AMELIA RESOURCES

Tuscaloosa Marine Shale

The Significance of Resistivity

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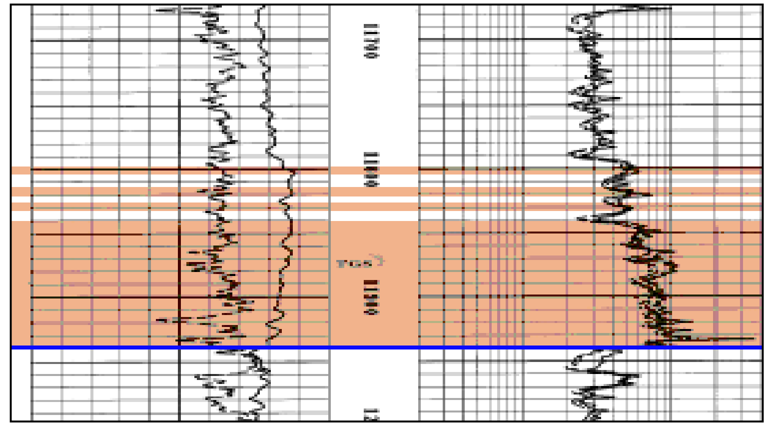
Discussion

Resistivity is one well log parameter that exhibits variability across the Tuscaloosa Marine Shale (TMS) Play. Higher resistivities, averaging 7 ohm-m, exist consistently across the area of the Louisiana-Mississippi state line in Wilkinson and Amites Counties, West and East Feliciana, St. Helena, and Tangipahoa Parishes. To the east in Washington Parish, resistivities are lower in the 2.5 ohm-m range. To the west in Rapides and Vernon Parish, resistivities average 3-5 ohm-m.

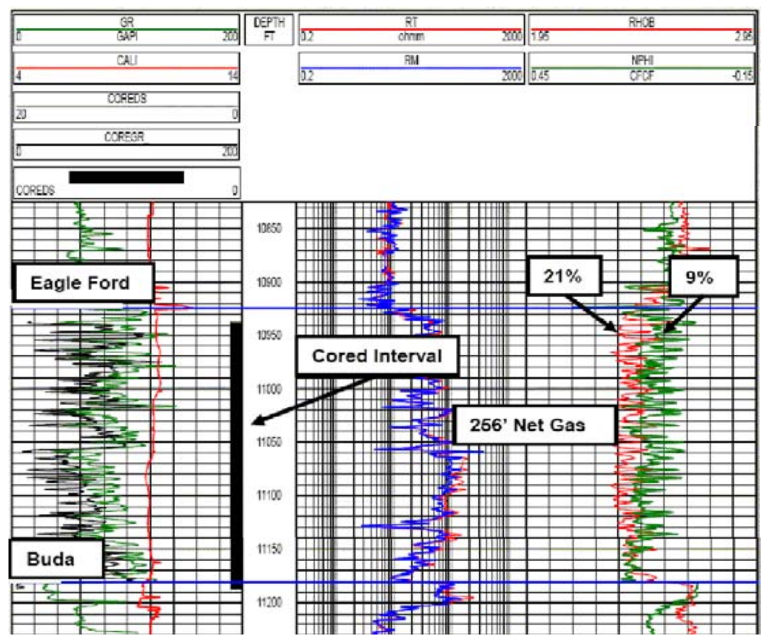
Resistivities in the Eagle Ford Shale of South Texas are much higher than those in the TMS mostly due to the abundance of calcareous material. Resistivities can be influenced by numerous factors and the reason for the variance in the TMS is still unknown.

The TMS sequence stratigraphically represents part of the Transgressive Systems Tract (TST) of the "A" Sequence. The top of the TMS is more marine than the base and subsequently, the basal portion tends to be more silty and calcareous. In the deeper portion of the play near the Lower Cretaceous Shelf Margin, the basal portion becomes very calcareous and is known locally as the Pilot Lime. An increase in silt and calcareous material would likely result in higher resistivities.

Tuscaloosa Marine Shale



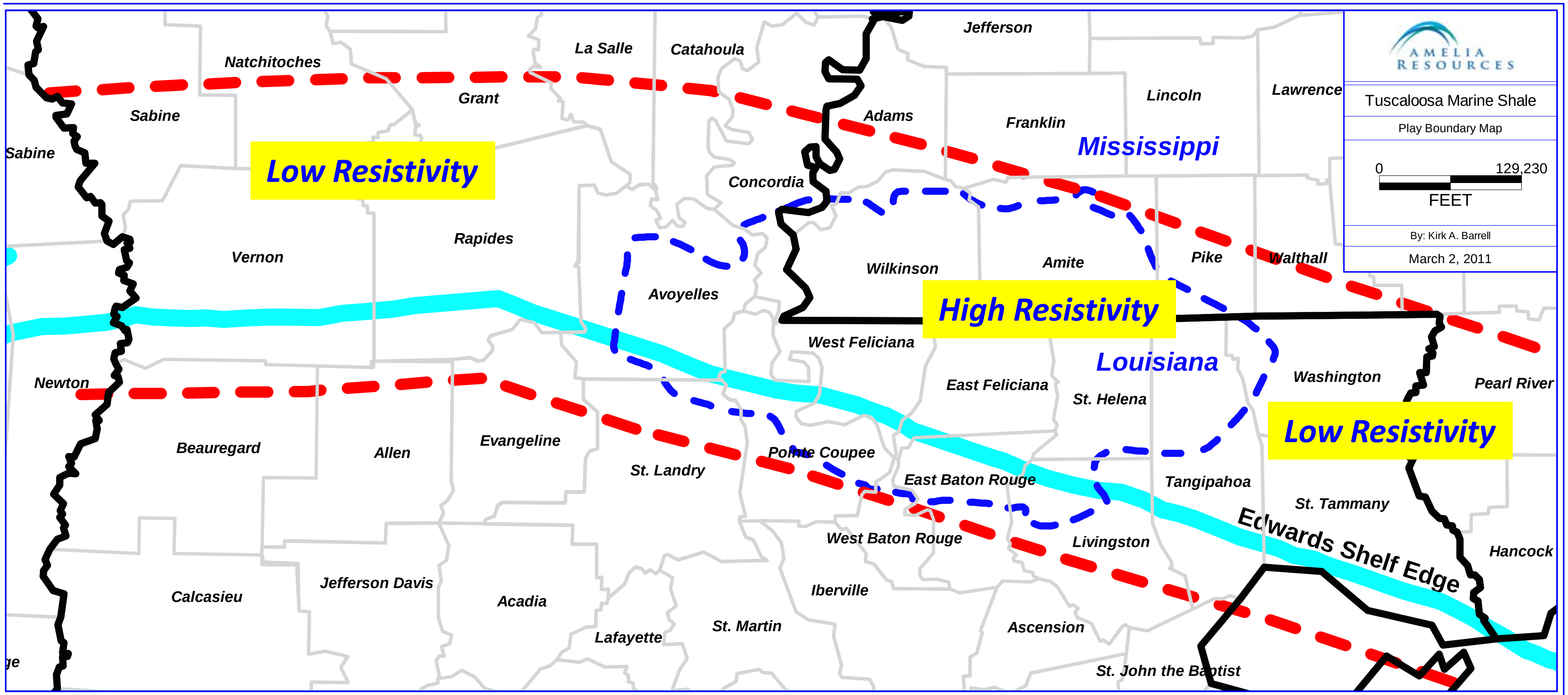
Eagle Ford Shale – S. Texas



Source: Petrohawk

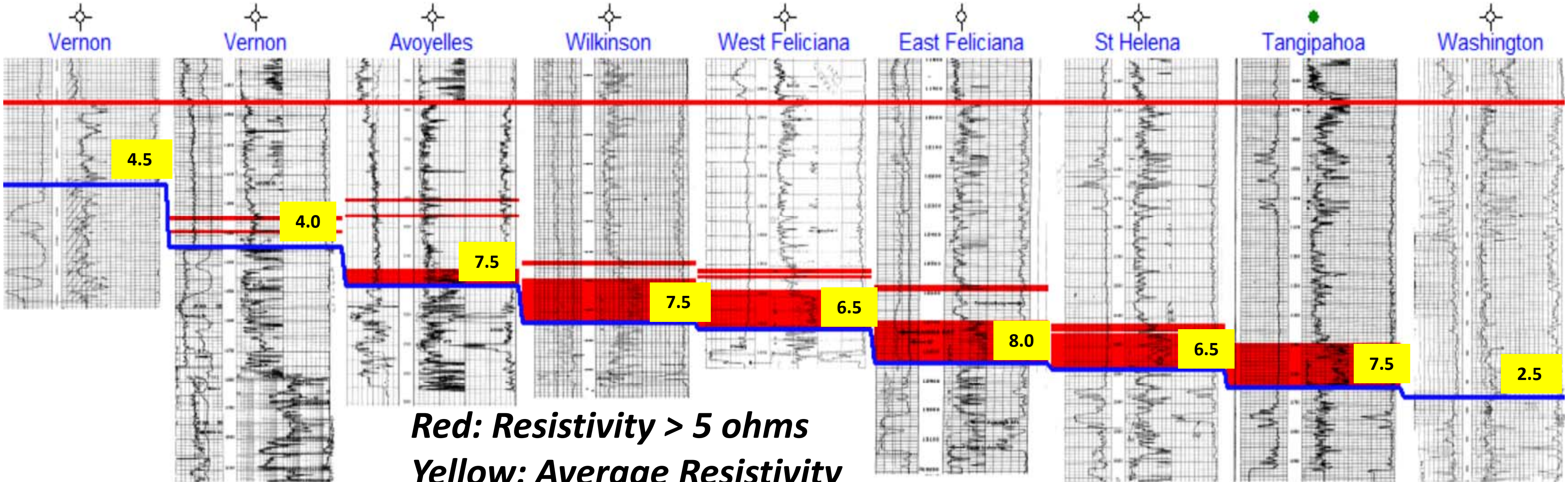
Tuscaloosa Marine Shale

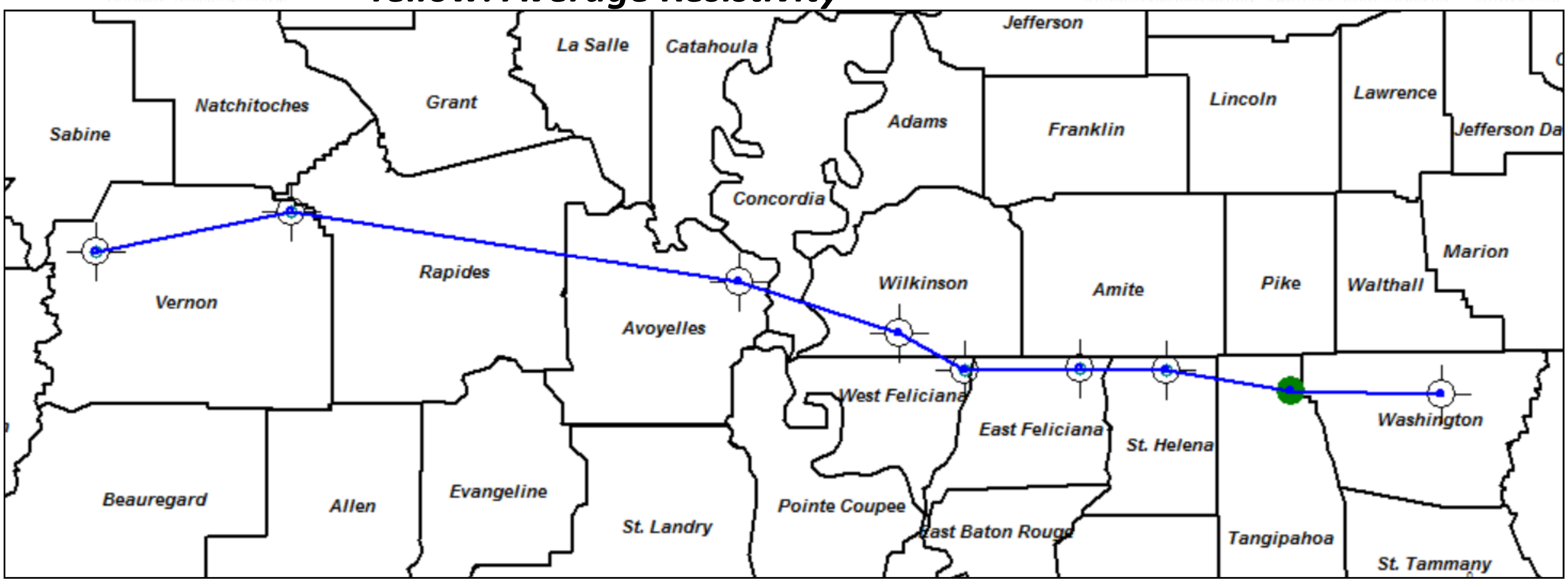
Play Boundary Map – Resistivity Trends



Regional Strike Stratigraphic Cross Section

Tuscaloosa Marine Shale – Average Resistivities





Kreis and Costa, in their 2005 paper "Hydrocarbon Potential of the Bakken and Torquay Formations, Southeastern Saskatchewan", address the variabilities of resistivity in the Bakken Formation.

> *In places, the Upper and Lower Member shales of the Bakken Formation show very high resistivity values (Figures 3 and 4) that are attributed to the presence of oil which has replaced conductive pore waters. With continued oil replacement, oil saturation increases to produce progressively higher formation resistivity values. Other rock characteristics such as mineralogy, porosity, tortuosity, and the salinity of water within pore volume also contribute to the resistivity-log response of the shale, but these parameters are apparently secondary to the presence of oil in the shales (Schmoker and Hester, 1990). Although resistivity values do not distinguish whether oil has been generated in situ within the shales at a given location or has migrated into or within the shales, extensive Bakken core research by Schmoker and Hester (1990) has indicated that a resistivity value of greater than 35 ohm-m coincides with the onset of observable oil generation within Bakken shale. Resistivity values for Upper and Lower Member shales were mapped in southeastern Saskatchewan (Figures 3 and 4) using only deep-reading laterologs and without applying borehole or environmental corrections. Areas having resistivity values in excess of 35 ohm-m in the Upper Member shale oversteps that of the Lower Member shale.*
>
> *It is noteworthy that the area of highest resistivities for Upper and Lower Bakken shales is located immediately north and west of the Nesson Anticline, a feature associated with the region of enhanced hydrocarbon generation in the United States and spatially located within the Trans Hudson Orogen (Kreis and Kent, 2000). This region has been documented to have anomalously high heat flow, probably related to basement tectonics (Majorowicz et al., 1986; Majorowicz et al., 1988), and enhanced hydrocarbon generation (Osadetz and Snowdon, 1995). A northeastsouthwest–striking trend of exceptionally high resistivities (e.g., 8-13-1-10W2 reads over 25 000 ohm-m in the Upper Member shale) is recognized on the Upper Member shale resistivity map, and is parallel to, and possibly a northeasterly extension of, the Brockton-Froid-Fromberg Fault Zone (Figure 4). Also, the salt-free area known as the Hummingbird Trough, where tectonic stress concentrations might be expected, is coincident with a region of anomalous resistivity values in both Upper and Lower Bakken shales. Recognition of these structural and resistivity trends has implications for hydrocarbon exploration in this area.*
>
> *Reservoir quality in Middle Bakken sandstones and siltstones is generally fair to poor. Porosity usually ranges from 5 to 15%, but can reach over 20% in some locales such as in the Rocanville Pool in Tp 15 and 16, Rge 31W1. Permeabilities commonly range from 1 to 20 md. The relatively low permeability of these rocks suggests they might best be developed using horizontal completion programs.*

Historically, exploration companies have targeted "clean" (i.e., generally low argillaceous content) sandstones with relatively high geophysical log resistivities as their primary reservoir in southern areas near to the U.S. border. However, perforated intervals of high resistivity are commonly calcite-cemented sandstone with moderate to poor reservoir characteristics. Careful examination of numerous cores in this study has shown that, where present, the "dirtier" (i.e., more silty and argillaceous) sandstone immediately overlying the calcite-cemented lower portion of unit B often shows a faint oil stain that produces a strong milk-white cut but gives a very low resistivity on geophysical logs (i.e., 1.5 to 3 ohm-m). When completing the calcite-cemented portion of the Middle Bakken, companies have regularly fractured and sometimes acidized the interval in an effort to enhance production, but they have often ignored the immediately overlying non-calcite-cemented "dirty" sandstone (Kreis et al., 2005). Resistivity values over this upper interval are only a few ohm-m but a faint oil stain and strong milk-white cuts were observed.

Worthington (2000) discusses factors controlling low-resistivity pay zones citing numerous examples from around the world. He indicates that the low-resistivity pay problem is focused upon the inability to accurately evaluate water saturations from a resistivity log in certain circumstances. He suggests that this problem is most common in reservoirs displaying one or more of the following characteristics: laminated sandstones and shales, fresh waters, conductive minerals, fine-grained sandstones, and microporosity. Careful examination of core in this study suggests that Middle Member reservoirs often show many of these characteristics. The Middle Member sandstone is commonly silty, argillaceous, very fine grained, interlaminated, and abundantly pyritiferous. For these reasons, it appears that considerable potential exists for by-passed pay in the Bakken Formation, and that care must be taken in evaluating the prospectivity of a Middle Member reservoir from geophysical logs. It should be noted that, over the Middle Member producing intervals, low-resistivity readings (i.e., <5 ohm-m) are often observed from rocks such as those described above. For example, a core from an oil-producing Middle Member sandstone in the 7-6-8-8W2 well of the Viewfield Pool shows a very silty, argillaceous, weakly interlaminated to massive, very fine-grained quartz sandstone with abundant pyrite over the perforated interval. Over most of this interval, a faint light brown oil stain is present, yet resistivity values range from only 3.4 to 4.7 ohm-m.

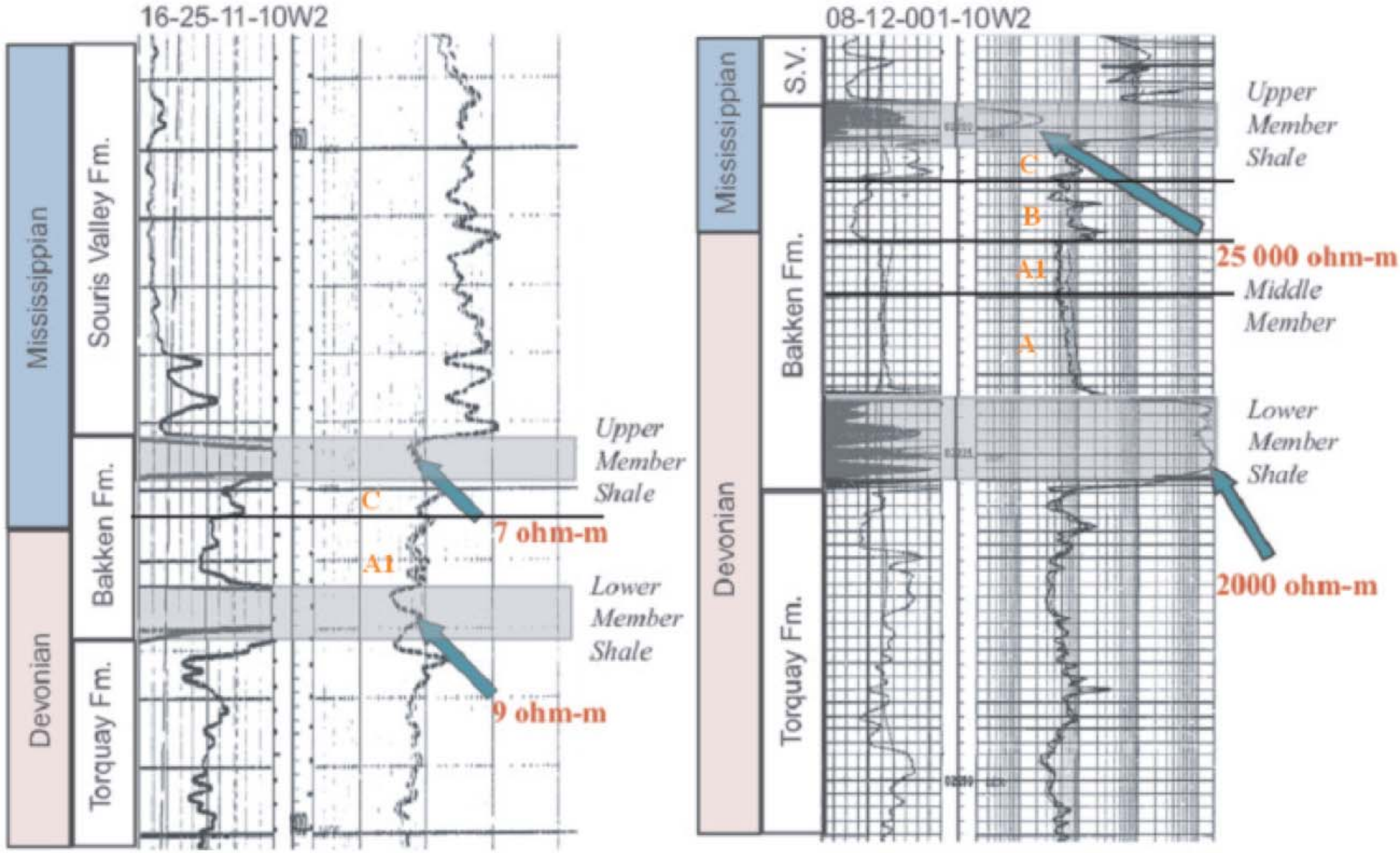


Figure 4 - Resistivity logs showing normal (left) and anomalous (right) readings in the Upper and Lower Member shales of the Bakken Formation. Units A1, B, and C are defined in the text.

Entire Paper: http://www.mogulenergy.com/pdf/EGYPT_hydrocarbon.pdf

Kreis, L.K. and Costa, A. (2005): Hydrocarbon potential of the Bakken and Torquay formations, southeastern Saskatchewan; in Summary of Investigations 2005, Volume 1, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 2005-4.1, CD-ROM, Paper A-10, 10p.

E.R. Crain states the following about the Bakken:

The Bakken formation in the Williston Basin of Saskatchewan, Manitoba, and North Dakota is a classic silt and sandy silt. It is low resistivity due to high salinity formation water with high irreducible water saturation (caused by very fine grain size), and the lithology is a mix of quartz and dolomite (and sometimes calcite). In Alberta and Montana, the Bakken equivalent, the Exshaw, and adjacent formations (Banff / Lodgepole and Big Valley /Three Forks) are "Tight Oil" prospects, as are the Duvernay, Second White Specks, Nordegg, and other formerly unattractive low porosity reservoirs.

In Saskatchewan, the naturally low resistivity in Bakken pay zones is further aggravated by thin clay laminations, clay filled burrows, laminated porosity, and dispersed pyrite. Even more confusing is the water resistivity variation on the northwest and northeast edges of the Basin. Here, wet wells have higher resistivity than oil wells further south because the water resistivity is 5 to 20 times higher than deeper in the Basin. This results from fresher water recharge from the Black Hills of North Dakota. An adequate production testing program is the only solution to this issue, as there is no log analysis model that will predict water resistivity in this reservoir.

Water salinity in the deeper North Dakota wells reaches 325,000 ppm, making for exceedingly low water resistivity. In Saskatchewan, salinity is usually at 200,000 ppm or more, but can be as low as 25,000 in the recharge area. Pore geometry in the deeper parts is more intergranular in texture and irreducible water saturation is lower than in Saskatchewan. Typical SW in Saskatchewan averages 50% grading southward to about 30% in the deeper North Dakota wells. Very low apparent SW in Saskatchewan usually means fresh water recharge, possibly with some residual oil. The "best-looking" wells are actually water producers, but have measured resistivity values 2 to 4 times higher than productive oil wells. Water resistivity values are sparse, so any water recovery should be sent to the lab and analyzed.

The low resistivity, high radioactivity, large density neutron separation caused by dolomite and pyrite, and the high PE value (near 3) conspire to make the zone look like shale on logs. Worse, some literature continues to name the producing zone the Bakken Shale, even though we know the Middle Bakken is a radioactive dolomitic sand or siltstone. These conflicts in the conventional data suggest strongly that some special core analysis should be done, namely electrical properties, capillary pressure, X-Ray diffraction and thin section mineralogy, and anything else that can help explain the petrophysical response to these complex rocks.

The Bakken is now the biggest oil play in North America, and may ultimately be the largest ever found, even larger than Alaska North Slope. It is sometimes termed an "unconventional" reservoir, due to the low permeability of the siltstone intervals. In North Dakota, it is also called a "resource" play because the oil was formed in place (from the Upper and Lower Bakken Shales), although in Saskatchewan the oil migrated from the deeper parts of the basin, and is not strictly speaking a resource play there. Alberta and Montana is also probably a resource play, but few facts have been published so it is hard to tell.

Vertical wells are not overly prolific due to the low intrinsic permeability of the silty sand, but most horizontal wells do OK. In the deep, hot, over-pressured region in North Dakota, some wells are flowing 1000 to 2000 barrels per day.

Pyrite is a conductive metallic mineral that may occur in many different sedimentary rocks. It can reduce measured resistivity, thus

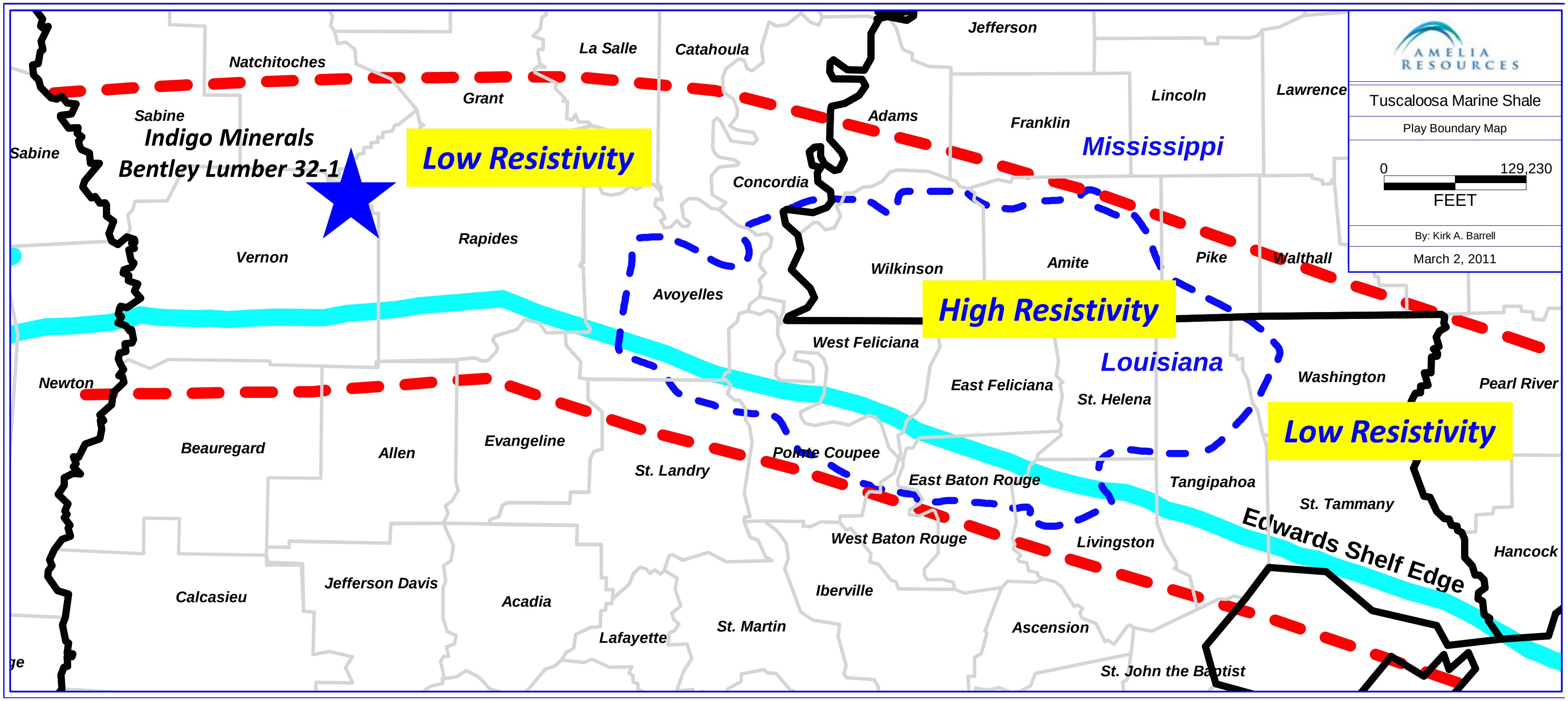
increasing apparent water saturation. The conductive metallic current path is in parallel with the ionic water conductive path. As a result, a correction to the measured resistivity can be made by solving the parallel resistivity circuit.
Although the math is simple, the parameters needed are not well known. The two critical elements are the volume of pyrite and the effective resistivity of pyrite. Pyrite volume can be found from a two or three mineral model, calibrated by thin section point counts or X-ray diffraction data.

The resistivity of pyrite varies with the frequency of the logging tool measurement system. Laterologs measure resistivity at less than 100 Hz, induction logs at 20 KHz, and LWD tools at 2 MHz. Higher frequency tools record lower resistivity than low frequency tools for the same concentration of pyrite. The variation in resistivity is caused by the fact that pyrite is a semiconductor, not a metallic conductor. It is nature's original transistor, and formed the main sensing component in early radios.

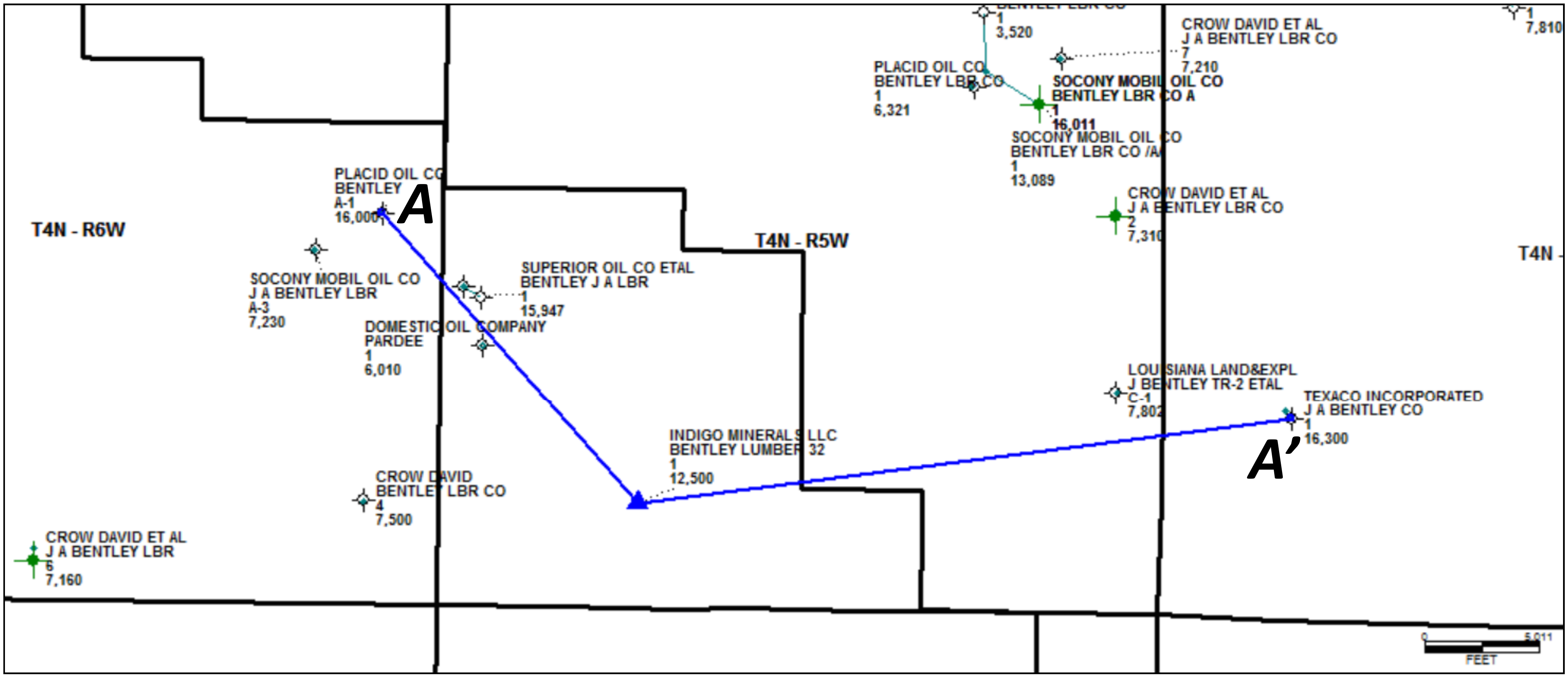
Typical resistivity of pyrite is in the range of 0.1 to 1.0 ohm-m; 0.5 ohm-m seems to work reasonably well. The effect of pyrite is most noticeable when RW is moderately high and less noticeable when RW is very low. The corrected resistivity can be plotted versus depth, along with the original log. Corrected water saturation will always be lower or equal to the original Sw. If CONDcorr goes negative, lower Vpyr or raise RE.

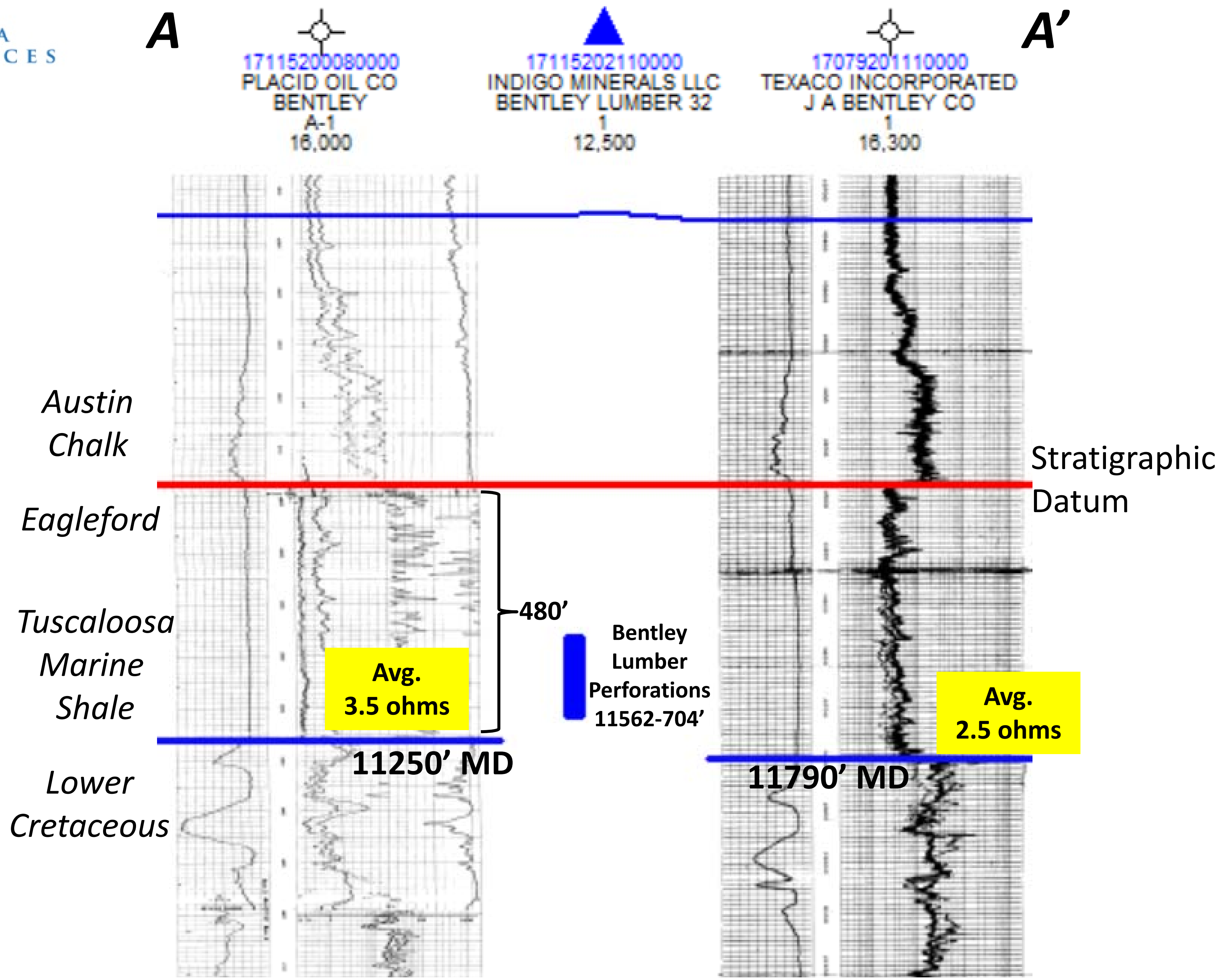
Source: Crain's Petrophysical Handbook; http://www.spec2000.net/18-tightoil.htm

The Indigo Minerals LLC Bentley Lumber 32-1 is the most recent Tuscaloosa Marine Shale test. The well was spud on 11-27-10 and was recently completed and hydraulically fractured in the vertical wellbore. As of 3-15-11, results are unknown. The well is located in the northeastern corner of Vernon Parish in the area of the play exhibiting lower resistivities averaging 2.5-3.5 ohm-m. This well has the potential to prove that lower resistivities are productive and economically attractive. If so, the geographic area of interest in this play will expand significantly.



Cross Section Map

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Avg. 2.5 ohms
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