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Preliminary Feasibility of Transporting and Geologically Sequestering Carbon Emissions in the Florida Pan-Handle

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PRELIMINARY FEASIBILITY OF TRANSPORTING AND GEOLOGICALLY SEQUESTERING CARBON EMISSIONS IN THE FLORIDA PAN-HANDLE

by

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Table of Contents

List of Figures

List of Tables

Abstract

According to the United States Department of Energy, fossil-fueled power plants account for 78% of stationary source CO_2 emission in the United States and Canada. This has led electric utilities across the globe to research different alternatives for energy. Carbon sequestration has been identified as a bridge between fossil fuels and clean energy.

This thesis will present research results regarding the transportation costs of CO_2 and the suitability of geology in the Florida Pan-Handle for sequestration infrastructure. The thesis will utilize various evaluation tools including GIS, numerical models, and optimization models.

Analysis performed for this thesis and review of published literature produced estimated carbon storage capacities for two areas in and near the Florida Pan-Handle. These areas were labeled Disposal Area 1 and Disposal Area 3. Disposal Area 1 was estimated to contain capacity for the storage of 5.58 gigatonnes of CO_2. Disposal Area 3 was estimated to contain capacity for the storage of 2.02 gigatonnes of CO_2. Transportation scenarios were analyzed over a 25 year period and the capacities above are sufficient to store the CO_2 emissions from the Pan-Handle network of power plants for the study period.

Four transportation routing scenarios were investigated using transportation costs from the Poiencot and Brown CO_2 pipeline capital cost model. The scenarios (models) consisted of the Right-Of-Way, Solo-Funded, Piece-Wise, and Authority models. Each presents a different method for the overall funding of the Florida Pan-Handle CO_2 network and produced different total levelized and mean unit costs. The cheapest

network on a mean unit cost basis was the network for Disposal Area 1 in the Authority Model, producing a mean unit cost of $0.64 per tonne of CO_2.

Chapter 1

INTRODUCTION

Greenhouse gases (GHGs) present in the atmosphere contribute to the trapping of radiant heat from the sun in the Earth's atmosphere, also known as the greenhouse effect. Carbon dioxide (CO_2) is the GHG of greatest interest because CO_2 is the most prevalent GHG (DOE, 2010). CO_2 is released into the atmosphere from manmade and natural sources. Manmade sources of CO_2 are mainly emitted from the burning of various fossil fuels for power generation, transportation, and numerous industrial activities (DOE, 2010). Focus lately has been directed at reducing the CO_2 emissions from power generation facilities. One technology currently under research, development, and testing is carbon capture and storage (CCS), or carbon sequestration.

Much of the technology and methods required for CCS has been used for over 30 years by the oil industry for enhanced oil recovery (EOR) practices (Esposito et al, 2010). The CCS process involves capturing CO_2 from the source, transporting the CO_2 in a supercritical or fluid phase to a storage location, and injecting the supercritical or fluid CO_2 into a saline aquifer, existing oil fields, depleted natural gas fields, or thin-nonmineable coal seams (Benson & Cook, 2005). The emission sources this thesis focuses upon are fossil fuel power plants which account for 78% of stationary source CO_2 emissions in the United States and Canada (DOE, 2011). According to 2005 Environmental Protection Agency (EPA) data, there are 136 large and small power plants in Florida which are fueled by fossil fuels. In total, Florida power plants accounted for 143 million tonnes of CO_2 emissions in 2007 (EPA, 2011).

Saline aquifers contain a majority of the potential sequestration capacity in the Southeastern United States representing approximately 92% of the total (DOE, 2010). Oil and gas reservoirs do exist in Florida but are not considered in this thesis because they are found much deeper than suitable saline aquifers and their sequestration capacity is more limited. Also, coal seam sequestration is not considered because there are limited opportunities in Florida (Pugh et al, 2008). The U.S. Department of Energy has identified possible formations for saline aquifer storage in Florida. Some preliminary detailed work has been completed in evaluating these potential storage repository zones (Roberts-Ashby, 2010). Transportation of the CO_2 is also an issue due to the great distances that can separate sources from their corresponding geologic sinks. A transportation network is required to make any large deployment of CCS technology a reality in Florida. The University of North Florida (UNF) has been investigating these issues in Florida since May 2010 using data collection, computer sequestration modeling, and transportation optimization modeling (Poiencot and Brown, 2011). It should be noted that this report will focus on the transportation costs associated with CCS in Florida and does not include the costs for capture, compression, injection, storage or monitoring.

The purpose of this paper is to assess the feasibility of CCS for the Florida Pan-Handle by presenting the results of CCS transportation and storage research, including the development of a CO_2 pipeline transportation model, a comparison of the Poiencot/Brown cost model to other published CO_2 transportation cost models, cost analysis of different CO_2 transportation network deployment scenarios using linear optimization, storage zone characterization, and numerical simulation of CO_2 sequestration in a saline aquifer. Florida is a state that is heavily dependent on fossil fuels for electricity generation with nearly 97% of generators in the state producing carbon emissions (EPA, 2011). While CCS is not a permanent solution to the world's GHG problems, the technology does provide a bridge between the world's current reliance on fossil fuel generated electricity and that of diversified clean energy production. This thesis is a step towards proving the preliminary feasibility of CCS in the Florida Pan-Handle.

1.1 Technology Overview

Carbon capture and storage is a technological innovation whereby carbon dioxide off-gas is captured, separated from other gases, concentrated, compressed, and then injected into underground repositories. Here the carbon dioxide is sequestered or stored for hundreds to thousands of years, effectively reducing the carbon footprint of the industrial emitter. In 2005, 83% of Florida's electrical energy was produced by fossil fuels while in 2010 the percentage was almost 89% (EIA, 2009). The continuing use of fossil fuels, in Florida, may depend upon finding suitable subsurface sequestration repositories in Florida and connecting them to an optimized network of pipelines and primary CO_2 sources.

According to the Intergovernmental Panel on Climate Change (IPCC), storage of CO_2 in geologic formations includes four primary storage repository categories: saline aquifers, existing oil fields, depleted natural gas fields, and thin-nonmineable coal seams (Benson & Cook, 2005). The capacity of each of these repository categories to sequester

CO_2 is an important planning variable to be considered during feasibility-level investigations of potential projects (Koide et al., 1992; Bradshaw et al., 2007). Deep saline aquifers appear to offer the highest potential capacity of the four primary options (Bachu et al., 1994; Van der Meer, 1995; Obdam et al., 2003; Herzog, 2009). In Florida, saline aquifers are the most likely storage option (DOE, 2010). According to the United States Department of Energy (DOE, 2010), the estimated capacity of oil/gas fields is relatively small by comparison (e.g., 100 times less) and their geographic distribution is rather limited. A typical CCS saline aquifer storage project will undergo several operational changes over time with the injected CO_2 ultimately becoming completely dissolved in the aquifer fluid. The various operation phases include site characterization, initial active injection, post-injection, and long-term monitoring. During the project lifecycle, there are significant changes in the state of injected CO_2 with it starting as a free-phase, becoming residually-trapped, being dissolved, and ultimately being precipitated as a mineral. The relative time scales for each process are different with residual trapping likely a decadal time scale, dissolution over hundreds of years, or more likely in saline waters, thousands of years and mineralization over even longer periods. During active operations, when liquid or supercritical CO_2 is being injected into a repository, the CO_2 will be highly mobile as a pure separate phase and concentrated aqueous phase (Bachu & Adams, 2003). Carbon dioxide is a highly compressible fluid compared to water and its density radically increases from 300 to 800 kg/m^3 at pressure ranging from 10 to 25 MPa (Han & McPherson, 2009). Since liquid or supercritical CO_2 has a density less than the typical density of the saline repository fluid (Sharqawy et al., 2010), it will be buoyant, tending to rise within the formation (MIT, 2010) until it intercepts a competent confining unit (primary seal) where it may spread laterally until it will becomes trapped (Flett et al., 2005). In some cases, depending upon formation dip, the supercritical CO_2 may migrate updip along the confining unit. The feasibility of any type of system will require the design and planning of a transportation system and suitable storage repositories.

Chapter 2

STUDY AREA

The study area consists mainly of the Florida Pan-Handle, or western Florida. A network comprises of sources and sinks. This chapter identifies the sources for the proposed Florida Pan-Handle network, which are fossil fuel power plants. Also identified are the sinks, which are the proposed CO_2 disposal areas. The CO_2 will be stored in saline aquifers and the general geology of each area is discussed.

2.1 Florida Emission Sources

The first task in developing an optimal CO_2 pipeline transportation network for Florida is to identify the location and magnitude of the largest sources of CO_2 within the state. Florida has 136 primary sources of CO_2 inventoried by the EPA. For the initial model development effort (Poiencot & Brown, 2011), the 40 largest sources of CO_2 were identified and summarized. These 40 sources comprise over 90% of the 2005 total CO_2 emissions for Florida. Poiencot & Brown (2012) later updated these 40 sources with 2007 CO_2 emission data from DOE (2011). The list of 40 sources is included in Appendix A. Because this thesis focuses on the pan-handle area of Florida, the list of sources was narrowed down to those in and around the Pan-Handle. The 13 sources along with a map identification number, location in UTM 1983 (meters) horizontal grid coordinates, and the respective annual CO_2 emissions for 2007 are listed in Table 1. Each of the 13 sources is also shown on Figure 1 along with two potential CO_2 repositories discussed later in this thesis. Also note that the power plant ID numbering is consistent with the original 40 sources from other publications (Poiencot and Brown, 2011; Poiencot & Brown 2012).

Table 1. Florida Pan-Handle CO_2 Emission Sources

Map ID	Plant Name	Northing	Easting	Annual CO_2 Emission (Mt)
1	Crystal River	3204678.076	334313.2099	14.53
3	St Johns River Power Park	3366685.069	447107.3266	9.38
4	Seminole	3289401.62	438698.3555	8.95
6	Crist	3398084.815	-97895.92908	6.62
10	Northside Generating Station	3365145.497	446936.553	4.46
13	Lansing Smith	3357948.163	47642.89122	3.44
22	Deerhaven Generating Station	3292844.025	365772.0841	1.58
26	Cedar Bay Generating Company LP	3365693.624	441618.5065	1.28
32	S O Purdom	3341056.505	191654.8001	0.64
33	Brandy Branch	3354692.44	408803.1779	0.63
37	Arvah B Hopkins	3373808.201	173480.9335	0.52
38	Scholz	3399359.3847	127519.0930	0.52
39	Putnam	3277742.366	443310.436	0.50

2.2 Geologic Storage Areas

2.2.1 Storage Zone Characterization

With the sources (supply nodes) identified, the CCS repository or demand locations are identified next. The locations of the various repositories were based upon the available geology, location of existing emission sources, and institutional concerns regarding possible CO_2 releases (Lewicki et al, 2007). Based upon the existing research, Florida has ample potential CCS repositories including depleted oil/gas fields, unminable coal seams, and deep, saline aquifers (Cole, 1942; Chen, 1965; Babcock, 1969; Vernon, 1970; Puri & Winston, 1974; Raymond & Copeland, 1988; Rupert, 1991; Yamamoto et al, 2009). Of the four primary disposal alternatives, saline aquifers present the best opportunity to store large quantities of CO_2 safely (DOE, 2008; DOE, 2010).

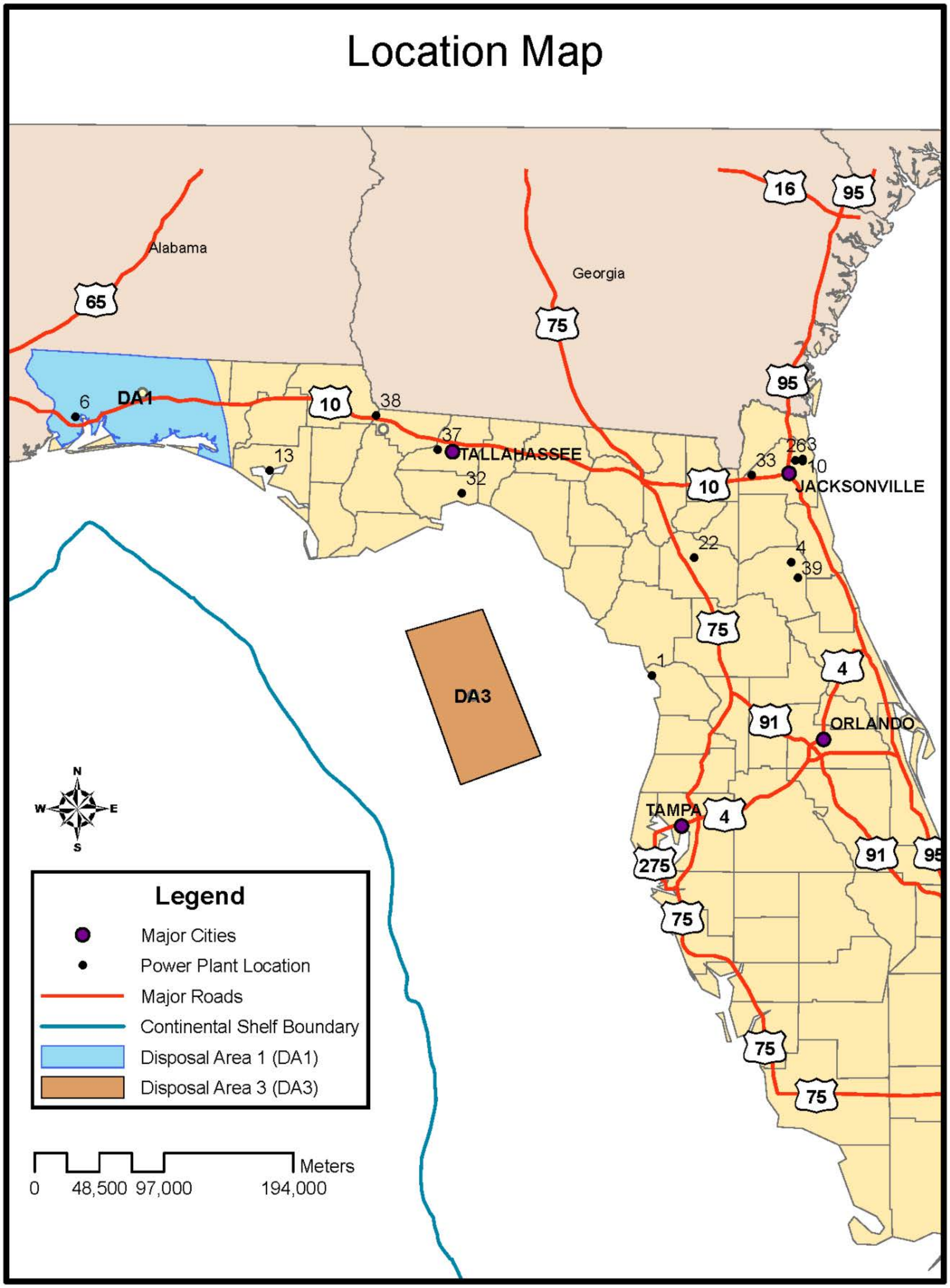


Figure 1. Study Area Location Map

Building upon the existing research, this thesis has chosen two separate saline aquifer CCS repository sites (see Figure 1) distributed throughout the Florida Pan-Handle. Each of the 2 sites represents a portion of an identified CO_2 disposal/repository site outlined in the "2010 Carbon Sequestration Atlas of the United States and Canada" (DOE, 2010). Each of these two sites is discussed herein. Figure 2 presents the overall saline aquifer sequestration potential for the southeastern United States, as defined by DOE in the Carbon Atlas (DOE, 2010).

The Florida panhandle contains ample potential capacity for carbon sequestration within the Upper Cretaceous Zone, specifically the Tuscaloosa Formation. This formation is present in several Gulf Coast states and is estimated to have a "low" estimate capacity

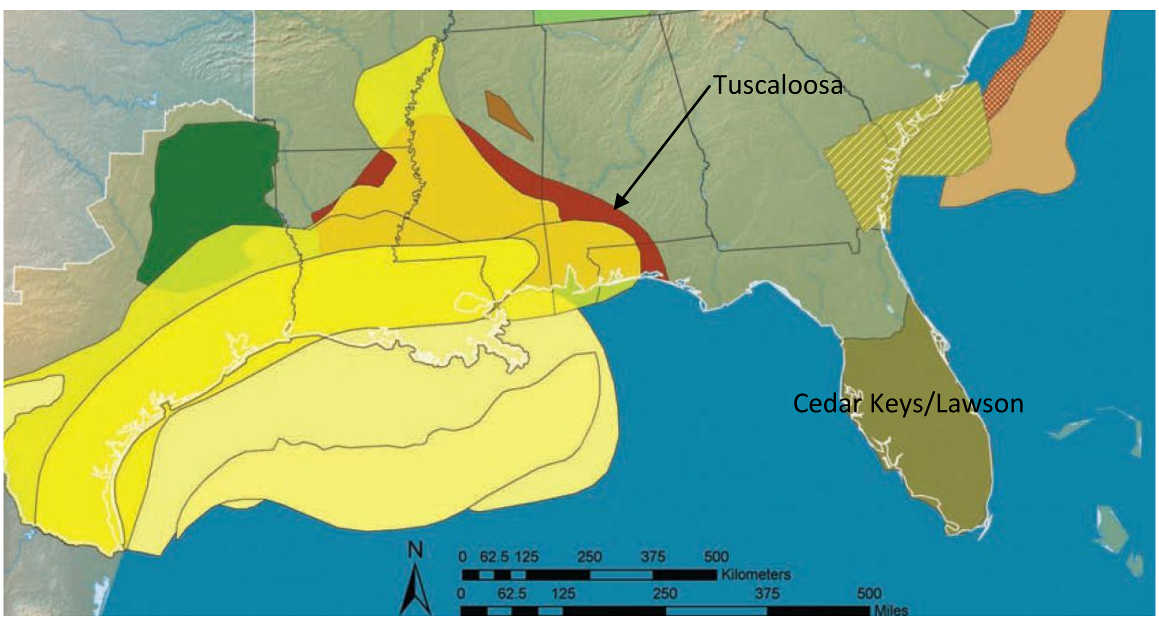


Figure 2. Southeastern United States Geologic Sequestration Potential (DOE, 2010)

of at least 5 gigatonnes (Gt) according to the (DOE, 2010). Disposal Area 1 (DA1) consists of the western Pan-Handle. Disposal Area 3 (DA3) is located off-shore of the

Pan-Handle in the Gulf of Mexico. Not much data exists to characterize this region however; preliminary assessment was completed by Poiencot and Brown (2011 & 2012), where geologic information was extrapolated offshore under the assumption that similar geology exists from the peninsula of Florida to the extents of the Florida shelf. Characterization of DA3 will be carried over from the initial studies and included here as an offshore, low impact alternative.

2.2.1.1 Selma Group

The Selma Group in the area of Cedar Keys, Florida is mainly white chalk with some chalky limestone (Cole, 1942). Pugh et al. (2008) describe the Selma in the area of Bay County as comprising of marls, clay, limestones, and interbedded sands and identify the Selma Group as a primary seal for CCS activities in the Florida Pan-Handle.

2.2.1.2 Eutaw Formation

In the area around Plant Scholtz (number 38 on Figure 1), the Eutaw Formation consists of hard, dark gray shales, some chalk and sands while in northern Jackson County, Florida the Eutaw contained much more sand and sandstone and the shale were micaceous (Cole, 1942). The Eutaw is also identified in the Coastal Province of Alabama as genetically related in sedimentary cycle as the Tuscaloosa where the Eutaw consists mainly of estuarine, inner-shelf marine and open bay sands and fine clastics (Raymond & Copeland, 1988). Pugh et al. (2008) identify the Eutaw formation as a candidate for CO_2 storage in the Florida Pan-Handle.

2.2.1.3 Tuscaloosa Group

In the area of Cedar Keys, Florida the Tuscaloosa consists dominantly of red, light red, brown or mottled shales with interbedded sandstones while in northern Jackson County, Florida, the Tuscaloosa is dominantly sand and sandstone interbedded with shales (Cole, 1942; Rupert, 1991). The Tuscaloosa is generally sub-divided in the upper, middle, and lower members however as far as Gulf County, Florida, only the lower member exists (Rupert, 1991). The general lithology in the area of Gulf, County consists of light-colored sands and interbedded calcareous and glauconitic sands and shales (Rupert, 1991). Raymond and Copeland state in the Coastal Plain Province of Alabama, the Tuscaloosa Group comprises mainly fossilferous, nearshore, marine clastics (Raymond & Copeland, 1988). In eastern-most Alabama, the formation is typically poorly sorted kaolinitic, arkosic sand and gravel interbedded yellowish-orange to reddish-green mottled kaolinitc clay. Thickness of the Tuscaloosa Formation ranges anywhere from 100 to 400 meters (Raymond & Copeland, 1988). The United States Department of Energy describes the proposed storage reservoir at Southern Company Plant Daniel in Mississippi as a "massive sandstone that is a thick, regionally extensive, porous and permeable coastal to deltaic-marine sandstone at the base of the lower Tuscaloosa" (DOE, 2010). According to the report, the Lower Tuscaloosa in this area is overlain by a thick section of 90 to 140 meters of shales and mudrocks that were deposited as sea level rose during a marine transgression. This deposit of shales and mudrocks is identified as the middle Tuscaloosa. Carbon sequestration activities utilizing the Lower Tuscaloosa for storage may utilize the Middle Tuscaloosa as a potentially effective seal (Pugh et al.

2008). This thesis will focus on a combination of the Eutaw Formation and Upper Tuscaloosa for CO_2 storage.

2.2.1.4 Cedar Keys/Lawson

The offshore repository (DA3) would inject CO_2 into the Cedar Keys/Lawson Dolomite formations. The USDOE estimates that the entire Cedar Keys/Lawson Dolomite formations capable of storing CO_2 have a "low" estimate capacity of approximately 11 Gt (DOE, 2010). For initial studies, the capacity of DA3 was estimated by the area-weighted share of the total estimated low capacity or 1 Gt. According to Chen (1965), the Cedar Keys Formation is widely spread across peninsular Florida and spreads into the Pan-Handle. In Brevard County, Florida, the top of the Cedar Keys Formation ranges from approximately 670 meters NGVD to 914 meters NGVD below land surface. The formation consists of dolomite and evaporates with a minor amount of limestone. Gypsum commonly fills pore spaces within the dolomite beds and occurs as thin irregular streaks or seams in the dolomite. The Lawson Formation is generally found at the base of the Cedar Keys Formation. The Lawson is comprised mainly of pure, clean, very light brown and fine crystalline dolomite and/or chalky dolomitic limestone (Chen, 1965).

Chapter 3

STORAGE CAPACITY

Important in assessing the feasibility of CCS for the Florida Pan-Handle is determining the available storage capacity of the proposed storage areas. Methods outlined by USDOE (2010) and Roberts-Ashby (2010) utilize existing oil and gas geophysical explorations to populate the storage equation used by the National Energy Technology Laboratory. This chapter outlines the process for estimating the storage capacity.

3.1 Storage Capacity Estimation

In conjunction with technical staff from Southern Company, the research effort compiled a series of pertinent geophysical and lithological logs for the purposes of developing a geological model to aid with estimating repository capacity. Wells were chosen if they had a bulk density, borehole compensated sonic, or dual induction geophysical logs. These logs provide a relatively simple method to determine the porosity of the formations in question based upon published standards. In order to determine the capacity of the formation, the volumetric equation for capacity estimation for saline formations was used. This formula is defined in National Energy Technology Laboratory (NETL) Carbon Sequestration Atlas for the United States and Canada (DOE, 2010) as follows:

$$G_{CO2} = Ah_g \quad \mathrm{tot} \quad \mathrm{E} \tag{1}$$

G_{CO2} - Carbon mass capable of being stored (kg);

A - Geographic area of the Disposal Area (m^2);

h_g- Gross thickness of the injection formation (m);

$_{tot}$- Average porosity of the injection formation;

– Density that the CO_2 would be at given the pressure and temperature of the formation (kg/m^3); and,

E – Storage efficiency factor (Typically 1 to 4%).

ArcGIS coverages obtained from NETL depicted the general areas of suitable saline aquifer formations for CCS across the United States. ArcGIS polygons were created around each area of interest in Florida and used to determine the geographic area of each of the proposed repository/disposal sites. The area of Disposal Area 1 (DA1) was created from a much larger coverage which spanned most of Alabama, Mississippi and the Florida Pan-handle, as shown previously in Figure 2. The overall coverage was edited to only include the portions that existed within the boundary of Florida. Disposal Area 3 (DA3) is an offshore area that is believed to share geologic characteristics with the Florida peninsula, as previously mentioned in this report. The polygon size for DA3 was arbitrarily selected. The original estimate for capacity for this site was approximately 1 Gt (Poiencot & Brown, 2011). For this thesis, a revised capacity estimate was determined for DA1 by using the ArcGIS polygon, storage zone thickness estimates, estimated porosities, estimated storage efficiencies, and assuming in-place CO_2 densities. The capacity estimate for DA3 was determined from data provided by the USDOE (2010), Roberts-Ashby (2010), and Poiencot and Brown (2012).

Well logs used in conjunction with existing cross section and lithologic data were needed to determine the depths of the repository/disposal zone. This information was required to determine an overall cross-section for DA1, as well as the total thickness of the various storage zones but also in formations, such as the Tuscaloosa, was required to determine the percentage of the formation that was available for sequestration given that much of the Tuscaloosa contains shale stringers. This analysis was accomplished by matching up the limited lithological well logs available to corresponding geophysical well logs. It should be noted that storage zone thickness shown on tables in this report generally indicates "total" sandstone stringer zone thicknesses rather than one continuous geologic zone. Corresponding figures report the total formation thickness including both shale and sandstone. Each well log interpretation is presented in detail in Appendix B.

3.1.1 Average Porosity

In order to calculate the average porosity of the injection formations, geophysical logs and the corresponding Schlumberger conversion graphs were used, similar to the methods used by Roberts-Ashby (2010). An average porosity value was obtained for each well and an average of these values was calculated in order to determine the average porosity of the injection formations. Tables listing the well log data and corresponding porosity values are included in Appendix C. Temperature and pressure data from the well logs were used when available or given a conservative estimate when not available.

3.1.2 Storage Efficiency

Storage efficiency relates to the ratio of available storage in a disposal area and the amount of storage area occupied by injected CO_2. Supercritical CO_2 is less viscous and less dense than the brine found in saline aquifers. Subsequently the injected CO_2 does not displace resident brine in a plug-flow fashion (Okwen, 2009). Instead the CO_2 migrates to the top of the brine as it is injected, forming a layer of CO_2 at the top of the confined formation (Nordbotten et al, 2006). It is important to calculate the storage efficiency to obtain accurate estimates of sequestration capacity within saline aquifers. Okwen et al. (2009) developed an analytical solution to determining the storage efficiency of saline storage reservoirs. The Okwen model focuses on initial active injection times when the primary trapping mechanisms for CO_2 are stratigraphic and structural trapping, or when the CO_2 is most mobile. Okwen et al. (2009) identify the importance of CO_2 buoyancy to storage efficiency, defined as epsilon (ϵ) below, and use the dimensionless group as defined below.

$$= \frac{2\pi\Delta\rho g k \lambda_b B^2}{Q_{well}} \tag{2}$$

Δ – difference in density of injected CO_2 and native brine (kg/m^3)

g – gravitational acceleration constant (m/s^2)

k – intrinsic permeability

λ_b – brine mobility equal to the relative permeability of the brine divided by the viscosity of the brine, $k_{r,b}/\mu_b$

B – thickness of aquifer

Q_{well} – injection rate of CO_2

Once importance of CO_2 buoyancy ( ) is quantified, the storage efficiency calculation can continue. The following efficiency equations are presented by Okwen et al. (2009) and each is used depending on the value of for the proposed storage area.

$$\epsilon \approx (1 - S_R)\frac{1}{\lambda};\ 0 \leq \quad < 0.5 \tag{3}$$

$$\epsilon \approx \frac{2(1-S_R)}{(0.0324\lambda-0.0952)\ \ +(0.1778\lambda+5.9682)\ \ ^{1/2}+1.6962\lambda-3.0472};\ \ 0.5 \leq \quad \leq 50 \qquad (4)$$

S_R – residual brine saturation following displacement of brine by CO_2

λ – ratio of CO_2 mobility to brine mobility, λ_{CO2}/λ_b

ϵ - storage efficiency

The calculated value for DA1 was approximately 0.95, meaning buoyancy would in fact affect the CO_2 plume. Table 2 presents the parameters and calculated values of ϵ, for DA1, for varying values of residual brine saturation (S_R). The residual brine saturation is not a readily definable term, therefore in following the methods of Okwen et al. (2009), a range of values was used. The calculation is presented in further detail in Appendix D.

Table 2. Storage Efficiency Parameters

	S_r = 0	**S_r = 0.15**	**S_r = 0.30**	**S_r = 0.45**
λ_c	12496.88	12496.88	12496.88	12496.88
λ_b	1361.90	1361.90	1361.90	1361.90
λ	9.18	9.18	9.18	9.18
ϵ	0.10	0.08	0.07	0.05

As mentioned previously, storage efficiency values typically range from 1 to 4% (NETL, 2007). The results of the above analysis show efficiency values of 5 to 10%. While higher than the commonly accepted values, they are not unreasonable due to the presence of the shale stringers within the proposed storage zones. These shale stringers could cause the injected CO_2 to stack in different zones and utilize more of the available storage space. It is also worth noting that other published studies have produced values within range and sometimes higher for storage efficiencies (Van der Meer, 1995; Okwen et al, 2009). The efficiencies and their interaction with the shale stringers within DA1 were analyzed using numerical modeling, which is discussed later in this chapter.

3.1.3 Storage Capacity

Disposal Area 1 had an abundance of high quality well logs to choose from. In the end thirteen wells were chosen for this thesis, seven for a west to east cross section and six for a north to south cross section. Figure 3 is a location map of the borings used in this study and presents the cross-section paths. The cross-sections are presented in Figure 4 and Figure 5. The scale on the cross-sections is exaggerated for clarity, showing the vertical axis in meters and the horizontal axis in kilometers. While formation dip may appear steep in the figures, the maximum dip calculated between two well logs for the Tuscaloosa formation was 1.46%.

Disposal Area 3 was considered as an alternative to DA1 because of its location offshore in the Gulf of Mexico. Unfortunately the offshore location also provided a lack of available data on the geology of that area. This was addressed by using information gathered for the Florida Peninsula and reviewing literature on the geology off the coast of Florida that was closest to this repository, then estimating the capacity based off of this information. This method will not give a highly accurate estimate of the true capacity of DA3, but it is the best estimate obtainable with the information available. The estimated geologic sequestration capacities for each of the two Florida Pan-handle areas are shown on Table 3. The capacities for DA1 with varying storage efficiencies are presented in Table 4.

Table 3. Geologic Sequestration Capacities for the Florida Pan-Handle

Disposal Area	Area (m^2)	Thickness (m)[1]	Porosity	Density (kg/m^3)	Capacity at 1% E (Gt)	Capacity at 4% E (Gt)
DA1	8.39×10^9	104.0	0.18	842.75	1.40	5.58
DA3	7.47×10^9	162.5	0.23	725.0	2.02	8.09

Note 1: Thickness represent combined thickness of sandstone stringer zones.

Table 4. Geologic Sequestration Capacities for Disposal Area 1 with Varying Storage Efficiencies

Disposal Area	Capacity at $\epsilon = .01$ (Gt)	Capacity at $\epsilon = .04$ (Gt)	Capacity at $\epsilon = .05$ (Gt)	Capacity at $\epsilon = .07$ (Gt)	Capacity at $\epsilon = .08$ (Gt)	Capacity at $\epsilon = .10$ (Gt)
DA1	1.40	5.58	7.00	9.80	11.21	14.01

3.2 Numerical Modeling

In an effort to analyze the effect of the shale stringers present in DA1 and further validate storage efficiency values, numerical modeling was performed. The software package used to conduct the analysis was UTCHEM-9.0. Research completed by University of Texas produced UTCHEM, a 3-D, multicomponent, multiphase, compositional model of chemical flooding processes which accounts for complex phase behavior, chemical and physical transformations and heterogeneous porous media properties, and uses advanced concepts in high-order numerical accuracy and dispersion control and vector and parallel processing (University of Texas, 2000, p. 1-1). The code was originally designed for simulating enhanced oil recovery but has since also been used to simulate multi-phase flow in aquifers at contaminated sites. Therefore, it is an ideal code to use for CCS simulations (Brown, 2011). The UTCHEM code provides the ability to model the migratory behavior of the CO_2 plume over time under different storage efficiency factors, assess the effects of shale stringers, and estimate the surface area of the CO_2 plume.

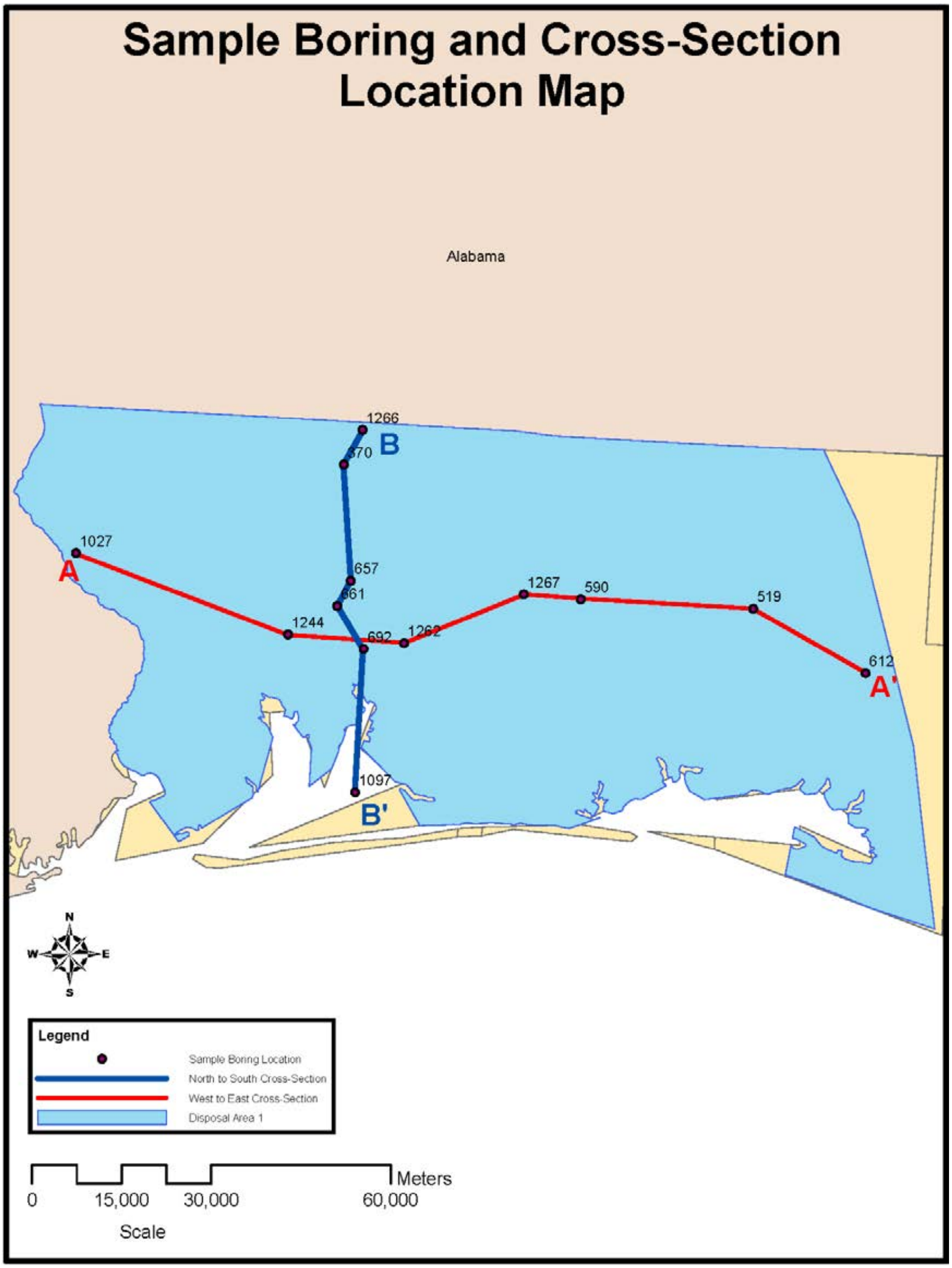


Figure 3. Sample Borings and Cross-Section Location Map

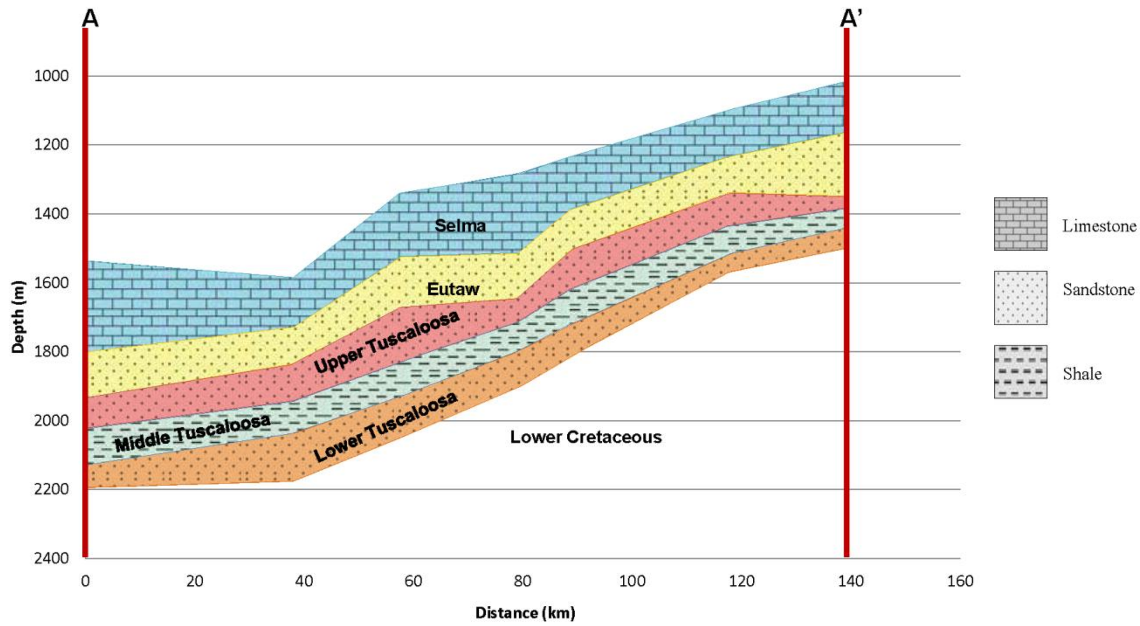


Figure 4. Disposal Area 1 West-East Cross-Section

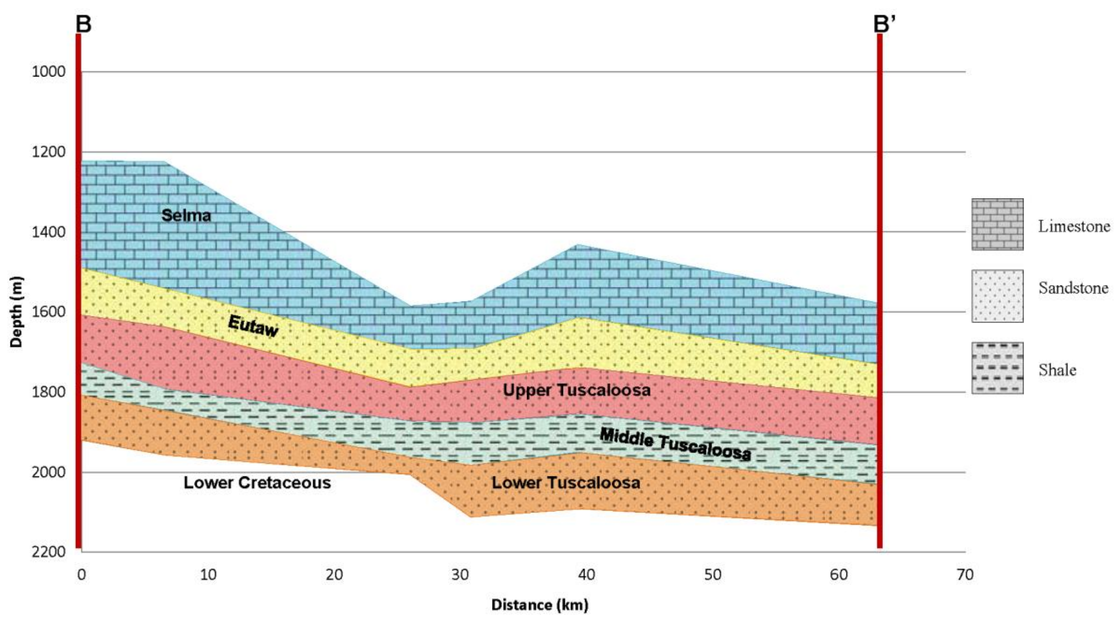


Figure 5. Disposal Area 1 North-South Cross-Section

Brown (2011) provided a model which was originally created to provide analysis in the creation of graphical planning envelopes for estimating the surface footprint of CO_2 injected into saline aquifers. A robust 3-dimensional finite difference model was created in UTCHEM and different injection scenarios were analyzed. The Brown (2011) model provided a "type-aquifer" to use as the foundation and revised for analysis of DA1. The model simulated a storage zone 100 meters thick and 500 meters long. Details of the original and revised models are provided in Appendix E.

The purpose for modeling DA1 was to analyze the effect of the shale stringers present in the Eutaw and Tuscaloosa formations in the Florida Pan-Handle. Porosity, temperature, pressure, and intrinsic permeability values were changed to match the data for DA1. The stringers were modeled by changing the permeability of particular layers of cells within the storage reservoir. Eight simulations in total were performed with varying percentages of shale versus sand. Four variations of shale percentage were applied to the model; 0, 25, 50, and 75%. For each variation of shale content, two values of hydraulic conductivity for the sandstone were used, 5 and 50 milidarcys (mD), in order to cover the commonly accepted range of hydraulic conductivities for sand/sandstone (Fetter, 2001). One value of hydraulic conductivity, 0.01 mD, was used for shale (Fetter, 2001). Each model run simulated a 180 day injection period and produced a 3-dimensional contour depicting the distribution of injected CO_2 within the aquifer.

One model simulation from Brown (2011) was replicated to portray an exaggerated case of how supercritical CO_2 is expected to behave in a sand aquifer with a very high, 5,000 mD, hydraulic conductivity. Figure 6 presents the results from this case. Notice how the CO_2, shown in variations of green, immediately migrates to the top of the aquifer and begins to spread in a thin layer along the top. The higher concentrations are near the top of the formation.

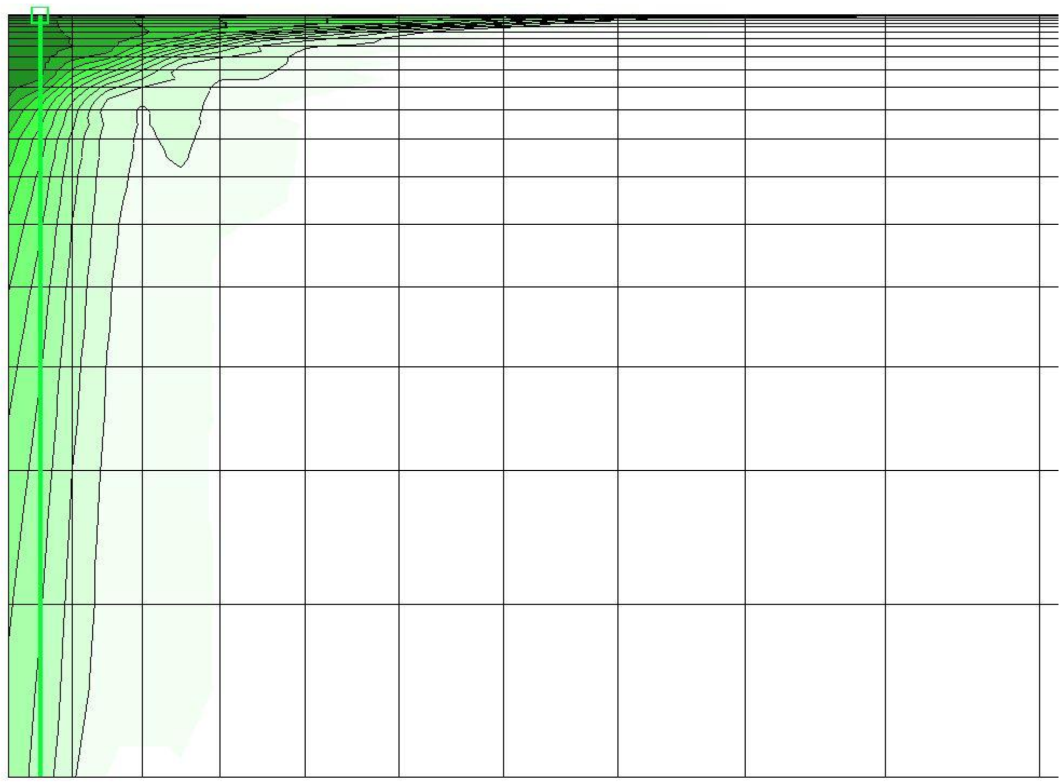


Figure 6. CO_2 Plume at 5,000mD Hydraulic Conductivity (Brown, 2011)

The expectation for DA1, was that the shale stringers would succeed in trapping the CO_2 in "stacked" layers, improving the storage efficiency. Also included in the process, the estimated percentage of shale contained in DA1 was calculated from the geologic characterizations. DA1 was estimated to have approximately 56% shale. All model results are provided in Appendix E, while the 0% and 50% shale simulations are presented and discussed below. The results from the 0% simulations provide comparison between shale stringers and no shale stringers for DA1.

Figure 7 and Figure 8 present the results from the simulations with 0% shale and 5 and 50 mD hydraulic conductivity, respectively. Notice the CO_2 behavior is similar to that of Figure 6; however the CO_2 migration is not as rapid. After 180 days, plenty of CO_2 remains around the injection point, but much has migrated to the top of the aquifer. Figure 9 and 10 present the results from the simulations with 50% shale and 5 and 50mD hydraulic conductivity, respectively. In these figures the contrast in hydraulic conductivity between the sand and shale is apparent. The CO_2 indeed is trapped in "stacked" layers.

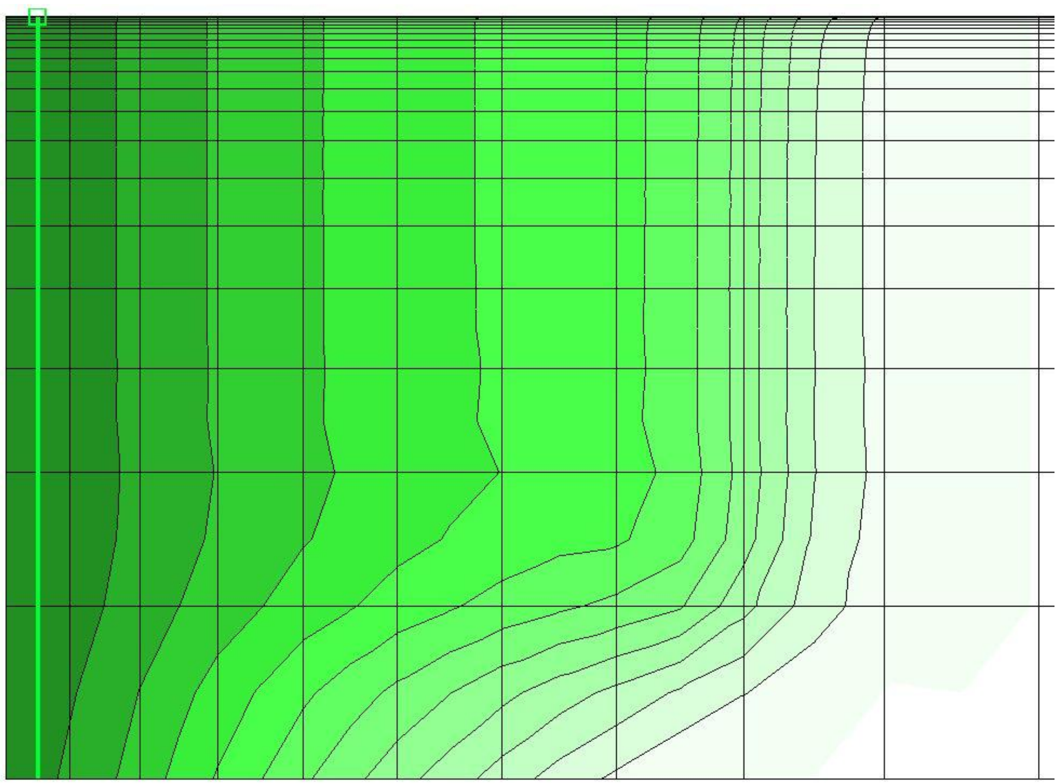


Figure 7. CO2 Plume Injected into Aquifer with 0% Shale at 5mD

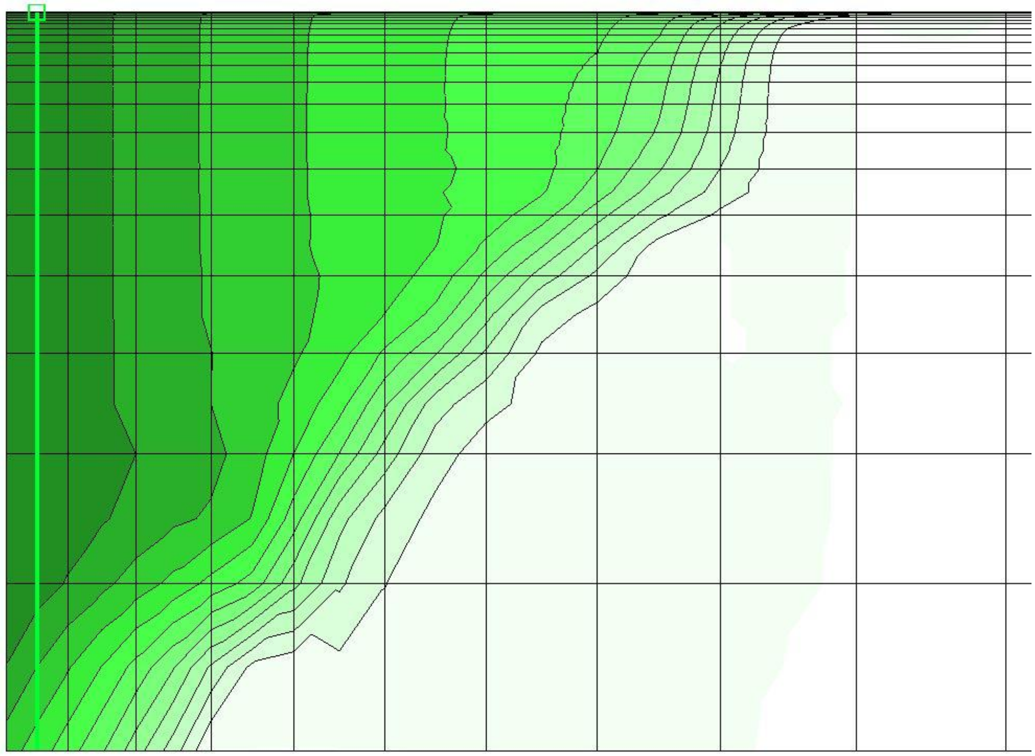


Figure 8. CO2 Plume Injected into Aquifer with 0% Shale at 50mD

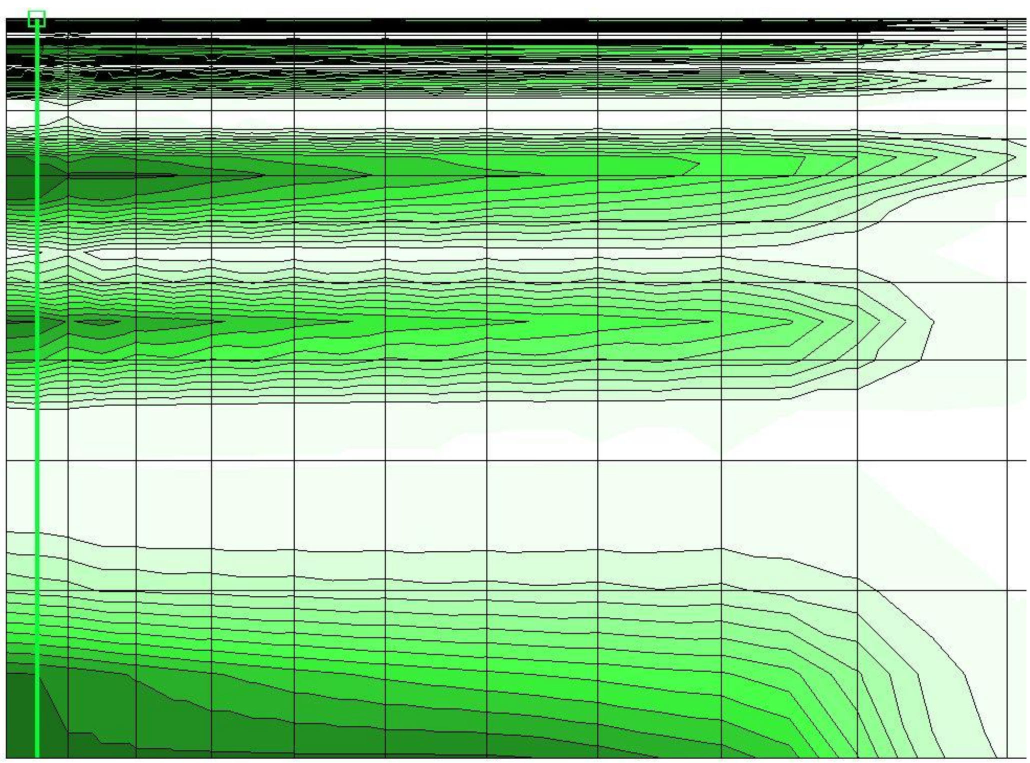


Figure 9. CO2 Plume Injected into Aquifer with 50% Shale at 5mD

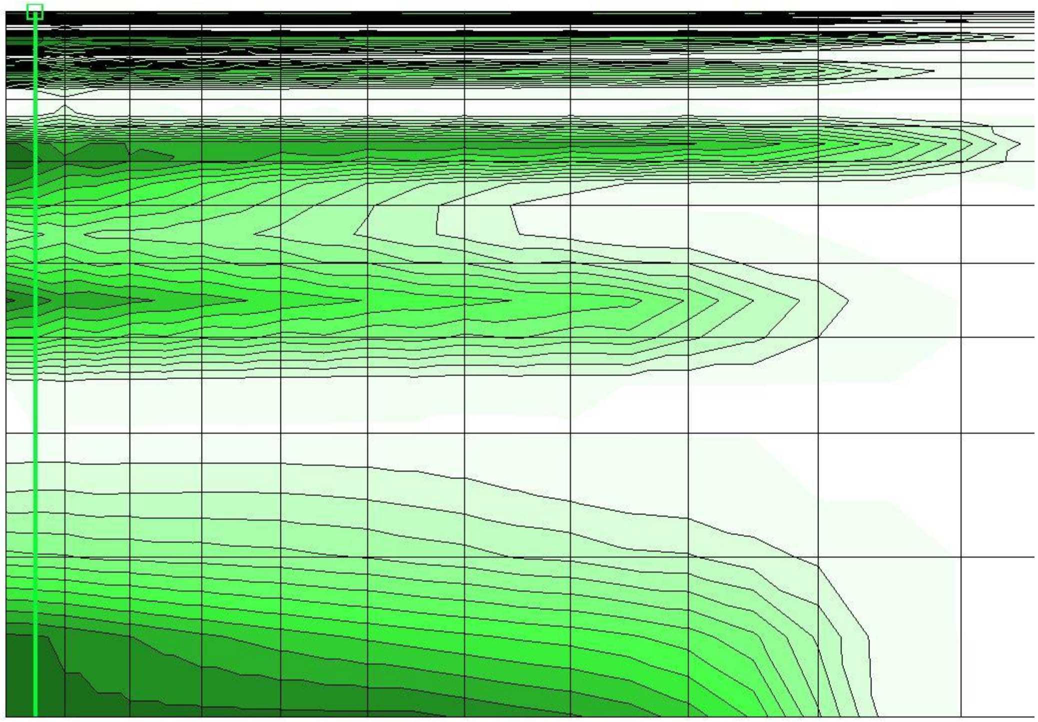


Figure 10. CO2 Plumes Injected into Aquifer with 50% Shale at 50mD

Of note is the difference in CO_2 migration from simply changing the hydraulic conductivity of the sand. In Figure 7 and Figure 8, there is a noticeable difference in the plume shape between 5mD and 50mD. The addition of the shale stringers, changes the behavior of the CO_2 even more. The CO_2, in these simulations remains in the areas of sand and slowly works its way through the shale. From a qualitative perspective, the aquifers modeled in Figure 9 and Figure 10 appear to be more efficient at trapping CO_2 than those without the shale. The CO_2 does migrate horizontally as in any other simulation however this lateral movement is achieved in multiple layers of the repository as opposed to the CO_2 collecting near the surface. Higher concentrations of the supercritical CO_2 remain distributed throughout the aquifer. Judging by the results of the numerical modeling, higher values of storage efficiency may be warranted. The Okwen et al. (2009) model, discussed earlier, produced efficiencies ranging between 5 and 10%.

The lower end of the Okwen range is applicable to DA1 but 10% or larger seems too high considering the model results and based upon the other literature estimates. To remain conservative while including results from the numerical modeling, a storage efficiency value of 4% was used for DA1 while analyzing transportation scenarios.

Chapter 4

CARBON DIOXIDE TRANSPORTATION ANALYSIS

Once the CO_2 sources and sinks were indentified, a pipeline network model was developed. Poiencot and Brown (2011) developed a feasibility-level pipeline cost model as the first step in developing the network model and later applied the cost estimates to different pipeline routing scenarios (Poiencot & Brown 2011; Poiencot & Brown 2012).

4.1 Transportation Costs

Poiencot and Brown (2011) reviewed a number of different cost models from sources such as Heddle et al. (2003), McCoy (2008), Bakken & Von Streng Velken (2008), and Zhang et al. (2006). These sources were chosen because they focused solely on the transport portion of CCS. Heddle et al. developed a simple linear model that includes capital cost and annual operation and maintenance (O&M) costs (Heddle et al., 2003). McCoy (2008) developed a model that provides for regional cost differences as well as further resolution of cost factors such as pipe materials, labor, real estate, permitting, design and construction management. Total capital cost of a pipeline is made up of four key categories; material cost, labor cost, right-of-way (ROW) cost and miscellaneous cost (Liu & Gallagher, 2010). After reviewing the literature, Poiencot and Brown (2011) chose the McCoy (2008) cost model to adapt for their study. The specific details of the model development are presented in Poiencot and Brown (2011) while the equation and parameters are included below.

$$[\text{Total Annual Cost} = [[\omega_m \times \beta_m \times L^{a6m} \times (D \times 39.38)^{a7m} \times CF] + [\omega_L \times \beta_L \times L^{a6L} \times (D \times 39.38)^{a7L} \times CF] + [\omega_{RE} \times \beta_{RE} \times L^{a6RE} \times (D \times 39.38)^{a7RE} \times CF] + [\omega_{MS} \times \beta_{MS} \times L^{a6MS} \times (D \times 39.38)^{a7MS} \times CF] + [0.0088 \times \varepsilon 2 \times L] \times \alpha]] \quad (5)$$

Where ω_m, ω_L, ω_{RE}, and ω_{MS} are cost adjustment coefficients to convert April 2004 costs to March 2010 costs and are $\omega_m = 1.18$, $\omega_L = 1.15$, $\omega_{RE} = 1.05$, and $\omega_{MS} = 1.26$; β_m, β_L, β_{RE}, and β_{MS} are cost coefficients for materials, labor, real estate, and miscellaneous (e.g., design, permitting, construction management) in 2004 dollars and are $\beta_m = 1{,}534.62$, $\beta_L = 30{,}690.22$, $\beta_{RE} = 8{,}912.51$, and $\beta_{MS} = 33{,}265.96$; L is the least-cost pipeline route length in kilometers; D is the pipeline diameter in meters and is a function of flow rate (see Poiencot & Brown, 2011); CF is a capital cost factor of 0.067574 assuming a 5% discount rate used to annualize the initial pipeline capital construction cost; $\varepsilon 2$ is CO_2 mass flow rate in tonnes per year; α is a factor to adjust costs for underwater construction, it is 1.75 for underwater projects and 1.0 for land pipeline projects; $a6_m$, $a6_L$, $a6_{RE}$, and $a6_{MS}$ are model pipeline length power exponents for materials, labor, real estate, and miscellaneous and are $a6_m = 0.901$, $a6_L = 0.82$, $a6_{RE} = 1.049$, and $a6_{MS} = 0.783$; and, $a7_m$, $a7_L$, $a7_{RE}$, and $a7_{MS}$ are model pipeline diameter power exponents for materials, labor, real estate, and miscellaneous and are $a7_m = 1.59$, $a7_L = 0.94$, $a7_{RE} = 0.403$, and $a7_{MS} = 0.791$. The new cost model for Florida is intended for use as a planning tool to be used in feasibility-level studies. It is applicable for use in Florida or other in other areas of similar flat topography.

For this thesis, the Poiencot and Brown model was validated against the previously referenced pipeline transportation models. UNF also conducted further validation against other recent CCS transportation models published by Liu and Gallagher (2010), McCollum and Ogden (2006), Ogden et al. (2004) and Parker (2004).

Liu & Gallagher (2010) provide an engineering-economic assessment for CO_2 pipeline transportation in China, utilizing methods outlined by McCollum and Ogden (2006). McCollum and Ogden (2006) took an average of a number of published cost models including Heddle et al. (2003), Ogden et al. (2004), and Parker (2004), after applying common bases to those models. A comparison of various model estimates from McCollum and Ogden (2006) is recreated in Figure 11 and includes the McCoy (2008), Poiencot and Brown (2011) and Liu and Gallagher (2010) cost models. The years for each model correspond to the costs used in each model. As shown in Figure 11, the Poiencot and Brown (2011) model falls within range of the previously published cost models.

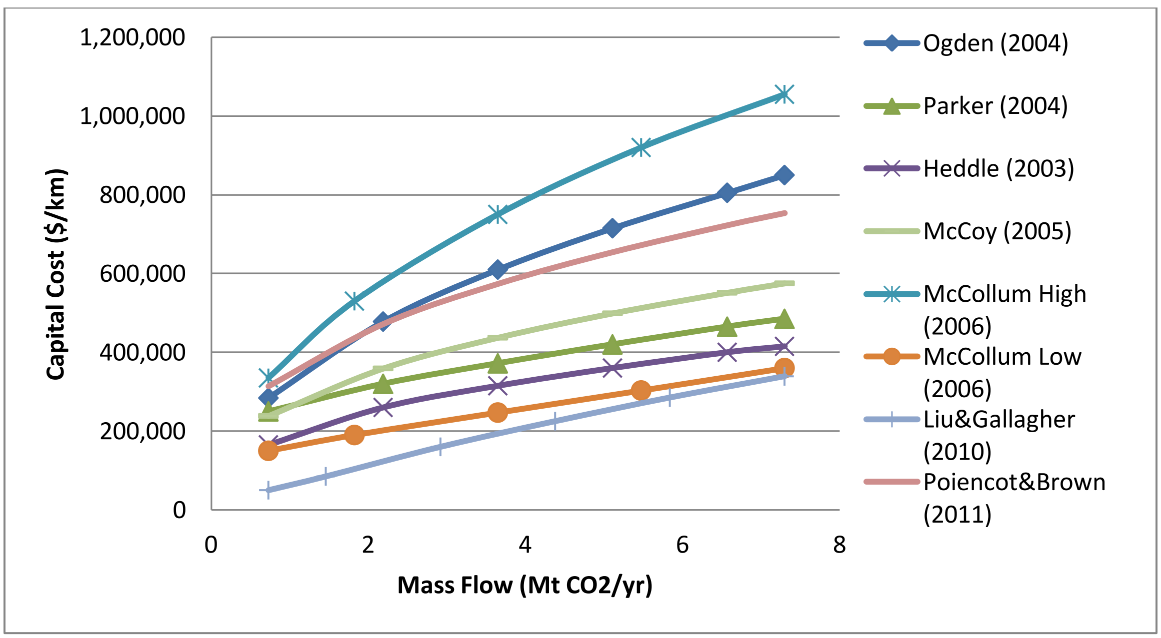


Figure 11. CO_2 Pipeline Capital Cost Model Comparison

The various published models used in validation testing for this thesis were also recently reviewed by Essandou-Yeddu and Gulen (2009). They determined that the various models use historical natural gas pipeline costs, which for the scale considered here were last constructed in the 1990s, to develop their respective cost equations. The models do well in predicting the capital costs for pipelines constructed in the past but falter when predicting the costs for more recent CO_2 pipelines (Essandou-Yeddu & Gulen, 2009). To remedy this situation, Essandou-Yeddu and Gulen (2009) provide a method for utilizing cost escalation factors for each of the models. Figure 11 compares all reviewed cost models before escalation factors were applied. In this case, the Poiencot and Brown (2011) model falls within the upper limits of the cost range provided by the other published cost models. Using the methods prescribed by Essandou-Yeddu and Gulen (2009) in conjunction with published cost factors from Lewis (2010), the estimated costs from each of the published models was escalated to March 2010 costs. The results including the cost escalation factors are displayed in Figure 12. Once the costs were escalated, the Poiencot and Brown (2011) model costs resulted in estimates fourth lowest of all the models but near the middle of the cost range, indicating the model is suitable for feasibility-level studies in Florida.

Another important factor in the transportation cost analysis is the O&M costs for the pipeline network. Pipeline O&M costs can include depreciation, amortization, financial, maintenance, materials, fuel, power, labor, administration and miscellaneous (Liu & Gallagher, 2010). Poiencot & Brown, through literature review, developed a reasonable mean O&M cost of 0.0088 \$/tonne CO_2/kilometer. Further analysis showed differing methods in the estimation of O&M for a CO_2 pipeline. Ogden (2006) and Liu and Gallagher (2010) estimate O&M as a percentage of the total capital cost of the pipeline, 4% and 3% respectively. Heddle et al. (2003) and McCoy (2008) apply a value of $3,100 per kilometer and $3,250 per kilometer of pipe respectively. Parker (2004) and McCollum and Ogden (2006) did not calculate O&M values. To compare the O&M values, all dollar amounts were escalated to March 2010 dollars using the Essandou-Yeddu and Gulen (2009) composite escalation factors as described earlier. Figure 13 displays a comparison of the different O&M values for each model in 2010 dollars. The results from this comparison are similar to the capital cost comparisons in that, Liu and Gallagher (2010) provide a low estimate, Ogden (2006) a high estimate and the Poiencot and Brown (2011) values are somewhere in the middle. The differences in the estimates lie in the methods used to calculate the O&M values. The Heddle (2003) and McCoy (2008) values rely only on length of pipe. The Ogden (2006) and Liu and Gallagher (2010) estimations rely on capital cost and therefore are affected by the same factors as capital costs, i.e. diameter, length, etc. The Poiencot and Brown (2011) estimates are based on capacity and length, making the values similar to the Ogden (2006) and Liu and Gallagher (2010) estimates and within range of the two models. Notice the behavior of the Poiencot and Brown (2011) estimate is more linear as opposed to the other models. Another deficiency identified in this thesis is the fact that the original Poiencot and Brown (2011) estimate relied only on pipeline length, not taking into account pipe diameter or capacity. Ogden (2004) and Liu and Gallagher (2010) estimate pipeline O&M costs as a percentage of the capital cost, 4% and 3% respectively. Poiencot and Brown (2012) later proposed to calculate O&M as 6% of the capital cost. Figure 14 presents a revised O&M cost comparison.

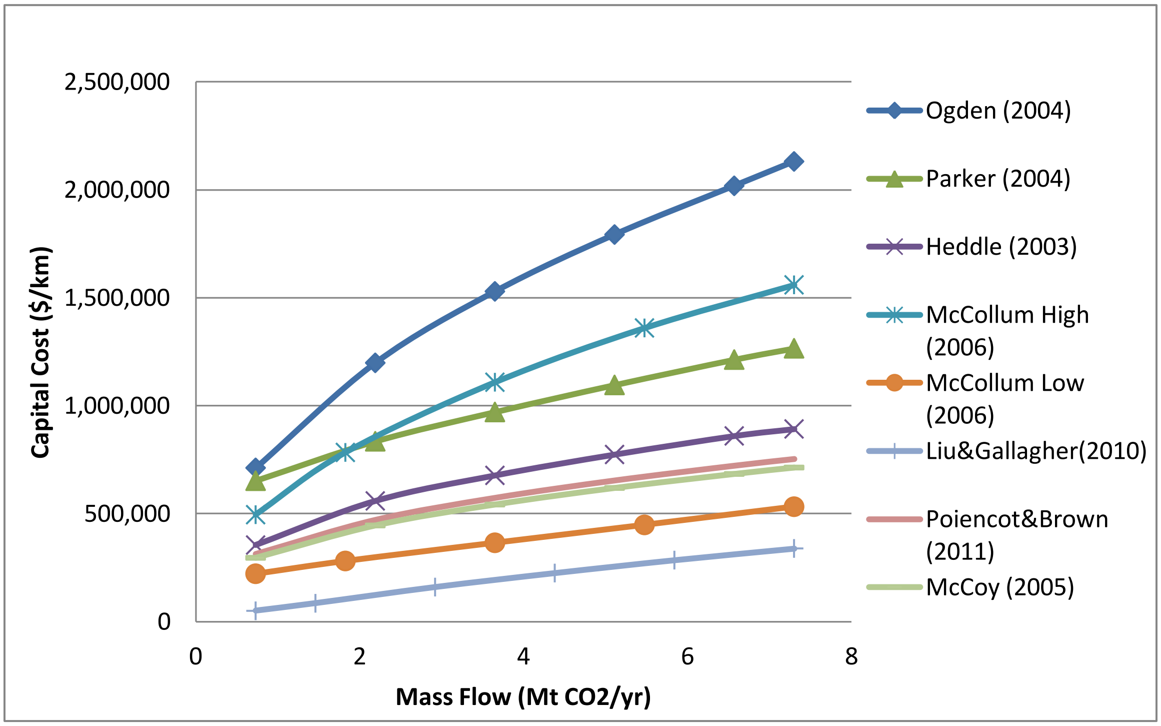


Figure 12. CO2 Capital Cost Model Comparison – Escalated Costs

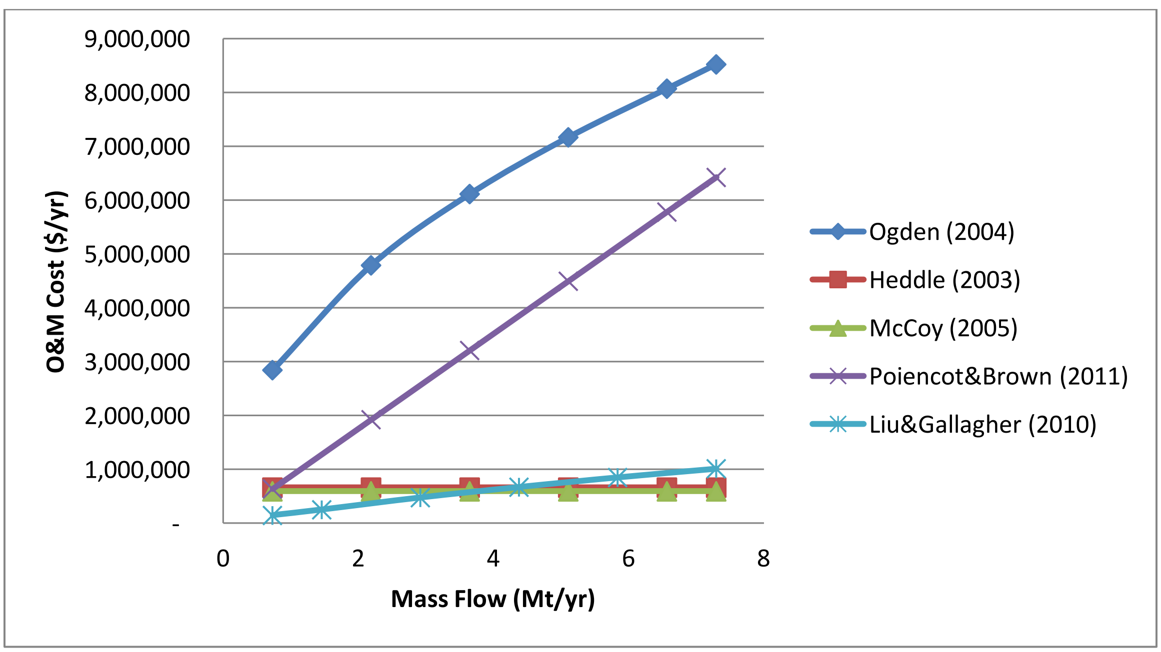


Figure 13. Operation and Maintenance Cost Model Comparison

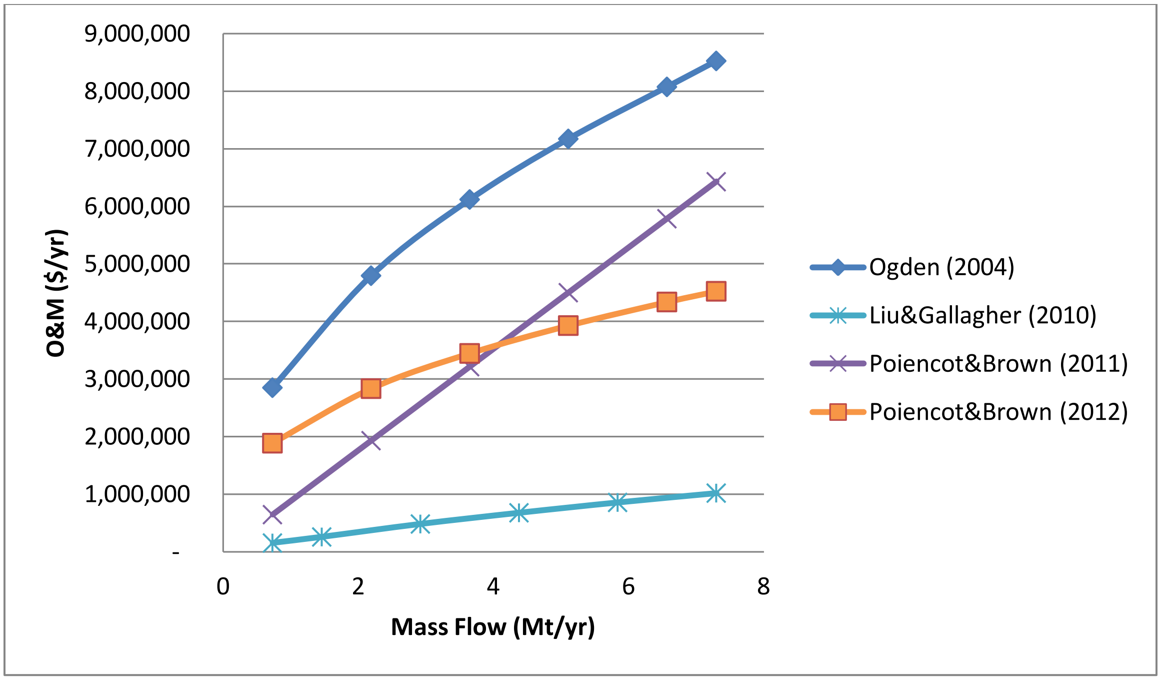


Figure 14. Revised Operation and Maintenance Cost Model Comparison

As previously mentioned, the capital cost is calculated based on materials, labor, and right-of-way factors and is a function of pipeline length and capacity. Estimating O&M as a function of capital cost is reasonable considering that actual pipeline O&M costs can include depreciation, amortization, financial, maintenance, materials, fuel, power, labor, administration, and miscellaneous costs (Liu & Gallgher 2010). Therefore, based upon the model validation testing, the revised Poiencot and Brown (2012) O&M model is reasonable. Carbon dioxide transportation deployment scenarios included in this thesis use the revised Poiencot and Brown (2012) model for cost determinations.

4.2 Transport Scenarios

4.2.1 Preliminary Research

Initially, Poiencot and Brown (2011) focused on a simple statewide transport model using straight line distance from each source to each sink. This method was not constrained by geography, real estate limitations, institutional concerns or practical engineering considerations regarding pipeline ROW selection (Poiencot & Brown, 2011). Later, this method was updated to a more "real-world" scenario using interstate and highway right-of-way (ROW) paths (Poiencot & Brown 2012). The measured distances and pipeline sizes for these networks were used to calculate the capital and O&M costs for the network and a least-cost transport optimization model was run using Microsoft Excel Solver™. This model is discussed below. The basic model equation and model constraints are included herein:

$$[Minimize\ \sum F_{ijk} \times X_{SiDjk} = Total\ Cost] \tag{6}$$

Where X is the annual CO_2 pipeline transportation cost (\$/tonne CO_2) from CO_2 supply node S_i (from i = 1 to 13) to demand node or repository D_j (from j = 1 to 2) at Time Year k (from k = 1 to 25 years) and F_{ijk} is the CO_2 flow through that pathway in tonnes CO_2/year during Year k.

$$[Subject\ to\ Constraint\ 1\ \sum_1^{26} Fijk \leq Capacity\ D_j]\ \text{Summed from 1:26 each Year} \tag{7}$$

$$[Subject\ to\ Constraint\ 2\ \sum_1^{26} Fijk \leq Emission\ Supply\ from\ S_i] \tag{8}$$

$$[Subject\ to\ Constraint\ 3\ \sum_1^{26} Fijk \geq 0] \tag{9}$$

4.2.2 Regional Networks

The purpose of this thesis is to focus on the Florida Pan-Handle. The preliminary research discussed earlier, was applied in more detail to DA1 and DA3 with a more regional emphasis. A statewide "authority model" was also used in this report in order to compare the changes in costs due to the revised O&M estimation and demonstrate the effectiveness of DA1 and DA3 as statewide repositories. All pipeline networks will follow major highway and interstate right-of-ways (ROW).

4.2.2.1 The Right-of-Way Model

Figure 15 displays an example of the Right-of-Way Model. This model assumes that all of the proposed disposal areas are permitted and operational at once. Each source is connected to each disposal area and the associated unit costs for each path are calculated. The transport optimization model developed by Poiencot and Brown (2011) was then used to determine the least-cost path for transporting CO_2 from each source to each disposal area over a 25 year period and calculate the associated levelized costs.

Transport Optimization was performed for the Right-of-Way Model over a 25 year period in one year increments. The optimization model determined the cheapest route to transport and store CO_2 from each source. As storage areas filled, flow was rerouted along the next cheapest route. Figure 16 presents the results of the transport optimization in spider diagram format. According to the analysis, there is plenty of capacity for the 25 year study period. DA1 and DA3 still have 83% and 82% capacity remaining respectively after 25 years. The total levelized cost for the regional network was $5.44 per tonne per year.

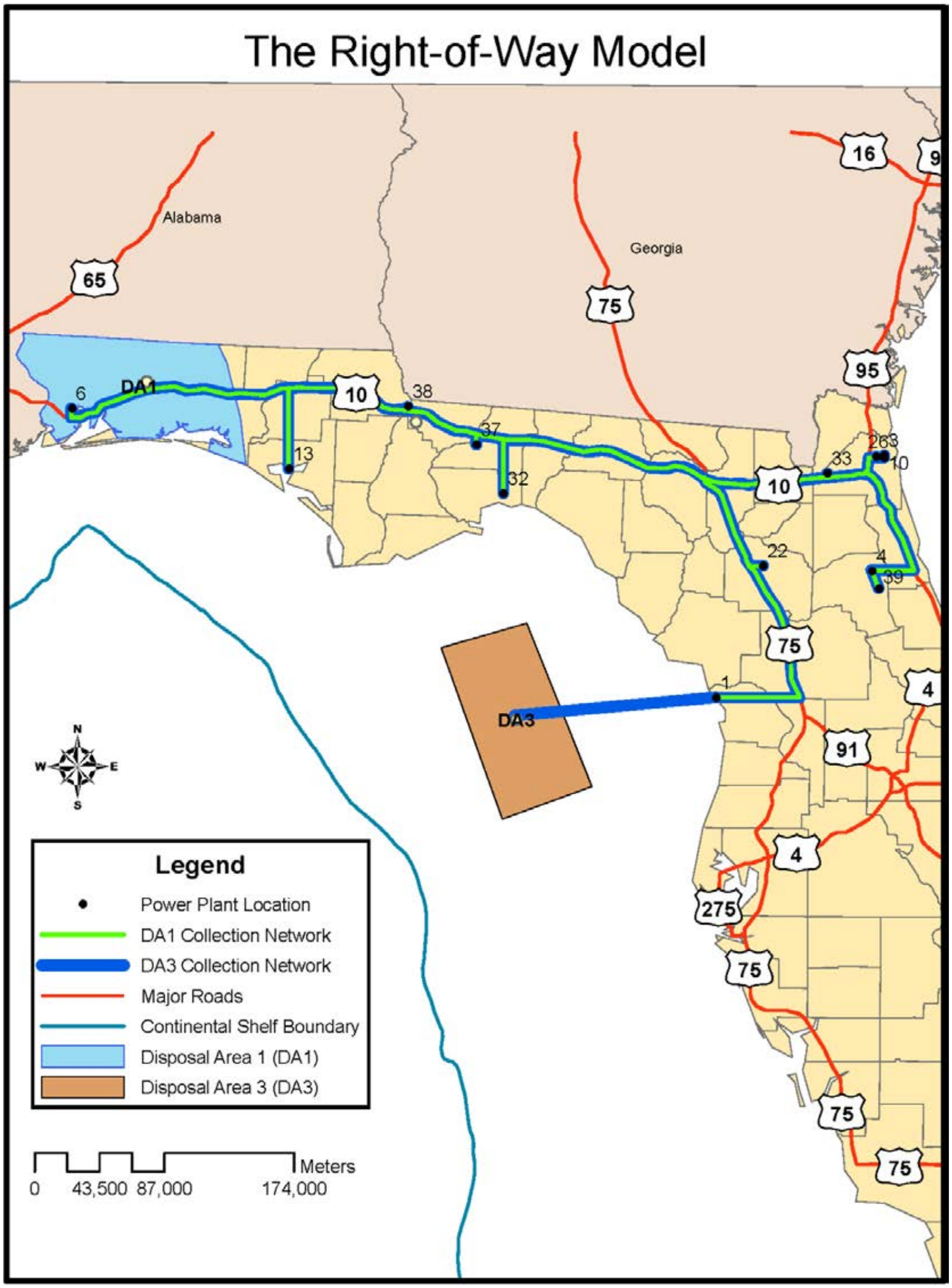


Figure 15. Right-Of-Way Model Collection Network

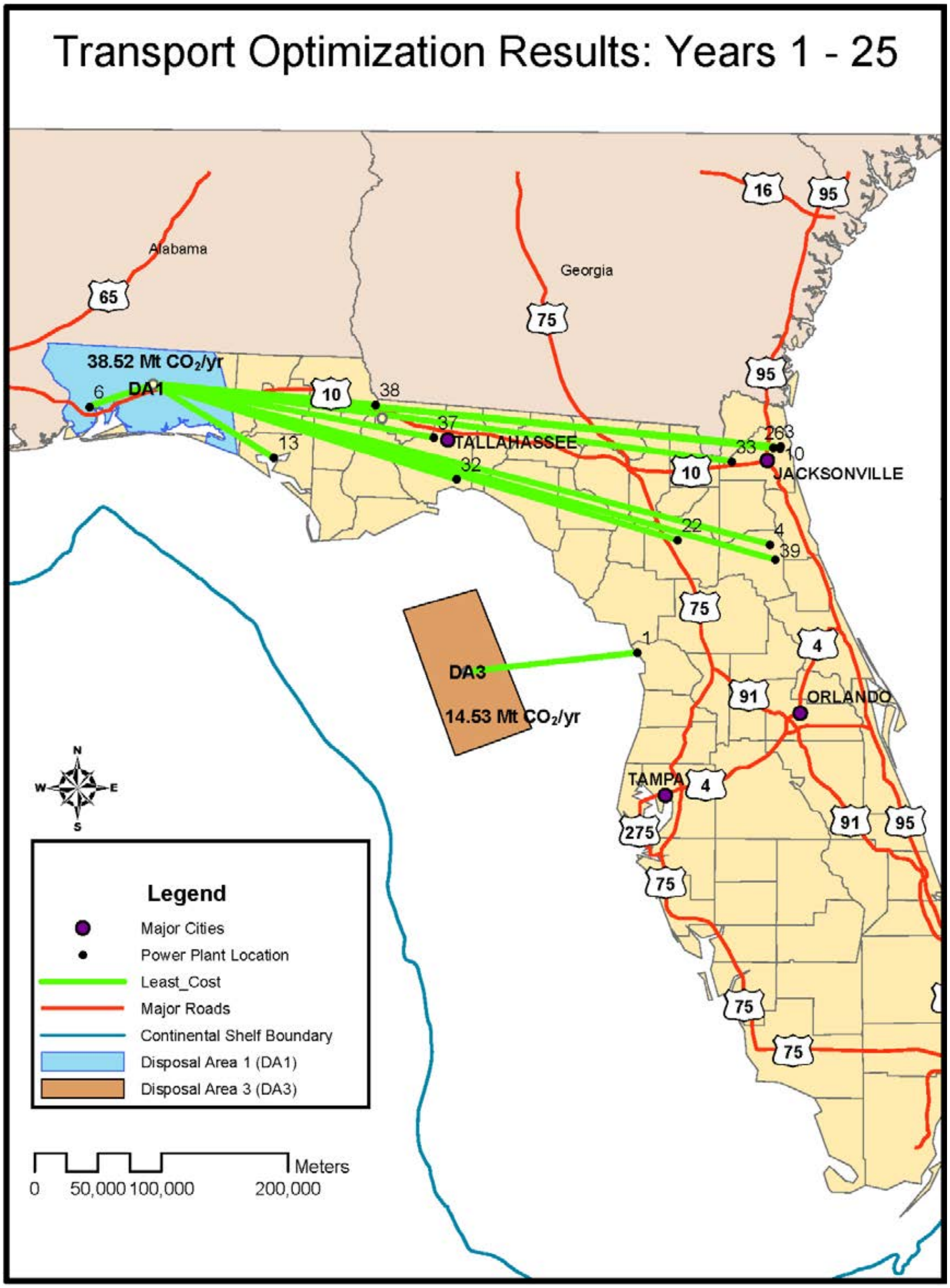


Figure 16. Right-Of-Way Model Results

4.2.2.2 The Solo-Funded Model

The Solo-funded model is an "every-man-for-himself" approach where each plant will fund its own pipeline to the disposal area. This model differs from the Right-of-Way Model in that transport optimization was not performed. Instead a simple comparison of unit costs to the other models was analyzed. Also different from the Right-of-Way Model, only one disposal area is available for storage. While not a realistic approach to developing a regional network, this model is significant because it can provide preliminary cost estimates for different phases of network construction when very few plants will be connected to the regional network. Table 5 presents the unit costs for the Solo-Funded Model for each disposal area, along with the mean unit cost for each disposal area. Disposal Area 1 provided the lowest mean unit cost of $12.24 per tonne per year. The total levelized cost for DA1 was $5.66 per tonne per year.

4.2.2.3 The Piece-wise Model

The Piece-wise Model is a cost sharing model based upon the ROW distances used in the Right-of-Way Model. This model assumes only one disposal area is available to store CO_2. Power plants which fall into the top 25 will fund the network while the smaller plants, 25 through 40, will simply pay to connect to the system. The unit costs for each source were calculated for each disposal area and compared to the other models. This model is significant because it provides a preliminary cost sharing scenario applicable to the planning of a regional network.

Table 6 presents the unit costs for the Piece-wise Model for each disposal area, along with the mean unit cost for each. Disposal Area 1 provides the network with the lowest mean unit cost of $1.11 per tonne per year. The total levelized cost for DA1 was $1.15 per tonne per year.

Table 5. Solo-Funded Model Unit Costs

Map ID	Plant Name	2007 Annual CO_2 Emissions (Mt)	DA1 Total Unit Cost/tonne CO_2	DA3 Total Unit Cost/tonne CO_2
1	Crystal River	14.530	$ 4.24	$ 3.43
3	St Johns River Power Park	9.384	$ 4.99	$ 6.01
4	Seminole	8.948	$ 4.67	$ 5.33
6	Crist	6.621	$ 1.05	$ 10.77
10	Northside Generating Station	4.459	$ 7.40	$ 8.92
13	Lansing Smith	3.436	$ 3.09	$ 14.14
22	Deerhaven Generating Station	1.582	$ 13.38	$ 14.64
26	Cedar Bay Generating Company LP	1.284	$ 15.47	$ 18.67
32	S O Purdom	0.638	$ 15.95	$ 36.38
33	Brandy Branch	0.630	$ 24.84	$ 31.70
37	Arvah B Hopkins	0.525	$ 16.66	$ 43.69
38	Scholz	0.519	$ 13.90	$ 46.56
39	Putnam	0.495	$ 33.54	$ 38.21
Mean Total Unit Cost ($/tonne CO_2)			$ 12.24	$ 21.42
Total Levelized Cost ($/tonne CO_2)			$ 5.66	$ 8.86

Table 6. Piece-Wise Model Unit Costs

Map ID	Plant Name	2007 Annual CO_2 Emissions (Mt)	DA1 Total Unit Cost/tonne CO2	DA3 Total Unit Cost/tonne CO2
1	Crystal River	14.530	$ 1.30	$ 0.74
3	St Johns River Power Park	9.384	$ 0.04	$ 1.25
4	Seminole	8.948	$ 2.13	$ 1.76
6	Crist	6.621	$ 1.00	$ 2.17
10	Northside Generating Station	4.459	$ 0.95	$ 0.77
13	Lansing Smith	3.436	$ 1.72	$ 4.62
22	Deerhaven Generating Station	1.582	$ 1.61	$ 1.20
26	Cedar Bay Generating Company LP	1.284	$ 0.04	$ 0.04
32	S O Purdom	0.638	$ 2.69	$ 2.77
33	Brandy Branch	0.630	$ 0.28	$ 0.29
37	Arvah B Hopkins	0.525	$ 0.84	$ 0.86
38	Scholz	0.519	$ 0.40	$ 0.41
39	Putnam	0.495	$ 1.43	$ 1.47
Mean Total Unit Cost ($/tonne CO_2)			$ 1.11	$ 1.41
Total Levelized Cost ($/tonne CO_2)			$ 1.15	$ 1.45

4.2.2.4 The Authority Model

The Authority Model operates as an authority run statewide network. This authority would completely fund the construction and operation of a statewide network connecting all of the top 40 power plants to a single disposal area. The capital costs and O&M costs for the entire network would be financed and charged to each user on a cost per tonne basis. This model differs from the Right-of-Way, Solo-Funded, and Piece-wise Models because the unit costs are based on the percentage of CO_2 each plant is supplying the system. The purpose of analyzing the Authority scenario is to compare the costs from Poiencot and Brown (2012) with the new costs incorporating the revised O&M calculation. Disposal Areas 1 and 3 were used for the comparison to Poiencot and Brown (2012). Smaller Regional Authority Models were also created and analyzed for the Florida Pan-Handle. Figure 17 and Figure 18 display the Regional Authority Model networks for DA1 and DA3 respectively. Table 7 presents the unit costs for the regional DA1 and DA3 networks.

Table 8 compares the unit costs for the statewide DA1 and DA3 networks with those from Poiencot and Brown (2012). The unit costs increased from Poiencot & Brown by 6.4% for DA1 and 6.0% for DA3. Figure 19 is a scatter plot comparing the O&M costs from each study. While the O&M unit costs using the new calculation are typically lower than previously estimated, the trend lines are similar to those in Figure 14.

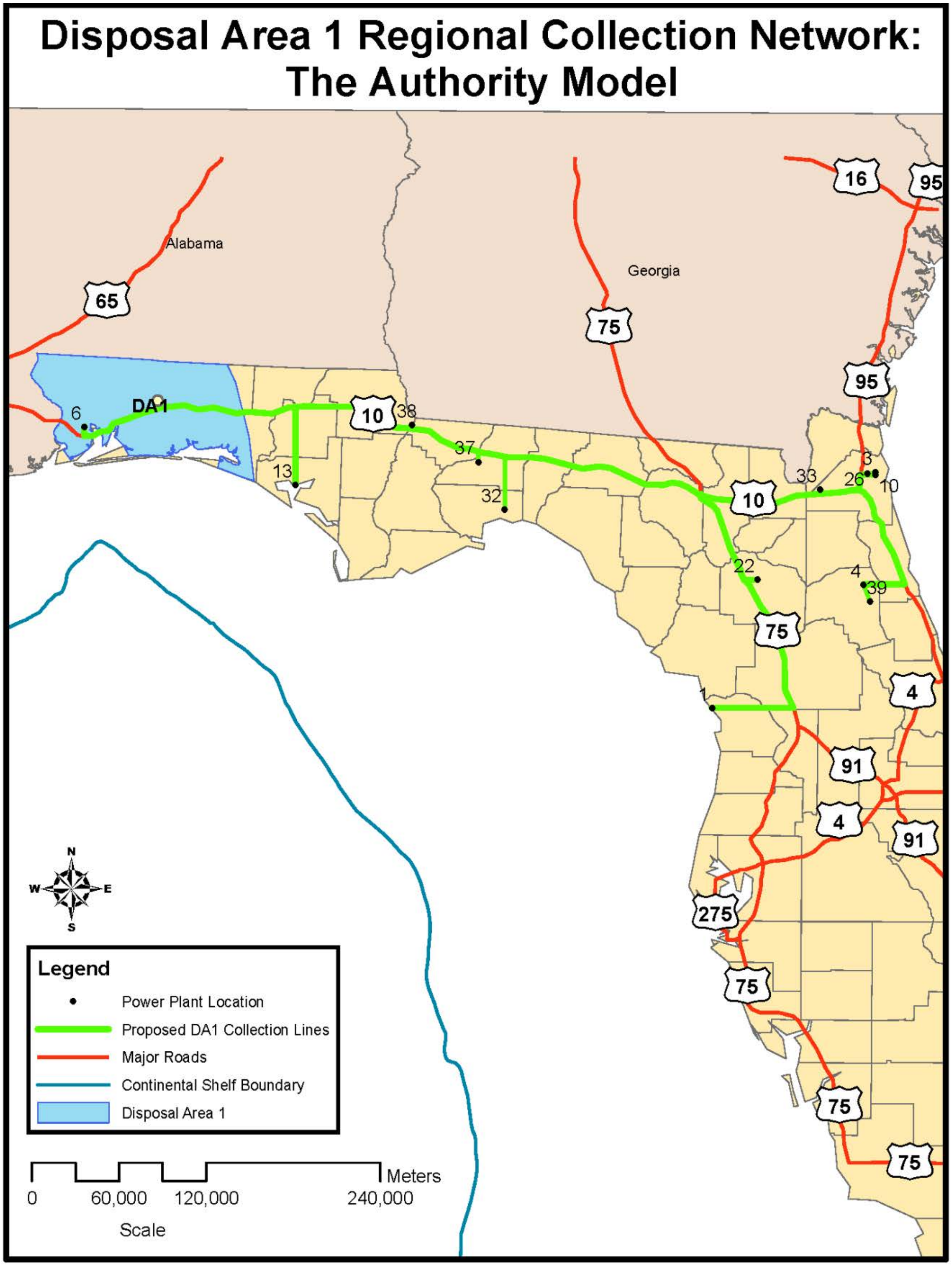


Figure 17. Authority Model: Disposal Area 1 Collection Network

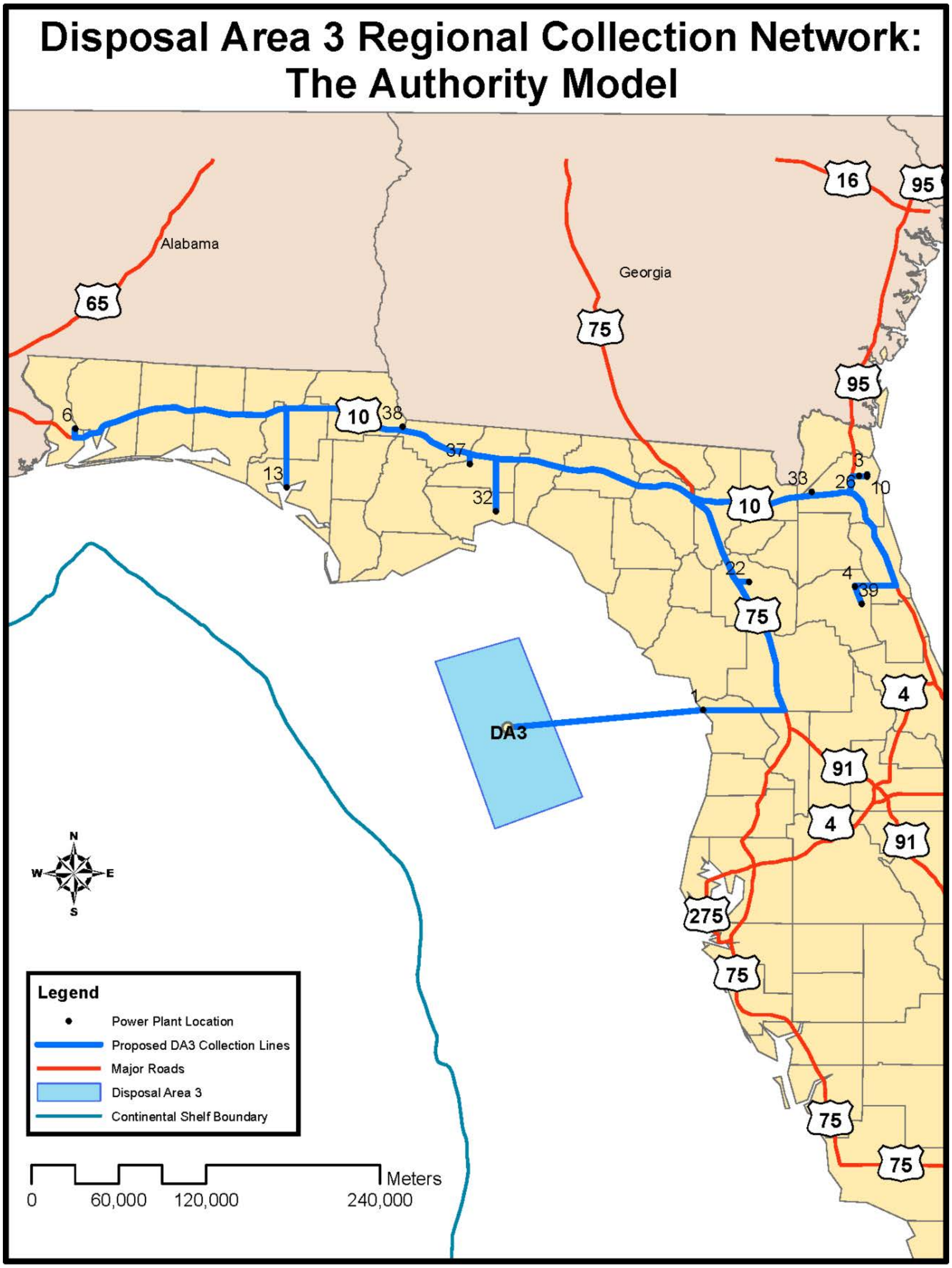


Figure 18. Authority Model: Disposal Area 3 Collection Network

Table 7. Authority Model Unit Costs

Map ID	Plant Name	DA1 Total Unit Annual Cost/tonne CO_2	DA3 Total Unit Annual Cost/tonne CO_2
1	Crystal River	$ 2.27	$ 2.62
3	St Johns River Power Park	$ 1.47	$ 1.69
4	Seminole	$ 1.40	$ 1.62
6	Crist	$ 1.03	$ 1.20
10	Northside Generating Station	$ 0.70	$ 0.80
13	Lansing Smith	$ 0.54	$ 0.62
22	Deerhaven Generating Station	$ 0.25	$ 0.29
26	Cedar Bay Generating Company LP	$ 0.20	$ 0.23
32	S O Purdom	$ 0.10	$ 0.12
33	Brandy Branch	$ 0.10	$ 0.11
37	Arvah B Hopkins	$ 0.08	$ 0.09
38	Scholz	$ 0.08	$ 0.09
39	Putnam	$ 0.08	$ 0.09
Mean Total Unit Cost ($/tonne CO_2)		$ 0.64	$ 0.74

Table 8. Authority Model Unit Cost Comparison

Map ID	Plant Name	Poiencot & Brown (2011)		Poiencot & Brown (2012)	
		DA1 Total Unit Annual Cost/tonne CO_2	DA3 Total Unit Annual Cost/tonne CO_2	DA1 Total Unit Annual Cost/tonne CO_2	DA3 Total Unit Annual Cost/tonne CO_2
1	Crystal River	$ 1.35	$ 1.44	$ 2.26	$ 2.40
3	St Johns River Power Park	$ 0.87	$ 0.93	$ 1.46	$ 1.55
4	Seminole	$ 0.83	$ 0.89	$ 1.39	$ 1.48
6	Crist	$ 0.62	$ 0.66	$ 1.03	$ 1.09
10	Northside Generating Station	$ 0.42	$ 0.44	$ 0.69	$ 0.74
13	Lansing Smith	$ 0.32	$ 0.34	$ 0.53	$ 0.57
22	Deerhaven Generating Station	$ 0.15	$ 0.16	$ 0.25	$ 0.26
26	Cedar Bay Generating Company LP	$ 0.12	$ 0.13	$ 0.20	$ 0.21
32	S O Purdom	$ 0.06	$ 0.06	$ 0.10	$ 0.11
33	Brandy Branch	$ 0.06	$ 0.06	$ 0.10	$ 0.10
37	Arvah B Hopkins	$ 0.05	$ 0.05	$ 0.08	$ 0.09
38	Scholz	$ 0.05	$ 0.05	$ 0.08	$ 0.09
39	Putnam	$ 0.05	$ 0.05	$ 0.08	$ 0.08
Mean Total Unit Cost ($/tonne CO_2)		$ 0.38	$ 0.40	$ 0.64	$ 0.67

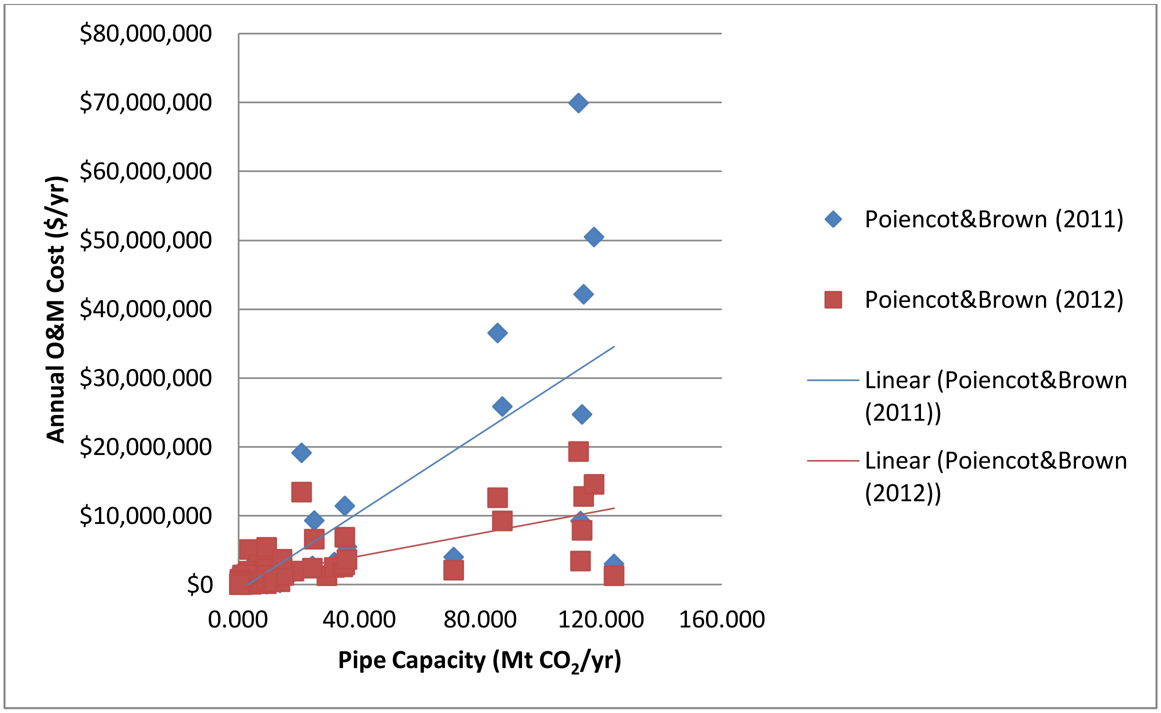


Figure 19. Operation and Maintenance Scatter Plot

Chapter 5

DISCUSSION AND CONCLUSION

This thesis has presented the results of storage capacity estimation and transportation cost analysis for CCS activities in the Florida Pan-Handle. Chapter 5 discusses the results presented and makes conclusions regarding the preliminary feasibility of transporting and geologically sequestering carbon emissions in the Florida Pan-Handle.

5.1 Discussion

Previously published information from DOE and research efforts by Roberts-Ashby (2010) has shown the potential for CCS in Florida. This thesis attempted to present the feasibility of potential storage zones in the Florida Pan-Handle and a pipeline network to transport CO_2 from sources in and around the Pan-Handle to the proposed storage sites. The results show the potential costs to be in the realm of other published investigations around the world. From a transport perspective, the quickest and most efficient solution may be the authority model. Because of the large initial capital cost to construct such a network, even a regional network, a toll road type authority would need to provide initial funding to connect as many sources as possible to help offset that initial cost.

DOE presented an initial estimate as to the amount of storage capacity available in Florida. This thesis confirms not only the validity of the initial estimates but also that they may be conservative. Again, the results presented here are preliminary and are based on oil and gas exploratory drilling logs. Some of the logs are old and difficult to read. Also these logs were not originally used for the purpose of geologic sequestration so the parameters needed to characterize a CO_2 storage area were not necessarily collected. A more accurate analysis of the proposed storage areas would need to be completed including new borings taking measurements meant specifically for carbon sequestration, such as accurate readings of native brine temperature and salinity. The majority of the reviewed logs for this thesis only included data on the drilling mud as opposed to the native brine. This holds especially true in the case of Disposal Area 3, where no well logging geophysics have been performed. While DA3 was a more expensive option from a transportation perspective, it remains a low-impact location. Low-impact in that development of DA3 would be free of land acquisition, property rights, and human impacts in the event of a release. The relative ease of acquiring ROW, zoning, permits, etc could be offset with DA3 and is another area which would benefit from further investigation.

The development of carbon sequestration in the Florida Pan-Handle, or anywhere, will depend greatly on economics, regulation, and demand. The main incentive pushing the R&D efforts of utilities across the country is the proposals presented in the 110th Congress to lower CO_2 emissions to 1990 levels by 2030 (Esposito et al., 2010). The ultimate decision on the feasibility of CCS or enhanced oil recovery technology will depend on the number of coal plants needing either of these technologies. The commercial deployment of CCS/EOR will require coal-fired utilities and other CO_2 emitters to develop a business model for how CCS/EOR operations will be managed (Esposito et al., 2010). Many factors will play into the development of a business model including the criteria presented within this report along with regulatory framework, availability of risk mitigation, and the desire to be vertically integrated (Esposito et al., 2010). The size of the system or population of sources would decide between saline aquifer storage and EOR. A larger number of sources would justify a regional network with aquifer storage while a smaller population of sources would be more suitable for EOR.

Jay Field, is one of the few oil fields in Florida that could potentially be a candidate for EOR; however more investigation is needed for those fields. The depth at which Jay Field is found produces uncertainty regarding the injection of CO_2 and the overall cost of drilling new wells if that is required.

Another factor in the feasibility of CCS is the shift from coal to natural gas and renewable energy sources. Using natural gas as a fossil fuel in power plants or using renewable sources results in lower emissions overall. Electric utilities may find that retooling their technology could be more cost effective.

5.2 Conclusion

The potential to implement a regional CO_2 sequestration infrastructure exists in Florida, warranting further analysis. This report presented a preliminary look at the transportation and storage capability in Florida. Areas of this study will require further investigations including a full-fledged feasibility study, as well as planning, permitting, and socioeconomic considerations in order to reach a definitive answer.

Appendix A

Carbon Dioxide Emission Sources

40 Largest Sources of CO_2 Emissions in Florida (2007)

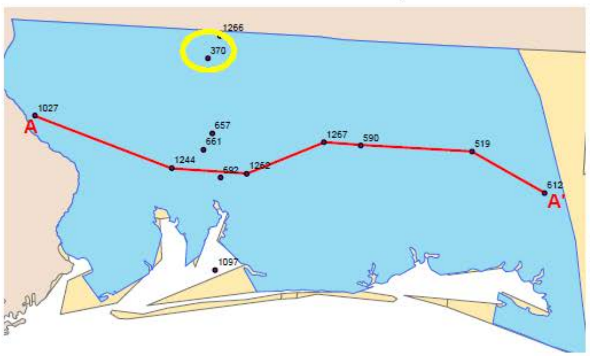
Map ID	Plant/Facility Name	Northing	Easting	Annual CO_2 Emissions (tonnes)
1	Crystal River	3204678.1	334313.21	14,530,258
2	Big Bend	3075217.2	361725.59	9,498,430
3	St Johns River Power Park	3366685.1	447107.33	9,384,220
4	Seminole	3289401.6	438698.36	8,947,766
5	Martin	2992447.2	543356.54	8,023,112
6	Crist	3398084.8	-97895.929	6,621,180
7	Stanton Energy Center	3150786.7	483497.41	5,890,437
8	Manatee	3054258.7	367211.87	5,205,981
9	Sanford	3190513.2	468238.35	4,767,698
10	Northside Generating Station	3365145.5	446936.55	4,459,034
11	Fort Myers	2953081.9	422095.77	3,765,060
12	Turkey Point	2813351.3	567289.72	3,447,477
13	Lansing Smith	3357948.2	47642.891	3,435,570
14	C D McIntosh Jr	3106509.9	409058.51	3,135,822
15	H L Culbreath Bayside	3087736.7	359949.38	3,033,718
16	Hines Energy Complex	3074087.8	414350.29	3,010,012
17	Anclote	3118924.3	324414.88	2,800,194
18	Lauderdale	2883472.1	580187.57	2,218,068
19	Port Everglades	2885457.2	587476.5	2,202,415
20	Indiantown Cogeneration LP	2990880.9	548162.48	1,856,566
21	Polk	3067530.7	402444.71	1,853,968
22	Deerhaven Generating Station	3292844	365772.08	1,581,549
23	Cape Canaveral	3149224.6	523083.25	1,470,463

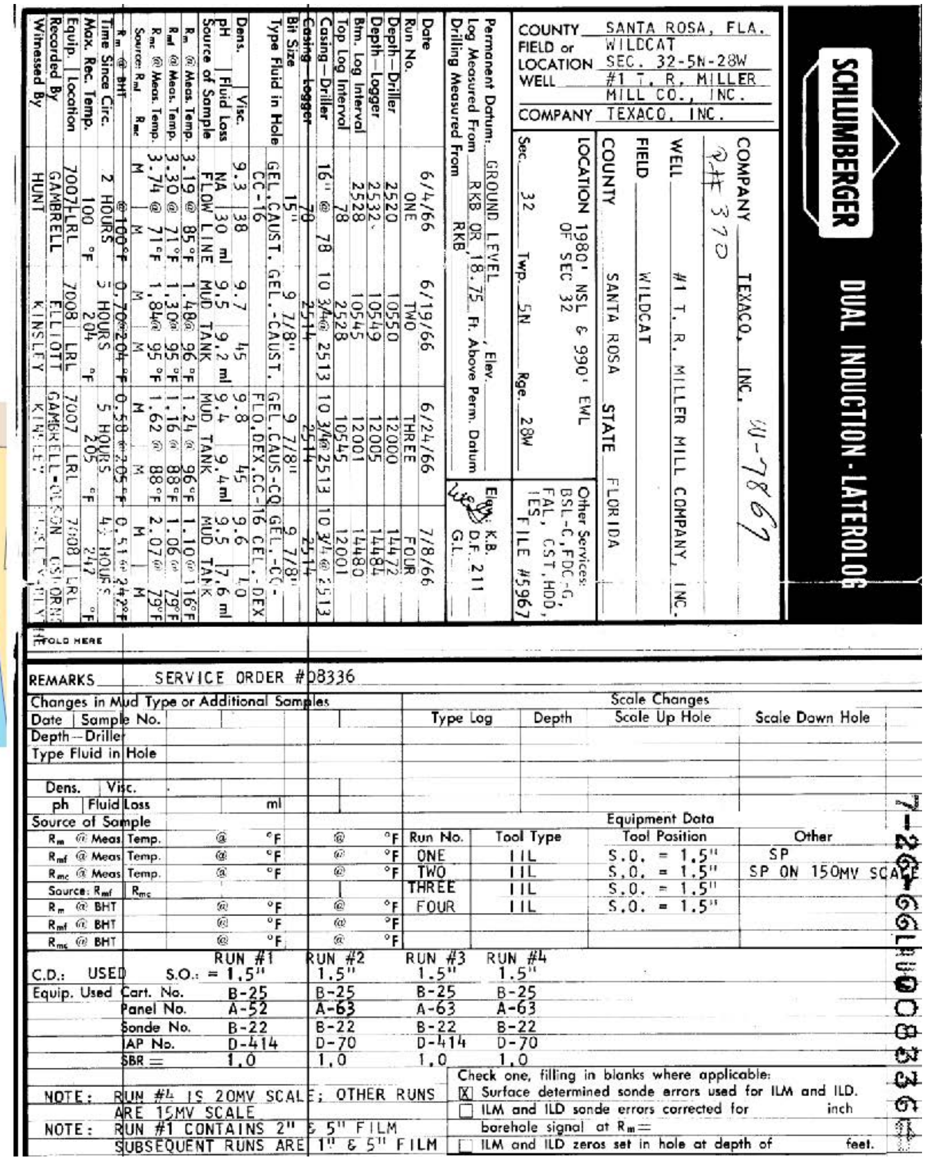
24	P L Bartow	3082867.6	342353.21	1,425,979
25	Riviera	2960791.1	594173.51	1,369,759
26	Cedar Bay Generating Company LP	3365693.6	441618.51	1,283,795
27	Curtis H Stanton Energy Center	3151285.1	483605.77	1,031,593
28	Osprey Energy Center	3103281.6	420562.98	910,493
29	Central Power & Lime	3162445.1	360123.38	766,241
30	Wheelabrator North Broward	2907830	584050.88	715,719
31	Wheelabrator South Broward	2883538.3	580157.15	707,480
32	S O Purdom	3341056.5	191654.8	638,142
33	Brandy Branch	3354692.4	408803.18	629,567
34	Shady Hills Generating Station	3138790.3	347216.72	603,715
35	Cane Island	3127936.4	447728	596,860
36	Intercession City	3126436.6	446191.23	541,897
37	Arvah B Hopkins	3373808.2	173480.93	524,922
38	Scholz	3399359.4	127519.09	519,116
39	Putnam	3277742.4	443310.44	495,412
40	Miami Dade County Resource Recovery Fac	2857602.5	564510.41	456,887

Appendix B

Geophysical Logs and Interpretations

Disposal Area #1
P#370
Gamma
Standard Potential
Resistivity





SCHLUMBERGER DUAL INDUCTION - LATEROLOG

COUNTY SANTA ROSA, FLA.
FIELD or LOCATION WILDCAT SEC. 32-5N-28W
WELL #1 T. R. MILLER MILL CO., INC.
COMPANY TEXACO, INC.

COMPANY TEXACO, INC. U-7867
P# 370
WELL #1 T. R. MILLER MILL COMPANY, INC.
FIELD WILDCAT
COUNTY SANTA ROSA STATE FLORIDA
LOCATION 1980' NSL & 990' EWL OF SEC 32
Sec. 32 Twp. 5N Rge. 28W
Other Services: BSL-C, FDC-G, FAL, CST, HDD, IES
FILE #5967

Permanent Datum: GROUND LEVEL, Elev.
Log Measured From RKB OR 18.75 Ft. Above Perm. Datum
Drilling Measured From RKB
Elev.: K.B. D.F. 211 G.L.

Date	6/4/66	6/19/66	6/24/66	7/8/66
Run No.	ONE	TWO	THREE	FOUR
Depth—Driller	2520	10550	12000	14472
Depth—Logger	2532	10549	12005	14484
Btm. Log Interval	2528	10545	12001	14480
Top Log Interval	78	2528	10545	12001
Casing—Driller	16" @ 78	10 3/4 @ 2513	10 3/4 @ 2513	10 3/4 @ 2513
Casing—Logger	78	2514	2514	2514
Bit Size	15"	9 7/8"	9 7/8"	9 7/8"
Type Fluid in Hole	GEL.CAUST. CC-16	GEL.CAUST.	GEL.CAUS-CQ FLO,DEX,CC-16	GEL.-CC-CEL.-DEX
Dens. / Visc.	9.3 / 38	9.7 / 45	9.8 / 45	9.6 / [illegible]
pH / Fluid Loss	NA / 30 ml	9.5 / 9.2 ml	9.4 / 9.4 ml	9.5 / 7.6 ml
Source of Sample	FLOW LINE	MUD TANK	MUD TANK	MUD TANK
R_m @ Meas. Temp.	3.19 @ 85 °F	1.48 @ 96 °F	1.24 @ 96 °F	1.10 @ 116 °F
R_{mf} @ Meas. Temp.	3.30 @ 71 °F	1.30 @ 95 °F	1.16 @ 88 °F	1.06 @ 79 °F
R_{mc} @ Meas. Temp.	3.74 @ 71 °F	1.84 @ 95 °F	1.62 @ 88 °F	2.07 @ 79 °F
Source: R_{mf} / R_{mc}	M / M	M / M	M / M	M / M
R_m @ BHT	@ 100 °F	0.70 @ 204 °F	0.58 @ 205 °F	0.51 @ 242 °F
Time Since Circ.	2 HOURS	5 HOURS	5 HOURS	4 1/2 HOURS
Max. Rec. Temp.	100 °F	204 °F	205 °F	242 °F
Equip. / Location	7007 / LRL	7008 / LRL	7007 / LRL	7008 / LRL
Recorded By	GAMBRELL	ELLIOTT	GAMBRELL-OLESON	OLESON
Witnessed By	HUNT	KINSLEY	KINSLEY	[illegible]

FOLD HERE

REMARKS SERVICE ORDER #08336

Changes in Mud Type or Additional Samples			Type Log	Depth	Scale Up Hole	Scale Down Hole
Date / Sample No.						
Depth—Driller						
Type Fluid in Hole						
Dens. / Visc.						
ph / Fluid Loss	ml					
Source of Sample						

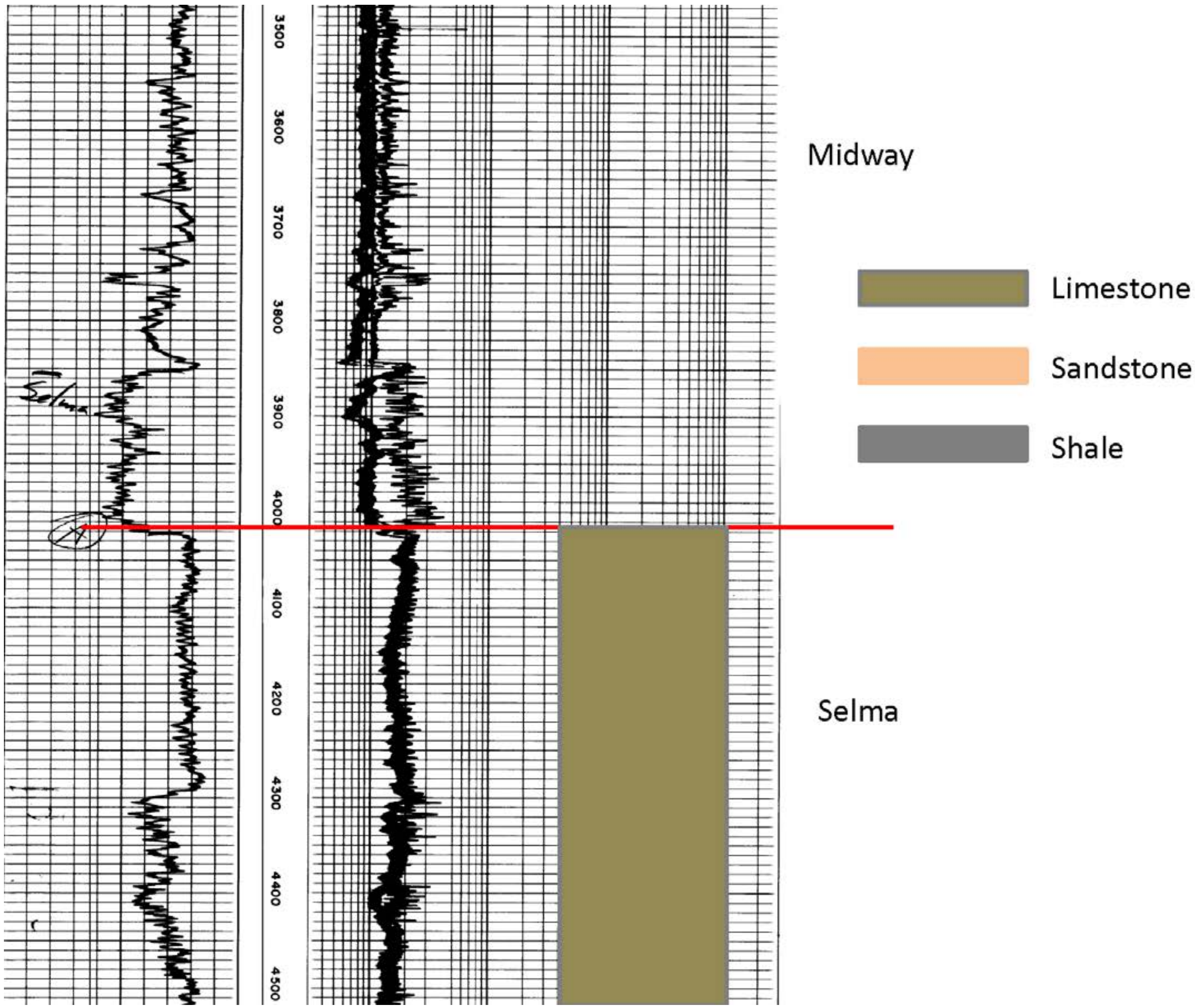
			Run No.	Tool Type	Tool Position	Other
R_m @ Meas. Temp.	@ °F	@ °F				
R_{mf} @ Meas. Temp.	@ °F	@ °F	ONE	IIL	S.O. = 1.5"	SP
R_{mc} @ Meas. Temp.	@ °F	@ °F	TWO	IIL	S.O. = 1.5"	SP ON 150MV SCALE
Source: R_{mf} / R_{mc}			THREE	IIL	S.O. = 1.5"	
R_m @ BHT	@ °F	@ °F	FOUR	IIL	S.O. = 1.5"	
R_{mf} @ BHT	@ °F	@ °F				
R_{mc} @ BHT	@ °F	@ °F				

		RUN #1	RUN #2	RUN #3	RUN #4
C.D.: USED	S.O.: =	1.5"	1.5"	1.5"	1.5"
Equip. Used	Cart. No.	B-25	B-25	B-25	B-25
	Panel No.	A-52	A-63	A-63	A-63
	Sonde No.	B-22	B-22	B-22	B-22
	IAP No.	D-414	D-70	D-414	D-70
	SBR =	1.0	1.0	1.0	1.0

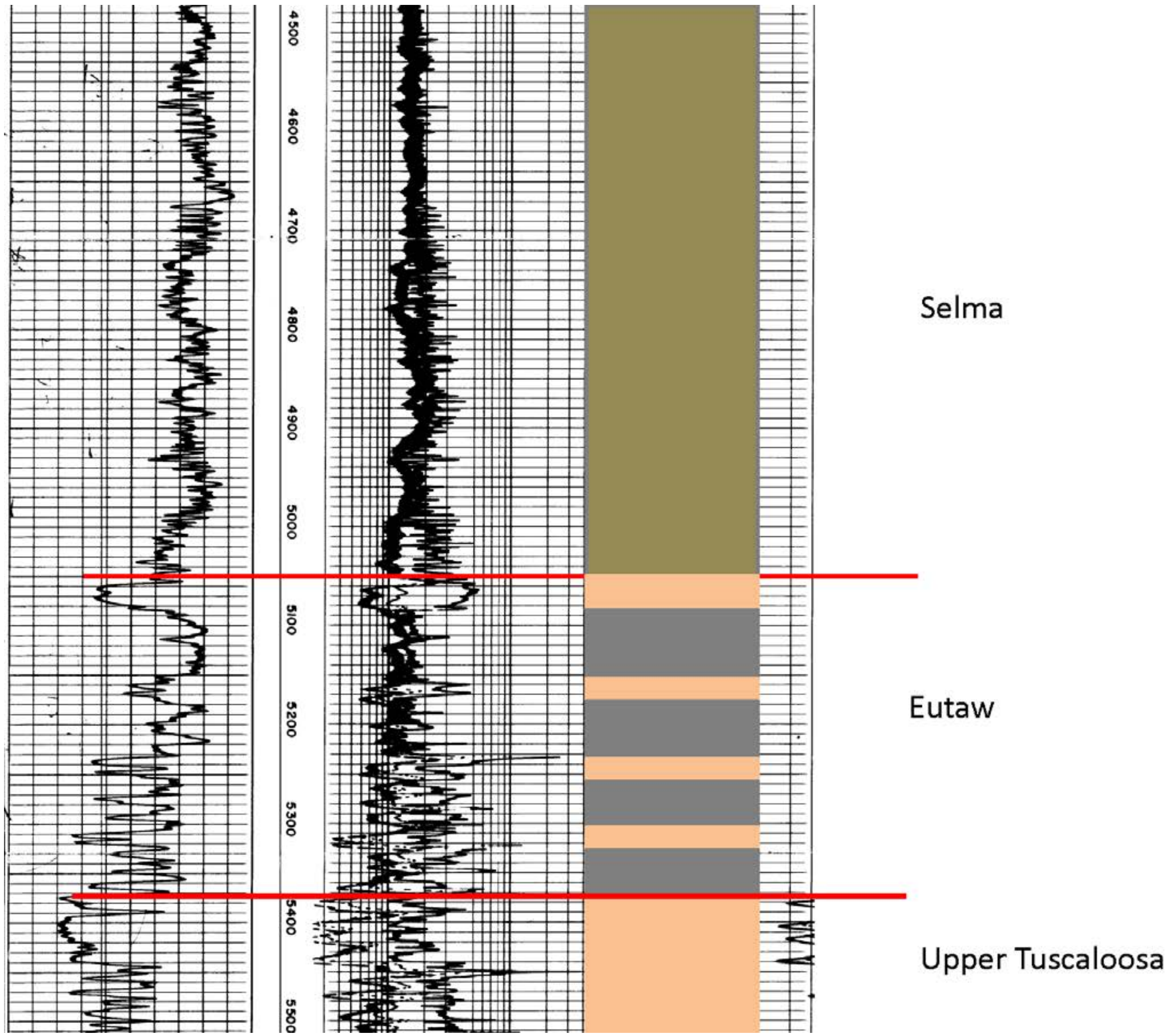
NOTE: RUN #4 IS 20MV SCALE; OTHER RUNS ARE 15MV SCALE
NOTE: RUN #1 CONTAINS 2" & 5" FILM SUBSEQUENT RUNS ARE 1" & 5" FILM

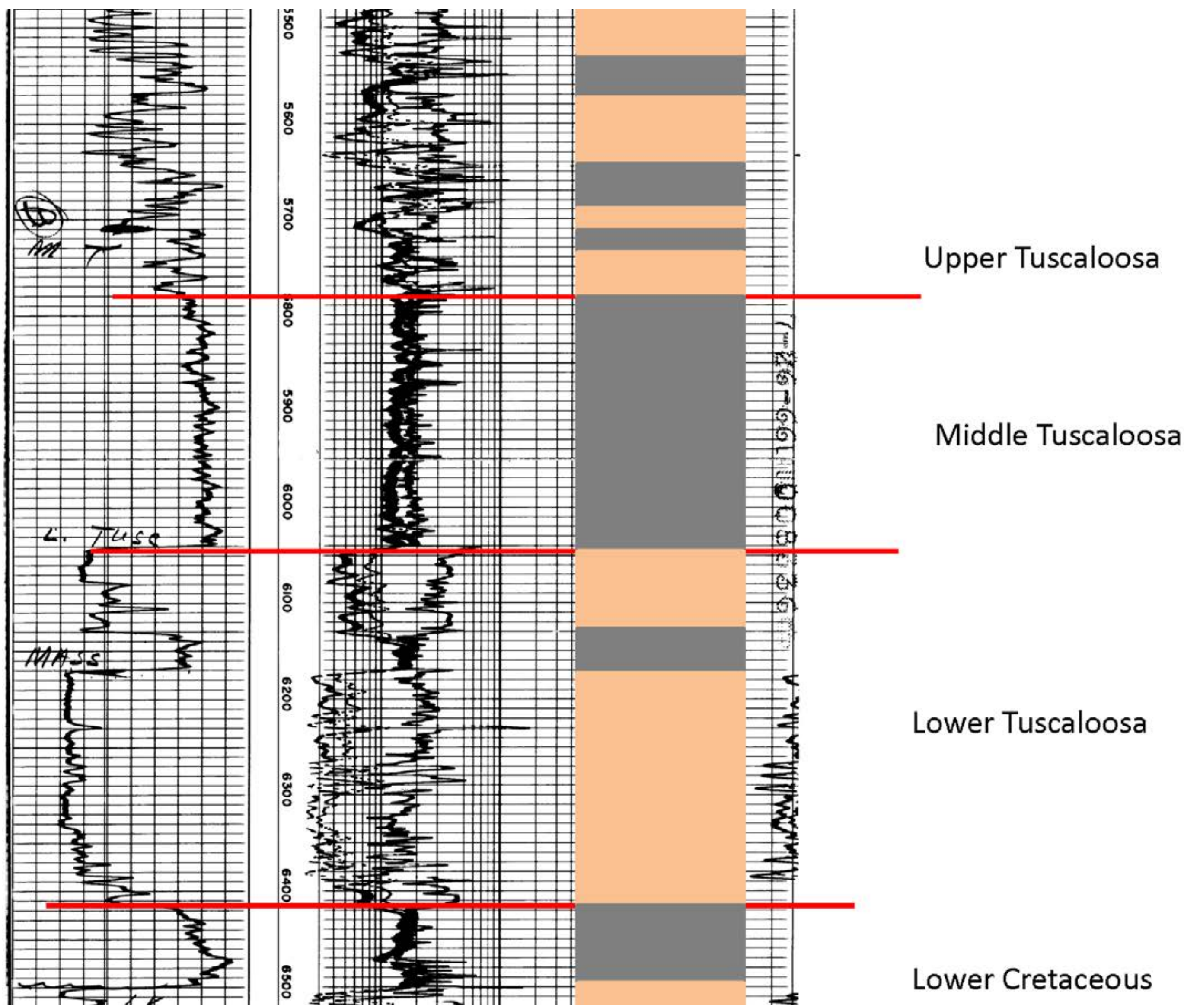
Check one, filling in blanks where applicable:
- [X] Surface determined sonde errors used for ILM and ILD.
- [ ] ILM and ILD sonde errors corrected for inch borehole signal at R_m =
- [ ] ILM and ILD zeros set in hole at depth of feet.

7-26-66LU008336

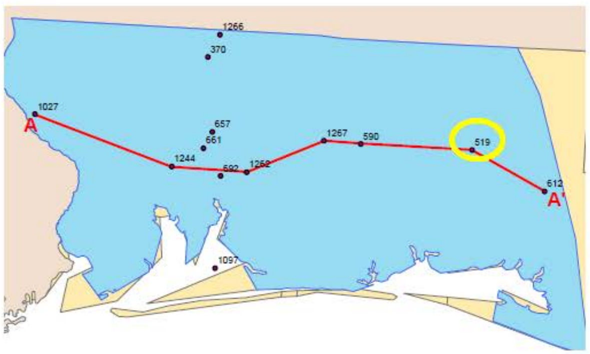


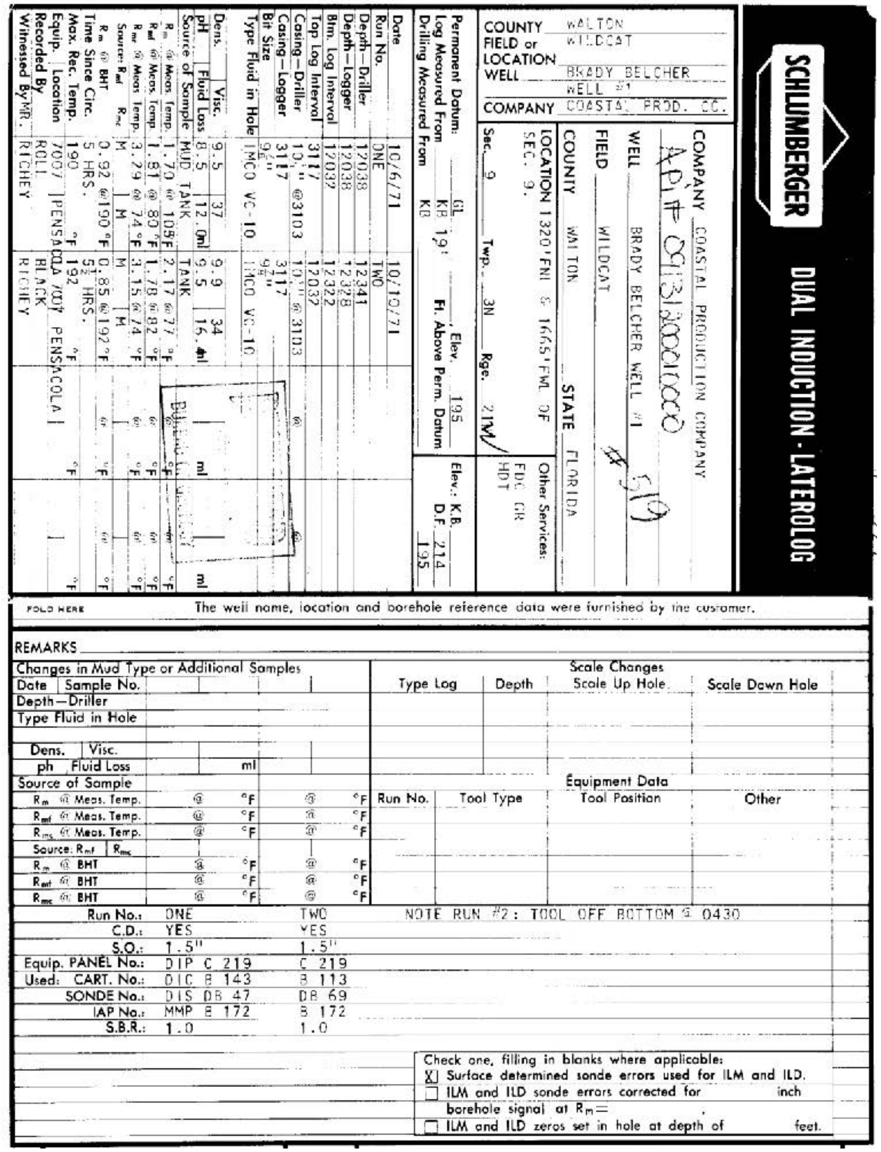
3500
3600
3700
3800
3900
4000
4100
4200
4300
4400
4500
Selma
Midway
Limestone
Sandstone
Shale
Selma

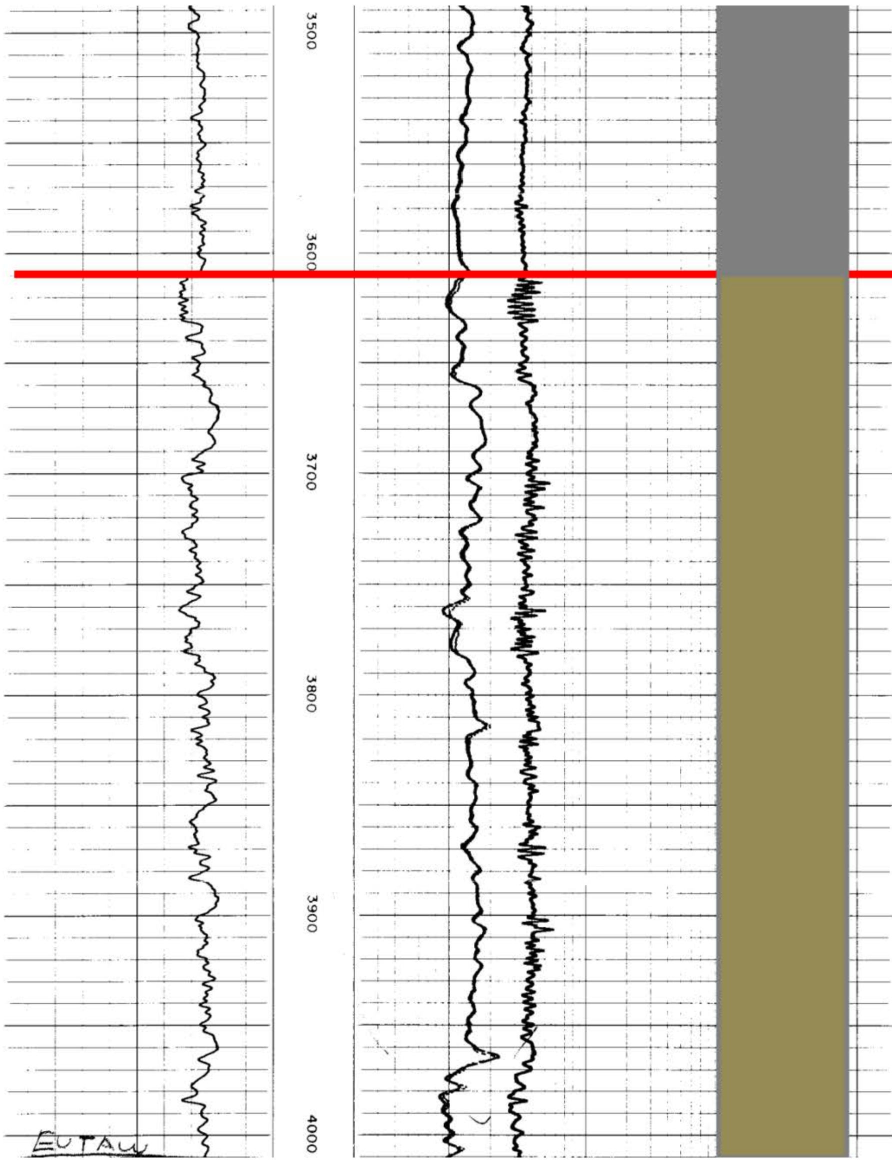

4500
4600
4700
4800
4900
5000
5100
5200
5300
5400
5500
Selma
Eutaw
Upper Tuscaloosa


Upper Tuscaloosa
Middle Tuscaloosa
Lower Tuscaloosa
Lower Cretaceous

Disposal Area #1
P#519
Standard Potential Resistivity

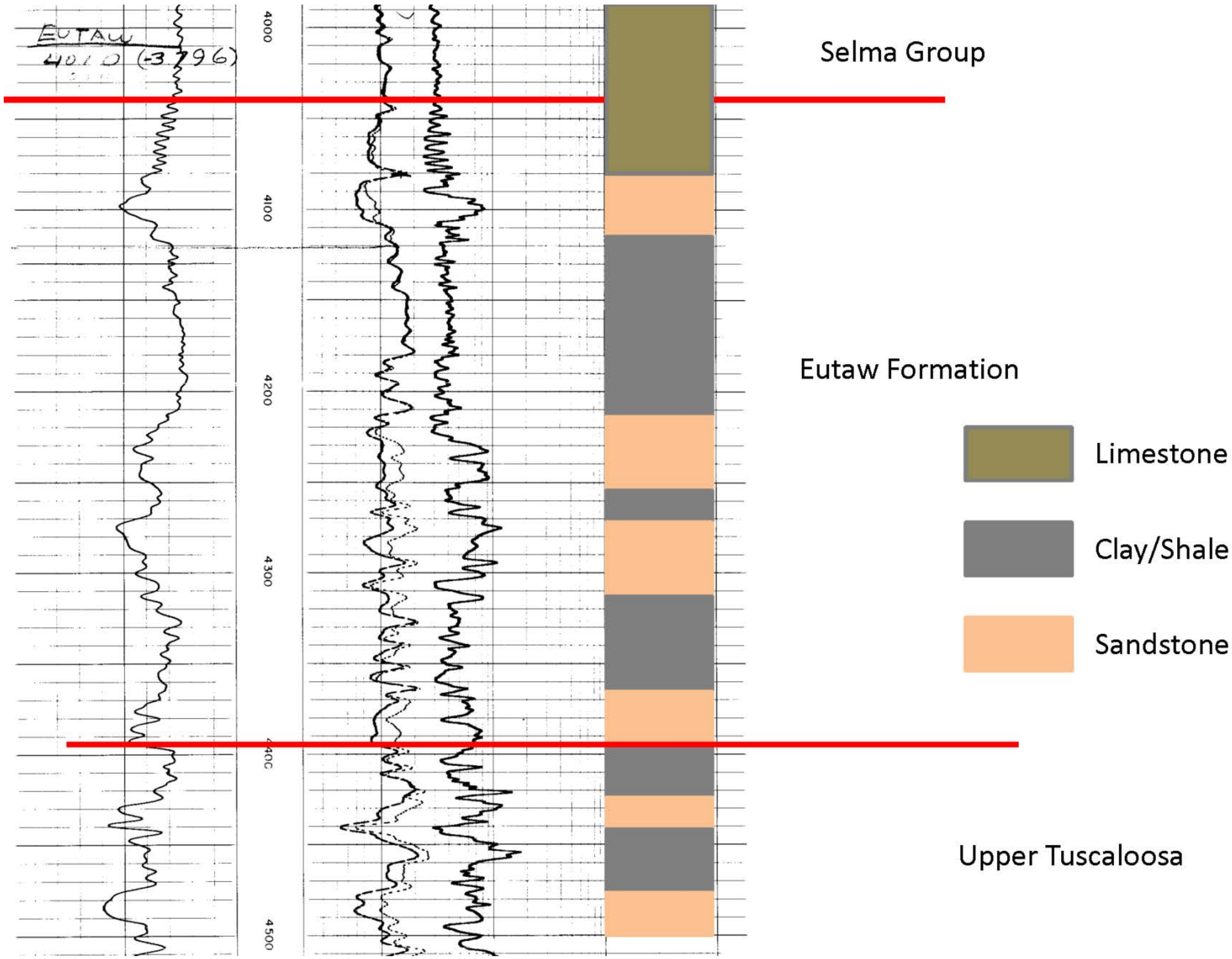


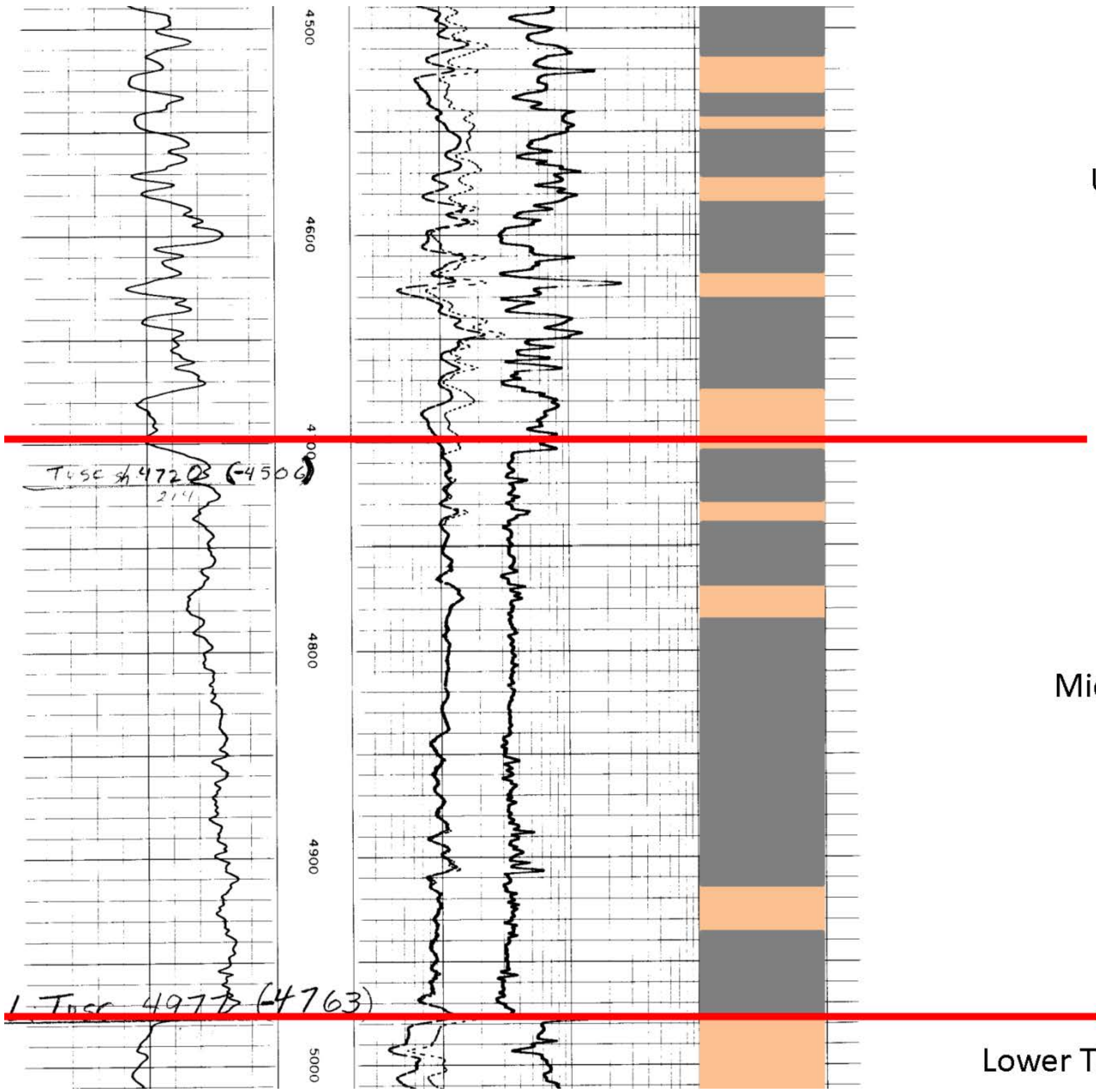


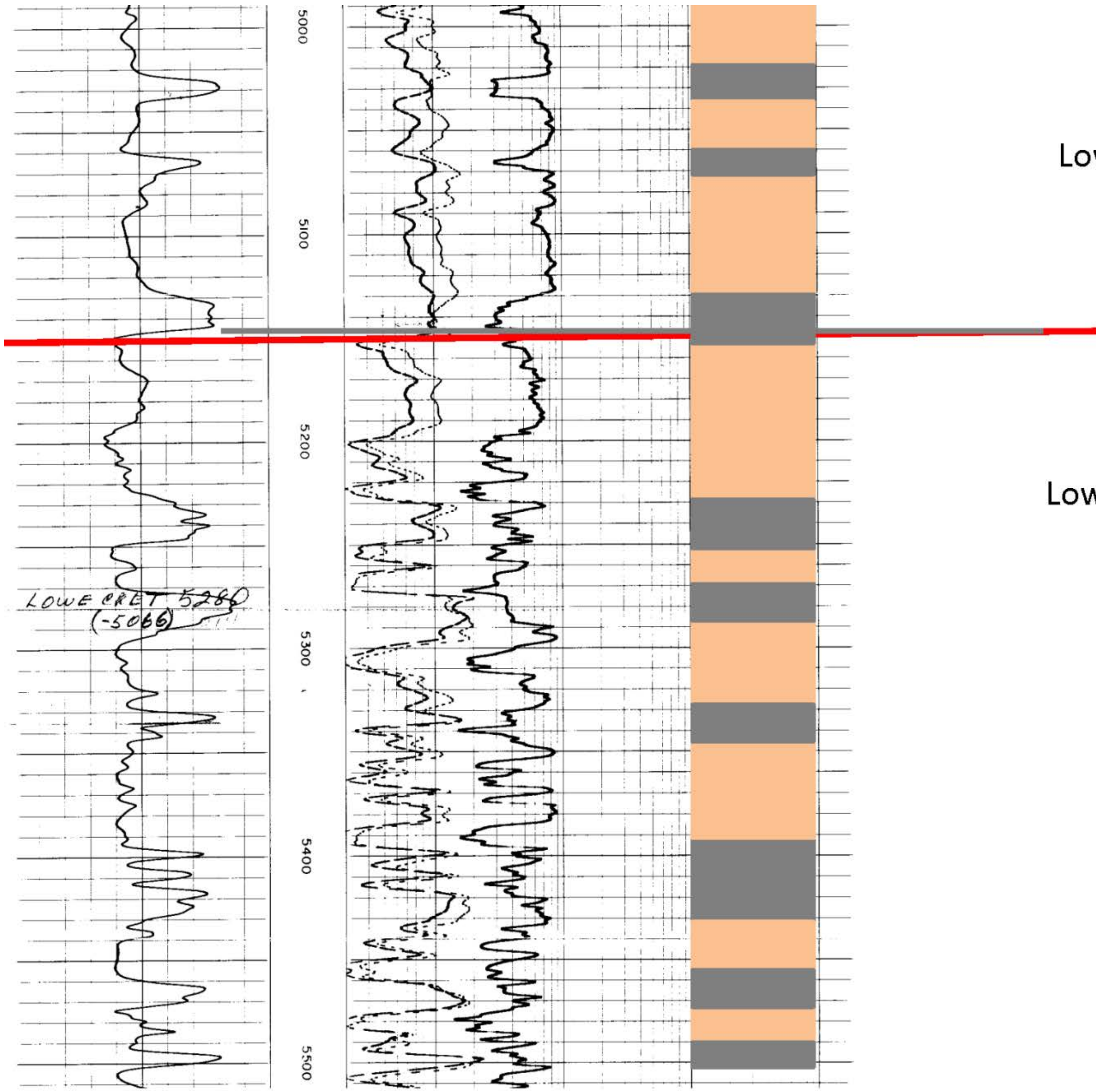


Midway Formation

Selma Group


EUTAW
4010 (-3796)
4000
4100
4200
4300
4500
Selma Group
Eutaw Formation
Upper Tuscaloosa
Limestone
Clay/Shale
Sandstone

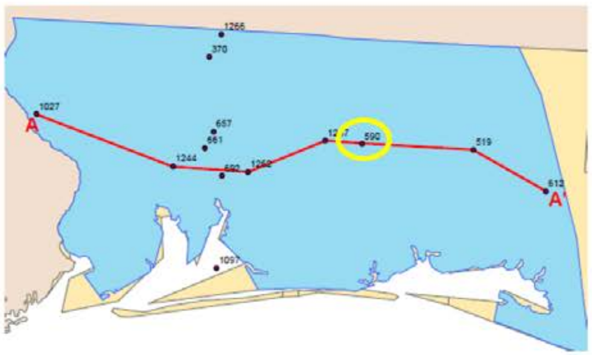

4500
4600
Tusc sh 4720 (-4506)
4800
4900
L Tusc 4977 (-4763)
5000
Upper Tuscaloosa
Middle Tuscaloosa
Lower Tuscaloosa

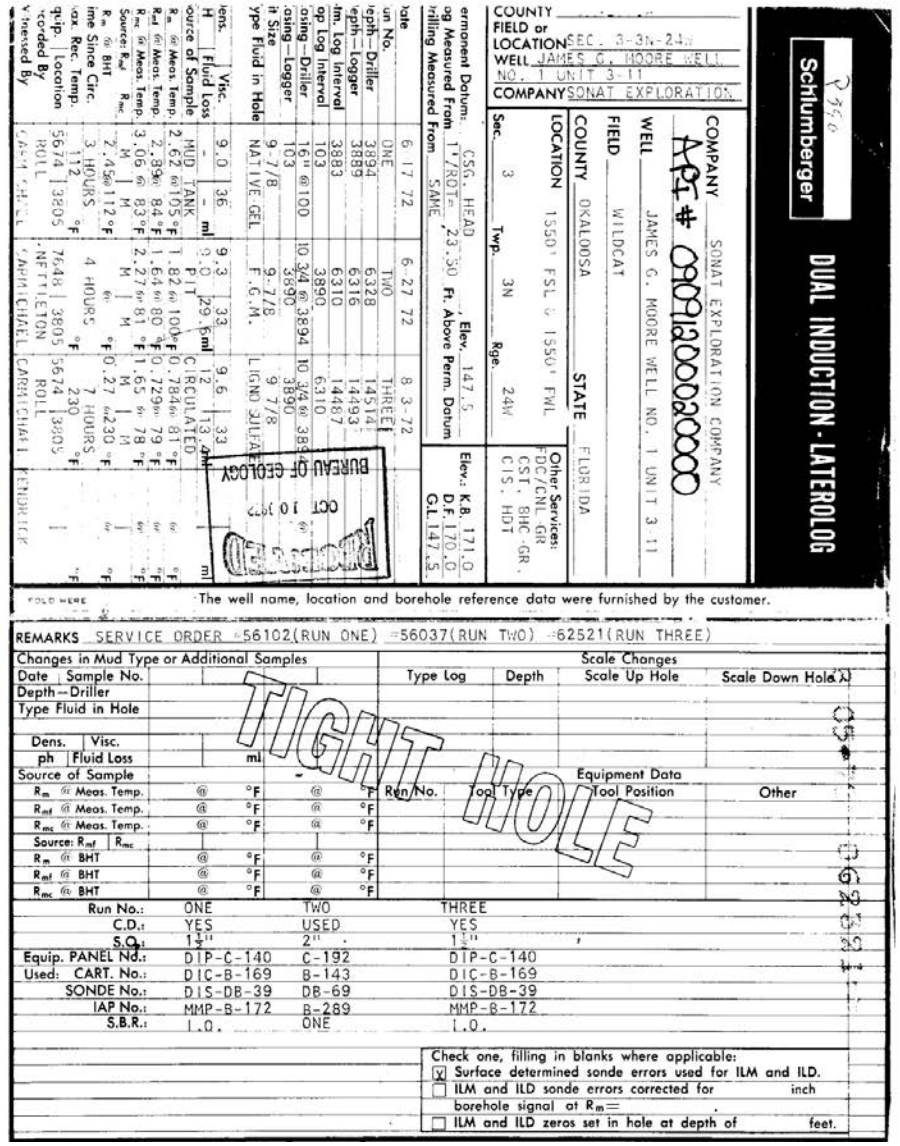


Lower Tuscaloosa

Lower Cretaceous

Disposal Area #1
P#590
Standard Potential Resistivity





Schlumberger

DUAL INDUCTION - LATEROLOG

COMPANY SONAT EXPLORATION COMPANY

API # 09091200020000

WELL JAMES G. MOORE WELL NO. 1 UNIT 3-11

FIELD WILDCAT

COUNTY OKALOOSA STATE FLORIDA

LOCATION 1550' FSL & 1550' FWL

Other Services: FDC/CNL-GR CST, BHC-GR, CIS, HDT

Sec. 3 Twp. 3N Rge. 24W

Permanent Datum: CSG. HEAD Elev. 147.5

Log Measured From 1' /ROT 23.50 Ft. Above Perm. Datum

Drilling Measured From SAME

Elev.: K.B. 171.0 D.F. 170.0 G.L. 147.5

Date	6 17 72	6-27 72	8 3-72
Run No.	ONE	TWO	THREE
Depth—Driller	3894	6328	14514
Depth—Logger	3889	6316	14493
Btm. Log Interval	3883	6310	14487
Top Log Interval	103	3890	6310
Casing—Driller	16" @ 100	10 3/4 @ 3894	10 3/4 @ 389[illegible]
Casing—Logger	103	3890	3890
Bit Size	9-7/8	9-7/8	9 7/8
Type Fluid in Hole	NATIVE GEL	F.G.M.	LIGNO SULFA[illegible]
Dens. / Visc.	9.0 / 36	9.3 / 33	9.6 / 33
pH / Fluid Loss	- / - ml	9.0 / 29.6 ml	12 / 13.4 ml
Source of Sample	MUD TANK	PIT	CIRCULATED
Rm @ Meas. Temp.	2.62 @ 105 °F	1.82 @ 100 °F	0.784 @ 81 °F
Rmf @ Meas. Temp.	2.89 @ 84 °F	1.64 @ 80 °F	0.729 @ 79 °F
Rmc @ Meas. Temp.	3.06 @ 83 °F	2.27 @ 81 °F	1.65 @ 78 °F
Source: Rmf / Rmc	M / M	M / M	M / M
Rm @ BHT	2.45 @ 112 °F	@ °F	0.27 @ 230 °F
Time Since Circ.	3 HOURS	4 HOURS	7 HOURS
Max. Rec. Temp.	112 °F	°F	230 °F
Equip. / Location	5674 / 3805	7648 / 3805	5674 / 3805
Recorded By	ROLL	NETTLETON	ROLL
Witnessed By	CARMICHAEL	CARMICHAEL	CARMICHAEL KENDRICK

BUREAU OF GEOLOGY OCT 10 1973

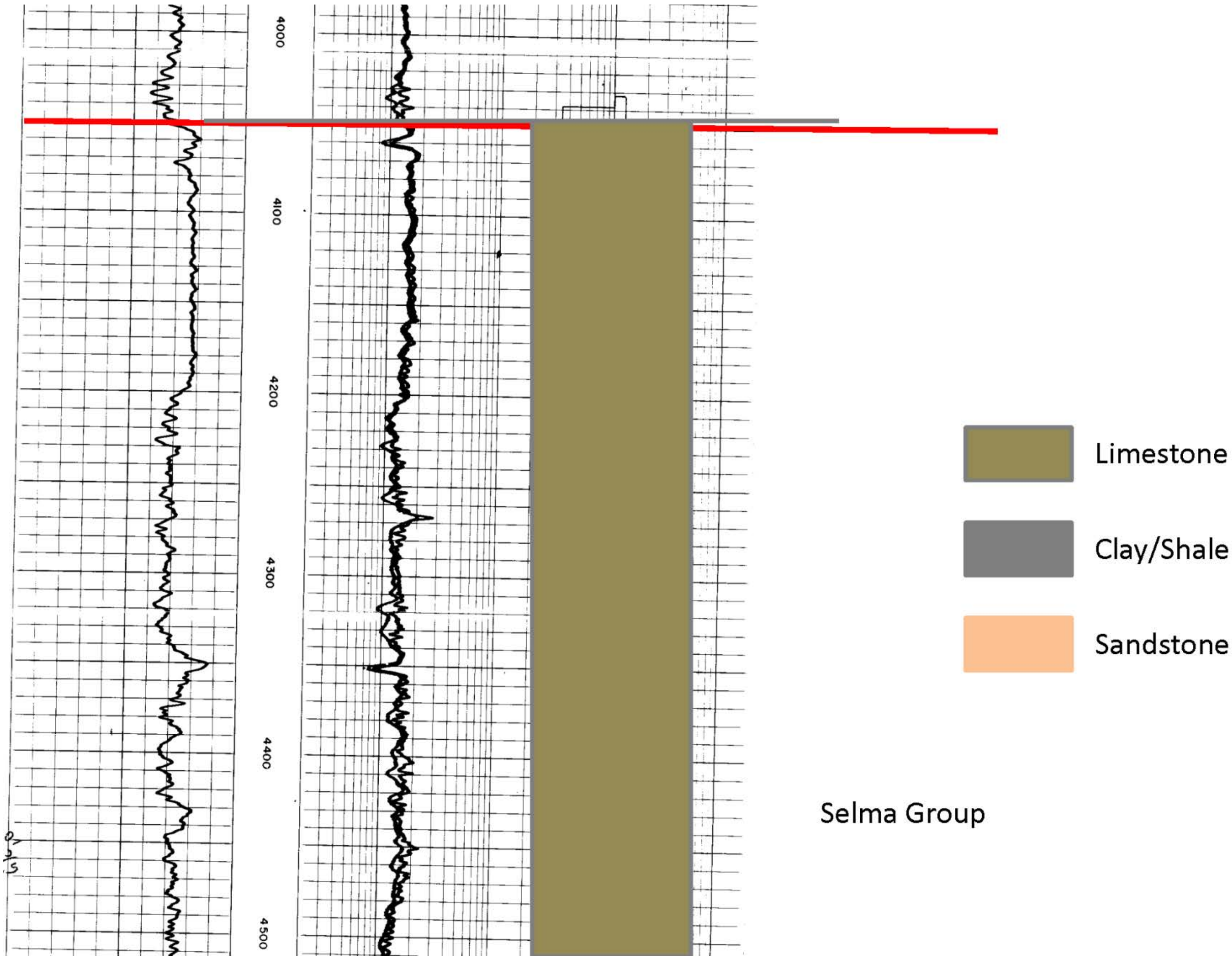
The well name, location and borehole reference data were furnished by the customer.

REMARKS SERVICE ORDER #56102 (RUN ONE) #56037 (RUN TWO) #62521 (RUN THREE)

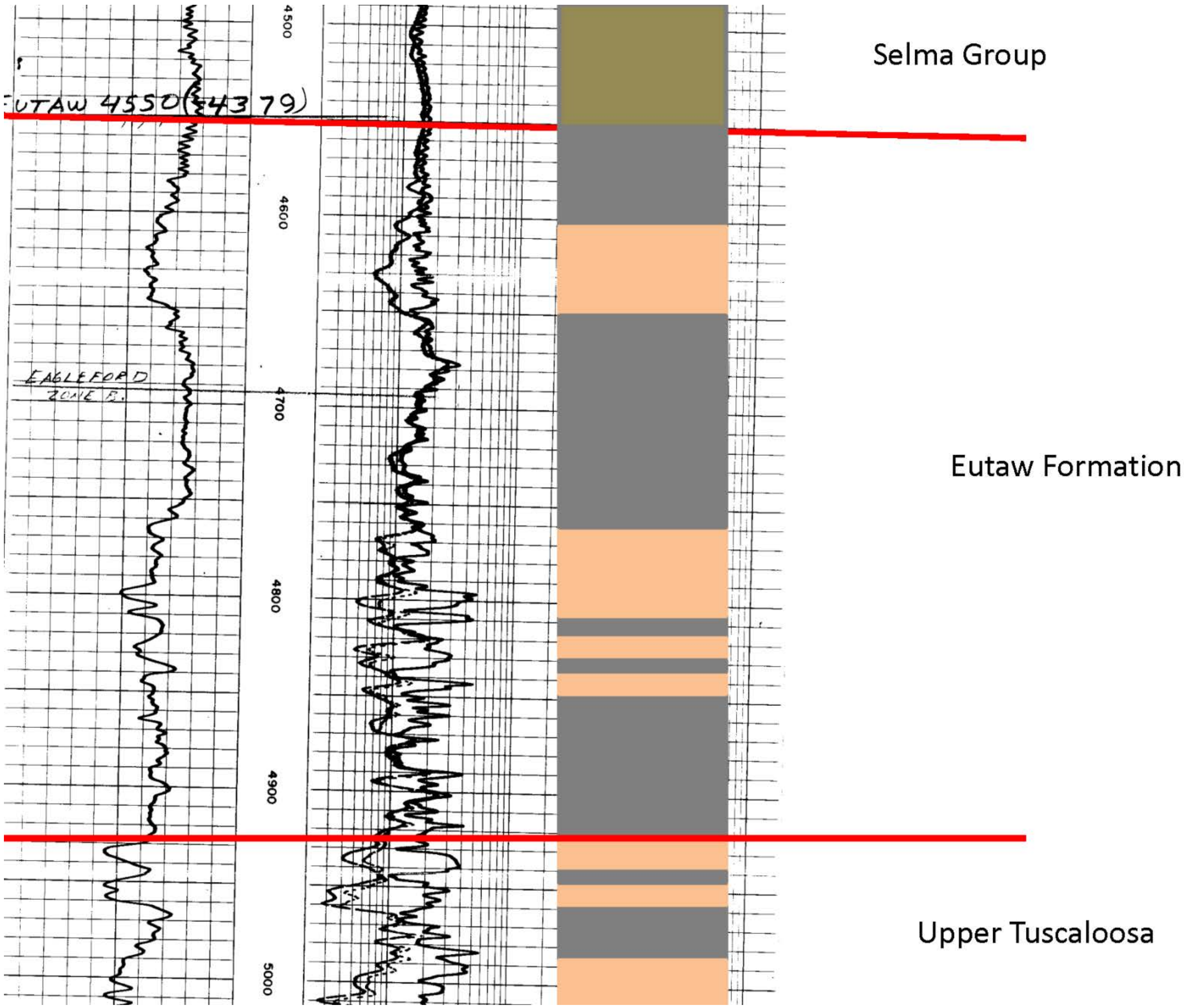
TIGHT HOLE

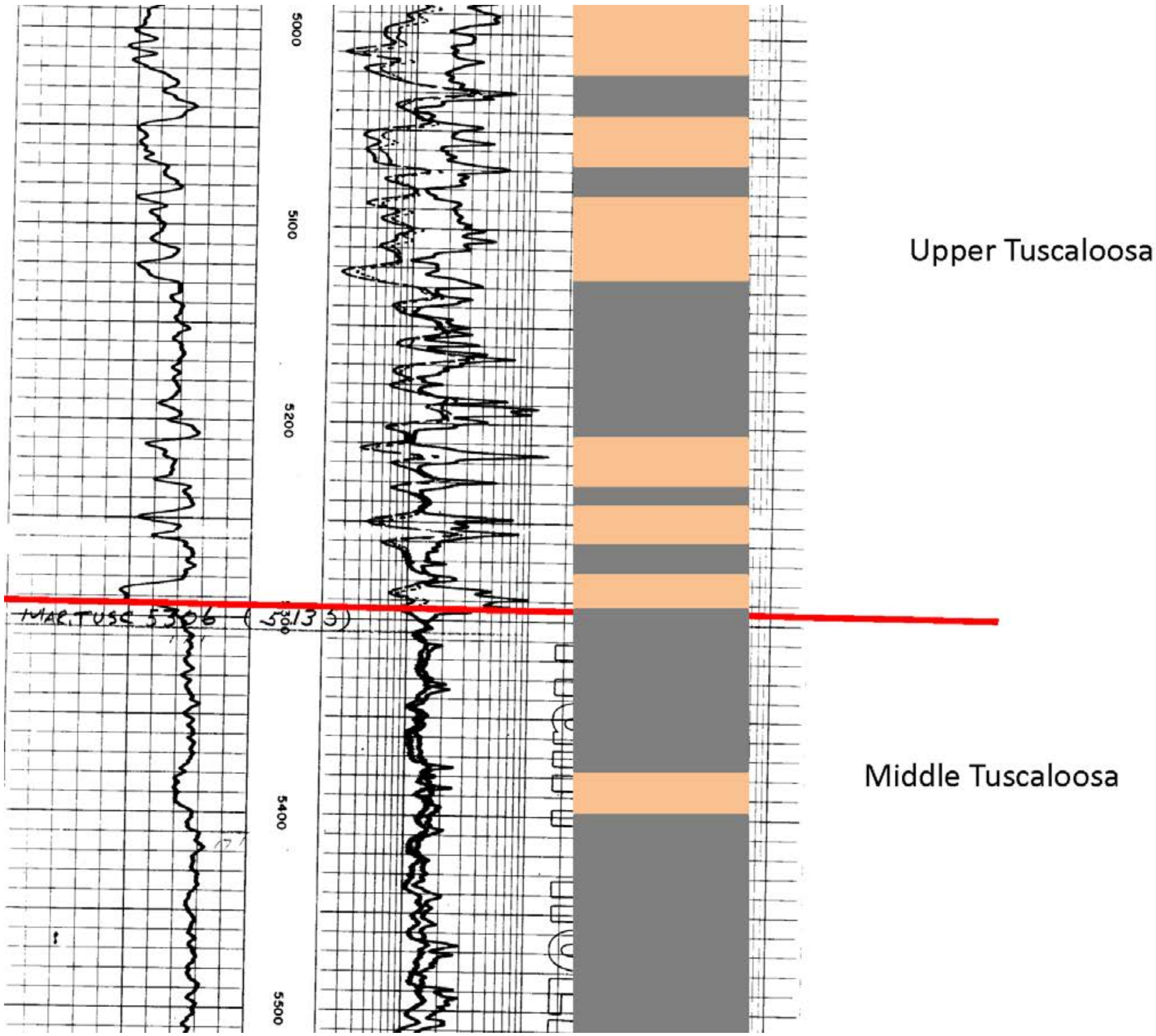
Run No.:	ONE	TWO	THREE
C.D.:	YES	USED	YES
S.O.:	1½"	2"	1½"
Equip. PANEL No.:	DIP-C-140	C-192	DIP-C-140
Used: CART. No.:	DIC-B-169	B-143	DIC-B-169
SONDE No.:	DIS-DB-39	DB-69	DIS-DB-39
IAP No.:	MMP-B-172	B-289	MMP-B-172
S.B.R.:	1.0	ONE	1.0

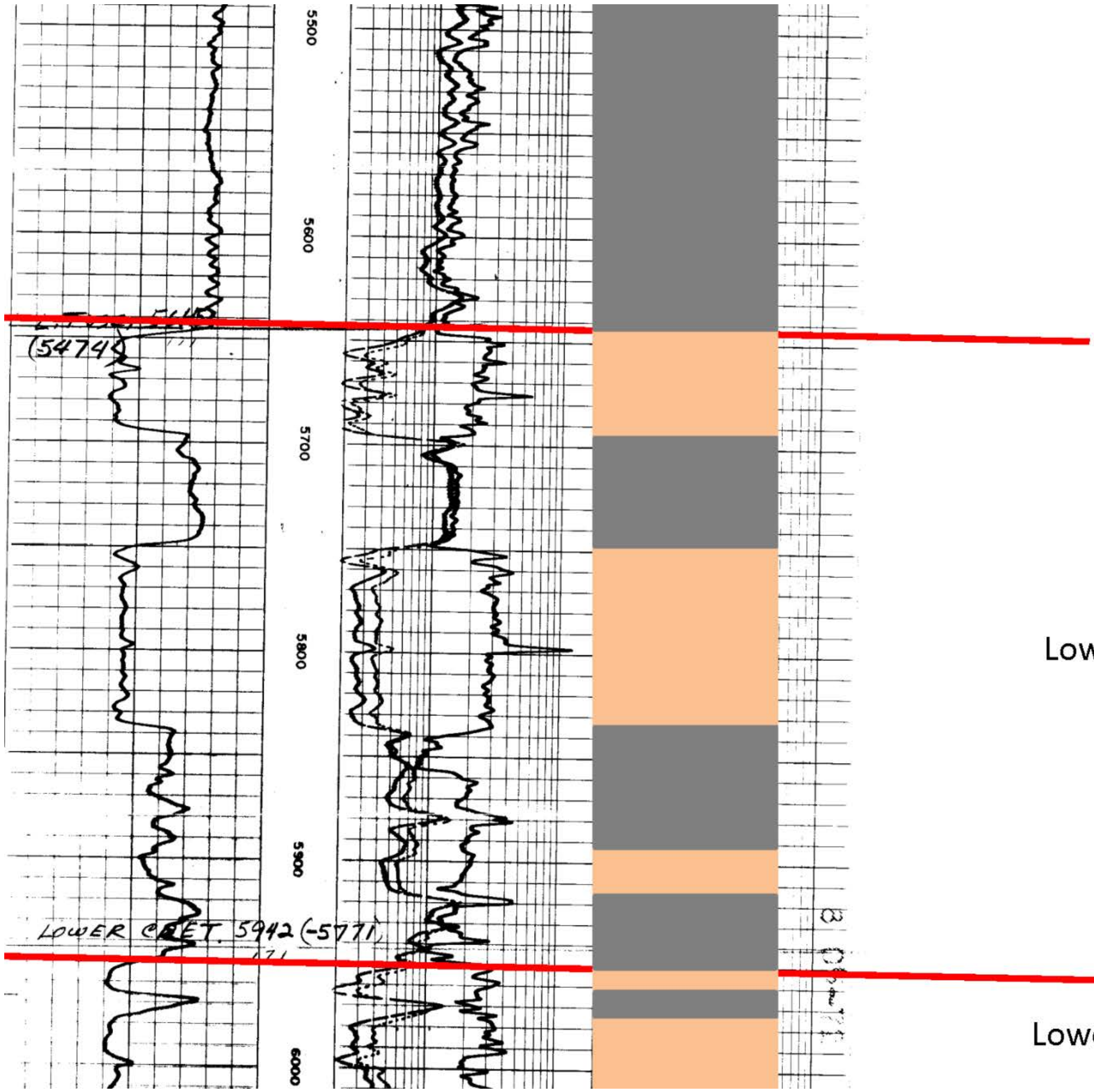
Check one, filling in blanks where applicable:
- [x] Surface determined sonde errors used for ILM and ILD.
- [ ] ILM and ILD sonde errors corrected for inch borehole signal at Rm=
- [ ] ILM and ILD zeros set in hole at depth of feet.



4000
4100
4200
4300
4400
4500
Limestone
Clay/Shale
Sandstone
Selma Group


EUTAW 4550(-4379)
EAGLEFORD ZONE B.
4500
4600
4700
4800
4900
5000
Selma Group
Eutaw Formation
Upper Tuscaloosa

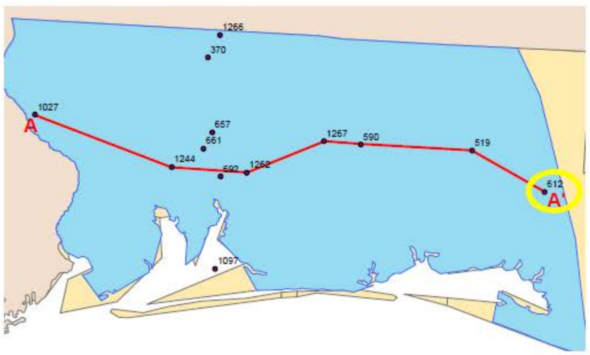

5000
5100
5200
5400
5500
Upper Tuscaloosa
Middle Tuscaloosa

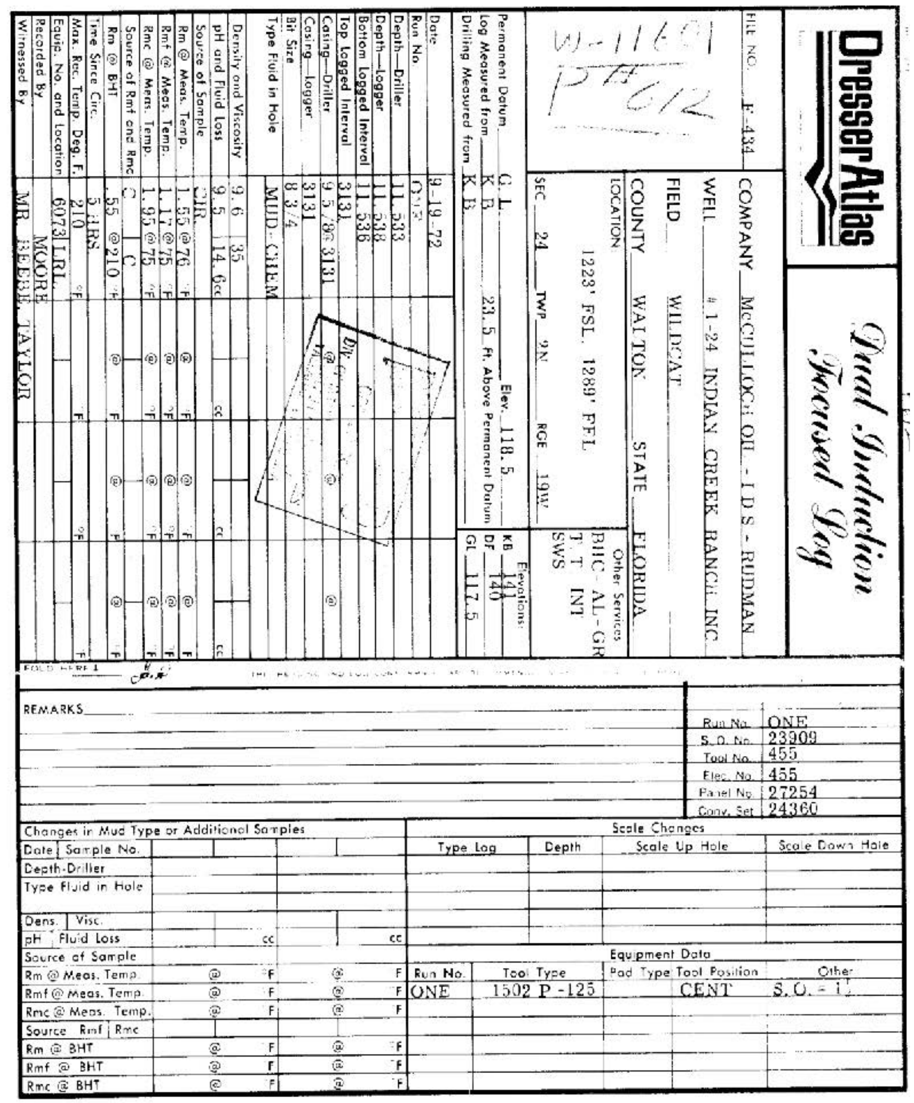


Lower Tuscaloosa

Lower Cretaceous

Disposal Area #1
P#612
Standard Potential Resistivity





DresserAtlas

Dual Induction Focused Log

W-11601
P#612

FILE NO. F-434
COMPANY McCULLOCH OIL - I D S - RUDMAN
WELL #1-24 INDIAN CREEK RANCH INC
FIELD WILDCAT
COUNTY WALTON STATE FLORIDA
LOCATION 1223' FSL. 1289' FFL
SEC 24 TWP 2N RGE 19W
Other Services: BHC-AL-GR, T.T. INT, SWS

Permanent Datum G.L. Elev. 118.5
Log Measured from K.B. 23.5 Ft. Above Permanent Datum
Drilling Measured from K.B.
Elevations: KB 141, DF 140, GL 117.5

Date	9-19-72
Run No.	ONE
Depth—Driller	11,533
Depth—Logger	11,538
Bottom Logged Interval	11,536
Top Logged Interval	3131
Casing—Driller	9 5/8 @ 3131
Casing—Logger	3131
Bit Size	8 3/4
Type Fluid in Hole	MUD-CHEM
Density and Viscosity	9.6 / 35
pH and Fluid Loss	9.5 / 14.6 cc
Source of Sample	CIR.
Rm @ Meas. Temp.	1.55 @ 76 °F
Rmf @ Meas. Temp.	1.17 @ 75 °F
Rmc @ Meas. Temp.	1.95 @ 75 °F
Source of Rmf and Rmc	C / C
Rm @ BHT	.55 @ 210 °F
Time Since Circ.	5 HRS
Max. Rec. Temp. Deg. F.	210 °F
Equip. No. and Location	6073 LRL
Recorded By	MOORE
Witnessed By	MR. BEBBE TAYLOR

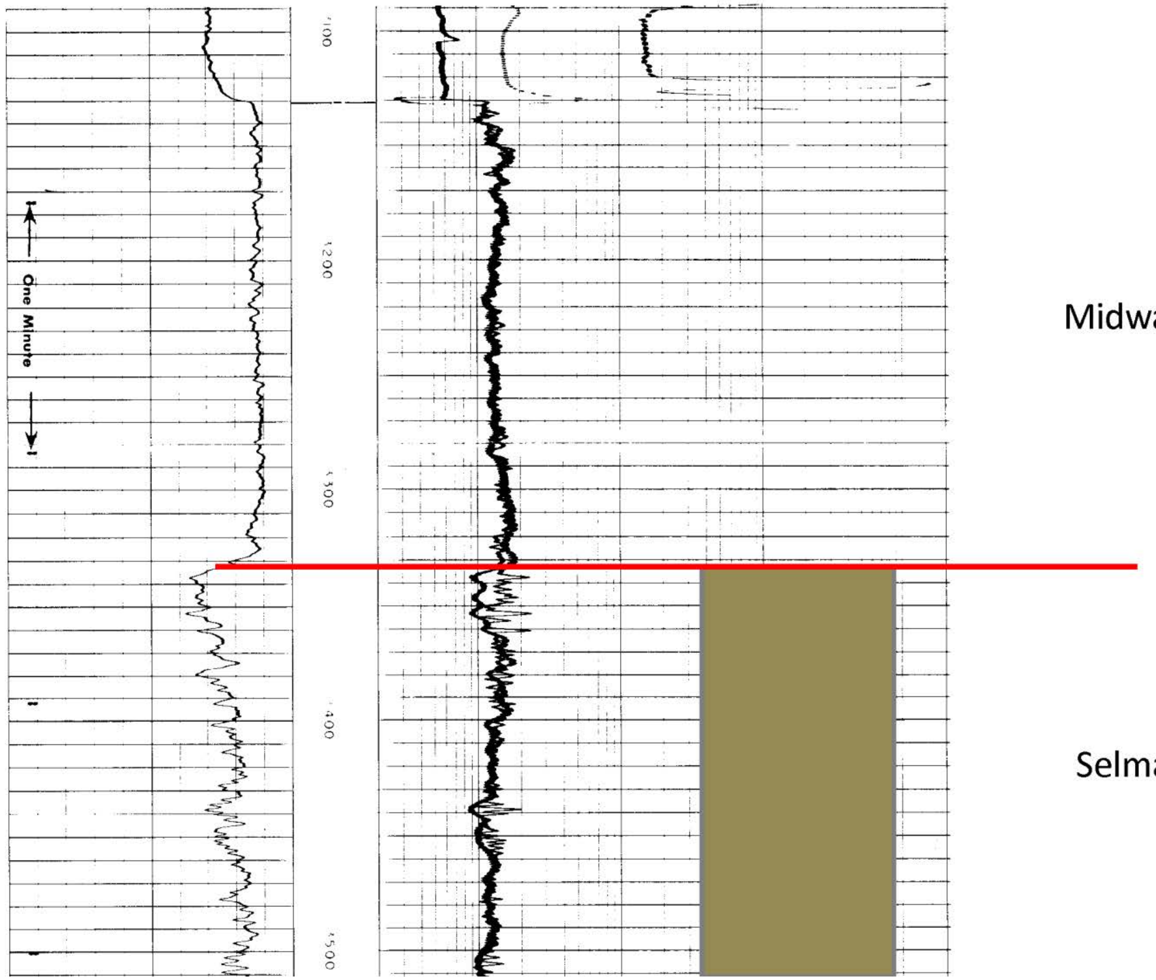
FOLD HERE

REMARKS

Run No.	ONE
S.O. No.	23909
Tool No.	455
Elec. No.	455
Panel No.	27254
Conv. Set	24360

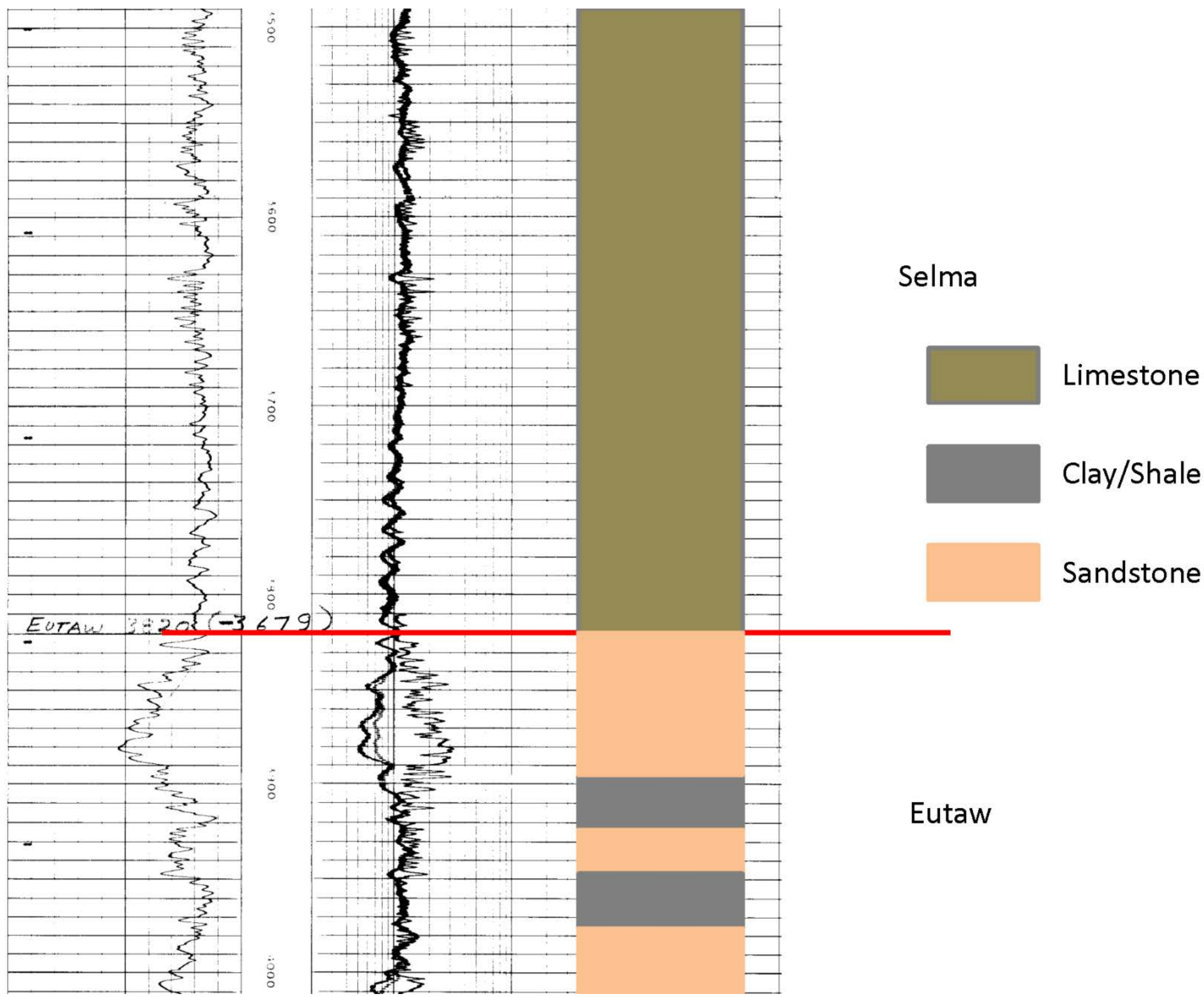
Changes in Mud Type or Additional Samples — Scale Changes — Equipment Data

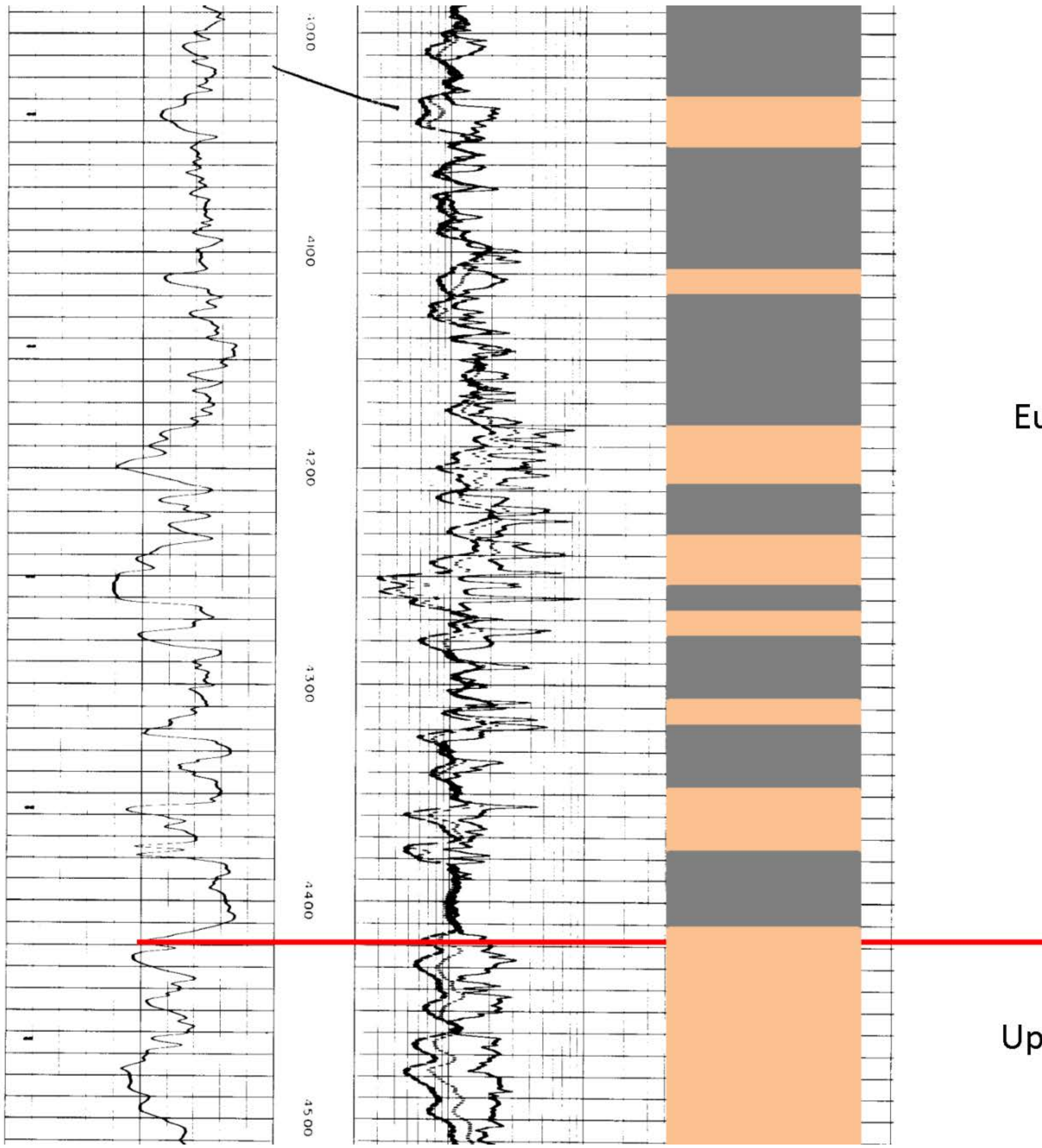
Run No.	Tool Type	Pad Type	Tool Position	Other
ONE	1502 P-125		CENT	S.O. = 1



Midway

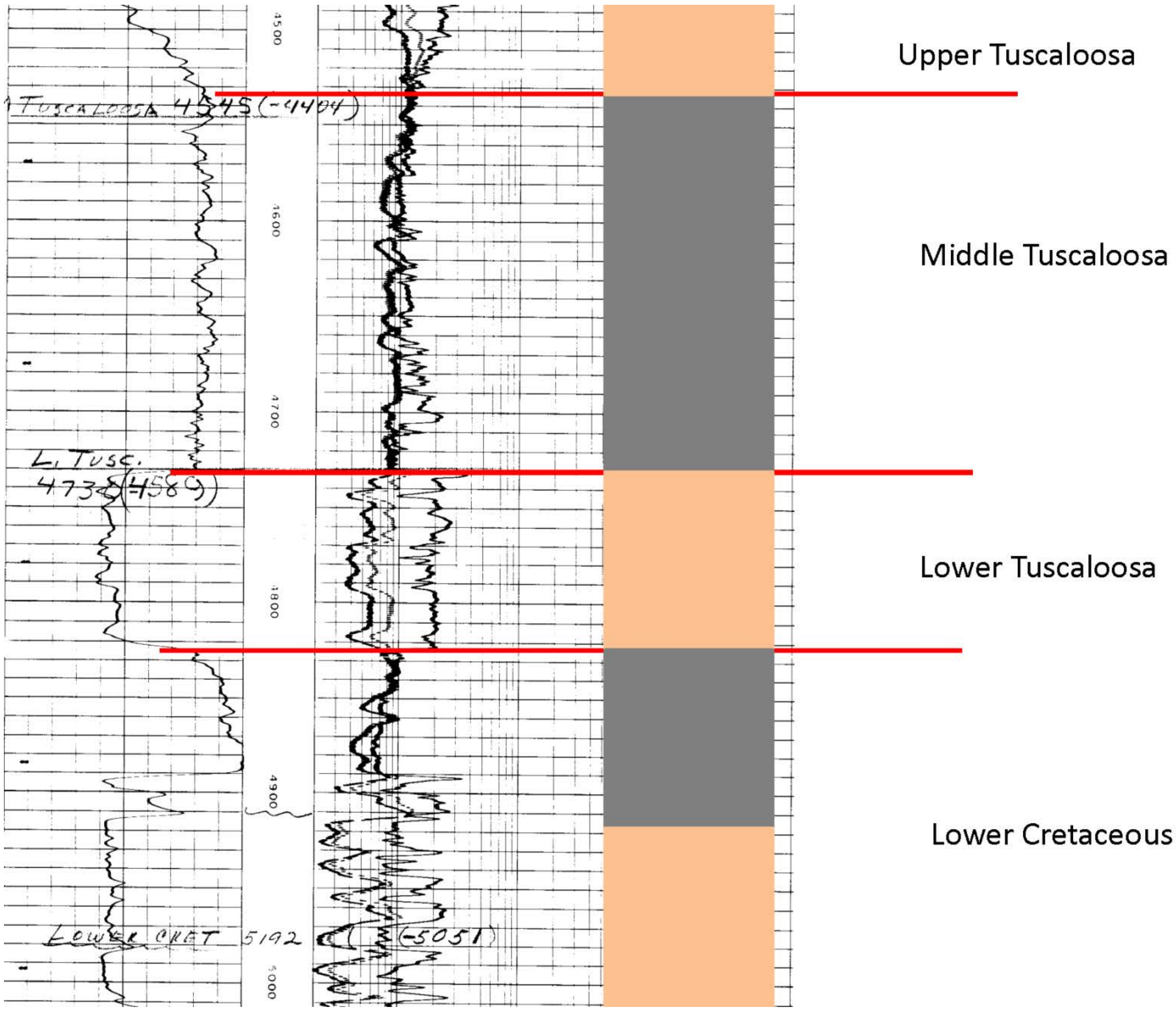
Selma


EUTAW
Selma
Limestone
Clay/Shale
Sandstone
Eutaw



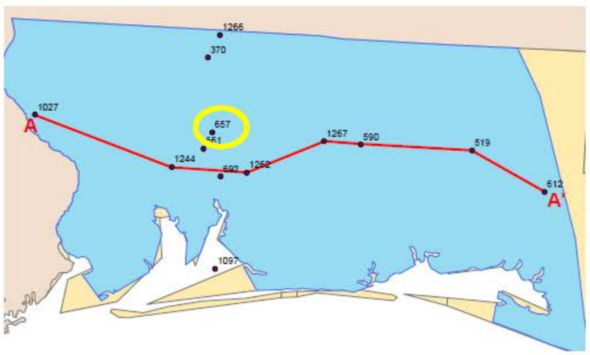
Eutaw

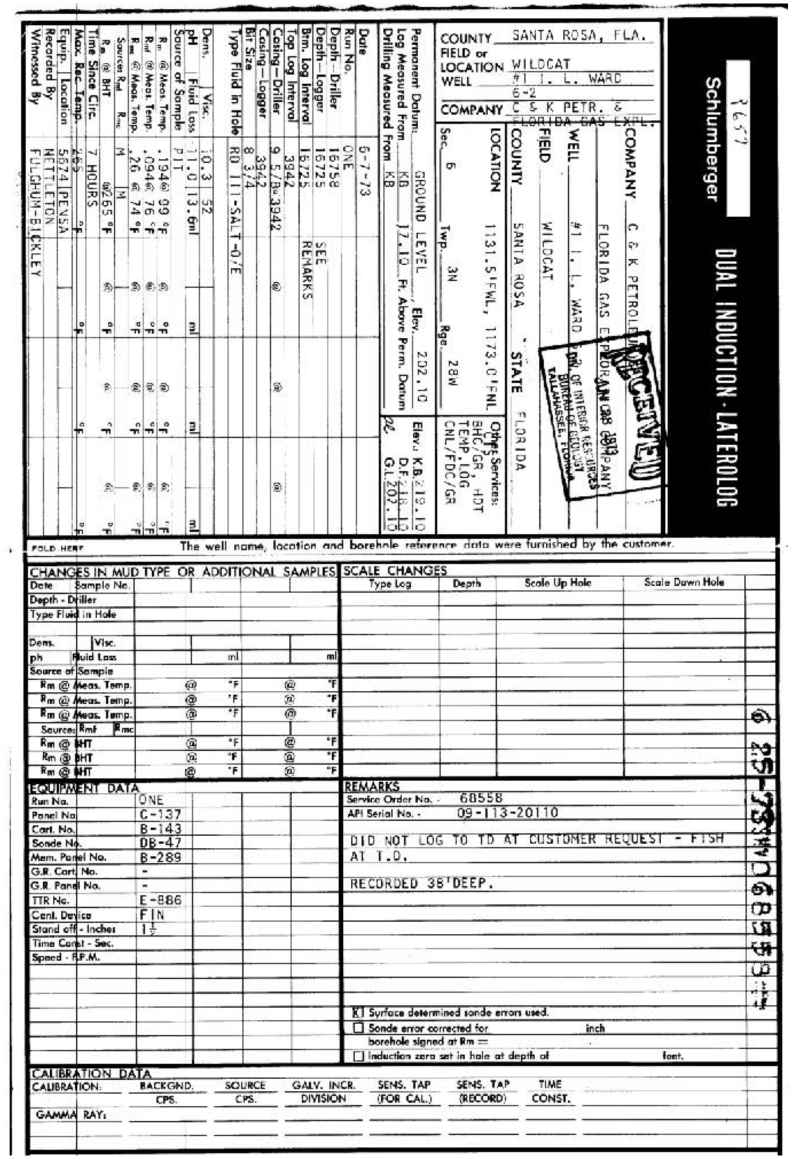
Upper Tuscaloosa



Upper Tuscaloosa
Middle Tuscaloosa
Lower Tuscaloosa
Lower Cretaceous
4500
4600
4700
4800
4900
5000
L. Tusc.
4738 (4589)
Lower Cret 5192 (-5051)

Disposal Area #1
P#657
Standard Potential Resistivity




Schlumberger
DUAL INDUCTION - LATEROLOG

COMPANY C & K PETROLEUM FLORIDA GAS EXPLORATION COMPANY
WELL #1 I. L. WARD
FIELD WILDCAT
COUNTY SANTA ROSA STATE FLORIDA
LOCATION 1131.5'FWL, 1173.0'FNL
Sec. 6 Twp. 3N Rge. 28W
Other Services: BHC/GR, HDT, TEMP.LOG, CNL/FDC/GR

Permanent Datum: GROUND LEVEL Elev. 202.10
Log Measured From KB 17.10 Ft. Above Perm. Datum
Drilling Measured From KB
Elev.: K.B. 219.10 D.F. 218.10 G.L. 202.10

RECEIVED JAN 08 1974 DIV. OF INTERIOR RESOURCES BUREAU OF GEOLOGY TALLAHASSEE, FLORIDA

Date	6-7-73
Run No.	ONE
Depth—Driller	16758
Depth—Logger	16725
Btm. Log Interval	16725
Top Log Interval	3942
Casing—Driller	9 5/8 @ 3942
Casing—Logger	3942
Bit Size	8 3/4
Type Fluid in Hole	RD 111-SALT-0/E
Dens. / Visc.	10.3 / 52
pH / Fluid Loss	11.0 / 13.6 ml
Source of Sample	PIT
R_m @ Meas. Temp.	.194 @ 99 °F
R_{mf} @ Meas. Temp.	.094 @ 76 °F
R_{mc} @ Meas. Temp.	.26 @ 74 °F
Source: R_{mf} / R_{mc}	M / M
R_m @ BHT	@ 265 °F
Time Since Circ.	7 HOURS
Max. Rec. Temp.	265 °F
Equip. / Location	5674 / PENSA
Recorded By	NETTLETON
Witnessed By	FULGHUM-BICKLEY

The well name, location and borehole reference data were furnished by the customer.

CHANGES IN MUD TYPE OR ADDITIONAL SAMPLES — SCALE CHANGES (Type Log, Depth, Scale Up Hole, Scale Down Hole)

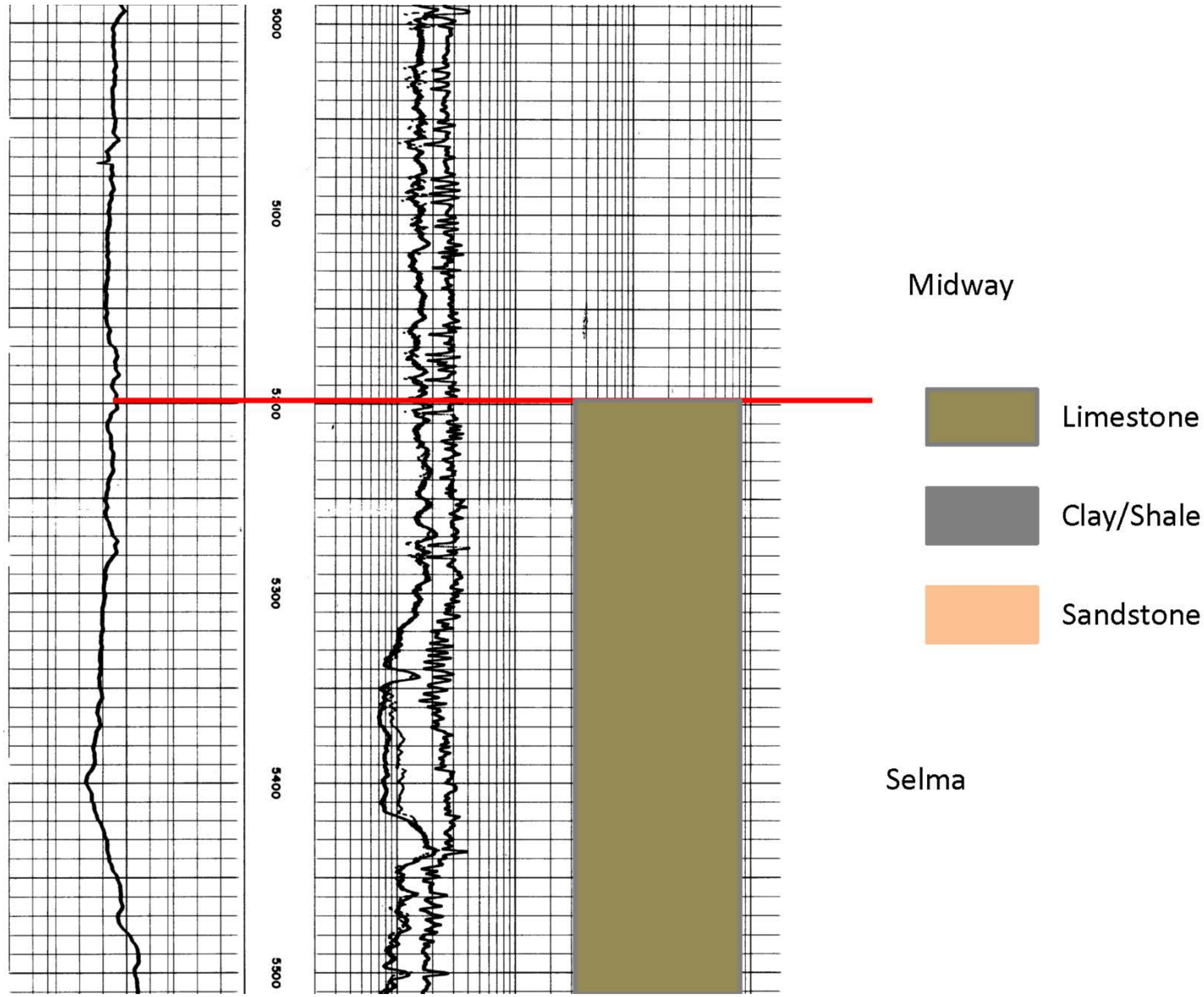
EQUIPMENT DATA

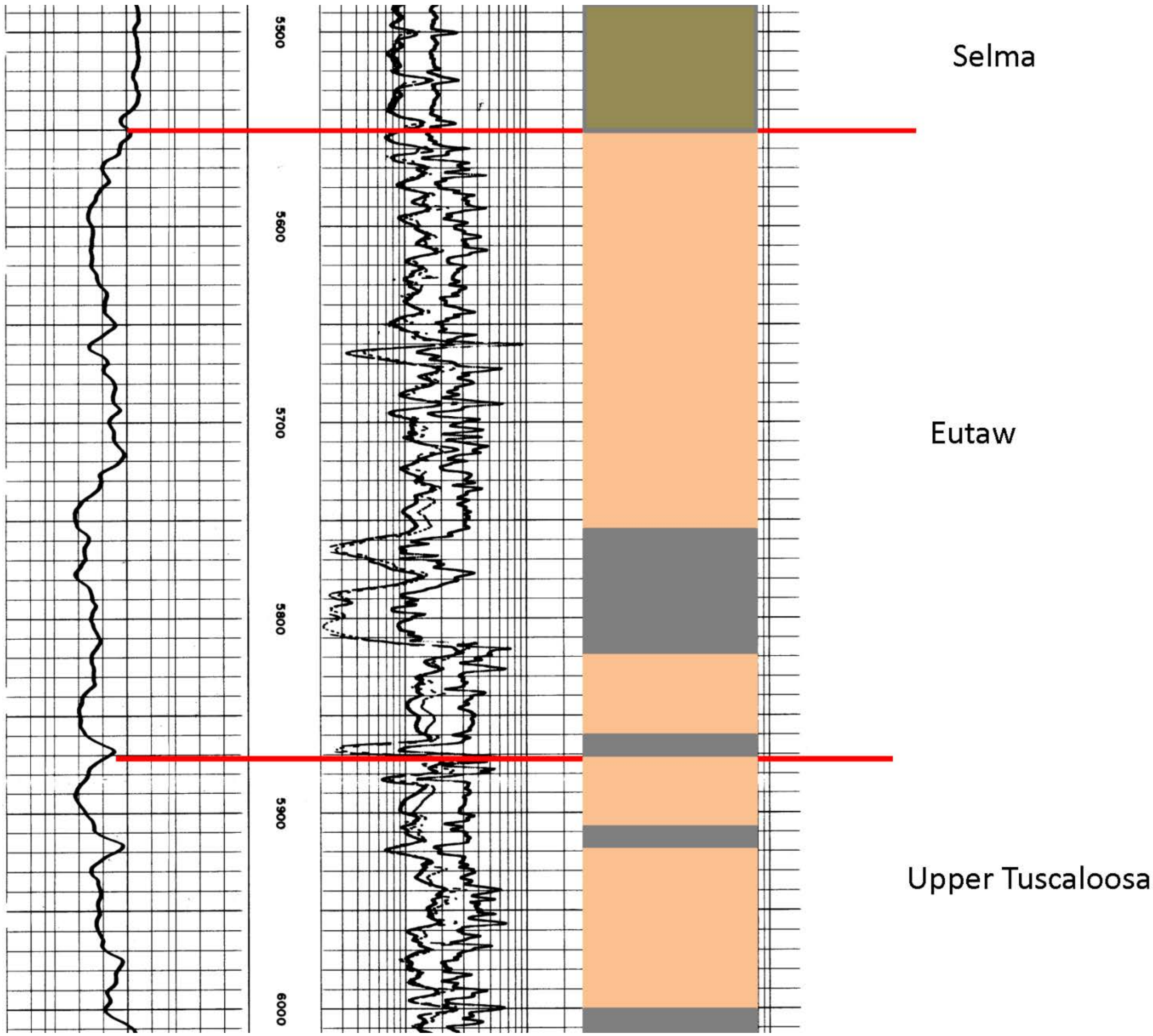
Run No.	ONE
Panel No.	C-137
Cart. No.	B-143
Sonde No.	DB-47
Mem. Panel No.	B-289
G.R. Cart. No.	-
G.R. Panel No.	-
TTR No.	E-886
Cent. Device	FIN
Stand off - Inches	1 1/2
Time Const - Sec.	
Speed - F.P.M.	

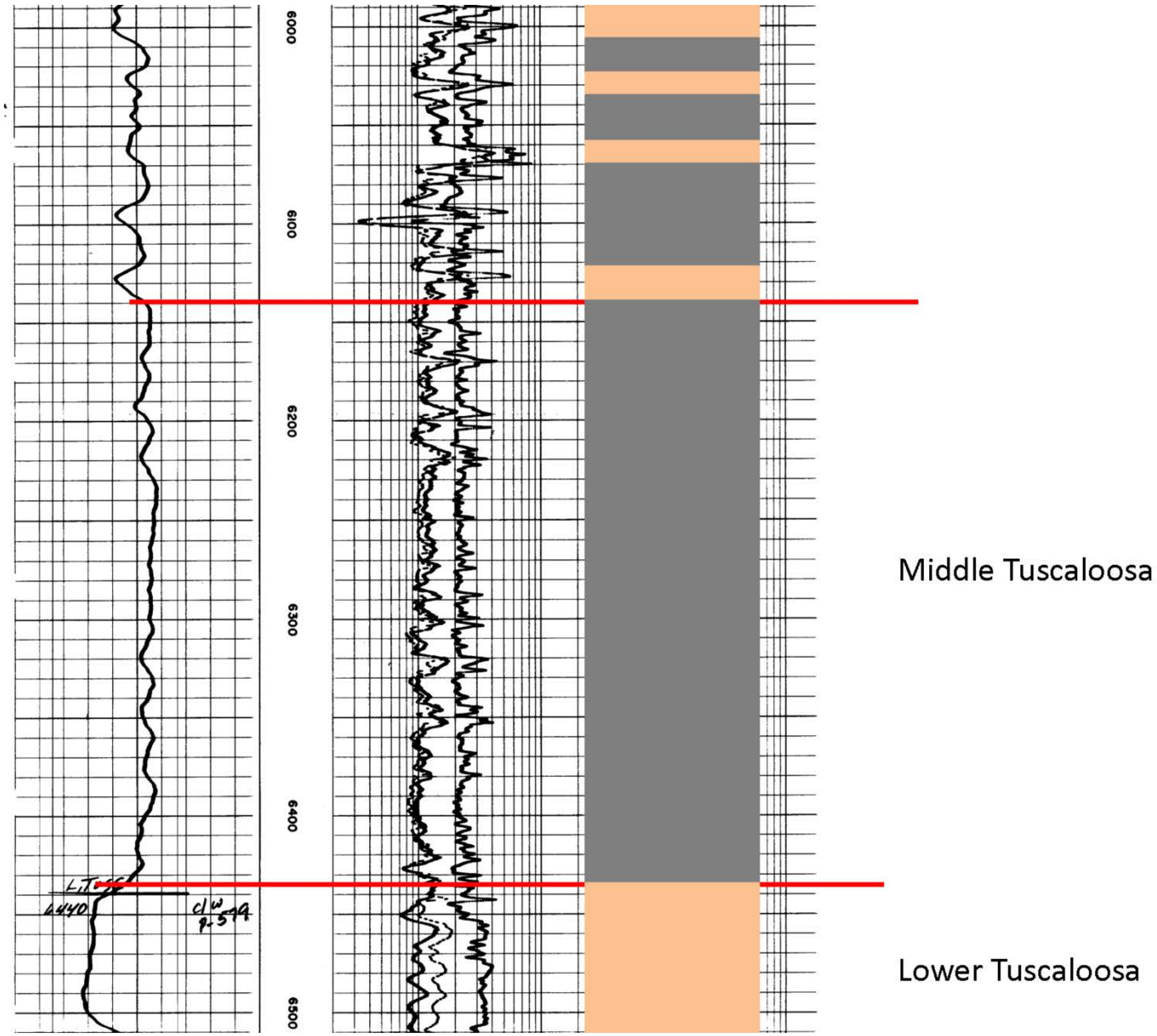
REMARKS
Service Order No. 68558
API Serial No. 09-113-20110
DID NOT LOG TO TD AT CUSTOMER REQUEST - FISH AT T.D.
RECORDED 38'DEEP.

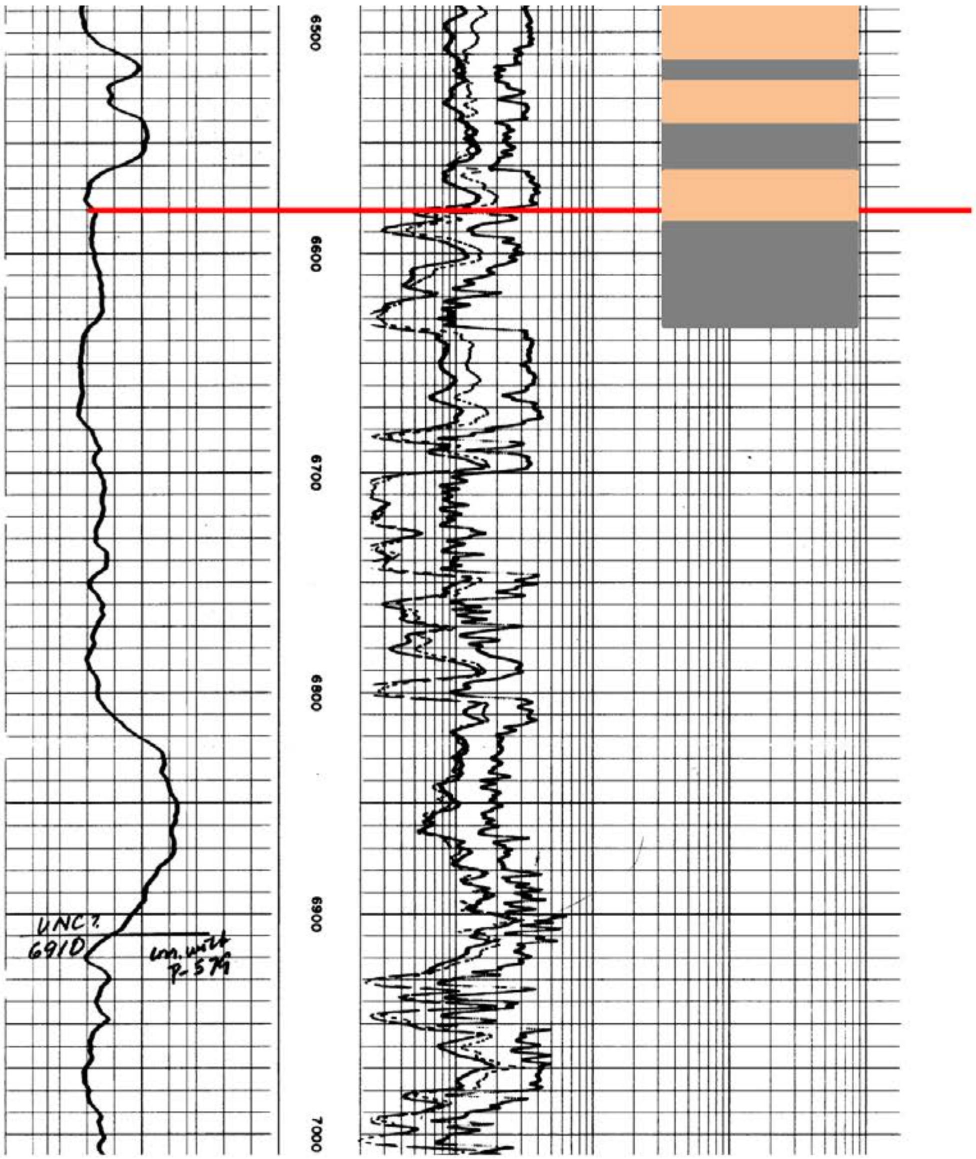
[X] Surface determined sonde errors used.
[ ] Sonde error corrected for borehole signed at Rm = inch
[ ] Induction zero set in hole at depth of feet.

CALIBRATION DATA
CALIBRATION: BACKGND. CPS. / SOURCE CPS. / GALV. INCR. DIVISION / SENS. TAP (FOR CAL.) / SENS. TAP (RECORD) / TIME CONST.
GAMMA RAY:


5000
5100
5200
5300
5400
5500
Midway
Limestone
Clay/Shale
Sandstone
Selma


5500
5600
5700
5800
5900
6000
Selma
Eutaw
Upper Tuscaloosa

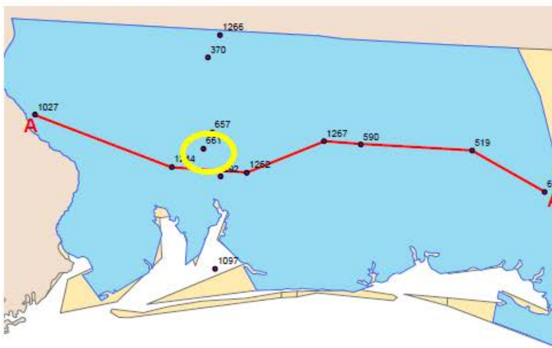

6000
6100
6200
6300
6400
6500
Middle Tuscaloosa
Lower Tuscaloosa

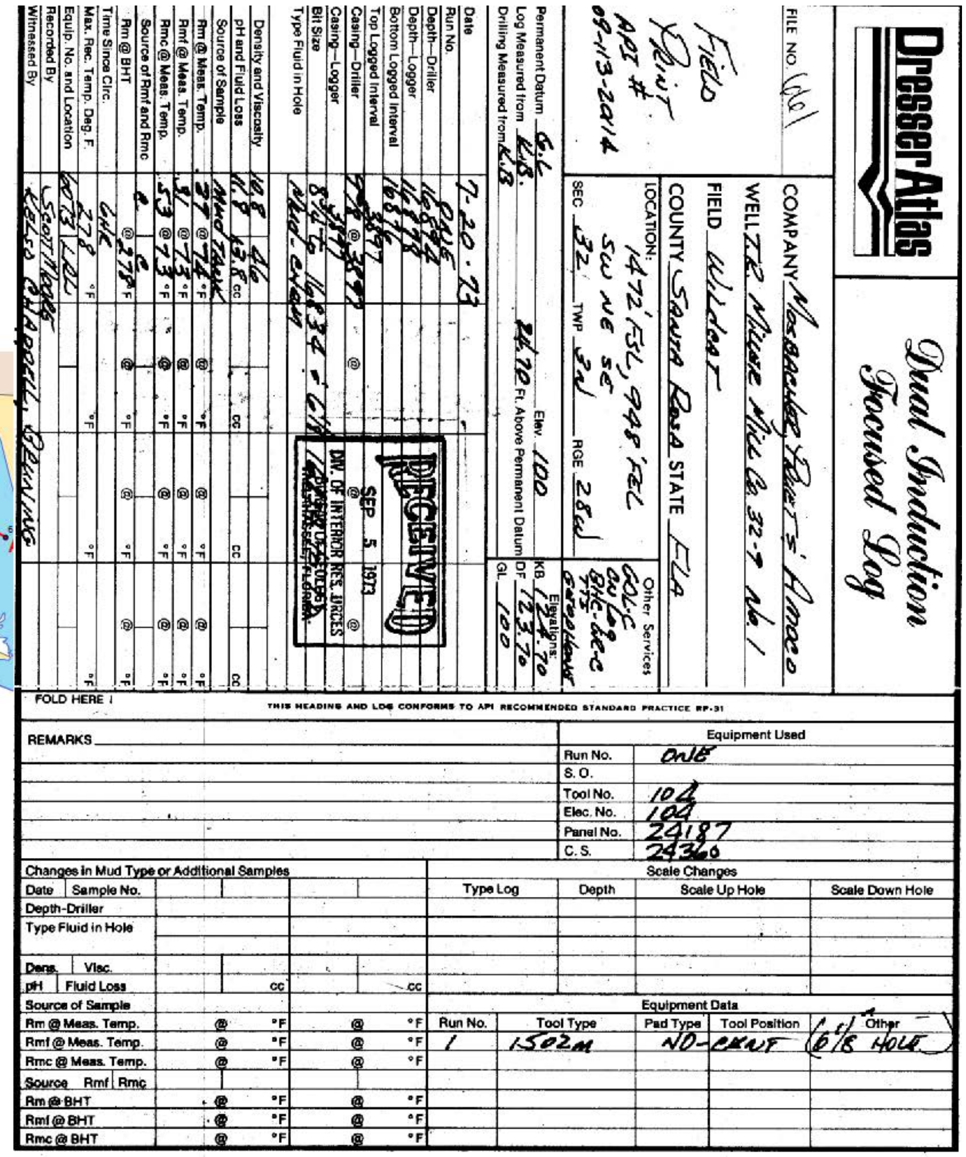


Lower Tuscaloosa

Lower Cretaceous

Disposal Area #1
P#661
Standard Potential
Resistivity





Dresser Atlas

Dual Induction Focused Log

FILE NO. 661

COMPANY Mosbacher Pruet's Amoco

WELL T.R. Miller Mill Co. 32-7 No. 1

FIELD Wildcat

COUNTY Santa Rosa STATE Fla

LOCATION: 1472' FSL, 998' FEL SW NE SE

SEC 32 TWP 3N RGE 28W

Other Services

Field Print

API # 09-113-2014

Permanent Datum G.L. Elev. 100

Log Measured from K.B. 24.70 Ft. Above Permanent Datum

Drilling Measured from K.B.

Elevations: KB 124.70 DF 123.70 GL 100

Date	7-20-73
Run No.	One
Depth—Driller	
Depth—Logger	
Bottom Logged Interval	
Top Logged Interval	
Casing—Driller	@
Casing—Logger	
Bit Size	
Type Fluid in Hole	
Density and Viscosity	
pH and Fluid Loss	cc
Source of Sample	
Rm @ Meas. Temp.	@ °F
Rmf @ Meas. Temp.	@ °F
Rmc @ Meas. Temp.	@ °F
Source of Rmf and Rmc	
Rm @ BHT	@ °F
Time Since Circ.	
Max. Rec. Temp. Deg. F.	°F
Equip. No. and Location	
Recorded By	
Witnessed By	

RECEIVED SEP 5 1973 DIV. OF INTERIOR RES. URCES

FOLD HERE

THIS HEADING AND LOG CONFORMS TO API RECOMMENDED STANDARD PRACTICE RP-31

REMARKS

Equipment Used	
Run No.	ONE
S.O.	
Tool No.	104
Elec. No.	104
Panel No.	24187
C.S.	24360

Changes in Mud Type or Additional Samples

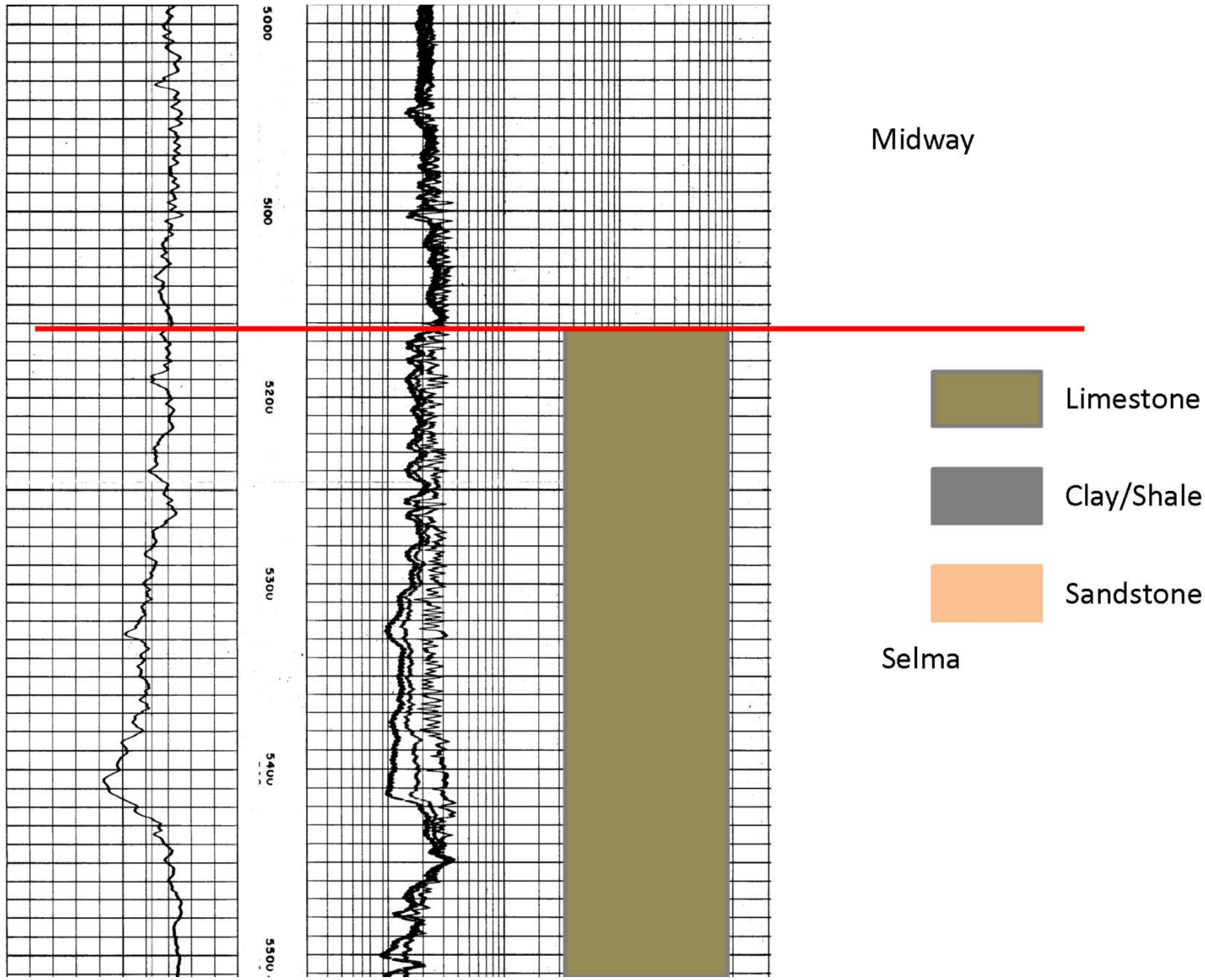
Date / Sample No.				
Depth-Driller				
Type Fluid in Hole				
Dens. / Visc.				
pH / Fluid Loss		cc		cc
Source of Sample				
Rm @ Meas. Temp.	@	°F	@	°F
Rmf @ Meas. Temp.	@	°F	@	°F
Rmc @ Meas. Temp.	@	°F	@	°F
Source Rmf / Rmc				
Rm @ BHT	@	°F	@	°F
Rmf @ BHT	@	°F	@	°F
Rmc @ BHT	@	°F	@	°F

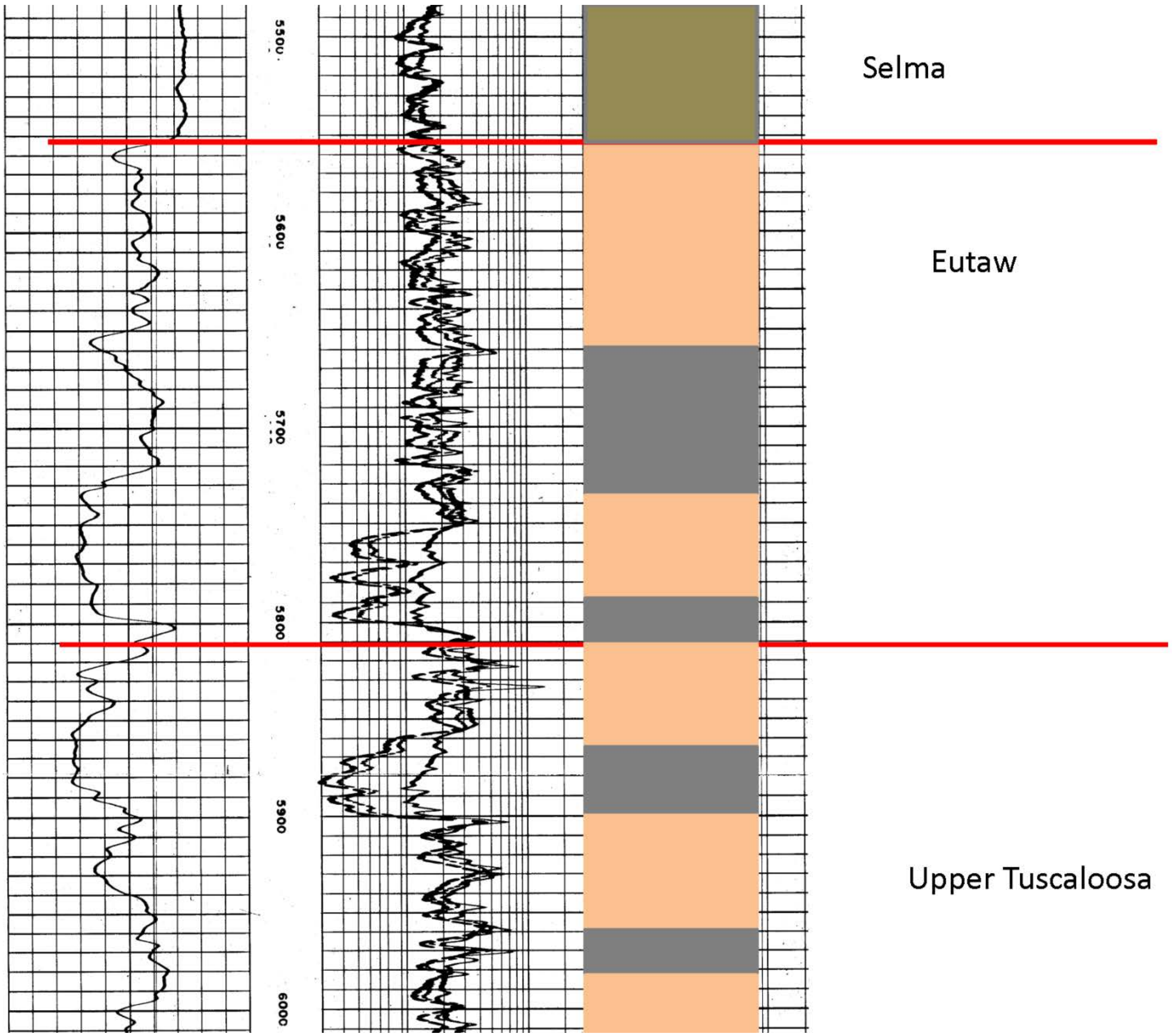
Scale Changes

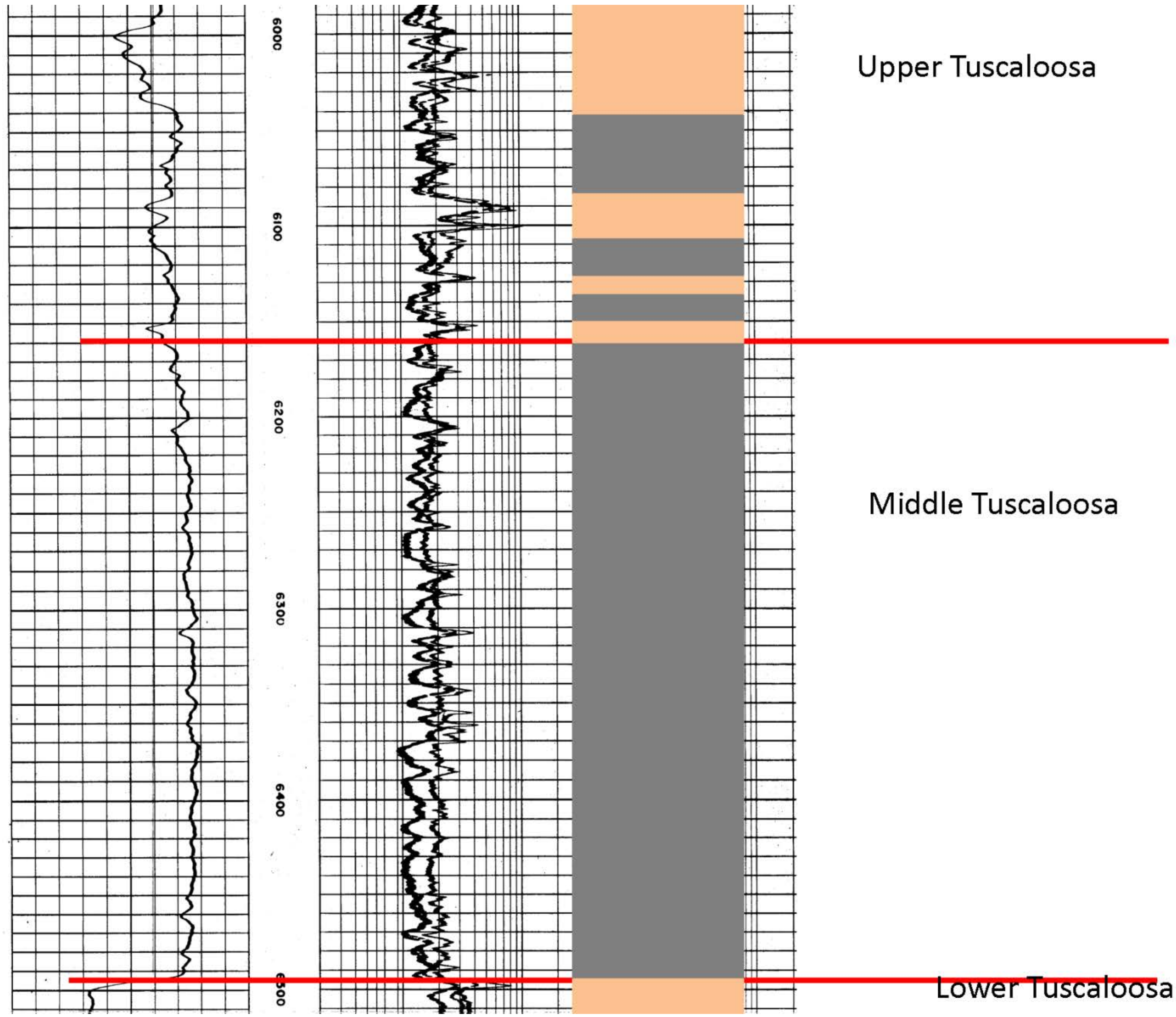
Type Log	Depth	Scale Up Hole	Scale Down Hole

Equipment Data

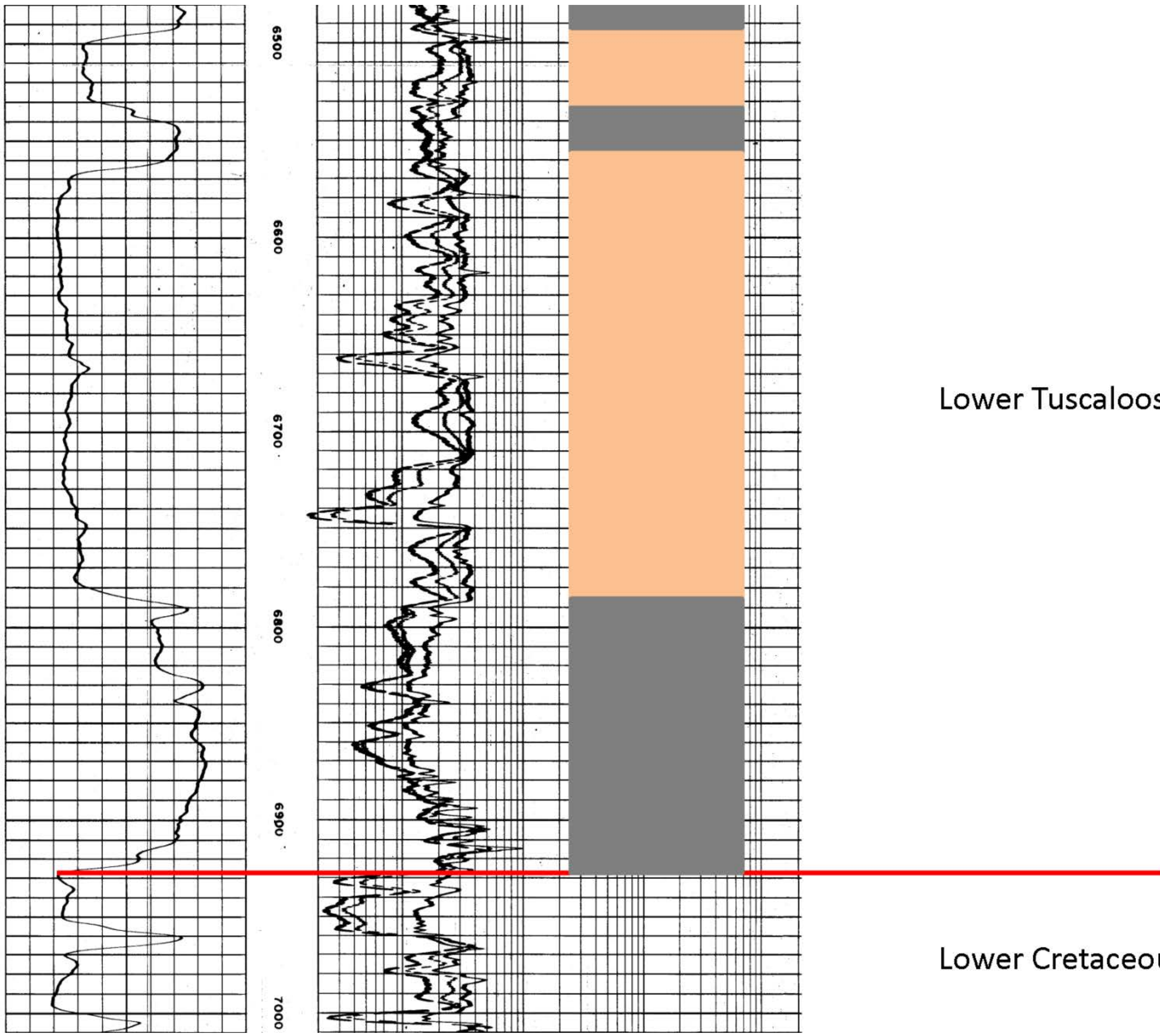
Run No.	Tool Type	Pad Type	Tool Position	Other
1	1502M	NO-CENT		6 1/8 HOLE


5000
5100
5200
5300
5400
5500
Midway
Limestone
Clay/Shale
Sandstone
Selma


5500
5600
5700
5800
5900
6000
Selma
Eutaw
Upper Tuscaloosa



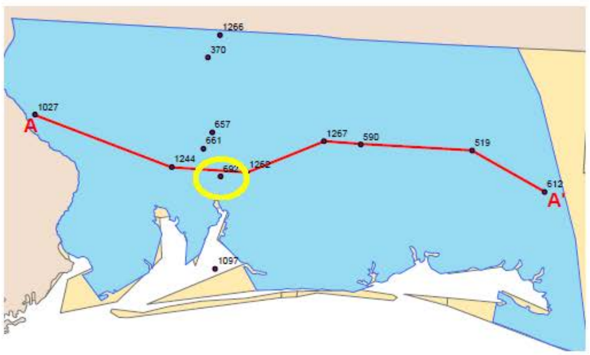
6000
6100
6200
6300
6400
6500
Upper Tuscaloosa
Middle Tuscaloosa
Lower Tuscaloosa

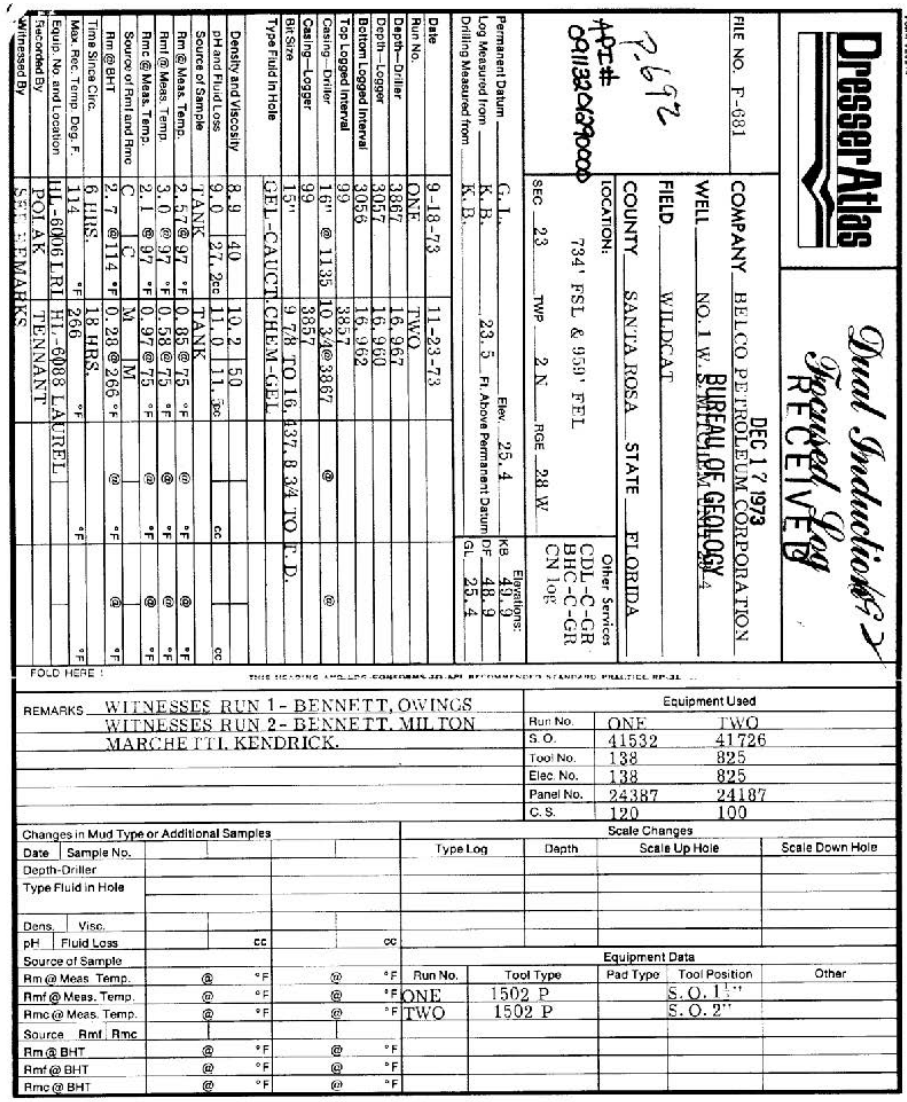


Lower Tuscaloosa

Lower Cretaceous

Disposal Area #1
P#692
Standard Potential Resistivity





FORM 626214

Dresser Atlas

Dual Induction Focused Log

RECEIVED
DEC 17 1973
BUREAU OF GEOLOGY

FILE NO. F-681

P-692
API# 0911320090000

COMPANY	BELCO PETROLEUM CORPORATION
WELL	NO. 1 W. S. MITCHELL
FIELD	WILDCAT
COUNTY	SANTA ROSA STATE FLORIDA
LOCATION:	734' FSL & 959' FEL
SEC	23 TWP 2 N RGE 28 W

Other Services: CDL-C-GR, BHC-C-GR, CN log

Permanent Datum G.L. Elev. 25.4
Log Measured from K.B. 23.5 Ft. Above Permanent Datum
Drilling Measured from K.B.

Elevations: KB 49.9, DF 48.9, GL 25.4

Date	9-18-73	11-23-73	
Run No.	ONE	TWO	
Depth–Driller	3867	16,967	
Depth–Logger	3057	16,960	
Bottom Logged Interval	3056	16,962	
Top Logged Interval	99	3857	
Casing–Driller	16" @ 1135	10 3/4 @ 3867	@
Casing–Logger	99	3857	
Bit Size	15"	9 7/8 TO 16,137, 8 3/4 TO T.D.	
Type Fluid in Hole	GEL-CAUCT.	CHEM-GEL	
Density and Viscosity	8.9 40	10.2 50	
pH and Fluid Loss	9.0 27.2cc	11.0 11.3cc	cc
Source of Sample	TANK	TANK	
Rm @ Meas. Temp.	2.57 @ 97 °F	0.85 @ 75 °F	@ °F
Rmf @ Meas. Temp.	3.0 @ 97 °F	0.58 @ 75 °F	@ °F
Rmc @ Meas. Temp.	2.1 @ 97 °F	0.97 @ 75 °F	@ °F
Source of Rmf and Rmc	C C	M M	
Rm @ BHT	2.7 @ 114 °F	0.28 @ 266 °F	@ °F
Time Since Circ.	6 HRS.	18 HRS.	
Max. Rec. Temp. Deg. F.	114 °F	266 °F	°F
Equip. No. and Location	HL-6006 LAUREL	HL-6088 LAUREL	
Recorded By	POLAK	TENNANT	
Witnessed By	SEE REMARKS		

FOLD HERE

REMARKS WITNESSES RUN 1 - BENNETT, OWINGS
WITNESSES RUN 2 - BENNETT, MILTON
MARCHETTI, KENDRICK.

Equipment Used

Run No.	ONE	TWO
S.O.	41532	41726
Tool No.	138	825
Elec. No.	138	825
Panel No.	24387	24187
C.S.	120	100

Changes in Mud Type or Additional Samples

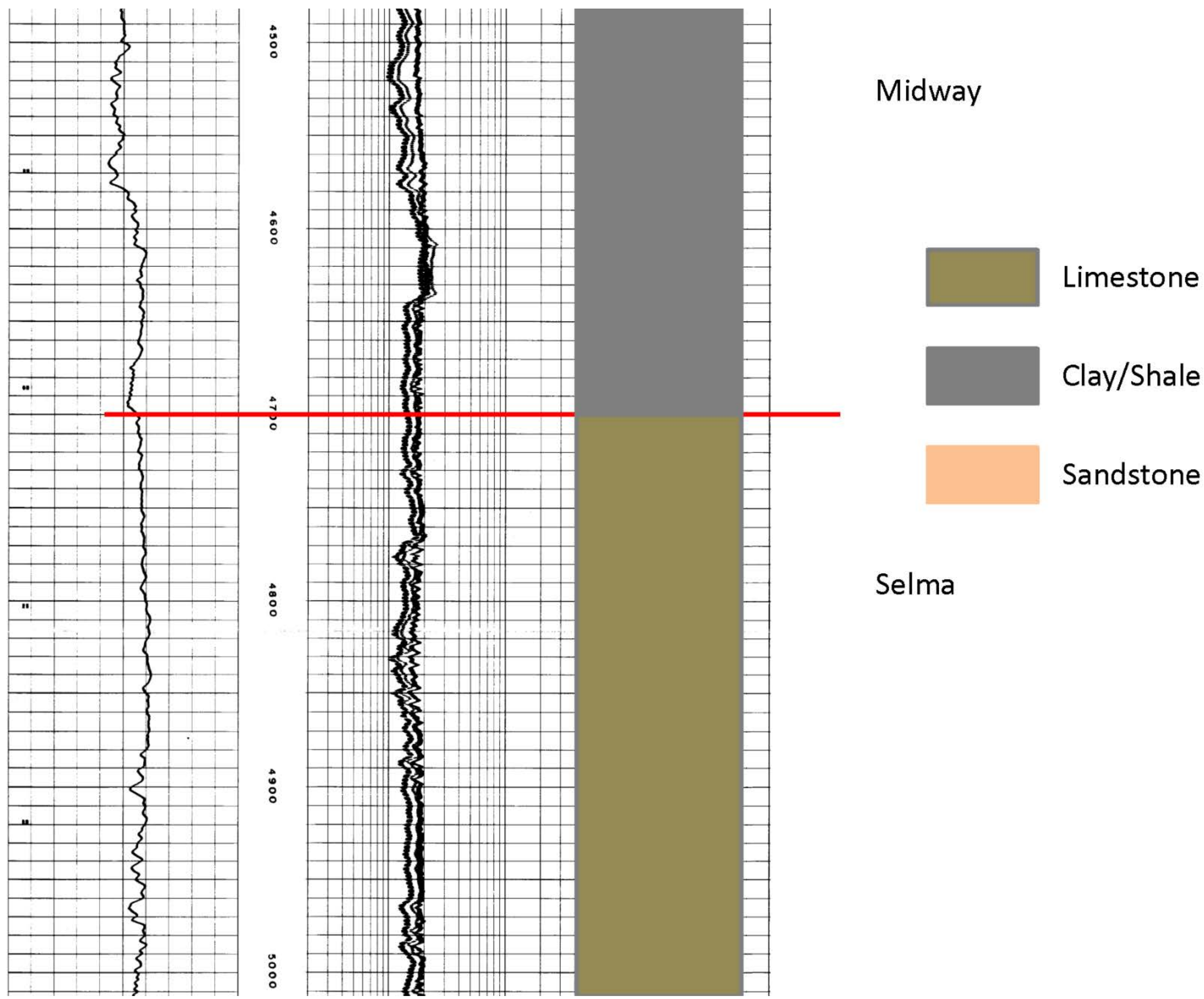
Date / Sample No.		
Depth-Driller		
Type Fluid in Hole		
Dens. / Visc.		
pH / Fluid Loss	cc	cc
Source of Sample		
Rm @ Meas. Temp.	@ °F	@ °F
Rmf @ Meas. Temp.	@ °F	@ °F
Rmc @ Meas. Temp.	@ °F	@ °F
Source Rmf Rmc		
Rm @ BHT	@ °F	@ °F
Rmf @ BHT	@ °F	@ °F
Rmc @ BHT	@ °F	@ °F

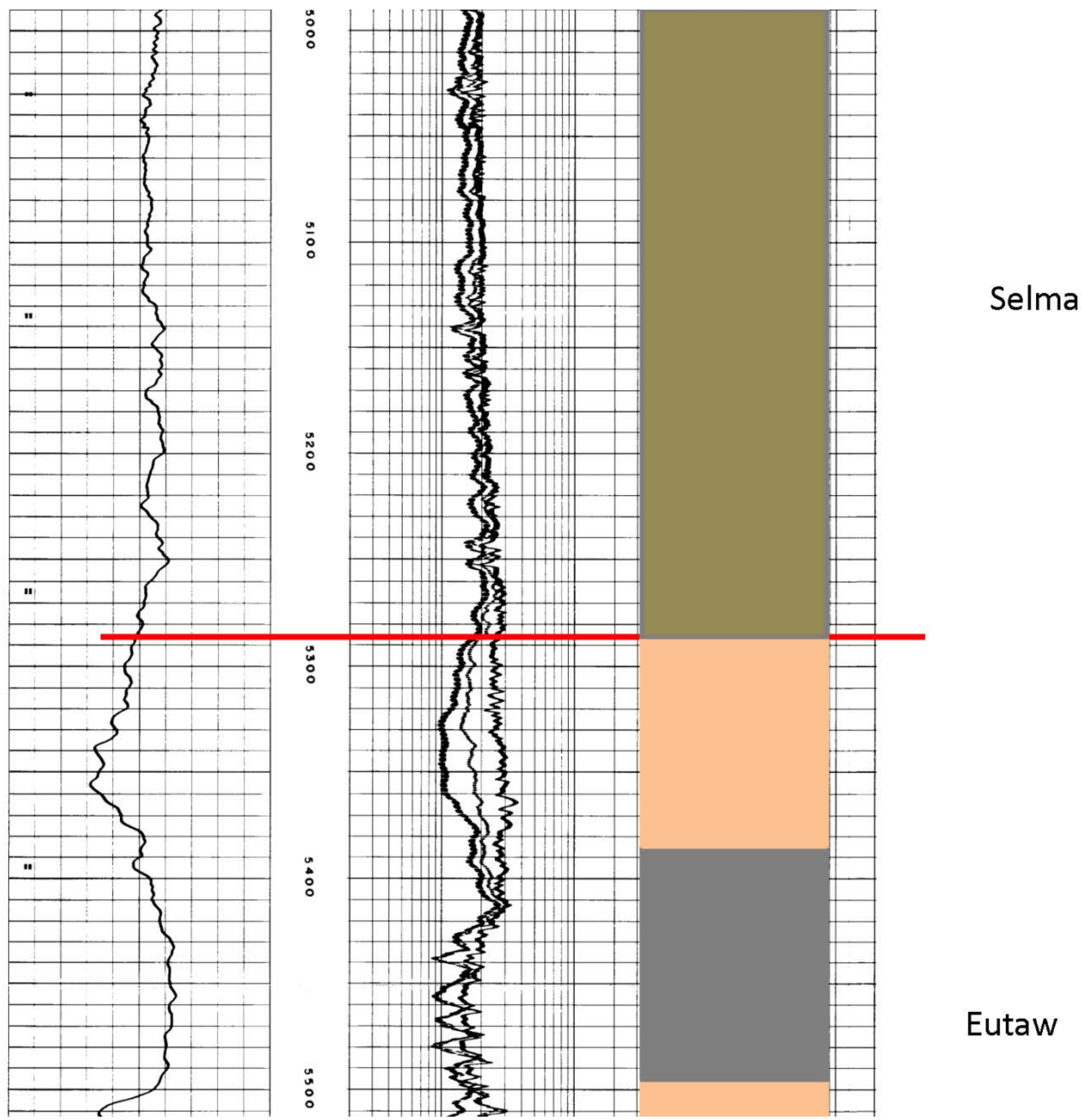
Scale Changes

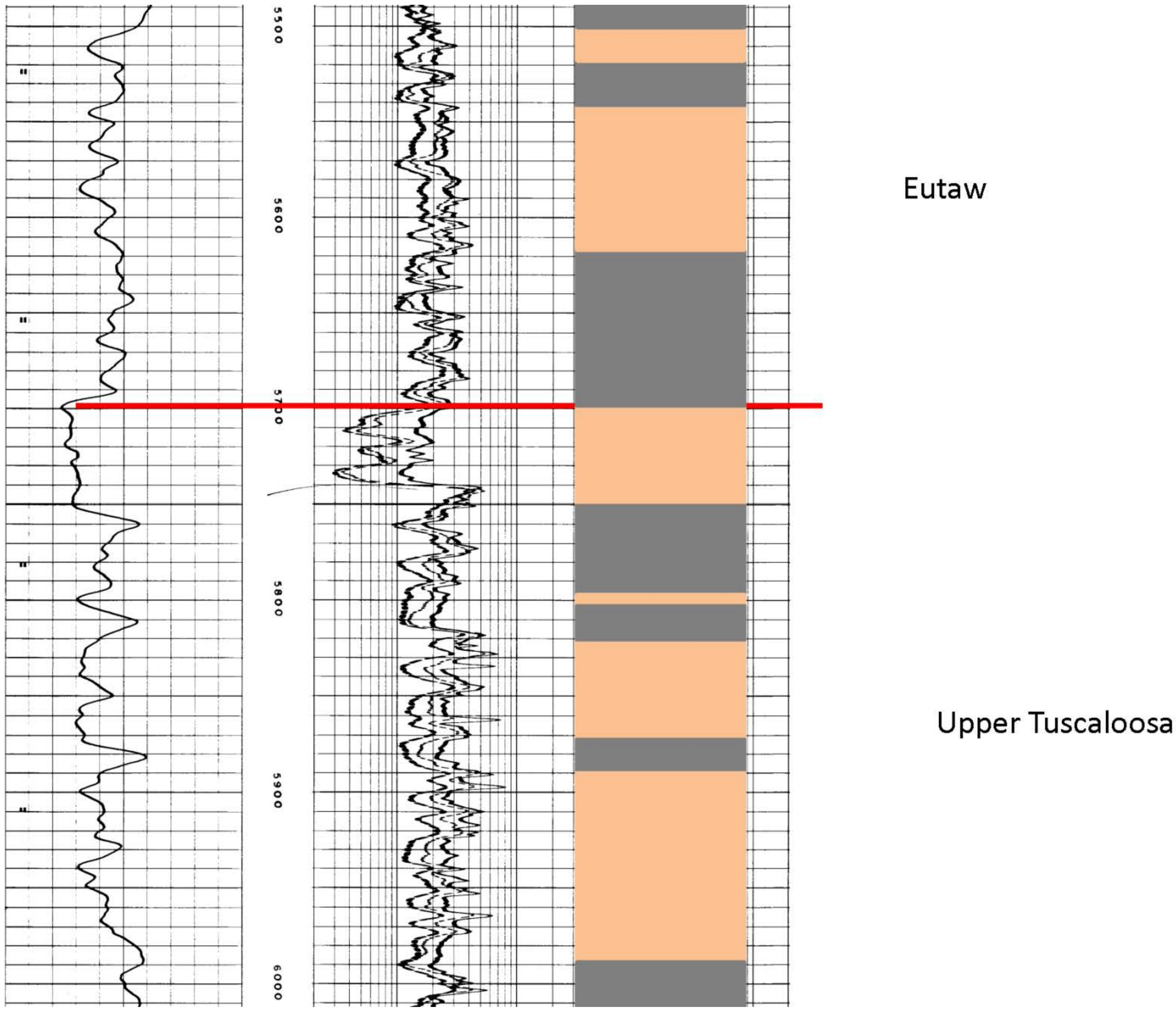
Type Log	Depth	Scale Up Hole	Scale Down Hole

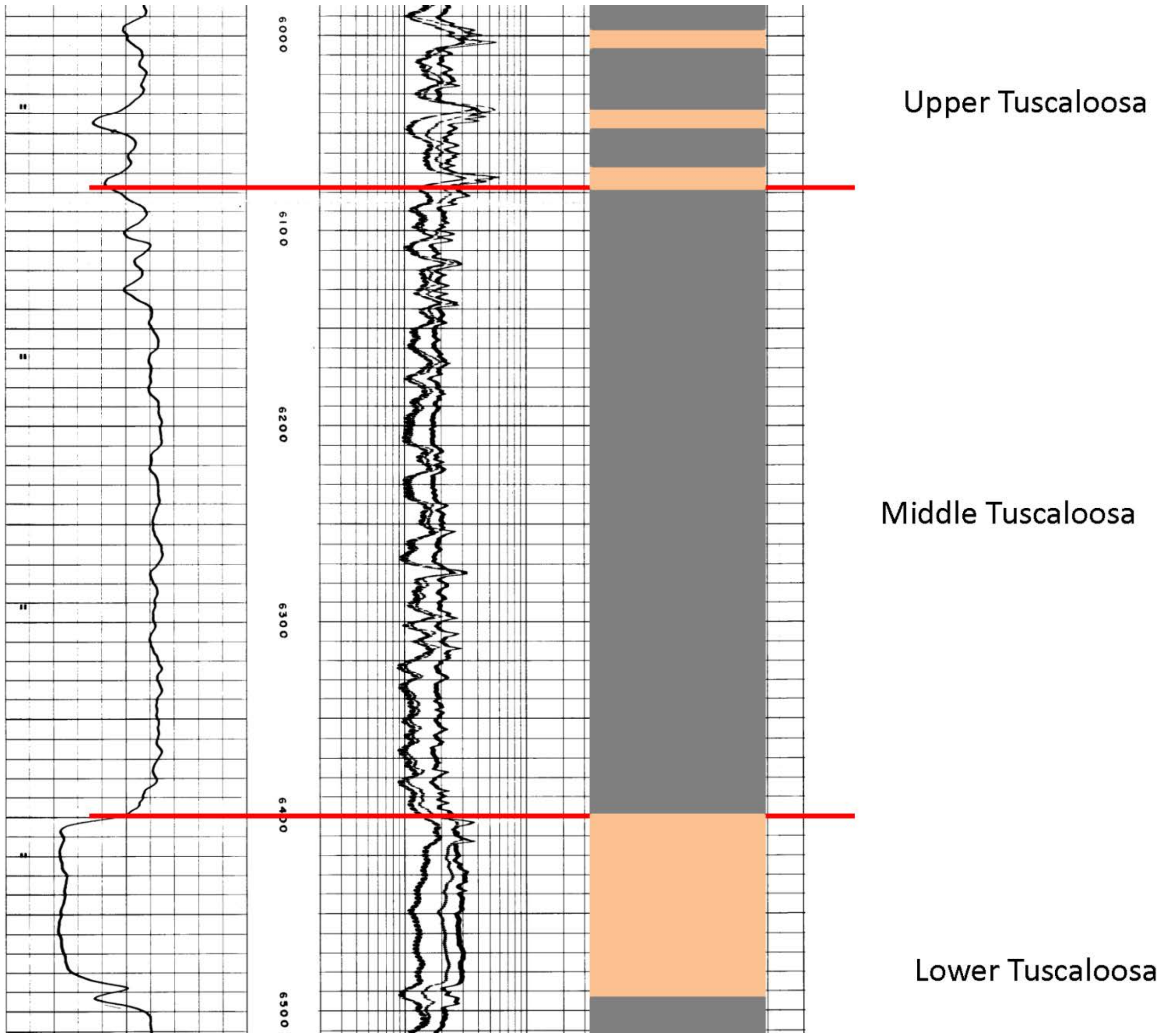
Equipment Data

Run No.	Tool Type	Pad Type	Tool Position	Other
ONE	1502 P		S.O. 1½"	
TWO	1502 P		S.O. 2"	


4500
4600
4700
4800
4900
5000
Midway
Limestone
Clay/Shale
Sandstone
Selma


5000
5100
5200
5300
5400
5500
Selma
Eutaw

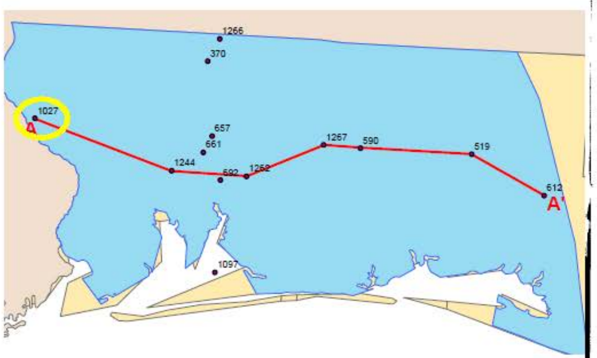

5500
5600
5700
5800
5900
6000
Eutaw
Upper Tuscaloosa

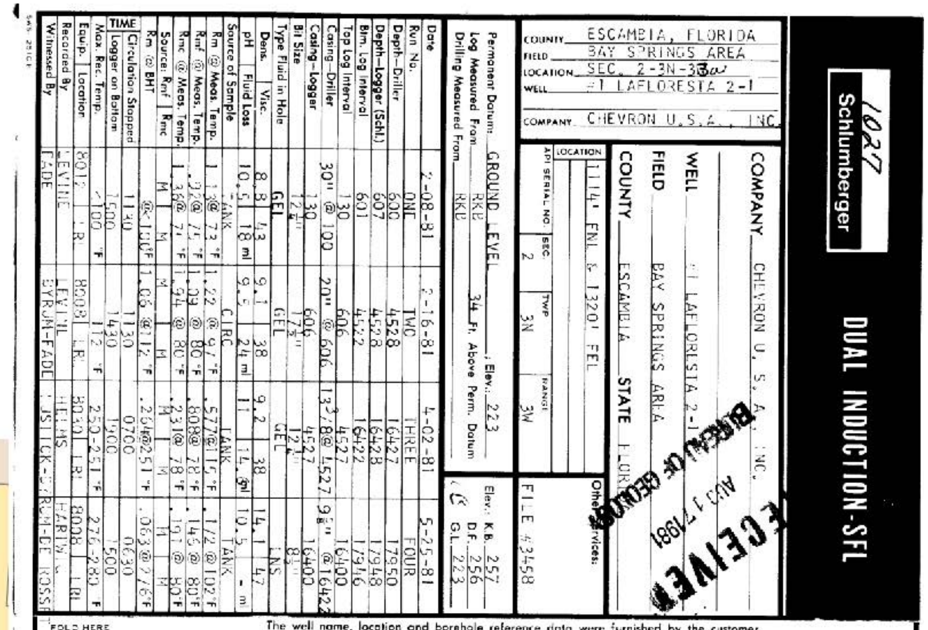

6000
6100
6200
6300
6400
6500
Upper Tuscaloosa
Middle Tuscaloosa
Lower Tuscaloosa

Lower Tuscaloosa

Lower Cretaceous

Disposal Area #1
P#1027
Standard Potential
Gamma
Resistivity





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The well name, location and borehole reference data were furnished by the customer.

Run No.	ONE	TWO	THREE	FOUR
Service Order No.	202726	202801	202748	154118
Fluid Level	FULL	FULL	FULL	FULL
Speed F.P.M.	200	60	30	30
Salinity ppm. cl	400	1700	2600	2500
EQUIPMENT DATA				
Panel	35	21	58	31
Cartridge	574	135	175	131
Sonde	589	143	595	143
Memorizer Panel	CSU	CSU	CSU	CSU
Centralizer Type	CSU	FIN	FIN	FIN
Stand-off - Inches	1½"	1½"	1½"	1½"
G.R. Panel	-	27	83	27
GR CART.			2617	
CALIBRATION DATA				
SBR	SEE	SEE	SEE	SEE
ILD Sonde Error	CALIB.	CALIB.	CALIB.	CALIB.
ILM Sonde Error	SUMMARY	SUMMARY	SUMMARY	SUMMARY
S.E. Set In Hole - Depth				
S.E. Corr. - Hole Size				
G.R. Background				
G.R. Source				
T.C. - Cal.				
LOGGING DATA				
SBR	SEE	SEE	SEE	SEE
ILD Sonde Error Log	CALIB.	CALIB.	CALIB.	CALIB.
ILM Sonde Error Log	SUMMARY	SUMMARY	SUMMARY	SUMMARY
G.R. Scale per 100 Div.				
G.R. - T.C. Log				

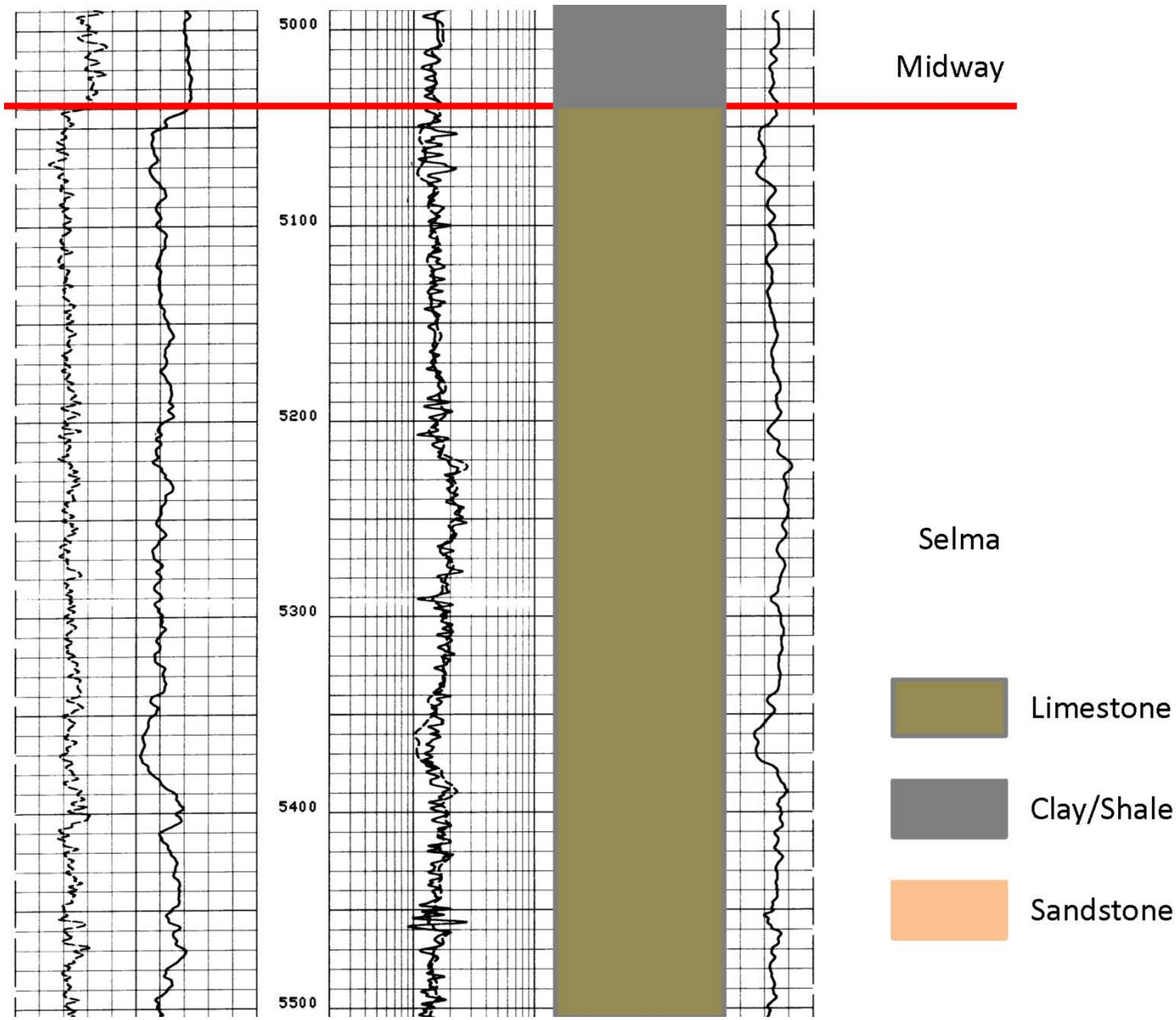
SCALE CHANGES

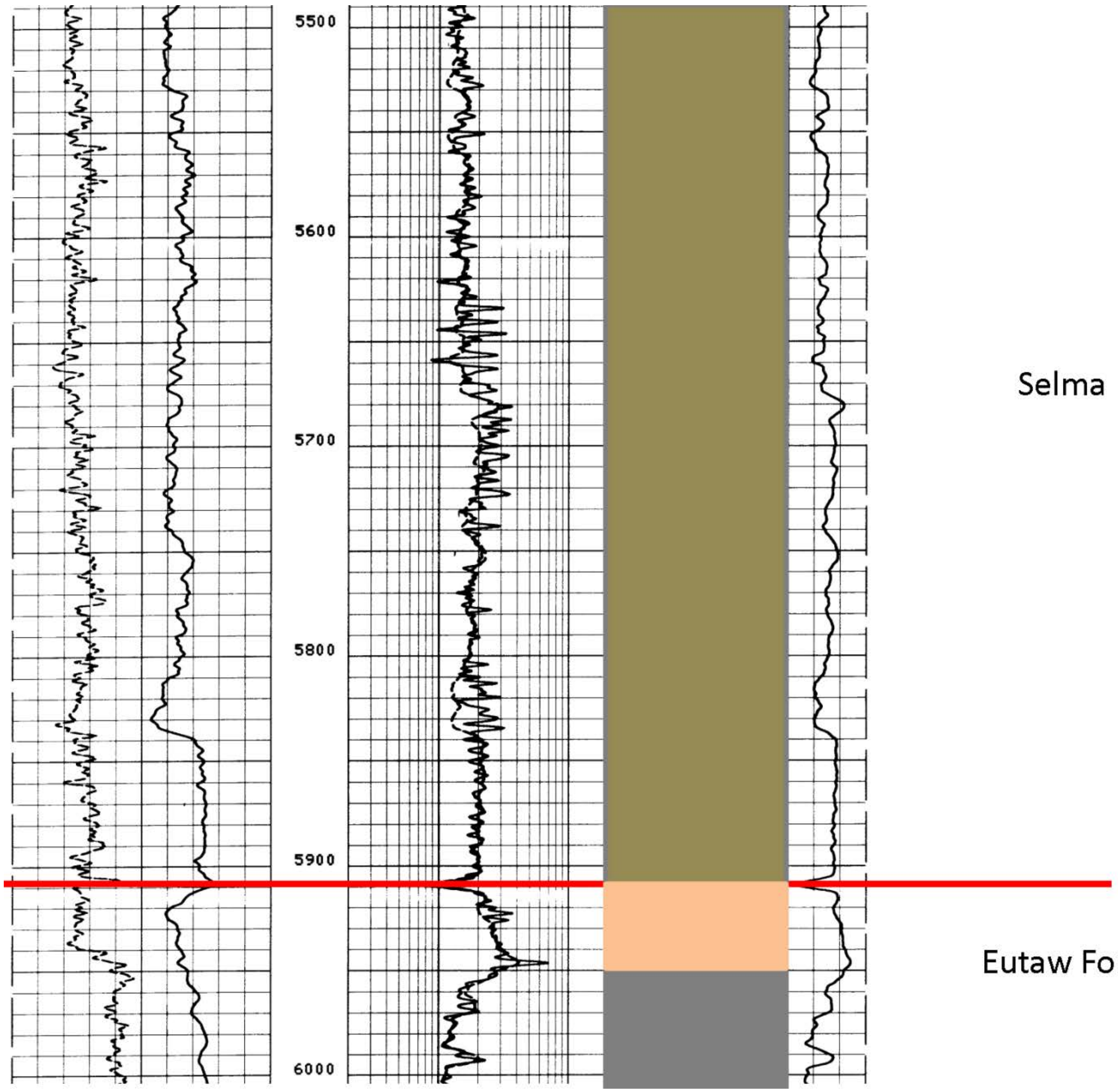
Type Log	DEPTH	Scale Up Hole	Scale Down Hole

REMARKS

RUN #3 SONIC PANEL - 352
SONIC CART. - 1221
SONIC SONDE - 1392

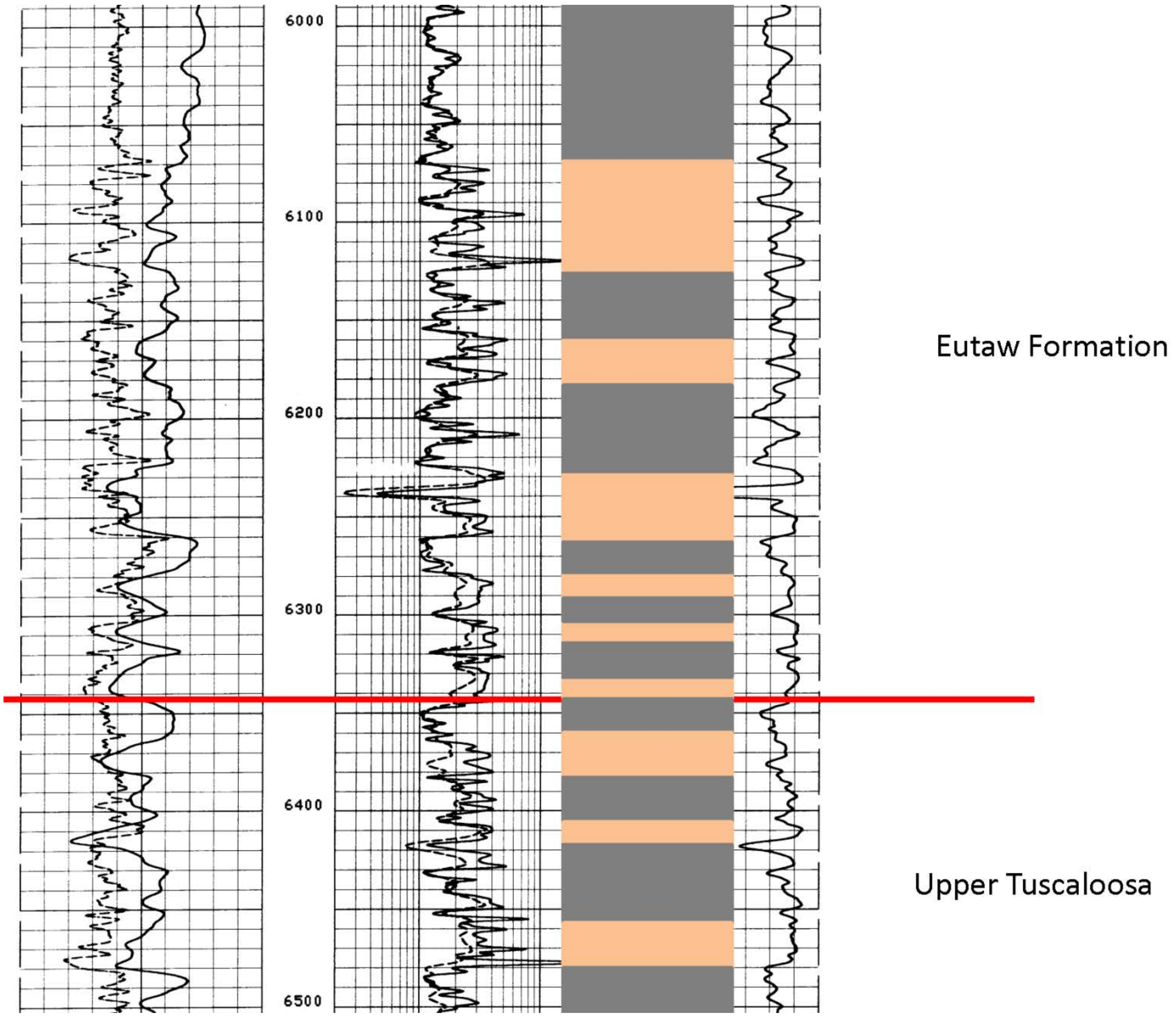
RUN #4 SONIC PANEL - 348
SONIC CART. - 363
SONIC SONDE - 69

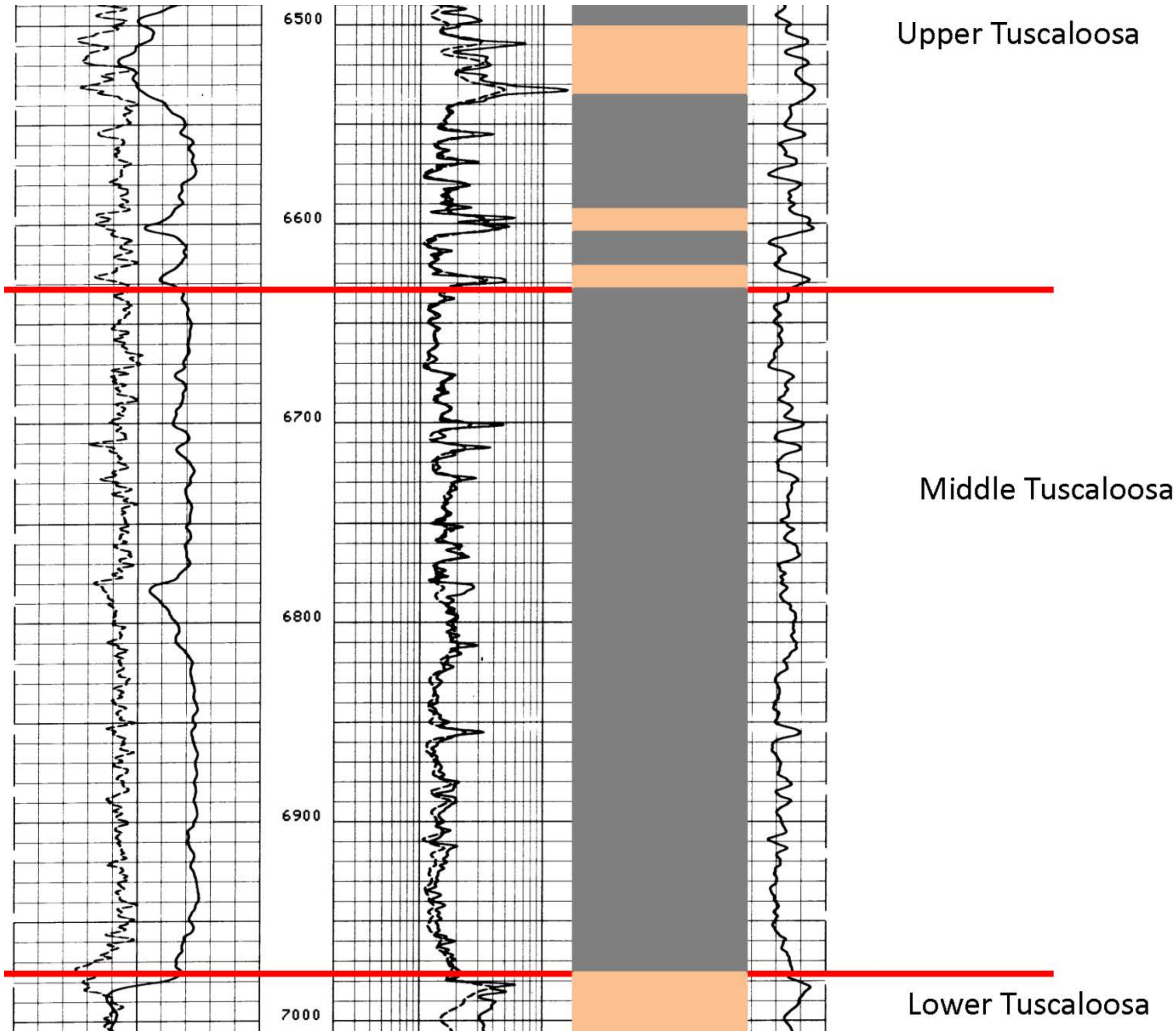

5000
5100
5200
5300
5400
5500
Midway
Selma
Limestone
Clay/Shale
Sandstone

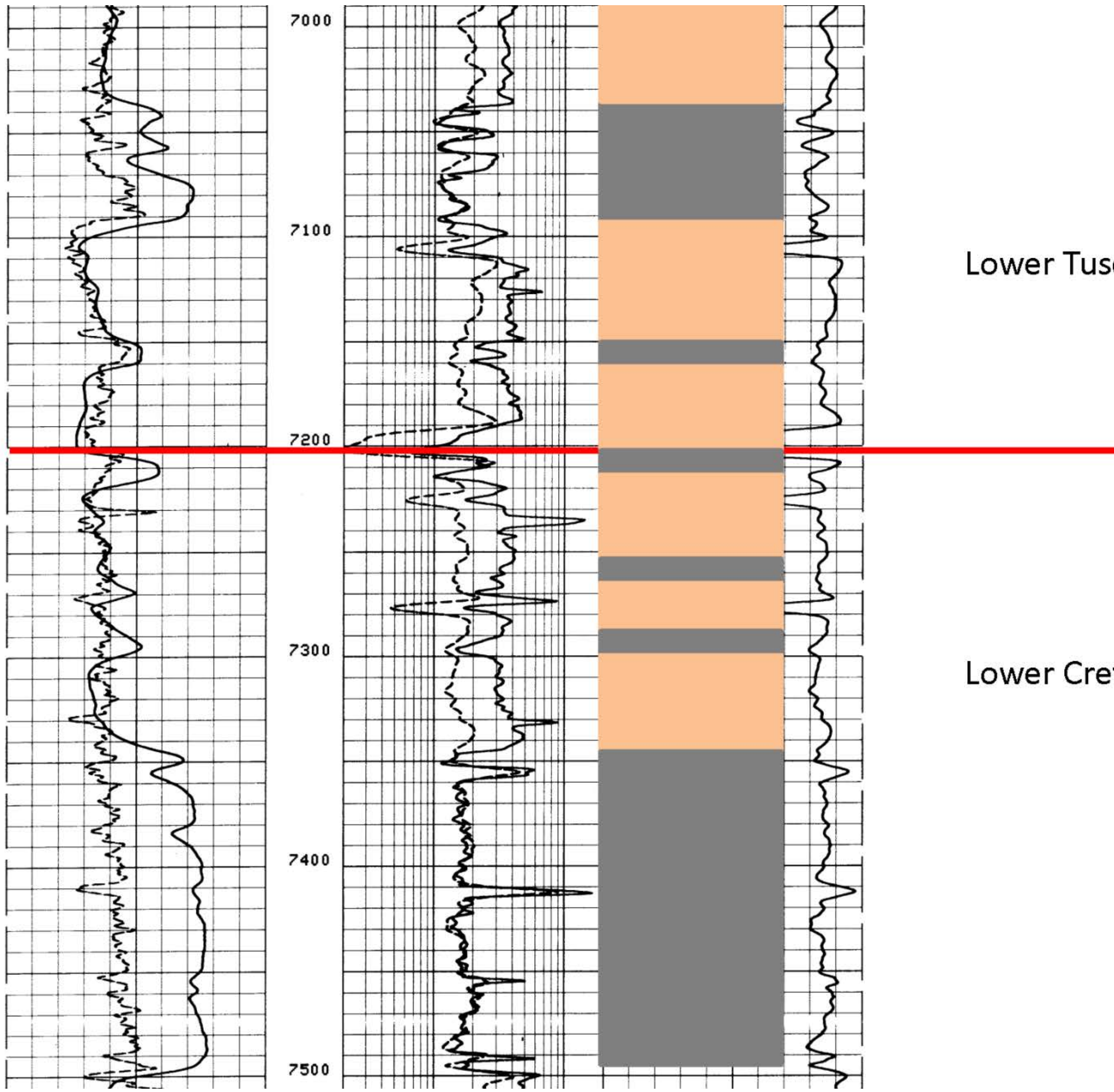


Selma

Eutaw Formation


6000
6100
6200
6300
6400
6500
Eutaw Formation
Upper Tuscaloosa

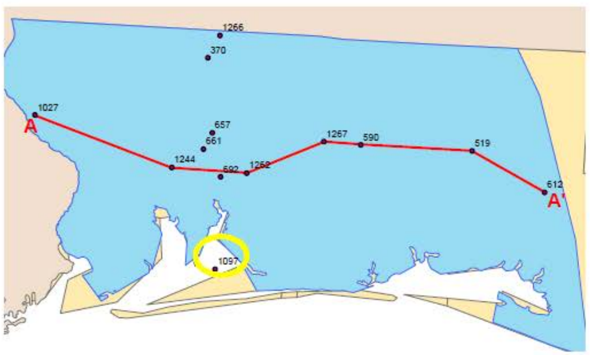

6500
6600
6700
6800
6900
7000
Upper Tuscaloosa
Middle Tuscaloosa
Lower Tuscaloosa

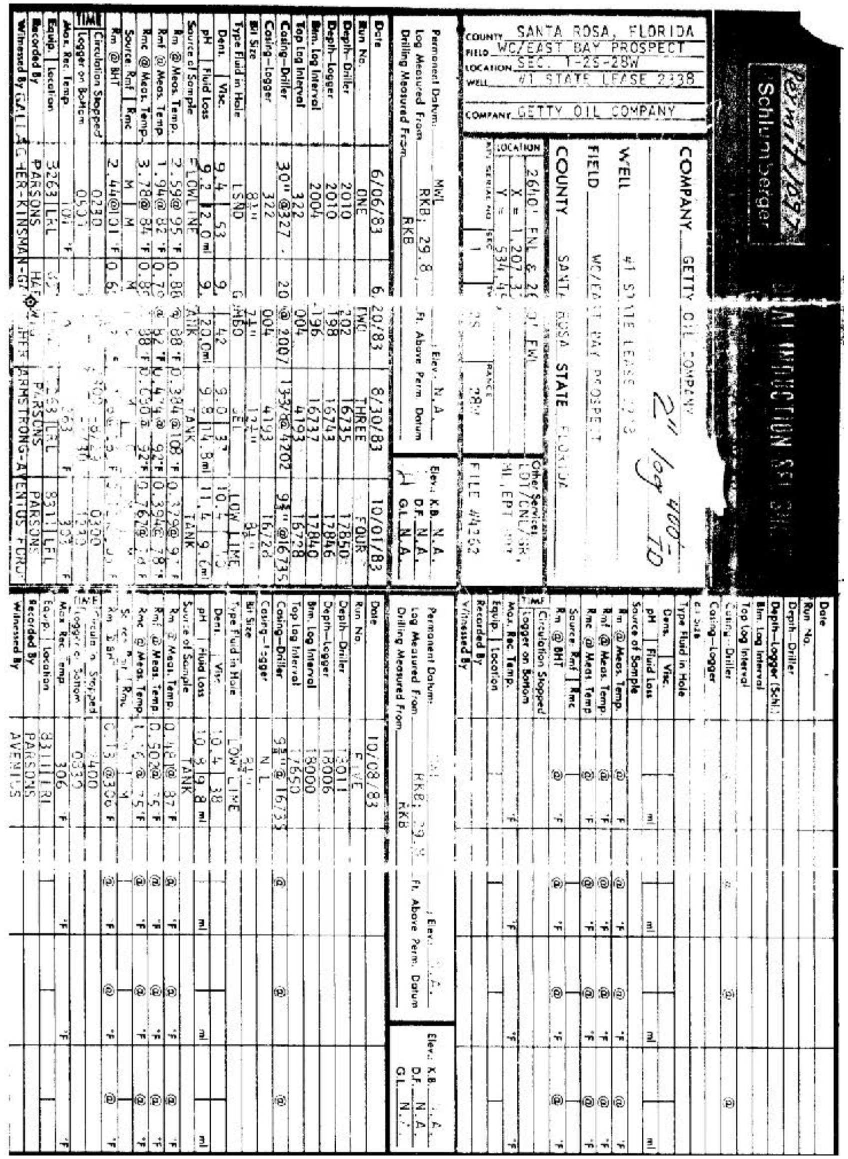


Lower Tuscaloosa

Lower Cretaceous

Disposal Area #1
P#1097
Standard Potential
Gamma
Resistivity





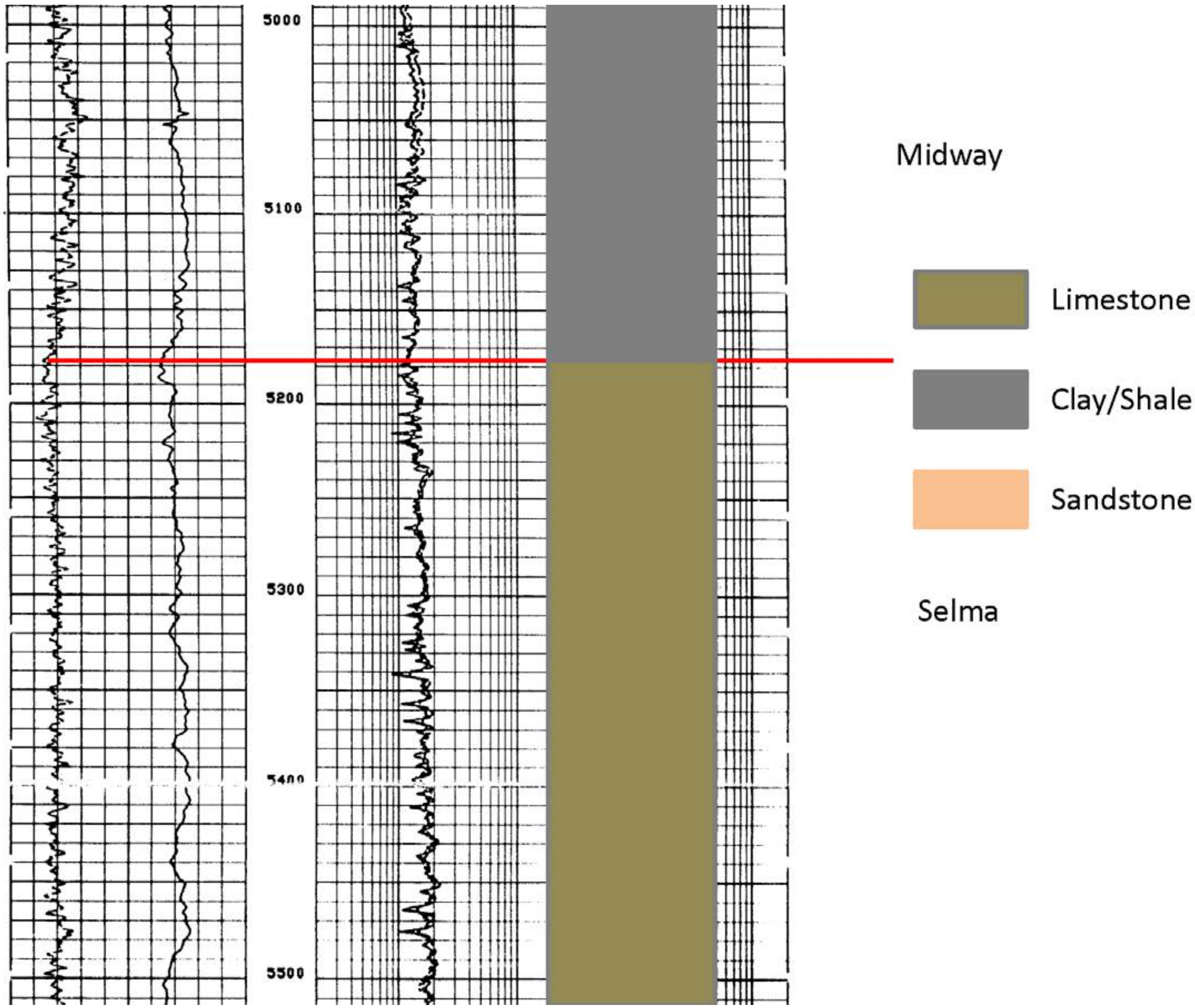
P#1097
Schlumberger
DUAL INDUCTION SFL
2" log 400'-TD

COUNTY SANTA ROSA, FLORIDA
FIELD WC/EAST BAY PROSPECT
LOCATION SEC. 1-2S-28W
WELL #1 STATE LEASE 2338
COMPANY GETTY OIL COMPANY

COMPANY GETTY OIL COMPANY
WELL #1 STATE LEASE 2338
FIELD WC/EAST BAY PROSPECT
COUNTY SANTA ROSA STATE FLORIDA
LOCATION 2610' FNL & 2[illegible]' FWL
SEC. 1 TWP. 2S RGE. 28W
FILE #4352

Permanent Datum: MWL ; Elev.: N.A.
Log Measured From RKB; 29.8 Ft. Above Perm. Datum
Drilling Measured From RKB
Elev.: K.B. N.A. D.F. N.A. G.L. N.A.

Date	6/06/83	6/20/83	8/30/83	10/01/83	10/08/83
Run No.	ONE	TWO	THREE	FOUR	FIVE
Depth–Driller	2010	[illegible]202	16735	17850	18011
Depth–Logger	2010	[illegible]198	16743	17846	18006
Btm. Log Interval	2004	[illegible]196	16737	17840	18000
Top Log Interval	322	[illegible]004	4193	16728	16750
Casing–Driller	30" @327	20 @2007	13 3/8 @4202	9 5/8" @16735	9 5/8" @16733
Casing–Logger	322	[illegible]004	4193	16726	N.L.
Bit Size	8 1/2"	[illegible]	12 1/4"	8 1/2"	8 1/2"
Type Fluid in Hole	LSND	GUMBO	GEL	LOW LIME	LOW LIME
Dens. / Visc.	9.4 / 53	9. / 42	9.0 / 37	10.4 / [illegible]	10.4 / 38
pH / Fluid Loss	9.2 / 12.0 ml	9. / 20.0 ml	9.8 / 14.8 ml	11.4 / 9.6 ml	10.8 / 9.8 ml
Source of Sample	FLOWLINE	TANK	TANK	TANK	TANK
Rm @ Meas. Temp.	2.59 @ 95 °F	0.88 @ 88 °F	0.384 @ 108 °F	0.379 @ 9[illegible] °F	0.181 @ 87 °F
Rmf @ Meas. Temp.	1.94 @ 82 °F	0.70 @ 82 °F	0.4[illegible] @ 92 °F	0.394 @ 78 °F	0.502 @ 75 °F
Rmc @ Meas. Temp.	3.78 @ 84 °F	0.8[illegible] @ 88 °F	0.630 @ 92 °F	0.767 @ [illegible] °F	[illegible] @ 75 °F
Source: Rmf / Rmc	M / M	M / [illegible]	[illegible]	[illegible]	[illegible]
Rm @ BHT	2.44 @ 101 °F	0.6[illegible]	[illegible]	[illegible]	0.13 @ 300 °F
Circulation Stopped	0230	[illegible]	[illegible]	0300	2400
Logger on Bottom	0501	[illegible]	[illegible]	[illegible]	0330
Max. Rec. Temp.	101 °F	[illegible]	263 °F	303 °F	306 °F
Equip. / Location	3263 / LKL	[illegible]	[illegible]63 / LKL	8311 / LFL	8311 / FRI
Recorded By	PARSONS	HAF[illegible]	PARSONS	PARSONS	PARSONS
Witnessed By	GALLAGHER-KINSMAN-G[illegible]	[illegible]HER	ARMSTRONG-A[illegible]	VENTOS-FORD	AVENTOS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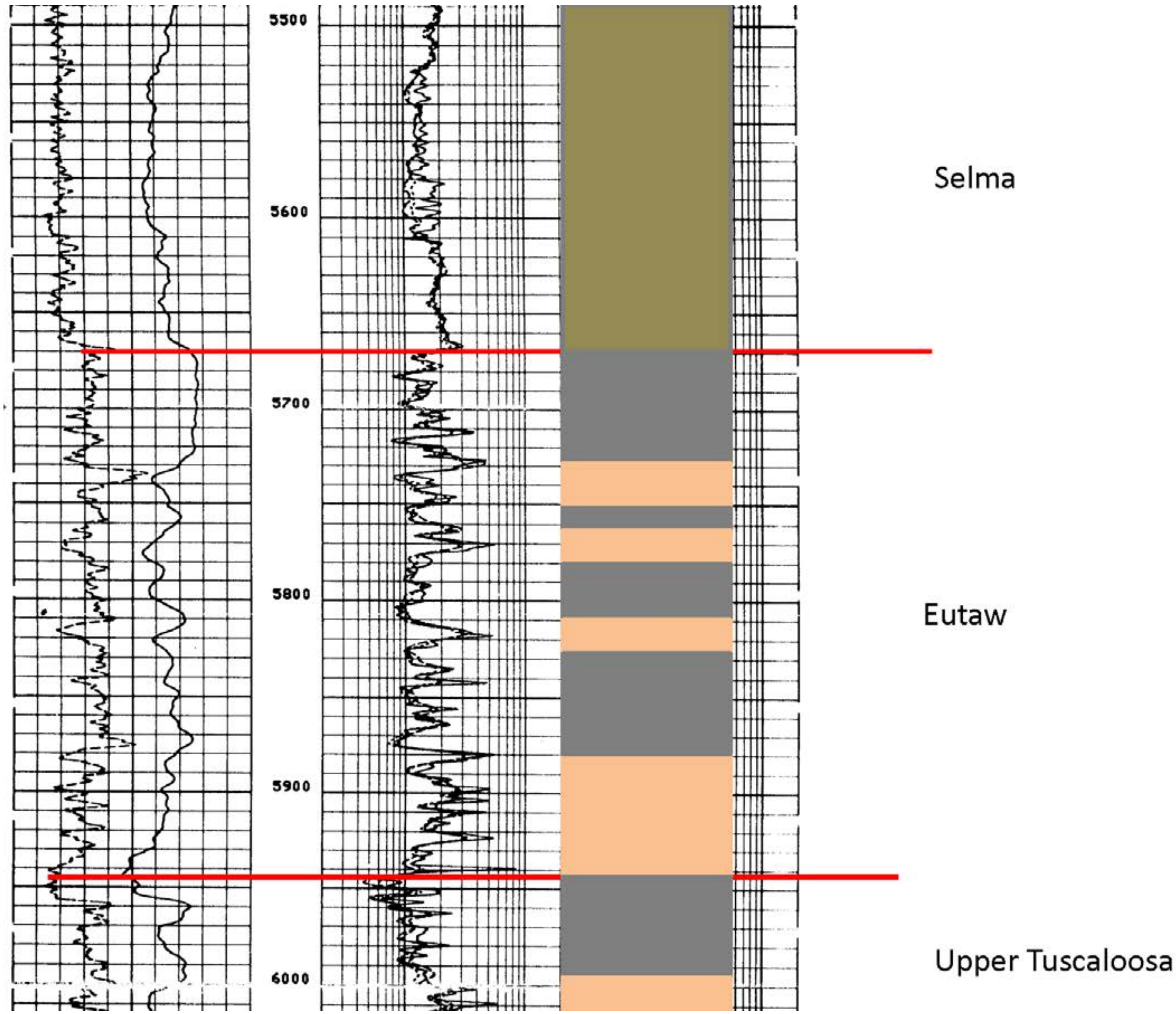
5200
5300
5400
5500
Midway
Limestone
Clay/Shale
Sandstone
Selma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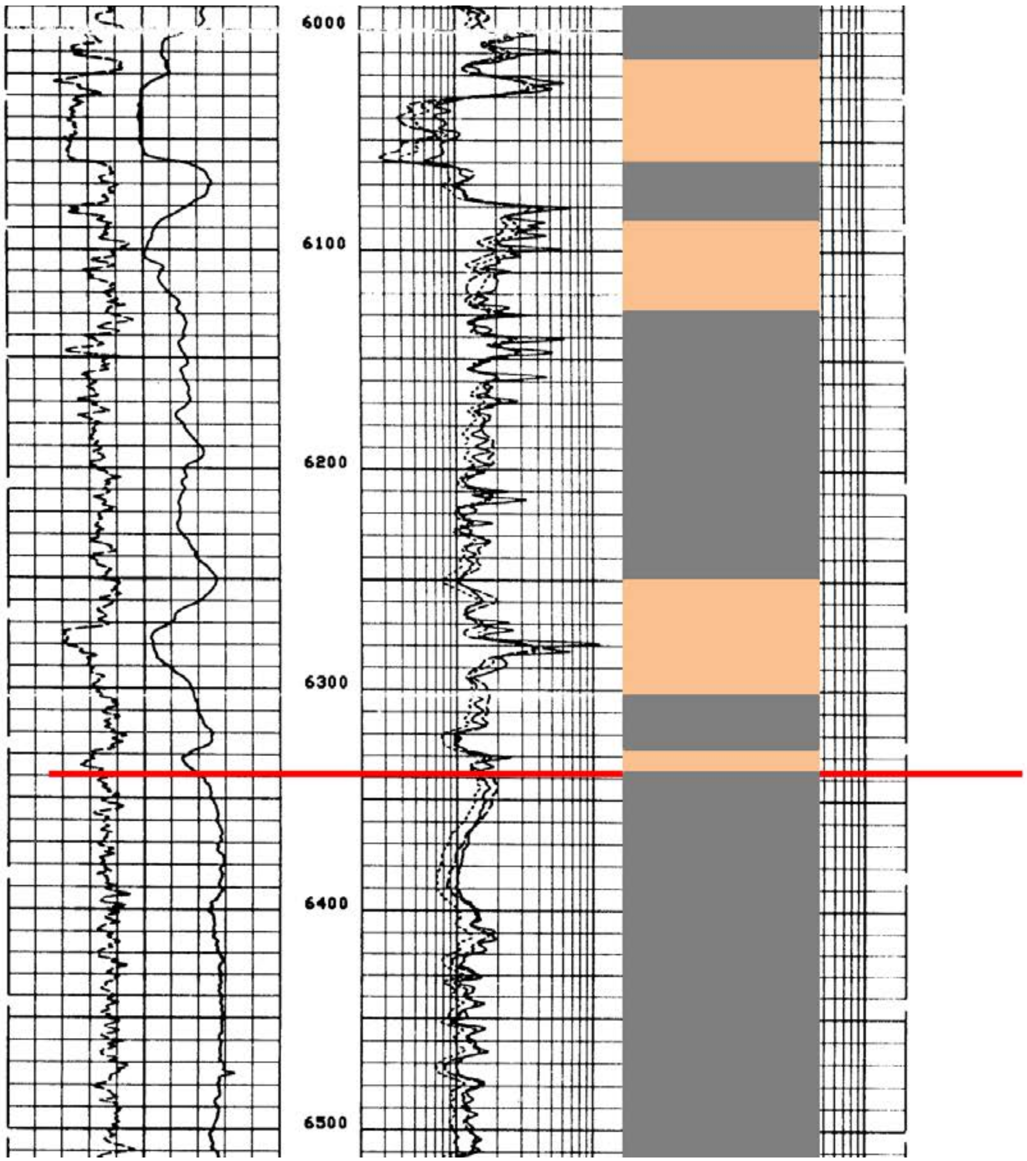
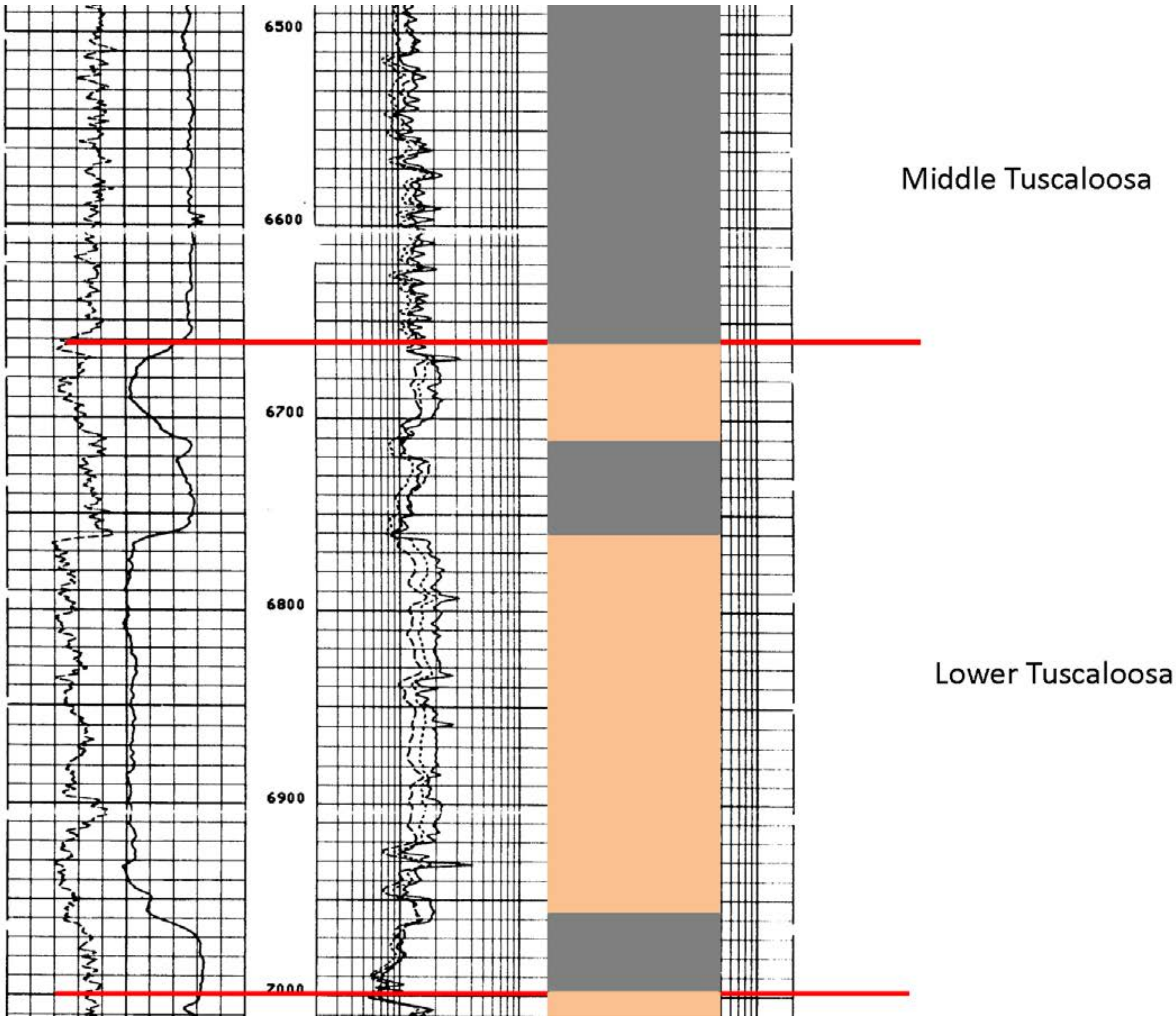
5700
5800
5900
6000
Selma
Eutaw
Upper Tuscaloosa

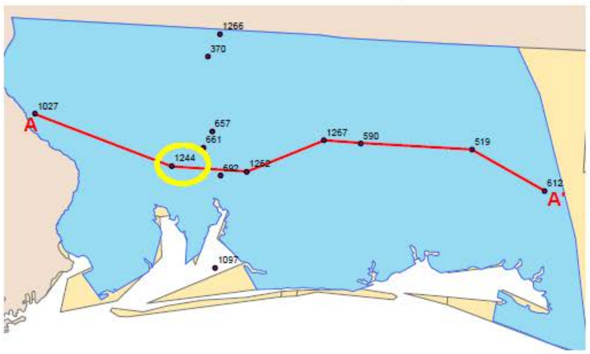


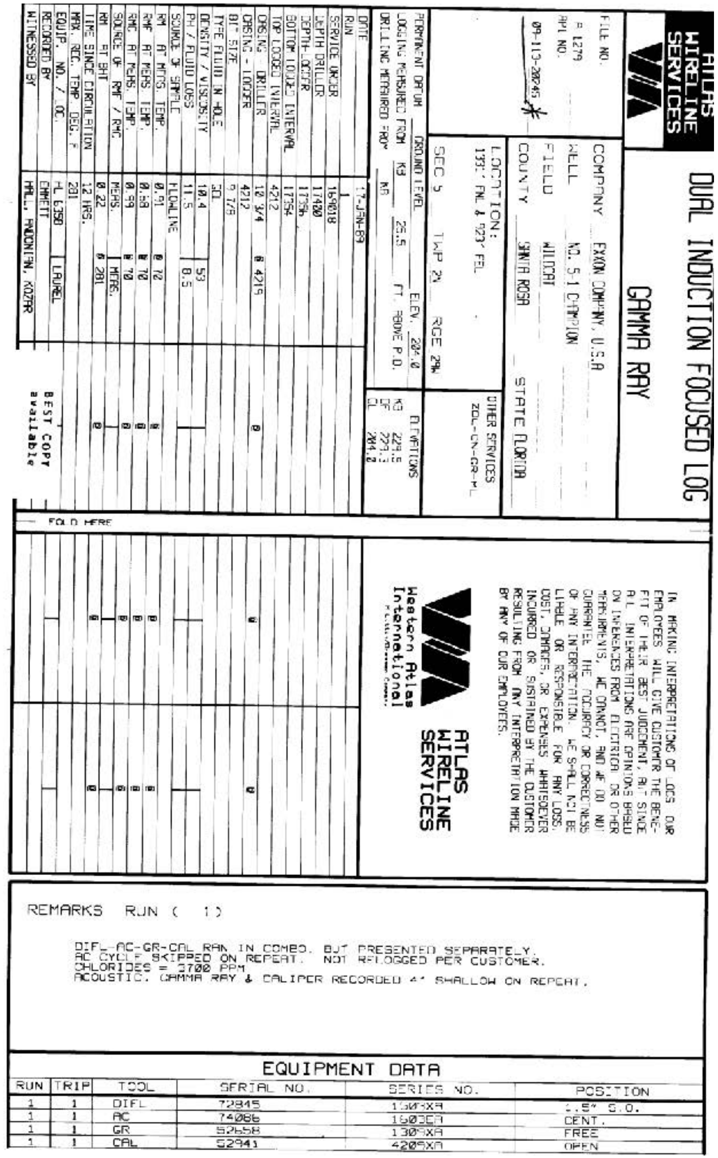
Upper Tuscaloosa

Middle Tuscaloosa


6500
6600
6700
6800
6900
7000
Middle Tuscaloosa
Lower Tuscaloosa

Disposal Area #1
P#1244
Gamma
Standard Potential
Resistivity




ATLAS WIRELINE SERVICES

DUAL INDUCTION FOCUSED LOG
GAMMA RAY

COMPANY EXXON COMPANY, U.S.A
WELL NO. 5-1 CHAMPION
FIELD WILDCAT
COUNTY SANTA ROSA STATE FLORIDA

BEST COPY available

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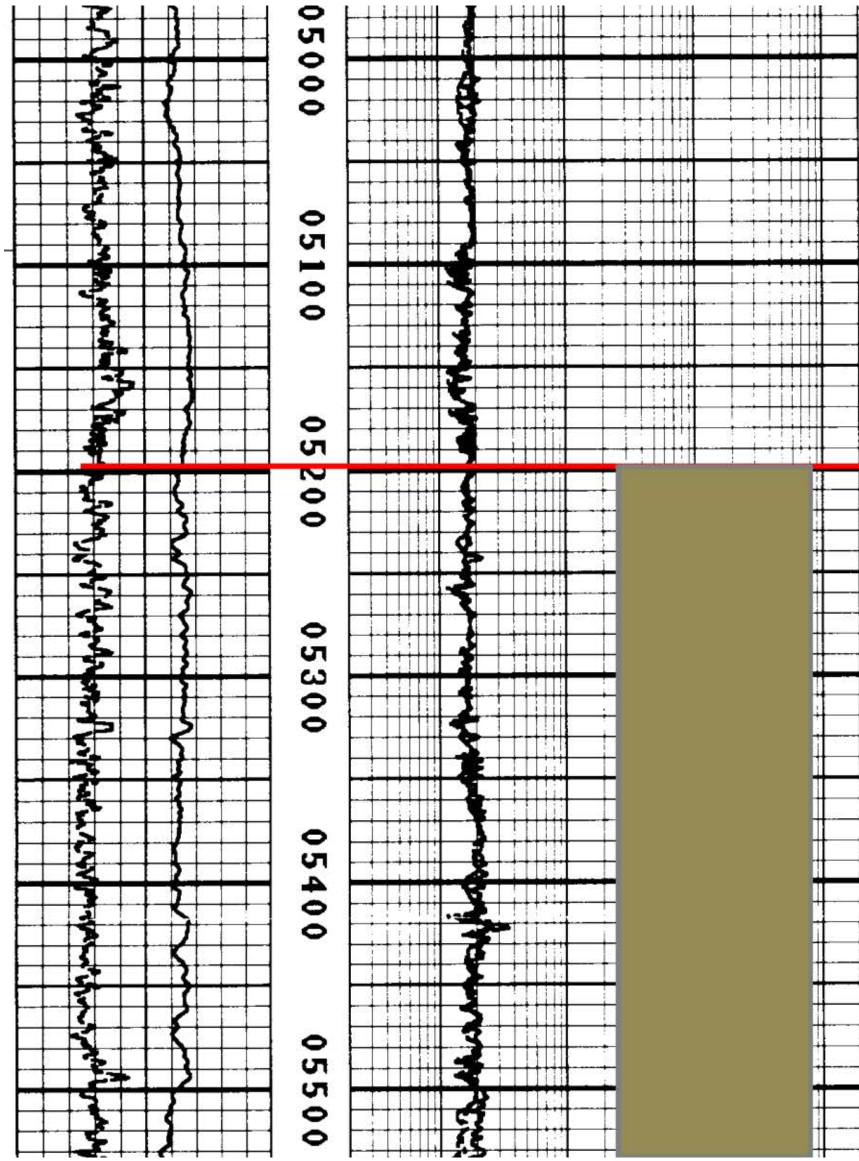
Western Atlas International
ATLAS WIRELINE SERVICES

REMARKS RUN (1)

DIFL-AC-GR-CAL RAN IN COMBO. BUT PRESENTED SEPARATELY.
AC CYCLE SKIPPED ON REPEAT. NOT RELOGGED PER CUSTOMER.
CHLORIDES = 3700 PPM
ACOUSTIC, GAMMA RAY & CALIPER RECORDED 4' SHALLOW ON REPEAT.

EQUIPMENT DATA

RUN	TRIP	TOOL	SERIAL NO.	SERIES NO.	POSITION
1	1	DIFL	72845	1500XA	1.5" S.O.
1	1	AC	74086	1603EA	CENT.
1	1	GR	52658	1309XA	FREE
1	1	CAL	52941	4209XA	OPEN



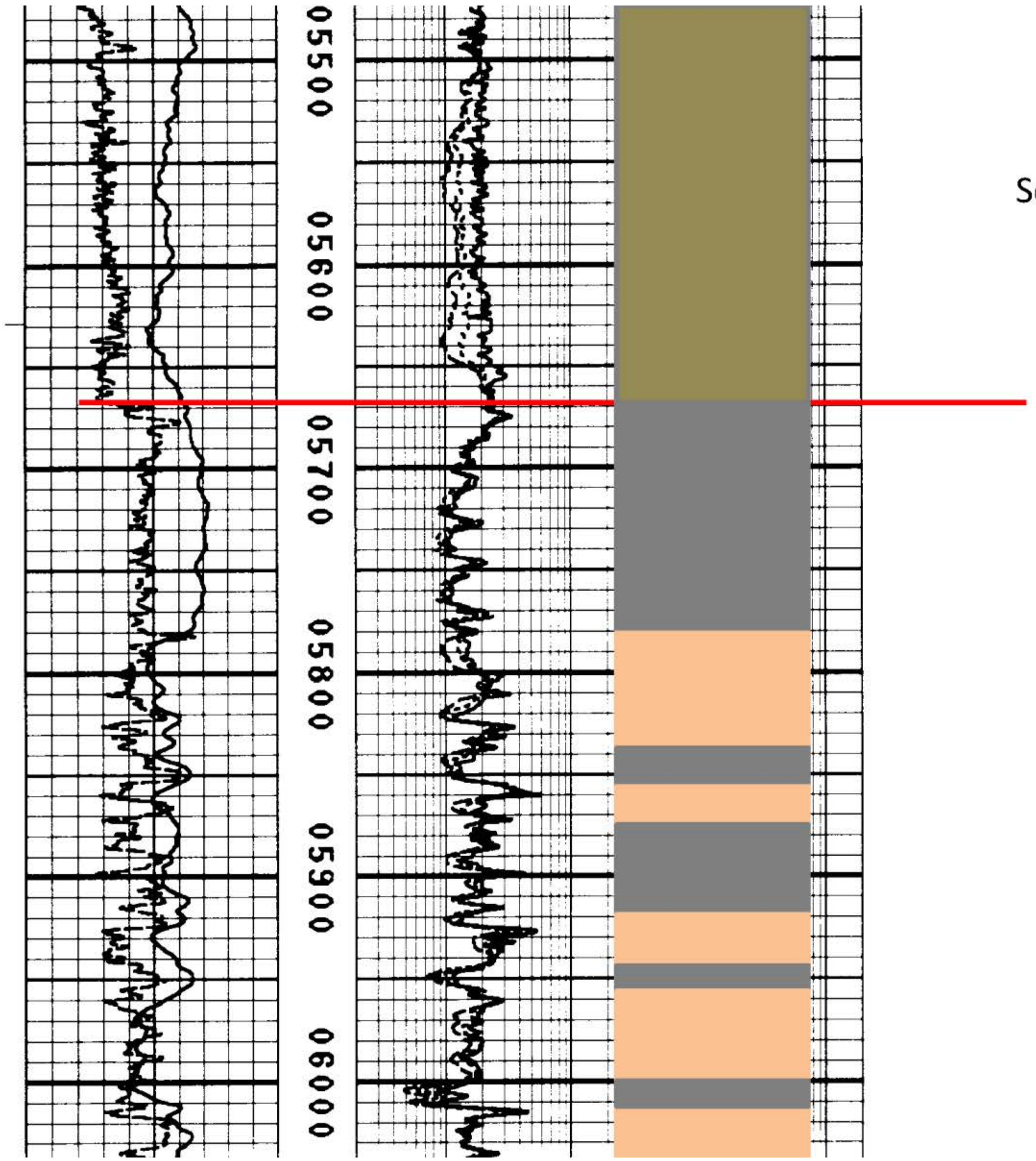
Midway

Limestone

Clay/Shale

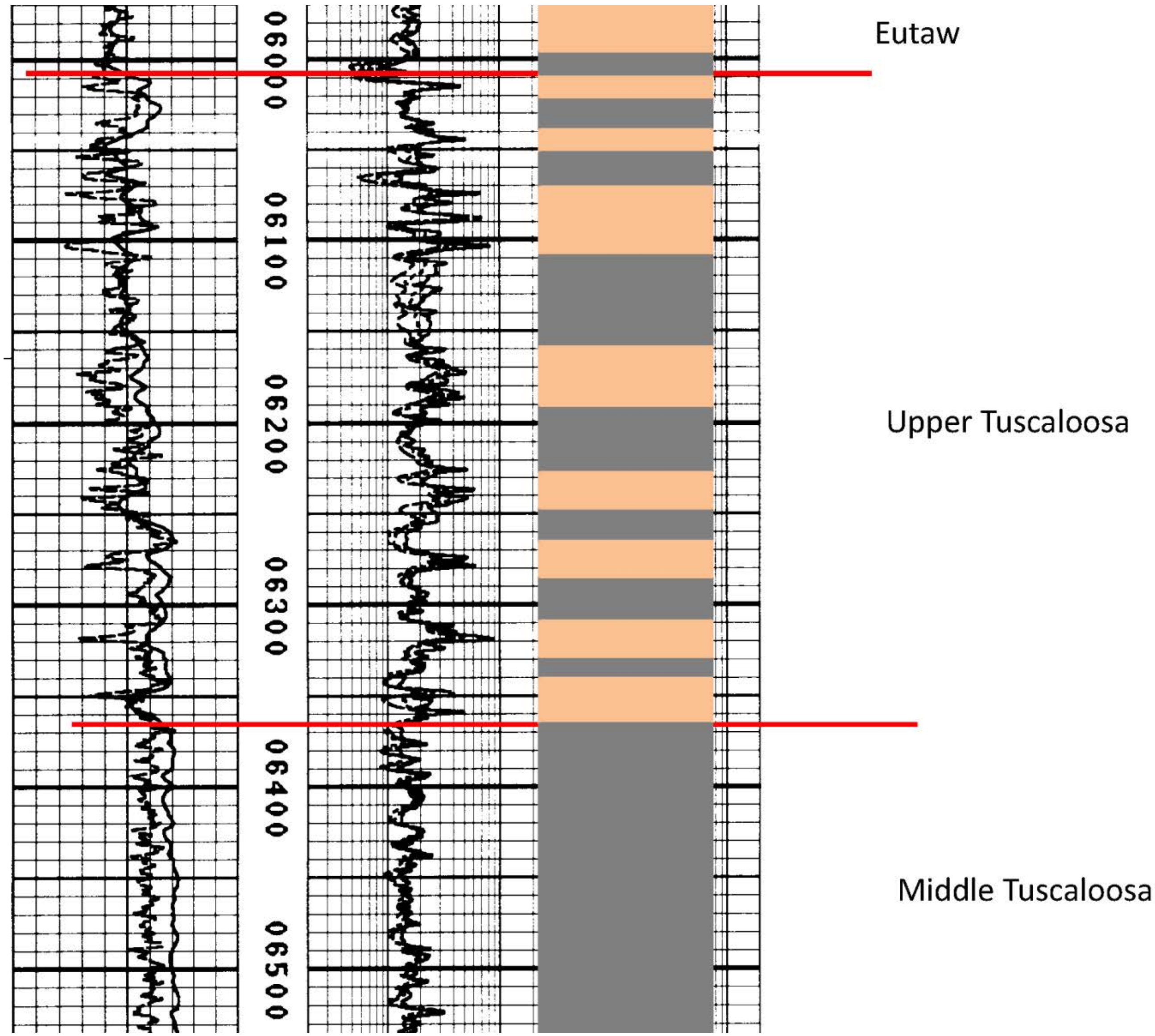
Sandstone

Selma

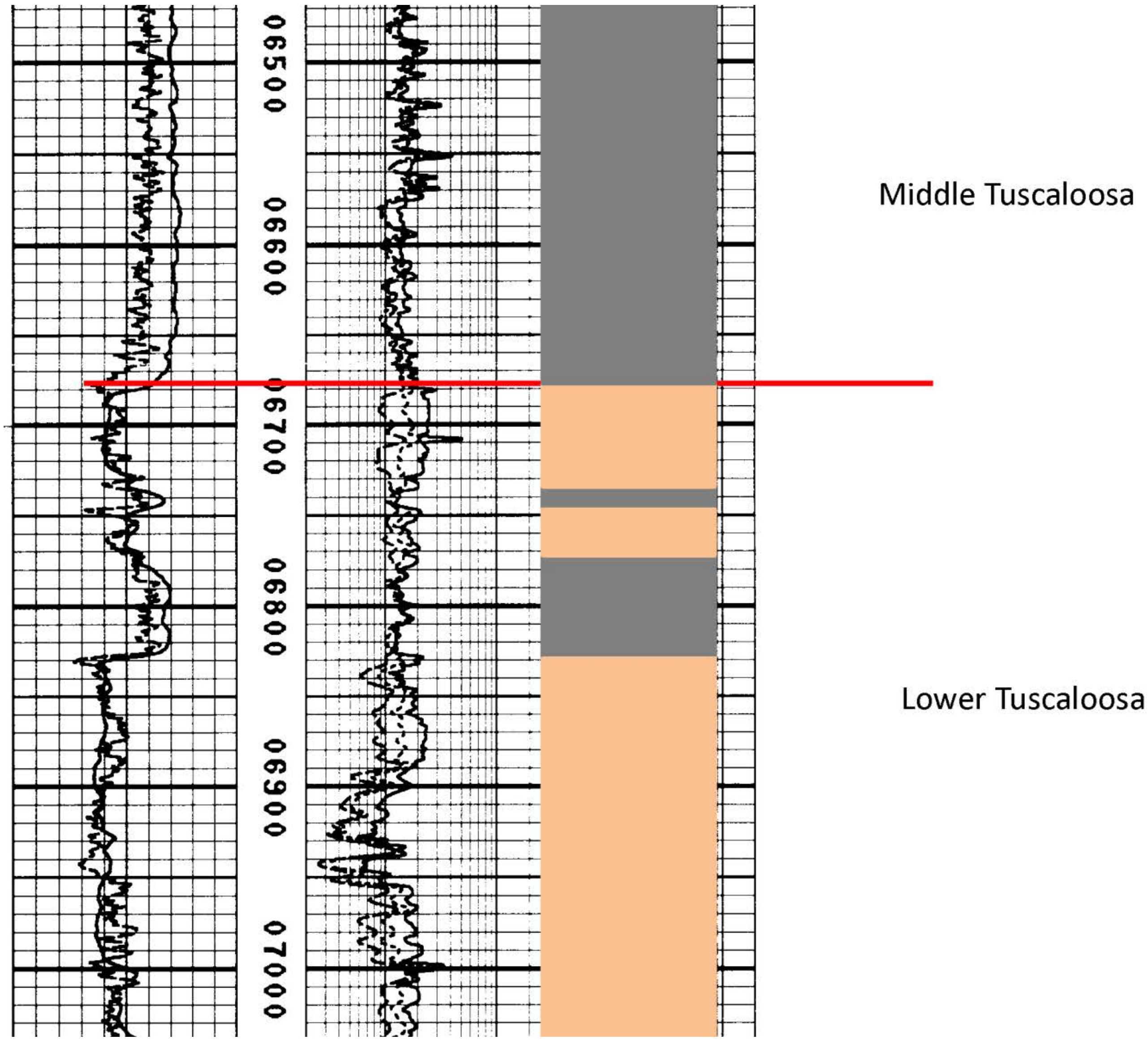


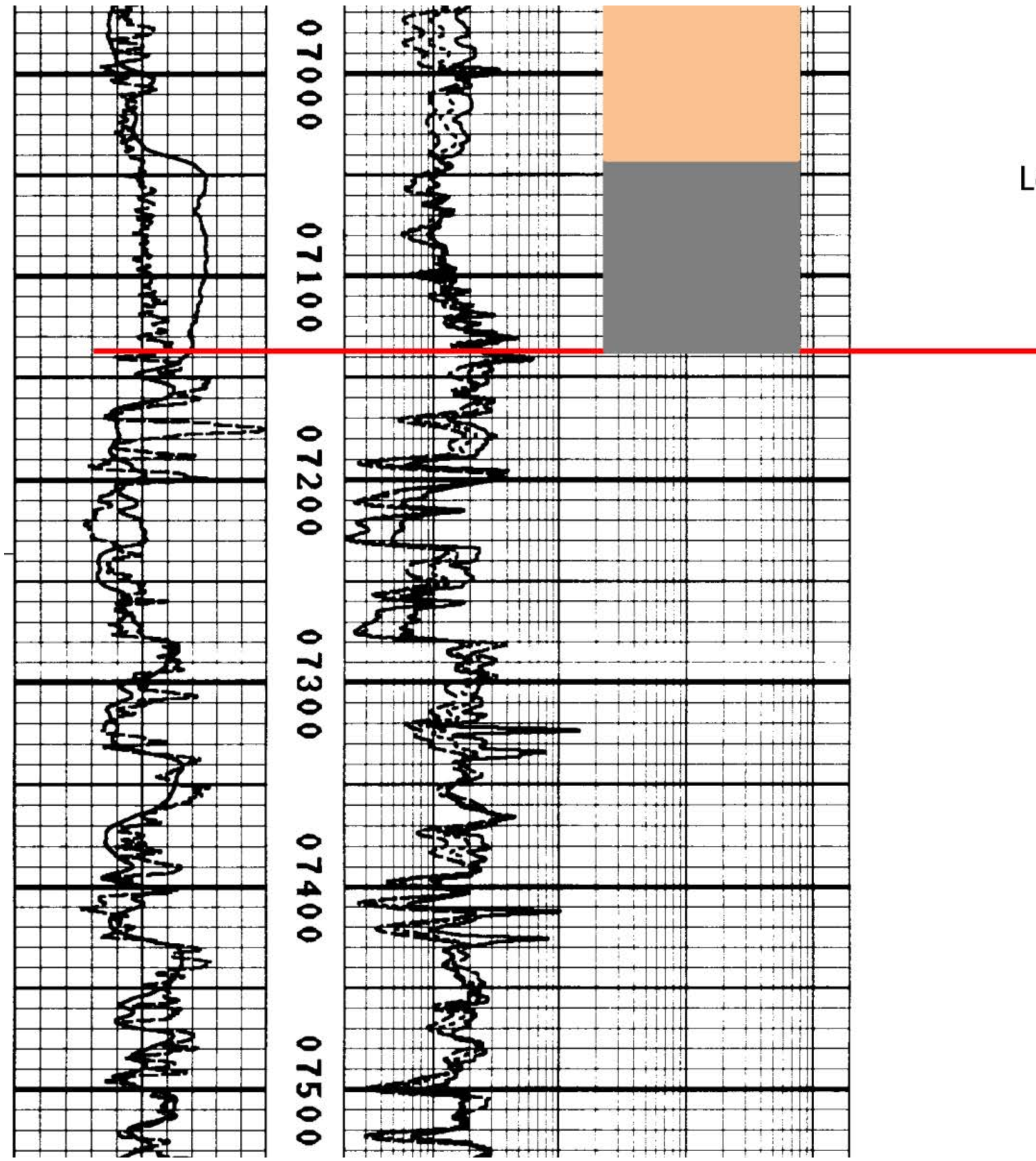
Selma

Eutaw



Eutaw
06000
06100
Upper Tuscaloosa
06200
06300
06400
Middle Tuscaloosa
06500

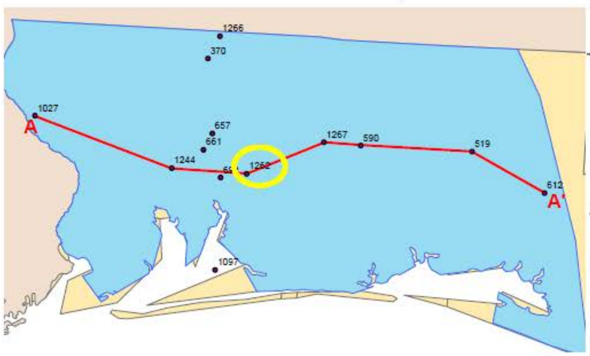

Middle Tuscaloosa
Lower Tuscaloosa

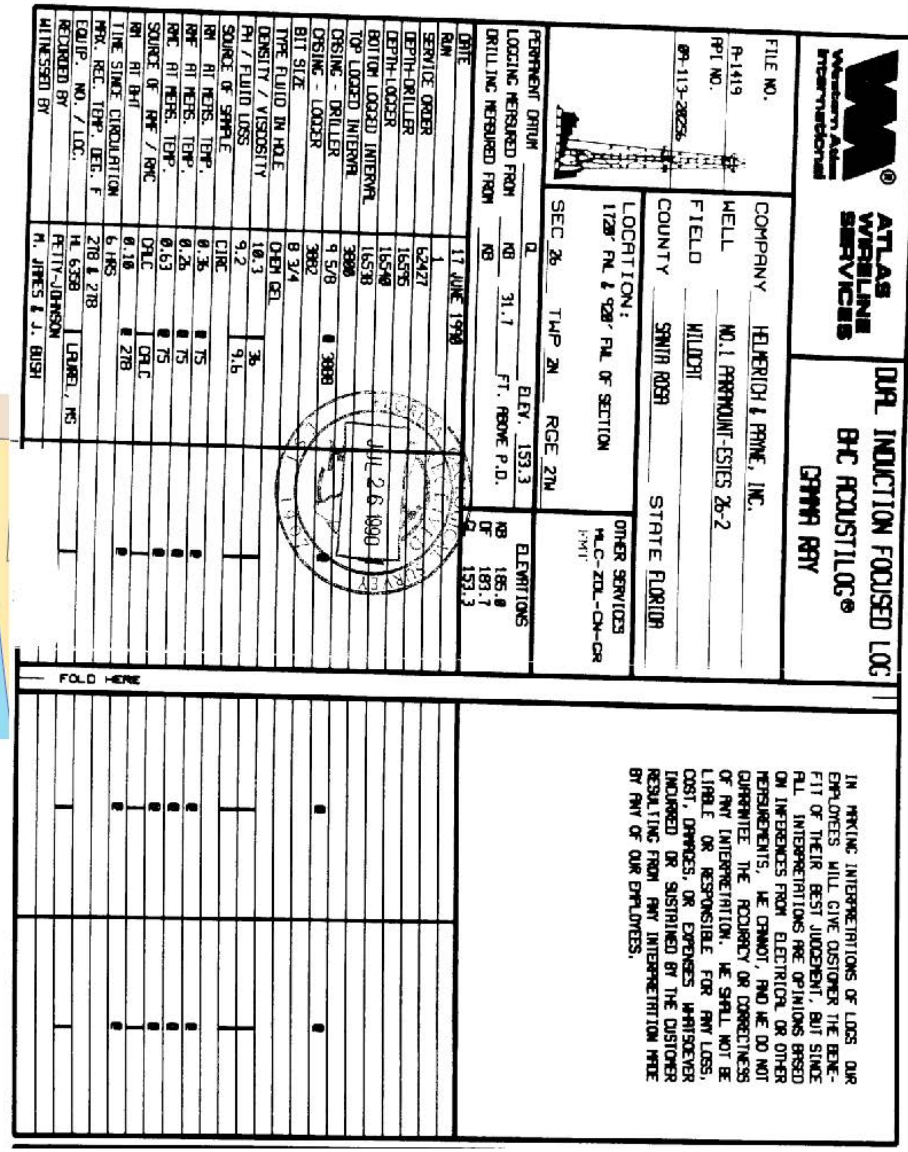


Lower Tuscaloosa

Lower Cretaceous

Disposal Area #1
P#1262
Gamma
Standard Potential
Resistivity





Western Atlas International
ATLAS WIRELINE SERVICES

DUAL INDUCTION FOCUSED LOG
BHC ACOUSTILOG®
GAMMA RAY

FILE NO. A-1419
API NO. 09-113-20256

COMPANY	HELMERICH & PAYNE, INC.
WELL	NO.1 PARAMOUNT-ESTES 26-2
FIELD	WILDCAT
COUNTY	SANTA ROSA STATE FLORIDA

LOCATION: 1720' FNL & 920' FWL OF SECTION
OTHER SERVICES MLC-ZDL-CN-GR FMT
SEC 26 TWP 2N RGE 27W

PERMANENT DATUM GL ELEV. 153.3
LOGGING MEASURED FROM KB 31.7 FT. ABOVE P.D.
DRILLING MEASURED FROM KB
ELEVATIONS KB 185.0 DF 183.7 GL 153.3

DATE	17 JUNE 1990	
RUN	1	
SERVICE ORDER	62427	
DEPTH-DRILLER	16595	
DEPTH-LOGGER	16540	
BOTTOM LOGGED INTERVAL	16538	
TOP LOGGED INTERVAL	3000	
CASING - DRILLER	9 5/8	@ 3000
CASING - LOGGER	3002	
BIT SIZE	8 3/4	
TYPE FLUID IN HOLE	CHEM GEL	
DENSITY / VISCOSITY	10.3	36
PH / FLUID LOSS	9.2	9.6
SOURCE OF SAMPLE	CIRC	
RM AT MEAS. TEMP.	0.36	@ 75
RMF AT MEAS. TEMP.	0.26	@ 75
RMC AT MEAS. TEMP.	0.63	@ 75
SOURCE OF RMF / RMC	CALC	CALC
RM AT BHT	0.10	@ 278
TIME SINCE CIRCULATION	6 HRS	
MAX. REC. TEMP. DEG. F	278 & 278	
EQUIP. NO. / LOC.	HL 6358	LAUREL, MS
RECORDED BY	PETTY-JOHNSON	
WITNESSED BY	M. JAMES & J. BUSH	

JUL 26 1990

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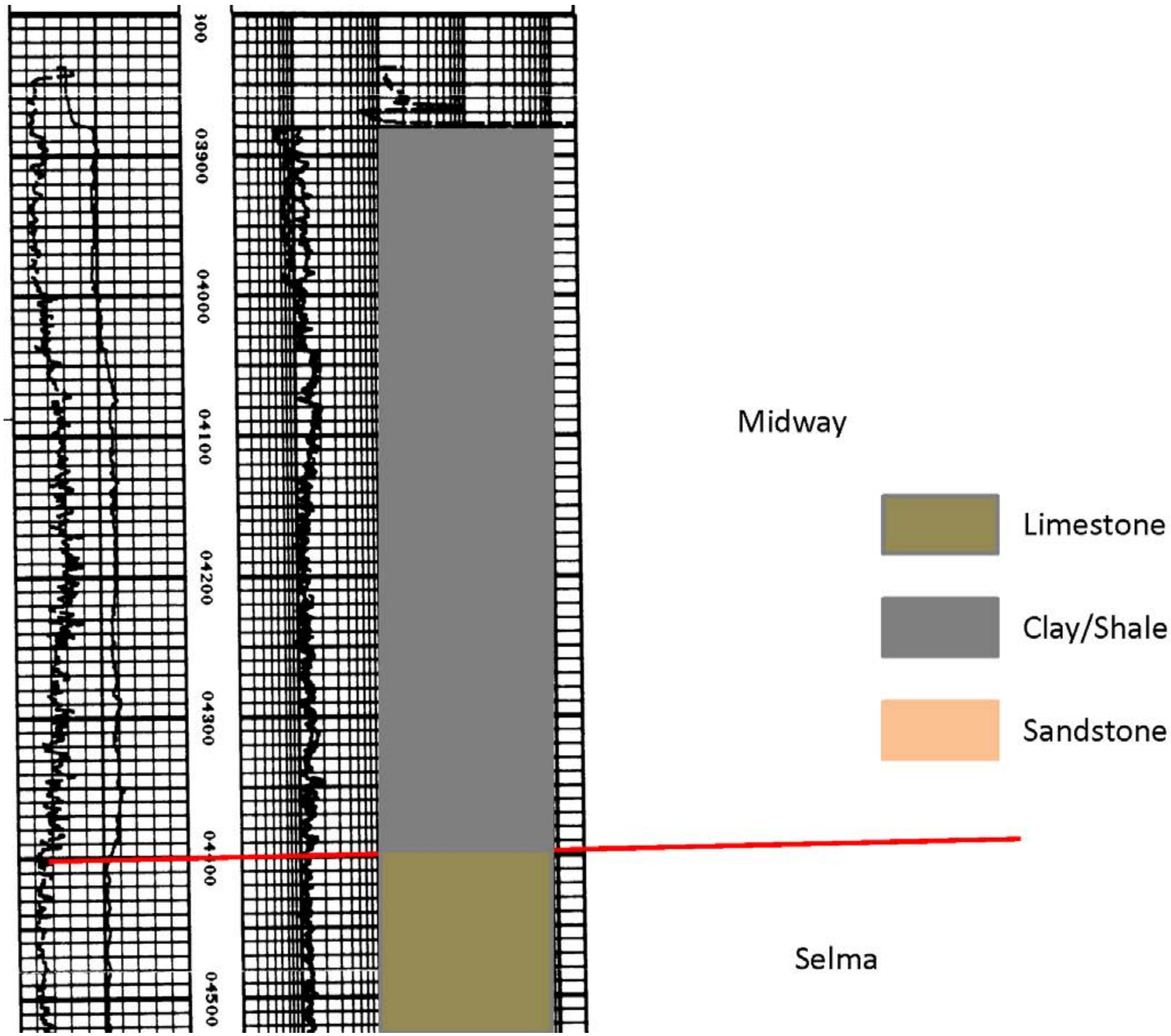
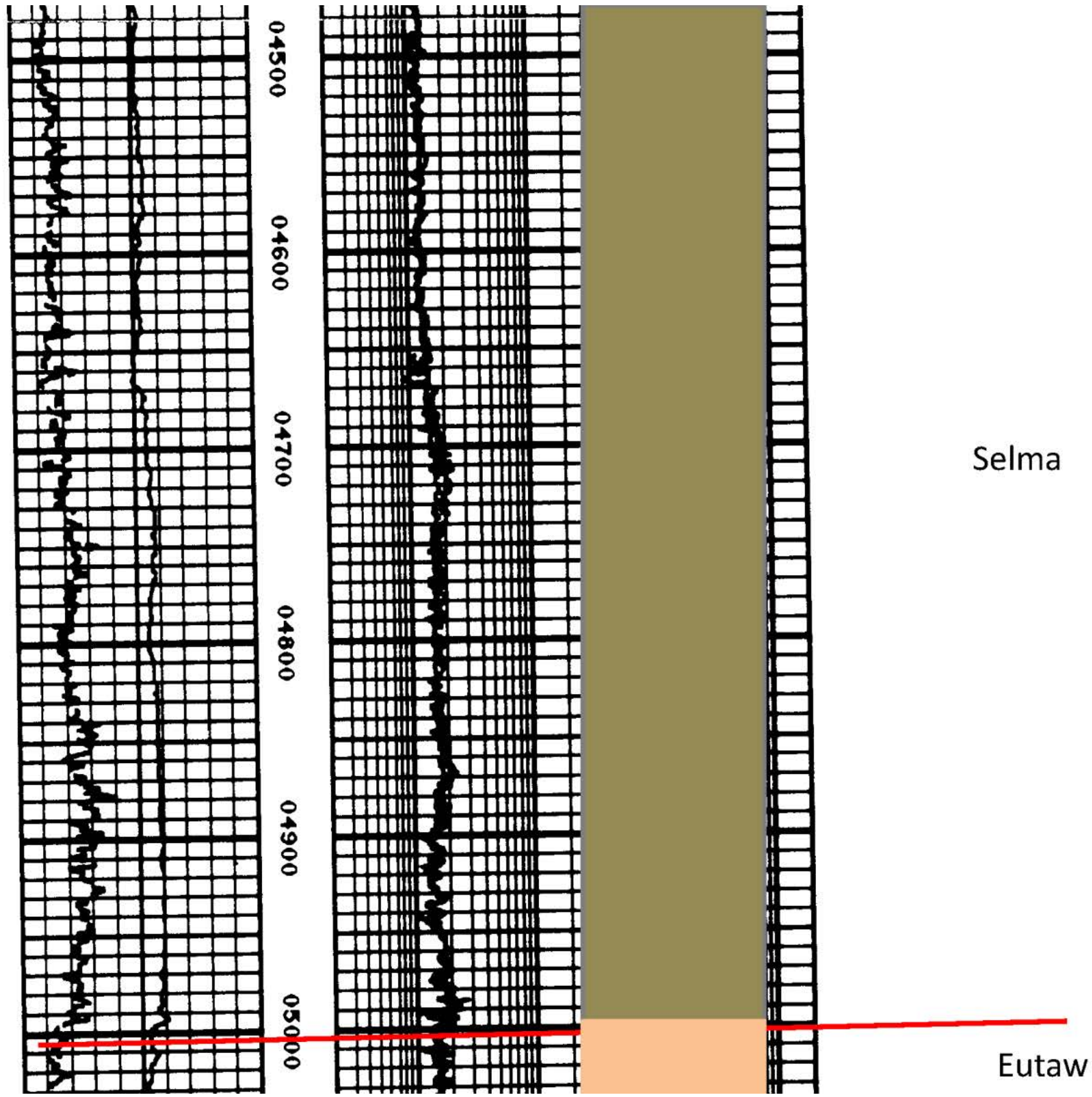
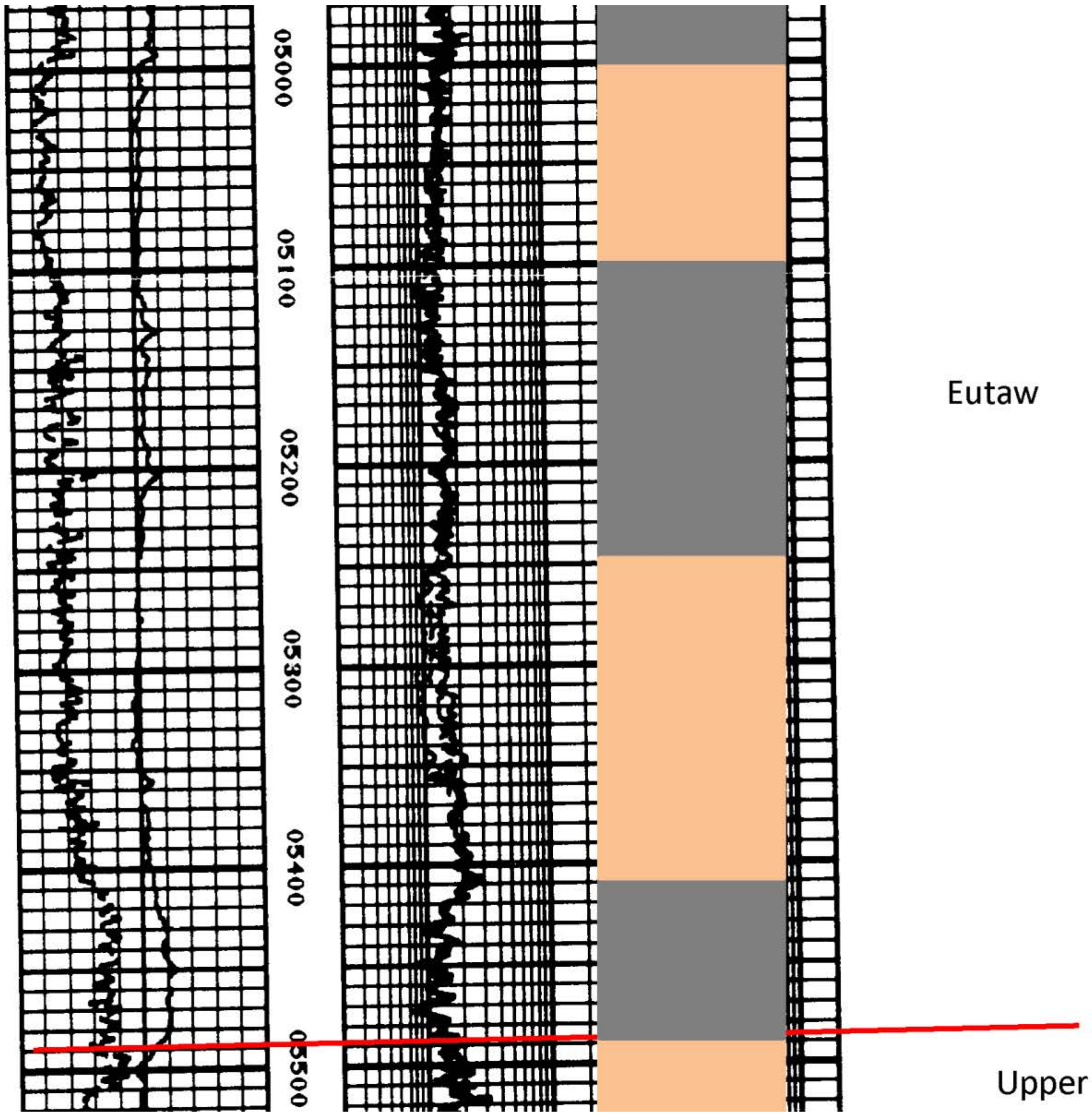
IN MAKING INTERPRETATIONS OF LOGS OUR EMPLOYEES WILL GIVE CUSTOMER THE BENEFIT OF THEIR BEST JUDGEMENT, BUT SINCE ALL INTERPRETATIONS ARE OPINIONS BASED ON INFERENCES FROM ELECTRICAL OR OTHER MEASUREMENTS, WE CANNOT, AND WE DO NOT GUARANTEE THE ACCURACY OR CORRECTNESS OF ANY INTERPRETATION. WE SHALL NOT BE LIABLE OR RESPONSIBLE FOR ANY LOSS, COST, DAMAGES, OR EXPENSES WHATSOEVER INCURRED OR SUSTAINED BY THE CUSTOMER RESULTING FROM ANY INTERPRETATION MADE BY ANY OF OUR EMPLOYEES.



300
03900
04000
04100
04200
04300
04400
04500
Midway
Limestone
Clay/Shale
Sandstone
Selma

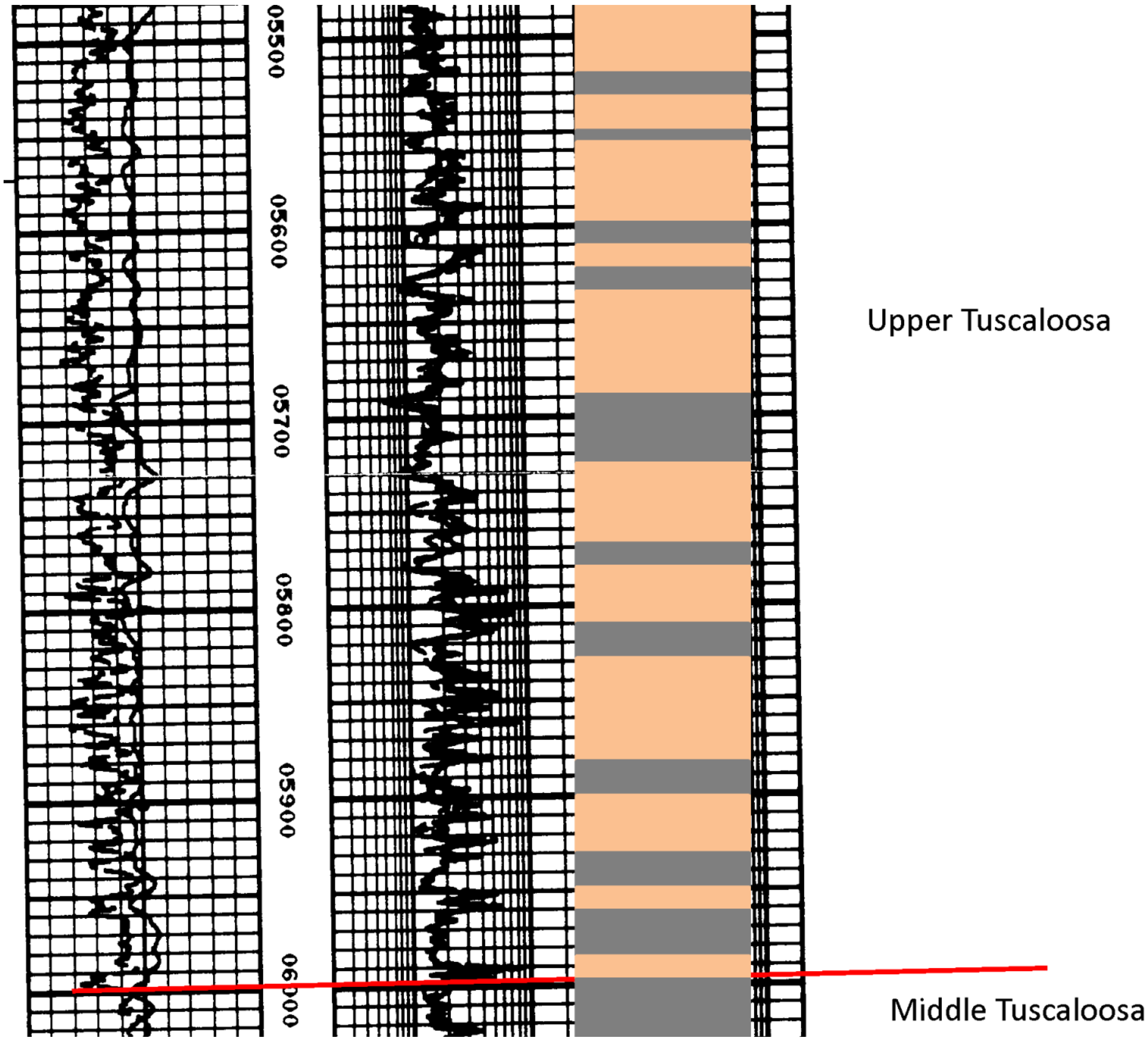


04500
04600
04700
04800
04900
05000
Selma
Eutaw



Eutaw

Upper Tuscaloosa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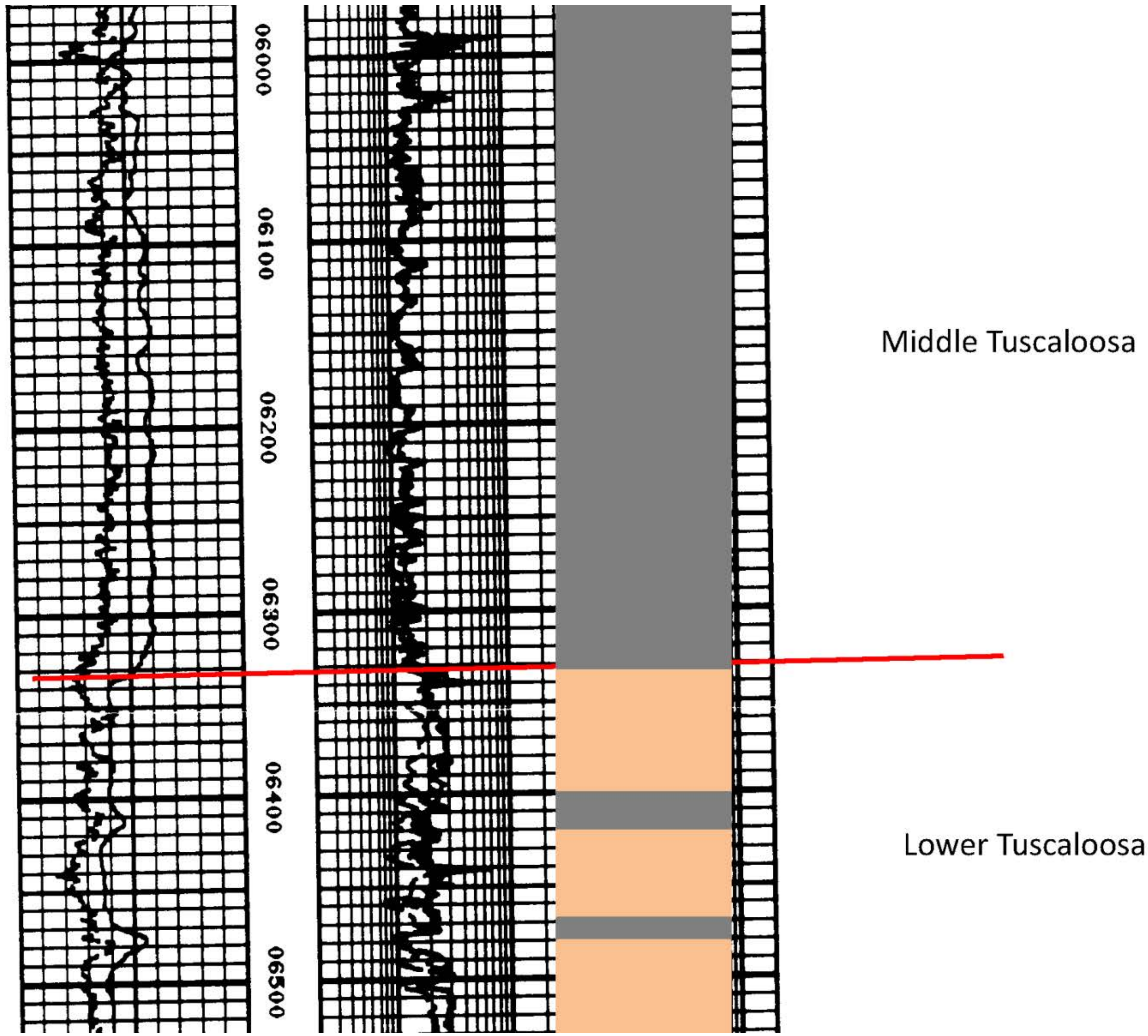
05600
05700
05800
05900
06000
Upper Tuscaloosa
Middle Tuscaloosa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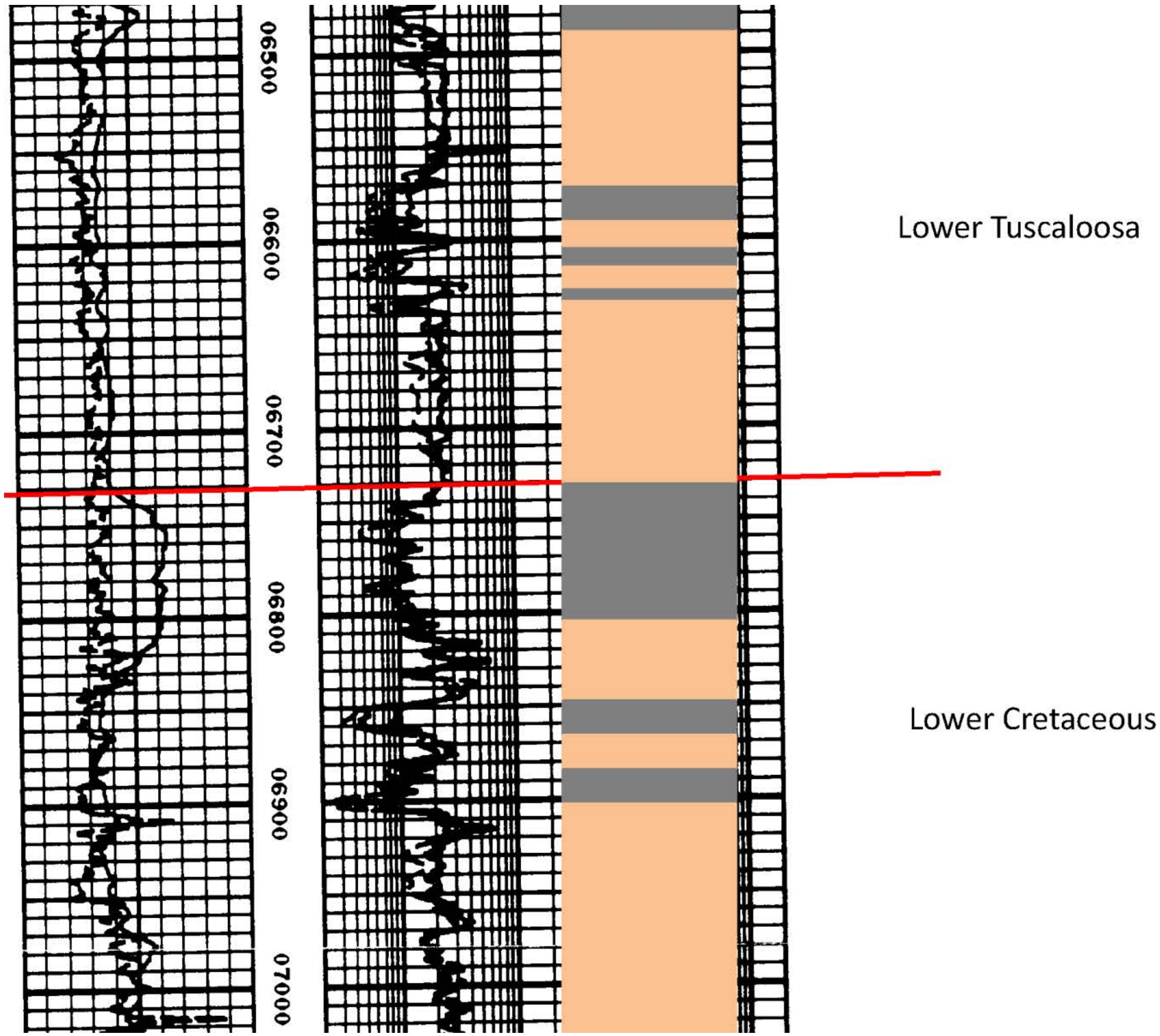
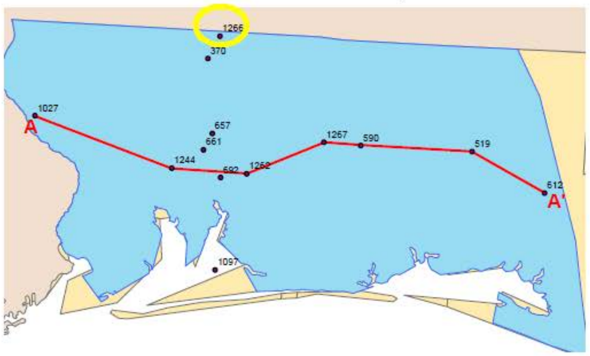
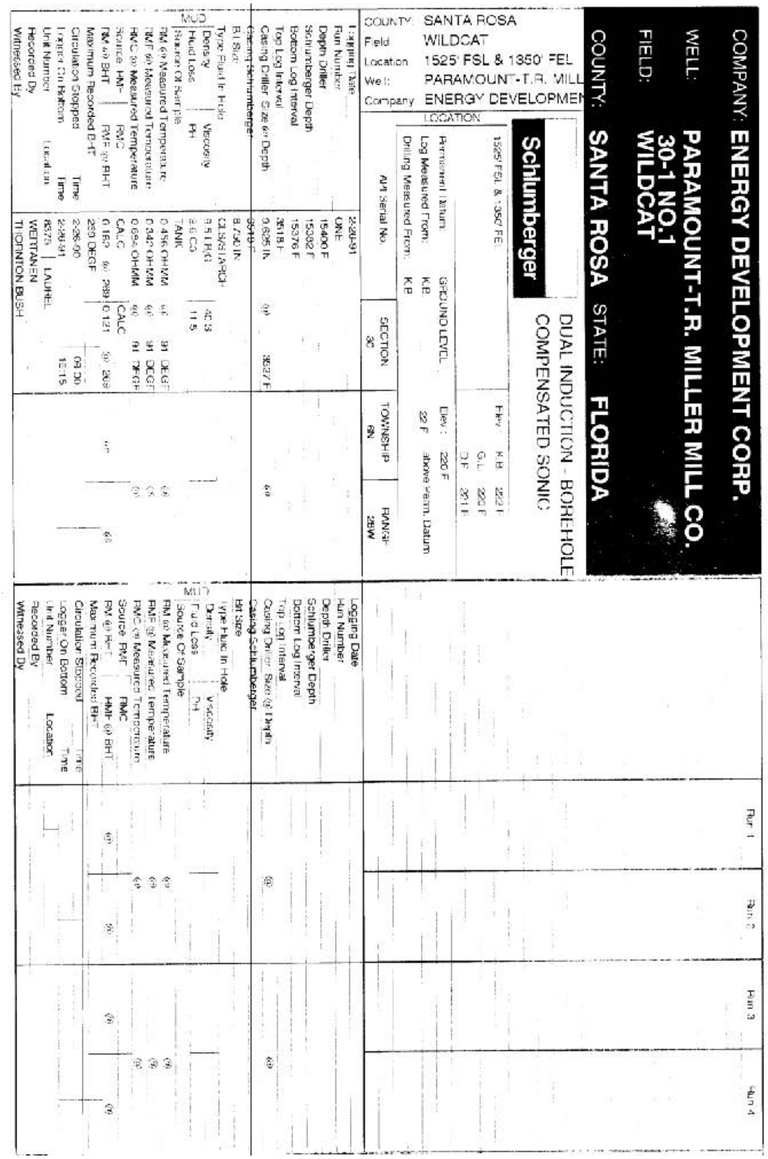
06100
06200
06300
06400
06500
Middle Tuscaloosa
Lower Tuscaloosa


06500
06600
06700
06800
06900
07000
Lower Tuscaloosa
Lower Cretaceous

Disposal Area #1
P#1266
Gamma
Standard Potential
Resistivity





COMPANY: ENERGY DEVELOPMENT CORP.
WELL: PARAMOUNT-T.R. MILLER MILL CO. 30-1 NO.1
FIELD: WILDCAT
COUNTY: SANTA ROSA STATE: FLORIDA

COUNTY SANTA ROSA
Field WILDCAT
Location 1525' FSL & 1350' FEL
Well: PARAMOUNT-T.R. MILL
Company ENERGY DEVELOPMEN

Schlumberger

DUAL INDUCTION - BOREHOLE COMPENSATED SONIC

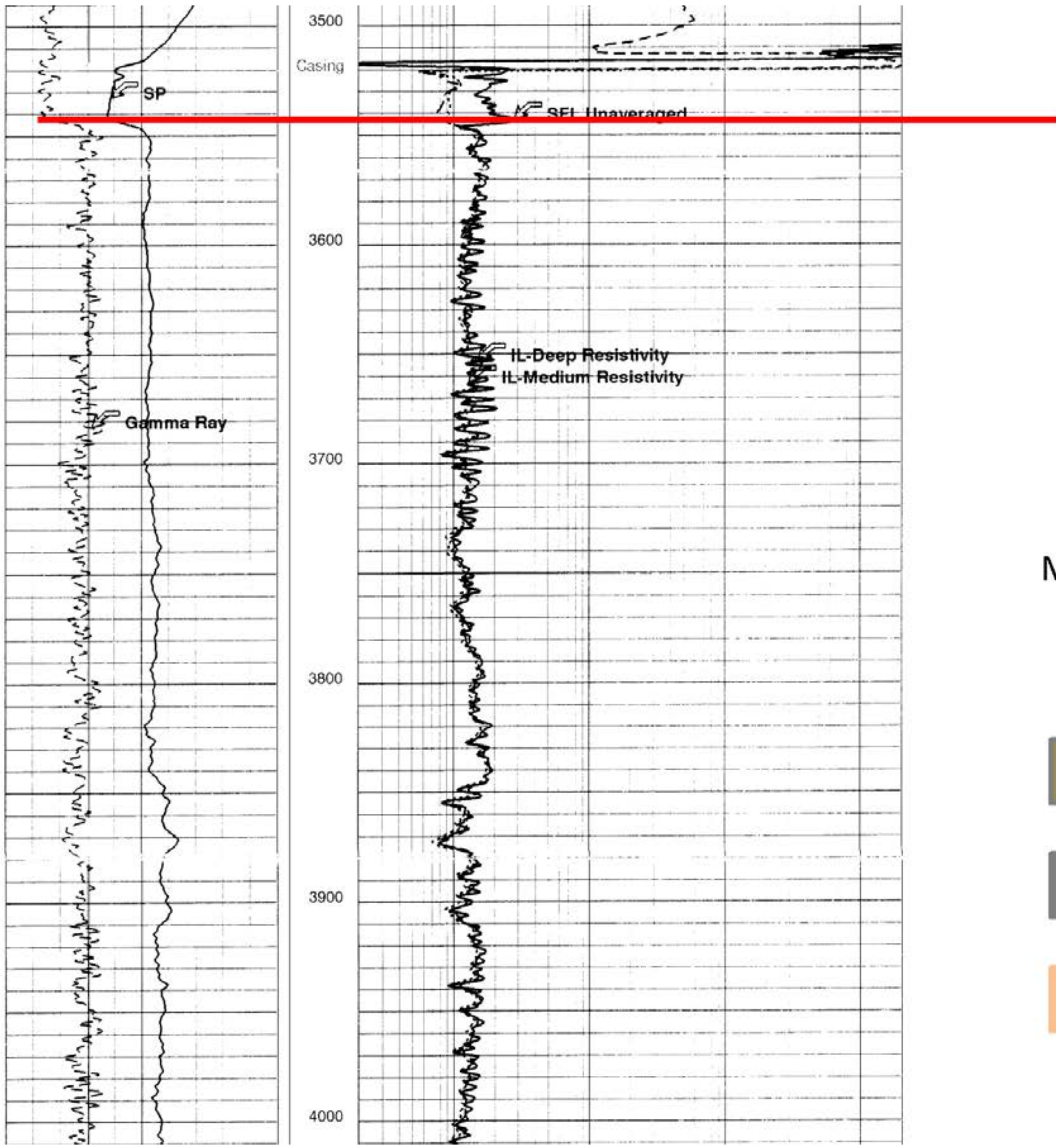
LOCATION
1525' FSL & 1350' FEL

Elev: K.B. 222 F, G.L. 220 F, D.F. 221 F

Permanent Datum:	GROUND LEVEL	Elev.: 220 F
Log Measured From:	K.B.	2.2 F above Perm. Datum
Drilling Measured From:	K.B.	

API Serial No.	SECTION	TOWNSHIP	RANGE
	30	6N	28W

Logging Date	2-28-91
Run Number	ONE
Depth Driller	15400 F
Schlumberger Depth	15392 F
Bottom Log Interval	15376 F
Top Log Interval	3518 F
Casing Driller Size @ Depth	9.625 IN. @ 3527 F
Casing Schlumberger	3519 F
Bit Size	8.750 IN
Type Fluid In Hole	CLS/STARCH
Density / Viscosity	9.51 LB/G / 40.8
Fluid Loss / PH	3.6 C3 / 11.5
Source Of Sample	TANK
RM @ Measured Temperature	0.456 OHMM @ 91 DEGF
RMF @ Measured Temperature	0.342 OHMM @ 91 DEGF
RMC @ Measured Temperature	0.694 OHMM @ 91 DEGF
Source RMF / RMC	CALC / CALC
RM @ BHT / RMF @ BHT	0.162 @ 269 / 0.121 @ 269
Maximum Recorded BHT	269 DEGF
Circulation Stopped Time	2-26-90 / 09:00
Logger On Bottom Time	2-28-91 / 15:15
Unit Number / Location	8575 / LAUREL
Recorded By	WEITTANEN
Witnessed By	THORNTON BUSH

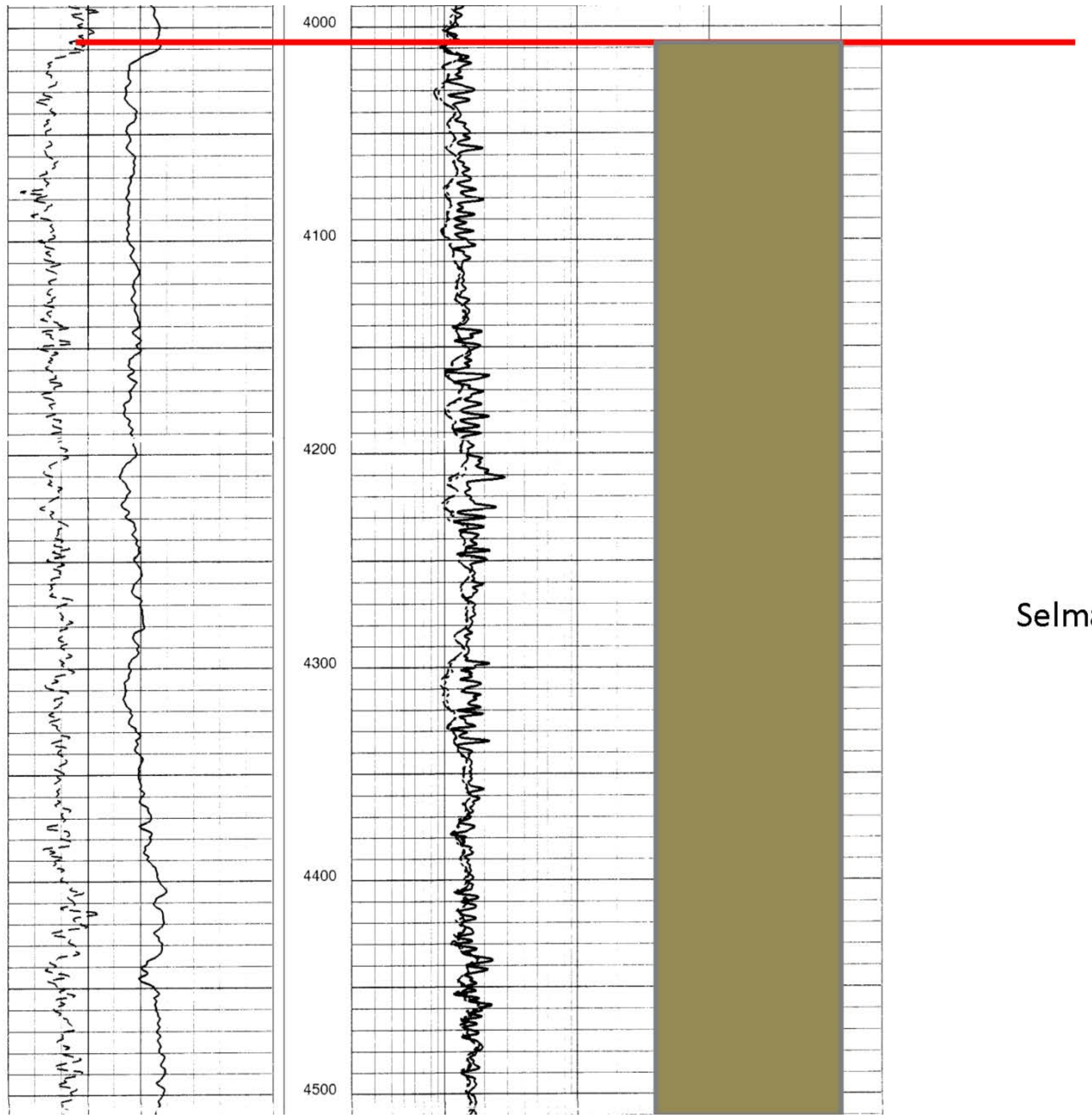


Midway

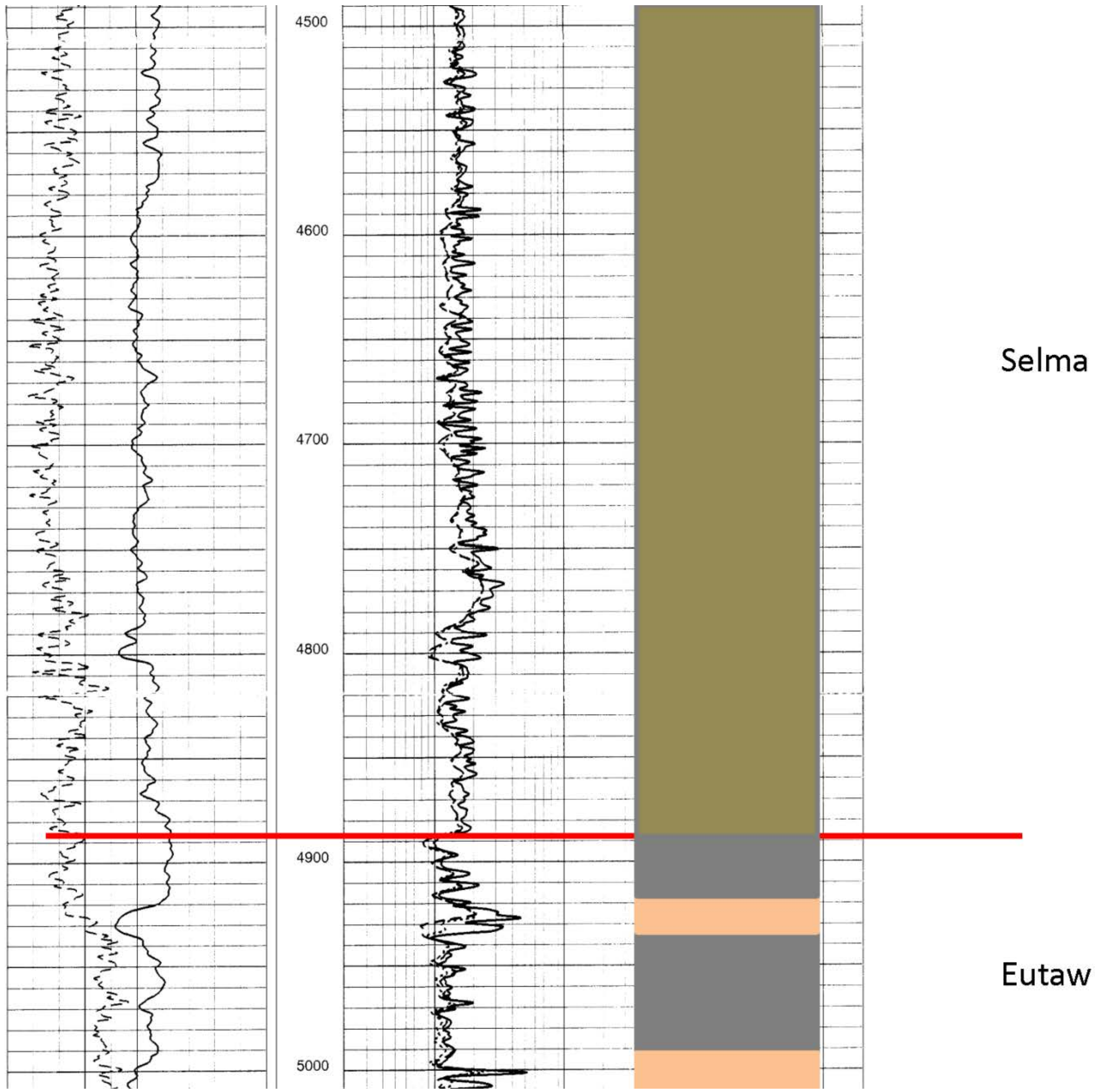
Limestone

Clay/Shale

Sandstone

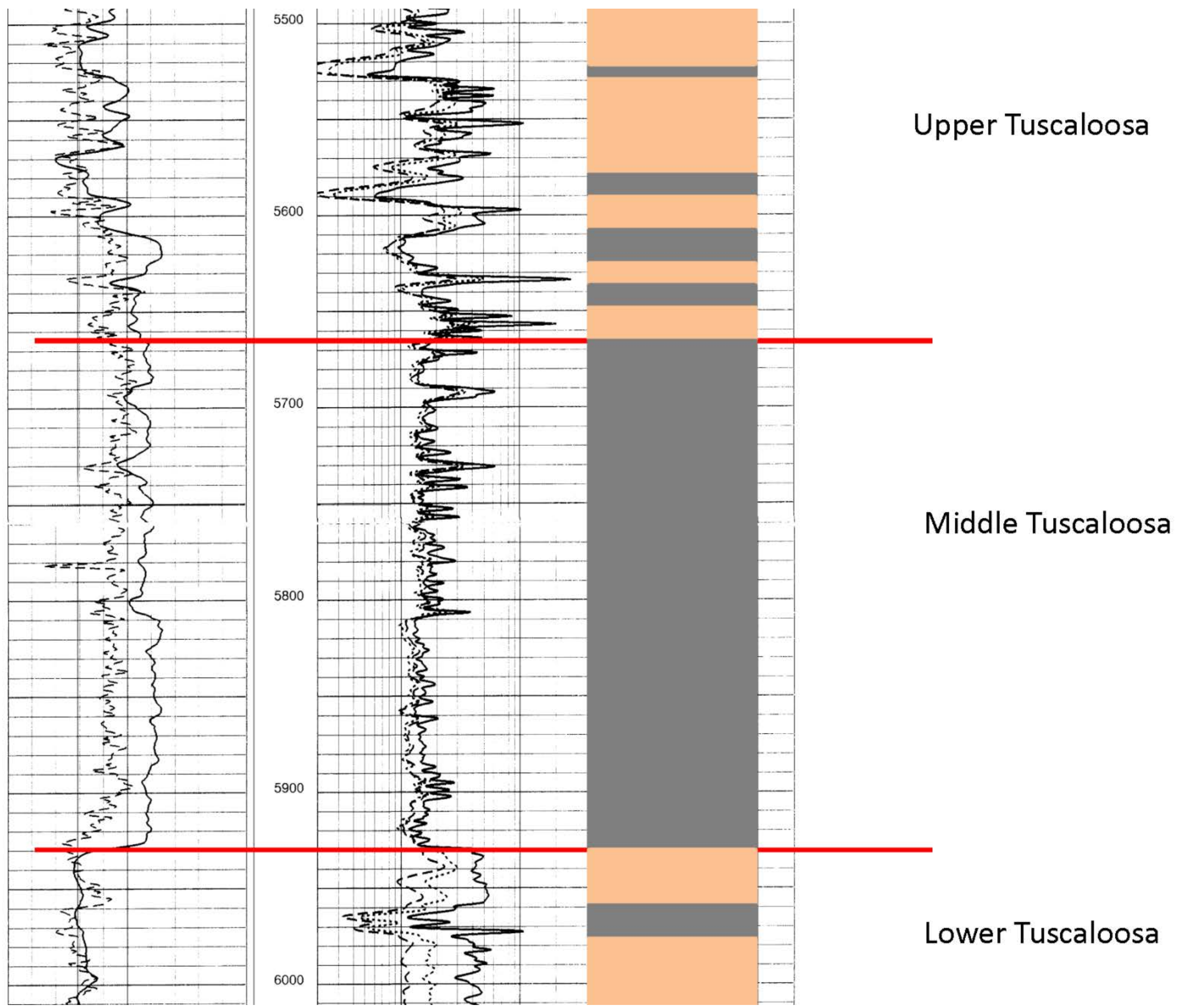


Selma


4500
4600
4700
4800
4900
5000
Selma
Eutaw

Eutaw

Upper Tuscaloosa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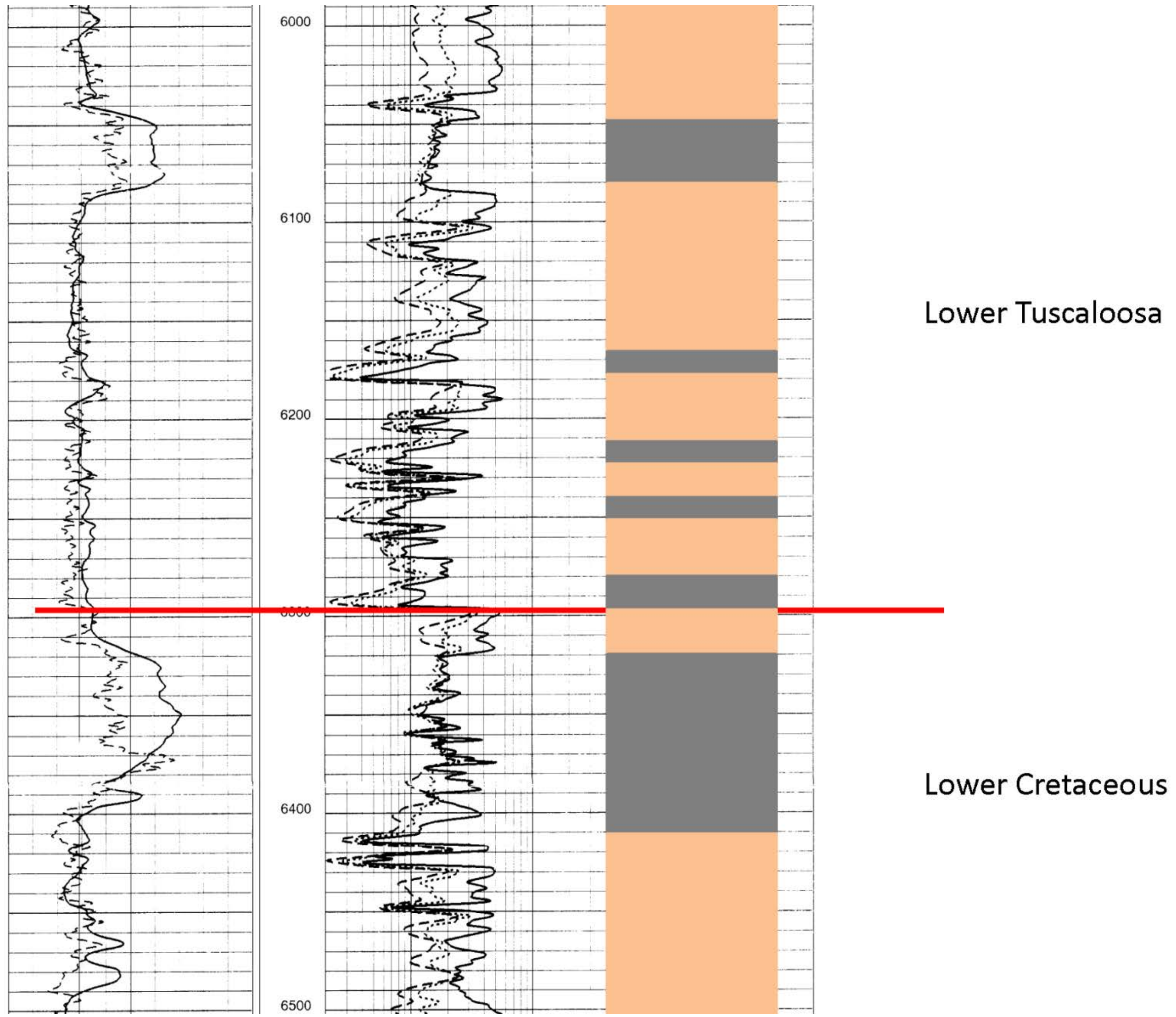
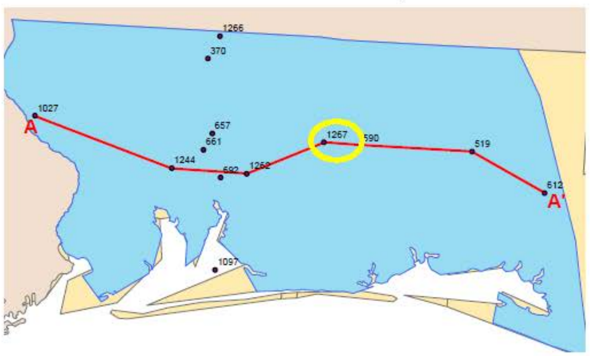
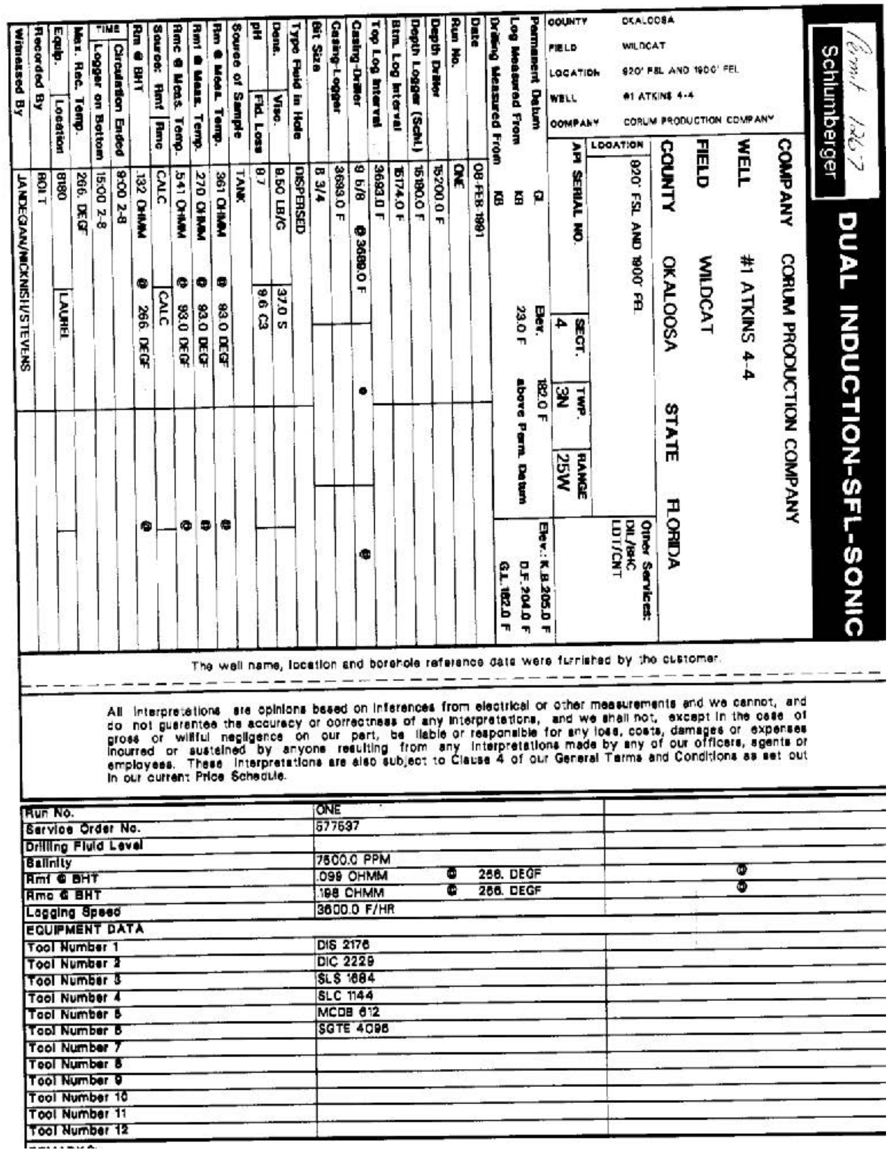
5600
5700
5800
5900
6000
Upper Tuscaloosa
Middle Tuscaloosa
Lower Tuscaloosa


6000
6100
6200
6400
6500
Lower Tuscaloosa
Lower Cretaceous

Disposal Area #1
P#1267
Gamma
Standard Potential
Resistivity





Permit 1267

Schlumberger

DUAL INDUCTION-SFL-SONIC

COUNTY	OKALOOSA	
FIELD	WILDCAT	
LOCATION	920' FSL AND 1900' FEL	
WELL	#1 ATKINS 4-4	
COMPANY	CORUM PRODUCTION COMPANY	

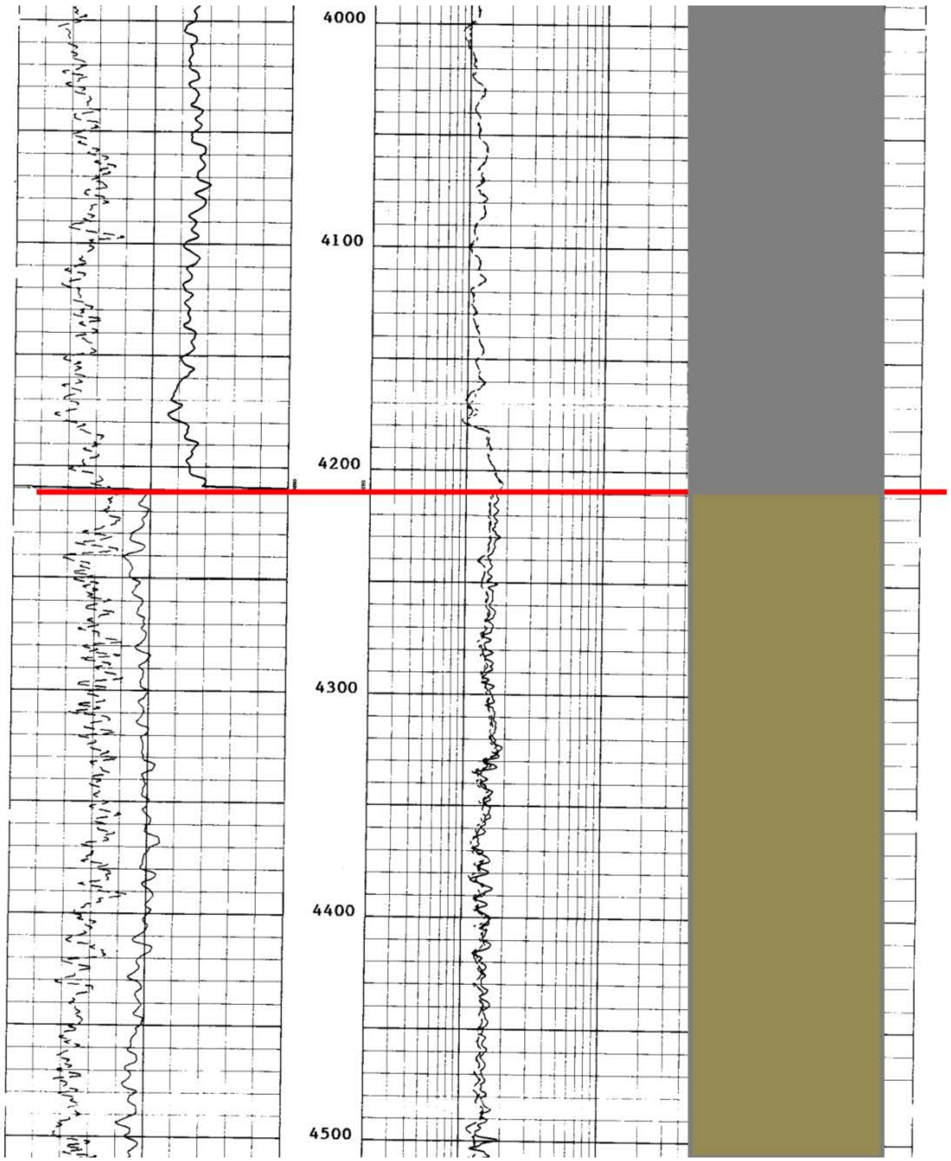
COMPANY	CORUM PRODUCTION COMPANY
WELL	#1 ATKINS 4-4
FIELD	WILDCAT
COUNTY	OKALOOSA STATE FLORIDA
LOCATION	920' FSL AND 1900' FEL
Other Services:	DIL/BHC LDT/CNT
API SERIAL NO.	SECT. 4 TWP. 3N RANGE 25W
Permanent Datum	GL Elev. 182.0 F
Log Measured From	KB 23.0 F above Perm. Datum
Drilling Measured From	KB
Elev.:	K.B. 205.0 F D.F. 204.0 F G.L. 182.0 F

Date	08-FEB-1991		
Run No.	ONE		
Depth Driller	15200.0 F		
Depth Logger (Schl.)	15180.0 F		
Btm. Log Interval	15174.0 F		
Top Log Interval	3693.0 F		
Casing-Driller	9 5/8 @ 3689.0 F	@	@
Casing-Logger	3688.0 F		
Bit Size	8 3/4		
Type Fluid in Hole	DISPERSED		
Dens. / Visc.	9.50 LB/G / 37.0 S		
pH / Fld. Loss	8.7 / 9.6 C3		
Source of Sample	TANK		
Rm @ Meas. Temp.	.361 OHMM @ 83.0 DEGF	@	@
Rmf @ Meas. Temp.	.270 OHMM @ 83.0 DEGF	@	@
Rmc @ Meas. Temp.	.541 OHMM @ 83.0 DEGF	@	@
Source: Rmf / Rmc	CALC / CALC		
Rm @ BHT	.132 OHMM @ 266. DEGF	@	@
Circulation Ended	9:00 2-8		
Logger on Bottom	15:00 2-8		
Max. Rec. Temp.	266. DEGF		
Equip. / Location	8180 / LAUREL		
Recorded By	BOLT		
Witnessed By	JANDEGIAN/NICKNISH/STEVENS		

The well name, location and borehole reference data were furnished by the customer.

All interpretations are opinions based on inferences from electrical or other measurements and we cannot, and do not guarantee the accuracy or correctness of any interpretations, and we shall not, except in the case of gross or wilful negligence on our part, be liable or responsible for any loss, costs, damages or expenses incurred or sustained by anyone resulting from any interpretations made by any of our officers, agents or employees. These interpretations are also subject to Clause 4 of our General Terms and Conditions as set out in our current Price Schedule.

Run No.	ONE		
Service Order No.	577597		
Drilling Fluid Level			
Salinity	7500.0 PPM		
Rmf @ BHT	.099 OHMM @ 266. DEGF	@	
Rmc @ BHT	.198 OHMM @ 266. DEGF	@	
Logging Speed	3600.0 F/HR		
EQUIPMENT DATA			
Tool Number 1	DIS 2176		
Tool Number 2	DIC 2229		
Tool Number 3	SLS 1684		
Tool Number 4	SLC 1144		
Tool Number 5	MCDB 612		
Tool Number 6	SGTE 4096		
Tool Number 7			
Tool Number 8			
Tool Number 9			
Tool Number 10			
Tool Number 11			
Tool Number 12			



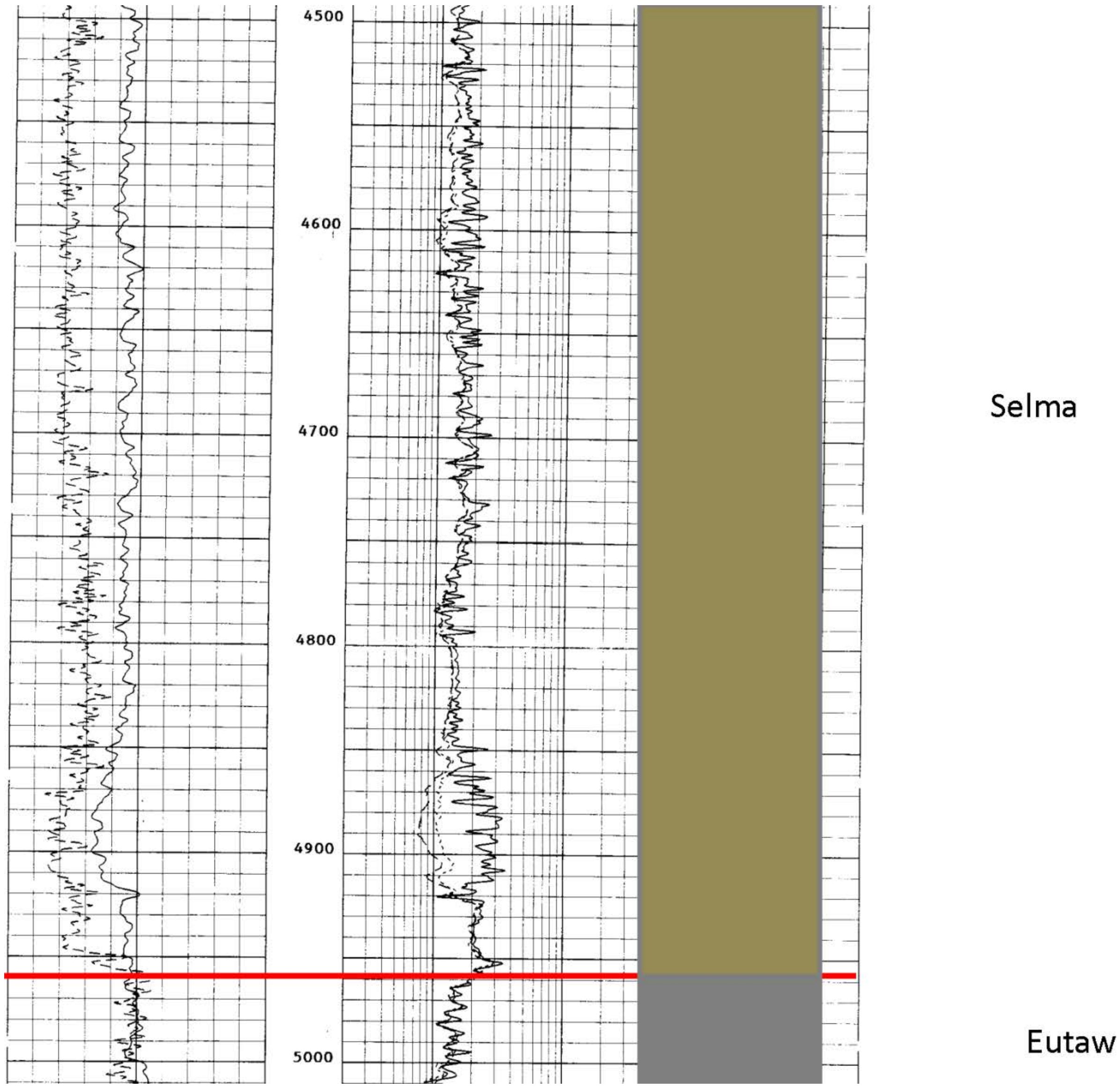
Midway

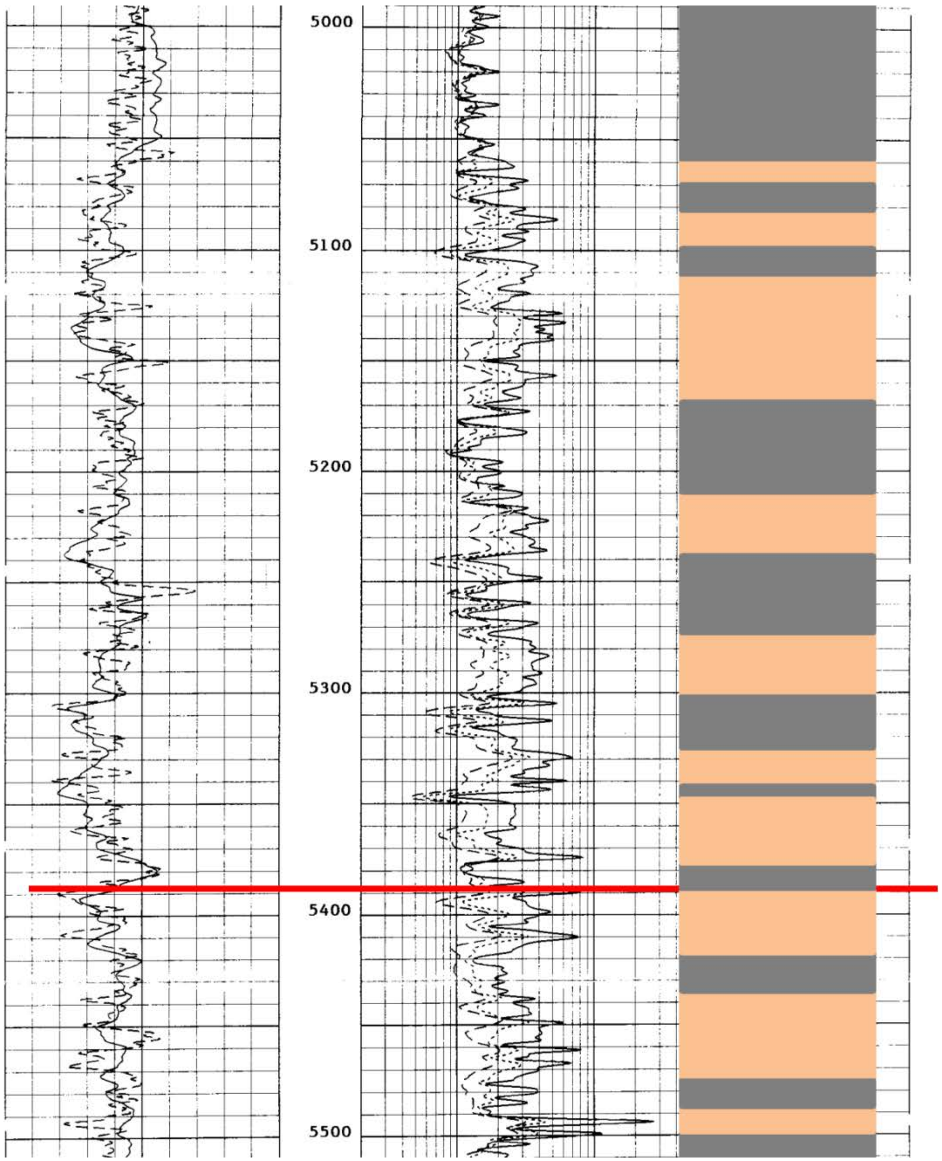
Limestone

Clay/Shale

Sandstone

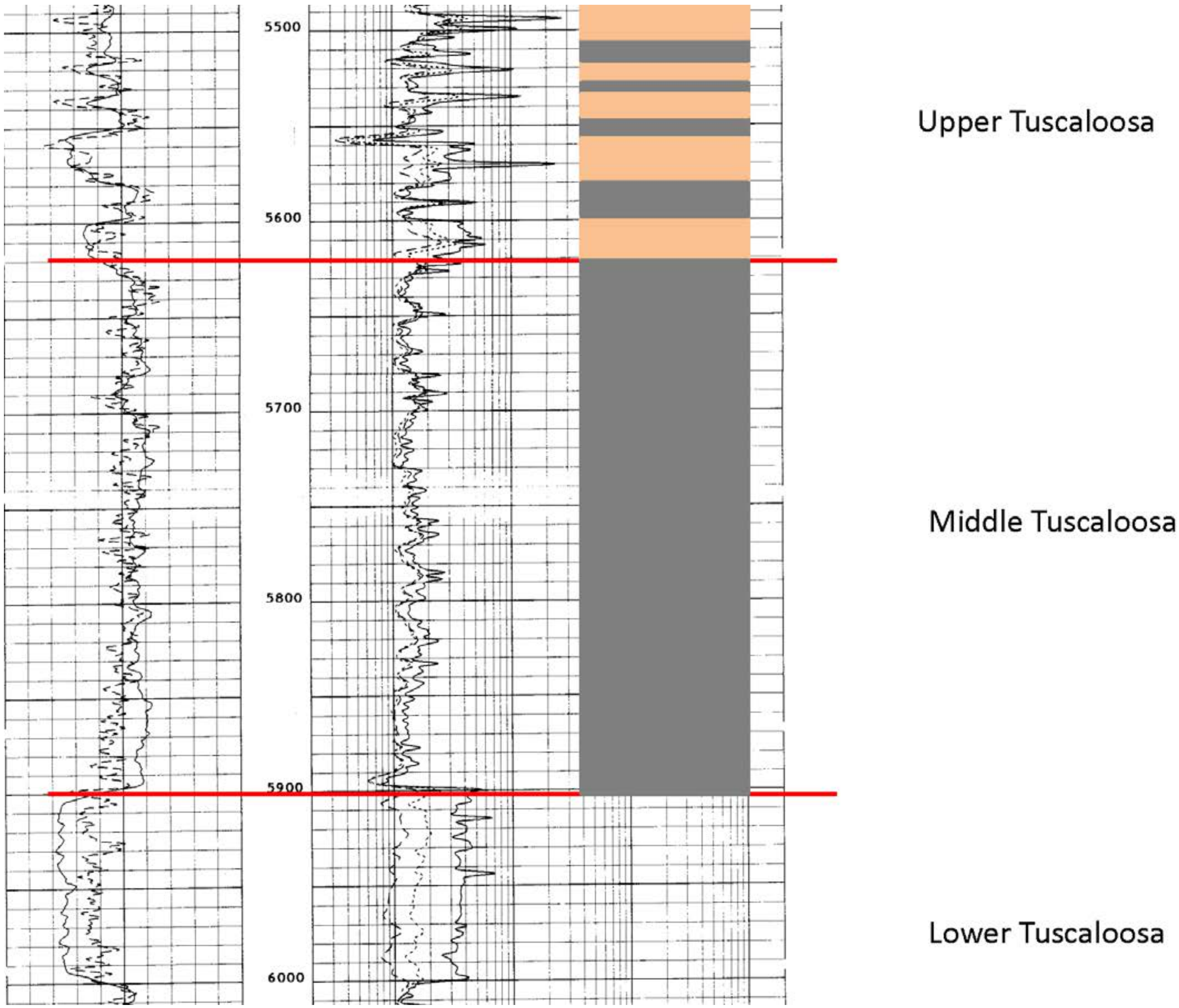
Selma


4500
4600
4700
4800
4900
5000
Selma
Eutaw

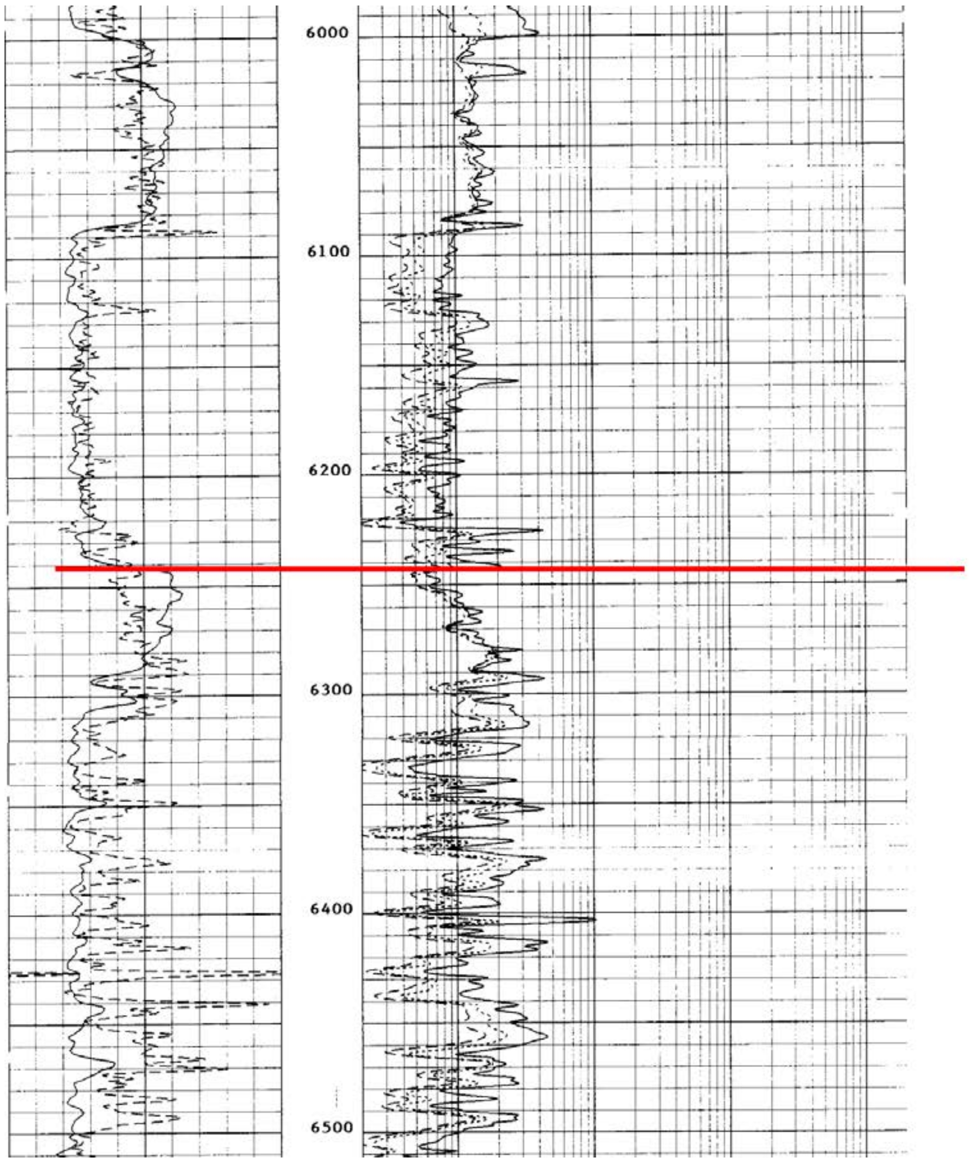


Eutaw

Upper Tuscaloosa



5500
5600
5700
5800
5900
6000
Upper Tuscaloosa
Middle Tuscaloosa
Lower Tuscaloosa

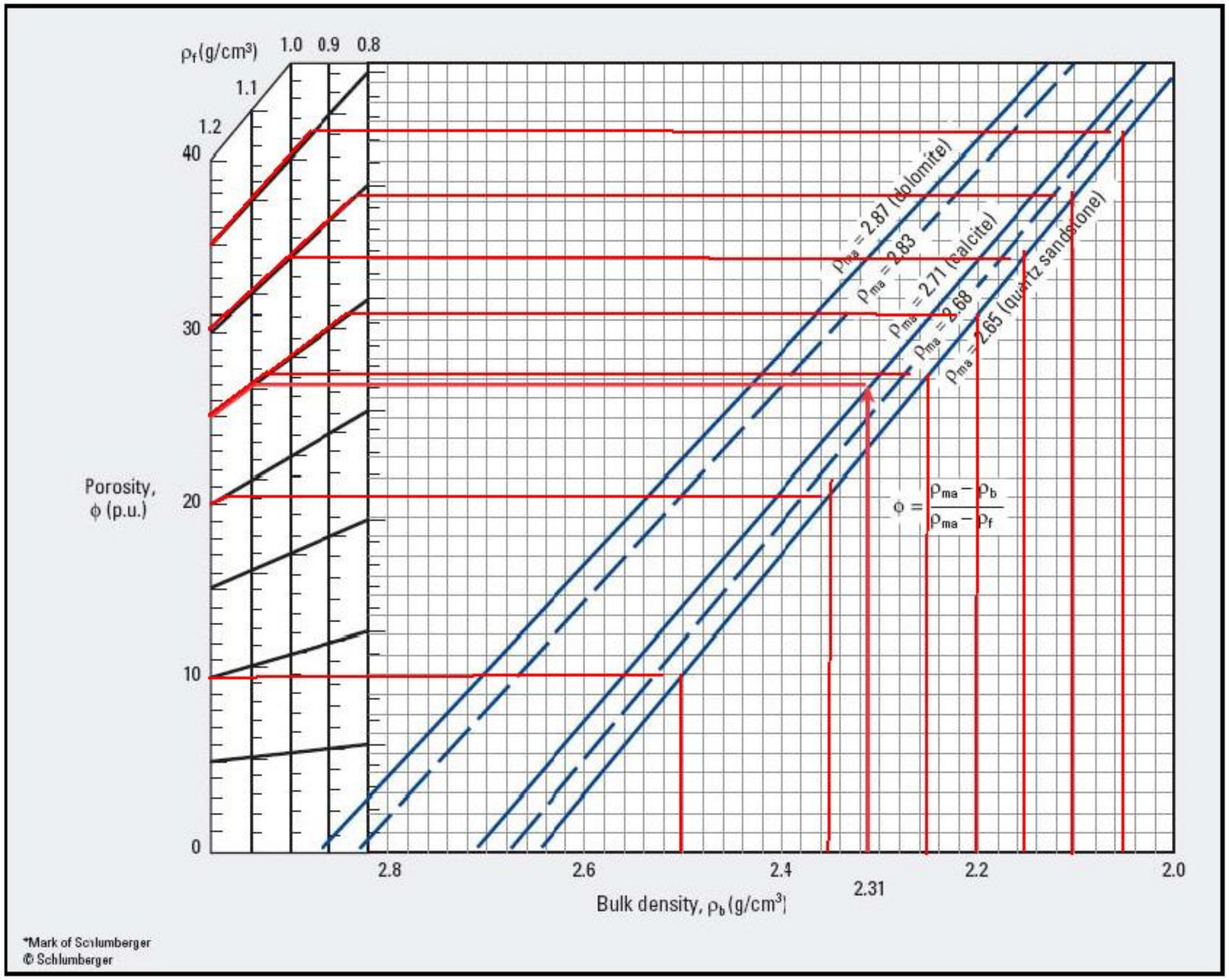


Lower Tuscaloosa

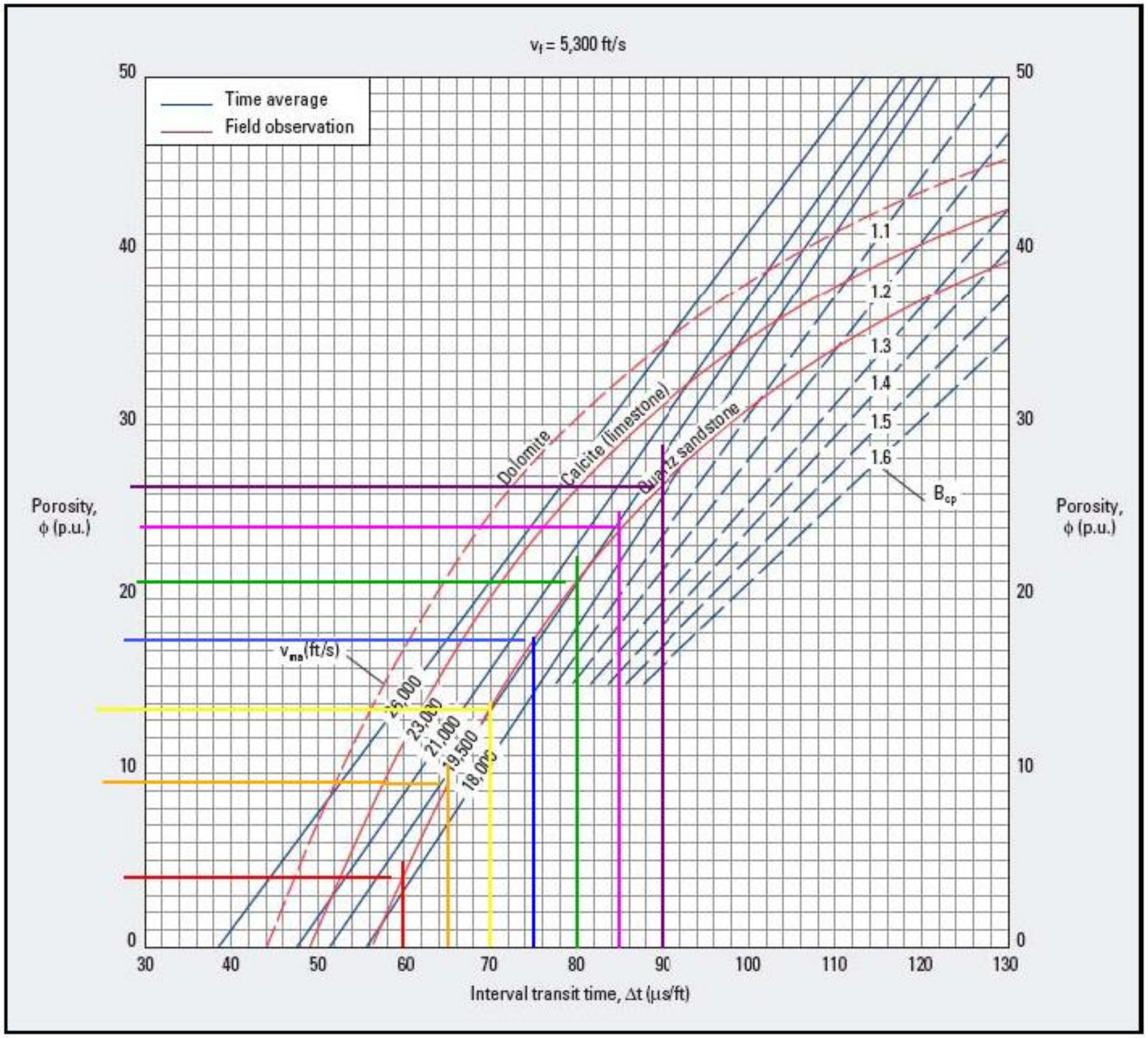
Lower Cretaceous

Appendix C

Schlumberger Porosity Graphs



Determination of porosity from true bulk density (from: Schlumberger, 2009).



Determination of porosity using interval transit time (from: Schlumberger, 2009).

Porous Zones																				
													Estimated Porosity Value (%)							
													Sandstone							
Permit #	County	Ground Elevation (ft)	Total Depth (ft)	Soil Group	Top (ft)	Bottom (ft)	Total Thickness (ft)	Interval Transit Time (µs/ft)	Neutron porosity	True Bulk Density (grams/cc)	Density Porosity	Lithlog	Figure AII-2	Figure AII-7	Figure AII-8	Figure AII-3	Figure AII-4	Figure AII-5	Figure AII-6	Figure AII-9
370	Santa Rosa	NA	14480	Eutaw	5050	5085	35	75	-	-	-	-	-	-	-	17.5	-	-	-	-
					5155	5180	25	75	-	-	-	-	-	-	-	17.5	-	-	-	-
					5230	5255	25	65	-	-	-	-	-	-	-	9.5	-	-	-	-
					5305	5325	20	70	-	-	-	-	-	-	-	13.5	-	-	-	-
				Upper Tuscaloosa	5400	5530	130	60	-	-	-	-	-	-	-	4	-	-	-	-
					5570	5640	70	60	-	-	-	-	-	-	-	4	-	-	-	-
					5690	5710	20	70	-	-	-	-	-	-	-	13.5	-	-	-	-
					5735	5780	45	70	-	-	-	-	-	-	-	13.5	-	-	-	-
612	Walton	113.5	11533	Eutaw	3820	3895	75	90	-	-	-	-	-	-	-	26.5	-	-	-	-
					3920	3945	25	90	-	-	-	-	-	-	-	26.5	-	-	-	-
					3975	4000	25	85	-	-	-	-	-	-	-	24	-	-	-	-
					4030	4050	20	85	-	-	-	-	-	-	-	24	-	-	-	-
					4110	4120	10	80	-	-	-	-	-	-	-	21	-	-	-	-
					4180	4210	30	75	-	-	-	-	-	-	-	17.5	-	-	-	-
					4230	4255	25	75	-	-	-	-	-	-	-	17.5	-	-	-	-
					4265	4280	15	70	-	-	-	-	-	-	-	13.5	-	-	-	-
					4305	4320	15	65	-	-	-	-	-	-	-	9.5	-	-	-	-
					4350	4375	25	65	-	-	-	-	-	-	-	9.5	-	-	-	-
				Upper Tuscaloosa	4410	4530	120	80	-	-	-	-	-	-	-	21	-	-	-	-
657	Santa Rosa	202.1	16758	Eutaw	5550	5755	205	-	-	2.35	-	-	20	-	-	-	-	-	-	-
					5820	5860	40	-	-	2.25	-	-	25	-	-	-	-	-	-	-
				Upper Tuscaloosa	5870	5910	40	-	-	2.25	-	-	25	-	-	-	-	-	-	-
					5920	6000	80	-	-	2.3	-	-	25	-	-	-	-	-	-	-
					6025	6035	10	-	-	2.5	-	-	10	-	-	-	-	-	-	-
					6060	6070	10	-	-	2.5	-	-	10	-	-	-	-	-	-	-
					6120	6140	20	-	-	2.3	-	-	25	-	-	-	-	-	-	-
1027	Escambia	223	17957	Eutaw	5910	5950	40	-	15	2.5	-	-	10	21	-	-	-	-	-	-
					6070	6125	55	-	30	2.2	-	-	25	37	-	-	-	-	-	-
					6160	6180	20	-	30	2.15	-	-	30	37	-	-	-	-	-	-
					6230	6260	30	-	30	2.1	-	-	30	37	-	-	-	-	-	-
					6280	6290	10	-	30	2.25	-	-	25	37	-	-	-	-	-	-
					6305	6315	10	-	33	2.2	-	-	25	40	-	-	-	-	-	-
					6330	6340	10	-	28	2.2	-	-	25	35	-	-	-	-	-	-
				Upper Tuscaloosa	6360	6380	20	-	39	2.05	-	-	35	na	-	-	-	-	-	-
					6405	6420	15	-	30	2.25	-	-	25	37	-	-	-	-	-	-
					6460	6480	20	-	21	2.35	-	-	20	38	-	-	-	-	-	-
					6500	6535	35	-	24	2.35	-	-	20	31	-	-	-	-	-	-
					6590	6605	15	-	39	2.15	-	-	30	na	-	-	-	-	-	-
					6620	6630	10	-	39	2.05	-	-	35	na	-	-	-	-	-	-

Appendix D

Storage Efficiency Calculations

Calculating Gamma (Okwen et al., 2009)

Estimated Flow Rate =	53,050,000	tonne/year	53.05	Mt/yr	<<< Annual flow rate from Florida Pan-Handle Network		
	145,342	tonne/day			5	MGD	<<< Assumed max flow for one pump (Brown, 2011)
	145,342,466	kg/day	45561901.49	gpd	45.56	MGD	
	168.2204	kg/s	52.7337	gps	4.56	MGD	<<< Flow used for thesis
Thickness of formation =	104	m					
Density of Brine in formation =	1019.12	kg/m3	Brown, 2011		0.4418	lb/in2/foot	
Density of CO2 in formation =	842.75	kg/m3	MIT Calculator 100°F @ 2750psi		0.3654	lb/in2/foot	
Δρ =	176.37	kg/m3					
Viscocity of Brine in formation =	0.000734268	kg/m s	Brown, 2011				
λb =	1361.90						
Intrinsic Permeability =	1.00E-09	m2	typical value for sandstone (Fetter, 1988)		1.00E-05	cm2	
Γ =	0.95193410		BOUYANCY AFFECTS PLUME		(Okwen et al., 2009)		

Viscocity ofCO2 in formation =	0.00008002	kg/m s (Pa- MIT Calculator 100°F @ 2750psi
λc =	12496.88	
λ =	9.1761	

No Bouyancy Effects

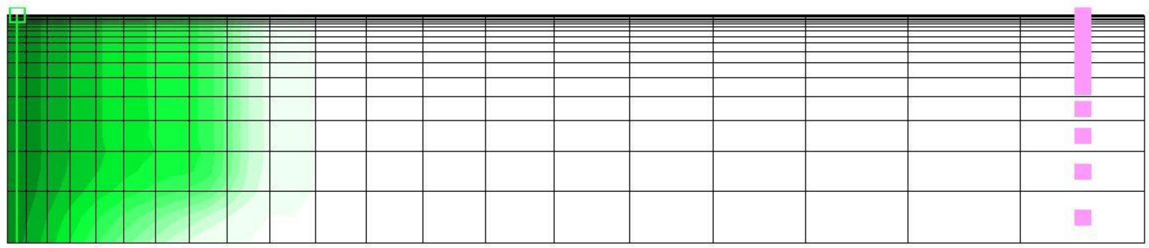
Sr	0	0.15	0.3	0.45
ϵ	0.11	0.09	0.08	0.06

Bouyancy Effects

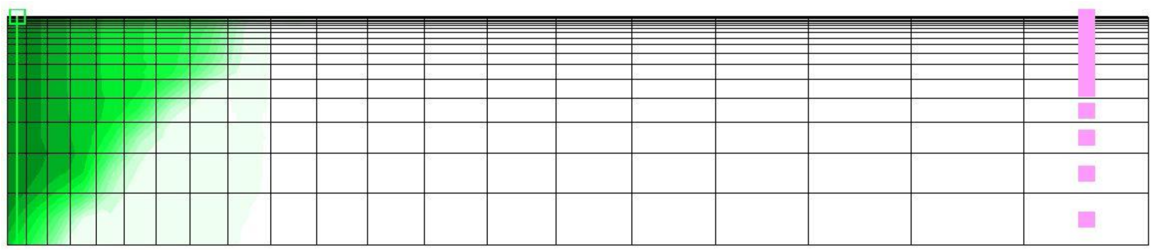
Sr	0	0.15	0.3	0.45
ϵ	0.10	0.08	0.07	0.05

Appendix E

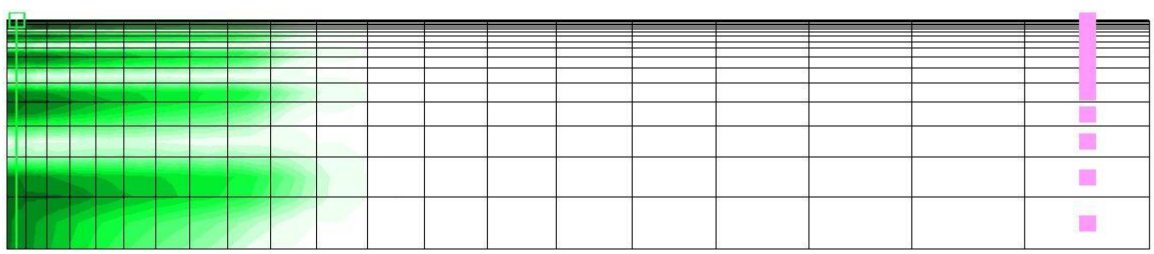
UTCHEM-9.0 Florida Pan-Handle Model



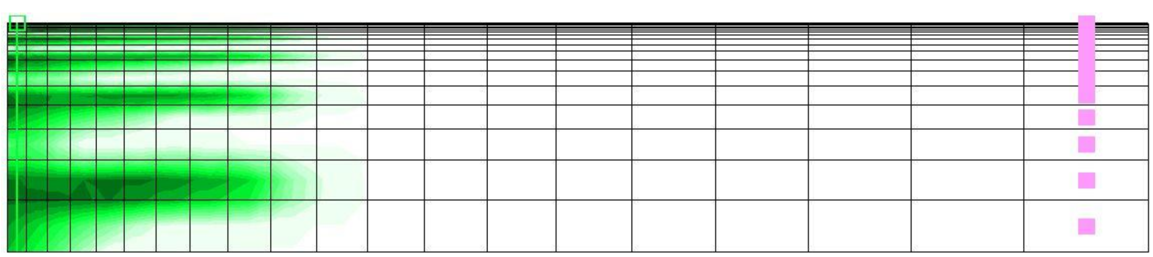
Model Run #1: 5mD Sandstone with No Shale



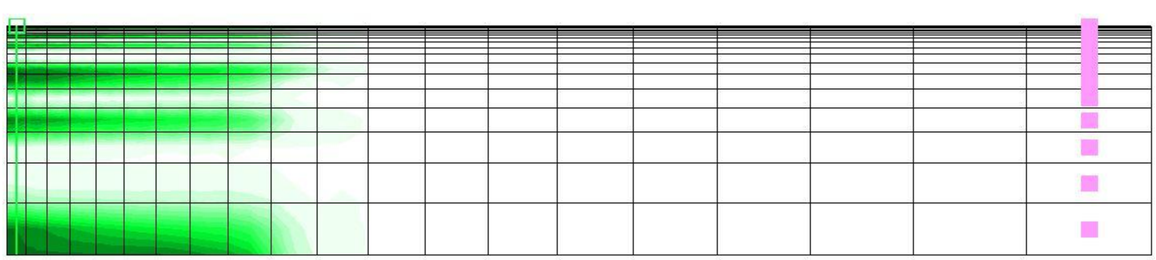
Model Run #2: 50mD Sandstone with No Shale



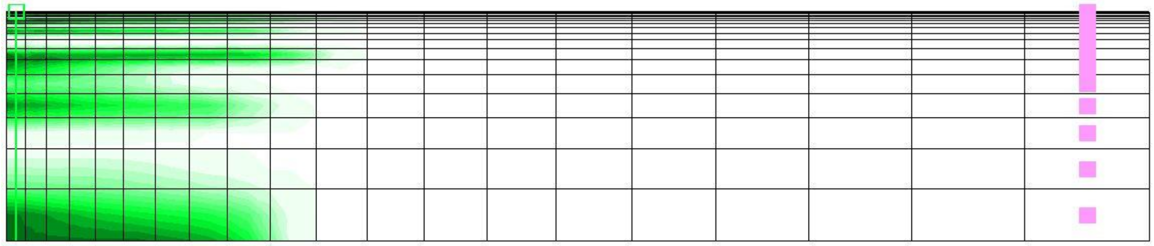
Model Run #3: 5mD Sandstone with 25% Shale



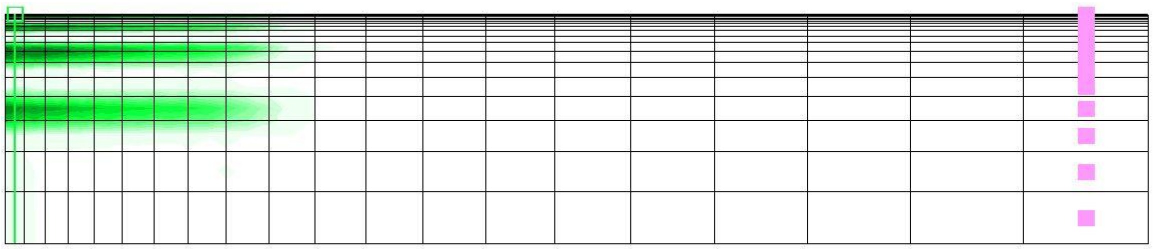
Model Run #4: 50mD Sandstone with 25% Shale



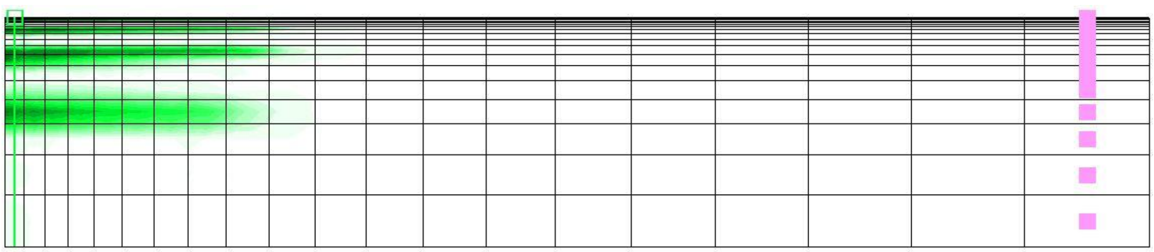
Model Run #5: 5mD Sandstone with 50% Shale



Model Run #6: 50mD Sandstone with 50% Shale



Model Run #7: 5mD Sandstone with 75% Shale



Model Run #8: 50mD Sandstone with 75% Shale

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Vita

Brandon Keith Poiencot was born to parents Kyle and Glenda Reagan. Glenda made a career in the food service industry and Kyle continues his career in the United States Navy where he will retire in 2013. The U.S. Navy moved the family from Summerville , for four years, where Brandon's sister, Kaitlynn Rhea Reagan, was born. Two years later the family moved to Jacksonville, Fla., where they have remained.

Brandon graduated high school and started college at the University of Central Florida in August 2000. Brandon would eventually earn a Bachelor of Science in Civil Engineering from the University of North Florida (UNF) in May 2007. Jones Edmunds & Associates, Inc. hired Brandon full-time as a civil engineer where he mostly performed work related to the design and permitting of water and wastewater treatment facilities and stormwater collection systems. In August 2010, he began pursuing a Master of Science degree at UNF.

Brandon continued his studies in civil engineering with a focus on water resources and environmental engineering. Graduate research work led to the topic of this thesis. Along the way to the completion of this thesis, Brandon has either been primary author or co-author for four published articles and two conference presentations. In December 2011, Brandon began working as a student intern with Golder Associates, Inc. and will start working full-time in May 2012.