Using Petrophysics to Determine the Presence of Residual Oil Zones for the thick Cypress Sandstone at Noble Field

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Abstract

The Cypress Sandstone is one of the most prolific oil producing formations in the Illinois Basin (ILB). In addition to prolific conventional oil reservoirs, there may be economically recoverable nonconventional residual oil zones (ROZs) within the fairway of thick, incised valley fill (IVF) facies of the Cypress Sandstone in the central ILB. ROZs are zones of low oil saturation relative to a conventional reservoir, typically below the producing oil-water contact (OWC). The use of carbon dioxide enhanced oil recovery (CO2-EOR) techniques in an ROZ is expected to provide a significant CO2 storage and EOR opportunity. A petrophysical method was developed to use geophysical logs to identify the presence of ROZs in the IVF Cypress Sandstone.

Open-hole well logs were digitized and Archie's equation was applied to resistivity and porosity curves to determine water saturation (Sw), or the percent of pore volume occupied by water, with the remainder assumed to be occupied by oil. Forty wells were selected from Noble Field in Richland County, Illinois, for petrophysical study because of known production from the IVF Cypress Sandstone. Previous geologic characterization has indicated the presence of a tilted oil-water contact, a key indicator of an ROZ. Preliminary results of the petrographic analysis suggest the possibility of an ROZ. Several wells display a Sw profile with a zone of slightly higher oil saturation consistently 49–66 ft (15–20 m) below the OWC. Several other wells display a gradual transition from the reservoir to the water-saturated zone instead of a sharp OWC. A map was produced from these 40 wells to show the spatial distribution of oil saturation below the OWC.

The petrophysical method can be validated through oil saturation measurements in the IVF Cypress Sandstone. A visible cut technique using solvents and cuttings is being developed as another indicator of oil in the lower part of the IVF Cypress to validate well log analyses. After the petrophysical assessment of the IVF Cypress Sandstone at Noble is complete, the method will be applied elsewhere in the IVF Cypress Sandstone fairway to evaluate the potential ROZ resource and better understand the spatial distribution of ROZs across the ILB. Ultimately, the findings of this study will aid in evaluating the economic feasibility of CO2-EOR implementation.

Background - thick Cypres Sandstone & ROZs

- Geophysical logs can be used to calculate water saturation (Sw)
- Archie equation is a well established method using logs to determine Sw
- Gradual transition in Sw between oil reservoir and 100% Sw zone potentialy indicate a Residual Oil Zone (ROZ)
- ROZs are zones where Sw < 100% below the producing oil-water contact (POWC) where immobile oil trapped in pore throats post oil reservoir charging
- Noble field selected due to extensive ongoing geologic studies which can serve to confirm petrophysical ROZ findings

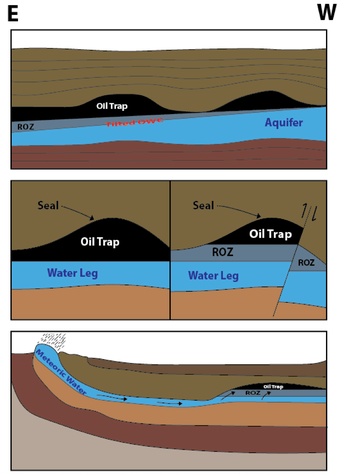


Figure 1 Three theoretical ways a ROZ may develop. At the top figure 1a shows the tilted oil water contact that would take place due to basin tilting.
The middle figure 1b shows a ROZ resulting from faulting of the seal rock.
At the bottom figure 1c shows ROZ development as a result of displacement by meteoric water entering the formation via outcrop. Adapted from (Ming and Melzer, 2010)

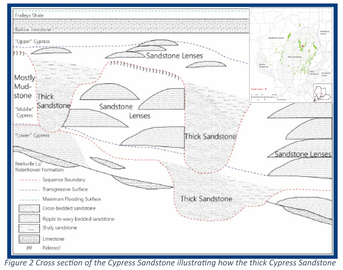
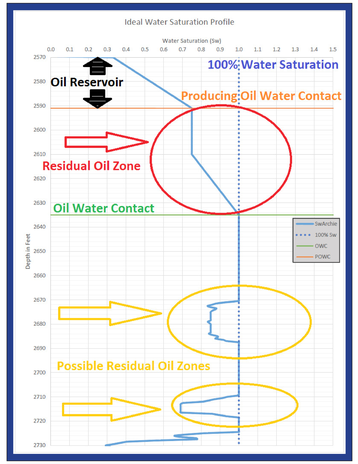


Figure 2 Cross section of the Cypress Sandstone illustrating how the thick Cypress Sandstone occurs within the incised valley fill facies. Taken from (Webb et al., 2016)

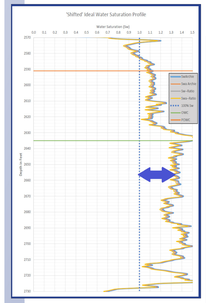
Method - Petrophysics

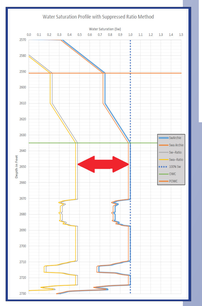
- Resistivity and porosity logs from 38 wells used to calculate Sw profiles
- Two methods were employed, one using only resistivity logs so that older e-logs without porosity data can still produce useful water saturation curves
- Both water saturation equations rely on the resistivity of formation water (Rw) but because it was not directly measured two equations were used to estimate
- Water resistivity was determined two ways, Rw is calculated from SP logs and Rwa is calculated from resistivity and porosity logs incase SP is unreliable due to waterflooding



Sw Equation	Water Resistivity Type: R_w	R_{wa}
Archie	$S_w(A)$	$S_{wa}(A)$
Ratio	$S_w(R)$	$S_{wa}(R)$

- The production of four water saturation curves helped to serve troubleshooting efforts to determine the cause of certian outcomes
- An ideal ROZ bearing water saturation profile will show a gradual transition over a long interval from the oil productive oil-water contact and the oil-water contact where the formation is completely water saturated
- It is possible that there are deep ROZs isolated from the transition zone between the thin oil reservoir at the top of the formation

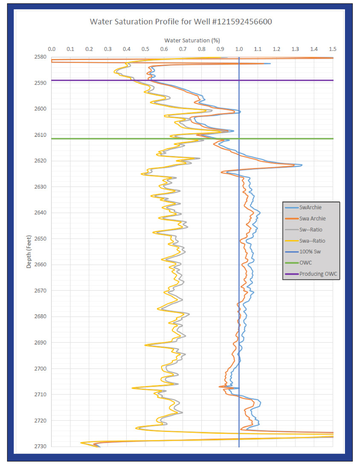


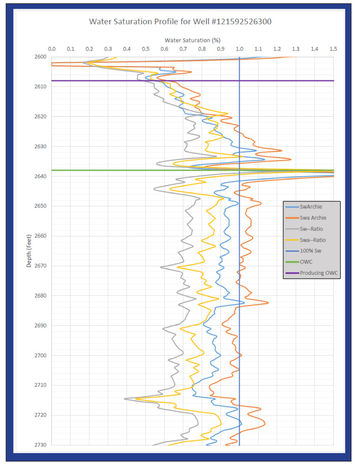


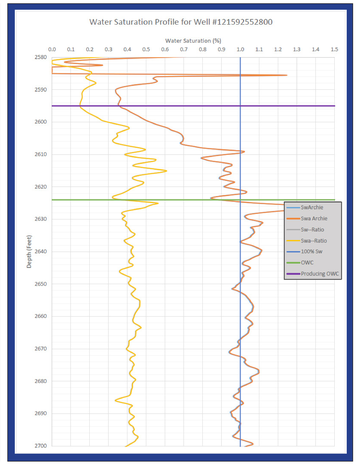
Results

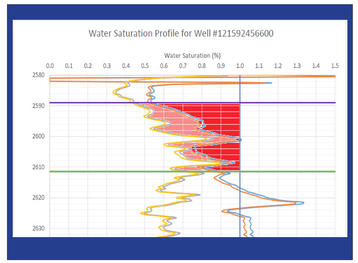
- As hypothesized some curves showed lower resistivity in upper portion of the thick Cypress Sandstone where shows-of-oil and oil production had been reported with a peeking out at 100% water saturation
- A quarter of the curves produced water saturation as expected with the water saturated zone matching up with Sw = 100% on the graph

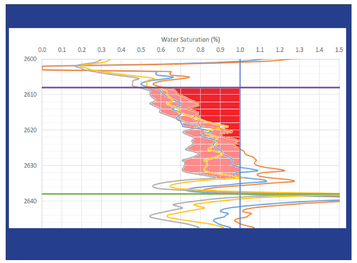
Curve Trends
- Consistent trends of a gradual transition from the POWC to OWC with remaining formation showing up water saturated
- Saturation curves show potential ROZ saturation between POWC and OWC

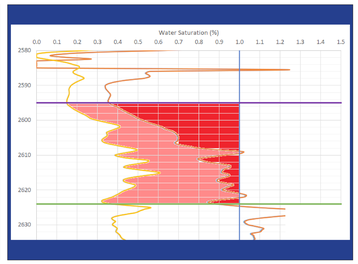












Discussion

ROZ vs. Capilary Transition Zone
- Similar phenomena, different mechanisms
- ROZs occur post reservoir charging and result of one of aforementioned theoretical processes
- Capillary Transition Zones occur due to reservoir characteristics and are result of charging
- Likely ROZ as trends were not effected by water injection flooding over the years

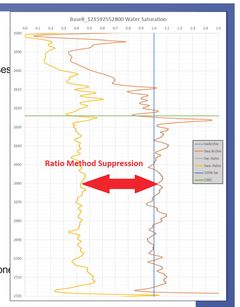
Ratio Method Suppression
- Of the 38 analyzed wells over half displayed a suppressed Ratio Method
- Ratio Method produced saturation values much lower than the Archie Method
- Like with water saturation shifting, conductive sandstone formations can throw off the ratio method since there is no porosity control and the method is dependent on resistivity values that are susceptible to conductive formations

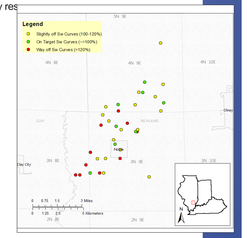
Water Saturation Shifting
- Of the 38 analyzed wells 29 produced anomalous water saturation curves
- Water saturation anomalies are caused by abnormally conductive sandstone formations

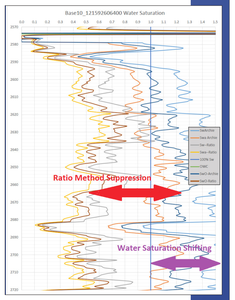
>Two possibilities for conductive sandstone formations
1. Microporosity caused by diagenetic clay mineralization
2. Negative electrical charges within clay sheets of detrital shaley material within the sandstone

Oil Looking Shale
- ROZs below the OWC appear to be shale beds due to volume of shale analysis
- Shale is more likely explanation than deep and isolated ROZs which require extra-ordinary res ervoir characteristics to exsist

Rw/Rwa
- Rw estimates were fairly consistent and accurate
- Rwa estimates were more prone to being effected by outliers and needed more scrutiny







Implications and Future Work

Implications
- Petrophysics seems to indicate the presence of ROZs, but the fact that so many curves have suppresed or shifted water saturation curves means that more work needs to be done before concrete conclusions can be drawn
- Variability in curves is likely due to micro-porosity caused by diagenetic clay minerals
- Water saturation results suggest evidence of residual oil below the producing oil water contact
- Water saturation results suggesting ROZ below the oil-water contact (Sw = 100%) likely due to shale as evidenced by shale volume analysis and fact that it's the most simple explanation and otherwise implies much more complex reservoir architecture
- Likely that ROZs, like the oil reservoirs above them, are very thin extending to 20ft max in most wells
- Because of thin ROZs, CO2 sequestration is likely to be a carbon negative source of energy

Future Work
- Petrophysical analysis of Noble Field reveals that there are indeed zones of residual oil saturation below the thin oil-producing reservoir and above the oil-water contact where the formation is entirely water saturated
- It is likely that the conclusions of future work will find ROZs between the POWC and OWC as evidenced in this research by petrophysical analysis throughout the thick Cypress Sandstone
- It will be helpful to future researchers to reference this study as a framework for using petrophysics in the determination of ROZs by applying the methods discussed and comparing with as much physical verification as possible
- The method can be improved by conducting brine analysis for the most accurate water resistivity values
- The Rwa method may be more trouble than it is worth and will likely not be necessary for future investigations

Acknowledgements

Many thanks to Nathan Webb for the opportunity of this research and all his guidance. Much appreciation for Nate Grigsby and his assistance in the production and revision of this project. Huge thank-you to Scott Frailey for his vital role in revealing the mysteries of petrophysics. Research herein was sup-ported by the US Department of Energy contract number DE-FE0024431. Through a university grant program, IHS Petra software was used for the geologic modeling.

http://www.isgs.illinois.edu/research/oil-gas/doe

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