Fall 2012

3-D Seismic Interpretation, Seismic Attribute Analysis, And Well Log Interpretation Of An Area Between Ellis And Rooks Counties, Kansas

Vilma I. Perez de Pottella
Fort Hays State University, perezvilmai@yahoo.com

3-D SEISMIC INTERPRETATION, SEISMIC ATTRIBUTE ANALYSIS, AND WELL LOG INTERPRETATION OF AN AREA BETWEEN ELLIS AND ROOKS COUNTIES, KANSAS

being

A Thesis Presented to the Graduate Faculty
of the Fort Hays State University in
Partial Fulfillment of the Requirements for
the Degree of Master of Science

by

Vilma I. Perez de Pottella
B.S., M.S., Fort Hays State University

Date ____________________ Approved ________________________________
Major Professor

Approved ________________________________
Chair, Graduate Council

Graduate Committee Approval

The Graduate Committee of Vilma I. Perez de Pottella approves this thesis as meeting partial fulfillment of the requirements for the Degree of Master of Science.

Approved ________________________________

Chairman, Graduate Committee

Approved ________________________________

Committee Member

Approved ________________________________

Committee Member

Approved ________________________________

Committee Member

Date____

ABSTRACT

The researched area covers the extent of the Keller 3D seismic survey [2 mi^2 (5.2 km^2)] and is located approximately 12 miles northeast of the city of Hays, Kansas and NW of Ellis and SW of Rooks counties, Kansas. Eight producing oil wells along with one dry hole are located within the research area. This study is focused on the Cambrian-Ordovician Arbuckle Group which is the principal oil bearing reservoir within the research area and in the region.

Interpretation of the Keller 3-D seismic data, well-log correlation and a study and description of the drilling samples suggest that the Arbuckle facies vary within short distances in the research area. Such facies variations create challenges to spot and drill productive intervals within the Arbuckle. The presence or absence of the Arbuckle "reservoir" facies depends on combined factors such as shape of the Precambrian paleotopography, the dolomitization process, the deposition and post-differential erosion processes, and the formation and distribution of paleokarsts and fractures within the unit. Oil accumulations in the Arbuckle Group within the research area seems to be associated to the occurrence of the Arbuckle reservoir (dolomites) with high permeability and porosity (karsts, micro-fractures or microcrystalline) combined with paleo-structures (paleo-highs).

3-D seismic interpretation and seismic attribute analysis of the thickness and attribute maps of the Arbuckle Group suggest that the non-productive well #4 was drilled on the flank (down-deep) of a paleo-high where karst features, fractures or porous dolomites were absent. Analysis suggests that Petroleum System elements such as charge, trap and seal except reservoir have a low risk in the study area. 3-D seismic

attribute analysis and a detailed reservoir characterization seem to be the clue to delineate and spot successful future drilling sites.

ACKNOWLEDGMENTS

Foremost, I would like to thank my thesis advisor Dr. Kenneth Neuhauser for giving me the reassurance and guidance I needed to complete this effort. I will always be thankful for his constant support throughout the completion of my graduate studies. In addition, I want to express my gratitude to my dear professors Dr. Richard Lisichenko and Dr. Tom Schafer. Their valuable teachings and kind assistance as honorable members of my graduate committee made the preparation and editing of this manuscript possible.

Moreover, I greatly thank my dear friends Don Bowman and Mike Davignon for their generous support. I'm greatly thankful to them for providing the main data for this study and for sharing their oil-field experiences and wide knowledge of the local petroleum geology with me. Furthermore, I thank them for becoming the honorable external members of my thesis committee. I would also like to acknowledge Butch Drylie, from Log-Tech, for generously sharing his time and knowledge with me during my petrophysical internship at Log-Tech. Thanks to my dear friend: Ms. Kathy Fisher for her support, friendship, and permanent encouragement.

Last, but not least, I thank my husband Jose Pottellá and daughter Ana Sofía Pottellá Perez for their unconditional love and support, which became a driving force while completing this work.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF APPENDIXES

Appendix Page

INTRODUCTION

To identify prospects and make drilling decisions, oil-operator companies around the world have used 3-D seismic since the early 1980's. 3-D seismic is a geophysical method used to interpret subsurface geology and is a valuable tool in allocating potential drilling targets. For example, it works well with small structural highs and narrow channels, which are difficult to identify with well-control alone or by interpreting with the traditional 2-D seismic data (Nissen et al., 2004). 3-D seismic is effective in improving re-exploration and development of mature oil-producing areas such as brown fields. It can also address issues related to reservoir quality and oil production, as well as source-rock description and characterization.

The principal data of this study is a Keller 3-D seismic survey recorded and first interpreted by Dawson Geophysical and Blake Exploration Companies in 2004. One of the results of this interpretation was a seismic amplitude map that

, along with other documents, guided the selection of a new oil well location. The new location was close to existent oil-producer wells, and over a high-amplitude seismic anomaly. However, when the planned oil well was drilled on the selected location it resulted in a dry and plugged nonproductive well (Energy files, Kansas Geological Survey (KGS).

OBJECTIVE

The main objectives of this research are to: 1) interpret the Keller "seismic cube", a 3-D seismic survey, acquired in 2003, covering an area of approximately 2 mi^2 (5.2 km^2);

2) carry out a seismic attribute (amplitude) analysis; 3) interpret wire-logs of selected oil wells; 4) tie the gamma-ray (GR) logs to 3-D seismic; and 5) use cross-correlated analysis data to explain why, in the middle of existing oil-producing wells, a newly drilled well turned out to be a non-producing well.

Secondary objectives are to: 1) understand and describe the processes and elements of the Arbuckle Petroleum System, such as source rock, reservoir, seal, and trap; 2) map the extent and thickness of the Arbuckle Group within the research area; 3) characterize the oil-productive reservoirs and oil-fields located within the research area; and 4) understand the efficiency of oil-trapping mechanisms, such as vertical seal, in oil fields within the research area that have the Arbuckle Group as the Dawson Geophysical Company main reservoir.

The ultimate goal of my study was to understand the root-cause of a dry-hole drilled on a site that was characterized by a high-amplitude seismic anomaly, surrounded by petroleum fields. The area of analysis centered on the Arbuckle Group reservoir, the most proliferous oil-bearing reservoirs in the Central Kansas Uplift region as well as in the research area. Specifically, this study includes an interpretation of the Keller 3-D seismic data using Seismic Micro Technology (SMT) Kingdom Suite software (version 8.2, 2011). It also includes an interpretation and correlation of well logs of the nine oil wells that penetrate the Arbuckle Group within the research area using Paradigm Geolog Formation Evaluation software. In addition, a description of the Arbuckle Group samples collected at the drilling sites outside and near the research area was included. An understanding of the Arbuckle Group facies and a review of previous works to comprehend the Arbuckle oil production and elements of the Arbuckle Petroleum System were conducted.

LOCATION

The area used for research in this study is located in central Kansas, restricted to the extent of the Keller 3-D seismic survey recorded within an oil-producing zone at 12 miles (19.3 km) NW of the city of Hays, Kansas and NW Ellis and SW Rooks Counties, Kansas (fig.1). It is surrounded by several oil fields formal names of which are Marcotte, Marcotte West, Berland East, Berland Southeast, Trico, Eagle Creek, Eagle Creek East, Warren, West Harris, Mendoza and Mendoza East oil fields where the Cambrian-Ordovician Arbuckle Group is the main oil-bearing reservoir. This surveyed area includes nine oil wells with eight oil-producers and a single dry hole.

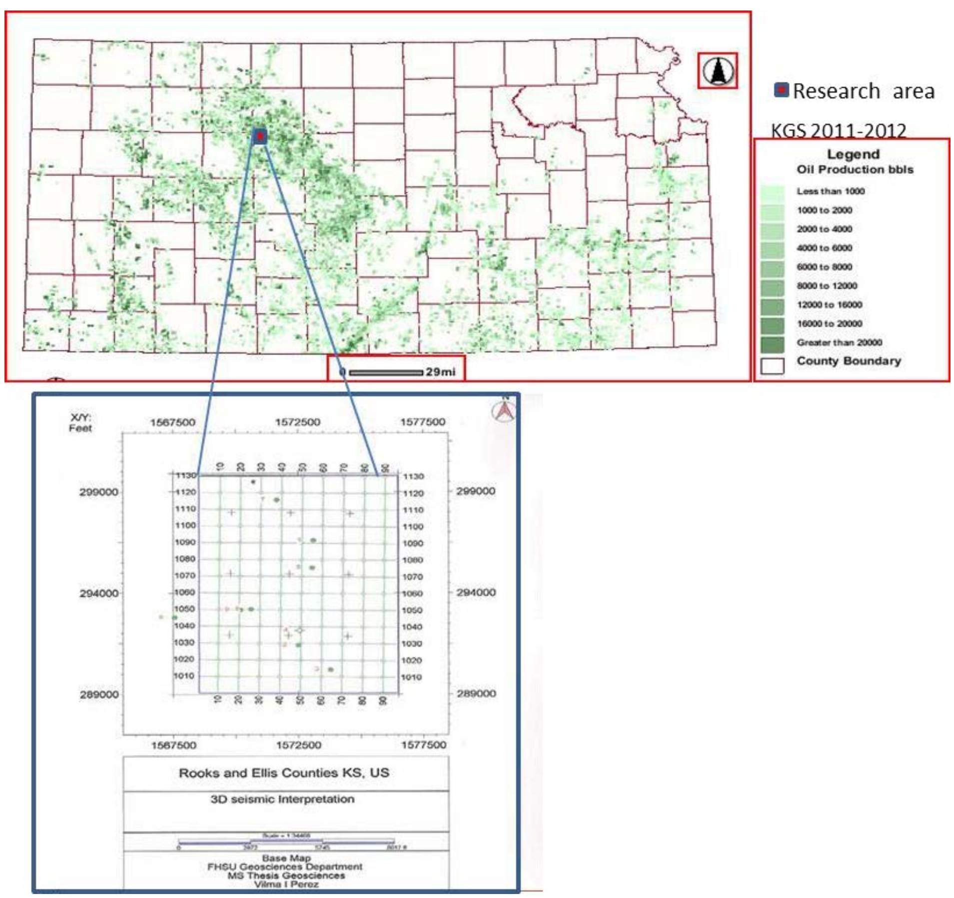


Figure 1: Index map and extent of the research area. (Obtained from http://hercules.kgs.ku.edu/kgs/oilgas/production/imageviewertest.cfm and modified)

DATA

The data collected and utilized to achieve the study objectives are:

1) Keller 3-D seismic survey (Blake Exploration Inc.).

2) Digital well logging data (Blake Exploration and Log ACII Standard (LAS) files (www.kgs.ku.edu)).

3) Well files containing depths to stratigraphic tops (www.kgs.ku.edu).

4) Rock samples of the Arbuckle Group (Field trips to well drilling sites).

5) Descriptions of cores taken in oil wells (www.kgs.ku.edu).

6) Oil production data and public records (KGS public library)

7) The Arbuckle Group core descriptions (Schlumberger oilfield glossary).

8) Interviews of and information provided by various personnel (Active oil operators, loggers, and drillers).

9) Relevant published reasearch.

METHODOLOGY

The Keller 3-D seismic survey, provided by the Blake Exploration Company, was loaded in Seismic Micro Technology (SMT) Kingdom Suite software (version 8.2, 2011) and interpreted with the 2d/3dPAK module.

Stratigraphic tops and digital well log data, Log ASCII Standard (LAS), from nine oil wells drilled located within the research area were downloaded from KGS Oil and Gas digital library, loaded, interpreted and correlated in the EarthPAK module of Kingdom Suite. A sonic log recorded in well number five was loaded and modeled in SynPAK module of Kigdom Suite (SynPAK module) and used to generate a synthetic seismogram that supported the geological calibration of the Keller 3-D seismic, facilitated seismic time / depth conversions and was the based to complete a geologic calibrated 3-D interpretation of 3-D Keller seismic. Figure 2 is an example of an analysis of a seismic profile generated in the Kingdom tool.

Paradigm Geolog Formation Evaluation software (version 6.7), a specialized petrophysical tool, was used to load, and create detailed interpretation of the digital well logs recorded in the wells drilled within the research area. Digital well logs files, Log ASCII Standard (LAS), obtained from the KGS database were loaded, interpreted and correlated in EarthPAK (Kingdom Suite module). Interpreted logs generated within Kingdom Suite were used to tie seismic to geology and validate Kelly 3-D seismic interpretation.

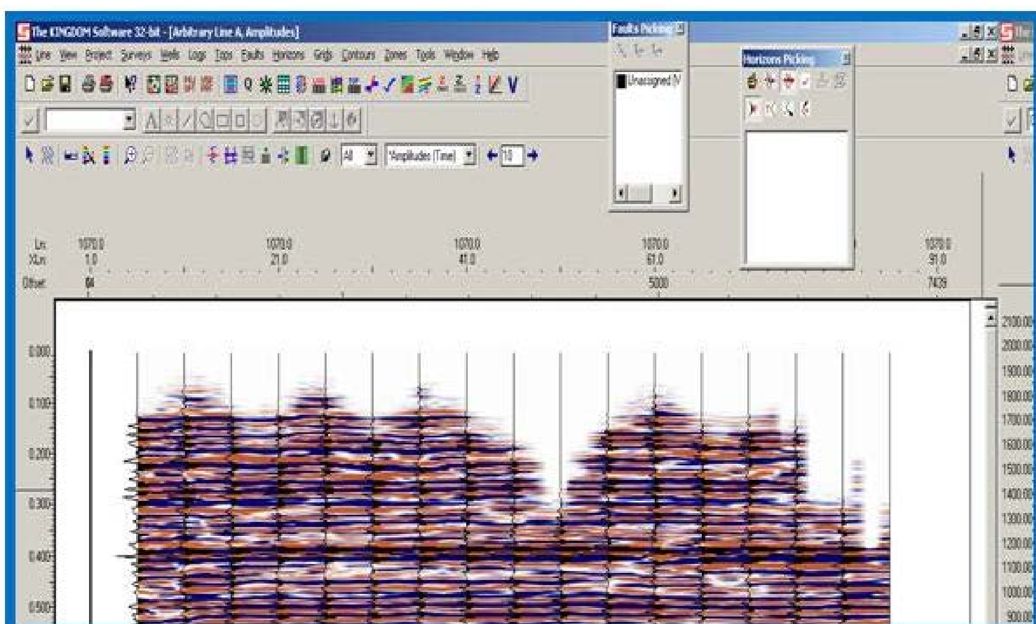


Figure 2: Example of an analysis of seismic profiles generated using Seismic Micro Technology (SMT) Kingdom Suite Software (version 8.2)

I. PUBLISHED RESEARCH

3-D seismic interpretations completed in this region of Kansas indicate that it provides a great deal of local success in the search for hydrocarbons (Nissen et al., 2004). A recent work interpreted a 3-D seismic survey recorded near the Catherine oil field in Ellis County, Kansas (Dreiling, 2005). This study summarized that the basement faults act as conduits for vertical fluid movements, thereby enhancing Arbuckle karstification and resulting in collapse and sagging of the overlying Lansing-Kansas City groups.

Multiple interpretations for 3-D seismic surveys of the Central Kansas Uplift region have been published in the recent past: Nissen et al., 2004, 2007, 2008, and Nissen and Sullivan, 2005. After completing a 3-D seismic interpretation in Rooks County, Kansas, near the research area of this study, Nissen reached a main conclusion: by using combined analysis of special seismic attributes, such as maximum negative, positive curvature, and acoustic impedance volumes, it is possible to 1) locate subsurface elements, including cockpit landscapes (karst features) in the Arbuckle Group; 2) elucidate lineaments related to joints and fractures; 3) better describe the distribution of reservoir porosity; and 4) define reservoir boundaries more precisely (Nissen et.al, 2007).

3-D seismic allows one to model and visualize the subsurface and, in this region, to identify paleotopography relief associated with karst development, and target sweet spots for hydrocarbons. Oil fields such as El Dorado field (Fath. 1921) that produce from the Arbuckle paleokarstic facies are very proliferous. 3-D seismic calibrated with subsurface geology can assist petroleum searchers in locating new and significant oil pools.

Commercial success rate of wells drilled from 3-D seismic data is relatively high (70%). The same statistical analysis points out that the success rate of wildcat wells drilled in Kansas over the last 3 years is around 30%. Figure 3 summarizes the data regarding successful oil wells drilled in Kansas after interpreting the subsurface with 3-D seismic surveys (Nissen et al., 2004).

Company	Well	Location	County	Producing interval	Product	Source
Pelican Hill Oil & Gas	#1-35 Young	35-T17S-R24W	Ness	Marmaton/Fort Scott	oil	Kansas Geological Society Bulletin
						September-October 2002, p. 36
Murfin Drilling Company	#4-25 Rusco-Davis	25-T11S-R20W	Ellis	Arbuckle	oil	Kansas Geological Society Bulletin
						November-December 2002, p. 33.
Imperial American Oil Corp.	#30-1 Evelyn	30-T12S-R16W	Ellis	Lansing-Kansas City	oil	Kansas Geological Society Bulletin
	#30-1 Verna Unit					May-June 2003, p. 33.
Murfin Drilling Company	#1-5 Keller (Bowman)	5-T11S-R19W	Ellis	Lansing-Kansas City	oil	RedTop Monthly News Service v.19, issue 4
						10-Apr-03
Vess Oil Corporation	Denton 'A' #1	1-T32S-R24W	Clark	Arbuckle	oil	RedTop Monthly News Service v.19, issue 11
						10-Nov-03

Figure 3: Oil discoveries in Kansas attributed to 3-D Seismic data (modified from Nissen et al., 2004).

II. GEOLOGIC SETTING

Stratigraphy of the research area

The stratigraphic record of Kansas indicates that units extend from the Precambrian to the Quaternary. Stratigraphic units older than the Mississippian are recognized only in the subsurface. Figure 4 lists a generalized stratigraphy of the subsurface geology of Kansas. It also highlights stratigraphic units characterized as potential hydrocarbon reservoir barriers, which include the Niobrara Formation (Cretaceous), the Chase Group (Permian), the Shawnee and Douglas groups (Upper Pennsylvanian), the Lansing-Kansas City groups (Lower Pennsylvanian), the Simpson Group (Ordovician), and the Cambrian-Ordovician Arbuckle Group (Moore et al., 1952).

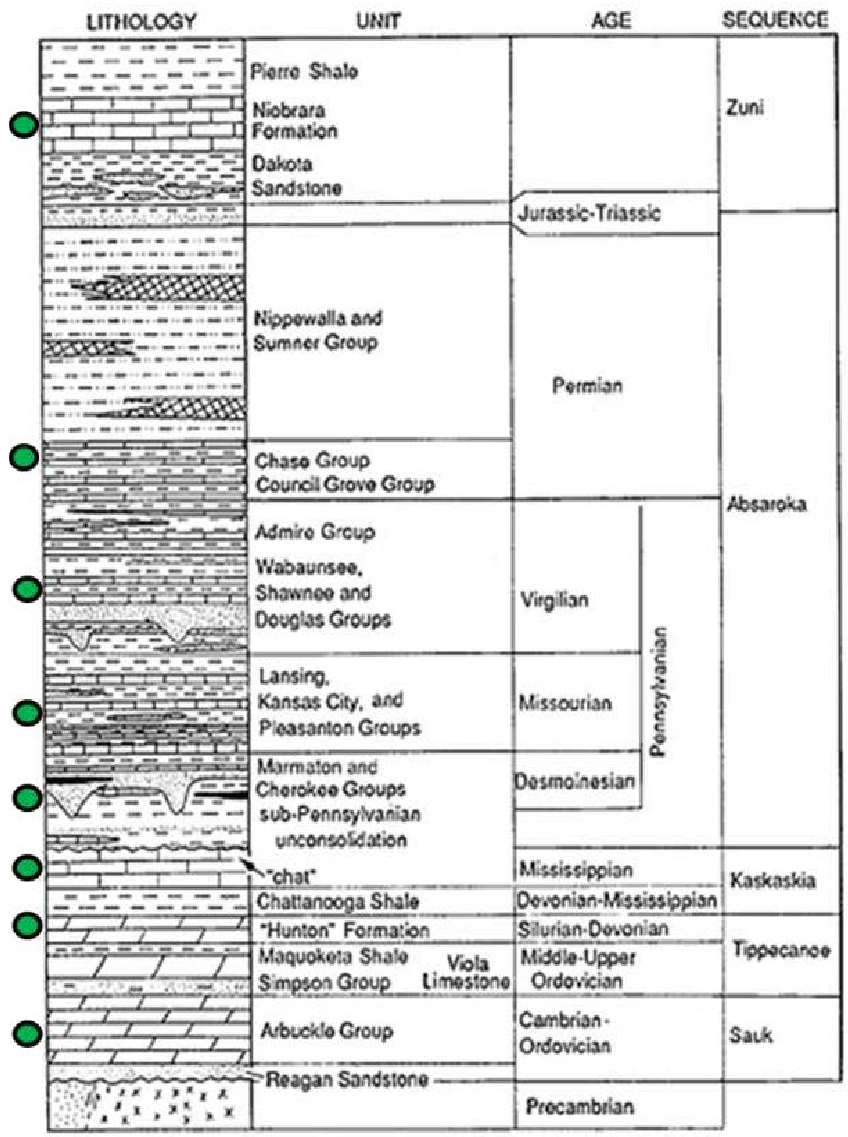


Figure 4: Kansas Stratigraphy and Petroleum Geology (Obtained from Moore et al., 1952 and modified). Green dots represent potential hydrocarbon-bearing units.

In Kansas, the Cambrian-Ordovician Arbuckle Group is divided into the Reagan Sandstone, the Bonneterre Dolomite, and the Arbuckle Group Units, older to younger respectively, (Cole, 1975). Figure 5 displays the time stratigraphic units of Cambrian and Ordovician.

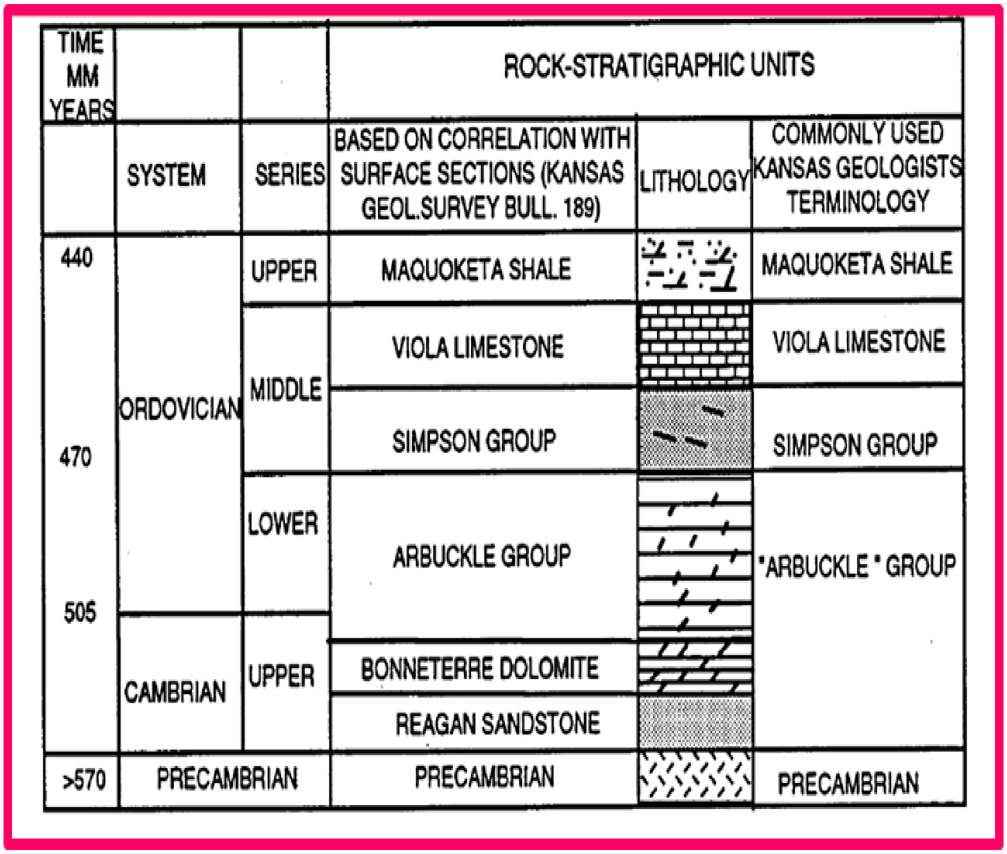


Figure 5: Time stratigraphic units of Cambrian and Ordovician (Obtained from Cole, 1975)

The subject of this study is the Arbuckle Group, one of the most significant hydrocarbon reservoirs in the subsurface of Kansas (Franssen et al., 2003). It is also the main oil-bearing reservoir for the oil fields where the selected research area is located (fig. 6).

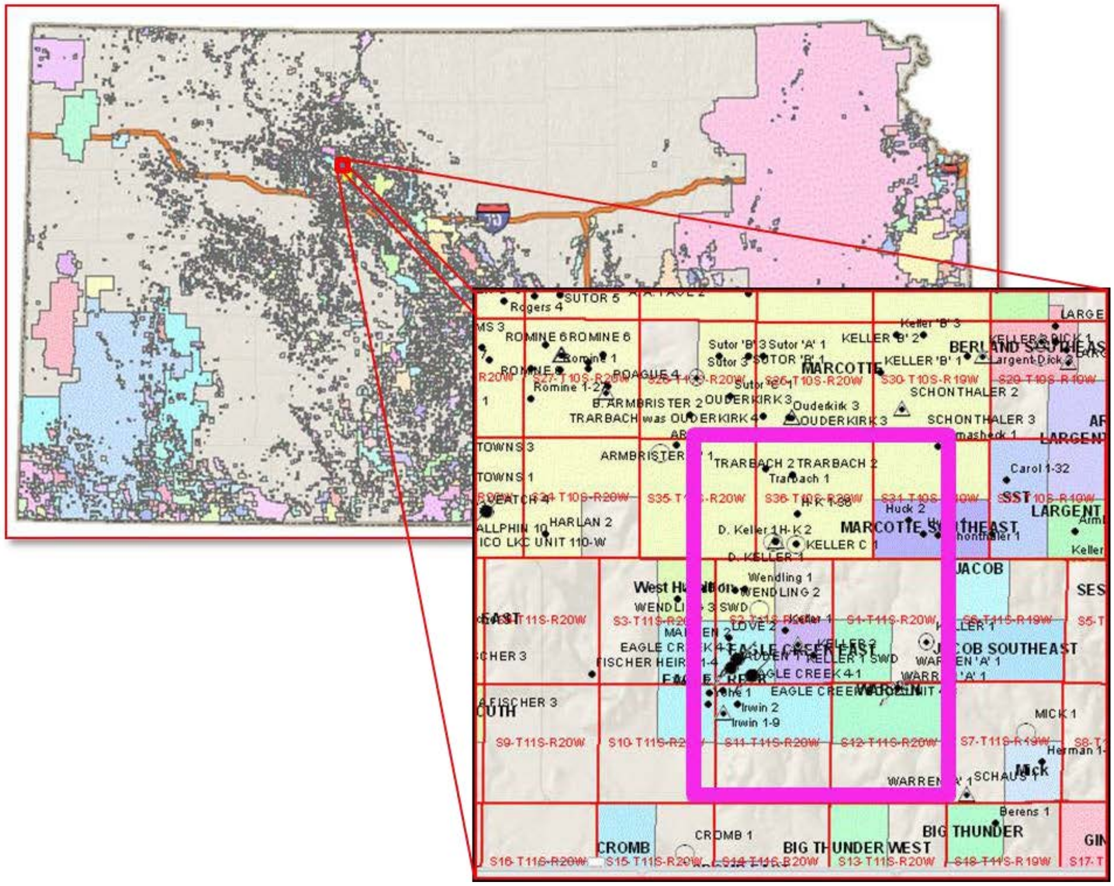


Figure 6: Research area (pink rectangle) in relation to the Central Kansas Uplift oil fields. (Obtained from KGS, Oil and Gas index, http://maps.KGS.ku.edu/oilgas/index.cfm and modified).

Figure 7 is a structural contour map showing either the presence or absence of the Arbuckle Group in the subsurface of Kansas (Nissen et al., 2007). The location of the research area on the contour map confirms the presence of Arbuckle Group in its subsurface (fig.7). For all the 9 wells, the depths that reached the top of the Arbuckle Group are consistent (3,200 to 3700 feet below sea level) and they aligned with the contours of the map.

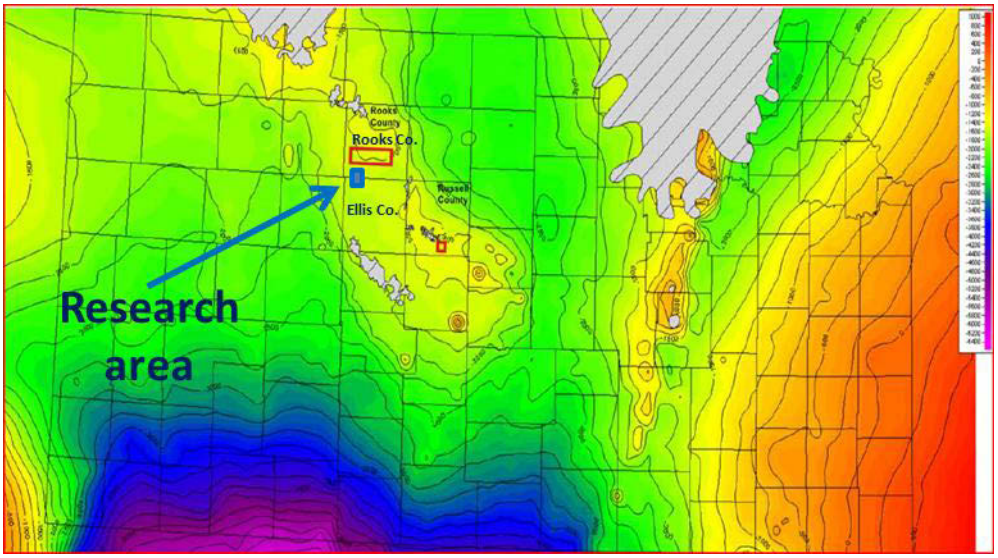


Figure 7: Top of Arbuckle Group structural map of Kansas showing my research area (blue rectangle). Nissen et al. studied Arbuckle Group in two areas (red rectangles). Arbuckle Group is not present in the grey areas. Contour interval = 250 ft (76 m). (Obtained from Nissen et al., 2005 and modified).

Average thickness of the Arbuckle Group in Ellis and Rooks counties, Kansas, was estimated at 300 feet (91.44 meters) (Walters, 1958). At a drilling site, (Copland No.1 located in Rook County, visited as a part of this study), the Arbuckle Group was reached at 3,700 feet and is characterized by a light-grey, sandy, cherty dolomite (fig.8).

Figure 8: Well-cuttings of the Arbuckle Group at Copland No.1, Rooks County, Kansas (Photos by the author).

The Arbuckle Group: Depositional Environment

In order to comprehend the trap formation mechanisms, and type and distribution of porosity within the Arbuckle Group, it is necessary to understand two fundamental aspects. First, the depositional environment under which this stratigraphic unit was deposited and second the diagenetic processes that occur through time. The Arbuckle Group rocks are shallow-shelf carbonate strata, and part of the Cambrian-Ordovician "Great American Bank" that stretched along the present southern and eastern flanks of the North American craton (Wilson et al., 1991). The bank consists of hundreds of meters of largely dolomitized, intertidal to shallow sub-tidal, cyclic carbonate rocks that are overlain by a regional unconformity (Wilson et al., 1991). The shallow sub-tidal to intertidal environment (fig.9) persisted throughout the Arbuckle depositional time and reflected in the uniform composition and texture of the Arbuckle Group rocks (Bliefnick, 1992).

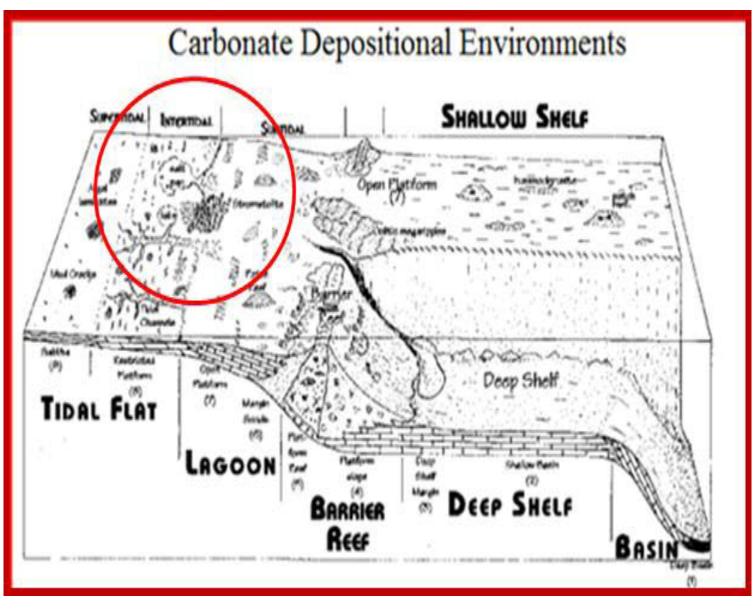


Figure 9: Carbonate depositional environment with the intertidal zone highlighted (Obtained from Reeckman A. and G.M. Friedman, 1982 and modified).

<u>The Arbuckle Group: Karstification</u>

The carbonates of the Arbuckle Group were sub-aerially exposed during the structural uplifts (that affected the Paleozoic rocks in Kansas, ones in the Nemaha Anticline and the Central Kansas Uplift (both represent the Early Pennsylvanian deformation features)) with similarly aged plate convergence along the Ouachita Mountains (the Orogenic belt in Arkansas) (Newell et al., 1989). Thus, erosion, dissolution and development of karsts topography took place.

Karst development occurs whenever the carbonate platforms are sub-aerially exposed. This process could occur over extensive areas and through large thicknesses. Such was the case of the Arbuckle dolomites which were sub-aerially exposed, altered by erosion and disillusion processes that facilitated the development of karsts. Figure 10 shows El Dorado dolomites and karst features of the El Dorado oil field (Butler County, Kansas).

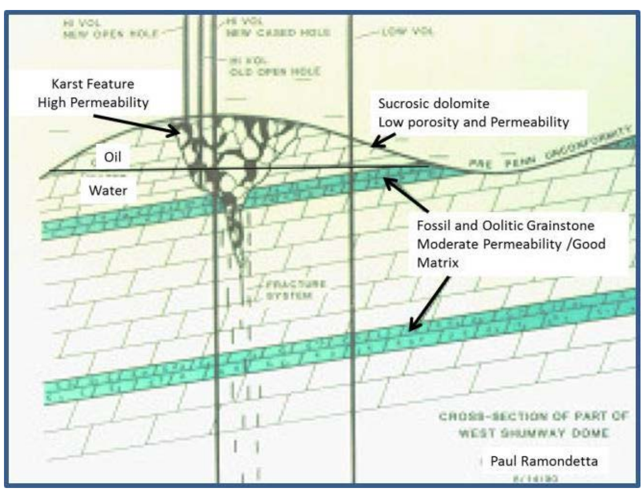


Figure 10: Karst topography profile from the El Dorado Field, Kansas (Obtained from Ramondetta, 2011 and modified).

Figure 11 shows a photomicrograph of a thin-section of Arbuckle revealing fractures and fill-sediments from post-Arbuckle paragenetic sequence (sub-aerial exposure).

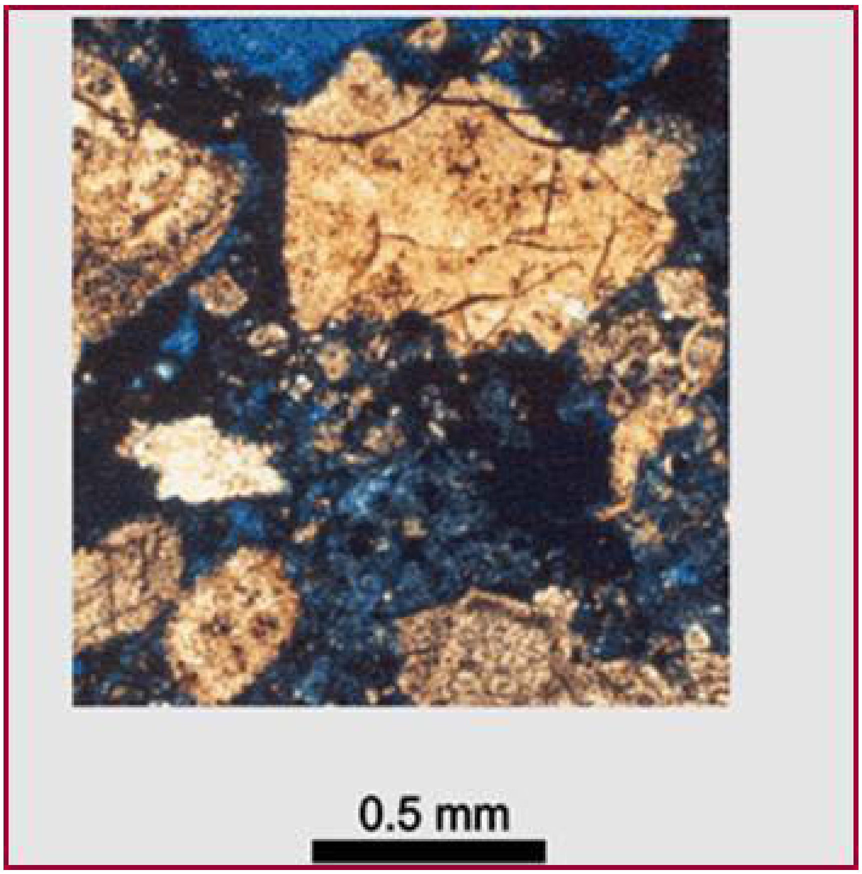


Figure 11: Photomicrograph of fracture and fill sediments from the post-Arbuckle paragenetic sequence (sub-aerial exposure) (Kansas geological Society Posters http://www.KGS.ku.edu/PRS/Poster/1998/98-55/P3-01.html)

Figure 12 is a schematic cross section showing differential erosion of the Precambrian basement rocks. It also highlights the relationship of overlying Cambrian-Ordovician strata, and karstic features associated with the upper Arbuckle unconformity surface (Walters, 1958).

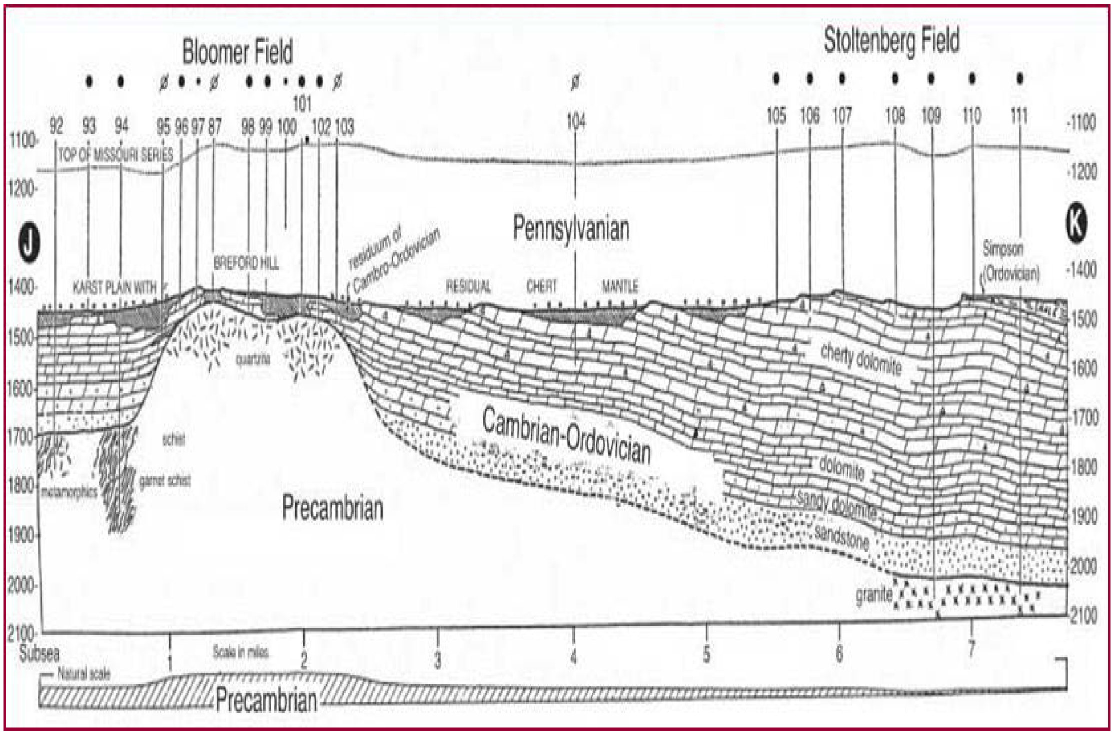


Figure 12: Cross section showing differential erosion of the Precambrian basement rocks, relationship of the overlying Cambrian-Ordovician strata, and karstic features paleo-highs associated with the upper Arbuckle unconformity surface (obtained from Walters, 1958 and modified).

The weathered Arbuckle rocks at the El Dorado field were extremely productive at a rate of 17,000 (barrels/day) (Fath, 1921). From the weathered Arbuckle rocks at the nearby South Augusta field, a daily production of 7,000 (barrels/day/well) was recorded (Berry and Harper, 1948). Generally these karstic or dissolution features display secondary vugular porosity.

Interpretation of well calibrated and extent 3-D seismic cubes could be used to generate 3-D models. These models facilitate visualization and location of the subsurface paleo-topographic features (paleo-karst relief). Figure 13 represents one such 3-D model that characterized the top of the Arbuckle Group.

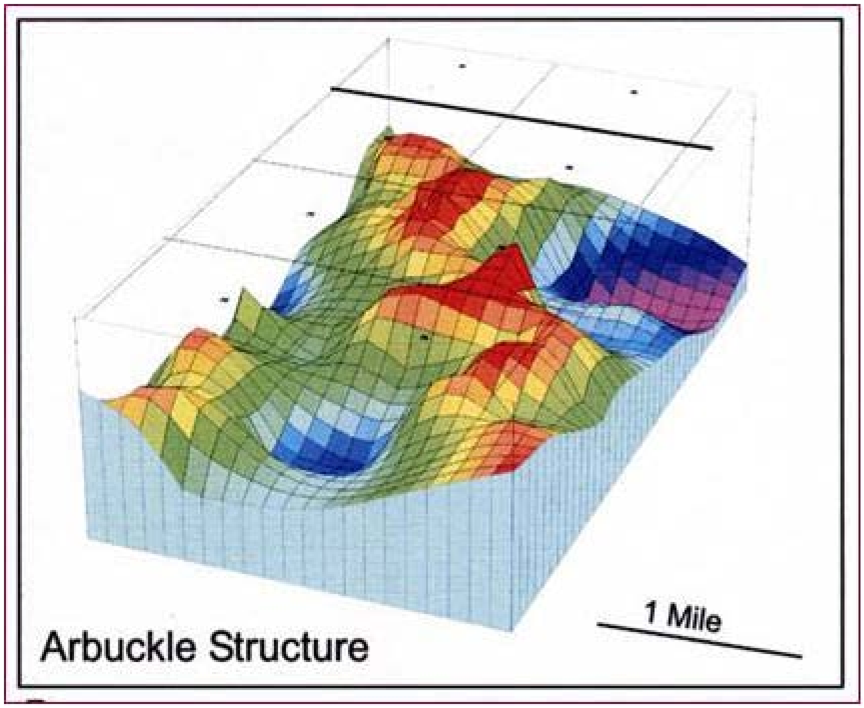


Figure 13: A 3-D seismic model of top of the Arbuckle Group (www.kgs.ku.edu).

Porosity (secondary or vugular) is significantly enhanced by solution and weathering at the top of the Arbuckle Group, particularly in the paleo-highs that crop beneath the sub-Pennsylvanian unconformity (Walters, 1959; Adler, 1971). Dolomitization also enhances porosity of the Arcbuckle (Walters, 1959). Arbuckle rocks have been extensively dolomitized (non-fabric destructive), thereby preserving the original depositional facies (Bliefnick, 1992).

Crysdale and Schenk (1989) reports the characteristics of the Arbuckle Group in the subsurface of Ellis and Rooks counties, Kansas where the reservoir has been penetrated. In these counties, the top of the Arbuckle can be reached at depths that range between 3,629 and 3,736 feet True Vertical Depth (TVD). Dolomite characterizes the Arbuckle reservoir and net pay thicknesses range between 3 and 13 feet. The API (American

Petroleum Institute) gravity varies between 18°and 20°. Heavy crude oils have API gravities that range between 11°-20° (fig. 14).

Average API Gravity of Oil produced foem Arcbuckle Gp. in field located in Ellis and Rooks Counties, Kansas								
County	Field	Reservoir	Stratigraphic Unit	Lithology	API Gravity (average range)	Depth (feet)	Thickness	
							Net Pay	Average
Ellis	Leimillera	Arbuckle	Arbuckle Gp.	Dolomite	20	3,695	13	13
Ellis	Salomon	Arbuckle	Arbuckle Gp.	Dolomite	19	3,629	3	3
Ellis	Salomon NE	Arbuckle	Arbuckle Gp.	Dolomite	20	3,637	6	10
Ellis	Salomon S	Arbuckle	Arbuckle Gp.	Dolomite	20	3,652	3	3
Ellis	Salomon SE	Arbuckle	Arbuckle Gp.	Dolomite	18	3,682	4	4
Rooks	Lynd South	Arbuckle	Arbuckle Gp.	Dolomite	20	3,760	8	5
Rooks	Williams	Arbuckle	Arbuckle Gp.	Dolomite	20	3,736	6	6
Rooks	Williams	Arbuckle	Arbuckle Gp.	Limestone	19	3,386	6	6

Figure 14: The average of API gravity measured in the Arbuckle Group at Ellis and Rooks counties, Kansas (Obtained from Crysdale and Schenk, 1985 and modified).

In the Central Kansas Uplift region, the Arbuckle pay zones are almost always close to the top of the unit (Bloesch, 1954). This observation is confirmed in the oil wells of Ellis and Rooks counties, Kansas reviewed in this study. Also, USGS data on the oil fields of Ellis and Rooks counties indicates that the net thickness of the Arbuckle reservoir ranges from 3-13 feet.

Petroleum System

Success in oil exploration or exploitation activity depends on the understanding of the way in which the sedimentary basins evolve and the identification of main elements and processes of the Petroleum System. The elements are source rock, reservoir, seal, and trap; and processes are generation, migration pathways, accumulation, and preservation. Figure 15 summarizes the ideal interactions among elements and processes in a Petroleum System. It also indicates that timing (synchronization) is critical, and the trap must be available before and during migration.

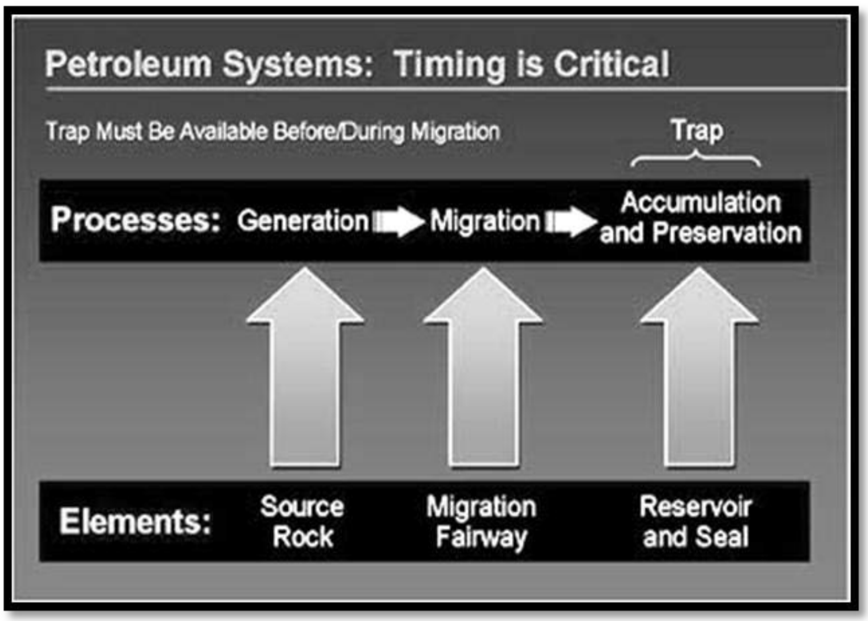


Figure 15: Elements and processes of the Petroleum System (Obtained from Geochemical International Solutions http://www.geochemsol.com/analitical-basinmodeling.html)

<u>The Arbuckle Petroleum System</u>

A high level appraisal of elements and processes of the Arbuckle Petroleum System was completed by me to understand the dynamics of oil entrapment within the research area. If the location and size of effective reservoirs is influenced by the creation of structural traps through uplift, erosional truncation of producing formations, and deposition of overlying low-permeability seal units, all tectonically related (Higley, 1995) then why are there cases when the drilling of structural highs resulted in dry holes?

Figure 16 shows the classification of the Arbuckle Group reservoir into three main lithofacies: 1) dolomites, 2) karst control facies and 3) fractured dolomite (all three with secondary porosity) (Franssen, 2004).

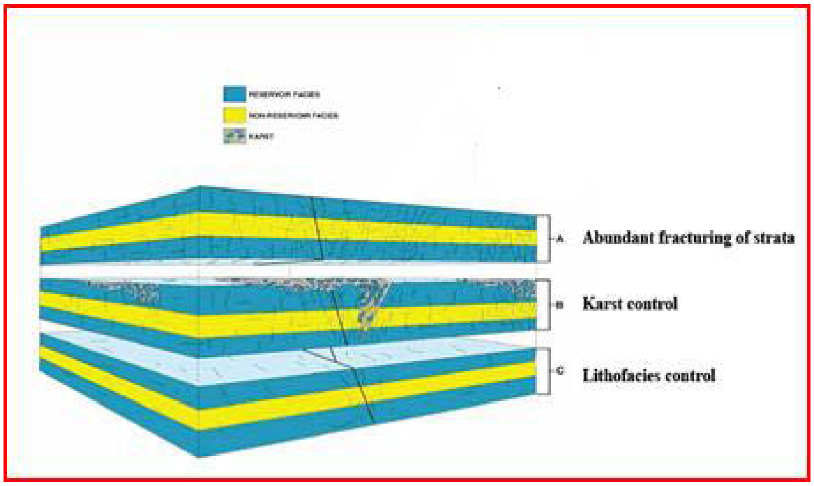


Figure 16: Classification of the Arbuckle Group (Obtained from Franssen et al., 2004 and modified).

Seals in the Arbuckle Petroleum System may be represented by non-permeable intervals (within the Group) and by overlaying stratigraphic units with low porosity and lack of permeability. There is a possibility that rocks beneath the Mississippian-Pennsylvanian erosional unconformity became a vertical seal. Sub-aerial exposure weathers rocks and in some instances into very fine particles (clay-size). These particles contribute to substantially reduced porosity and permeability, thereby creating a sealing layer.

Most traps are combine; structural-stratigraphic traps with a complex genesis of paleo-relief of the Precambrian basement and uplift (erosion) that occurred between the Late Mississippian to the Early Pennsylvanian, had a great influence in their formation (Higley, 1995). In Kansas, the source rocks are somewhat well known; the most prolific are the Chattanooga Shale, a Late Devonian-Early Mississippian black, organic-rich shale; the Middle Ordovician Simpson Group containing algal-rich, brown and waxy, shales; and the more deeply buried, dark shales of the Pennsylvanian age (www.kgs.ku.edu). Migration is described as a long distance migration. The distribution of oil and gas in the Arbuckle pay zones over the Central Kansas Uplift conforms to the principles of differential entrapment as described by Gussow (1954). Oil-water contacts increase with elevation, and gas content decreases systematically northward in several Arbuckle fields on the Central Kansas Uplift. This indicates a northward migration of the Arbuckle oil, most possibly derived from Oklahoma. Figure 17 shows a map with the postulated long distance oil migration paths to the research area. (http://www.KGS.ku.edu/ Current/2004/Gerhard/06_petrol.html)

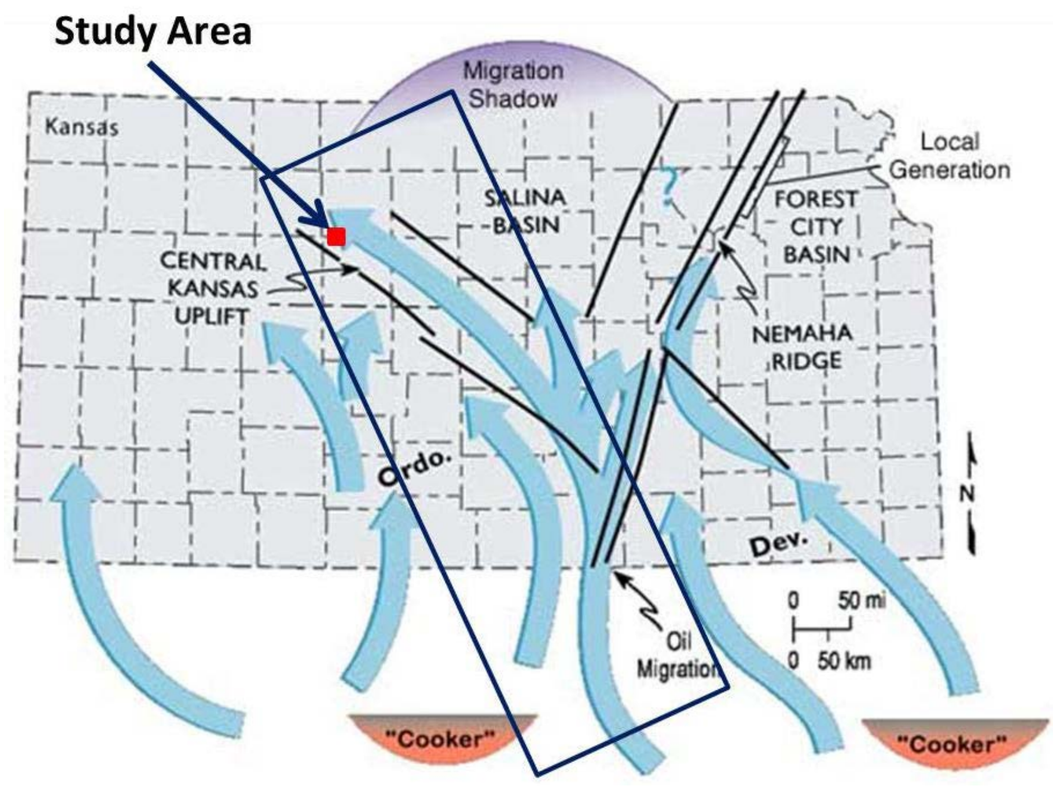


Figure 17: Hydrocarbon migration pathways from “cookers” or kitchens to traps in the research area (Obtained from http://www.kgs.ku.edu/ and modified.)

Figure 18 shows a hypothetical graph with the elements of the Arbuckle Petroleum System (Henry and Hester, 1995). Information related to charge, seal, reservoir, and trap formation was assembled and referenced from various KGS publications. Reservoir rocks are the Cambrian-Ordovician dolomites with three potential facies exhibiting high porosity and permeability. Source rocks are the Simpsom Group Shales (Middle Ordovician) and the Chattanooga Shale (Late Devonian-Early Mississippian). Seals are intra-Arbuckle non-permeable layers (Ordovician) and trap formation (Pensylvanian). One "critical moment" (when all conditions are set, and the preservation process begins) is inferred. However, a more detailed study and calibrated burial charts might result in more "critical moments".

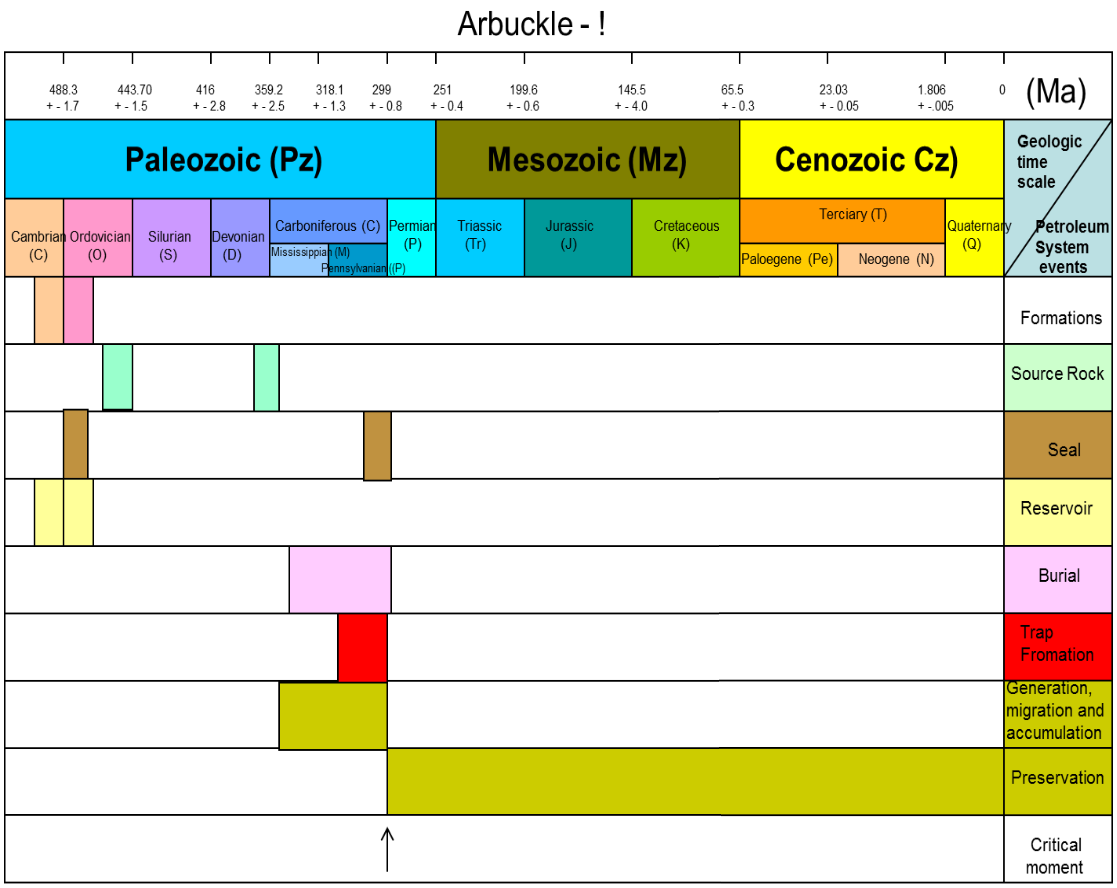


Figure 18: Elements and Processes of the Arbuckle (!) Petroleum System. (Obtained From Mitchell E. Henry and Timothy C. Hester, 1996 and modified)

Interviews of Various Personnel

Several interviews were conducted with the collaboration of various personnel (well-loggers, petroleum geologists, oil operators, oil producers), with broad knowledge in petroleum geology of the research area, and west-central Kansas. The lessons learned and valid observations compiled from these interviews are:

1) The Arbuckle Group is the most significant oil-bearing reservoir (pay zone) in the Central Kansas Uplift.

2) The majority of the oil producing wells within the research area are producing from near the top of the Arbuckle Group.

3) The productive interval is thin, but proliferous.

4) Sometimes it is necessary to inject polymers to manage the water invasions.

5) Arbuckle in the research area produces from a buff colored dolomite with a vuggy ("pinpoint") porosity.

6) There is no gas in the research area.

7) There are three different reservoir dolomite facies that produce in the area.

8) Structure seems to be the real key.

III. PETROGRAPHY ANALYSIS

The Arbuckle Group Facies

Since none of the oil wells drilled within the research area had rock core samples, the petrographic analysis was completed by interpreting and describing rock "cuttings" from drilling sites located in Ellis and Rooks, counties near the research area. Rock core descriptions of Ellis and Rooks wells were obtained from KGS (Appendix). Rock "cuttings," collected during planned field trips to drilling sites located in the vicinity of the research area, were independently described. The gathered descriptions of the "cuttings" were further analyzed and compared to the core photographs of the Arbuckle Group facies (published and described in Schlumberger Oil glossary, 2012) (fig.19).

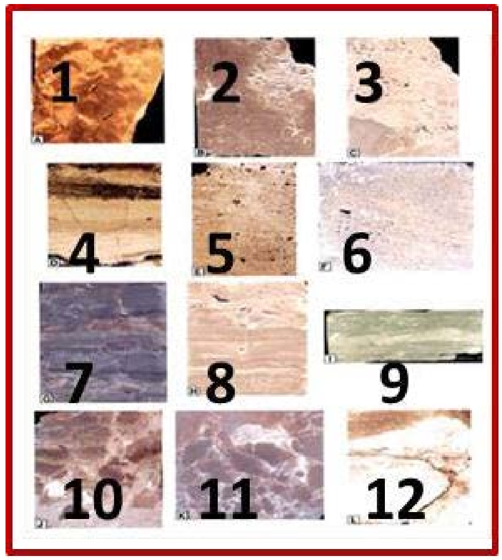


Figure 19: Core Photographs of the Arbuckle Group facies (Obtained from Schlumberger oil glossary, 2012 and modified).

Core descriptions of each of the Arbuckle Group facies shown above in core photographs (from 1 to 12) are:

1) Clotted Algal Boundstone (muddy): Peloid-rich mottled (thrombolytic) to wavy-laminated, clotted algal carbonate lithology. Porosities are generally less than 6%, and permeabilities are below 0.1 millidarcies (md).

2) Laminated Algal Boundstone (muddy): Wavy-laminated algal boundstones and stromatolites. Porosities are generally less than 6%, and permeabilities are below 0.1 millidarcies (md).

3*)* Laminated Algal Boundstone (grainy): Wavy-laminated algal boundstones and tromatolites. Some of the *best reservoir rock* with porosity of up to 32% and permeability of up to 1,500 millidarcies (md).

4) Peloidal Packstone-Grainstone: Massive, horizontally laminated or bedded. Porosities range from 0% to 4%, and absolute permeabilities range from 0.0003 md to 0.1 md (but generally below 0.005 millidarcies (md).

5) Packstone-Grainstone: Massive, horizontally bedded, or cross-bedded. Porosities range from 6% to 18%, and permeabilities range from 0.1 md to 50 millidarcies (md).

6) Ooid Packstone-Grainstone: Massive, horizontally bedded, or cross-bedded. Porosities range from 11% to 30%, and permeabilities range from 10 md to 1,500 millidarcies (md).

7) Wackestone: Massive to horizontally laminated. Porosities range from 2% to 11%, and permeabilities range from 0.01 md to 1 millidarcies (md).

8) Mudstone: Massive to horizontally laminated. Porosities range from 0% to 10%, and absolute permeabilities range from <0.0001 md to 0.1 millidarcies (md).

9) Intra-Arbuckle Shale: Some are interbedded with carbonate rocks suggesting they were deposited during the Arbuckle deposition. Shales are tight and represent permeability barriers.

10) Breccia: Brecciation and fracturing occur with various textures. This example shows chaotically-oriented class of various lithologies. Breccia facies typically have variable porosities and permeabilities that are primarily a function of the lithologies that were brecciated.

11) Fracture-fill Shale**:** Most of it is green and clearly present as a fracture or a cave fill, with sediment originating from above the upper Arbuckle unconformity surface. This shale occludes original fracture porosity.

12) Chert: Locally occurs as a replacement of carbonate facies. Chert replacement commonly results in tight and impermeable areas.

<u>Cores from Ellis County, Kansas</u>

Descriptions of cores samples taken in three oil wells located in Ellis County, Kansas, near the research area were obtained from the KGS virtual library. Following are well summaries of the core description of the Arbuckle Group oil barrier reservoir of interest in the present study:

<u>Well BERMIS 1</u>: This well penetrated the top of the Arbuckle Group at 3,403 feet. At this depth oil is seen. The rocks are described as shale and sand. At 3,420 feet, a dolomite is reported.

<u>Well N. ANDERSON “A” No 6</u>**:** This well penetrated the top of the Arbuckle Group at 3,418.5 feet. The rock is described as limestone and shale. At 3,527 feet, (total depth) the well penetrated an interval containing chert, limestone, pyrite and shale.

<u>Well KOLLMAN No 6 (Dry and Plug)</u>**:** This well penetrated the top of the Arbuckle Group at 3,331 feet. The rock is described as green shale. Additional report indicates that the Arbuckle Group, penetrated at an interval of 3,331- 3,414 feet, contains oil and water.

Rock Samples: "Cuttings"

Field trips to the drilling sites located in Ellis and Rooks counties, Kansas were conducted while the Arbuckle Group was drilled (courtesy of the team leaders at Blake Exploration, Bowman Oil Company and various independent oil operators of Kansas) (Fig.20).

Figure 20: Field trip to a drilling site of an oil well located in Ellis County, Kansas (Photo by Kathleen Fisher).

I collected and described rock "cuttings" recovered from the Arbuckle Group (Fig. 21). The Arbuckle Group in this site is a light grey microcrystalline dolomite.

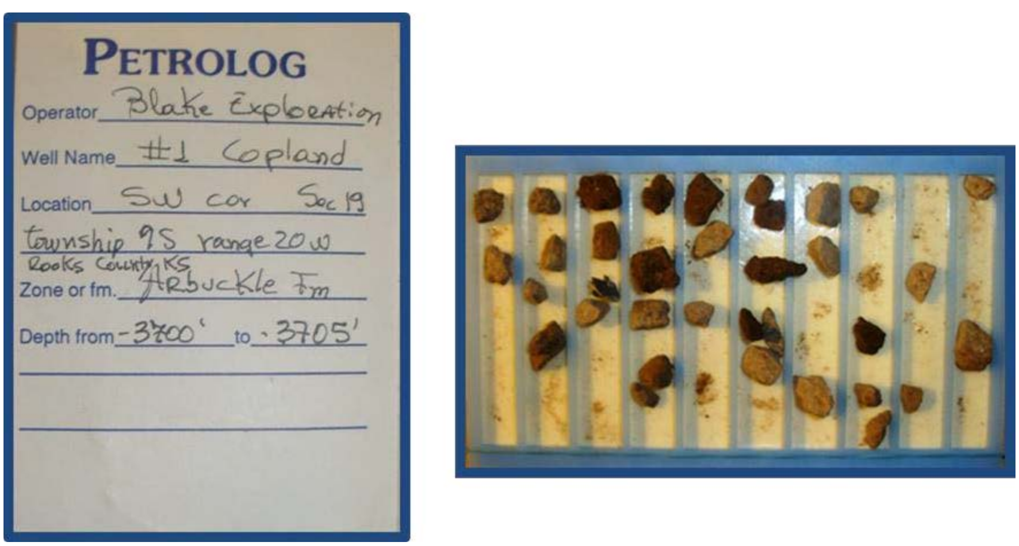


Figure 21: Drilling "Cuttings" from the Arbuckle Group (Photos by the author).

IV. PETROPHYSICAL ANALYSIS

Digital wireline well logs

For more than 80 years, petroleum geologists, geophysicists, petrophysicists and subsurface interpreters have been using wireline well logs to interpret, correlate subsurface units, and characterize reservoirs. Wireline logs hold distinctive features, which permit interpretation and characterization of the subsurface rocks and containing fluids. Gamma-ray (GR), Spontaneous Potential (SP), Caliper (CA), and Resistivity (ILD, RILD, RILM), and Porosity (RHOD) logs from 9 oil wells drilled within the research area were collected and interpreted. Lithology and thickness of the penetrated stratigraphic units, depth to the tops, and porosity are some properties interpreted to complete the basic petrophysical analysis of this study.

Gamma-ray (GR) logs

Gamma-ray (GR) log is routinely included in a basic suite of wireline oil well logs. It records natural radioactivity existing in the rocks and is expressed in API units. High GR readings suggest that the penetrated stratigraphic unit contains radioactive minerals. Shales are rocks units with a high content of radioactive mineral; therefore, a high GR reading is associated with the presence of shale. Volcanic ash, granite wash and some salts display a high GR reading. Sandstones, carbonates and evaporates typically display low GR values.

Figure 22 illustrates typical deflections of a gamma-ray (GR) log while penetrating dissimilar lithologies, with a horizontal scale of 1-150 API. It shows how shales display high GR readings, whereas sandstones, cherts, limestones, dolomites, halites, anhydrites and gypsum exhibit low GR readings.

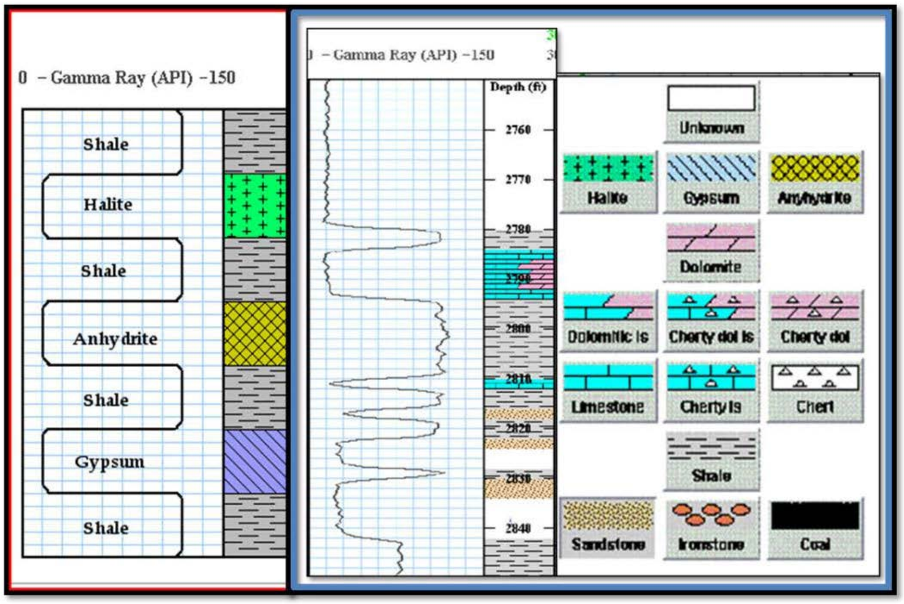


Figure 22: Gamma-ray (API) curve responses to different lithologies (Obtained form KGS and modified).

Porosity Logging

Sonic, density, neutron or magnetic resonance logs are regularly used to calculate porosity of subsurface intervals. In some instances, porosity estimations are made from one of the above mentioned logs. However, if more than one of these logs is available, a combined log interpretation can be achieved. A Porosity Bulk Density log (RHOB) was recorded in the oil well Trarbach # 1 and a sonic log was recorded in the oil well Keller 1. Both these oil producer-wells from the Arbuckle Group are located within the research area. However, an interpretation was not possible due to the lack of digital logs.

Figure 23 shows an example of porosity logs recorded on a south-central Kansas oil well. This is used to illustrate the benefits of interpreting combined porosity logs (sonic, density and neutron) and to interpret a GR log using the concepts described above. In the left track of the plotted log is a GR log, with a horizontal scale of 0-150 (API). A plot with the combination of three porosity logs (sonic, neutron and density (%)) is in the right track. Using basic GR log interpretation principles, the logged interval is divided into 4 distinctive stratigraphic units: 1) two shale units (Stark Shale and Rushpuckney Shale), both characterized by high GR values (>150 API) and 2) two carbonate-limestone units (Bethany Ls. and Sniabar Ls.) displaying low GR values (<5 API).

Combined porosity plotted in the right track shows that porosity of this particular limestone ranges from 3% to 30%. The primary porosity (inter-particle porosity) quantified in the sonic log ranges from 2% to 3%. The secondary porosity (vugs and/or fracture-associated porosity) computed as the difference between the sonic porosity and the neutron and/or density porosity varies from 15% to 25% in Bethany Falls Ls. In this example, neutron and density logs show high porosities associated to the oomoldic limestones and to the oil/gas producer. Sonic logs are useful to determine intervals with secondary porosity.

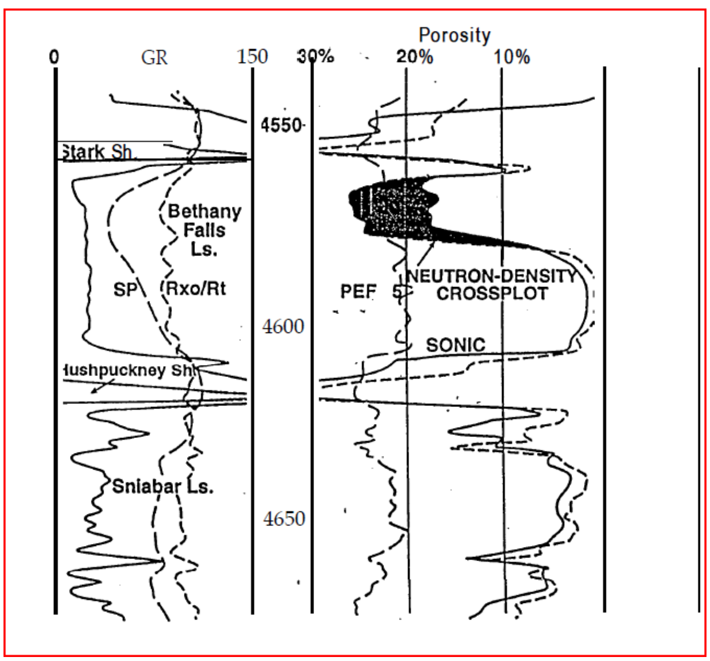


Figure 23: Combined logs showing the averaged neutron-density porosity log along with a sonic log in a Pennsylvanian limestone-shale sequence in a Kansas well (Obtained from KGS and modified).

Resistivity Logs

Resistivity logging is a well logging technique that works by characterizing subsurface rocks or sediments and determining their electrical resistivity. Resistivity is an attribute that reveals the strength with which a rock unit or a sediment resists the flow of electric current. The log must be recorded in boreholes containing electrically-conductive mud or water. Resistivity logging is commonly used for formation evaluation in oil-and gas-well drilling and is expressed in ohm-m. Most rocks are essentially insulators while the ones containing fluids are conductors. Hydrocarbon fluids are highly resistive. Salty underground water (formation water) is conductive, hence has a very low resistivity. Formations that contain hydrocarbons are characterized by a low porosity, and display higher resistivities.

Resistivity logs recorded in each of the 9 oil wells drilled within the research area were collected, loaded in GEOLOG, plotted in a detailed 1:5000 vertical scale and interpreted (Appendix). Resistivity logs are graphically represented on a logarithmic scale (0.2 to 2000 ohm-m).

Archie's Equation

Archie (1942) proposed two equations that described the resistivity behavior of reservoir rocks, based on his measurements on core data. The first equation governs the resistivity of rocks that are completely saturated with formation water. He defined a formation factor (F), as the ratio of the rock resistivity to that of its water content (R_w), and found that the ratio was closely predicted by the reciprocal of the fractional rock porosity (a) powered by an exponent (m). The value of m increased in more consolidated sandstones and is named as the cementation exponent. However, it seemed to reflect increased tortuosity in the pore network. For generalized descriptors of a set of rocks with a range of m values, workers after Archie introduced another constant, “a” (Fig.24)

In the second equation, Archie described resistivity changes caused by hydrocarbon saturation. Archie defined a resistivity index (I) as the ratio of the measured resistivity of the rock (R_t) to its expected resistivity if completely saturated with water (R_o). He proposed that ‘I’ was controlled by the reciprocal of the fractional water saturation (S_w) to a power of n. ‘n’ is named as the saturation exponent. The two equations, when combined into one, is known as “the Archie equation”. Written in this form, the desired, but unknown, water saturation (SW) may be solved.

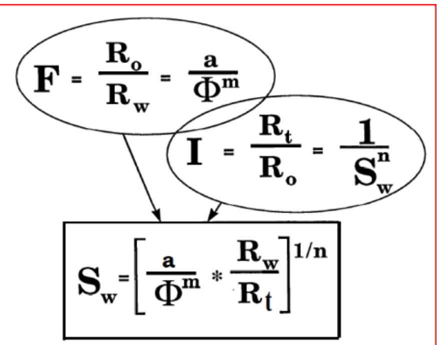


Figure 24: Archie’s equations.

<u>Logging Intership</u>

A well-logging internship was completed to obtain drilling and logging experience and to acquire data to finish this study (Courtsey of Log-Tech technical logging team, Summer 2007). Log-Tech, located in Hays, Kansas, supported and participated in the design to plan activities to finish theoritical and practical sessions in oil well logging, assisted in guided visits to drilling and logging sites, and planned logging activities. Figure 25 shows the interactions with the Log-Tech team.

The following things were accomplished during the internship:

1) A guided visit to an oil well drilling site located nearby my research area.

2) Proccurement and description of rock “cuttings” collected during the drilling process.

3) Active participation in the logging activity.

4) Analysis and interpretation of well logs, specifically of the Arbuckle Group logged at the interval of interest.

Figure 25: Logging team from Log-Tech getting ready to depart to oil well drilling and logging site, in Ellis County, Kansas (Photo by C. Schaffer).

Specific questions during the intership:

1) What is a wireline log?

2) How are logging operations & data collection acheived?

3) What type of log information should be written in the log headers?

4) What is the expected response of the different subsurface stratigraphic units of the research area to different logs?

5) How do we recognize the Arcbukle Group in wirelogs?

Well logging and log interpretation

Wireline logging is performed by lowering a 'logging tool' on the end of a wireline into an oil well (or borehole) and recording petrophysical properties using a variety of sensors. Drilling-time records and wireline logs are basic sources of data to a Petroleum Geologist. The drilling-time is traditionally recorded while drilling any oil well and is a good data to review before the start of the logging process. Drilling time is directly proportional to the type of the rock that is being drilled. It is commonly known among oil well drillers and loggers that porous sandstones and limestones drill fast, whereas shales tend to drill slowly. It is also known that slow-drilling formations will be hard and non-porous (sandstones and limestones).

Usually, after the well-drilling process is completed, the logging procedures start. In some cases, both the two processes (drilling and logging) are done simultaneously. During the logging process, a sonde (string of geophysical instruments) is dropped down into the borehole. This is done to systematically record the petrophysical properties of the subsurface units. It is also known as wireline well logging or borehole logging. Resulting digital data is transferred to and recorded in specialized computers located in the logging vehicle. Final logs are digitally saved and/ or printed/ plotted onto special log-size papers.

<u>The Arbuckle Group wireline log interpretation</u>

Figure 26 shows photos A, B and C taken during Log-Tech field trip to a new oil well drilling site in the vicinity of the research area. Figure 26, photos A and B show the review and interpretation of the suite of log papers run while the well was drilled. Figure 26, photo C shows a gamma-ray (GR) profile where tops of the Kansas City Group and the Arbuckle Group are interpreted. The top of the Arbuckle Group is defined by an abrupt, left shift of the gamma-ray (GR) curve. Gamma-ray (GR) logs are used to interpret lithological changes and stratigraphic tops. In this well, the top of the Arcbuckle Group is interpreted at 3,406 feet.

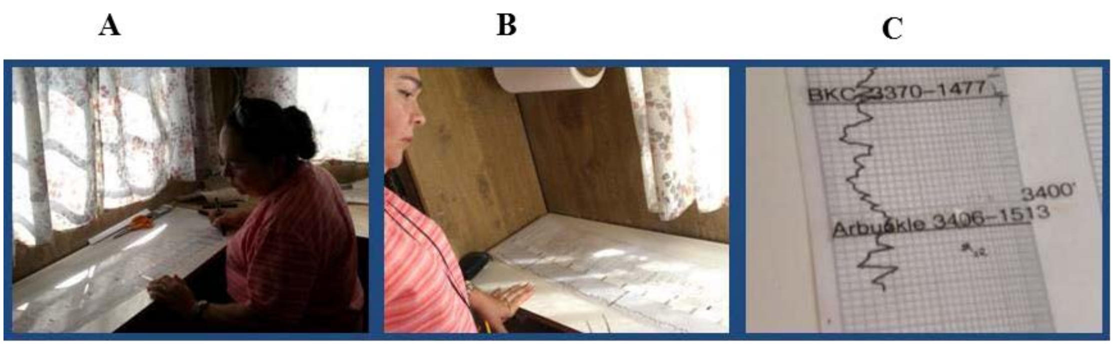


Figure 26: Work session on a drilling site of an Ellis County, Kansas oil well to interprete wireline well logs and place stratigraphic tops. (Photos **A** and **B** by Carol Schaffer and photo **C** by the author).

Figure 27 shows the process of measuring ground level elevation and geographical location at the drilling site by using a GPS unit. Geographical location and ground elevation of oil wells are commonly written in the header of wireline logs. The preciseness of these measurements supports real-time validation and accuracy of the original well-prognosis. This data can be compared with the predicted depth to the tops of different subsurface units and see whether they are aligned with the encountered drill values.

Additionally, precise location and elevation of the drilled oil wells reduces uncertainties and enhances accuracy of subsurface mapping and correlations.

Figure 27: Manipulation of a GPS unit to validate geographic location and ground elevation of the oil well (Photo by C. Schaffer).

Description of rock "cuttings", while the oil well is being logged, is a common practice to validate early log interpretation. Figure 28 shows the author using a basic low-power stereo microscope to examine and describe drilling samples collected while drilling the Arbuckle interval. In order to complete a petrographic description, the properties and mineralogical composition of the drilling samples were described in terms of color, grain size, luster, hardness, cleavage, and crystal forms.

Figure 28: Description of rock "cuttings" of the Arbuckle Group (Photo by C. Schaffer).

The Arbuckle Group in this location has the following petrographic properties:

1) Color: Ranges from dark brown towards the top to light-grey at the bottom

2) Hardness: The brown minerals are soft, the light-grey minerals are light and the grey samples are harder.

3) Luster: The brown minerals have a non-metallic (earthy) luster and the light-grey minerals have a non-metallic (crystalline) luster.

Texture and color of the drilling samples suggest that the brown cuttings are shales, and the light, light-grey, fine-grained with crystalline luster are dolomites.

Stratigraphic and Petrophysical Data from Oil wells

Digital wirelog data was collected from 9 oil wells drilled within the research area in Ellis and Rooks counties, Kansas. The Lansing-Kansas City Group and the Arbuckle Group are the main oil-bearing reservoirs. Both the reservoirs are main petroleum targets in this area. A well ID (numbers 1-9) was assigned to each well. The data was then tabulated, loaded on a specially designed Completion Template within Geolog, printed on a 1:5000 vertical scale and stratigraphically interpreted (Apendix B1-B9). The final depth and the True Vertical depth (TVD) in these oil wells range between 3,177 ft and 3,735 ft.

The oil well wirelog profiles Gamma-ray (GR), Spontaneous Potential (SP), Caliper (Ca) and Resistivity (LLD)) were loaded, adjusted (in Geolog) and interpreted to identify tops and thickness of the subsurface stratigraphy units. Wirelogs from local oil wells were also used to characterize and stratigraphically locate main reservoirs, top seals and/or source rocks which comprise the main elements of the local petroleum geology (fig 29).

The formation tops reported in well files and Log ASCII Standard (LAS) digital files of well logs (obtained from KGS; recorded by Log-Tech and Scientific Data System Log companies) were loaded into Seismic Micro Technology (SMT) Kingdom Suite software (version 8.2) and Geolog (version 6.7).

Oil wells located within the research area Well name, operator, oil field, log information, final depth and productive reservoir										
Oil well ID (in Reseach)	Oil Company / Operator	Official Well name	Oil Field	Location	County	Log Date	Logging Service Company	Final TVD (feet)	API	Well type / producti vereser voir
1	Blake Exploration, LL(	H-K#1-36	Marcotte	1950' FSL and 1900' FWL	Rooks	)3.13.200!	Data System, Inc.	3698	5-163-2343	OIL Lansing-Kansas City GP
2	Blake Exploration, LL(	Keller#1	Eagle Creek Eas	2310' FSL and 2150' FEL	Ellis	)9.13.2004	Log Tech	3716	5-051-2530	OIL Lansing-Kansas City GP
3	Blake Exploration, LL(	Keller#2	Eagle Creek Eas	1120' FSL and 850' FEL	Ellis	)6.27.200!	cientific Data Systems, In	3735	5-051-2541	Dry and abandoned / Arcbuckle
4	Harry A Spring	Keller -Heirs #1	Marcotte	SW-SE-SW 600' FSL and 1850' FE	Rooks	1.08.200(	cientific Data Systems, In	3670	5-163-2356	Oil producer / Arcbuckle
5	Blake Exploration, LL(	Keller "C"#1	Eagle Creek	250' FNL and 2100' FEL	Ellis	1.05.200	cientific Data Systems, In	3177	5-051-2526	Oil producer / Arcbuckle
6	Harry A Spring	Love #2	West Hamilton	/2 NW SW-1980' FSL and 575' F\	Ellis	)1.23.200	Log Tech	3712		Oil producer / Arcbuckle
7	Blake Exploration, LL(	Trarback #1	Wildcat	1325' FNL and 450' FWL	Rooks	)5.29.200(	Log Tech	3700	5-163-2352	Oil producer / Arcbuckle
8	Blake Exploration, LL(	Wending No. 1	Salomo	1450' FNL and 1350' FWL	Ellis	)1.14.200!	Log Tech	3715	5-051-2535	Oil producer / Arcbuckle
9	Blake Exploration, LL(	Wending # 2	Marcotte	1460' FNL and 900' FWL	Ellis	)7.08.200!	Log Tech	3715	5-051-2541	Oil producer / Arcbuckle

Figure 29: Summary of stratigraphic and petrophysical data from oil wells within the research area (Obtained from http://www.kgs.ku.edu/Magellan/Tops/index.html and modified)

Geolog

Paradigm Geolog Formation Evaluation software was used to load, adjust, visualize, and plot Log ASCII Standard (LAS) files conforming the suite of digital logs from nine oil wells drilled within the research area. Original data was provided by Blake Exploration and/or obtained form KGS. Geolog was used to create a composite layout template and also to make a detailed review of the logs (Apendix B1-B9).

Gamma-ray (GR) and Resistivity (LLD) logs recorded for all the nine wells were used in the interpretation. For each of the selected wells, original stratigraphic tops (driller's tops) and reported depths (ft) to each penetrated stratigraphic unit were reviewed and transcribed on the paper logs. Later, original logs were cross-correlated, and stratigraphic tops were adjusted (Appendix B1-B9). Gamma-ray (GR) and Density Neutron logs have a specific behavior that is usefull to identify lithology, especially for the carbonate rocks (fig. 30).

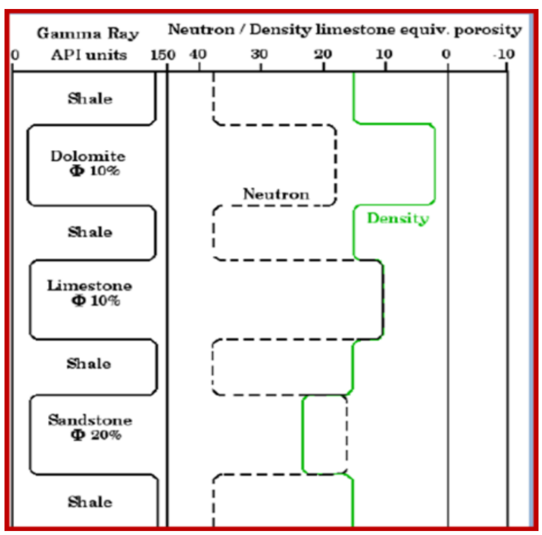


Figure 30: Readings of the gamma-ray (GR), the Density, and the Neutron logs in carbonates (Obtained form KGS and modified).

The previous illustration based on real logs was used to support the interpretation of gamma-ray (GR) logs measured on five of the oil wells drilled and logged within the research area. Figure 31 shows a N-S well log correlation based on GR curves. Tops of the Lansing Group, the Kansas City Group and the Arbuckle Group are identified and correlated. The Arbuckle Group, characterized by dolomite in this zone, is easy to identify by analyzing the behavior of the GR curve. When the dolomite is logged, it displays an abrupt shift to the left (low values). GR logs for dolomites measure very low to zero values owing to their lack of radioactive minerals (fig. 31).

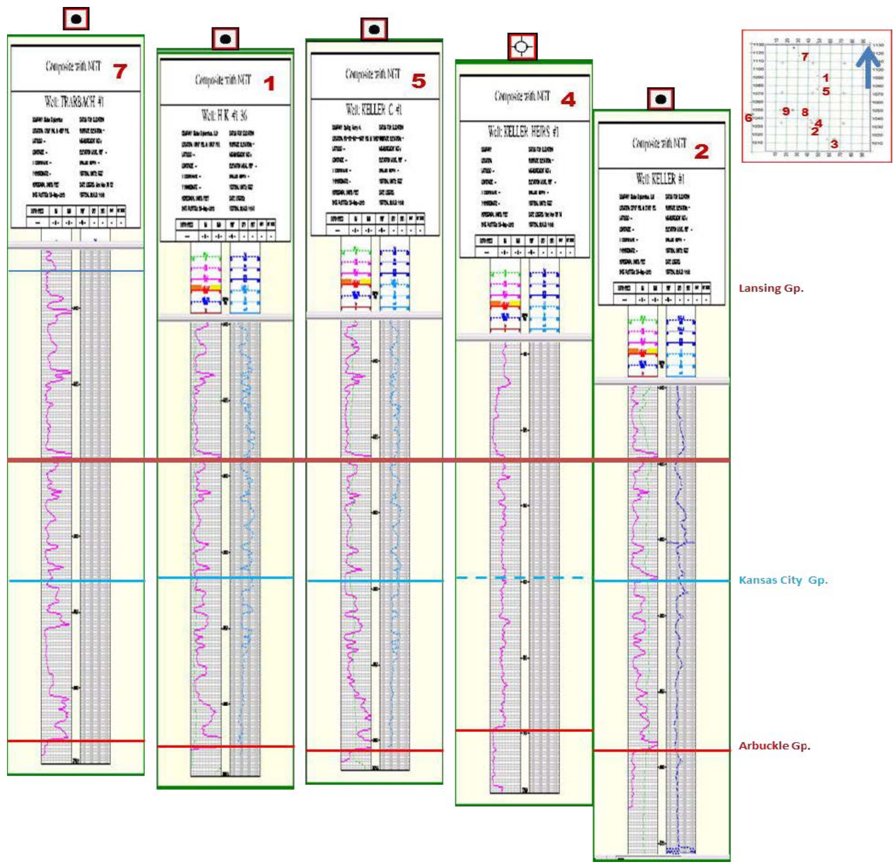


Figure 31: N-S Stratigraphic correlation of wells (7,1,5,4,and 2) located within the research area. Gamma-ray curve abruptly shifts to the left (low values) when the Arbuckle is logged.

Figure 32 shows the shift of the GR curve (red) when the Arbuckle Group dolomites are penetrated. Resistivity curve (blue) also shifts to the left (low values), which probably indicates the presence of fluids.

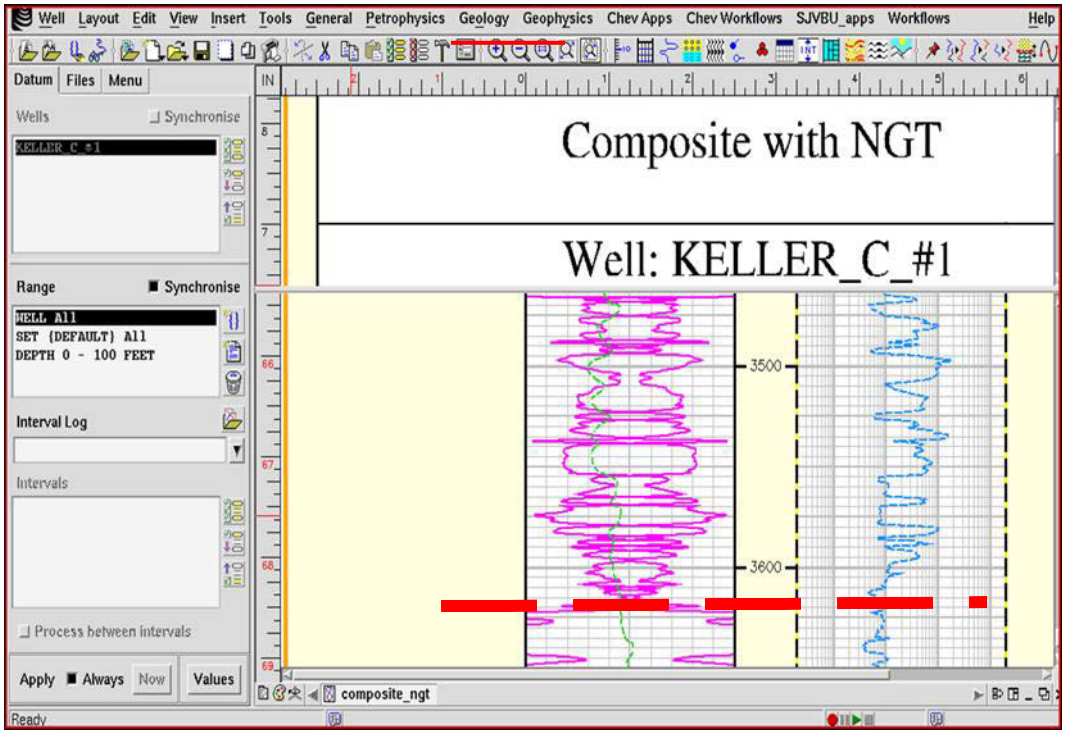


Figure 32: Composite log of well Keller_C_#1 (Well #5) with two gamma-ray (GR) curves, plotted in inverted scales, to visualize changes in lithology and a resistivity curve (compressed) showing the top of the Arbuckle.

Gamma-ray (GR), Spontaneous Potential (SP), Caliper (Ca) and Resistivity (LLD) logs were interpreted to identify tops and thickness of the Arbuckle Group.

Stratigraphic cross sections and correlations of oil well data were also completed with the SMT Kingdom Suite tool. The reported data in the well-files indicate that the thickness of the main stratigraphic unit is constant within the research area

V. PRODUCTION DATA- OIL FIELDS

<u>Oil Production</u>

The Central Kansas Uplift, located in west-central Kansas, covers an area of about 37,000 mi^2 (Higley, 1995). Oil and gas fields of the Central Kansas Uplift region are mainly associated to anticline structures (fig. 33). The largest oil fields (Bemis-Shutts (1928), Chase-Silica (1931), and Trapp (1936)) in the province are located along the axis of the Central Kansas Uplift.

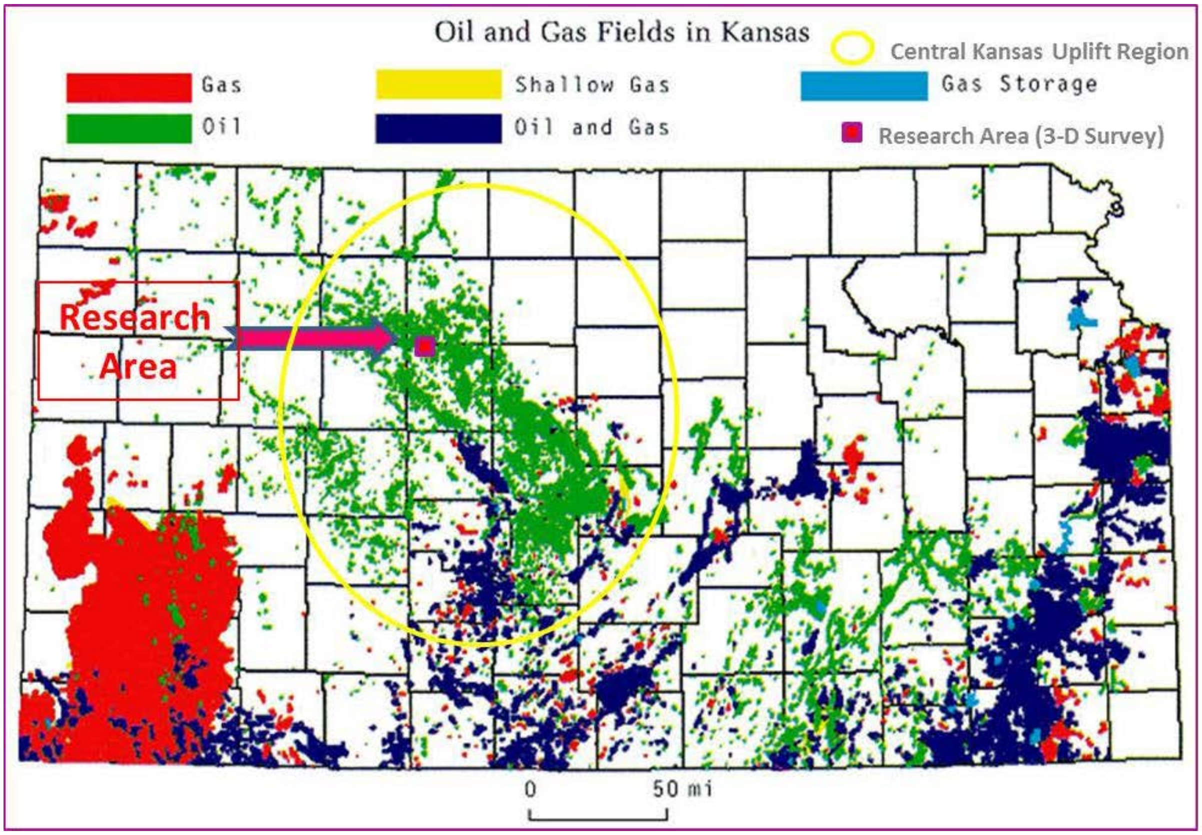


Figure 33: Kansas Oil Fields (Obtained from KGS and modified).

The extent of my research area is restricted to the area covered under the Keller 3-D seismic survey. The Keller 3-D seismic survey was recorded in the vicinity of Marcotte, Marcotte West, Berland East, Berland Southeast, Trico, Eagle Creek, Eagle Creek East, Warren, West Harris, Mendoza and Mendoza East oil fields of Ellis and Rooks counties, Kansas (fig. 34).

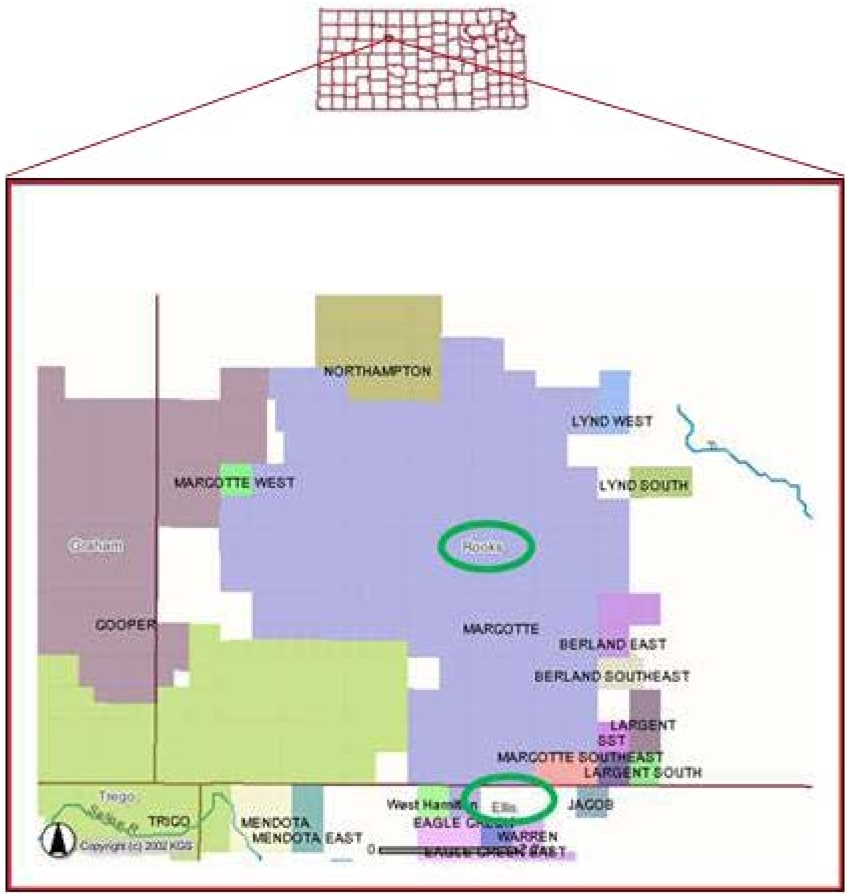


Figure 34: Map showing oil fields located in NE Ellis and SE Rook counties in the vicinity of the research area (Obtained from www.kgs.ku.edu and modified).

Pay Zones and Oil gravity (Oil Density API)

2011 oil and gas well statistics for Ellis and Rooks counties, Kansas specify that 61% of the total wells drilled in both the counties are localized in Ellis County (Kansas Geological Survey). Below is a summary with the Ellis County production data (fig. 35).

Oil and Gas Well Statistics for Kansas

Updated: **Dec. 30, 2011**

County	Total	Oil, Gas *	P&A *	D&A *	Service *	Intents *	Oil, Gas (no dates)	Remainder (total-*)
Ellis	14,784	3,616	3,349	5,798	1,263	29	181	729
Rooks	9,444	2,317	2,139	3,564	918	15	79	491

Figure 35: 2011 oil and gas well statistics for Ellis and Rooks Counties, Kansas (Obtained from KGS energy data and modified).

Oil Production Data

The oil fields located in the vicinity of the research area are Marcotte, Marcotte West, Berland East, Berland Southeast, Trico, Eagle Creek, Eagle Creek East, Warren, West Harris, Mendoza and Mendoza East (fig. 36). The Marcotte field produces oil from 4 reservoirs: the Topeka Fm., the Lansing-Kansas City Groups (Pennsylvanian), and the Arbuckle Group.

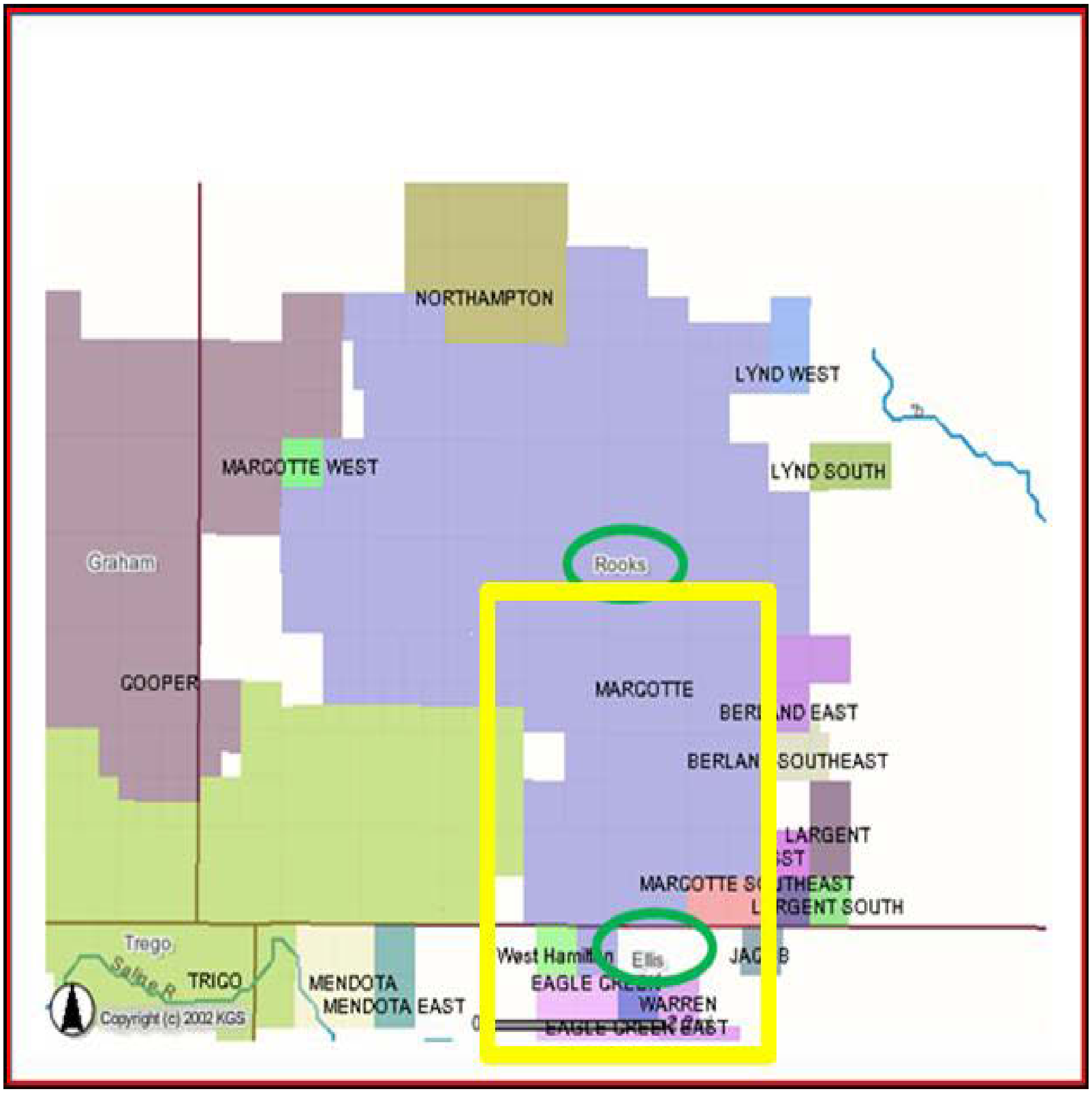


Figure 36: Main reported production for Eagle Creek, Eagle Creek East, West Hamilton and Warren oil fields near the research area (marked with the yellow square) is from the Lansing- Kansas City Group.

Oil production data reported by KGS, by field, indicates that the majority of the oil fields that surround the research area produce from the Lansing-Kansas City Group. However, oil wells within the Keller 3-D seismic survey area, hence the research area, produce from the Arbuckle Group (fig. 37).

FIELD	
Name:	EAGLE CREEK EAST
Status:	Active
Type of Field:	Oil
Produces Oil:	Yes
Produces Gas:	No
Producing Formations:	LANSING-KANSAS CITY

FIELD	
Name:	West Hamilton
Status:	Active
Type of Field:	Oil
Produces Oil:	Yes
Produces Gas:	No
Producing Formations:	Lansing-Kansas City

FIELD	
Name:	MARCOTTE
Status:	Active
Type of Field:	Oil
Produces Oil:	Yes
Produces Gas:	No
Producing Formations:	TOPEKA LANSING-KANSAS CITY PENNSYLVANIAN ARBUCKLE

FIELD	
Name:	WARREN
Status:	Active
Type of Field:	Oil
Produces Oil:	Yes
Produces Gas:	No
Producing Formations:	LANSING-KANSAS CITY

FIELD	
Name:	EAGLE CREEK
Status:	Active
Type of Field:	Oil
Produces Oil:	Yes
Produces Gas:	No
Producing Formations:	LANSING-KANSAS CITY

Figure 37: Production data of oil fields located in the vicinity of the research area.

VI. GEOPHYSICS

Hydrocarbon Exploration

Gravity and magnetic surveys are the two preliminary geophysical techniques applied indirectly to explore for hydrocarbons (oil or gas). Resulting images of the magnetic and gravity surveys are traditionally used to determine large scale features of the subsurface geology. Features or indicators suggested the need of employing a more detailed geophysical exploration tool like 3-D seismic survey. In recent times, gravity and magnetic surveys are used to explore stratigraphic traps, for example, a “pinchout zone” might produce a recognizable gravity anomaly as a result of the density contrast between the porous sandstone and the adjacent beds or between the water-saturated and oil-saturated parts of the sandstone section. Another example of gravity anomalies are reefs, these anomalies might be the result of differences in density between the reef material and the laterally contiguous beds that could be salt, limestone, or shale. Figure 38 shows aeromagnetic, gravity and oil field location maps of Rooks and Ellis counties in Kansas. There is a positive magnetic anomaly (high) around the research area. The gravity maps show low- high to middle-low values in the research area. The trend of the anomaly patterns are aligned with the trends of oil fields patterns. In the study area, aeromagnetic and gravity anomalies are indicators of possible hydrocarbon accumulations which are confirmed by oil wells and oil fields.

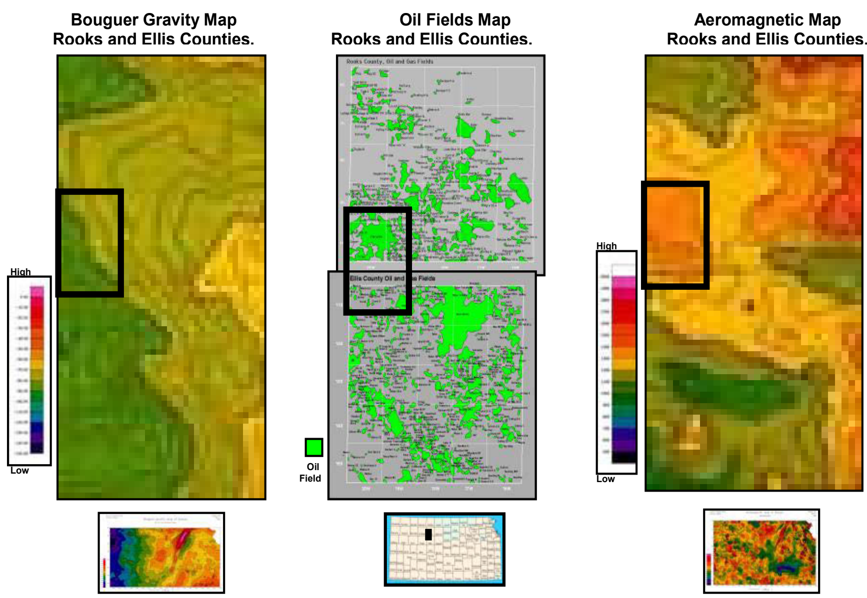


Figure 38: Aeromagnetic, gravity, and oil field location maps of Rooks and Ellis counties in Kansas (Obtained from Lam and Yarger, 1989 and modified).

<u>3-D seismic basic concepts</u>

3-D seismic is one of the most powerful and effective geophysical method to obtain a clear picture of what is below the Earth's surface. 3-D seismic is based on the principles of Earth physics commonly known as the transmitter and receiver principle. Shock waves are set off at the surface (vibroseismic unit) to penetrate deep into earth's layers, similar to Sonar. The returning-reflected echos which are recorded by receivers (geophones or microphones) are transmitted to specialized computers. Collected information is then processed and tranformed into images that can be interpreted and used to tell what is below in the subsurface (fig. 39).

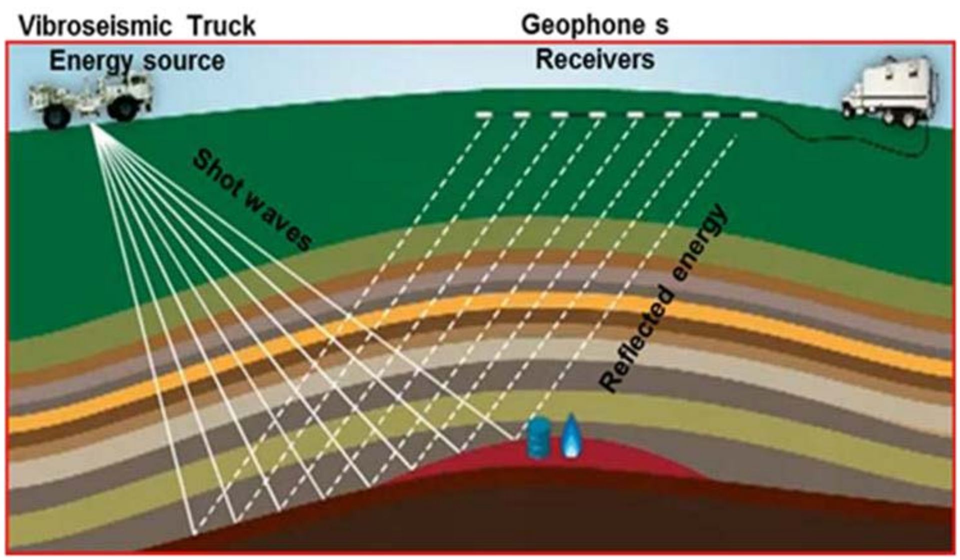


Figure 39: Acquisition of 3-D seismic data (Obtained from Schlumberger Oil Glossary and modified)

The key phases of a 3-D seismic method are acquisition, processing and interpretation. Each of these phases is usually completed by a team of specialists with varying backgrounds (Geophysics, Geology, Mathematics, Physics, Engineering etc).

The Keller 3-D Seismic Survey

The present study is focused on the interpretation phase of the Keller 3-D migrated seismic survey provided by Blake Exploration Inc. (recorded in 2003). It was then processed, migrated and interpreted by Dawson Geophysical Company in 2004.

The Keller 3-D survey was acquired with Vibroseis using sweep frequencies of 20-128 Hz. Geophone and source intervals of 165 feet resulted in a bin size of 82.5 x 82.5 feet. Data was processed using spiking deconvolution, stacking, migration and static corrections. Figure 40 summarizes the acquisition parameters of the Keller 3-D seismic survey.

Table . Keller 3-D Seismic Survey Parameters	
Energy source:	Vibroseis
Sweep frequency:	28-128 Hz
Bin size:	82.5 x 82.5 ft
Inline	1001-1130
Xline	1 - 96
Datum	2100 ft.

Figure 40: Summary of recording parameters of the Keller 3-D seismic survey.

The Keller 3-D seismic survey data was loaded, adjusted and interpreted in SMT, Kingdom Suite tool (version 8.2). Figure 41 shows the base map of the seismic data generated with the (SMT) Kingdom Suite software (version 8.2), for the research area. The base map shows location, extent, and configuration of the Keller 3-D seismic grid, which also has oil wells drilled within the research area. Eight of these oil wells are active oil producers. Well #4 was targeted in 2004 using the Keller 3-D seismic data, but resulted in a dry and plugged well and abandoned.

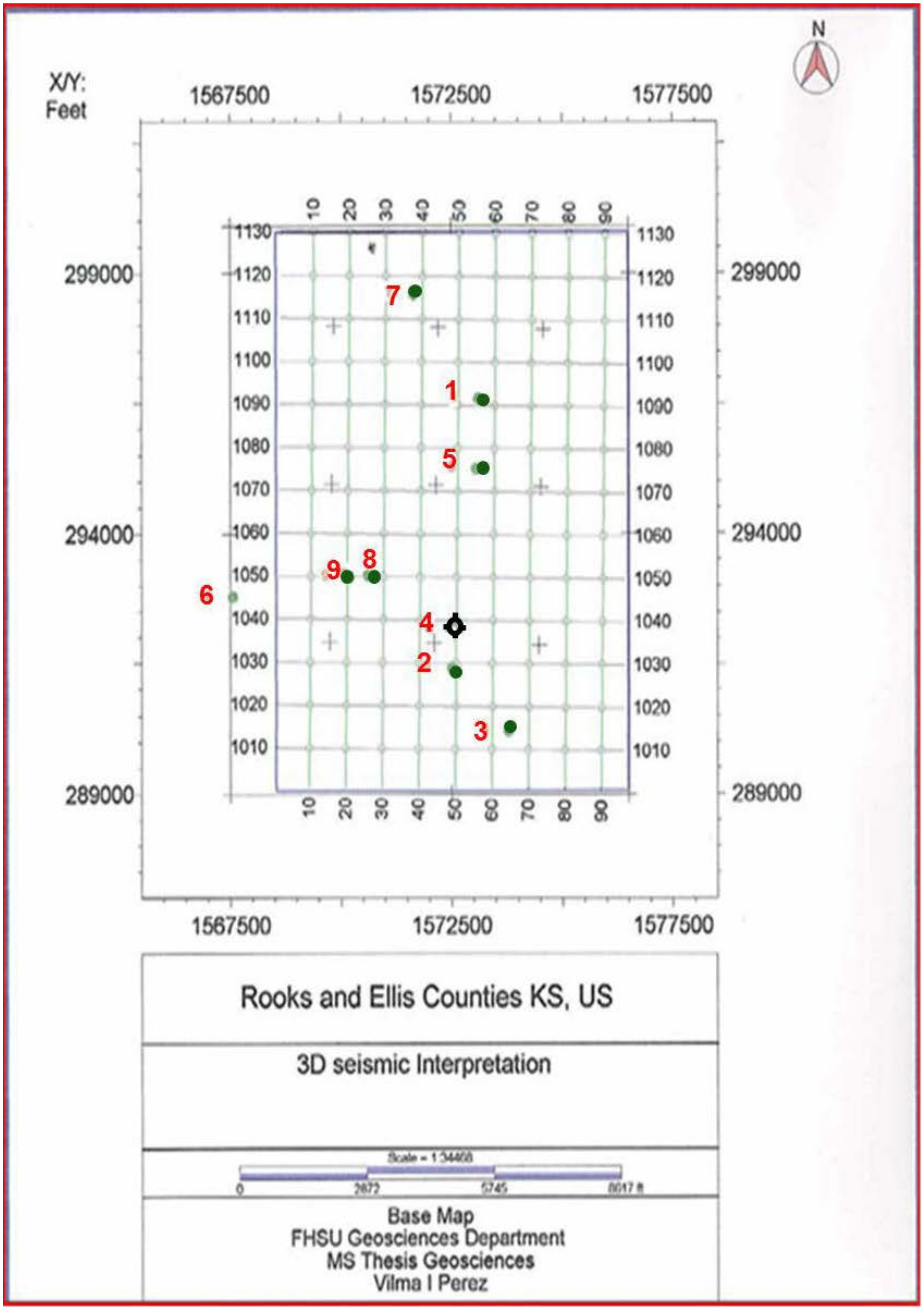


Figure 41: Base map showing the extent of the 3D seismic data (research area) and location of the 8 productive oil wells (solid dots) and a dry well (#4, black dot).

<u>Digital well logs [Log ASCII Standard (LAS) files]</u>

Digital well logs obtained from the KGS database were loaded, interpreted and correlated in EarthPAK (Kingdom Suite module). Elevation of formation tops of each borehole were loaded into SMT Kingdom Suite software (version 8.2). Interpreted well logs were projected and correlated with reflection seismic (fig. 42). Seismic vertical profiles along the crosslines and the inlines were geologically calibrated (as mentioned in figure 2).

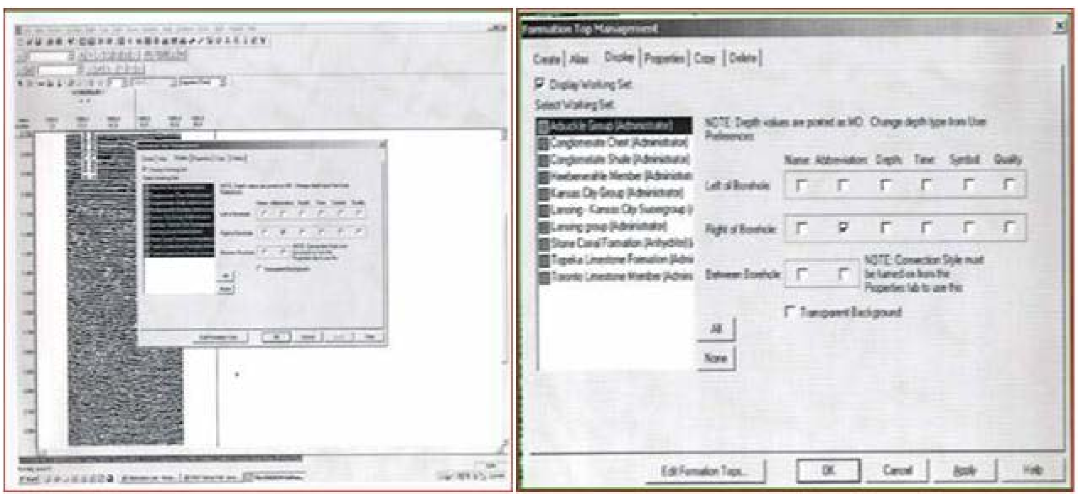


Figure 42: Formation tops well management with SMT Kingdom Suite software (version 8.2) and EarthPAK module.

Well-logs from the nine oil wells drilled within the research area were loaded into Geolog (version 6.7). A composite layout template with a vertical scale of 1:5000 was created in Geolog, to display, interpret, and plot the selected well-logs. Subsurface data (stratigraphic tops) was added to the plotted logs (Appendixes B1-B9).

A standard suite of oil well wire-log profiles or curves generally contains: 1) Gamma-ray (GR) log; 2) Spontaneous Potential (SP) log; 3) Caliper (ca) log; 4) Resistivity deep lateral log (LLD); 5) Conductivity log; 6) Sonic log; 7) Density (RHO) log; 8) Density correction; and 9) Neutron log. Additionally, the log suite can also contain a tension curve and a rate of penetration curve.

Figure 43 is a table with the inventory of the well-log profiles recorded in each one of the nine oil wells drilled within the research area. Only few of these records were continuously recorded along the whole wells. Some digital records were technically impossible to display or to download on a digital format. Geolog was used to create composite logs of the studied wells. GR and LLD logs were continuously recorded in all studied wells, therefore, selected to be displayed in the composite wells. GR is used to interpret lithology type and vertical changes in it. LLD curves are selected because resistivity log helps in interpreting the fluid content.

Wirelogs recorded in Oil-wells located in study area

Available Wirelog / Oil-Well number	SP	GR	LGRD	SCAL	MCAL	DCAL	LSPD	LTEN	TBHV	ABHV	SWPOR	SWLS	SWSS	SWDL	SWNC	MN	MI	DT	ITT	SPOR	CILD	RLL3	RILM	RHOB	DPOR	CNLS	RxoRt
1-R /H-K#1-36	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X										
2-E /Keller#1	X	X			X	X	X	X	X	X						X	X				X	X	X	X	X	X	X
3-E /Keller#2	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X										
4-R /Keller -Heirs #1		X				X												X	X	X							
5-E /Keller C #1	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X										
6-E /Love #2	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X										
7-R /Trarbach #1		X		X														X	X	X							
8-E /Wending No. 1	X	X			X	X	X	X	X	X						X	X				X	X	X	X	X	X	X
9-E /Wending # 2	X	X	X	X	X		X	X	X	X	X	X				X	X										

Figure 43: Table with a list of well-logs recorded in all the nine wells in the research area.

Following is a list of well-log names (full and abbreviated names):

SP= SPONTANEOUS POTENTIAL

GR= GAMMA-RAY

LGRD= LONG GUARD

SCAL= SWN CALIPER

MCAL= CALIPER FROM MICROLOG

DCAL= CDL CALIPER

LLD= DEEP LATEROLOG

LSPD= LINE SPEED

LTEN= SURFACE LINE TENSION

TBHV= BOREHLE VOLUME TICKS

ABHV= ANNULAR VOLUME TICKS

SWPOR= SWN POROSITY

SWLS= SWN LIMESTONE POROSITY

SWSS= SWN SANDSTONE POROSITY

SWDL= SWN DOLOMITE POROSITY

SWNC= SWN COUNTS

MN= MICRO NORMAL RESISTIVITY

MI= MICRO Inverse Resistivity

DT= DENSITY

ITT= INTERVAL TRNASIT TIME

SPOR= SANDSTONE POROSITY

CILD= DEEP CONDUCTIVITY

RLL3= DIL SHALLOW RESISTIVITY

RILM= DIL MEDIUM RESISTIVITY

RHOB= CDL BULK POROSITY

DPOR= CDL DENSITY POROSITY

3-D Seismic interpretation

3-D seismic data loaded into 2d/3dPAK was calibrated with a synthetic seismogram generated from sonic log of Keller#1 well. Figure 44 shows a synthetic seismogram compared to a trace started from a 3-D seismic recorded near my research area. Figure 45 is a geologically-calibrated seismic profile from the same study. It shows, identifies and correlates strong seismic reflectors with tops of the local stratigraphic units (Nissen et al., 2004).

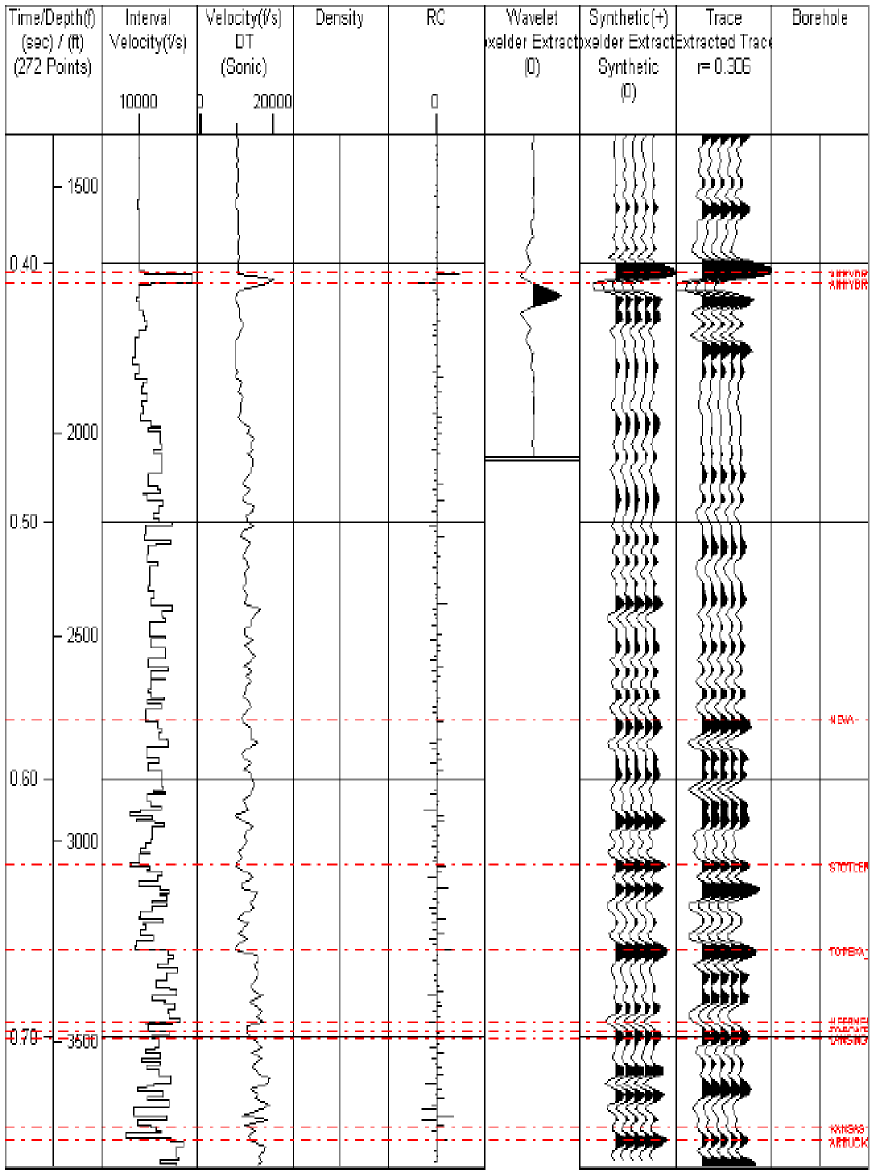


Figure 44: Synthetic seismogram created from sonic and density logs and used to tie and calibrate known stratigraphic tops to a seismic trace of a 3-D seismic survey recorded near the research area (Obtained form Nissen et al., 2004 and modified).

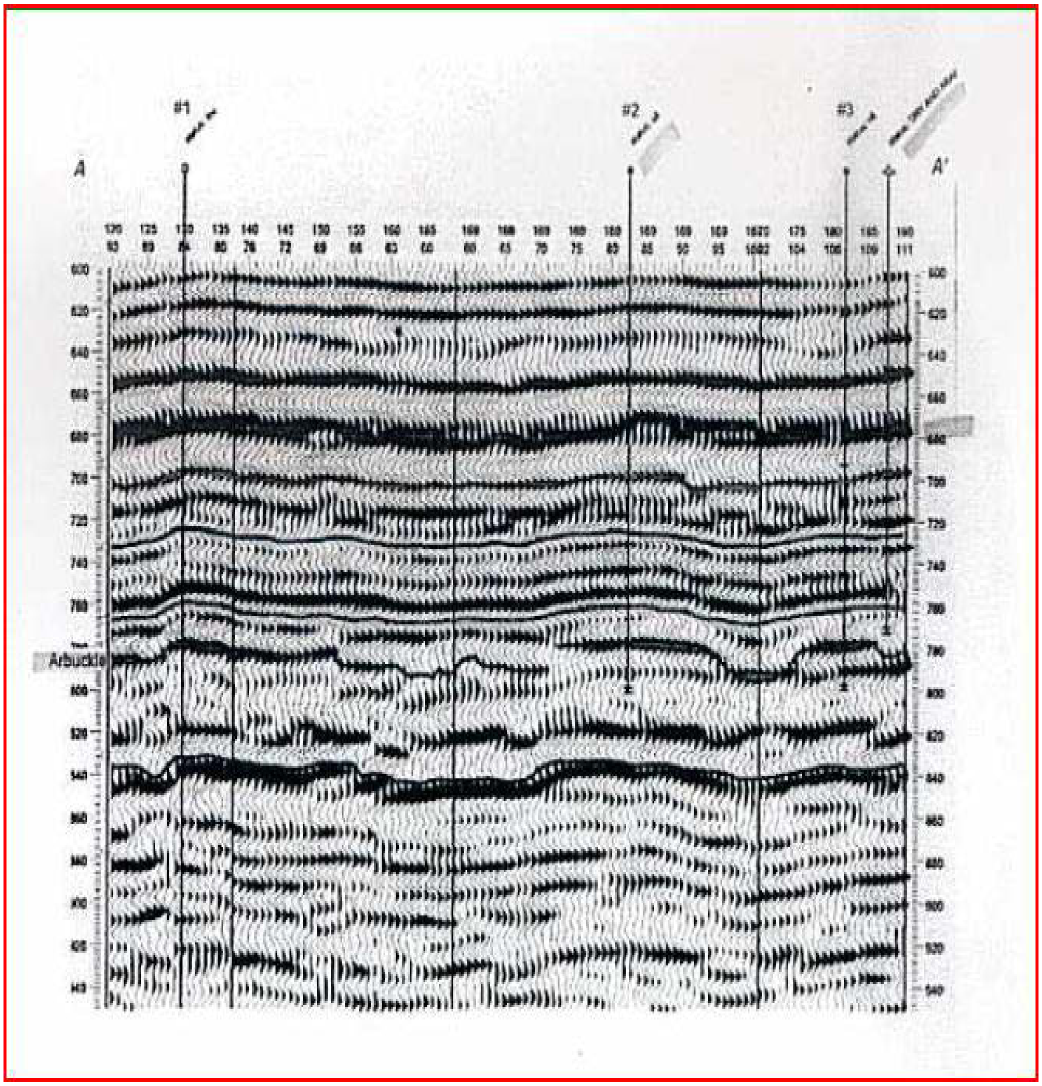


Figure 45: Seismic profile from a 3-D seismic survey recorded near the research area and calibrated with the well data. (Obtained from Nissen et al., 2004 and modified).

<u>Research Area: 3-D Seismic Profiles</u>

I built and interpreted the seismic profiles (N-S and W-E) along the inlines and the cross-lines of the Keller 3-D seismic survey. Interpretation was calibrated with the well tops and log data (fig. 46). Figure 47 shows a seismic profile calibrated with a well from the research area and with a log (including a sonic log) that reached the Arbuckle Group.

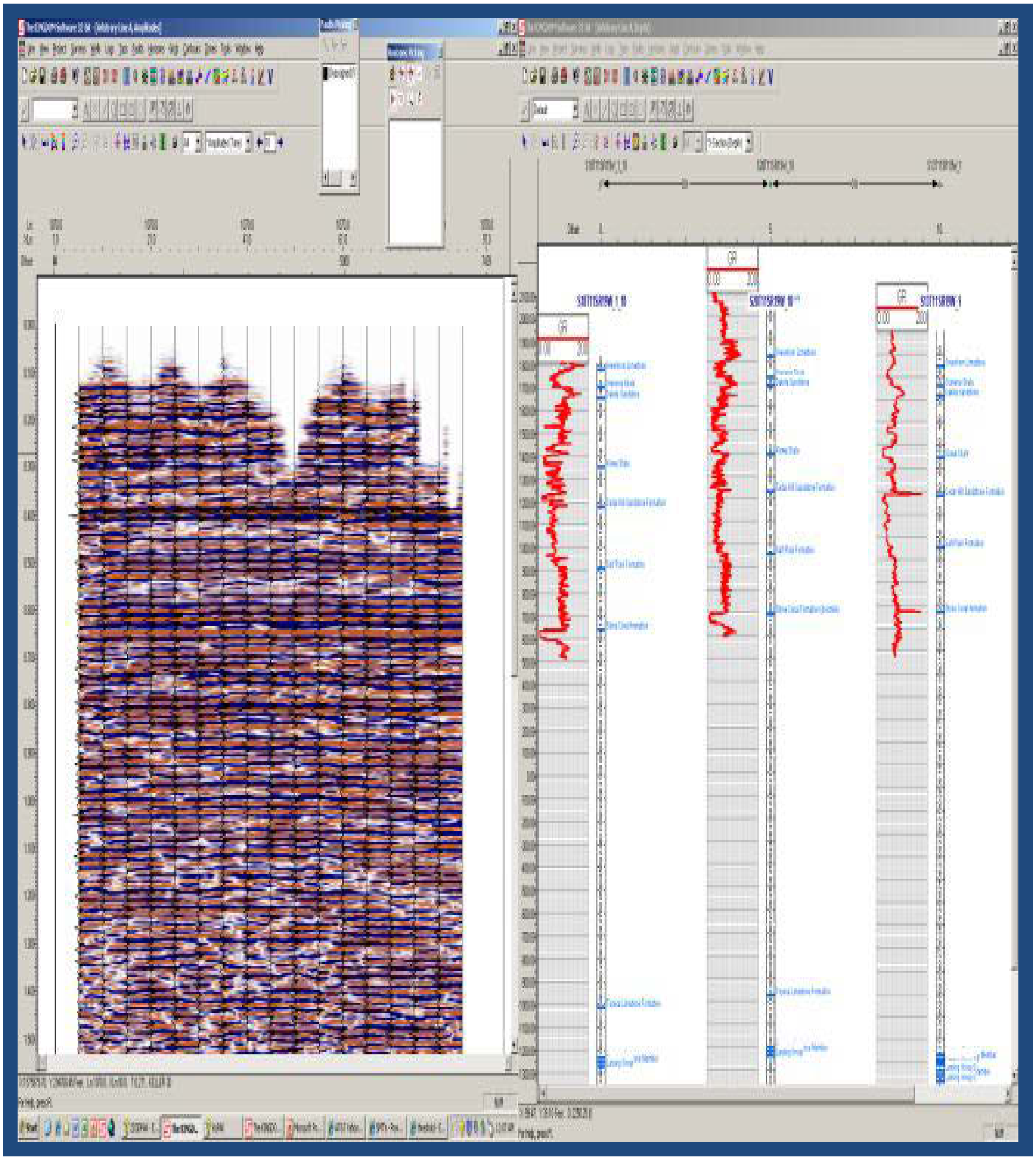


Figure 46: A carefully calibrated and interpreted seismic cross section identifying the tops of the stratigraphic horizons, from the Keller 3-D seismic survey.

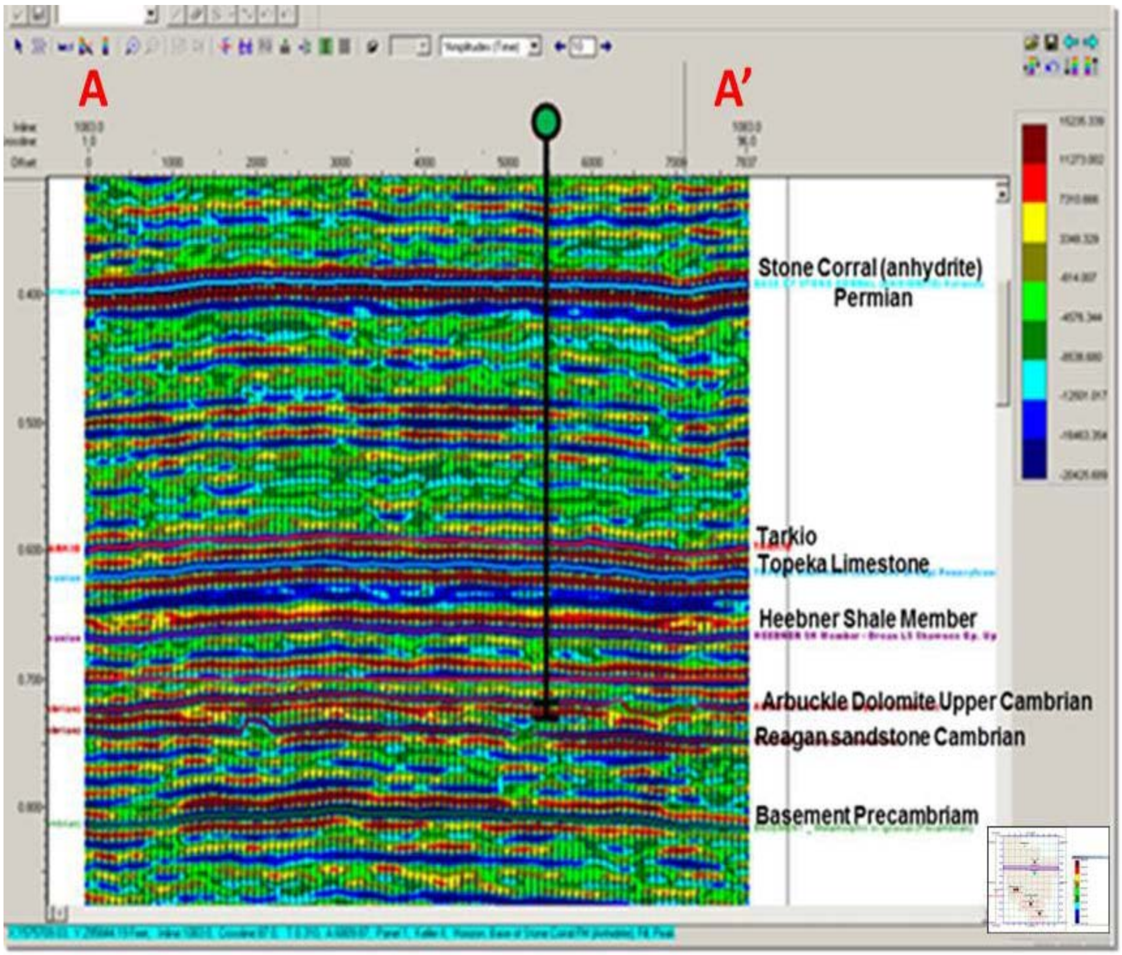


Figure 47: The Keller 3-D seismic profile (amplitude time) was interpreted and geologically calibrated (tied) with the local well data (green circle and black line). Seismic reflectors are correlated (tied) to the stratigraphic tops.

<u>Seismic Attibutes</u>

The 3-D seismic interpretation is enhanced with the interpretation of seismic attributes such as amplitude, instantaneous frequency, reflection strength, instantaneous phase polarity. These attributes help in identifying geological features and indicate the presence of fluids. Geological features such as gross porosity and lithological contrast are predicted with the interpretation of seismic amplitude maps. Figure 48 sumarizes the geological significance of some of these seismic attributes.

Geological Significance of Seismic Attributes	
Amplitude	Lithological contrasts Bedding continuity Bed spacing Gross porosity Fluid content
Instantaneous Frequency	Bed thickness Lithological contrasts Fluid content
Reflection Strength	Lithological contrasts Bedding continuity Bed spacing Gross porosity
Instantaneous Phase	Bedding continuity
Polarity	Polarity of seismic Lithological contrasts

Figure 48: Seismic attributes and associated geological characteristics (Obtained from Schlumberger Oil glossary and modified).

Computer-based interpretation and display of the 3D seismic data helps to obtain a detailed analysis. The Keller 3-D seismic survey data was loaded in SMT Kingdom Suite. The funtionality of the 2D/3DPAK, a Kingdom suite module, allows one to map seismic attributes such as the seismic amplitude. Boreholes, log and well data from the local wells was also incorporated to calibrate the interpretation of the seismic profiles.

Figure 49 shows the seismic amplitude map on top of the Arbuckle Group. Brown color areas are the zones of high amplitude, which are associated to or interpreted as paleo-highs (structural highs). The blue areas are interpreted as lower zones or paleo-depressions. The majority (89%) of the oil producing wells, within the research area, penetrated the Arbuckle Group on tops or flanks or highs (light brown areas). The dry hole (#4), which is located near the oil producing wells (#1,2,3,5,6,7,8) reached the structurally low portion

(N-E flank) of a small Arbuckle paleo-high. This down-deep (structural) location is the cause for the unexpected results in case of this hole.

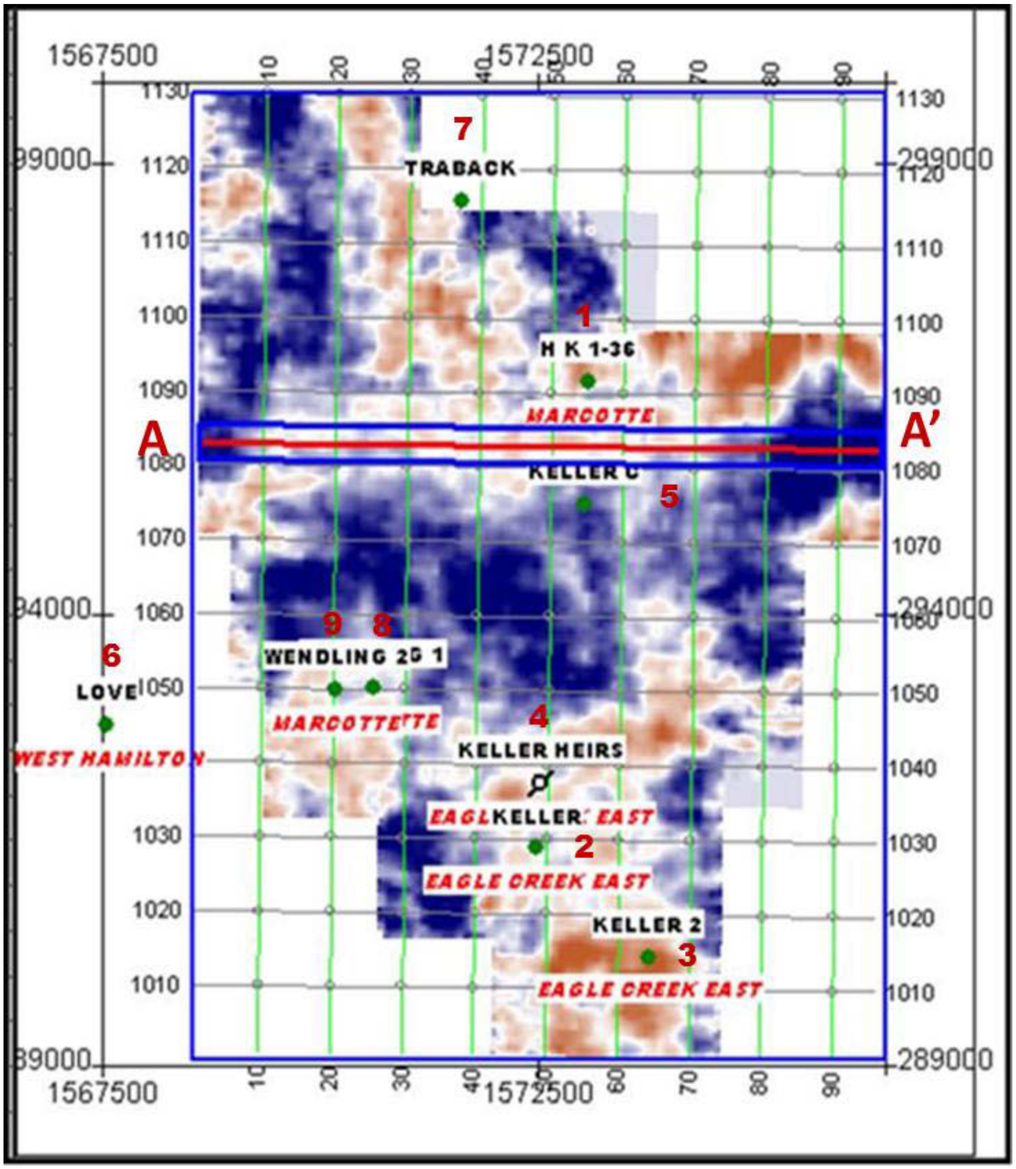


Figure 49: Seismic amplitude map (time slide) on top of the Arbuckle Group. High amplitudes are shown in brown/light grey, and low amplitudes are shown in blue/dark color.

Figure 50 shows is an isochron map, in seismic time, built after interpreting the Keller 3-D survey. The mapped interval (time) extends from top of the Arbuckle Group down to top of the Precambrian basement. Circular features (red) that stand out in the map are interpreted as paleo-depressions (possible sinkholes) related to the Precambrian paleo-relief. All the oil producing wells, located in the research area, penetrated the top of the Arbuckle Group (green zones) where the mapped interval is not very thick. Most probably these green areas are associated to tops or flanks of the paleo-highs. Well #4 (dry hole) penetrated the Arbuckle Group on a yellow zone where the mapped interval is thick.

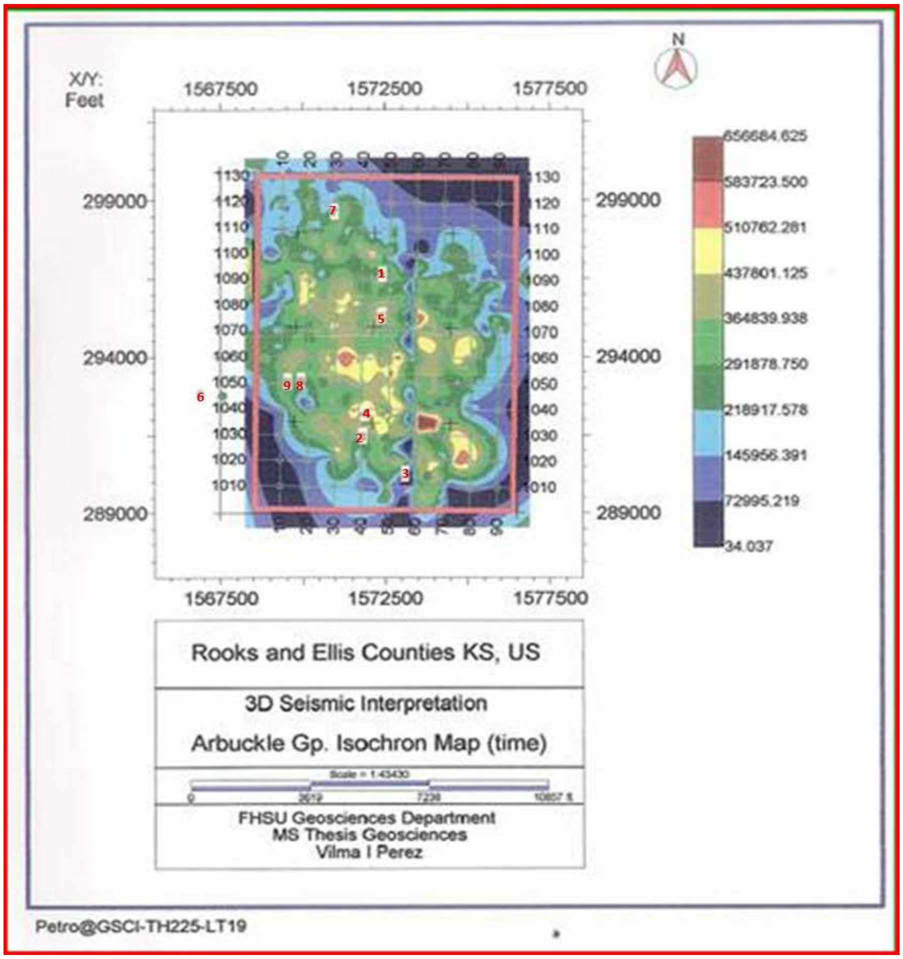


Figure 50: Isochron map (seismic time) of the study area. A thickness map: from the top of the Arbuckle Group to the top of the Precambrian basement. Map was created using Seismic Micro Tecnology (SMT) Kingdom Suite software (version 8.2, 2011).

Figure 51 shows a velocity map at the top of the Arbuckle Group. An attribute (velocity) map in depth (feet) was generated after completing a time/depth transformation. SMT Kigdom Suit tool has a module that allows one to load a sonic log and create a synthetic seismogram. The sonic log recorded in the well # 2 was used to built a synthetic seismogram and create the time depth transformation shown in this velocity map. The velocity map indicates that the top of the Arbuckle Group in the research area is between 3,568 ft. and 3,761 ft. deep. This is consistent with tops reported in the well reports. There is an elliptically-shaped structural high feature in the southeast corner of the velocity map. The top of this high is around 2,022 ft. This mapped feature is an artificial element (noise), or is a structural high and a potential new drill site.

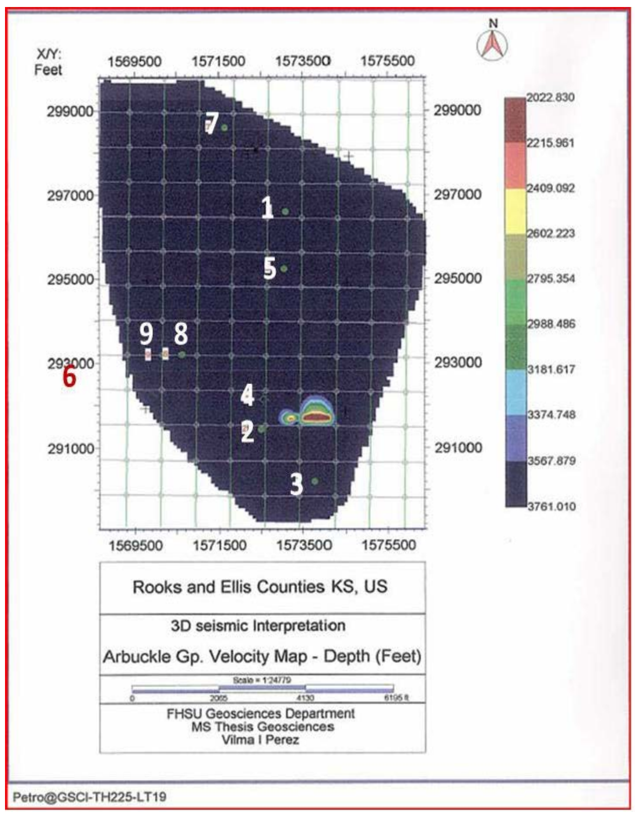


Figure 51: Attribute Map (Velocity) on top of the Arbuckle Group with eight oil producing wells (1-3 and 5-9) and one dry well (4). Map was created using Seismic Micro Technology (SMT) Kingdom Suite software.

Figure 52 shows a 3-D Seismic data volume cube from the Keller 3-D seismic survey. The uppermost part of the cube shows a seismic time-slice of the top of the

Arbuckle Group-Basement isopach. Oil production wells 1, 5, 9, and 3 are projected on the map. All these oil wells penetrated the Arbuckle Group. Dry hole (well#4) is located on the edge of a high-amplitude anomaly.

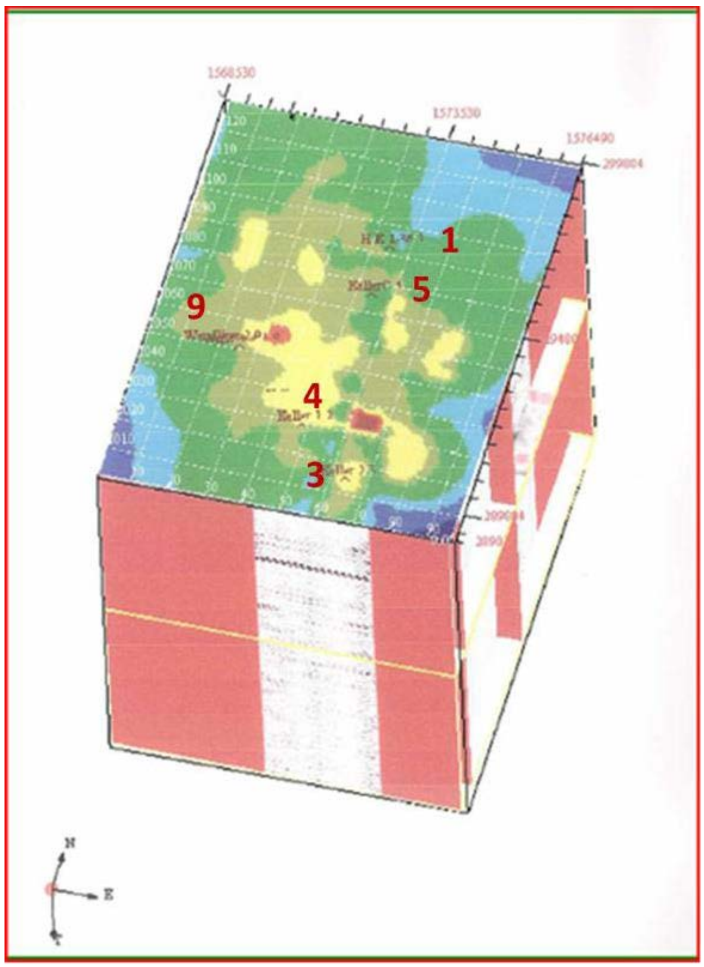


Figure 52: 3-D Seismic data volume cube from the Keller seismic survey.

VII. RESULTS

My study produced many tangible outcomes which are:

1) Self-training in how to load and tune up data, and use Seismic Micro Technology (SMT) Kingdom Suite software (version 8.2) and Geolog (version 6.7) to interpret a 3-D seismic survey, well data, and well logs.

2) Creation of base maps with Seismic Micro Technology (SMT) Kingdom Suite software (version 8.2).

3) Interpretation of nine well logs suite recorded in oil wells located within the research area.

4) Stratigraphic correlation well logs located within the research area to study GR and resistivity logs.

5) Generation of a high-level chart to understand local elements and processes of the Arbuckle Petroleum System.

6) A summary of lessons learned and best practices shared by various experienced personnel of the locality.

7) A summary with descriptions of cuttings.

8) Geological-geophysical interpretation of logs, lithological well tops, and the Keller 3-D seismic survey.

9) Creation of a seismic profile where seismic reflectors are calibrated with stratigraphic tops.

10) Creation of a seismic amplitude map on top of the Arbuckle Group to illuminate lithology, structural relief and fluid content.

11) Velocity map to depth on top of the Arbuckle Group.

12) Detailed interpretation of nine log profiles on a vertical scale of 1:5000 in Paradigm Geolog Formation Evaluation software.

13) Isochron map of the interval that extends from the top of the Arbuckle Group (Cambrian Ordovician) to the top of the Precambrian basement.

14) Analysis of recorded gamma-ray and resistivity logs to identify the location of the top of the Arbuckle Group dolomite.

VI. CONCLUSIONS

Results of gravity and magnetic surveys conducted in the region show high anomalies in the research area. Such anomalies are indicators of a possible accumulation of hydrocarbons in the locality and suggest that a further, more detailed geophysical exploration such a 3-D seismic surveys are needed.

Oil fields surrounding the research area produce oil from two main reservoirs: the Lansing-Kansas City (Lower Pennsylvanian) and the Arbuckle (Cambrian-Ordovician) Groups. The Arbuckle Group is the most proliferous oil-bearing reservoir in the region.

The Arbuckle Group is characterized by a shallow-shelf, marine carbonates which are out-cropping the Kansas subsurface. The reservoir quality of the Arbuckle Group is controlled by the primary depositional environments and a subsequent diagenetic history. The latter includes both dolomitization and karstification processes. Karstification occurred during sub-aerial exposures and enhanced reservoir porosity.

In the research area, the Arbuckle Group reservoir produces oil from three different lithofacies: 1) dolomites with vugular porosity (karst features); 2) dolomites with original high porosity; and 3) dolomites with fractures.

The thickness of the Arbuckle Group in Ellis and Rooks counties, Kansas is about 300 feet (91.44 meters). However, this oil-bearing reservoir produces mainly from the first 5 to 10 feet (1.524 -3.048 meters).

Observations of local operators suggest that oil wells in the Arbuckle Group are characterized by high initial potential and steep decline rates and that Arbuckle oil wells tend to produce large quantities of oil at high water/oil ratios.

There was no evidence of gas accumulations in the Arbuckle Group reservoir within the research area. The oil that has been produced from the Arbuckle Group reservoir is classified as heavy oil with an API gravity that ranges between 18-20 °. The best pay-zones with high porosity and permeabilities are associated to the presence of karst features in high paleo-topographic relief.

In this study, the Keller 3-D seismic survey is interpreted to reach a balance between geophysics, geology, and computer science.

Analysis of the 3-D seismic and the geological data suggests that the selected location of the well #4 was based on a misconception. Interpretation of the seismic amplitude map (fig. 49) at the top of the Arbuckle Group reservoir reveals that the dry hole (#4) penetrated the top of the Arbuckle reservoir at the edge of a brown anomaly (high-amplitude anomaly). The seismic amplitude map also shows that the eight oil producing wells penetrate the Arbuckle at the top or near the tops (flanks) of positive anomalies. By displaying paleo-relief, the isochron map (top of the Arbuckle to basement) shows red circular features interpreted as paleo-depressions. It is worth noting that none of the discussed wells penetrated these red circular features. Overall, all the maps presented in this study indicate that the dry hole (# 4) missed both the trap and the reservoir.

The thicknesses of the stratigraphic units penetrated and logged by the oil wells, located within the research area, are consistent. This implies that faults are not evident in the logged data and therefore no fault traps are present. Gamma-ray measurements are used to identify stratigraphic tops, vertical changes in lithology, and LLD information allows for the estimation of fluid content in the surveyed area. An abrupt shift to the left in the GR curve marks the top of the Arbuckle Group. The GR curve recorded on the dry hole (#4) indicates a dolomite was penetrated; nevertheless, the resistivity log (LLD) does not indicate any presence of oil.

Moreover, information from previous drilling sites indicates that it is not a good production prognosis when a well (drilled in the research area) penetrates an Arbuckle Group interval characterized by green shales. A sample in the Arbuckle facies described in the Kollman No#6 well, drilled in Ellis County is characterized by green shales. Kollman No#6 was reported dry and abandoned. Fracture-fill shale facies of the Arbuckle Group are described as green colored shales and classified as a fracture or a cave fill with sediment originated from above the upper Arbuckle unconformity surface. Thus, the green shales occlude the Arbuckle Group's original fracture porosity.

A high-level analysis of the Arbuckle Petroleum System suggests that the risks of not having a charge and an effective, top seal in the research area are small. However, there are large uncertainties and risks associated with the existence of the trap and of an effective reservoir. The finding of a dry hole on well #4, where both trap and reservoir failures are evidenced, serves as an example of these risks.

Within the seismic attribute analysis, the amplitude map provided valuable information. High amplitude anomalies are commonly interpreted as good indicators of fluid presence and high gross porosity. The seismic amplitude map on top of the Arbuckle Group, built in this study after interpreting the Keller 3-D seismic survey, indicates that well #4 (dry hole) was drilled in the external margin of a high seismic amplitude (anomaly), where the porous dolomite (reservoir) was absent. This further indicates that the drilling site was erroneously selected.

REFERENCES CITED

Adler, F.J., 1971, Future petroleum provinces of the Midcontinent, region 7, in Cram, I.H., ed., Future petroleum provinces of the United States--their geology and potential: American Association of Petroleum Geologists, Memoir 15, p. 985-1,120.

Archie, G.E., 1942, The electrical resistivity log as an aid in determining some reservoir characteristics. Petroleum Transactions of AIME 146: 54–62.

Berry, G. F., Jr., and Harper, P. A., 1948, Augusta field, Butler County, Kansas; in, Structure of typical American oil fields, v. 3: Am. Assoc. Petroleum Geologists, Tulsa, p. 213-224.

Bliefnick, D. M., 1992, Karst-related diagenesis and reservoir development in the Arbuckle Group, Paschall #2 core, Wilburton field Oklahoma; in, Permian Basin Section: Society of Economic Paleontologists and Mineralogists, Publication No. 92-33, p.137-152.

Bloesch, Edward, 1954, Unconformities in Oklahoma and Their Importance in Petroleum Geology

Cole, V.B, 1975, Subsurface Ordovician-Cambrian rocks in Kansas, Kansas Geological Survey, Subsurface Geology Series, no. 2, 18 pages http://www.kgs.ku.edu/Publications/Bulletins/Sub2/index.html.

Crysdale B.L. and C.J. Schenkusgs, 1989, Heavy Oil Resources of the United States, USGS Bulletin No 1885. 134 p. http://pubs.usgs.gov/bul/1885/report.pdf

Dreiling, M.L., 2005, 3-D seismic interpretation in the Catherine oil field area of Ellis County, Kansas, unpublished MS Thesis, 65 p.

Fath, A. E., 1921, Geology of the El Dorado oil and gas field: Kansas Geol. Survey Bull. 7, 187 p.

Franseen, E.K., 2000, A review of Arbuckle Group strata in Kansas from a sedimentologic perspective: insights for future study from past and recent studies; The Compass of Sigma Gamma Epsilon, v. 75, numbers 2 and 3, p. 68-69.

Franseen, E.K.; Byrnes, A.P.; Cansler, J.R.; Steinhauff, D.M.; and Carr, T.R., The geology of Kansas, Arbuckle Group, 2004, Kansas Geological Survey, Current Research in Earth Sciences, Bulletin, no. 250, pt. 2, Available online: http://www.kgs.ku.edu/Current/2004/franseen/index.html

Franssen, E.K., Byrnes P., Cansler, J.R., Steinhauff, D.M., Carr T.R., and Dubois M.K., 2003, Geological controls on variable character of Arbuckle reservoirs in Kansas: an emerging picture, KGS Open File Report 2003-59. http://www.nmcpttc.org/CASE_STUDIES/GELPOLYMER/ARBUCKLE.HTML.

Geolog, (version 6.7). Paradigm Geolog Formation Evaluation Software. www.pdgm.com/products/geolog.aspx

Gussow William, 1954, Differential Entrapment of Oil and Gas: A Fundamental Principle, American Association of Petroleum Geologists (AAPG) May Bulletin, Volume 38, May, p 816-853.

Henry, M.E., and T.C. Hester, 1996, Map showing petroleum exploration intensity and production in major Cambrian to Ordovician reservoir rocks in the Anadarko Basin: U.S. Geological Survey Miscellaneous Field Studies Map, MF-2313, 3 sheets.

Higley, D.K., 1995, Cambridge Arch/Central Kansas Uplift Province (053), in Gautier, D. L., Dolton, G.L., Takahashi, K.I., and Varnes, K.L., eds., 1995 National Assessment of United States oil and gas resources--Results, methodology, and supporting data: U.S. Geological Survey Digital Data Series DDS-30, Release 2, one CD-ROM. http://certmapper.cr.usgs.gov/data/noga95/prov53/text/prov53.pdf

KGS, Energy web site, Current Study in Earth Sciences, 3-D seismic model on top of Arbuckle, Kansas Geological Survey, Bulletin 250. http://www.kgs.ku.edu/General/copyright.html

Lam, C-K., and Yarger, H.L., 1989, State gravity map of Kansas; in Steeples, D.W., ed., Geophysics in Kansas: Kansas Geological Survey, Bulletin 226, p.

Moore, R. C., and et al., 1952, Graphic column of Kansas rocks: Kansas Geol. Survey, chart. http://www.kgs.ku.edu/General/copyright.html.

Newell, K.D., Watney, W.L., Cheng, S.W.L., Brownrigg, R.L., 1987, Stratigragraphic and spatial distribution of oil and gas production in Kansas: Kansas Geological Survey, Subsurface Geology Series 9, 86 p.

Nissen, S. E., Carr, T. R., and Marfurt, K. J., 2007, Using new 3-D seismic attributes to identify subtle fracture trends in Mid-Continent Mississippian carbonate reservoirs: RMAG-DGS 13th Annual 3-D Seismic Symposium expanded abstract (also published in Geophysical Society of Kansas May-June newsletter: http://gsks.seg.org/newsletter/MAY-JUN07.pdf

Nissen, S.E. and E. Charlotte Sullivan, 2005, Improving Geologic and Engineering Models of Midcontinent Fracture and Karst-Modified Reservoirs: Using New 3-D Seismic Attributes, The University of Kansas Center for Research, Inc. Kansas Geological Survey, University of Kansas, Lawrence, Kansas

Nissen, S. E., Doveton, J. H., and Watney, W. L., 2008, Petrophysical and geophysical characterization of karst in a Permian San Andres reservoir, Waddell field, West Texas: abstract, AAPG Annual Convention and Allied Geophysical Laboratories, Department of Geosciences, University of Houston, Houston, Texas. Semiannual Scientific/Technical. DE-FC26-04NT15504: http://www.KGSku.edu/SEISKARST/DE_FC26_04NT15504_April05_semiannual.pdf

Nissen, S. E., Rundle K., Lockhart E., and Morrison E., 2004, Seismic Applications by Independent Operators in Kansas. Kansas Geological Survey, Consulting Geophysicist, and Mull Drilling Company. http://www.nmcpttc.org/Case_Studies/PTTC

Ramondetta, Paul J., 2011, A comparison of karstification in the El Dorado oil field to other major Arbuckle oil fields in Kansas, Kansas Geological Society, Bulletin Volume 86, 5 September -October 2011. http://www.KGSlibrary.com/downloads/bulletins/2011/Sept-Oct%2011.pdf

Reekman, A., and G.M. Friedman, 1982, Exploration for carbonate petroleum reservoirs**:** New York, John Wiley and Sons, p. 113-118.

Seismic Micro Technology (SMT) Kingdom Suite software (version 8.2, 2011)

Schlumberger Ltd., 2012, Oil Glossary. http://www.glossary.oilfield.slb.com/

Walters, R.F., 1958, Differential entrapment of oil and gas in the Arbuckle dolomite of central Kansas: American Association of Petroleum Geologists Bulletin, v. 42, p. 2,133-2,173.

Walters, R.F., 1991, Gorham Oil field, Russell County, Kansas; Kansas Geological Survey Bulletin 228, 112 p.

Watney, W.L.; Franseen, E.K.; Byrnes, A.P.; and Nissen, S.E., 2008, Evaluating structural controls on the formation and properties of Carboniferous carbonate reservoirs in the northern midcontinent, U.S.A., Controls on carbonate platform and reef development, SEPM (Society for Sedimentary Geology), Tulsa, OK, Special Publication, no. 89, 364 p.

Wilson, J.L., Fritz, R.D., and Medlock, P.L., 1991, The Arbuckle Group-relationship of core and outcrop analyses to cyclic stratigraphy and correlation, in Johnson, K.S., ed., Arbuckle Core Workshop and Field Trip: Oklahoma Geol. Survey, Spec. Publ. 91-3, p. 133-144.

APPENDIX

Appendix A: (A1-A9): Logging Data and Stratigraphic tops per oil well. (LAS files, obtained from KGS and modified)

A.1. Well Name: H K 1-36. Study well Number 5.

Surface Location (feet): X=1573070.062 Y=296586.316.

Sub-Sea Elevation (Feet): not reported.

Ground Level: not defined. Datum: 0.0.

Depth (Feet): 3692.0 TD (MD).

Number of Boreholes = 1: 1.H K 1-36;

UWI: 1516323436

Bore Depth (Feet): no defined reported.

Top: not defined.

Bottom: 3692.0

Company: BLAKE EXPLORATION, LLC.

Kelly Bushing: 2095.0 (Elevation Feet) Formation @ TD: LANSING-KANSAS

Completion: not reported.

Date = 2005/04/16

Stratigraphic Top Data: Number of Tops = 6 (Depth) Name of the Stratigraphic Unit:

1. (1524.0) Stone Corral Formation: Anhydrite.

2. (3113.0) Topeka Limestone Formation

3. (3327.0) Heebenerahle Member.

4. (3358.8) the Lansing group.

5. (3585.0) the Kansas City Group.

6. (3676.0) the Arbuckle Group.

7. (3113.0) Topeka Limestone Formation

Well Log Data: Number of Logs = 16

No.	Type	Start (Ft)	End (Ft)	Rate (Ft)	Min Va	Max Va
1	LSPD	195.0	3693.5	0.50	0.00	124.97
2	LTEN	195.0	3695.0	0.50	0.05	895.37
3	TBHV	195.0	3693.5	0.50	0.00	2.00
4	ABHV	195.0	3693.5	0.50	0.00	2.00
5	SWNC	195.0	3691.5	0.50	0.00	1933.63
6	SCAL	195.0	3689.0	0.50	3.18	18.55
7	SWPOR	195.0	3689.0	0.50	0.81	92.17
8	SWLS	195.0	3689.0	0.50	0.81	92.17
9	SWSS	195.0	3689.0	0.50	3.81	95.17
10	SWDL	195.0	3689.0	0.50	-1.19	90.17
11	SP	195.0	3698.0	0.50	0.00	80.61
12	LGRD	195.0	3684.0	0.50	-2.00	2859.97
13	GR	195.0	3681.0	0.50	0.01	355.39
14	MCAL	3293.5	3693.0	0.50	4.91	10.41
15	MI	3293.5	3693.0	0.50	1.51	63.64
16		3293.5	3693.0	0.50	1.21	47.72

A.2. -Well Name: KELLER. Study well Number 3.

Surf ace Location: (X, Y Feet) = (1572478.170, 291414.564)

Sub-Sea Elevation (Feet): not reported.

Ground Level: 2050.0.

Seismic Datum: 0.0, Depth (Feet): 3700.0 TD (MD)

Number of Boreholes = 1, 1.KELLER

UWI: 1505125303

Bore Depth (Feet): Top: not defined.

Bottom: 3700.0

Company: BLAKE EXPLORATION, LLC

Kelly Bushing: 2055.0 (Elevation Feet)

Formation @ TD: ARBUCKLE

Completion:

Date = 2004/09/14

Symbol = 0 (DarkGreen, 0.381)

Stratigraphic Top Data: Number of Tops= 6 (Depth) Name of the Stratigraphic Unit:

1. (1458.0) Stone Corral Formation (Anhydrite).

2. (3068.0) Topeka Limestone Formation.

3. (3282.0) Heebenerahle Member.

4. (3315.3) the Lansing group.

5. (3537.0) the Kansas City Group.

6. (3637.1) the Arbuckle Group.

Well Log Data: Number of Logs = 20

No.	Type	Start(Ft)	End(Ft)	Rate(Ft)	Min(Va)	Max (Va)
1	LSPD	197.0	3710.5	0.50	17.33	104.01
2	LTEN	198.5	3712.0	0.50	1.78	2430.42
3	TBHV	195.0	3710.5	0.50	0.00	2.00
4	ABHV	195.0	3710.5	0.50	0.00	2.00
5	CILD	198.0	3711.0	0.50	0.00	1514.20
6	RLL3	195.0	3696.0	0.50	0.01	1820.06
7	SP	202.0	3715.0	0.50	-160.04	132.07
8	RILD	198.0	3711.0	0.50	0.66	100000.00
9	RILM	202.5	3715.5	0.50	0.72	100000.00
10	DCAL	195.0	3690.0	0.50	3.18	17.77
11	RHOB	195.0	3693.0	0.50	0.00	4.26
12	RHOC	195.0	3693.0	0.50	-2.13	0.39
13	DPOR	195.0	3693.0	0.50	-90.46	158.48
14	CNLS	195.0	3683.0	0.50	-50.00	43.37
15	CNDL	195.0	3683.0	0.50	-31.99	40.73
16	GR	195.0	3678.0	0.50	0.01	373.96
16	MN	3293.5	3693.0	0.50	1.21	47.72

A-3. Well Name: KELLER 2. Study well Number 2.

Surface Location: (X,Y Feet) = (1573758.196, 290203.258)

Sub-Sea Elevation (Feet): Ground Level: 2061.0.

Seismic Datum: 0.0

Depth (Feet): 3724.0 TD (MD).

Number of Boreholes = 1: KELLER 2.

UWI: 1505125416

Bore Depth (Feet): Top: not defined.

Bottom: 3724.0

Company: SPRING HARRY

Kelly Bushing: 2066.0 (Elevation Feet)

Formation @ TD: LANSING-KANSAS CITY

Completion: not defined

Date = 2005/09/07

Stratigraphic Top Data: Number of Tops = 6 (Depth) Name of the Stratigraphic Unit:

1. (1474.0) Stone Corral Formation (Anhydrite).

2. (3078.3) Topeka Limestone Formation.

3. (3292.0) Heebenerahle Member

4. (3325.1) the Lansing group

5. (3544.0) the Kansas City Group.

6. (3644.0) the Arbuckle Group.

Well Log Data: Number of Logs = 16

No.	Type	Start (Ft)	End (Ft)	Rate (Ft)	Min (Va)	Max (Va)
1	LSPD	195.0	3730.5	0.50	0.00	119.85
2	LTEN	195.0	3732.0	0.50	0.06	892.04
3	TBHV	195.0	3730.5	0.50	0.00	2.00
4	ABHV	195.0	3730.5	0.50	0.00	2.00
5	SWNC	195.0	3728.5	0.50	0.00	1901.39
6	SCAL	195.0	3726.0	0.50	3.18	18.55
7	SWPOR	195.0	3726.0	0.50	0.89	92.56
8	SWLS	195.0	3726.0	0.50	0.89	92.56
9	SWSS	195.0	3726.0	0.50	3.89	95.56
10	SWDL	195.0	3726.0	0.50	-1.11	90.56
11	SP	195.0	3735.0	0.50	-24.24	34.53
12	LGRD	195.0	3721.0	0.50	-2.00	2528.34
13	GR	195.0	3718.0	0.50	0.00	363.65
14	MN	2996.0	3728.0	0.50	0.90	122.91
15	MI	2996.0	3728.0	0.50	0.50	120.38
16	MCAL	2996.0	3728.0	0.50	4.90	12.09

A-4. Well Name: KELLER C. Study well Number 5.

Well Number: 1. Surface Location: (X, Y Feet) = (1573031.171, 295236.650)

Subsea Elevation (Feet): NOT DEFINED.

Ground Level: NOT DEFINED

Seismic Datum: 0.0. Depth (Feet): 3660.0 TD (MD)

Number of Boreholes = 1.1. KELLER C

UWI: 1516323562

Bore Depth (Feet): Top: NOT DEFINED.

Bottom: 3660.0

Company: SPRING HARRY

Kelly Bushing: 2071.0 (Elevation Feet)

Formation @ TD: ARBUCKLE

Completion:

Date = 2007/01/02

Stratigraphic Top Data: Number of Tops = 6 (Depth) Name of the Stratigraphic Unit:

1. (3095.0) Topeka Limestone Formation.

2. (3305.0) Heebenerahle Member

3. (3339.4) the Lansing Group.

4. (3565.4) the Kansas City Group.

5. (3654.1) the Arbuckle Group.

Well Log Data: Number of Logs = 16

No.	Type	Start (Ft)	End (Ft)	Rate (Ft)	Min(Va)	Max (Va)
1	LSPD	195.0	3664.0	0.50	0.00	97.77
2	LTEN	195.5	3665.5	0.50	0.05	1054.53
3	TBHV	260.0	3664.0	0.50	0.00	2.00
4	ABHV	260.0	3664.0	0.50	0.00	2.00
5	SWNC	195.0	3662.0	0.50	0.00	1845.58
6	SCAL	195.0	3659.5	0.50	3.12	18.14
7	SWPOR	195.0	3659.5	0.50	1.25	92.76
8	SWLS	195.0	3659.5	0.50	1.25	92.76
9	SWSS	195.0	3659.5	0.50	4.25	95.76

A5. Well Name: KELLER HEIRS. Study well #4.

Well Number: 1

Surface Location: (X, Y Feet) = (1572527.113, 292138.990).

Subsea Elevation (Feet): Not reported.

Ground Level: 2100.0. Seismic Datum: 0.0

Depth (Feet): 3700.0 TD (MD).

Number of Boreholes = 1. 1. KELLER HEIRS

UWI: 1505125260

Bore Depth (Feet): Top: NOT DEFINED.

Bottom: 2100.0

Company: BLAKE EXPLORATION, LLC

Ground Level: 2100.0 (Elevation Feet)

Formation @ TD: ARBUCKLE

Completion: not reported

Date = 2003/11/05

Symbol =

Stratigraphic Top Data: Number of Tops = 6 (Depth) Name of the Stratigraphic Unit:

1. (1467) Stone Corral Formation - Anhydrite

2. (3285) Heebner Member

3. (3641) Arbuckle Group

Well Log Data: Number of Logs = 5

No.	Type	Start (Ft)	End (Ft)	Rate (Ft)	Min (Va)	Max(V)a
1	GR	195.0	3699.0	0.50	0.00	395.97
2	DT	195.0	3704.0	0.50	-2.00	245.47
3	SPOR	195.0	3704.0	0.50	-34.98	139.91
4	ITT	195.0	3704.0	0.50	0.00	2.00
5	DCAL	195.0	3708.0	0.50	4.68	15.90

A-6 Well Name: LOVE. Study well number 6.

Well Number: 1. Surface Location: (X, Y Feet) = (1567544.461, 292784.812)

Subsea Elevation (Feet): not reported.

Ground Level: NOT DEFINED.

Seismic Datum: 0.0

Depth (Feet): 3686.0 TD (MD).

Number of Boreholes = 1. 1. LOVE

UWI: 1505125496

Bore Depth (Feet): Top: NOT DEFINED.

Bottom: 3686.0

Company: BLAKE EXPLORATION, LLC

Kelly Bushing: 2082.0 (Elevation Feet)

Formation @ TD: LANSING-KANSAS CITY

Completion: Date = 2006/03/01

Symbol = 0 (Dark Green, 0.381)

Well Log Data: Number of Logs = 16

No.	Type	Start (Feet)	End (Feet)	Rate (Feet)	Min Va	Max Va
1	LSPD	3095.0	3706.0	0.50	9.37	32.10
2	LTEN	3095.0	3707.5	0.50	0.13	2070.69
3	TBHV	3095.0	3706.0	0.50	0.00	2.00
4	ABHV	3095.0	3706.0	0.50	0.00	2.00
5	SWNC	3095.0	3705.0	0.50	0.05	1819.49
6	SCAL	3095.0	3702.0	0.50	7.25	15.60
7	SWPOR	3095.0	3702.0	0.50	1.48	94.29
8	SWLS	3095.0	3702.0	0.50	1.48	94.29
9	SWSS	3095.0	3702.0	0.50	4.48	97.29
10	SWDL	3095.0	3702.0	0.50	-0.52	92.29
11	SP	3095.0	3711.5	0.50	-201.00	79.99

A-7. Well Name: TRABACK. Study well number 7.

Well Number: 1. Surface Location: (X, Y Feet) = (1571626.457, 298598.489)

Subsea Elevation (Feet): not defined.

Ground Level: 2125.0.

Seismic Datum: 0.0

Depth (Feet): 3690.0 TD (MD).

Number of Boreholes = 1. 1. TRABACK

UWI: 1516323529

Bore Depth (Feet): Top: not defined

Bottom: 3690.0

Company: BLAKE EXPLORATION, LLC. Kelly Bushing: 2120.0 (Elevation Feet)

Formation @ TD: ARBUCKLE

Completion: not defined

Date = Symbol = 0 (Dark Green, 0.381)

Well Log Data: Number of Logs = 5

No.	Type	Start (Ft)	End (Ft)	Rate (Ft)	Min (Va)	Max(Va)
1	SCAL	195.0	3690.5	0.50	7.23	18.25
2	GR	195.0	3696.0	0.50	0.00	439.27
3	DT	195.0	3686.0	0.50	-1.96	190.42
4	ITT	195.0	3686.0	0.50	0.00	2.00
5	SPOR	195.0	3686.0	0.50	-35.05	101.00

A-8. Well Name: WENDLING 1. Study well number 8.

Well Number: 1. Surface Location: (X, Y Feet) = (1570596.595, 293193.668)

Sub-Sea Elevation (Feet): Ground Level: 2101.0.

Seismic Datum: 0.0

Depth (Feet): 3704.0 TD (MD).

Number of Boreholes = 1. 1.WENDING 1

UWI: 1505125352

Bore Depth (Feet): Top: not defined

Bottom: 3704.0

Company: BLAKE EXPLORATION, LLC

Kelly Bushing: 2106.0 (Elevation Feet)

Formation @ TD: LANSING-KANSAS

Completion: not defined. Date = 2005/02/18.

Stratigraphic Top Data: Number of Tops = 5 (Depth) Name of the Stratigraphic Unit:

1. (3134.0) Topeka Limestone Formation.
2. (3349.0) Heebenerahle Member
3. (3386.0) the Lansing group.
4. 3598.0 the Lansing - Kansas City Suoergroup
5. (3698.0) the Arbuckle Group

Well Log Data: Number of Logs = 20

No.	Type	Start (Ft)	End (Ft)	Rate (Ft)	Min(Va)	Max(Va)
1	RAWDSP	195.0	3709.5	0.50	0.00	0.00
2	LSPD	195.0	3709.5	0.50	0.00	101.87
3	LTEN	195.0	3711.0	0.50	1.16	1651.67
4	TBHV	195.0	3709.5	0.50	0.00	2.00
5	ABHV	195.0	3709.5	0.50	0.00	2.00
6	CILD	195.0	3709.5	0.50	0.00	1263.11
7	RLL3	195.0	3695.0	0.50	-0.99	1014.18
8	SP	195.0	3714.5	0.50	80.00	169.35
9	RILD	195.0	3709.5	0.50	0.79	100000.00
10	RILM	195.0	3715.0	0.50	0.97	100000.00
11	DCAL	195.0	3689.0	0.50	3.45	14.66
12	RHOB	195.0	3692.0	0.50	0.00	4.12
13	RHOC	195.0	3692.0	0.50	-1.85	0.30

A-9. Well Name: WENDLING 2. Study well number 9.

Well Number: 2

Surface Location: (X, Y Feet) = (1570176.007, 293170.469)

Subsea Elevation (Feet): Ground Level: not defined.

Seismic Datum: 0.0

Depth (Feet): 3712.0 TD (MD).

Number of Boreholes = 1. 1. WENDING 2

UWI: 1505125415

Bore Depth (Feet): Top: NOT DEFINED.

Bottom: 3724.0

Company: BLAKE EXPLORATION, LLC

Kelly Bushing: 2112.0 (Elevation Feet)

Formation @ TD: **ARBUCKLE**

Completion:

Date = 2005/06/30.

Stratigraphic Top Data: Number of Tops = 6 (Depth) Name of the Stratigraphic Unit:

1. (1528.0) Stone Corral Formation (Anhydrite).

2. (3138.0) Topeka Limestone Formation

3. (3352.0) Heebenerahle Member.

4. (3390.0) the Lansing group

5. (3602.0) Kansas City Group

6. (3696.0) the Arbuckle Group

Well Log Data: Number of Logs = 13

No.	Type	Start (Ft)	End (Ft)	Rate (Ft)	Min (Va)	Max (Va)
1	LSPD	3095.0	3719.0	0.50	3.95	27.70
2	LTEN	3095.0	3720.5	0.50	1.51	2162.53
3	TBHV	3095.0	3719.0	0.50	0.00	2.00
4	ABHV	3095.0	3719.0	0.50	0.00	2.00
5	SCAL	3095.0	3715.0	0.50	6.80	15.60
6	SWPOR	3095.0	3715.0	0.50	1.51	92.36
7	SWLS	3095.0	3715.0	0.50	1.51	92.36
8	SP	3095.0	3724.0	0.50	-123.60	-0.00
9	LGRD	3095.0	3709.5	0.50	-0.38	343.53
10	GR	3095.0	3706.5	0.50	0.00	433.70
11	MCAL	3095.0	3719.5	0.50	4.75	11.46
12	MI	3095.0	3719.5	0.50	2.50	135.59
13	MN	3095.0	3719.5	0.50	2.50	

Appendix B.

(**B1-B9):** Geolog Displays: Paper logs displaying gamma-ray and Resistivity logs of each well on a vertical scale of 1:5000.

B1. Composite Log well H K #1-36. Study well number 1

B2. Composite Log well KELLER #2. Study well number 2

B3. Composite Log well KELLER #1. Study well number 3

B4. Composite Log well KELLER HEIRS#1. Study well number 4

B5. Composite Log well KELLER C #1. Study well number 5

B6. Composite Log well LOVE #2. Study well number 6

B7. Composite Log well TRABACK #1. Study well number 7

B8. Composite Log well WENDLING No 1. Study well number 8

B9. Composite Log well WENDLING #2. Study well number 9

Stratigraphic Abbreviations used in well logs (Obtained and modified from KGS)

-ABCK--Arbuckle Group (Cambrian-Ordovician)

-HEEB--Heebner Shale Member (Pennsylvanian, Virgilian)

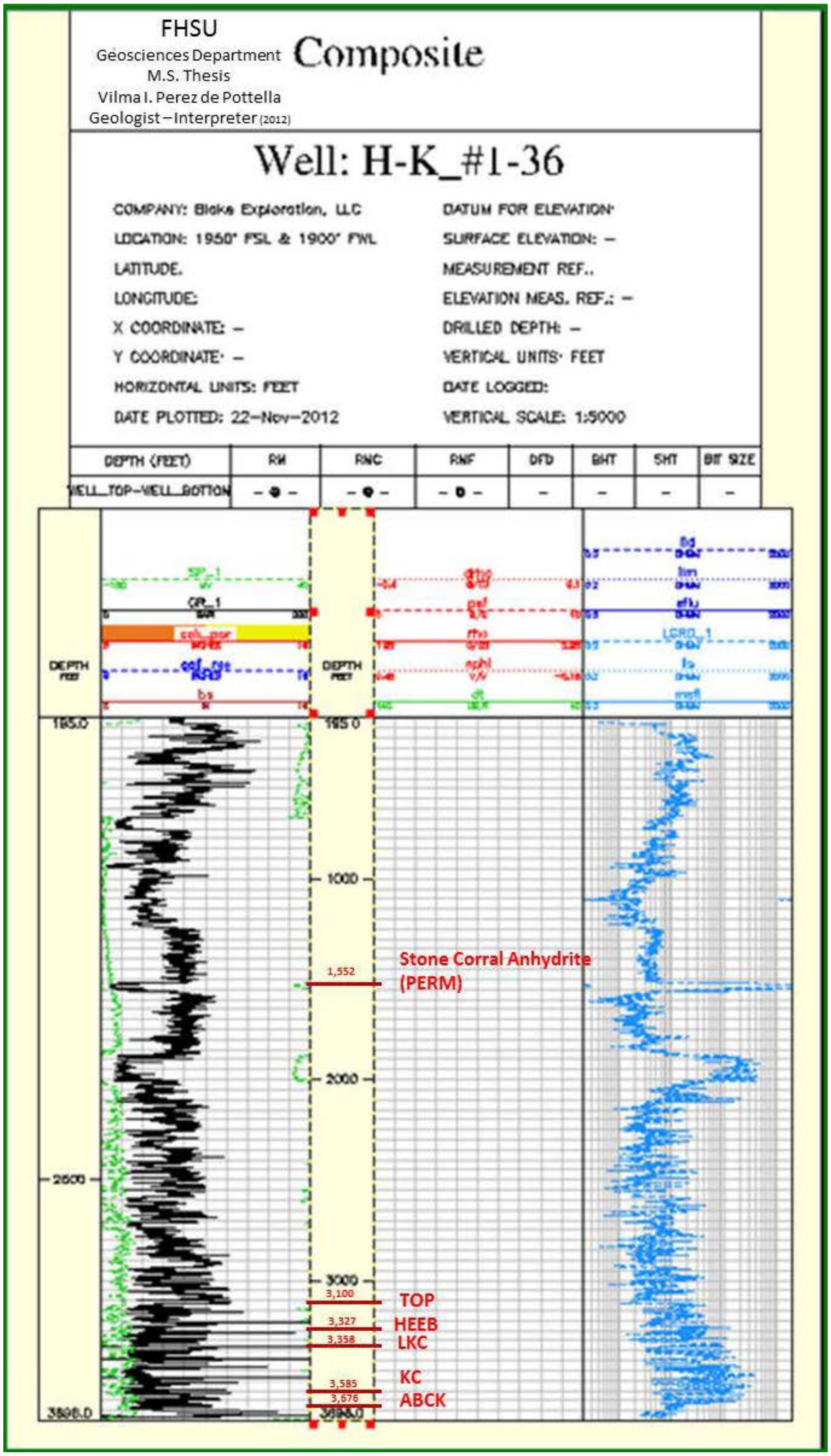
-KC--Kansas City Group (Pennsylvanian, Missourian)

-LKC--Lansing-Kansas City groups (Pennsylvanian, Missourian)

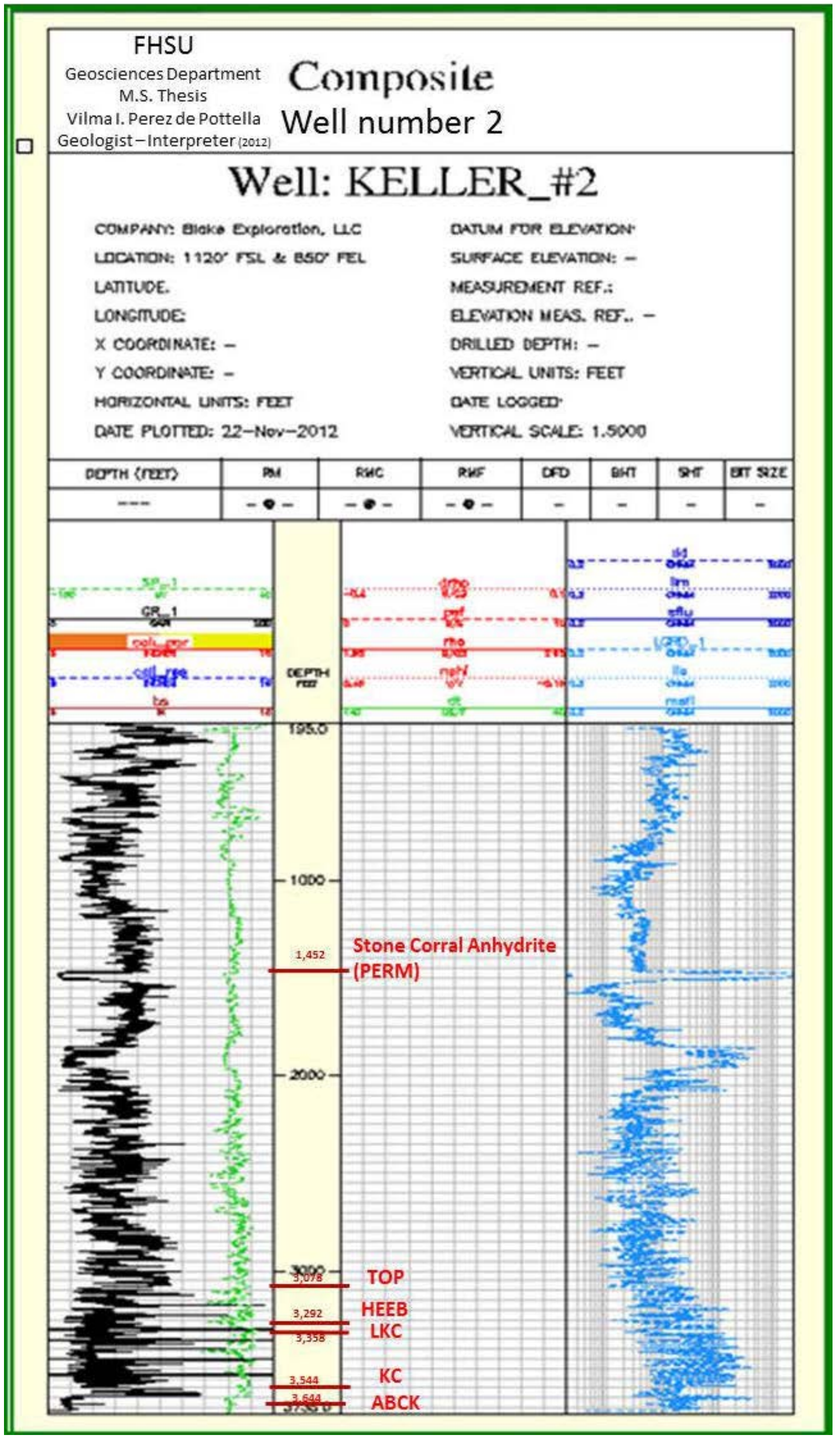
-PERM—Permian

-TOP--Topeka Limestone (Pennsylvanian, Virgilian)

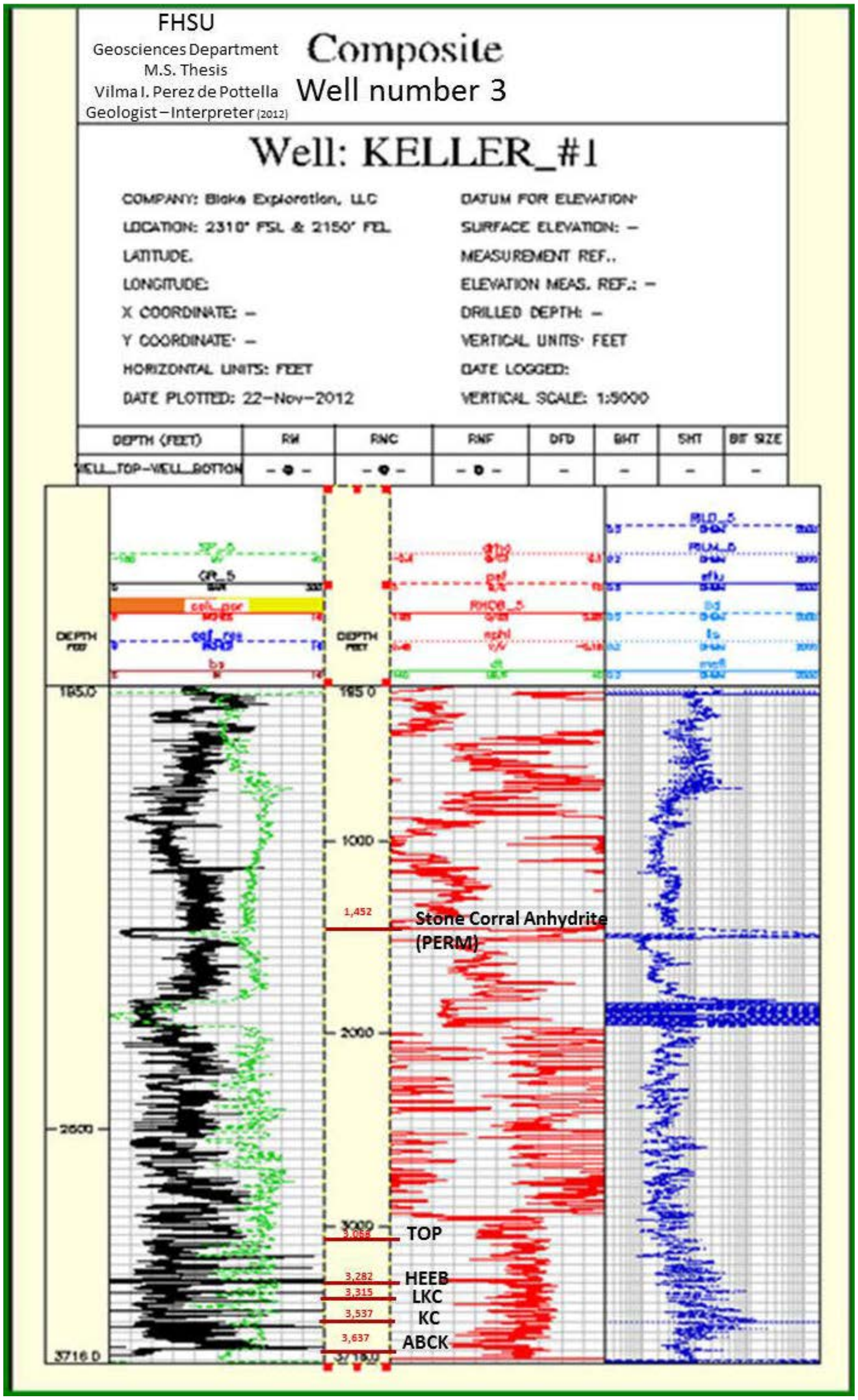
Appendix B1


FHSU
Geosciences Department
M.S. Thesis
Vilma I. Perez de Pottella
Geologist – Interpreter (2012)
Composite
Well: H-K_#1-36
COMPANY: Blake Exploration, LLC
LOCATION: 1950' FSL & 1900' FWL
LATITUDE.
LONGITUDE:
X COORDINATE: –
Y COORDINATE: –
HORIZONTAL UNITS: FEET
DATE PLOTTED: 22–Nov–2012
DATUM FOR ELEVATION:
SURFACE ELEVATION: –
MEASUREMENT REF..
ELEVATION MEAS. REF.: –
DRILLED DEPTH: –
VERTICAL UNITS: FEET
DATE LOGGED:
VERTICAL SCALE: 1:5000
DEPTH (FEET)
RM
RMC
RMF
DFD
BHT
SHT
BIT SIZE
WELL_TOP–WELL_BOTTOM
DEPTH
1,552
Stone Corral Anhydrite
(PERM)
3,100
TOP
3,327
HEEB
3,358
LKC
3,585
KC
3,676
ABCK

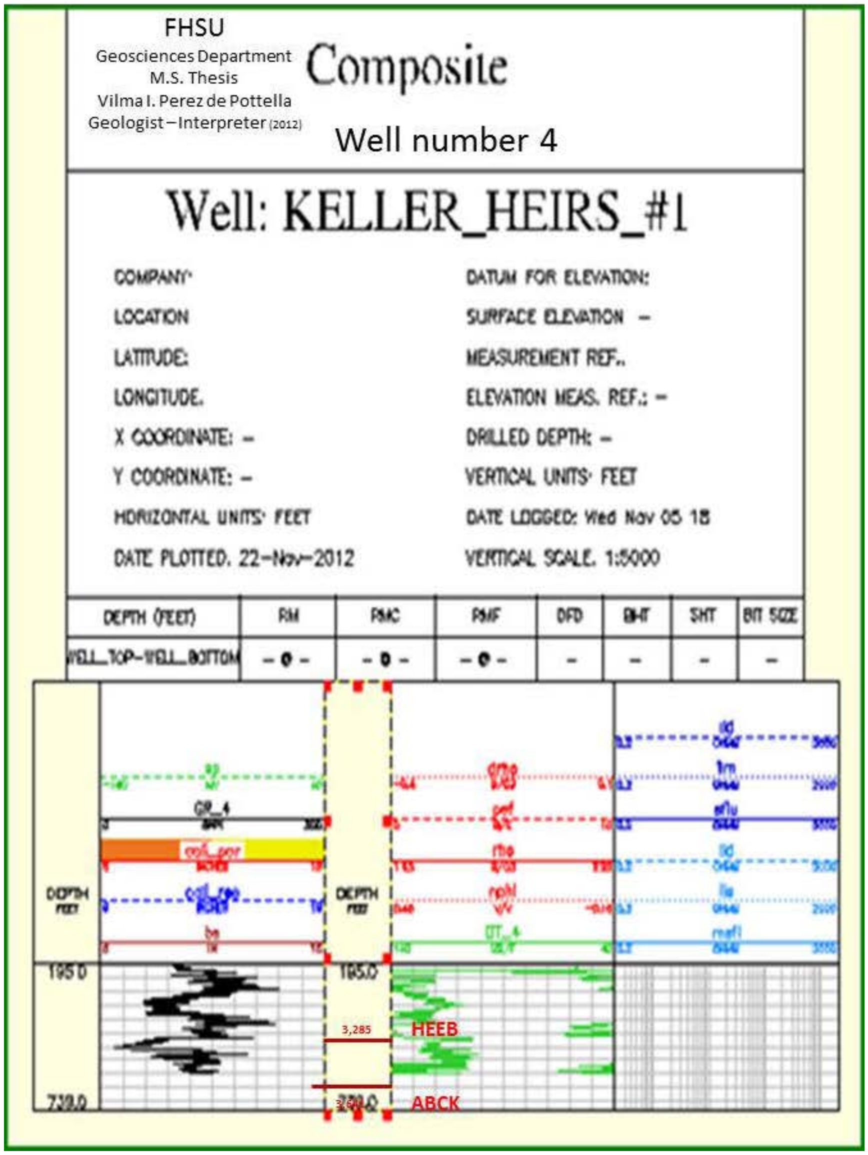
Appendix B2


FHSU
Geosciences Department
M.S. Thesis
Vilma I. Perez de Pottella
Geologist – Interpreter (2012)
Composite
Well number 2
Well: KELLER_#2
COMPANY: Blake Exploration, LLC
LOCATION: 1120' FSL & 850' FEL
LATITUDE.
LONGITUDE:
X COORDINATE: –
Y COORDINATE: –
HORIZONTAL UNITS: FEET
DATE PLOTTED: 22–Nov–2012
DATUM FOR ELEVATION:
SURFACE ELEVATION: –
MEASUREMENT REF.:
ELEVATION MEAS. REF.. –
DRILLED DEPTH: –
VERTICAL UNITS: FEET
DATE LOGGED:
VERTICAL SCALE: 1.5000
DEPTH (FEET)
RM
RMC
RMF
DFD
BHT
SHT
BIT SIZE
DEPTH FEET
195.0
1000
1,452
Stone Corral Anhydrite
(PERM)
2000
3000
3,078
TOP
3,292
HEEB
3,358
LKC
3,544
KC
3,644
ABCK

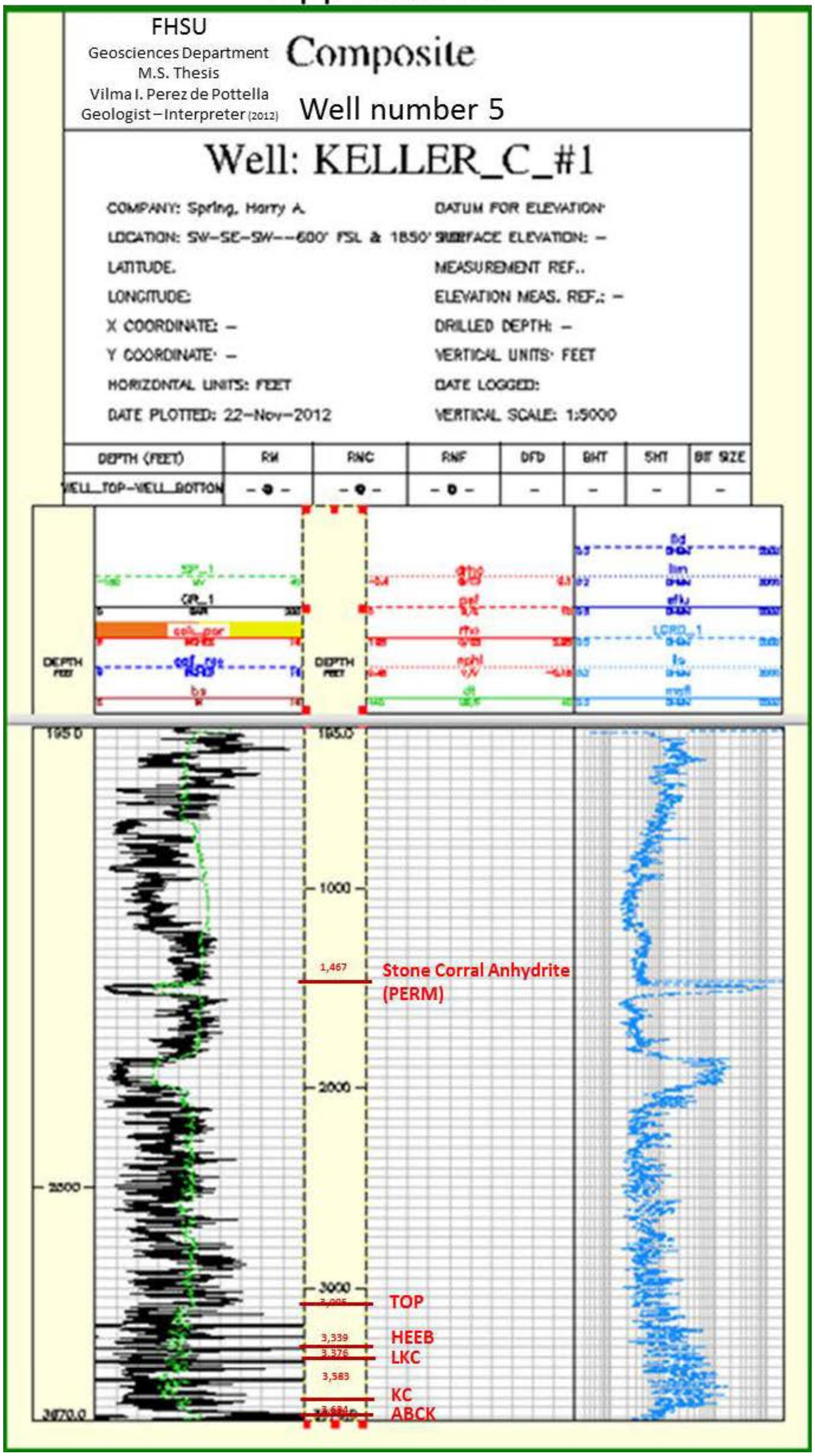
Appendix B3


FHSU
Geosciences Department
M.S. Thesis
Vilma I. Perez de Pottella
Geologist – Interpreter (2012)
Composite
Well number 3
Well: KELLER_#1
COMPANY: Blake Exploration, LLC
LOCATION: 2310' FSL & 2150' FEL
LATITUDE:
LONGITUDE:
X COORDINATE: –
Y COORDINATE: –
HORIZONTAL UNITS: FEET
DATE PLOTTED: 22–Nov–2012
DATUM FOR ELEVATION:
SURFACE ELEVATION: –
MEASUREMENT REF.:
ELEVATION MEAS. REF.: –
DRILLED DEPTH: –
VERTICAL UNITS: FEET
DATE LOGGED:
VERTICAL SCALE: 1:5000
DEPTH (FEET)
RM
RMC
RMF
DFD
BHT
SHT
BIT SIZE
WELL_TOP–WELL_BOTTOM
DEPTH FEET
185.0
1000
1,452
Stone Corral Anhydrite (PERM)
2000
2500
3000
TOP
3,282
HEEB
3,315
LKC
3,537
KC
3,637
ABCK
3716.0

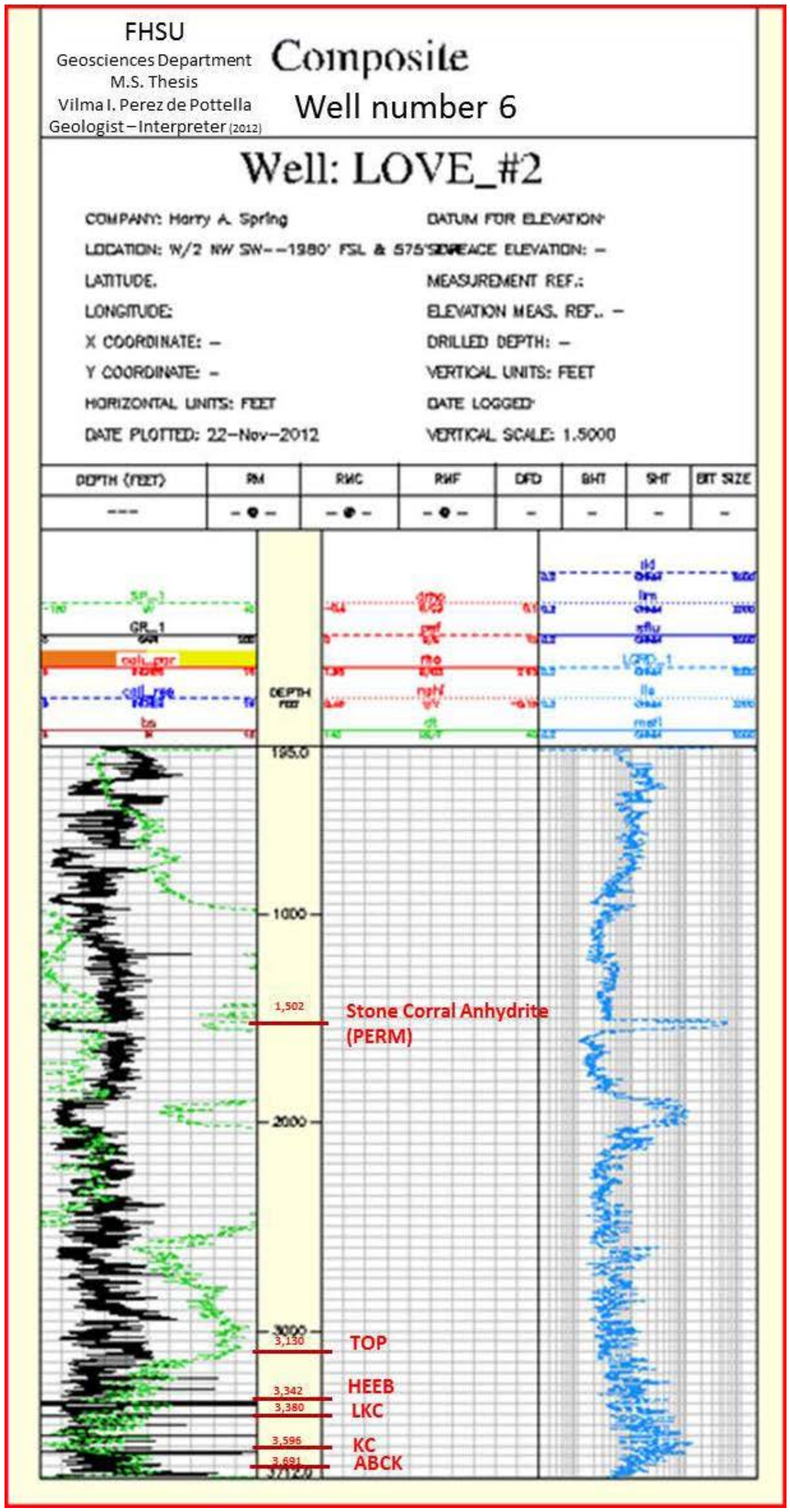
Appendix B4


FHSU
Geosciences Department
M.S. Thesis
Vilma I. Perez de Pottella
Geologist – Interpreter (2012)
Composite
Well number 4
Well: KELLER_HEIRS_#1
COMPANY:
LOCATION
LATITUDE:
LONGITUDE.
X COORDINATE: –
Y COORDINATE: –
HORIZONTAL UNITS: FEET
DATE PLOTTED. 22-Nov-2012
DATUM FOR ELEVATION:
SURFACE ELEVATION –
MEASUREMENT REF..
ELEVATION MEAS. REF.: –
DRILLED DEPTH: –
VERTICAL UNITS: FEET
DATE LOGGED: Wed Nov 05 18
VERTICAL SCALE. 1:5000
DEPTH (FEET)
RM
RMC
RMF
DFD
BHT
SHT
BIT SIZE
WELL_TOP-WELL_BOTTOM
DEPTH FEET
GR_4
DEPTH FEET
195.0
3,285
HEEB
ABCK

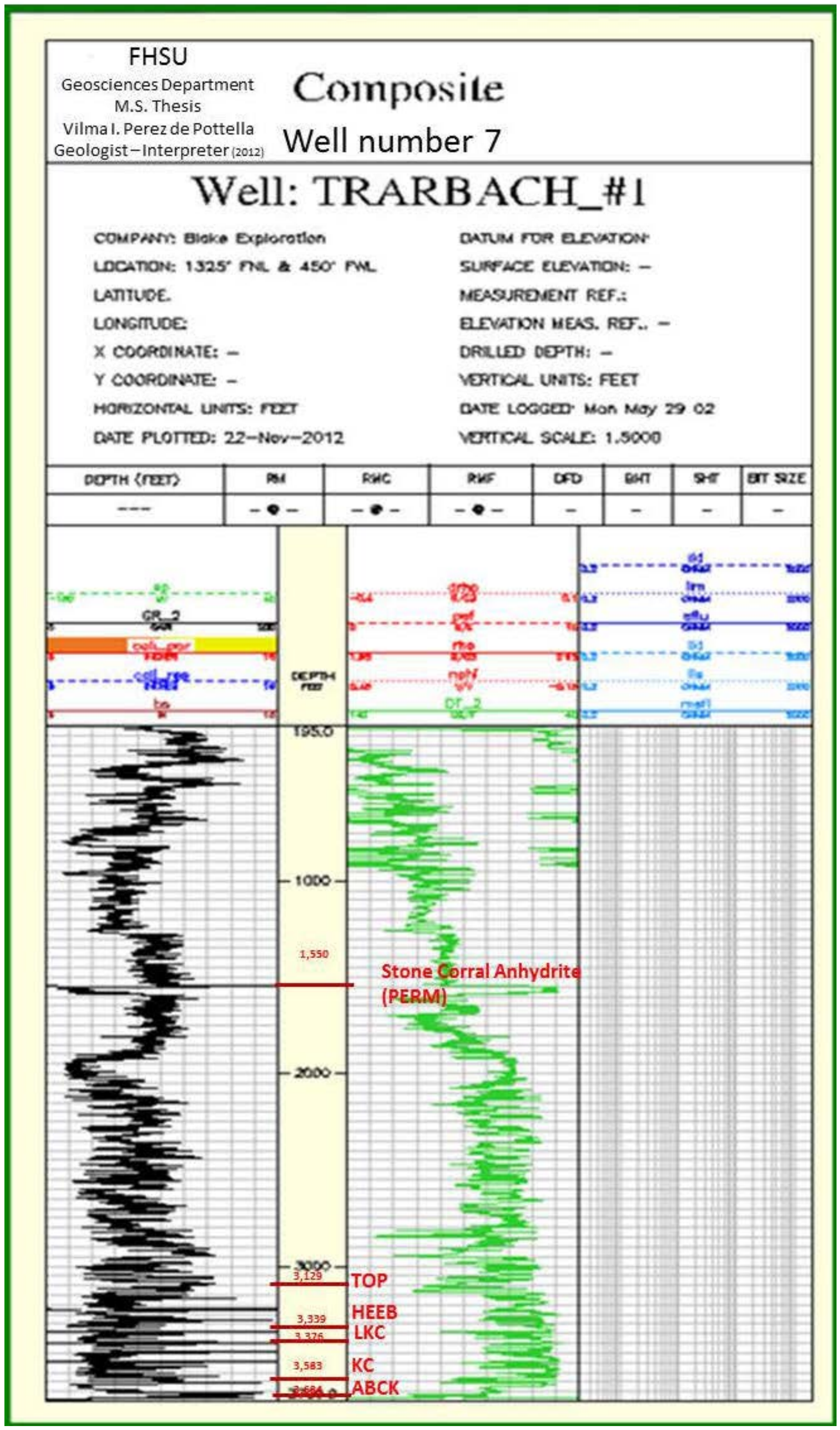
Appendix B5


FHSU
Geosciences Department
M.S. Thesis
Vilma I. Perez de Pottella
Geologist – Interpreter (2012)
Composite
Well number 5
Well: KELLER_C_#1
COMPANY: Spring, Harry A.
DATUM FOR ELEVATION:
LOCATION: SW-SE-SW--600' FSL & 1850'
SURFACE ELEVATION: –
LATITUDE.
MEASUREMENT REF..
LONGITUDE:
ELEVATION MEAS. REF.: –
X COORDINATE: –
DRILLED DEPTH: –
Y COORDINATE: –
VERTICAL UNITS: FEET
HORIZONTAL UNITS: FEET
DATE LOGGED:
DATE PLOTTED: 22-Nov-2012
VERTICAL SCALE: 1:5000
DEPTH (FEET)
RM
RMC
RMF
DFD
BHT
SHT
BIT SIZE
WELL_TOP-WELL_BOTTOM
DEPTH FEET
1000
2000
3000
1,467
Stone Corral Anhydrite
(PERM)
TOP
3,339
HEEB
3,376
LKC
3,583
KC
ABCK

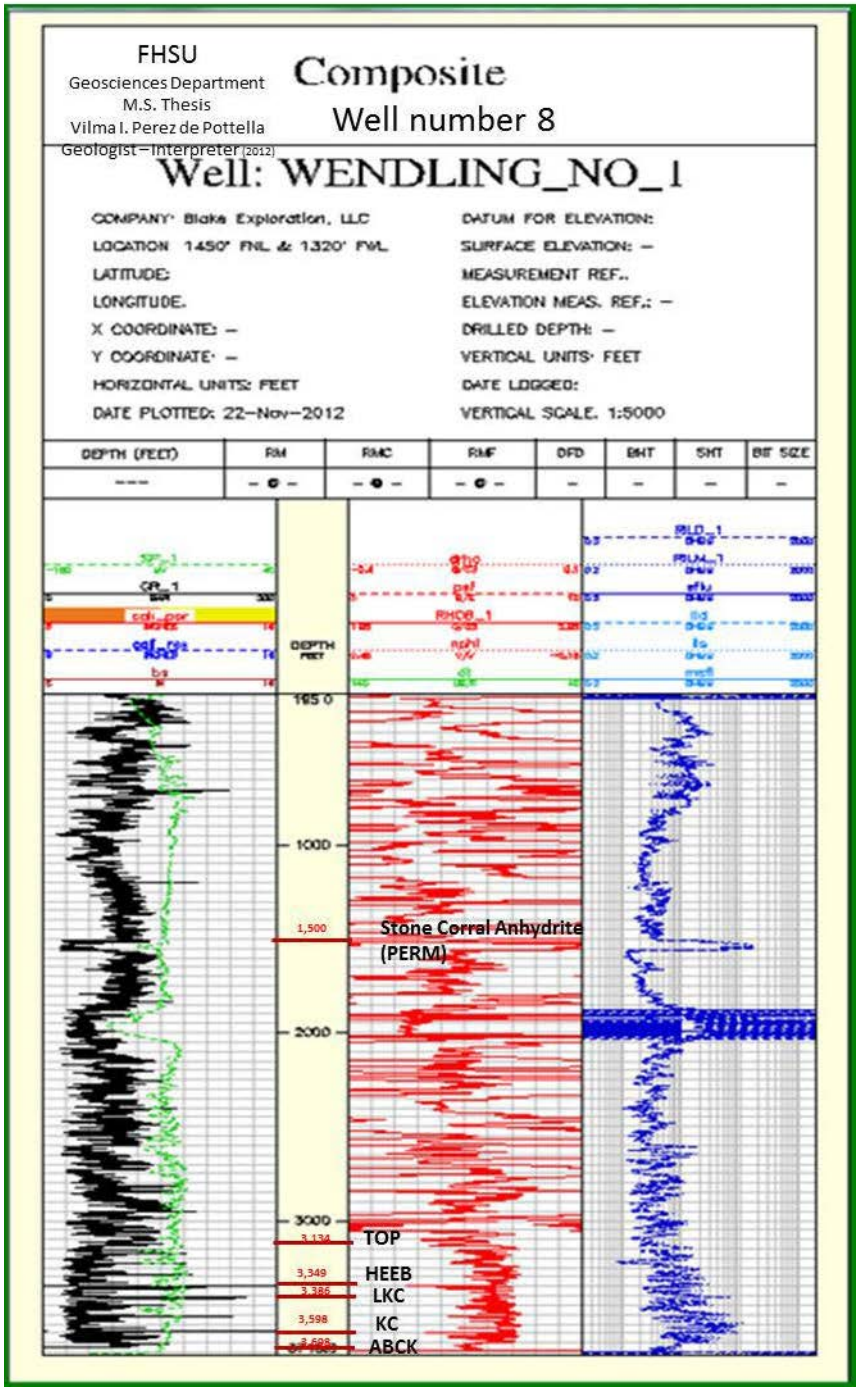
Appendix B6


FHSU
Geosciences Department
M.S. Thesis
Vilma I. Perez de Pottella
Geologist – Interpreter (2012)
Composite
Well number 6
Well: LOVE_#2
COMPANY: Harry A. Spring
LOCATION: W/2 NW SW--1980' FSL & 575' SURFACE ELEVATION: –
LATITUDE:
LONGITUDE:
X COORDINATE: –
Y COORDINATE: –
HORIZONTAL UNITS: FEET
DATE PLOTTED: 22-Nov-2012
DATUM FOR ELEVATION:
MEASUREMENT REF.:
ELEVATION MEAS. REF.: –
DRILLED DEPTH: –
VERTICAL UNITS: FEET
DATE LOGGED:
VERTICAL SCALE: 1.5000
DEPTH (FEET)
RM
RMC
RMF
DFD
BHT
SHT
BIT SIZE
GR_1
DEPTH FEET
1000
1,502
Stone Corral Anhydrite (PERM)
2000
3000
3,130
TOP
3,342
HEEB
3,380
LKC
3,596
KC
3,691
ABCK

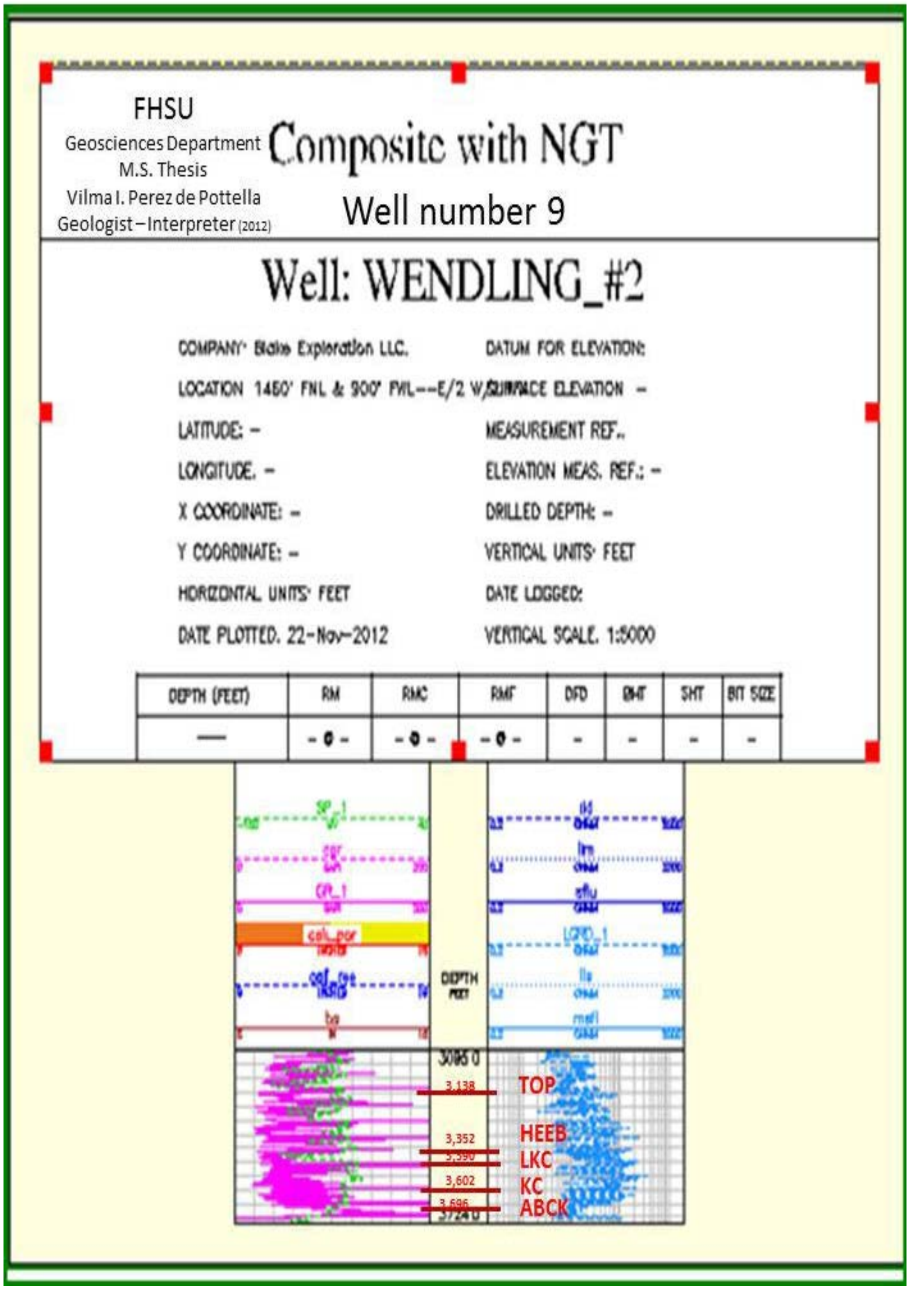
Appendix B7


FHSU
Geosciences Department
M.S. Thesis
Vilma I. Perez de Pottella
Geologist – Interpreter (2012)
Composite
Well number 7
Well: TRARBACH_#1
COMPANY: Blake Exploration
LOCATION: 1325' FNL & 450' FWL
LATITUDE.
LONGITUDE:
X COORDINATE: –
Y COORDINATE: –
HORIZONTAL UNITS: FEET
DATE PLOTTED: 22–Nov–2012
DATUM FOR ELEVATION:
SURFACE ELEVATION: –
MEASUREMENT REF.:
ELEVATION MEAS. REF.. –
DRILLED DEPTH: –
VERTICAL UNITS: FEET
DATE LOGGED: Mon May 29 02
VERTICAL SCALE: 1:5000
DEPTH (FEET)
RM
RMC
RMF
DFD
BHT
SHT
BIT SIZE
DEPTH FEET
1000
1,550
Stone Corral Anhydrite (PERM)
2000
3000
3,129
TOP
3,339
HEEB
3,376
LKC
3,583
KC
ABCK

Appendix B8


FHSU
Geosciences Department
M.S. Thesis
Vilma I. Perez de Pottella
Geologist – Interpreter (2012)
Composite
Well number 8
Well: WENDLING_NO_1
COMPANY: Blake Exploration, LLC
LOCATION 1450' FNL & 1320' FWL
LATITUDE:
LONGITUDE.
X COORDINATE: –
Y COORDINATE: –
HORIZONTAL UNITS: FEET
DATE PLOTTED: 22-Nov-2012
DATUM FOR ELEVATION:
SURFACE ELEVATION: –
MEASUREMENT REF..
ELEVATION MEAS. REF.: –
DRILLED DEPTH: –
VERTICAL UNITS: FEET
DATE LOGGED:
VERTICAL SCALE. 1:5000
DEPTH (FEET)
RM
RMC
RMF
DFD
BHT
SHT
BIT SIZE
DEPTH FEET
1000
1,500
Stone Corral Anhydrite
(PERM)
2000
3000
3,134
TOP
3,349
HEEB
3,386
LKC
3,598
KC
ABCK

Appendix B9



FHSU
Geosciences Department
M.S. Thesis
Vilma I. Perez de Pottella
Geologist – Interpreter (2012)
Composite with NGT
Well number 9
Well: WENDLING_#2
COMPANY: Blake Exploration LLC.
DATUM FOR ELEVATION:
LOCATION 1450' FNL & 900' FWL--E/2 W/
SURFACE ELEVATION –
LATITUDE: –
MEASUREMENT REF.
LONGITUDE: –
ELEVATION MEAS. REF.: –
X COORDINATE: –
DRILLED DEPTH: –
Y COORDINATE: –
VERTICAL UNITS: FEET
HORIZONTAL UNITS: FEET
DATE LOGGED:
DATE PLOTTED: 22-Nov-2012
VERTICAL SCALE: 1:5000
DEPTH (FEET)
RM
RMC
RMF
DFD
BHT
SHT
BIT SIZE
DEPTH
3,138
TOP
3,352
HEEB
LKC
3,602
KC
ABCK