THE MORROW FORMATION IN EASTERN DEWEY COUNTY, OKLAHOMA

BY

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PREFACE

This study will investigate the Morrow formation in Eastern Dewey County, Oklahoma. This will be accomplished by the traditional methods of construction of maps and cross sections and the study of core and thin sections. Unique to this thesis is the extensive use of computers in data management. Subsurface geology is often bogged down by the considerable volume of numerical data and the transfer of those numbers to their proper place on a map. With the proper arrangement of hardware and programs, this task is greatly facilitated.

This writer would like to express his sincere appreciation to Dr. Arthur Cleaves. His position as main adviser required thoughtful consideration and probing insight. His knowledge of clastic deposition systems has proved most helpful. Dr. Zuhair Al-Shaieb and Dr. Gary Stewart, thesis committee members, have provided useful help and encouragement. Dr. John Groves's help in the identification of microfossils is most appreciated.

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Thanks are in order for my parents Kay and Ben Bentkowski and my sister Susan for their patience during the early years.

And finally the journey would not have been bearable without the love and support of my sons, Chris and Matthew, and my wife, Kathy, who provided much loving care and support throughout these last couple of years.

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CHAPTER I

PURPOSE

The purpose of this study is to inspect the stratigraphic, petrologic and diagenetic characteristics of the Morrow formation in eastern Dewey County, Oklahoma. The objectives are seven-fold:

1. Determine the facies relationships and hence, the depositional environments.

2. Investigate the nature of the contacts between the Morrow Formation and the underlying Chester Formation and the overlying Atoka Formation.

3. Construct isopach and structural maps, as well as stratigraphic cross sections, which document local facies.

4. Describe selected cores in the area as an aid to interpreting facies relationships, petrography, and porosity genesis.

5. Conduct petrographic and clay minerals analysis of the samples selected from core and determine the diagenetic history of the sandstones.

6. Develop an exploration strategy for future drilling activity in eastern Dewey County.

Separate from the geologic considerations, the other main thrust of this study will be to take full advantage of the J. M. Huber Corporation's (thesis sponsor) commitment to computer assisted geology. This includes the accessing of commercial geologic information, the building of a geologic database, the generation of base maps, assistance in the contouring of maps, and word processing of the text of the thesis. The blending of traditional geologic techniques with the speed and data management capabilities of computers will allow for the completion of a detailed study over a larger area with greater ease than is normally possible.

CHAPTER II

INTRODUCTION

Location

The study area is composed of sixteen contiguous townships in eastern Dewey County, Oklahoma, T16N to T19N, R14W to R17W, inclusive (Figure 4). This area is approximately one hundred and twenty miles west of the Nemaha Ridge and one hundred and fifty miles north of the Wichita Uplift (Figure 2). Regionally, it is within the transition zone between the Northern shelf and the deeper part of the Anadarko Basin. The surface rocks are the Cloud Chief and Rush Springs Formations of Permian age as well as various sandstone and gravel deposits of Quaternary Age (Miser, 1954). The north and south branches of the Canadian River flow through the study area.

Previous Works

The Anadarko Basin has been the subject of considerable study. The Morrow Formation began to receive attention in the late 1950's as economics allowed the industry to pursue deeper exploration targets. The Morrow within the study area ranges from seven to eleven thousand feet. Although the following discussion does not cover every paper in which the word "Morrow" appeared; it does review most of the important papers on the topic.

Evans (1979) reviewed the major structural and stratigraphic

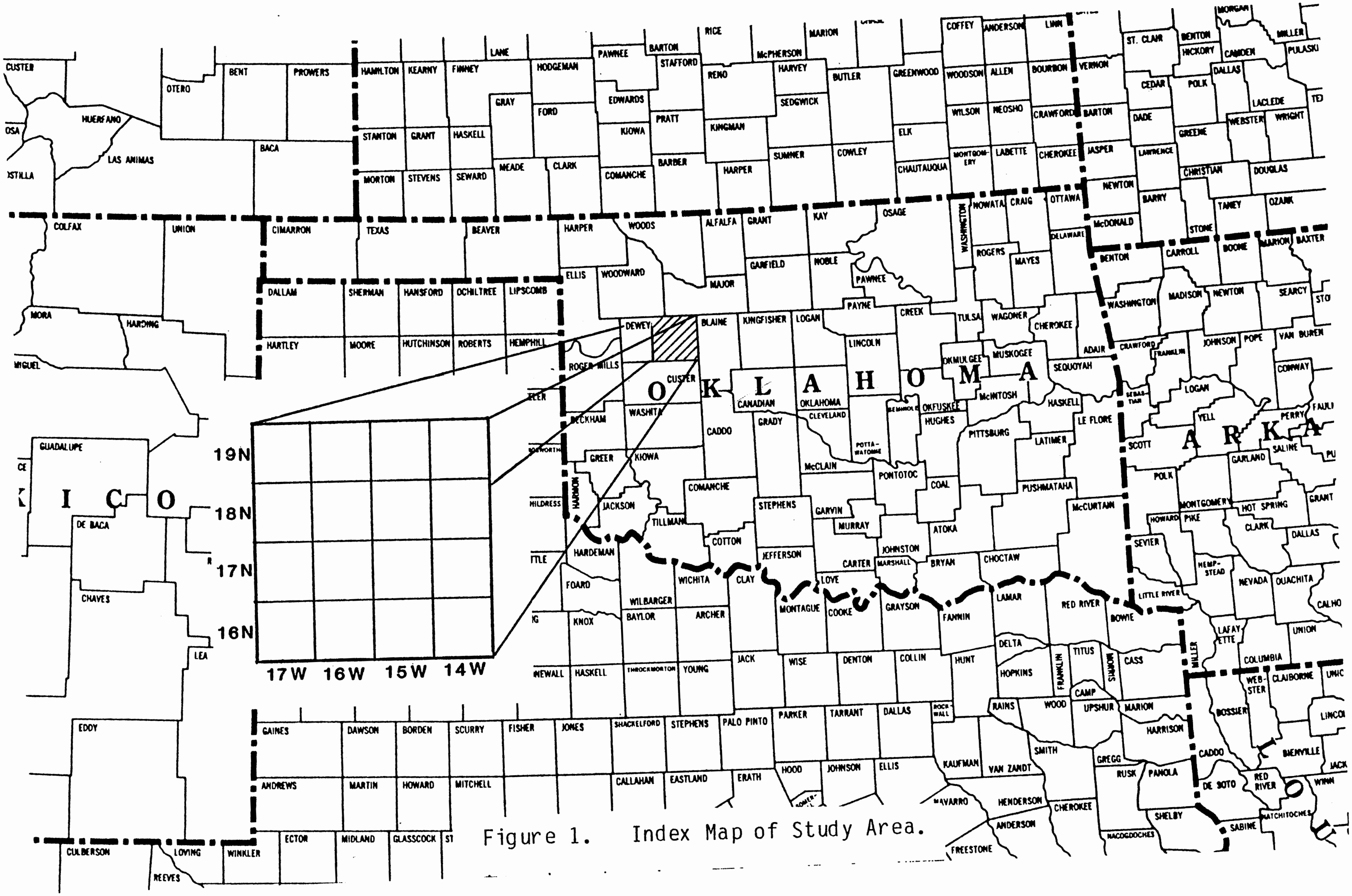

Figure 1. Index Map of Study Area.

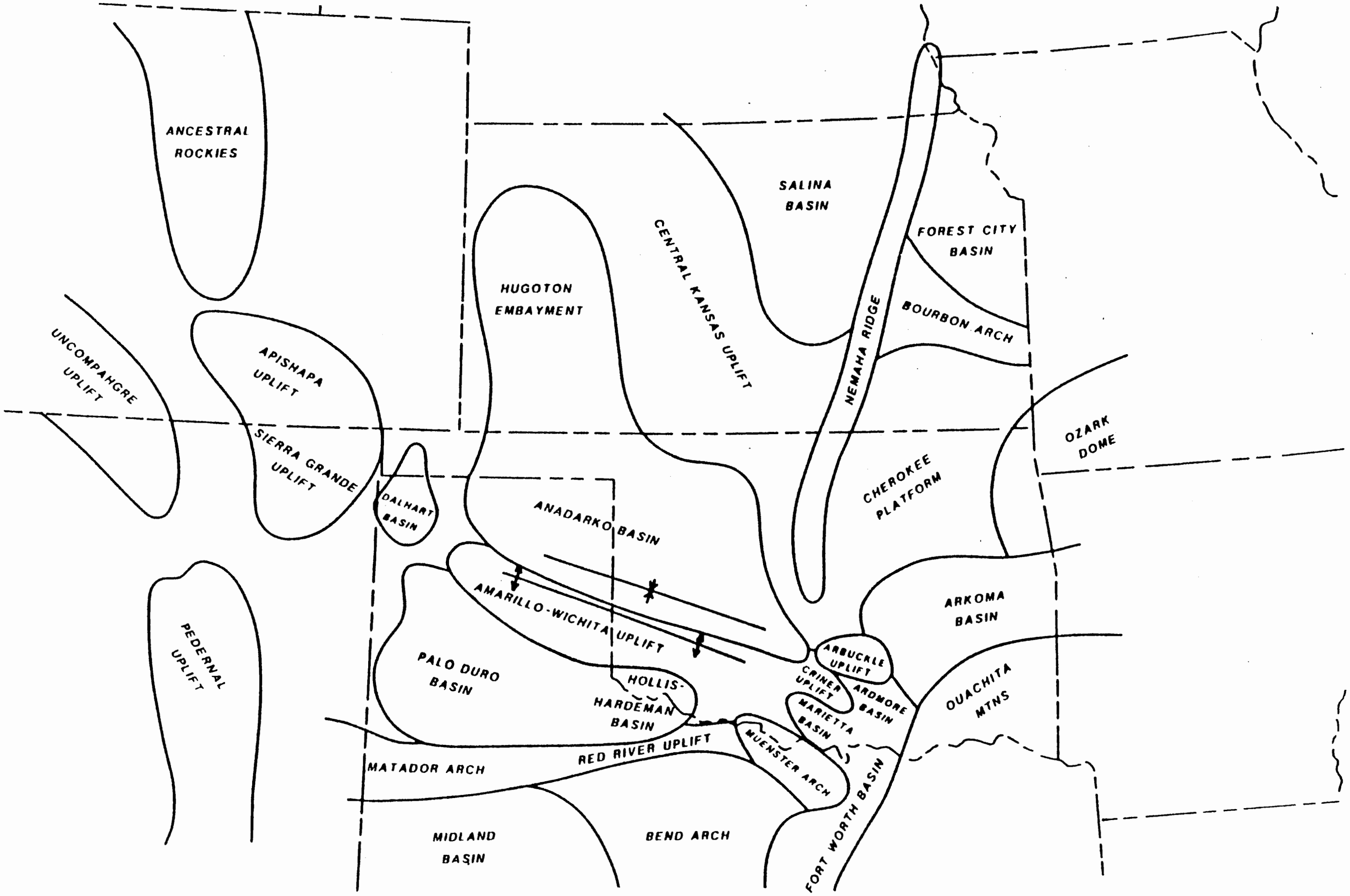

Figure 2. Principal Pennsylvanian Physiologic and Tectonic Features of the Southern Midcontinent. (Moore, 1979)

features of the Anadarko Basin and Moore (1979) provided a regional analysis of the paleogeography of the Pennsylvanian System in the southern Mid-continent. A 1981 paper by Hill and Clark discussed regional petroleum accumulation within the Anadarko Basin, Gibbons (1965) carried out a study of the Pennsylvanian System in western Oklahoma and a portion of Texas in which he discusses the stratigraphic and lithologic relationships. Rascoe and Alder (1983) studied the Permo-Carboniferous hydrocarbon accumulations in the mod continent. Their study included paleographic maps at different stages through the time period studied.

The next apparent grouping of papers in those of a regional scale covering several counties in the northwestern part of the Anadarko Basin. This includes southwest Kansas, southeast Colorado, the panhandles of Texas and Oklahoma. Forgotson (1970) worked in northwest Oklahoma and in the Panhandles, divided the Morrow into five units, and correlated them with present and most probable future production. This work was done in 1959 and shows the early use of computers in data management of geologic information. Ables (1962) did a subsurface lithofacies study in the northern Anadarko Basin which attempted to show the sediment source, paleoenvironment and tectonic framework during Morrowan time. Adams (1964) published an early work which stressed the diagenetic aspects of the lower Morrow within his study area. He divided the Morrow into high energy and low energy environments and investigated how the mineral constituents affected the diagenesis and hence the reservoir quality. Barrett (1965) did a subsurface study of most of Beaver County, Oklahoma for oil and gas possibilities. Khaiwka (1968) carried out extensive correlations of Morrowan sand in northwest

Oklahoma and revealed a series of shorelines and associated sand development during the transgressive pulses of the Morrowan seas.

Mannhard and Bush (1974) investigated stratigraphic traps in a sixteen township area of northwest Oklahoma and neighboring Kansas. By reconstructing the depositional environment and correlating this with known oil fields, they developed a model for trapping of hydrocarbons based on a modification of Gussow's Principal which accounts for water trapped up dip from oil and oil trapped up dip from gas within the same reservoir. In two papers Davis (1971, 1974) discussed the considerable potential of the Morrow to give up hydrocarbons especially the high pressure gas trend in Canadian and Blaine Counties, Oklahoma. A later paper by Davis (1975) was a lithologic and petrographic study of the Morrow which set up classifications for six types of sand and recommended treatment procedures for the best production.

Godard (1981) reviewed the depositional environments and sandstone trends in southern Harper and Woodward Counties, Oklahoma. Swanson (1979) describes extensive deltaic environments and the associated facies within the Upper Morrow of the Oklahoma Panhandle. Kasino & Davies (1979) investigated the paleoenvironments and diagenesis of Morrow sands in Cimarron County, Oklahoma. Webster (1983) related the Lower Morrow sandstone and porosity trends to the Chester paleogeomorphology in Woodward County, Oklahoma. Shirley (1984) reported on the extensive work of the personnel of Grand Resources in southeast Colorado which described an extensive system of fluvial point bars and its relationship with the underlying Chester. Similar ideas were proposed by Orchard and Kidwell (1984) for the Sorrento Field of Eastern Colorado.

Two additional papers actually overlap the eastern Dewey County study area covered here. The first is by Slate (1965) who, in spite of low well density, set up a stratigraphic framework for this area. Secondly is South's (1983) Masters thesis at Oklahoma State University which is an extensive study of the Morrow reservoirs of the Southwest Canton Field present on the Blaine-Dewey County line.

CHAPTER III

METHODS AND PROCEDURES

An initial review of electric logs from within the study area indicated the presence of an easily recognized marker unit in the Chester, the Okeene lime (Slate, 1965). A structure map was made on this unit and from that map, six stratigraphic cross sections were laid out: three dip-oriented and three strike-oriented. This allowed for the establishment of a stratigraphic fromework that could be used for the detailed correlation of the rest of the electric logs in the study area. A review of the scout tickets from the study area showed that nine hundred and sixty-eight wells penetrated the Morrow Formation. Of these, six hundred and seventy two well logs were readily available. This is approximately seventy percent coverage.

Detailed correlation of all logs was made and the following values were picked:

1. Base of the Atoka "Thirteen Finger" lime
2. Base of the Morrow Formation (Pennsylvanian)
3. Top of the Okeene Lime
4. Top of the M8 sand
5. Gross and net sand values for the eight sands within the Morrow Formation (M1-M8)

The gross sandstone isolith value was derived from the number of feet of sand greater than seventy percent clean on a gamma ray log. When no gamma ray log was present a value of thirty ohms resistivity was used (Ripley, 1984).

A problem was encountered when using compensated neutron formation density logs. The logs are generally calibrated to a limestone matrix density of 2.71 g/cc (Ripley, 1984). After consultation with Schlumberger, a set of criteria were established to give a "quick look" value for sandstone porosity greater than eight percent. First, the sand must exceed the seventy percent clean sand cut off. Secondly, the neutron porosity must be greater than six percent and the density porosity be at least ten percent. The criteria were tested against cross plotting neutron and density porosities, as well as the average of the neutron and density porosities ($\emptyset = (\emptyset_n + \emptyset_d)/2$). On two tests totaling fifty five data points, there was a greater than ninety percent agreement. The variance appeared in areas of low neutron and high density porosity. This is attributable to gas effect and allowances were made for this during data collection. For sonic logs, a value of 18,750 f/s was used to indicate net clean sand (Ripley, 1984). This calculates out to interval transit time of 63 microseconds/foot. For bulk density logs, a value of 2.54 gm/cc was used to indicate net clean sand (Ripley, 1984). All of these values were then used to construct a suite of structural and isolith maps. The gross interval isopach values were internally generated by the Zycore mapping program.

There were twenty cores taken from various Morrow sands within the study area. For various reasons, ranging from use in a previous study to loss by an operator, this number was reduced to four. These four cores were logged lithologically and samples were taken for thin sections and X-ray analysis. These tests allowed mineral and clay identification. Scanning electron microscopy was also be performed on selected samples.

Aside from the traditional methods of investigation, the other main thrust of this study is to use the computer as a tool for management of geologic data. All of the formation tops and isolith values were entered on a PCI 78 Networker tied to an IBM 3083. This information is stored in a database known as System 2000 and is interactive with Petroleum Information's subscription service of wellhead data. The mapping and contouring program is by Zycor Inc. of Austin, Texas and is run using an IBM 3033 mainframe, a Textronix 4114 interactive graphics terminal, and a Zeta 3610 thirty six inch drum plotter. There is also a Telex 286f printer hooked up to the system. All of this equipment allows the management of considerable volumes of data and removes several possible sources of human error.

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CHAPTER IV

GEOLOGIC HISTORY

The Anadarko Basin contains 35,000 feet of rocks ranging from Pre-Cambrian gabbros and basalts to recent alluvium (Hill & Clark, 1981). Papers covering the complete geologic history are rare. The best information is obtained by combining the reports of specialists such as Amdsen (1975) for the Hunton or Gatewood (1978) for the Arbuckle. This report will concentrate on the time which brackets the Morrow, Late Mississippian (Chesterian) through Early Pennsylvanian (Atokan).

The rocks of Early and Middle Mississippian time are characterized by fine grained cherty limestones and dolomites (Slate, 1965). This lithology is indicative of a quiet environment with little clastic sediment and a slow rate of subsidence (Barrett, 1963). With the start of Chesterian time the character of the sediments makes a major change from the carbonates of the Arbuckle, Hunton and Mississippian to the clastics of the Pennsylvanian and Permian (Hill and Clark, 1981). The Anadarko Basin began gradual subsidence which allowed for deposition of fine grained clastics in the deep, while carbonate banks are developed along the northern shelf areas. The facies change is visible on the cross sections of the study area. Latest Chesterian is represented by carbonates in the north and changes to black shales in the south.

With the close of Chester time, a regression takes place causing wide spread erosion, in some places down to Ordovician age rocks. It is thought, however, that sedimentation was continuous across the systemic boundry in the deepest portions of the Anadarko basin (Moore, 1979). Traditionally, epeirogenic uplift is given the credit for the regression. Recently, Saunders, Ramsbottom and Mangner (1979) credited the regression to worldwide sea level changes related to glaciation.

The start of Pennsylvanian time was the start of a period of great tectonic downwarping and active uplift along the Amarillo-Wichita uplift. Moore (1979) characterized the depositional setting as a progressively deepening basin having a coarse-grained sediment supply from the west and south and occasional fine grain sediment from the east and northeast. The seas transgressed with occasional regressional stand still during which, the sediment began filling up the basin. Small deltas and beach environments were formed in the northeast while larger delta complexes were deposited in the northwest (Swanson, 1979, Forgotson, 1979). Alluvial fans and braided stream complexes were shed from the Wichita-Amarillo Uplift (Moore, 1979).

The close of Morrowan time is marked by an unconformity caused by the Wichita Orogeny. This event was a result of the collision between the North American and South American plates (Rascoe and Adler, 1983).

The COCORP Deep Seismic Project, conducted under the auspices of Cornell University, has recently conducted research into the deep crustal structure in the Arkoma region. Lillie (1983) reports that most probably there was a southern dipping subduction zone in which the North American plate was subducted under the South American plate. This subduction caused a deepening in the Arkoma Basin in the early Pennsylvanian. The subsequent continent-continent collision resulted in crustal deformation, thrust faults and accretion of a southern land mass onto the northern plate. In the Anadarko Basin region all of the major structural features appear to have been active during this time. These include the Amarillo Wichita Uplift, Nemaha Ridge, Central Kansas Uplift, and the Keyes Dome (Barrett, 1963). This uplift and subsequent erosion is visible on the cross sections of the study area. The upper shale unit is greater than 600 feet thick in the deepest portion and thins to extinction towards the northeast. Just to the northeast of the study area the Morrow formation is completely eroded and the Atoka rests uncomfortably on the Chester (Rascoe and Alder, 1983).

Atoka time is marked by very diverse sedimentation in different portions of the region. Extensive fan deltas and braided stream complexes were shed from the Wichita-Amarillo Uplift, forming the granite washes and arkoses of the Atoka formation on the north (Moore, 1979). In the northern portion of the Anadarko Basin the Atokan is marked by the repetitive "Thirteen Finger" limestone and fine grained clastics. These facies indicate quiet conditions with little tectonic activity (Barrett, 1963). The close of Atoka time is marked by an extensive transgression which continued throughout Des Moinesian time.

CHAPTER V

STRUCTURAL AND TECTONIC FRAMEWORK

Regional

The Anadarko Basin is an asymmetrical basin which trends northwest-southeast. It is bounded on the east by the Nemaha Ridge, on the south by the Wichita-Amarillo uplift and on the north and west by broad gentle shelf areas (Figure 2). The term "Oklahoma Aulocogen" is often applied to this area. An aulacogen is defined as a fault bounded, intercratonic trough or graben. Plate tectonic theory allows for the explanation of the history of aulacogens with a three part cycle (Reading, 1978). The first is a rifting stage in which a mantle plume causes thermal swelling of the crust. This uplift causes normal faults, graben structures and emplacement of igneous rocks. These fracture patterns ideally align into three trends spaced at 120°, thus forming a ridge-ridge-ridge triple junction (McKenzie and Morgan, 1973). As the rifting continues, two of the trends form a passive continental margin and the third trend, the "failed arm" forms an aulocogen (Figure 3). The second stage is triggered by the thermal cooling of the continental crust. This causes a marine transgression and rapid sedimentation into the aulocogen. The third stage is one of deformation generally triggered by a local continent-continent collision which reactivates old fault trends, provides a mechanism for formation of smaller localized basins, and triggers conglomeratic sedimentation.

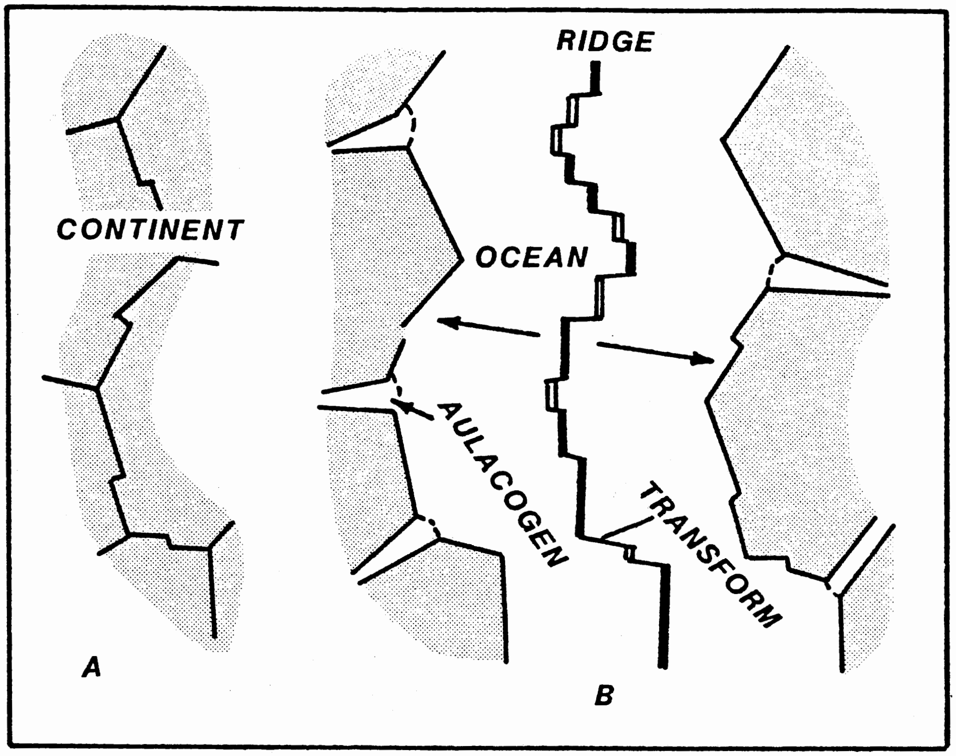

Figure 3. Idealized Plate Boundaries During the Opening and Closing of Oceans. The Triple Point Configuration in A Leads to an Irregular Plate Margin in B. Non-Spreading Rifts, Form Aularogens (Simpson, 1983).

This three staged model fits well when applied to the southern mid continent. The igneous rocks of Cambrian and Pre-Cambrian time described by Ham et al. (1964) and redefined by Powell (1980) fit well into the rifting stage. The carbonates of the Arbuckle, Hunton and Mississippian groups are an indication of widespread marine transgression, a major feature of the subsiding stage. The deformation stage in this area is actually the last phase of the Appalachian Orogeny. This series of orogenic pulses started in Newfoundland in Ordovician time and progressed southward, closing the proto-Atlantic (Williams and Stevens, 1974). The siliclastic sedimentation in the Anadarko basin which starts in late Mississippian time and peaks in Atoka time is indicative of the collision stage. The Wichita Orogeny is credited with reactivation of ancient faults, presumably the normal faults of the rifting stage, uplifting the Wichita-Amarillo Mountains and causing the other major structural features of this area (Barrett, 1963). Walper (1974) proposes that a major left lateral megashear reactivated many of the basement faults which accentuated the major structural features of the area and formed several of the smaller basins such as the Hollis, Marietta and Ardmore. These series of events fit the aulocogen cycle model well.

Local

The local structure is simple with no major faults observed and the beds dipping to the southwest. After study of the enclosed structure maps (Plates 7 through 10), several facts become apparent. The dip gradient to the southwest varies from 17% to 2.9%. The dip is the steepest in the south-central part of the study area and the most gentle in the east-central part. In the far southwest corner (T16N, R17W) there is a strong anticlinal nosing seen on all four maps. This is evidence of deeper structure and there is Hunton and Viola gas production associated with this feature. In the west-central and east-central parts of the study area there is a noticeable spreading of the contour lines. This is indicative of a flatter than normal area with a gradient less than 0.75%. This also may be an indication of a deeper structure although gentler than the one previously mentioned. There is deeper Hunton gas production associated with both of these features.

The remainder of the anomalies are minor. In most cases when the mapped horizon is an erosional surface (i.e. Top of the Morrow). These anomalies may represent erosional channels. One final point to consider is that these structural maps were contoured by the computer with the aid of the Zycor mapping program. There are places where the contours are less fluid or less subjective than ones drawn by human hands. They are however, in agreement generally with published maps and the author's work maps of this area.

A review of the six stratigraphic cross sections (Plates 1 through 6) can reveal several other facts about this area. The rock of the latest Mississippian (Kimball) zone appears to have a facies change from massive limestone in the northwest to predominately shale in the southeast. The transition zone roughly bisects the study area equally in a southwest-northeast direction (Figure 4). This implies that the carbonate facies is in the shallower water and that the shale facies is down-dip in a deeper water environment. This would give a south easterly dip during latest Mississippian time. Within the lower Morrow

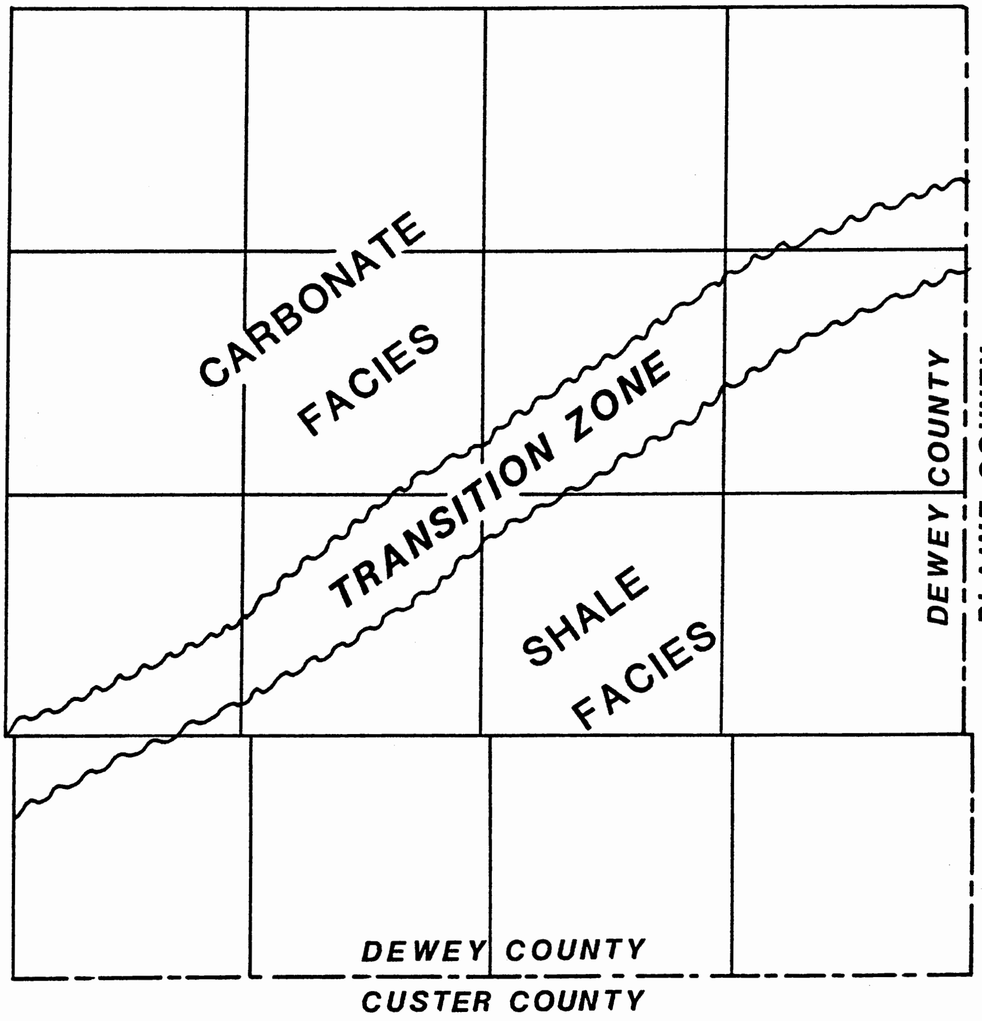

Figure 4. Facies Distribution of Kimball Zone Late Mississippian, Eastern Dewey County.

there is a shelf break which is apparent in the dipwise cross sections (Plates 1, 2 and 3). The shelf break is oriented diagonally across the study area from the northwest to the southeast (Figure 5). However, this feature may be partially post-Morrowan in timing. An examination of the sandstone isoliths (Plates 11 through 17) indicates a change in depositional strike of the sands from the oldest (M2) to the youngest (M8). The shelf break for each map is visible in the area where the major channels begin to blossom out. As one compares isolith maps of successively younger sandstone bodies this feature shifts to a northwest-southeast orientation. The further enhancement of the shelf break may have taken place during the rest of the Pennsylvanian as the basin subsided to the southwest.

The total Morrow isopach (Plate 18) shows the considerable thinning that takes place within the Morrow Formation. The isopach values range from 53 feet thick in the northeast to 1,023 feet thick in the southwest. The onlap of the Morrow sands can account for some of the variability of the section's thickness. However, the erosional truncation of the Upper Morrow shales accounts for the majority of the change. On the southwestern margin of the study area the Upper Morrow is in excess of 600 feet thick and thins to extinction in the northeast. Were the Upper Morrow shales 600 plus feet thick over the entire study area? This question is unanswerable due to the pre-Atokan erosional event.

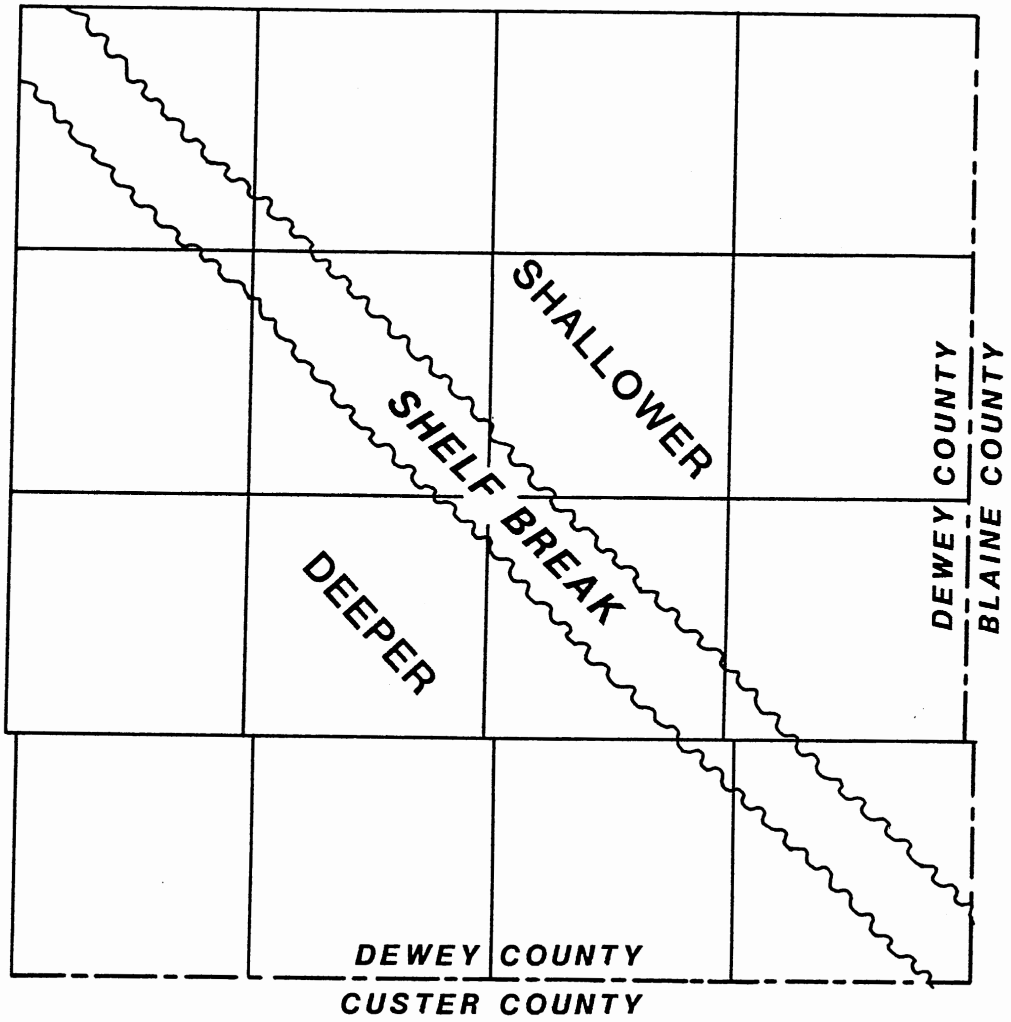

Figure 5.Representation of Shelf Break Within Morrow Formation, Eastern Dewey County.

CHAPTER VI

STRATIGRAPHY

The interval under study is the Morrow Formation, a collection of sandstones, shales and thin limestones, of earliest Pennsylvanian age (Figure 6). The Morrow rests uncomformably on Chesterian rocks of Late Mississippian age. The Morrow is overlain unconformably by younger Pennsylvanian age Atoka rocks. This contact is an angular unconformity, as seen in the truncation of three Morrow sands on cross-section B_1-B_2 (Plate 2).

Two major problems to be addressed initially are the presence of "Springer" age rocks in the study area and the placement of the Mississippian-Pennsylvanian systemic boundary. These problems are closely related. The author consulted with two well respected local geologists as to the identification of the Springer on electric logs. Both Herbert G. Davis (1984) and Suzanne Taaken (1984) said the Springer is a deep water facies represented by low resistivity shale (less than 2 ohms) of a uniform nature. Slate (1965) describes such a shale that is black, glauconitic, pyritic, and carbonaceous above the Okeene limestone and below the limestone of the Kimball zone. This same log signature is visible on all the cross-sections from the study area (Plates 1 thru 6). The problem arises in that the limestone of the Kimball zone undergoes a facies change from limestone in the northwest to shale in the southeast. Most workers (Forgotson, 1967; Khaiwa, 1968) agree that on the northern

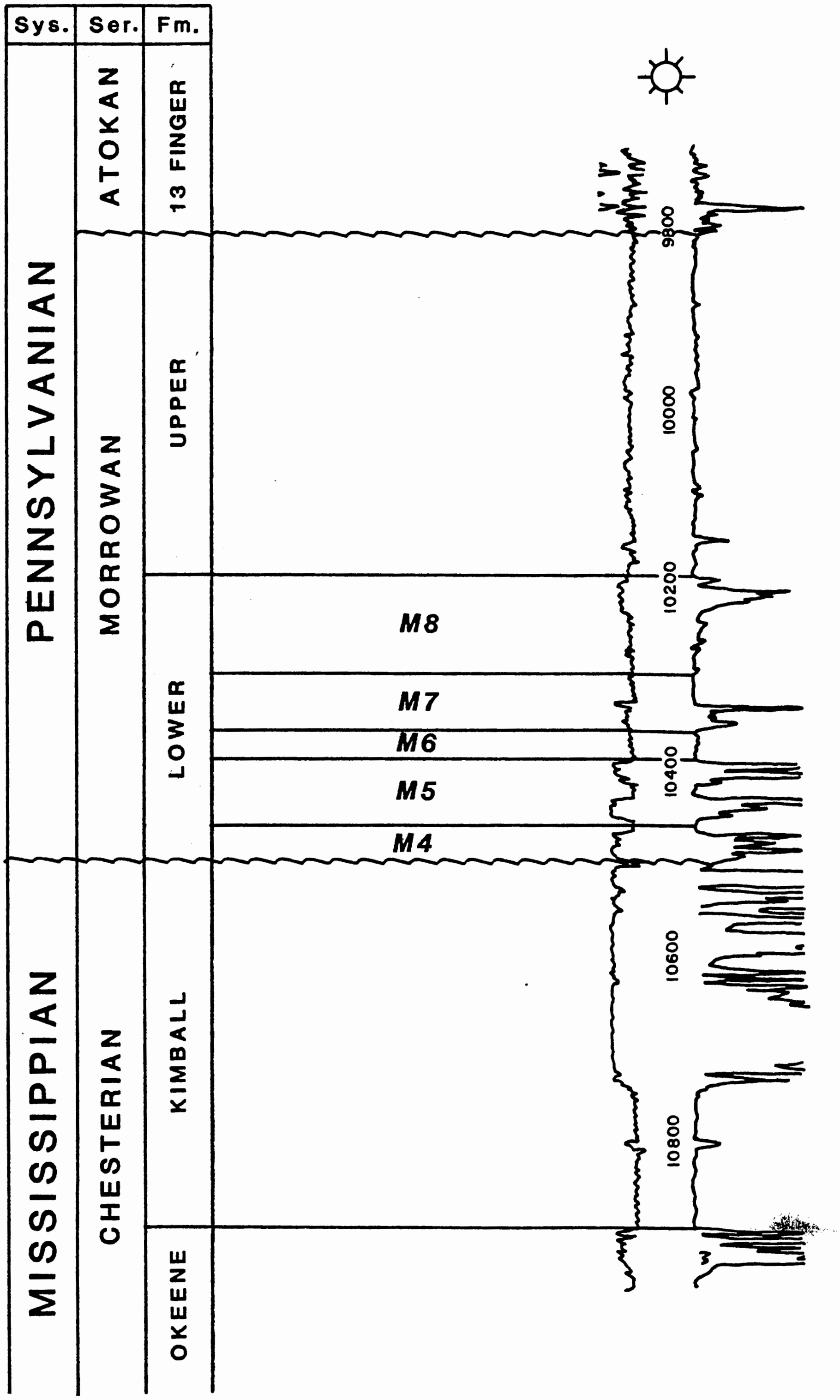

Figure 6. Type Log, Morrow Study, Eastern Dewey County.

shelf the Morrow is underlain by Chesterian carbonates. Peace (1965) states that in the southeast Anadarko Basin the Morrow rests unconformably upon the Springer sandstones and shales, which in turn rest conformably upon the Caney shale of Mississippian age.

In an effort to place the Pennsylvanian-Mississippian boundary, a core was examined which contained the erosional contact between the Kimball Limestone and the overlying shales. The core was from the Helmrich & Payne 2-4 Ward Sec. 4-29N-15W and covered the interval 8,286-8368'. Two thin sections were prepared with the hope of identify distinctive microfossils. With the help of Dr. John Groves, it was determined that the foraminifera Neoarcheodiscus spp. was present. This organism ranges from latest Meramecian through Middle Pennsylvanian. There were no exclusively Pennsylvanian foraminifera present. Rather, the fauna was more typically Mississippian in age. Since the test did not find that this limestone was Pennsylvanian in age, but rather that the evidence leaned towards the Mississippian, it was decided that this erosional surface seen in the core was the top of the Mississippian and the superjacent sediments were the earliest Pennsylvanian. With this point established, correlations revealed that the carbonate facies which underlies the Morrow in the northwest was stratigraphically equivalent to the shale facies seen in the southeast.

Now that the systemic boundary was established within the study area, the problem was to resolve the Springer dilemma. In 1922 Goldston described the Springer Formation in the Ardmore Basin and recognized that the Mississippian-Pennsylvanian boundary is represented throughout the mid continent as an unconformity. He also stated that Springer deposition most probably was continual across the systemic boundary.

This idea held true until redefinition by Tomlinson and McBee (1959) placed the Springer as the earliest Pennsylvanian rocks. Many workers attempted to find the key which would resolve the confusion surrounding the rocks of this age.

The type section of the Springer is in the Ardmore Basin of southern Oklahoma. The type section for the Morrow is in western Arkansas and the type section for the Chester is in western Illinois. In 1974 two conodont workers, Lane and Straka, published a conodont zonation scheme based upon their work at the type sections for the Springer and Morrow and at outcrops in northeast Oklahoma and north-central Arkansas. Their work revealed that the upper Springer beds correlated with the lower beds of the Morrow type section and that the lower Springer beds were definitely older than the oldest Morrow beds. In fact, the lower Springer beds correlated with the type Chesterian of Illinois. This showed that the deposition of the Springer was continuous across the systemic boundary and in fact the Springer "series" was half Chesterian and half Morrowian in age. Lane and Straka proposed that the "usage of the term Springeran as a visible subdivision of the Lower Pennsylvanian be discontinued". This statement resolved the nomenclature problem within the study area by eliminating the term Springer. It does not however, eliminate the years of use and familiarization by exploration geologists with a lithologic unit known as Springer. The exploration for hydrocarbons is not encumbered by the academic problems of stratigraphic nomenclature.

The lowest unit studied for the present project was the upper Okeene limestone of late Mississippian age known locally as the Flag lime due to its pennant shaped log signature (Campbell, 1985). It has been described as brown to white, mottled, coarse crystalline, and fossiliferous (Slate, 1965). The abrupt contact between this limestone and the overlying shales makes it an excellent regional marker. All of the cross sections show this bed as a lower structural marker.

The latest Chesterian unit is the Kimball. This is represented by a thick carbonate build-up above a black shale in the northwest of the study area. In the southeast this carbonate under goes a facies change to a low resistivity shale with occasional thin limestones. This shale section may be what is known as Springer in the deeper parts of the basin.

The placement of the Mississippian-Pennsylvanian boundary is a subject of considerable controversy. Workers in the shelf region (Forgotson, 1969) place the unconformity just above the first massive limestone in the Chester. Workers in the deeper positions of the basin (Slate, 1965; Swanson, 1979) place the uniformity at the base of the first well developed sandstone. This study area is on the transition zone between these two. Following the criterion explained previously in this chapter, the unconformity was picked throughout the study area.

The Morrow is divided into Upper and Lower units by facies differences. The Lower Morrow is a sequence of sandstone and shale units laid down by deltaic progradation into shallow waters. Woody fragments, coals and shell fragments were found within a short interval upon examination of cores of the area (see Appendix). This facies gives way to the Upper Morrow which is dominated by deep water shales and occasional limestones (Slate, 1965). There were no cores taken across the authors Upper Morrow-Lower Morrow boundary. Detailed biostratigraphic studies were not performed. But rather the division was made visually using the log signature. To the author there appeared to be two separate facies represented; the Lower Morrow was represented by sandstone deposition primarily with some interbedded shale, the Upper Morrow war primarily dominated by shales with occasional thin limestones. Overall, these regressive deposits (deltaic) which appear to onlap the Mississippian surface (see cross sections A_1-A_2, B_1-B_2, C_1-C_2), fit quite nicely into a model proposed by Swanson (1968). In his paper he describes deltaic deposits as regressive, because they prograde out into their receiving basin. He describes the early and middle Pennsylvanian as being transgressive overall. During minor regressions deltaic facies prograde, filling in the basin. He describes this as regressive deposits in the stratigraphic framework of onlap. One of his examples involves the depositional framework of the Morrow, Atoka and Cherokee formations of Early to Middle Pennsylvanian time. These formations are comprised basically deltaic systems and as they partially fill the basin, they exhibit 1500 feet of stratigraphic onlap (Figure 7). Note that the shape of the basin is referenced to Pennsylvanian-Permian time.

The close of Morrowan time is marked by angular unconformity within the study area. As seen on the cross sections, the Upper Morrow thins to extinction from southwest to northeast. In fact, three of the lower Morrow sandstone units are truncated in the far northeast of the study area (Plate 2).

The lowest Atoka is represented in the study area by a group of several thin limestone beds known as the Thirteen Fingers Limestone. South (1983) describes these separate limestones as actually onlaping the pre-Atoka unconformity surface. He described the limestones as gray

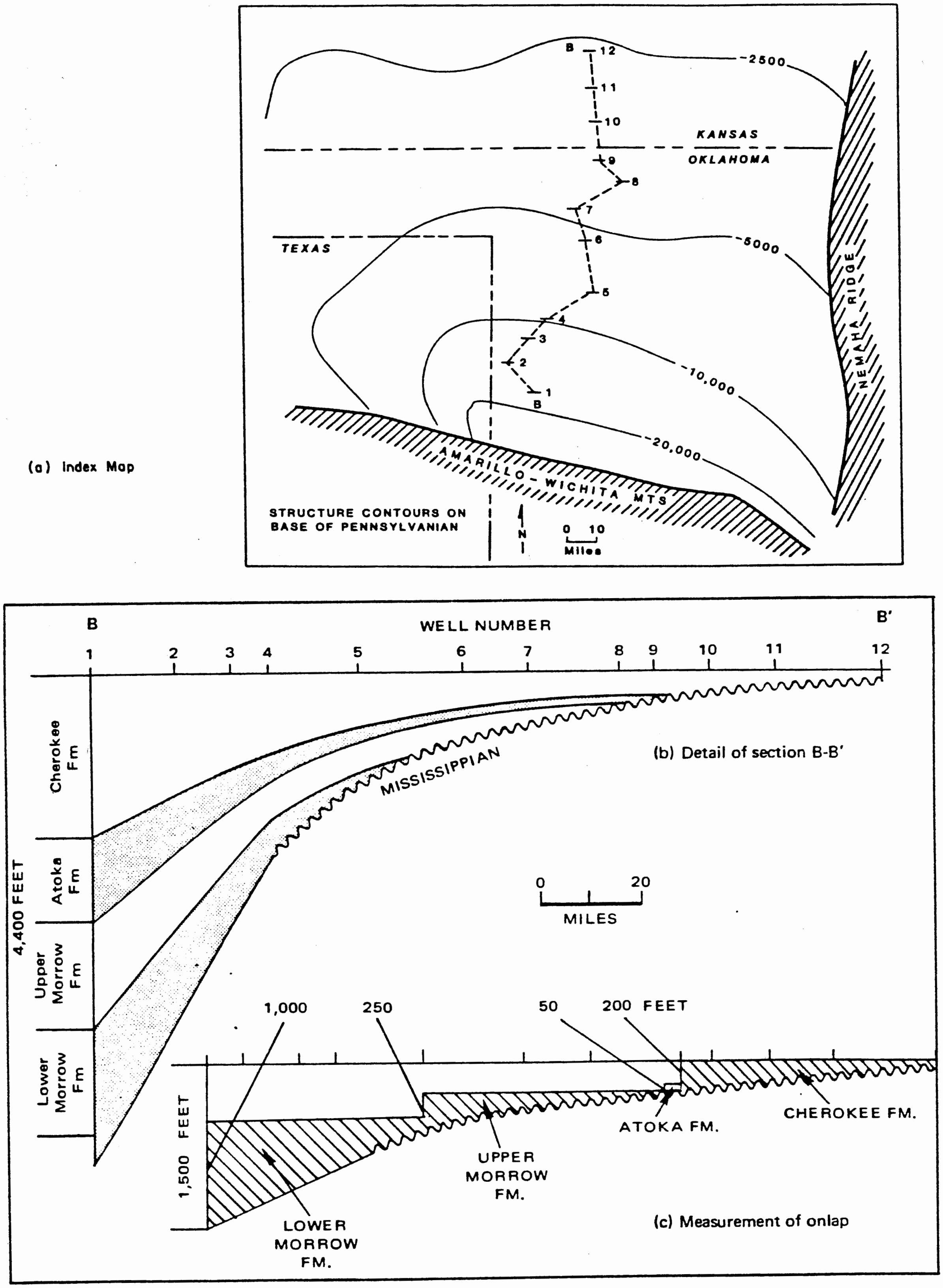

Figure 7. Onlap and Depositional Thickening in Morrow-Desmoinesian Clastic Sediments, Anadarko Basin (Swanson, 1968).

to greenish gray, argillaceous, skeletal wackestones and crystaline mudstones. The interbedded rocks are calcareous siltstones and black shales. The contact between the limestones and the finer grained rocks is transitional.

The points of correlation used in this study include the top of the Okeene limestone, the Mississippian-Pennsylvanian boundary, as well as eight genetic units in the lower Morrow (M_1 through M_8). M_1 is only present in cross section F_1-F_2 and is just outside the study area. The top of unit M_8 was picked as the dividing point between the Upper and Lower Morrow. The base of the Atokan Thirteen Fingers Limestone was picked as the Atoka-Morrow boundary. The base of the Cherokee was used as an uphole correlation point. The lower portion of the Red Fork and the adjacent Inola limestone exhibited a very distinctive log signature recognizable throughout the study area. All names and nomenclature were taken from previous works in the area.

CHAPTER VII

DEPOSITIONAL ENVIRONMENT

Regional Settings

The asymmetrical shape of the Anadarko Basin provided diverse settings for the Morrowan clastic deposition. Evans (1979) described fan deltas shed from the Amarillo-Wichita Mountains on the south. Some of these deltas are composed of chert conglomerates derived from the recently uplifted Meramec and Osage limestones of Mississippian age. The northwestern quarter of the Anadarko Basin has been extensively studied and provides a picture of transition during Morrowan time from terrestrial to marine depositional environments. In southeastern Colorado both Shirley (1984) and Orchard and Kidwell (1984) describe point bars and channels characteristic of fluvial systems. With the groundwork done by early workers such as Forgotson (1970), Ables (1982) and Khaiwka (1968), Swanson's (1979) paper was an excellent job in presenting the Upper Morrow as the transition of deltaic environments. His model depicts upper deltaic plain deposits in Eastern Colorado, middle deltaic plain facies in southeastern Colorado and southwestern Kansas and lower deltaic plain in the Panhandle regions of Texas and Oklahoma. Delta front, prodelta and offshore marine conditions are described in west-central Oklahoma. Kumar and Slatt (1984) reported submarine fan and slope facies within the Tonkawa. Based on their work on this late Pennsylvanian sandstone, they proposed that similar deep water marine facies could be found in the central Anadarko basin (Figure 8).

Paleoclimatology

The paleoclimate of western Oklahoma was quite different during Morrowan time than the present. Habicht (1980) characterized the Carboniferous (of which the Morrow is Middle Carboniferous) of North America as "very warm and moist." His maps depict a Carboniferous equator traversing the United States from southwestern Arizona across to the Upper Peninsula of Michigan. This would give the Anadarko Basin a paleolatitude of approximately 5° south. Within the southwestern United States, his paleoclimate indicators include carbonates and evaporites, both of which require warm conditions. Also extensive coal deposits are also noted. Paleo-wind indicators show an orientation of from the present day north. This puts the north edge of the Anadarko Basin under the influence of onshore breezes during Morrowan time.

Shift of Depocenter

Another major change in the Anadarko Basin is the shift of the depocenter. Curtis and Champlin (1959) indicate that the Anadarko Basin is the center for deposition for Chesterian rocks in the Mid-continent. This is southeast of the study area and gives a southeasterly dip during latest Mississippian time. Starting in the Pennsylvanian the depocenter began a shift to the west. Rascoe and Adler (1983) show the shift with a series of paleogeography/paleocology maps ranging from the Chester of Late Mississippian through the Wolfcamp of Early Permian time. The depocenter is to the southwest of the study area at the close of

LEGEND

LAND AREAS

▨ **High or moderately high relief**

▧ **Low relief**

MARGINAL AREAS

⁙ **Principally Deltaic deposition**

◌ **Coarse clastic**

SHALLOW MARINE

▤ **Principally terrigenous clastic deposition**

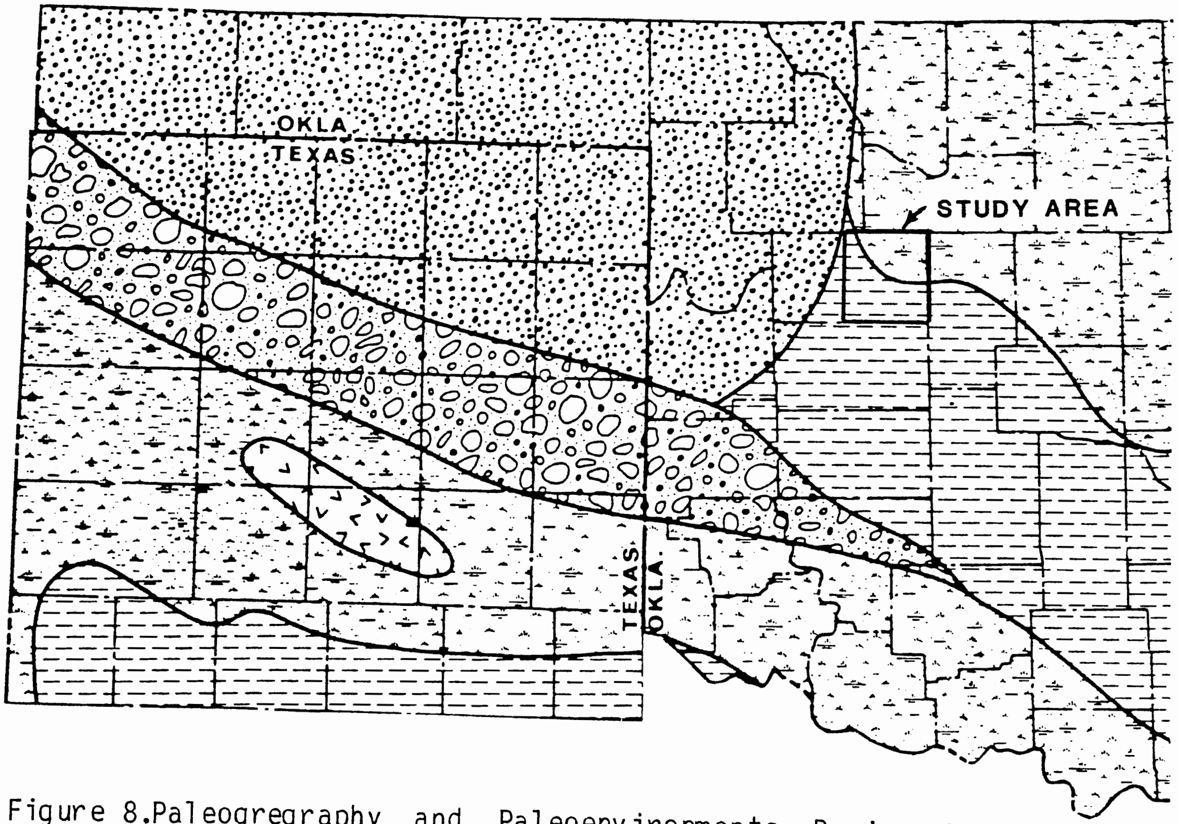

Figure 8.Paleogregraphy and Paleoenvironments During Morrowan Time (after Moore, 1979).

Morrowan time. The switch of the direction of dip from the southeast to the southwest is visible on the gross sand isopachs (Plates 11 through 17).

Local Settings

A review of the included gross sandstone isopachs and core analysis gives clues which help define the local depositional setting with the lower Morrow Formation. The orientation of the channels changes from the NW-SE direction for the M2 sand to the N-S direction of the M5 and M6 sands to the NE-SW direction of the M8 sand. This shift can be traced to the change in the depocenter of the basin during early Pennsylvanian time. The onlap of the erosional Mississippian surface can be seen in the increase of aerial coverage of the progressively younger sands. M2 covers the least area while M7 and M8 cover the entire study area.

The M2 sand trends to the southeast and is poorly represented in the study area. The core analysis of the Mobil Oil #1 Dobbins, Sec. 33-16N-15W shows a quartz-arenite with very few other minerals and an absence of sedimentary structures. This indicates reworking, possibly a littoral setting. The core itself was composed of minor pieces with no continuous piece longer than two inches.

The M3 sand is depicted by three main distributary channels which cover the lower half of the study area. These channels bifurcate down dip and have occasional splays indicative of a low wave, low tide environment.

The M4 sand map shows the best developed example of a deltaic setting. The channels here shifted to a more north-south orientation and exhibit a considerable increase in splaying at the mid-point of the map. This channel environment is supported by the core analysis of the Texas Pacific #1 Shafer Section 22-18N-14W. The lowest sand body in this core is interpreted as a minor deltaic distributary channel.

By the time of the deposition of the M5 sand, the setting began to change. Along the western side of the study area the deltaic channels continue their southward progradation, while in the northeast there appears to be more northeast-southwest. The anastomosing channels in the east-central portion of the study area indicate a shoaling or decrease in dip. This sand interval in the Texas Pacific #1 Shafer is interpreted as a tidal flat.

The M6 sand map shows the continuation of the decrease in sediment supply as growing thinner and fewer channels and the shift of the orientation of the sand trends. The major sand deposition is in the southwest quadrant of the study area with the remainder showing thin "shoe string" sands. The core analysis of the Woods Petroleum #5-2 Edwards across this sand interval has been interpreted as a distributary channel sandstone in a shallow marine setting.

Both the M7 and M8 sand maps show meandering, anastomosing channels with their depositional trends distinctly to the southwest. This shift from the southeast, plus the decrease in sediment supply, can be explained by the deepening of the basin to the southwest during Morrowan time. This change in dip is most likely exhibited by a switching of the delta site to the west.

Depositional Model

Coleman (1981) of the Coastal Studies Group at Louisiana State University has proposed a series of eleven (I through XI) variables by which deltas can be differentiated. The paleoclimate (I) in this area has been described as "warm and moist". This along with the equatorial latitude would give a high average rainfall, which provides for a high and relatively stable water discharge rate (II). This high rate coupled with a medium sediment yield (III) will result in semi-linear bifurcating channels similar to but on a smaller scale than the present day Mississippi River delta. The bifurcating channels (river mouth processes (IV)) are indicative of several coastal conditions including low wave influence (V), low tidal (VI) influence (although some is seen in the study areas) and a low shelf slope (IX). These three factors are also indicative of depositional system that would undergo delta switching as proposed earlier. Although Habicht (1980) proposed prevailing onshore winds in the region, wind processes (VII) are not directly visible in the rock record (i.e. an oriented core from an aeolian sand). An offshore wind increases wave energy and an onshore wind limits wave energy. The geometry of the sandstone bodies tend to infer low wind influence.

Nearshore currents (VIII) are a result of deep oceanic water movements and the tidal flux (Coleman, 1981). The Anadarko Basin of Morrowan time is similar to the Black Sea of modern time as far as both are semi-enclosed basins (receiving basin Geometry (XI)). The Black Sea is removed from deep oceanic currents and is not greatly affected by tides (Coleman, 1981). The sand distribution patterns (lack of barrier bars or chenier plains), coupled with the Black Sea model, shows that the effect of longshore currents in the study area was minimal.

The tectonics of the receiving basin (X) is the least studied of Coleman's eleven variables. It can be noted that this region was fairly stable tectonically. The major subsidence in the Anadarko was far to the south. This is seen in the thickening of the Morrow sands to the south as exhibited in the cross sections. This is also visible on the total Morrow Isopach, although its effect is masked by the pre-Atoka erosional event.

The presence of marine fossils and glauconite grains in several of the cores indicates some form of marine influence. The fossil hash seen in the Woods Petroleum 5-2 Ward is within the M6 sand unit. Tidal influx could account for marine fossils that far north in the study area. However, the sand geometry leads the author to discount the tidal influence. A more feasible model involves a series of minor transgressions and regressions. Within the Lower Morrow there are primarily sandstones and shales. The shales could have been deposited during a minor transgression. The sandstones could be deposited during the subsequent minor regression. At this time some of the marine sediments (shales) could have been reworked and deposited the fossil hash seen in the sandstone sequence. The study area was one of very low slope and a small change in sea level would have produced considerable migration of the shoreline.

In summary, the Lower-Morrow sandstone units mapped in this study were most likely a minor delta prograding over a very low relief topography into waters of low wave energy and low tidal influence. The changing dip of the basin caused a shift in the site of deltaic sediment

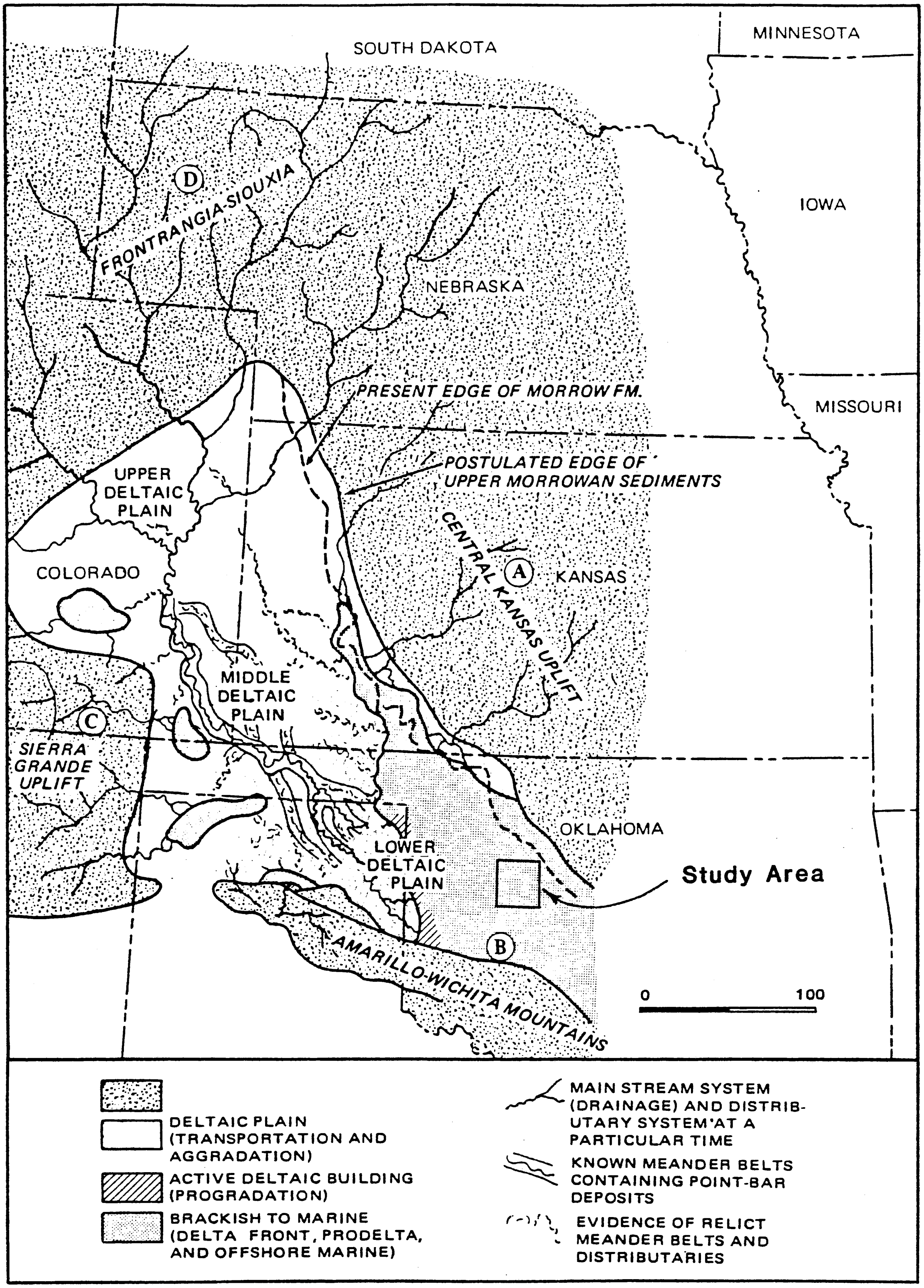

Figure 9. Paleographic Map, Upper-Morrow Time (Shelton, 1973).

and this area most likely became estuarine in nature.

Upper-Morrow Depositional Model

The Upper Morrow has been described as black fissile shale (Slate, 1967). The log signature across this interval shows predominately shale with occasional thin resistive beds, possibly limestones. Both Swanson (1979) (Figure 9) and Rascoe and Alder (1983) indicate that this is an area of deep water sedimentation. These ideas conform to the author's conclusions about this interval within the study area. There are no major sand bodies within this interval as well as no major carbonate development. These rocks were deposited in deeper marine water away from the site of major clastic deposition.

Other Ancient Examples

Shelton (1973) summarized the work that Fisher and McGowen did on the lower Wilcox depositional system of southeast Texas. He reports on the Rockdale delta system and the Mt. Pleasant fluvial system (Figure 10). A similar situation existed during the Morrowan of the northern Anadarko Basin but as the mirror image. In Oklahoma and Colorado a fluvial system is to the west and a deltaic system is seen to the east. The delta of the study area would similar to one of the minor lobes on the left of the Rockdale delta system. Visher (1968) reported on the deposition of the Bluejacket-Bartlesville sandstone. Although he has since changed his ideas about the depositional setting, the sand body geometry on his map (Figure 11) bears a strong similarity to the author's M4 sand isopach.

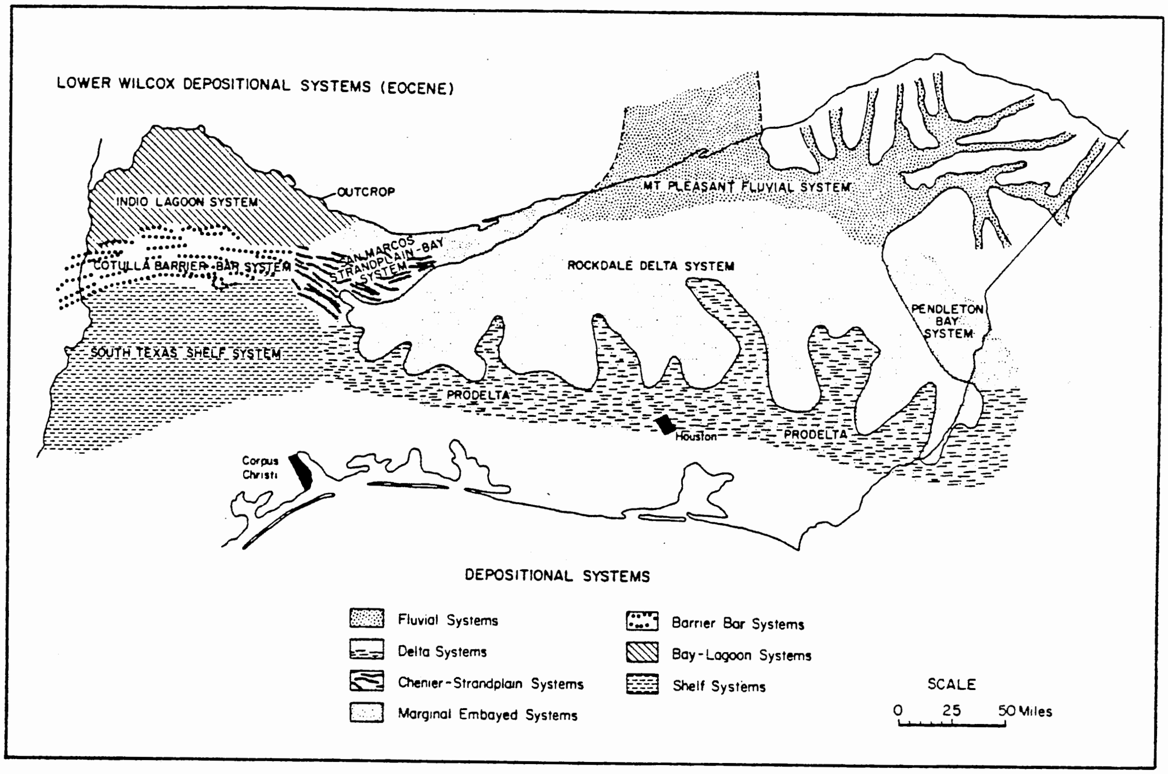

Figure 10. Lower Wilcox Depositional Systems (Eocene) Regional Model for Morrowan Deposition, Ancient Example (Shelton, 1973).

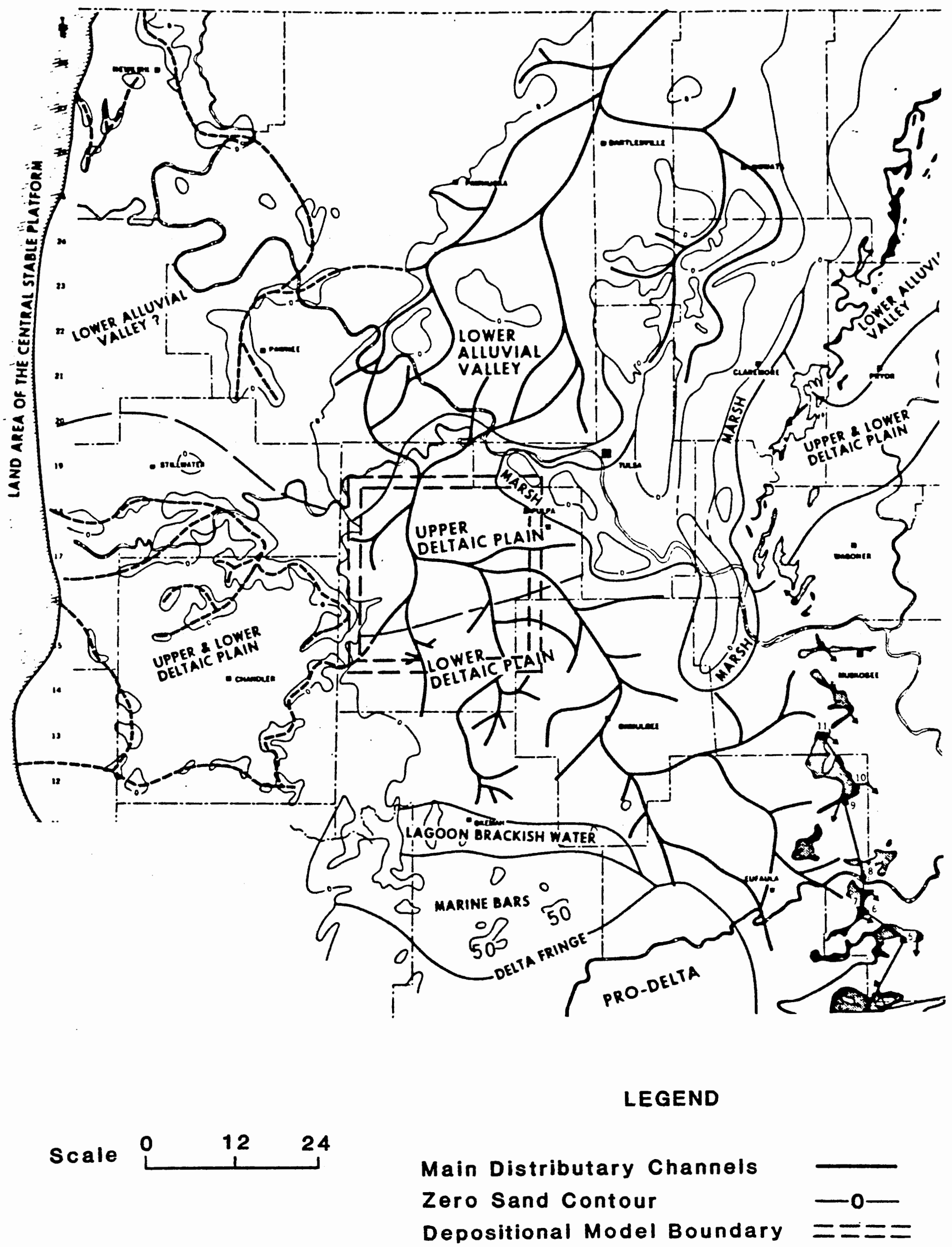

Figure 11. Paleogeography of Blue Jacket (Bartlesville) Sandstone Complex with Depositional Model Boundary (Visher, 1968).

CHAPTER VIII

PETROLOGY

Introduction

Following Leeder's sandstone classification, the cores studied fall into seven rock types (Figure 12). They are:

1. Quartz Arenite
2. Skeletal Quartz Arenite
3. Skeletal Quartz Sublitharenite
4. Quartz Sublitharenite
5. Arenaceous Pebble Conglomerate
6. Quartz Wacke
7. Mudstone

Mobil Oil #1 Dobbins

The quartz arenite of the #1 Dobbins was primarily monocrystalline quartz with trace amounts of polycrystalline quartz. The polycrystalline grains exhibited sutured grain contacts. The quartz grains exhibit considerable quartz overgrowth and dust rims are visible in places. Small vacuoles are visible in numerous grains as well as needle like mineral inclusions probably rutile. Undulose extension was observed as well as Boehm Lamallae. These are both indicators that the rock has undergone strain. Glauconite grains were a minor constituent but since have been dissolved to form 5-8% secondary porosity. Chert

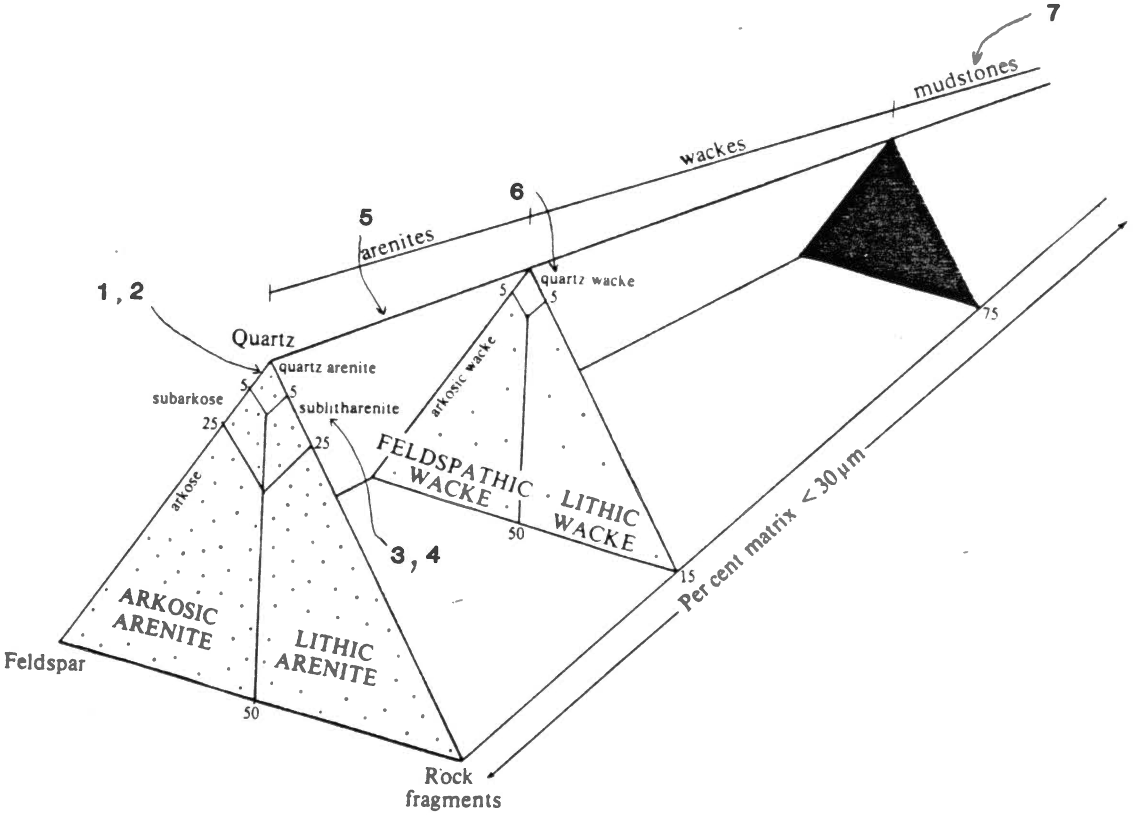

Figure 12. Sandstone Classification (Leeder, 1982).

and zircon are present in trace amounts. The SEM photos reveal vermicular kaolinite as well as edge to face chlorite. (Figures 13 and 14). The base of this sandstone is an arenaceous pebble conglomerate. The pebbles are siderite in composition as revealed by the X-Ray analysis. Piokilotopic calcite cement is typical within the conglomerate. Carbonacous woody fragments were observed. Porosity within this interval is limited to microfracture porosity.

Helmrich & Payne #2-4 Ward

The #2-4 Ward is only represented by one sample and that is described as a skeletal sublitharenite. The sample contains abundant skeletal fragments including brachopods, mollusks, echinoderm plate fragments, crinoids and brozoans. The quartz grains were encased in calcite cement which is piokilotopic in places. There were clay clast present with silt size quartz inclusions. Kerogen residue is visible within one of the clay clasts and between the quartz grains in a few places. Glauconite grains are present (5%) and are deformed by compaction in most cases. Some glauconite had undergone green to brown transition. A coal streak has logged within the cored interval. There was pyrite associated with this unit.

Woods Petroleum #5-2 Edwards

The #5-2 Edwards exhibits quartz sublitharenites, skeletal sublitharenites, and mudstones. The quartz sublitharenite was in the upper portion of the core. There was both monocrystalline and polycrystalline observed. There was less than 1% porosity seen as it was filled by porelining clays such as kaolinte, illite-smectite and

Figure 13. Vermicular Kaolinite, Mobil Oil #1 Dobbins Sample 11,332. Magnification 540X.

Figure 14.Face to Edge Chlorite in a Pore, Mobil Oil #1 Dobbins Depth 11,330. Magnification 2200X.

chlorite. Siderite cement was present. Intraformational conglomerates and carbonaceous styolites are noted in the lower portions of this unit. The skeletal sublitharenites range from 50% to 5% skeletal fragments. They include echinoderm plates, brachipods and crinoids. The quartz is of two varieties. Mono-crystalline quartz often has quartz overgrowths and dustrims. Undulose extension is noted, as is Boehm Lamellae. Microcrystalline quartz and polycrystalline quartz are present in trace amounts. Microfracture porosity is the only type present here. Accessory minerals such as zircon are noted within the stylolites. The mudstone at the top of the cored interval contained thin brachiopods shells.

Texas Pacific #1 Shafer

The #1 Shafer exhibits quartz wackes and skeletal quartz arenites. The quartz wackes are bioturbated monocrystalline quartz with 20-25% mud matrix. The skeletal quartz arenites have from 40 to 2% skeletal fragments. Those sands with the highest skeletal percentage have calcite cement. Those with the least, show a predominance of quartz overgrowths. Authigenic clays are present primarily as vermicular pore filling kaolinite (Figure 15) with trace amounts of chlorite and illite. Zircon and chert were observed in trace amounts.

Providence

The source of these sands is not immediately discernable as the rocks give conflicting clues. In general there are two sources for the Pennsylvanian sediments of the northern Anadarko Basin; the metamorphics of the Frontrangia province in Colorado and the plutonic and

Figure 15. Pore-filling Authigenic Vermicular Chlorite, Texas Pacific #1 Shafer Sample Depth 9,195. Magnification 440X.

pre-Pennsylvanian sedimentary rocks of the Central Kansas Uplift (Swanson, 1979). The quartz grains show undulose extinction and polycrystalline grains, both possible indicators of metamorphic sources. The polycrystalline grains are rare. Blatt (1972) states that metamorphic rocks are about 75% polycrystalline quartz. A metamorphic source would provide more polycrystalline grains than are seen here. The undulose extinction could well be due to the fact that the C-Axis of the quartz grain is not lined up with the rotation of the microscope stage. The grains visible with early calcite cement are quite round. This indicates a mature sand, one that is possibly been through a second cycle of deposition (Leeder, 1982). The Boehm Lamallae are evidence for strain of a quartz grain. It may be a sign of metamorphic processes but the strain may have been *in situ*. (Scholle, 1979). Kaolinite is a weathering product of feldspar, a common mineral in plutonic rocks. Almost all of the samples contained kaolinite in authigenic form. This would indicate a plutonic source. When one considers the proximity of the possible source areas and take into account the orientation of the basin, the Central Kansas Uplift is the most likely source for the Lower Morrow sands deposited in this area.

CHAPTER IX

DIAGENESIS

Diagenesis is defined as all chemical and physical changes that sediments undergo from the time they are deposited but before they are metamorphosed (Al-Shaieb, 1984). Since its deposition in early Pennsylvanian time considerable changes have taken place in these Morrow sands. These changes will be discussed with the aid of the information derived from thin section analysis, SEM photography, and X-ray diffraction analysis.

The diagenesis of these sands manifests itself in many ways. Mechanical compaction and deformation is seen in the ductile deformation of detrital grains such as glauconite. It is also seen in fracturing of the rock fabric which cuts across both quartz and skeletal grains. Pressure solution is seen as both rare styolititc grain contacts and the more common carbonaceous styolities. Dissolution and precipitation are reverse processes and both are seen in the Morrow. Dissolution of detrital grains like quartz (Figure 16) and glauconite can result in porosity. Precipitation fills in the voids either from primary porosity or secondary porosity. Figure 16 shows the filling of porosity by chlorites. Figures 17 & 18 shows quartz overgrowths and how they have reduced the primary porosity. Often times calcite cements or clays are precipitated which reduce the primary porosity. Glauconite grains can undergo an alteration from green to brown in color.

Figure 16. Dissolution of Quartz Grain, Texas Pacific #1 Shafer Depth 9.195. Magnification 860X.

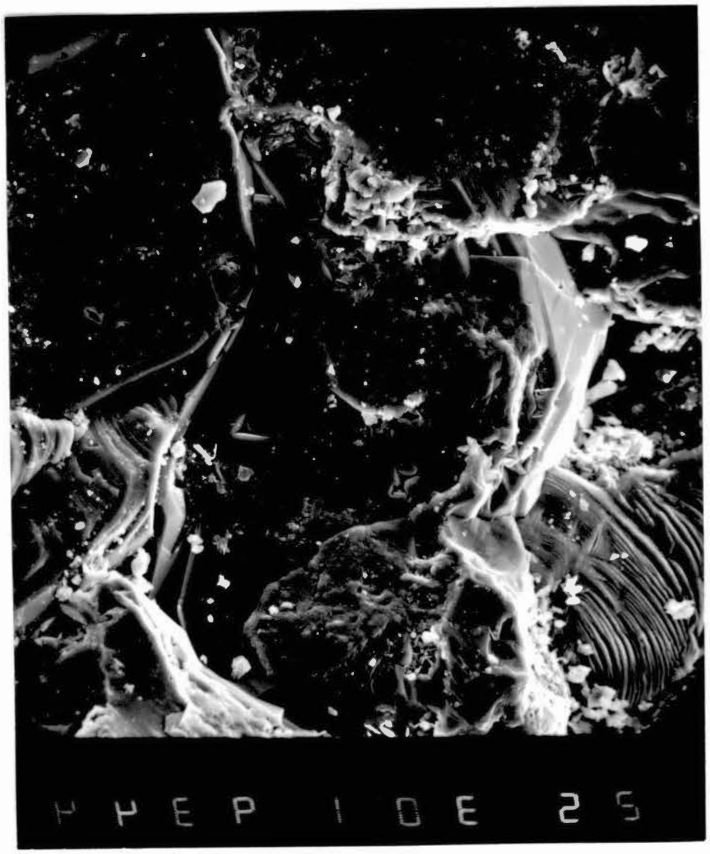

Figure 17. Reduction of Porosity by Quartz Overgrowth Chlorite Lining Pore (Figure 14), Mobil Oil #1 Dobbins Sample Depth 11,330. Magnification 220X.

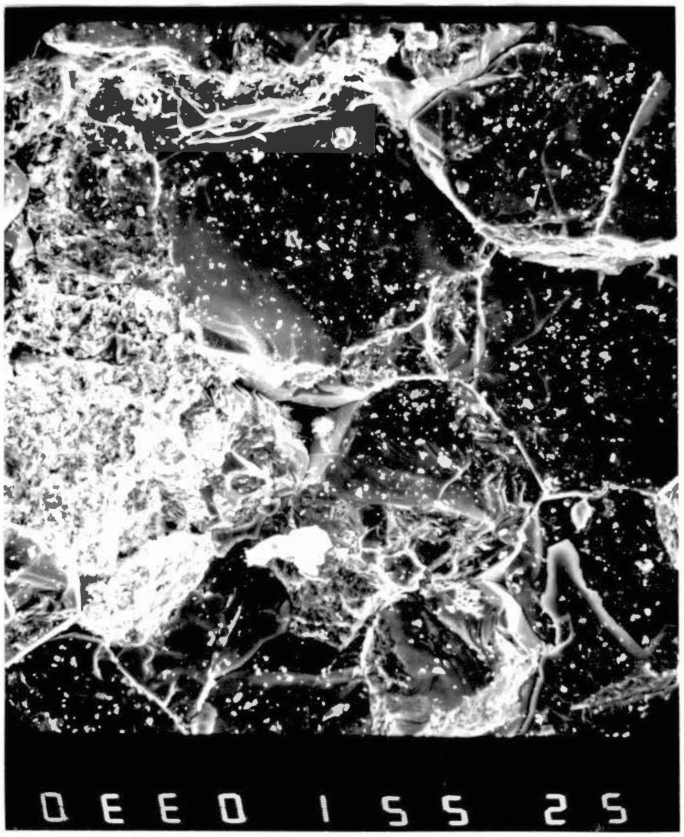

Figure 18. Reduction of Porosity due to Quartz Overgrowth Mobil Oil #1 Dobbins Sample Depth 11,332. Magnification 300X.

Diagenetic processes can be described in terms of porosity and its changes (Figure 19) which in turn are controlled by residence time and temperature (Schmidt and McDonald, 1979). During the immature stage the most notable change is the loss of porosity. This may be due to mechanical compaction or the formation of eogenic carbonates.

The semimature stage is marked by a continued loss of porosity. Eogenic carbonate formation still continues but is surpassed in importance by the generation of mesogenic carbonates. The generation of quartz cements in the form of overgrowths becomes important at this time. As the sand stone enters the mature stage, secondary porosity in created by decarbonatization, dissolution of detrital grains and decarboxylation of any organic matter present. Towards the end of the mature stage, the secondary porosity is destroyed by continued increase in the precipitation of quartz cement. This process continues until virtually all the secondary porosity is gone and the sand reaches a super mature stage.

The cores studied show either a semimature or mature stage of development depending upon the detrital make up of the particular sands. The quartz arenites of the Mobil Oil #1 Dobbins show a mature stage of development. There are quartz overgrowths which cause nearly complete loss of porosity (Figure 17). Seen in the thin sections are dissolution of glauconite grains creating secondary porosity. However, if a sand has a sizable portion of skeletal grains such as the Texas Pacific #1 Shafer or the Woods #5-2 Edwards, it may be in a semimature stage. The skeletal grains provide a source of carbonate for both poikilotopic cement and mosaic calcite cement. These cause a complete loss of primary porosity which inhibits the circulation of formation water.

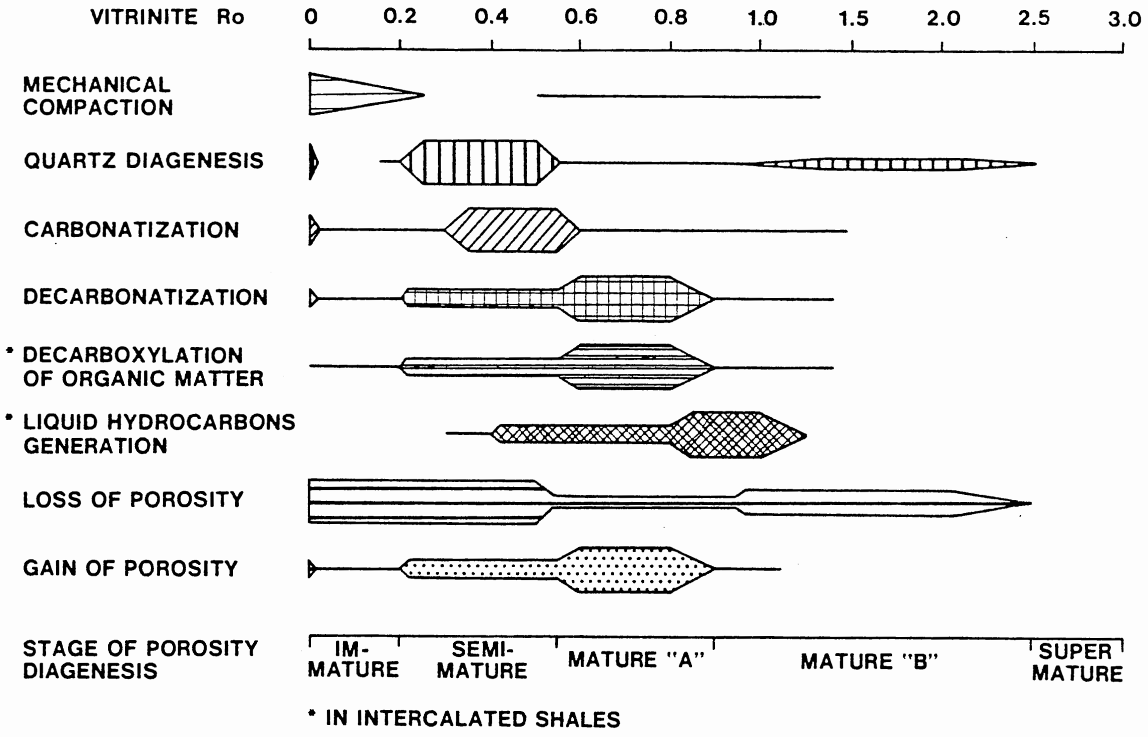

Figure 19.Burial Diagenesis of Quartz Arenites (Schmidt and McDonald, 1979).

The presence of authigenic kaolinite and chlorite suggests a more mature stage of diagenesis. Leeder (1982) describes the weathering process where by K-feldspar breaks down in illite which in turn forms kaolinite. The underformed appearance of delicate crystal habits as face to edge chlorite (Figure 14) and vermicular kaolinite (Figure 15) suggest their authigenic nature (Wilson and Pittman, 1977).

p 56 absent
(2) p. 57

Red Fork and Atoka. The deeper, older formations are generally gas productive. They include the Chester, Mississippian, Hunton and one well in the Viola. The Morrow is productive of both oil and gas depending upon the location. This past history provides considerable economic incentive for continued exploration in this area.

Morrow Oil and Gas

All of the Morrow sandstone units are productive within the study area except the M8 sand. The majority of the wells are producing from the M3, M4, or M5 interval. This information was derived by correlating the perforated interval on the scout ticket with the sandstone units as marked on the individual log. Some operators perforated many zones, some of which may not have been productive. A well by well production history was beyond the scope of this study.

In an effort to find a key to the production, several factors were studied area-wide. When a sand was productive it was marked on the gross sand isolith map. This was then overlain by the author's porosity distribution maps (not published here). Not too surprisingly, the production was generally associated with the combination of a higher gross sand value and a higher porosity value. What was significant is that the production was often found in an up-dip stratigraphic trap. A review of the depositional model shows that the majority of the sand bodies (M3, M4, and M5) were deposited with dips between southeast and south. As the basin subsided to the southwest, the sand bodies (reservoirs) were tilted also. This forced the hydrocarbons into up-dip stratigraphic traps.

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Exploration Considerations

A good prospect in this area would have both a well-defined clean sand trend and a well-defined porosity trend. The sand trend or lobe should be orientated so that when post-depositional dip change is figured into the geology of the prospect, it allows for an up-dip stratigraphic pinchout.

There are other possibilities for prospects which are more developmental in character. Several times it was noted that as a sand trend was traced across the study area, the production was not observed in every well which had both the clean and porous sand present. Individual well histories need to be examined to determine whether the interval had been tested. Perhaps there were problems with the drilling or completion of the well. Because of the varied clay lithologies present in the Morrow, particular care must be used when selecting drilling fluids or completion practices. One example which stands out in that of a gas well which had a natural production of 700 MCF per day but was later declared dry and abandoned due to completion problems. Considerable oil and gas remains to be found in the Morrow study area by the geologist with the time, the patience, and the eye for detail required for successful exploration.

CHAPTER XI

SUMMARY AND CONCLUSIONS

1. During Chesterian time the depositional center for the Anadarko Basin was located near present day Ardmore. This gave a southeasterly dip during Chesterian time within the study area.

2. The lower Morrow sands were deposited unconformably on the eroded Chesterian surface.

3. As the different sands were deposited, the dip of the local surface started to shift to the Southwest. This shift affected the sediment supply and the sand deposition.

4. The sands were lain down in a deltaic setting with progradation dip shifting to the Southwest.

5. The Upper Morrow shales were lain down in a deep water marine setting in advance of the deltaic sedimentation to the west.

6. The provenence of the Lower Morrow sands is from the Central Kansas Uplift.

7. Through diagenesis most of the primary porosity has been destroyed. The secondary porosity has mainly resulted from dissolution of detrital glauconite grains or incomplete filling of pore space by quartz overgrowths.

8. The present day trap for the hydrocarbons of this area is formed when a sandstone unit undergoes post-depositional dip change and traps the hydrocarbons in an updip stratigraphic pinchout.

9. The use of computers have proved invaluable in the timely completion of this study. From the storage of eighteen tops (maximum) for each of almost 700 wells to the generation of eighteen separate maps, this system, used by the J. M. Huber Corporation, has allowed the assimilation of a tremendous amount of data and synthesis of geological models in a relatively short time.

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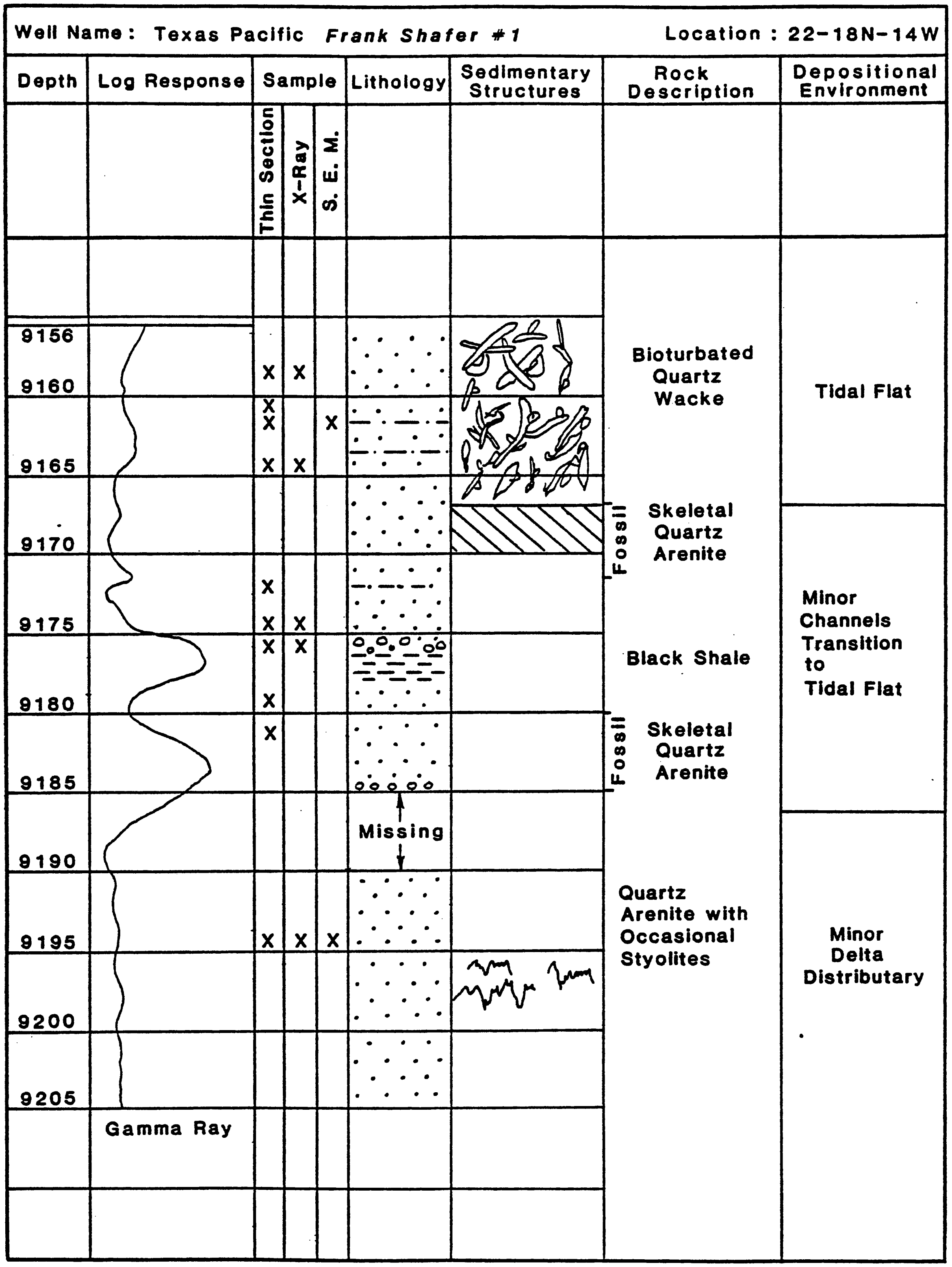
APPENDIX A

CORE DESCRIPTIONS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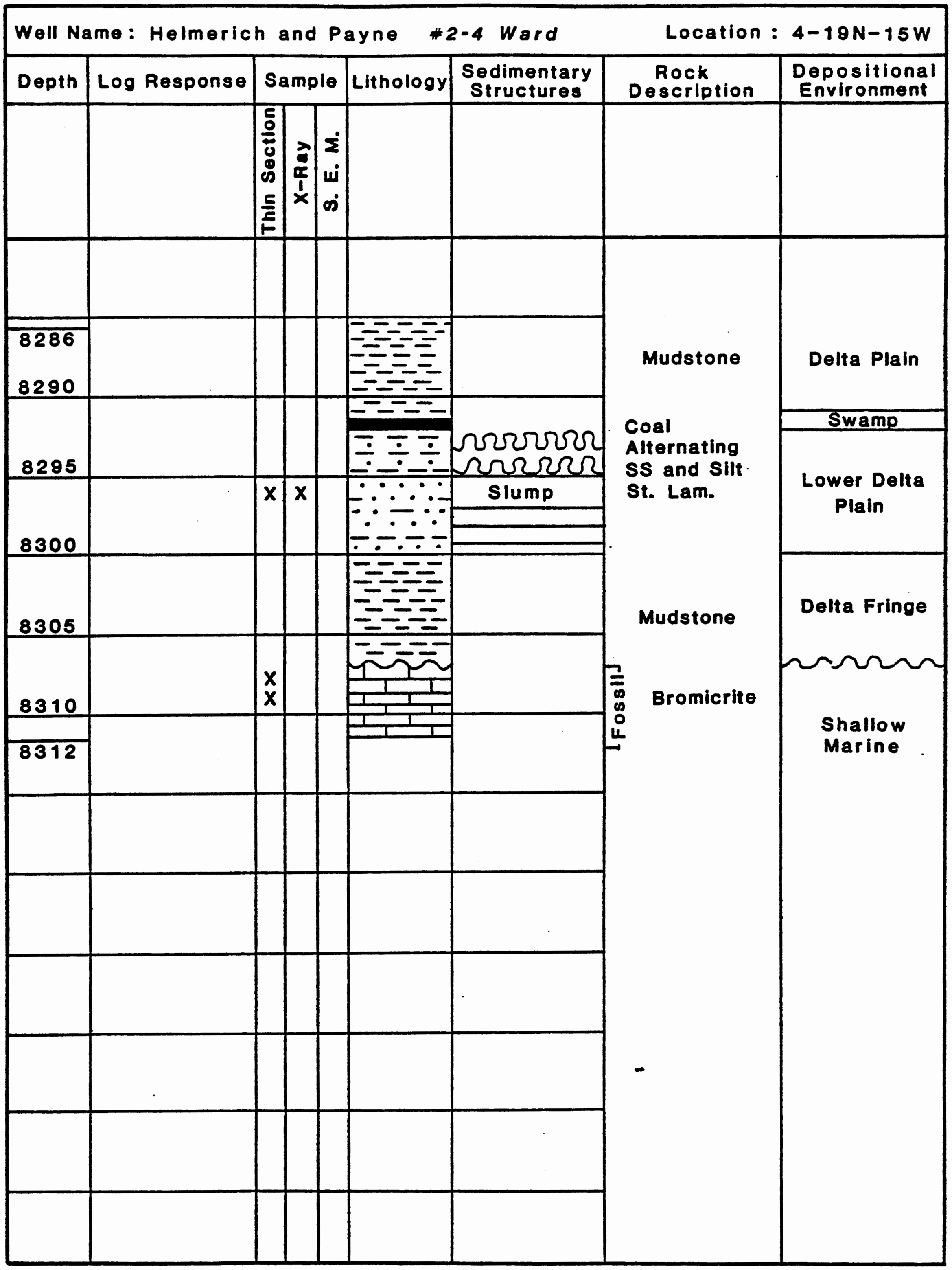
Log Response
Sample
Thin Section
X-Ray
S. E. M.
Lithology
Sedimentary Structures
Rock Description
Depositional Environment
9156
9160
9165
9170
9175
9180
9185
9190
9195
9200
9205
X
X
X
X
X
X
X
X
X
X
X
X
X
X
X
X
X
Missing
Gamma Ray
Fossil
Fossil
Bioturbated Quartz Wacke
Skeletal Quartz Arenite
Black Shale
Skeletal Quartz Arenite
Quartz Arenite with Occasional Styolites
Tidal Flat
Minor Channels Transition to Tidal Flat
Minor Delta Distributary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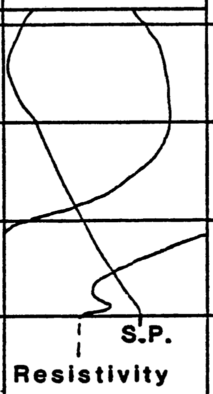
Location: 4-19N-15W
Depth
Log Response
Sample
Lithology
Sedimentary Structures
Rock Description
Depositional Environment
Thin Section
X-Ray
S. E. M.
8286
8290
8295
8300
8305
8310
8312
X
X
X
X
Slump
Mudstone
Coal
Alternating SS and Silt St. Lam.
Mudstone
Fossil
Bromicrite
Delta Plain
Swamp
Lower Delta Plain
Delta Fringe
Shallow Marine

Well Name : Mobil Oil 1 *Dobbins* **Location : 33-16N-15W**



Depth	Log Response	Sample			Lithology	Sedimentary Structures	Rock Description	Depositional Environment
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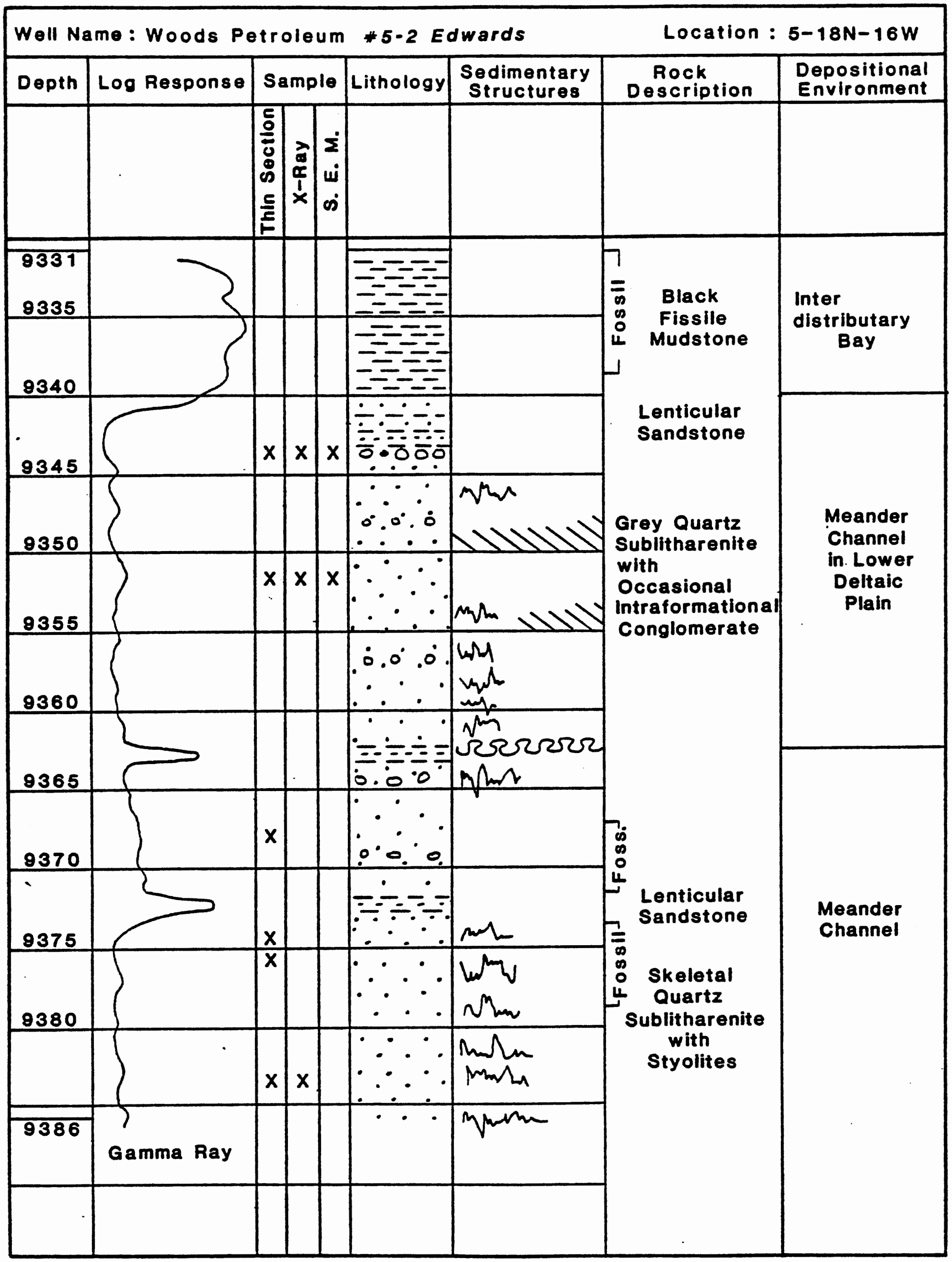
11329		X	X	X	· · · ·			
11335		X X	 X	X	· · · · ·		Quartz Arenite	Reworked Litoral Sand
11340		X			· · · · ·			
11345		X X	 X		· · · · · o·o·o·o·o		Pebble Conglomerate	
	S.P. Resistivity							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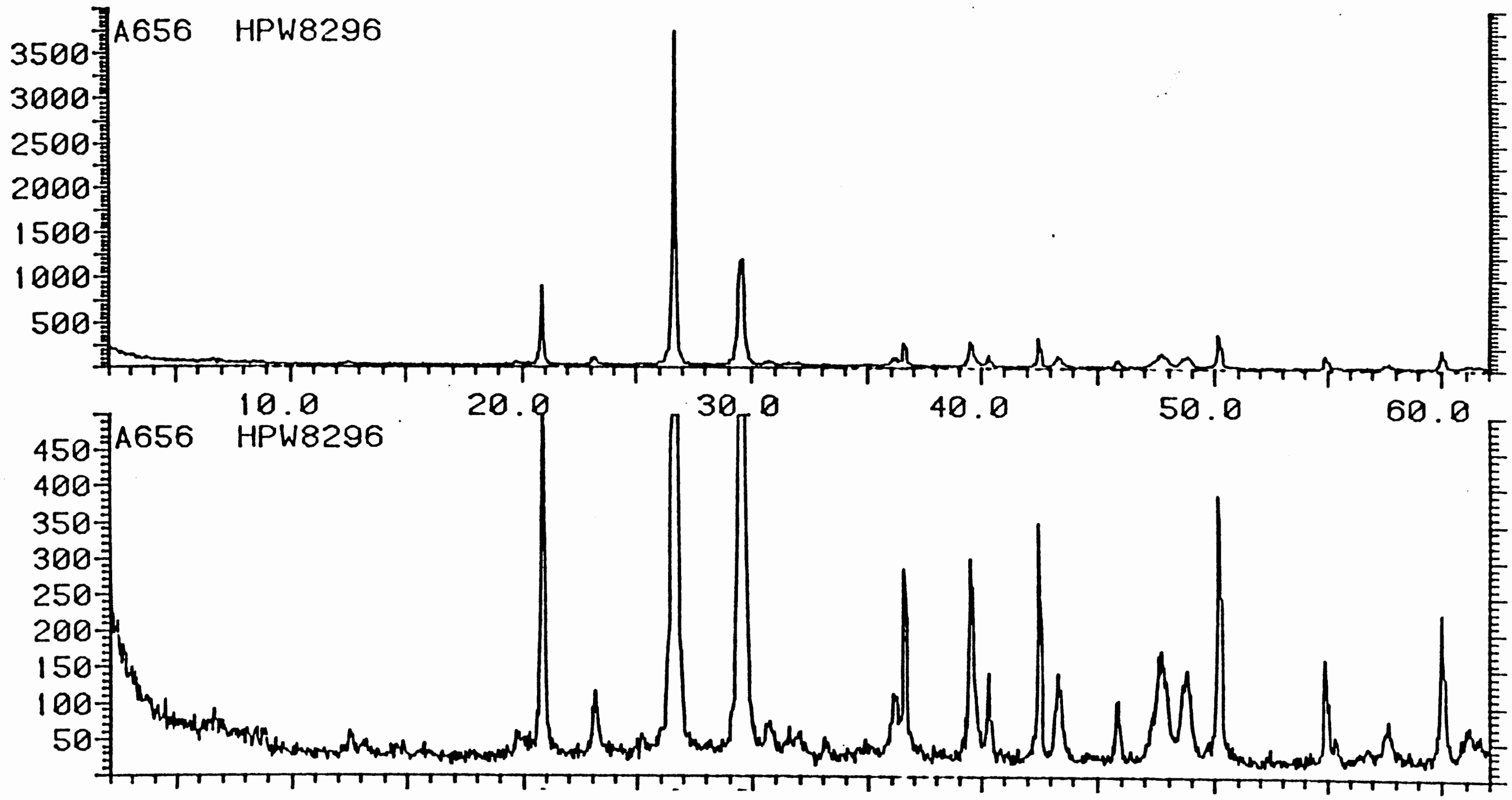
Location : 5-18N-16W
Depth
Log Response
Sample
Lithology
Sedimentary Structures
Rock Description
Depositional Environment
Thin Section
X-Ray
S. E. M.
9331
9335
9340
9345
9350
9355
9360
9365
9370
9375
9380
9386
Gamma Ray
X
X
X
X
X
X
X
X
X
X
X
X
Fossil
Black Fissile Mudstone
Lenticular Sandstone
Grey Quartz Sublitharenite with Occasional Intraformational Conglomerate
Foss.
Lenticular Sandstone
Fossil
Skeletal Quartz Sublitharenite with Styolites
Inter distributary Bay
Meander Channel in Lower Deltaic Plain
Meander Channel

APPENDIX B

X-RAY DIFFRACTION PATTERNS



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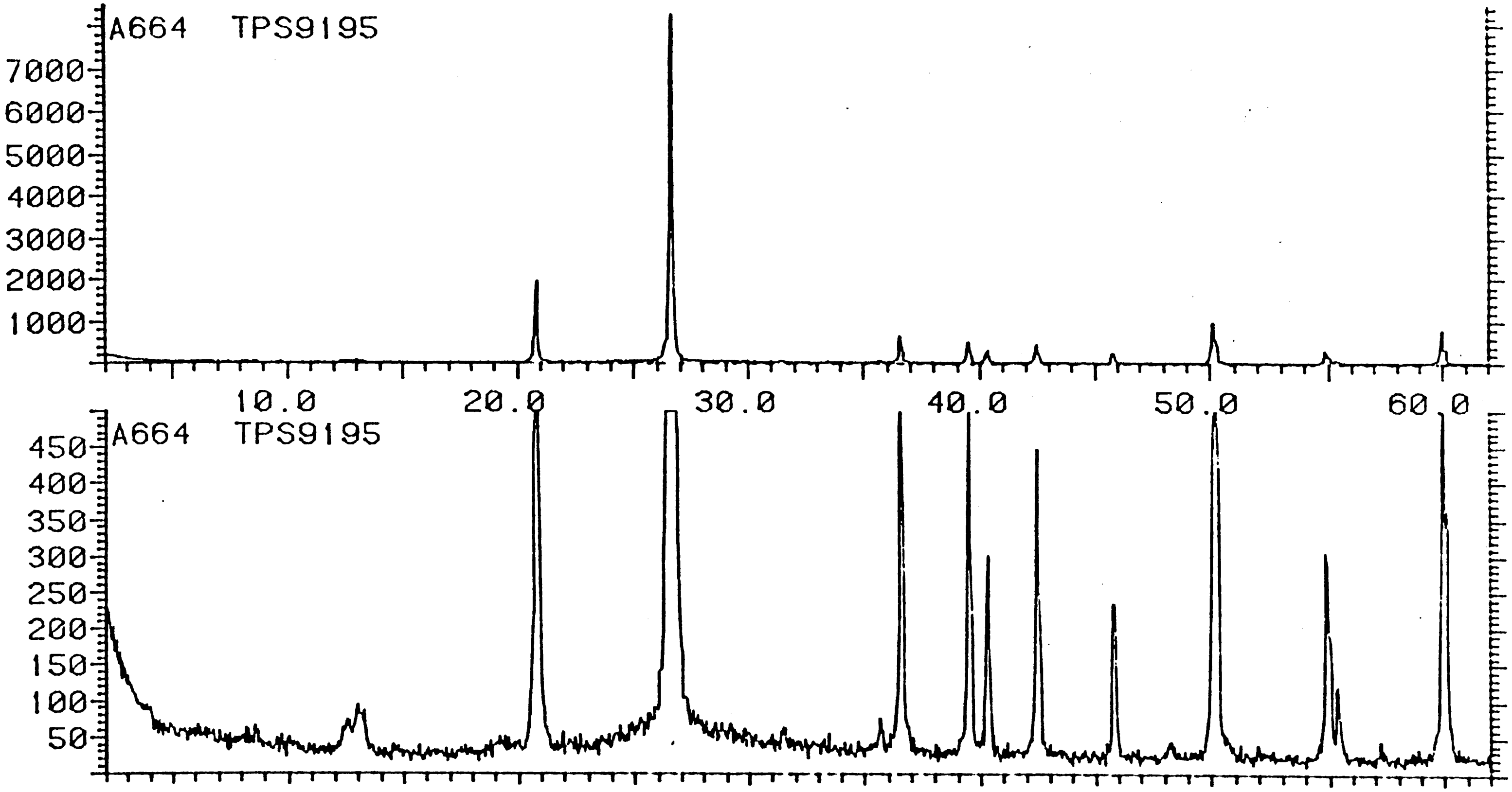

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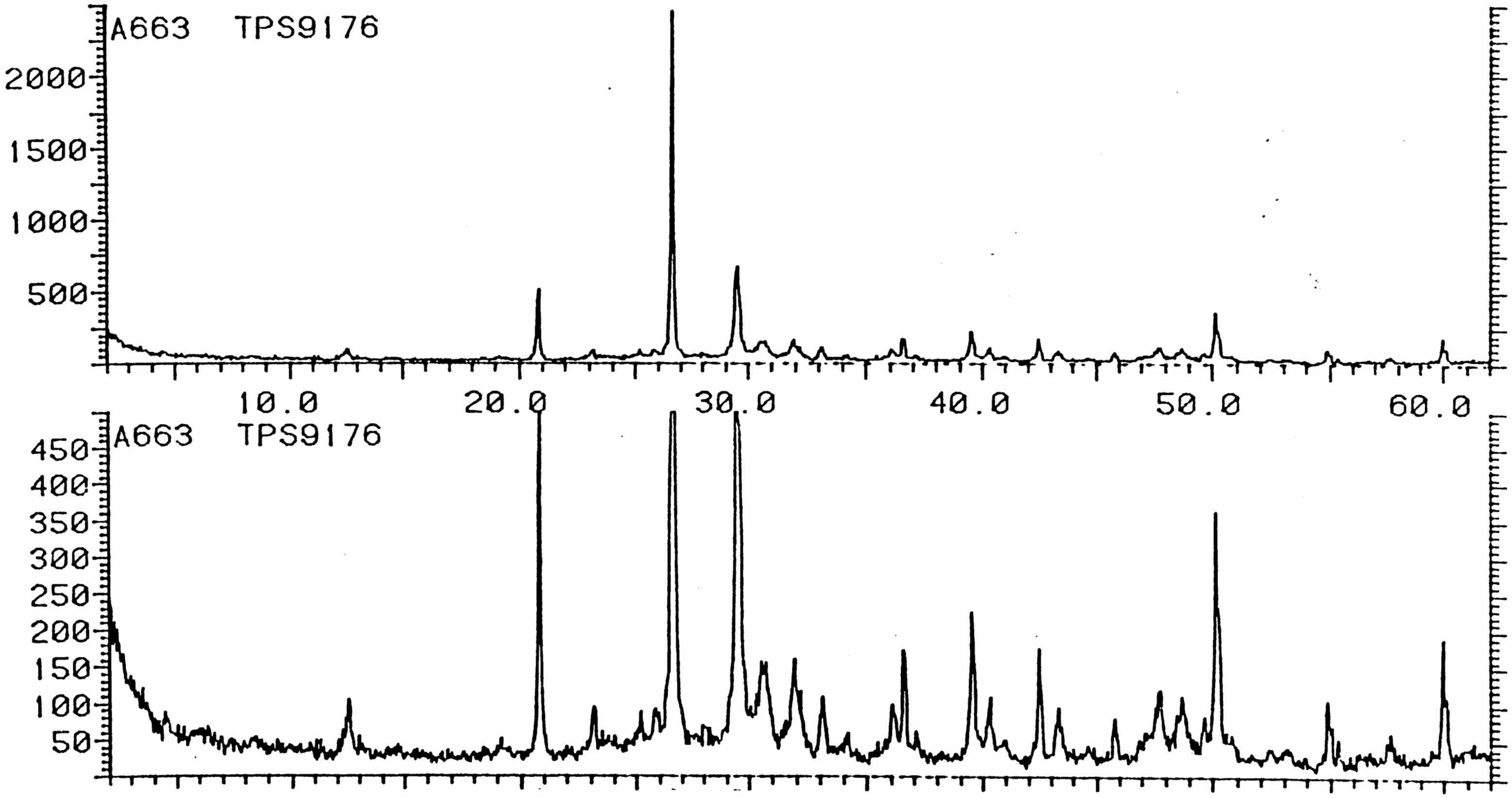

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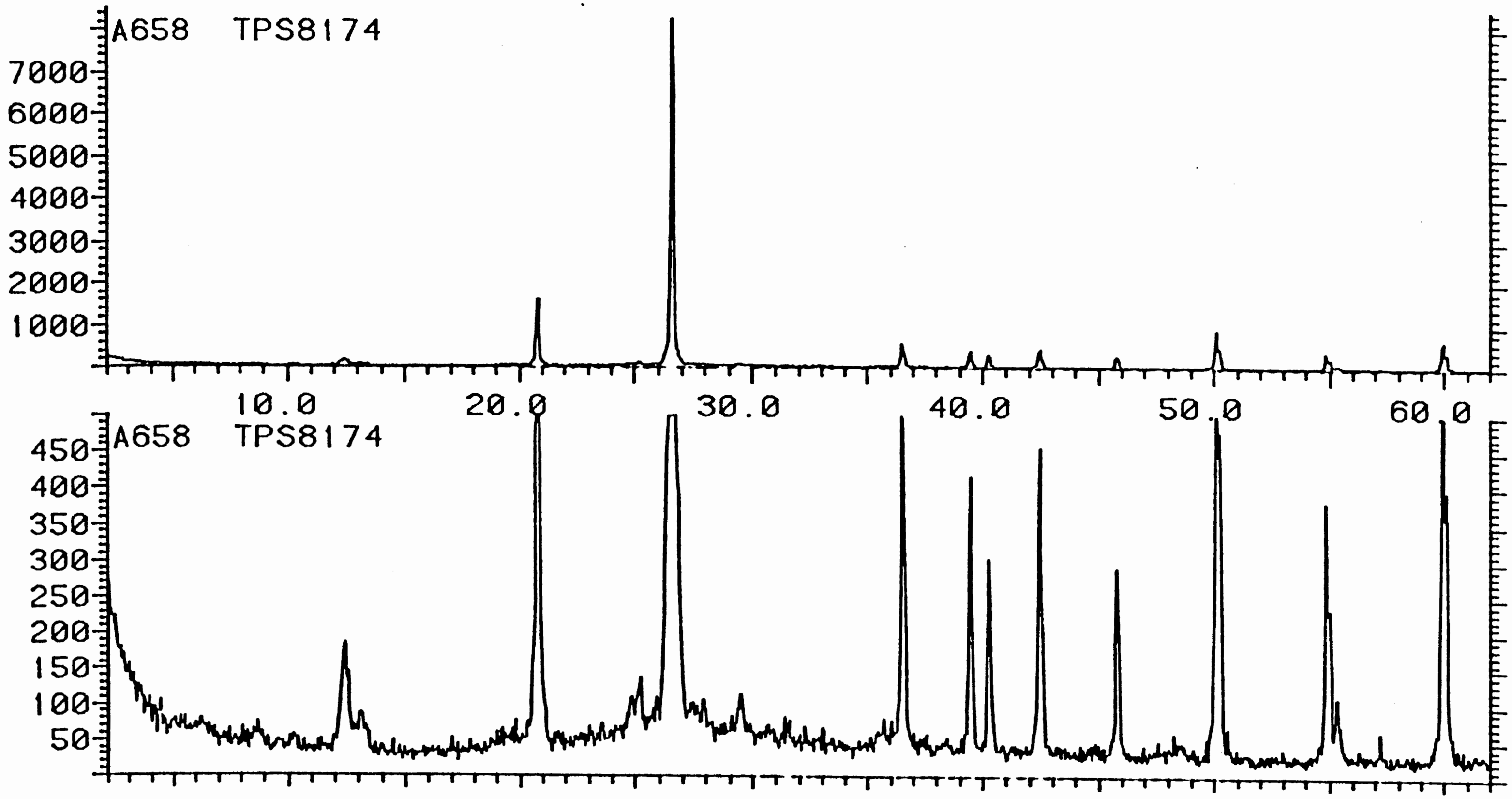

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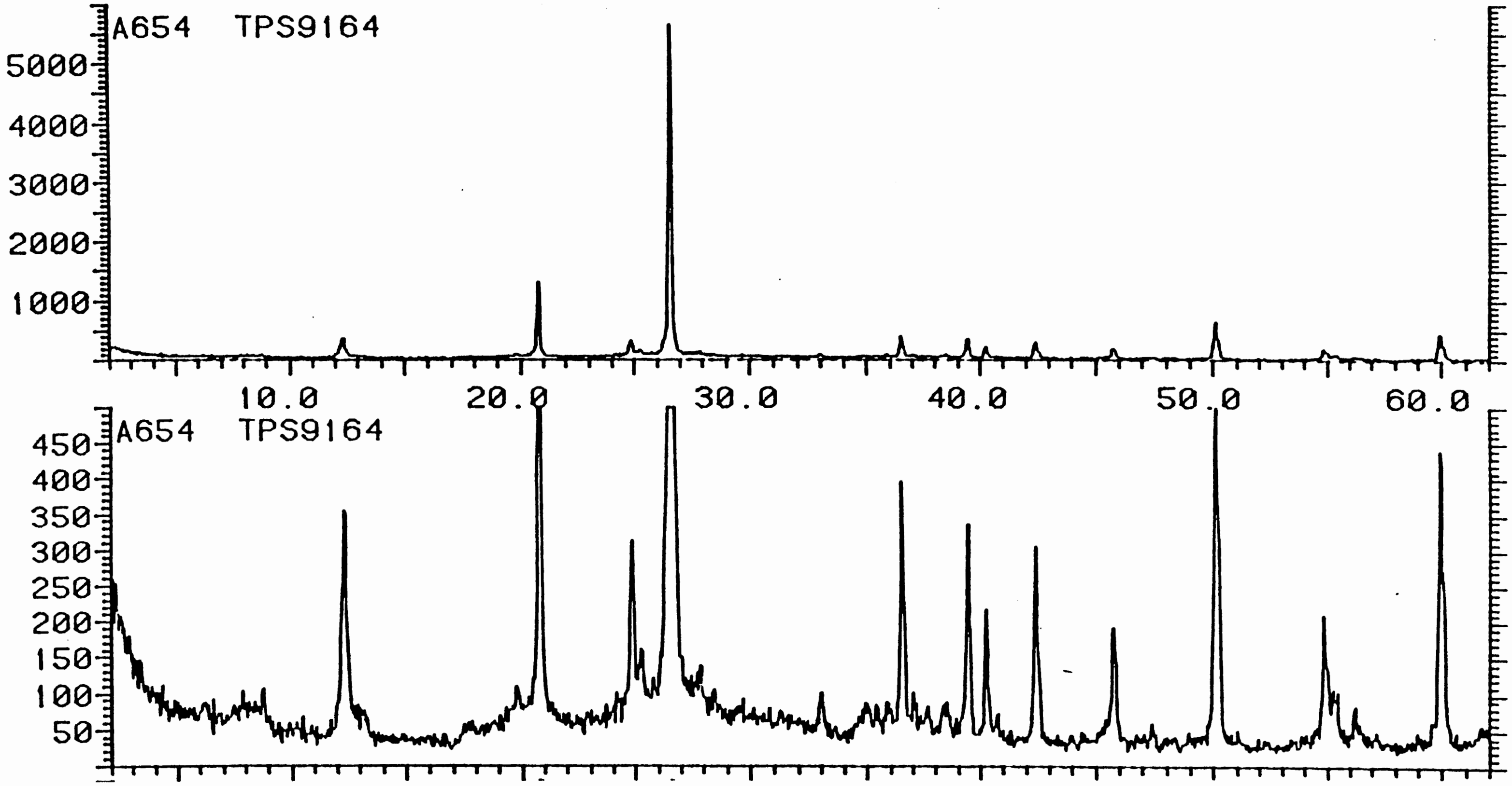

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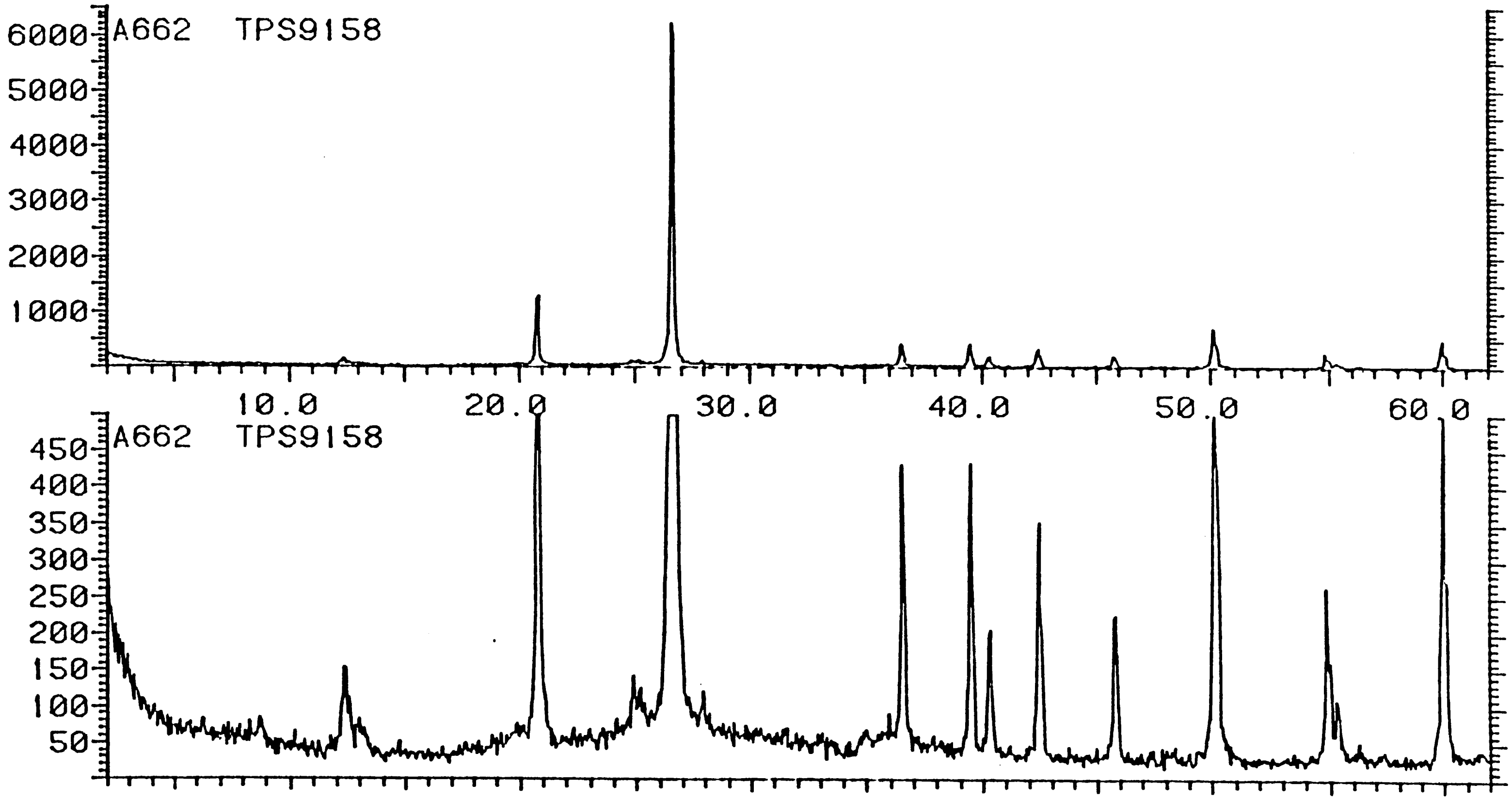

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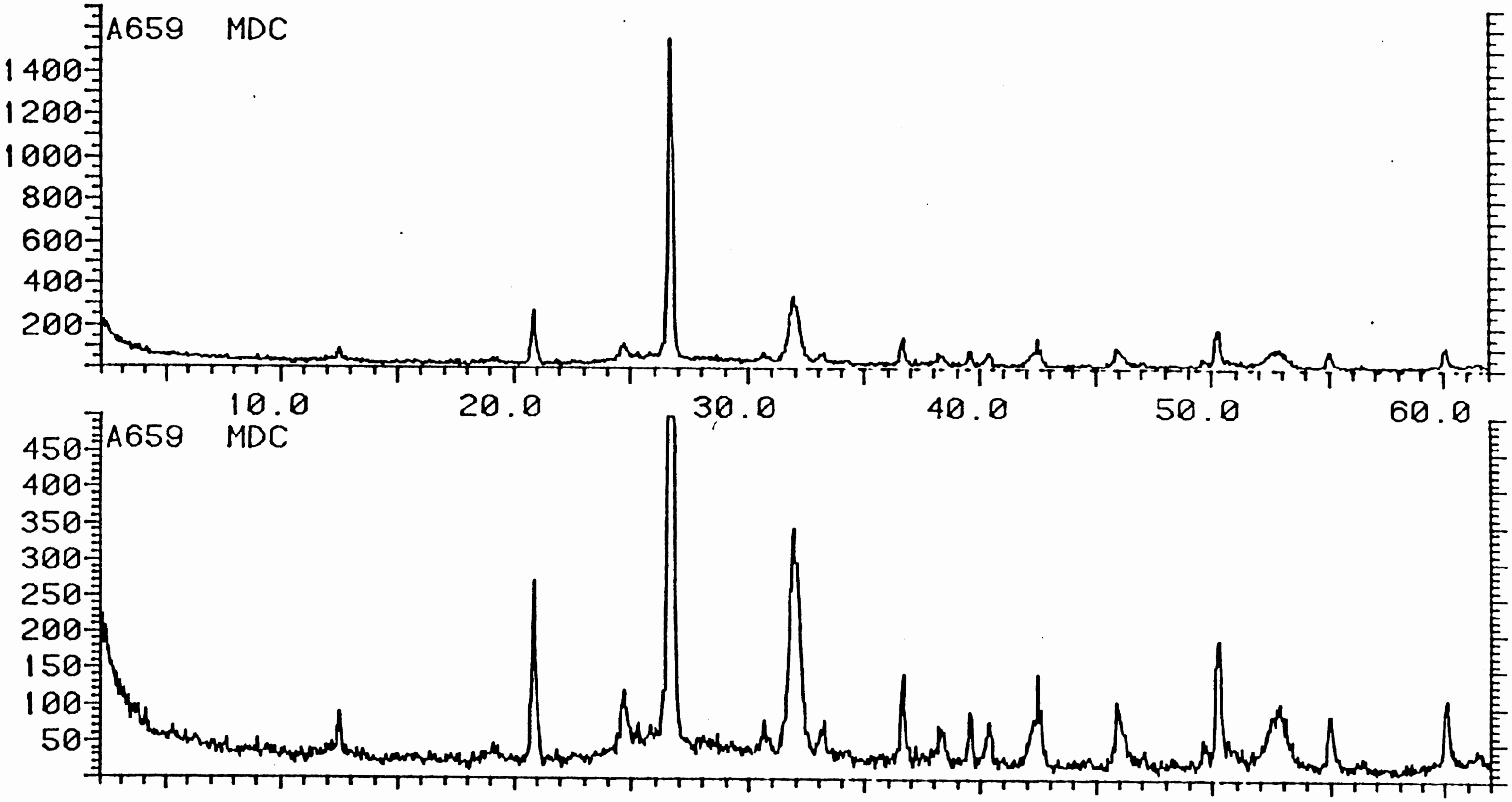

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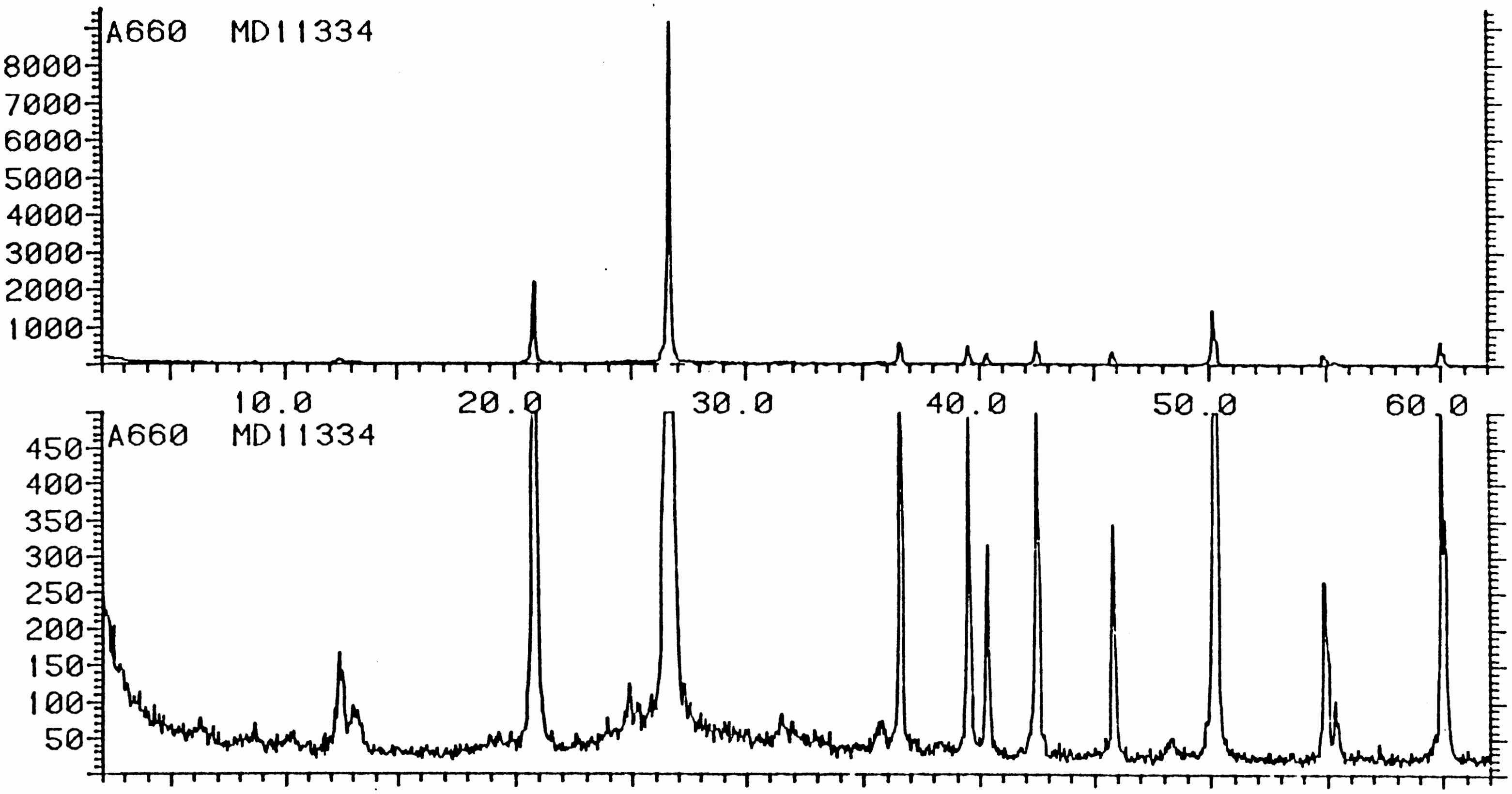

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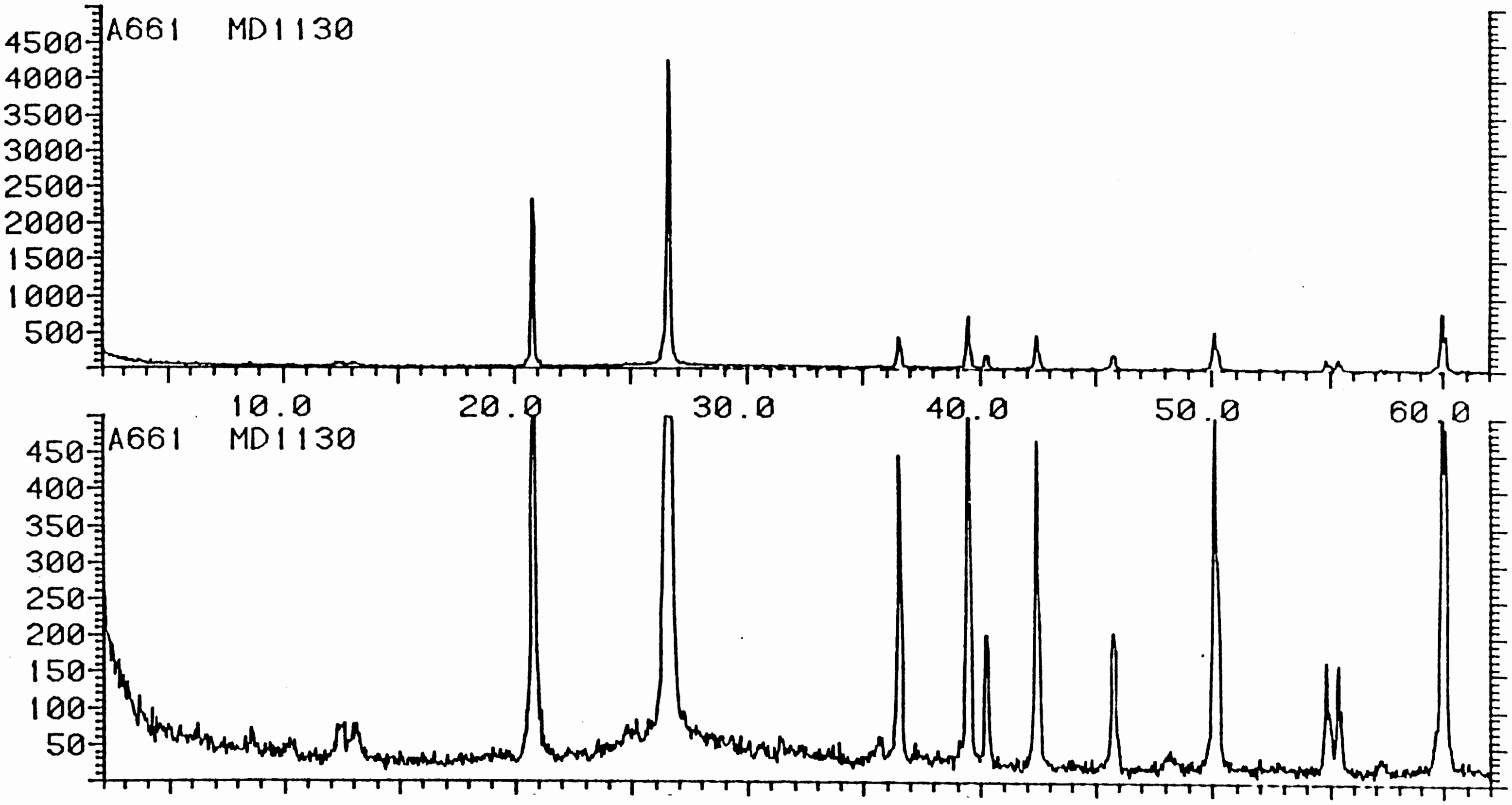

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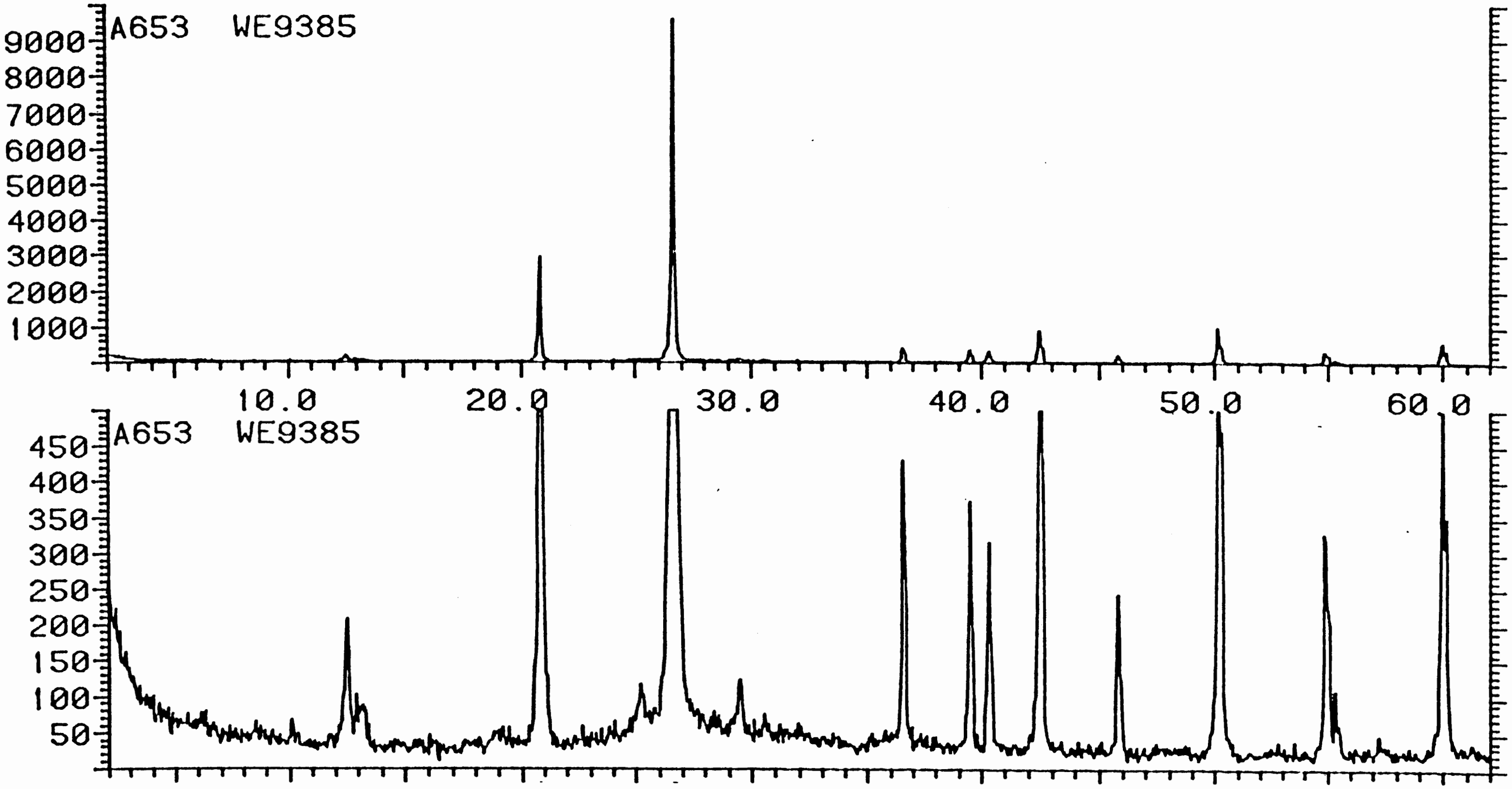

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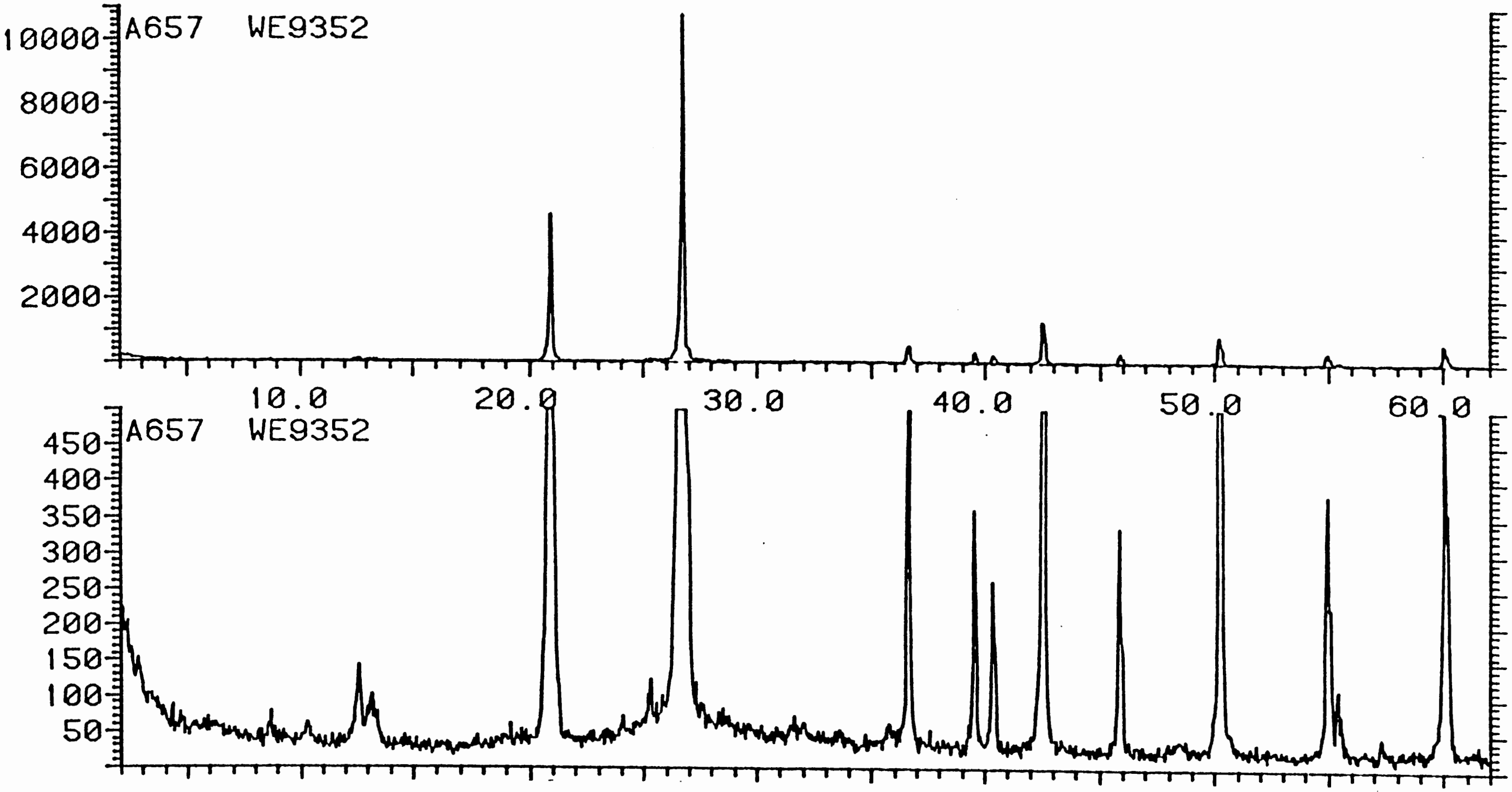

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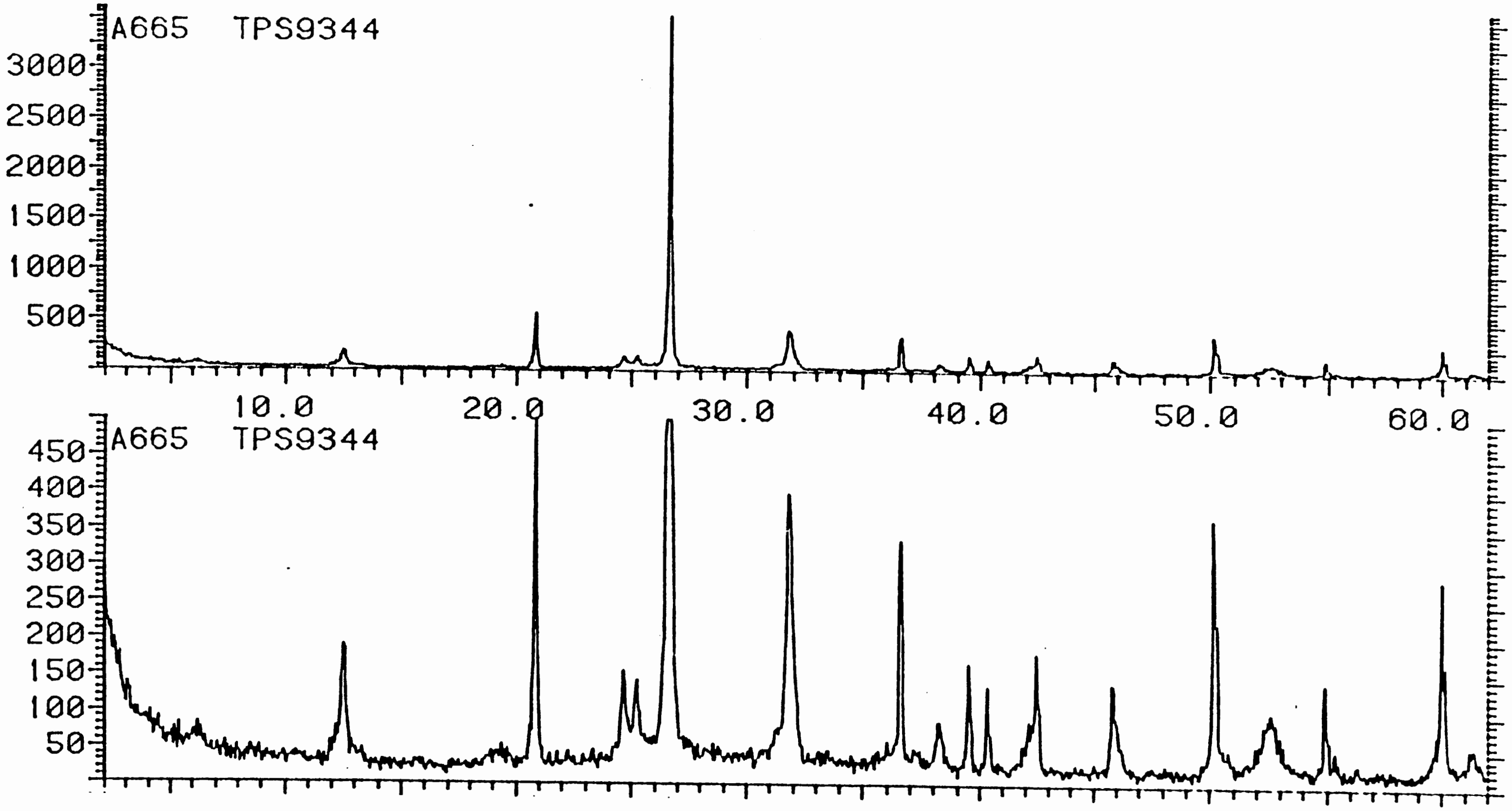

X-Ray Diffraction Pattern **Woods #5-2 Edwards** **Sample Depth 9344'**

VITA

James Edward Bentkowski

Candidate for the Degree of

Master of Science

Thesis: STUDY OF THE MORROW FORMATION IN EASTERN DEWEY COUNTY, OKLAHOMA

Major Field: Geology

Biographical:

Personal Data: Born in Heidleburg, Germany, December 26, 1954, the son of Leonard E. and Katherine W. Bentkowski. Married to Kathaleen Wilson on May 15, 1982. Father to Christopher, 8, and Matthew, 1.

Education: Graduated from The Webb School, Bell Buckle, Tennessee, in June, 1972; received Associate of Arts degree from Pensacola Junior College in August, 1974; received Bachelor of Science degree from Florida Atlantic University in June, 1979; completed requirements for the Master of Science degree at Oklahoma State University in May, 1985.

Professional Experience: Operations Supervisor, Tripoli, Libya; Core Analysis, Oklahoma City, Oklahoma; Wellsite Geologist, Kansas and Oklahoma, Core Laboratories, July 1979 to November 1981; Staff Geologist, Herbert G. Davies Inc., November 1981 to April, 1982; Wellsite Geologist, Sens Anom, Inc. April, 1982 to September 1982; Staff Geologist, Interstates Oil and Gas, January 1983 to July 1984; Graduate Research Grant Recipient, J. M. Huber Corporation July 1984 to present.

Professional Societies: American Association of Petroleum Geologists, Oklahoma City Geology Society.

PLATE 1

STRATIGRAPHIC CROSS SECTION, A1-A2

DATUM: BASE OF ATOKA LIME

JAMES E. BENTKOWSKI

PLATE 2

STRATIGRAPHIC CROSS SECTION, B1-B2

DATUM: BASE OF ATOKA LIME

JAMES E. BENTKOWSKI

PLATE 3

STRATIGRAPHIC CROSS SECTION, C1-C2

DATUM: BASE OF ATOKA LIME

JAMES E. BENTKOWSKI

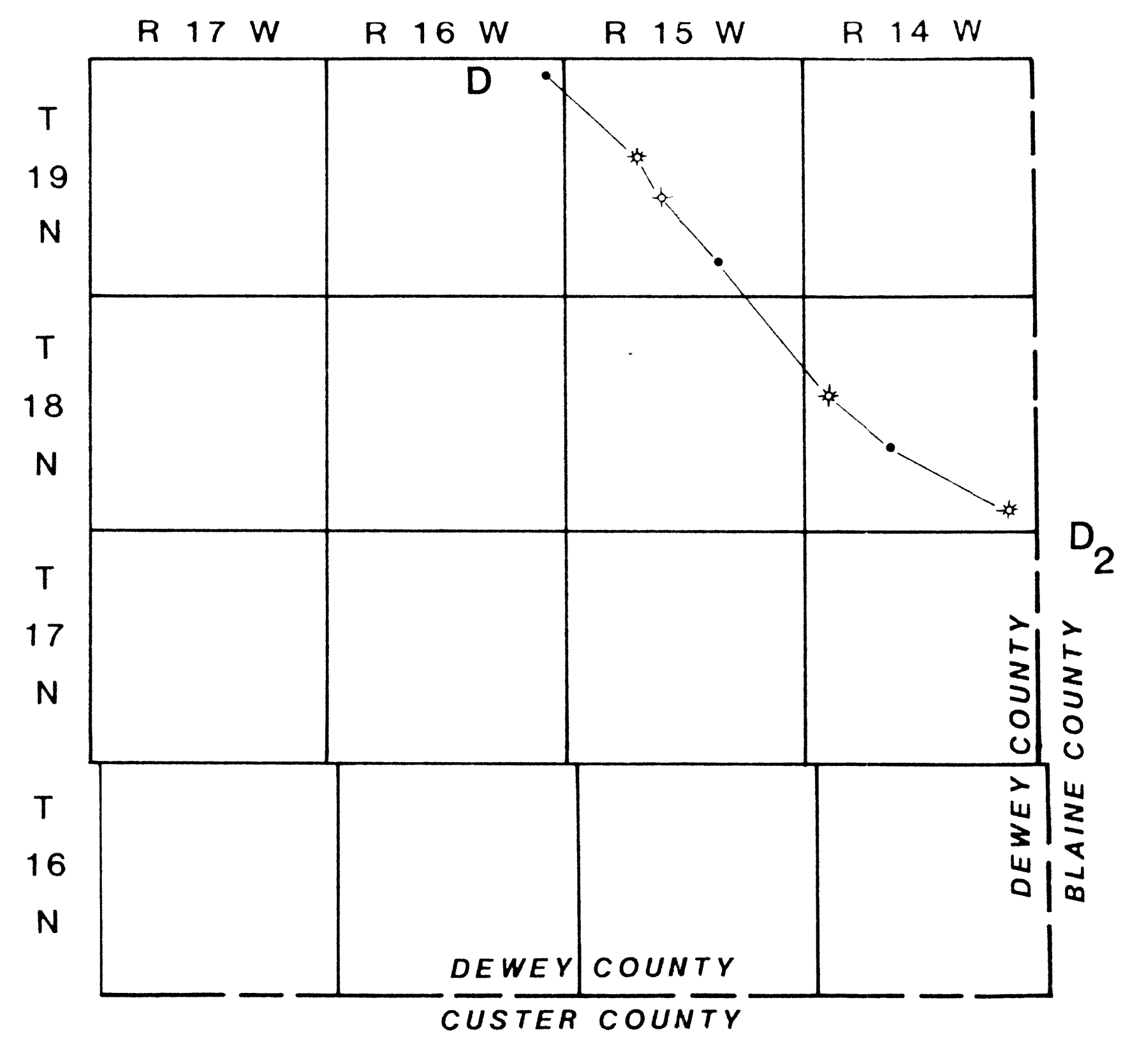

PLATE 4

STRATIGRAPHIC CROSS SECTION, D1-D2

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JAMES E. BENTKOWSKI

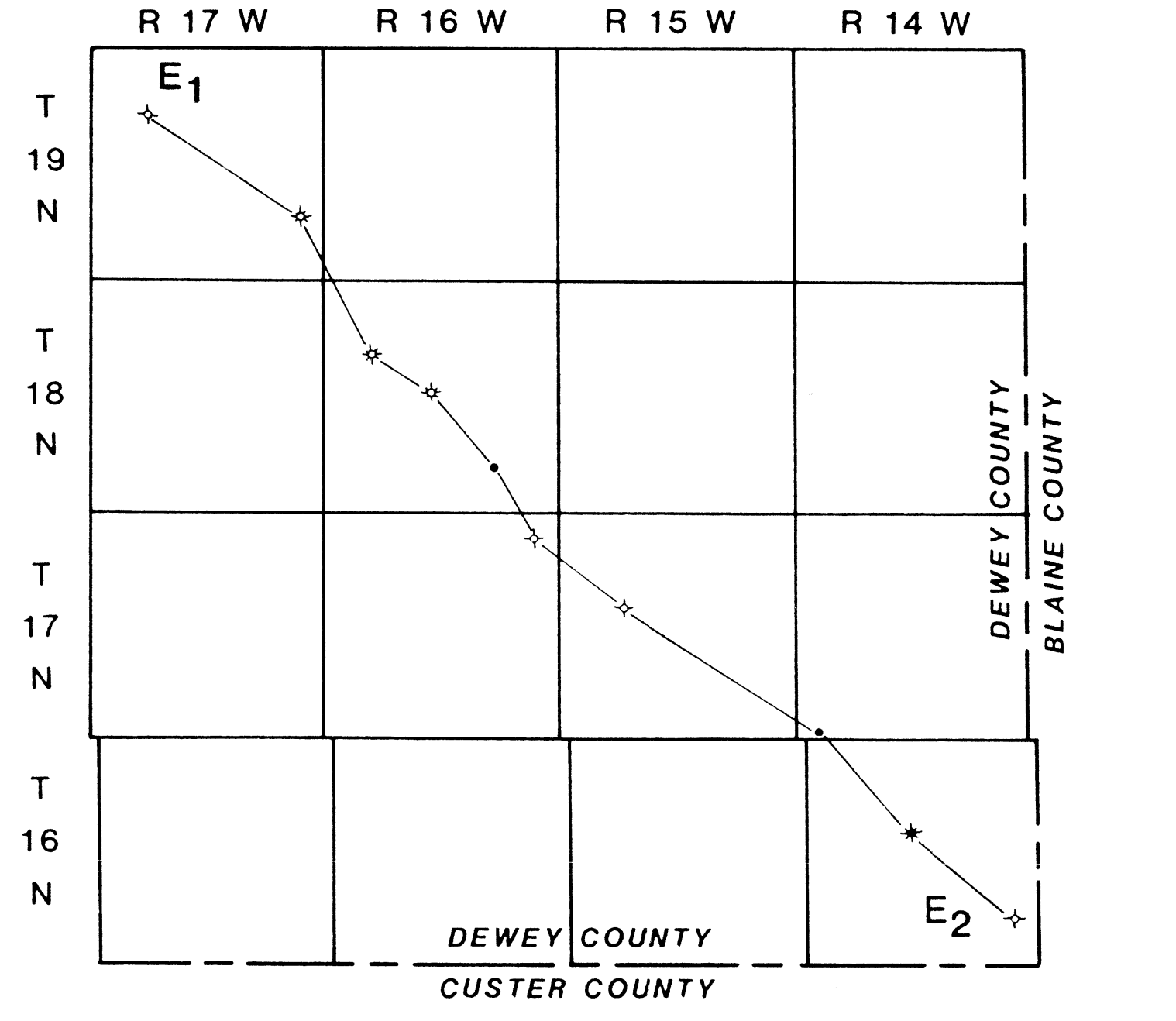

PLATE 5

STRATIGRAPHIC CROSS SECTION, E1-E2

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JAMES E. BENTKOWSKI

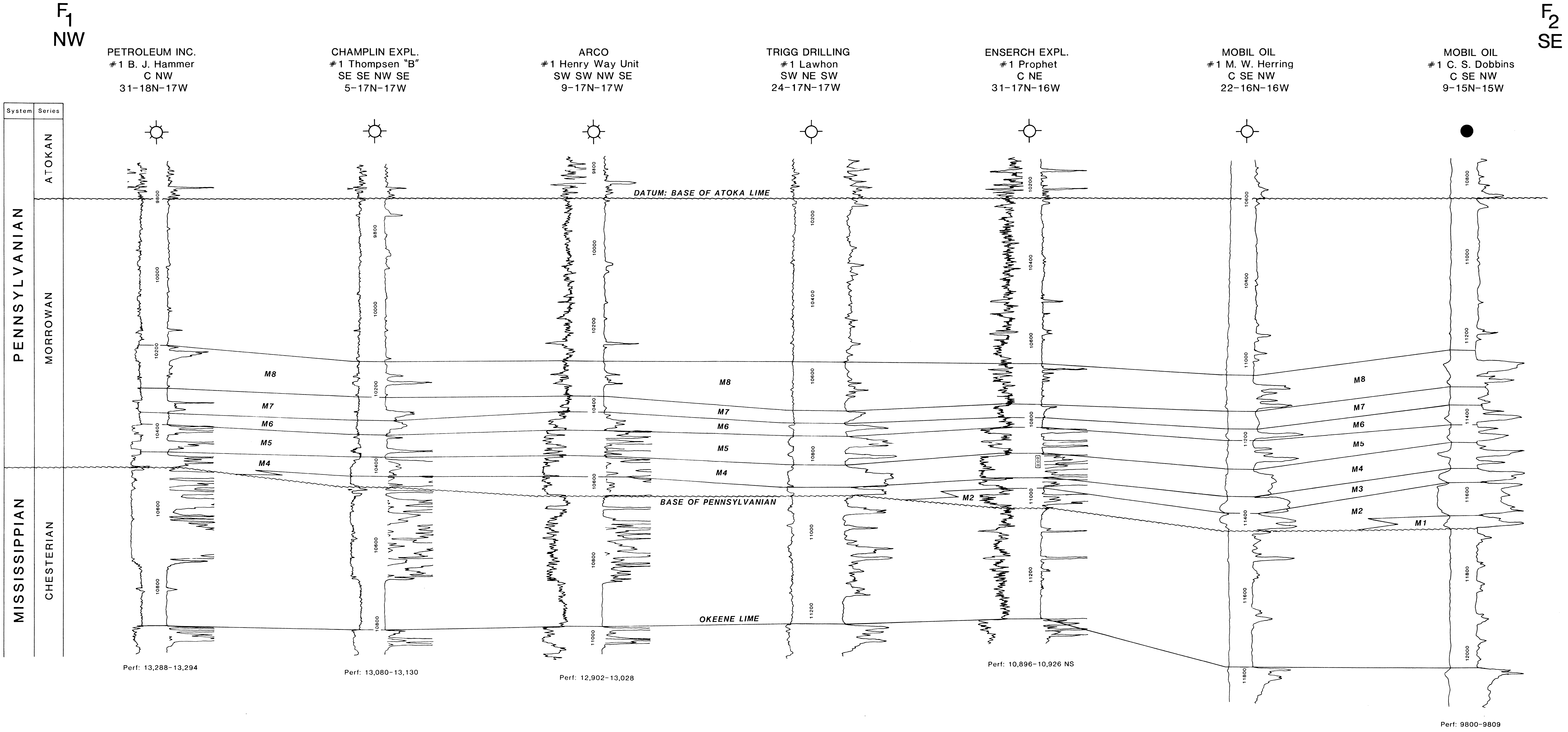

PLATE 6

STRATIGRAPHIC CROSS SECTION, F1-F2

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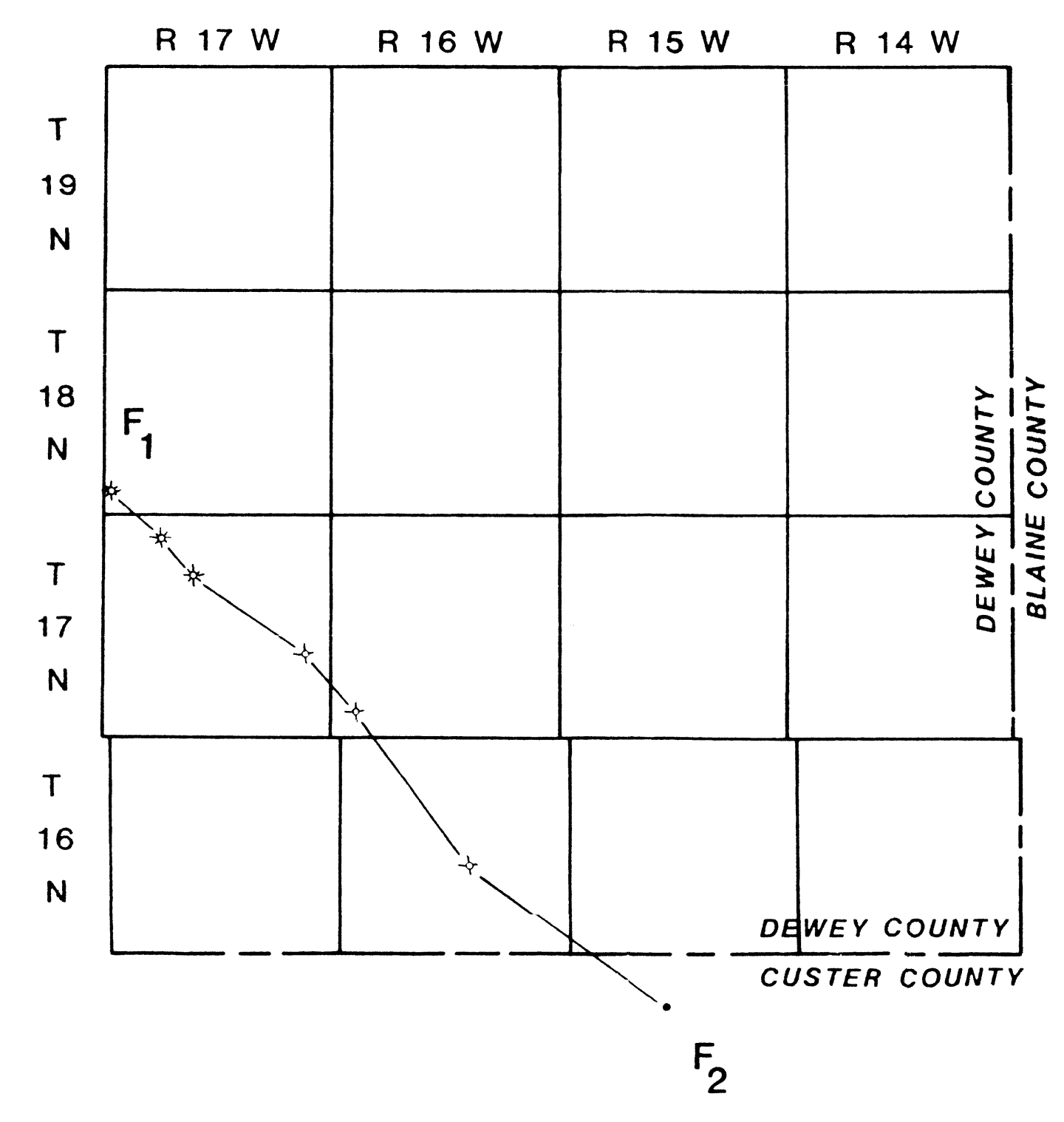
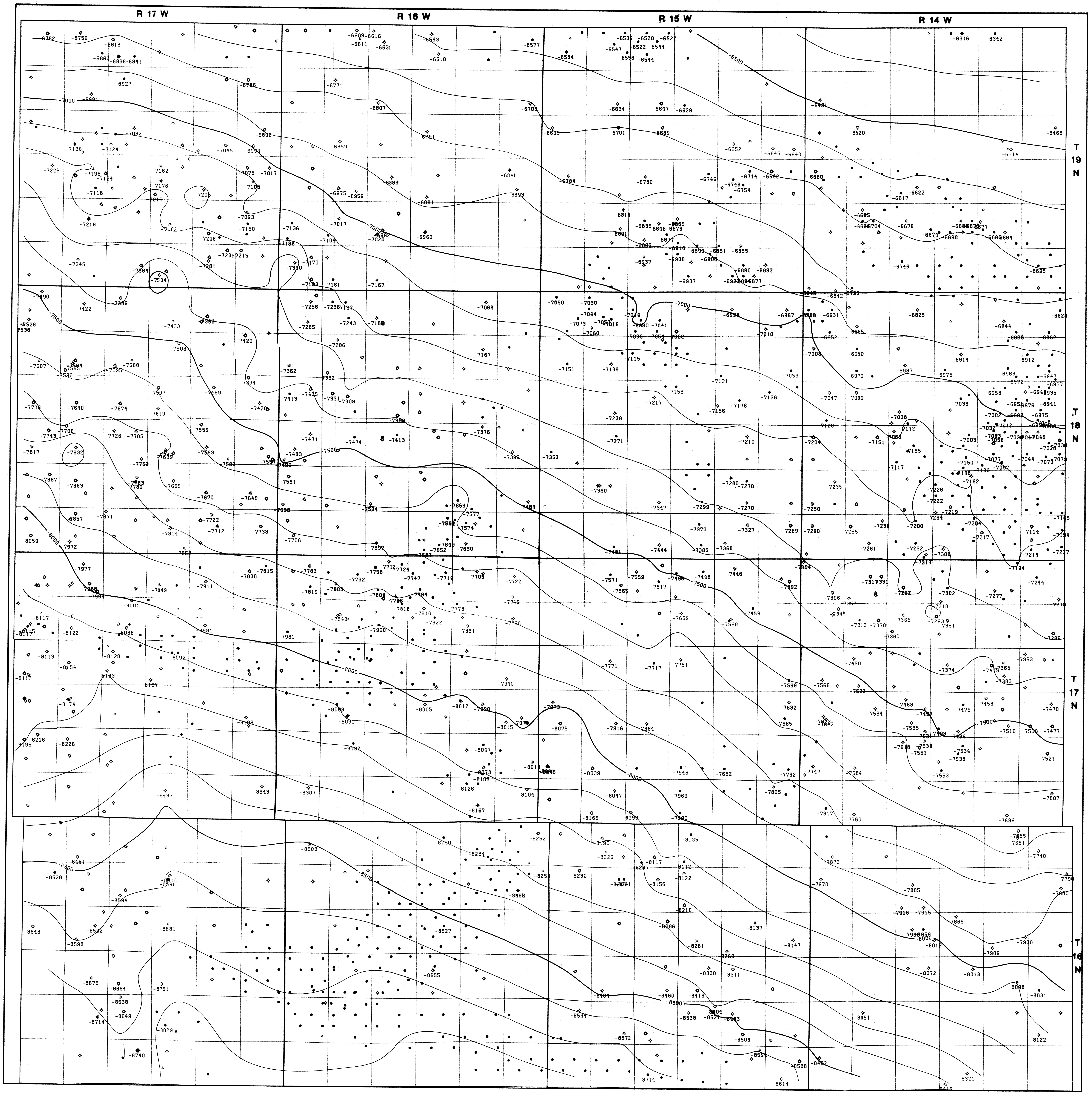
JAMES E. BENTKOWSKI



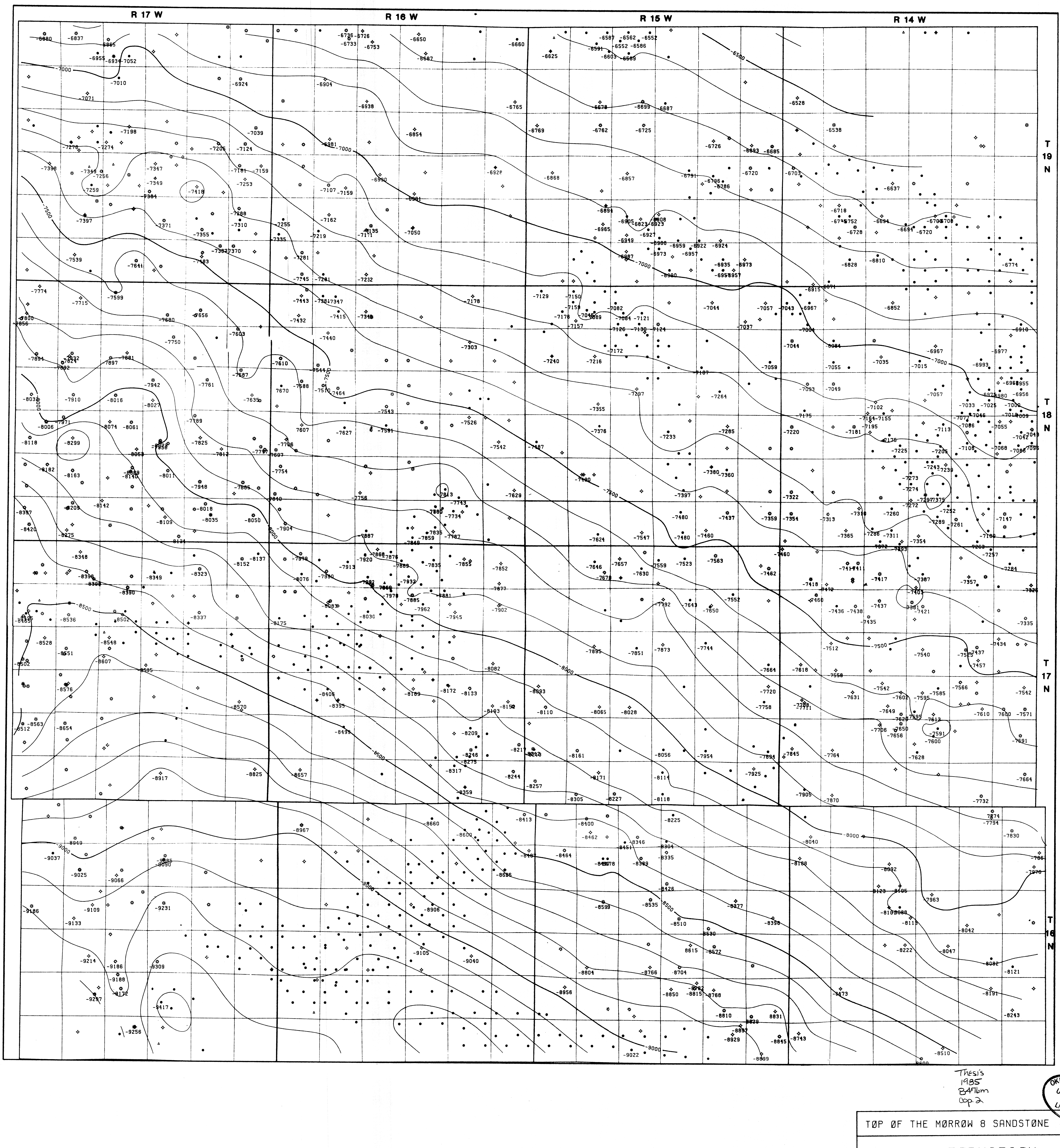


TOP OF THE MORROW

MORROW FORMATION
IN EASTERN
DEWEY COUNTY

1:48000
J E BENTKOWSKI
2-15-85
Plate 7
C.I. = 100'

STATUTE MILES 0 1 2 STATUTE MILES
1:48000
KILOMETERS 0 1 2 3 4 5 KILOMETERS

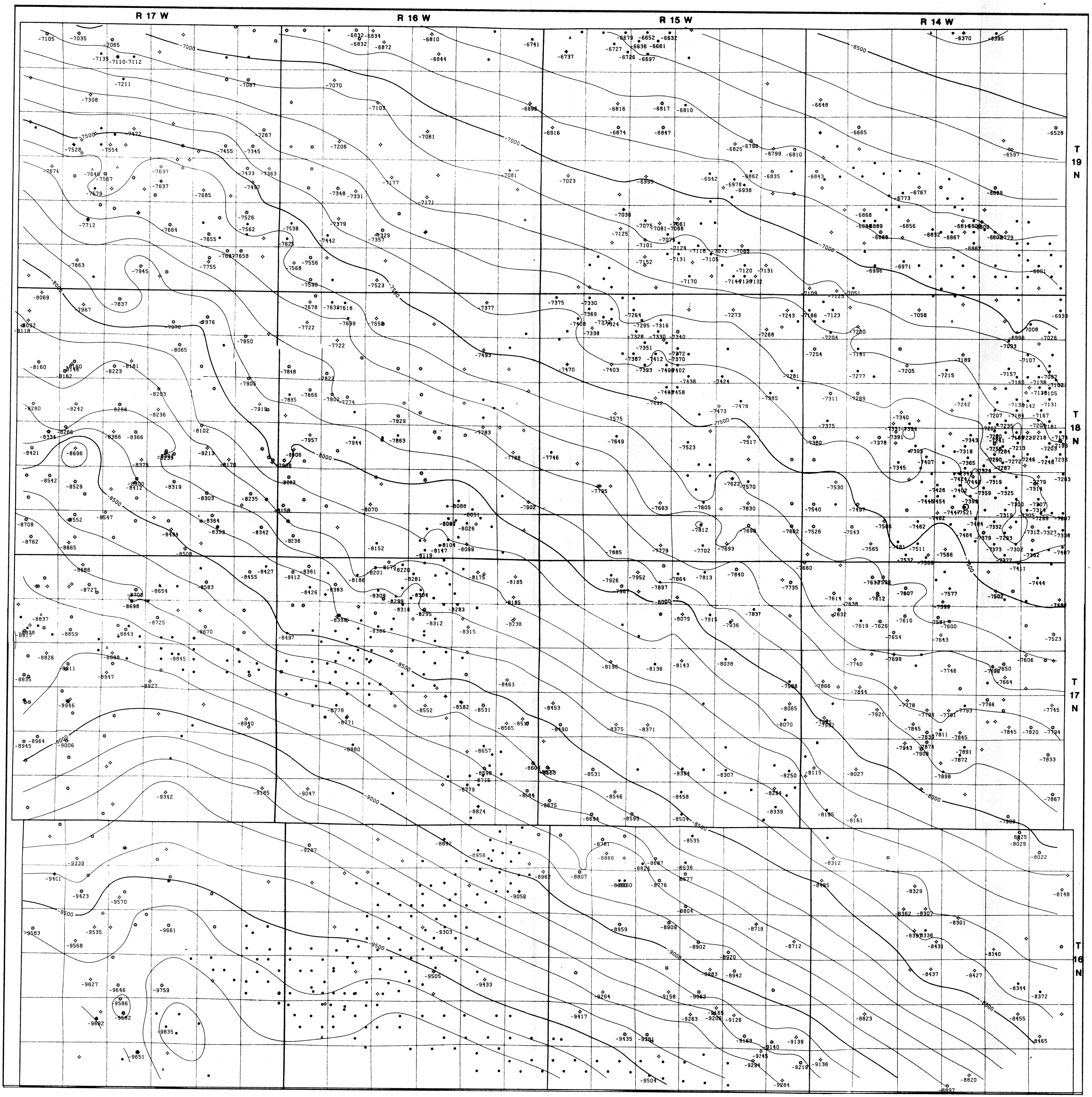


STATUTE MILES 0 1 2 STATUTE MILES
1:48000
KILOMETERS 0 1 2 3 4 5 KILOMETERS

TOP OF THE MORROW 8 SANDSTONE

MORROW FORMATION
IN EASTERN
DEWEY COUNTY

1:48000	J E BENTKOWSKI	2-15 -85
Plate 8	C.I. = 100'	

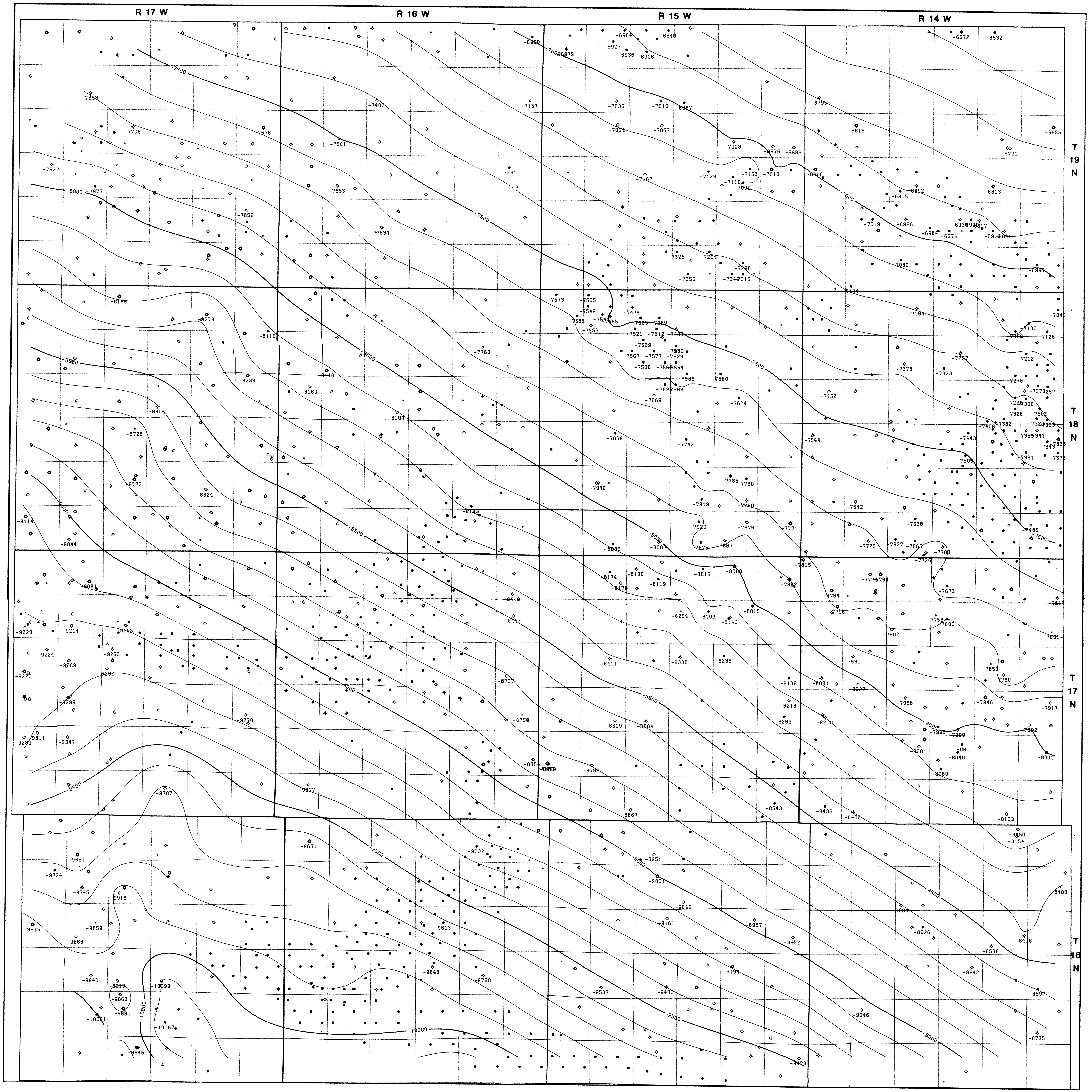


STATUTE MILES 0 1 2 STATUTE MILES
KILOMETERS 0 1 2 3 4 5 KILOMETERS
1:48000

BASE OF PENNSYLVANIAN

MORROW FORMATION
IN EASTERN
DEWEY COUNTY

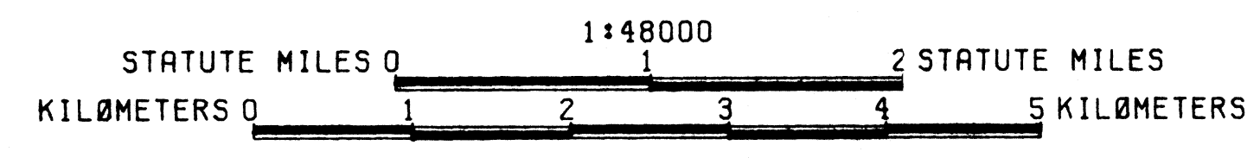
SCALE 1:48000 | AUTHOR J E BENTKOWSKI | DATE 2-15-85
FILE NO. Plate 9 | C.I. = 100'

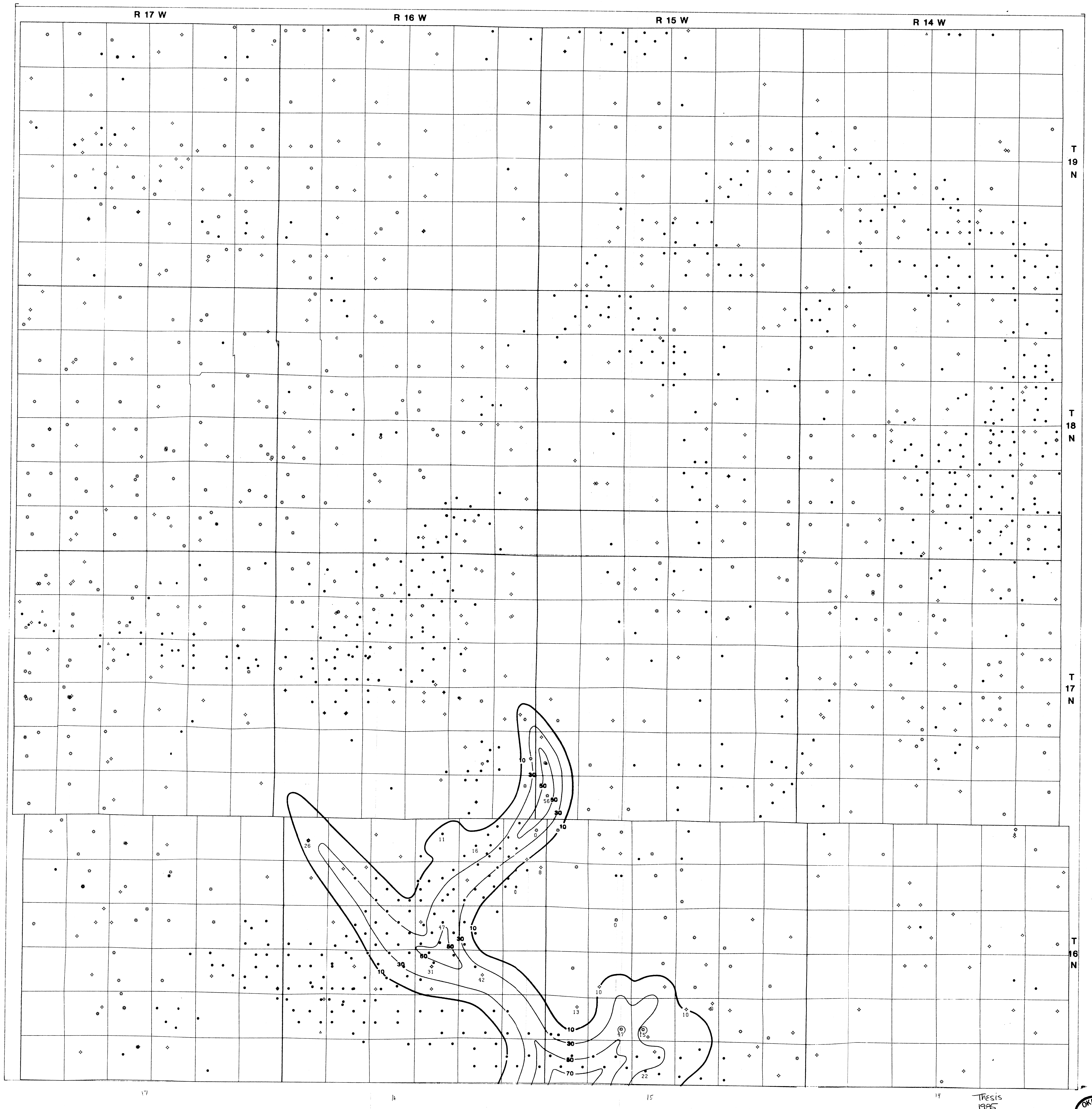


TOP OF THE OKEENE LIMESTONE

MORROW FORMATION IN EASTERN DEWEY COUNTY

SCALE 1:48000	AUTHOR J E BENTKOWSKI	DATE 2-15 -85
FILE NO. Plate 10	C.I. = 100'	





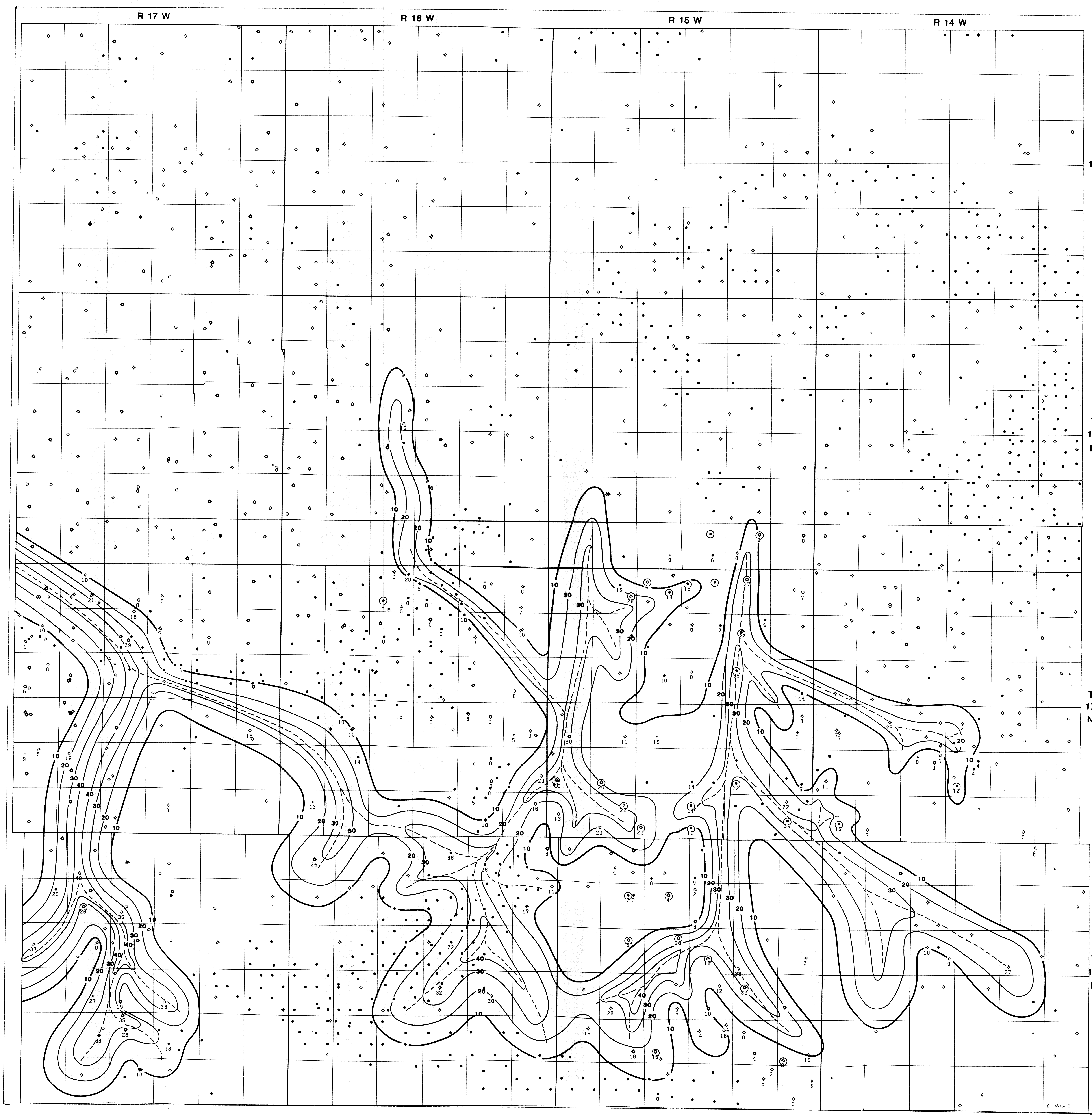
1:48000
STATUTE MILES 0 1 2 STATUTE MILES
KILØMETERS 0 1 2 3 4 5 KILØMETERS

⊛ **Denotes Wells Perforated in This Sand**

MORROW 2 GROSS ISOLITH

MØRRØW FØRMATIØN
IN EASTERN
DEWEY CØUNTY

SCALE 1:48000	AUTHOR J E BENTKØWSKI	DATE 2-15 -85
FILE NO. **Plate 11**	**C. I. = 10'**	



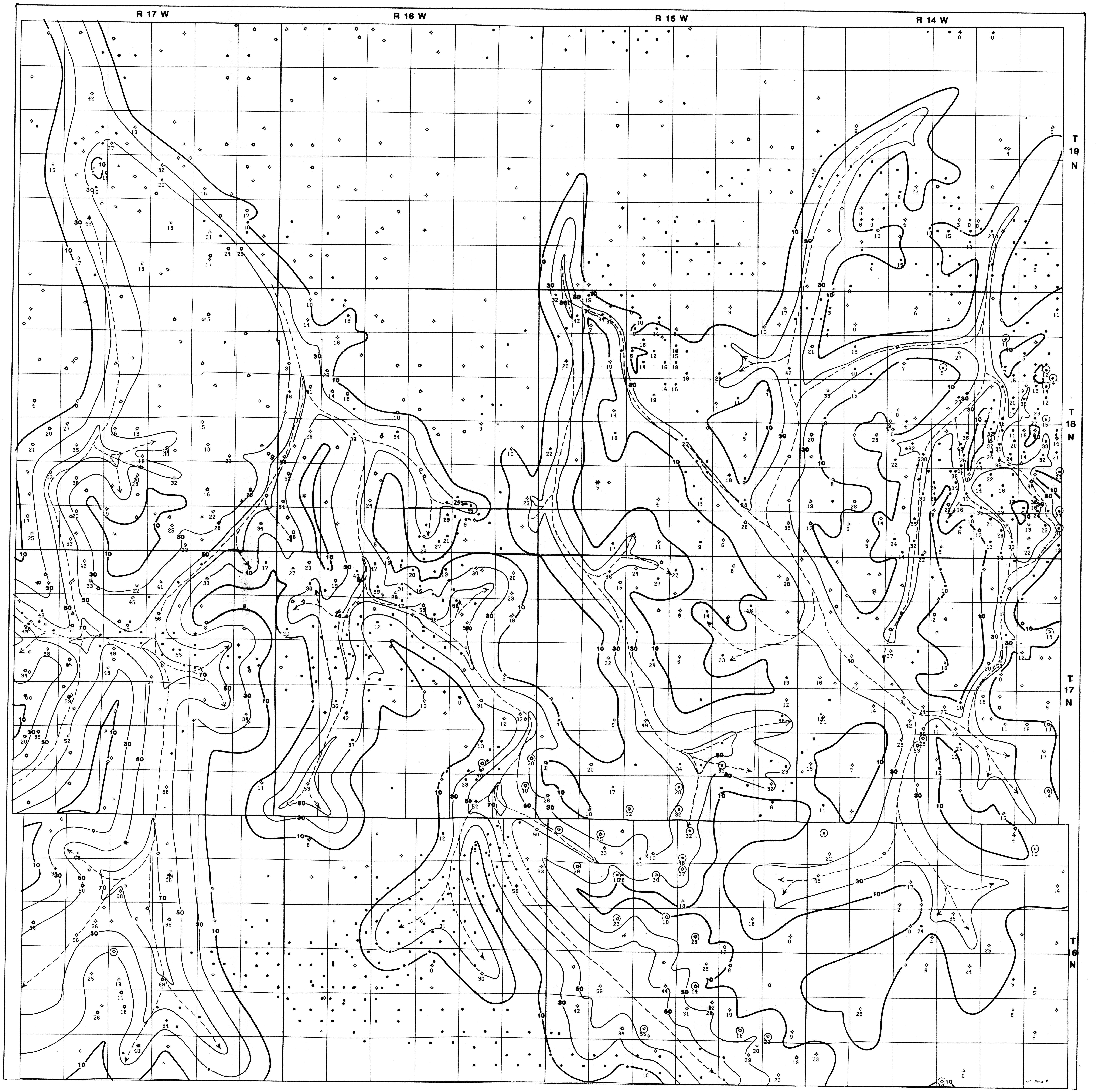
MORROW 3 GROSS ISOLITH

MORROW FORMATION
IN EASTERN
DEWEY COUNTY

SCALE 1:48000
AUTHOR J E BENTKOWSKI
DATE 2-15-85
FILE NO. Plate 12
C. I. = 10'

⊙ Denotes Wells Perforated In This Sand

1:48000
STATUTE MILES 0 1 2 STATUTE MILES
KILOMETERS 0 1 2 3 4 5 KILOMETERS



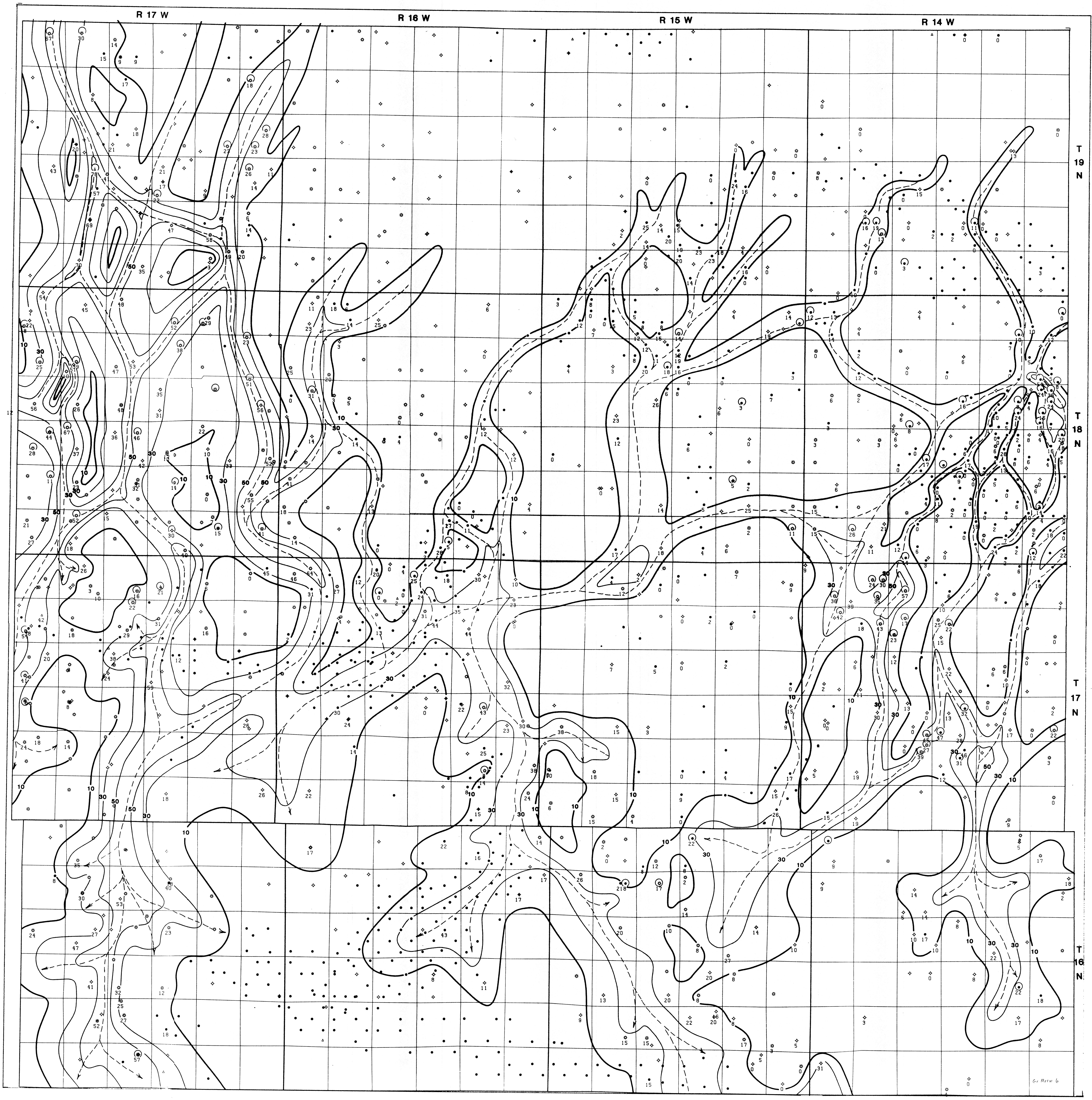
MORROW 4 GROSS ISOLITH

MORROW FORMATION
IN EASTERN
DEWEY COUNTY

SCALE 1:48000	AUTHOR J E BENTKOWSKI	DATE 2-15 -85
FILE NO. Plate 13	C. I. = 20'	

STATUTE MILES 0 1 2 STATUTE MILES
1:48000
KILOMETERS 0 1 2 3 4 5 KILOMETERS

⊙ Denotes Wells Perforated in This Sand



1:48000

STATUTE MILES 0 1 2 STATUTE MILES

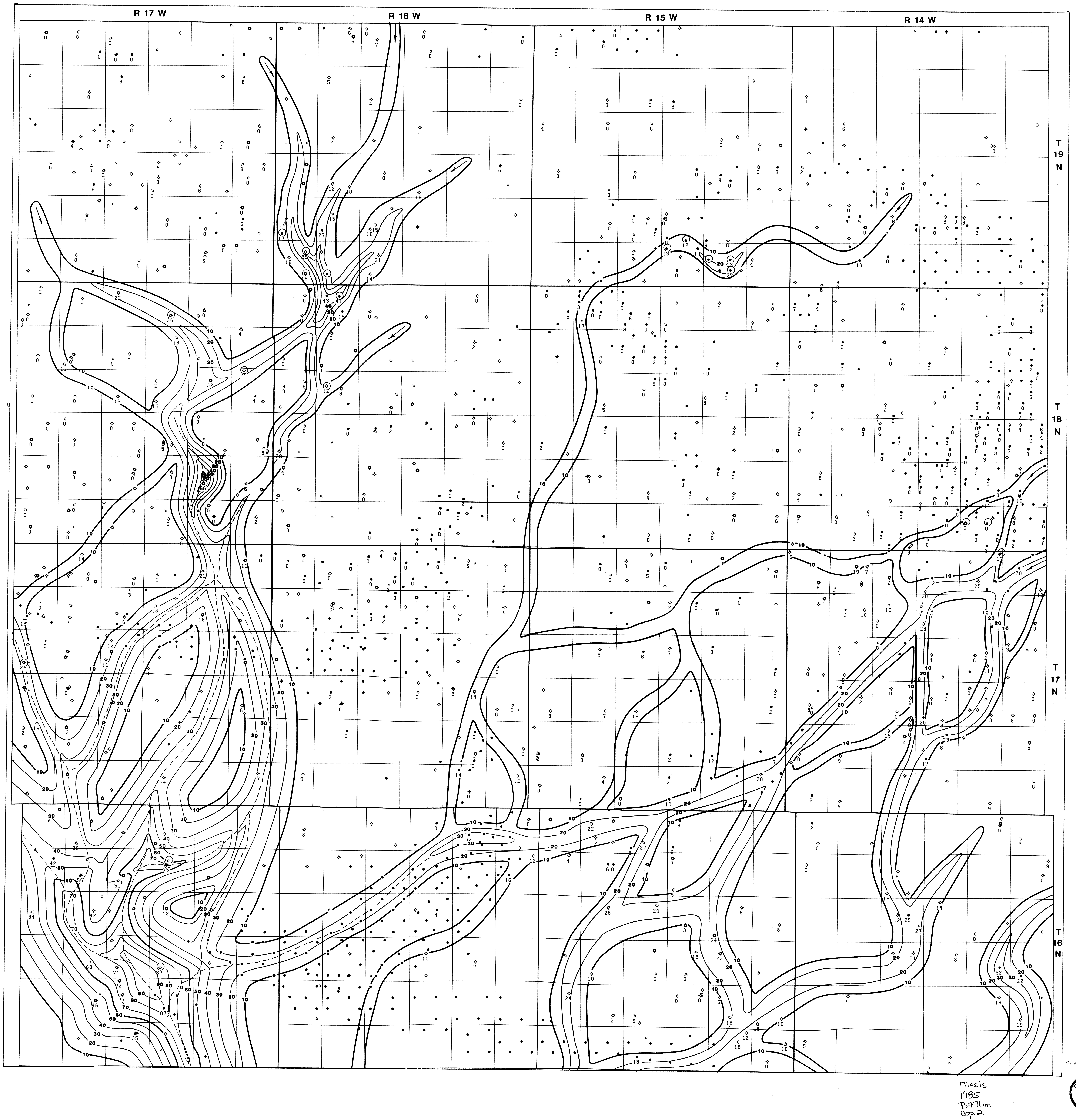
KILOMETERS 0 1 2 3 4 5 KILOMETERS

⊙ Denotes Wells Perforated In This Sand

MORROW 5 GROSS ISOLITH

MORROW FORMATION
IN EASTERN
DEWEY COUNTY

SCALE 1:48000	AUTHOR J E BENTKOWSKI	DATE 2-15 -85
FILE NO. **Plate 14**	**C. I. = 20'**	



Gr Mrrw 6

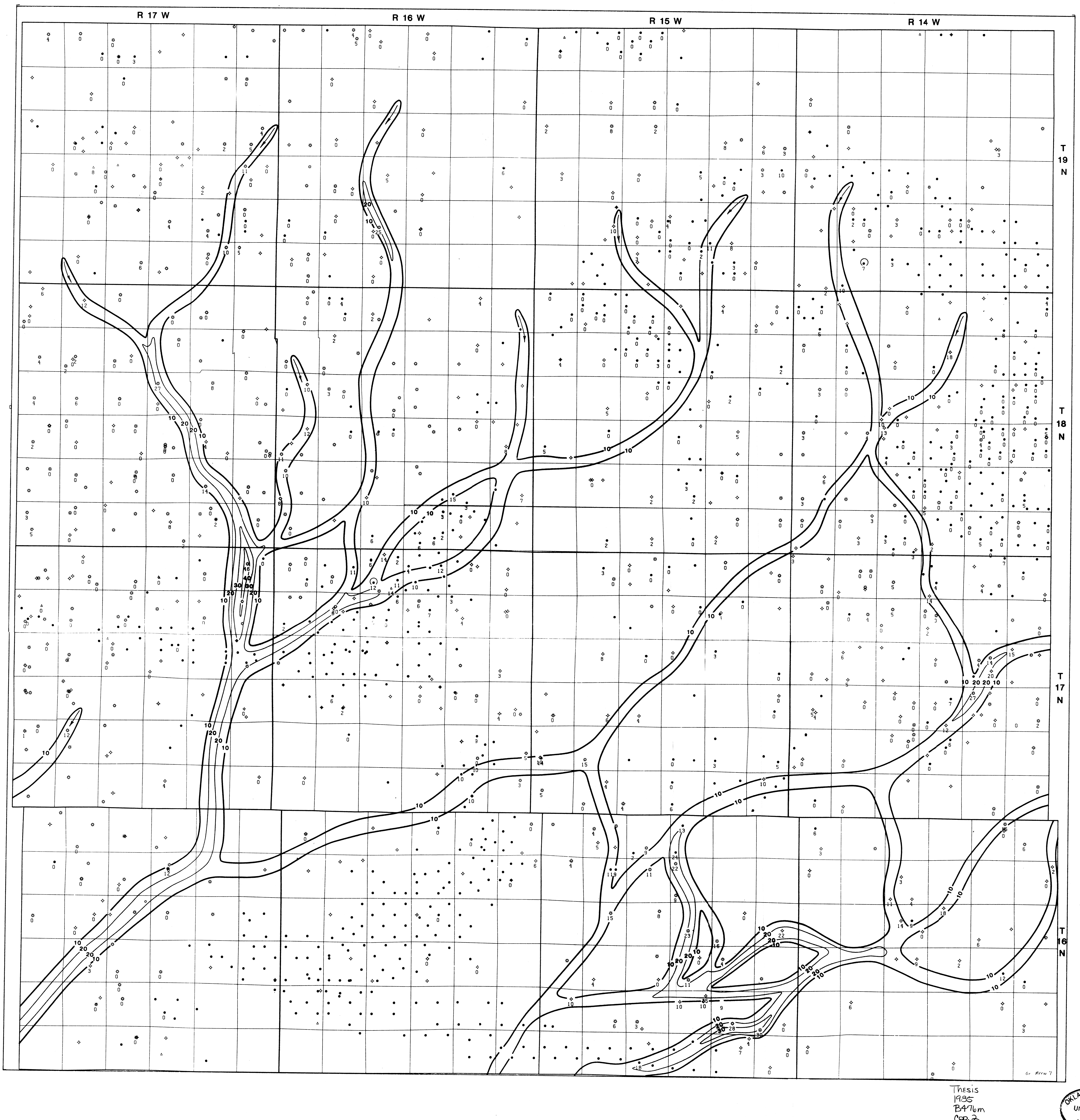
MORROW 6 GROSS ISOLITH

MORROW FORMATION
IN EASTERN
DEWEY COUNTY

SCALE 1:48000
AUTHOR J E BENTKOWSKI
DATE 2-15 -85
FILE NO. **Plate 15**
C. I.=10'

1:48000
STATUTE MILES 0 1 2 STATUTE MILES
KILOMETERS 0 1 2 3 4 5 KILOMETERS

⊙ **Denotes Wells Perforated in This Sand**



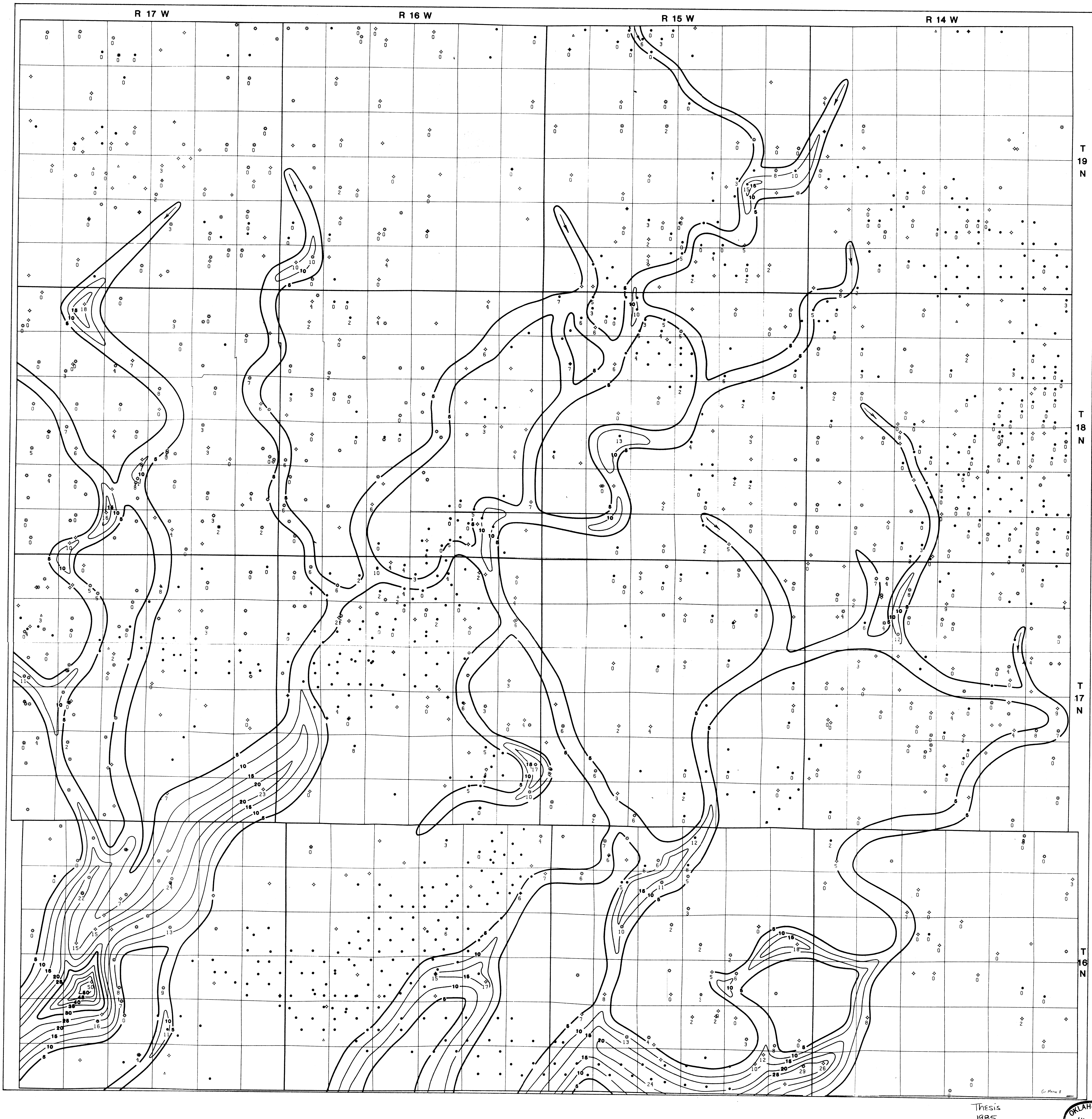
MORROW 7 GROSS ISOLITH

MORROW FORMATION
IN EASTERN
DEWEY COUNTY

SCALE 1:48000
AUTHOR J E BENTKOWSKI
DATE 2-15 -85
FILE NO. Plate 16
C. I. = 10'

STATUTE MILES 0 1 2 STATUTE MILES
1:48000
KILOMETERS 0 1 2 3 4 5 KILOMETERS

○ Denotes Wells Perforated in This Sand

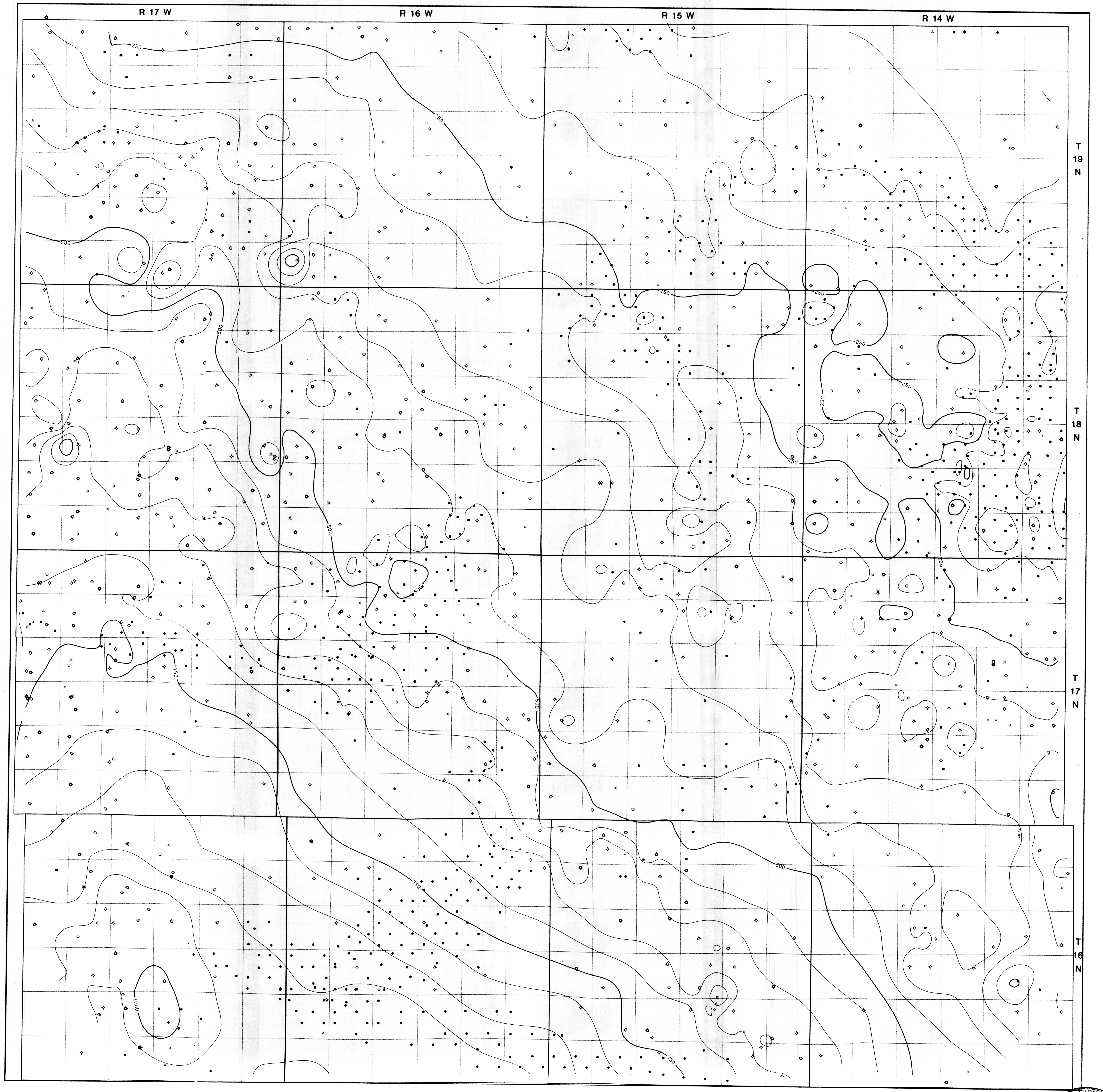


1:48000
STATUTE MILES 0 1 2 STATUTE MILES
KILOMETERS 0 1 2 3 4 5 KILOMETERS

MORROW 8 GROSS ISOLITH

MORROW FORMATION
IN EASTERN
DEWEY COUNTY

SCALE 1:48000
AUTHOR J E BENTKOWSKI
DATE 2-15-85
FILE NO. Plate 17
C. I. 5'



TOTAL MORROW ISOPACH

MORROW FORMATION
IN EASTERN
DEWEY COUNTY

SCALE 1:48000	AUTHOR J E BENTKOWSKI	DATE 2-15 -85
FILE NO. **Plate 18**	**C. I. = 50'**	

1:48000
STATUTE MILES 0 1 2 STATUTE MILES
KILOMETERS 0 1 2 3 4 5 KILOMETERS