THEORY AND PRACTICE OF A WEB-BASED INTELLIGENT AGENT IN THE LOCATION OF PAY ZONES ON DIGITAL WELL LOG FILES

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ABSTRACT

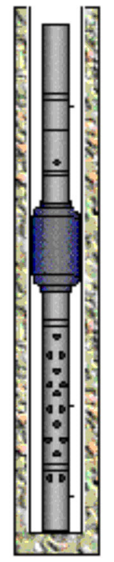
Traditional log analysis methods locate pay in a deductive ("top-down") mode by applying the Archie equation in the calculation of water saturation. A computed saturation log is a serviceable reconnaissance procedure to locate potentially productive zones, although additional insight on pore size is needed to predict actual fluid production. In an alternative approach, pay zones may be located by an inductive ("bottom-up") mode in which the fluids produced from DST intervals and perforated zones are used in the categorization of associated well log patterns. In several exploratory case-studies, a Java applet was trained to distinguish fluid types by enumerating data-point densities of log measurements on a neural lattice framework and classification by Bayesian probability methods. Endmember categories of oil, water, and mud, were classified in terms of their gamma-ray, neutron and density porosities, photoelectric factor, and resistivity in Kansas Paleozoic carbonates and sandstones. Mappings of the separate fluid data clouds within this multivariate log space were examined, both as a means of quality control and in the pattern recognition of reservoir properties that control production. At the conclusion of learning and validation phases, the trained intelligent agent was applied to a database of digital LAS log files to assess potential pay within stratigraphic equivalents of new wildcats and bypassed pay on older wells.

$$S_w = \sqrt[n]{\frac{a \cdot R_w}{\Phi^m \cdot R_t}}$$

"TOP-DOWN":
Deduction from log analysis

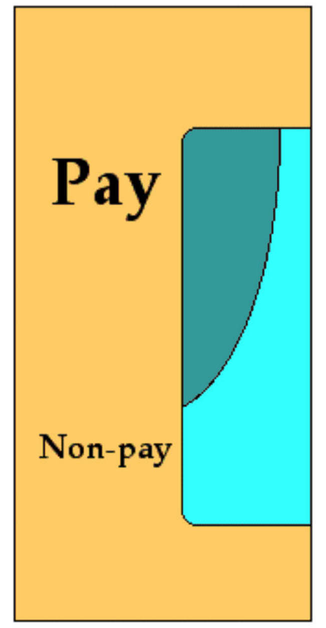
PAY ZONES

"BOTTOM-UP":
Induction from association of well-log patterns with DST fluid recoveries



"Top-down determination of pay relies on use of a water saturation model such as the Archie equation and supplying parameters like "n" the saturation exponent and "m" the cementation exponent. The assumption is that the reservoir behaves as an "Archie Rock".

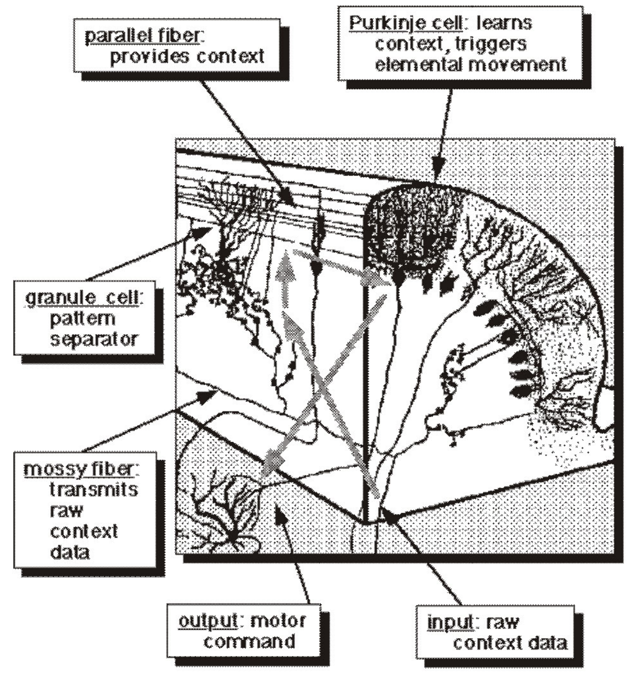
LOG ANALYSIS UNCERTAINTIES



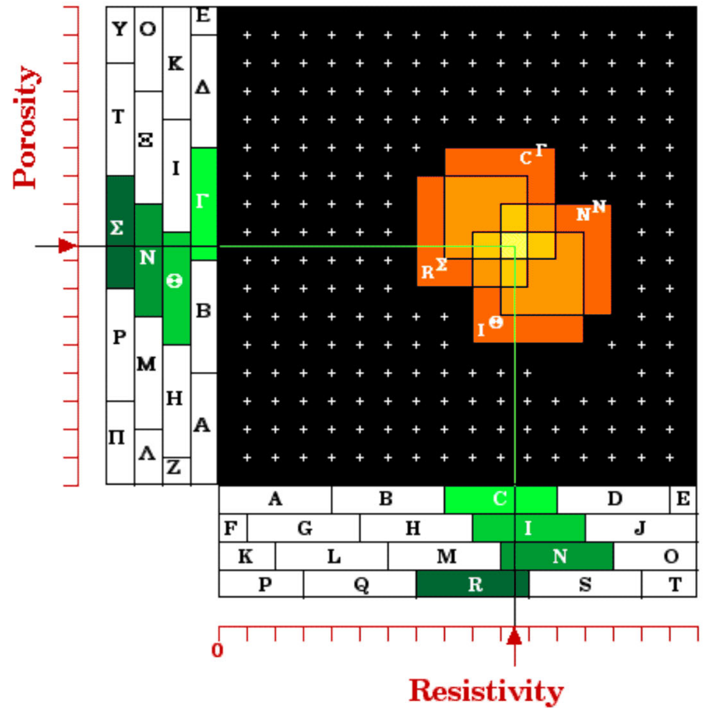
ASSOCIATED WITH THE APPLICATION OF THE ARCHIE EQUATION IN EVALUATING PAY

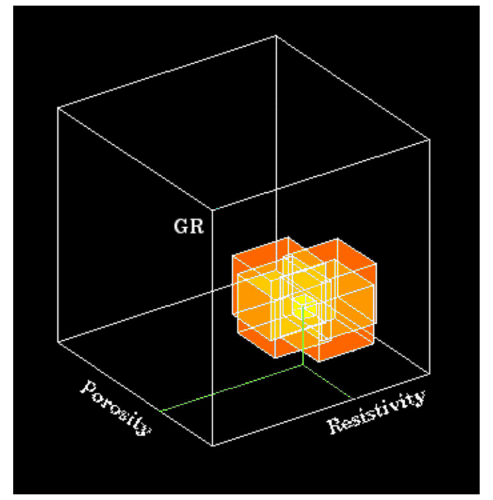
- *Log input measurement errors
- *Variability in Archie constants of cementation exponent, m and saturation exponent, n
- *Water resistivity, Rw
- *Pore-size distribution
- *Permeability

A "bottoms-up" approach to evaluate pay offers the opportunity to circumvent uncertainties with the water saturation model. The potential also exists to use this inductive approach to build a robust pay model that encompasses many reservoirs and permits processing of large volumes of data.



The Albus model of the structure of the cerebellum that is the basis for the CMAC (Cerebellar Model Arithmetic Computer) robotic controller. The CMAC allocation of memory as a "shingled lattice" of bins in multivariate space that is gridded by smaller cells is used within KHAN for non-parametric prediction and classification. In the illustrations below, the concept is shown for two log variables (resistivity and porosity) and three log variables (incorporating gamma ray).





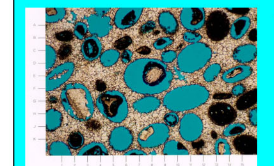
Structure of KHAN classification is a shingle-block lattice is based CMAC (Cerebellar Model Arithmetic Computer), originally designed by Albus (1975)

Albus, J.S., 1975, A new approach to manipulator control: The Cerebellar Model Articulation Controller (CMAC): Transactions of the ASME, September, p. 220-227.

Problems With Supervised Classification of Hydrocarbon Pay

-- Defining log derived porosity and water saturation cutoffs in limestone reservoirs with varying oomoldic content

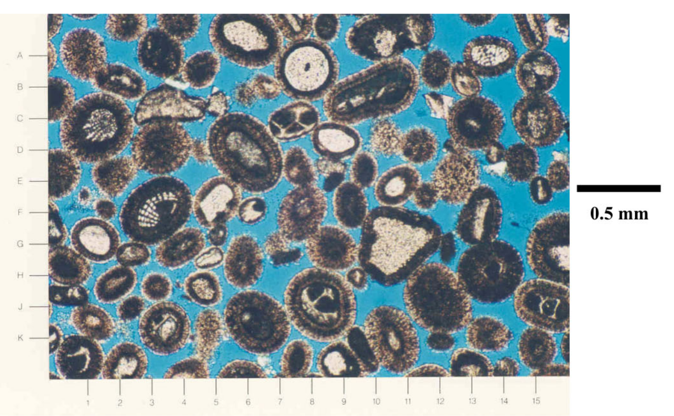
- **Measured Archie cementation exponent is as high as 3.5 for highly oomoldic lithofacies but decreases to m=2 for interparticle porosity**
- **Porosity cutoff is dependent on permeability (flow) and storage, cutoff can range from 15%-20% for this system**
- **Water saturation cutoff is dependent on water cut that can be sustained and still be economic**
  - **Sorw (residual water saturation) and fractional flow**



e.g., 2 BO + 100 BW (2% oil cut)
*** Sorw depends on relative permeability and fractional flow and for a highly oomoldic LKC reservoir, the Sorw = 65%**
*** Thus, a reasonable Sw cutoff is 65%, reflecting an economic decision as to whether complete an oomoldic zone**

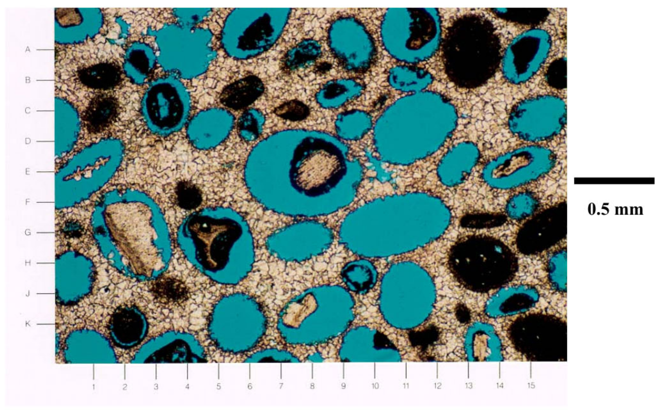
Archie Rocks

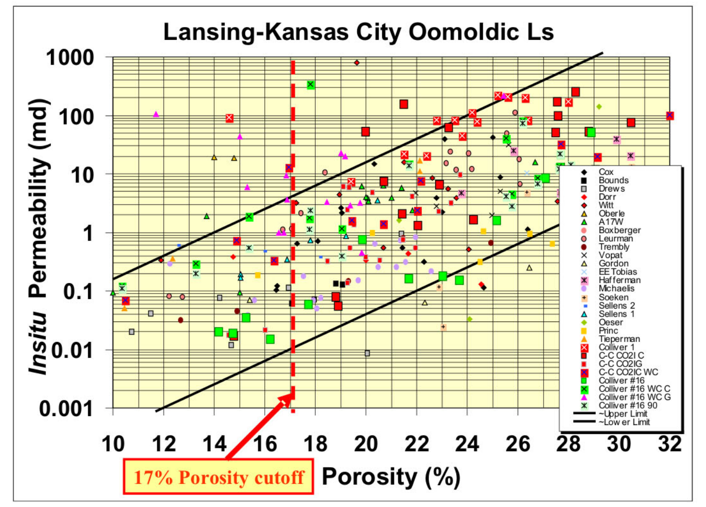
Oolite Lithofacies with Interparticle Porosity:
Terry Field, McCoy Six M Farms "A" 3-22
St. Louis "C" Limestone
4787.6 ft, thin section photomicrograph
40x transmitted light; core analysis: 25.6% porosity, 28.8 md



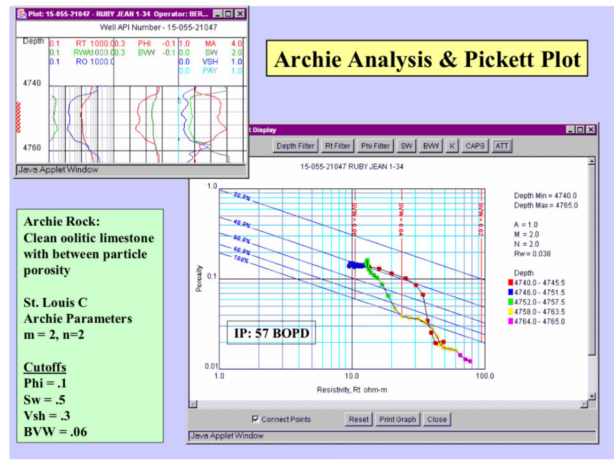
Non-Archie Rocks

Oomoldic Lithofacies:
Terry Field, McCoy Six M Farms "A" 3-22
Marmaton B (Altamont Ls.)
4288.5 ft, thin section photomicrograph
40x transmitted light; core analysis: 15.2% porosity, 180 md



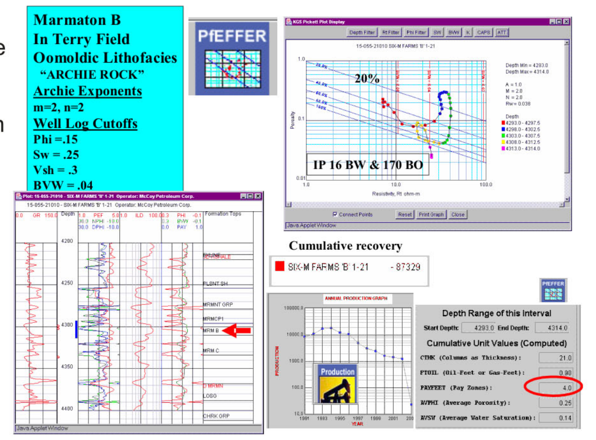


Variations in pore type among the oomoldic lithofacies makes application of single cut-offs to define hydrocarbon pay difficult, providing a compelling reason for a "bottom-up" approach to defining pay.

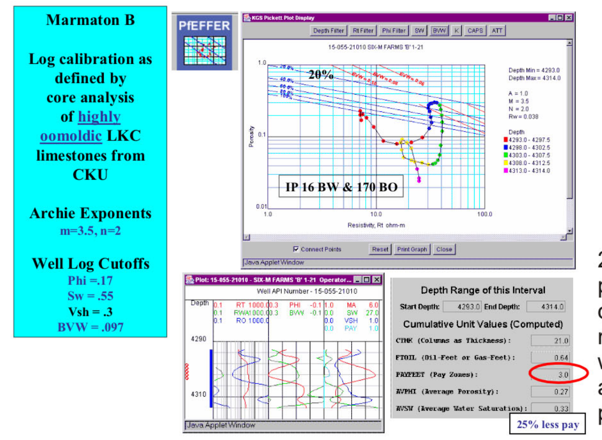


Well-behaved Archie Rock

Case #1: Use standard Archie exponents, m & n = 2, for oomoldic rock.



Case #2: Use core-derived m&n for oomoldic rock and adjusted log cutoffs to define pay.



25% less pay in oomoldic reservoir when using adjusted parameters

Petrophsical Variations in Oomoldic Limestone Reservoirs -- Example from Hall Gurney Field, Russell County, Kansas

Archie Cementation Exponent

Oomoldic limestones from Kansas and globally exhibit extremely high Archie cementation exponents. This is consistent with the interpretation that the oomoldic pores are similar to micro-vugs. Modified Archie parameters for the Carter-Colliver Lease rocks are: **m=1.36, a=9.59.** Conversely, if m is considered to change with porosity then m can be predicted for the higher porosity rocks using: **m = 0.05****Porosity(%)*** + 1.9.** Cementation exponents are near 2.0 in the bioclastic wackestone overlying the 'C' zone. Cementation exponents increase into the top of the 'C' and then decrease with increasing depth to the base. This is associated with the higher porosity at the top of the 'C' zone but is also influenced by pore structure changes associated with the unconformity surface.