[PS]Source Rock of Woodford/Mississippian Tight Oil Play on the Cherokee Platform (Oklahoma)*

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Abstract

Tight oils recently produced from the Woodford Formation on the Central-Northern Cherokee Platform (Oklahoma) are light API-gravity oils (40-45°API). The producing formation is the Woodford Shale of Late Devonian to Early Mississippian age (~385 Ma to ~360 Ma), an organic-rich (4~12% TOC) black shale widely distributed in the southern mid-continent with very low porosity (<1.25%) and extremely low permeability (<1mDa). All of these characteristics have led to the presumption the oils being produced in this area were generated in-situ. Based on the previous vitrinite reflectance measurements (VRo) the thermal maturity of the Woodford Shale in the study area is in the range of 0.52% to 0.58% VRo corresponding to the immature-to-early-mature stage of oil generation. A detailed geochemical study on oil samples and Woodford cores extracts has been conducted to investigate possible sources for these oils. Results obtained to date have led to the following observations and deduction: (i) oils produced close to the Nemaha Uplift (Logan and West Payne Counties) were not only Woodford sourced but also had a Mississippian source contribution based on the presence of abundant extended tricyclic terpanes and other source specific biomarker fingerprint characteristics; (ii) oils sampled from the East of the Cherokee Platform (Central-East Payne County) share strong Woodford source characteristics but were not generated in-situ from the Woodford Shale, which is not mature enough in that area but probably migrated from the Woodford Shale in the deeper Anadarko Basin. The preliminary results of this research are consistent with some new findings reported by the Devon geologists that abundant marine coarse-grained biogenic silica (radiolarian-rich chert facies) found in Woodford cores (Central-East Payne County) in this area may be a contributor to good reservoir petrophysical properties suggesting the Woodford Formation may not be the source rock in this area but simply a tight reservoir.

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Source Rock of Woodford/Mississippian Tight Oil Play on the Cherokee Platform (Oklahoma)

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Abstract

A comprehensive organic geochemical analysis was performed to a suite of cores from the Woodford Shale in Central Oklahoma with the aim of characterizing variations in organic matter source, depositional environments and thermal maturity. A total of 40 oils and condensates produced from the Woodford Shale and Mississippian Limestone in Central Oklahoma were analyzed to determine the origin of these liquids.

The Woodford Shale in this study is a typical marine siliciclastic mudstone (organofacies B). TOC and Rock-Eval parameters show the Woodford Shale has excellent source rock potential and is dominated by Type II kerogen of a marine origin. Distributions of regular steranes, hopanes and monoaromatic steroids (MAS) point towards a marine siliciclastic depositional environment. Aryl isoprenoids and paleorenieratanes /isorenieratanes suggest the occurrence of episodic periods of photic zone anoxia (PZA) during deposition of the Woodford Shale in this study. In addition, n-alkanes, steranes distribution, and the tentative identification of gammacerane suggest deposition under hypersaline conditions in Central Oklahoma. Source-dependent biomarker parameters indicate that in the area in proximity to the Nemaha Uplift the Woodford Shale was deposited under a condition rich in clay contents, reflecting the influence of the paleo-Nemaha Uplift. Thermal maturity parameters indicate that the Woodford Shale is immature to marginally mature in Payne County, and show a progressive increase in maturity towards the southeast following the regional dip. In the area in proximity to the Nemaha Uplift, the Woodford Shale is in the main stage of oil generation.

Three main conclusions regarding the origin of the liquids in this study: (i) oils produced from the Woodford Formation and that from the overlying Mississippian Formation share very similar fingerprint suggest the Woodford Formation and the overlying Mississippian Formation are connected; (ii) oils produced in the area in proximity to the Nemaha Uplift (Logan and West Payne Counties) were not only Woodford sourced but also had a Mississippian source contribution based on the presence of abundant extended tricyclic terpanes and other source specific biomarker fingerprint characteristics; (iii) oils sampled from the East of the Cherokee Platform (Central-East Payne County) share strong Woodford source characteristics but were not generated in-situ from the Woodford Shale, which is not mature enough in that area, but probably migrated from the Woodford Shale in the deeper part of the Anadarko Basin in Southern Oklahoma. The results of this research are consistent with the new findings reported by the Devon geologists that abundant marine coarse-grained biogenic silica (radiolarian-rich chert facies) found in Woodford cores (Central-East Payne County) in this area may be a contributor to good reservoir petrophysical properties suggesting the Woodford Formation may not be the source rock in this area but simply a tight reservoir.

Motivation & Objectives

The primary objective of this project is to answer two questions: 1) what is the origin of the tight oils: are they generated in-situ from the Woodford Shale or migrated; 2) if generated in-situ, how could they be generated from immature Woodford Shale; if migrated, how could they charge a very tight shale formation. To answer these questions, it is necessary to evaluate hydrocarbon generation potential of source rocks in the study area as well as examine a detailed geochemical characterization of both crude oils and source rocks to determine several key geochemical parameters including: a) litho- and organofacies of the potential source rocks and their depositional environment; b) thermal maturity; c) oil-oil and oil-source rock correlations; d) biodegradation if any.

Woodford Unconventional Play "Provinces" with Max IP Oil (BOD) and General Thermal Maturity

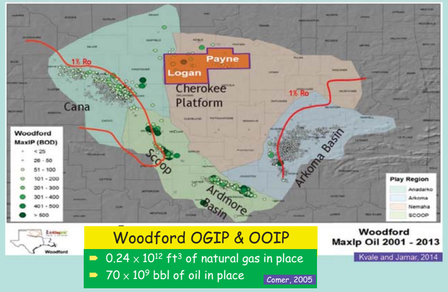


Fig. 1. Woodford Unconventional Play "Provinces" in Oklahoma

Since 2009 tight oil (API: 40~45°) has been producing from immature Woodford in Logan and Payne

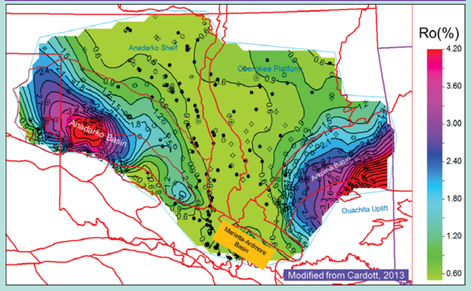


Fig. 2. Woodford Shale Iso-reflectance Map in Oklahoma

I. Study Area

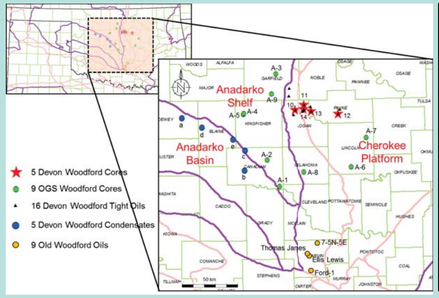


Fig. 3. Map of Central Oklahoma showing locations of the cores and oils samples in this study

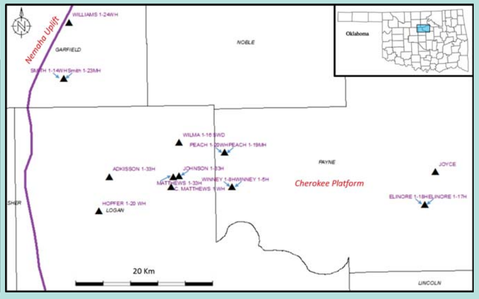


Fig. 4. Map of Logan & Payne County showing locations of the oil samples in this study

II. Geological Setting

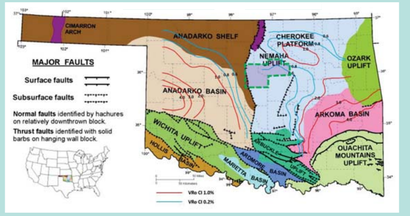
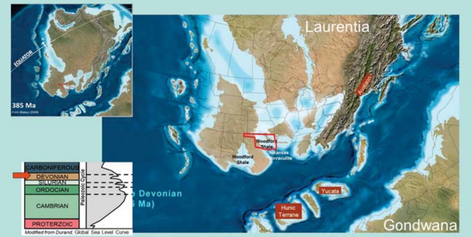


Fig. 5. Woodford vitrinite isoreflectance map in Oklahoma (Cardott, 2014; without Woodford in Oklahoma panhandle; Devon tight oil play in Logan & Payne County masked in light purple)

Late Devonian - 385 Ma:
Worldwide Global Sea Level Rising and Onset Deposition of Woodford Shale



Early Mississippian - 365 Ma:
Worldwide Global Sea Level Maximum and Woodford Deposition Coverage Maximum

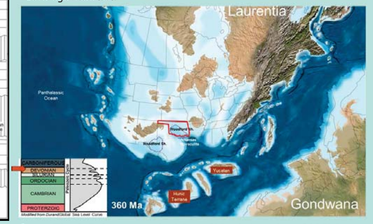


Fig. 8. Paleogeography Map of North America of 385Ma - 360Ma (Oklahoma in red solid line; Blakey, 2013)

Woodford Log Characteristics

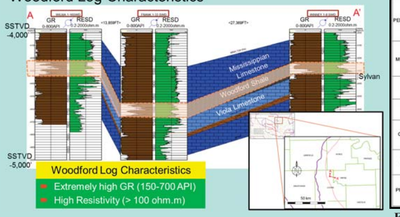


Fig. 6. Woodford log characteristics on Cherokee Platform

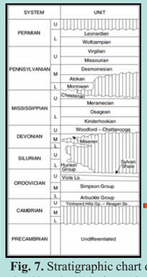


Fig. 7. Stratigraphic chart of the Cherokee Platform, Central Oklahoma (Charpentier, 2001)

III. Source Rock Characterization

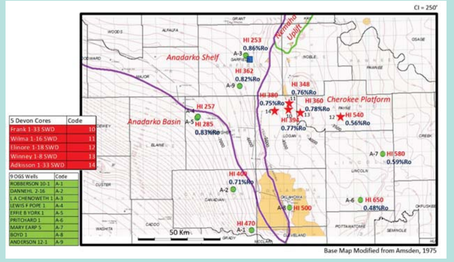


Fig. 9. Woodford Structural Map (in SSTVD) with Woodford HI and measured vitrinite reflectance values (VRo)

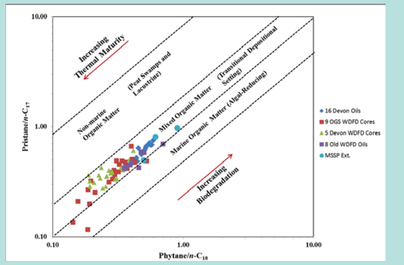


Fig. 10. Isoprenoids plot of Pristane/n-C_{17} vs. Phytane/n-C_{18}

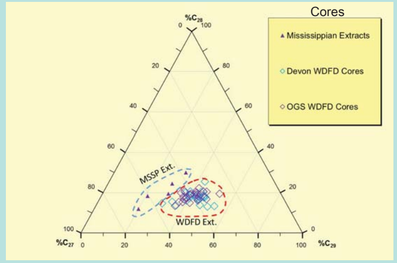


Fig. 11. Regular sterane ternary diagram of rock samples using C_{27}, C_{28}, and C_{29} 14α(H), 17α(H) (20R) regular sterane isomers (MSSP = Mississippian; WDFD = Woodford)

II. Source Rock & Crude Oil Characterization

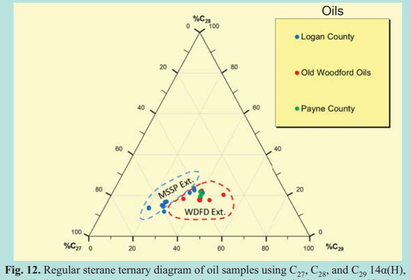


Fig. 12. Regular sterane ternary diagram of oil samples using C_{27}, C_{28}, and C_{29} 14α(H), 17α(H) (20R) regular sterane isomers overlapped with Mississippian and Woodford cores extracts "outlines" (light blue and red dash lines, respectively)

III. Oil-Source Rock Correlation

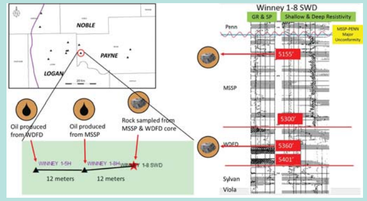


Fig. 13. Map of Logan and Payne with the well site highlighted for oil-to-oil correlation study and the well log of Winney 1-8 SWD showing Mississippian and Woodford rock sampling depth

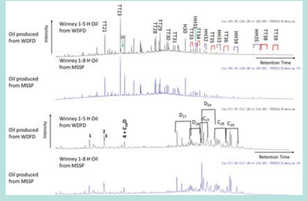


Fig. 14. Correlation between an oil produced from the Woodford Shale and an oil produced from the Mississippian Limestone at a same well site (IS: Internal Standard)

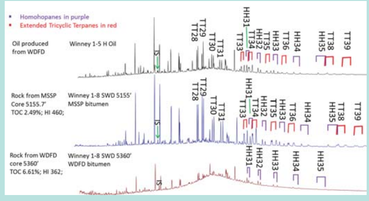


Fig. 15. SIM *m/z* 191.3 mass chromatograms showing distribution of terpanes in the Saturate fractions of the oil samples and rock extract (Red brackets denote tricyclic terpane (TT) isomers and purple brackets denote homohopane (HH) isomers)

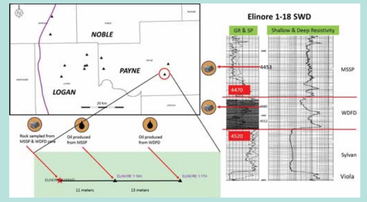


Fig. 16. Map of Logan and Payne with the well site highlighted for oil-to-oil correlation study and the well log of Elinore 1-18 SWD showing Mississippian and Woodford rock sampling depth

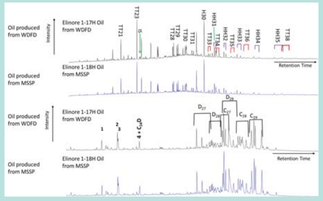


Fig. 17. Correlation between an oil produced from the Woodford Shale and an oil produced from the Mississippian Limestone at a same well site

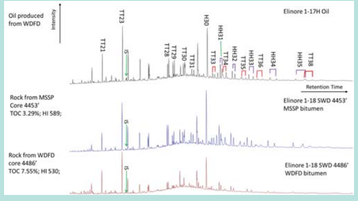


Fig. 18. SIM *m/z* 191.3 mass chromatograms showing distribution of terpanes in the Saturate fractions of the oil samples and rock extract

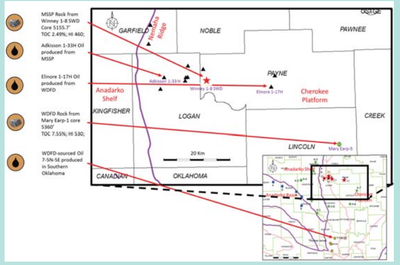


Fig. 19. Map of Logan and Payne with the well site highlighted for oil-to-source rock correlation study

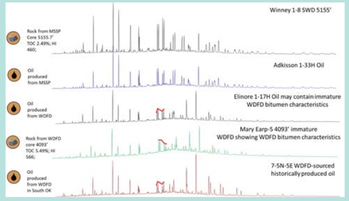


Fig. 20. SIM *m/z* 191.3 mass chromatograms showing distribution of terpanes in the Saturate fractions of the studied oil samples and rock extract.

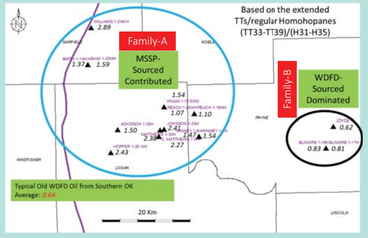


Fig. 21. Well Location Map of Logan and Payne with the extended tricyclic terpanes vs. homohopanes ratios (TT33~TT39)/(H31~H35) for oil-to-source rock correlation

III. Oil-Source Rock Correlation

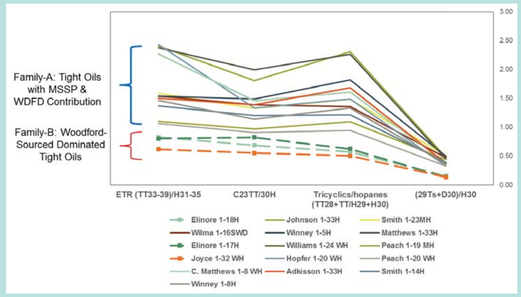


Fig. 22. Biomarker (Terpanes) distribution of the studied tight oil samples for oil-oil correlation (MSSP = Mississippian; WDFD = Woodford)

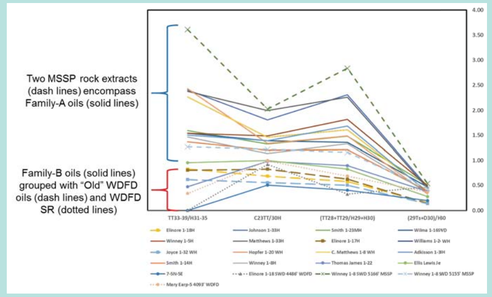


Fig. 23. Biomarker (Terpanes) distribution of the studied tight oil samples and source rock extracts or oil-source rock correlation (MSSP = Mississippian; WDFD = Woodford)

III. Oil-Source Rock Correlation

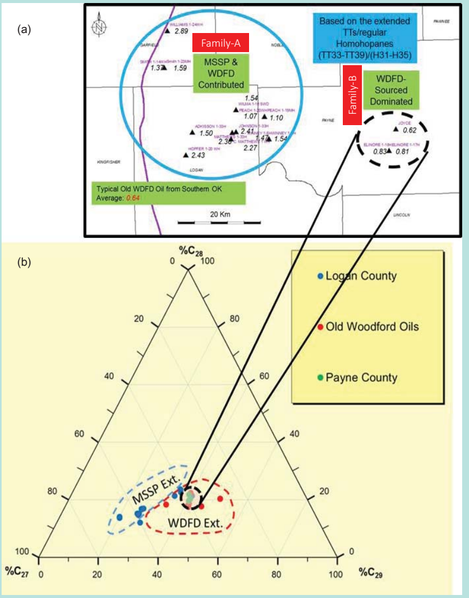


Fig. 24. (a) Well Location Map of Logan and Payne with the extended tricyclic terpanes vs. homohopanes ratios (TT33~TT39)/(H31~H35) for oil-to-source rock correlation;
(b) **.** Regular sterane ternary diagram of oil samples using C_{27}, C_{28}, and C_{29} 14α(H), 17α(H) (20R) regular sterane isomers overlapped with Mississippian and Woodford cores extracts "outlines" (light blue and red dash lines, respectively)

- Family A: Tight oils produced near Nemaha Uplift sourced by local Woodford & Mississippian source rocks (light blue circle);
- Family B: Tight oils in Central Payne County mainly sourced by Woodford Shale suggested by the ternary diagram in Fig. 23 (b) as well

VI. Proposed Petroleum System & Migration Pathway

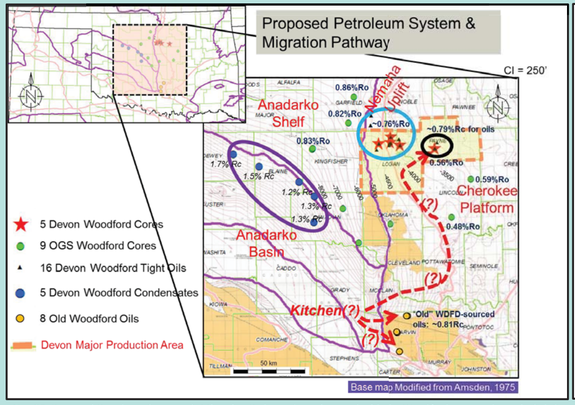


Fig. 25. Proposed Petroleum Systems & Migration Pathway (superimposed with the Woodford structural map in Sub Sea Total Vertical Depth in feet; Contour Increment = 250 ft)

- Woodford condensates in the Anadarko Basin flank generated in-situ (purple circle);
- Tight oils produced near Nemaha Uplift sourced by local Woodford & Mississippian source rocks (light blue circle);
- Tight oils in Central Payne County probably migrated from the Woodford Shale in deep Anadarko Basin ((red dash line).

Conclusions

The origin of the oils sampled in this study were related to their possible source beds based on oil-oil and oil-source rock correlation by comparing biomarker fingerprints. Three major conclusions were made: (i) oils produced from the Woodford Formation and Mississippian Formation share very similar fingerprints suggesting the Woodford Formation and the overlying Mississippian Formation are connected in the study area; (ii) oils produced in the area in the proximity of the Nemaha Uplift (Logan and West Payne Counties) were not only sourced by the local Woodford but also had a significant local Mississippian source contribution based on the presence of abundant extended tricyclic terpanes and other source-specific biomarker characteristics; (iii) oils sampled from the East of the Cherokee Platform (Central-East Payne County) share strong Woodford source characteristics but were not generated *in-situ* from the Woodford Shale since the Woodford in that area is not mature enough. Therefore, the oils may probably be migrated from the Woodford Shale in the deeper part of the Anadarko Basin in Southern Oklahoma. The results of this research are consistent with recent findings that abundant marine coarse-grained biogenic silica (radiolarian-rich chert facies) found in Woodford cores (Central-East Payne County) in this area may be a contributor to good reservoir petrophysical properties suggesting the Woodford Formation may not be the source rock in this area but simply a tight reservoir.