THE DEPOSITIONAL ENVIRONMENT OF THE MORRISON FORMATION IN THE WEST POISON SPIDER FIELD AND SURROUNDING AREAS, SOUTHEAST WIND RIVER BASIN, WYOMING

BY

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PREFACE

The purpose of this research was to study evidence available about sandstone in the lower Morrison Formation, and to make a stable interpretation of its depositional environment. The interpretation was based upon evidence from petrographic analysis, core analysis, outcrop analysis, and analysis of general subsurface geology.

The Morrison Formation of Wyoming has long been believed to have been deposited under fluvial and lacustrine conditions, but some workers have found implications of marine deposition. However, sandstone of the Lower Morrison studied in this report was interpreted as eolian. This conclusion was based on (1) well sorted and very fined grained grayish white sand in cores and outcrops (2) large-scale, high-angle dip of cross-bedding, (3) consistent stratigraphic position of the sandstone (4) absence of fluvial characteristics (5) bounding surfaces in the core that are suggestive of interdune deposits, (6) abundance of bioturbation, and (7) general composition, textures, and sedimentary structures.

The sandstone is as thick as 186 feet. It was deposited on a low-lying surface that was formed after withdrawal of the last Sundance Sea. Winds across this surface deposited sand as dunes in and around the study area. Weathered sedimentary rocks as well as flashy discharges from distant positive areas were also probable sources.

The climate during sedimentation is believed to have been semi-arid to arid. An apparent change of climate led to stabilization of dunes; fluvial and lacustrine deposits overlie the dunes.

In outcrop two distinct sand facies make up the Morrison Formation; lower is interpreted as eolian and the upper as fluvial.

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CHAPTER I

INTRODUCTION

The study area is located in the southeastern section of the Wind River Basin in Natrona County, Wyoming (Figures 1 and 2). The area consists of approximately ten townships (T33-36n, R83-85W) which are located about 30 miles west of Casper. Within the area are three oil and gas fields that produce from the Morrison Formation: West Poison Spider, Pasture Canyon, and Powder River (Figure 2). The West Poison Spider field is emphasized because the cores analyzed in this investigation are from this field.

The study was concentrated upon interpreting the depositional environments, a diagenetic history, and areal distribution of sandstone bodies in the Morrison Formation.

Topics addressed in the course of research were regional tectonic history, geologic setting, stratigraphy, depositional environment, petrography, diagenesis, paragenesis, subsurface geology, and reservoir quality. The methods of investigation in this study involved core analysis, interpretation of wireline logs, thin-section analysis, construction and interpretation of maps and cross-sections, analysis of outcrops, and study of clay mineralogy.

This problem was proposed by Barry Gouger and Joe Schwab, of the Union Oil Company. Special thanks are given to them.

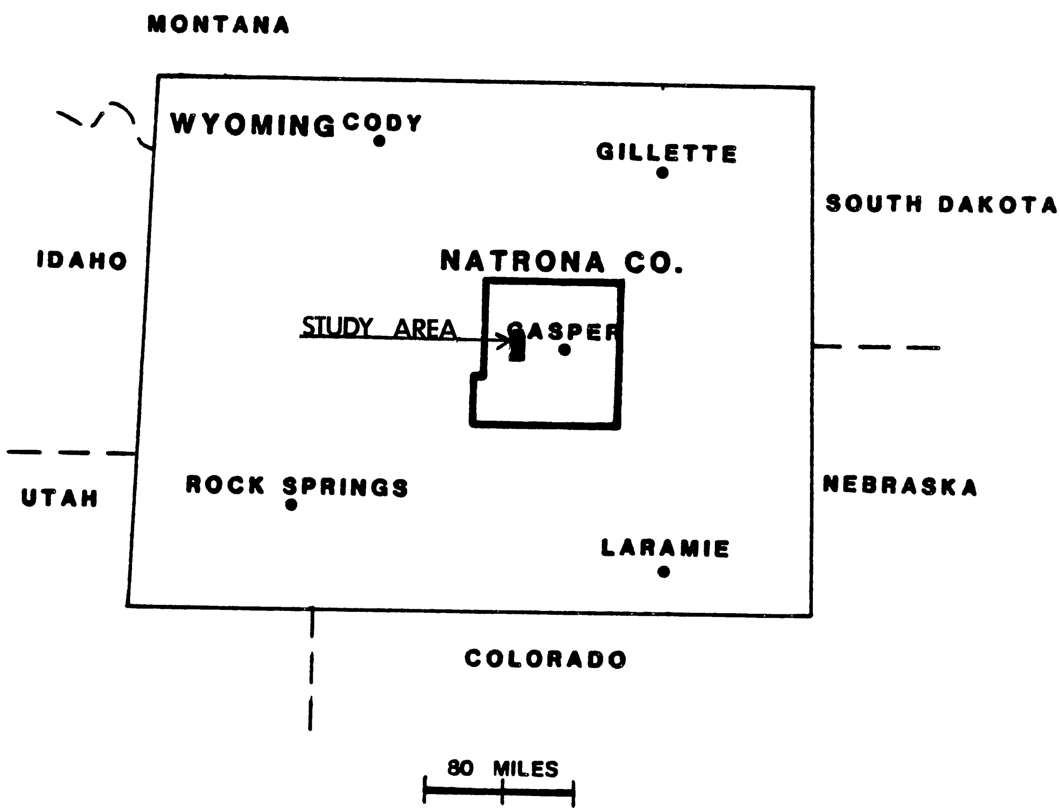


Figure 1. Location of Natrona Co.

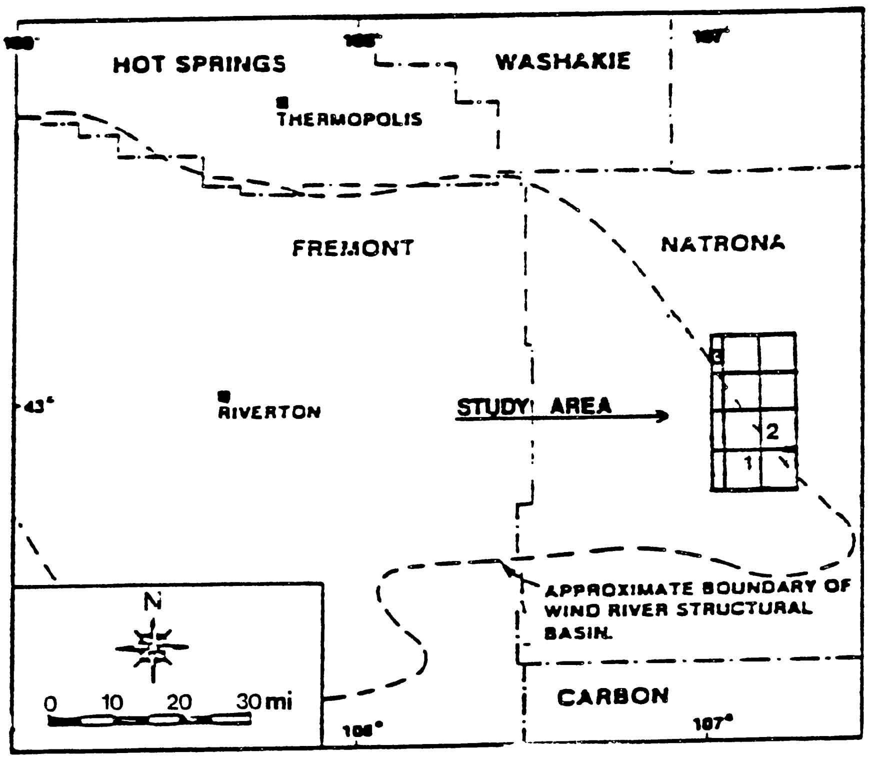


Figure 2. Location of study area showing the general locations of oil fields that produce from sandstones of the Morrison formation.
1. West Poison Spider field
2. Pasture Canyon field
3. Powder River field
(After Casey 1982.)

Gratitude is expressed to the Union Oil Company for financial support of this study. Special recognition should also be given to Dr. Zuhair Al-Shiaeb, the major research advisor. Dr. Gary Stewart and Bryan Lee also deserve recognition for serving on my thesis committee and for their encouragement.

CHAPTER II

PREVIOUS WORK

Numerous documents have been written on the Upper Jurassic Morrison Formation in the western interior of the United States. Pure Oil Co. (by Chisholm, 1963) published three papers describing the stratigraphy, petrology, and sedimentation of Upper Jurassic and Lower Cretaceous strata of the western interior. However, little information has been published strictly on the Morrison sandstones of the Wind River Basin in the region that includes the West Poison Spider field. Papers of importance to the problem addressed here are: Clark (1978) and Keefer (1969).

Henderson (1981) and Casey (1982) of the Union Oil exploration and production research department analyzed cores of the Morrison Formation from two wells in West Poison Spider field. Two reports described depositional environments, petrography, and reservoir qualities of the Morrison. Although unpublished, results of this work were made available to me.

CHAPTER III

PHYSIOGRAPHY

The landscape within the study area is mostly "flat-lying". General elevation is near 6000 feet above sea level. Rocks at the surface are of Tertiary age. The landscape is made up of small hills and gullies. Figure 3 illustrates the landscape of the West Poison Spider area and is exemplary of the overall appearance of the study area.

Vegetation chiefly is grass and sagebrush (Figure 3). These plants are adapted to the less-than-10 inches of precipitation per year and the temperature range of -30 degrees Farenheit to 100 degress Farenheit.

Figure 3. Landscape within the study area. Photograph taken from Pine Mountain, looking southwestward.

CHAPTER IV

HISTORY OF THE WEST POISON SPIDER FIELD

The West Poison Spider Field was discovered in 1947 by the Pure Oil Company. The discovery well produced from the Cretaceous Frontier Formation at 14,187 feet to 14,309 feet; at the time of discovery this was the deepest producing oil well in Wyoming. More wells were drilled following this initial discovery which produced from other pay zones. Clark (1978) explains that in 1951, Unit Well No. 3 was re-entered and drilled to 16,608 feet. It then was plugged back to 16,094 feet and produced from the Morrison Formation. In 1978, this was at the world's deepest producing oil well.

The deep-seated anticlinal structure at West Poison Spider field has proven to be very profitable, chiefly because of the five pay zones. Table 1 shows a summary of data concerning reservoirs of the West Poison Spider field, as of 1978.

The anticlinal at West Poison Spider field was formed during the Laramide disturbance. Situated along the eastern edge of the basin, the fold trends northwesterly.

TABLE I

RESERVOIR DATA

Name	Teapot	Parkman	Phayles	Frontier	Morrison
Depth of discovery well, ft.	9228	9742	10,155	14,192	15,678
Age	CRE	CRE	CRE	CRE	JUR
Date of discovery (well No.)	1948 (#2)	1961 (#6)	1955 (#2)	1948 (#1)	1952 (#3)
Lithology	SS	SS	SS	SS	SS
Porosity, % (Avg.)	12.0	13.7	11.9	7.3	8.9
Permeability, md. (Avg.)	17.7	0.5	1.4	0.3	1.0
Average Pay, ft.	45	15	25	40	45
Oil-water Contact	-3650	NA	-4900	NA	NA
Oil column, ft.	450	NA	800	NA	NA
GOR	870	1000 (Est.)	1050	1800	2500?
Initial Press., psi	4010	4200?	4470	6200	7150
Drive Mechanism	Sol. Gas	Sol. Gas	Sol. Gas	So. Gas	Sol. Gas
No. of wells that have produced	15	1	23	1	1
API Gravity of Oil	42.8°	43.5°	42.8°	42.8°	45.2°
Productive Area, acres	1800	80 (est.)	2100	320 (est.)	80 (est.)
Cumulative Production, bbl.	5,686,000	61,609	1,094,000	534,000	17,255
Status of Res.	Prod. (Sec.)	Prod. (Pri.)	Prod. (Sec.)	Prod. (Pri.)	P. & A. Aug. 1955

Summary of physical and historical reservoir data for producing horizons (From Clark, 1978).

CHAPTER V

TECTONIC AND GEOLOGIC HISTORY OF THE WIND RIVER BASIN

The Wind River Basin is located in central Wyoming; it trends northwesterly. Strata dip 10 to 20 degrees eastward and northward in western and southern portions of the basin. According to Keefer (1969) beds commonly are vertical to overturned along the northern and eastern margins. The main axis of this asymmetrical basin is near the northern and eastern margins, directly south and west of the Owl Creek Mountains and Casper Arch respectively (Figure 4).

Formation of the Wind River Basin began in late Cretaceous time and extended to the Eocene (Keefer, 1965). Major uplifts that form the boundaries of the basin developed during the Laramide orogeny during this time. Figure 5 (Keefer, 1965) shows configuration of the Wind River Basin at the close of Eocene time.

The Laramide orogeny created extensive faulting and folding. Strata along the margins of the basin were folded and faulted extensively during the Laramide disturbance. Such folds are the traps from which most of the oil and gas in the Wind River Basin are produced.

The western boundary of the basin is the Wind River Mountain Range (Figure 6). Along the eastern flank of these

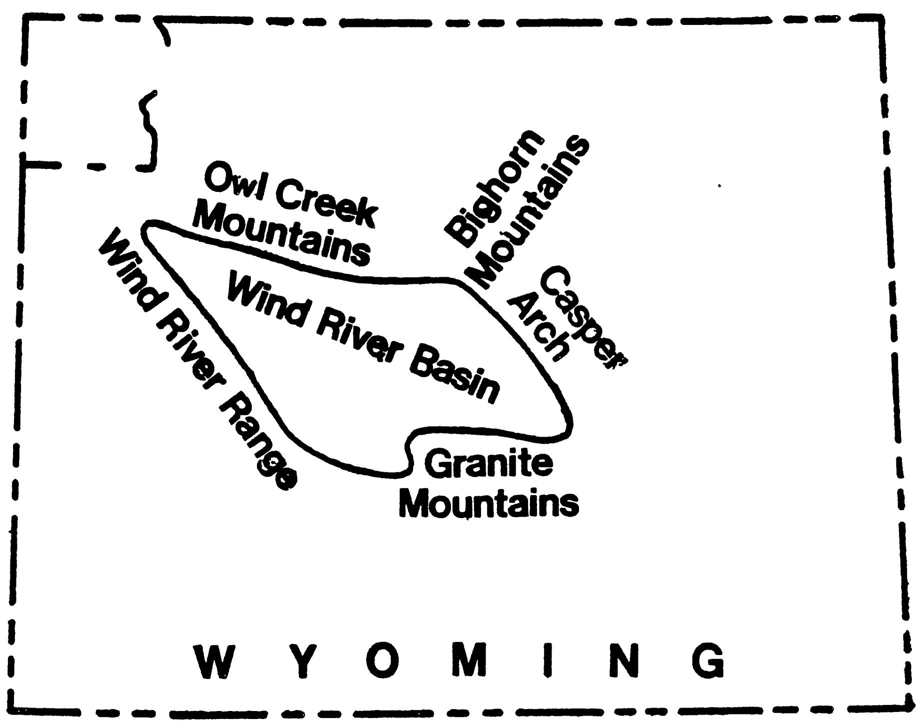


Figure 4. Position of the Wind River basin and it's bounding structures. (From Keefer, 1969)

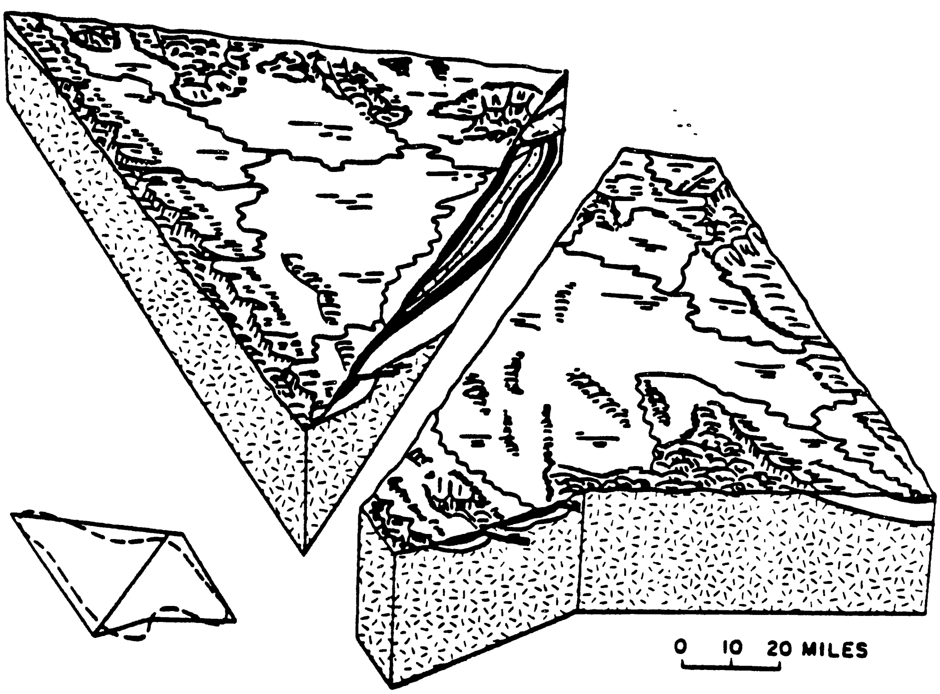


Figure 5. Cross-sectional view (SW-NE) of the Wind River basin. (From Keefer, 1965)

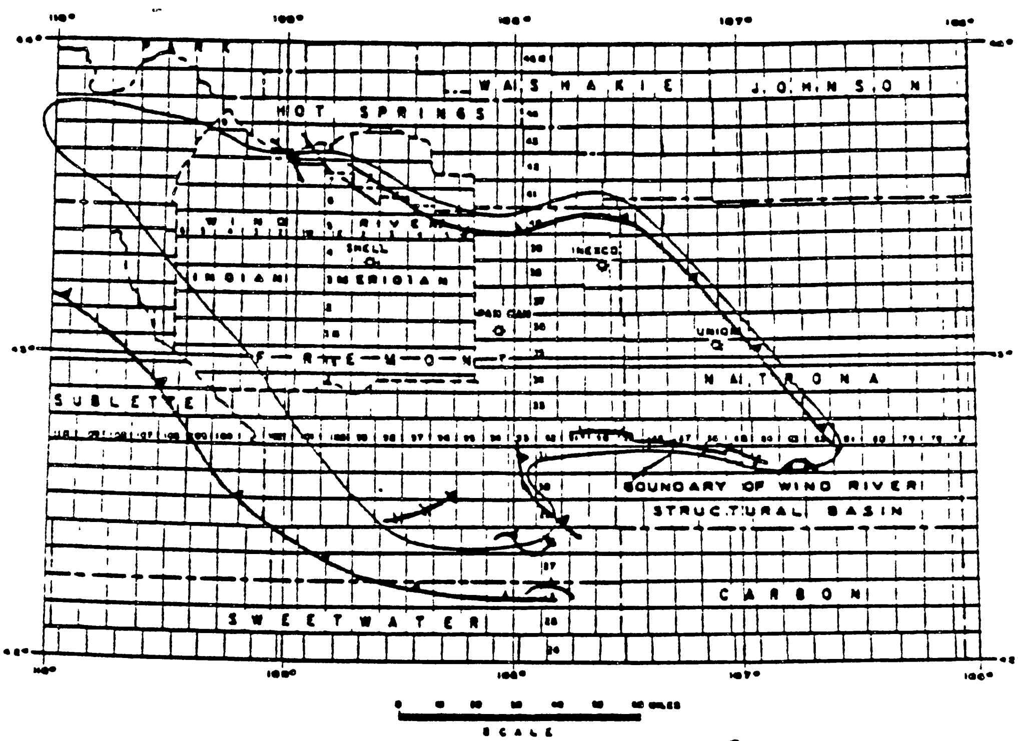


Figure 6. Positions of the prominent faults and folds within the Wind River gasin. (From Bilyeu 1978 and Hausel 1979)

▲ ▲ ▲ Thrust fault

Surface faults and folds of unknown subsurface extent

Normal or reverse faults

mountains numerous folds are associated with the uplift. Blackstone (1948) explained that low-angle easterly-dipping reverse faults are associated with these folds. Reverse faulting of this general type commonly is associated with other Laramide uplifts of central Wyoming.

The basin is bounded on the south by the Granite Mountains (Figure 4). This range is typified by low-angle reverse faults. The uplifts associated with the Granite mountains are the Sweetwater and Rattlesnake uplifts.

Northern and northwestern portions of the basin are bounded by the Owl Creek and Bighorn Mountains (Figure 4). The major tectonic feature of these bounding mountains is a thrust fault along the southern limit (Figure 6), referred to as the Casper arch thrust. According to Woodward (1957), vertical displacement of this fault is approximately 16,000 feet, with probable horizontal displacement of 6 miles. The fault is concealed under Tertiary sedimentary rock. This thrust fault extends along the northern and northeastern boundaries of the basin, and can also be traced along the eastern flank of the basin. Sedimentary rocks are thickest near the eastern margin of the basin; they may be as thick as approximately 30,000 feet.

The eastern flank of the basin is formed by the Casper Arch. The Casper arch thrust trends essentially parallel to the western margin of the arch. Several anticlines are along the leading edge of this thrust. Some of the oil fields that have been discovered in this area are the Powder River, Clark

Ranch, Pine Mountain, Pasture Canyon, South Casper Creek, and Poison Spider (Plates 5, 6, and 7). McCaslin (1983) concluded that the anticlines on which these fields exist are separate closures, superimposed on a major asymmetrical anticlinal fold that trends northwestward.

Keefer (1969) explained that at the close of Tertiary time the entire area was uplifted approximately 5000 feet, which movement was accompanied by normal faulting and collapse of major Laramide uplifts along zones of former reverse faults.

Precambrian metasedimentary rocks are in cores of the mountains that bound the basin. Keefer (1969) explained that the sediments probably were deposited during early Precambrian and were intruded by igneous rock. In Keefer's opinion (1969), prior to Cambrian time the Wind River Basin was a broad flat-lying plain produced by extensive erosion. During the Paleozoic and Mesozoic the basin was part of a stable shelf located east of the Cordilleran geosyncline. All of systems that compose the Paleozoic and Mesozoic are recorded by sedimentary rock except the Silurian. Woodward (1957) and Keefer (1969) agree that absence of Silurian rocks is due to extensive erosion. Most of sediment of other Paleozoic and Mesozoic systems was deposited during transgressions of epicontinental seas. Thus, marine carbonaceous sediments were the dominant lithotypes.

Keefer (1969) explained that in Late Cretaceous time seaways shifted eastward as a result of uplift in southeastern

Idaho and thick accumulations of alternating marine and non-marine material (Frontier, Cody, Mesa Verde, Lewis, and Meeteetse Formations) resulted (Table 2). Laramide structured events had ceased by the end of the early Eocene, but approximately 20,000 feet of sediment had accumulated in deep parts of the basin. During the Tertiary, 3000 feet of volcanic material were deposited in the basin. As mentioned above, the entire region was uplifted about 5000 feet and block faulted by the end of the Tertiary. During the present major cycle of erosion, Lower Eocene and older strata have been exposed in central portions of the basin.

CHAPTER VI

STRATIGRAPHY OF THE WIND RIVER BASIN

The stratigraphic section is nearly fairly complete throughout much of the Wind River basin. As mentioned previously, Cambrian through Cretaceous strata compose most of the stratigraphic section, which ranges generally from 10,000 to 20,000 feet thick. The systems tend to be thicker and nearly complete in the western parts of the basin (Keefer, 1965).

During Paleocene time, while the Laramide orogeny was occurring, the basin subsided and infill of clastic sediment accelerated. The Fort Union Formation--the record of this event--is as thick as 9000 feet in some parts of the basin.

The Laramide orogeny ceased in Early Eocene, by which time an estimated 8000 feet of additional sediment was deposited in the basin. Most of this increment is made up of the Indian Meadows Formation; the Wind River Formation is appreciably thinner, ranging from about 700 to about 1400 feet, in the northwestern portion of the basin (Woodward, 1957).

In Oligocene, Miocene, and Pliocene time chiefly volcanic material was deposited, accumulating to as much as 3000 feet. Quarternary deposits are made up of gravels in alluvial terraces and alluvium within stream valleys.

Relative thicknesses of the formations in the stratigraphic column of the Wind River Basin are shown in Table 2.

TABLE II

STRATIGRAPHIC UNITS AND PRINCIPAL PETROLEUM PRODUCING ROCKS IN WIND RIVER BASIN

Unit	Principal Reservoir Rock	No. Fields
Eocene		
Wind River and Indian Meadows Formations (0–9,000 ft; N)	Sandstone	4
Paleocene		
Fort Union Formation (0–8,000 ft; N) }		
Cretaceous (Upper) }	Sandstone	13
Lance Formation (0–6,000 ft; N) }		
Meeteetse Formation and Lewis Shale (200–1,335 ft; N)	—	—
Mesaverde Formation (700–2,000 ft; N)	Sandstone	2
Cody Shale (3,600–5,000 ft; M)	Sandstone	6
Frontier Formation (600–1,000 ft; M)	Sandstone	11
Cretaceous (Lower)		
Mowry Shale (250–700 ft; M)	Sandy shale	2
Thermopolis Shale (125–250 ft; M)	Sandstone	14
Cretaceous and Jurassic		
Cloverly and Morrison Formations (200–700 ft; N)	Sandstone	14
Jurassic		
Sundance Formation (200–550 ft; M)	Sandstone	5
Gypsum Spring Formation (0–250 ft; M)	—	—
Triassic(?) and Jurassic(?)		
Nugget Sandstone (0–500 ft; M)	Sandstone	2
Triassic		
Chugwater Group (1,000–1,300 ft, M)	Sandstone	6
Dinwoody Formation (50–200 ft; M)	—	—
Triassic and Permian		
Goose Egg and Park City Formations (200–400 ft; M)	Carbonate	20
Pennsylvanian		
Tensleep Sandstone (200–600 ft, M)	Sandstone	20
Pennsylvanian and Mississippian		
Amsden Formation (0–400 ft, M)	Sandstone	1
Mississippian		
Madison Limestone (300–700 ft; M)	Carbonate	2
Mississippian and Devonian		
Darby Formation (0–300 ft; M)	—	—
Ordovician		
Bighorn Dolomite (0–300 ft; M)	—	—
Cambrian		
Gallatin Limestone (0–365 ft; M)	—	—
Gros Ventre Formation (0–700 ft, M)	—	—
Flathead Sandstone (50–500 ft, M)	—	—

Table showing the stratigraphic units and principal petroleum producing rocks in the Wind River basin. M=chiefly marine, N=chiefly nonmarine. Notice that the diagram interprets the Morrison as being partially Cretaceous in age. This discrepancy will be discussed in the following section. (Keefer, 1969)

CHAPTER VII

STRATIGRAPHY OF THE MORRISON FORMATION AND BOUNDING UNITS

The stratigraphy of the Morrison Formation and its bounding formations, the Sundance below the Cloverly above, has been a matter of some confusion. The lack of order mainly has been due to problems of nomenclature and correlation that exist in different parts of Wyoming.

The Sundance-Morrison boundary is less distinguishable than the Morrison-Cloverly boundary. The Sundance Formation is marine; it contains various glauconitic limestones, glauconitic limy sands, and carbonaceous shales. On the other hand, the Morrison is nonmarine and contains mainly noncalcareous muds and sands with no glauconite. Nevertheless, the contact between the Morrison and the Sundance is not distinct.

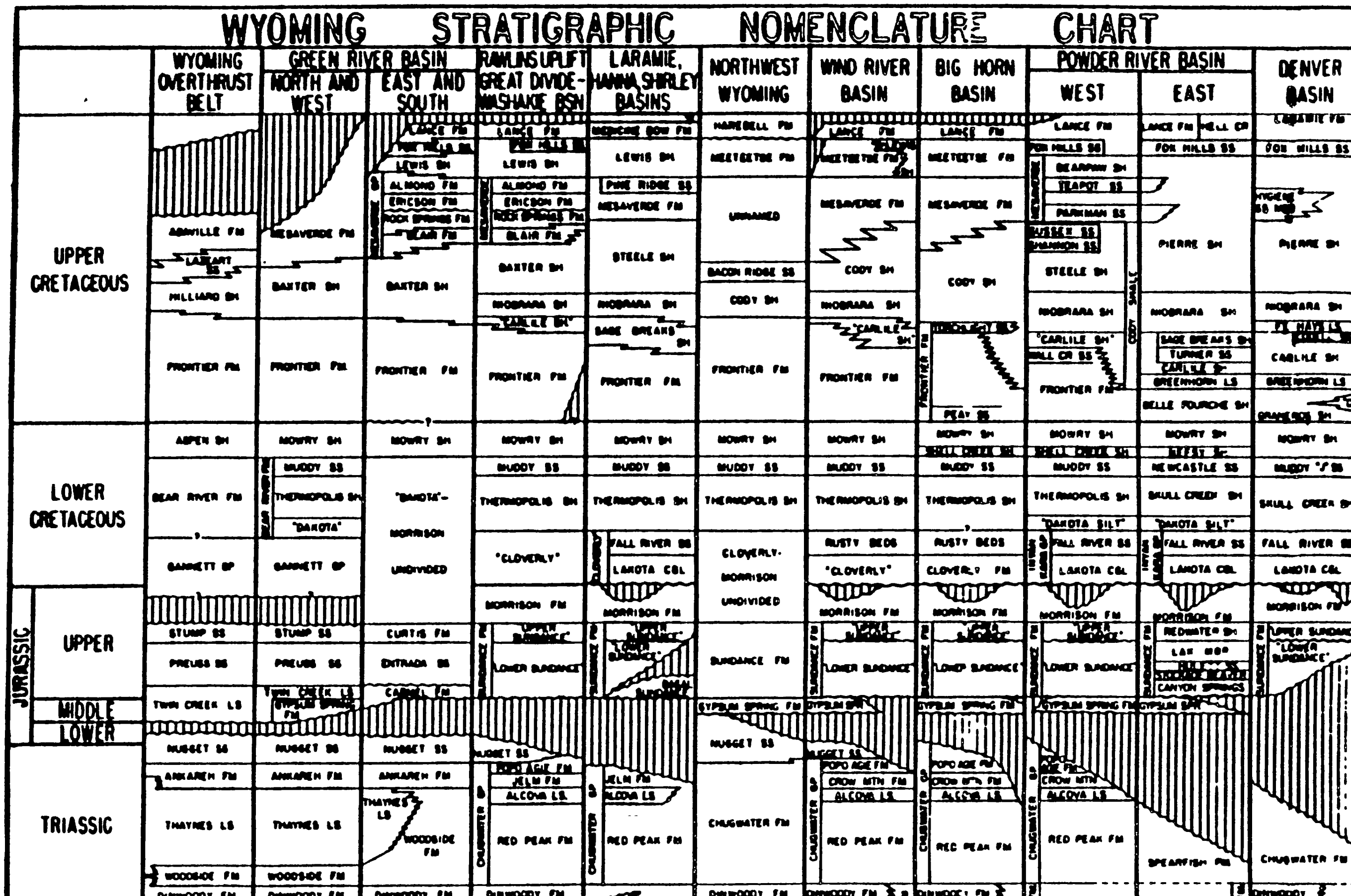
In study of outcrops and wireline logs limestone beds of the upper Sundance can be shown to be inconsistent in occurrence. In the field, the contact was defined as the top of the highest pelycepod-, ooid-, or belemnite-bearing rock unit in the Sundance. As numerous places this bed was a tan marine very fine grained sandstone, the Windy Hill Member. Mirsky (1962) described the Sundance-Morrison contact as being at the top of a fossiliferous sandy limestone or a glauconitic sandstone.

In some parts of Wyoming the formation overlying the Morrison is referred to as the Lakota Formation; elsewhere it is called the Cloverly Formation. Love (1948) considered the Cretaceous Cloverly to include all strata above the Jurassic Morrison and below the Cretaceous Thermopolis Shale. The upper part of Thermopolis interval is known as the "Rusty Beds" (Chisolm, 1962; Peck, 1948; Love, 1948). As can be seen in Table 3, stratigraphic interval in which the Cloverly is located includes other formations and groups, such as Fall River, Dakota, and Gannett. The Dakota, Fall River, and "Rusty Beds" formations generally refer to the uppermost sand in the Cloverly. The Lakota often is used to designate the lowermost sandstone body in the Cloverly. In many instances the Morrison and Cloverly Formations are considered as one formation because of the common indistinguishability in outcrop and in the subsurface. For the purpose of this study, I will consider the Morrison and Cloverly as two distinct units. In Figure 7 the nomenclature used in this investigation is set out.

The matter of correlating and pinpointing exact boundaries of these Jurassic and Cretaceous rocks present some problems. Young (1970) attributed this circumstance to various facies changes, absences of time indicators (i.e. widespread diagnostic fossils), lack of continuous outcrops, and similarity of depositional histories. Enyert (1970), Love (1948), and Young (1970) believed that the Morrison-Cloverly contact is determined best by lithology and by the presence

TABLE III

WYOMING STRATIGRAPHIC NOMENCLATURE CHART



Stratigraphic nomenclature for the state of Wyoming. (Enyert, 1970.)

Stratigraphic Section

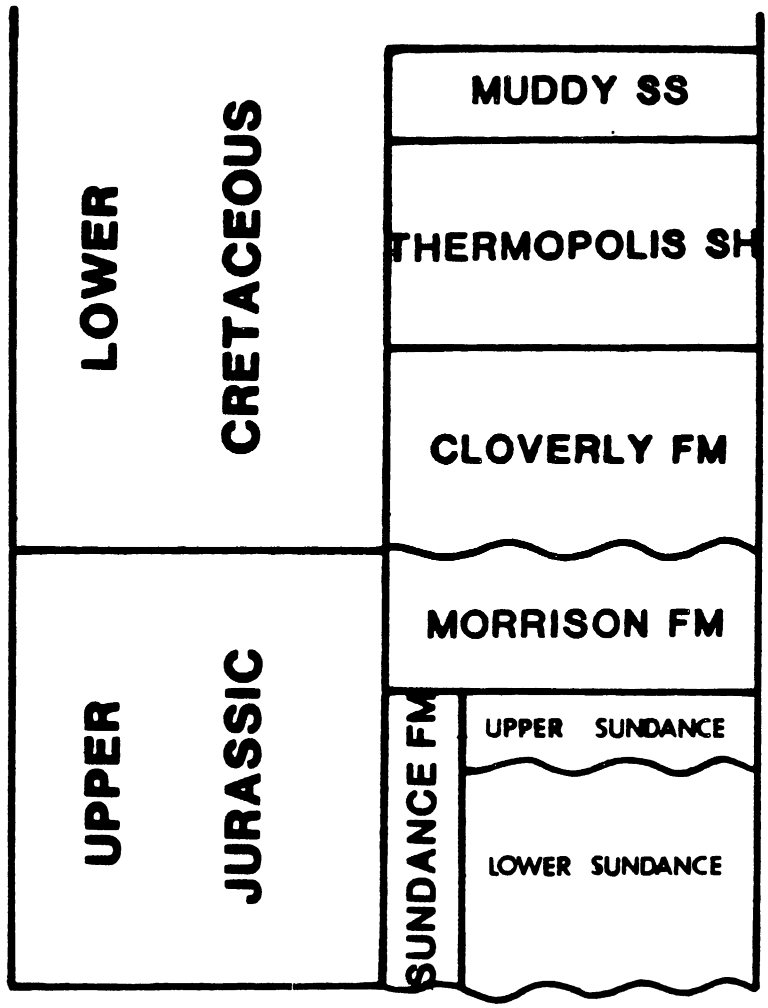


Figure 7. Stratigraphic nomenclature used in this study.

of an unconformity. By convention, change of lithology is the major distinguishing charcteristic. The lower portion of the Cloverly is coarse-grained conglomerate that records a change in source area and a period of erosion. Love (1948) and Keefer (1969) refer to part of this conglomerate as the "quartz-crystal sandstone," which is very distinguishable in hand samples.

An example of boundaries of the Morrison as expressed on wireline logs is shown in Figure 8.

The following are descriptions of features diagnostic of the Sundance, Morrison, and Cloverly Formations in the Wind River Basin.

The Sundance Formation was assigned its name by a man named Darton (1899). According to Peterson (1954), Darton described an outcrop of green and gray shale, buff sandstone, and red beds near the town of Sundance, Wyoming. The Sundance generally is considered to be divisible into two parts, both of which are of marine origin. Downs (1948) described the lower unit as a sequence of gray shales, oolitic limestones, and fine grained sandstones with little or no glauconite. This unit ranges from 80 to 340 feet thick. The upper unit ranges from 100 to 200 feet thick; it contains glauconitic fossiliferous limestone, glauconitic sandstone, and green calcareous shales.

The Morrison Formation was named by Eldridge (1896) from exposure near Morrison, Colorado. The Morrison is believed to have been deposited under fluvial and lacustrine conditions.

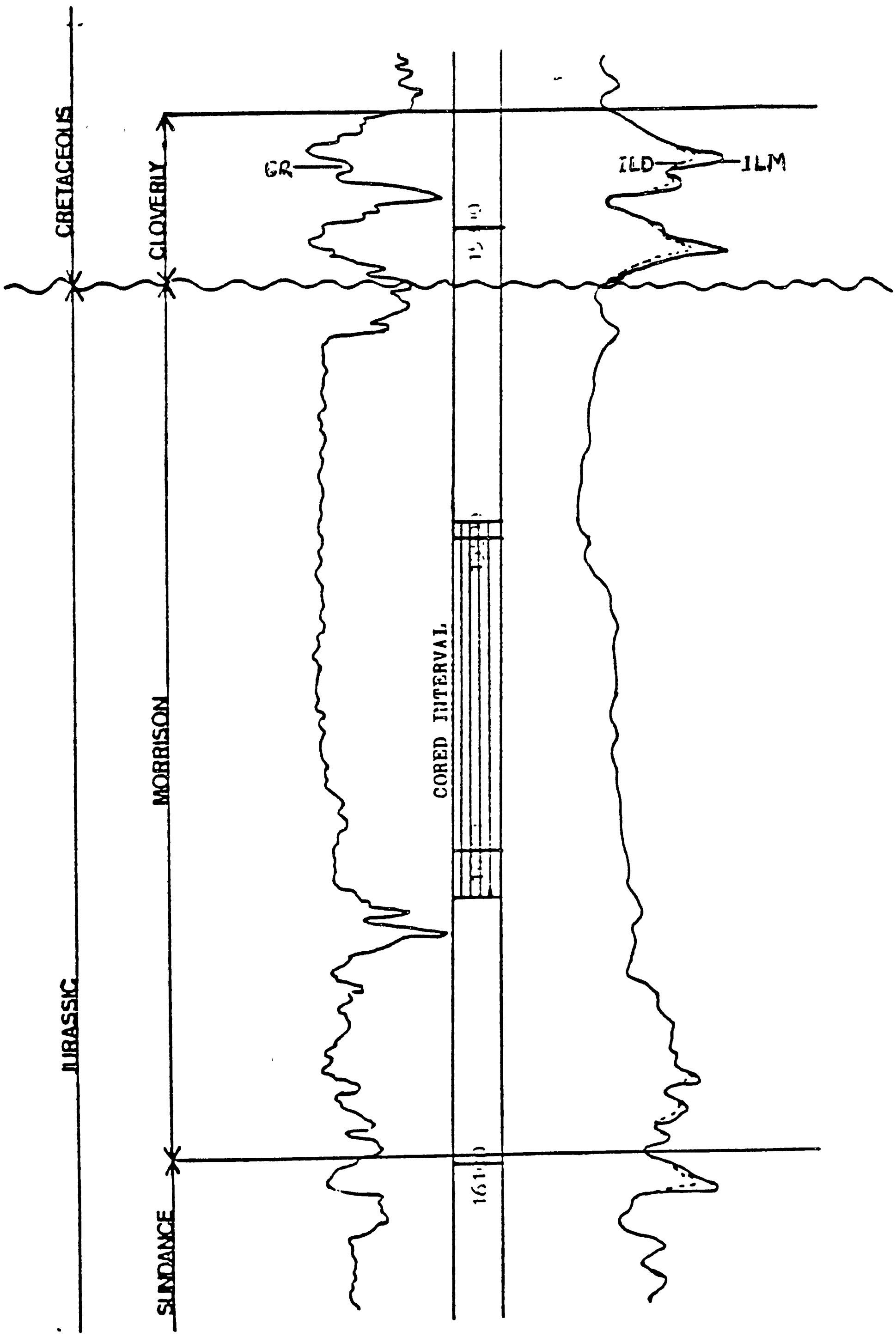


Figure 8. Type log, Union well 36 B-10, Natrona Co., Wyoming West Poison Spider Field.

It consists of a series of nonglauconitic and mostly noncalcareous shales, mudstones, and sands. Shales and mudstones generally are various shades of green, gray, and red. Chisholm (1962) says that these colors are suggestive of fluvial environments. Thin beds of dense freshwater limestones are also present at some localities. Most are interbedded with shales. Chishlom (1962), Love (1948), Woodward (1957), and Downs (1948) described Morrison sandstones of the Wind River Basin as well sorted, very fine grained, light gray to buff, and lenticular. Some sections of sandstone are more than 180 feet thick. The total thickness of the Morrison Formation ranges from about 100 to about 300 feet.

Mirsky (1962) described the Morrison in the nearby Big Horn Basin as having mudstones predominantly in the lower and middle portions, siltstones throughout, and possible localized limestones in the lower part. Some of the wireline logs studied in this report show evidence of probable calcareous beds (1 to 3 feet) close to the lower Morrison contact and a calcareous unit (ranging from 1 to 3 feet) in the middle portion of the Morrison. These latter units might be illustrative of a slight transition zone between the Morrison and Sundance.

According to Peck (1948), the Cloverly Formation was named by Darton in 1904, for rocks exposed near a post office in the eastern portion of the Big Horn Basin. By convention the Cloverly is divided into three lithotypes. They were deposited under nonmarine conditions, similar to those that existed during deposition of the Morrison. Pekarek (1978) described the lowermost unit as dirty gray to buff chert- and quartz-pebble conglomerate. This conglomerate also contains fine to medium grained sandstone. Average thickness of the unit is about 40 feet. The middle section is a series of variegated mudstones that are as thick as 30 feet at some places. The upper unit is a rusty colored, sandstone of rather large areal extent. It is made up of claystones, siltstones, and very fine grained sandstones. The upper unit is more than 130 feet thick at some localities. Commonly it is referred to as the "Rusty Beds."

CHAPTER VIII

GEOLOGIC SETTING OF THE MORRISON FORMATION

The Morrison Formation extends throughout a vast area of the western interior of the United States, from Canada to central New Mexico and from western Utah into eastern Colorado and western Nebraska. Campbell (1976) explains that some Morrison sediment extends into central Kansas. Thickness of the Morrison throughout the western interior ranges from near 1000 feet in the southern areas to 0 feet in the north and some mountainous areas of Colorado. This implies that the further away from the source the thinner the deposit. This is generally the case most of the time. Peterson (1952) explains that the limits of the Morrison are truncated edges.

The environment under which the Morrison was deposited is believed to have been fairly warm and humid. Colbert (1945) described it as flat-lying land with swamps, jungles, and marshes. Baker (1965) spoke of broad flood-plains on which a savanna-type environment probably existed. The supposed tropical area and areas of jungle could have been near lakes and river systems.

Assuming that my interpretation of eolian sandstones in cores described previously is correct, the environment of deposition of the Morrison within the study area probably was semiarid to arid. Collinson (1986) discussed several features characteristic of desert environments. He concluded that areas of 20-30 latitude have a tendency to have high aridity. Habicht (1984) inferred that the latitude of Wyoming during late Jurassic was close to 30^{o}-35^{o} north. Arid regions usually are inland and a considerable distance from the ocean. Such was the position of Wyoming, as judged from Figures 9 thru 11 . Mountainous areas that were west and southwest of the study area should have caused a rain shadow effect across the area that now is Wyoming.

These surrounding positive areas were gradually rising during the latest Jurassic period because of the onset of the Laramide orogeny. The overlying Lakota Formation contains much coarser (pebble to cobble) material, which implies uplift of source areas. Change in topography could have altered the weather patterns and the overall climate (Schwab 1986, oral communications). Thick fluvial deposits that in outcrop are above and in between eolian sandstones could have resulted from change from an arid to a less arid climate. Szigeti and Fox (1981) mentioned that a more humid climate developed during Late Jurassic time, which stabilized the eolian sands of the Morrison of South Dakota. Petrified wood and dinosaur bones commonly were found in the associated fluvial sandstones.

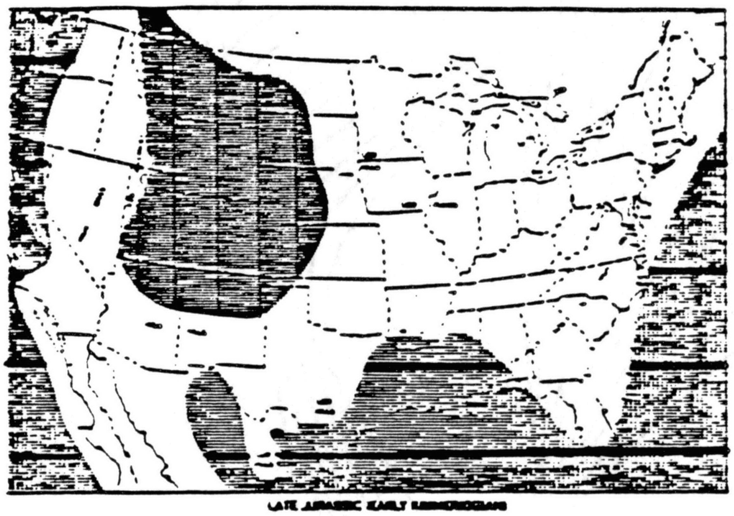


Figure 9. Paleogeographic map. (From Imlay, 1956)

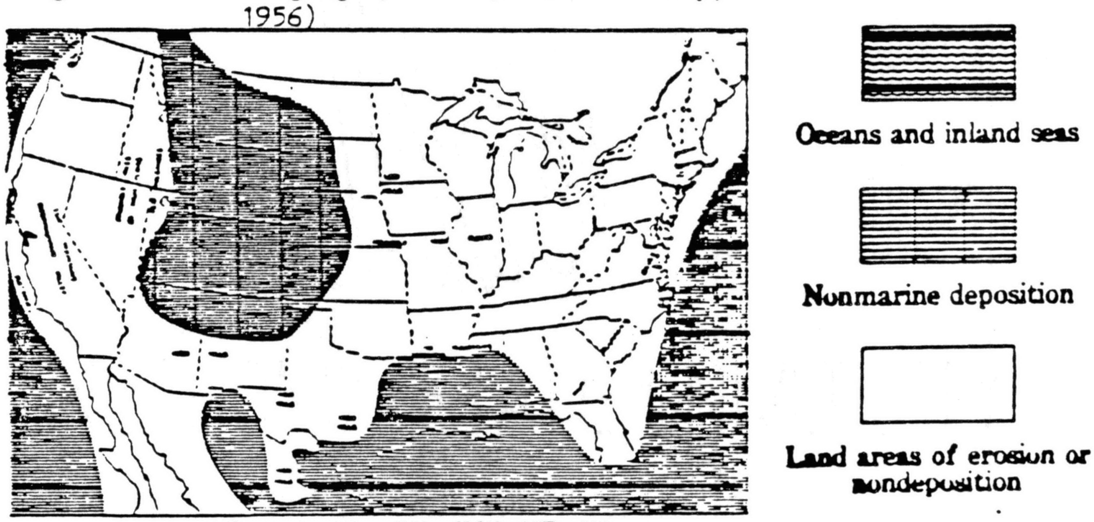


Figure 10. Paleogeographic map. (From Imlay, 1956)

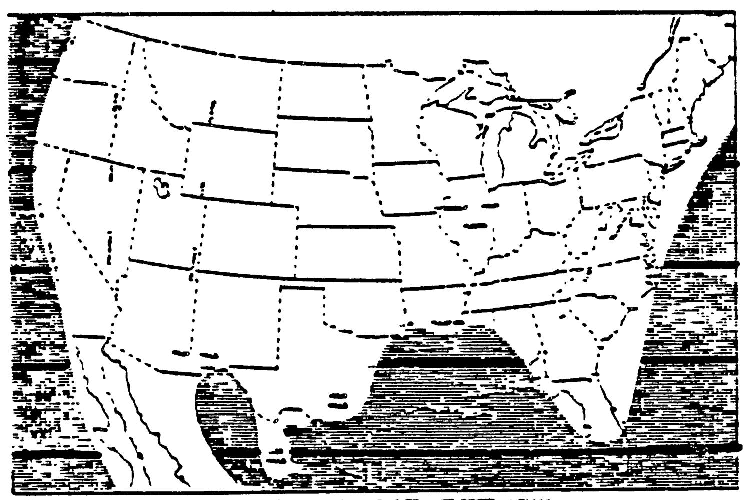


Figure 11. Paleogeographic map. (From Imlay, 1956)

CHAPTER IX

STUDY OF OUTCROPS

Several outcrops near the thesis area were studied (Fgirue 12). In the outcrops two sandstones can be distinguished. Where they did occur together, the lower seems to be eolian and the upper fluvial. Thicknesses vary from 0 to about 120 feet. "Pinchouts" occur across short distances.

The assumed eolian lithotype is white to greenish gray. It is very fine grained and thickly bedded. The lower boundary of the sandstone is "horizontal" but the upper boundary is hummocky. The sandstone is very friable and is weathered to distinctive roundness. Large-scale trough cross-beds were observed in some outcrops (e.g. Figure 15) whereas in others such bedding seemed to be absent (Pine Mountains No. 2 and Alcova). Weathered surfaces are "pitted" or "pocked". Gouger and Schwab (oral communication 1986) interpret this as being due to possible bioturbation. The surface was mottled. Such mottling could have been caused by ants and other organisms that are capable of obliterating of bedding, Szigeti and Fox, 1981 (from oral communications with McKee). Tracks, trails, and burrows are sparse. Examples of a trail can be seen in Figure 13.

Trough cross-bedding is in sets as long as 30 feet and as thick as 10 feet. These cross-beds dip steeply and

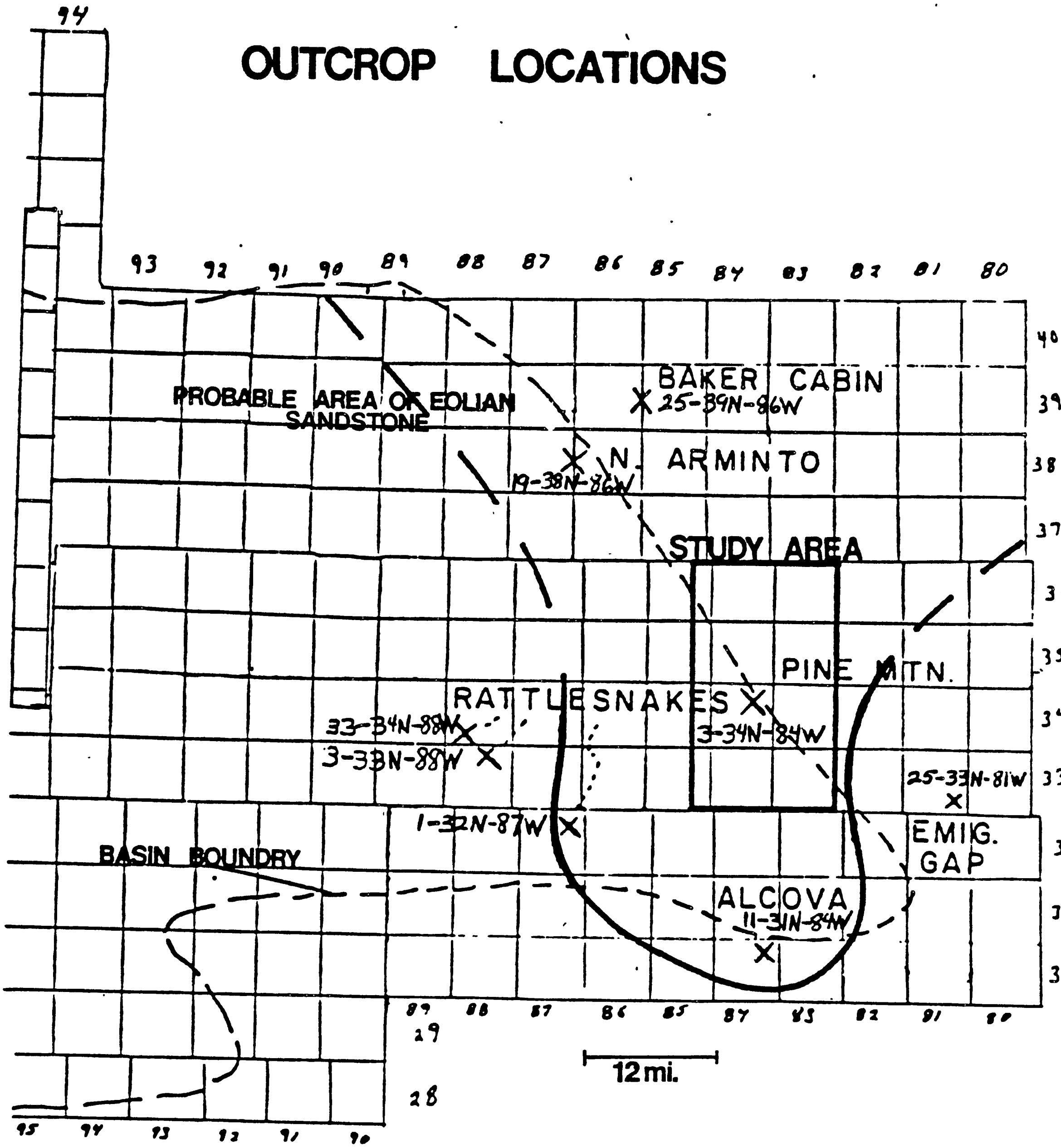


Figure 12. Map showing the locations of the outcrops. The heavy solid and dashed line illustrates the probable area of eolian sand occurrence. (From Schwab 1986, modified by Jobe 1986)

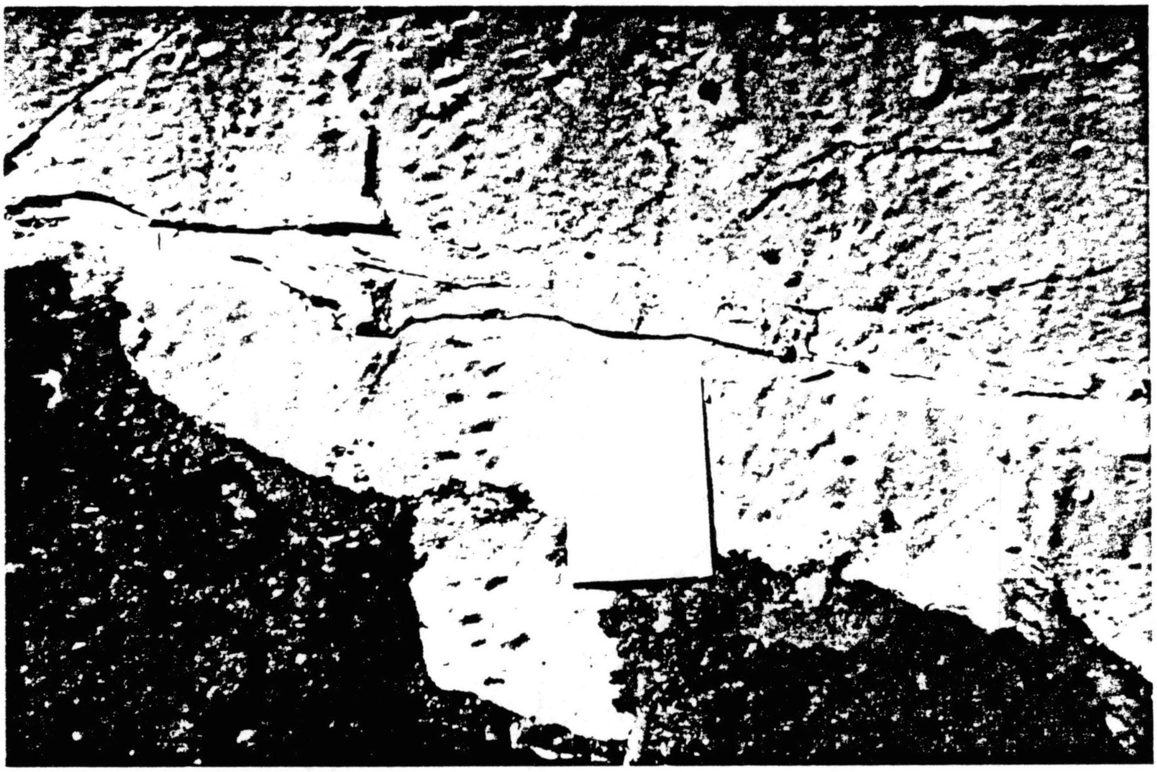


Figure 13. Possible animal tracks at Baker Cabin outcrop. (Photo by Gouger, 1986)

consistently throughout the sandstone at Baker Cabin outcrop (Figures 14 and 15).

Paleo-readings at the Baker Cabin outcrop show dominant northwesterly dip. Figure 16 illustrates the adjusted dip directions. Dip of cross-bedding was as much as 29 degrees. Szigeti and Fox (1981) concluded that the eolian Unkpapa Sandstone of South Dakota, stratigraphic equivalent of the Morrison, was deposited by prevalent southerly winds.

Sandstone assumed to be fluvial is tan to whitish gray. Typical fluvial graded beds and rip-up clasts are near the base but very fine to fine grained sandstone is in the remainder of the unit. Large-scale (six feet) trough cross-beds grade upward into small-scale trough cross-beds. Distinct individual rock units deposits (presumedly point bar sequences) are stacked. The general range in thickness is 5 to 20 feet. Pinchouts are common. Petrified wood, dinosaur bones, and iron concretions also are common.

At the North Arminto outcrop intraformational limestone conglomerate is present. The limestone intraclasts are rounded and granule to pebble in grain size. Probably the conglomerate originated by fluvial currents' ripping up of lacustrine limestone.

Small, isolated beds of chert are in the upper portions of the Morrison.

This sandstone that is in the upper part of the Morrison occupies "cutouts" in the lower, presumedly eolian sand body (Figure 17).

Figure 18 is a sketch (not to scale) of the outcrop pattern at the North Arminto location. It illustrates the general geometry of the supposed fluvial and eolian sand bodies in profile.

Figures 19 through 22 show descriptions of outcrops. Figure 23 shows relationships of measured sections at Pine Mountain to nearby wells.

Figure 14. Large-scale cross-beds at Baker Cabin outcrop.

Figure 15. Large-scale cross-beds at Baker Cabin outcrop.

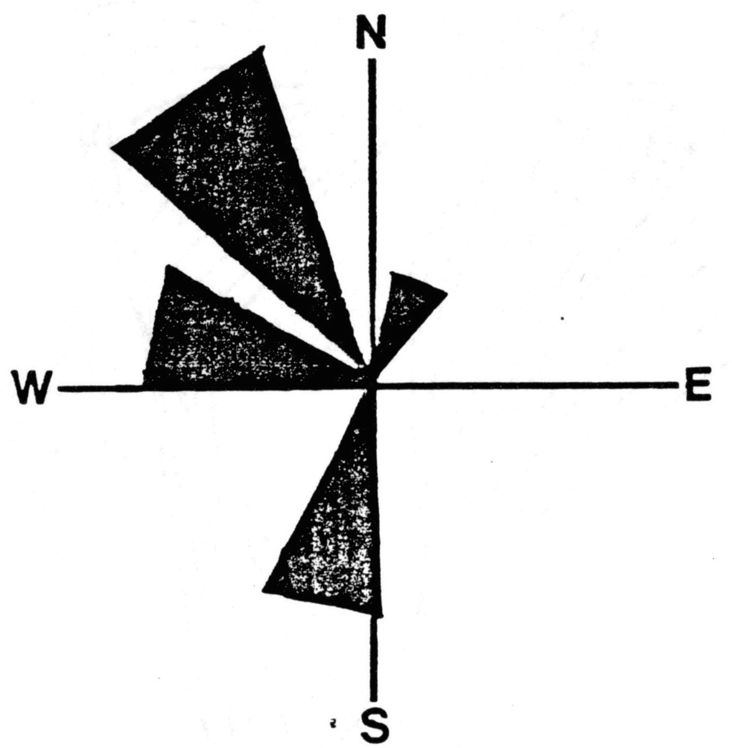


Figure 16. Rose diagram, paleo-readings, Baker Cabin outcrop. The dominant wind direction during the formation of the cross-beds was from the southeast.

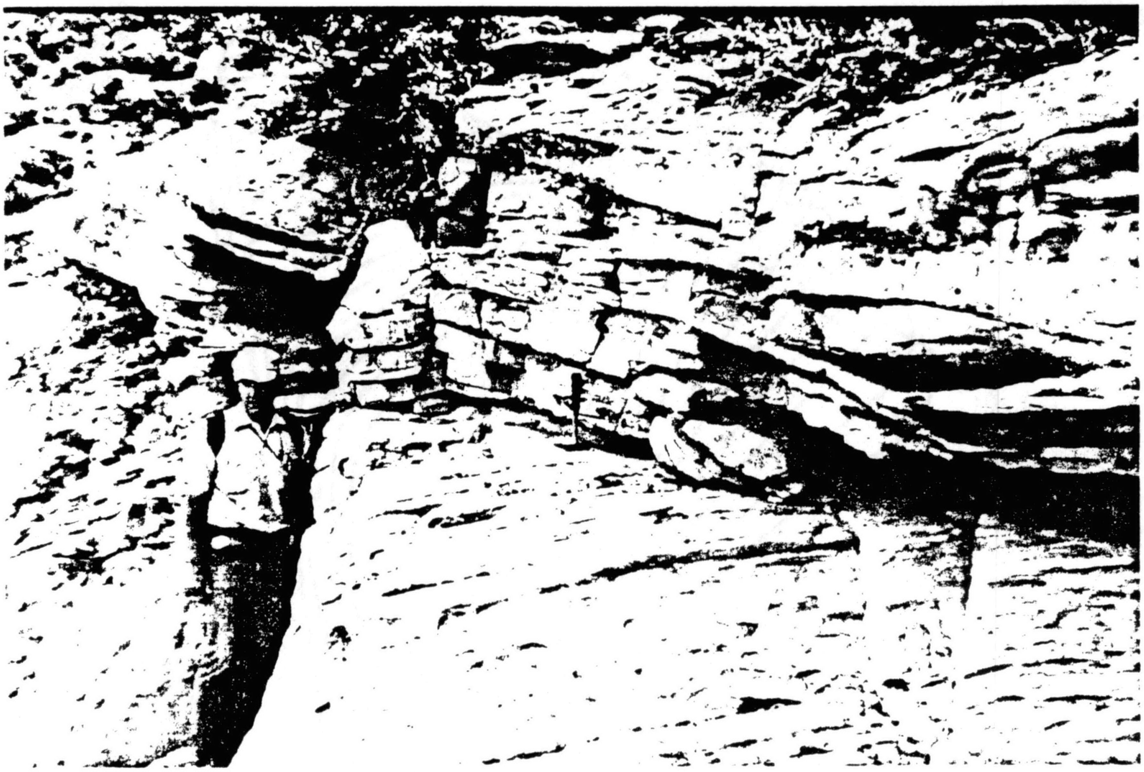


Figure 17. Sandstone believed to be fluvial origin cut into sandstone of probable eolian origin, Baker Cabin outcrop. (Photograph by Gouger, 1986)

PROJECTED NORTH ARMINTO CROSS-SECTION

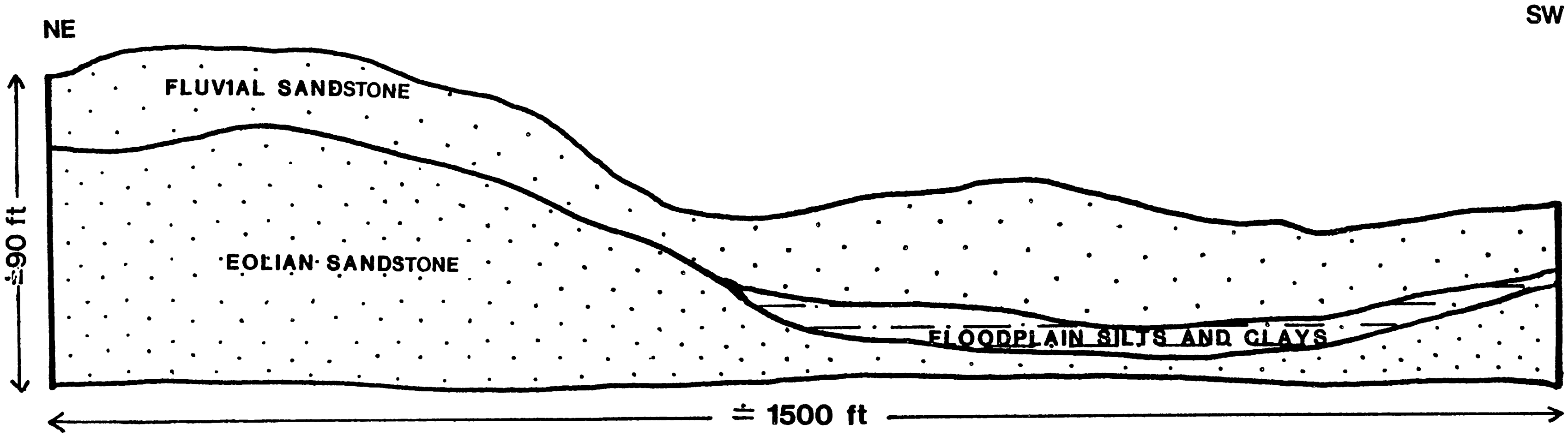
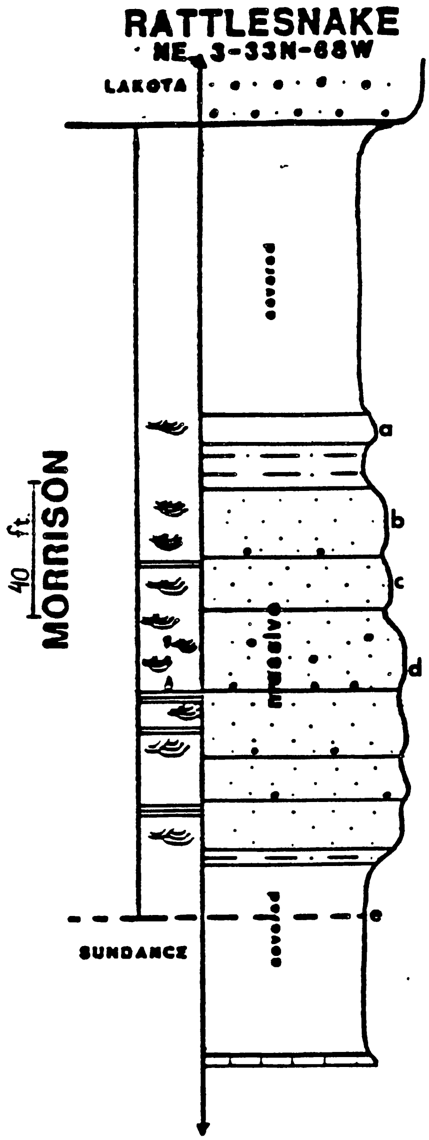


Figure 18. Projected cross-section of the North Arminto outcrop.



- Fluvial conglomeratic Lakota Fm.

- Covered interval, probably green and red siltstones and shales. Perhaps floodplain and/or lacustrine deposits.

Figure 19. Graphic description of exposure at the Rattlesnake outcrop; NE, section 3-T33N-R88W. Seven stacked point bar deposits are present (i.e. a, b, and c). Sandstones are very fine to fine grained, gray, friable, and calcareous. Rip-up clasts and graded beds are present locally near bases of some cycles. The fourth unit from the bottom of sequence shows braided-stream characteristics with graded beds and reverse grading (d). The lower portion of the Morrison as well as the upper portion of the Sundance is covered but probably consisted of greenish gray siltstones and shales. The dashed line (e) represents possible Windy Hill member of the Sundance (upper contact).

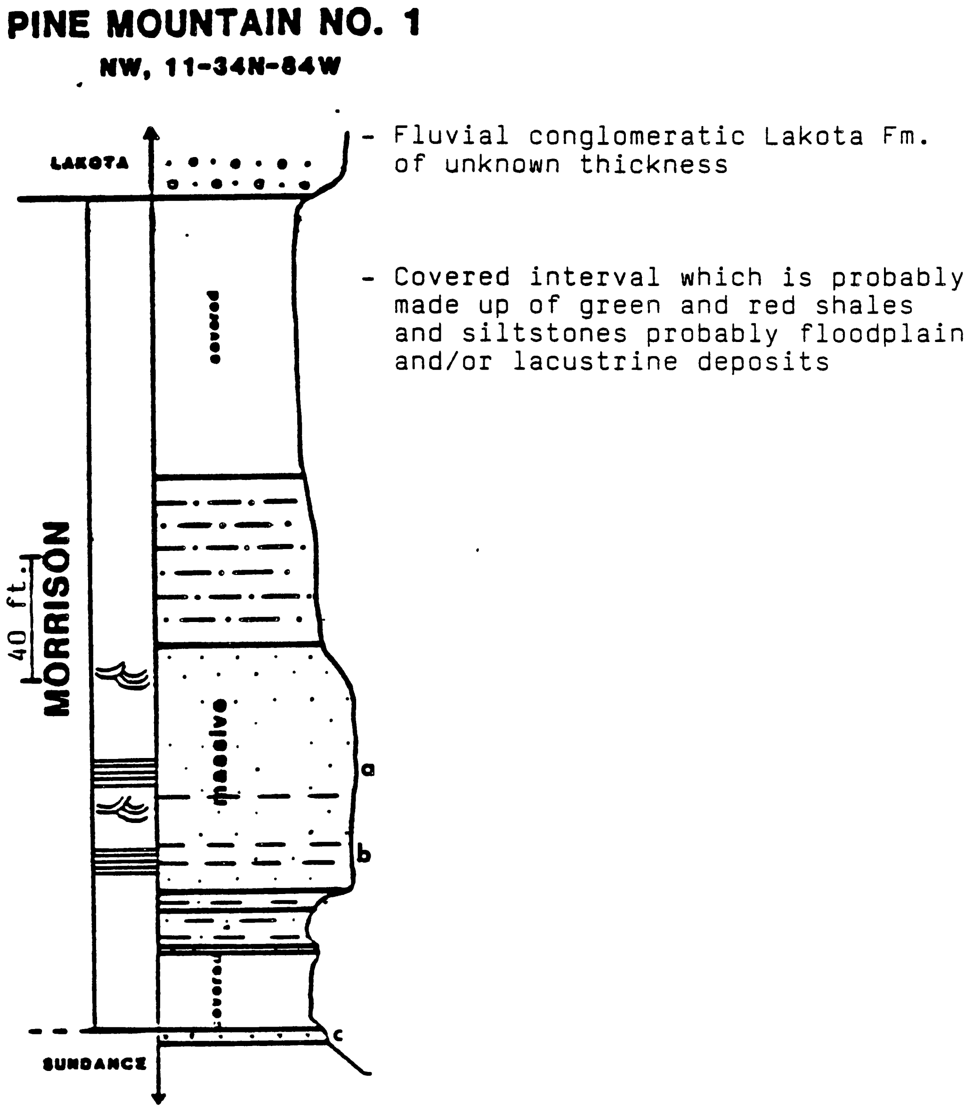


Figure 20. Graphic description of exposure at the Pine Mountain No. 1, NW, sec 11-T34N-R84N. The lower massive sandstone at (a) is white, calcareous, very fine grained, friable, and well sorted. Large-scale trough cross-beds as well as horizontal laminations and thin green shale beds (b). The lower Morrison consisted of thin tan sandstones and green and red siltstones. Sandstone at (c) represents the Windy Hill member of the Sundance. It is tan, calcareous, very fine grained and cross-bedded.

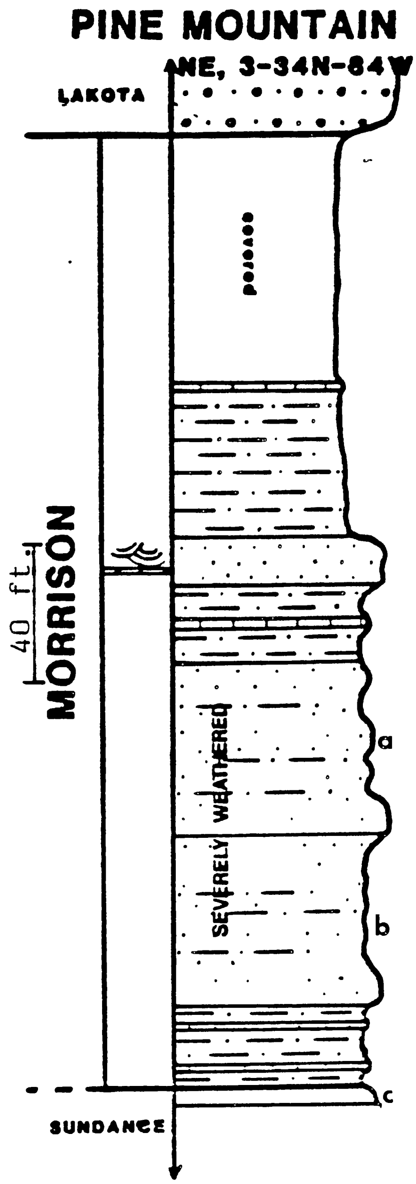


Figure 21. Graphic description of exposure at the Pine Mountain No. 2 outcrop, NE, sec 3 - T34N-R84W. Massive lower sandstone is very fine grained, friable, calcareous and severely weathered. Upper half (a) was white while lower portion (b) was stained red possibly from overlying red siltstone. The lower portion of the Morrison is alternating layers of green siltsones and tan very fine grained sandstone. The tan very fine grained calcareous sandstone at (c) is the Wind Hill member of the Sundance.

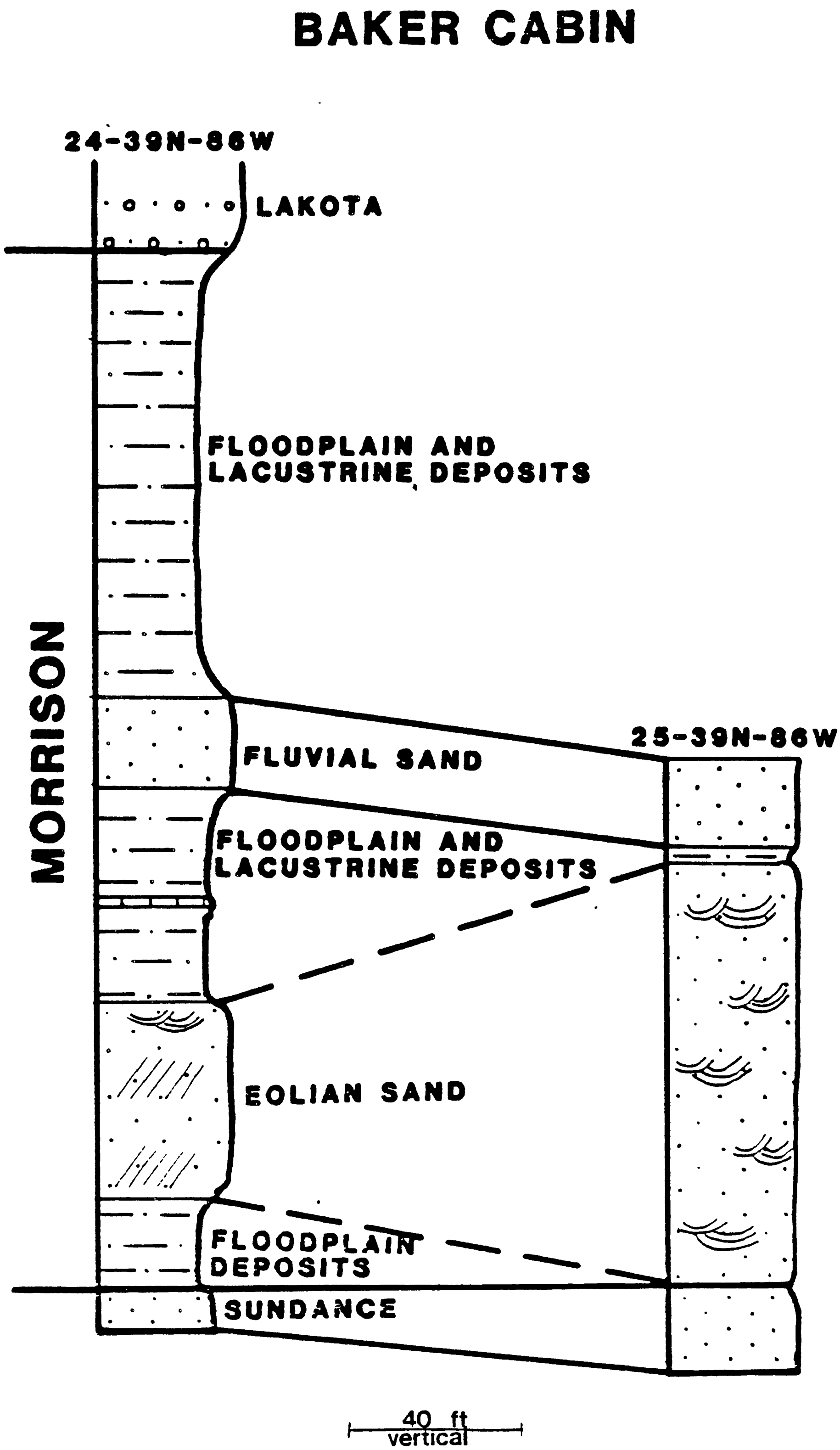


Figure 22. Correlation of section at Baker Cabin outcrop (Schwab and Gouger, 1986; redrawn by Jobe, 1986).

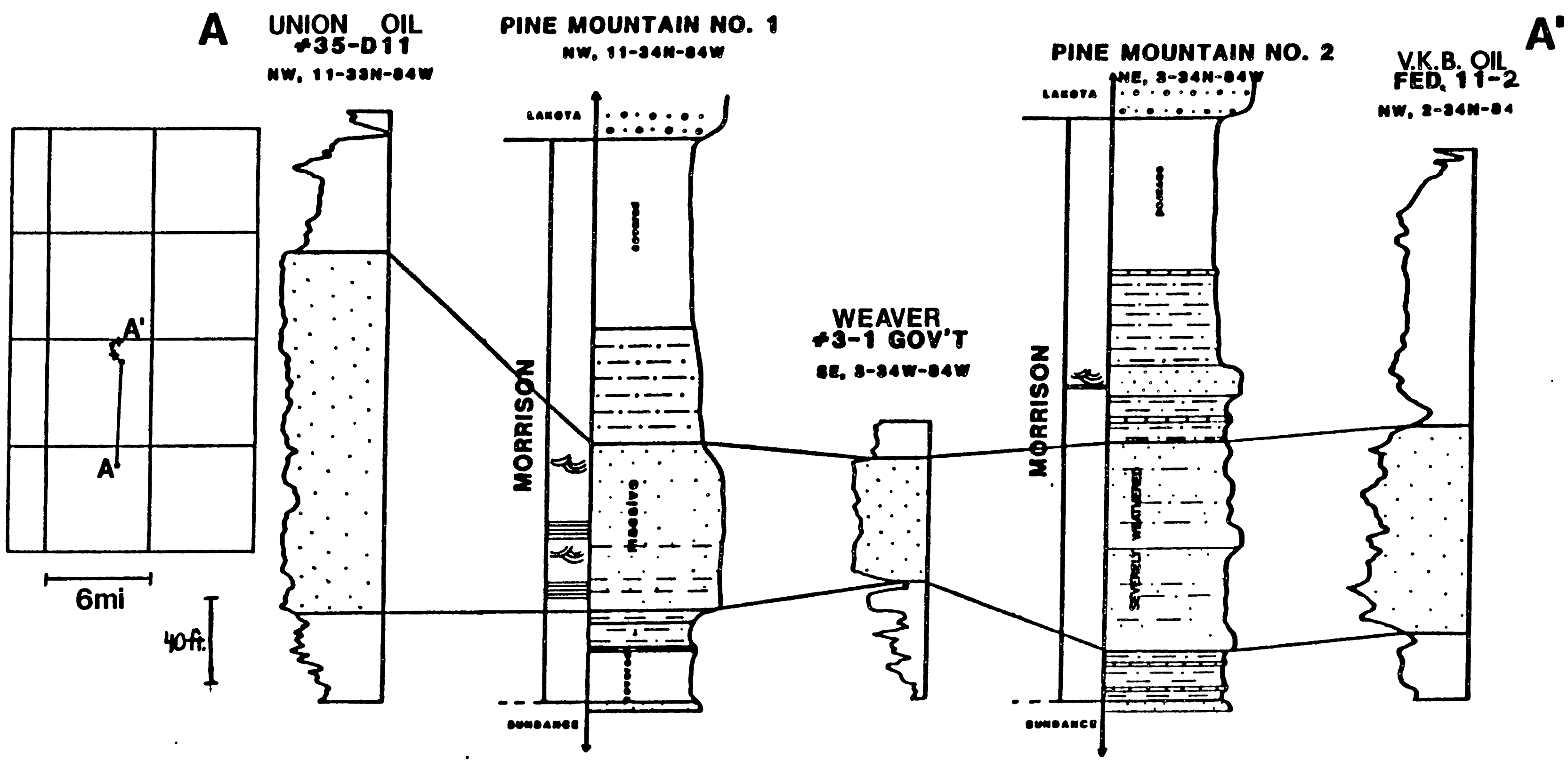


Figure 23. Correlation of measured sections with logs of nearby wells.

CHAPTER X

CORE ANALYSIS

Lithotypes

Grayish White Sandstone

Grayish white sandstone is abundant in both cores. The Union 35-D11 core (sec. 11-T33N-R84W) contained 49 feet of it, whereas the Union 36-B10 (sec. 10-T33N-R84W) contained 63 feet. This sandstone is a very fine grained, well rounded, well sorted subarkose. Wisps or stringers of dark gray shale are abundant within this lithotype. Small pyrite nodules also are common. Some of the sandstone had a greenish white tint. Bioturbation produced a mottled appearance. Generally the grayish white sandstone has low porosities and permeabilities, due to compaction and larger amounts of silt.

Brownish White Sandstone

Brownish white sandstone of the cores is similar to grayish white sandstone in grain size and texture. Henderson (1981) attributed the brownish tint to oil stain. Stained sandstone constituted about 69 feet of the 35-D11 core and about 57 feet of the 36-B10 core. The sandstone is a very fine grained, well rounded, and well sorted subarkose.

Evidence of bioturbation is abundant, as are laminations and cross-beds. Whitish "patches" of calcite (2 mm across) were present. Petrographic evidence indicates that calcite and ferroan dolomite are present throughout. "Patchy" calcite predominantly is in the brownish stained sandstone. These areas of occurrence can be seen on Plates 1 and 2.

Apparently the stained sandstone has more porosity and permeability than the unstained sandstone. Several bioturbated parts within the stained zones were unstained, illustrating that they are less permeable than the surrounding rock. Apparently some burrows had been filled with finer-grained sediment. Pyrite nodules and stringers of shale are also present.

Greenish To Grayish Black Shale

Thin layers of (0.5 cm to 2 cm) of greenish to grayish black shale are in the grayish white sandstone only. They tend to occur at boundaries of depositional cycles. Location of such boundaries are recorded in Plates 1 and 2.

Sedimentary Structures

Laminations

Horizontal and inclined laminations were abundant throughout both cores. These strata are in sequences as thick as 10 feet. Individual laminae are 0.25 to 2 mm thick. Dip of laminae ranges from 5 to 23 degrees in what appear to be two principal directions. The steeper laminae are in the stained sandstone. Laminations are gradually steeper upward in depositional cycles, which suggests possible increase upward in levels of energy.

Dipping laminations also could be segments of medium- to large-scale trough cross-beds and tabular cross-beds.

Cross-Bedding

Cross-bedding of two apparent forms is common in both cores: small-scale, low-angle tabular cross-beds and small-scale trough cross-beds. Tabular cross-bedding formed by migration of straight-crested ripples whereas trough cross-bedding arose from migration of sinuous to linguoid ripples (Leeder, 1983).

The individual small-scale tabular sets are 0.5 to 2 cm thick. These sets are horizontal and inclined (of course, within a horizontal set, small beds are inclined). Inclined sets could be parts of large-scale sets of trough cross-beds.

Trough cross-bedding also was recorded as small-scale features. Individual troughs range from about 1 cm to about 10 cm long. Heights range from 0.5 to 5 cm.

The smaller scaled cross-beds mainly are confined to lower portions of depositional cycles. These cross-beds could represent truncated ends of larger scale cross-bedding, but no direct evidence of cross-bedding of larger scales was observed.

Ripple Marks

Ripples are most abundant in grayish white sandstone. These ripples have a grayish black, hair-like appearance. They are both horizontal and inclined. The formation of these inclined climbing ripples was due to an increase in sedimentation rate accompanied by decrease in flow rate. The ripples are asymmetrical, suggesting possible unidirectional flow. What appeared as a sinuous pattern of ripples was most common, but some possible plane-crested patterns were observed. On the whole, ripples probably were deposited under low-energy levels, the evidence for which is thin delicate appearance. Most ripples are in lower portions of depositional cycles as described on petrologic logs (Plates 1 and 2).

Bioturbation

Bioturbated rock is very abundant in both cores. In some instances, bioturbation was so extensive that there appeared to be none. Henderson (1981) described these intervals as massive zones of intense mottling. The word "mottling," in this context, refers to areas of intense random infilling of burrows, pods, and pockets. Burrows are vertical, horizontal, and inclined forms. They range from 1 to 7 cm long and 0.3 to 0.5 cm wide.

Fractures

Horizontal fractures are quite numerous. Amplitudes are less than 1 cm and maximal lengths are not known.

Faulting

Evidence of faulting was noticed only in one core, Union 36-B10, at 15,921 feet and 15,974 feet. The faults seem to have resulted from unbalanced loading of sediment. Displacement appears to be only a few centimeters. Walker (1980) attributes small scale soft sediment faulting as a possible eolian indicator. I, too, agree with this statement.

Core Descriptions

Cores studied were the West Poison Spider 35-D11 located in section 11,T33N,R84W and the 36-B10 located in section 10, T33N,R84W. The D11 core consists of 118 feet of sandstone, between 15,817 and 15,935 feet. Cored in the B10 were 120 feet of sandstone between 15,895 and 16,015 feet.

Sandstone in cores is very well sorted throughout; grain size of approximately 0.11 mm is almost constant. Sedimentary structures and other depositional characteristics are extremely subtle, making determinations of them difficult. Therefore, conclusions drawn from cores necessarily are based on subtle variations of the several characteristics.

Both cores showed evidence of several (35-D11 has 5 cycles and 36-B10 has 10 cycles) stacked depositional cycles and parts of others. A "typical" cycle was defined on the basis of sedimentary structures, angles of sedimentary structures, shaley intervals, and silt content.

The "typical" sedimentary cycle averaged about 14 feet thick. Range in thickness of cycles was 6.5 to 33 feet.

More cycles were described in well 36-B10, because more parts of the core showed horizontal laminae and ripple marks, which suggest bounding surfaces. Thicknesses of cycles were within the range of thicknesses Walker (1980) described for ancient eolian sandstones.

Each cycle appeared to have a basal portion and a capping portion. Basal intervals contain thin beds of shale (1 to 2 cm), shallow-dipping and horizontal laminations, ripple marks, small-scale cross-bedding, and abundant silt. Areas of high bioturbation activity, resulting in mottled texture, also seemed to be concentrated in these portions. All characteristics are representative of fairly low-energy environments. Of course, horizontal laminations can be developed under conditions of high energy, but horizontal laminae in the core tend to be close to beds of shale.

Capping intervals contain multidirectional, steeply-dipping planar laminations (as much as 23^{o} in well 35-D11 and 15^{o} in well 36-B10). These structures may be segments of large-scale trough and tabular-planar cross-beds, and they may imply higher energy of formation. Bioturbation in capping intervals is not as intense as in lower portions of the cycles.

Based on characteristics described above and upon the fact that the cores show "constant" very fine grain size and good sorting, I conclude that the cores are made up of stacked eolian sands. The cycles are taken as being the record of migration of sand dunes. Interareas of dunes should have been sites of deposition of parts of the sequence where shale beds, horizontal laminae, ripple marks, bioturbated rock, abundant silt, and small-scale cross-bedding exist.

Figure 24 shows the distribution of sedimentary structures in an area of migrating dunes. As the dunes migrate, so do interdune areas. Thus, an area of horizontal laminations and low-energy structures could be preserved. The location of where I believe one of the core cycles would exist, in this model is shown in Figure 24.

Estimation of whether the interdune deposits originated from dry or wet interareas is made best on the basis of shale beds. Cycles that contain thin beds of shale probably would be wet interdune areas.

Figure 25 illustrates how bounding surfaces can develop between deposits that record episodes of migrating dunes. In this model, the groundwater anchors the lower portion of a dune, while the wind blows the upper portion away. As more dunes accumulate, groundwater rises. As a result, horizontal lamination develops.

Scanning Electron Microscopy

Scanning-electron microscopy was performed on samples from both cores in order to test the proposition that etched grains are present. Etching or frosting of grains is indicative of transportation and deposition by wind. No distinct etching or frosting was recorded. Perhaps the clay coatings on grains (Figure 26) obscured the etching. The coatings tend to have undulatory surfaces which could be due to etched or frosted surfaces on the quartz below.

Figures 27 through 30 show various sedimentary structures seen in the cores.

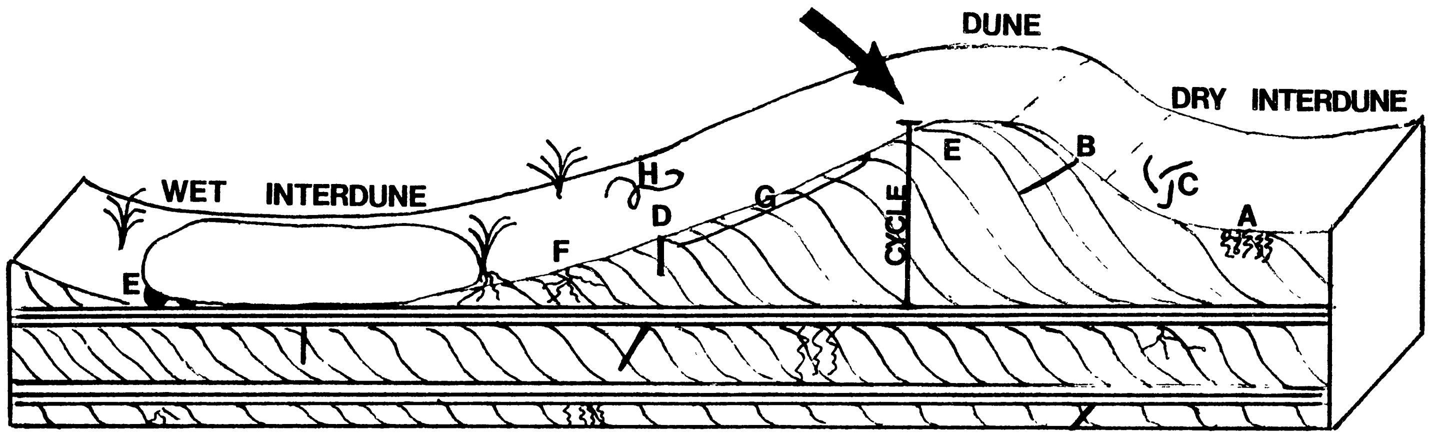


Figure 24. Profile showing stacked dune sequences as well as areas of probable bioturbation. The arrow indicates the location of a "typical" cycle believed to be shown in cores in study. (A) burrows and disrupted sediment by ants (B) cricket burrow (C) root molds (D) spider burrow (E) gastropod burrows (F) plant root traces (G) feeding burrow of an insect (H) fly burrow. (After Ahlbrandt and Fryberger 1982, redrawn by Jobe 1986.)

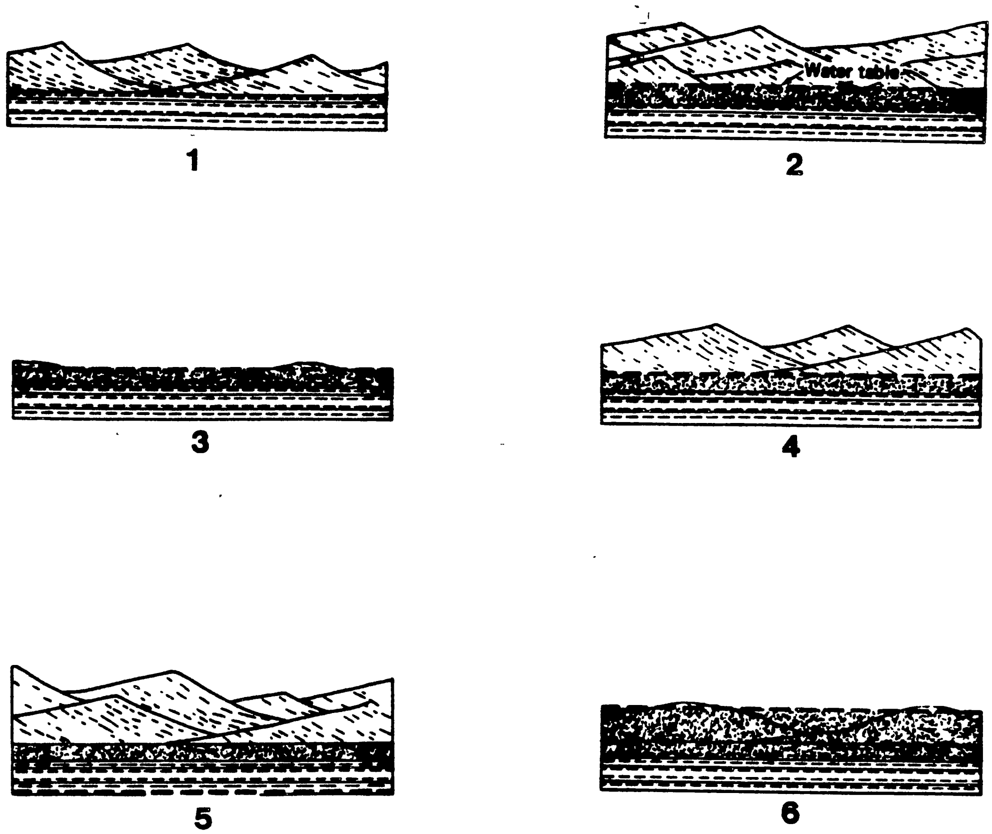


Figure 25. Depiction of the formation of bounding surfaces: (1) sand dune accumulates on a level surface (2) sand accumulation continues while water table rises (3) removal of sand by wind action to water table (4) second sand dune accumulates on water table surface (5) rise in water table to new surface (6) removal of sand by wind action to second water table, etc. (From Stokes, 1968)

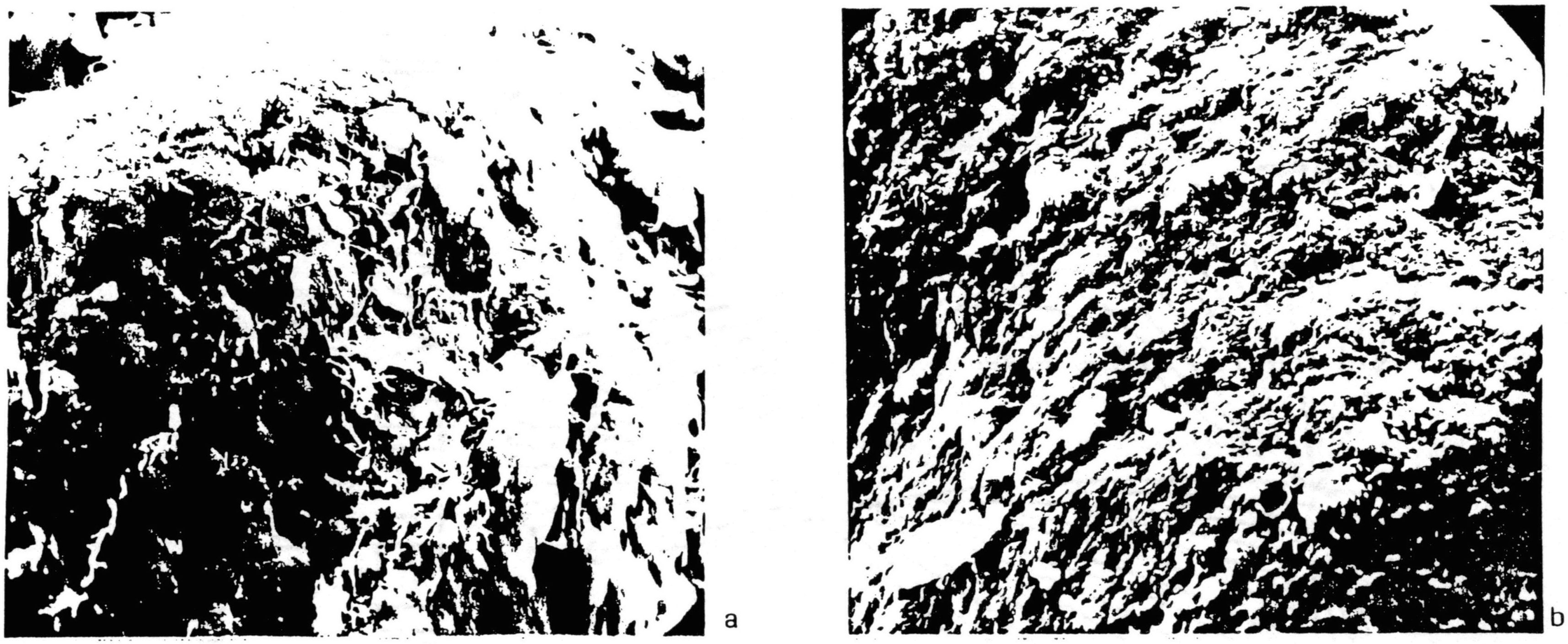


Figure 26a and 26b. S.E.M. photographs of grain surfaces. Figure 26a: 36 B-10 core, is 2000X magnification. Figure 26b: 35 D-11 core, 1500X magnification Both photographs show authigenic clays coating grains. Chlorite in pseudo rosettes in Figure 26a's curved surfaces suggest that the grain of quartz beneath is etched.

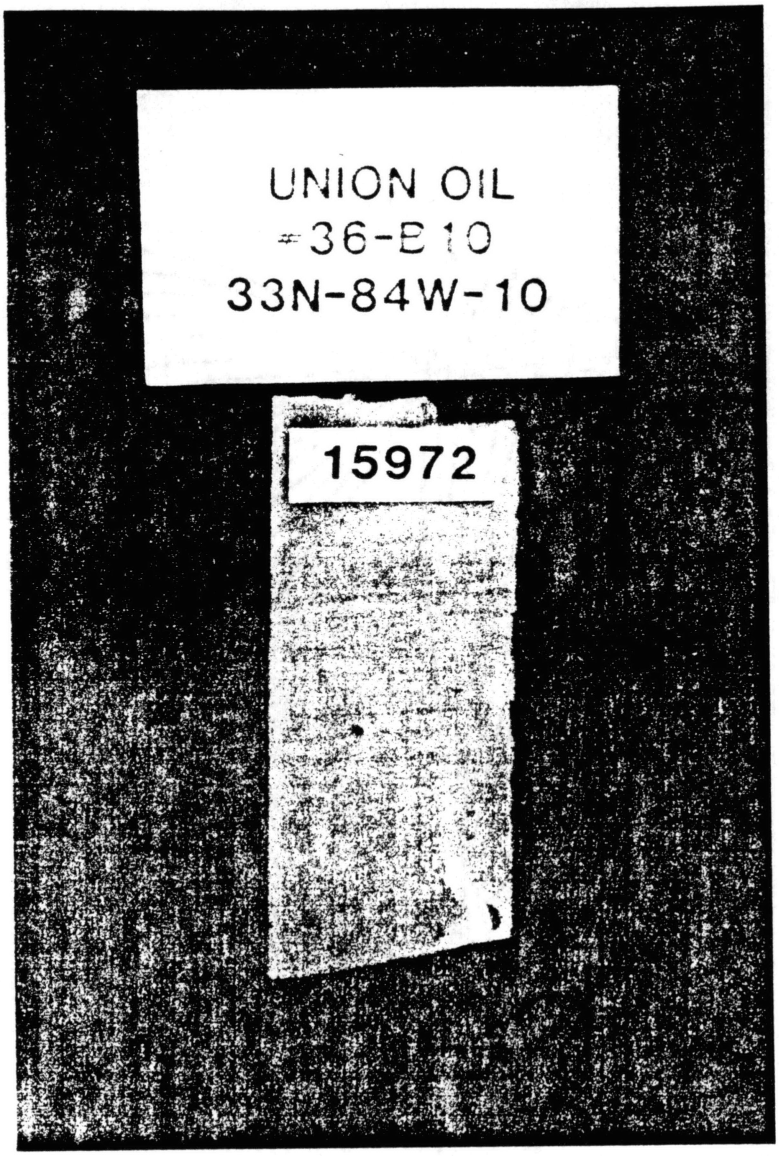


Figure 27. Horizontal laminations, inclined laminations, and possible small-scale cross-bedding (trough and tabular). A fairly distinctive portion of trough can be seen in the lower part of this photograph. The white pattern is glare.

60 mm

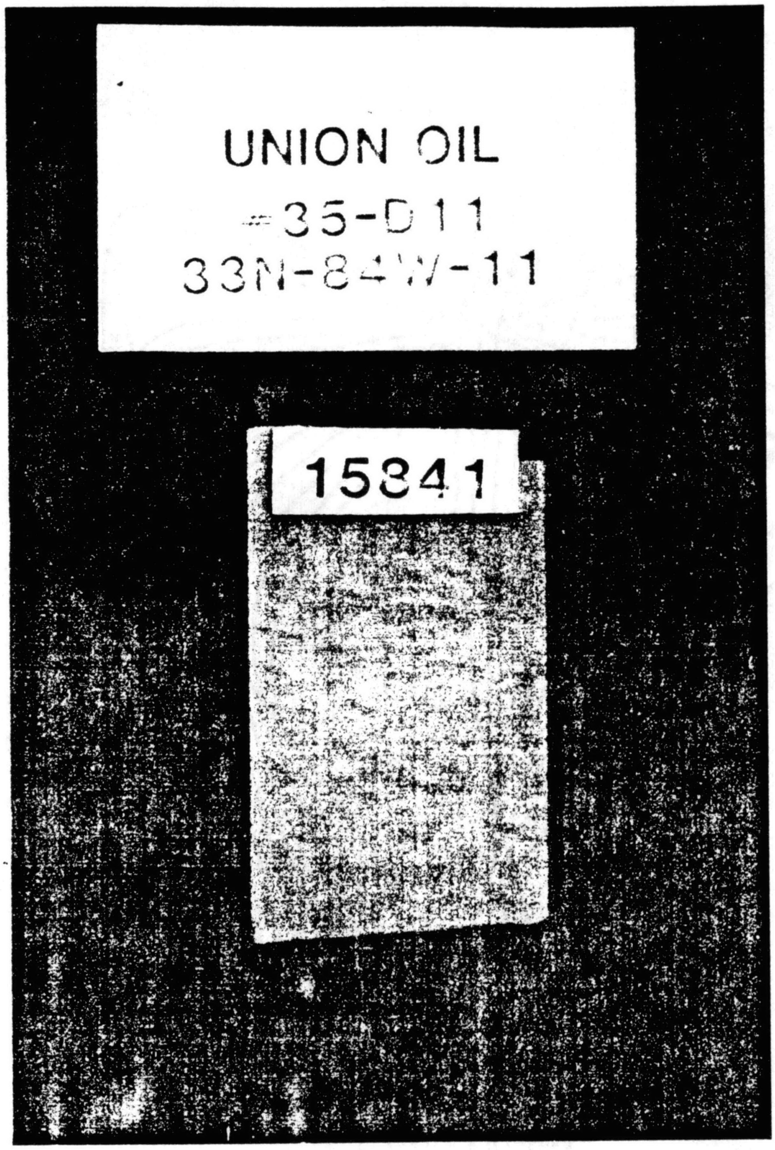


Figure 28. Multidirectional inclined laminae (possibly large-scale cross-bedding).

60 mm

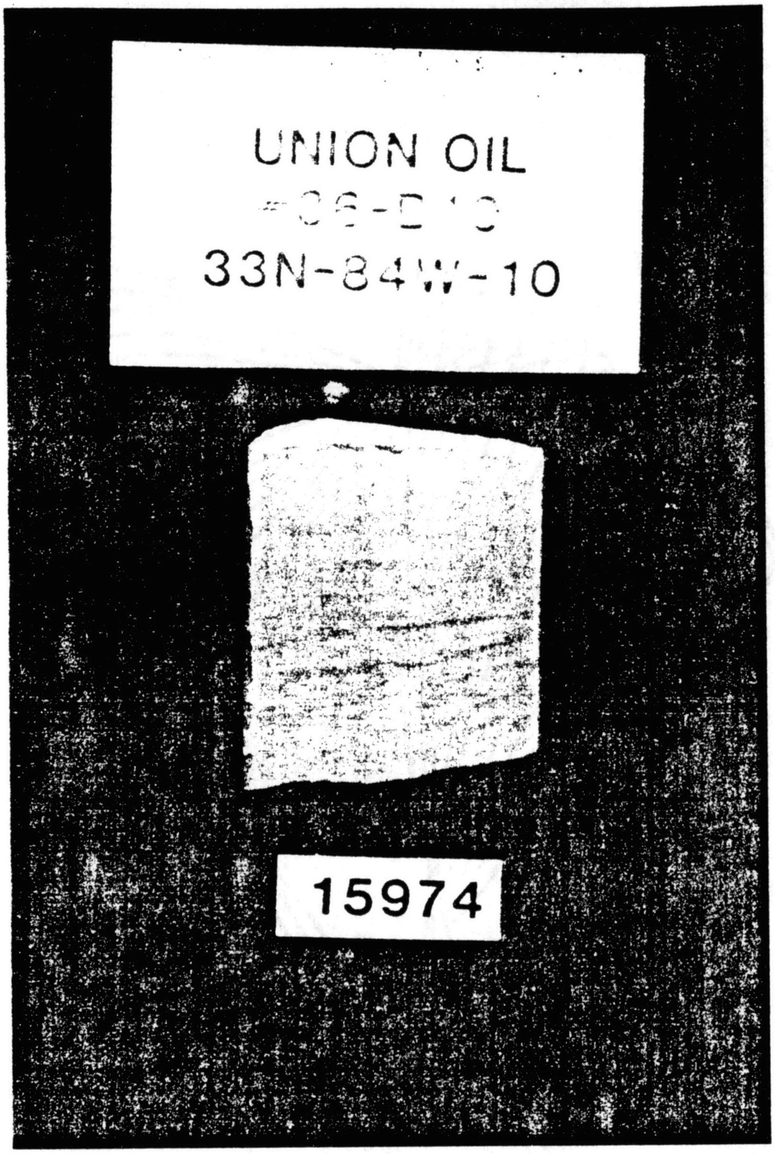


Figure 29 . Horizontal laminations and probable ripple marks.

60 mm

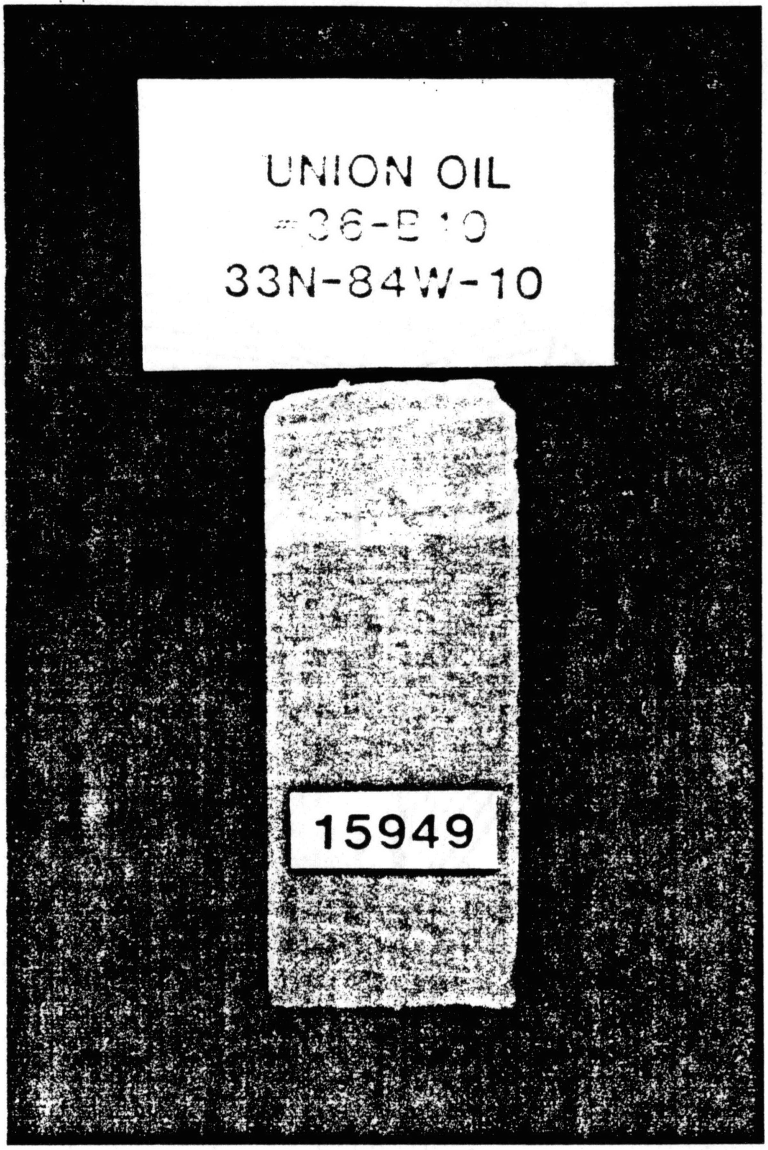


Figure 30. An inclined burrow. Horizontal laminae, inclined laminae, and pyrite nodules are noticeable.

60 mm

CHAPTER XI

PETROGRAPHY

The section of this paper that deals with petrography concerns mostly the analyses of thin-sections and clays from two cores within the West Poison Spider field. Twenty-four thin-sections were made from the Union 36-B10 well and 21 were made from the Union 35-D11 well. Point counts were made on each thin-section to estimate percentages of detrital constituents, detrital matrix, diagenetic constituents and porosity. Composite data concerning all these constituents are shown in Tables 4 and 5. Overall, samples from the two cores were very fine grained, well sorted, subrounded to rounded and supermature. Figure 31 depicts a plot with regard to the recalculated values of quartz (Q), feldspar (F), and rock fragments (R). The samples indicate that the rock is subarkose.

Clay analyses involved X-ray defraction of all samples. The samples were first powdered. A complete 2θ sweep was performed on powdered samples. Samples were selected for clay extraction. Additional X-ray analysis enhanced peaks.

TABLE IV

THIN-SECTION CONSTITUENTS (%) CORE 35-D11

Depth	Monocrystalline Quartz	Polycrystalline Quartz	Feldspar	Metamorphic Rock Fragments	Chert	Chalcedony	Muscovite	Tourmaline	Pyrite	Zircon	Detrital Chlorite	Pseudomatrix	Quartz Cement	Carbonate	Anhydrite	Silica Replacement of Anhydrite	Authigenic Illite	Authigenic Chlorite	Porosity	Silt
15817	68	2	5	tr	2	tr	-	tr	tr	3	tr	tr	2	1	1	tr	3	1	12	5
15823	63	2	4	-	2	-	tr	tr	1	2	-	2	1	2	tr	-	5	2	14	3
15827	61	1	6	tr	3	-	-	tr	3	1	tr	3	1	1	tr	-	3	1.5	17	2
158295	75	2	5	-	3	-	tr	tr	1	tr	-	2	2	1	tr	-	4	1	5	9
15833	63	2	4	-	3	-	-	tr	1	1	tr	2	1	2	tr	-	5	1	15	2
15845	59	1	3	-	3	tr	-	tr	1	1	-	2	1	1	tr	-	7	3	18	3
15851.7	63	2	5	-	3	-	-	tr	tr	1	-	tr	1	1	tr	-	7	2	14	4
15854	60	2	6	-	3	tr	-	1	1	1	tr	3	2	2	tr	-	4	1	14	5

Composite view of rock constituents, Morrison Formation, Union Oil No. 35 D-11 core.

TABLE IV continued

15862	69	2	7	-	3	tr	-	tr	tr	1	-	-	3	1	-	-	7	2	5	9
15869	72	2	6	-	2	-	-	tr	tr	1	-	-	1	1	tr	-	4	1	10	4
15872	77	1	4	-	1	-	-	tr	tr	1	tr	tr	1	1	tr	-	3	1	10	5
15875	69	tr	4	-	1	-	-	1	1	tr	-	2	1	2	tr	-	6	2	11	3
15879	76	1	5	-	1	-	-	tr	tr	tr	-	2	1	2	1	tr	4	1	12	2
15888	71	1	5	-	3	-	-	tr	1	tr	-	2	1	2	tr	-	5	1	10	3
15895	68	1	4	-	1	-	-	tr	1	tr	tr	3	1	2	1	-	5	2	11	7
15899	68	1	5	-	1	-	-	tr	1	2	-	2	1	2	tr	tr	3	1	13	6
15907	76	1	3	-	1	-	tr	1	1	tr	tr	3	2	1	-	-	6	2	3	11
15913	70	2	4	-	3	-	tr	1	1	tr	tr	3	2	1	tr	tr	8	1	4	15
15922	67	2	6	-	2	-	-	1	5	tr	tr	3	2	1	tr	tr	5	1	5	7
15927	70	2	5	-	3	-	tr	tr	2	tr	-	-	2	1	1	-	3	1	10	3
15935	69	2	4	-	2	-	-	1	1	1	tr	2	1	1	-	-	6	2	8	10

Compostite view of rock constituents, Morrison Formation, Union Oil No. 35 D-11 core.

TABLE V

THIN-SECTION CONSTITUENTS (%) CORE 36-B10

Depth	Monocrystalline Quartz	Polycrystalline Quartz	Feldspar	Metamorphic Rock Fragments	Chert	Chalcedony	Muscovite	Tourmaline	Pyrite	Zircon	Detrital Chlorite	Pseudomatrix	Quartz Cement	Carbonate	Anhydrite	Silica Replacement of Anhydrite	Authigenic Illite	Authigenic Chlorite	Porosity	Silt
15895.5	62	2	6	-	2	-	-	1	1	tr	tr	tr	1	1	-	-	4	1	19	2
15898	66	2	6	-	2	-	tr	tr	1	tr	-	1	1	1	-	-	3	1	16	3
15903	62	1	4	-	1	-	1	1	1	1	tr	2	1	-	-	-	7	1	17	2
15908.5	63	2	7	tr	1	-	tr	tr	1	tr	-	1	2	1	-	-	3	1	18	2
15910	62	3	6	-	2	-	tr	1	1	tr	tr	tr	1	2	-	1	4	1	16	4
15917	68	2	5	-	2	-	tr	1	1	-	tr	-	2	tr	tr	-	3	1	15	5
15918	63	2	6	1	1	-	tr	-	2	tr	-	tr	2	1	-	tr	4	1	17	2
15926	62	3	6	tr	2	-	tr	1	2	tr	tr	3	2	tr	-	tr	3	2	14	3

Composite view of rock constituents, Morrison Formation, Union Oil No. 36 B-10 core.

TABLE V continued

15936	68	2	5	tr	1	-	tr	tr	1	1	-	2	2	3	-	tr	3	2	10	5
15944	71	2	5	tr	2	-	-	tr	1	tr	-	tr	3	1	-	-	3	1	11	5
15946	73	1	4	-	2	tr	tr	1	1	tr	tr	1	3	1	-	-	3	1	9	6
15951	64	2	5	-	2	-	-	tr	2	-	-	-	2	3	-	-	3	2	15	4
15956	73	2	4	-	1	-	tr	1	1	tr	tr	tr	3	1	-	-	3	2	9	10
15958	70	1	5	tr	2	-	-	1	2	1	tr	1	2	1	-	-	3	1	11	8
15960	63	2	5	tr	2	-	tr	tr	1	tr	-	-	2	3	-	tr	5	2	15	4
15965	67	2	4	-	2	-	tr	tr	2	tr	-	2	2	1	-	-	3	2	13	4
15971	64	1	4	-	1	-	-	1	1	tr	tr	2	1	1	-	-	10	3	10	6
15975	65	2	6	-	2	tr	tr	1	1	1	tr	2	2	1	-	-	5	1	8	6
15978	71	1	5	tr	2	-	tr	1	1	tr	tr	tr	3	2	-	-	3	1	10	5
15979	69	1	4	tr	2	-	-	1	2	tr	tr	2	2	2	-	tr	3	1	11	7
15986	64	2	5	tr	1	-	-	1	1	tr	tr	tr	1	3	-	1	3	1	18	4
15990	63	2	4	-	2	-	-	1	1	tr	tr	1	2	3	-	-	6	3	12	4
16004	69	tr	5	-	2	-	-	1	1	tr	tr	1	1	2	-	tr	4	3	10	8
16015	76	1	3	-	1	-	-	1	1	tr	tr	1	2	2	-	-	5	2	5	11

Composite view of rock constituents, Morrison Formation, Union Oil No. 36 B-10 core.

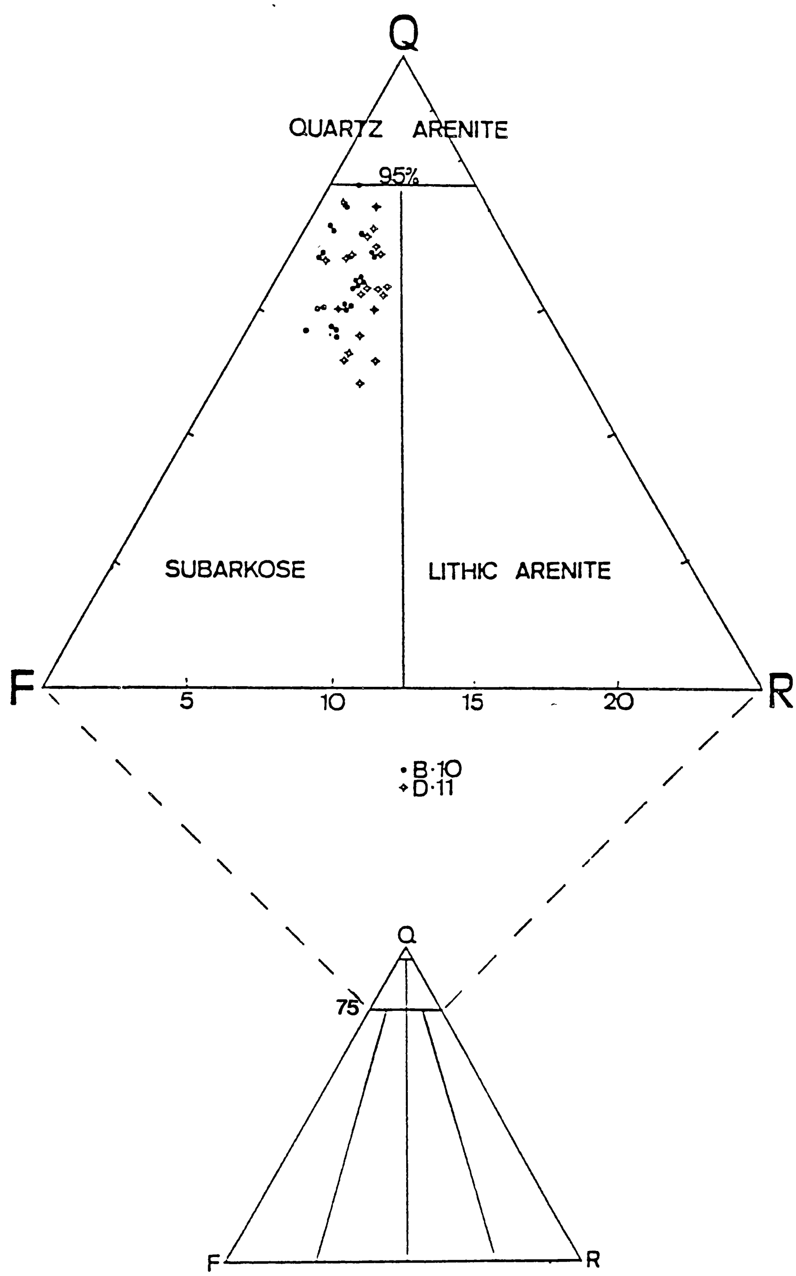


Figure 31. Triangular diagram showing the classification of the thin-sections.

Detrital Constituents

Quartz

Quartz constituted about 70% of the rock volume. The subrounded to rounded grains ranged in diameter from 0.03 to 0.2 mm; average grain size is about 0.11 mm. Quartz is both monocrystalline and polycrystalline; the latter constitutes only a trace to 3% of the total. Crenulated boundaries among grains suggest a certain degree of pressure solution. Corroded edges are indicative of dissolution of silica.

Feldspar

Feldspar is the second most abundant detrital grain. Averaged diameter of grains is in the range of 0.1 to 0.12 mm. Many show cross-hatch, carlsbad, or albite twinning. Microcline, orthoclase, and plagiclase feldspar are present, but plagiclase is most dominant. Feldspars are in various stages of dissolution, which contributes to secondary porosity. Illitic rims around dissolved feldspar grains would appear to show that dissolution probably occurred late; otherwise the delicate illite would have been destroyed by compaction. Some grains have been broken by compaction. Feldspar composes about 5% of the rock.

Chert

On the average, chert is about 2% of the total rock, but in some samples is as much as 4%. It is in all thin-sections.

The chert shows uniform microcrystalline quartz fabric and black-and-white coloration under cross nicols. Average grain size is 0.1 mm.

Metamorphic Rock Fragment

Crystalline structure of some grains appeared to be altered or strongly mixed; the most probable interpretation was judged to be that these grains are fragments of metamorphic rocks. Grain size ranged from 0.1 to 0.12 mm. Such rock fragments are only trace amounts to 1% of the rock.

Chalcedony

Chalcedony was recorded only in trace amounts, only in three slides. It showed the distinctive pattern of radiating fibers of silica. Grain size of chalcedony is about 0.1 mm.

Muscovite

Mica is present in trace amounts in more than one-third of the thin-sections. It showed high birefringence under cross nicols and occurred as thin elongated crystals (0.05 to 0.25 mm long). Some grains of muscovite are squeezed between other framework grains, illustrating the elastic deformation due to compaction.

Tourmaline

Tourmaline is present throughout both cores but rarely exceeds 1% of the total rock. Grains range from about 0.08

to 0.1 mm in diameter, and are brown to green with high relief under plain light. Under crossed nicols tourmaline showed fairly high birefringence. Grains were pleochroic and usually showed evidence of having undergone some rounding.

Pyrite

Amounts of pyrite range from about 1% to about 5%; average content is near 1%. Grains mostly are anhedral, and are as much as 0.1 mm in diameter; some grains are euhedral and cubic. Leucoxene was present with pyrite in some samples, but amounts were so small that both were grouped and recorded simply as pyrite.

Zircon

Zircon was recorded in almost every thin-section. Most grains were about 0.08 mm in diameter, but "gritty" grains of 0.01 mm in diameter were fairly common. Zircon ranges from a trace to about 3% of the rock volume. Some crystals are euhedral. Rounded grains also were observed. Trace amounts of sphene and garnet were grouped with zircon.

Detrital Chlorite

Detrital chlorite occurred in trace amounts, as rounded green grains. Grains averaged about 0.08 to 0.1 mm in diameter.

Silt

Silt is dependent on grain size alone. Any particle less than or equal to 0.06 mm was classified as silt. For example, 0.01 mm grain of zircon is considered a silt sized particle. Most silt is quartz. Silt sized particles constituted 2 to 15% of the samples described.

Detrital Matrix

Pseudomatrix

The term "pseudomatrix" refers to detrital matrix that has been squeezed and deformed (or recrystallized) due to compaction and other diagenetic processes. Most pseudomatrix appeared to be of illitic nature. Pseudomatrix showed goldish brown color under plain light; it composes only a trace to 3% of the volume of rock.

Diagenetic Constituents

Quartz Cement

Only 1% to 3% of the sandstone is quartz cement. Overgrowths do not show well developed syntaxial forms. No doubt this formation was inhibited by illitic rims that coat most of quartz grains. A second stage of quartz overgrowths were indicated by crystals in the middle parts of pores.

Carbonate (calcite and dolomite)

Carbonate material constitutes a trace to about 3% of the total rock volume. Calcite and ferroan dolomite were observed, in the amounts about equal.

Calcite is present as pore-filling cement and as grain-replacements. Calcite appears as "patches" about 2 mm in diameter, that creates a poikilitic texture enclosing framework grains.

Dolomite is in most of the thin-sections. It has two forms: pore-filling cement and (less commonly) grain-replacement.

Anhydrite

Anhydrite is more sparse in the thin-sections than calcite and dolomite. It is present in amounts less than 1% of the total volume. The anhydrite also occurs, in two fashions: pore-filling anhydrite, and in rare instances, grain-replacements.

Silica Replacement of Anhydrite

Silica has replaced anhydrite cement in trace amounts. Pseudomorphs of anhydrite retain anhydritic cleavage, but have a grayish white siliceous appearance under cross nicols. In some instances texture is poikilitic.

Authigenic Illite

Authigenic illite, in amounts ranging from about 3% to

10%, is present as distinct grain coatings. Illite flakes line grains and pores in a parallel fashion and clog pore throats. Illite appears as illuminated "halos" around framework grains, under cross nicols. Under plain light illite is a greenish brown to gold. The greenish tint is due to small amounts of chlorite.

Authigenic Chlorite

Green flakes of authigenic chlorite fill pores in the sandstone. Clustering of chlorite reduces porosity and permeability, but also produces trace amounts of microporosity. Chlorite constituted 1% to 3% of the rock.

Porosity

In thin-sections, porosity ranges from 5% to 19%. Most porosity is secondary, and is owing mainly to dissolution of of grains of feldspar.

CHAPTER XII

TYPES OF POROSITY

Primary porosity, secondary porosity and micro porosity were recorded from samples of Morrison sandstone. Each of these forms have unique morphology.

Primary Porosity

When sandstones are deposited the maximal hypothetical porosity that can exist is approximately 47.6% of the total rock volume. This is governed by the manner of sorting and stacking of grains. However, in nature this maximal porosity is not achieved. In the cores studied, original intergranular primary porosity probably was about 30%. Evidence for the making of this estimate is the well sorted nature and almost uniform size of the sand grains. At present, primary porosity seems to range from a trace amount to about 6%. (Figure 32 shows primary and secondary pores.)

Diagenetic processes reduce primary porosity. A major diagenetic process that the two cores in this study have undergone is compaction. Ductile grains and micas were forced into available pore spaces and reduced primary porosity. Some grains of feldspar were crushed and forced into pores. Pressure solution presumably associated with compaction, is suggested by crenulated boundaries between grains of quartz. Silica taken into solution precipitated as quartz overgrowths in areas of low compactional pressure (i.e. pore spaces and pore throats.)

Rims of illite that coated most quartz grains probably helped to preserve primary porosity, because they seemed to inhibit quartz overgrowths. (However, these rims reduced permeability because they clogged pore throats.)

Secondary Porosity

The formation of secondary porosity in sandstone is controlled by processes of dissolution. These involve disintegration of metastable framework grains, matrix minerals, and cements. Metastable framework grains of feldspar, rock fragments, and matrix dissolve under hydrogen-ion metasomatism. This process involves reaction between the grain and pore fluid, in which hydrogen ions in water replace the K^+ ions in the grain.

Dissolution of carbonate cements in sandstones involves decarbonization. Schmidt and McDonald (1979a) explained that decarbonization results from the decarboxylation of organic matter in strata adjacent to the sandstone. Decarboxylation generates CO_2, which with water produces carbonic acid. The acid reacts with carbonate minerals and disassociates them.

In this investigation extensive carbonate dissolution could have occurred because of the dissolved edges of the calcite patches. However, framework grain dissolution was very evident throughout the cores.

Partial Dissolution

Partly dissolved grains compose the porosity-texture that is the most common in the studied cores. Sandstones observed in this investigation illustrated this texture by incompletely dissolved feldspar grains. Figure 33 is an excellent example of porosity generated by partial dissolution.

Heterogeneous Packing

In instances where sandstones differ in degree and kind of packing, the more compacted sandstone will have less secondary porosity, because grains tend to be tightly compressed, more cemented. This compaction causes smaller amounts of pore fluid migration; therefore dissolution is reduced. Differences in amounts of secondary porosity due to heterogeneous packing are illustrated in Figure 34.

Elongated Pores

Elongated pores are produced by dissolution along grain boundaries, which results in channel-like passages. Some such passages are not linked; thus permeability is enhanced very little. In some elongated pores, as well as other kinds of secondary pores, authigenic clays were pushed to one side of the pore space. This phenomenon suggests that pore fluids had fairly high migration rates. The fluids may have had "flushing" effects that helped to create and maintain secondary porosity. The possibly high fluid motion might explain why so little pore-filling authigenic clay was observed.

Intraconstituent Pores

The term "intraconstituent pores" refers to feldspar grains that have been partly dissolved. These grains have "honeycomb" appearances because dissolution was preferential along cleavage planes. Figure 35 illustrates honeycombed grains.

Microporosity

Microporosity exists between individual clay flakes. Pittman (1979) defined micropores as having aperture radii less than 0.5 m. These minute pore spaces are created during formation of the clay. Microporosity in thin-sections is within pore-filling chlorite, and it is a very small amount of the total porosity.

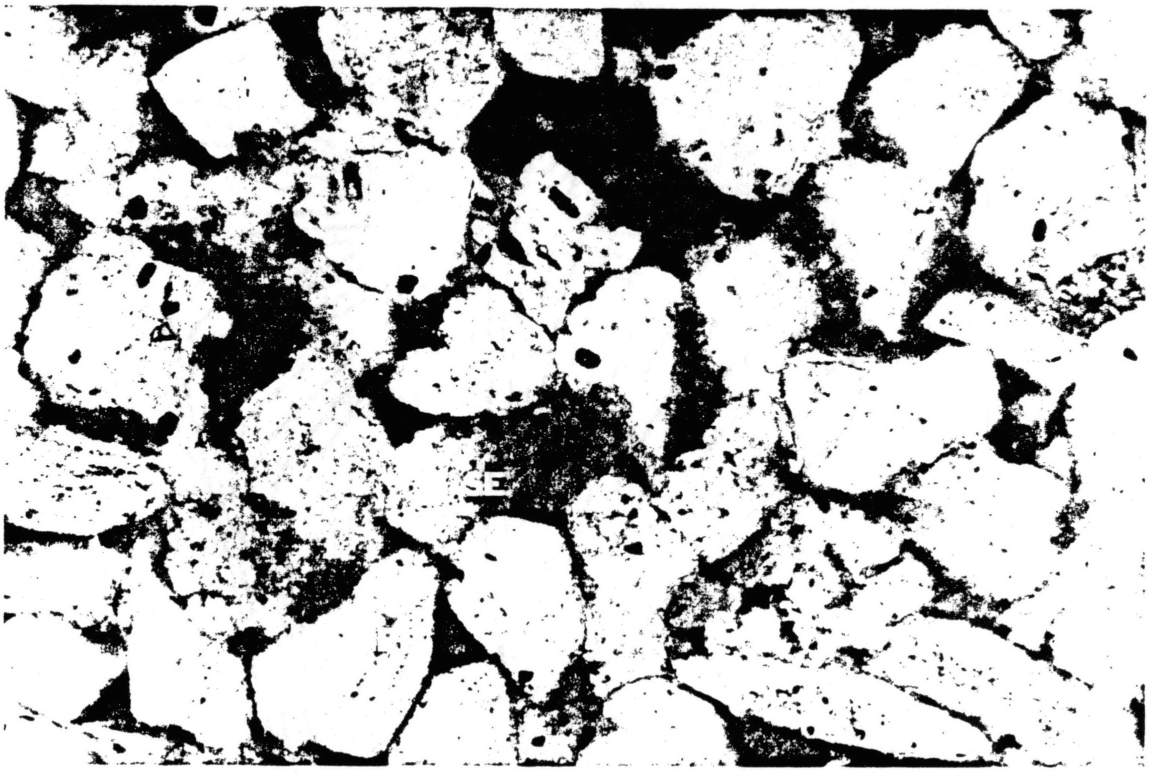


Figure 32. A typical secondary pore space (SE) formed by dissolution. "PE," on the other hand, is an example of a primary pore space. Primary and secondary pore spaces commonly were difficult to differentiate. (100X: core 35-D11, 15,833')

Figure 33. Two types of secondary-porosity textures are shown: elongated pores (El) and pores due to partial dissolution (Pd). Diagenetic pyrite (Py) is porefilling mineral. (100X: core 36-B10, 15,898').

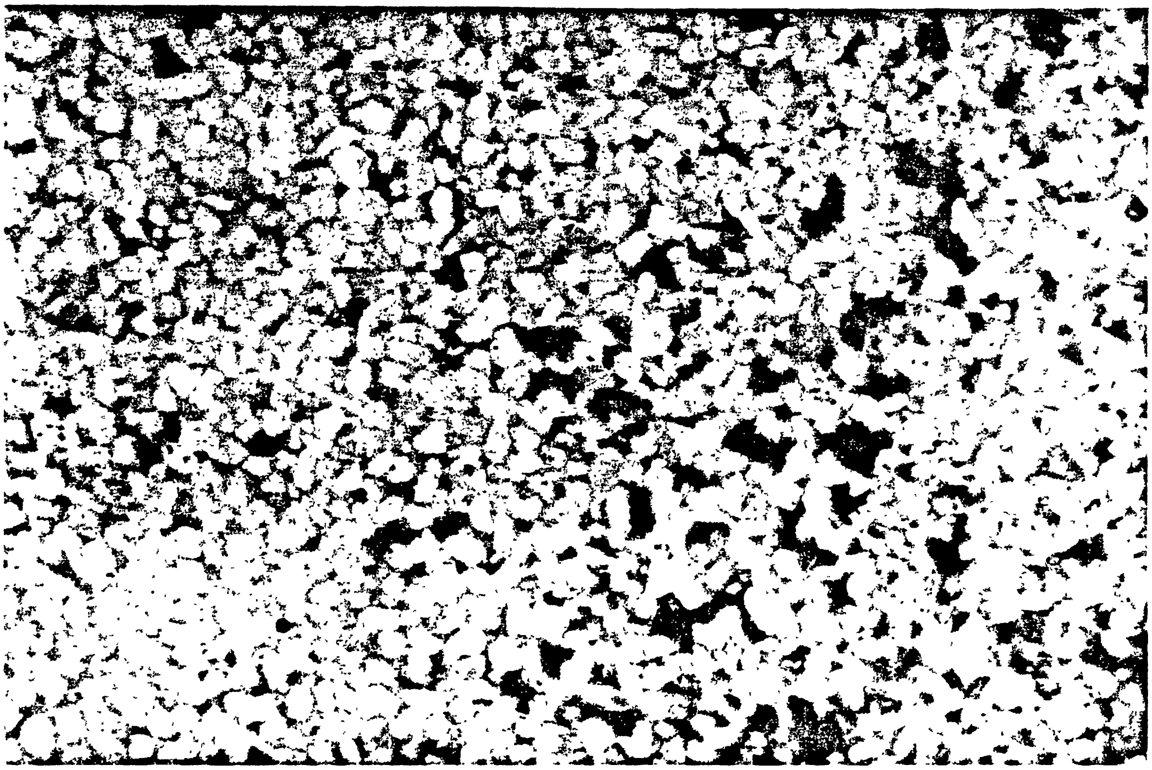


Figure 34. Secondary porosity related to heterogeneous packing. Where one part of a rock is subjected to compaction than another, dissolution is greater in the rock that is the less compacted. (40X: core 35-D11, 15,839.5')

Figure 35. Intraconstituent pores or "honeycombed graines." (400X: core 35-D11, 15,845')

CH4PTER XIII

DIAGENETIC HISTORY

Physical processes of diagenesis involved mainly compaction due to burial. Reduction of porosity was evident in thin-section by the occurrence of crenulated pressure-solution boundaries between quartz grains, by rigid crushed grains of feldspar that had filled pore spaces, and by ductile muscovite and pseudomatrix squeezed into pores.

Chemical diagenesis involved various stages of dissolution, precipitation, and replacement. Dissolution was evident with regard to feldspar, but silica, carbonate, and anhydrite also showed some evidence of having been dissolved. Precipitation involved cementation by quartz (two stages), calcite, ferroan dolomite, and anhydrite. In addition to cementation, pseudomatrix, illite, chlorite, and pyrite were precipitated. Small amounts of calcite and ferroan dolomite replaced detrital grains, anhydrite replaced quartz, and silica replaced anhydrite.

The following is a list and description of diagenetic constituents. Relative timing of these constituents is discussed and is illustrated by a paragenetic sequence shown in Figure 36. The sequence is based on my own observations; these tend to agree with information in Henderson's (1981) report.

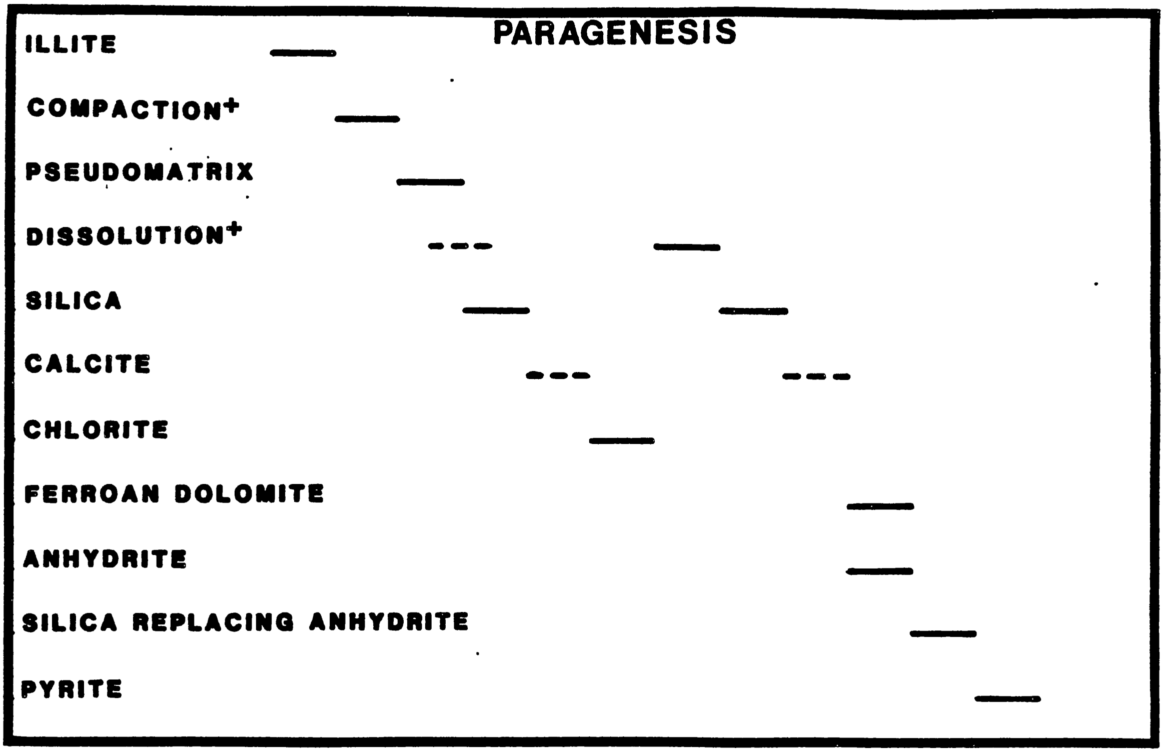


Figure 36. Paragenetic sequence of sandstone in cores of the Union Oil Nos. 36-B10 and 35-D11.

____ time of occurrence

---- probable time of occurrence

\+ probably occurred throughout paragenetic sequence but is only marked as such at most noticeable times

Illite

Formation of authigenic illite coated most of framework grains. They were between quartz grains where apparently no silica had overgrown quartz grains and some instances even under lay apparent overgrowths. This is evidence that rims of illite formed before quartz overgrowths; they probably inhibited growth of quartz. More than likely illite originated from detrital material and pore fluids. In some specimens rims of illite are agents of cementation.

Pseudomatrix

Pseudomatrix was present in both cores. It is remnant material from a detrital matrix (clay) that had been squeezed between grains and into pore spaces during compaction. The pseudomatrix seems to be illitic; possibly it had undergone some form of neomorphism. Henderson (1981) discussed this pseudomatrix but was uncertain of its exact origin and referred to it as clayey grains which had been squeezed into pores.

Silica

Available evidence indicates that cementation by silica occurred in two stages. The first stage was early in diagenetic history. It involved formation of quartz overgrowths which originated from compactional processes. The second stage involved syntaxial quartz overgrowths on silt sized quartz grains in pore spaces. Henderson (1981) explained that this event occurred before dolomitization, because syntaxial quartz crystals encompassed by ferroan dolomite cement. However, I did not see such evidence in the thin-sections.

Chlorite

Authigenic chlorite precipitated next, as flakes infilling pore spaces. Source of the chlorite probably was from dissolution of feldspars and rock fragments within the sandstone; possibly the constituents were in fluids that had dissolved the constituents in other rock units. Sparsity of chlorite might be due to a large migration rate of pore fluid or low amounts of available material for chlorite precipitation.

Dissolution

A second phase of dissolution probably followed deposition of chlorite. Some secondary pore spaces, where grains once had been, were devoid of chlorite. Dissolution involved mainly feldspar. According to Surdam (1984) dissolution of aluminosilicates is governed by mobility of aluminum. He concluded that aluminum-mobility of plagioclase is greater than that of potassium-feldspars. Results of this study indicate that plagioclase was dissolved in larger amounts. Timing of the feldspar dissolution was relatively late, because in some instances entire grains were dissolved, leaving rims of illite. These delicate rims could not have survived if subjected to stresses associated with early compaction.

Calcite

Timing of formation of calcite cement in sandstone of the Morrison is poorly understood. Because of its sparseness few relationships give clues as relative times of events. However, because its texture is similar to that of dolomite, probably they formed almost at the same time. When calcite precipitates, Ca^{++} is removed from solution; thus the ratio of Mg^{++} to Ca^{++} rises and precipitation of dolomite is more probable. Therefore, I believe that calcite formed somewhat earlier than ferroan dolomite in the cores.

The patchy appearance of calcite suggests that at one time more of the rock might have been cemented by calcite. If this is the case, dissolution of calcite would have created some of the porosity that is present.

Ferroan Dolomite

Precipitation of ferroan dolomite, probably the next diagenetic event, filled spaces where framework grains once had been. Some of the dolomite replaced parts of framework grains. Ferroan dolomite can precipitate under deep burial and reducing conditions. The fact that it could occur under deep burial conditions suggests it might have formed fairly late in the paragenetic sequence.

Anhydrite

Cementation of anhydrite also occurred late because it too infilled void pore spaces. Because of occurrences similar to those of dolomite, it is believed to have developed at about the same time.

Anhydrite Replaced by Silica

Silica replaced some of the anhydrite which was present. Evidently, the anhydrite hydrated and a quartz pseudomorph resulted (Phillips, 1981).

Pyrite

Pyrite is believed to have formed quite late. It occurs in amorphous shapes and cubes, superimposed on grains and within pore spaces. Pyrite probably formed from migrating pore fluids rich in sulfur and iron, or it could have formed from migrating hydrocarbons. Markert (1982) explained that precipitation of euhedral pyrite can result from alteration of sandstone by hydrogen sulfide gas associated with petroleum.

Most of the rock constituents and evidence of the diagenetic events are shown in Figures 37 through 42.

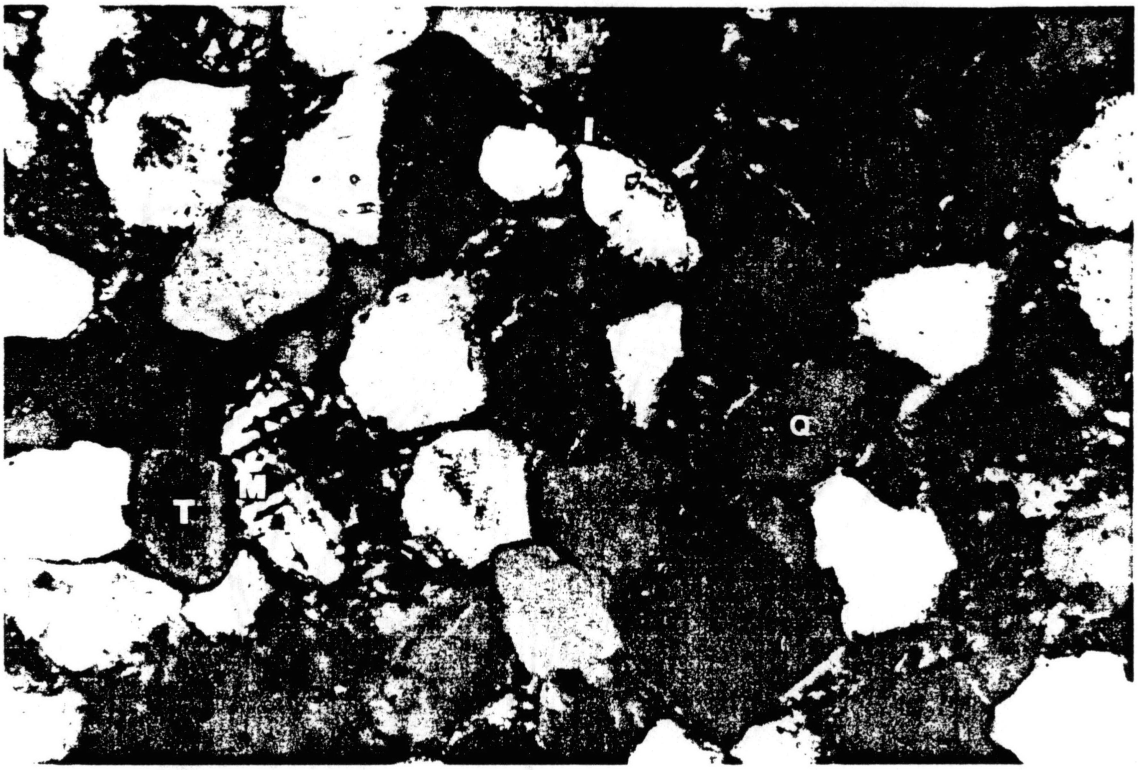


Figure 37. Examples of tourmaline (T), microcline (M), quartz (Q), and illite (I). The illitic rims are goldish brown coatings on grains. (100X: core 36-B10, 15,903')

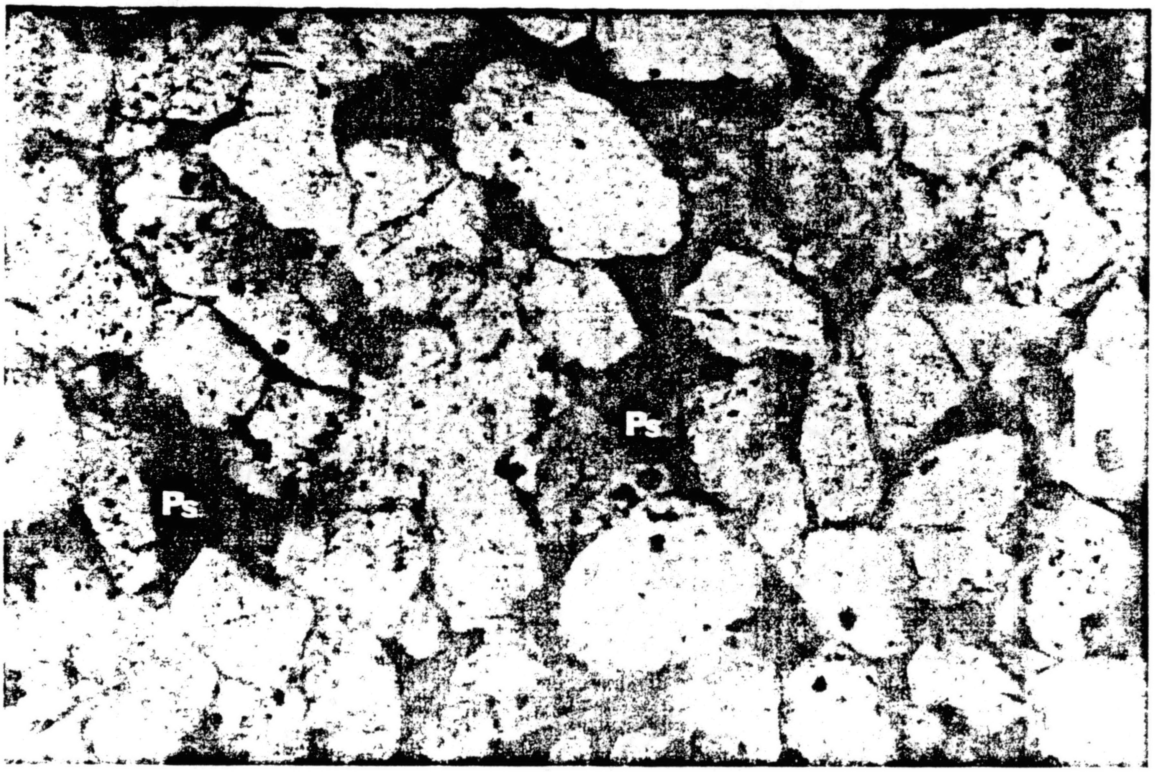


Figure 38. Pseudomatrix (Ps), with evidence of former ductility. Partly dissolved grains and elongated pore near top of photograph. (100X: core 36-B10, 15,978')

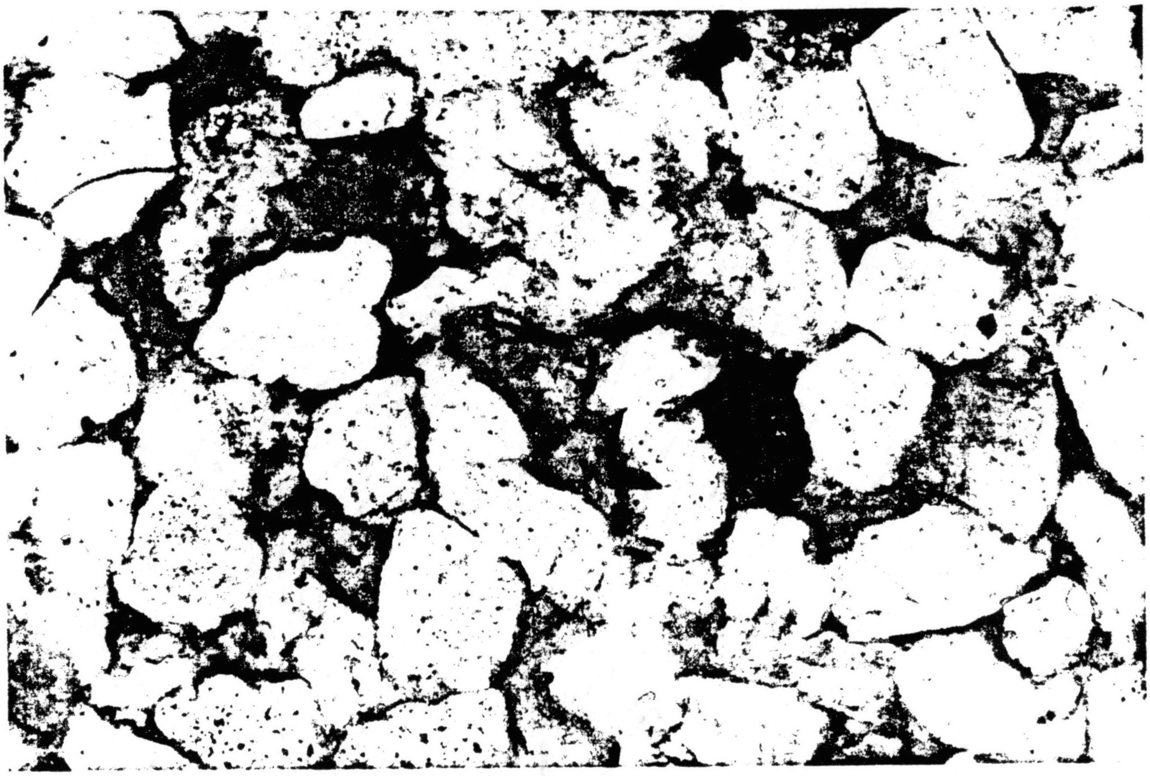


Figure 39. Excellent illite rims coat most framework grains. Rims show evidence of former grains. (100X: core 36-B10, 15,903')

Figure 40. Chlorite (Chl) fills one pore, but not adjacent pore. Chlorite formed before dissolution of grain in adjacent pore. Diagenetic pyrite (Py). Microporosity between particles of chlorite. (100X: core 36-B10, 15,990')

Figure 41. Well developed secondary syntaxial quart overgrowths (2nd). Probable first-order silica overgrowth in the area of the "1st." (400X: core 36-B10, 15,978')

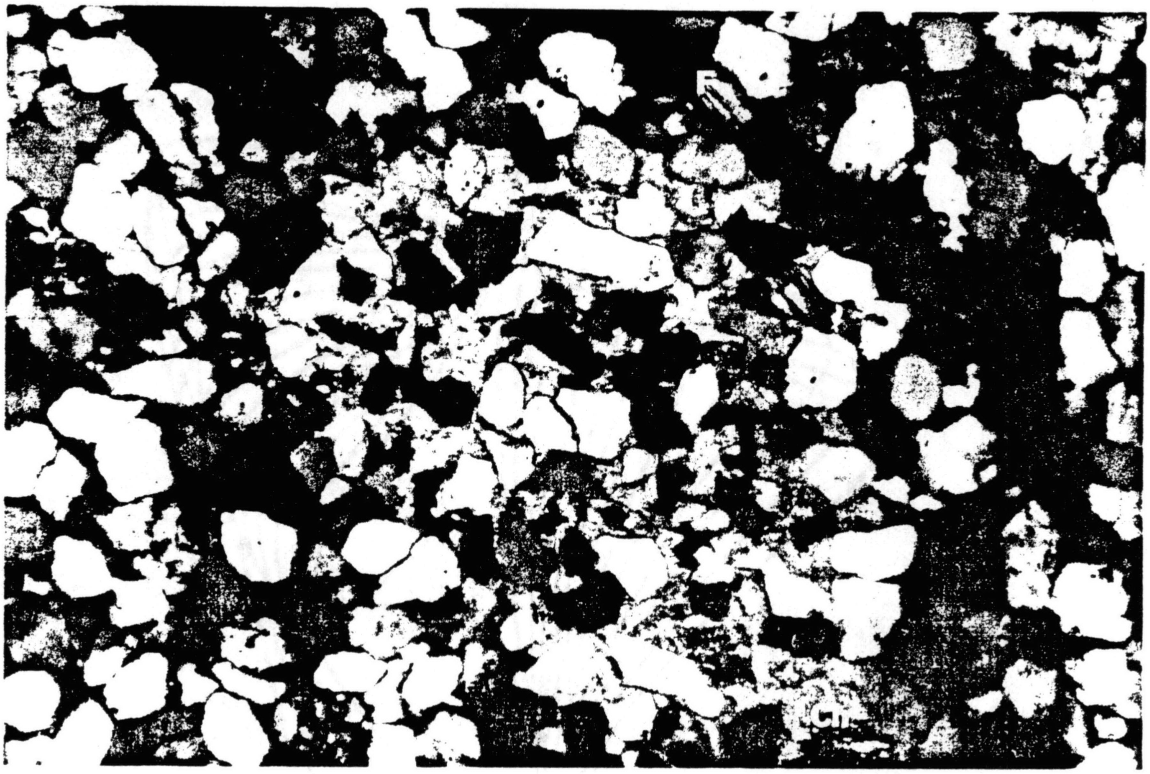


Figure 42. Example of "patchy" nature of the calcite (C). Calcite also has replaced framework grains within this pathc. Chert (Ch) is in the lower portions of this picture. Feldspar grain (F) is in the upper part. (40X: core 35-D11, 15,833')

CHAPTER XIV

CLAY MINERALOGY

Clay extraction was performed on 21 samples (core D11: 15817, 15829.5, 15845, 15851.7, 15862, 15867.5, 15875, 15888, 15913, 15913.5, 15935, core B10: 15895.5, 15898, 15903, 15917, 15926, 15944, 15958, 15965, 15978, 16004). All of these samples showed prominent illite ($2\theta = 8.8$) and chlorite ($2\theta = 12.5$) peaks. Samples were taken at 15867.5 and 15913.5 of the D11 core were of shale. Both of these showed presence of illite and chlorite.

Nine of the 21 samples were glycolated in order to test for mixed-layered clays. A shift in the clay peaks would prove positive; but no shifts were seen. However, some small peaks appeared in the area ($2\theta = 6$) of mixed-layered clays before and after glycolation. Montmorillonite has been known to be a fairly common clay in the Morrison Formation and could be representing this mixed-layered clay peak. It gains its origin from the volcanic bentonite found in the Morrison.

The variety of chlorite present appears to be uncommon. It is the 7-angstrom species, which is iron-rich. In some instances this type is referred to as chamosite.

The following figures (43-47) illustrate X-ray defraction peaks of a typical powdered run, an extracted-clay run, and a glycolated run. Some of the prominent constitutents are identified. Peaks that lie to the right of chlorite in the extracted-clay runs are peaks associated with the mount plate, quartz, and feldspar.

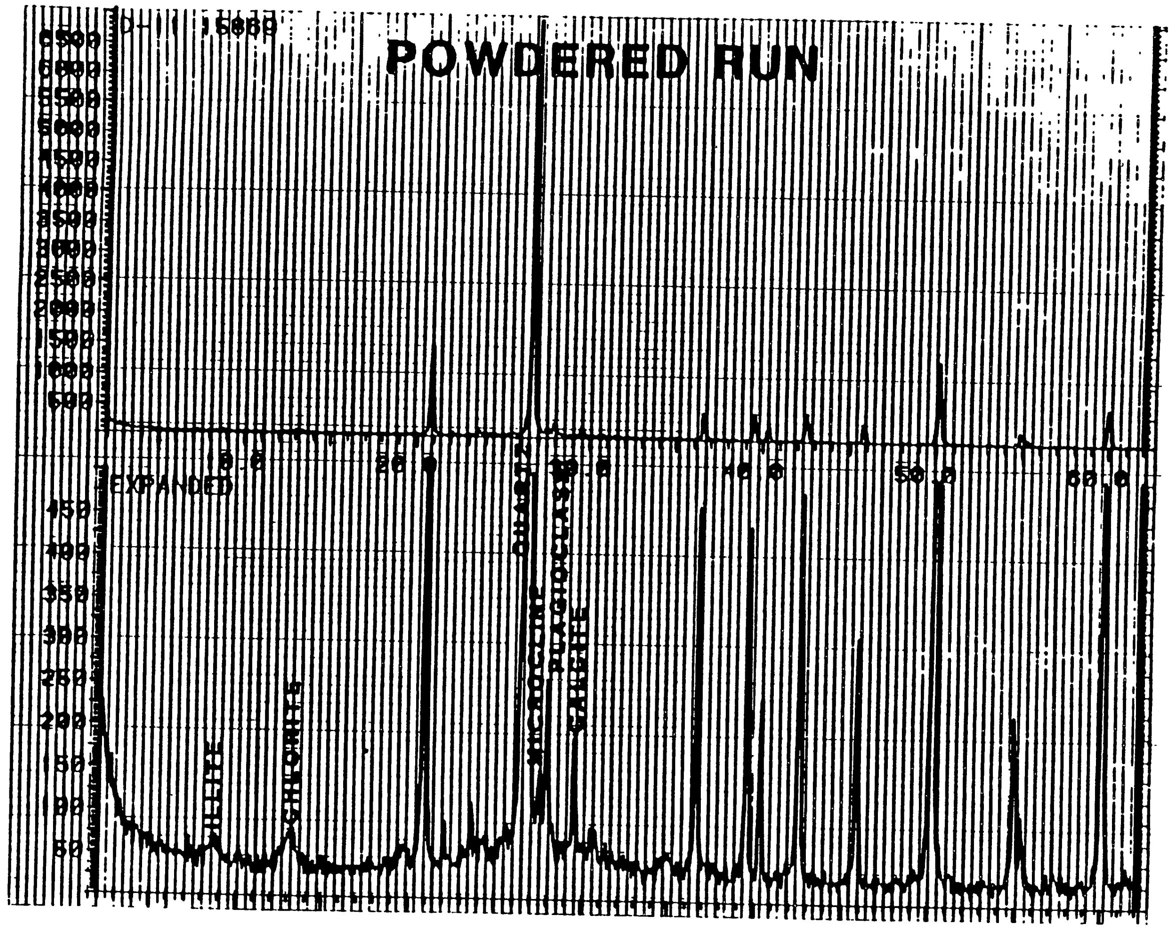


Figure 43. Powdered run of sample, core D-11, 15,869'.

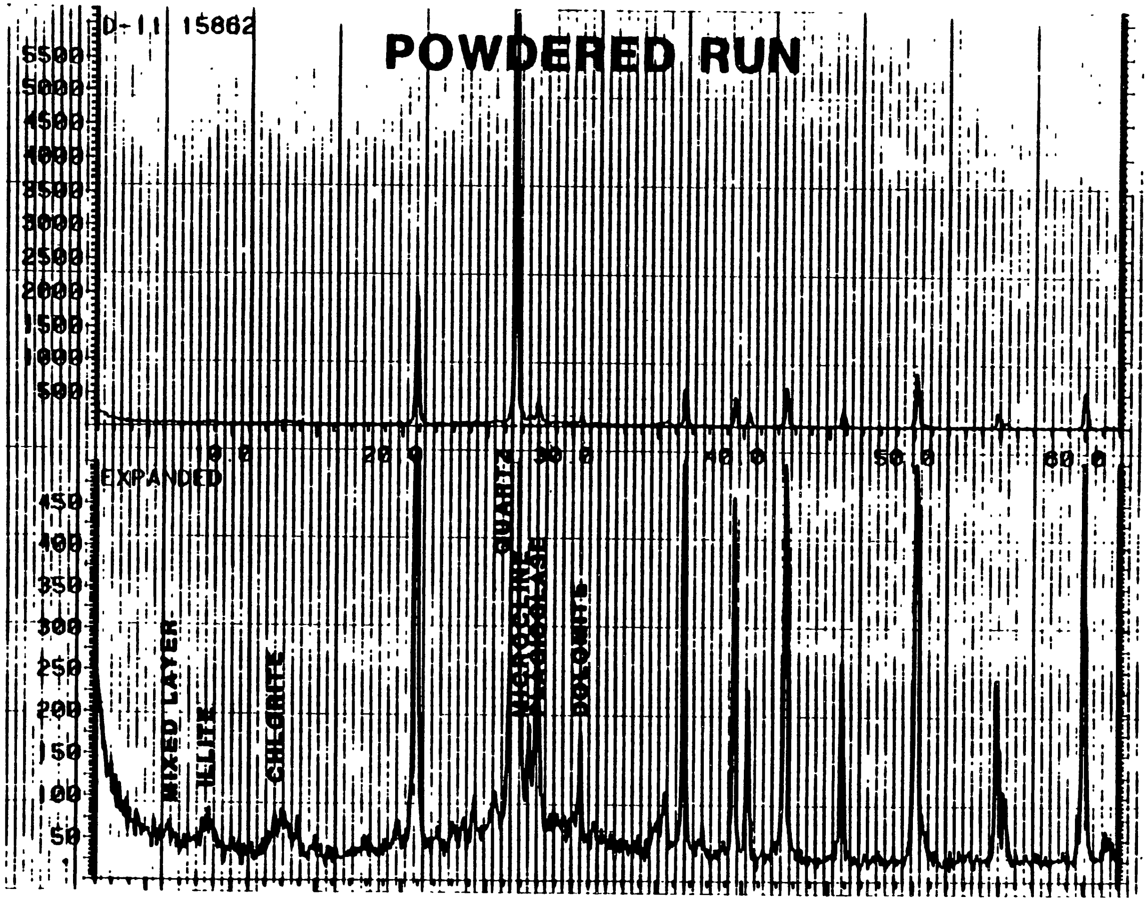


Figure 44. Powdered run of sample, core D-11, 15,862'.

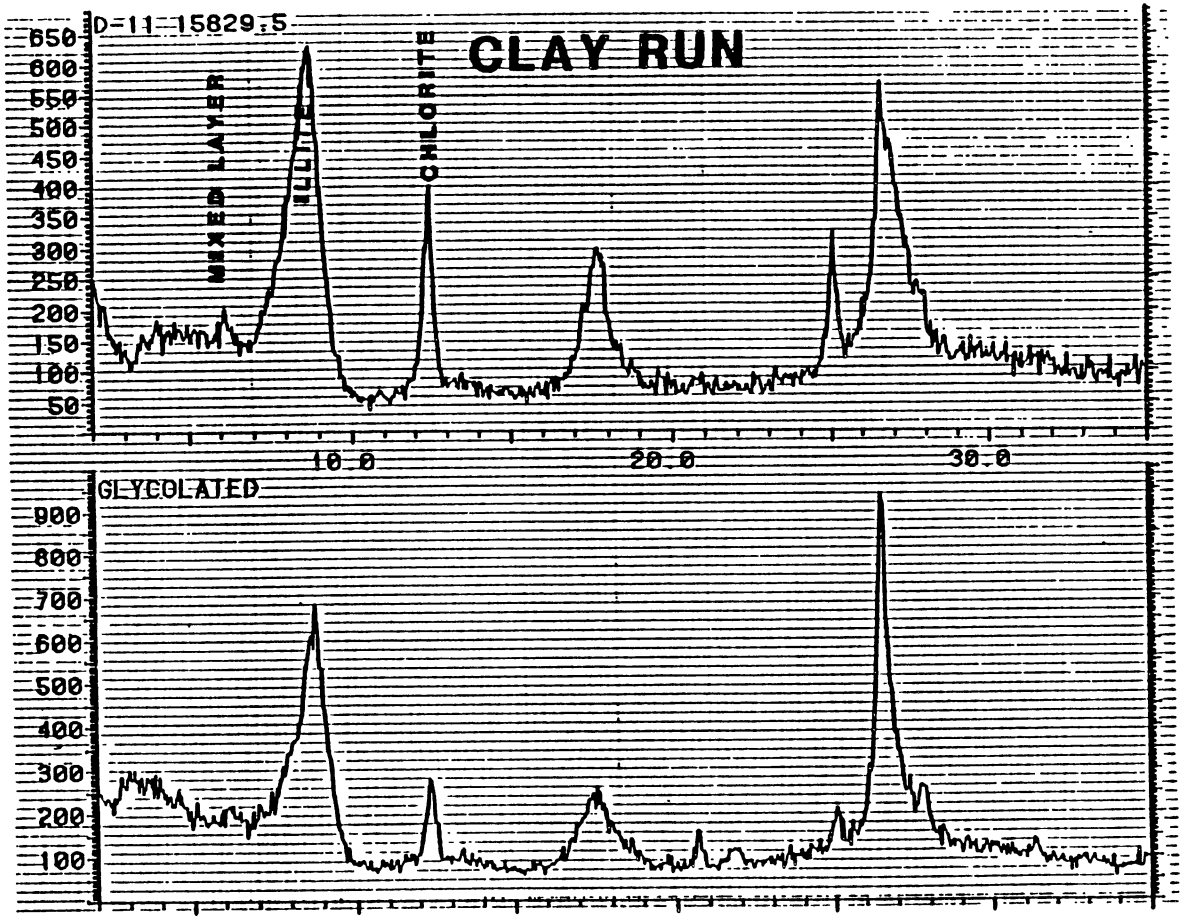


Figure 45. Extracted-clay run of sample, core D-11, 15,829.5'.

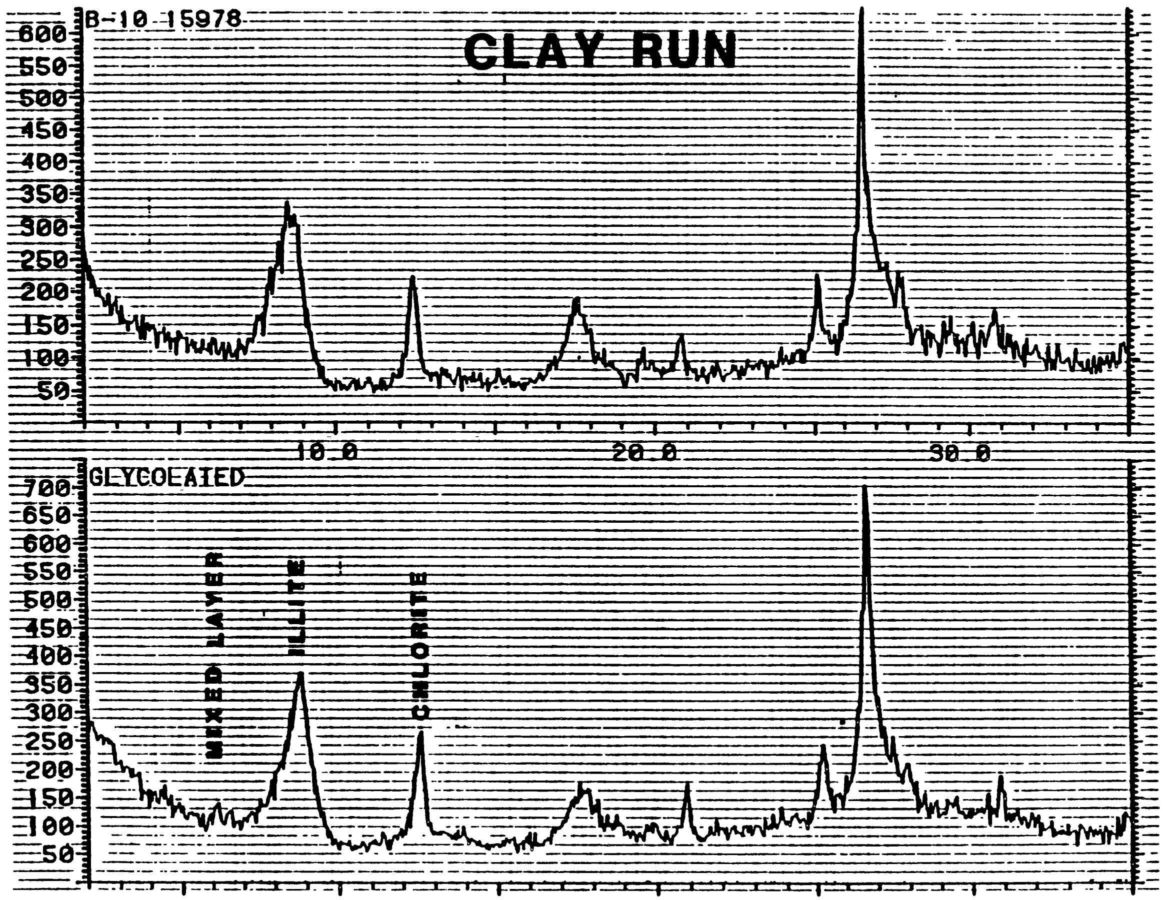


Figure 46. Extracted-clay run of sample, core B-10, 15,978'.

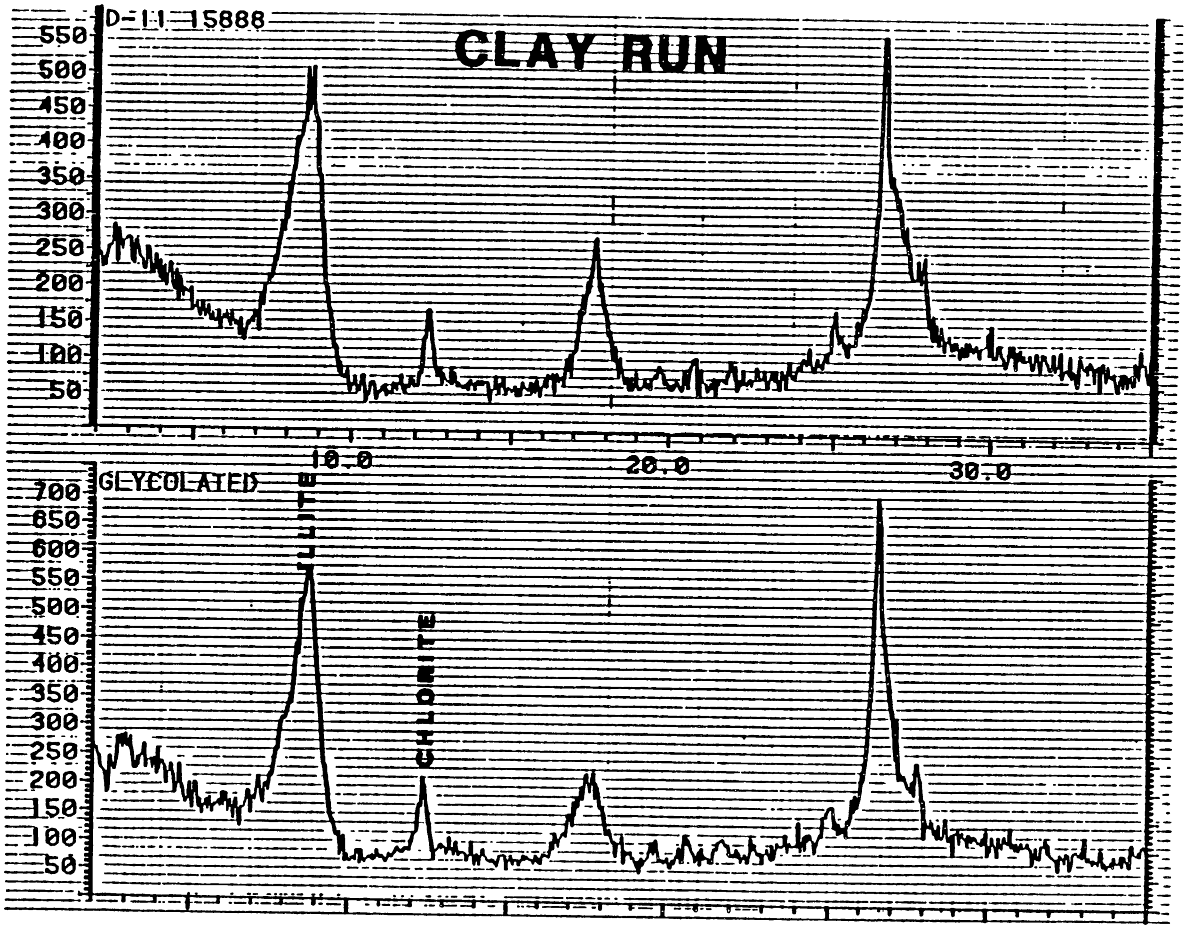


Figure 47. Extracted-clay run of sample, core D-11, 15,888'.

CHAPTER XV

DEPOSITIONAL ENVIRONMENT

The term "depositional environment" refers to all physical and chemical conditions to which strata are subjected during deposition. Variables used herein to interpret environments of deposition were developed from petrolographic analyses.

Past Interpretations

Over the past one hundred years or so numerous interpretations and conclusions have been made on the mode of deposition of the Jurassic Morrison in the western interior. Table 6 illustrates these numerous interpretations.

The latest evaluation of the Morrison Formation that relates directly to the present investigation was done by Casey (1982). He interpreted the Union Oil 36-B10 as the record of stacked shoreface sequences, possibly associated with a wave-dominated delta. He believed that in the West Poison Spider the Morrison area is transitional with the underlying marine Sundance Formation. He concluded that the sandstone body is arcuate to cuspate, with a northeastward trend. These conclusions were based on (1) an upward decrease in bioturbation, (2) upward change from burrow-disrupted parallel bedding and ripple stratification to low- and

TABLE VI

PAST INTERPRETATIONS

Fluvial	Fluvial - Deltaic	Deltaic- Lacustrine	Lacustrine	Eolian	Marginal Marine
Chamberlin and Salisbury 1907	Hatcher 1903	Riggs 1901	White 1886	Szigeti and Fox 1981	Baker 1965
Mook, 1918					Casey 1982
Stokes 1944					
Down 1948					
Chisholm 1963					
Cadigan 1967					
Suttner 1969					
Young 1970					
Campbell 1976					

Morrison Formation's various depositional environments in the Western interior.

moderate-angle cross-bedding, and (3) slight increase upward in mean grain size. Decrease in grain size was judged to be associated with increase in porosity and permeability. The very fine grained, well sorted, subrounded to rounded sandstone of the core is evidence of sand deposited in an environment of reworking, such as that of a shoreface terrain. Casey's procedure was excellent. However, an alternative explanation for the depositional environment of the sand body in the West Poison Spider area seems to be justified by physical evidence. Casey's interpretation may not have included consideration of outcrops and the regional geologic setting.

Most work on the Morrison of the western interior has led to the conclusion that no arm of a sea was in the western interior during Late Jurassic. For example Imlay's (1956) paleogeographic maps depict areas of oceanic and nonmarine deposition, and land areas of nondeposition during the Kimmeridgian and Portlandian (i.e., during time of Morrison deposition, Figures 9-11).

Depositional cycles that Casey chose are subject to reinterpretation. Depositional units do show evidence of upward coarsening. However, comparison of petrologic logs of the 35-D11 and 36-B10 cores show repetitious units containing (1) thin layers of shale (i.e., clay drapes) in the lower portions (2) upward increase in angles of sedimentary structures, and (3) upward decrease in silt content can be defined. Bioturbation was so intensive that in some beds texture is mottled. This feature tends to occur in lower portions of some cycles. All of these characteristics are indicative of eolian-dune sequences. Thus, I conclude the sandstones are eolian origin and that they represent stacked eolian deposits.

The interpretation of shoreface sequences also was based on the subrounded, rounded, well sorted, and very fine grained nature of the sandstone. These properties also are inherent in fluvial and eolian systems.

The source area is another point of question about Casey's interpretation. He explained that the shoreface deposits were oriented northeasterly, and that the source was to the northwest. Considerable evidence suggests that the source lay in another direction. Craig (1955) interpreted the source of the Morrison to mainly be from the south and southwest, relative to the state of Wyoming this being the Basin and Range province of Nevada, Arizona, and New Mexico. Furer (1970) concluded that the source area for the Wyoming interior during Late Jurassic was part of western Utah and northern Arizona. Chisholm (1963) explained that the source of the Morrison was in northwestern New Mexico and north central Arizona. According to Peterson (1952), positive areas in southeastern Arizona and southwestern New Mexico provided sediments distributed to the northeast in the Tri-assic and Jurassic.

Craig (1955), Keller (1962), Moberly (1960), and Chisholm (1963, August 8-10) conclude that some of the Mor-rison was derived from sedimentary rock. This could account for the subrounded to rounded shapes of some grains of heavy minerals in the sandstones. Chert and chalcedony also support the proposition of sedimentary rocks as a source.

The proposed volcanic source seen in Figures 9 to 11 was in west-central Utah and eastern Nevada. These areas supplied volcanic ash, and perhaps other detritus.

The lack of any shell hash in the cores is a piece of evidence which also could weigh against the hypothesis of a marine environment. Reworking of the sediment by waves could account for some decrease in shell hash but surely not all of it.

Numerous species of freshwater invertebrate and vertebrate fossils in the Morrison of Wyoming are strong evidence of nonmarine envirnoments. Freshwater pelecypods, gastropods, ostrocads, charophytes, and dinosaurs are a few examples (Stanton, 1915; Mook, 1916; Roth, 1933; Peck, 1937; Peck and Baker, 1948; Yen, 1952; Branson, 1964).

Bioturbation was used by Casey in support of his interpretation. However, worms, insects, and freshwater pelecypods, and gastropods also could burrow and create mottled textures. For example, Moberly (1960) explained that contorted bedding, mottling, and bioturbation are indicative that the Morrison probably was formed in lacustrine and floodplain environments. Absence of glauconite in the cores is also suggestive of nonmarine conditions.

Interpretation of Study Area

Sandstone of the Morrison in the study area and in cores is grayish white, massive, very fine grained, well sorted, and friable. Cross-bedding is large-scale. Angles of dip are as much as 29^{o} and directions of dip are quite variable.

In the outcrop, bioturbated rock is sparse. Tracks, trails, and burrows are not as abundant as in cores, perhaps because of weathering. Mottled rock was seen at some localities. Ahlbrandt (1978) reported that ants and plant roots disturb bedding enough possibly to develop mottling. Ahlbrandt and Fryberger (1982) explained that in wet interdune areas activity of both plants and animals result in bioturbation and organic debris in the sediment.

Dunes that assumedly accumulated in the study area possibly formed from southerly winds blowing across the plains around the area. It is believed that shortly after the final retreat of the Sundance Sea the entire Wyoming area was covered by fine grained sediment. This sediment along with upper Sundance material were probably two sources for the dunes. I also believe that a wadi environment might have existed.

The model of my interpretation of deposition of the Morrison Formation within the study area is in Figure 48. Dunes seem to have been deposited on a plain, and then to have been dissected by erosion and eventually buried by fluvial and lacustrine deposits. Evidence for this comes from the stratigraphic position of the fluvial sandstone relative to the underlying eolian sandstone.

Some dunes of the eolian sandstone could be traced for more than a mile and other times only for 100 yards or so.

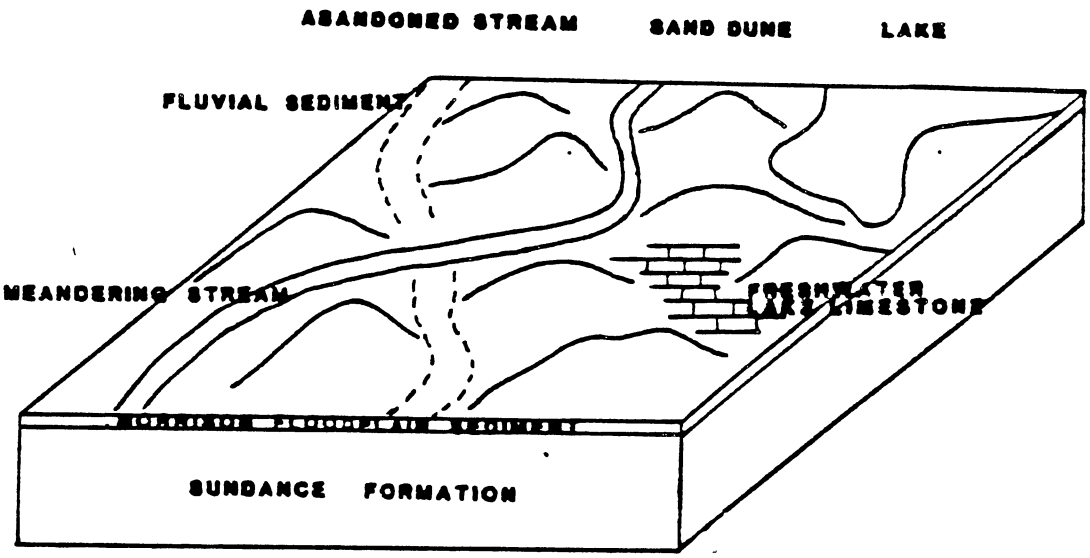


Figure 48. Schematic block diagram illustrating hypothetical depositional conditions of the Morrison Formation within the study area.

Fluvial sandstone in outcrops seemed to be thickest in areas where eolian facies are absent and thinner where in direct contact with dunes. I conclude that the basal Morrison eolian sand that exists in the southeastern portion of the Wind River Basin was not a thick, extensive "sand sea" but more a terrain of "patchy" sand bodies, some as thick as 186 feet.

The following is a list of characteristics that support the interpretation of a dominantly eolian depositional environment during deposition of the Morrison Formation:

1. Large-scale trough- or wedge-shaped cross-bedding.
2. Large-scale planar/tabular cross-bedding.
3. Well-sorted very fine grained sand.
4. Evidence of bioturbated rock and mottled textures.
5. Evidence of interdune deposits.
6. Evidence of animal tracks.
7. Evidence of high index ripples oriented up and down the leeside of eolian dune deposits (Ahlbrandt and Fryberger, 1982).
8. Soft-sediment faulting.
9. Absence of evidence generally taken as being indicative of marine deposits, (e.g., marine fossils, glauconite, herringbone cross-bedding, ect.) or of fluvial deposits (e.g., conglomerate, rip-up clasts, clay drape, etc.).

This interpretation seems to explain the observable facts in the manner judged most likely to be true.

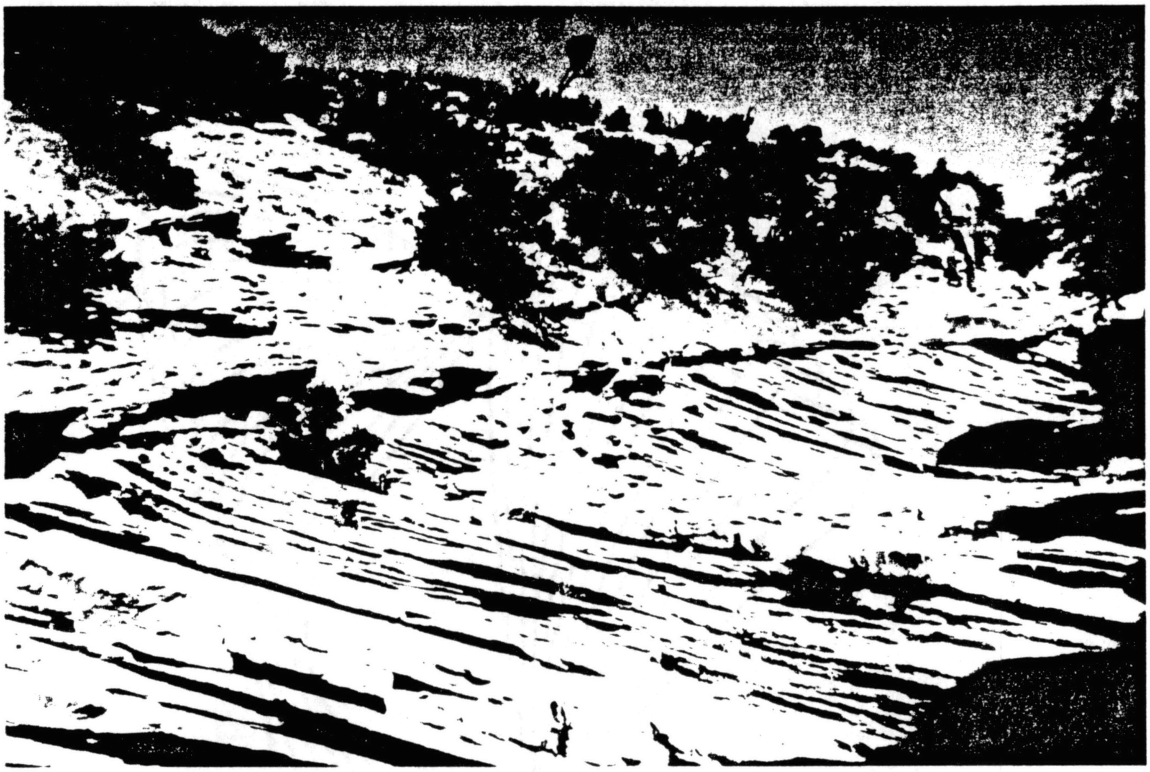


Figure 49. Large-scale tabular/planar cross-bedding at the Baker Cabin outcrop. An eolian indicator. (Photograph by Gouger, 1986)

Figure 50. High-index ripple marks, along the possible lee-side of a dune, which is similar to one of Ahlbrandt's and Fryberger's (1982).

CHAPTER XVI

SUBSURFACE GEOLOGY

Maps constructed for use in this study consist of a structural contour map, a full-interval isopach map, and a net isopach map of sandstone. The structural geologic map (Plate 5) shows configuration of the top of the Morrison Formation. This surface is an unconformity so configuration of contour lines might be influenced locally by paleotopography. However, in areas where the Morrison produces oil (West Poison Spider, Pasture Canyon, and Powder River fields) closure ranges from 100 to 300 feet.

Plate 6 depicts total thickness of the Morrison. The sandstone isopach map (Plate 7) suggests possible accumulations of sand transverse to the postulated wind direction (from the southeast). Types of dunes should not be inferred from configurations of contour lines because well data are much too sparse and differentiation between eolian sand fluvial sand on well logs is difficult, especially if the bodies of sandstone are stacked. Implied southeast-northwest trends of sandstones on the isopach map are introduced partly because the well data are concentrated along subsurface anticlinal folds. Because well control is poor, numerous other interpretations of thicknesses and trends of sand bodies could be made. I have presented the distribution that I judge to be most probable.

Thicknesses of sandstone were calculated from gamma ray and induction logs. The values calculated are approximately equal to 50% of the gamma ray delfection; therefore, some siltstones might be included in the measurements. Thus the measurements are somewhat optomistic.

Because of relatively uniform grain size and general absence of shale, the log signature of eolian sandstone generally would be expected to be cylindrical, with a somewhat abrupt lower contact and an abrupt upper contact. Selley (1980) explained that "clean", low-A.P.I. gamma-ray logs with "occasional" upward asymmetric sawtooth patterns are diagnostic features of eolian sandstones. I believe that log signatures of some sandstones in the Morrison of the West Poison Spider Field show these characteristics (Figure 51).

On the other hand, a cylindrical log signature with abrupt contacts and slight serration is indicative of stacked marine-deltaic deposits (i.e. barrier bars and distributary channel-fill sandstone). The logs of 36-B10 and 35-D11 have such an appearance (Figure 51). Probably this is one reason why Casey (1982) interpreted the depositional environment of the Morrison as being related to marine conditions. Of course, log signatures are a single, nonconclusive line of evidence.

Figure 52 depicts log signatures of the Morrison in selected other parts of the study area. Slight fining-upward

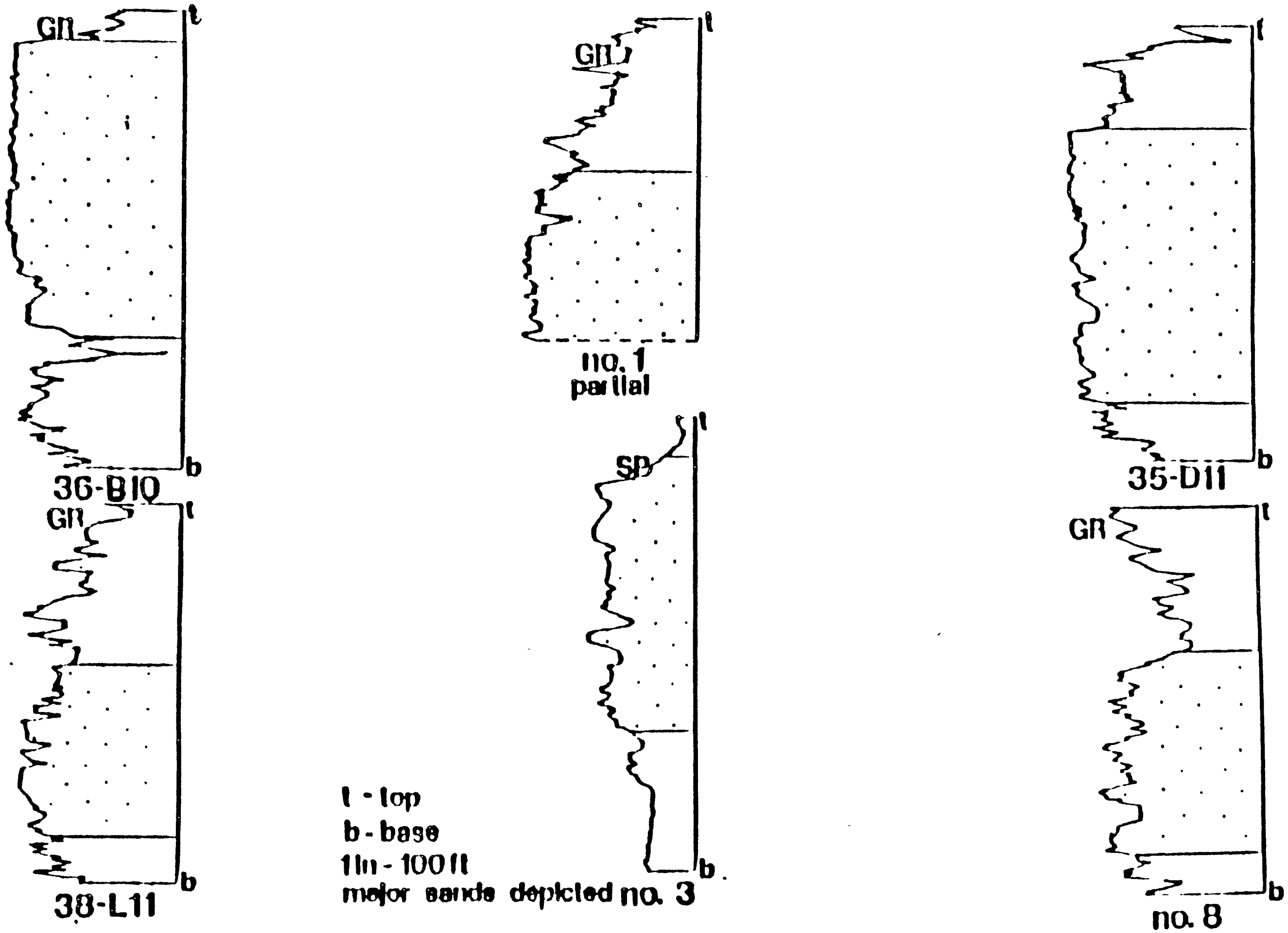


Figure 51. The cylindrical appearance of log signatures of the Morrison in the West Poison Spider Field. The boundaries of the eolian sand bodies are depicted. All of these wells are the property of Union Oil. The numbers of each well are given. Unit No. 1 was only partial'y logged. The scale given is a vertical scale.

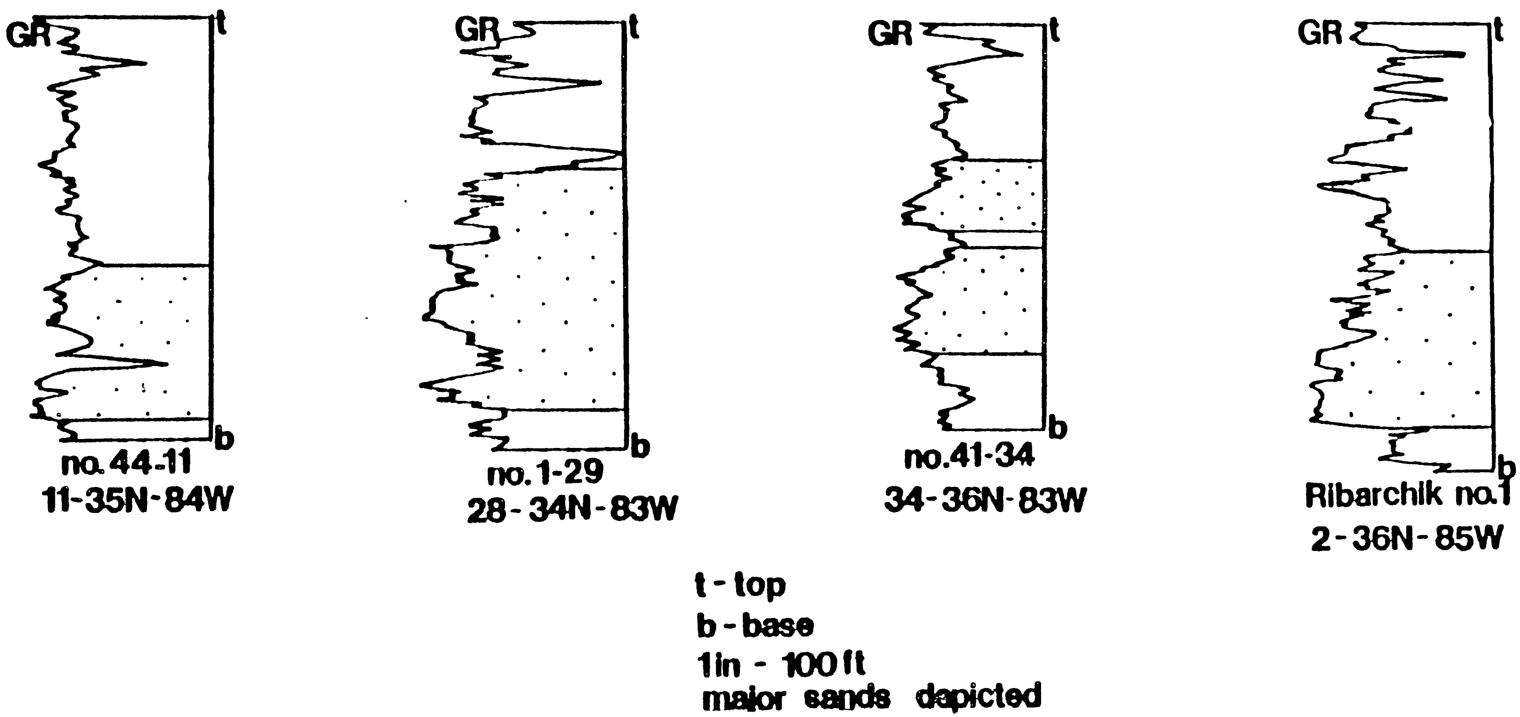


Figure 52. Log signatures of the Morrison from within the study area. The scale given is a vertical scale.

sequences can be inferred from these, especially in the Rib-archik No. 1 well, which could be indicative of fluvial deposits.

A fourth interpretation of the log signatures is that of a hybrid environment, one including deposits under both marine and nonmarine conditions. Figure 53 illustrates sandstone interpreted as a thin delta-marine fringe underlying a thicker alluvial deposit. The bell shape of the supposed alluvial implies a fining upward sequence.

Parts of the Morrison have sometimes been described as being somewhat of a transitional phase between the marine Sundance below and the nonmarine sediments of the Morrison above (Casey, 1982).

A cross-sectional view of the Morrison is shown in Plates 3 and 4. The Morrison appeared to have rather similar lithologic characteristics in most parts of the study area. The upper most 100 feet or so dominantly is shale, underlain by a thick unit of sandstone with interbeds of shale. This interval of sandstone is composed of one to four distinctive sandstone bodies ranging in thickness from 10 to 186 feet. Average thickness of the thickest sandstone is approximately 50 feet. The relative consistency of the Morrison throughout the study area indicates that it was deposited under generally similar conditions during a stable tectonic period. Slight variation in thickness of the Morrison, as shown in cross-sections probably is due to variation in configuration of the unconformity.

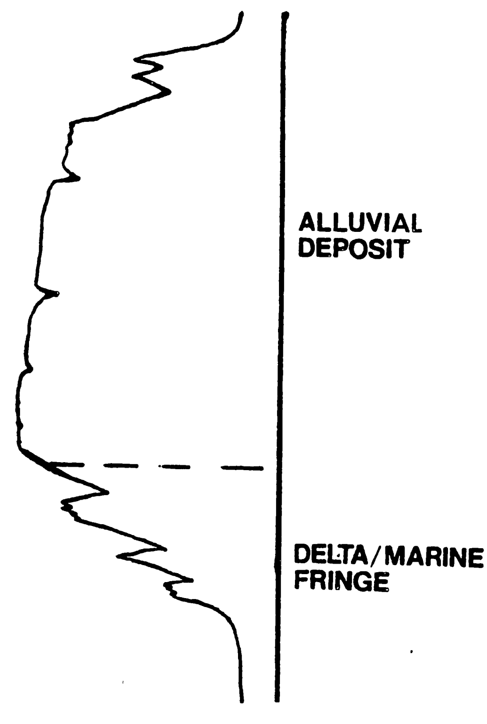


Figure 53. Log signature of a possible hybrid environment.

CHAPTER XVII

RESERVOIR QUALITY

The major trapping mechanism within the West Poison Spider field is a northwest-trending anticline, a Laramide fold (Plate 5). It is deep-seated, located on the footwall side of a major thrust fault that defines the eastern boundary of the Wind River Basin.

Prior to the Laramide orogeny Wyoming was part of the stable shelf that sloped gently westward toward the Cordilleran geosyncline. This circumstance favored up-dip migration of hydrocarbons. Hydrocarbons migrated eastward to contact with some barrier, whether structural or stratigraphic. Keefer (1969) believed that primary hydrocarbon accumulations in pre-Laramide strata occurred before the Laramide orogeny. Keefer (1969) believed that the hydrocarbons which exist today in Laramide structures migrated secondarily into them from nearby areas.

Hunt and Forsman (1957) and McIver (1962) believed that because hydrocarbons in some of the Triassic and Jurassic reservoirs in the Wind River basin had their source from both older and younger rock. Oil from older and/or Cretaceous strata could have migrated secondarily into Triassic and Jurassic reservoirs through faults and fractures created during Laramide deformation. Keefer (1969) commented that thick gray shales of the Sundance Formation in western portions of the Wind River Basin may have been a source, but that if so the Sundance should be more abundantly productive than it is. The organic-rich red and purple shales and claystones of the Cretaceous "Rusty beds" are also believed to be a source of petroleum in the Morrison (Keefer, 1969).

According to Hunt and Forsman (1957) crude oils in reservoir rocks of the Morrison are lighter (greater than 30 API), more paraffinic and less sulfuric than are the asphaltic oils or Paleozoic reservoirs. Because of similarity of composition and widespread occurrence of oil in the Morrison, the Morrison itself could be a source of hydrocarbons. However, because of the Morrison's presumed terrestrial depositional environments, gas would be more probable than oil.

Sealing mechanisms of Morrison reservoirs probably are within the Morrison. Throughout the Wind River Basin the upper portion of the Morrison comprises shales, muds, and siltstones. Commonly these intervals are thicker than 100 feet. Thus, an impermeable barrier would seem to be highly likely. Furthermore, fine-grained strata are numerous in the middle and lower portions of the Morrison, and these could function as seals. Thin, tightly cemented sandstones that are in some cores could form permeability barriers.

A good reservoir rock has enough porosity and permeability to allow accumulation and production of hydrocarbons in profitable quantities. Entities that govern the amount of porosity and permeability are cements and "fines" (clays and silts). Within the West Poison Spider area the Morrison has as much as 20% porosity at some places, but permeability is fairly low (range .01-7.4 md, mostly is less than 1 md). Nonetheless, locally the Morrison is a good producer with good flow rates (cum 300 MBO).

Diagenetic events govern the amounts of cements and authigenic clays that occur in sandstones. Thus, the porosities and permeabilities of sandstones are directly affected. Quartz overgrowths, pseudomatrix, carbonate, anhydrite, illite, and chlorite all had a decreasing effect on the amount of porosity and permeability in the cores studied. Each constituent, taken alone, seemed not to have much effect. But when considered in pairs, distinct relationships are detectable. Silt probably is the single most influential variable in reduction of porosity and permeability.

Figures 54 and 55 show plots of (permeability values supplied by Union Oil's personal well file) porosity versus permeability values of the studied cores. General increase of permeability with increase of porosity is evident. Authigenic clays (illite and chlorite) were present in noticeable amounts in the samples studied. No doubt they affect porosity and permeability but no distinct trends or relationships were documented.

Figures 56 through 59 depict how various diagenetic constituents and silt are related to porosity and permeability of cores. Points plotted represent measurements from point counts made on the thin-sections.

Only six wells have penetrated the Morrison in the West Poison Spider Field. These are Union Oil of California's: Whitting No. 1, Unit No. 3, Unit No. 8, No. 35-D11, No. 36-B10, and No. 38-L11. Four of these have produced from the Morrison (35-D11, 36-B10, 38-L11) and Unit No. 3. The Unit No. 3 no longer produces from the Morrison. The Whitting No. 1 produced only water, whereas the Unit No. 8 contained approximately 140 feet of tight, nonproductive sandstone.

Access to data from the Whitting No. 1 is limited. The Morrison was penetrated but only the upper portion was logged. On the top-of-Morrison datrum, the Whitting No. 1 structurally is the lowest well in the West Poison Spider field.

In Unit No. 3, according to Clark (1978), the Morrison is very similar in sorting, rounding, grain size, and color to rocks in Nos. 35-D11 and 36-B10. Porosity and permeability tend to increase upward in the stratigraphic section. Henderson (1981) speculated that such increases could be controlled by decrease in silt. The core that Clark described has been lost, so no opportunity existed for petrographic analysis. Sandstone in the Unit No. 3 and Unit No. 8 was reported as being slightly calcareous (Clark, 1978, Amstrat log).

According to Clark (1978) and by inspection of the Amstrat log, Unit No. 8 also appears to be very similar lithologically to cores from the No. 35-D11 and No. 36-B10. On the Amstrat log grain size is described as being fairly consistently 0.125 mm throughout. Low permeability of the rock probably is the primary reason for nonproductivity of this sandstone. Henderson (1981) attributed the low porosity to change in depositional environments, in comparison to those that existed during deposition of the Morrison in the No. 35-D11.

Rocks of the Morrison in the Unit No. 8 contain much more shale and silt, probably the result of low-energy depositional environments. Recorded on the Amstrat log are several calcareous strata that may have originated in freshwater lakes.

Very little data are available on the Morrison in the No. 38-L11 well, but thickness and log signature similar to those of the No. 35-D11 and 36-B10.

Henderson (1981) analyzed pore throats in samples from the 35-D11 core. Basically he concluded that portions of the rock with larger amounts of porosity and permeability have wider pore throats (4.5 to 30μm). Henderson concluded that larger amounts of primary porosity were preserved in these areas, contributing to fluid circulation and removal of dissolved silica. Such circulation could have introduced framework-grain dissolution. In parts of the rock with low porosity and permeability, narrow pore throats are narrow (0.31 to 0.9μm). These pore throats are indicative of reduced preservation of primary porosity and absence of secondary porosity.

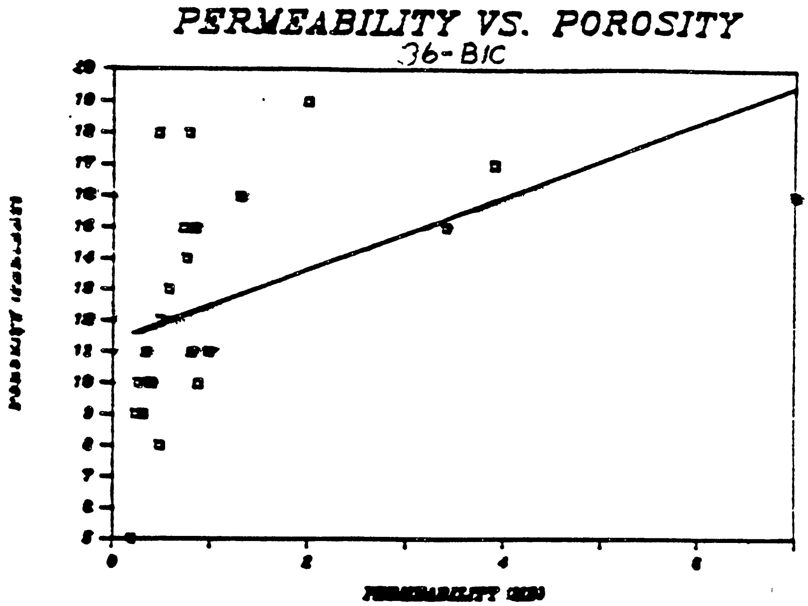


Figure 54. Graph showing general increase of porosity with an increase in permeability. Permeability enhances porosity generation. (1MD increase equals 1% increase in porosity).

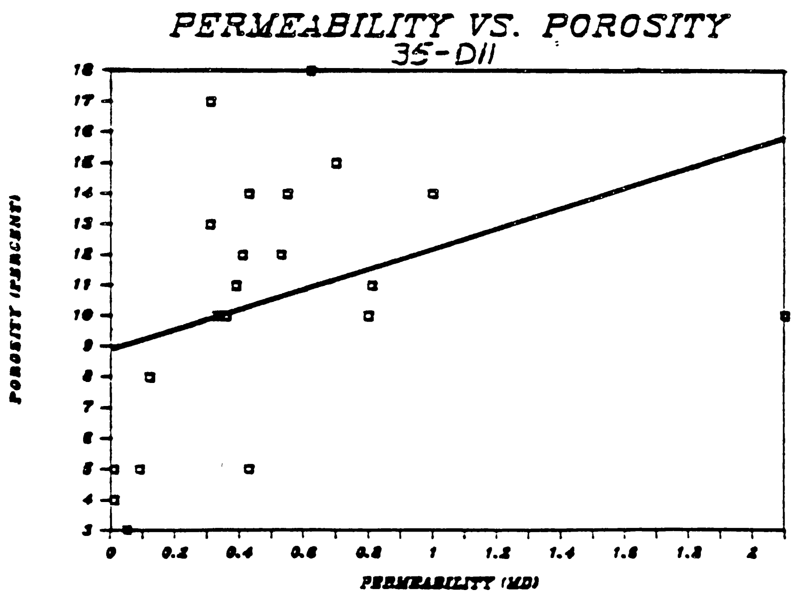


Figure 55. Graph showing an increase in porosity with increase in permeability. Permeability enhances porosity generation (1MD increase equals 3% increase in porosity).

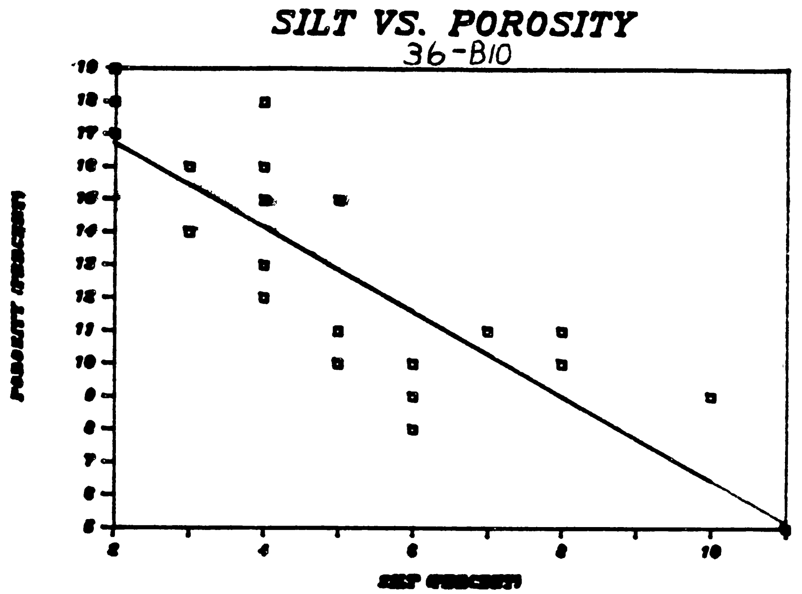


Figure 56. Graph showing a decrease in porosity with an increase in silt.

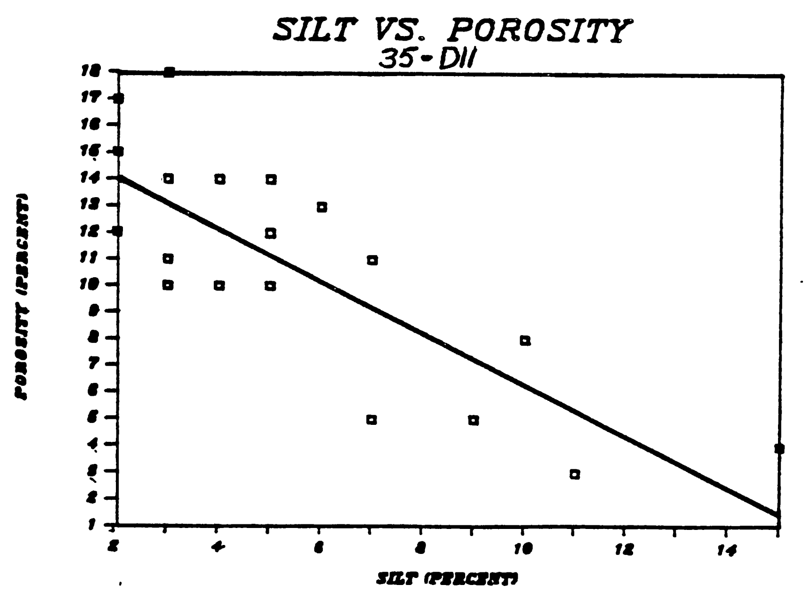


Figure 57. Graph showing a decrease in porosity with an increase in silt.

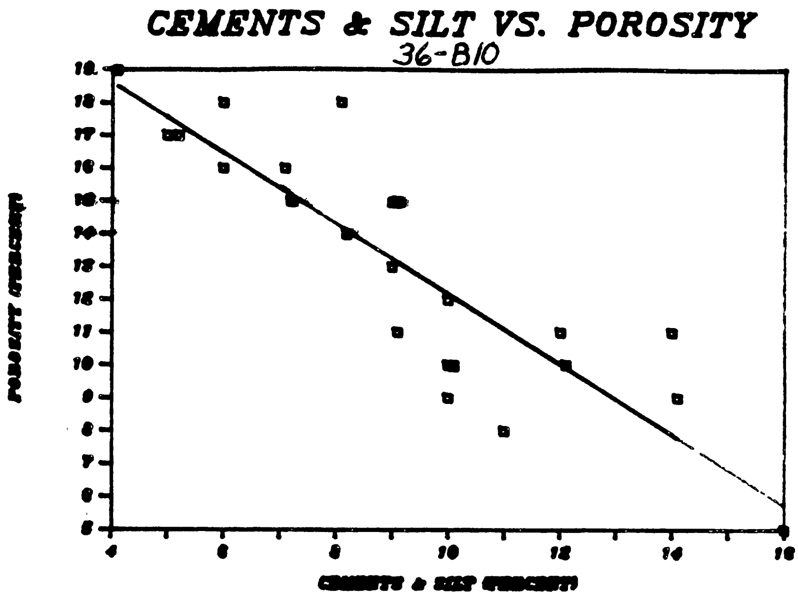


Figure 58. Graph showing a decrease in porosity with an increase in cements and silt.

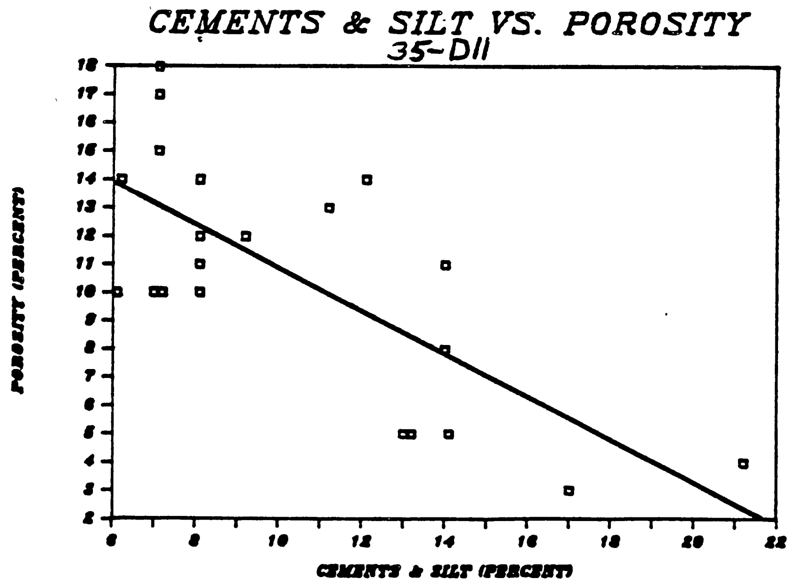


Figure 59. Graph showing a decrease in porosity with an increase in cements and silt.

CHAPTER XVIII

CONCLUSIONS

1. Sandstones of the Morrison Formation in cores are subarkose, noticeable amounts of illite and chlorite.
2. In the Union Oil No.'s 35-D11 and 36-B10, sandstones of the Morrison are stacked eolian deposits that ranged from 6.5 to 33 feet thick.
3. Silt content was the major controller of porosity and permeability.
4. From study of outcrops two distinct sandstone lithotypes are dominant in the Morrison: fluvial and eolian sandstone.
5. The thick sandstone of the Morrison at West Poison Spider Field is judged to be eolian.
6. This eolian sandstone underlies the fluvial sandstone.
7. The eolian sand was deposited in a semiarid to arid environment and buried by fluvial and lacustrine sediment.
8. Maximal recorded thickness of sandstone is 186 feet. The dune field probably never reached the stage of being a "sand sea".
9. The presumed dunes seemed to have been discontinuous laterally. In some instances the strata can be traced in outcrop for as much as a mile; in other instances,

dimensions of the sandstone bodies are only a few hundred yards. The base of the sandstone seemed to be "horizontal", whereas the top apparently was hummocky.

10. Angles of dip on cross-beds of the dunes were recorded as 29 degrees; individual sets of cross-beds were as thick as 10 feet.
11. Large-scale trough cross-beds and tabular cross-beds are apparent in outcrops.
12. A complete and detailed study of outcrops of the Morrison Formation in the region of the study area should be very productive.

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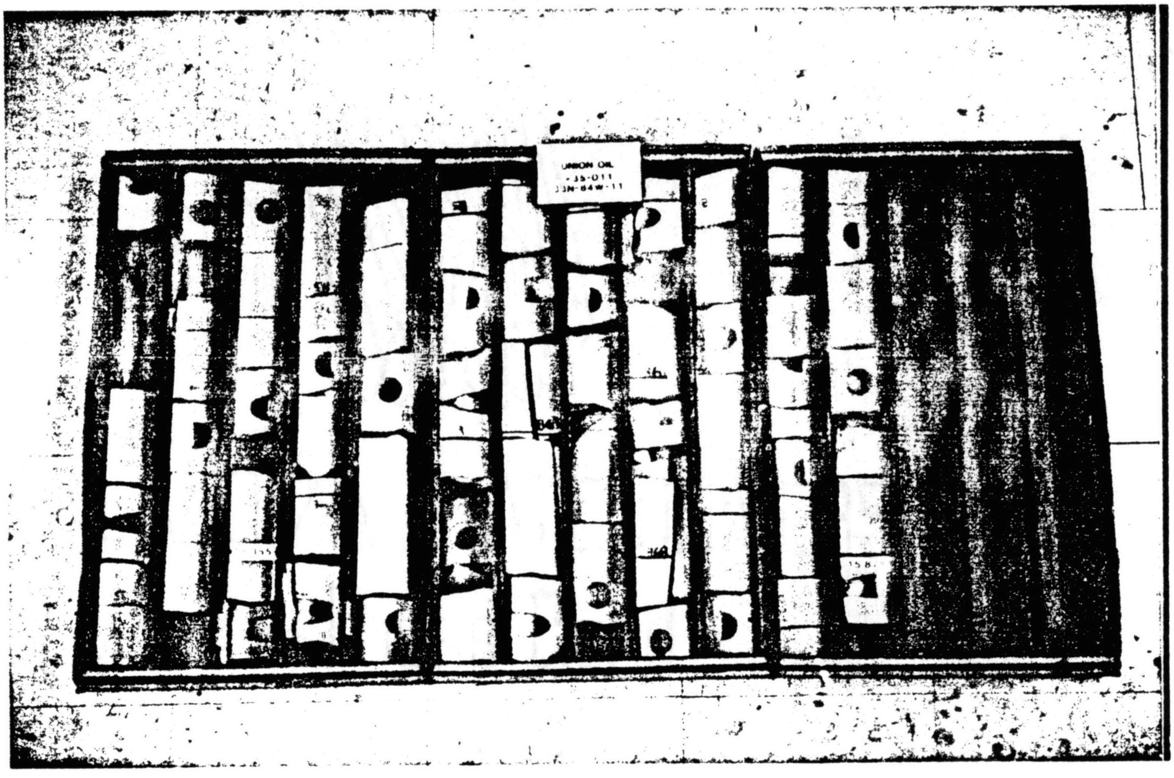
APPENDIX

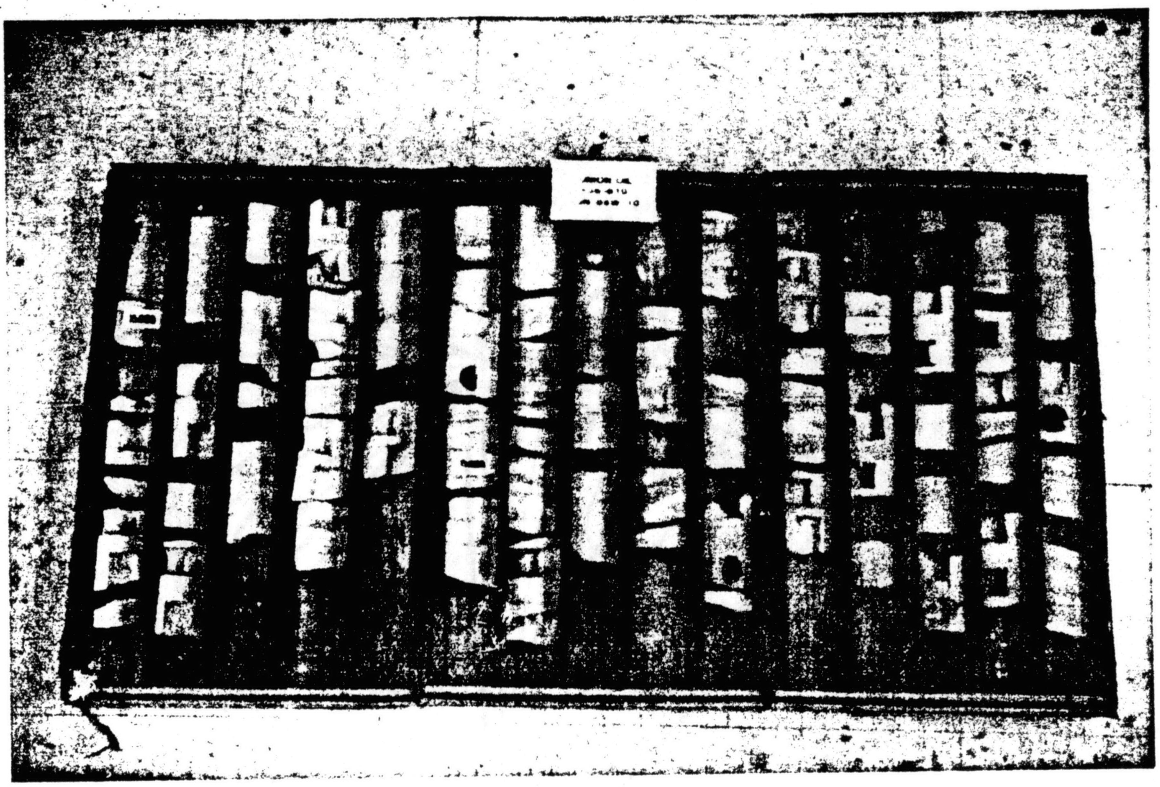
Core Photographs

The follow photographs are of the cores studied. The first four are of 35-D11 whilethe second four are of 36-B10. The depths are marked on the cores themselves.

35-D11 15817-15849



35-D11 15849-15875



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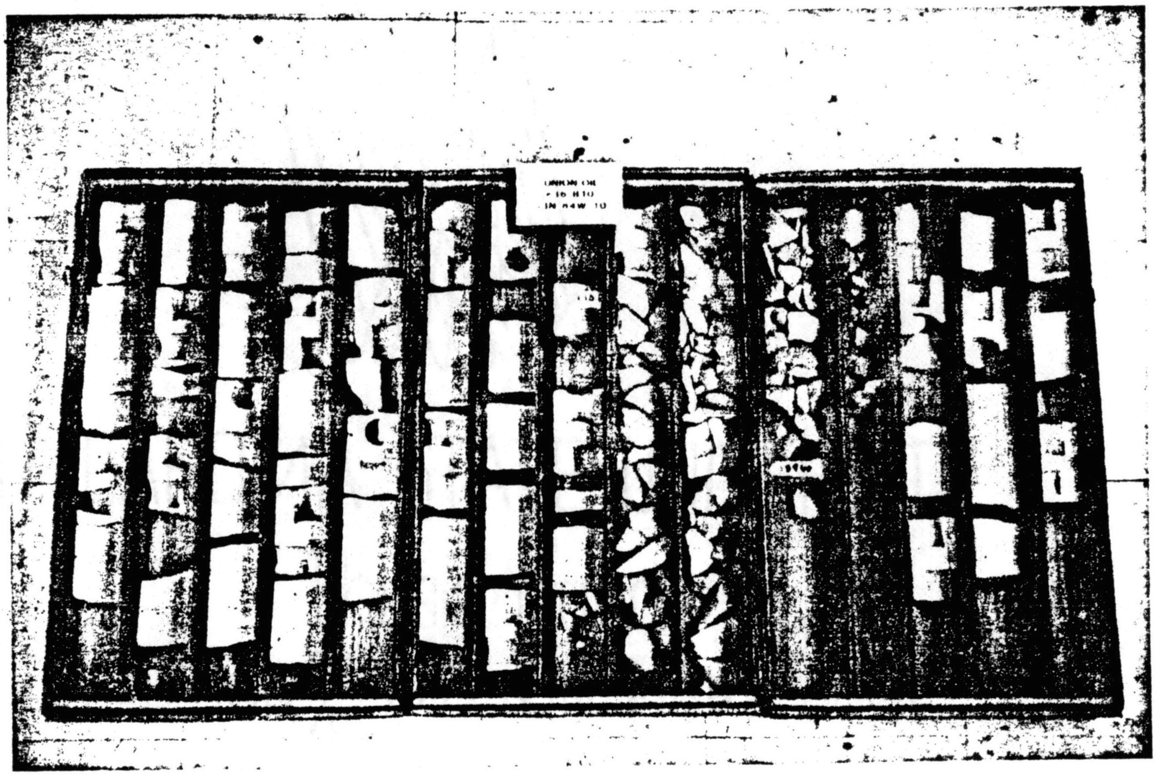

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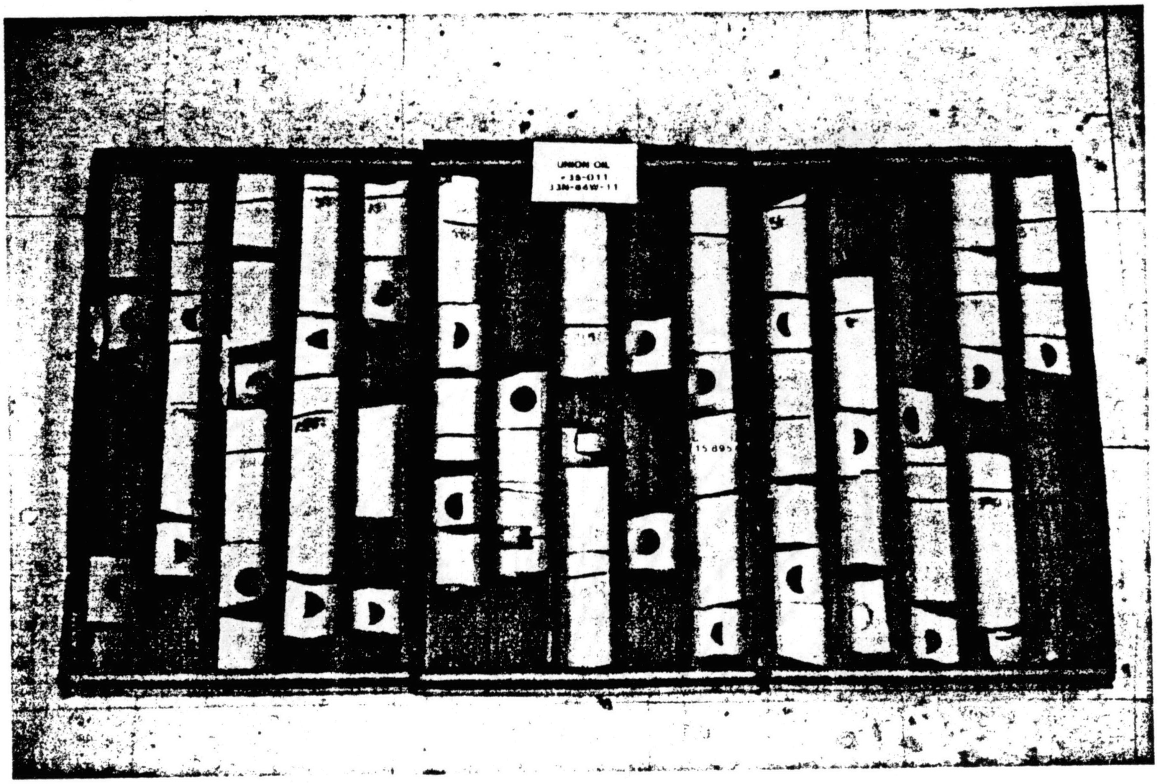

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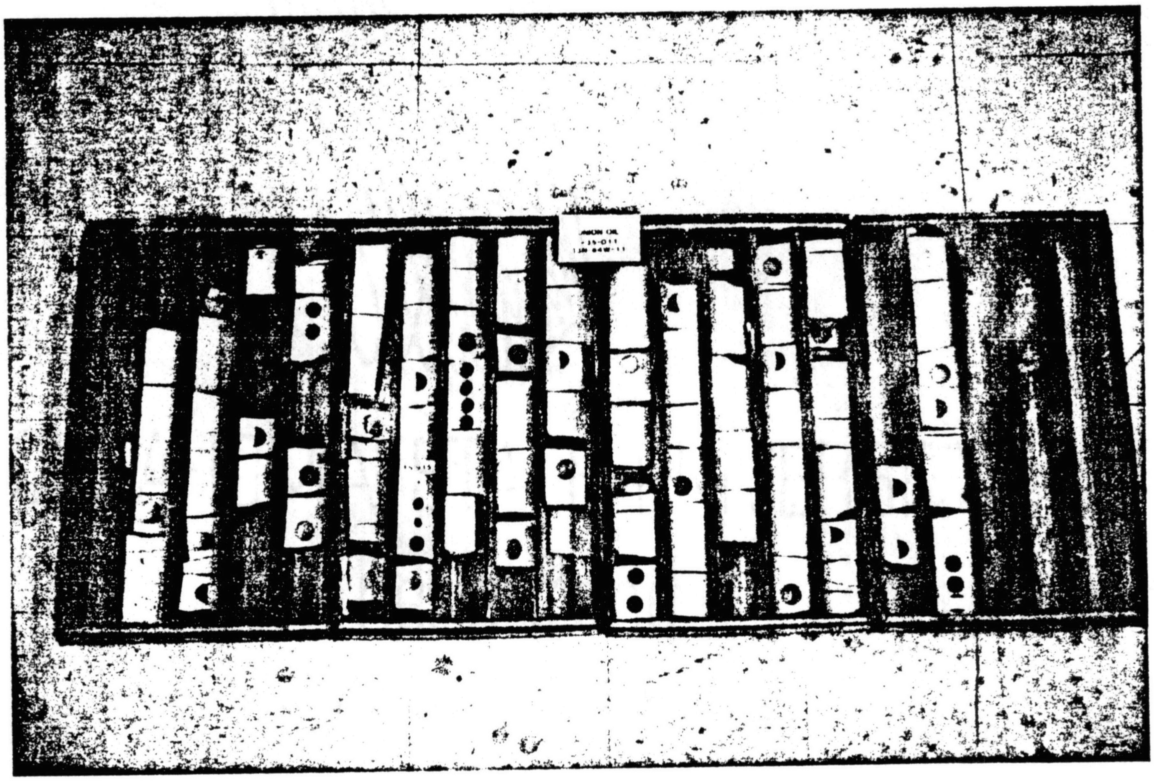

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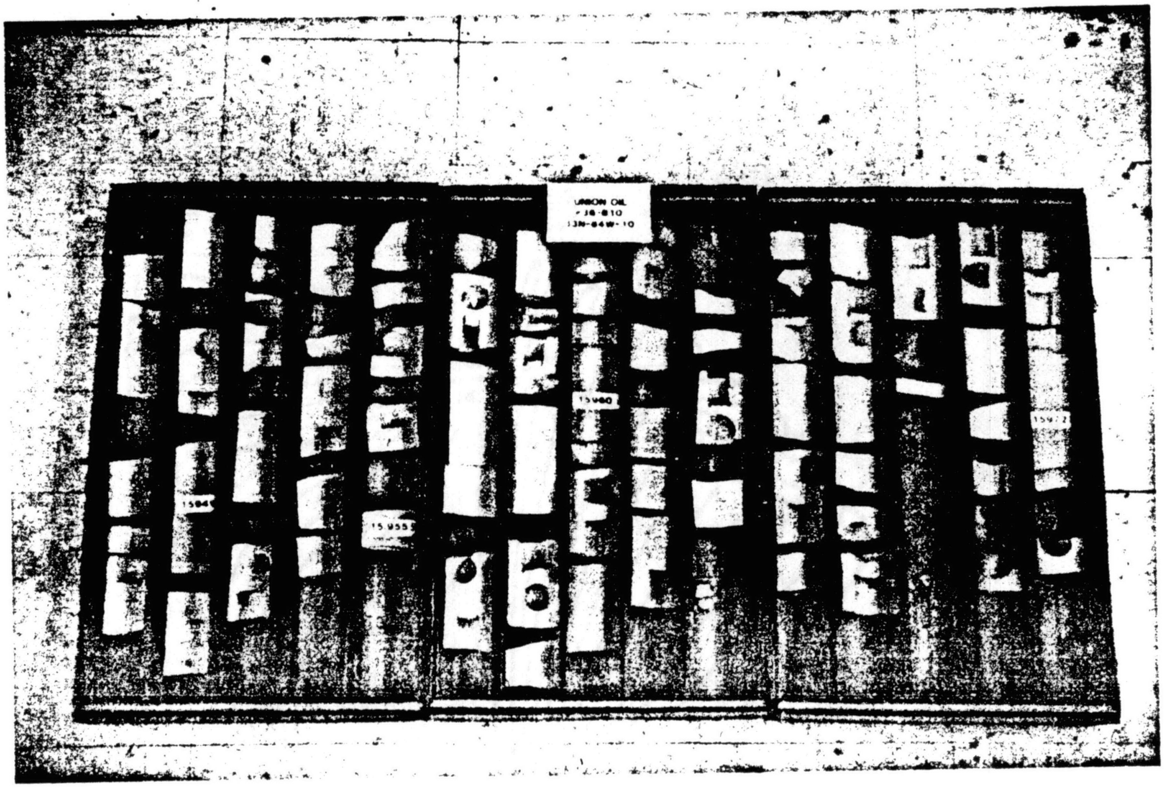

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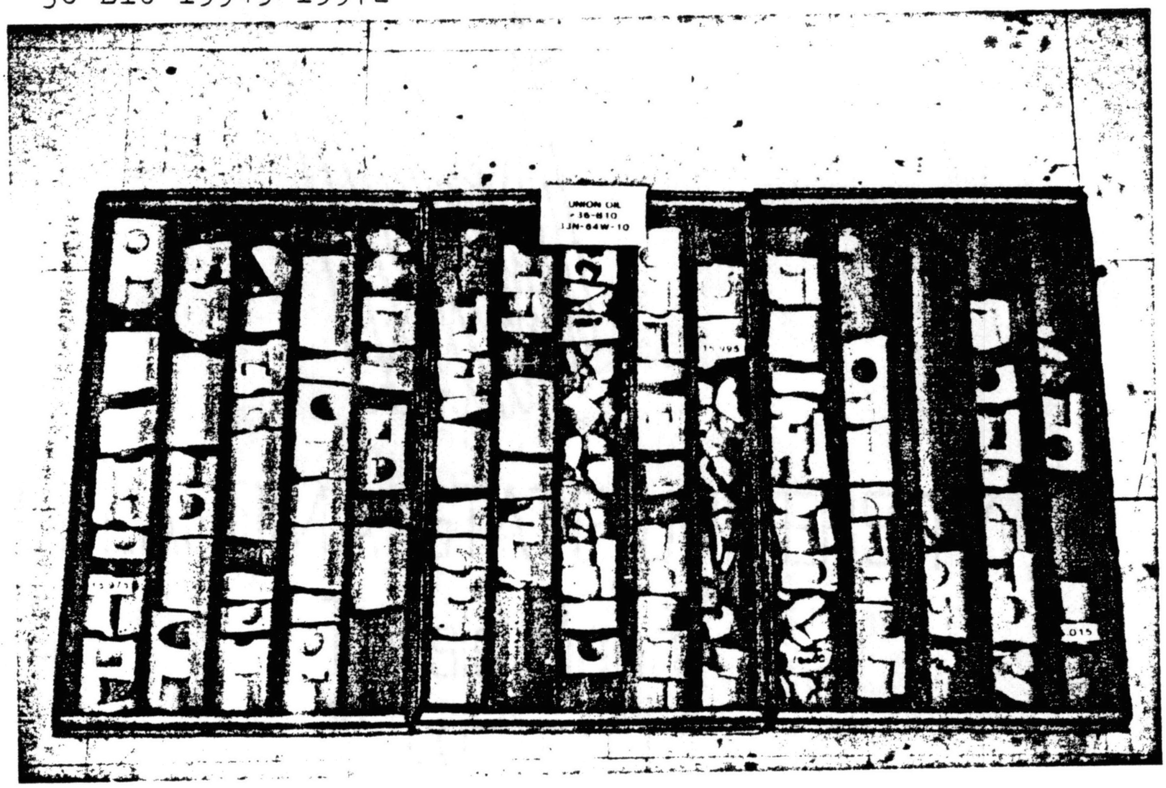


36-B10 15972-16015

VITA

Tracy Hutch Jobe

Candidate for the Degree of

Master of science

Thesis: THE DEPOSITIONAL ENVIRONMENT OF THE MORRISON FORMATION IN THE WEST POISON SPIDER FIELD AND SURROUNDING AREAS, SOUTHEAST WIND RIVER BASIN, WYOMING

Major Field: Geology

Biographical:

Personal: Born in Ponca City, Oklahoma, on June 20, 1962, the son of Mr. and Mrs. J.M. Jobe.

Education: Received Bachelor of Science degree in Geology, May 1984, form Oklahoma State University, Stillwater, Oklahoma; completed requirements for the Master of Science degree at Oklahoma State University in December, 1986.

Professional Experience: Summer geologist for Union Oil of Califormia in Casper, Wyoming, May to August, 1985; Graduate Teaching Assistant, Department of Geology, Oklahoma State University, Stillwater, Oklahoma, August 1984 to May 1986.

Company **UNOCAL UNIT 35-D11**
Well Location **11-33N-84W**

Petrologic Log

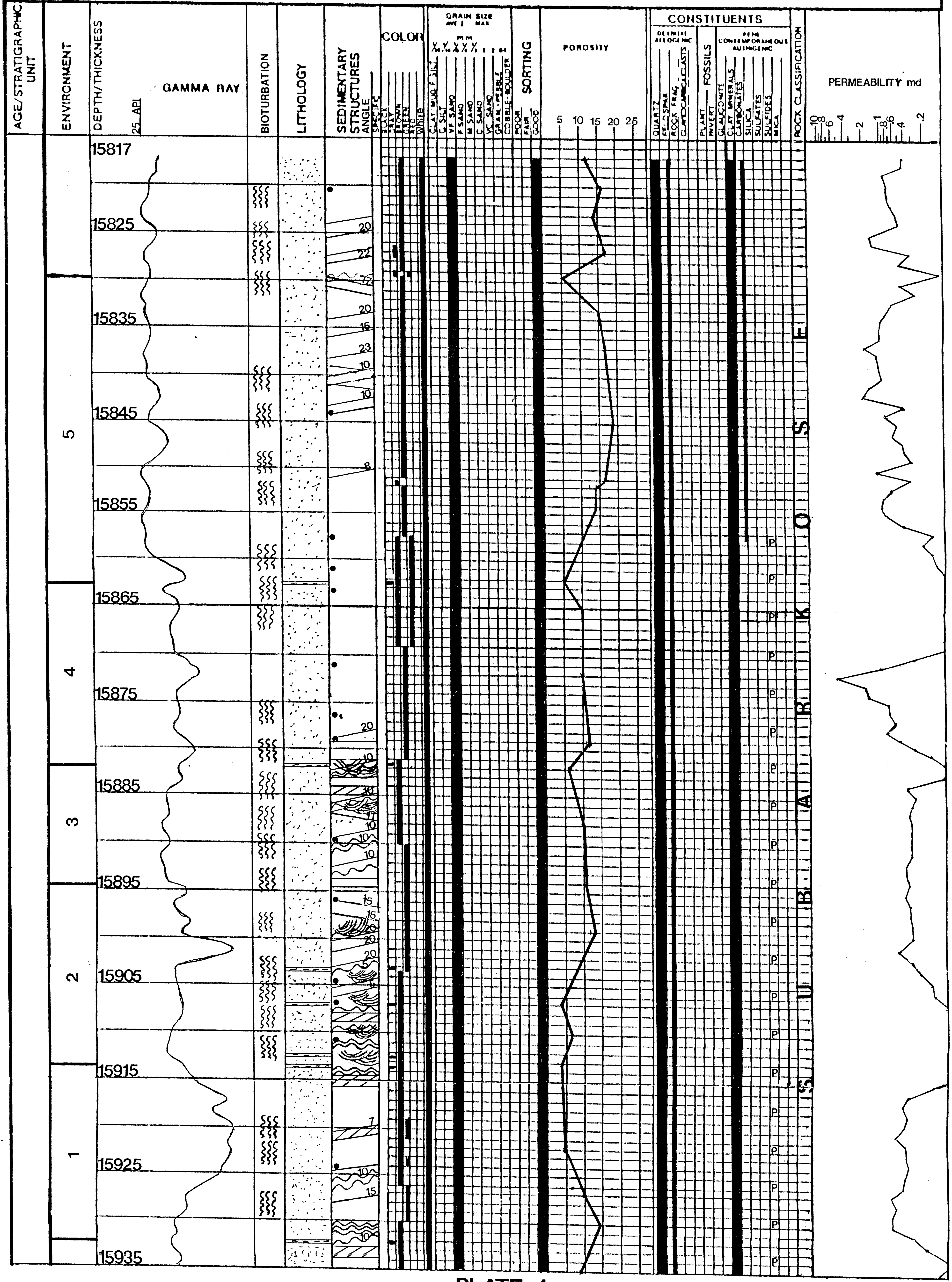


PLATE 1

Petrologic Log

Company UNOCAL UNIT 36-B10
Well Location 10-33N-84W

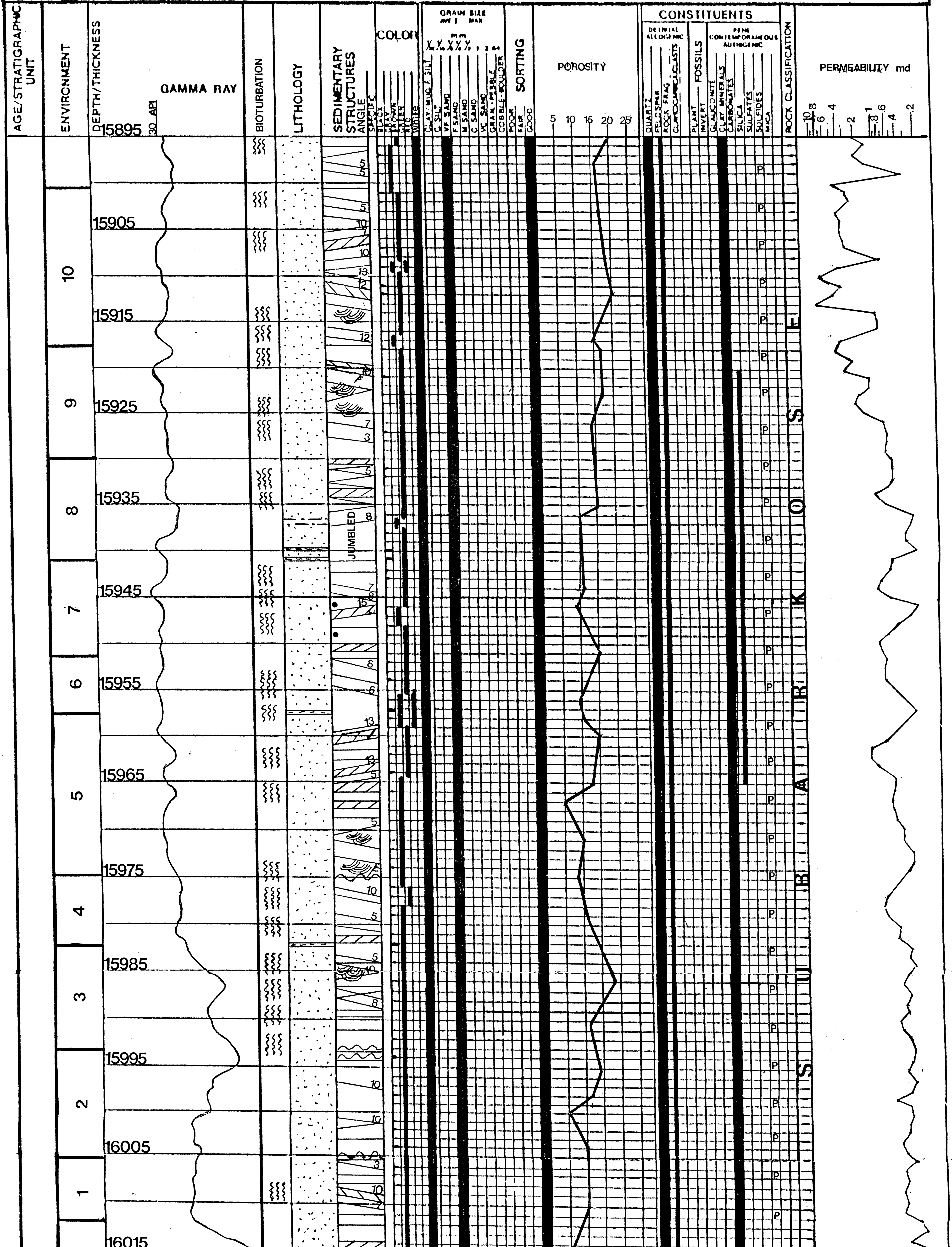


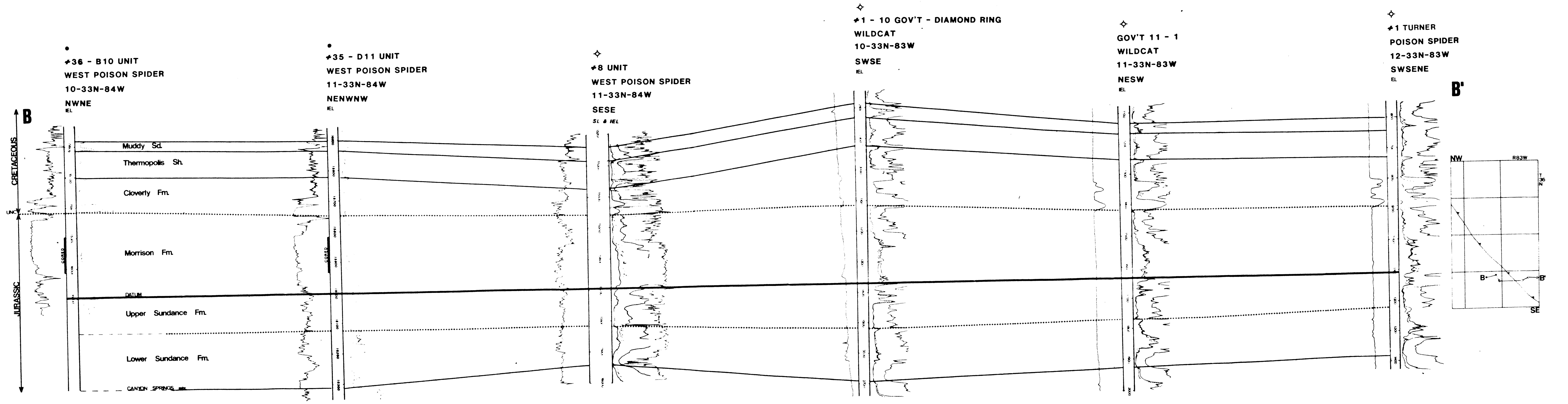
PLATE 2

PLATE 3 STRATIGRAPHIC CROSS-SECTION OF NATRONA COUNTY, WYOMING

BY HUTCH JOBE

PLATE 4 STRATIGRAPHIC CROSS-SECTION OF NATRONA COUNTY, WYOMING

BY HUTCH JOBE



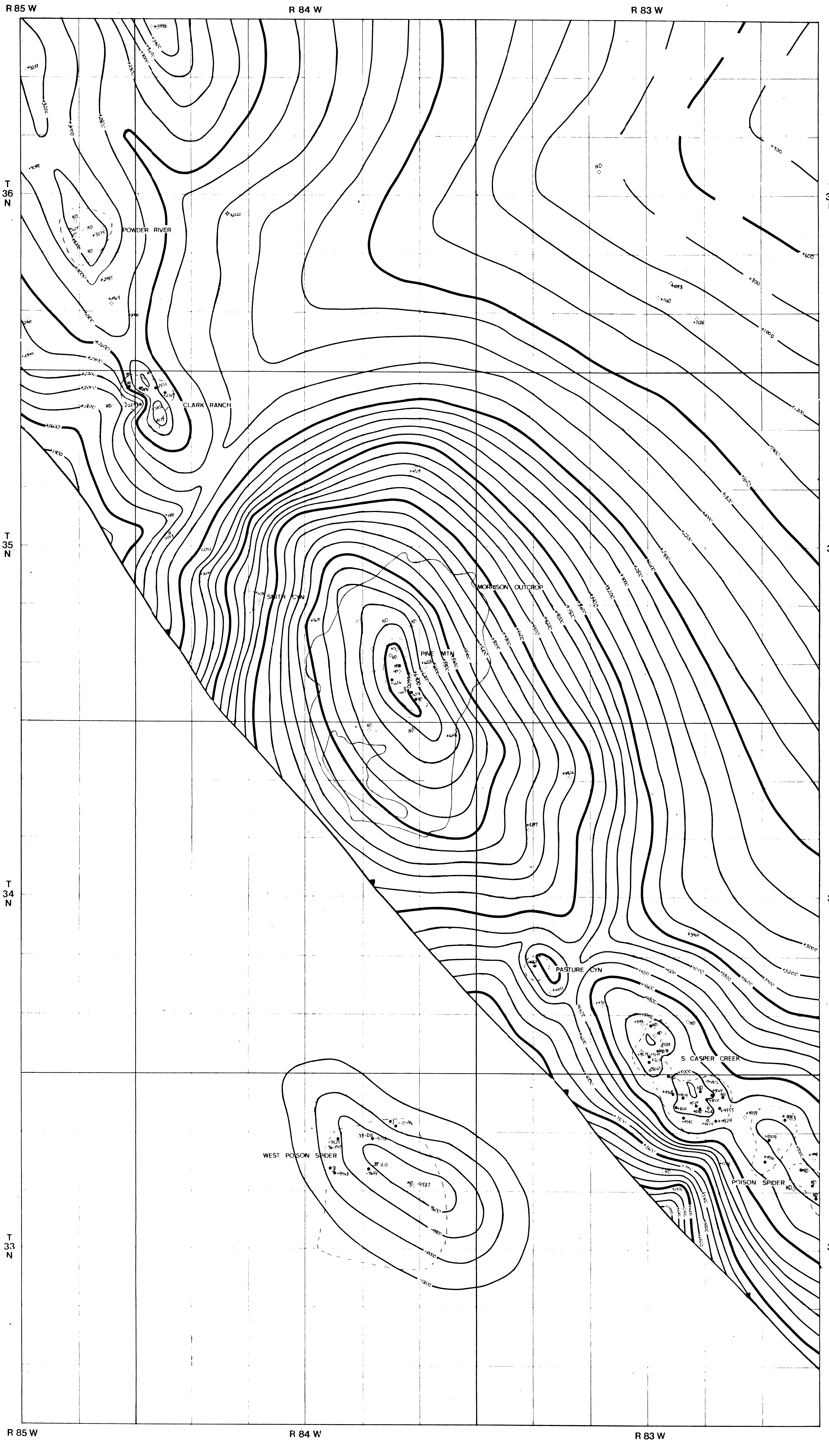


PLATE 5
STRUCTURAL CONTOUR MAP

OF THE MORRISON FORMATION
WIND RIVER BASIN
NATRONA CO., WY
BY HUTCH JOBE
FEB. 1986

N
0 1 MILE
N.D. - NO DATA
C.I. - 200 FEET

PLATE 6

FULL INTERVAL ISOPACH MAP

OF THE MORRISON FORMATION
WIND RIVER BASIN
NATRONA CO., WY
BY HUTCH JOBE
FEB. 1986

N.D. - NO DATA
C.I. - 10 FEET

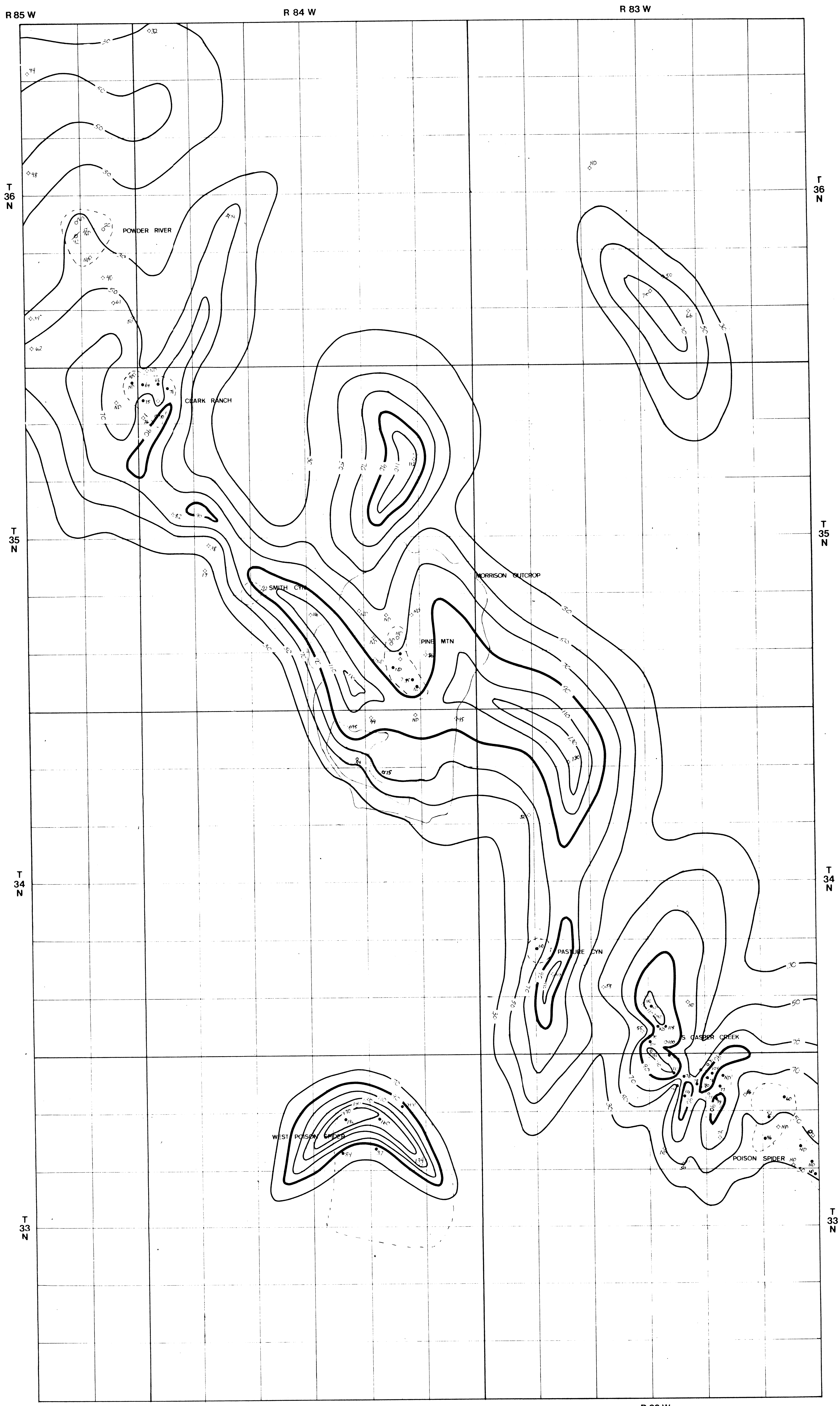
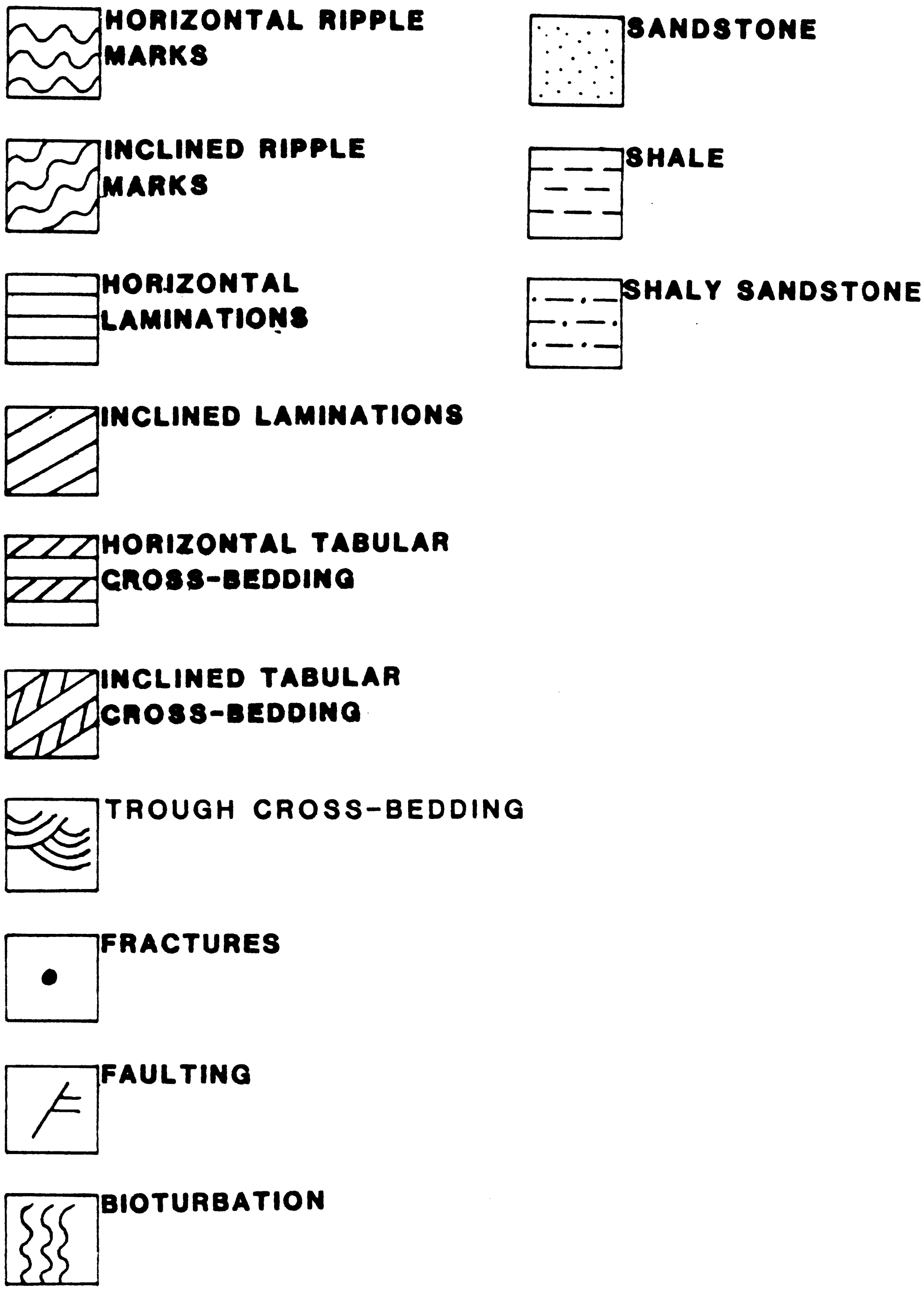


PLATE 7
SANDSTONE ISOPACH
OF THE MORRISON FORMATION
WIND RIVER BASIN
NATRONA CO., WY
BY HUTCH JOBE
FEB. 1986

N
0 1 MILE
ND – NO DATA
C.I. – 20 ft.

LEGEND



HORIZONTAL RIPPLE MARKS
INCLINED RIPPLE MARKS
HORIZONTAL LAMINATIONS
INCLINED LAMINATIONS
HORIZONTAL TABULAR CROSS-BEDDING
INCLINED TABULAR CROSS-BEDDING
TROUGH CROSS-BEDDING
FRACTURES
FAULTING
BIOTURBATION
SANDSTONE
SHALE
SHALY SANDSTONE