PS Redefining the STACK Play from Subsurface to Commercialization: Identifying Stacked Pay Sweet Spots in the Northern Anadarko Basin*

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Search and Discovery Article #11104**
Posted July 23, 2018

*Adapted from poster presentation given at 2018 AAPG Annual Convention & Exhibition, Salt Lake City, Utah, May 20-23, 2018.

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Abstract

Independent unconventional specialist companies continue to be drawn to the STACK (Sooner Trend, Anadarko Basin, Canadian and Kingfisher counties) play of northern Oklahoma. Situated in the northern portion of the Anadarko Basin. The STACK play boasts stacked pay potential from at least five major reservoir units, all of which contain varying amounts of oil and gas reserves. To date, just over 2000 horizontal wells have been brought online in the greater STACK area, and estimated break-evens for many of these earlier wells fall below $30 per barrel. The early core of the play covers approximately 3500 square miles in southwestern Kingfisher County, Oklahoma, and nearby areas in Canadian, Blaine, and Dewey Counties. Here, operators have focused on the Mississippian Meramec Formation, with average peak monthly rates approaching 800 boe/d (6:1) in early 2017. Further, estimated ultimate recoverable volumes (EURs) for Meramec horizontals are approaching 1 Mmboe (6:1), making it competitive with the prolific Bone Spring and Wolfcamp Delaware plays, which have estimated EURs around 1 Mmboe (6:1) and 1.2 Mmboe (6:1), respectively. As the STACK play develops, unconventional experts are also succeeding in secondary reservoirs that have historically been developed using conventional vertical well completions, namely the Hunton, Woodford, Osage, and Oswego. Delineation and de-risking of these additional horizontal targets has not advanced as quickly as the Meramec; however, peak monthly rates in these secondary reservoirs have been on par with the Meramec. Multiple horizons in the STACK play allow for stacked horizontal development–similar to what is taking place in the Permian today, where operators enjoy economic advantages from concentrated operations. In addition, operators have extended STACK success into nearby areas and renamed some areas as individual plays. This study serves to detangle the Silurian-Pennsylvanian-aged stacked pays in the Anadarko Basin by standardizing the stratigraphic nomenclature, to identify accurately commercial inventory and localized well productivity by reservoir. Further, integration of geological, economic, production, and completion data from each of the pay zones throughout the greater STACK area aids in identifying production drivers and inhibitors, which enable more accurate prediction of total STACK resource and future production growth potential of the STACK play and surrounding areas.

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Higley, D.K., and S.B. Gaswirth, 2014, Petroleum systems and assessment of undiscovered oil and gas in the Anadarko Basin province, Colorado, Kansas, Oklahoma, and Texas – USGS Province 58: USGS Digital Data Series DDS-69-EE, p. 1-5.

Johnson, K.S., 2008, Geologic history of Oklahoma: Oklahoma Geological Survey Educational publication 9, p. 3-8.

Acknowledgements

A sincere Thank You to Vyetta Jordan at the OGS for providing IHSM with the necessary core data, and to Joe Landry and Bill Price with PSI for providing IHSM with quality petrophysical logs.

REDEFINING THE STACK PLAY FROM SUBSURFACE TO COMMERCIALIZATION: IDENTIFYING STACKED PAY SWEET SPOTS IN THE NORTHERN ANADARKO BASIN

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OBJECTIVE

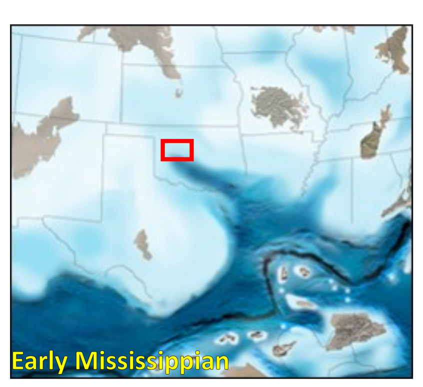
The purpose of this study is to begin detangling the Silurian-Pennsylvanian aged stacked reservoirs in the Anadarko Basin by standardizing the stratigraphic nomenclature to accurately analyze well productivity by reservoir and estimate commercial inventory. The liquids-rich Mississippian section of the northern Anadarko Basin, or STACK (Sooner Trend, Anadarko Basin, Canadian and Kingfisher counties) play, has been the most widely targeted reservoir in recent years, accounting for about 60% of the horizontal wells on production in the area. Further, STACK operators are able to maximize returns by producing from up to 4 target intervals per unit in some areas of the play, termed herein as "stacked pay sweet spots". Operators in the STACK play continue to announce aggressive development plans, namely for the Mississippian section, therefore the primary focus of this study is two-fold: (1) identify geologic sweet spots and discrete areas of high productivity for each bench, and (2) delineate stacked pay sweet spots.

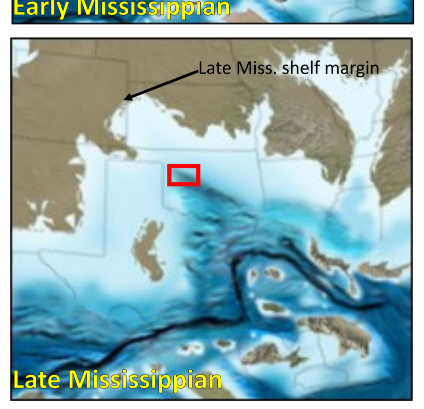
The early core of the play covers approximately 1,000 square miles in Kingfisher and northern Canadian counties, Oklahoma. Based on recent horizontal completions in the Mississippian to the west of the traditional STACK "core" area, however, IHS Markit has revised its definition of the STACK play to include much of Dewey and Blaine counties, and the southernmost portions of Woodward and Major counties. Further, IHS Markit has subdivided the Mississippian section, which exceeds over 1,000 ft. in thickness throughout much of the play area, into four distinct reservoir targets, or benches, to better understand and delineate the stacked pay potential of the play: Lower Osage, Upper Osage, Lower Meramec, and Upper Meramec.

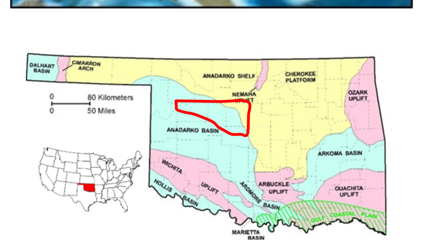
METHODOLOGY

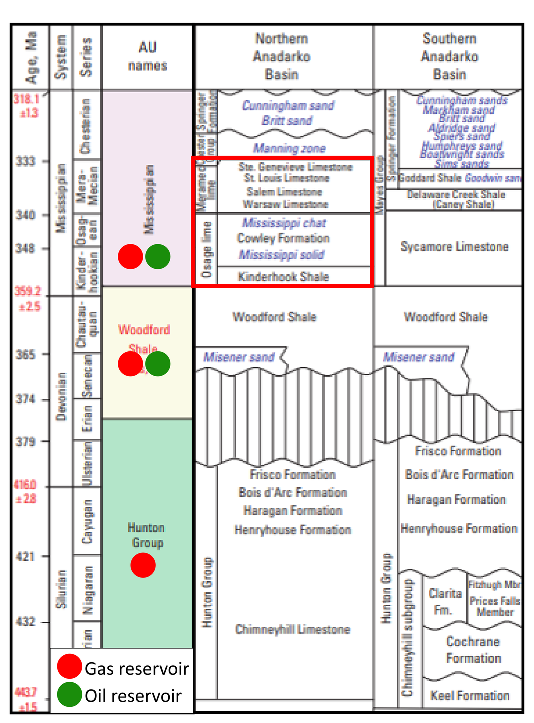
- Regional mapping of individual benches
- Identify major bench lithofacies and upscale to petrophysical logs
- Assign horizontal target interval, or "bench"
- Generate petrophysical maps for each bench
- Analyze production, completion, and economic data at the bench level
- Identify geologic sweet spots for each bench
- Identify areas of high productivity for each bench
- **Delineate stacked pay sweet spots & estimate remaining commercial inventory**

GEOLOGIC SETTING & BACKGROUND

(1) 

(2) 

(3) 

(4) 

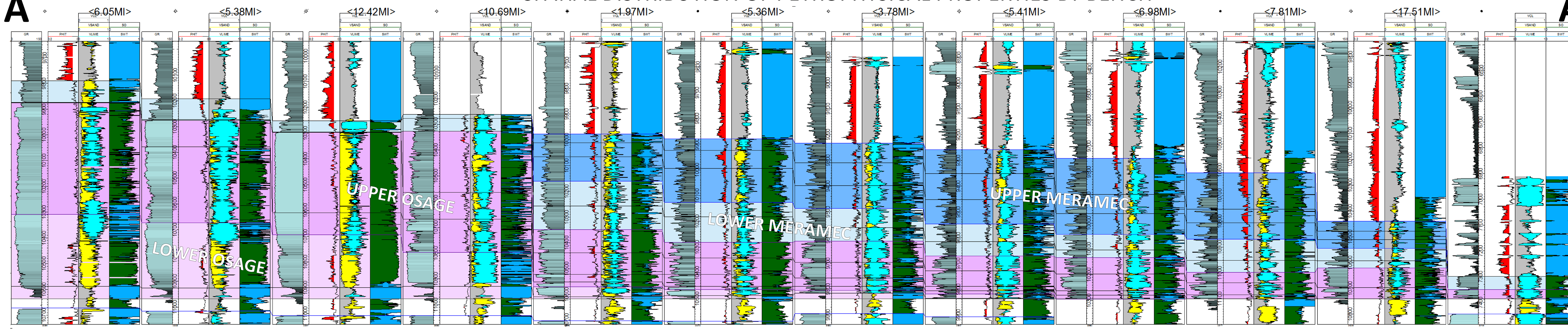
(1)Paleogeographic map of the early Mississippian (Kinderhookian-Osagean) (mod. From Blakey, 2017)

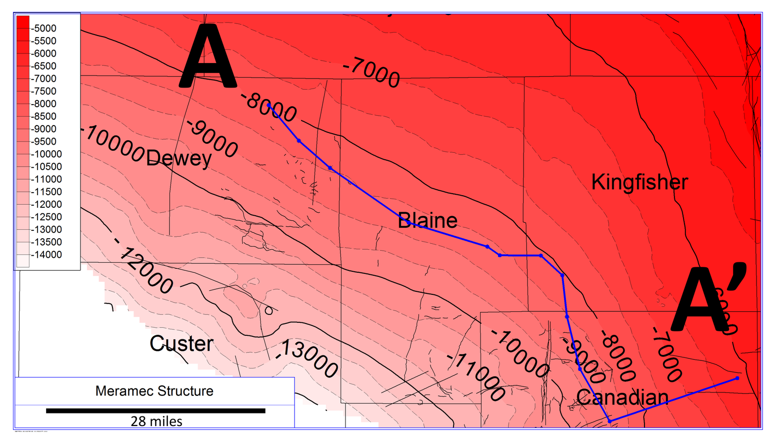
(2)Paleogeographic map of the late Mississippian (Meramacian-Chesterian) (mod. From Blakey, 2017)

(3)Major geologic provinces of Oklahoma. Red polygon highlights IHS Markit defined STACK play (modified from Johnson, 2008)

(4)Anadarko Basin stratigraphy with Osage-Meramec formations highlighted (modified from Higley and Gaswirth, 2014 and references therein)

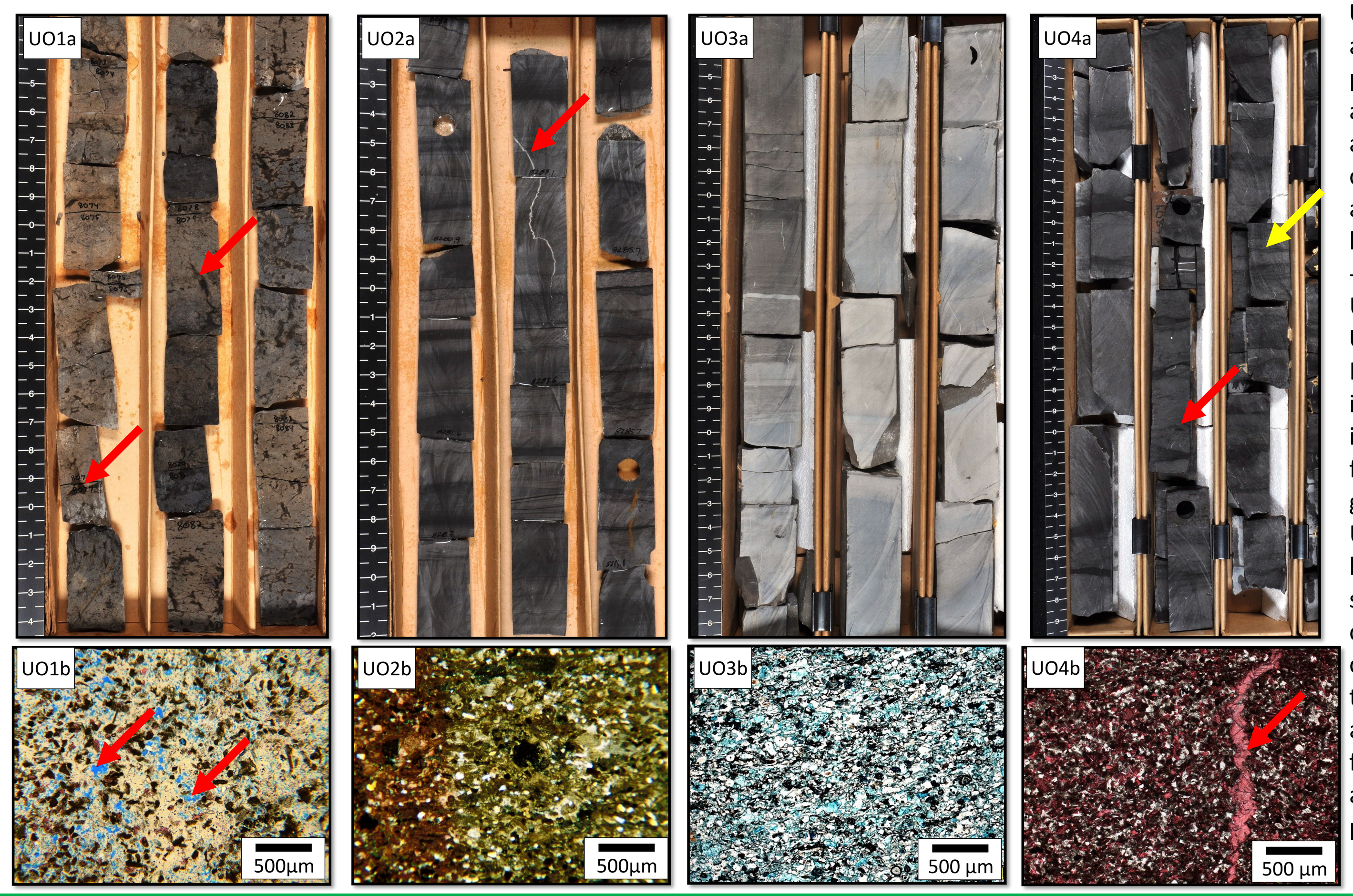
SPATIAL DISTRIBUTION OF PETROPHYSICAL PROPERTIES BY BENCH





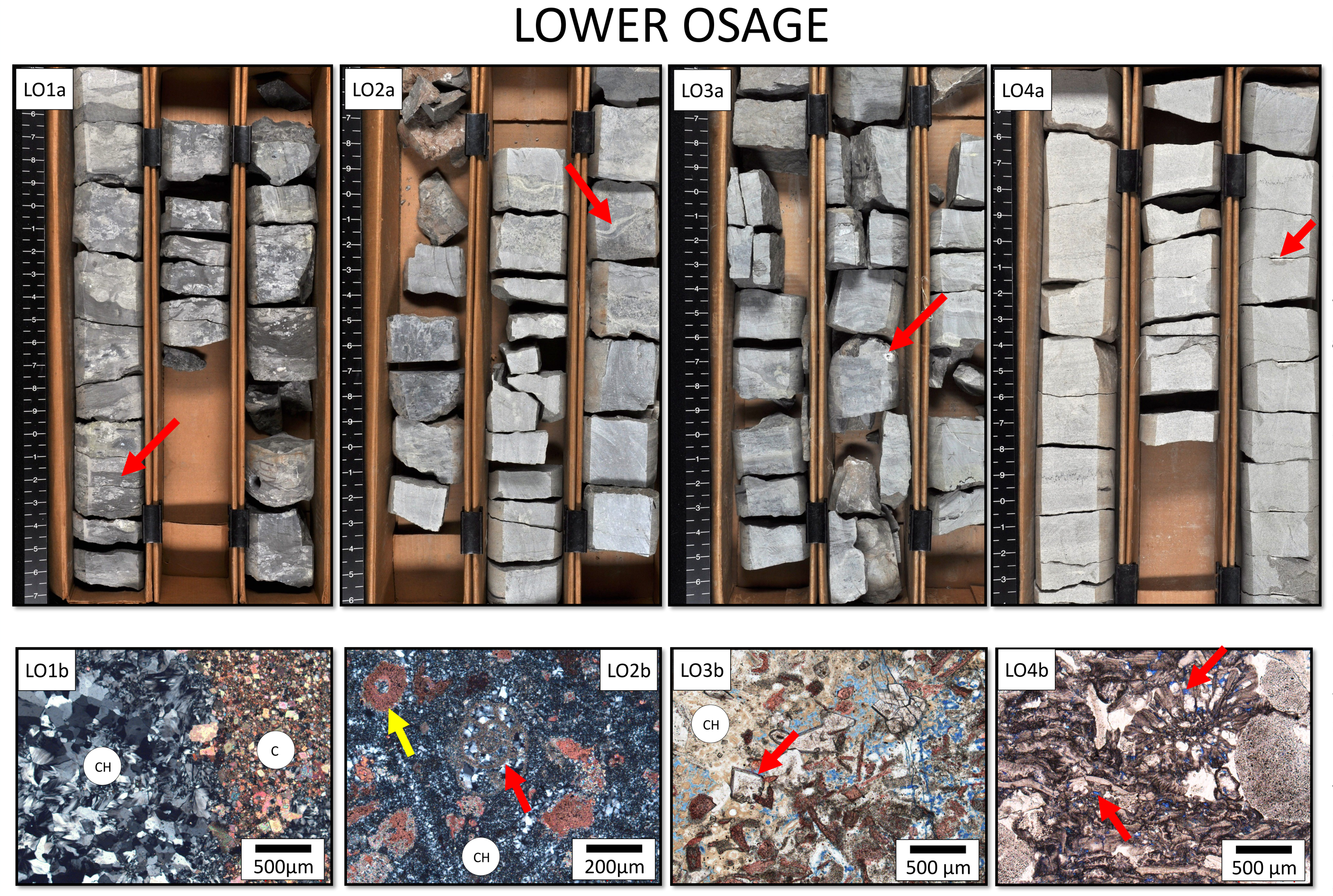
- Osage strata exhibit aggradational and progradational stacking patterns with overall low clay content, while Meramec strata form high frequency coarsening-upward sequences with an overall retrogradational (fining-upward) character and have overall higher clay volumes. Porosity is generally higher in the Meramec than in the Osage.
- Osage and Meramec strata can be further subdivided into 4 stratigraphic intervals that each have distinct petrophysical log characteristics: Lower Osage, Upper Osage, Lower Meramec, Upper Meramec.

UPPER OSAGE



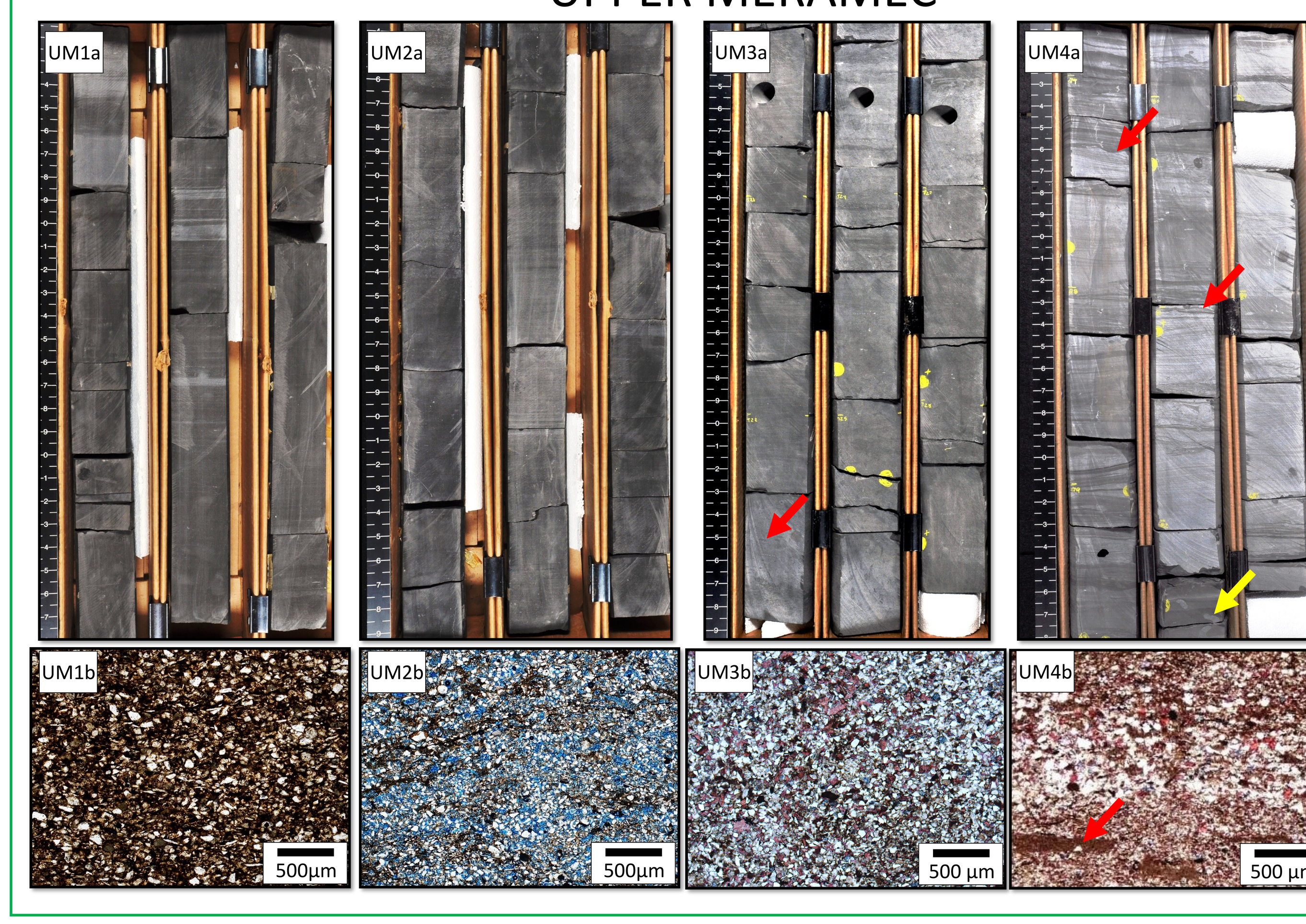
UO1: Chert (CH) with high amounts of visible vuggy porosity (red arrows, UO1b) and "bleeding oil" in core (red arrows, UO1). **UO2:** Alternating calcareous siltstones and argillaceous siltstones; calcite-healed fractures occur in calcite -rich intervals (red arrow, UO2a). No visible porosity. **UO3:** Silty skeletal grainstone. High amounts of moldic, intercrystalline and intracrystalline porosity created from dissolution of carbonate grains and crystals (blue, UO3b). **UO4:** Alternating silty limestones with argillaceous siltstones. High occurrence of clay seams and elongate clay clasts oriented roughly parallel to bedding (yellow and red arrows, UA4b). Calcite-healed fractures are common (red arrow, UA4b). No visible porosity.

LOWER OSAGE



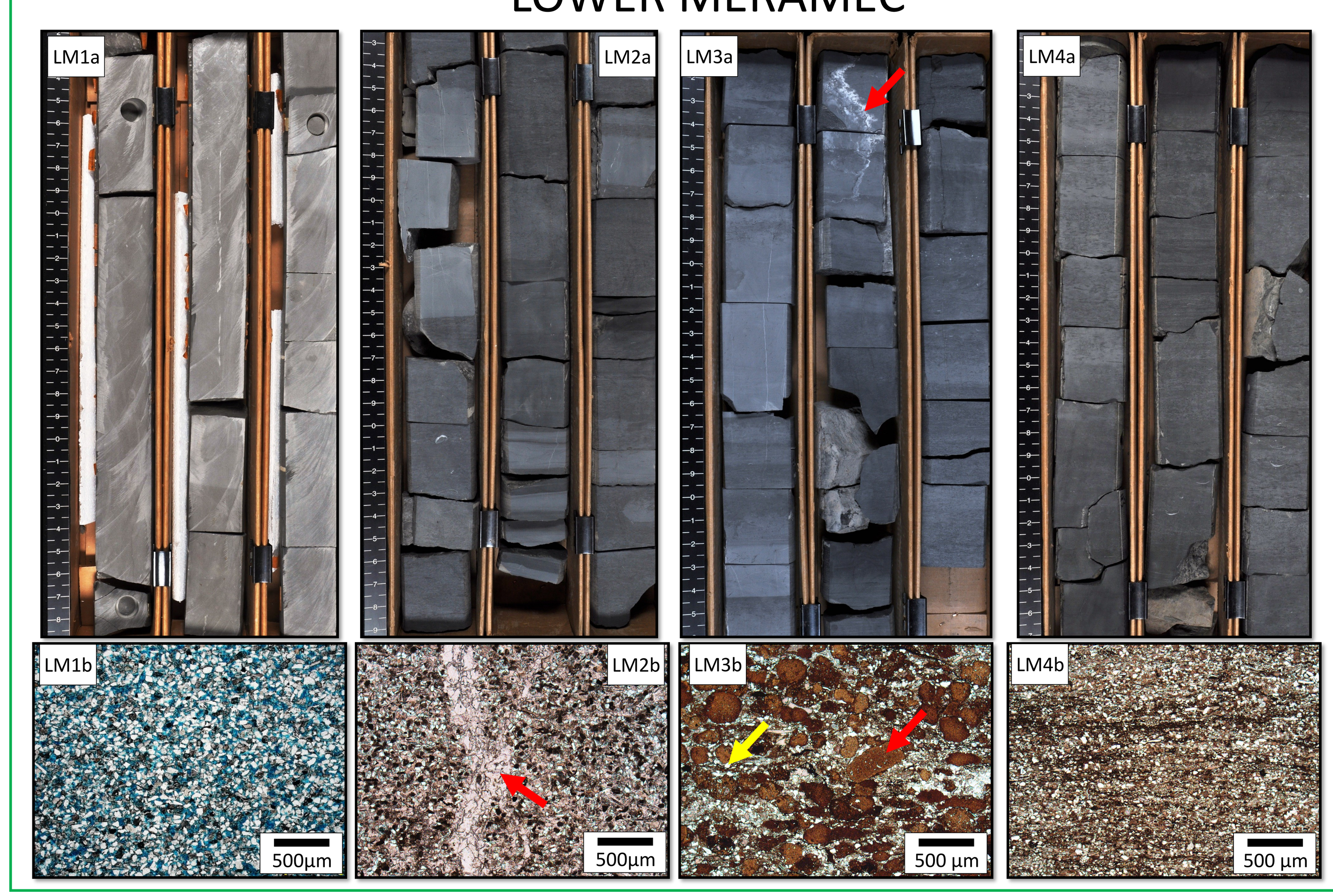
LO1: Grainstone comprised of pillow-shaped carbonate clasts and clay clasts chaotically distributed in a clay-rich fine-crystalline chert (CH)- and calcite (C)-rich matrix. Clay seams (red arrow, LO1a) common. No visible porosity. **LO2:** Chert-rich wackestone comprised of skeletal grains; brachiopod spines (yellow arrow, LO2b) and fusulinids (red arrow, LO2b). Slumping occurs in clay-rich intervals (red arrow, LO2a). No visible porosity. **LO3:** Chert (CH)-rich grainstone with abundant zoned dolomite crystals (red arrow, LO3b) and partially dissolved skeletal grains. Chert nodules common (red arrow, LO3a). Fairly high amounts of well -connected vuggy porosity associated with chert (blue, LO3b). **LO4:** Skeletal packstone with fair amounts of mainly isolated intraparticle porosity (red arrows, LO4b). Chert nodules common (red arrow, LO4a).

UPPER MERAMEC



UM1: Laminated silty shale with no visible porosity. Main constituents are silt-sized quartz and feldspar grains, and platy micas. **UM2:** Argillaceous siltstone with high amounts of intergranular porosity (blue, UM2b). **UM3:** Calcareous siltstone with high degree of bioturbation. Laminated in places. Elongate clay clasts oriented roughly parallel to bedding (red arrow, UM3a). Fair amount of intergranular & intracrystalline porosity throughout. **UM4:** Crudely laminated argillaceous calcareous siltstone consisting predominantly of silt-sized quartz and feldspar grains. Elongate clay clasts are oriented roughly parallel to bedding (red arrow, UM4b). High frequency of erosional surfaces (red arrows, UM4a). Burrows are frequent in both carbonate-rich (yellow arrow, UM4a) and clay-rich intervals Porosity mostly occluded by clay & calcite cement.

LOWER MERAMEC



LM1: Calcareous siltstone with high amounts of intergranular porosity (blue, LM1b). **LM2:** Argillaceous calcareous siltstone with calcite-healed fracture (red arrow, LM2b). Calcareous fossil fragments are present throughout. High amounts of pore-occluding calcite. Heavily bioturbated. **LM3:** Silty peloidal grainstone with calcareous fossil fragments and calcite cement throughout. Major constituents are rounded peloids (red arrow, LM2b) and quartz (yellow arrow, LM2b) grains. No visible porosity. Calcite-filled fluid escape structure present in core sample (red arrow, LM3a). **LM4:** Crudely laminated argillaceous siltstone. High amounts of bioturbation disrupts bedding. No visible porosity.

- Based on log and core data , the Upper and Lower Osage are dominated by chert-rich grainstones and packstones, while the Upper and Lower Meramec consist of argillaceous and calcareous siltstones. Calcite-healed fractures are common in carbonate-rich intervals.
- The Upper Meramec and Lower Osage have the highest porosities, particularly in calcite-poor siltstone facies and calcite-poor chert facies where moderately- to well-connected vuggy and intergranular pore types are common.
- Oil saturation is overall high throughout the Meramec-Osage section. The highest amounts of estimated oil-in-place occur in the chert-rich Lower Osage in the western part of the play.

SPATIAL DISTRIBUTION OF PETROPHYSICAL PROPERTIES BY BENCH

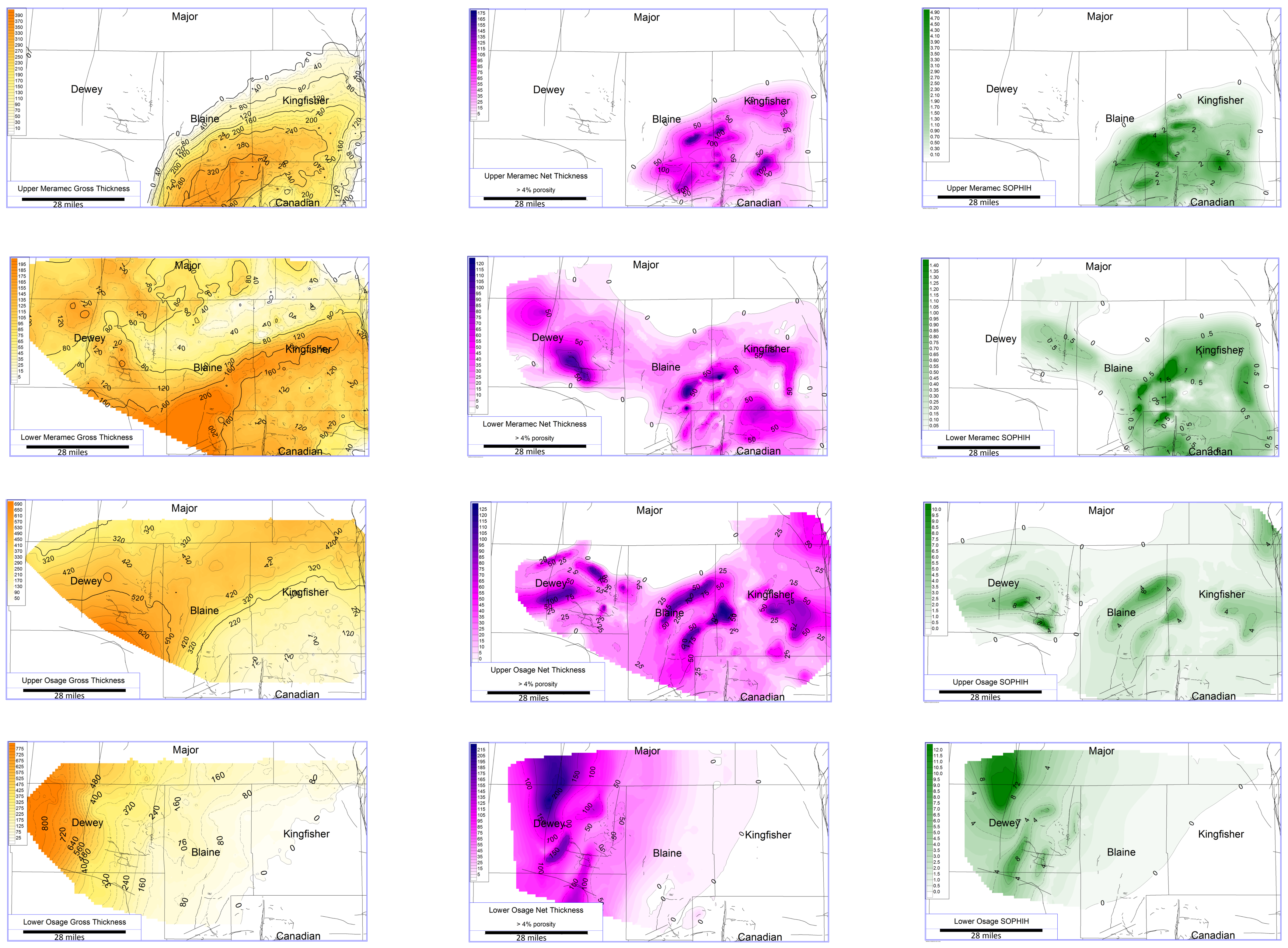
Gross thickness (ft.) | Net thickness (ft.) | SOPHIH

UPPER MERAMEC

LOWER MERAMEC

UPPER OSAGE

LOWER OSAGE

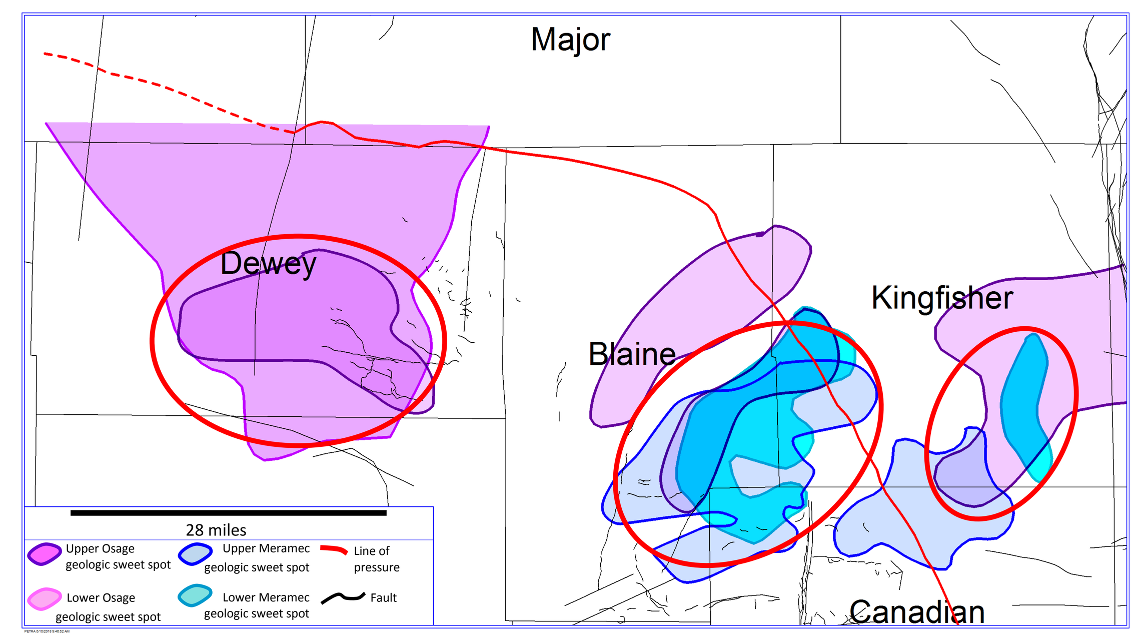


•Gross thickness trends for each bench are consistent with an overall progradational system in which each individual depocenter is oriented roughly southwest-northeast, sub-parallel to the paleo-shoreline, gradually shifting from northwest to southeast.

•Lower Osage strata occur in the northwest part of the play, pinching out to the east into eastern Blaine and western Kingfisher counties. Upper Meramec sediments only exist in the central to eastern part of the play due to erosion related to subaerial exposure to the northwest.

•Net thickness and SOPHIH trends for each bench generally follow gross bench thickness trends, where the highest values occur in areas of high gross thickness. Areas of high net thickness and SOPHIH are oriented sub-parallel to the paleo-shoreline (see Geologic Setting Figure 2).

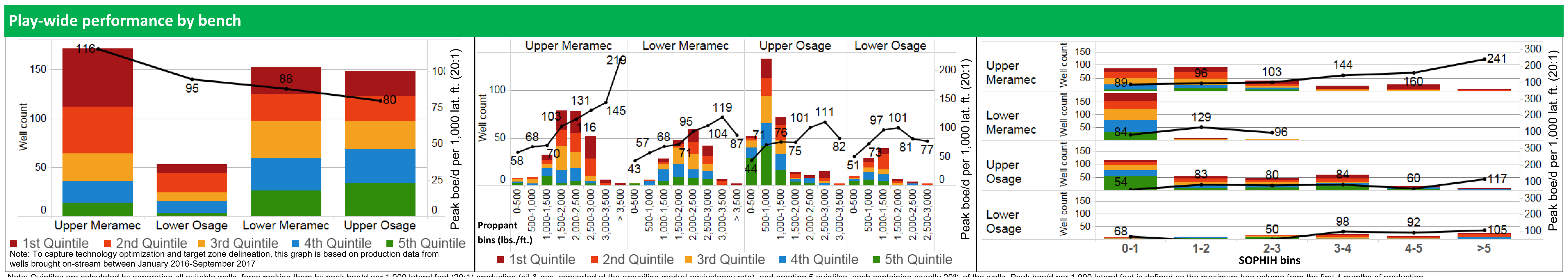
Geologic Sweet Spots



Using SOPHIH as a proxy for reservoir quality, 3 areas appear to have stacked pay potential (red circles above). Most of the stacked pay potential is situated in the over-pressured area of the play.

PRODUCTION ANALYSIS

Play-wide performance by bench

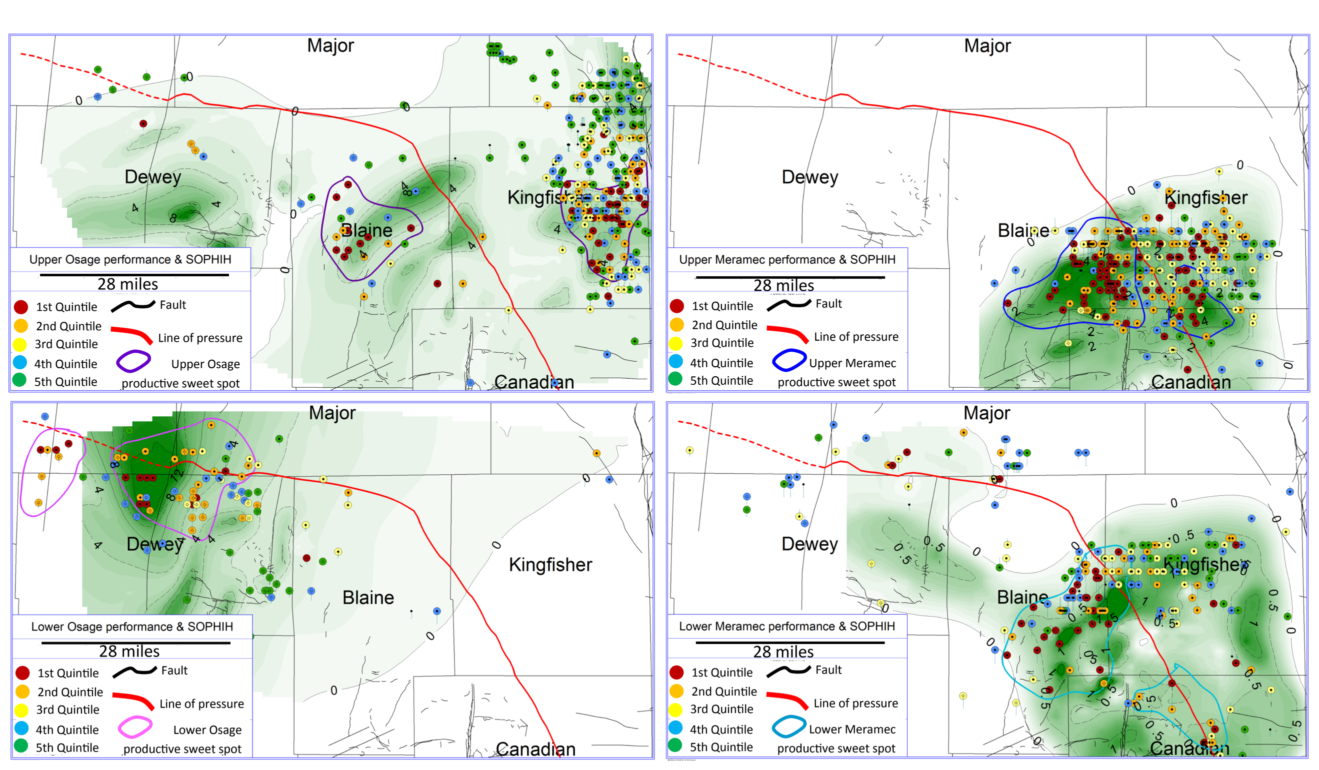


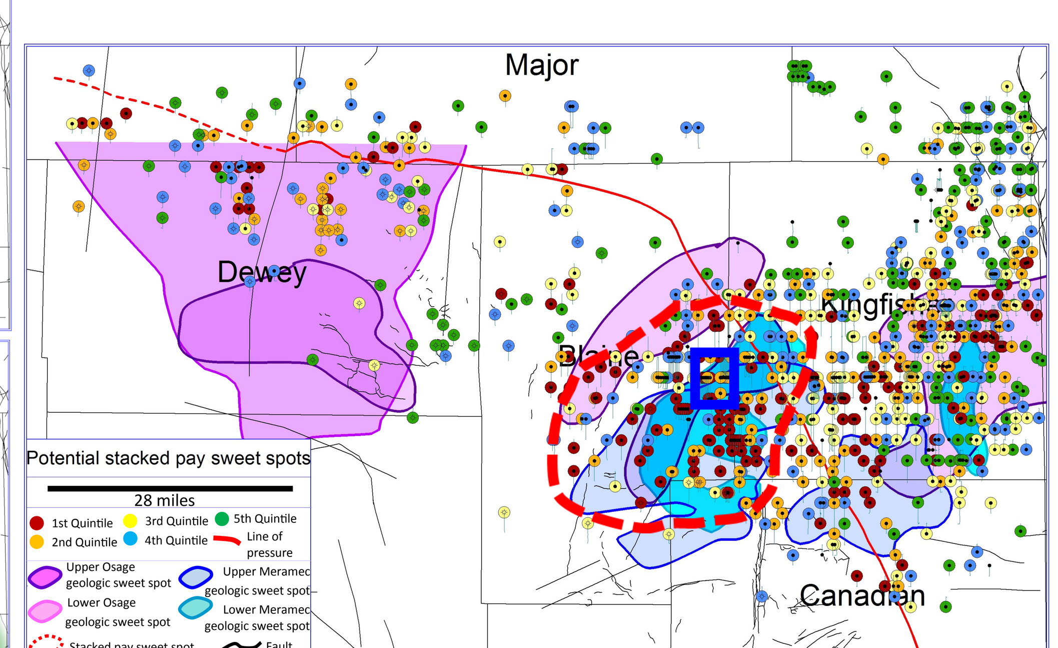
Note: Quintiles are calculated by separating all suitable wells, force ranking them by peak boe/d per 1,000 lateral feet (20:1) production (oil & gas, converted at the prevailing market equivalency rate), and creating 5 quintiles, each containing exactly 20% of the wells. Peak boe/d per 1,000 lateral feet is defined as the maximum boe volume from the first 4 months of production.

The Upper Meramec is the most widely targeted bench in recent years, and is overall the most productive. Upper and Lower Osage generally outperform Meramec benches with proppant intensities less than 1,500 lbs..ft. Above 1,500 lbs./ft., Upper Meramec is most productive, followed by the Upper Osage.

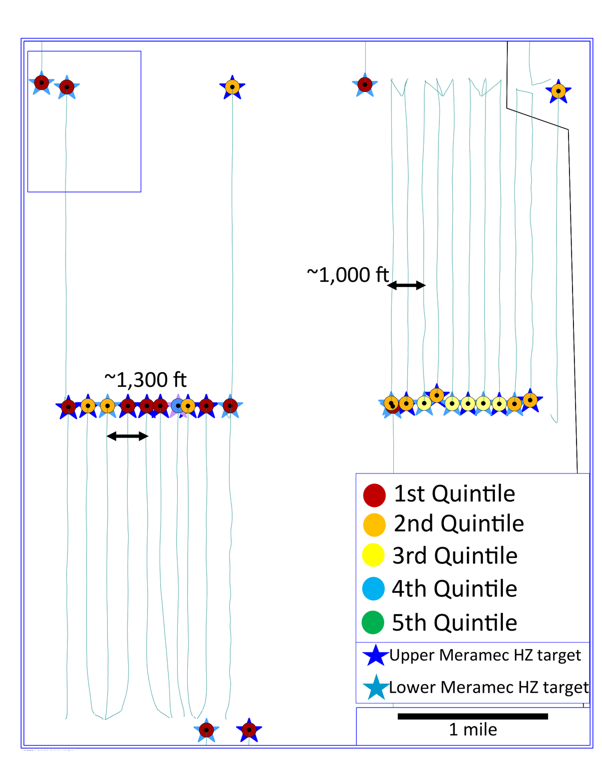
Stacked pay sweet spots: Where? How much?

A positive relationship exists between higher SOPHIH values and bench productivity in all benches less Lower Meramec where SOPHIH values are overall low. Nevertheless, areas where SOPHIH values appear low still yield favorable productivity.





The most significant area with stacked pay potential is situated largely in an over-pressured part of the play, in SE Blaine and SW Kingfisher counties.



STACKED PAY SWEET SPOT REMAINING INVENTORY		Upper Meramec	Lower Meramec	Upper Osage
Oil Metrics	IP rate (bbl/d)	872	669	778
	12-month decline	74%	70%	74%
	EUR (Mbbl)	554	512	458
	Break-even price ($/bbl)	$27.42	$29.33	$34.51
Gas Metrics	IP rate (Mcf/d)	3,254	3,086	2,729
	12-month decline	52%	51%	59%
	EUR (Bcf)	4.04	4.03	2.62
Remaining locations in stacked pay sweet spot at 1,320' spacing/HZ wells on-stream as of October		1,354/92	1,365/71	1,391/18

Type curve data are normalized to 7,000 ft. lateral length using wells completed with 2,000-4,000 lbs./ft. proppant

CONCLUSIONS

- Calcite-poor siltstone facies within the Meramec benches and vuggy chert facies in the Lower Osage have the best overall reservoir quality. Peloidal grainstones, calcareous siltstones, and silty limestones of the Lower Meramec and Upper Osage benches have overall poor reservoir quality largely due to high amounts of pore-occluding calcite cement.
- Porosity and SOPHIH trends are relatively predictable, consistent with gross thickness trends and oriented roughly parallel to the Mississippian paleo-shoreline.
- High SOPHIH areas serve as a good proxy for identifying geologic sweet spots, however, low SOPHIH areas also yield favorable productivities, particularly in the Upper and Lower Meramec benches.
- The primary stacked pay sweet spot identified herein is confined to a relatively small area (~350 sq. mi.) in SE Blaine and SW Kingfisher counties, where the Upper and Lower Meramec and Upper Osage have relatively high estimated SOPHIH values, favorable well productivity, and are generally over-pressured.
- IHS Markit estimates there are over 1,300 remaining locations for each of the three benches in the stacked pay sweet spot.

REFERENCES & ACKNOWLEDGEMENTS

Blakey, R.C., 2017, Paleogeography: Colorado Plateau Geosystems, Phoenix, AZ

Higley, D.K. and Gaswirth, S.B., 2014, Petroleum systems and assessment of undiscovered oil and gas in the Anadarko Basin province, Colorado, Kansas, Oklahoma, and Texas – USGS Province 58, USGS Digital Data Series DDS-69-EE, p. 1-5

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