UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

EXPLORATION OF THE WICHITA/ALBANY RESERVOIR, SANDHILLS FIELD, CRANE COUNTY, TEXAS. SEARCHING FOR HYDROCARBONS IN A PREVIOUSLY UNDER-EXPLOITED RESERVOIR ON THE CENTRAL BASIN PLATFORM

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EXPLORATION OF THE WICHITA/ALBANY RESERVOIR, SANDHILLS FIELD, CRANE COUNTY, TEXAS.SEARCHING FOR HYDROCARBONS IN A PREVIOUSLY UNDER-EXPLOITED RESERVOIR

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APPROVED FOR THE SCHOOL OF GEOLOGY AND GEOPHYSICS

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ABSTRACT

The Permian age Wichita/Albany formation was deposited on the Central Basin Platform in the Permian Basin of west Texas during the upper Wolfcampian and lower Leonardian periods. The Sandhills structure, an uplifted block on the Central Basin Platform contains the 456th largest oil field in the world. The Sandhills field is 52,000 acres in size and the Permian section rests directly on the Ordovician due to the Base of Permian Unconformity.

This study focuses on the Wichita/Albany formation in the Sandhills Oil Field. The Wichita/Albany occurs as a 1000 ft. thick formation consisting of uranium rich, peritidal dolomite, with porosity relating to the degree of dolomitization. Production of hydrocarbons from this zone has been limited to three wells producing 100% hydrocarbons and 0% water. Only 16 wells have penetrated the complete Wichita/Albany formation. Production occurs from the stratigraphic units directly on top of and below the Wichita/Albany. These are the Permian Lower Clearfork, above, and the Ordovician Ellenburger formation, below. Porosity and water saturation values determined from well logs indicate much untapped potential for exploitation in the Wichita/Albany reservoir. Mapping porosity trends is difficult due to limited production and drillwells. Controls on porosity and exact depositional environment can not be confirmed because no core data available from the Wichita/Albany section. Based on available data, it seems that production is possible from the Wichita/Albany wherever porosity is present. This porosity occurs in thin, lenticular, pods that are

discontinuous throughout the field. Structure does not seem to play a part in porosity distribution. The occurrences of this porosity may be related to structure during deposition and not present day structure.

CHAPTER 1

Introduction

1.1. Background of the Field

The Sandhills field area is located in Crane County, Texas approximately fifteen miles west of the town of Crane and fifty miles southwest of the city of Midland (Figure 1). Sandhills was first developed by Humble Oil Corporation (now Exxon) in the mid to late 1930's. Most of Exxon's acreage lies within the Public School Land Survey Blocks 32 and B27 of Crane County (Figure 2). The 52,000 acre field is located on the southern half of the Central Basin Platform. Most of the field's production has been from formations above the Permian unconformity. Producing regulatory reservoirs in this field include the Grayburg, San Andres, Judkins, McKnight, Upper Clearfork, Tubb, Lower Clearfork, Wichita/Albany and the Ellenburger. In the American Association of Petroleum Geologists' reference book, Future Petroleum Provinces of the World, the Sandhills Field is Ranked 456th largest oil field in the world. The estimated recoverable reserves for the entire field are 246 million barrels of oil and 1.59 trillon cubic feet of gas. This results in overall reserves totalling 512 million barrels of oil equivalent.

The study began with a focus on the geology of the Sandhills Field. The controlling structure of this field is an asymmetrical anticline trending northeast to southwest that dips off steeply to the east and more gently to the west. Within the field area, the Permian Wichita/Albany formation directly overlyies the Ordovician Ellenburger Formation. At the eastern boundary of the field, a series of nearly vertical faults, some with throw in excess of 4000 feet, drops the section abruptly down to the

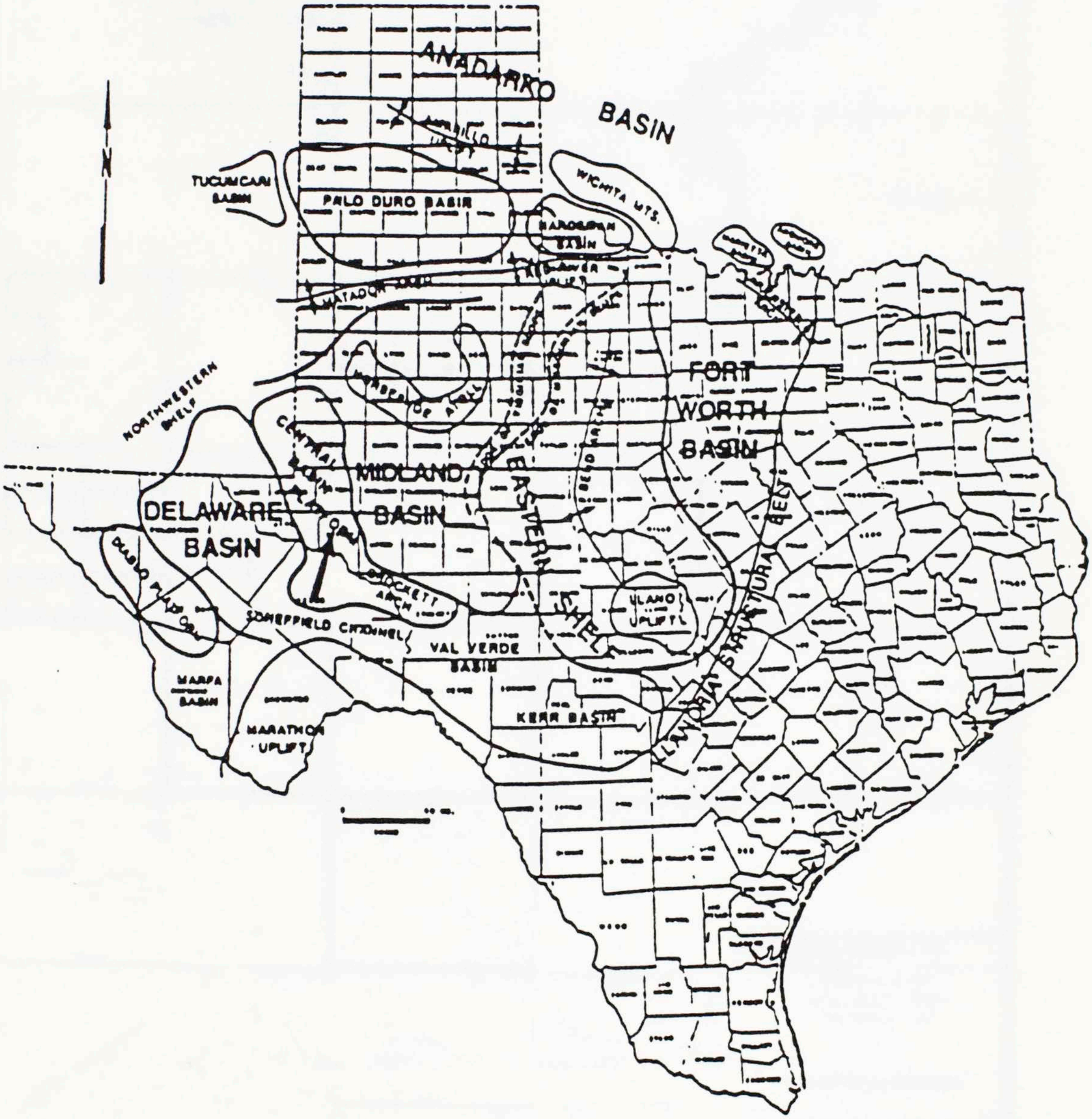

Figure 1: Map of West Texas depositional basins.
The arrow denotes the location of the Sandhills Field (Exxon, 1996)

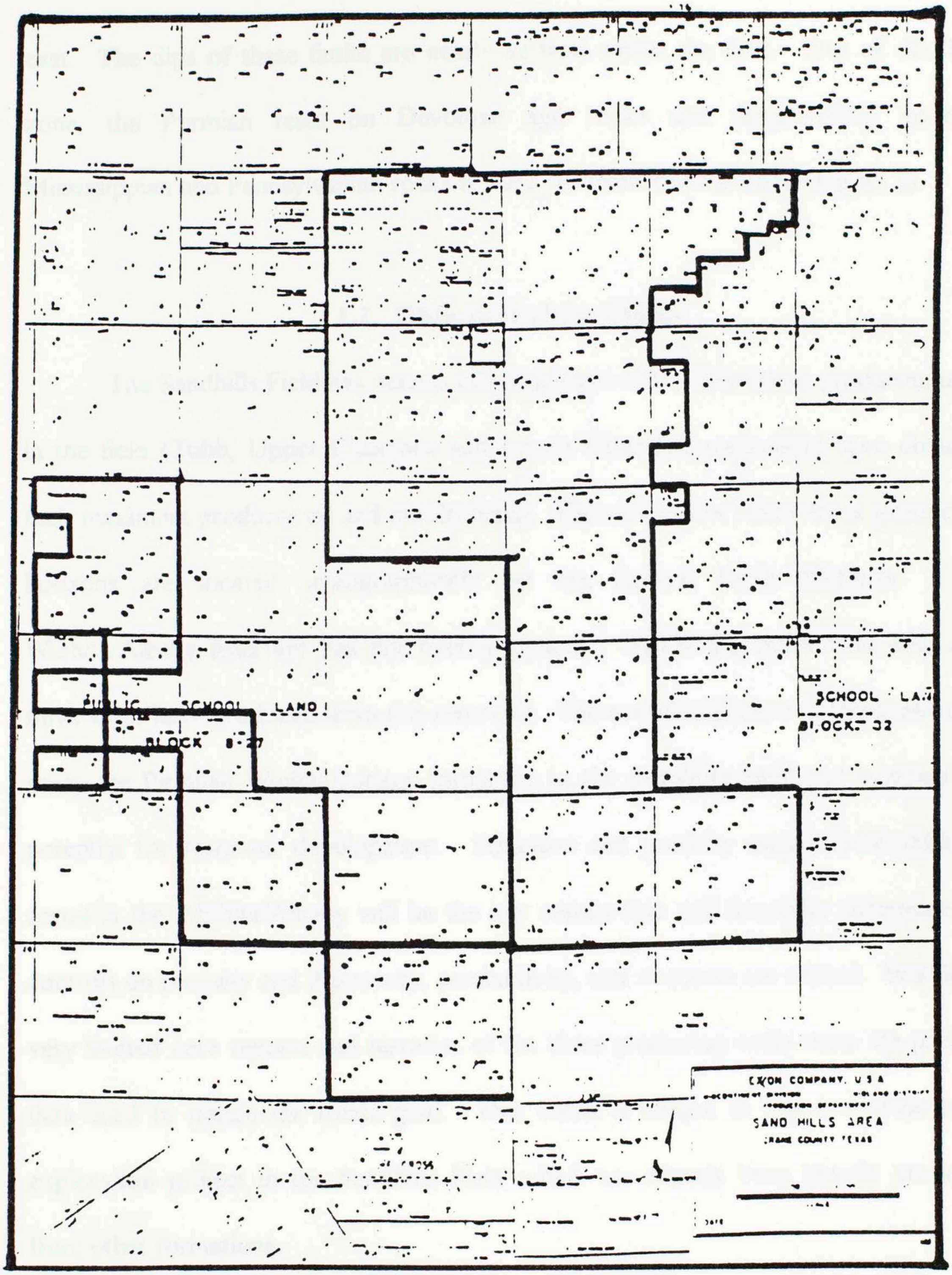

Figure 2: Exxon operated acreage, outlined in black (Exxon, 1996)

esat. The dips of these faults are nearly vertical within the field. East of the fault zone, the Permian rests on Devonian age rocks and progressively younger Mississippian and Pennsylvanian rocks toward the middle of the basin (Figure 3).

1.2. Objectives of the Thesis

The Sandhills Field has been producing since 1931. The major producing units in the field (Tubb, Upper Clearfork and Lower Clearfork reservoirs) have obtained their maximum productivity and are declining. Figure 4 shows where these productive hotizons are located stratigraphically on the Central Basin Platform. The Wichita/Albany reservoir has not been exploited. Within the entire field area only three wells have produced from this reservoir. The overall objective of this thesis is to study the Permian Wichita/Albany formation in the Sandhills Field and evaluate the potential for reservoir development. Structure and porosity maps of the different zones in the Wichita/Albany will be the key results that will hopefully determine the controls on porosity and if porosity, productivity, and structure are related. Well logs, very limited core reports and histories of the three producing wells were the primary data used to obtain the thesis goal. This thesis is unique in that it represents an exploration project in the Sandhills Field which has already been heavily produced from other formations.

1.3. Introduction to the Wichita/Albany Formation

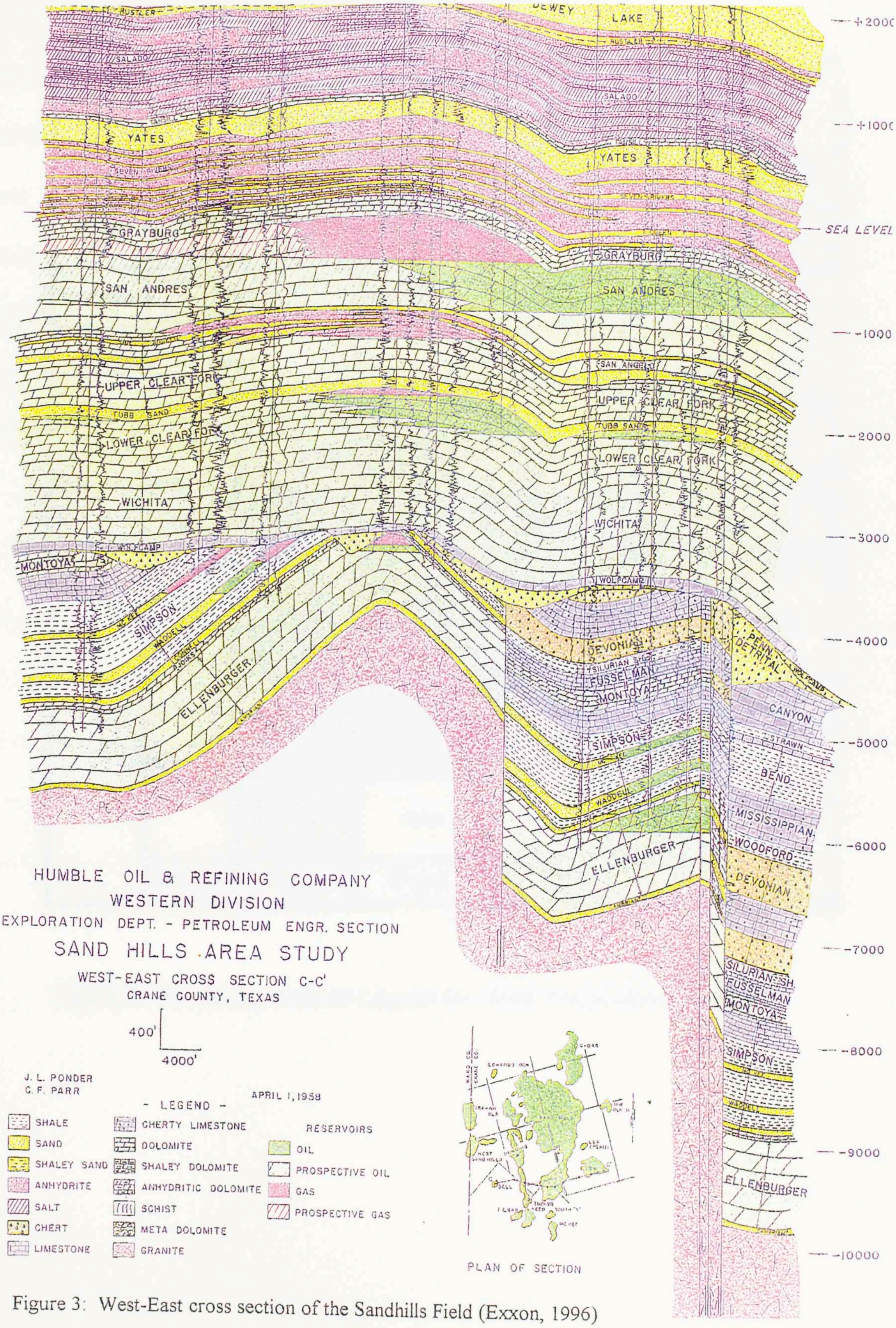

Figure 3: West-East cross section of the Sandhills Field (Exxon, 1996)

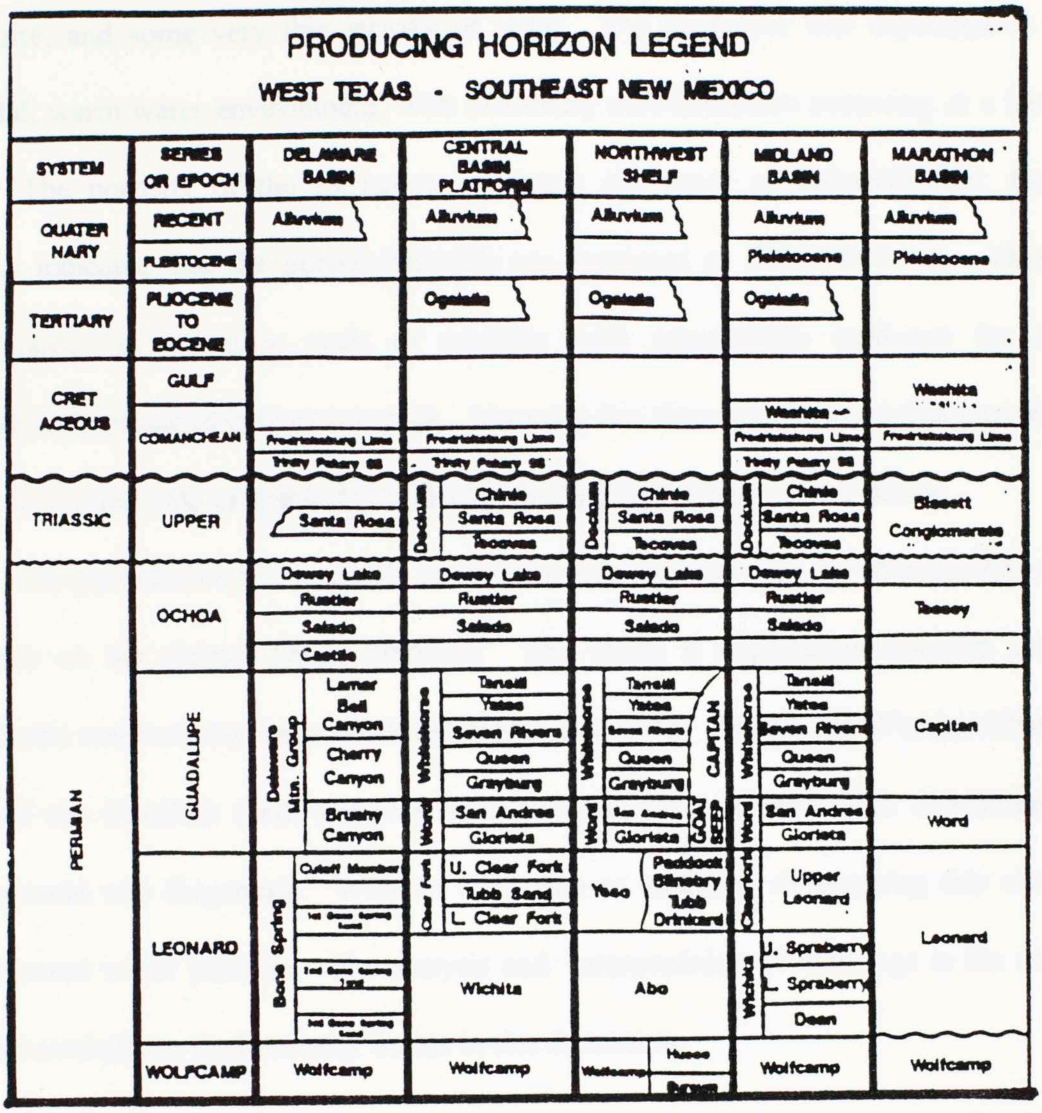

Figure 4: Producing Horizon Legend for West Texas (Exxon, 1996)

The Wichita/Albany formation is composed of mostly dolomite, limestone, anhydrite, and some very thin streaks of shale. The limestone was deposited in a peritidal, warm water environment, with secondary dolomitization occurring at a later time. The porosity of the formation is largely the result of dolomitization. Log analysis indicatse that the porous intervals are restricted to dolomite zones. These zones occur as lenticular pods of porosity with permeability sufficient for an economically producable reservoir rock. Mapping this discontinuous and thin porosity using the limited data available in the field is the major challenge of this study.

No publications are available in the literature that describe the Wichita/Albany reservoir on the Central Basin Platform. This thesis is exploration oriented even though the reservoir has been produced from three wells. Within the Wichita/Albany zone of the Sandhills field, porosity in carbonates varies greatly with depositional environment and diagenesis. With no core data to examine, determining this exact environment is not possible. The analysis and interpretiaion of well logs is the only method available to find porosity trends in this formation.

CHAPTER 2

Regional Geology

2.1. Central Basin Platform

The Central Basin Platform located in the central part of the Permian Basin is bordered on the east by the shallower Midland Basin and on the west by the deeper Delaware Basin (Figure 5). The Ozona arch meets the Central Basin Platform in the South. The Central Basin Platform contains a 10,000 foot thick deposit of warm water, shallow shelf carbonates and evaporites of Permian age. Crustal deformation in the foreland area Marathon Orogen during the late Paleozoic formed the Central Basin Platform. Uplift of the Central Basin Platform was caused by the fault system on the west side bordering the Delaware Basin (Shumaker, 1992). Others believe the uplift was formed by the fault system on the east, or a combination of both.

Studies by Robert Shumaker in 1992 show that the uplift of the Central Basin Platform occurred in steps that produced several asymmetric blocks. This departs from previous concepts of the platform being a single uplifted unit (Henderson et. al., 1984). These blocks have an alternating symmetry along the uplift axis, the Fort Stockton Block faces west, the Sandhills block faces east, the Emperor block faces southwest, and the Eunice block faces east. These uplifted blocks were eroded to form a flat platform surface in the Late Pennsylvanian that would support reef growth.

The Sandhills Field area is an east facing block (Figure 6) that contains folds and faults which break the block. These local structures have symmetry that match the larger structures at the block boundaries. It is interesting to note that each individual block in the Central Basin Platform uplift may have smaller faults and folds which vary

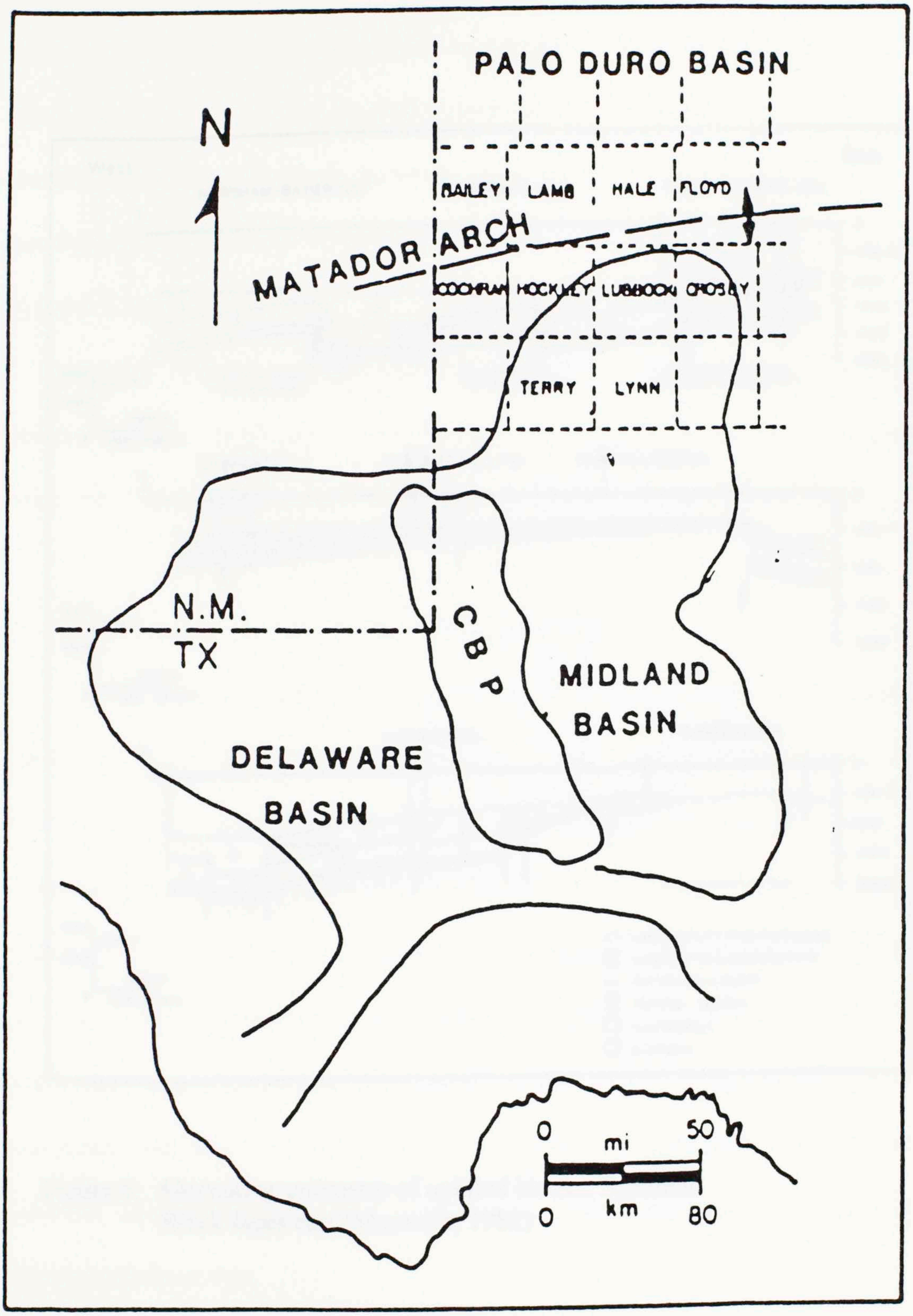

Figure 5: Central Basin Platform (CBP) bordered on the west by the Delaware Basin and on the east by the Midland Basin (Mazzullo, 1982)

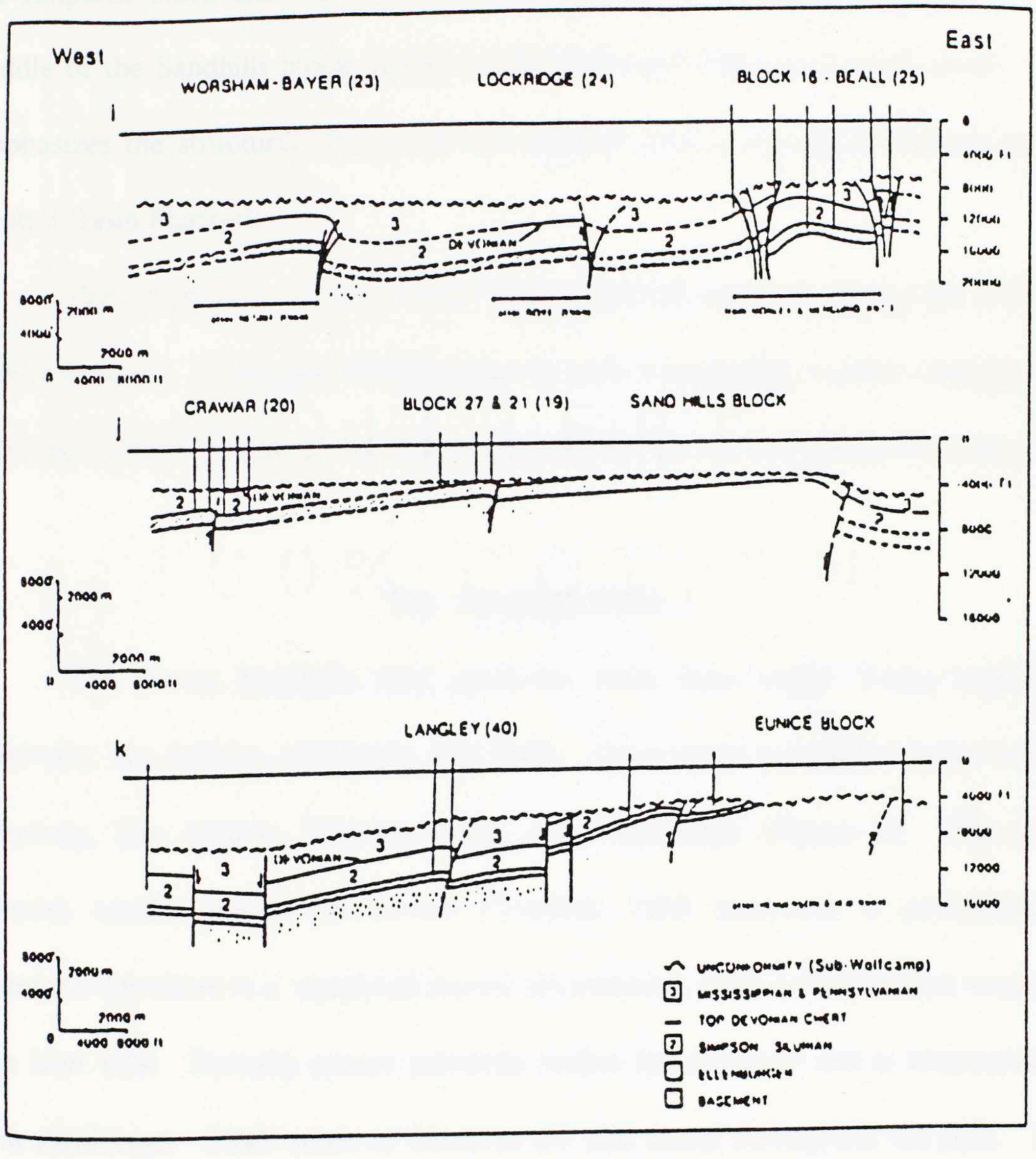

Figure 6: Alternating symmetry of uplifted blocks, Sandhills Block faces east (Mazzullo, 1982)

in trend and symmetry from one block to the next. For example, the fault separating the Emperor block and the Sandhills block on the north, trends northwest. In the middle of the Sandhills block, however, the faults and folds trend north-south. This emphasizes the structural complexity encountered over a very short distance on the Central Basin Platform.

Most deposition of the Central Basin Platform occurred during the lower to middle Permian. In the late Wolfcampian to early Leonardian, a major transgression took place on the Central Basin Platform depositing the Wichita/Albany Formation.

2.2. Sandhills Field

The Exxon Sandhills field produces from three major Texas regulatory reservoirs: the Judkins, McKnight, and Tubb. Other lesser productive zones are the Grayburg, San Angelo, Wichita/Albany, and Ellenburger (Figure 7). The entire Permian section except the Lower Clearfork Tubb sandstone is predominantly limestone deposited in a restricted marine environment, with dolomitization occurring at a later time. Porosity occurs primarily within the dolomite and is intercrystaline with small vugs. Small zones of fractures are also found throughout the field. Thin anhydrite beds and very little shale are scattered throughout the entire Permian interval. Most of the cores from the field show gypsum and anhydrite partially filling the dolomite porosity.

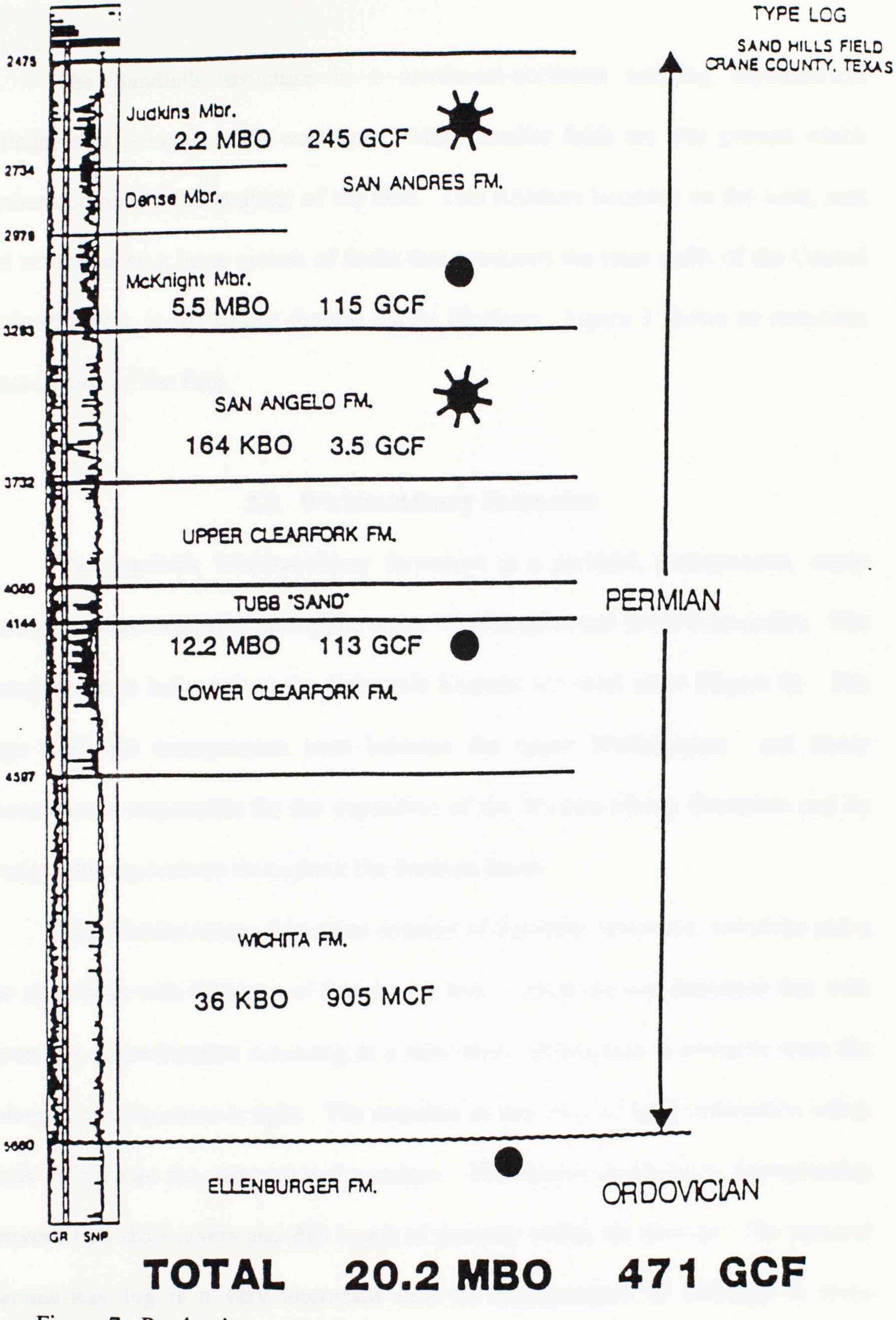

Figure 7: Productive reservoirs in the Exxon, Sandhills Field (Exxon, 1996)

The Sandhills structure is a southwest-northeast trending asymmetrical anticline that plunges to the northeast. Many smaller folds are also present which further complicate the geology of the field. This structure bounded on the west, east and southeast by a large system of faults that produced the main uplift of the Central Basin Platform, is the largest feature on the Platform. Figure 3 shows an east-west cross section of the field.

2.3. Wichita/Albany Formation

The Sandhills Wichita/Albany formation is a peritidal, transgressive, warm water carbonate deposited during the upper Wolfcampian and lower Leonardian. The transgression is indicated on the Paleozoic Eustatic sea level chart (Figure 8). The large landward transgression seen between the upper Wolfcampian and lower Leonardian is responsible for the deposition of the Wichita/Albany formation and its stratigraphic equivalents throughout the Permian Basin.

The Wichita/Albany formation consists of dolomite, limestone, anhydrite and a few shale beds with thickness of 6 inches or less. Limestone was deposited first with secondary dolomitization occurring at a later time. Production is primarily from the dolomite, the limestone is tight. The dolomite in this field is highly radioactive which tends to increase the gamma-ray log values. This causes problems in distinguishing between thin shale layers and thin layers of porosity within the interval. The Spectral Gamma-Ray log is a very important tool for interpretation of lithology in these

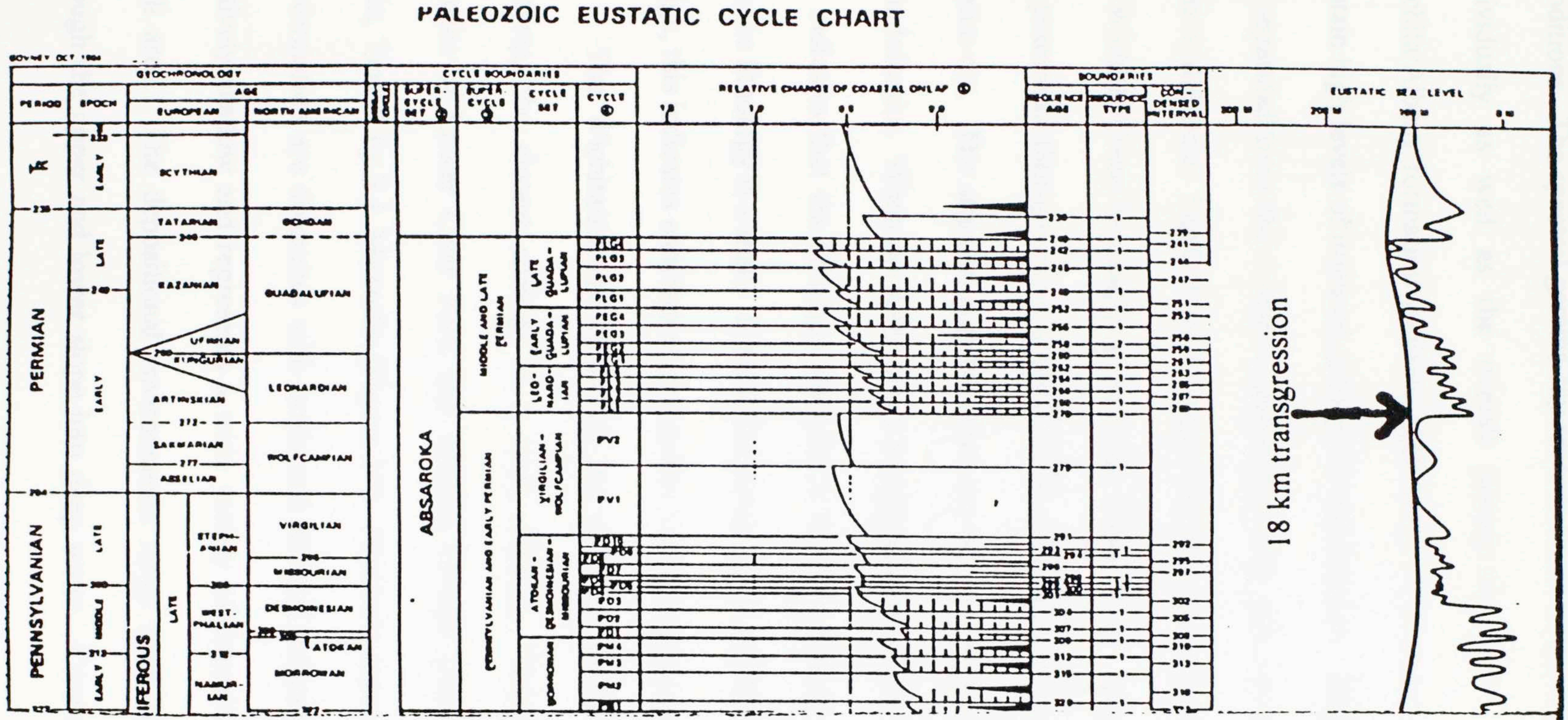

Figure 8: Paleozoic Eustatic Sea Level Chart showing the transgression between the Wolfcampian that deposited the Wichita/Albany (Exxon, 1996)

conditions. The spectral gamma-ray records levels of potassium, thorium and uranium individually as well as the overall gamma-ray curve. The dolomite in the Wichita/Albany formation contains high levels of uranium. The thin shales present contain high levels of uranium, potassium and thorium. When potassium and thorium are separated from the complete gamma-ray, they can indicate whether the interval is shale or dolomite. Figure 9 shows a spectral gamma-ray curve for the lower section of the Wichita/Albany in producing well J.B. Tubb "I" #1. The dark curve on the left is the potassium-thorium curve marked KTH. The thin curve on the right is the overall gamma-ray. The stippled area between the curve can be used to differentiate shale from dolomite. When the KTH curve is high and the overall gamma-ray curve is high, this indicates that the lithology sampled is high in uranium, potassium and thorium, thus the lithology is a shale. If the KTH curve is low and the overall gamma-ray curve is high, this indicates enrichment in uranium only indicating radioactive dolomite.

The Wichita/Albany formation has not been studied on the Central Basin Platform, the closest analogy is a study entitled, "Stratigraphy and Depositionl Mosaics of Lower Clear Fork and Wichita Groups (Permian), Northern Midlend Basin, Texas" by S.J. Mazzullo (Figure 10). Mazzullo reported that the lithologies of the formation are dolomites with ooids and skeletal material. The Midland basin is relatively shallow and represents a wide variety of depositional conditions within a small area. The depositional environments range from high to low energy shelf through the upper and lower slope into deep water. Core samples were studied by

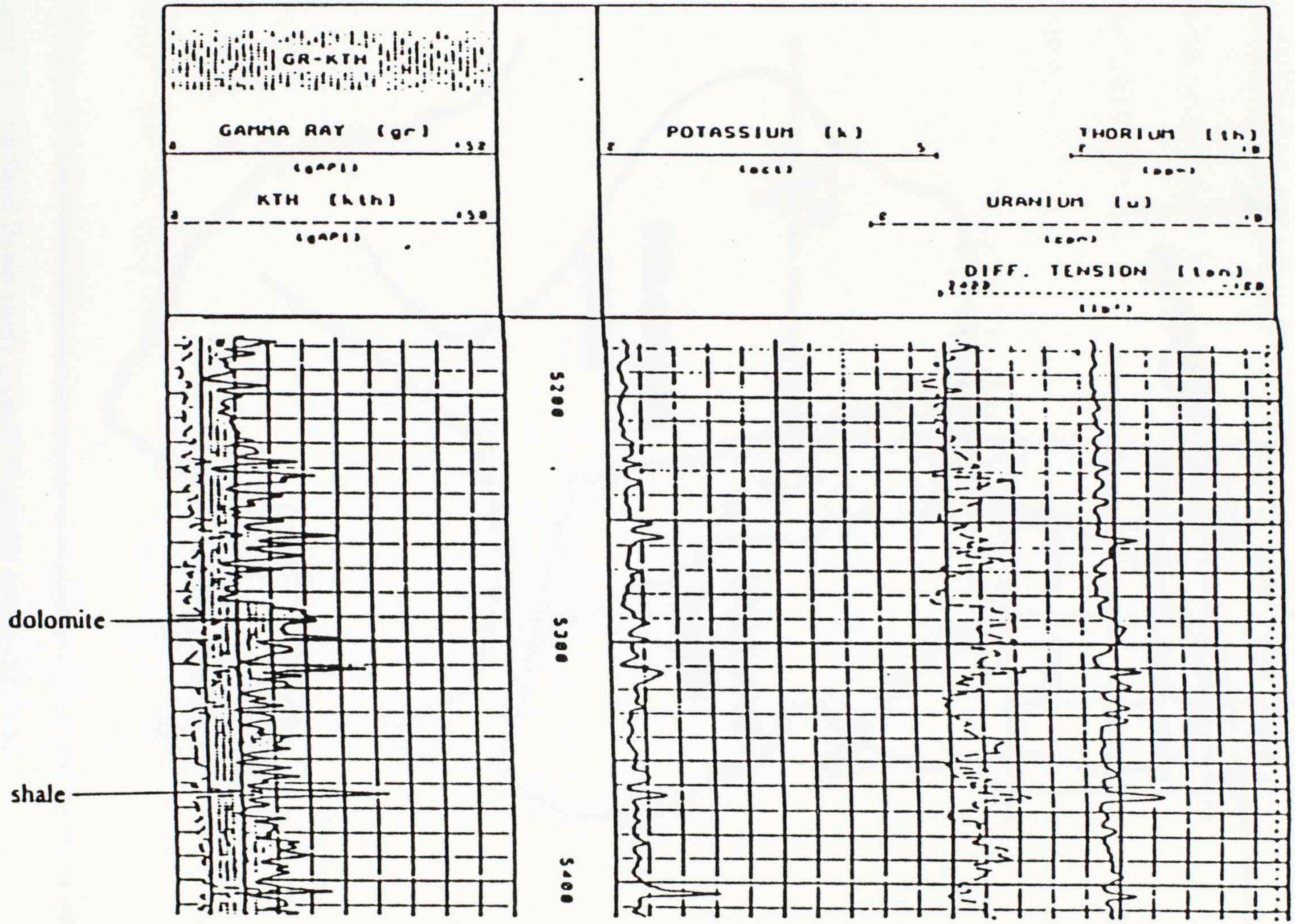

Figure 9: Spectral Gamma Ray curve from well J.B. Tubb "I" #1
(Western Atlas, 1996)

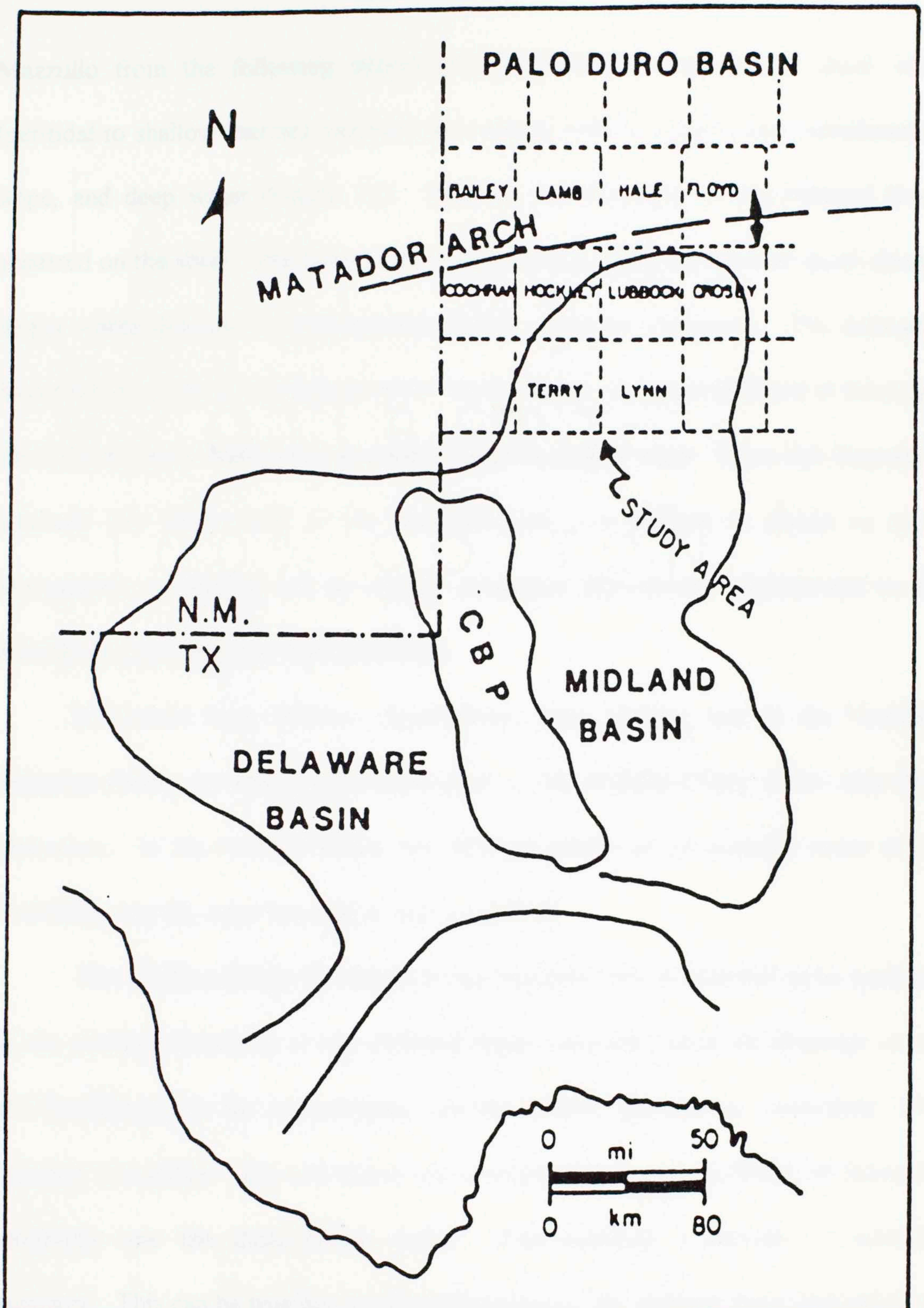

Figure 10: Midland Basin study area of Mazzullo (Mazzullo, 1982)

Mazzullo from the following depositional environments: high-energy shoal, shelf (peritidal to shallow marine), peritidal, low-energy shelf to upper slope, resedimented slope, and deep water (Figure 11). Most of the deposition in the Midland Basin occurred on the shelf. The deep water central part of the basin received much thinner deeper wated deposits of predominately marine and reef carbonates. The dolomites recovered from the Wichita group were varied but not extremely different in lithology. The Central Basin Platform is an isolated high in deeper water. Since this deposition occurred 100 miles north of the Sandhills area it is difficult to obtain an exact srtatigraphic correlation and an exactly analogous depositional environment to the dolomites of the Sandhills Wichita/Albany.

In Central New Mexico, Southeastern New Mexico, and in the Northern Delaware Basin, the stratigraphic equivalent to the Wichita/Albany is the Abo Reef Formation. In the Midland Basin, the Wichita/Albany group includes some of the Wolfcamp, but the exact boundaries are not defined.

The Wichita/Albany formation in the Sandhills field is believed to be peritidal. In the peritidal dolomites of the Midland Basin, Mazzullo finds the lithology of the Wichita/Albany to be dolomicrites, peloid-pisolitic grainstones associated with anhydric red shales. The red shales are probably due to the oxidizing of terrestrial sediments near the shore before burial. This indicated a peritidal or subaerial exposure. This can be true due to the shallowness of the Midland basin and proximity to a mainland clastic sediment supply. The Sandhills Wichita/Albany formation

Dolomite and Limestone Types	Lithologies	Allochems, Syndepositional Textures	Environment
Dol. A	Oolitic dolomites, grainstone texture	Ooids, skeletal; peloids	High-energy shoal
Dol. B	Sandy dolomites, replace lime packstones; associated with sandstones and dolomite types A and C	Ooids, skeletal	Shelf: variously peritidal to shallow marine
Dol. C	Dolomicrites, peloid-pisolitic grainstones; associated with anhydritic red shales	Nodular-mosaic anhydrite, bird's-eyes, cryptalgalamites	Peritidal loferites, sabkha
Dol. D	Argillaceous, siliceous dolomites replace lime wackestones; commonly associated with outer shelf Tubb	Crinoids, spicules	Low-energy shelf to upper slope
Lst. A	Packstone-grainstone; associated with dark limestones (B, C) and shales	Ooids, skeletal	Resedimented slope
Lst. B, C	Argillaceous, siliceous wackestones and mudstones; associated with limestone type A and Dean siliciclastics	Skeletal	Deep water (slope-basinal)
—	Sandstones, siltstones; variously associated with all lithologies above	Skeletal	Variously terrestrial to shallow marine to deep water
—	Dark shales	Rare skeletal	Low-energy, outer shelf to basinal
—	Green and red shales	Nodular-mosaic anhydrite	Sabkha

Figure 11: Wichita lithologic asscoiations and depositional environments (Mazzullo, 1982)

contains very little shale, it is probably black rather than red. This is due to the depositional differences between the Midland Basin environment (shelf/slope) and the Central Basin Platform (isolated mid. basin uplift). The peritidal depositional environment studied in the Midland Basinis the closest asscociation of environment to determine lithology of the Wichita/Albany formation on the Central Basin Platform. This study may not apply to all of the Wichita/Albany formation on the Central Basin Platform due to the distance and change in depositional environment but it is the closest correlative study.

A compensated borehole imaging log of Exxon well J.B. Tubb "I" #1 shows a section of the Wichita/Albany at the Sandhills Field. Vugular porosity can be seen as dark areas on the image while the white surrounding the porosity is anhydrite. The anhydrite partially fills the vugular dolomite porosity (Figure 12).

2.4. Bounding Formations

The bounding formations to the Wichita/Albany in the Sandhills field are the Lower Clearfork above and the Ordovician Ellenburger below the Base of Permian unconformity surface. The Lower Clearfork is composed of shelf dolomites, evaporites and varicolored shales. The Tubb Sandstone is included as a member in the dolomitic Lower Clearfork. The Lower Clearfork, a solution drive gas reservoir that produces very little water, is the most productive unit in the Exxon Sandhills Field. The Ellenburger Formation is a gray Ordovician dolomite equivalent to the

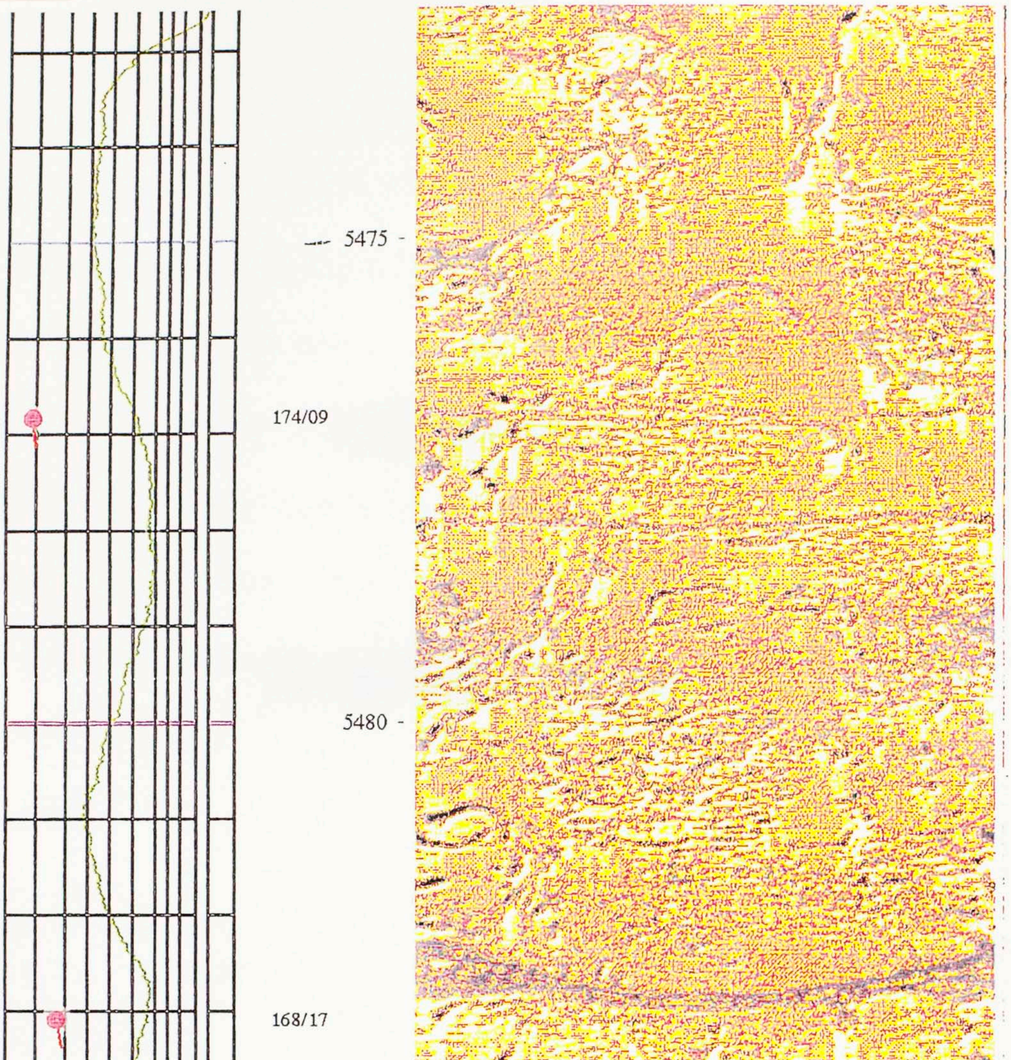

Figure 12 Compensated Borehole Imaging Log (CBIL) of well J.B. Tubb "I" #1 (Western Atlas, 1996)

CHAPTER 3

Available Data

3.1. Well Logs

The data available to study the Sandhills field is very limited. Only sixteen of the over 400 wells in the field are drilled below the top of the Wichita/Albany Formation to the Ellenburger. These wells include 10 Exxon wells and 5 wells operated by others. Two modern logging suites are available from the most recent drilled wells: J.B. Tubb I#1 in 1995 and the J.B. Tubb #64 well in 1996. These logs are complete and provide a foundation for interpreting the other scattering of well logs. The logging suite for well #64 was done by Schlumberger and includes the following logs:

a. Gamma-Ray
b. Borehole Compensated Sonic Log
c. Formation Micro Scanner Log
d. Compensated Neutron Litho-Density Log
e. Phasor Induction SFL Log w/SP
f. Caliper Log
g. Array Induction Log w/SP

The logging suite for well J.B. Tubb "I" #1 was done by Western Atlas and included the following logs:

a. Gamma Ray Log
b. Dual Laterlog
c. Micro Laterlog
d. Caliper Log
e. Digital Spectralog (Spectral Gamma Ray Log)
f. Borehole Compensated Acoustilog
g. Compensated Z-Densilog (RHOB)
h. Compensated Neutron Log

This well also has a Compensated Borehole Imaging Log (CBIL) acquired by Moroco Geologic Services of Carlsbad, New Mexico

The other 14 wells have a variety of logs that include Gamma Ray, Spontaneous Potential, Compensated Neutron, Sidewall Neutron, Formation Density, and Sonic Logs. The disadvantage is that most wells contain only one type of log. For example, one well has a gamma-ray, neutron porosity log and another may have a gamma-ray formation density or sonic log. All of these logs, except the two modern suites were acquired in the late 1950's and 1960's. Porosity data on most of these logs is in neutron counts and had to be converted with appropriate log charts and equations.

3.2. Core Data

Within the entire Exxon Sandhills field area no cores are available for examination from the Wichita/Albany formation interval. Whole cores were taken from two of the past producing wells: J.B. Tubb C#8 and J.B. Tubb #68 (1959-1960). These cores were analyzed for Exxon by Darrell W. Smith Co. of Midland, Texas for horizontal permeability, effective porosity, residual oil and water saturation. Through the years Exxon has destroyed or given away every foot of the cored intervals. These core analysis reports are useful to calibrate porosity of the old style well logs to those cored intervals. The neutron logs from both these wells were recorded using an arbitrary scale, that is they were not scaled to porosity or neutron counts. By correlating the porosity in the core report with corresponding sections of the logs, a relationship was developed between the neutron log readings and the actual porosity. Details of this procedure are explained in the next chapter on research methods. Cores from wells to be drilled in the future would provide unique insight into the exact depositional conditions of the Wichita/Albany formation.

3.3 Well Database and Landgrids

The first task in this thesis was to prepare a well database for future generation of cross sections and a structure map. Exxon Company U.S.A. supplied a TSO Flat File Database of all wells in the field. Exxon operated and wells operated by others were included in this database. Information provided in the database consisted of the following items for each well: X/Y Texas State Plane coordinates of each borehole, total drilled depth of the well, Texas Railroad Commission reference number and individual well number.

Digital Landgrids for Crane County, Texas were provided by Steve Banks of Topographic Mapping, Inc. of Oklahoma City. The Blocks included in my study area are 32, and B-27 of the Public School Lease Survey in Crane Co. TX. These Landgrids arrived in Latitude/Longitude coordinates and were converted into the Texas State Plane Coordinate System by Geographix so that wells could be posted to maps using the original State Plane Coordinates.

3.4. Past History of Producers

The Wichita/Albany reservoir in the Sandhills field has only been produced in the past from three Exxon wells (J.B. Tubb C#8, 68, and I#1). These wells are all in Exxon's northern Sandhills acreage (P.S.L. Block 32, Sections 5 and 6) (Figure 13) . Well I#1 spudded in 1996 is still productive. The other wells spudded in 1959 and 1960, respectively, have been abandoned. The two older wells produced from initial completion until the early 1970's and 1980's. A middle gas zone and a lower oil and gas zone were identified in each of these wells with neutron log data. Well C#8 was drilled first and perforated only in the lower oil and gas zone. The middle zone containing gas was not produced. In the 1950's, the gas was not economical to produce and was left in the middle zone by Exxon. Well J.B. Tubb #68 was drilled one year later as an Ellenburger producer and was re-completed three years later in the Wichita/Albany after the Ellenburger had watered out. The cumulative production from wells C#8, 68 and I#!1 was 36 KBO, 708 MCFG and 93 KBO, 1.0 GCFG respectively.

Original reservoir pressure in the J.B. Tubb #68 Wichita-Albany was 2410 psig from perforations at 5610-5640 feet. This well was produced to depletion over a 12-year period (1962-1974) to 300 psig. The reservoir pressure for the Exxon, J.B. Tubb I#1 well was 2490 psig. from perforations at 5570-5680 feet, which is comparable to original reservoir pressure in the Wichita/Albany field. Since the J.B. Tubb #68 well

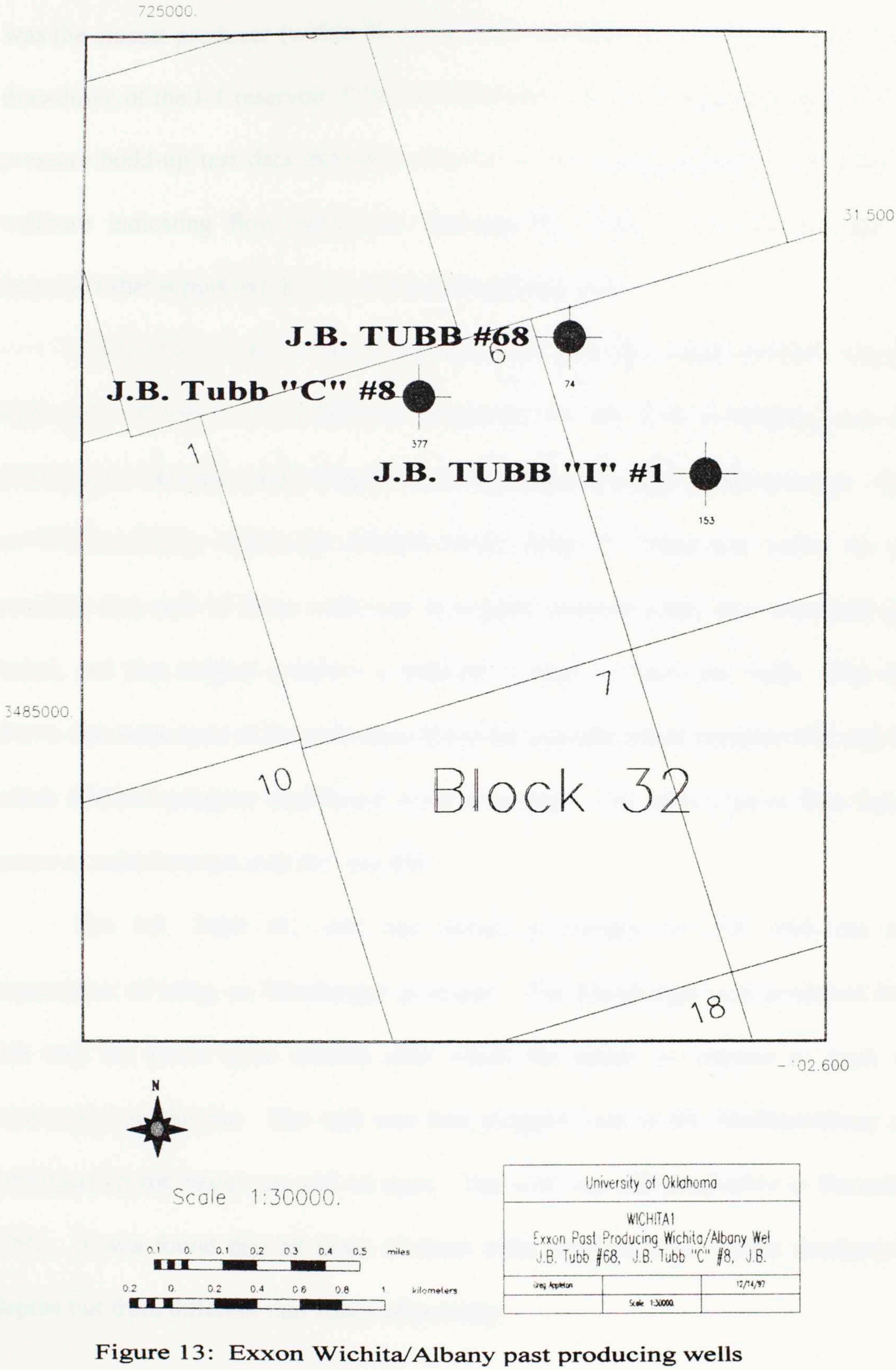

Figure 13: Exxon Wichita/Albany past producing wells

was the closest producer (within 80 acres) and was depleted, one would expect some drawdown of the I-1 reservoir if the two reservoirs were in communication. Well I#1 pressure build-up test data indicates a barrier to flow approximately 30 ft. from the wellbore indicating flow separation between the reservoir in well I#1 and the reservoirs that supported the J.B. Tubb #68 and C#8 wells.

Additionally, wells C#8 and #68 were both drill stem tested in 1959. The drill stem tests measured very different pressures for the C#8 (2100psig) and #68 (2400psig) at the same relative depths in the oil and gas section of the reservoir. Since no Wichita/Albany offsets are located within miles of these two wells, we may conclude that each of these wells was at original pressure when they were drill stem tested, and that original pressure is different in each of these two wells. This data shows that some type of discontinuous lenticular porosity exists between C#8 and #68 which inhibited pressure equilibrium from occurring. This same type of flow barrier seems to exist between well I#1 and #68.

The J.B. Tubb I#1 well was drilled in January of 1996 with the sole expectation of being an Ellenburger producer. The Ellenburger was produced from this well for about three months after which the water cut became to great for economical production. The well was then plugged back to the Wichita/Albany and perforated in the lower gas and oil zone. The well was still productive in December 1997. It was found that all three of these wells produce from similar stratigraphic depths but from different thin zones of porosity.

3.5. Limitations of the Data

The Wichita/Albany Formation has been overlooked as a productive unit of the Sandhills Field. The largest reason for this is lack of data. Determination of exact lithologic components is not possible due to lack of core. These wells produce from small discontinuous zones of porosity. These zones are difficult to identify with only neutron logs. More data could encourage further exploration and production

CHAPTER 4

Research Methods

4.1. Structural Cross Sections

Fifty-five structural cross sections were prepared showing the interval from the San Andres Formation to the top of the Wichita/Albany including five cross sections to the base of the Wichita/Albany formation. These were used to determine overall thickening, thinning, deepening and shallowing trends across the field. Three hundred and fifty-five wells drilled on Exxon and non-Exxon acreage at Sandhills were digitized and placed in a database. Structural tops of the San Andres, Upper Clearfork, Tubb Sand , Wichita/Albany, and Ellenburger (where available) were picked for each well and entered into the database. The tops were picked by first examining an Exxon type log J.B. Tubb #185 and loop tying all of the cross sections back to this first type well. The cross sections were constructed from the south to north and from east to west until all of the wells were tied. Structure maps on the tops of each zone were generated. Because only sixteen well logs show the entire Wichita/Albany section in the Sandhills Field, a structure map on top of the formation was the only one that could be accurately generated (Plate 1), although a structure map on the bottom of the Wichita/Albany formation would have been useful. The tops of the Wichita/Albany were picked and posted to the wells. Maps were printed and contoured by both the computer and by hand to determine the overall structure of the Wichita/Albany formation throughout the field.

4.2. Log Digitizing

Log analysis in the Wichita/Albany is the primary method of investigation in the Exxon Sandhills field. The Wichita/Albany zone is the most under-explored, and poorly logged zone in the field. For analysis, logs from sixteen(16) wells were collected. These logs included two full modern suites logged by Schlumberger and Western Atlas within the past two years. The modern logs were the backbone of this analysis because most of the other logs were limited to older gamma ray-neutron and formation density logs.

The first step in the process was to collect the logs. Eight(8) of the logs were provided by Exxon and the remaining eight were retrieved from the Texas Well Log Library in Midland, Texas. Two of the Exxon Wells (J.B. Tubb I1 and J.B. Tubb #64) were logged within the past two years and have complete modern logging suites. Other Exxon producers (C-8, 68, and C-9) were limited to 1960's style Formation Density Counts and Gamma-Ray, along with Neutron Porosity and Gamma-Ray. The remainder of the logs are an assortment of Compensated Neutron, Sidewall Neutron, Sonic, Formation Density and Gamma-Ray Logs. Each of the different log types had its own set of challenges and limitations for porosity determination.

The second step in the analysis was to digitize the logs. All logs from each well were digitized, including any resistivity or other logs not indicative of porosity. The logs were digitized into .LAS format using the program DIGI-RULE and a RAT 1000. The only logs that were not digitized were the Laterlog and Microlaterlogs with an arbitrary scale. This arbitrary scale was neither linear nor logarithmic. According to DIGI-RULE Corp. logs with this type of scale could not be digitized accurately. When all of the logs were digitized, the DIGI-RULE program was also used to convert these logs into .LBS format, this format is required by the program Quantitative Log Analysis II (QLAII) which would be the next step in log analysis.

4.3. Quantitative Log Analysis for Porosity and Water Saturation Calculations

After conversion from .LAS to .LBS format, the logs were imported into the QLAII program for analysis and presentation. The first analysis was done on the two modern logging suites from wells J.B. Tubb "I" #1 and #64. It was possible to calculate accurate lithology and porosity from the Bulk Density (RHOB) and the Photoelectric (P_e) curves. This calculation was done using Schlumberger's Porosity and Lithology Determination from the Litho-Density Log (FIGURE). When these wells were logged, the porosity values were calculated using limestone as the matrix. Using the RHOB and P_e curves, the porosity was re-calculated automatically to the corrected porosity for the appropriate lithology.

Although a few shale streaks are evident, shale is not considered a major component in the lithology of the Wichita/Albany formation. Lithology was calculated for three end members (anhydrite, limestone and dolomite). Results showed that most of the logged interval contained dolomite as the primary lithologic component, with limestone second highest and anhydrite third. All of the production and porosity

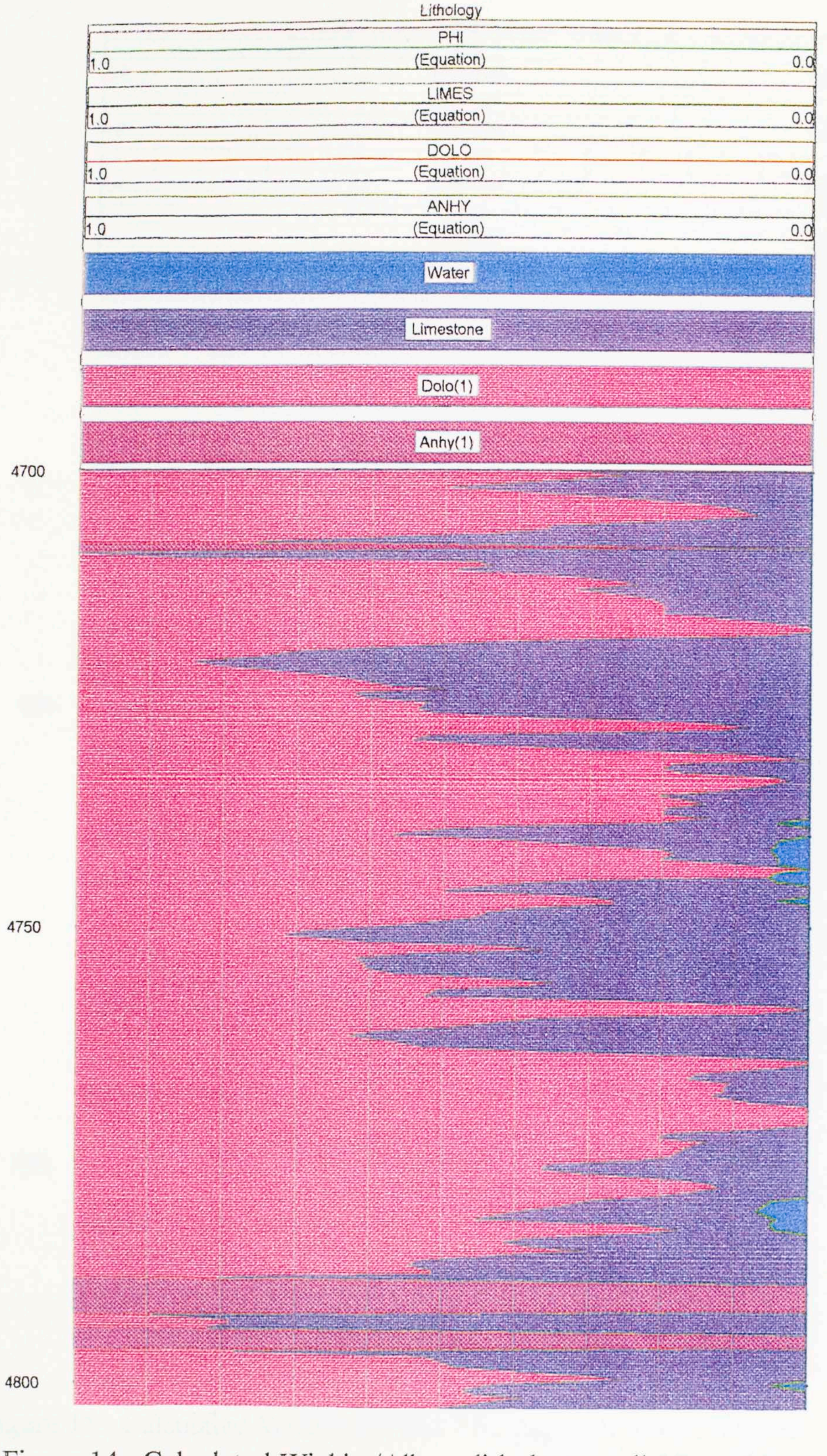

Figure 14: Calculated Wichita/Albany lithology, well J.B. Tubb "I" #1

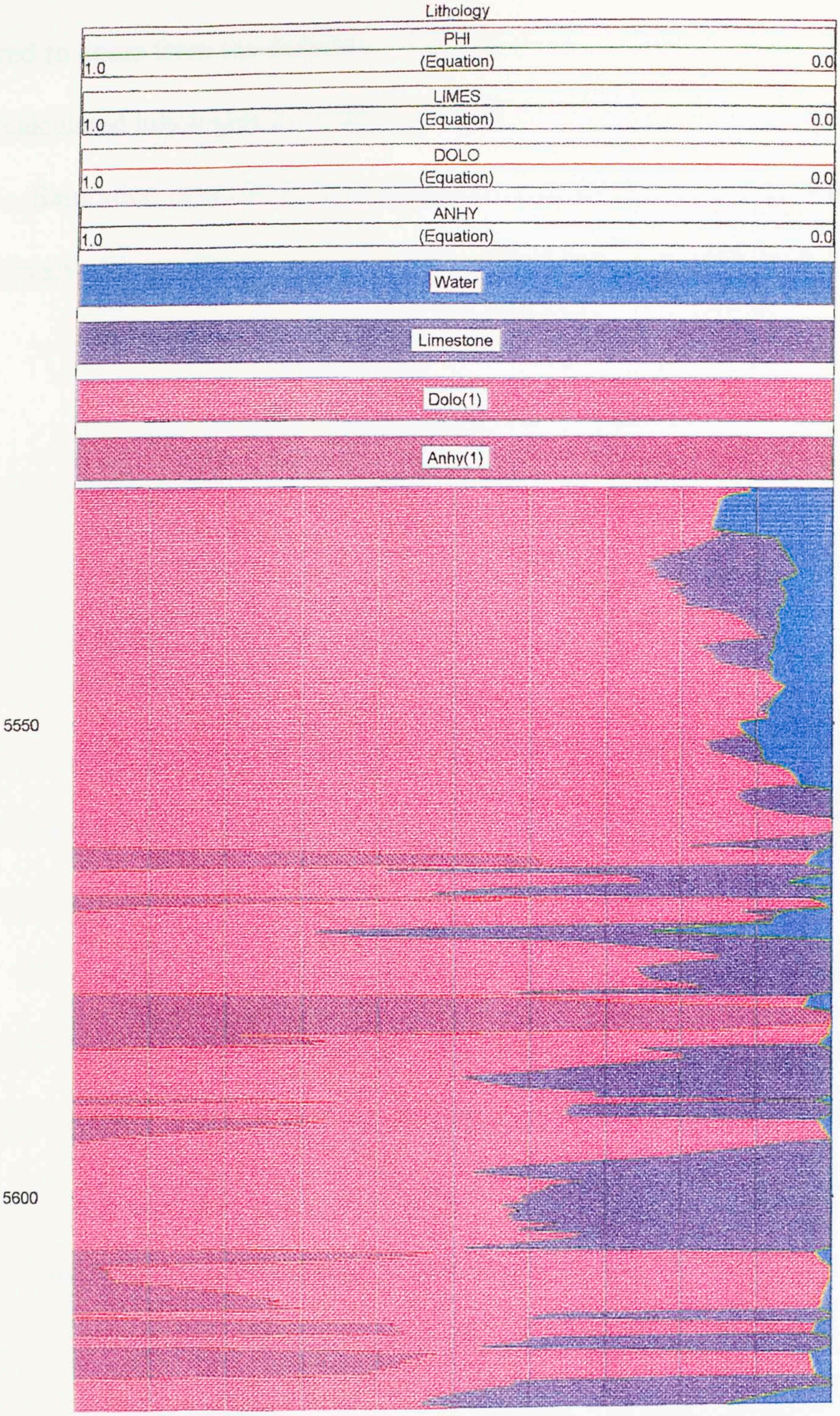

Figure 15: Calculated Wichita/Albany lithology, well J.B. Tubb #64

appeared to come from the dolomite. Figures 14 and 15 show a representitive section of the calculated lithologies for wells J.B. Tubb "I" #1 and J.B. Tubb #64.

Saturation of water (S_w) and Saturation of Hydrocarbons (S_h) was calculated for intervals with porosity greater than 4%. The water saturation was calculated using Archie's equation:

$$Sw^n = (a * Rw)/(\varnothing n^m * Rt) \text{ where:}$$

Sw = water saturation
a = tortional constant = 1
Rw = resistivity of water
∅n = neutron porosity
m = cementation factor = 2
n = exponential factor = 1.7

The exponential factor was set to 1.7 instead of 2 because the Wichita/Albany reservoir is fractured in the Sandhils field. The hydrocarbon saturation was calculated by the equation 1-Sw.

The remaining wells in the study had logs that were also taken based on a limestone matrix. Some of the logs that are used to indicate porosity (neutron, formation density, and sonic) were scaled in neutron counts per second and not converted to a porosity scale. The lithologic determination based on the suites of modern logs from two wells indicates the majority of the Wichita/Albany formation is composed of dolomite. Porosity values from the old style logs were converted to reflect the dolomite lithology, and most of the very old logs without a porosity scale were converted from standard neutron counts to porosity. The following is the method of conversion for each of the well log types considered.

Wells J.B. Tubb "C" #9 and "C" #10 had Formation Density Logs taken in neutron counts per second. Using Schlumberger's Historical Charts reference manual, these logs were converted to porosity using the bulk density of dolomite 2.87g/cc, fluid density of 1.1g/cc and a 7 and 7/8 inch borehole (Figure 16). The final equation used for conversion was:

$$\text{Porosity \%} = (\rho_g - \rho_b)/(\rho_g - \rho_f) * 100 \quad \text{where}$$

ρ_g = 2.87 g/cc
ρ_f = 1.1 g/cc
ρ_b = determined by historical chart conversion of old logs

The TXO #3 well had neutron porosity and density porosity logs. The final porosity was determined by taking the crossplot values of the two logs to account for the effect of lithology on porosity. Wells J.B. Tubb #185 and J.B. Tubb #172 had older sidewall neutron logs with neutron count data. These were converted to final porosity using Haliburton's 1968 historical chart conversion book (Figure 17). Well J.B. Tubb G #1 had a compensated neutron log scaled in porosity. Converting this porosity to reflect the dolomite lithology requires two equations based on the apparent porosity. If the apparent porosity is greater than 10%, one must subtract 6% and if the apparent porosity is less than 10% one must subtract 4% from the log value (Dresser Atlas, 1979). Wells J.B. Tubb #68 and "C" #8 had logs with an arbitrary neutron porosity based neither on standard counts nor limestone porosity. Fortunately, a core report was available for each of these two wells. To get the true porosity, the core report porosities were correlated with the log at every depth from

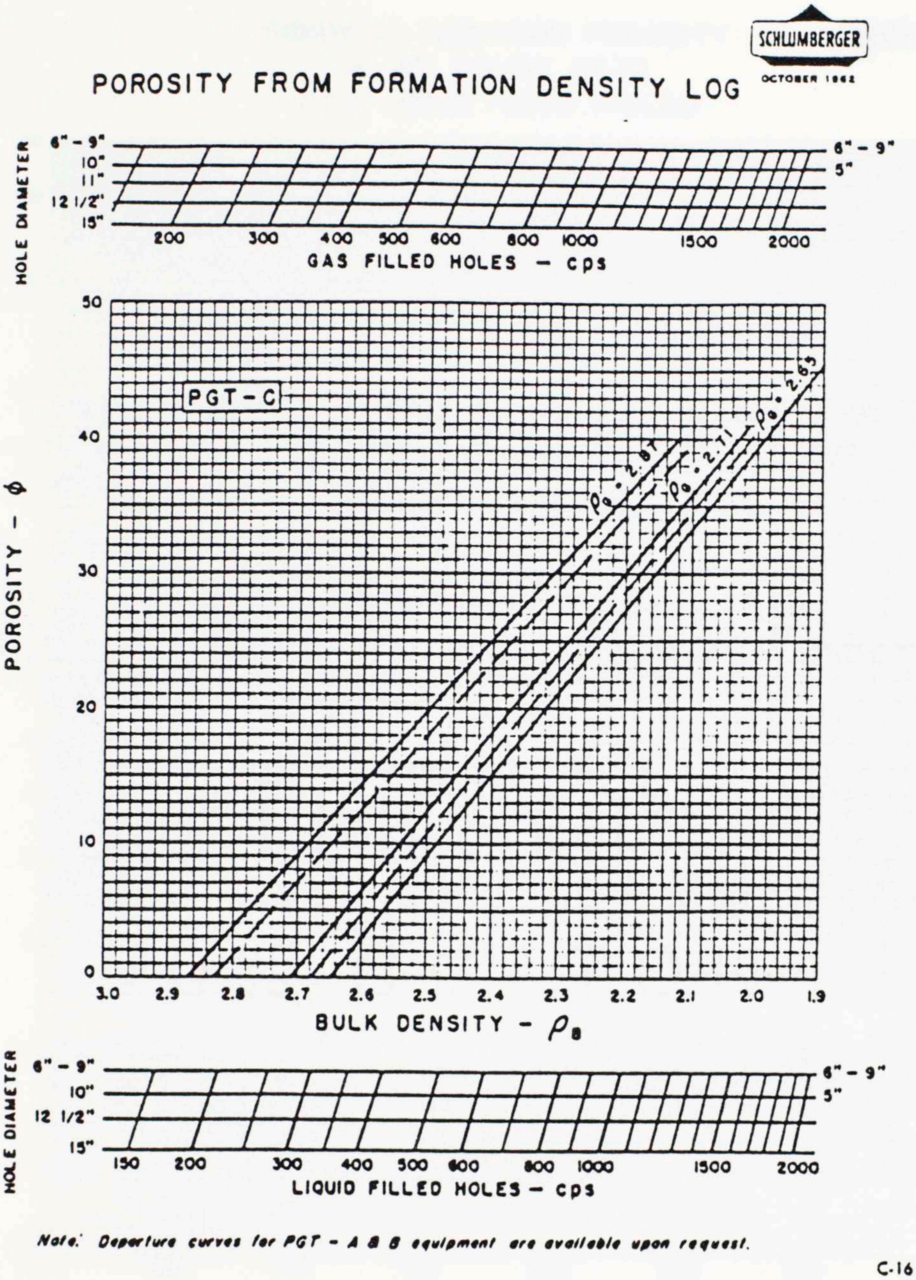

Figure 16: Conversion chart for old formation density logs (Schlumberger, 1990)

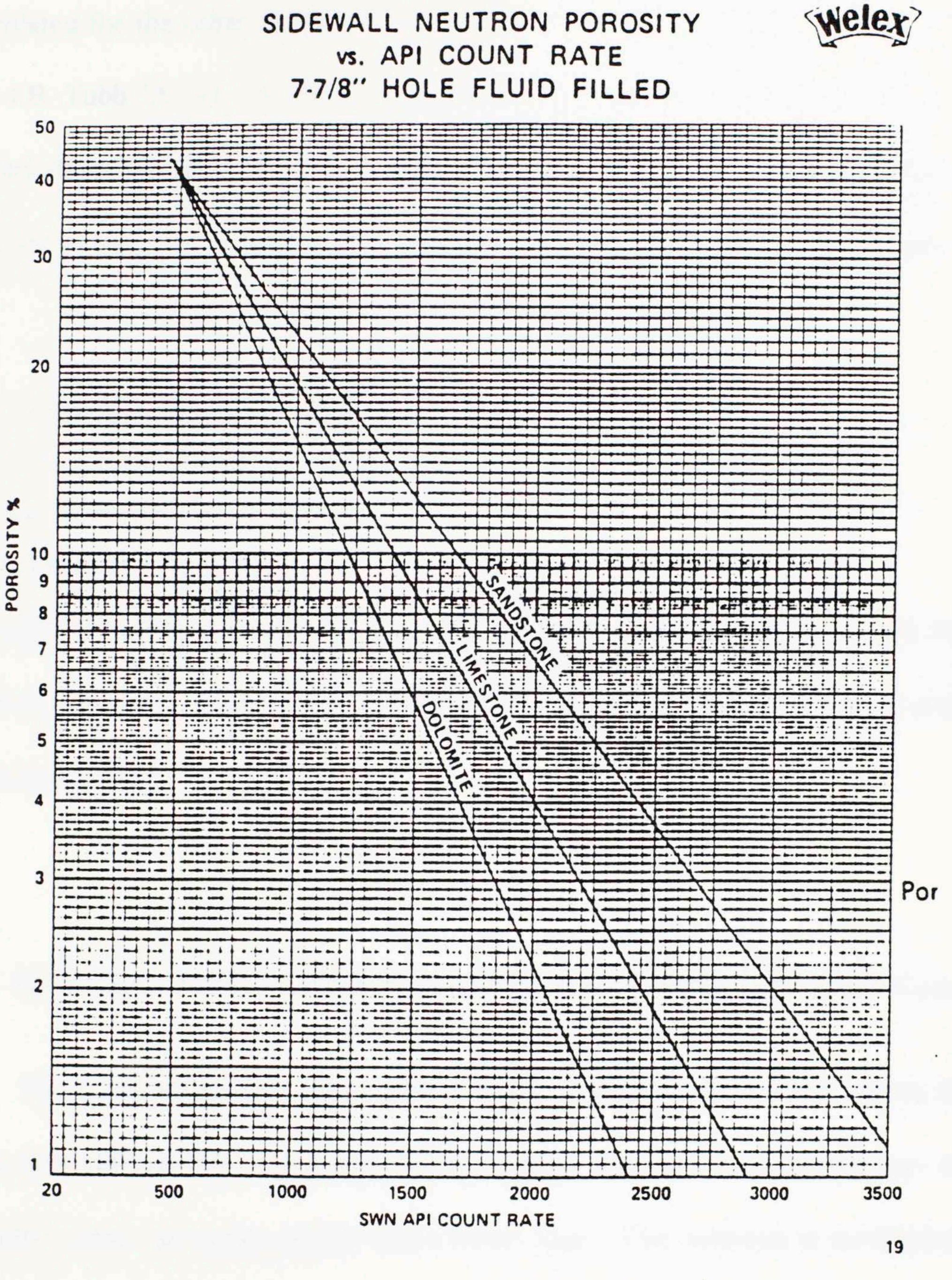

Figure 17: Conversion chart for old sidewall neutron logs (Haliburton, 1968)

the core report. The corresponding porosities were then transferred to the log and interpolated for the other sections of the log where core porosities were not present. Wells J.B. Tubb "A" #1, "A" #9, "A" 11-E, "B" #10, "B" #11 and J.V. Terrill "A" #9 only had sonic logs showing travel times in micro seconds per foot. These logs were converted to true dolomite porosity using the Raymer-Hunt equation from Haliburton:

$$\text{Sonic Porosity} = [1-(\Delta t_{ma}/\Delta t_c)] / (\rho_{ma}-\rho_f) \text{ where:}$$

Δt_{ma} = matrix slowness for dolomite = 43.5 μs/ft
Δt_c = interval travel time = log data in μs/ft
ρ_{ma} = matrix density for dolomite
ρ_f = fluid density = 1.1 g/cc

This method was used because it does not require a correction factor as the Wylie transform does, and it calculates porosity more accurately then an empirical method (Haliburton, 1991).

4.4. Subdivision of the Wichita/Albany into Upper, Middle and Lower Zones

The Wichita/Albany is about 1000-1200 ft. thick throughout the Sandhills field. Rather than dealing with this as one cohesive unit, the zone was divided into three productive zones: an upper, middle and a lower zone. This zonation is modeled after past producing zones in the field. These zones are also correlated based on small shale markers and very clean zones that produce gamma-ray characteristics common to all logs of the Sandhills Wichita/Albany interval. Plate 2 shows well J.B. Tubb "I" #1 divided into the three zones

The J.B. Tubb "C" #8 well has three major zones of porosity. Production (mostly oil) was obtained from the lower zone only. The next producer J.B. Tubb #68 was produced in the lower and middle zones, the lower containing more oil than gas, and the upper containing more gas than oil. The third producer J.B. Tubb "I" #1 has already been completed in the lower oil and gas zone with plans to recomplete to the middle zone when present production declines. The "I" #1 well does not show any porosity development in the upper zone, and therefore would not be productive. Each zone will be analyzed for porosity as a separate unit.

4.5. Porosity Maps

The results of the porosity determination are shown on six porosity maps, two for each zone. Porosity was determined on a foot by foot basis for each of the three zones (upper, middle, lower) of the Wichita/Albany. Exxon considers intervals in these types of carbonates with a porosity above 4% to be possibly productive. A thickness cutoff of two feet was used arbitrarily to define potentially productive intervals. Any zone having at least 4% porosity and a thickness of at least two feet was included in the summation to obtain the cumulative thickness of potential productive section. This number was then posted to each respective well and maps for each zone were contoured based on these values. This process was repeated for intervals of porosity greater than 10%, the only difference being that the footage to be economically producable was reduced to 1 ft. or greater. The data was then posted to the wells in the same manner and contoured.

The maps were contoured using Geographix 7.7.3. The adaptive fit contouring method was selected after tests indicated that it was the most appropriate for sparse, irregularly spaced data. Minimum curvature was considered and tried but the contours did not honor the data points as well as those based on adaptive fitting. The 4% and greater porosity footage maps were contoured with 20 foot interval contours while the 10% and greater footage maps were contoured with 10ft. lines. This was done due to the wider ranges of data in the 4% porosity intervals. The 4% maps were too cluttered with 10 foot contour intervals to accurately interpret the data. Color was then added to provide a greater contrast between areas of porosity and non-porosity. Because the data were limited to sixteen wells within such a large area, the final maps were cropped to eliminate edge effects produced by the contouring algorithm. Figures 19 -30 show all three zones, with 4% and 10% porosity with color highlights and in black and white.

CHAPTER 5

Results and Interpretation

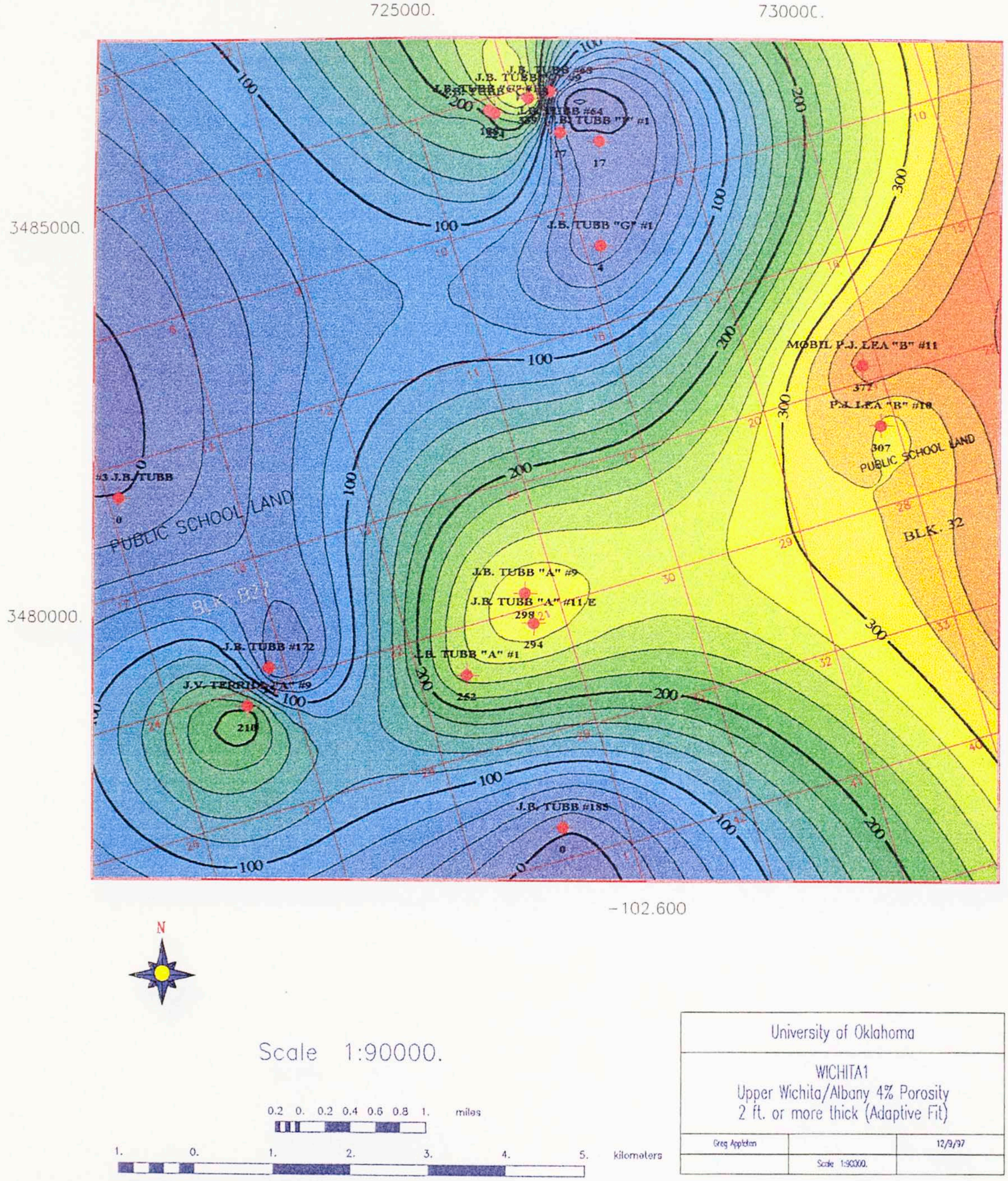

Figure 19: Contoured footage of 4% porosity in the upper zone

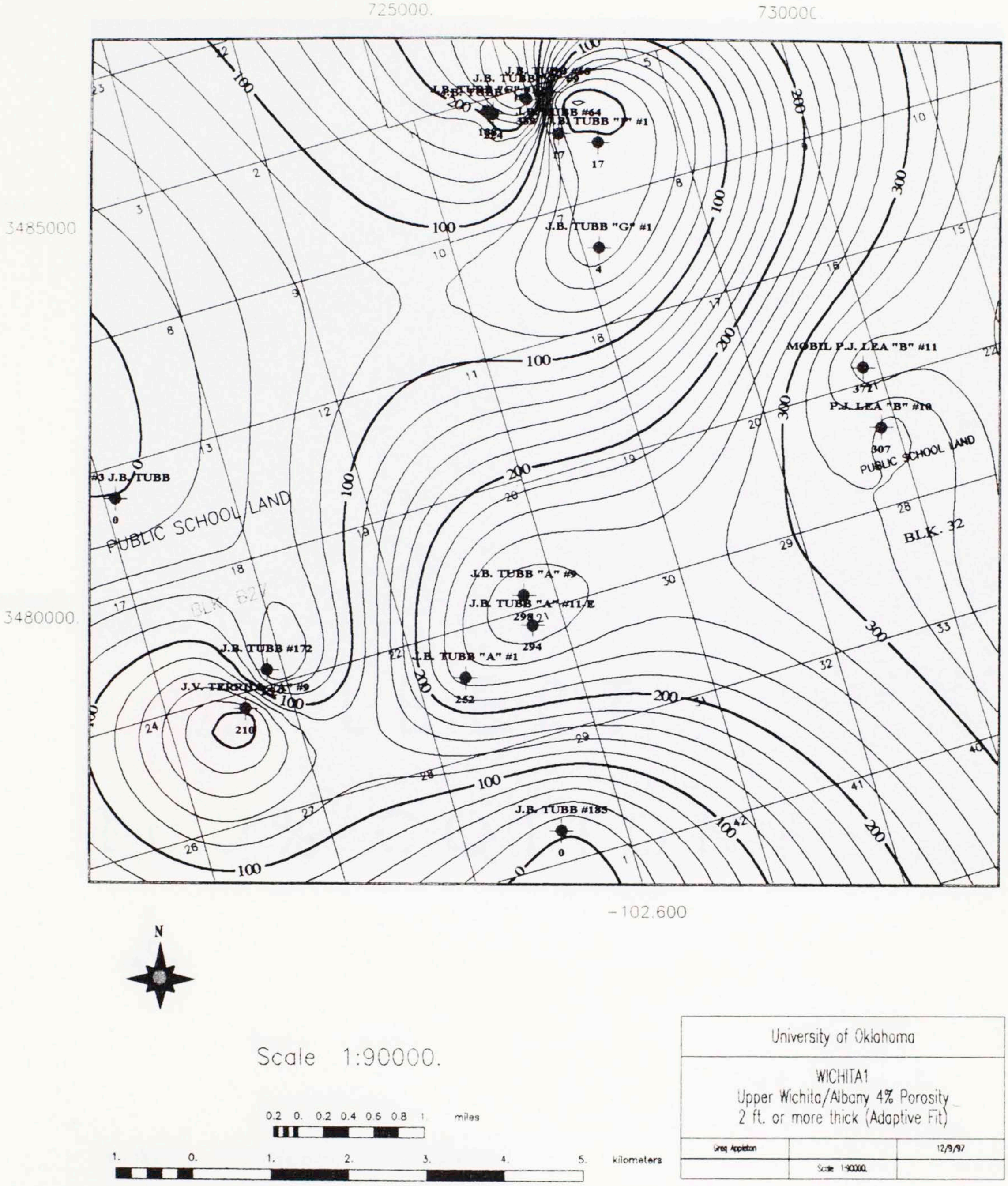

Figure 20: Contoured footage of 4% porosity in the upper zone

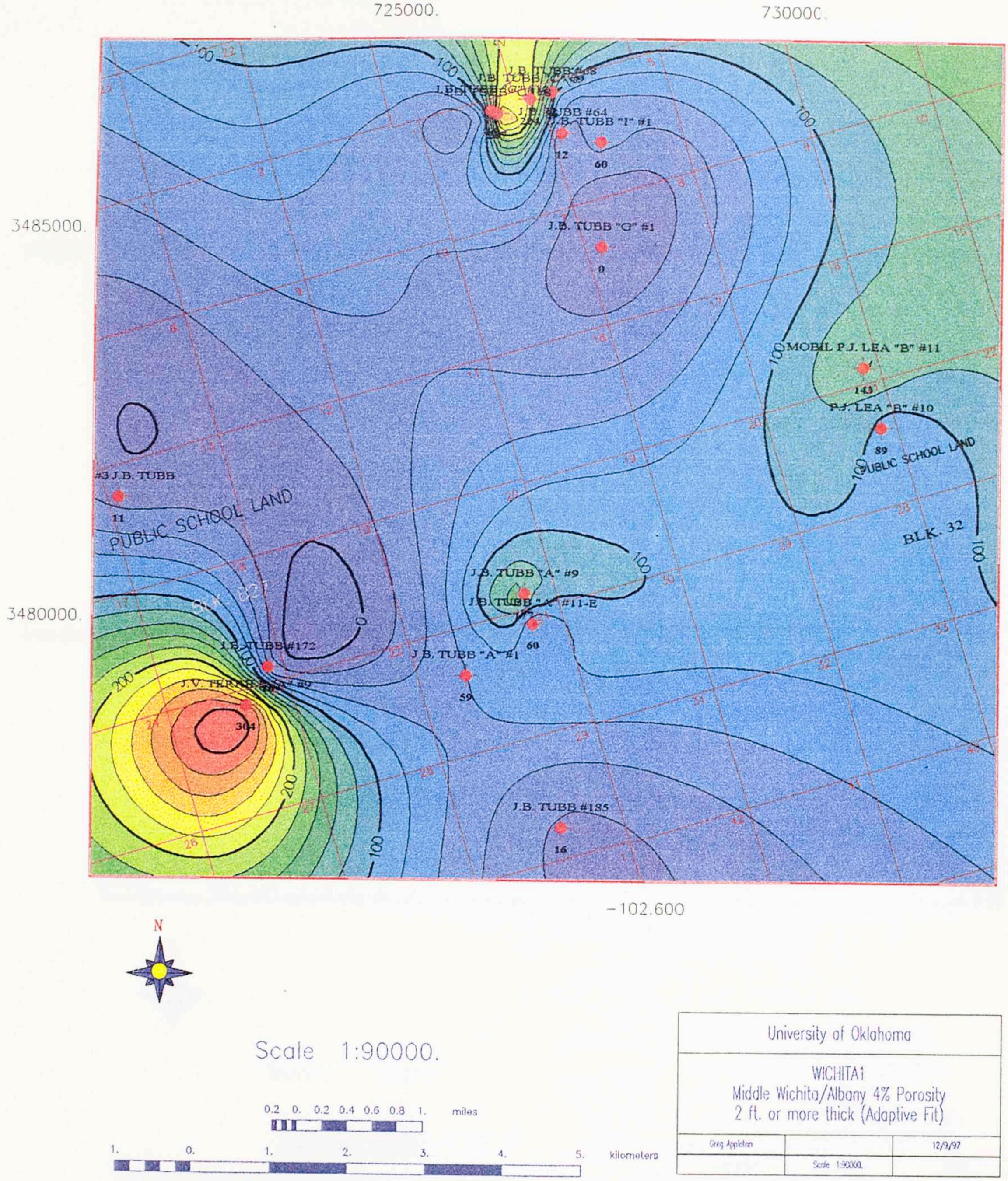

Figure 21: Contoured footage of 4% porosity in the middle zone

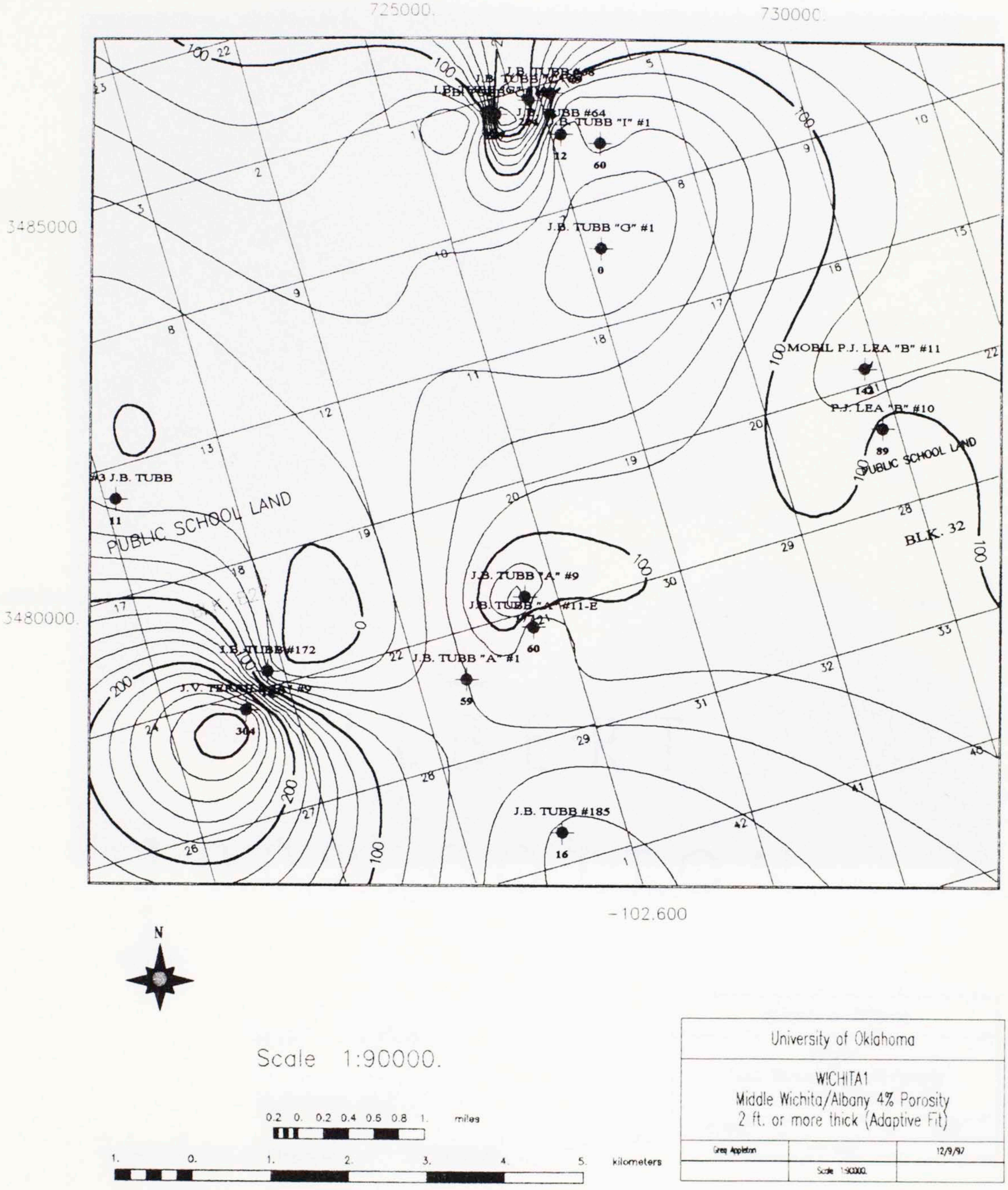

Figure 22: Contoured footage of 4% porosity in the middle zone

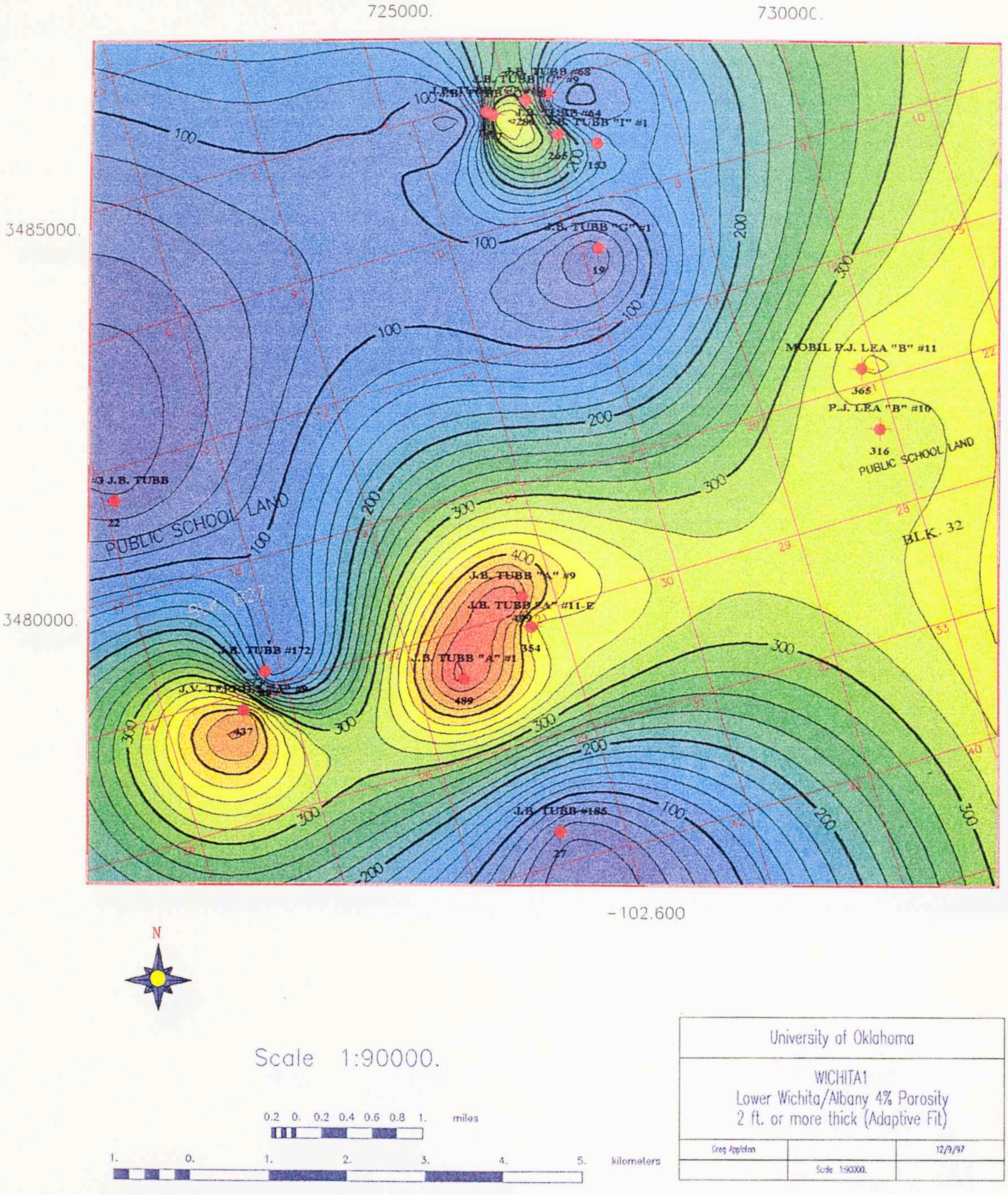

Figure 23: Contoured footage of 4% porosity in the lower zone

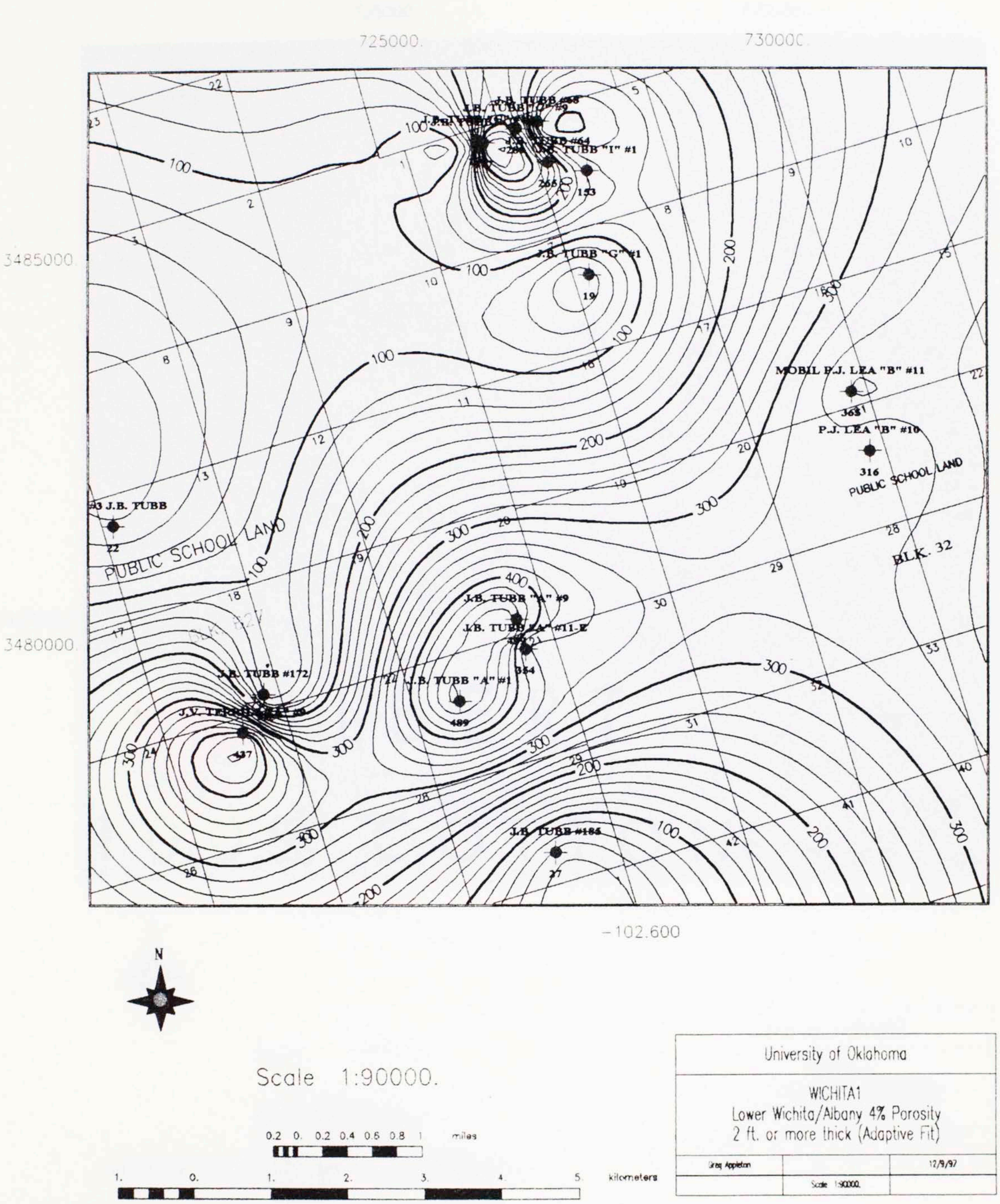

Figure 24: Contoured footage of 4% porosity in the lower zone

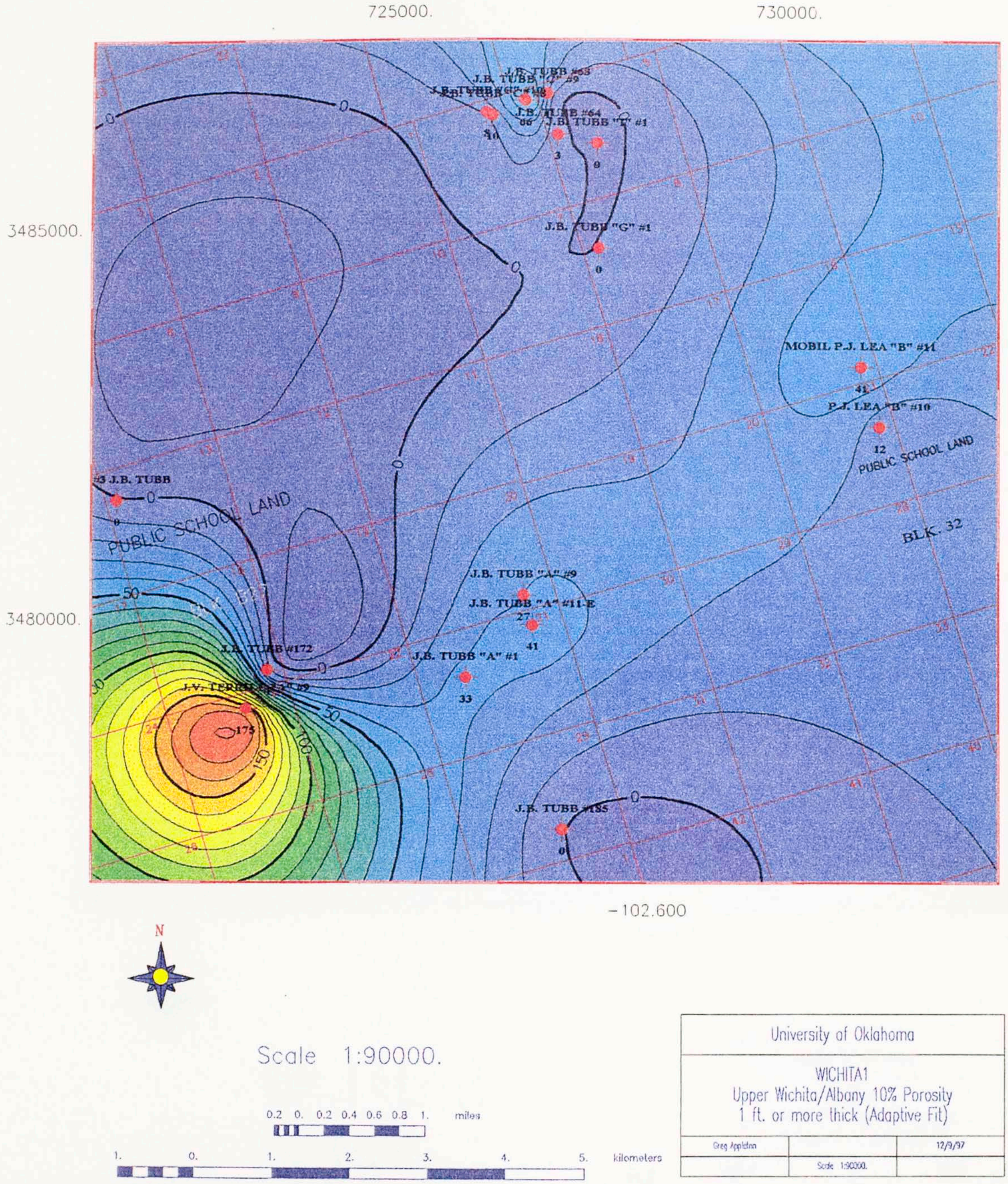

Figure 25: Contoured footage of 10% porosity in the upper zone

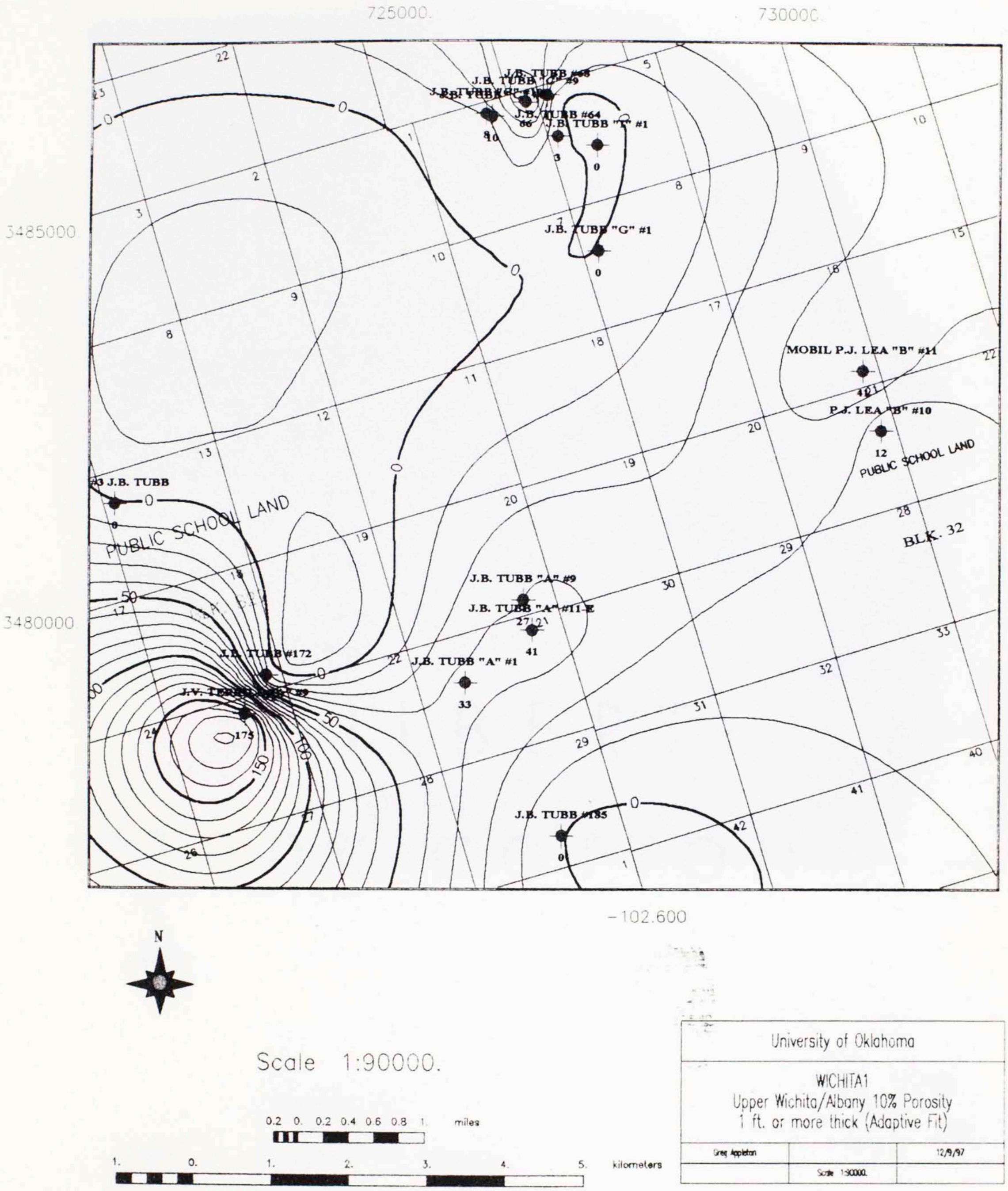

Figure 26: Contoured footage of 10% porosity in the upper zone

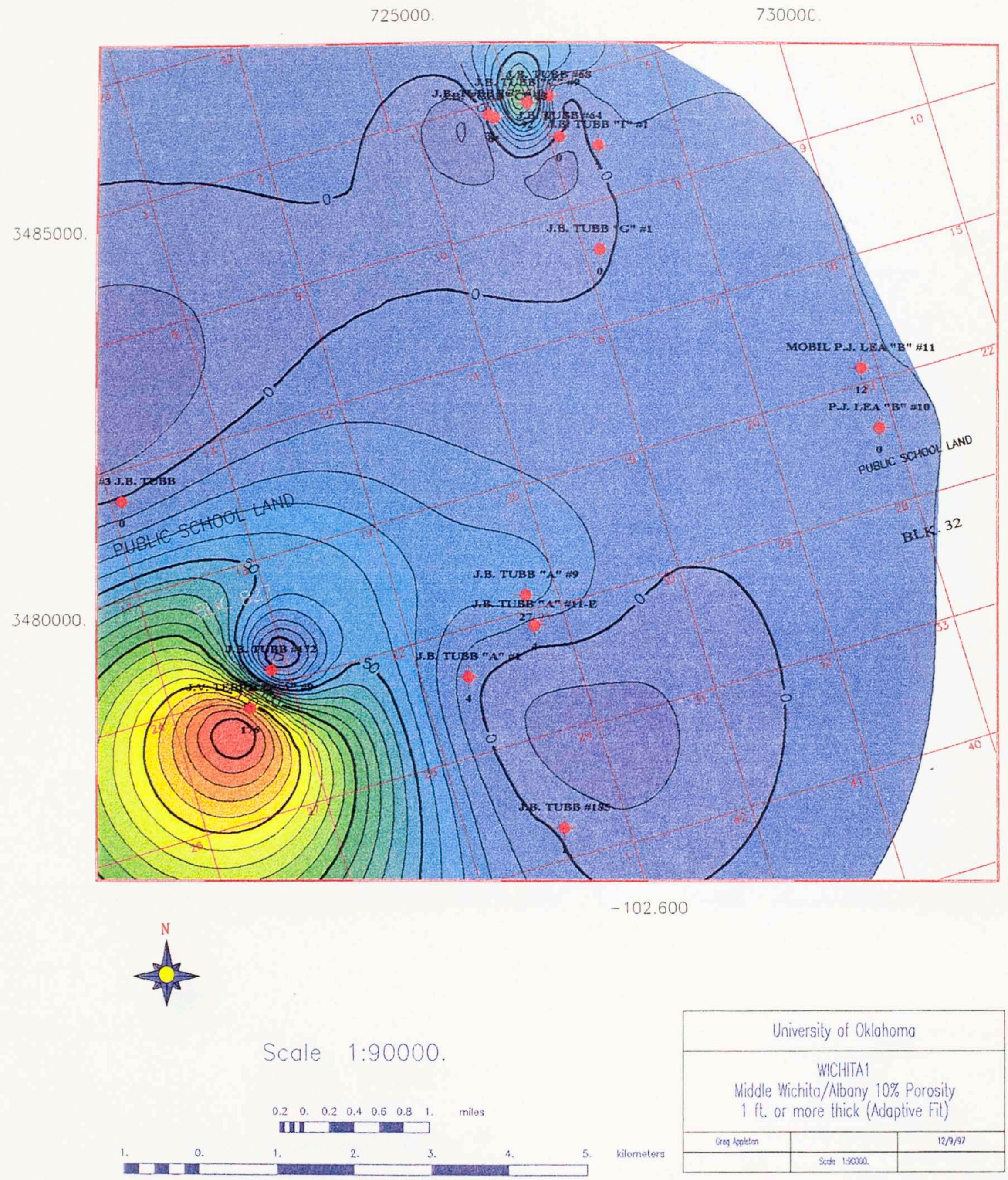

Figure 27: Contoured footage of 10% porosity in the middle zone

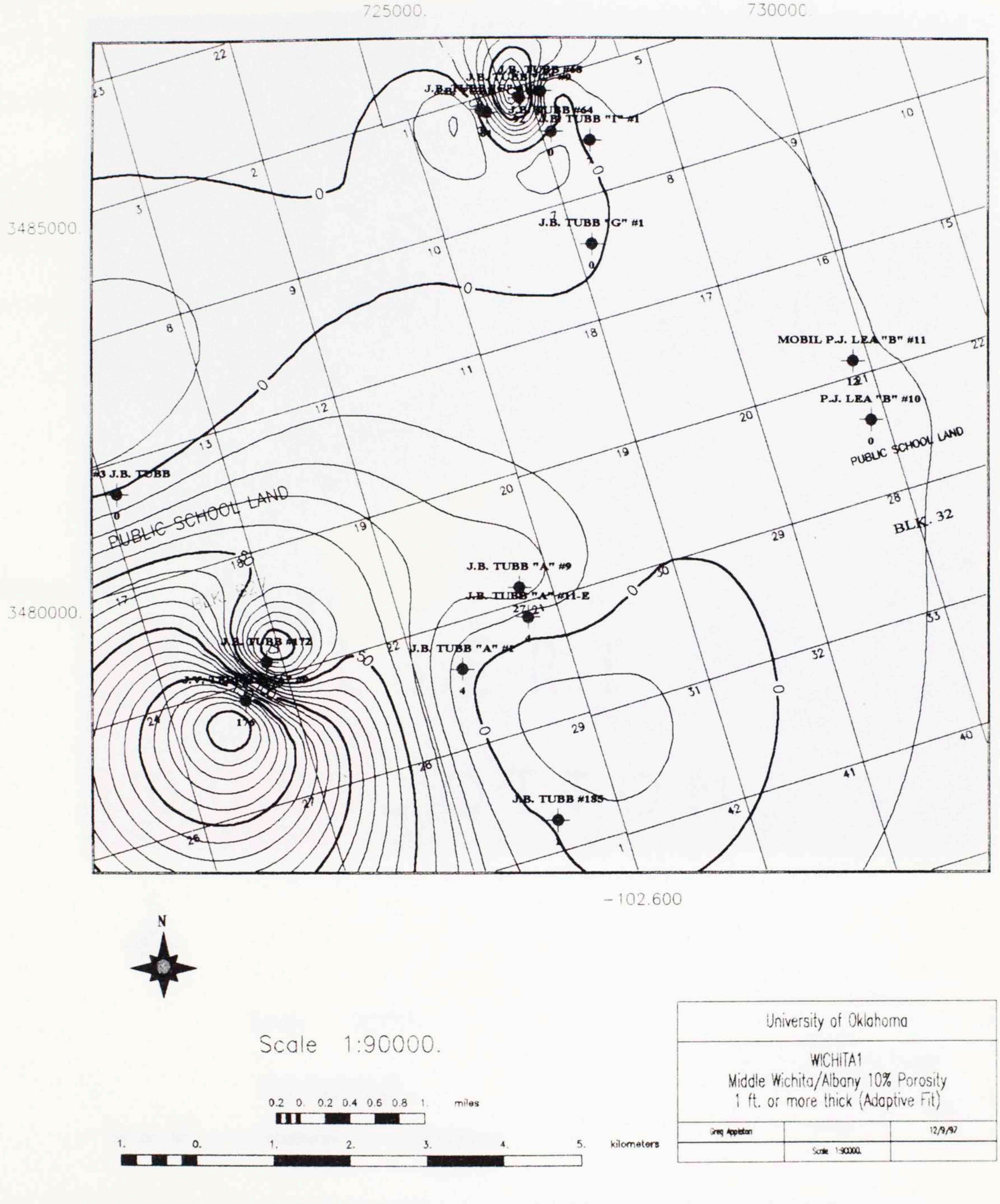

Figure 28: Contoured footage of 10% porosity in the middle zone

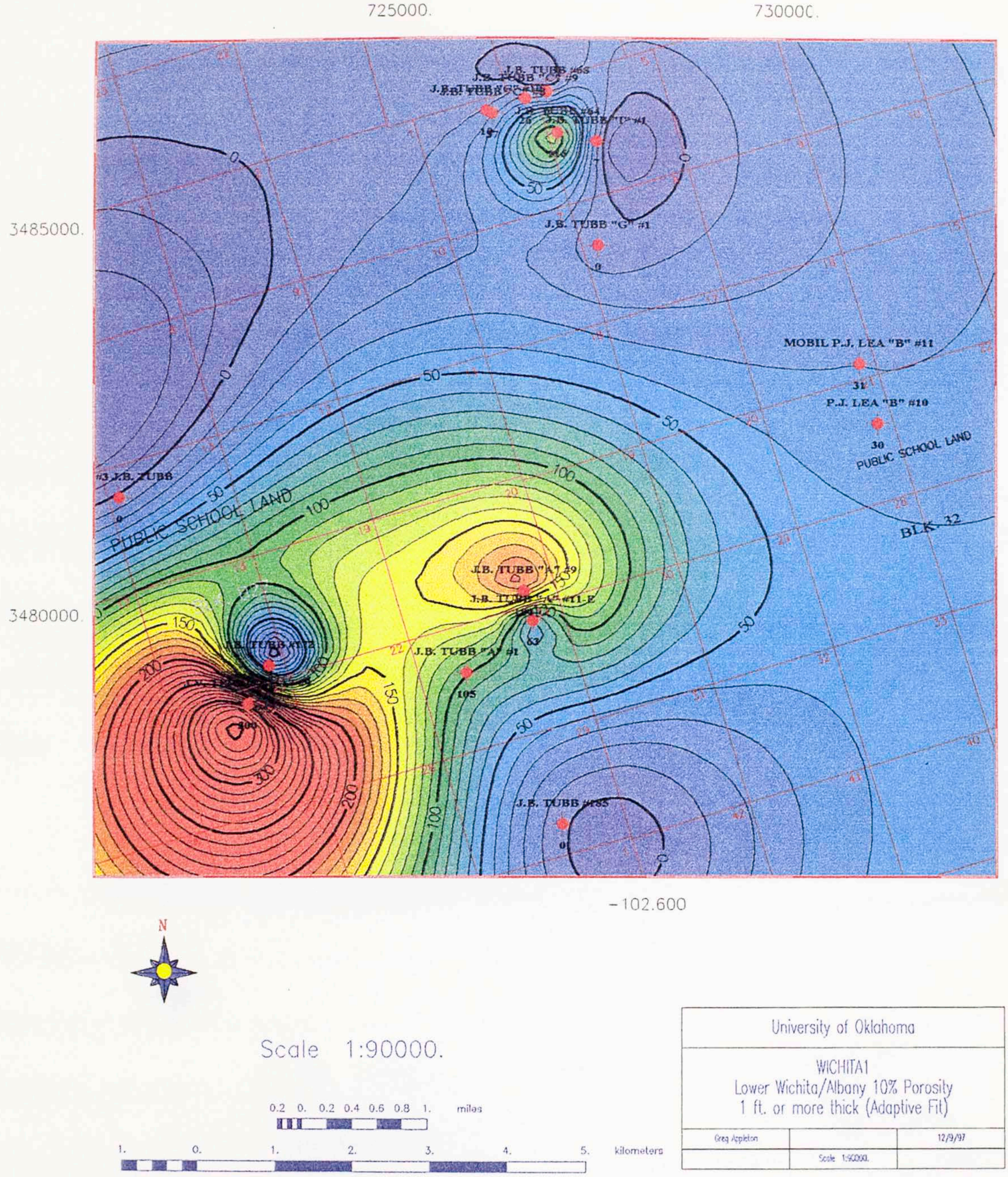

Figure 29: Contoured footage of 10% porosity in the lower zone

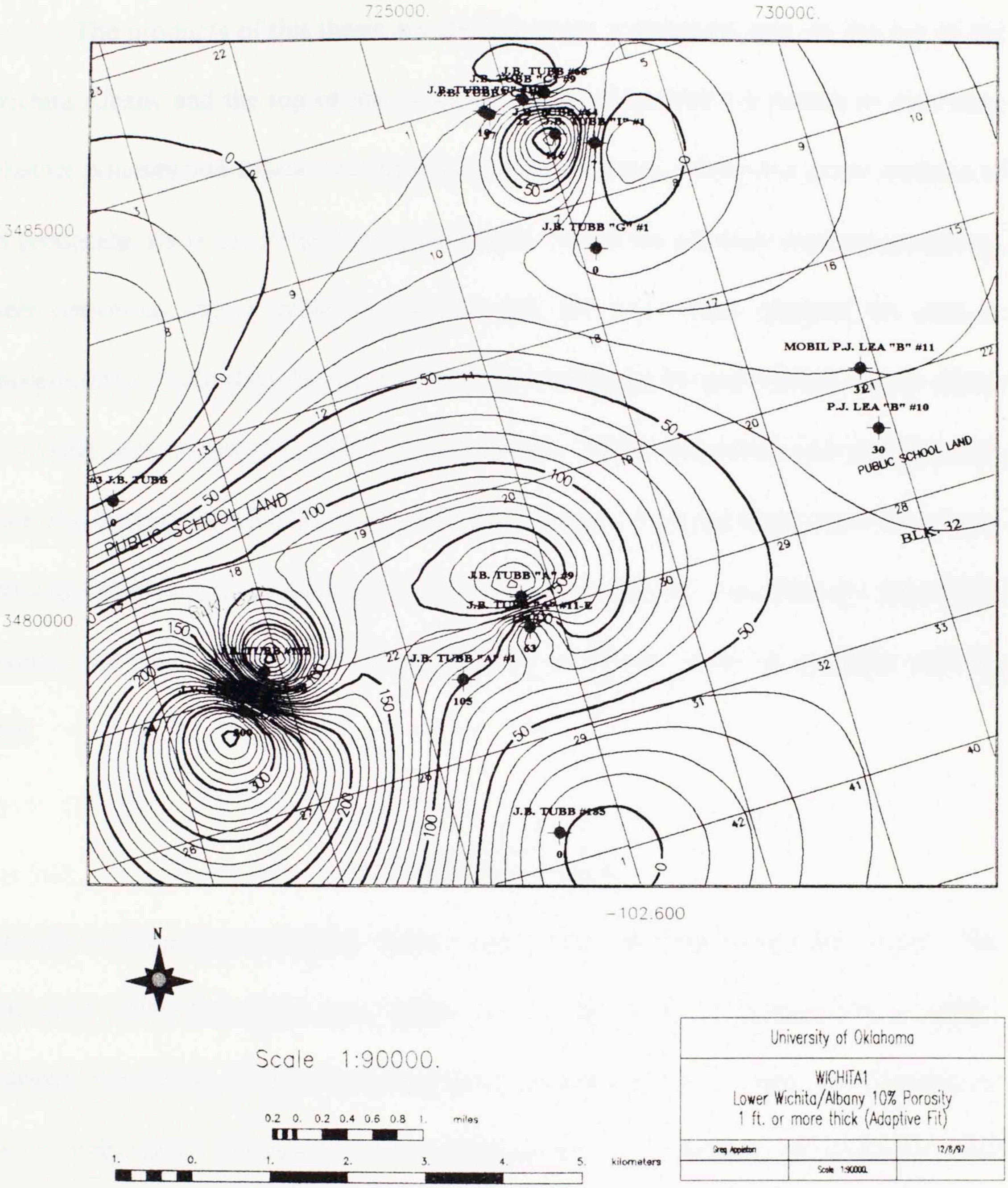

Figure 30: Contoured footage of 10% porosity in the lower zone

5.1. Products Generated

The products of this thesis are the following: a structure map on the top of the Wichita/Albany and the top of the overlying Lower Clearfork Formation to determine whether porosity will follow any regional structural trends. Fifty-five cross sections of all producing zones in the field were generated. All of the old-style neutron count logs were converted into a useable porosity scale and have been digitized for ease in interpretation. Lithology has been determined using the Pe and RHOB curves of the two wells with complete modern logging suites. Water saturation and oil saturation have also been calculated for the two modern suites. Porosity maps have been made showing thickness of porosity greater than 4% and greater than 10% for the upper, middle, and lower zones of the Sandhills Wichita/Albany, based on available well log data.

5.2. Porosity Trends

Porosity seems to occur in three distinct zones in the Wichita/Albany Formation. The first zone called the upper zone begins at the top of the formation and is usually between 400-600 ft. thick. This zone has never been drill stem tested or produced by Exxon in this field! When the first two Wichita/Albany producers were drilled in 1959 and 1960 the main goal of Humble Oil was to recover hydrocarbons in the form of oil only, usually the gas was just considered a by-product of the operation. Since it is believed that the upper zone contains mostly gas, that is probably why it was never tested or produced. Now that gas is desirable, this zone could provide a valuable resource. In most of the wells the porosity of the upper zone is not nearly as well developed as that in the middle and lower zones.

The middle zone of the Wichita/Albany encompasses about 300-400 ft. directly below the upper zone. This zone has good porosity development in all three of the past producers. Productive porosity values for this zone range between 4%-18%. Mostly gas and some oil are produced from this zone .

The lower zone usually contains the best developed porosity ranging from 4%-25%. This zone produces more oil than gas and has been perforated in all three of the past producing wells. All past producers have sustained production where porosity is present.

The porosity maps that were made show two levels of porosity, 4% and 10%. These porosity cutoffs were used based on the productive limits of the Exxon Sandhills Wichita/Albany. Exxon believes that a porosity cutoff of 4% can be productive in the Wichita/Albany dolomite. Arbitrarily, a 2 foot thick zone of 4% porosity was the lowest thickness to be added into the footage sum. The upper, middle, and lower zones of the Wichita/Albany were mapped separately.

The results show that in the upper zone with 4% porosity, there is an isolated high in the northern acreage where the 3 Exxon producers are located (Figure 31). Also, there is a zone of higher porosity that trends east-west running through the center of the field (Figure 19). The map of porosity greater than 4% for the middle

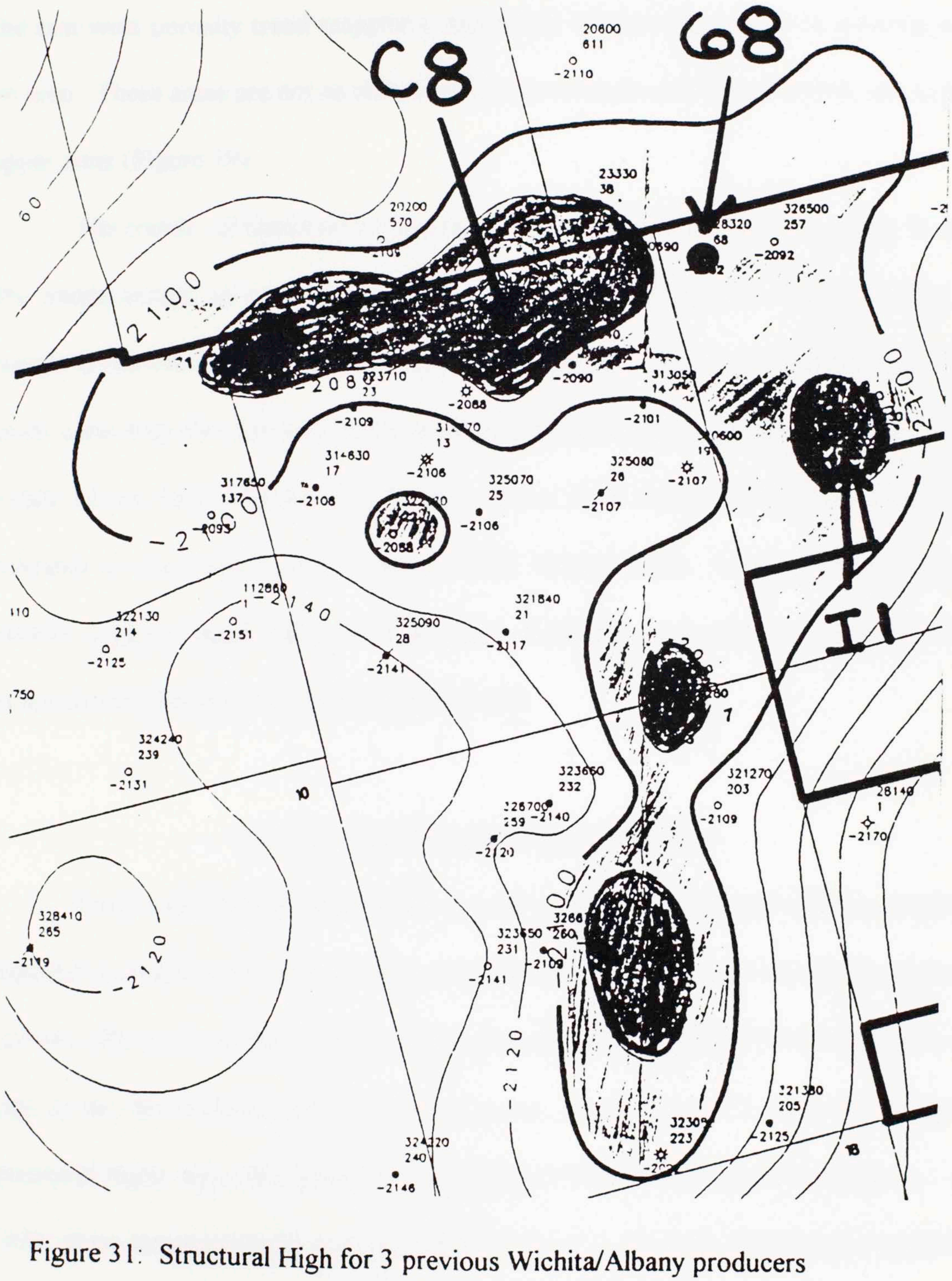

Figure 31: Structural High for 3 previous Wichita/Albany producers

zone also shows an area of thick porosity in the north. (Figure 23). In the lower zone, the east west porosity trend reappears, and larger isolated areas of thick porosity can be seen. These areas are not as clearly defined in the east-west trend as they are in the upper zone (Figure 19).

The trends of thickness of porosity greater than ten percent are similar to the 4% trends except an area of very high porosity footage greater than 10% that is present in the southwest corner of the field in the upper, middle, and lower zones. The lower zone map also shows an isolated area of thick porosity greater than 10% in the middle of the field. (Figures 27, 27,29). These thick areas may not be isolated as indicated by the maps based on sparse well control. More drilling and analysis of modern logging suites obtained from new wells are necessary to determine the locations and continuity of these possible trends.

5.3. Porosity Relationship to Structure

The present day Wichita/Albany structure map for the Sandhills Field shows no apparent correlation between present structural highs or lows and the distribution of porosity (Plate 1). In the Sandhills Field, porosity in the Wichita/Albany formation is high in the far northern and far southern parts of the field. In the northern part, structural highs were the basis for the original drilling which led to production. In 1958, these structural highs were recognized highs in the Tubb and Upper Clearfork, and it was assumed the Wichita/Albany structure would follow the same trend. The structure map on top of the Tubb is included as plate 3 to show structural highs in the north and south of the field. This follows the same trend as the Wichita/Albany formation. The productive limits of the Wichita/Albany were thought to be that part of the areas where the Top of the Wichita/Albany was higher than 2100 ft below sea level (Plate 1). Wells J.B. Tubb "C" #8 and #68, both produced the Wichita/Albany from the structure in the North. When well J.B. Tubb #185 was drilled in the southern acreage, it, too, was drilled on a high structure, where the top of the Wichita/Albany structure was above 2100 ft. In this instance, the Wichita/Albany reservoir zone showed no porosity development. Structure seems to have no relationship with the lenticular pods of porosity or water level.

It is possible that porosity follows a historical tectonic trend throughout the center of the field. In the past, this area may have been a higher energy environment, leading to increased dolomitization and increased porosity. The result of this could be that a porosity trend may occur southwest to northeast along the axis of the anticline. This can not be substantiated at this time due to lack of wells penetrating the Wichita/Albany zone. A porosity trend running from west to east occurs in the southern to middle part of the field (Figure 24). This trend follows no structural pattern, it crosses both highs and lows of the Top of the Wichita/Albany Formation. This trend includes mostly Ellenburger wells that have been drilled by companies other than Exxon. It cannot be verified at this time as to whether Wichita/Albany production has occurred in the wells along this trend. However, the porosity maps indicate, there is potential for such production.

It should be pointed out that the vast areas of zero porosity shown on the porosity footage maps are almost certainly wrong. From an exploration point of view, these areas are undervalued. Analysis of variance would show that three widely spaced wells cause the machine contouring to treat broad areas as low porosity, even though all closely spaced data show very rapid change in porosities. This trend must be expected throughout the unexplored portion of the field!

5.4. Production from Dolomite

Analysis of the two modern logging suites from wells J.B. Tubb "I" #1 and J.B. Tubb #64 show that porosity and production are from dolomite and not the limestone present in the Wichita/Albany formation. The limestone and anhydrite zones of the formation showed little to no porosity. The crossplots seen as figures 32 and 33. also substantiate the lithology and porosity calculations for J.B. Tubbb "I" #1 and J.B. Tubb #64. The first crossplot was generated from the neutron porosity and the bulk density logs of well "I" #1 and the second was generated from the neutron porosity and the density porosity of well # 64. These two crossplots show that the lithology is mostly dolomite with porosities ranging from 0 to about 20%. Well J.B. Tubb "I" #1 has more dolomite than well J.B. Tubb #64 whereas well #64 has more limestone than "I" #1.

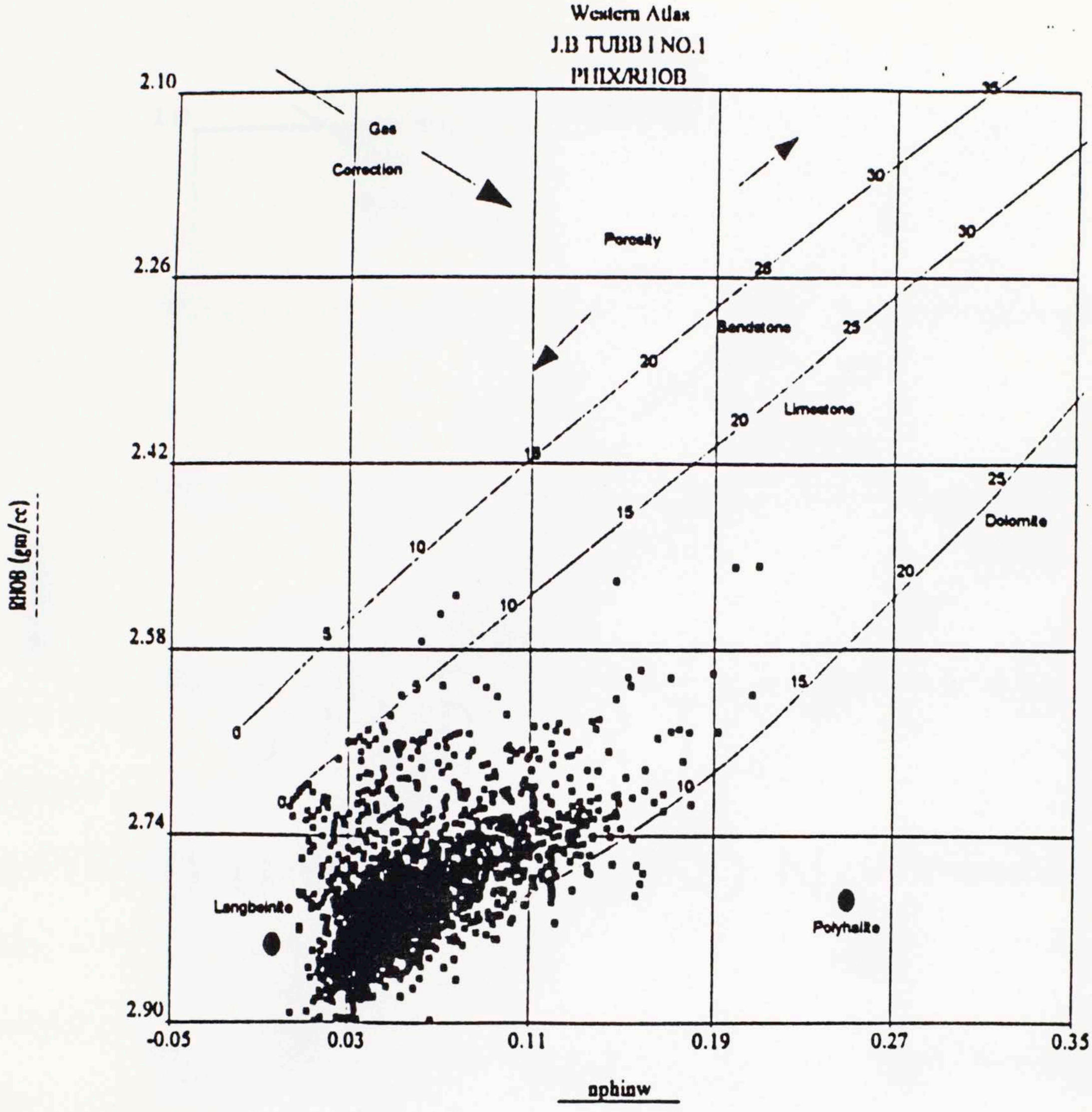

Figure 32: Crossplot of Neutron Porosity vs. Bulk Density for well J.B. Tubb "I" #1 to determine lithology

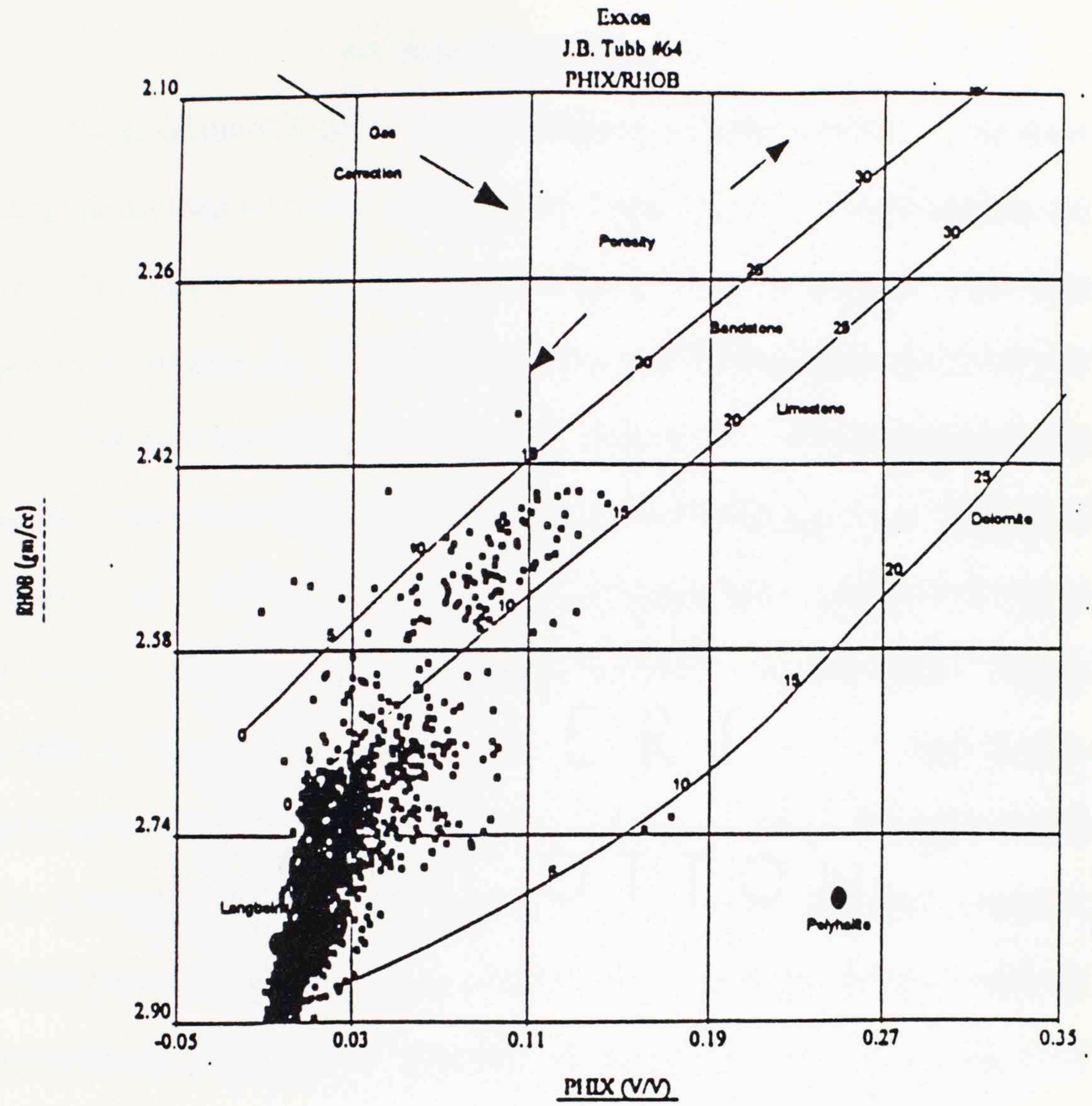

Figure 33: Crossplot of Neutron Porosity vs. Bulk Density for well J.B. Tubb #64 to determine lithology

5.5. Radioactive Dolomites

The dolomites throughout the field are highly enriched in uranium. This makes porosity determination difficult, as thin zones of high porosity could be mistaken for shales. The Spectral Gamma-Ray tool is important for distinguishing shales from radioactive dolomite as shown in chapter 2. The only Wichita/Albany well in the field with a Spectral Gamma-Ray Log is the J.B. Tubb "I" #1. Distinguishing between shales and dolomite on other logs is difficult. One possibility is to try to correlate all other logs to well "I" #1 for determination of the shale zones. Based on the sparse well control, it is not possible to determine the continuity of the thin shales. Another possibility is to ignore the shales in the existing wells with very high porosity characteristics. This may be possible based on information from past producers that shales in the Wichita/Albany zone are few and usually not more than 6 inches in thickness (Exxon Proprietary). It may also be possible that shale content is higher in other unexplored areas of the Sandhills Wichita/Albany and would have to be accounted for.

5.6. Controls on Porosity

The Wichita/Albany porosity varies greatly throughout the field. Porosity seems to be related to the degree of dolomitization occurring within the limestone interval. With higher degrees of dolomitization, there is higher porosity. Where dolomitization is not as well developed, there tends to be more limestone and less porosity. Wells J.B. Tubb "I" #1 and #64 both have lithology and porosity calculated by QLAII. Porosity and lithology were plotted on the same track in QLAII. Where porosity is developed in either of these two wells, the corresponding lithology is primarily dolomite.

The porosity may also be controlled by specific depositional environment related to water depth trends on the platform. Since the exact lithology is not known for the Wichita/Albany on the Central Basin Platform, the exact depostional environment can not be interpreted. Future core data could be helpful to relatively determine depositional environments and possibly map porosity based on paleo-depositional trends.

5.7. Controls on Production

Production in the Wichita/Albany is controlled by the porosity of the formation. If there is porosity, production will be likely. Reservoir pressures in all producing wells were original. These wells (J.B. Tubb #68, "C" #8, and "I" #1) are no more than 80 acres apart from one another. The reservoirs produced are small, lenticular and are probably discontinuous pods of porosity. Because the entire reservoir is solution gas drive, water production does not pose a problem as it does in the Ellenburger. Production can take place with porosity as low as 4%. The engineers must decide how thick an interval of 4% and greater porosity or 10% and greater are required to make an economical well.

CHAPTER 6

Conclusions and Recommendations

CONCLUSIONS and RECOMMENDATIONS

The porosity in the Sandhills, Wichita/Albany occurs primarily in the dolomitized zones of the reservoir, the limestones present are tight. The porosity does not correlate to present day structure. Though the Wichita/Albany produces from an isolated high in the north, the structure of the same height is tight in the south. Porosity may follow a trend based on older tectonics that influenced water depth during deposition that caused coarser grained limestone to have been deposited in shallower water. This could have led to more intense dolomitization creating more porosity. Mapping of 4% and greater, and 10% and greater porosity indicated a trend of thick intervals of high porosity existing from east-west across the field with the thickest porosity occurring in the southwest corner of the field. A north-south trend was not recognized due to sparse well data but may also exist along the axis of the Sandhills anticline structure.

3D seismic is currently being acquired in this field, but the results of this survey will not be available until well into next year. Using this seismic data, it may be possible to observe wavelet characteristics in known zones of porosity and compare these characteristics to parts of the field that have no data. This may give clues to porosity distribution in interwell areas of the field. It may be possible to locate hydrocarbons with the 3D seismic also depending on their thickness. More drillwells and modern logging suites are necessary to exploit this untapped resource. The most important data to project porosity trends could come from detailed petralogical and palentological interpretation of whole core or high speed rotary sidewall cores. Percussion cores are not advised, because they have atendency to destroy the core information by compaction. These cores will be used to determine the exact mineralogy and depositional environment of the porous zones in the Wichita/Albany. Cores from the non porous zones would also be useful to evaluate the depositional controls on non-productive versus the productive portion of the formation.

This project is far from complete, and the accurate prediction of porosity may never be understood. Based on the past production of the three wells in the Wichita/Albany, it seems this reservoir will be worth investigating and exploiting to its full potential. More research is needed to pinpoint the exact depositional nature and trends of the porosity before future exploitation takes place.

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