Core evaluation and clay analysis of the Newcastle Sandstone, Osage Wyoming.
Prepared for Osage Partners, LLC
By EORI

Jones, Chopping, and Yin
2013

Outcrop of Lower Cretaceous Newcastle Fm. near Lak Lake, Wy.

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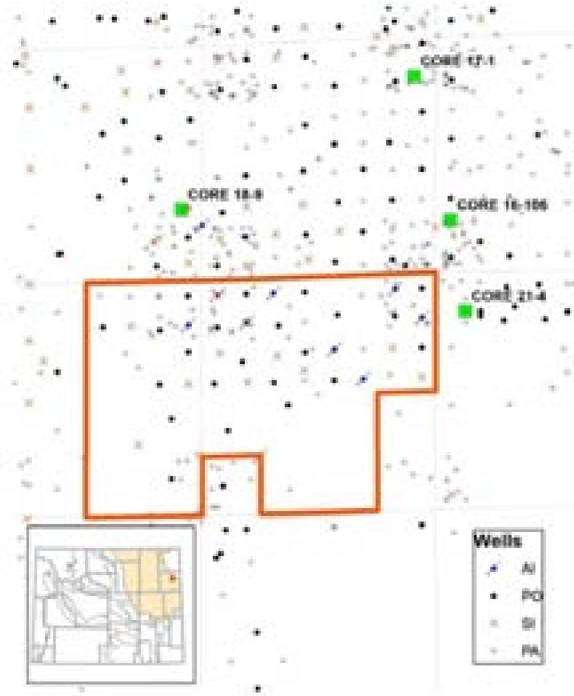

Location of cores and the Bradley Unit in the Osage Field

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Executive Summary

Osage Partners, LLC. a Wyoming based operator contacted EORI and requested the institute's assistance regarding their Muddy/Newcastle assets. The operator provided EORI with core from four wells and associated data related to the Osage field in the Powder River Basin. The operator requested that EORI characterize the clay mineralogy of the pay sands using XRD, SEM, and CEC analysis of samples from the provided core.

The purpose of performing this clay analysis was to:

- Identify clays in the formation
- Quantify clay content
- Approximate clay distribution in the formation and throughout the field
- Relate clay content to both productive and nonproductive intervals within the formation
- Determine whether or not clay inhibitors should be used (Osage Partners)
- Provide basis for SP and A/SP formulations regarding fluid rock interactions (TIORCO)
- Increase general knowledge about clays in Cretaceous Reservoirs
- Other

The results of this work are summarized in the following sections and detailed result sets are included in the appendices.

Background

The Osage field is currently producing ~120 BOPD and ~950 BWPD. The field was discovered in 1919 (Dobbin and Miller, 1941) and has since produced approximately 32.1 MMbls oil, 78.5 MMbls water and 142 MMcf gas (WOGCC). There are up to seven separate oil bearing intervals in the Muddy / Newcastle Formation within the Osage area. The operator has contracted with TIORCO to conduct fluid studies for their reservoirs and has also moved forward on developing a water study for the Osage field. Currently the operator is injecting roughly 200 BWPD and recovering approximately 3 BOPD from three producers from the Halbouty unit. The focus of this project is the Bradley Unit of the Osage field.

The Bradley Unit at Osage is divided into 4 separate tracts. Of interest is Tract 4, this tract is located along the western third of the unit and has produced nearly 70 percent of all Bradley production. Production in this tract began in between 1919 and 1922 and a water flood was started in 1969 and continued until 1998. The water flood was reactivated again near the end of 2000 and continued until 2009. Source water for injection is from the underlying Madison Formation. At the present it is undetermined whether or not source water was treated prior to injection. Evaluation of core analysis generated between 2006 and 2008 indicate a remaining oil resource of approximately 3 thousand bbls/acre. This determination is based on an average pay thickness of 5 feet, S_o of 40%, and 20% porosity.

In order to optimize their assets at Osage the operator spoke with the owner of Thompson Creek (another Muddy/Newcastle field located northeast of Osage) and learned that fluid compatibility studies should be performed prior to drilling in order to minimize reservoir damage. The operator has also expressed interest in the use of Potassium Hydroxide (KOH) as a clay inhibitor with respect to the known clays in the Newcastle Formation as they reactivate the injection in the Bradley Unit. It is important to note that the operator plans to use a portion of the Bradley Unit to identify best practices that can then be later applied to other areas within the larger Osage Field.

Project Objectives and Scope

The objective of this project was to assist Osage Partners, LLC with the characterization of the Muddy/Newcastle reservoirs at the Osage Field in the Powder River Basin (PRB), WY. The goal of this work is to provide the operator with information that may be used to enable decision making for the purpose of enhancing the recovery of oil from their Muddy/Newcastle assets (Osage, Mush Creek, etc…) in the PRB – specifically for the purpose of providing information relative to designing a water/chemical flood for the Bradley Unit of the Osage Field. Data for this project was provided to EORI by the operator and compiled from existing datasets at EORI and the Wyoming Oil and Gas Commission.

EORI conducted clay analysis on core samples from the Muddy/Newcastle Formation from four cores surrounding the Bradley Unit at the Osage Field. The analysis required compilation of available existing data, core preparation and sampling, petrographic analysis, core descriptions, and clay analysis using XRD and SEM. CEC analysis was also conducted.

This project directly supports the intended purpose and mission of EORI through the institute's strategic objectives which include benchmarking, technology transfer and providing technical expertise to a Wyoming based operator for the purpose of developing additional resources by way of enhanced oil recovery methods.

Data overview

Core that was used for this project was originally collected between 2006 and 2008 by Rockwell Petroleum Co.. The four wells that were cored include: 21-4 (api 4529132), drilled in 2006; 18-9 (api 4529128), drilled 2007; 17-1 (api 4529141), drilled 2007; and 16-106 (api 4529202), drilled in 2008.

Of the core that was provided to EORI, only two of the wells (16-106 and 17-1) included the main pay sands of the Newcastle Formation. The pay sand intervals for wells 18-9 and 21-4 were provided to TIORCO for analysis prior to the start of this project. TIORCO was later contacted and provided samples of the pay sands from well 21-4 to EORI (note: these samples have not yet been analyzed).

Other information including field data, production data, core analysis, and log data were compiled by the operator and provided to EORI early on in the project. A literature search was conducted by EORI which resulted in a compilation of references relative to the project objectives.

The provided core analysis data were used to identify appropriate samples for clay analysis. Apart from an overall lithologic criteria, samples of similar lithogies having drastically different porosities and permeabilities were selected in order to evaluate the relative percent clay and its affect on reservoir quality.

Several factors including historic development, production, depletion, stimulation, and injection have already affected the distribution and character of clays within the Newcastle reservoir in the Osage Field. As this core was collected after primary and secondary recovery, this core is likely representative of a clay damaged reservoir.

Of the core from the four wells that was evaluated, the core from well 17-1 is most representative of the Newcastle Formation within the study area because of the completeness of the cored interval and representation of the depositional sequences that occurred within this portion of the Osage Field.

Previous Work

Bell Creek 1989, Townsend Field 1990- Russ Welch, Denbury Resources 2012

Bell Creek, Muddy field in Montana along Recluse Bell Creek Trend

Presence of clays can reduce oil recovery after waterflood from 15-35%

Clays retain surfactant and polymer through adsorption, ion exchange, and precipitation

Increasing preflush periods to increase effective salinity improves oil recovery

Townsend Field, Newcastle field naturally fractured reservoir, clays, low K and phi due to matrix heterogeneity

Treat injection wells with KOH to permanently stabilize clays

Use polymer to close off fractures

Use a blend of phosphates and anionic polymers to maximize imbibition

Clay Assessment –

Previous petrographic work on the Newcastle/Muddy Formation in regard to clays occurred at the Bell Creek field in Montana, Mush Creek, Highlight, Recluse and other fields in Wyoming. The general consensus is that clays found in the shales include kaolinite, chlorite, mixed-layer illite/smectite, mixed-layer illite/mica, and sectite. The kaolinite in the Newcaslte sandstone is authigenic, a result of the diagenetic alteration of K-feldspar (Stone, 1972). Volcanic ash is another major source for clays associated with Newcastle/Muddy sediments. The contrast in clay composition and abundance in in the different sandstones of the Newcastle/Muddy Formation is evidence that volcanic activity was likely at a maximum during the initial Newcastle/Muddy regression and likely waned significantly prior to the major Mowry transgression. The result being basal clay rich sands with clay content diminishing into upper clay poor sandstones. It is the upper clay poor sands in the vicinity of Osage that serve as the conventional target reservoir.

Depositional facies also contribute greatly to the abundance of clays associated with these sands. Low energy environments present during deposition such as lagoons and mud flats trapped clay particles whereas high energy systems such as wave and current dominated facies flushed out the clay particles. Indicators of this contrast include grain size, current ripple and wavy to flaser bedded sands and are supported by the measured porosity and permeabilities of the different sands. Consequently Newcastle sands can be subdivided into clay rich and clay poor units.

Geologic Overview of the Newcastle Sandstone

The Newcastle Sandstone, a correlative of the Lower Cretaceous Muddy Sandstone, represents a rapid sequence of regression, erosion, deposition, and ultimate transgression of the Mowry Sea. The Newcastle sands were deposited upon the exposed black carbonaceous Thermopolis Shale (locally referred to as Skull Creek Shale) during a major regression of the interior Cretaceous Seaway. Incision and valley development along the western flanks of Black Hills demarcate three distinct trends, the Bell Creek – Recluse and Fiddler Creek trends to the north and the similarly SW-NE trending Clareton trend to the south, these trends are the result of thrugoing basement related faults (Martinsen 2003b) (Figure 1a & 1c).

During deposition of the Newcastle, numerous minor transgressive/regressive cycles occurred and are represented by cyclical shale/mudstone/sandstone sequences. Within these sequences are distinct claystone/bentonite layers indicative of periodic volcanism and ash fall events. Depositional environments of the Newcastle grade from shallow marine shales into transitional tidal and supratideal sediments. Facies include tidal flats and channels, estuaries, and marshes.

In the vicinity of the Osage Field the transition from the major lowstand of the previous regression and the developing transgression is a pair of distinct yellow to tan cross bedded sandstones (the 3 / 4 sands), above which there exists erosional remnants (1 and 2 sands) of a fining upward succession into the overlying siliceous marine Mowry Shale. This succession has been previously well documented in the literature and is evident in both available core and geophysical log data (Figure 1b).

The dominant lithologies of the Newcastle are bioturbated- very fine to fine-grained white to gray wavy (flaser) bedded sandstones intercalated with dark gray to black mudstones with abundant coalified plant fragments. Minor lithologies include fine grained tan, to yellow crossbedded sandstone, tan and grey to black shale and carbonaceous shale, and white to dark grey clay (bentonites). The characteristics of this suite of lithologies provide evidence of low energy intertidal mud flats and estuaries.

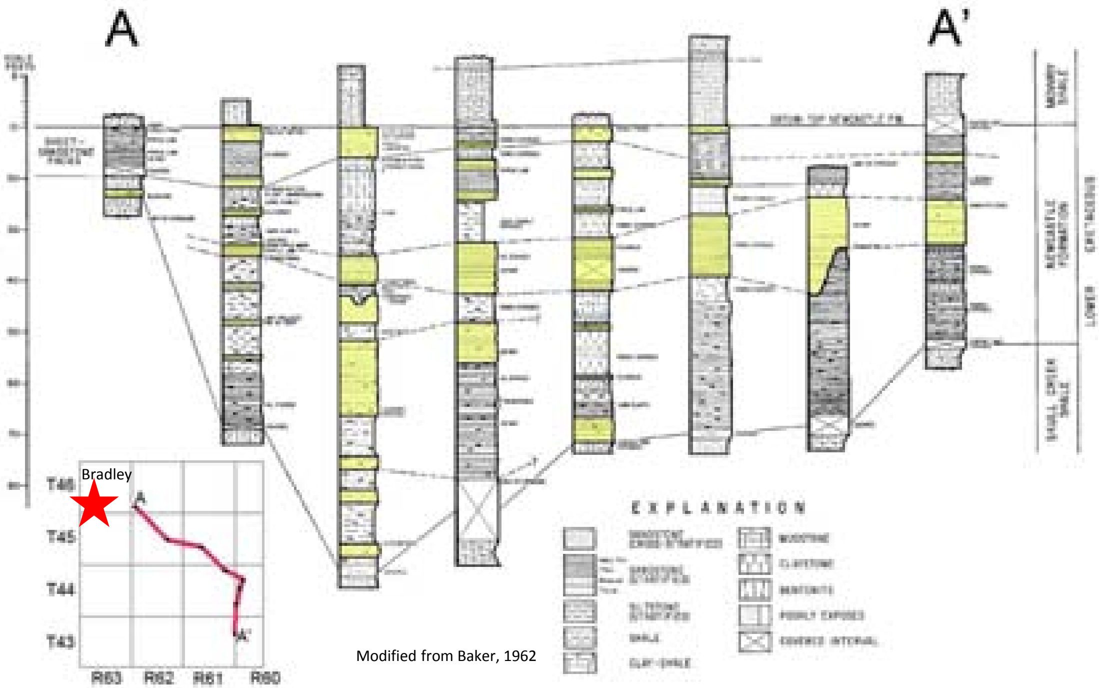

Figure 1b -Location of the Bradley Unit with respect to mapped Newcastle outcrops.

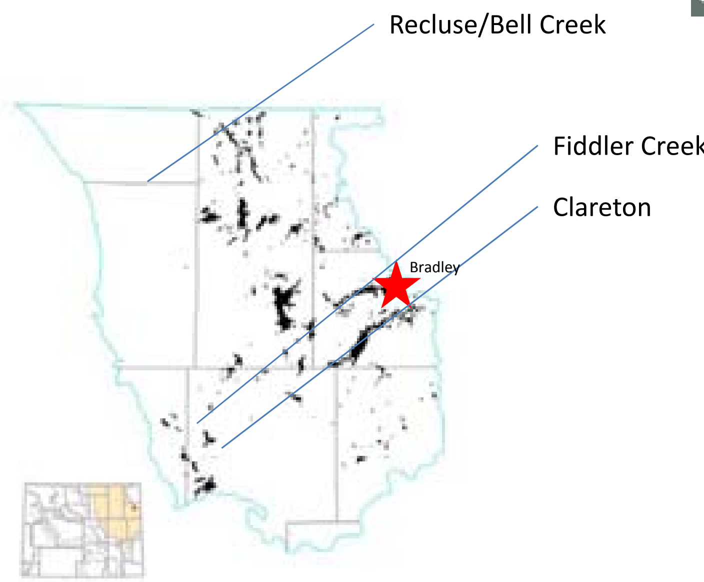

Figure 1a -Location and orientation of structural trends.

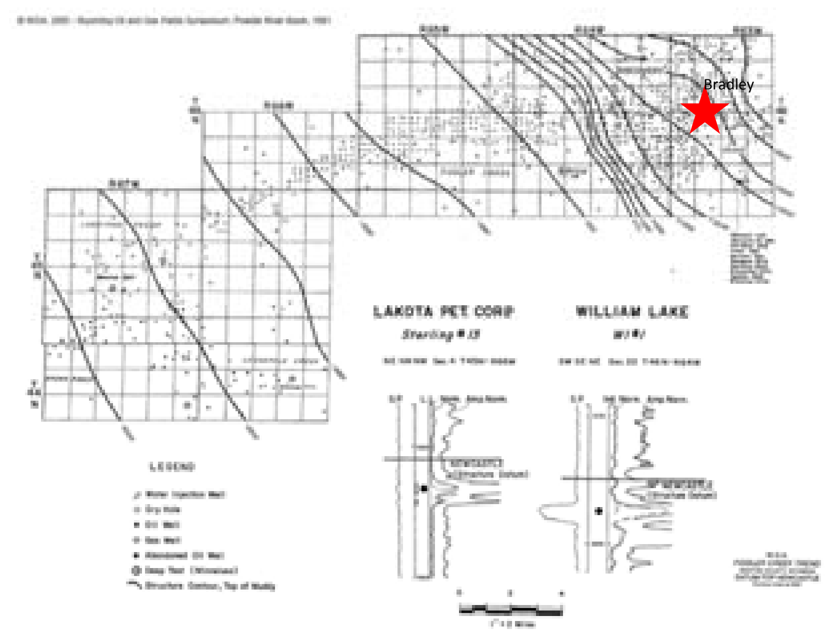

Figure 1c -Location and distribution of development along the FiddlerCreek trend.

Summary of Petrographic Analysis

Petrographic analysis was performed on (35) thin sections prepared from samples collected from the four cores provided to EORI. Samples were collected from areas adjacent to locations where plugs were previously collected for the purposes of determining permeability, porosity, and saturation. The purpose of this was to associate petrographic interpretations with known core analysis values in order to better correlate reservoir properties with petrology.

The results of the petrographic analysis confirmed the presence of the following minerals - quartz, clay, feldspar, pyrite, and calcite. This analysis also identified the following clays listed in relative abundance – kaolinite, chlorite, illite, and mixed layer illite/smectite. Petrographic descriptions of the samples are grouped by intervals 1, 3 / 4, and 5 / 6 / 7 which are designated E, C, and A/B on existing core analysis.

1 Sand

The major sands within this interval include clean, cross-bedded and laminated, very fine-grained sandstone (Figures 2 and 3). Detrital grains are dominated by subrounded and subangular quartz, with minor amounts of chert and feldspar particles. Glauconite pellets and mica flakes are commonly observed (Figure 3). Minor amounts of organic streaks and carbonaceous fragments are dispersed in the 1 Sand. In general framework grains are loosely packed except where cemented by authigenic calcite (Figure 2). Porosity is dominated by well-connected intergranular macropores. Permeability in most of the observed 1 Sand is above 200 md. Kaolinite is the major clay mineral in these sandstones (Figure 4), but a minor amount of greenish chlorite is concentrated in certain laminae (Figure 5). Matrix clays are almost absent. Incipient quartz overgrowth cement is identified, probably as a function of strengthening the framework grains, but not seriously plugging the sandstone porosity. Traces of feldspar dissolution are also observed. The 1 and 3 / 4 sandstones are excellent reservoir rocks for EOR, but migration of kaolinite crystals may cause some problems during fluid injection.

Figure 2. Loosely-packed quartz sandstone with isolated calcite-cemented nodules. Well 17-1, 292.50 feet.

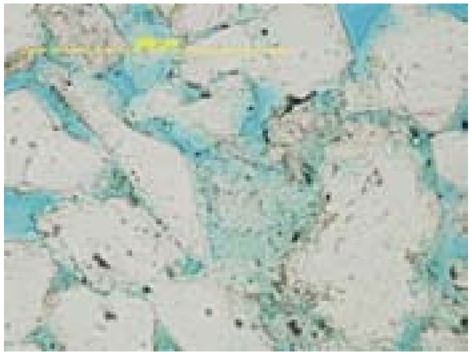

Figure 4. Kaolinite filling intergranular pores, associated with a partially-dissolved feldspar grains. Well 17-1, 296.40 feet.

Figure 3. Glauconite pellets are concentrated in certain laminae, and mica flakes are also dispersed. Well 17.1, 291.60 feet.

Figure 5. Greenish chlorite clay filling intergranular pores in some spots. Well 17-1, 291.60 feet.

Summary of Petrographic Analysis

3 / 4 Sands

The 3 / 4 interval contains laminated very fine-grained sandstones and siltstones, with clean sand laminae intercalated with dirty sand laminae (Figure 7). The tight dirty sand laminae consist of very fine sands, clays and carbonaceous materials. Bioturbation is severe, and burrows are common (Figure 8). This interval includes two different groups of sandstones based on the grain composition. Group one is dominated by subrounded, well-sorted quartz grains, and the second group is rich in subangular to angular feldspar grains (Figure 10). Dispersed glauconite pellets are observed in clean sand laminae. A few calcite-cemented nodules and trace of quartz overgrowth are were also observed (Figure 9). Clay matrix constitutes a significant portion of the rocks. Authigenic kaolinite and leached feldspar fill intergranular pores, while detrital grains are coated with greenish chlorite (Figure 11). Chlorite coatings do pose a hazard and may damage permeability due to blocking the narrow pore throats, however it also prevents quartz overgrowths. Porosity is good to fair in most of the this sand but permeability is fair to low due to lamination and clay plugs.

Figure 7. Clean sand laminae alternated with shaly laminae. Well 17-1, 321.40 feet.

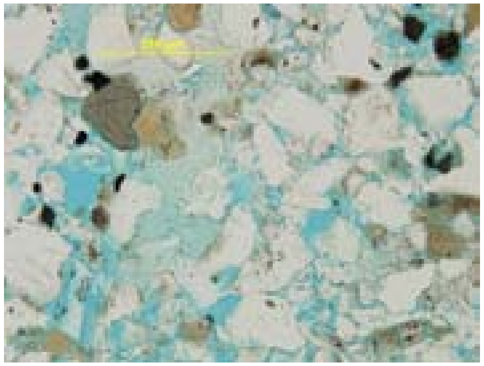

Figure 10. This sandstone rich in angular feldspar grains. Authigenic kaolinite associated with leached feldspar grains. Well 17-1, 320.90 feet.

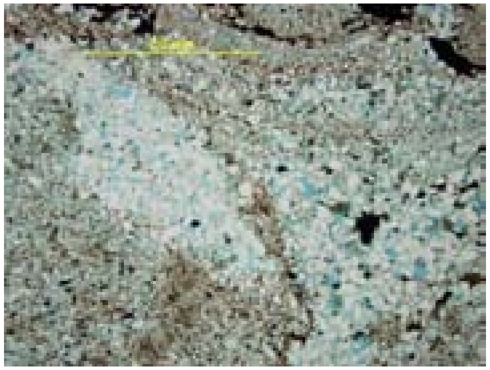

Figure 8. Original lamination destroyed by severe bioturbation. Well 16-106, 375.10 feet.

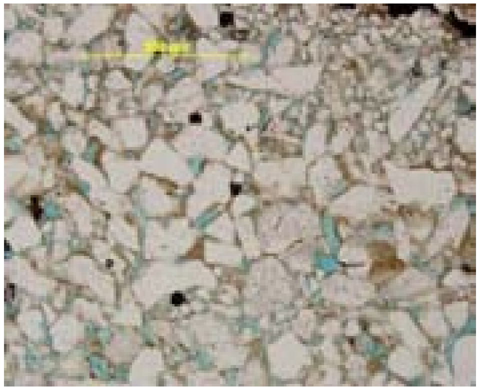

Figure 11. Chlorite coating on detrital grains. Well 16-106, 371.80 feet.

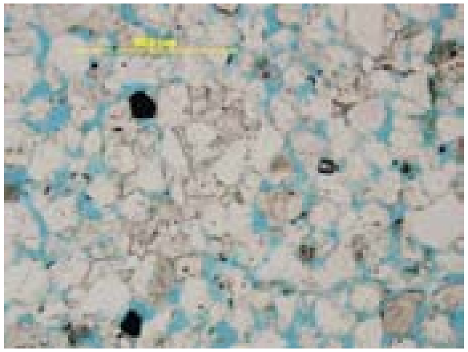

Figure 9. Subrounded quartz sandstone with a calcite-cemented nodule. Well 21-4, 708.60 feet.

Summary of Petrographic Analysis

5 / 6 / 7 Sands

This interval is dominated by flaser to wavy and irregular bedding (Figure 12). This interval is a mud-rich, poorly sorted, very fine-grained sandstones, siltstones, and shaly sandstones (Figure 14). Traces of bioturbation are common. Subangular quartz grains are the principal constituent in most of these sandstones with only a few samples containing feldspar grains as the major constituent of the detrital components. Rip-up clasts, mainly fusinite, are observed in some samples. Few tuffaceous sandstones within these sands are characterized by very poorly immature texture, a large portion of microcrystalline groundmass, and dispersed coarse quartz particles (Figure 15). Permeable sand lenses or patches of sand are enclosed by matrix-rich shaly sandstones (Figure 14). Even in relatively matrix-poor sandstones, clay streaks are still very common. Trace amounts of glauconite pellets are deposited together with detrital quartz grains. Carbonaceous streaks and fragments are ubiquitous in mud-rich sandstones and abundant pyrite associated with the organic materials is also present. Siderite nodules are observed within clay-rich intervals. Authigenic kaolinite clusters are only recognized in clean sand patches (Figure 16) and are associated with trace amounts of calcite cement, and incipient quartz overgrowths. Chlorite is common in matrix-poor sandstones, filling intergranular pores or coating grains (Figure 17). Micropores in the matrix are abundant, but macropores are rare, and only occur in the clean sand intervals. Permeability is very poor, but oil saturation is still high, ranging from 20 to 60%.

Figure 13. Matrix-rich sandstone with bioturbation textures. Well 18-9, 755.50 feet.

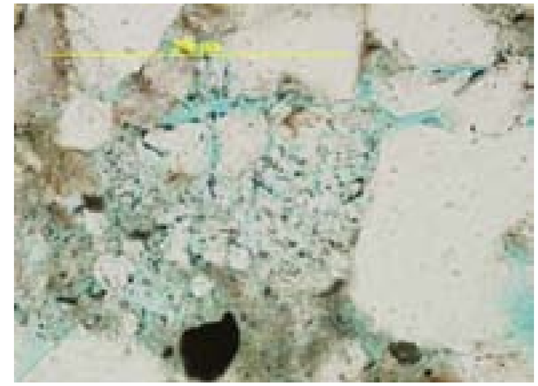

Figure 16. Well-crystallized kaolinite filling the intergranular pores. Well 16-106, 392.60 feet.

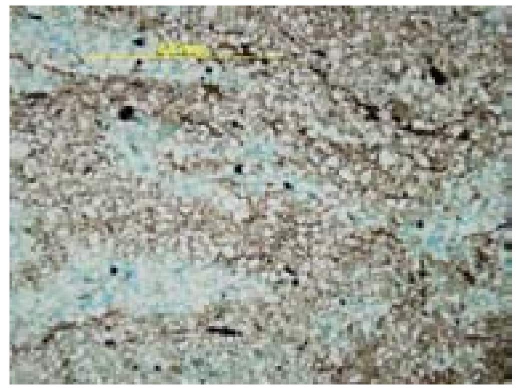

Figure 14. Clean sand patches enclosed in shaly sands laminae. Well 17-1, 342.20 feet.

Figure 17. Chlorite coating detrital grains or infilling intergranular pores. Well 17-1, 342.20 feet.

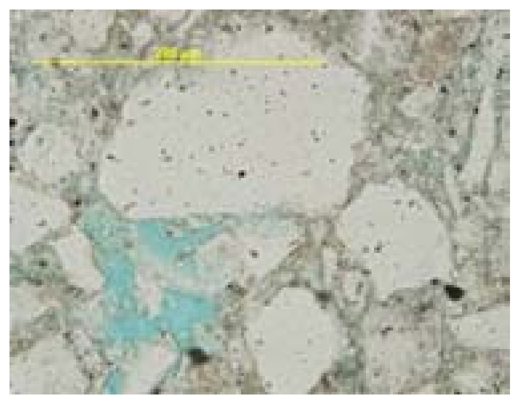

Figure 15. Poorly sorted tuffaceous sandstone. Well 17-1, 336.30 feet.

Recommendations

Based on the findings of this work……

The purpose of performing this clay analysis was to:

- Identify clays in the formation
- Quantify clay content
- Approximate clay distribution in the formation and throughout the field
- Relate clay content to both productive and nonproductive intervals within the formation
- Determine whether or not clay inhibitors should be used (Osage Partners)
- Provide basis for SP and A/SP formulations regarding fluid rock interactions (TIORCO)
- Increase general knowledge about clays in Cretaceous Reservoirs
- Other

Table 1. Comparison of 1, 3 / 4 , and 5 / 6 / 7 sandstones.

	Lithology	Texture	Detrital Minerals	Clay Minerals	Calcite Cement	Quartz Cement	Pores
1 Sand	Very fine-grained sandstones	Cross-bedded or laminated	Dominated by quartz, minor chert and feldspar, glauconite concentrated in certain laminae, mica flakes	Kaolinite dominant, minor chlorite	Calcite-cemented nodules common	Incipient	Rich in intergr-anular pores
3/4 Sands	Very fine-grained sandstones and siltstones	Laminated, severe bioturbation, Burrows common	Dominated by quartz and feldspar, glauconite in clean sand spots	Authigenic kaolinite and chlorite, matrix clays rich in laminae	Few calcite-cemented nodules	Incipient	Intergr-anular pores in clean sands
5/6/7 Sands	Very fine-grained sandstones, siltstones, and shaly sandstones	Wavy laminated or irregular beddings, bioturbation common	Dominated by quartz, feldspar rich in few samples, trace glauconite	Authigenic kaolinite and chlorite in clean sands, matrix clays rich	Trace calcite cement	Incipient	Rich micro-pores, rare macro-pores

Enhanced Oil Recovery Institute

Project: Clay Analysis of Osage Partners, LLC

Analyst: Curtis Chopping

Date: December 17, 2013

Analytical Techniques: whole-rock X-ray diffraction (XRD)[1], orientated clay mount XRD[2], flow injection analysis (FIA) for cation exchange capacity (CEC)[3].

	Whole Rock Weight (%)[1]			Relative Clay Percentages (%)[2]				CEC[3]
	Quartz	Feldspar	Clay	Kaolinite	Illite	Chlorite	Smectite	meq/100g
16-106 (API# 4529202)								
371.8	45	20	32	38	<1 %	42	20	32
374.3	50	10	40	30	13	19	38	34
375.1	70	5	25	46	7	25	22	34
378.4	[redacted]	[redacted]	[redacted]	35	22	22	21	[redacted]
386.5	[redacted]	[redacted]	[redacted]	69	21	< 1	10	[redacted]
388.5	[redacted]	[redacted]	[redacted]	67	23	< 1	10	26
389.6	[redacted]	[redacted]	[redacted]	72	17	< 1	11	[redacted]
391.5	60	< 1	40	68	22	< 1	10	[redacted]
392.6	44	25	28	69	20	< 1	11	68
395.5	[redacted]	[redacted]	[redacted]	70	19	< 1	11	[redacted]
18-9 (API# 4529128)								
748.2	[redacted]	[redacted]	[redacted]	42	32	< 1	26	24
750.2	[redacted]	[redacted]	[redacted]	46	21	< 1	33	[redacted]
754.5	[redacted]	[redacted]	[redacted]	32	27	19	22	25
755.5	[redacted]	[redacted]	[redacted]	33	27	20	20	[redacted]
759.4	52	< 1	48	21	28	22	29	28
17-1 (API# 4529141)								
291.6	[redacted]	[redacted]	[redacted]	47	9	20	24	19
293.7	[redacted]	[redacted]	[redacted]	29	17	27	27	[redacted]
296.4	[redacted]	[redacted]	[redacted]	37	< 1	< 1	63	[redacted]
320.9	[redacted]	[redacted]	[redacted]	27	< 1	20	53	50
321.4	64	5	31	29	< 1	22	49	56
322.6	53	7	40	3	< 1	3	94	70
333.7	80	< 1	20	78	2	< 1	20	[redacted]
334.5	[redacted]	[redacted]	[redacted]	85	4	< 1	11	[redacted]
336.3	[redacted]	[redacted]	[redacted]	83	9	< 1	8	[redacted]
342.2	[redacted]	[redacted]	[redacted]	81	8	< 1	11	[redacted]
345.7	[redacted]	[redacted]	[redacted]	55	25	< 1	20	[redacted]
347.3	[redacted]	[redacted]	[redacted]	47	46	< 1	7	[redacted]
350.4	[redacted]	[redacted]	[redacted]	60	22	< 1	18	32
351.4	[redacted]	[redacted]	[redacted]	63	20	< 1	17	[redacted]
21-4 (API# 4529132)								
708.6	70	< 1	30	24	30	23	23	[redacted]
709.5	47	< 1	53	23	31	23	23	62
711.6	34	10	56	25	25	25	25	40
712.6	33	16	51	23	28	24	25	[redacted]
727.3	31	32	37	46	32	< 1	22	[redacted]

a) Differentiation of feldspar species was not determined (K-spar vs Plagioclase)

b) Total relative clay content

c) Kaolinite

d) Illite/Smectite mixed layer

Due to limitations in X-ray diffraction quantification, results must be considered semi-quantitative.

Summary of Whole Rock - XRD Analysis

Whole rock x-ray diffraction analysis (XRD) was performed on 14 samples from the Newcastle Sandstone on a SCINTAG XDS 2000 with a copper tube using K_α. Analysis shows that;

- Well 16-106 is composed primarily of quartz with lesser amounts of feldspar, clays, and trace amounts of calcite.
- Well 17-1 is primarily composed of quartz with lesser amounts of feldspar and clays.
- Well 18-9 is composed of quartz and clays, with little to no feldspar.
- Well 21-4 is composed mainly of quartz and clays, with an increasing amount of feldspar with depth.

Recommendations of future work would be to determine speciation of feldspar types. Determination of this was beyond the scope of work.

Summary of XRD Clay Analysis

Orientated clay mounts were prepared for x-ray diffraction (XRD) analysis from 35 samples from the Newcastle Sandstone on SCINTAG XDS 2000 with a copper tube using K_α. Analysis shows that;

- Well 16-106 is primarily composed of Kaolinite. With Chlorite becoming non-detectable at this resolution at the bottom of well sample. Mixed-layered illite/smectite also decrease in relative abundance towards the bottom of well sample.
- Well 17-1 is primarily composed of Kaolinite. Relative Illite abundance varies inversely to that of chlorite..
- Well 18-9 is primarily composed of Kaolinite with varying amounts of Illite and Chlorite.
- Well 21-4 is composed relatively in equal amounts of Kaolinite, Illite, chlorite and mixed-layered illite/smectite.

Recommendations of future work would be to determine the amount of Smectite in mixed layer illite/smectite.

Summary of CEC Analysis

Fifteen samples were analyzed for cation exchange capacity (CEC) focusing on the pay zones and other intervals within the well. ASTM D7503 was followed with modifications due to the overly high abundance of clays contained within the samples. Therefore, centrifugation (Standard Soil Methods, 1999) was substituted for filtration. Flow injection analysis (FIA) was the analytical technique used for analyzing nitrogen (as NH_3) concentrations.

Recommendations for future work would be to conducted a coreflood to measure CEC, because crushing the samples effectively increases total surface area and thus CEC is increased (Austin and Ganley, 1991). BET work would also be recommended.

Recommendations

Summary conclusions and recommendations

High permeability clay poor sands (Upper)- 1 and 3 / 4 sand intervals

- Historic pay interval, little to no clay content with exception of kaolinite, historically waterflood w/o inhibitors, thin – generally less than 10 feet
- Likely not completely swept – recommend detailed stratigraphic/correlation and injection/production analysis – assume C sand is laterally continuous
- Sands are bound by low permeability bentonites and shales.
- Use of clay inhibitors and oil based muds is suggested regarding further drilling and reactivation of waterflood based on economic limit
- Infill drilling

Low permeability clay rich sands (Lower)– 5 / 6 / 7 sand intervals

- Unconventional pay interval, high clay content, historically not produced, oil saturations range up to 60 percent, thicker – two intervals each range up to 15 feet
- Likely never developed – recommend stratigraphic work and trial and error based approach
- Use of clay inhibitors for intended flood is recommended dependent on economic limits
- For further development drill underbalanced using oil based muds
- Lab studies for determining clay effects– core floods – two samples, one using clay inhibitor plus Madison water the other with only Madison water-

1 and 3 / 4 sand intervals (Main Pay)

- Questionable correlation/delineation of 1 and 3 / 4 sands based on presence of erosion surface and poro/perm plot patterns (page 13, Figure 18).
- Conduct Newcastle outcrop studies.

Recommendations

- Conduct stratigraphic correlations to better define distribution of sands.
- Detailed clay analysis of samples to be used for core flooding.
- Evaluate techniques that aid in preventing formation damage for drilling and waterflood design.
- Develop Field Demonstration pilot study .

References

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Generalized Cross Section

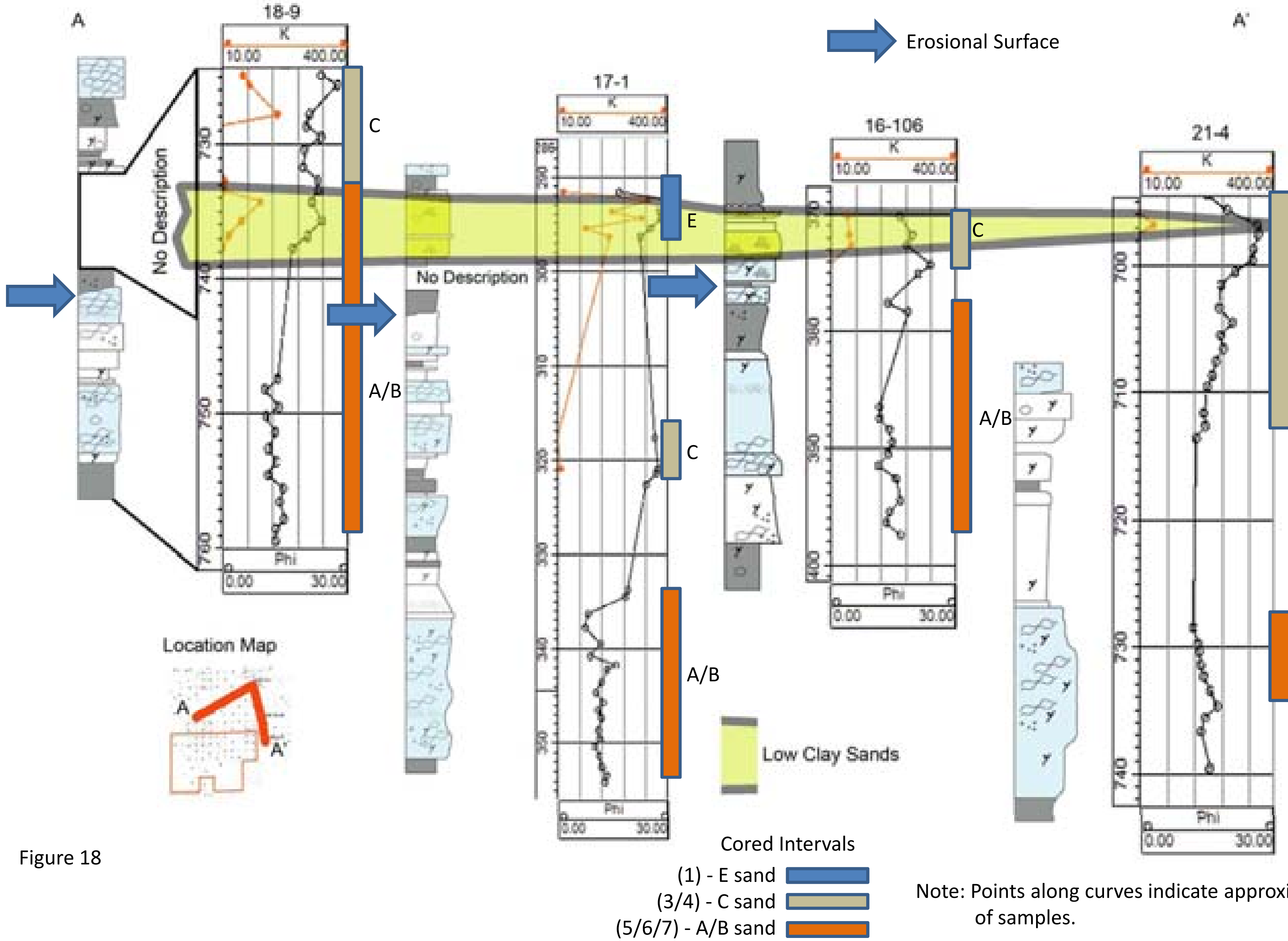
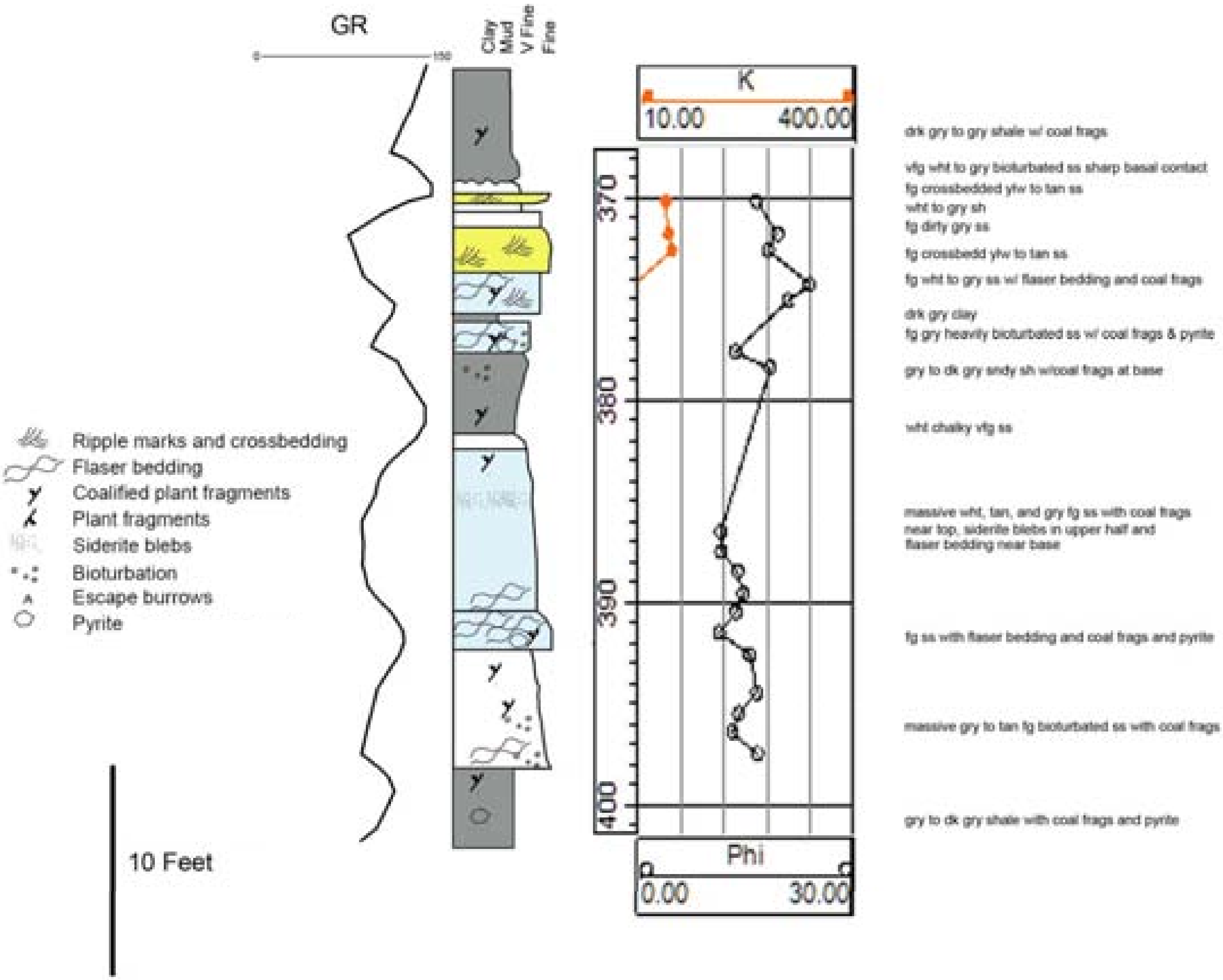


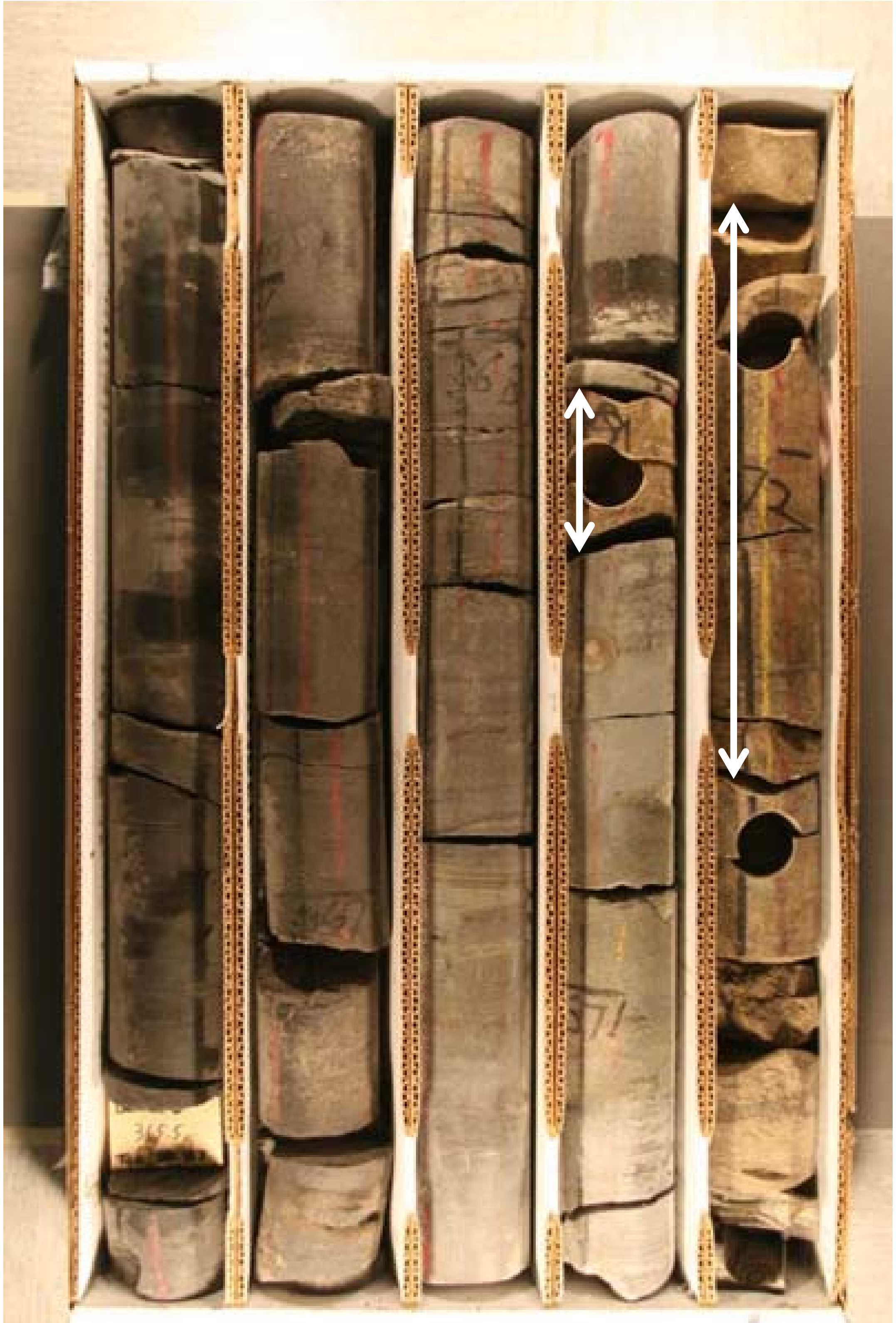
Figure 18

Note: Points along curves indicate approximate location of samples.

Well 16-106



Well 16-106 API 4529202



16-106 Box 5
364' to 374'

Pay interval (371-373) within the Newcastle Sandstone is a fine grained, yellow to tan, crossbedded sandstone (sample 371.8).

16-106 Box 6
374’ to 384’

Crossbeds within and at base of pay sand (sample 374.2).

Fine sand/mud couplets and ripple lamina (sample 374.4).

16-106 Box 7
384' to 394'

Very fine sand with rip ups (sample 386.5).

Fine sand with siderite blebs (sample 388.5).

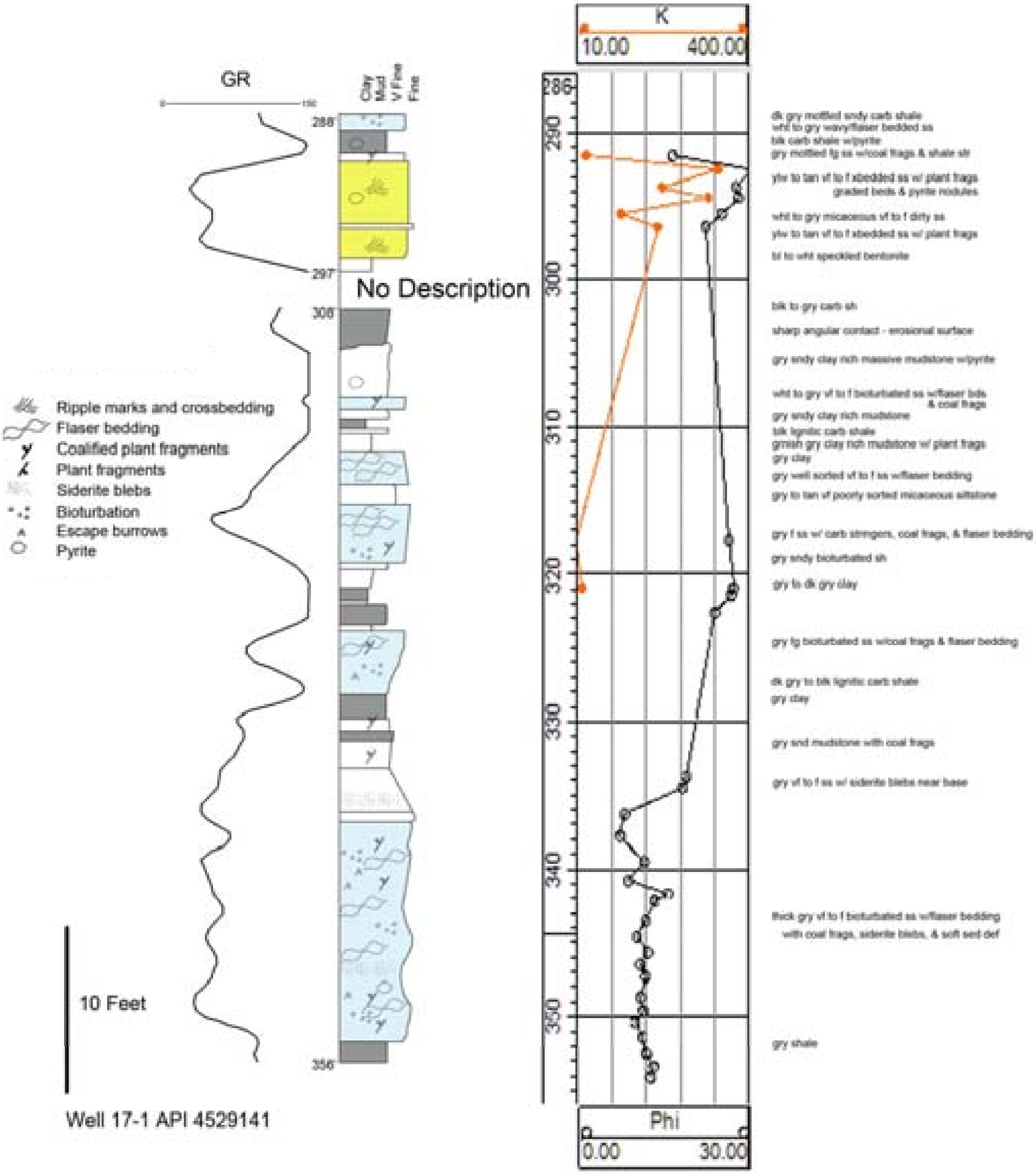
Sand/mud flaser bedded (sample 392.6).

16-106 Box 8
394' to 404'

Very fine grained sandy mudstone with coal streak (sample 394.5).

Sand/mud flaser bedded with coal fragments (sample 395.5).

Well 17-1



GR
Clay
Mud
V Fine
Fine
288'
297'
No Description
308'
356'
Ripple marks and crossbedding
Flaser bedding
Coalified plant fragments
Plant fragments
Siderite blebs
Bioturbation
Escape burrows
Pyrite
10 Feet
Well 17-1 API 4529141
K
10.00
400.00
286
290
300
310
320
330
340
350
Phi
0.00
30.00
dk gry mottled sndy carb shale
wht to gry wavy/flaser bedded ss
blk carb shale w/pyrite
gry mottled fg ss w/coal frags & shale str
ylw to tan vf to f xbedded ss w/ plant frags
graded beds & pyrite nodules
wht to gry micaceous vf to f dirty ss
ylw to tan vf to f xbedded ss w/ plant frags
bl to wht speckled bentonite
blk to gry carb sh
sharp angular contact - erosional surface
gry sndy clay rich massive mudstone w/pyrite
wht to gry vf to f bioturbated ss w/flaser bds
& coal frags
gry sndy clay rich mudstone
blk lignitic carb shale
grnish gry clay rich mudstone w/ plant frags
gry clay
gry well sorted vf to f ss w/flaser bedding
gry to tan vf poorly sorted micaceous siltstone
gry f ss w/ carb stringers, coal frags, & flaser bedding
gry sndy bioturbated sh
gry to dk gry clay
gry fg bioturbated ss w/coal frags & flaser bedding
dk gry to blk lignitic carb shale
gry clay
gry snd mudstone with coal frags
gry vf to f ss w/ siderite blebs near base
thick gry vf to f bioturbated ss w/flaser bedding
with coal frags, siderite blebs, & soft sed def
gry shale

17-1 Box 30
288’ to 297’

Fine grained cross bedded sandstone (sample 291.6).

Fine grained massive sandstone (sample 292.5).

Fine grained sandstone (sample 293.7).

17-1 Box 32
308’ to 318’

No samples.

17-1 Box 33
318’ to 328’

Fine grained cross bedded sandstone (sample 320.9).

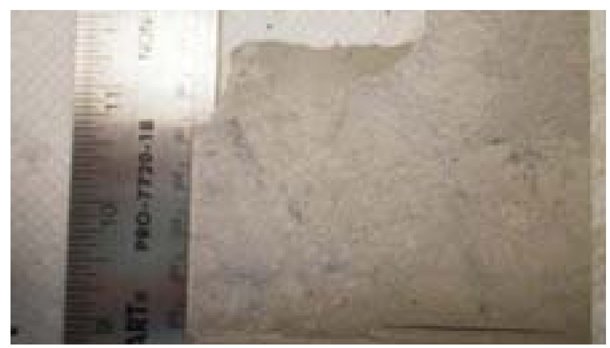
Fine grained cross bedded sandstone (sample 321.4).

Very fine to fine wavy bedded sandstone (sample 322.6).

17-1 Box 34
328’ to 338’

Very fine muddy sandstone with coal rip ups (sample 333.7).

Very fine bioturbated, massive muddy sandstone (sample 334.5).



Very fine bioturbated sandstone with siderite blebs (sample 336.3).

17-1 Box 35
338’ to 348’

Very fine wavy bedded sandstone (sample 342.2).

Very fine wavy to flaser bedded sandstone (sample 345.7).

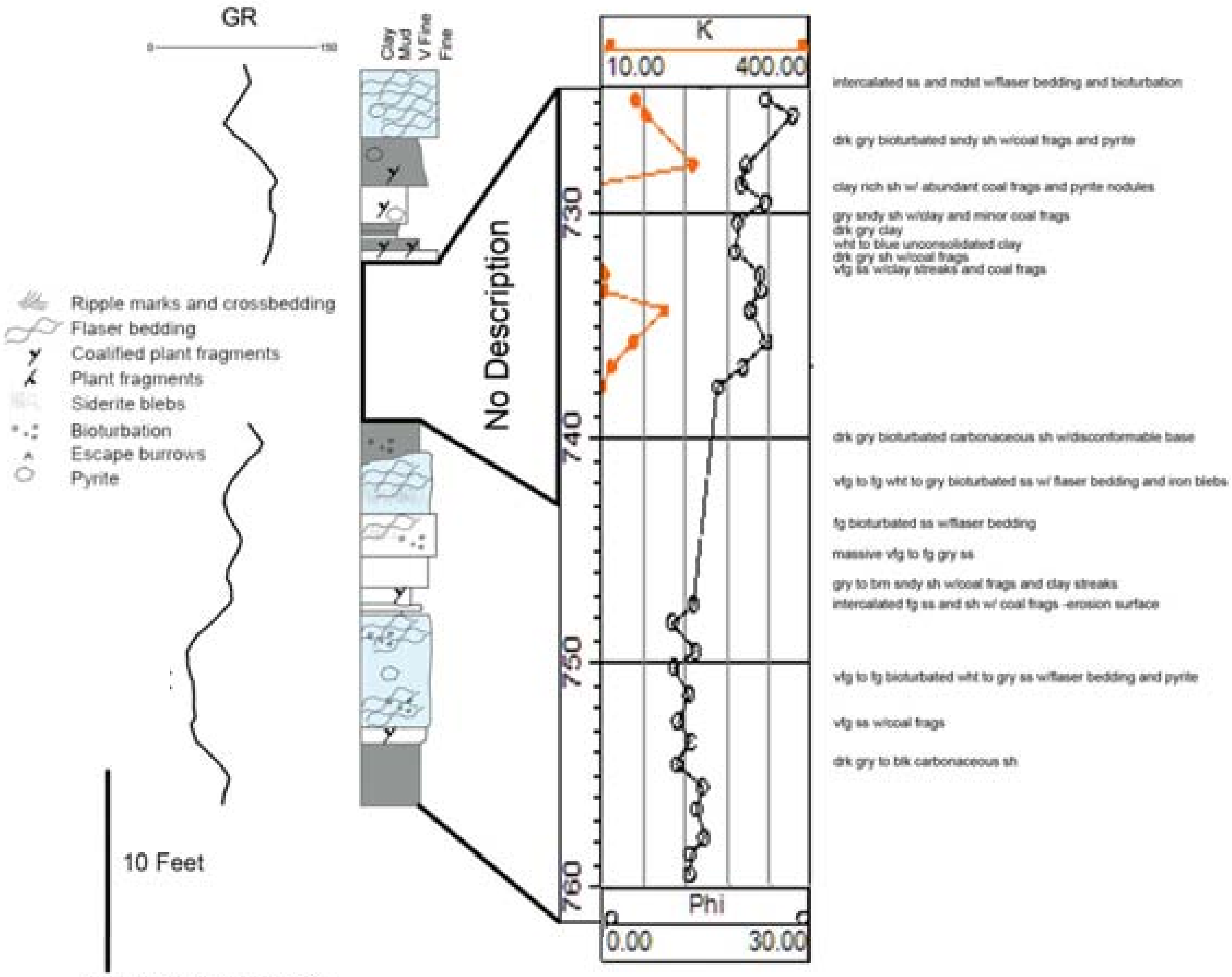
Very fine sandstone with soft sed-deformation (sample 347.3).

17-1 Box 36
348' to 358'

Very fine, clay rich wavy bedded sandstone (sample 350.4).

Very fine wavy bedded sandstone (sample 351.4).

Well 18-9



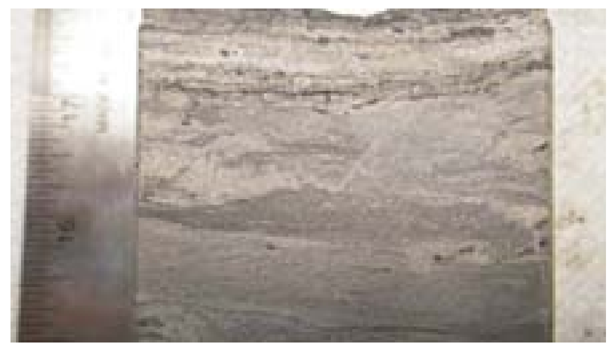
Well 18-9 API 4529128

18-9 Box 74
714’ to 724’

No samples.

18-9 Box 77
743' to 753'

Very fine wavy bedded sandstone (sample 748.2).



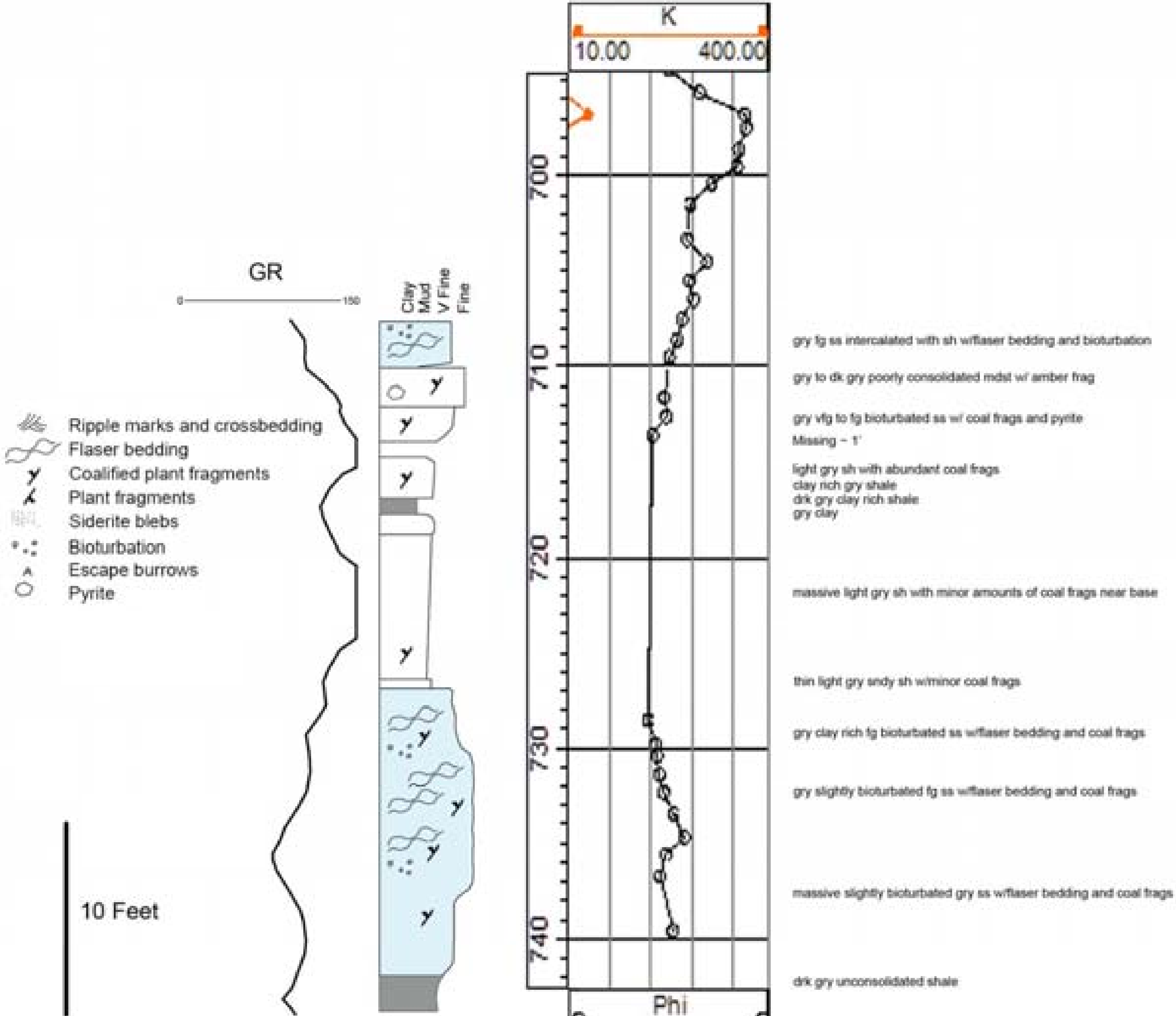
Very fine wavy bedded sandstone (sample 750.2).

18-9 Box 78
753’ to 763’

Very fine bioturbated sandstone (sample 754.5).

Very fine flaser bedded sandy mudstone (sample 759.4).

Well 21-4



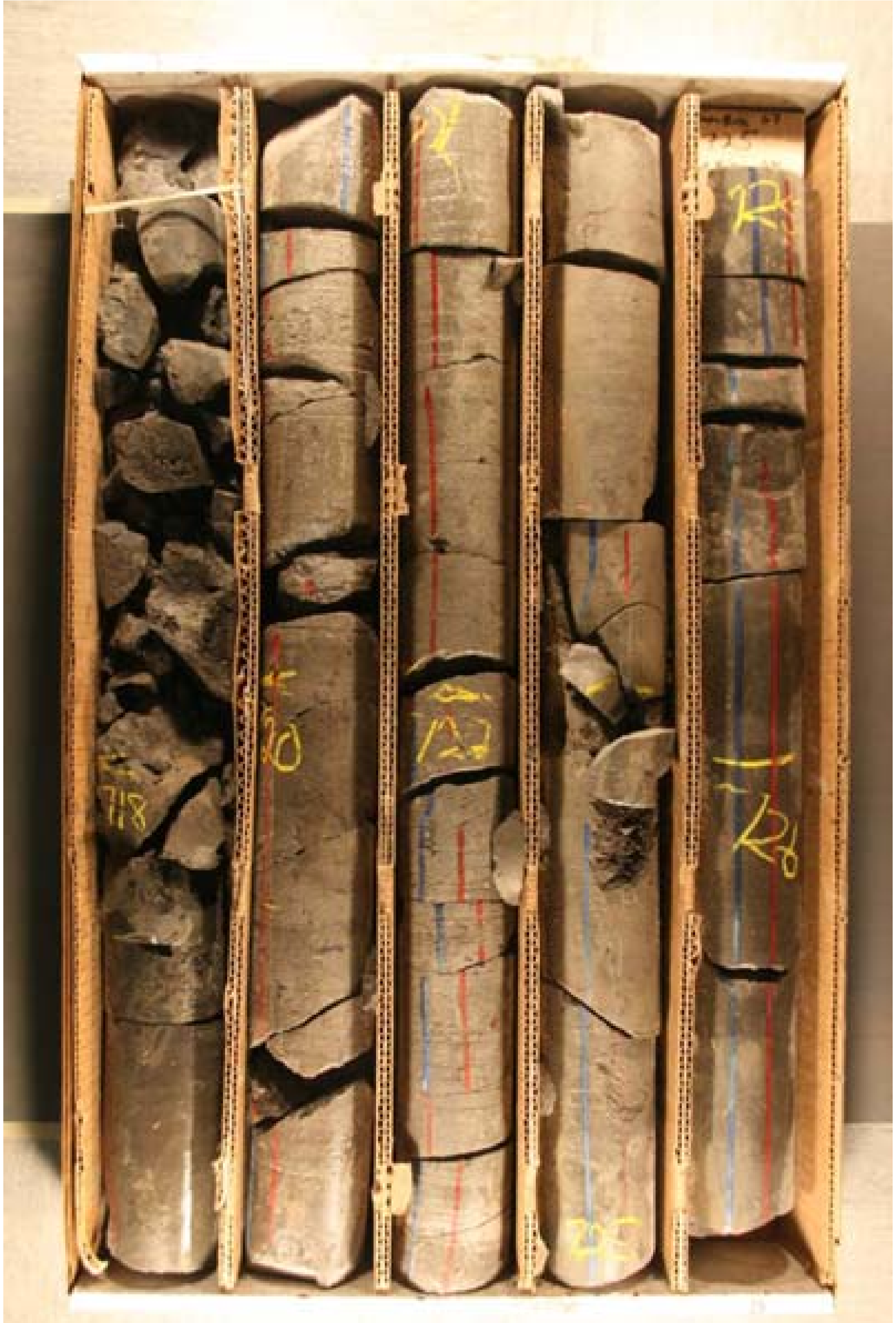
Well 21-4 API 4529132

21-4 Box 66
708’ to 717’

Very fine bioturbated wavy bedded sandstone (sample 708.6).

Very fine bioturbated flaser bedded sandstone (sample 709.5).

Very fine bioturbated sandstone with mud rip ups (sample 711.6).



21-4 Box 67
717’ to 726’

No samples.

21-4 Box 68
726' to 736'

Clay rich mudstone (sample 727.3).

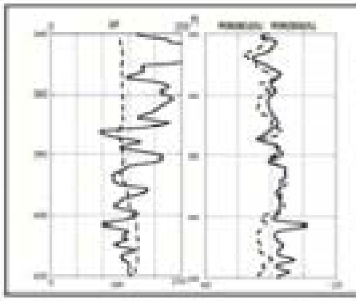
21-4 Box 69
736’ to 745’

No samples.

Addendum (Appendix B)

Summary Analysis Results

Osage 16-106 API: 4529202 371.8 ft



Laminated very fine-grained sandstone with abundant clay-rich laminae. Detrital grains are dominated by quartz, with a small portion of chart and feldspar grains. Most of the quartz grains are either cemented by overgrowths (Qog) or coated by clays. Carbonaceous materials are abount in clay-rich laminae. Intergranular pores are well developed, but the interconnection is damaged by quartz overgrowths and chlorite coatings (Ch).

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
71.0	62.3	19.4	19.3	2.60	21.2	63.1

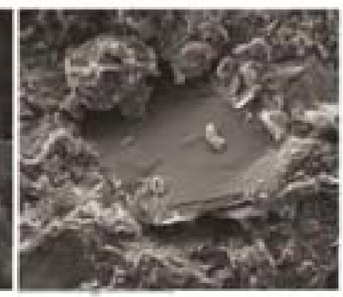
Whole Rock Weight

Mineral	%
Quartz	45
Feldspar	20
Total Clay	32
Total	97

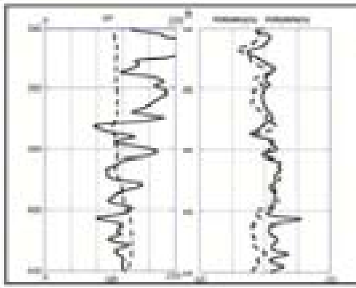
Relative Clay

Clay Mineral	%
Kaolinite	38
Illite	<1
Chlorite	42
Illite/Smectite	20
Total	100

CEC(Meq/100 gm)	32



Osage 16-106 API: 4529202 374.3 ft



Laminated siltstone composed of permeable sand laminae and clay-rich tight laminae. The permeable laminae are dominated by quartz and feldspar grains, with a small portion of glauconite pellets, whereas the dirty laminae are rich in clay matrix and carbonaceous streaks. Few burrows are recognized in the shaly layers. Traces of calcite cement (Cal) and kaolinite (Kao) are observed.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
7.93	6.42	23.8	23.7	2.62	37.5	34.7

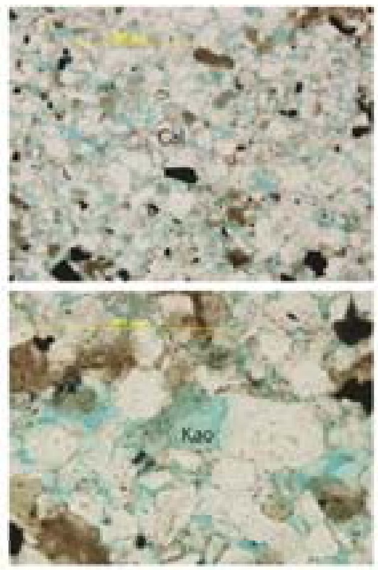
Whole Rock Weight

Mineral	%
Quartz	50
Feldspar	10
Total Clay	40
Total	100

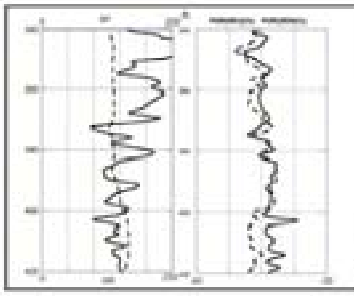
Relative Clay

Clay Mineral	%
Kaolinite	30
Illite	13
Chlorite	19
Illite/Smectite	38
Total	100

CEC(Meq/100 gm)	34



Osage 16-106 API: 4529202 375.1 ft



Laminated clayey sandstones with traces of bioturbation. The framework grains are dominated by quartz, with abundant glauconite particles. Partially dissolved feldspar grains (Fd) are observed. Carbonaceous streaks and inclusions are ubiquitous, but more concentrated in the clay-rich laminae. Well-connected intergranular pores are developed in the clean sand laminae, but tight clay-rich laminae damage permeability.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
1.80	1.22	20.8	20.8	2.63	45.2	35.2

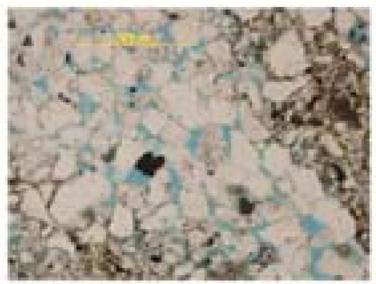
Whole Rock Weight

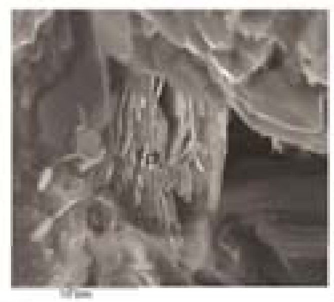
Mineral	%
Quartz	70
Feldspar	5
Total Clay	25
Total	100

Relative Clay

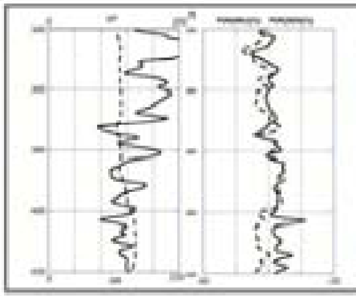
Clay Mineral	%
Kaolinite	46
Illite	7
Chlorite	25
Illite/Smectite	22
Total	100

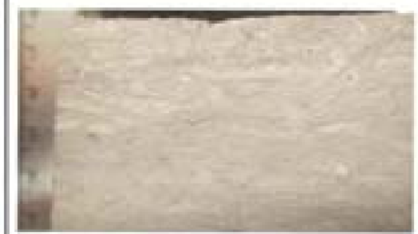
CEC(Meq/100 gm)	34





Osage 16-106 API: 4529202 378.4 ft





Shaly siltstone with irregular bedding, probably resulted from bioturbation. Organic streaks and inclusions are common. Visual, poorly interconnected dissolution pores are products of feldspar leaching. Most clay minerals are detrital components in matrix.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
0.470	0.265	18.3	18.3	2.64	41.3	29.2

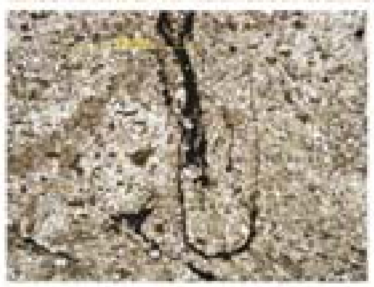
Whole Rock Weight

Mineral	%
Quartz	
Feldspar	
Total Clay	
Total	

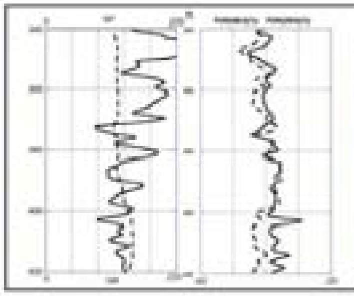
Relative Clay

Clay Mineral	%
Kaolinite	35
Illite	22
Chlorite	22
Illite/Smectite	21
Total	100

CEC(Meq/100 gm)	



Osage 16-106 API: 4529202 386.5 ft



Shaly siltstone with dispersed very fine-grained sand grains. The fine-grained sands are also concentrated in some spots, with visible intergranular pores and trace of authigenic kaolinite (Kao). Shale streaks are abundant, and siderite nodules (Sid) are common.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
0.018	0.0081	11.6	11.6	2.66	66.4	15.0

Whole Rock Weight

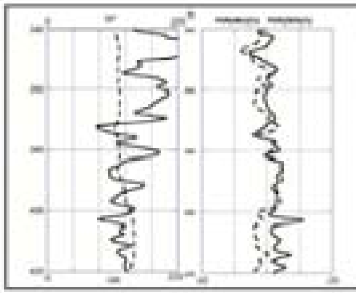
Mineral	%
Quartz	
Feldspar	
Total Clay	
Total	

Relative Clay

Clay Mineral	%
Kaolinite	69
Illite	21
Chlorite	<1
Illite/Smectite	10
Total	

CEC(Meq/100 gm)	

Osage 16-106 API: 4529202 388.5 ft



Poorly sorted sandstone with mixture of very fine-grained and silty detrital grains. Abundant rounded fusinite grains are dispersed, probably from re-worked rip-up shale layers. Siderite nodules are ubiquitous. Fair porosity is contributed by intergranular pores in spots lack of clay minerals. These permeable spots are separated by tight, matrix-rich rocks.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
0.069	0.042	13.9	13.9	2.67	52.6	24.7

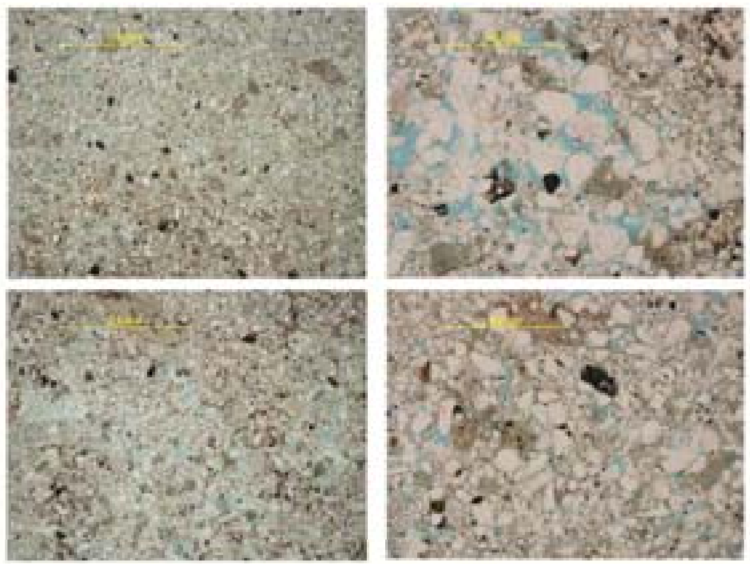
Whole Rock Weight

Mineral	%
Quartz	
Feldspar	
Total Clay	
Total	

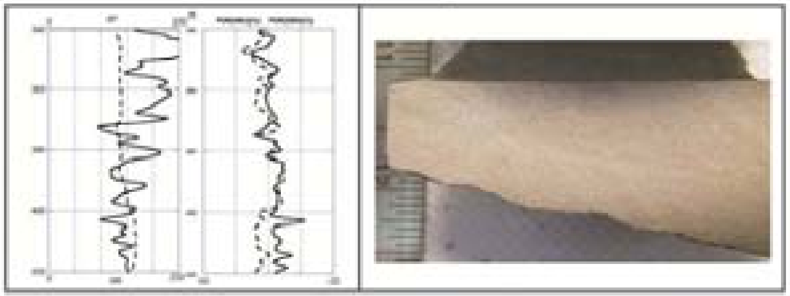
Relative Clay

Clay Mineral	%
Kaolinite	67
Illite	23
Chlorite	<1
Illite/Smectite	10
Total	100

CEC(Meq/100 gm)	26

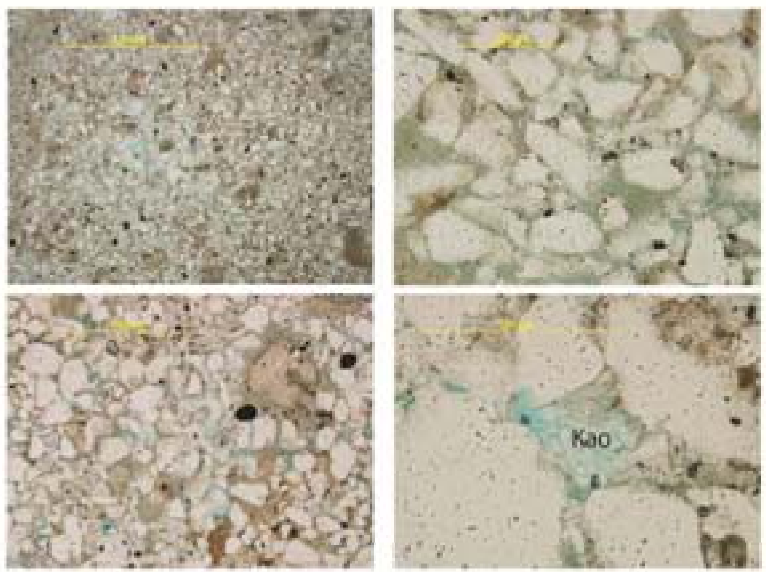


Osage 16-106 API: 4529202 389.6 ft



Very fine-grained sandstone with significant amounts of clay matrix and sedimentary clasts. Most of the intergranular pores are filled by greenish authigenic clays, and trace of kaolinite (Kao) is also recognized. Porosity is dominated by micropores in matrix and clay-filled intergranular spaces.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
5.06	3.93	14.6	14.6	2.65	42.7	23.1



Whole Rock Weight

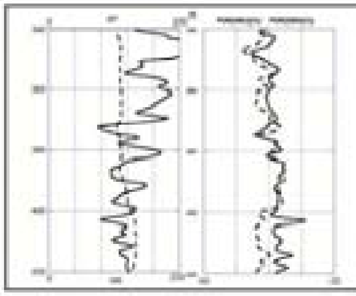
Mineral	%
Quartz	
Feldspar	
Total Clay	
Total	

Relative Clay

Clay Mineral	%
Kaolinite	72
Illite	17
Chlorite	<1
Illite/Smectite	11
Total	100

CEC(Meq/100 gm)	

Osage 16-106 API: 4529202 391.5 ft



Poorly sorted, very fine-grained sandstone. Clay matrix and silty grains constitute a large portion of the rock. Carbonaceous bits and chunks are common. Kaolinite (Kao) fills seceral pores in the clean sand patches, and trace amounts of calcite cement (Cal) is also observed.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
0.048	0.024	11.3	11.3	2.63	57.1	27.0

Whole Rock Weight

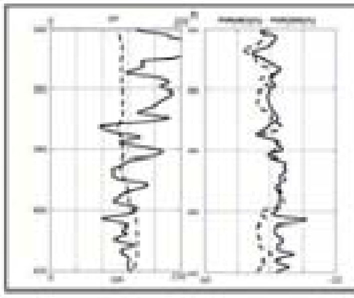
Mineral	%
Quartz	60
Feldspar	<1
Total Clay	40
Total	100

Relative Clay

Clay Mineral	%
Kaolinite	68
Illite	22
Chlorite	<1
Illite/Smectite	10
Total	100

CEC(Meq/100 gm)	

Osage 16-106 API: 4529202 392.6 ft



Poorly laminated sandstone with abundant shale streaks and rip-up clasts. The very fine-grained sands are dominated by subrounded and subangular quartz grains. Organic matter and carbonaceous streaks are abundant. Minor amounts of kaolinite (Kao) fill pores. Traces of calcite cement are observed. Visual pores exist in clean sand patches, and open slots are associated with shale streaks.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
0.802	0.450	15.5	15.5	2.63	43.8	31.9

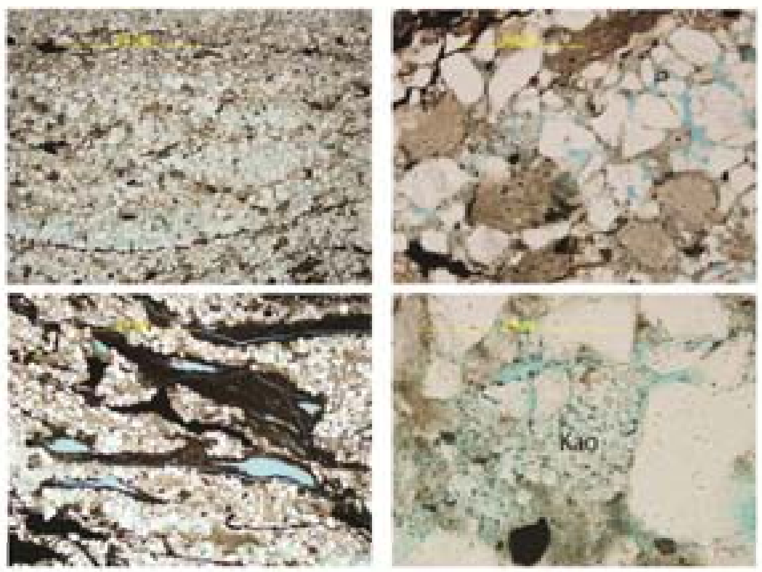
Whole Rock Weight

Mineral	%
Quartz	44
Feldspar	25
Total Clay	28
Total	97

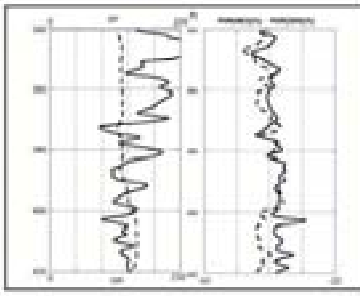
Relative Clay

Clay Mineral	%
Kaolinite	69
Illite	20
Chlorite	<1
Illite/Smectite	11
Total	100

CEC(Meq/100 gm)	68



Osage 16-106 API: 4529202 395.5 ft



Poorly sorted shaly sandstone with detrital components from fine-grained sands to silts. Clay matrix is rich, creating a large amount of micropores. Visual macropores are only observed in the clean sand patches, and a portion of these pores are of secondary origin, resulted from dissolution of detrital grains.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
0.045	0.021	14.0	14.0	2.65	61.3	20.3

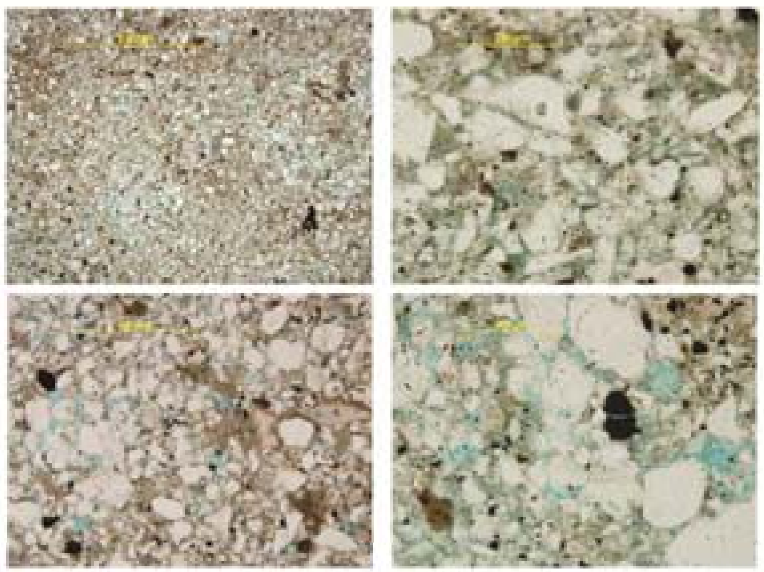
Whole Rock Weight

Mineral	%
Quartz	
Feldspar	
Total Clay	
Total	

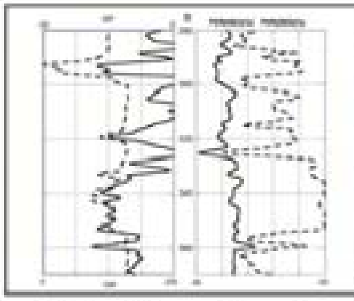
Relative Clay

Clay Mineral	%
Kaolinite	70
Illite	19
Chlorite	<1
Illite/Smectite	11
Total	100

CEC(Meq/100 gm)	



Osage 17-1   API: 4529141   291.6 ft



Very fine-grained, laminated sandstones. Detrital grains are dominated by quartz with minor amounts of chert and feldspar particles. Glauconite is concentrated in laminae. Greenish chlorite (Ch) is distributed in laminae or irregular patches. Few spots are cemented by poikolotopic calcite. Traces of carbonaceous streaks and fragments are observed. Porosity is dominated by well-connected intergranular pores.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
32.5	27.6	16.6	16.6	2.65	54.0	55.4

Whole Rock Weight

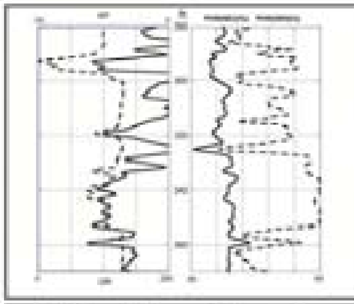
Mineral	%
Quartz	
Feldspar	
Total Clay	
Total	

Relative Clay

Clay Mineral	%
Kaolinite	47
Illite	9
Chlorite	20
Illite/Smectite	24
Total	100

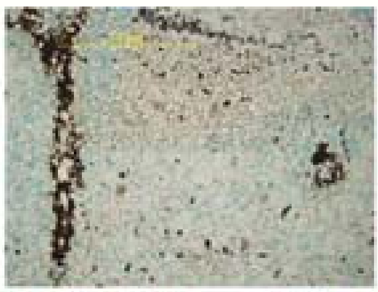
CEC(Meq/100 gm)	19

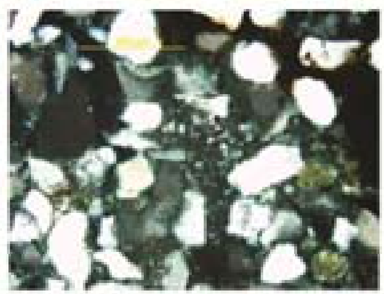
Osage 17-1 API: 4529141 292.5 ft



Very fine-grained sandstone dominated by loosely packed quartz grains, with abundant glauconite pellets. Minor amounts of feldspar grains and mica flakes are also observed. Organic streaks with pyrite particles and calcite-cemented patches (Cal) are common. Pore-filling kaolinite (Kao) is the major clay mineral in this sample, with trace amounts of greenish chlorite concentrated in patches. The loosely-packed kaolinite crystals potentially generate mobile fines during fluid injection.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
342	317	30.3	30.2	2.65	13.0	45.8





Whole Rock Weight

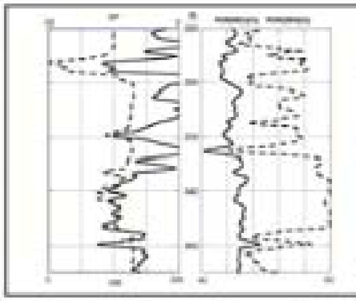
Mineral	%
Quartz	
Feldspar	
Total Clay	
Total	

Relative Clay

Clay Mineral	%
Kaolinite	
Illite	
Chlorite	
Illite/Smectite	
Total	

CEC(Meq/100 gm)	

Osage 17-1 API: 4529141 293.7 ft



Very fine-grained sandstone. Irregular bedding is demonstrated by chlorite-concentrated laminae altered with clean sand laminae. Detrital grains are dominated by subangular quartz, with abundant chert and feldspar grains and glauconite pellets. Few mica flakes exist. Both kaolinite (Kao) crystals and calcite-cemented nodules (Cal) are rare.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
211	193	27.6	27.5	2.66	2.4	44.6

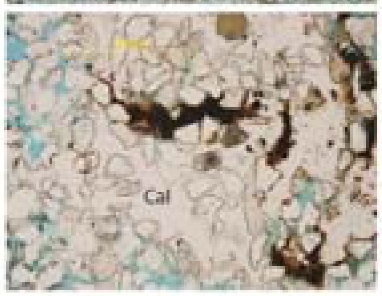
Whole Rock Weight

Mineral	%
Quartz	
Feldspar	
Total Clay	
Total	

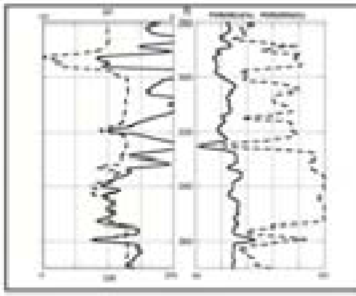
Relative Clay

Clay Mineral	%
Kaolinite	29
Illite	17
Chlorite	27
Illite/Smectite	27
Total	100

CEC(Meq/100 gm)	

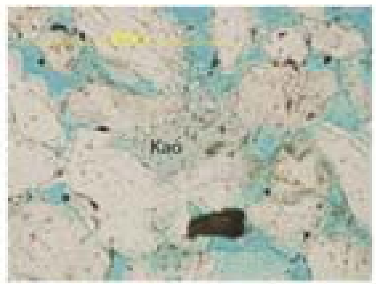


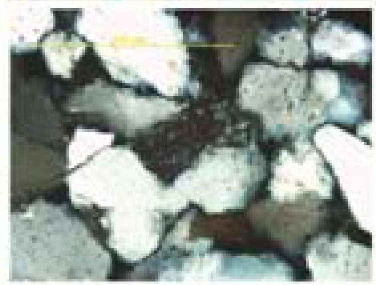
Osage 17-1 API: 4529141 296.4 ft



Cross-bedded, very fine-grained sandstone. Quartz grains is the major constitute of the detrital grains, with less amounts of chert and feldspar particles. Few clay-concentrated laminae are observed. Both glauconite and mica flakes are in minor amounts. Rich in pore-filling kaolinite. Few calcite-cemented nodules are observed.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
201	183	22.4	22.3	2.65	27.5	35.6





Whole Rock Weight

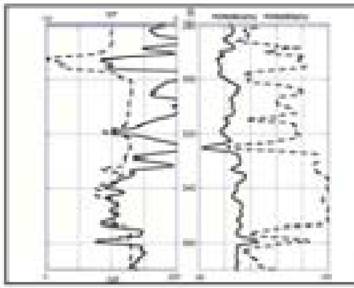
Mineral	%
Quartz	
Feldspar	
Total Clay	
Total	

Relative Clay

Clay Mineral	%
Kaolinite	37
Illite	<1
Chlorite	<1
Illite/Smectite	63
Total	100

CEC(Meq/100 gm)	

Osage 17-1 API: 4529141 320.9 ft



Stratified, very fine-grained sandstone composed of alternating clayey sand laminae and clean sand laminae. Equal amounts of detrital feldspar and quartz grains in this sandstone. Glauconite is pervasive. Dissolution of feldspar grains is common. Rich in pore-filling kaolinite (kao). Disseminated organic materials and pyrite are observed.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
22.8	19.1	27.2	27.1	2.65	58.9	22.9

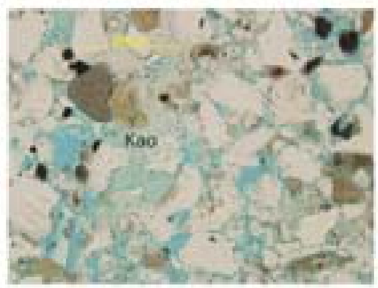
Whole Rock Weight

Mineral	%
Quartz	
Feldspar	
Total Clay	
Total	

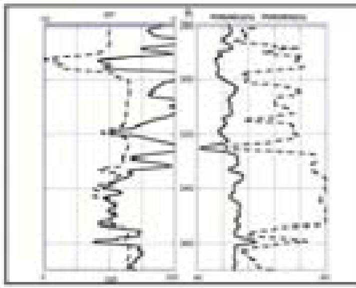
Relative Clay

Clay Mineral	%
Kaolinite	27
Illite	<1
Chlorite	20
Illite/Smectite	53
Total	100

CEC(Meq/100 gm)	50



Osage 17-1 API: 4529141 321.4 ft



Cross-bedded siltstone composed of clayey laminae with clean laminae. Angular feldspar and quartz grains are the principal constitutes of the rock. Abundant glauconite is pervasively distributed. Feldspar dissolution (Fd) is ubiquitous, and kaolinite (Kao) is commonly observed. Dispersed pyrite particles (Py) are identified.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
5.47	4.40	26.7	26.6	2.65	53.5	27.4

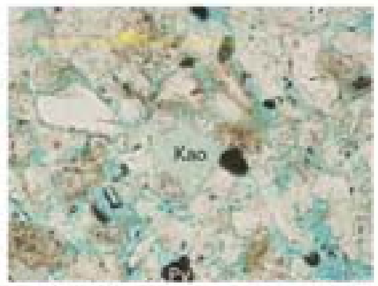
Whole Rock Weight

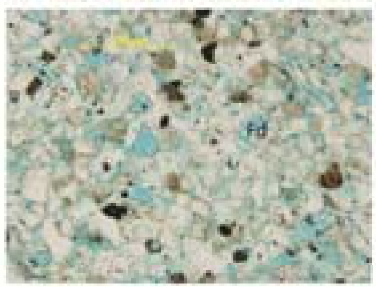
Mineral	%
Quartz	64
Feldspar	5
Total Clay	31
Total	100

Relative Clay

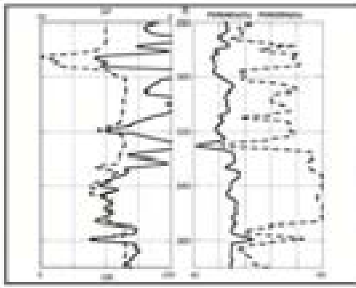
Clay Mineral	%
Kaolinite	29
Illite	<1
Chlorite	22
Illite/Smectite	49
Total	100

CEC(Meq/100 gm)	56





Osage 17-1 API: 4529141 322.6 ft



Not well stratified siltstone with abundant clay matrix. Glauconite pellets and mica flakes are ubiquitously distributed. Carbonaceous streaks and floating organic particles are common. Most of clays are matrix, deposited together with detrital grains. Not well euhedral kaolinite crystals are observed in SEM photos.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
0.635	0.411	24.0	23.9	2.65	61.0	24.1

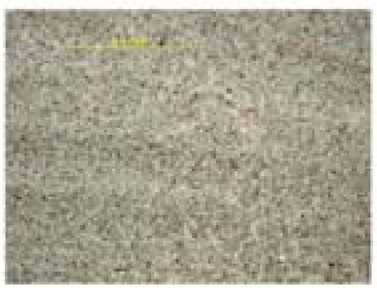
Whole Rock Weight

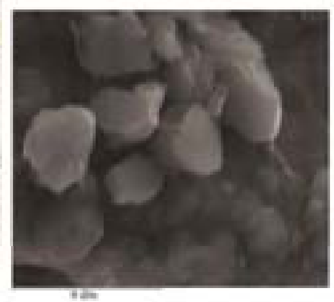
Mineral	%
Quartz	53
Feldspar	7
Total Clay	40
Total	100

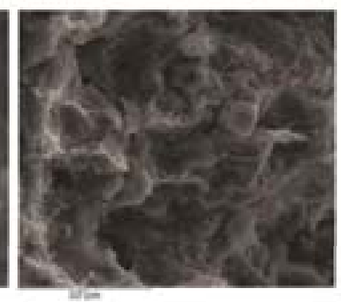
Relative Clay

Clay Mineral	%
Kaolinite	3
Illite	<1
Chlorite	3
Illite/Smectite	94
Total	100

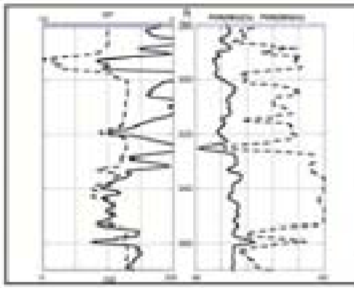
CEC(Meq/100 gm)	70







Osage 17-1 API: 4529141 333.7 ft



Heavily bioturbated clayey siltstone with occasional clean sand spots. Rich in floating charcoal fragments and carbonaceous streaks. Poikilotopic calcite fills the chambers inside some charcoal fragments. Intergranular pores are visible only in the clean sand spots. Pyrite particles are common, dispersed in the matrix or associated with charcoals fragments.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
2.48	1.97	19	18.9	2.63	26.3	38.4

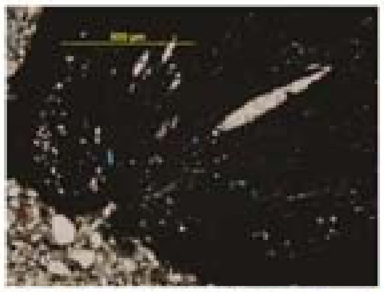
Whole Rock Weight

Mineral	%
Quartz	80
Feldspar	<1
Total Clay	20
Total	100

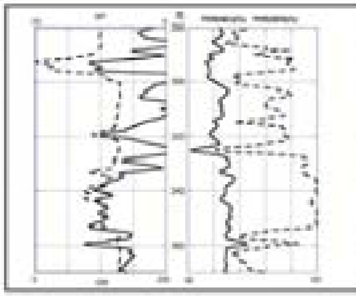
Relative Clay

Clay Mineral	%
Kaolinite	78
Illite	2
Chlorite	<1
Illite/Smectite	20
Total	100

CEC(Meq/100 gm)	



Osage 17-1 API: 4529141 334.5 ft



Not well stratified clayey siltstone with clean sand laminae. Rich in carbonaceous inclusions and streaks. Pyrite and iron oxide particles are pervasive. Trace of calcite cement are recognized. Fair porosity is observed only in clean sand laminae.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
0.636	0.411	18.4	18.3	2.61	31.0	40.6

Whole Rock Weight

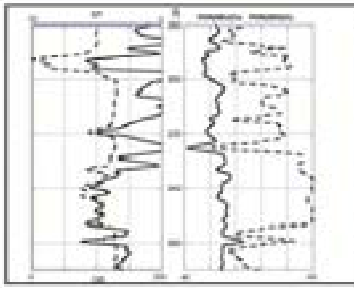
Mineral	%
Quartz	
Feldspar	
Total Clay	
Total	

Relative Clay

Clay Mineral	%
Kaolinite	85
Illite	4
Chlorite	<1
Illite/Smectite	11
Total	100

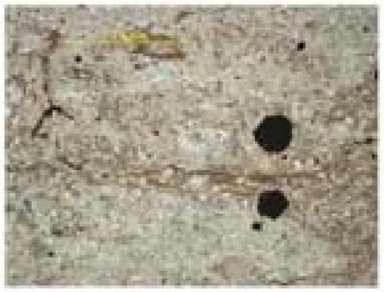
CEC(Meq/100 gm)	

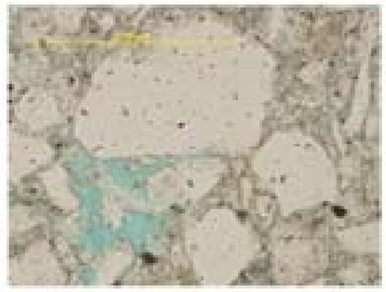
Osage 17-1 API: 4529141 336.3 ft

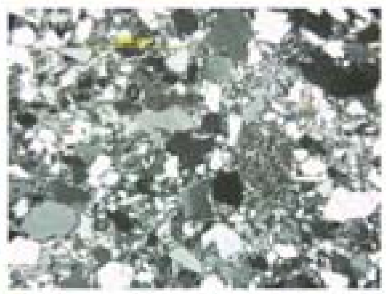


Tuffaceous sandstone with dispersed clay streaks. This sandstone is very poorly immature with respect of mineralogy and texture, containing a large portion of microcrystalline groundmass and dispersed quartz phenocrysts. Some siderite nodules (Sid) are observed. Rich in micropores, but few macropores are visible.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
0.012	0.0043	8.3	8.3	2.65	63.8	16.8







Whole Rock Weight

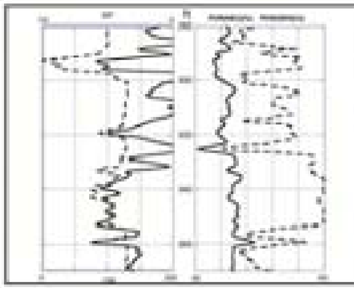
Mineral	%
Quartz	
Feldspar	
Total Clay	
Total	

Relative Clay

Clay Mineral	%
Kaolinite	83
Illite	9
Chlorite	<1
Illite/Smectite	8
Total	100

CEC(Meq/100 gm)	

Osage 17-1 API: 4529141 342.2 ft



Wavy siltstone composed of less immature laminae and mature laminae. Bioturbation modified some original texture. Carbonaceous streaks are common, associated with clay-rich laminae. Calcite-cemented nodules (Cal) exist in clean laminae. Matrix clayesrich in dirty laminae. Good porosity and permeability within the clean patches, but not well connected.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
2.28	1.82	13.5	13.4	2.65	38.5	30.3

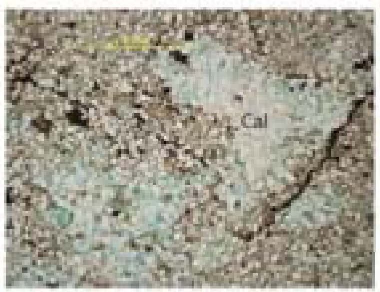
Whole Rock Weight

Mineral	%
Quartz	
Feldspar	
Total Clay	
Total	

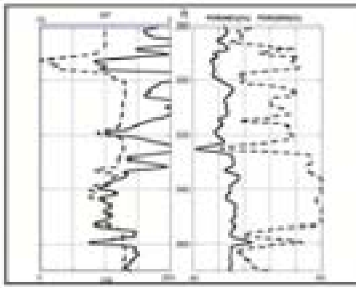
Relative Clay

Clay Mineral	%
Kaolinite	81
Illite	8
Chlorite	<1
Illite/Smectite	11
Total	100

CEC(Meq/100 gm)	



Osage 17-1 API: 4529141 345.7 ft



Cross lamination with carbonaceous streaks and floating plant fragments. Rich in altered matrix clays. Visual connected pores are observed within isolated clean sand patches. Pyrite and iron oxide particles are common.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
0.112	0.066	12.3	12.2	2.65	59.9	17.4

Whole Rock Weight

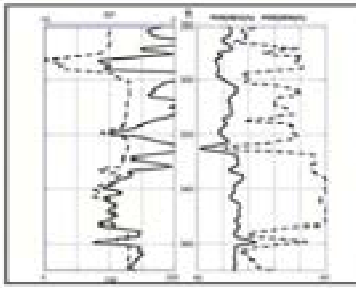
Mineral	%
Quartz	
Feldspar	
Total Clay	
Total	

Relative Clay

Clay Mineral	%
Kaolinite	55
Illite	25
Chlorite	<1
Illite/Smectite	20
Total	100

CEC(Meq/100 gm)	

Osage 17-1 API: 4529141 347.3 ft



Clayey very fine-grained sandstones with wavy lamination. Better sorted sand laminae and patches contain less clay, and authigenic kaolinite (Kao) fills some intergranular pores. Laminae of silt size are rich in detrital clays. Disseminated charcoal particles are common. Interconnected pores are only observed within the better sorted sand laminae.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
0.036	0.018	11.9	11.8	2.66	64.1	20.5

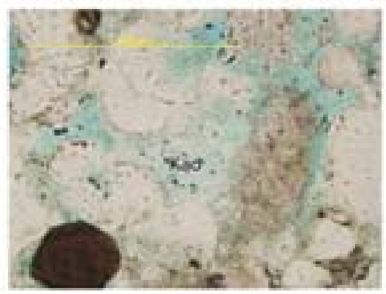
Whole Rock Weight

Mineral	%
Quartz	
Feldspar	
Total Clay	
Total	

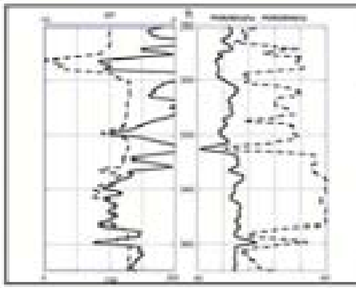
Relative Clay

Clay Mineral	%
Kaolinite	47
Illite	46
Chlorite	<1
Illite/Smectite	7
Total	100

CEC(Meq/100 gm)	



Osage 17-1 API: 4529141 350.4 ft



Shaly, very fine-grained sandstone with occasionally clay-poor laminae. Wavy Lamination composed of very fine sand laminae and clay-rich silt laminae. Kaolinite clusters (Kao) are observed within the clay-poor sand patches. Few large charcoal fragments are observed.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
0.023	0.010	10.1	10	2.66	75.5	11.9

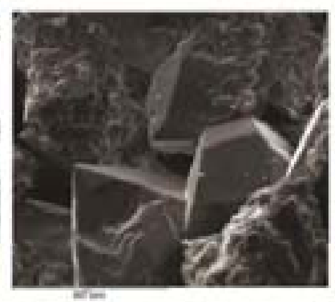
Whole Rock Weight

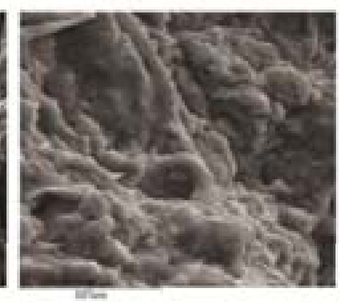
Mineral	%
Quartz	
Feldspar	
Total Clay	
Total	

Relative Clay

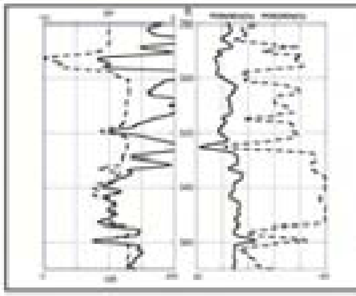
Clay Mineral	%
Kaolinite	60
Illite	22
Chlorite	<1
Illite/Smectite	18
Total	100

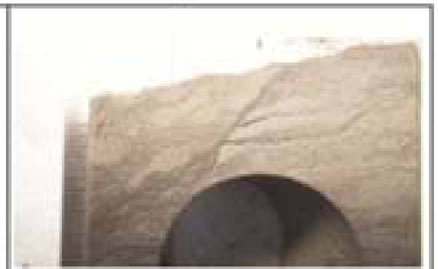
CEC(Meq/100 gm)	32





Osage 17-1 API: 4529141 351.4 ft





Wavy lamination. Very fine-grained sandstone laminae alternated with clayey silty laminae. Loosely-packed kaolinite mineral fills few of the intergranular pores. Well interconnected macropores are only observed in the relatively clean sands. No visual pores are recognized in the matrix-rich laminae. Carbonaceous inclusions are ubiquitous.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
0.0041	0.0011	11.4	11.3	2.66	60.4	24.6

Whole Rock Weight

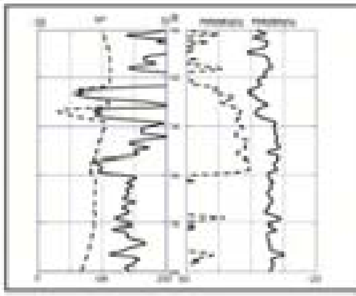
Mineral	%
Quartz	
Feldspar	
Total Clay	
Total	

Relative Clay

Clay Mineral	%
Kaolinite	63
Illite	20
Chlorite	<1
Illite/Smectite	17
Total	100

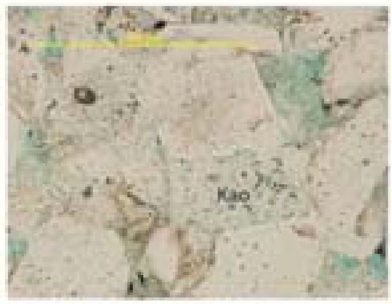
CEC(Meq/100 gm)	

Osage 18-9 API: 4529128 748.2 ft



Wavy laminated, very fine-grained sandstone. The better sorted laminae are dominated by quartz grains and greenish chlorite mineral, with good intergranular pores and minor amounts of kaolinite (Kao). The tight laminae are rich in clay matrix, silty particles, and carbonaceous streaks and inclusions. Authigenic kaolinite is also ovserved in some pores of the tight laminae.

Horizontal Permeability (md)				Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
0.254	0.140	10.2	10.2	2.64	56.8	38.2



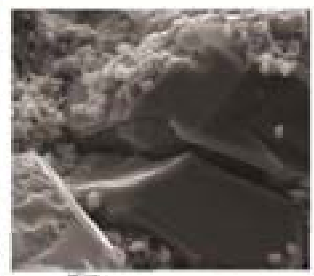
Whole Rock Weight

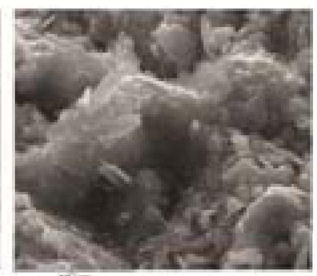
Mineral	%
Quartz	
Feldspar	
Total Clay	
Total	

Relative Clay

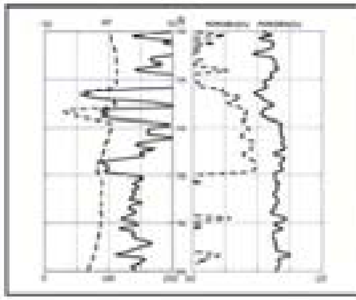
Clay Mineral	%
Kaolinite	42
Illite	32
Chlorite	<1
Illite/Smectite	26
Total	100

CEC(Meq/100 gm)	24





Osage 18-9 API: 4529128 750.2 ft



Very fine-grained shaly sandstone with wavy lamination. The clean sand laminae are composed of subrounded quartz grains with incipient overgrowth cement, and portion of these laminae are cemented by poikilotopic calcite (Cal). The shaly laminae are rich in carbonaceous streaks and inclusions. Kaolinite (Kao) occurs infew pores. Fragmental bits and chunks of charcoal are common.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
0.090	0.1051	10.4	10.2	2.62	58.7	40.4

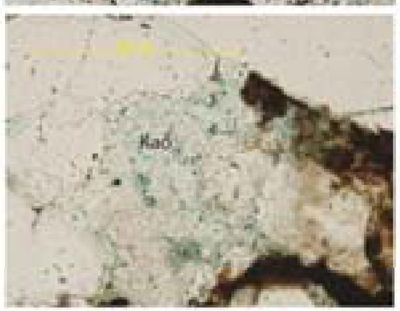
Whole Rock Weight

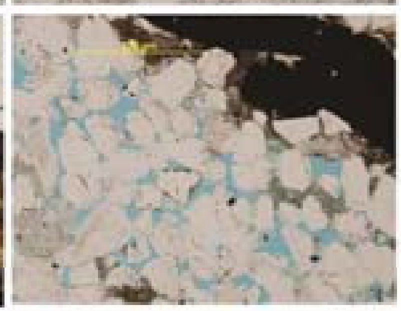
Mineral	%
Quartz	
Feldspar	
Total Clay	
Total	

Relative Clay

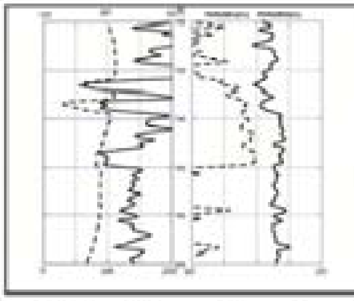
Clay Mineral	%
Kaolinite	46
Illite	21
Chlorite	<1
Illite/Smectite	33
Total	100

CEC(Meq/100 gm)	





Osage 18-9 API: 4529128 754.5 ft



Bioturbated shaly siltstone with very fine-grained sand laminae or patches. Some of these patches contain subrounded quartz grains with good intergranular pores. Carbonaceous inclusions are common. Porosity is low, and permeability is poor due to rich in matrix clays

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
0.022	0.010	10.8	10.8	2.66	58.2	35.3

Whole Rock Weight

Relative Clay

Whole Rock Weight

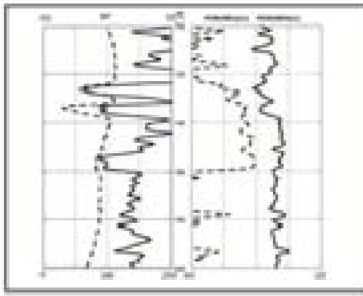
Mineral	%
Quartz	
Feldspar	
Total Clay	
Total	

Relative Clay

Clay Mineral	%
Kaolinite	32
Illite	27
Chlorite	19
Illite/Smectite	22
Total	100

CEC(Meq/100 gm)	25

Osage 18-9 API: 4529128 755.5 ft



Laminated, very fine-grained sandstone contains tight silty laminae and permeable sand laminae. The silty laminae are rich in detrital clays and carbonaceous inclusions. Glauconite pellets are common in the permeable laminae. Traces of kaolinite (Kao) are observed in few intergranular pores.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
1.46	1.16	14.4	14.4	2.65	44.9	29.5

Whole Rock Weight

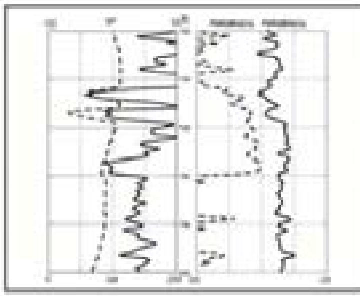
Mineral	%
Quartz	
Feldspar	
Total Clay	
Total	

Relative Clay

Clay Mineral	%
Kaolinite	33
Illite	27
Chlorite	20
Illite/Smectite	20
Total	100

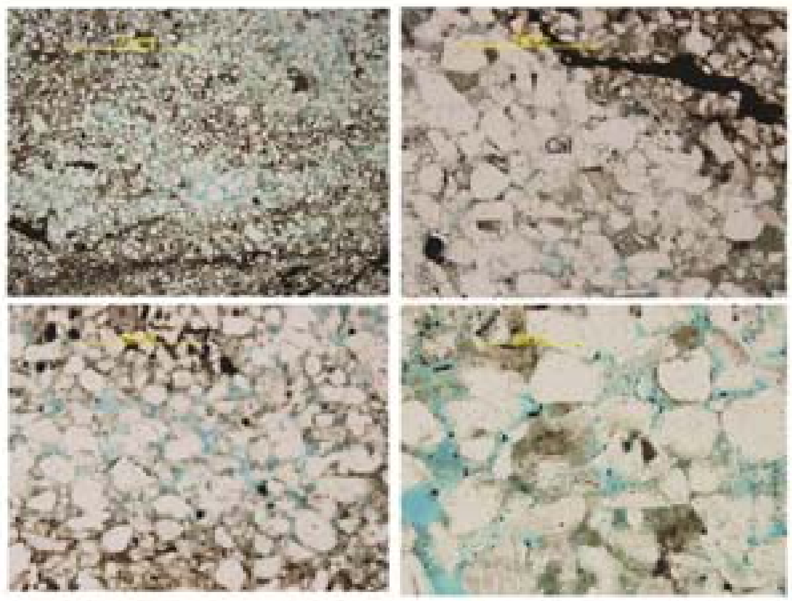
CEC(Meq/100 gm)	

Osage 18-9 API: 4529128 759.4 ft



Bioturbated silty sandstone with irregular lamination. This sandstone is composed of shaly silty laminae, with less portion of better sorted sand patches. Glauconite particles are observed in the clean sand patches. Carbonaceous streaks are common, concentrated within the silty laminae. Calcite-cemented nodules (Cal) and authigenic kaolinite are observed.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
0.089	0.051	12.7	11.6	2.63	56.2	34.8



Whole Rock Weight

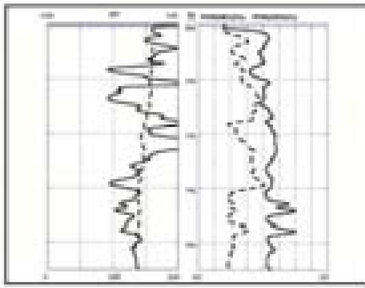
Mineral	%
Quartz	
Feldspar	
Total Clay	
Total	

Relative Clay

Clay Mineral	%
Kaolinite	21
Illite	28
Chlorite	22
Illite/Smectite	29
Total	100

CEC(Meq/100 gm)	28

Osage 21-4 API: 4529132 708.6 ft



Very fine- to fine-grained sandstone dominated by subangular to subrounded quartz grains. The sandstone is characterized by well-connected intergranular pores with isolated calcite-cemented nodules (Cal). Kaolinite (Kao) and chlorite are observed in SEM images. Clay-rich, very fine-grained sands are concentrated as laminae or patches, reducing permeability. Traces of bioturbation are observed.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
0.781	0.595	15.8	15.8	2.65	43.9	33.8

Whole Rock Weight

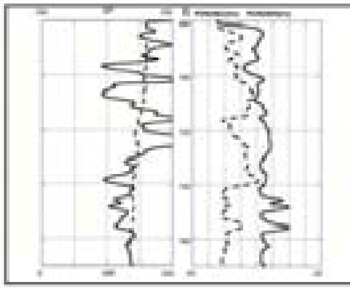
Mineral	%
Quartz	70
Feldspar	<1
Total Clay	30
Total	100

Relative Clay

Clay Mineral	%
Kaolinite	24
Illite	30
Chlorite	23
Illite/Smectite	23
Total	100

CEC(Meq/100 gm)	

Osage 21-4 API: 4529132 709.5 ft



Shaly sandstone with clean sand laminae or patches. Rich in clay matrix. Wavy lamination with many rounded worm borrows. Carbonaceous streaks and inclusions are ubiquitous. The isolated clean sand laminae contain fairly-connected intergranular pores. Traces of calcite cement (Cal) are observed in the clean sand patchs. Authigenic kaolinite Kao) is not recognized in the thin section, but observed in SEM images.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
2.58	2.07	14.7	14.7	2.63	44.8	34.1

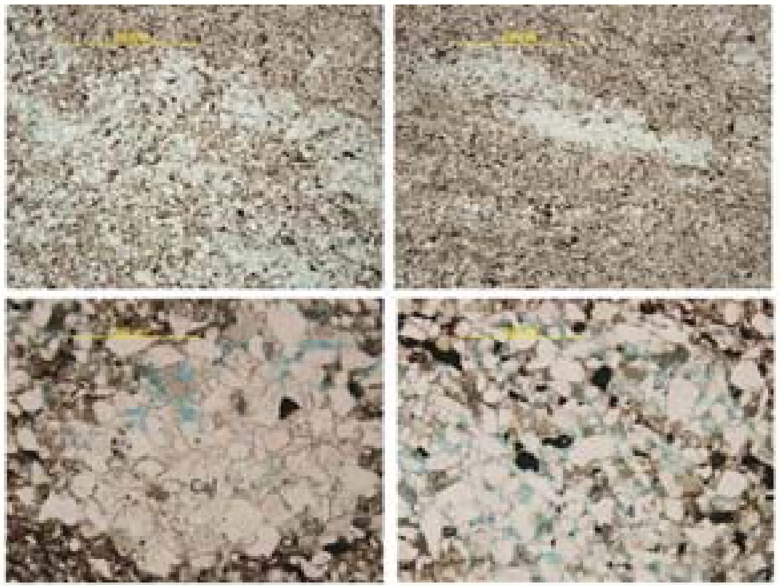
Whole Rock Weight

Mineral	%
Quartz	47
Feldspar	<1
Total Clay	53
Total	100

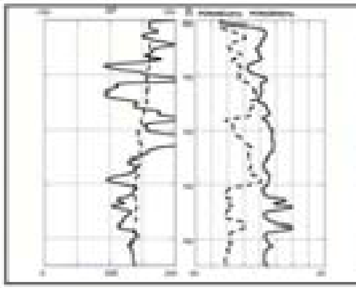
Relative Clay

Clay Mineral	%
Kaolinite	23
Illite	31
Chlorite	23
Illite/Smectite	23
Total	100

CEC(Meq/100 gm)	62



Osage 21-4 API: 4529132 711.6 ft



Severely bioturbated sandstone. Subangular to angular detrital grains. Poorly sorted. Rich in clay matrix. Shale laminae and patches are ubiquitous. Carbonaceous inclusions are common. Microscopic pores are abundant, but visual macropores are rare. Kaolinite (Kao) and authigenic greenish chlorite (Ch) fill some of the intergranular pores.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
0.0042	0.0011	14.0	14.0	2.66	65.6	25.5

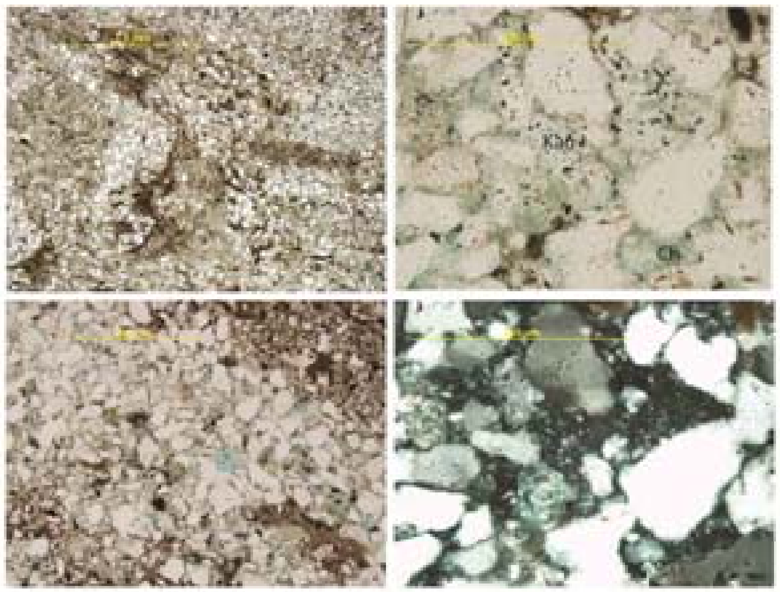
Whole Rock Weight

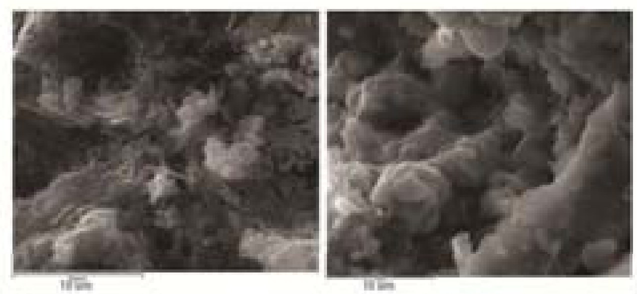
Mineral	%
Quartz	34
Feldspar	10
Total Clay	56
Total	100

Relative Clay

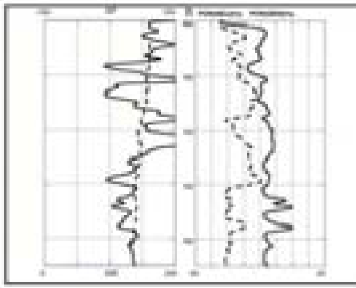
Clay Mineral	%
Kaolinite	25
Illite	25
Chlorite	25
Illite/Smectite	25
Total	100

CEC(Meq/100 gm)	40





Osage 21-4 API: 4529132 712.6 ft



Wavy laminated shaly sandstone with abundant carbonaceous streaks and inclusion. Detrital clay minerals constitute a significant portion of the rock. Micropores are common, and only few small intergranular pores are observed in clean sand spots.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
0.013	0.0062	14.3	14.3	2.65	70.1	26.0

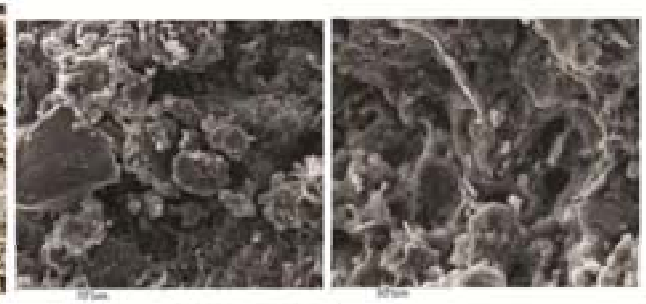
Whole Rock Weight

Mineral	%
Quartz	33
Feldspar	16
Total Clay	51
Total	100

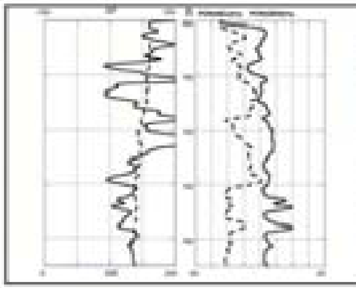
Relative Clay

Clay Mineral	%
Kaolinite	23
Illite	28
Chlorite	24
Illite/Smectite	25
Total	100

CEC(Meq/100 gm)	



Osage 21-4 API: 4529132 727.3 ft



Tight shaly siltstone. Angular quartz and feldspar grains. Rich in clay matrix. Disseminated carbonaceous inclusions and dispersed fusinite are common. Authigenic kaolinite are identified associated with partially dissolved feldspar grains.

Horizontal Permeability (md)		Porosity (%)		Grain Density (gm/cc)	Fluid Saturation (%)	
to Air	Klinkenberg	Ambient	NCS		Water	Oil
0.047	0.024	11.4	11.4	2.65	80.2	11.2

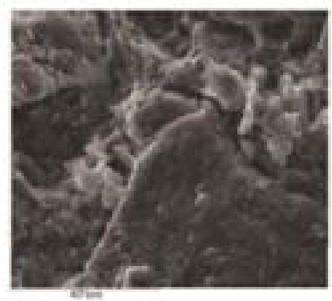
Whole Rock Weight

Mineral	%
Quartz	31
Feldspar	32
Total Clay	37
Total	100

Relative Clay

Clay Mineral	%
Kaolinite	46
Illite	32
Chlorite	<1
Illite/Smectite	22
Total	100

CEC(Meq/100 gm)	



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