[PS]Let's Make Outcrops Recover Their Value, Understanding the Rock on the Surface for Predicting into the Subsurface: Woodford Shale Case Study, Ardmore Basin, Oklahoma*

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Abstract

Due to the high cost to acquire well cores, along with today's low-oil-price scenarios, sizeable challenges are emerging especially for unconventional reservoir characterization. Thus, detailed and integrated outcrop data tied to well log responses provide means to understand shales on the surface and give supporting notions while predicting reservoir properties into the subsurface. In this work, first we present a multi-scale approach to characterize the vertical and lateral heterogeneities of a fresh Woodford Shale Outcrop in southern Oklahoma, the exposed succession is about 350 feet thick, comprising the entire Upper-Devonian and Lower Mississippian Woodford Shale and partially the overlying Sycamore Limestone and underlying Hunton Group. About 14 detailed lithofacies were recognized, which relate direct observations and/or measurements such as color, texture, lithology, mineral assemblages and composition, bioturbation, presence and frequency of laminations and organic richness. Secondly, by cross-correlation with nearby well-logs and using clustering analysis a supervised electro-lithofacies classification was conducted, in which a statistical model was generated for permitting the prediction and propagation of up-scaled lithofacies in non-cored wells. In our case for the Ardmore Basin, the propagated model of lithofacies covers an area of about 64,000 acres and includes well-log information of 22 wells; depths of the Woodford Shale in the subsurface range from 1000 to 3500 feet. The most remarkable outcrop-to-subsurface finding of this study is a laterally continuous cyclic pattern of two end-member groups of lithofacies: (1) clay-rich, silica-poor, organic-rich, ductile lithofacies, and (2) clay-poor, silica-rich, carbonate-rich, brittle, fractured, organic-poor lithofacies. As if they were imitating a cyclic source-reservoir system, in which some lithofacies acts as an oil/gas source and others as reservoirs or fracturable rocks. Thickness and frequency of these cycles varies stratigraphically throughout the Woodford Shale, resulting in better gross intervals for unconventional resources within the Upper-Middle and Upper Woodford Shale in the Ardmore Basin.

Let's Make Outcrops Recover Their Value, Understanding the Rock on the Surface for Predicting Into the Subsurface: Woodford Shale Case Study, Ardmore Basin, Oklahoma

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ABSTRACT

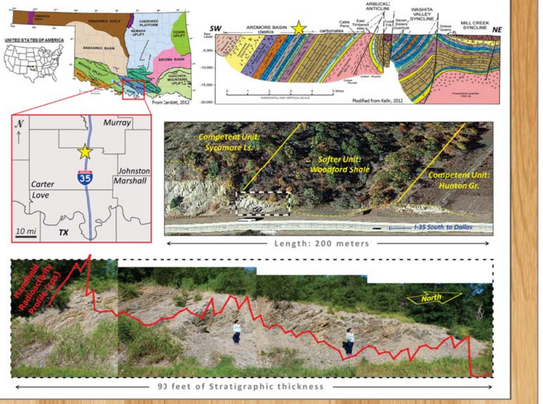
Due to the high cost to acquire well cores along with today's low-oil-price scenarios, sizeable challenges are emerging especially for unconventional reservoir characterization. Thus, detailed and integrated outcrop data tied to well log responses provide means to understand shales on the surface and give supporting notions while predicting reservoir properties into the subsurface.

In this work, first we present a multi-scale approach to characterize the vertical and lateral heterogeneities of a Woodford Shale Outcrop in southern Oklahoma, the exposed succession is about 90 feet thick, comprising the Upper member of the Late Devonian-Early Mississippian Woodford Shale and partially the overlying Sycamore Limestone. Detailed rock characterization was conducted, relating direct observations and/or measurements such as color, texture, lithology, mineral assemblages, elemental composition, organic richness, as well as geomechanical proxies such as rock hardness, and abundance and distribution of natural fractures.

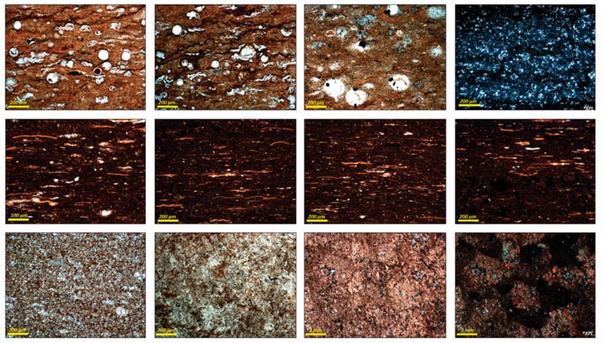
Secondly, by cross-correlation with nearby well-logs and using statistical analyses a supervised electro-lithofacies classification was conducted, in which a statistical model was generated for permitting the prediction and propagation of up-scaled lithofacies in non-cored wells.

The most remarkable outcrop-to-subsurface finding of this study is a laterally continuous cyclic pattern of two end-member groups of lithofacies: i) clay-rch, silica-poor, organic-rich, ductile lithofacies, and ii) clay-poor, silica-rich, carbonate-rich, brittle, fractured, organic-poor lithofacies. As if they were imitating a cyclic source-reservoir system, in which some lithofacies acts as oil/gas source and others as reservoirs or frac-able rocks. Thickness and frequency of these cycles varies stratigraphically throughout the Woodford Shale, resulting in better gross intervals for unconventional resources within the Upper-Middle and Upper Woodford shale in the Ardmore basin.

THE OUTCROP IN THE ARDMORE BASIN SOUTH-CENTRAL OKLAHOMA



LITHOFACIES, VERTICAL STACKING PATTERNS & STRATIGRAPHY



Quartz-rich lithofacies (Quartz > 80%)

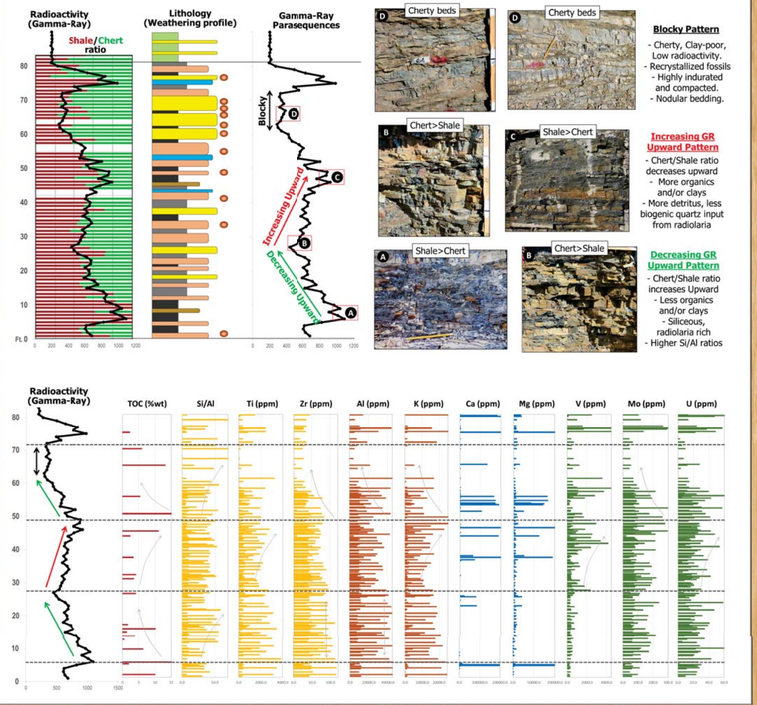
- Massive and highly indurated
- Micro- to crypto- crystalline quartz aggregates
- Very well preserved siliceous recrystallized tasmanites and radiolaria (biogenic quartz)
- TOC 1,4 - 2,5 wt%

Clay-rich lithofacies (Clays ~ 20%)

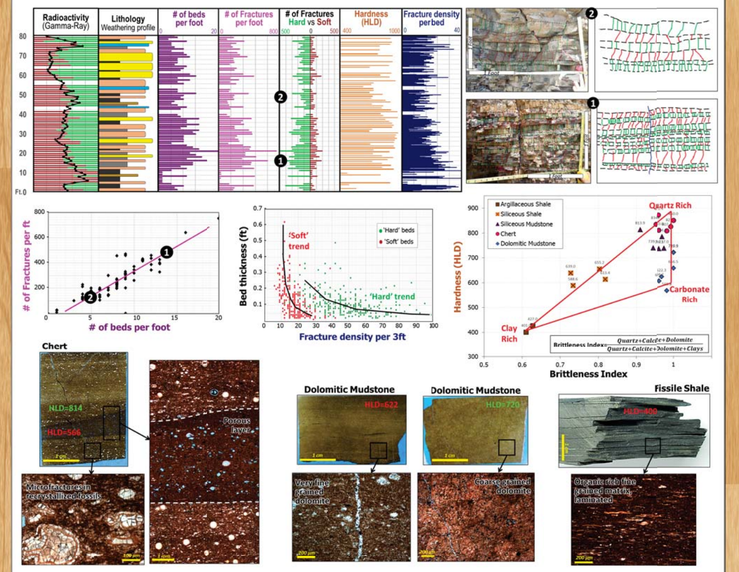
- Fissile, flaky, finely laminated
- Flattened tasmanites spores
- High Zr, Ti, Al and K (terrigenous influence)
- Scattered traces of angular detrital quartz
- High TOC 8 – 15 wt%

Carbonate-rich lithofacies (Carbonates > 50%)

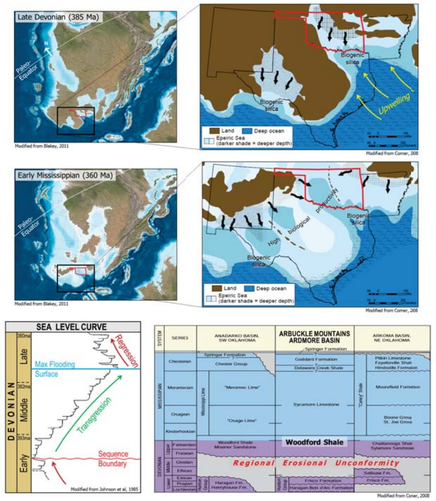
- Massive, crystalline dolomite
- Very fine- to coarse-grained subhedral dolomite and ankerite crystals forming equigranular fabrics
- Traces of anhydrite, gypsum
- TOC 2,3 – 5 wt%



NATURAL FRACTURES & MECHANICAL STRATIGRAPHY



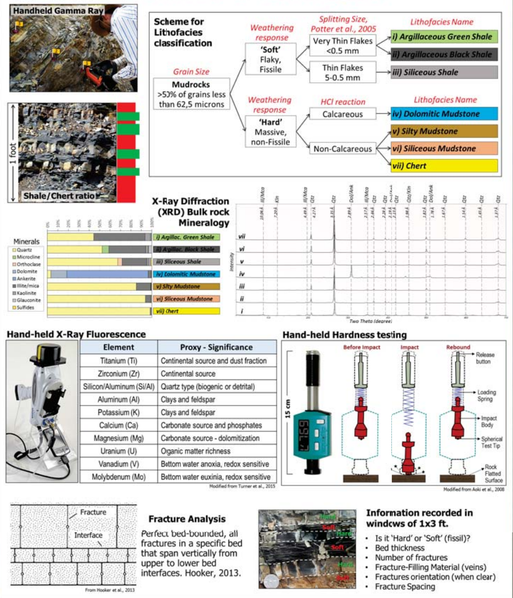
GOING BACK TO THE LATE DEVONIAN - EARLY MISSISSIPPIAN



Major conditions during Woodford Shale Deposition

- ✓ Semi-restricted to open marine
- ✓ Global sea level rise, transgression
- ✓ Near equatorial latitudes and high organic productivity
- ✓ Poorly oxygenated waters, Anoxia

MULTI-SCALE ROCK CHARACTERIZATION, METHODS & TECHNIQUES



Element	Proxy - Significance
Titanium (Ti)	Continental source and dust fraction
Zirconium (Zr)	Continental source
Silicon/Aluminum (Si/Al)	Quartz type (biogenic or detrital)
Aluminum (Al)	Clays and feldspar
Potassium (K)	Clays and feldspar
Calcium (Ca)	Carbonate source and phosphates
Magnesium (Mg)	Carbonate source - dolomitization
Uranium (U)	Organic matter richness
Vanadium (V)	Bottom water anoxia, redox sensitive
Molybdenum (Mo)	Bottom water euxinia, redox sensitive

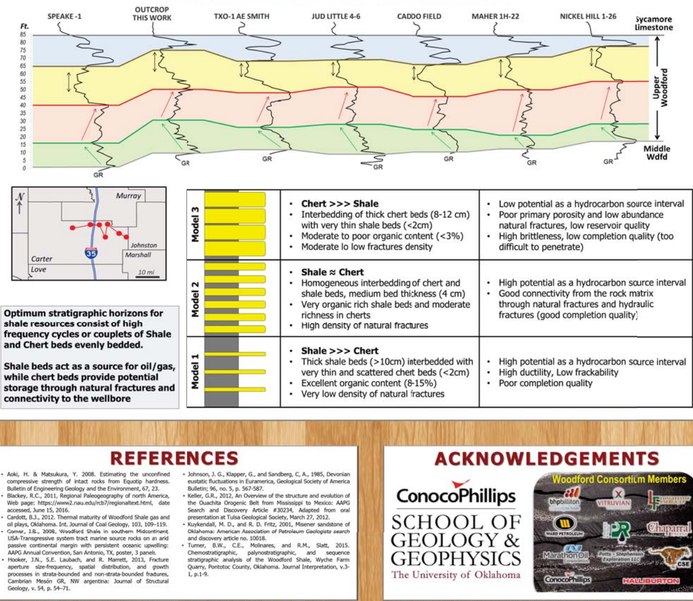
Fracture Analysis

Perfect bed-bounded, all fractures in a specific bed that span vertically from upper to lower bed interfaces. Hooker, 2013.

Information recorded in windcws of 1x3 ft.

- Is it 'Hard' or 'Soft' (fissil)?
- Bed thickness
- Number of fractures
- Fracture-Filling Material (veins)
- Fractures orientation (when clear)
- Fracture Spacing

OUTCROP TO SUBSURFACE REGIONAL CORRELATIONS & RESERVOIR CONSIDERATIONS



Optimum stratigraphic horizons for shale resources consist of high frequency cycles or couplets of Shale and Chert beds evenly bedded.

Shale beds act as a source for oil/gas, while chert beds provide potential storage through natural fractures and connectivity to the wellbore

Model 3

- **Chert >>> Shale**
  - Interbedding of thick chert beds (8-12 cm) with very thin shale beds (<2cm)
  - Moderate to poor organic content (<3%)
  - Moderate to low fractures density
- Low potential as a hydrocarbon source interval
- Poor primary porosity and low abundance natural fractures, low reservoir quality
- High brittleness, low completion quality (too difficult to penetrate)

Model 2

- **Shale ≈ Chert**
  - Homogeneous interbedding of chert and shale beds, medium bed thickness (4 cm)
  - Very organic rich shale beds and moderate richness in cherts
  - High density of natural fractures
- High potential as a hydrocarbon source interval
- Good connectivity from the rock matrix through natural fractures and hydraulic fractures (good completion quality)

Model 1

- **Shale >>> Chert**
  - Thick shale beds (>10cm) interbedded with very thin and scattered chert beds (<2cm)
  - Excellent organic content (8-15%)
  - Very low density of natural fractures
- High potential as a hydrocarbon source interval
- High ductility, Low frackability
- Poor completion quality

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