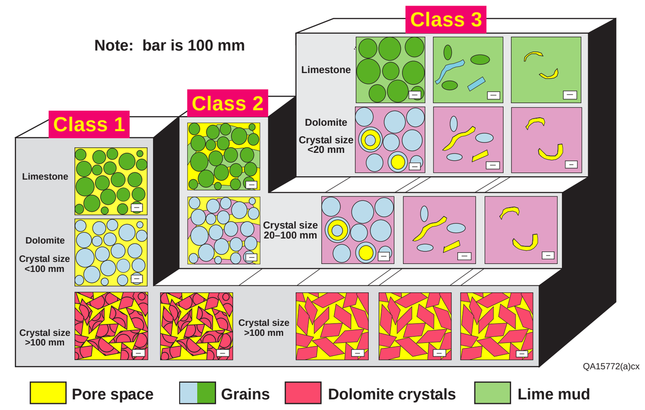
ESTIMATION OF PETROPHYSICAL PROPERTIES INTEGRATING ROCK-FABRIC APPROACH WITH STRATIGRAPHY AND WIRELINE POROSITY

Rock-Fabric Technique

Estimation of Permeability and Original Water Saturation

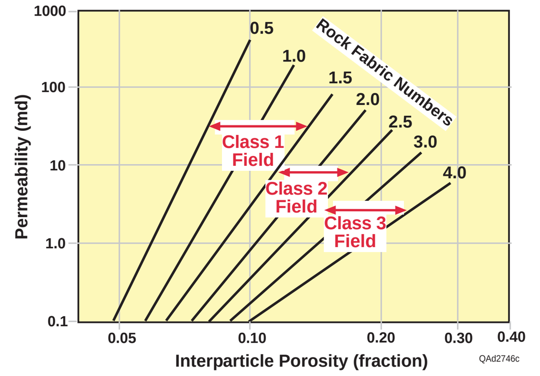
We think the most accurate calculations of permeability and original water saturation are derived from good- quality wireline porosity data using transforms defined from rock-fabric relationships. Requirements of this technique are good-quality core analyses (to define porosity and permeability), thin sections (for rock-fabric typing), a cycle-based stratigraphic framework (for rock-fabric distribution), and complete log suites (including acoustic logs).

Rock-Fabric Petrophysical Classes



The rock-fabric method of petrophysical characterization is based on relationships that exist between pore type, pore size, particle size, and sorting. Once rock fabrics are identified, they can be assigned to petrophysical classes that have rock-fabric-specific porosity/permeability transforms (rock-fabric numbers [RFN]).

Rock-Fabric Method Based on Interparticle Porosity



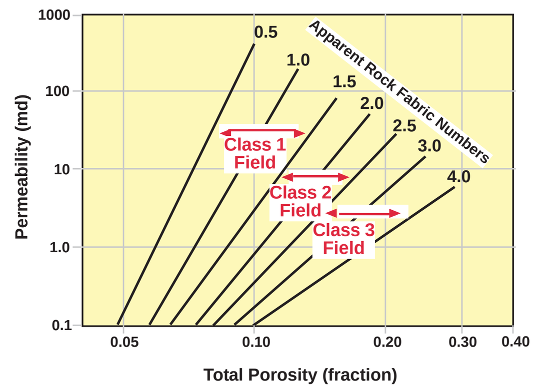
The direct relationship between interparticle porosity and permeability (Lucia, 1995, 1999) allows permeability to be accurately calculated when interparticle porosity and rock-fabric number (RFN) can be defined (below).

Rock-Fabric Porosity/Permeability Relationship

$$\log k = [9.7982 - (12.0838 \times \log RFN)] + [8.6711 - (8.2965 \times \log RFN)] \times \log \phi_{IP}$$

When available wireline logs are insufficient to distinguish interparticle porosity from vuggy porosity, total porosity must be used. Rock-fabric numbers defined by this approach (termed "Apparent Rock-Fabric Numbers" [ARFN]) are less accurate and may overstate permeability and saturation if vuggy porosity is present. Because most wells at Fullerton lack acoustic logs and usable resistivity logs (making it impossible to define interparticle porosity and vuggy porosity), the Apparent Rock-Fabric Number (ARFN) system was employed.

Rock-Fabric Method Based on Total Porosity



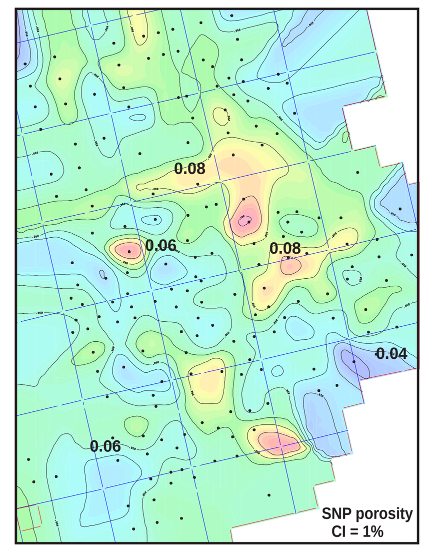
Porosity Log Calibration

Spatial Normalization of Porosity Logs

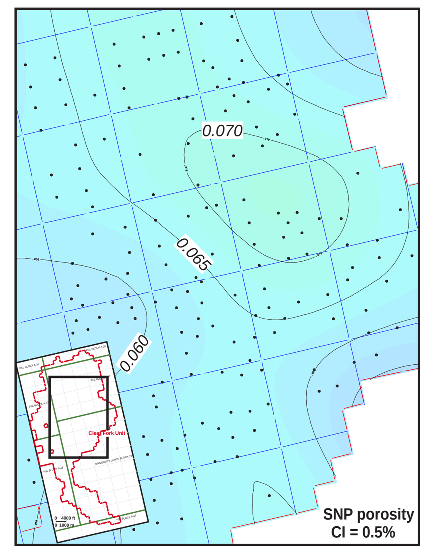
Following conventional log normalization and calibration, porosity logs were spatially normalized to minimize individual well acquisition and calibration errors. Maps below illustrate the effects of spatial normalization of sidewall neutron log values using various search radii for contouring average porosity data of entire reservoir interval for all wells.

Differences between normalized values and actual well values were used to adjust log data over the entire reservoir interval.

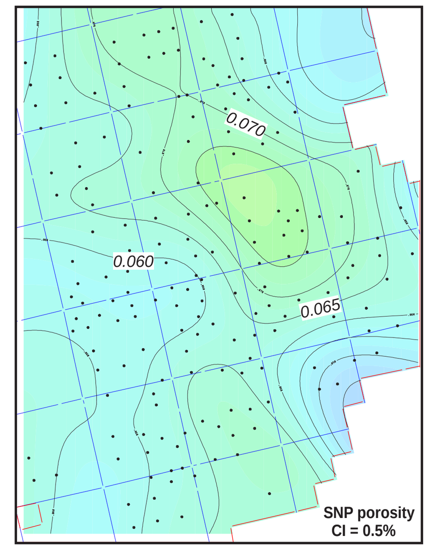
1000-ft search radius: too many bull's eyes (well acquisition problems or calibration errors)



5,000-ft search radius: masks too much small-scale variability



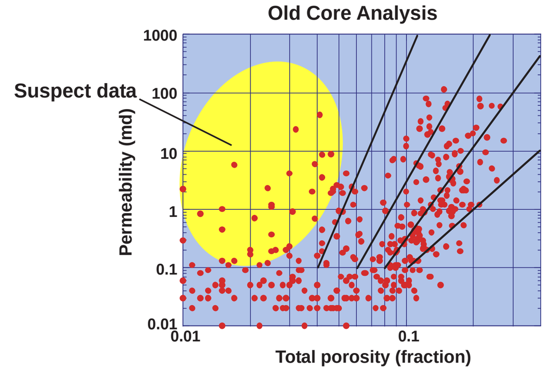
3000-ft search radius: provides detail and reduces random error. This was used to normalize raw wireline log porosity data in the field.



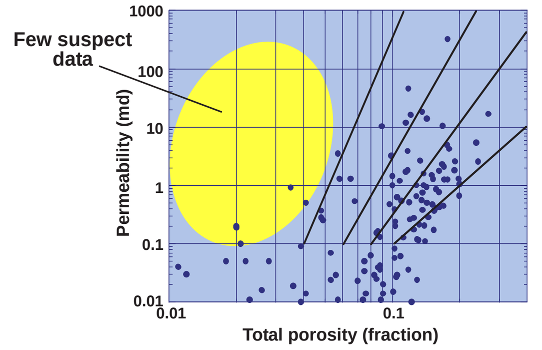
Data Quality

Core analysis data commonly contain suspect data, as evidenced by low-porosity/high-permeability data points (below). Many of these data are the result of poor sample cleaning. For this study we obtained new plugs that were carefully cleaned and analyzed. Note the difference in the two data sets from the same core.

Old Core Analysis

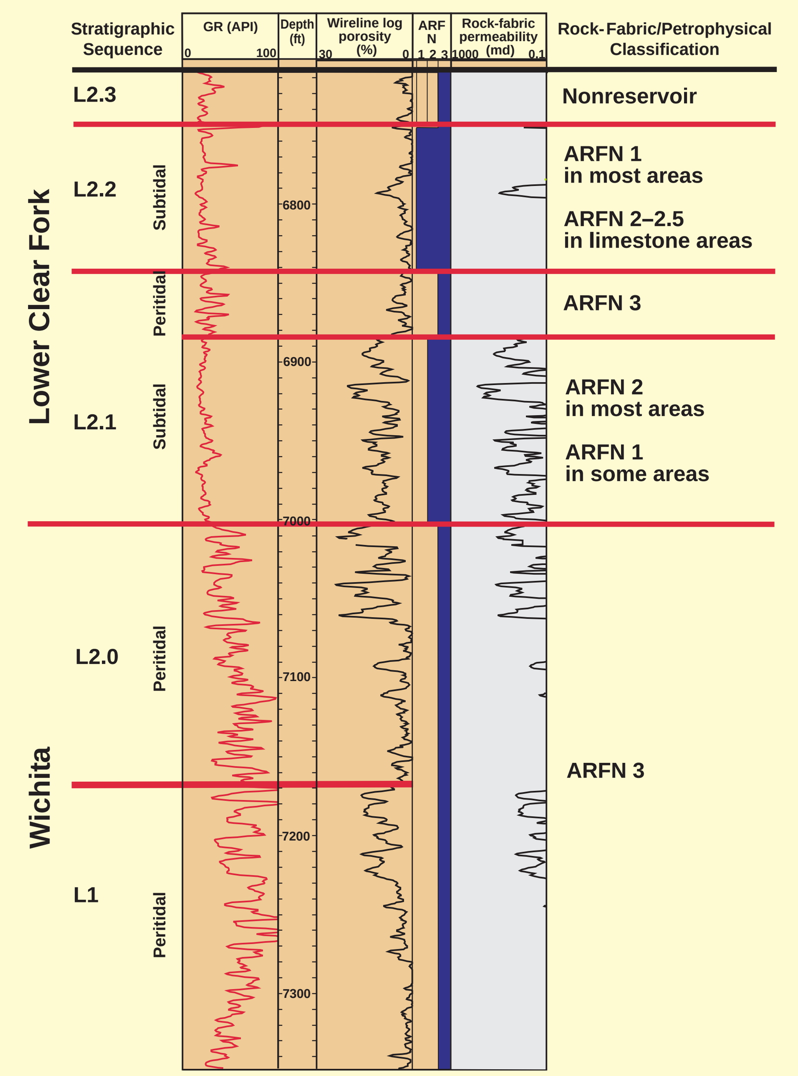


New Core Analysis



Rock Fabric Distribution

Stratigraphic Distribution

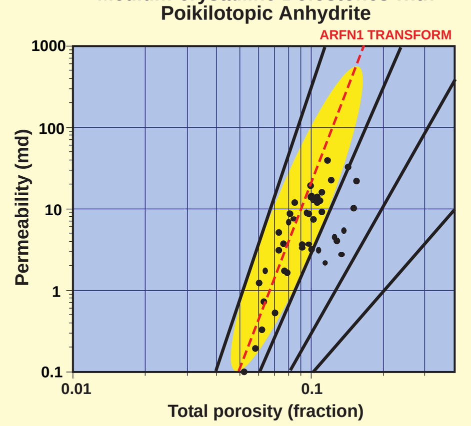


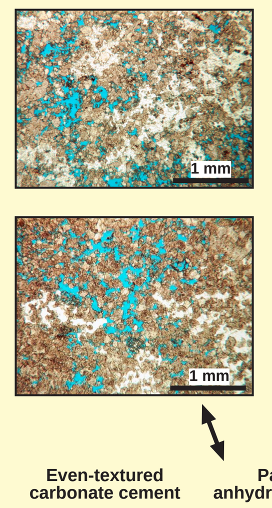
Type log showing general stratigraphic position of apparent rock-fabric numbers.

Lower Clear Fork L2.2 Rock Fabrics/Petrophysics

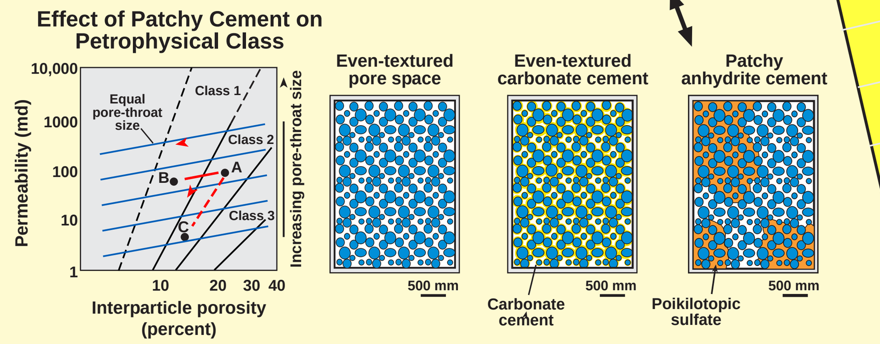
HFS L 2.2 is dominated by petrophysical Class 2 medium-crystalline anhydritic dolostone. Because of the differential effect of patchy, poikilotopic anhydrite on porosity and permeability, these rocks generally plot in the Class 1 field and are characterized by an ARFN of 1. Less common moldic grainstones and grain-dominated packstones are best represented by an ARFN of 2 to 2.5.

ARFN1: Medium-crystalline Dolostones with Poikilotopic Anhydrite

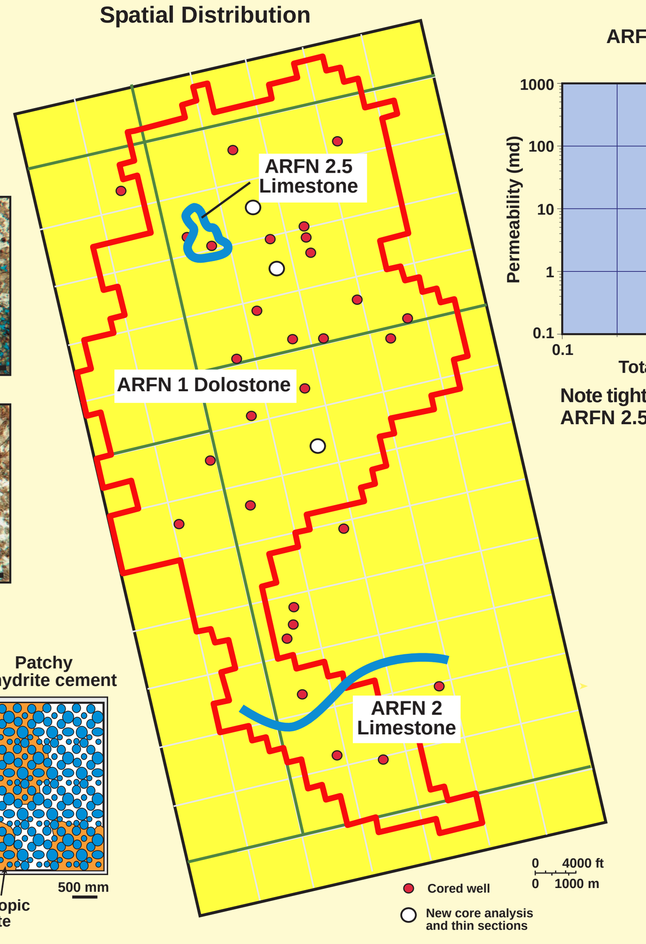




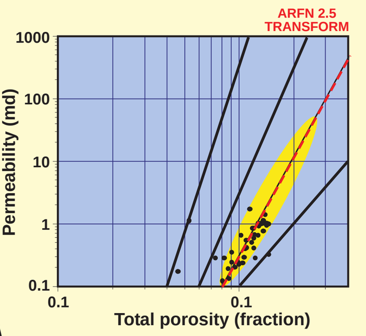
Effect of Patchy Cement on Petrophysical Class



Spatial Distribution

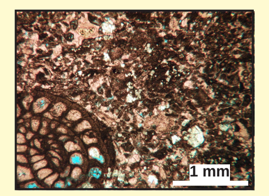


ARFN 2- 2.5 limestones

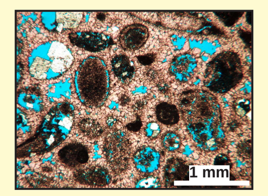


Note tight clustering of data along ARFN 2.5 transform.

Grain-dominated Packstone



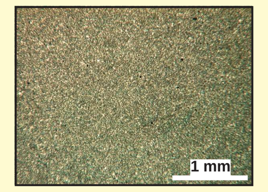
Grainstone



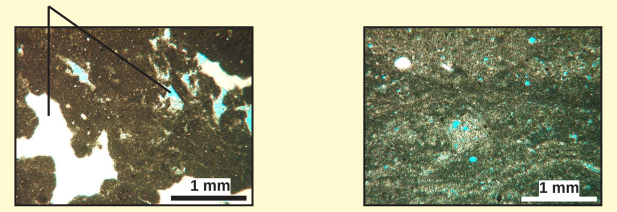
Wichita (L1, L2.0) Rock-Fabrics/Petrophysics

Thin-section descriptions are mostly Class 3 fine-crystalline wackestones with little vuggy porosity. Therefore, most of the Wichita can be charactercized using a rock-fabric number and an ARFN of 3. The rare class 2 grain-dominated dolopackstone and vuggy tidal-flat fabrics in the Wichita will not be properly classified using this method (see crossplot below).

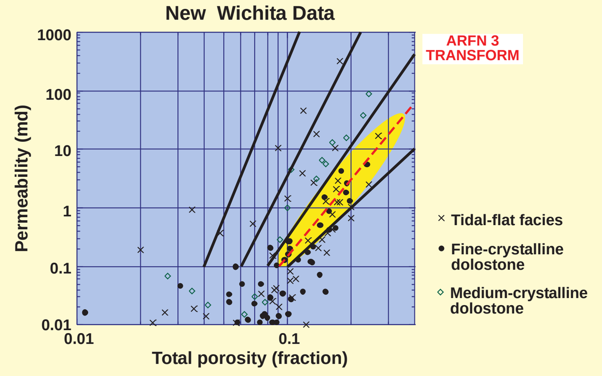
Typical Class 3 Fine-crystalline Dolowackestone Fabrics



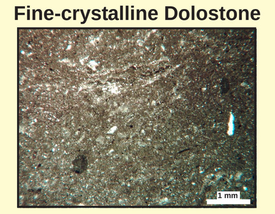
Fenestral pores



New Wichita Data



ARFN 3: Fine-crystalline Dolostone



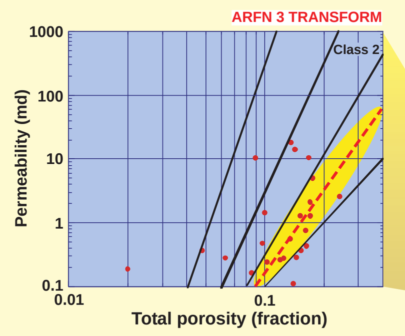
Sequence-top peritidal facies consist of Class 3 dolostones. These rocks have limited vuggy porosity and are characterized by an ARFN of 3.

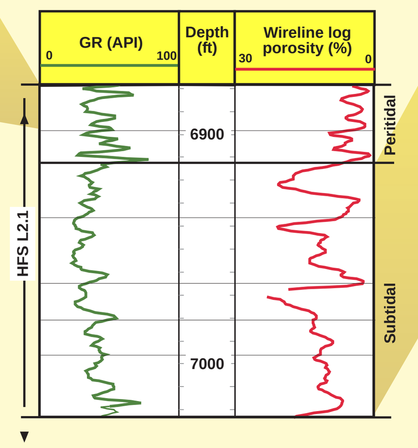
Lower Clear Fork L2.1 Rock Fabrics/Petrophysics

Intrasequence Variability: Lower Clear Fork L2.1

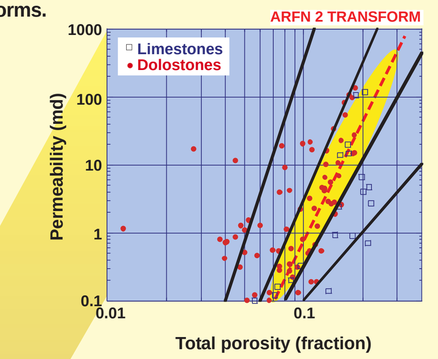
Transgressive (subtidal) and highstand (peritidal) legs of high-frequency sequences contain different rock fabrics and thus require different porosity/permeability transforms.

Peritidal Cycles

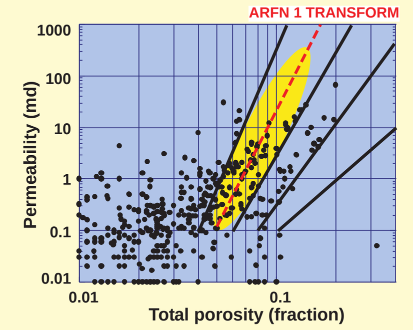




Subtidal Cycles

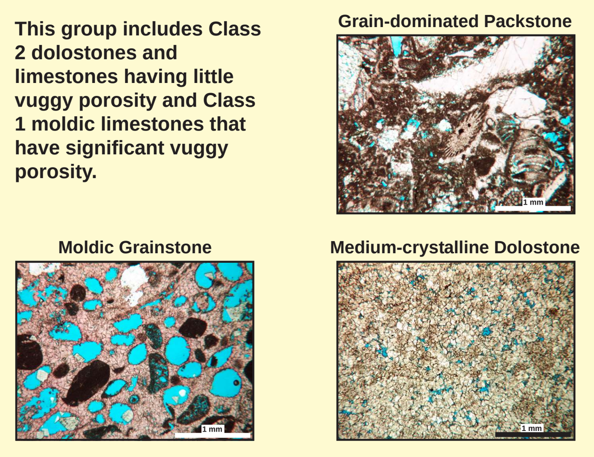


Subtidal facies consist of complex assemblages of Class 2 dolostones and limestones and Class 1 dolostones



ARFN 2 Limestone and Dolostone

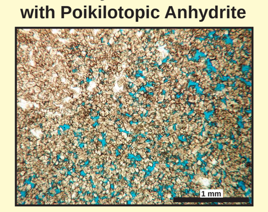
This group includes Class 2 dolostones and limestones having little vuggy porosity and Class 1 moldic limestones that have significant vuggy porosity.



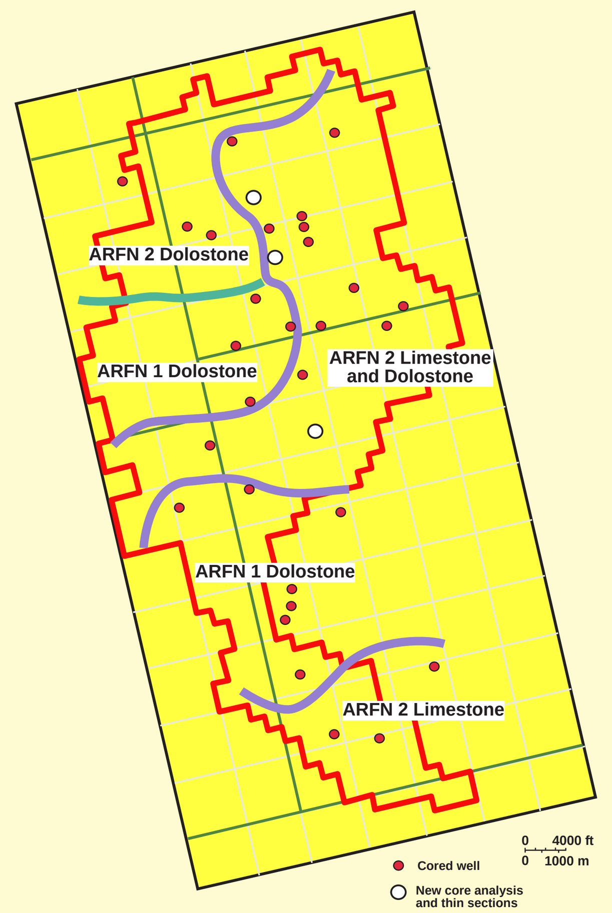
ARFN 1 Dolostone

Class 2 dolostones with abundant anhydrite behave as ARFN 1 rocks because of their patchy porosity (see L 2.2 above).

Medium-crystalline Dolostone with Poikilotopic Anhydrite



Spatial Trends within Subtidal Cycles of L2.1

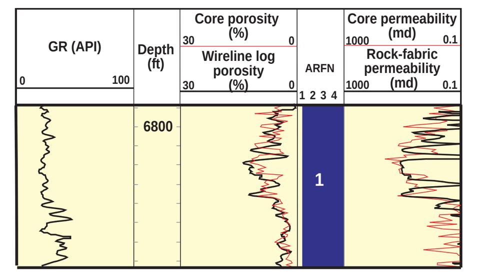


Permeability Estimation

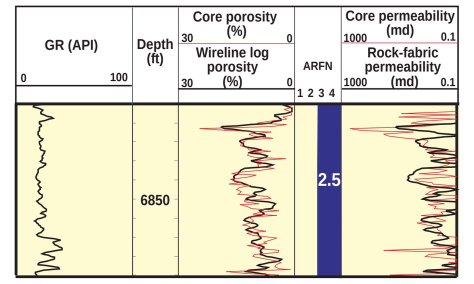
ARFN-based Permeability Estimation vs. Core Data

Excellent match between measured core permeability (red) and permeability estimated using apparent rock-fabric numbers and total porosity (black).

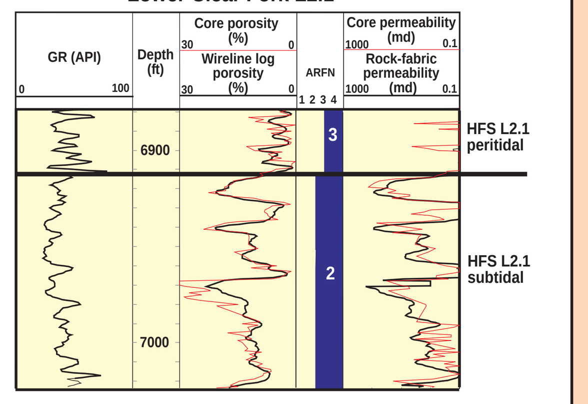
Lower Clear Fork L2.2 Rock-Fabric 1 Dolostone



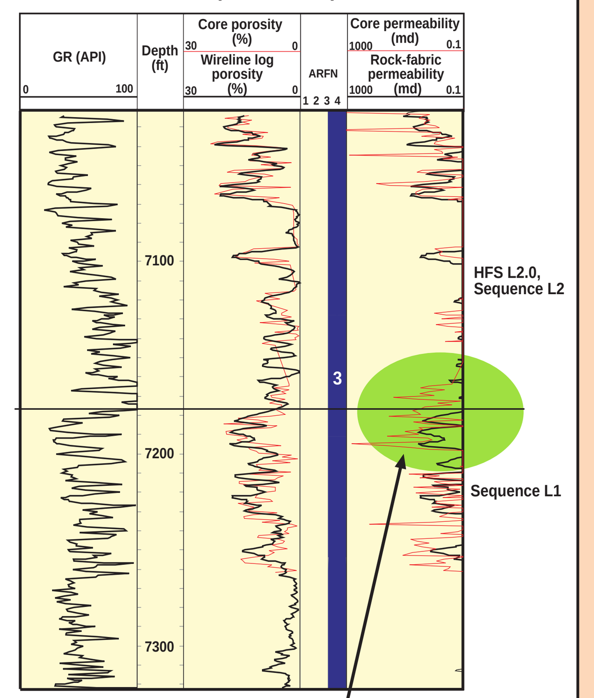
Lower Clear Fork L2.2 Rock-Fabric 2.5 Limestone

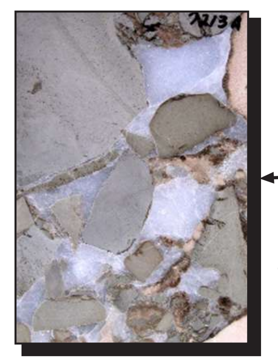


Lower Clear Fork L2.1



Wichita (L1 and L2.0)





Discrepancies between predicted permeability and core permeability may be due to touching-vug pore system associated with karst breccia.

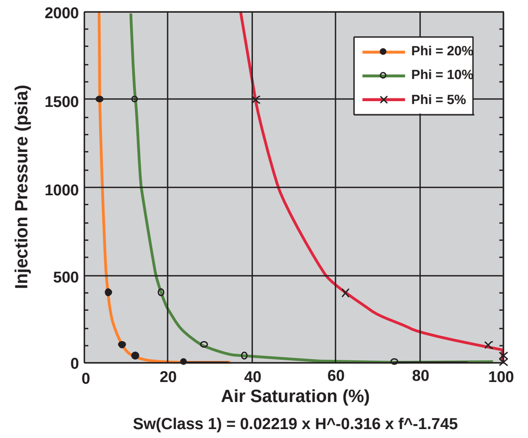
Saturation Modeling

Capillary Pressure Models for Estimation of Original Water Saturation

Rock-fabric-specific capillary pressure models were developed by Lucia (1995, 1999). New data acquired in this study compare well with the existing Class 1 model. However, new data from ARFN 2 and 3 samples do not fit previous models. We developed new models for ARFN 2 and 3 rocks using the Thomeer method.

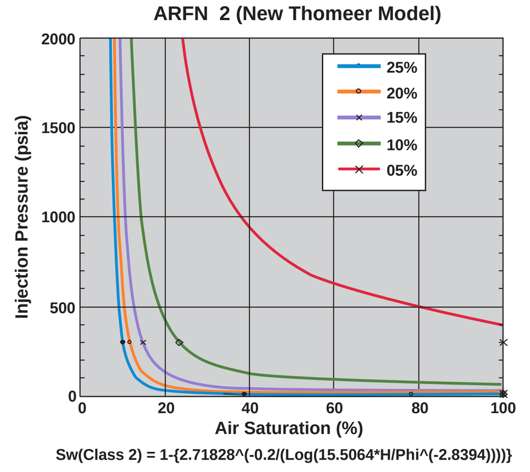
Saturation was calculated for the reservoir using these capillary pressure models, wireline log porosity, ARFN framework, and reservoir column height.

ARFN 1 (Lucia, 1995, 1999)



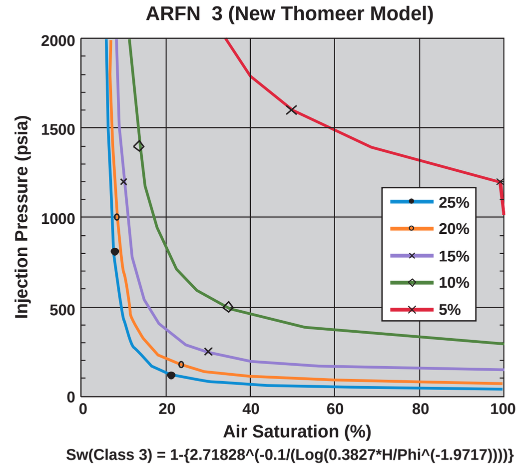
Sw(Class 1) = 0.02219 x H^-0.316 x f^-1.745

ARFN 2 (New Thomeer Model)



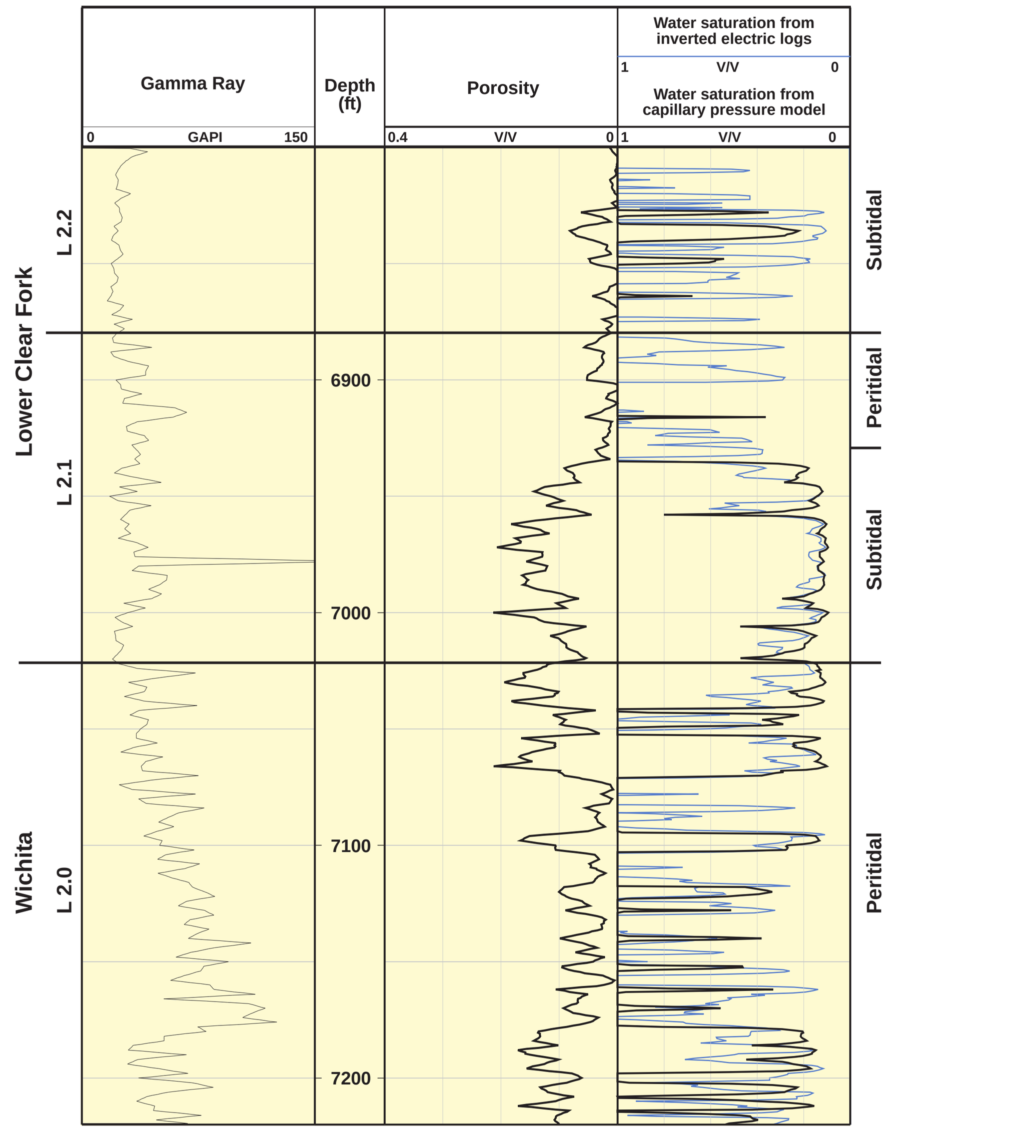
Sw(Class 2) = 1-(2.71828^(-0.2/(Log(15.5064*H/Phi^(-2.8394)))))

ARFN 3 (New Thomeer Model)



Sw(Class 3) = 1-(2.71828^(-0.1/(Log(0.3827*H/Phi^(-1.9717)))))

Water Saturation Model Comparison: Capillary Pressure vs. Log Resistivity



Overall excellent match supports use of capillary pressure model. Areas of poor match are the result of inaccurate resistivity tool response in intervals of low porosity.

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