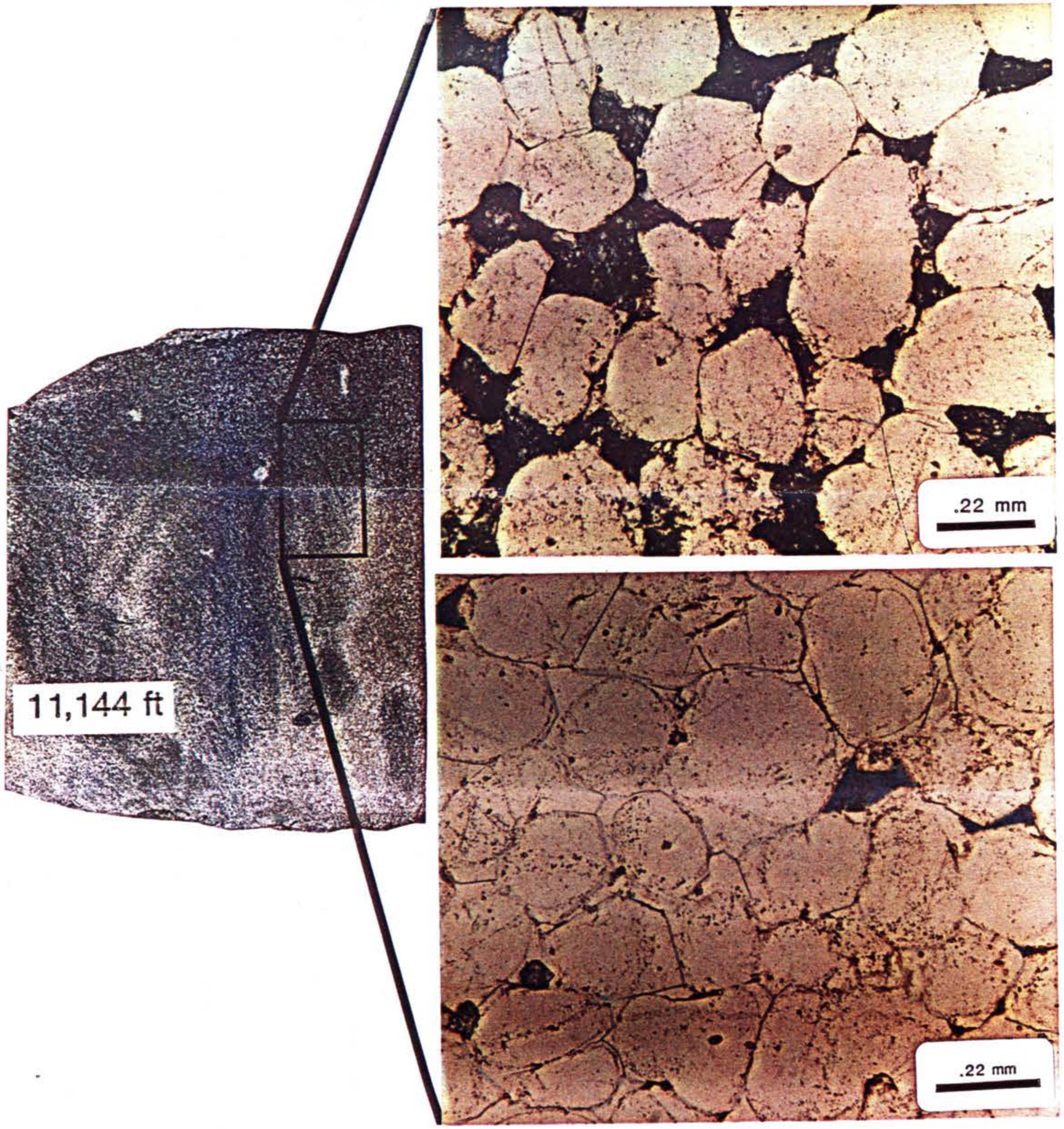


PLATE XIII. DIAGENETIC BANDING PATTERNS

OIL-STAINED SANDSTONES ALTERNATE
WITH OIL-FREE SANDSTONES



SILICA-CEMENTED SANDSTONES ALTERNATE
WITH CLAY-COATED SANDSTONES

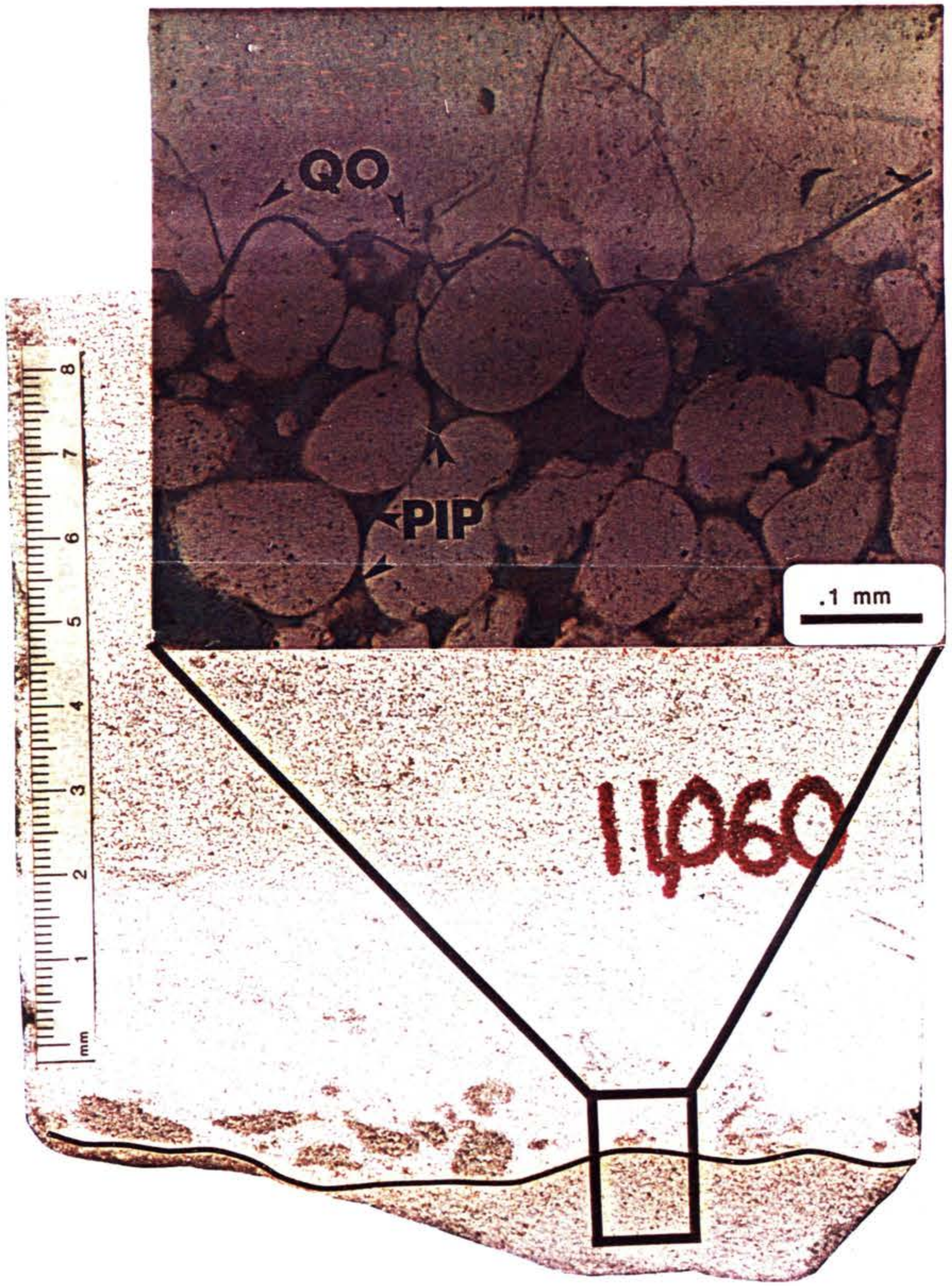
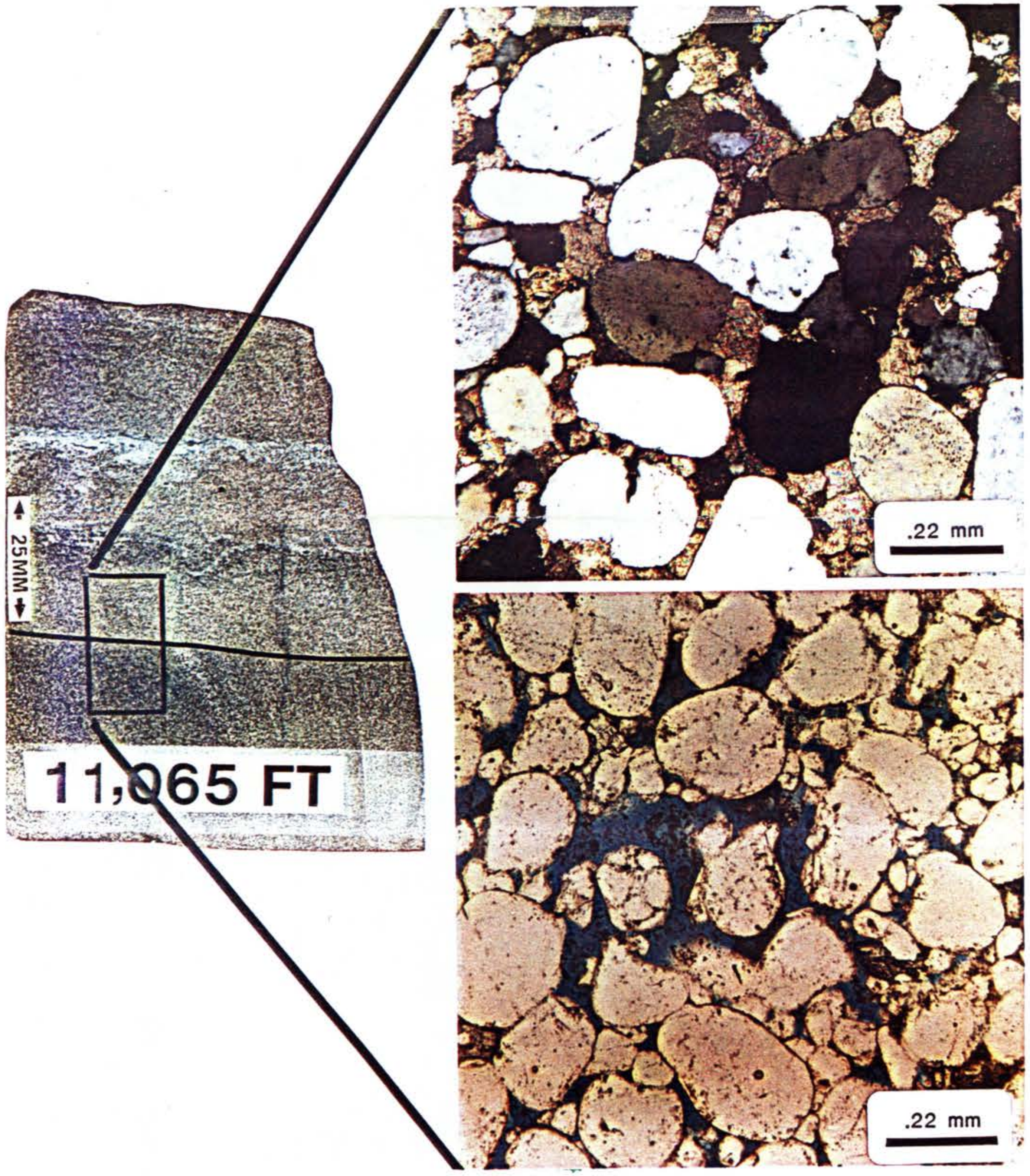


PLATE XIV. DIAGENETIC BANDING PATTERNS

CARBONATE-CEMENTED SANDSTONES ALTERNATE WITH POROUS SANDSTONES



SILICA-CEMENTED SANDSTONES ALTERNATE WITH CARBONATE-CEMENTED SANDSTONES