Identifying Reservoir Development in Carbonate Rocks by Qualitative Analysis of the Spontaneous Potential Curve: Example from the Caddo Limestone of Western Jack County, Texas*

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Abstract

A significant portion of the world's hydrocarbon reserves are found in carbonate reservoirs. North and West Central Texas have seen oil and gas fields produced from multiple limestone formations. Many of the early discoveries were made when logging suites consisted of only a resistivity log with a spontaneous potential curve.

The spontaneous potential curve, also referred to as the SP Curve, can detect permeable beds. The only requirements are a conductive wellbore fluid, a porous and permeable bed sandwiched between low or impermeable beds, a difference in salinity between the borehole fluid and the formation fluid and lastly, the fluid salinity needs to be the same within the permeable bed and the upper and lower bounding, low or impermeable beds.

The Caddo Limestone produces hydrocarbons in Jack County, Texas. Many of the wells drilled through the Caddo, were drilled prior to the advent of the density log. Many of the recently drilled wells only release to the public the induction log, containing a SP curve and possibly a Gamma Ray. Therefore, in many cases, the only publicly available log is a resistivity log with spontaneous potential curve.

The SP curve can be qualitatively analyzed as being poor, fair, good or excellent depending on the deflection of the curve in the formation of interest. Little to no deflection is considered poor and is referred to as the baseline. As the SP curve deflects from the baseline the reservoir class will change from poor, to fair, to good and in extreme cases as excellent.

The SP curve can be compared with the SP in other well logs, by normalizing the SP log grid scale. By using the same grid scale for all well logs, the SP can be directly compared. The magnitude of the grid units is immaterial, as long as the same unit is used for all well logs. A prospect lead was identified in west central Jack County by integrating the Caddo Limestone structure, isopach and reservoir characterization maps. Six wells were drilled on the prospect and have produced a combined total of 285,135 BO and 868,111 MCF since July 2008.

Selected References

Darby, James R., 1984, Limestones of the Mid-Continent: Tulsa Geological Society, Special Publication No. 2, p. 1.

Schlumberger, Global Map of Carbonate Reservoirs. Website accessed April 28, 2019. https://www.slb.com/services/technical_challenges/carbonates.aspx

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**To explore for carbonate reservoirs,
John Bradley of Amoco Research advised
that a prospector should**

"Just look for a fat limestone with holes in it".*

**The difficulty in exploring for carbonate reservoirs
is identifying where the rocks have holes.**

*** - Limestones of the Mid-Continent, Tulsa Geological Society**

The USA's first ever well log is performed in 1929, by Schlumberger, in Kern County, California.

Schlumberger introduced the Spontaneous Potential Logs in 1931.

Lane Wells commercializes the Neutron Log in 1945.
Schlumberger introduces the Microlog in 1948.

The Density Log and Sonic Log were introduced in 1957.

Presenter's notes: Many of the early discoveries were made when logging suites consisted of only a resistivity log with a spontaneous potential curve. A smaller subset of logging suites might have contained curves from one or several of these tools; gamma ray, sonic or acoustic, microlog, or cased-hole neutron. Carbonate reservoir characterization prior to 1957, when the density log was introduced, was limited at best.

It is estimated that more than 60% of the world's oil and 40% of the world's gas reserves are held in carbonate reservoirs.

https://www.slb.com/services/technical_challenges/carbonates.aspx

North and West Central Texas have oil and gas fields which have produced from the Gunsight Limestone, Palo Pinto Limestone, Caddo Limestone, Marble Falls Limestone, and Miss Missippian Chappel Limestone, just to name a few carbonate formations.

Hydrocarbons were first produced from the Caddo Limestone in Stephens County Texas in 1916.

The Caddo Limestone is a major hydrocarbon producing formation in the Fort Worth Basin and Bend Arch Region. In this area, many of the wells, drilled through the Caddo, were drilled prior to the advent of the density log.

Recently drilled wells may contain an induction log combined with a density-neutron log. But the induction log, containing resistivity, SP and possibly Gamma Ray curves, is commonly the only log released to the public. Therefore, in many cases the only publicly available log is a resistivity log with a spontaneous potential curve.

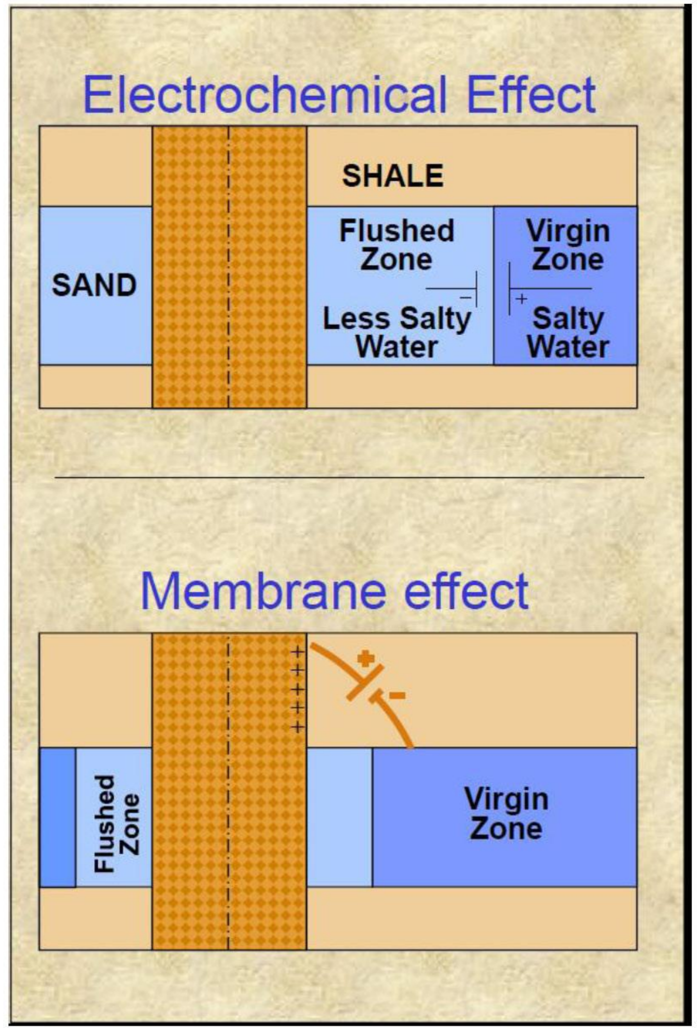
SP PRINCIPLES

- **Must have water-based mud**
- **Mud--formation water**
  salinity difference causes battery effect

- **Battery effect components**
  - Electrochemical
    - Liquid Junction Potential, E_j
    - In permeable region
    - Anions more mobile than cations

    - Membrane Effect, E_m
    - Shale acts as membrane
    - Repels anions / passes cations

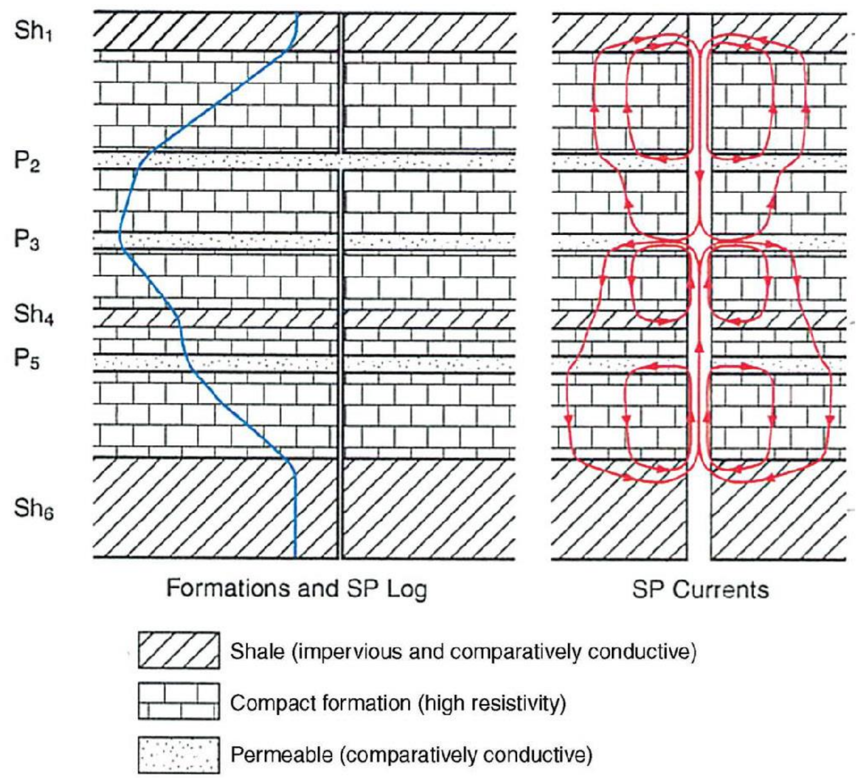
  - Electrokinetic (Streaming)
    - Usually minor, disregarded



TEXAS A&M 2010

Presenter's notes: The spontaneous potential curve, also referred to as the SP Curve, can detect permeable beds. The only requirements are a conductive well bore fluid (i.e. water-based mud), a porous and permeable bed sandwiched between low or impermeable beds, a difference in salinity between the bore hole fluid and the formation fluid and lastly, the fluid salinity needs to be the same within the permeable bed and the upper and lower bounding, low or impermeable beds.

SPONTANEOUS POTENTIAL CURVE IN HIGH RESISTIVITY FORMATIONS



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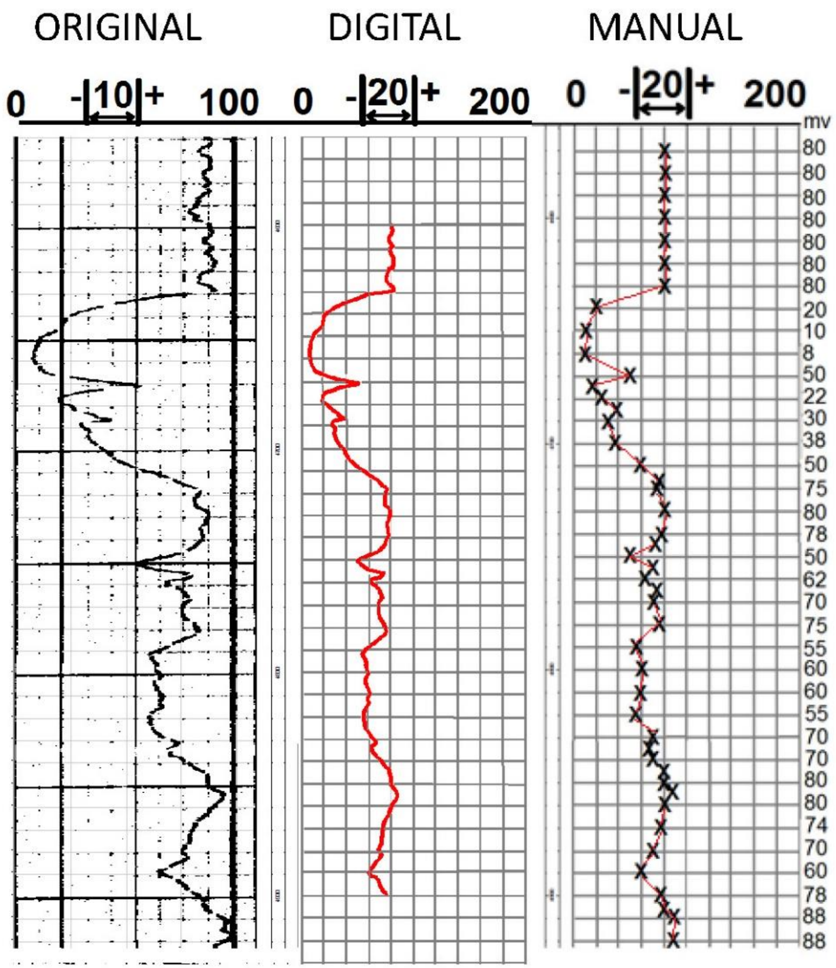
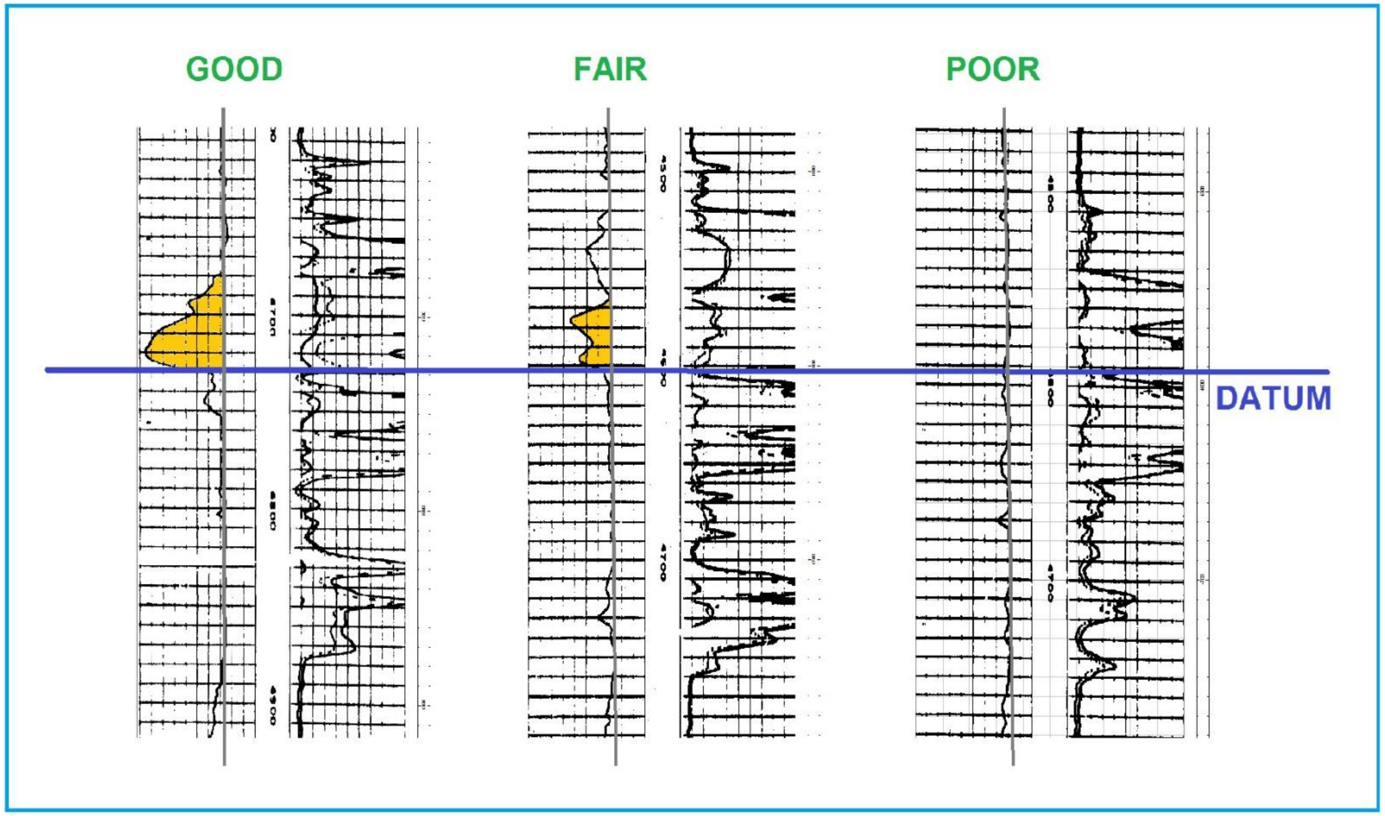
Presenter's notes: In highly resistive formations, the SP curve may have an irregular shape, but if permeable beds are still present, the SP curve will show a deflection related to the permeable intervals.

NORMALIZATION OF THE SPONTANEOUS POTENTIAL CURVE



Presenter's notes: The SP curve can be compared with the SP in other well logs, by normalizing the SP log grid scale. By using the same grid scale for all well logs, the SP can be directly compared. The magnitude of the grid units is immaterial, as long as the same unit is used for all well logs.

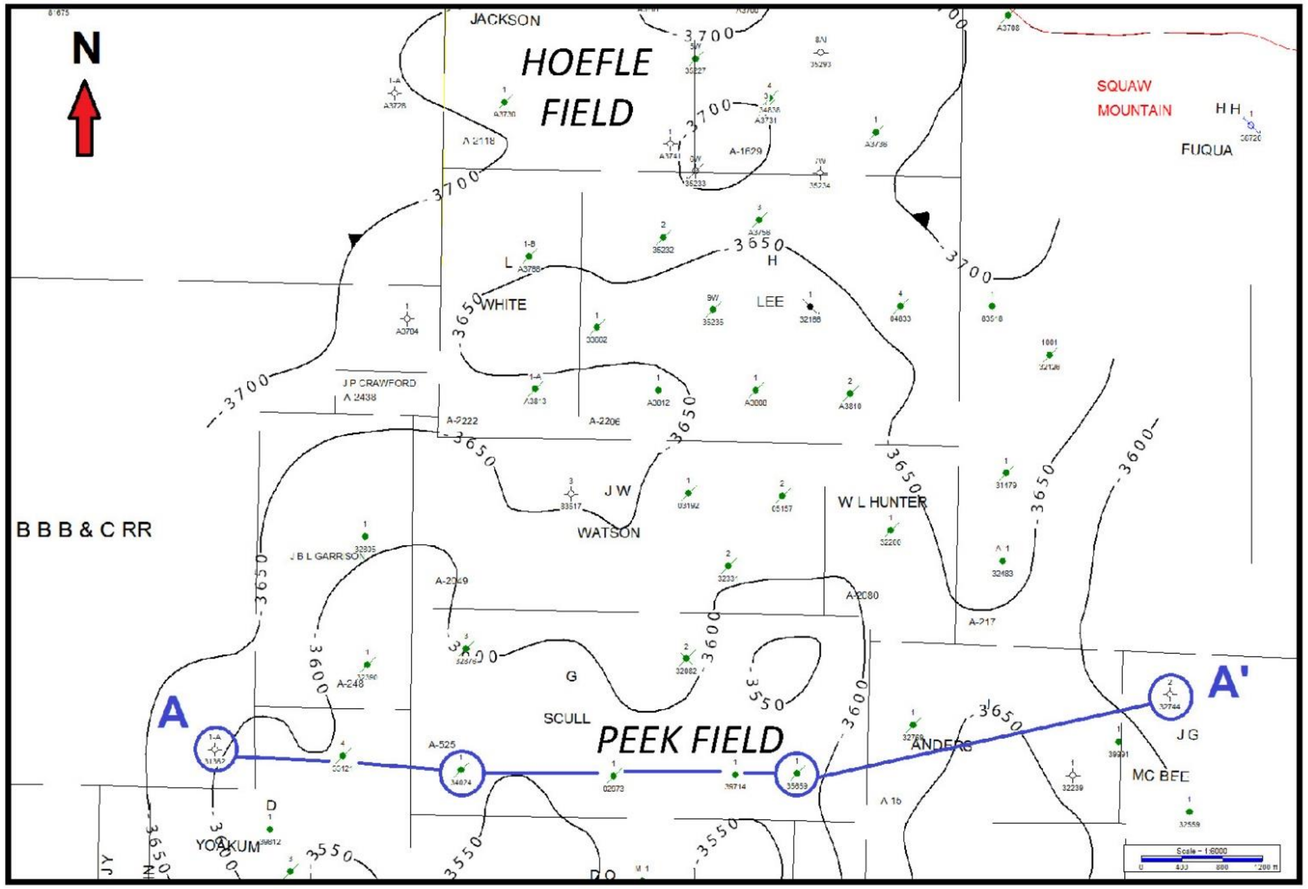
QUALITATIVE RANKING OF THE SPONTANEOUS POTENTIAL CURVE



Presenter's notes: In this study an attempt was made to utilize the SP curve to, "find the holes in the fat limestone". The SP curve can be qualitatively analyzed as being poor, fair, good or excellent depending on the deflection of the curve in the formation of interest. Where the formation is tight and impermeable, the SP curve will be approximately the same reading as the impermeable beds adjacent to the bed of interest. This reading is classified as poor and is referred to as the baseline. As the porosity and permeability of the formation increases, the SP curve will start to deflect away from the baseline. A moderate deflection is classified as fair. In better porosity and permeability, the SP curve will deflect further from the baseline and is classified as good and in extreme cases as excellent.

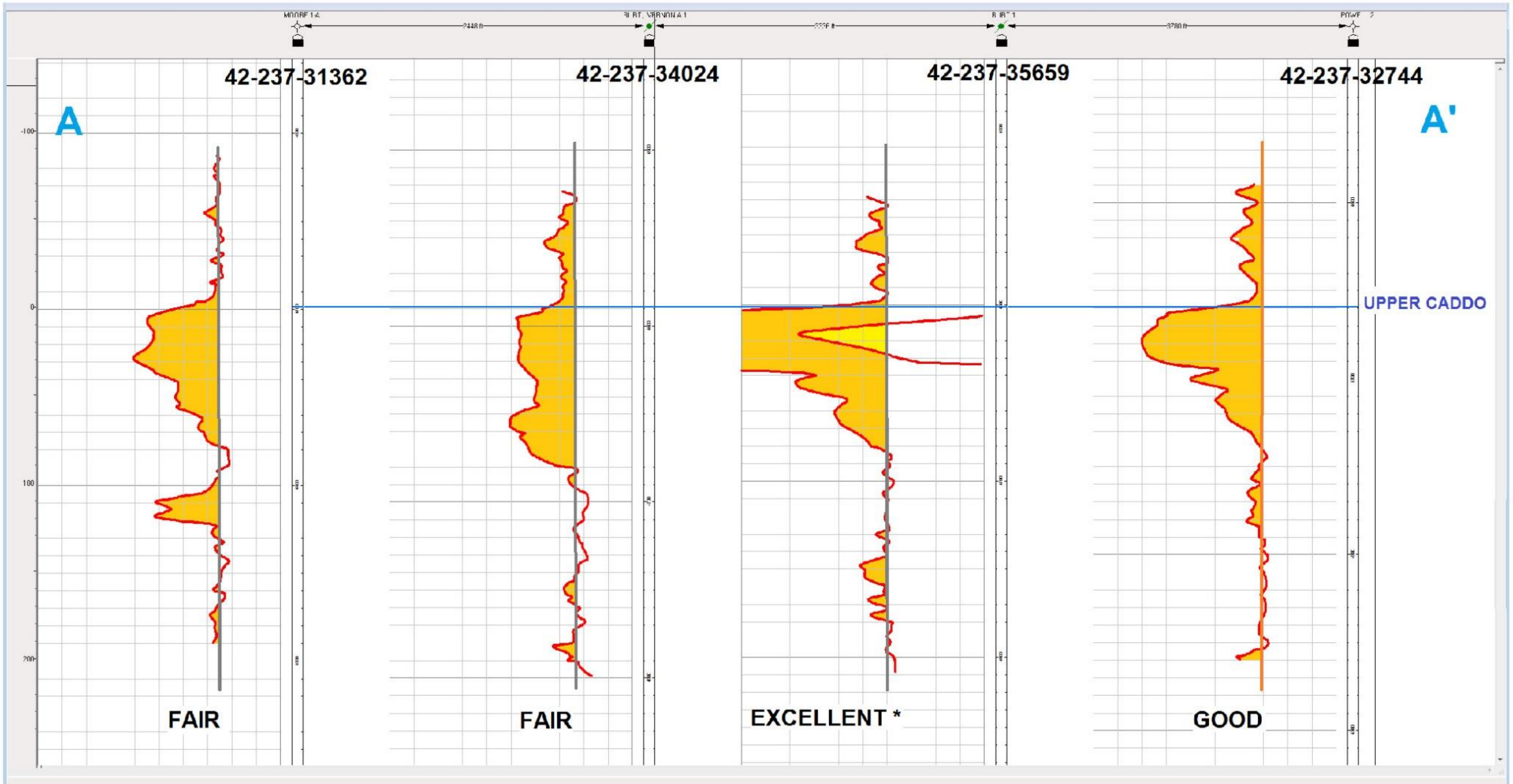
**It must be noted that when the SP curve has an extreme deflection, possibly "wrapping" back on the log grid, care must be taken, as this may be an indication of depletion in the subject reservoir.*

STRUCTURE MAP ON THE UPPER CADDO LIMESTONE



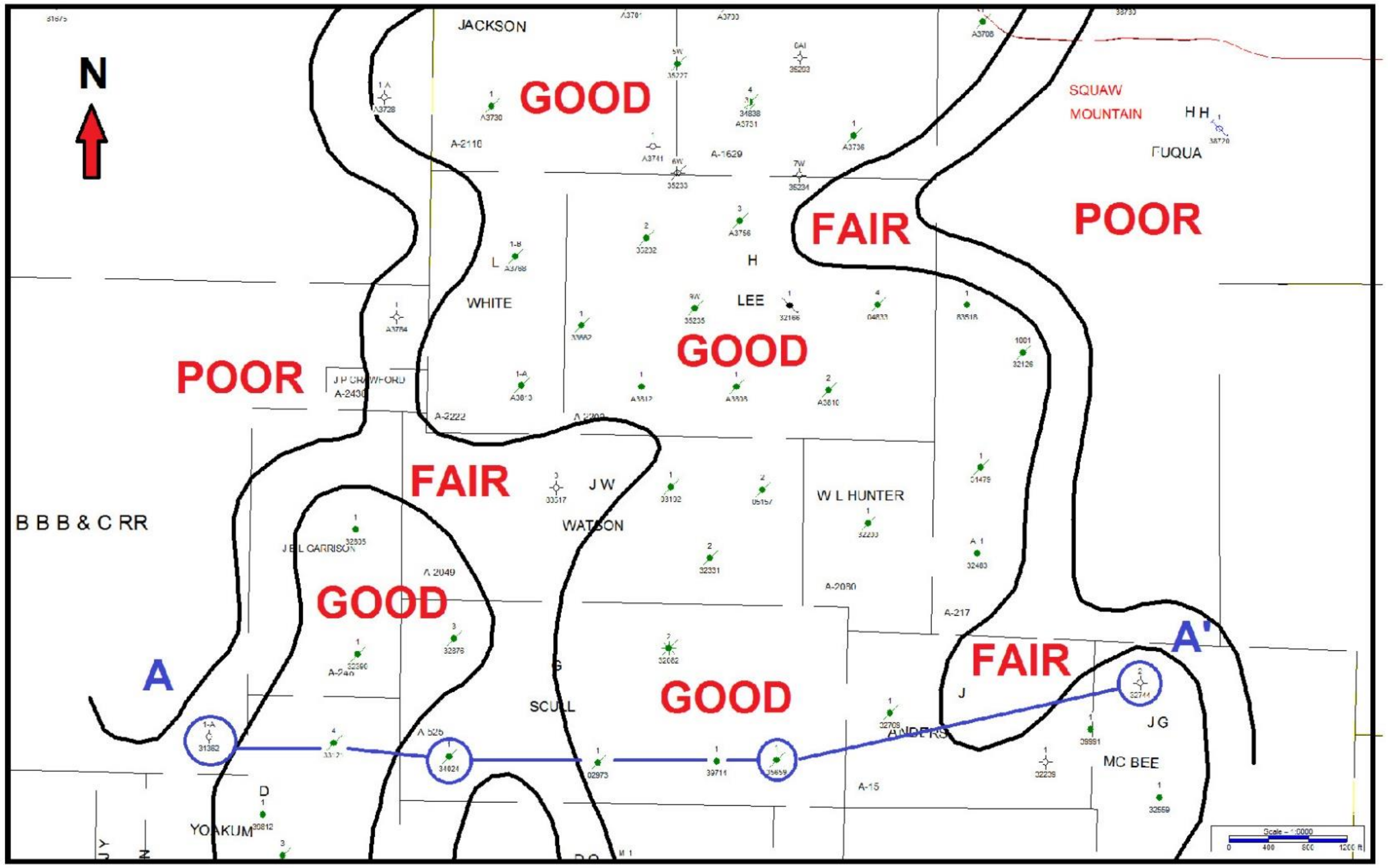
Presenter's notes: A structure map was prepared on top of the Upper Caddo Limestone reservoir in the Hoefle and Peek Caddo Fields of Northwest Jack County, Texas. The first wells were drilled in the Hoefle Field in the early 1940s. The two fields have combined to produce over 1,380,209 BO. A structural high with a north plunging nose can be observed. Stratigraphic cross section A-A' crosses the structural high at the bottom of the map.

STRATIGRAPHIC CROSS SECTION A-A’



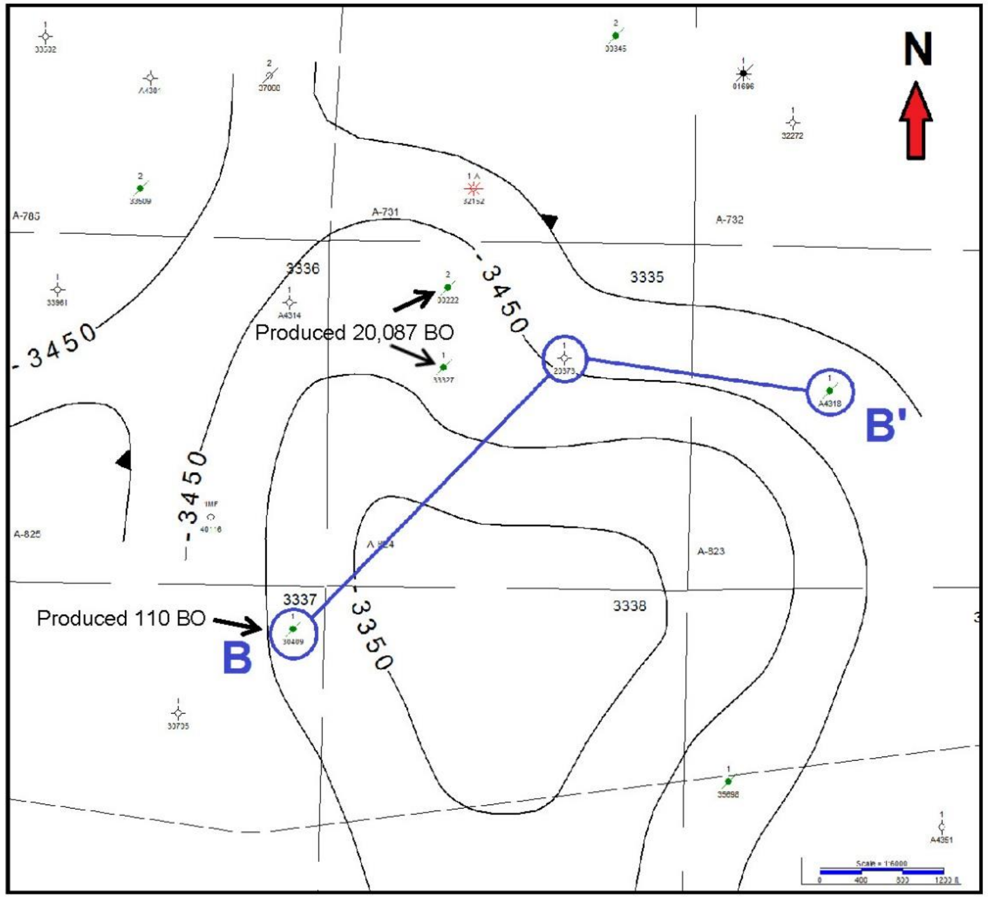
Presenter’s notes: By comparing the amplitude of the deflection between the shale line (or base line) and the SP curve for each well, a qualitative ranking system can be assigned to each well.

SPONTANEOUS POTENTIAL DEVELOPMENT IN THE UPPER CADDO LIMESTONE



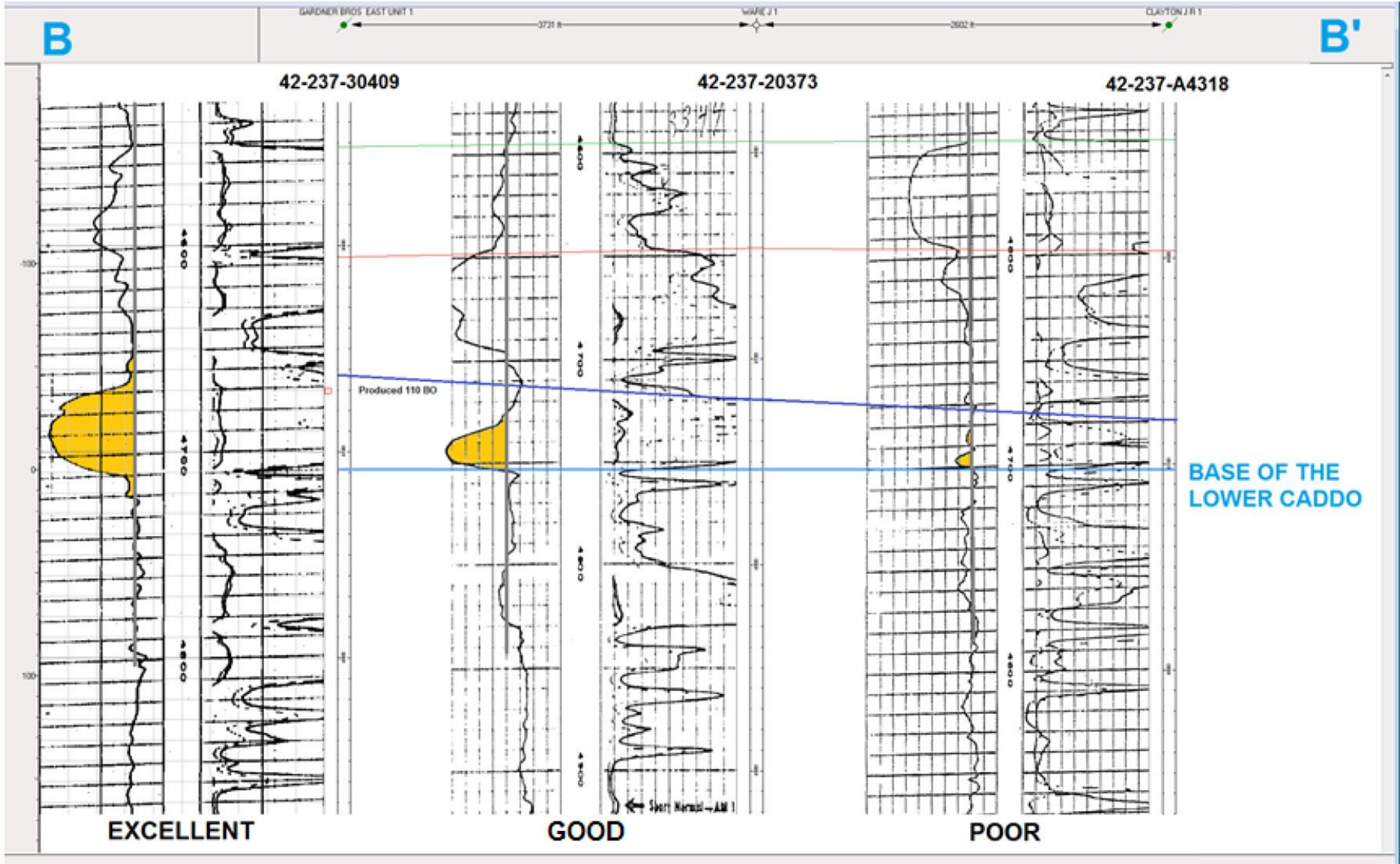
Presenter's notes: A map view of the distribution of the Upper Caddo reservoir development is prepared based on the SP development.

STRUCTURE MAP ON THE LOWER CADDO LIMESTONE PRE-DRILL



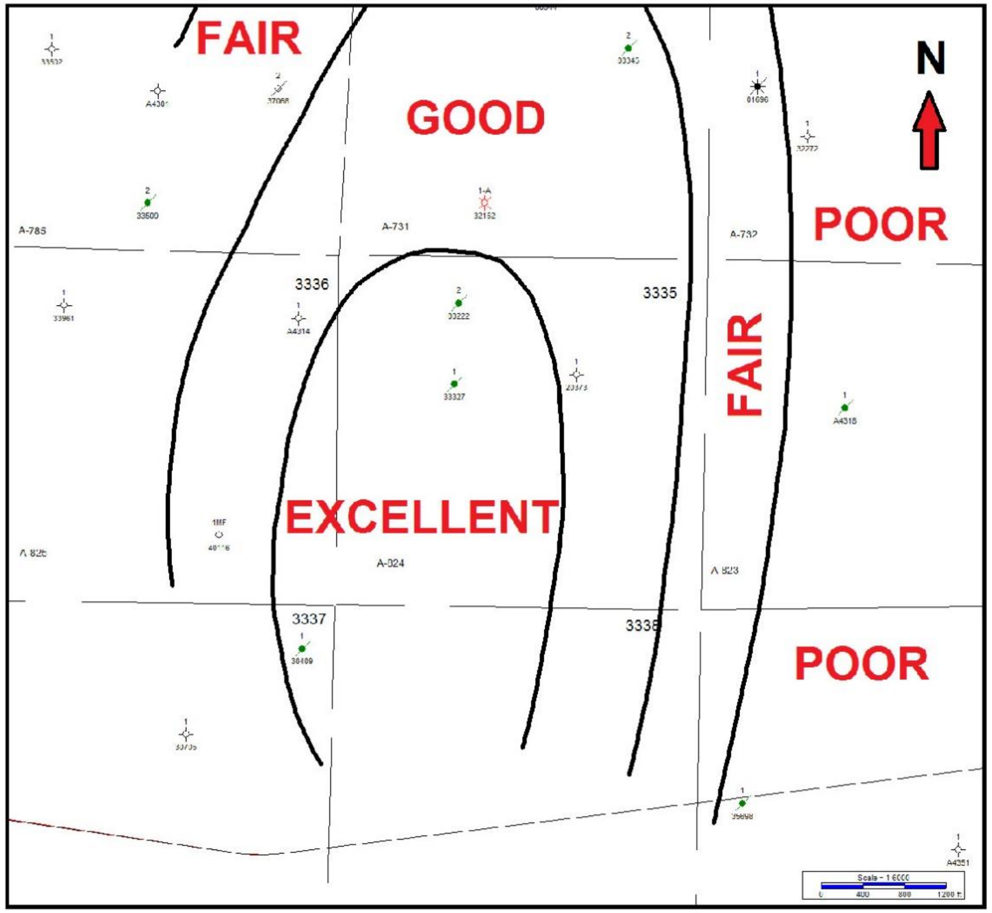
Presenter's notes: Regional mapping of the Caddo Limestone indicated a structure in west central Jack County. The structure map on top of the Lower Caddo Limestone marker reinforced the structural interpretation.

STRATIGRAPHIC CROSS SECTION B-B’



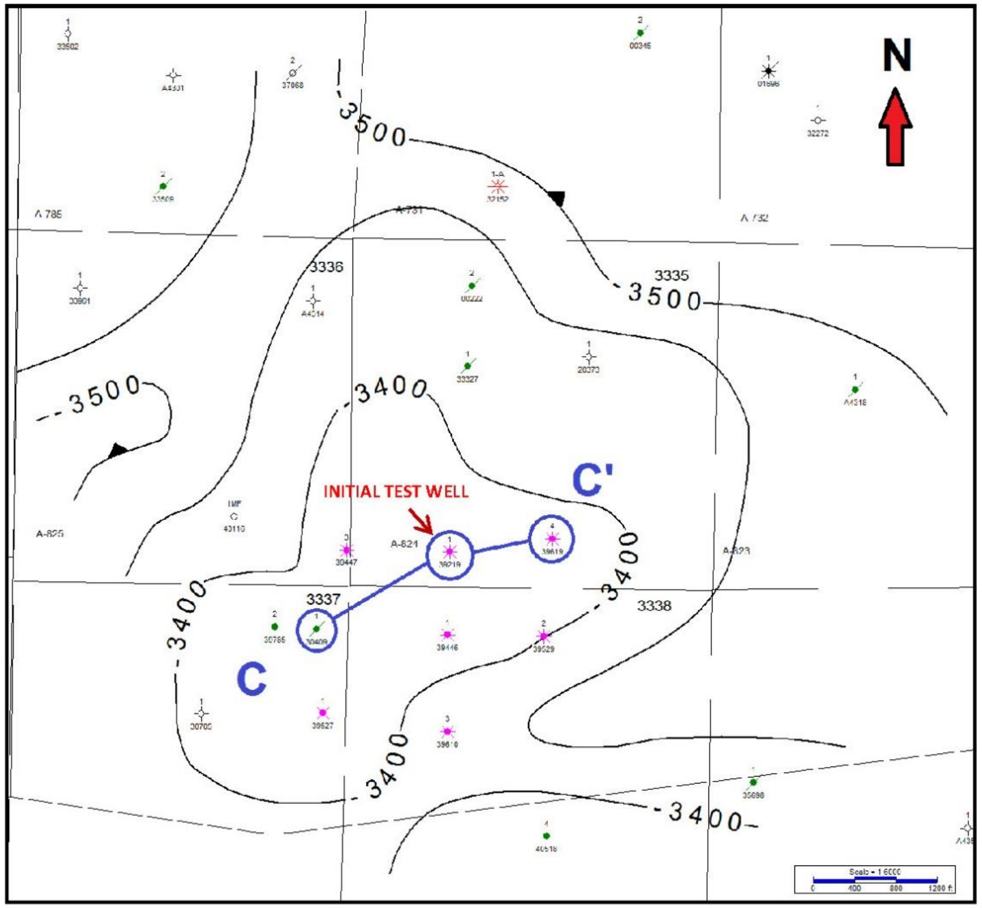
Presenter’s notes: Three wells on the structure contained oil shows. B-B’ is a stratigraphic cross section with a datum at the base of the Lower Caddo. Stratigraphic cross section B-B’ was created by correlating the well logs, normalizing the SP curves to a common grid scale, and qualitatively ranking the SP development in the area wells.

SPONTANEOUS POTENTIAL DEVELOPMENT IN THE LOWER CADDO LIMESTONE



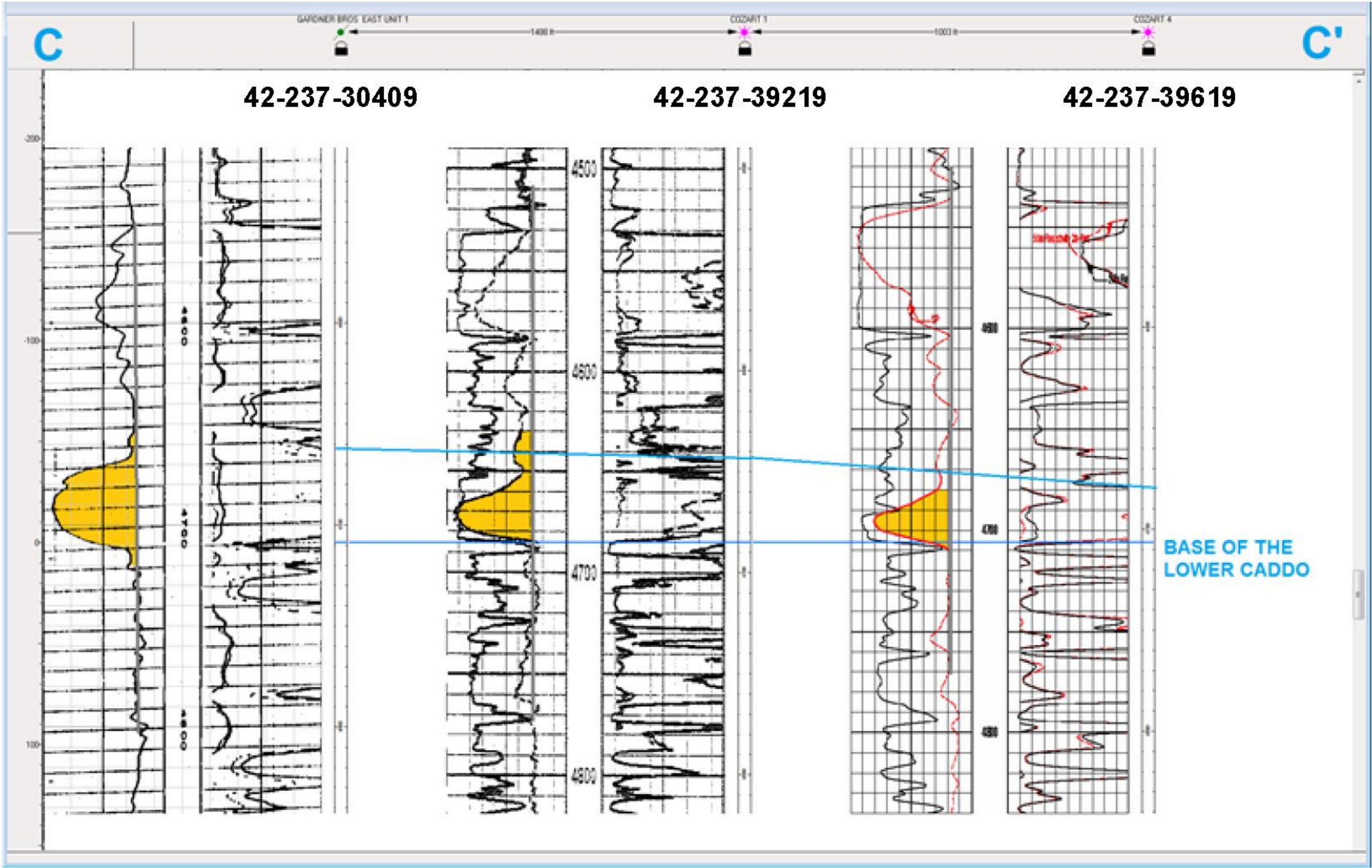
Presenter's notes: A reservoir characterization map was created using the qualitative analysis of the SP curve.

STRUCTURE MAP ON THE LOWER CADDO LIMESTONE POST DRILL



Presenter's notes: Based on the integration of the Caddo Limestone structure, isopach and reservoir characterization maps, a prospect lead was identified. The Lower Caddo structure map was revised with the development drilling.

STRATIGRAPHIC CROSS SECTION C-C’



Presenter’s notes: The initial well tested at the rate of 42 BOPD and 118 MCFPD. Five additional wells were drilled and completed in the Caddo Limestone. The six wells have produced a combined total of 285,135 BO and 868,111 MCF since July 2008. C-C’ is a southwest-to-northeast stratigraphic cross section which shows the SP development across the structure.

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MJ LOGS

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