Woodford Shale Source Rock Characterization in a Horizontal Well*

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Abstract

The benefits to hydrocarbon exploration from geochemical and petrologic analysis have been known for many years. Yet the advent of smaller, cheaper and more specialized equipment is now providing the ability to make highly precise and critical measurements during the drilling process. This greatly reduces the time it takes to obtain results that may take weeks or even months. When this data is coupled with standard surface logging techniques of gas and formation analysis, they provide valuable information about the hydrocarbon source rock to the reservoir. This will aid with production of the subject well and future development planning. For this case study, several instruments were used in a mobile laboratory during the drilling of a Woodford horizontal well on cutting samples taken at regular intervals: Rock Eval®, GCIR II for Gas Isotopes, Niton® XRF, Hitachi TM-3000 SEM. The Rock Eval pyrolysis provided data on producible hydrocarbons, thermal maturity and total organic content in each sample. The GCIR II analyzed the gas isotopes from both isotubes and isojars yielding data on c1, c2, c3 and c4 isotopes. This data provided insight into permeability, porosity and provided information on hydrocarbon compartmentalization. In addition, GCIR data analysis composed regional stable isotope mapping (DNA) of the target formation. XRF analysis was able to quantify the elemental composition of the cutting samples. This provided an understanding of the best locations to fracture based on silica and aluminum content, changes in mineral composition due to alterations of depositional environment, better regional understanding of the reservoir and an indication of Total Organic Carbon assisting with, "sweet spot" identification. Petrologic analysis was done using the SEM. This instrument gave direct observation of both microstructures and available pore space. In turn, this data gave corroboration to the previous geochemical and elemental analysis. As a control to the measurements made during the drilling of the well, two Woodford outcrops from the Arbuckle Mountains of Oklahoma were examined from samples taken at specified intervals through the formation using the standard practices of Stratigraphy. These samples were subjected to analysis using the XRF and SEM. Not only did this provide a benchmark for the test well, it provided information to assist with regional variations within the Woodford source rock.

Selected References

Comer, J.B., 2008, Woodford Shale in southern Midcontinent, USA - Transgressive system tract marine source rocks on an arid passive continental margin with persistent oceanic upwelling: AAPG Annual Convention, San Antonio, TX, poster, 3 panels.

McCarthy, K., M. Niemann, D. Palmowski, K. Peters, and A. Stankiewicz, 2011, Basic petroleum geochemistry for source rock evaluation: Oilfield Review, v. 23/2, p. 32–43.

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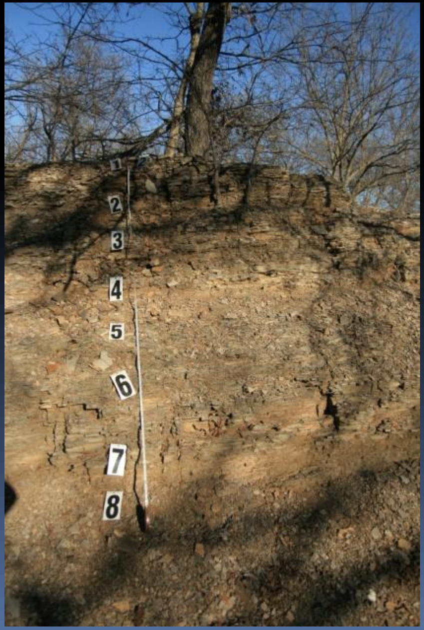
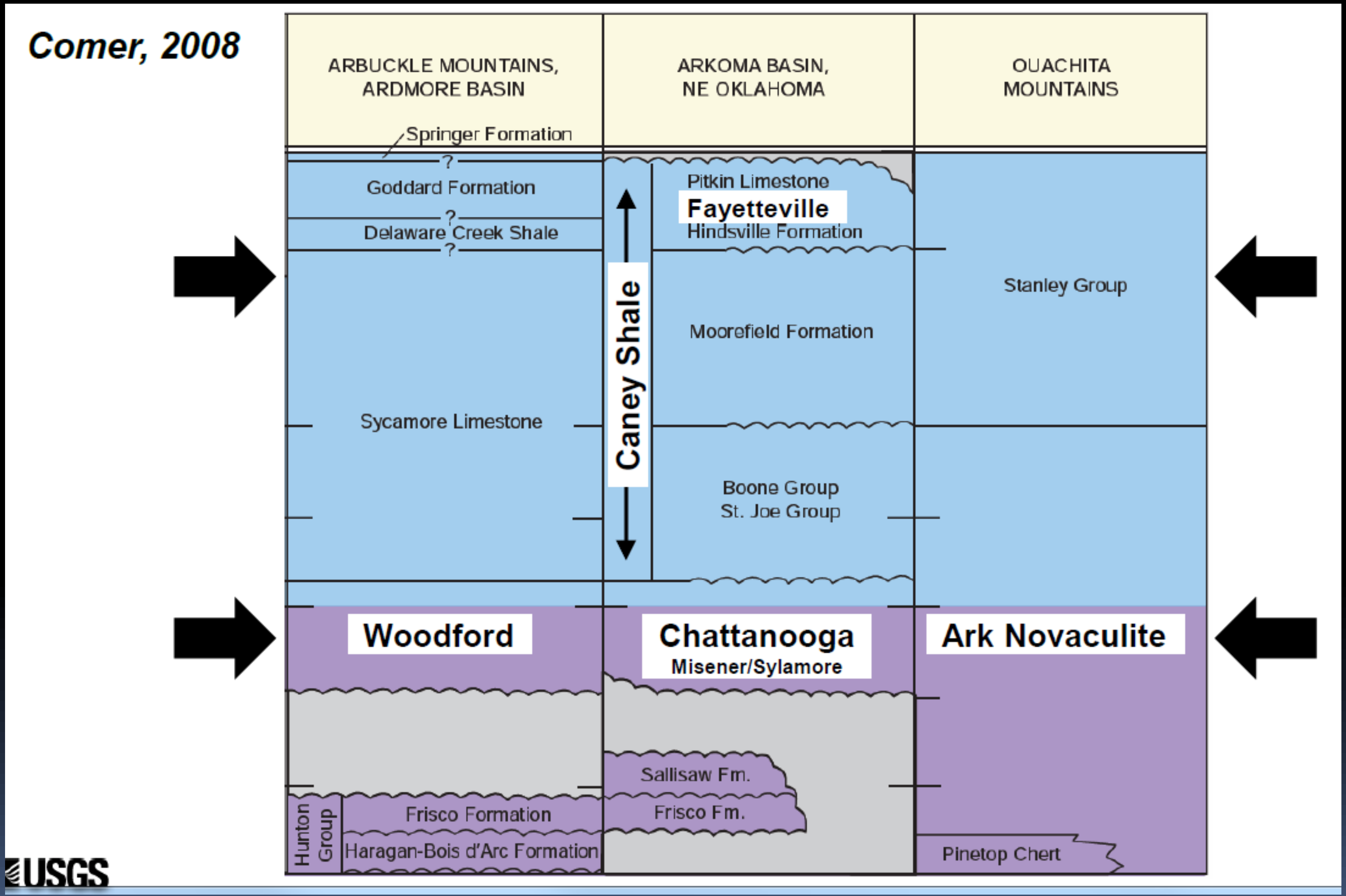
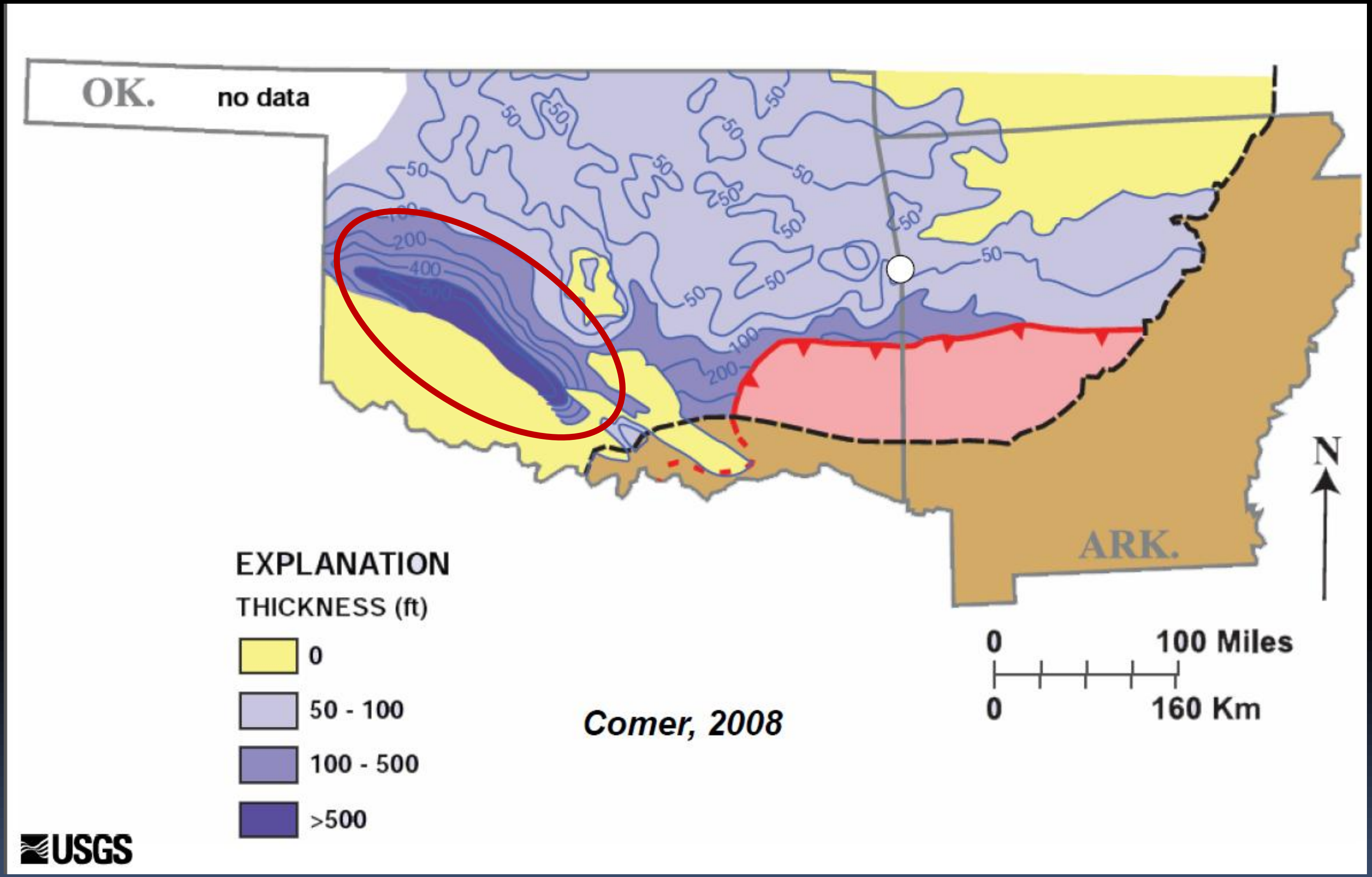
Devonian Age - Woodford Shale Geological Setting



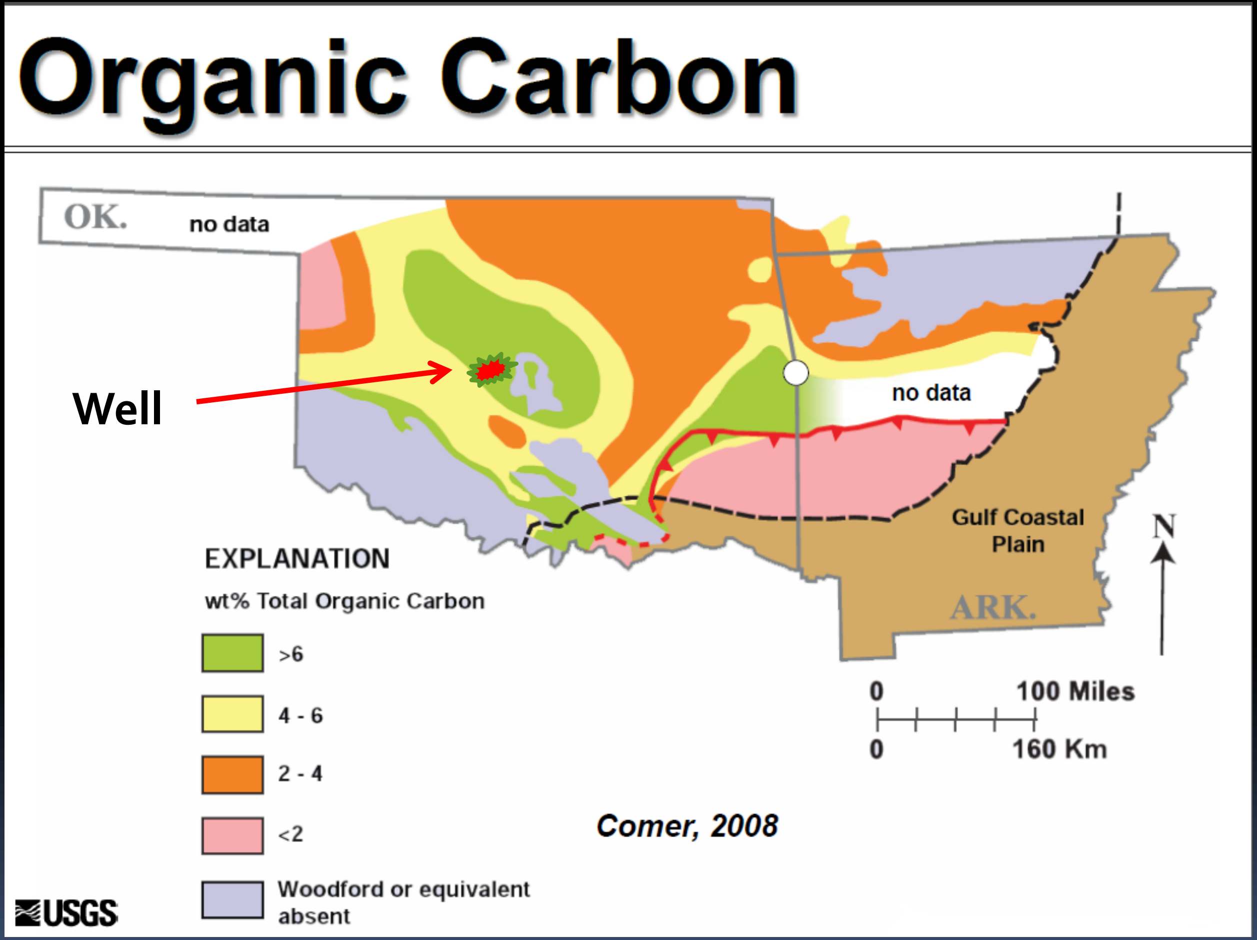
Regional Stratigraphy



Woodford Thickness



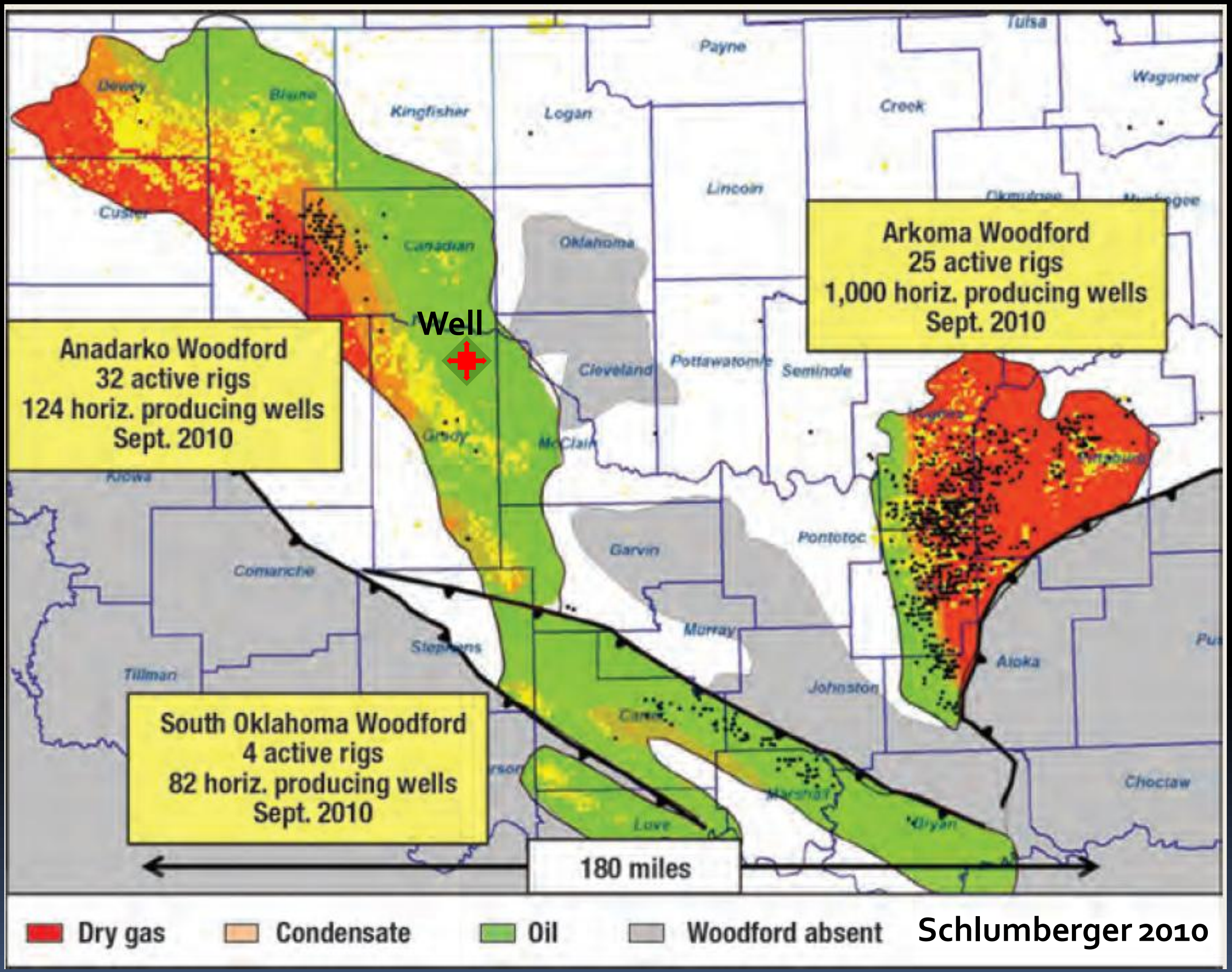
Woodford Shale: Oklahoma



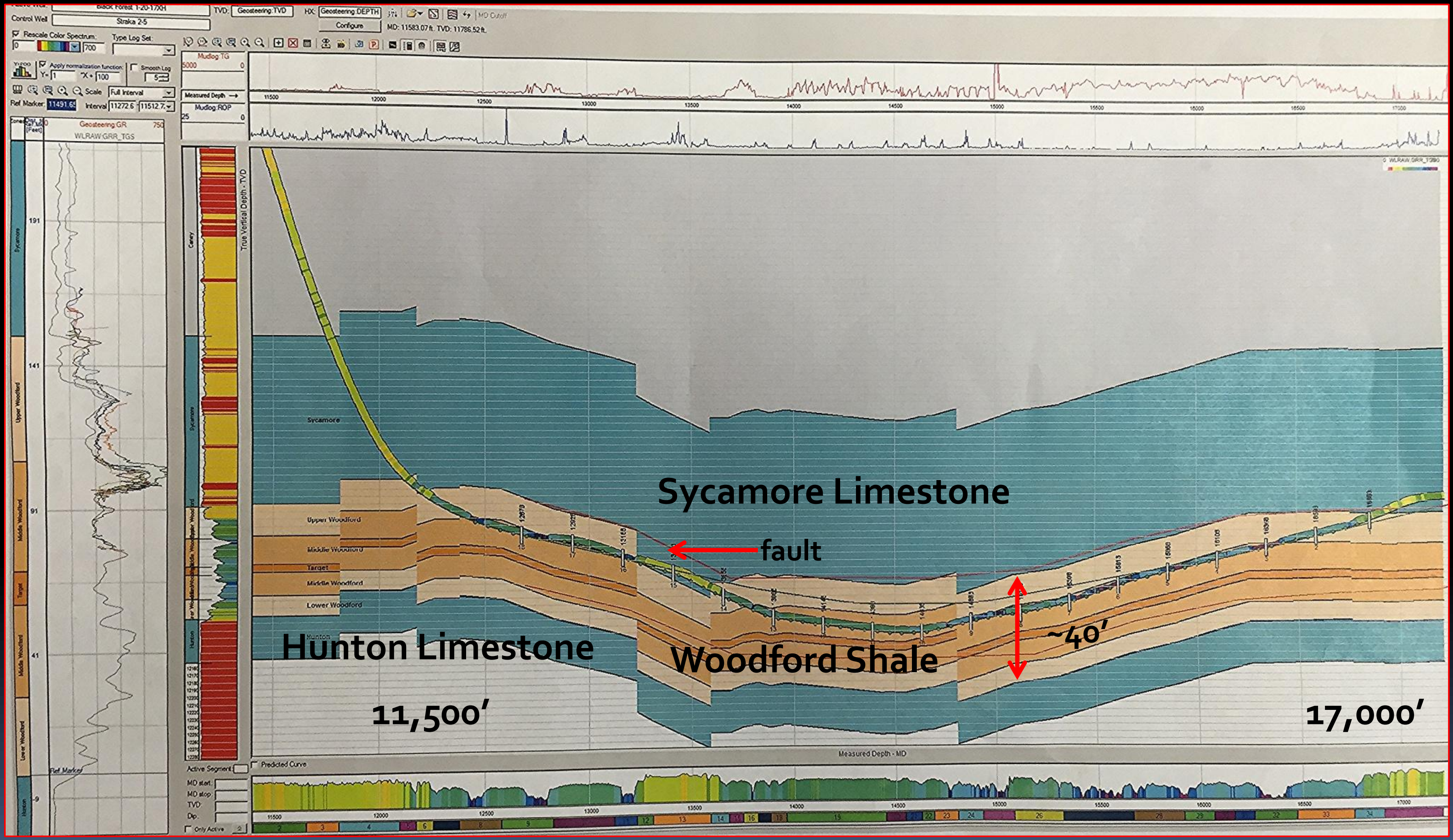
Average TOC in subject well 13000-17240: 2.9786 (wt %)

Note: TOC is an indicator or hydrocarbon quantity not quality.

Previous Drilling Activity



Horizontal Cross-Section



Analysis provided: Rock Pyrolysis, XRF, Gas Isotopes, SEM, Mudlogging

Background on Rock Pyrolysis and XRF

Rock Pyrolysis

Meaning of the Data

Stage 1 (S0): 0 to 90 C^0 - hydrocarbons are released from bitumen followed by the release of CO_2 as the temperature rises

Stage 2 (S1): 90 to 300 C^0 - free hydrocarbons are released without cracking and represents the amount of hydrocarbon that can be thermally distilled from one gram of sample

Stage 3 (S2): 300 to 600 C^0 - these are residual hydrocarbons and represent the amount of hydrocarbon a source rock might produce if maturation continues

Stage 4 (S3): 300 to 600 C^0- CO_2 from the thermal cracking of kerogen

Tmax- temperature at maximum release of hydrocarbons during pyrolysis, generally the top of the S2 peak. Tmax represents the maturation parameter that is kerogen dependent.

Rock Pyrolysis Data Provides….

CP: Productive Carbon
CP = 0.083*(S0+S1+S2)

PG: Potential of Generation
PG = S0+S1+S2

GPI: Gas Potential Index
GPI = S0/(S0+S1+S2)

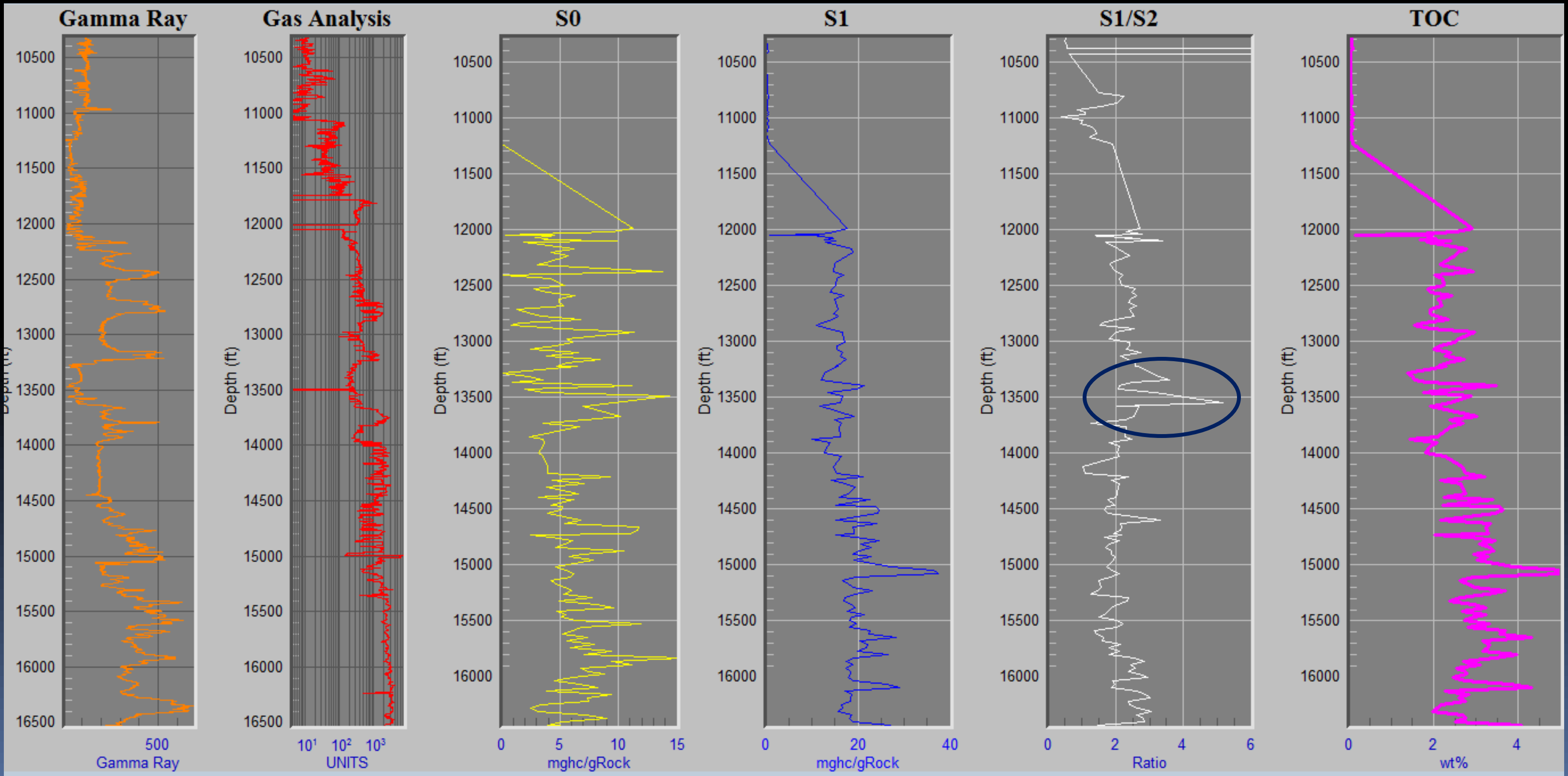
OPI: Oil Potential Index
OPI = S1/(S0+S1+S2)

TPI: Total Oil Potential Index
TPI = (S0+S1)/(S0+S1+S2)

LHI: Light/Heavy index
LHI = (S0+S1+S21)/(S22+S23)

Rock Pyrolysis

The TOC is important because hydrocarbon production is related to its carbon content (McCarthy et al., 2011). The sensitivity of the S1/S2 ratio to hydrocarbons and TOC provide the primary indicators for these zones of interest.



X-Ray Fluorescence - XRF

Meaning of the Data

•The relationship of sulfur to iron indicates the presence of pyrite in a sample that could potentially reduce the presence of usable porosity.

•The relationship of vanadium, molybdenum and manganese provides evidence of the paleo-environment in which sediments were deposited.

•Rock hardness, which relates directly to a rocks ability to be fractured, can be assessed by examining the amount of silica and aluminum present. The higher the amount of these two elements the easier it is to break the rock; ie frackability.

•Depositional sources can be identified; transgressive vs regressive cycles.

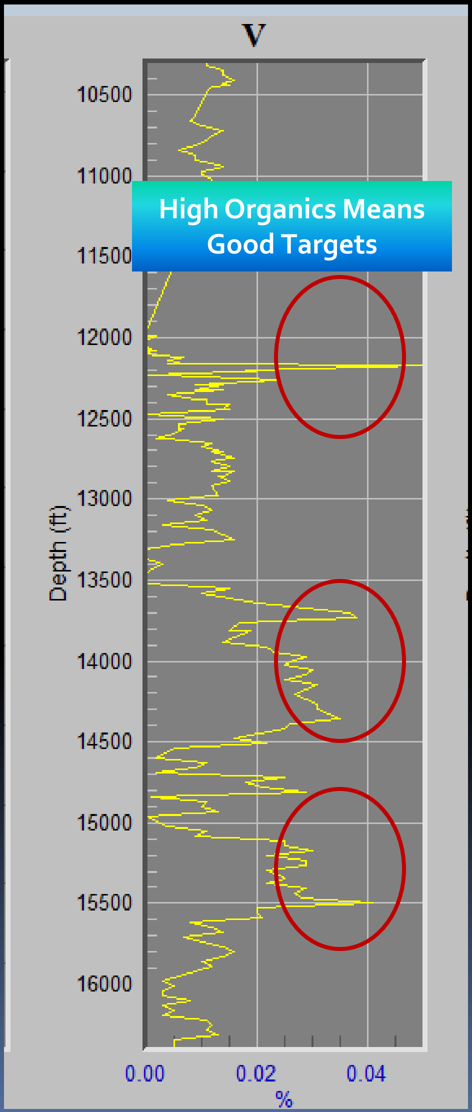
•Assist with correlation when biostratigraphic and lithostratigraphic markers are absent

•Distinguish carbonate facies changes: limestone vs dolomite, etc.

...Much More

Molybdenum & Vanadium

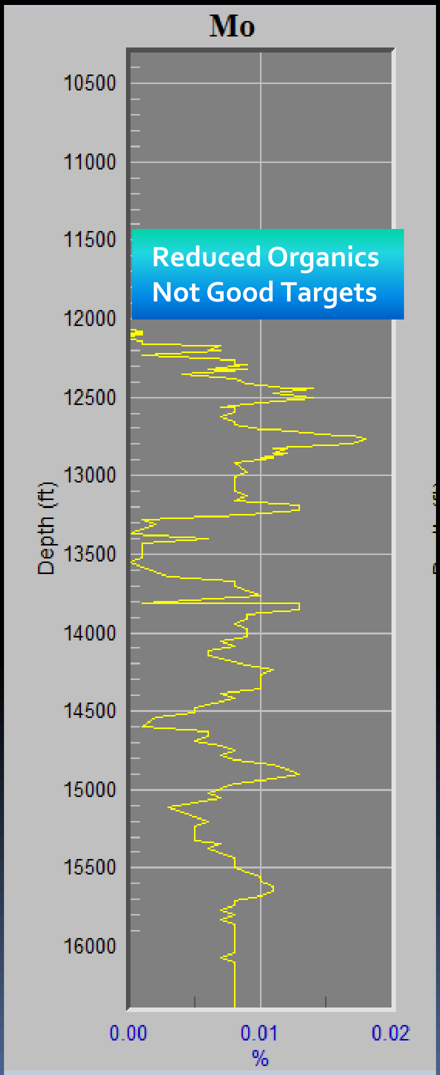
Marine bacteria and algae produce high amounts of Mo & V.



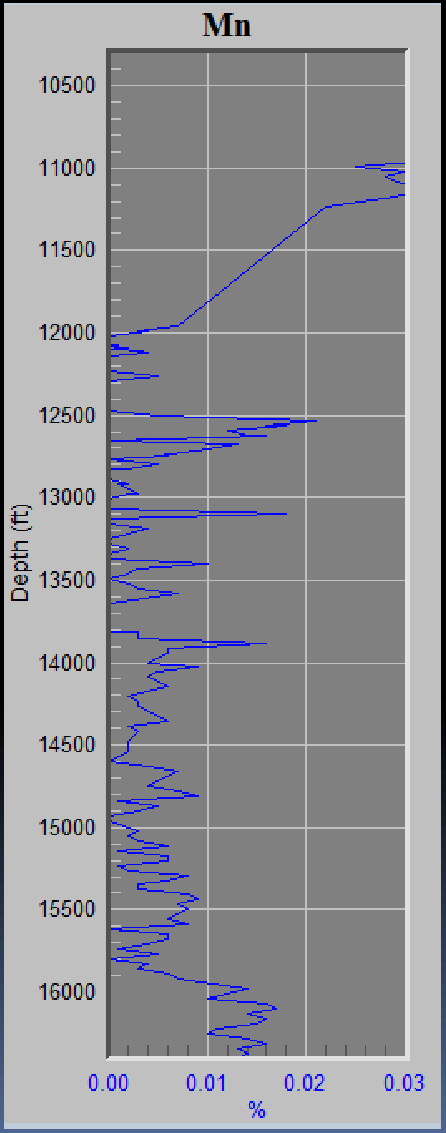
V is sourced from organics and is locked under both oxidizing and reducing conditions, its concentration is related to organic production.

Mo concentration is very sensitive to changes in changes in redox conditions because it is mobile when reduced and is locked when oxidized.

Therefore elevated levels of Mo and V indicate a paleoenvironments where significant amounts of organic matter accumulate under anoxic conditions.



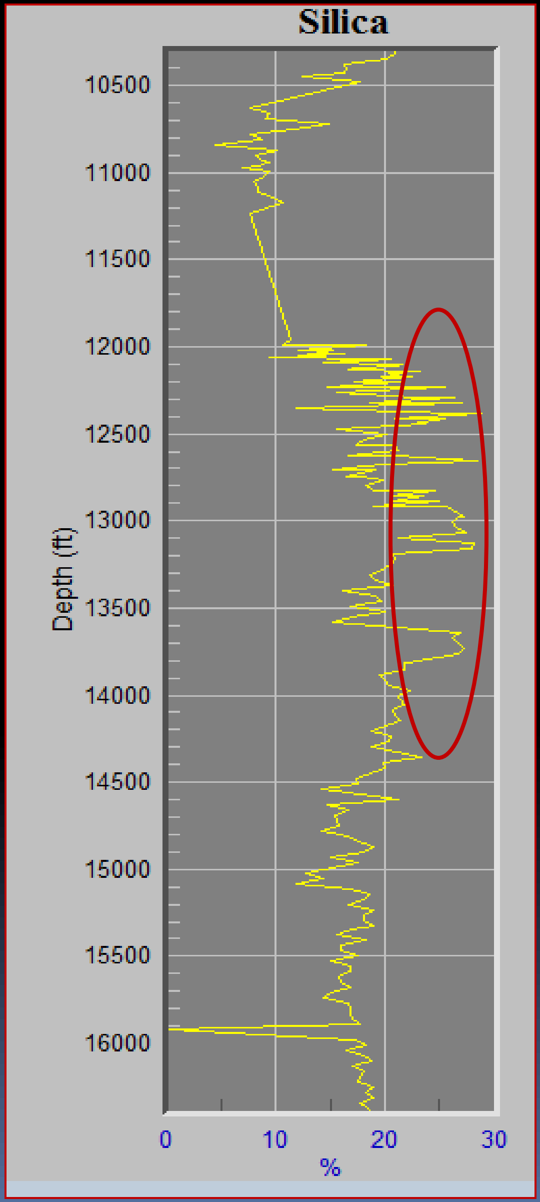
Meaning of Manganese



A decrease of Mn is related to a paleoenvironment where significant organic accumulation has occurred under anoxic conditions.

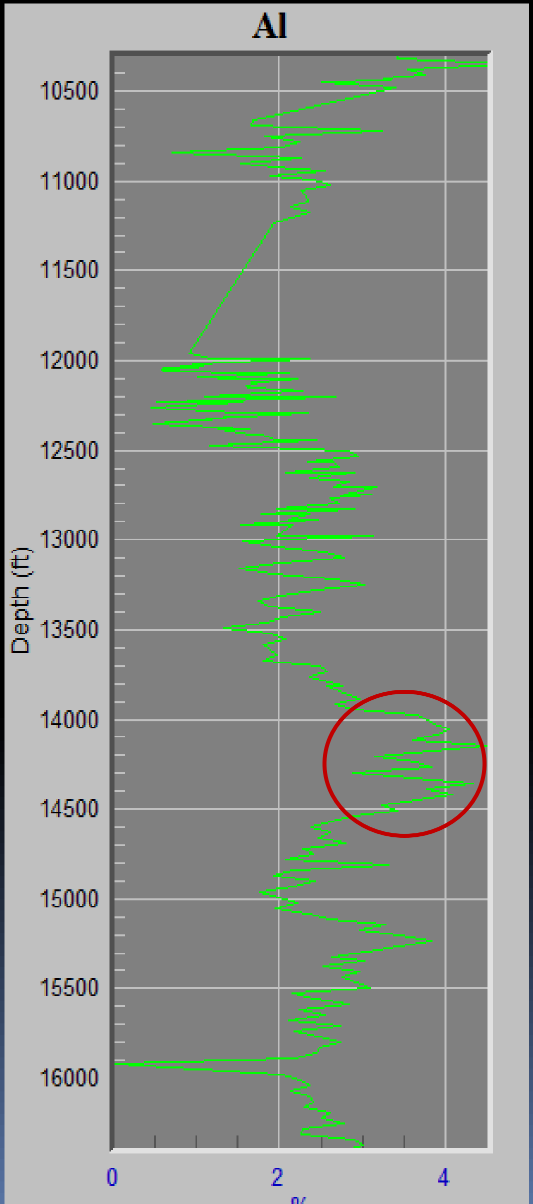
Where values of V and Mo are high, Mn should be low for the creation of organic shale.

Silica and Aluminum

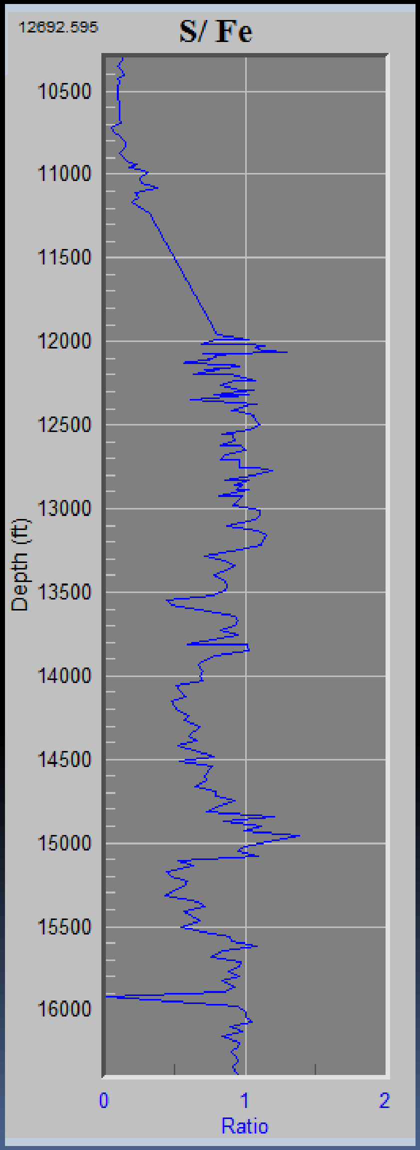


The higher the silica value the easier a rock is to break, frac.

The higher the aluminum concentration the harder it is to break a rock. High Chromium values also make a formation harder.



Iron Limited System



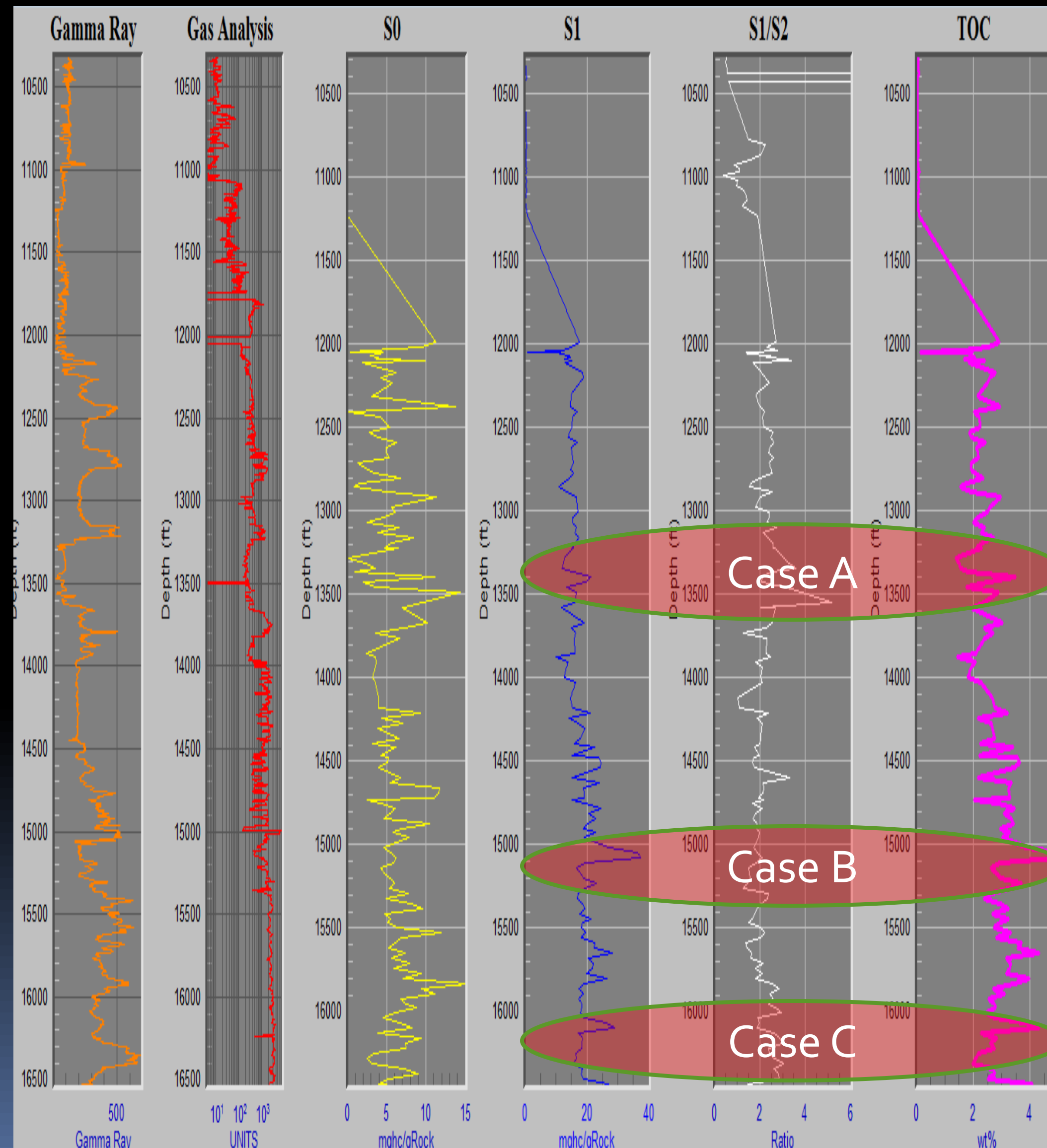
The ratio of Sulfur to Iron indicates values between .9 to 1.3. This is a constant ratio indicating pyrite within an iron poor environment. This means that there is no reactive iron present after pyrite formation, placing pyritization at essentially 100%.

Woodford Characteristics

Important Zones Within The Lateral

Case Study

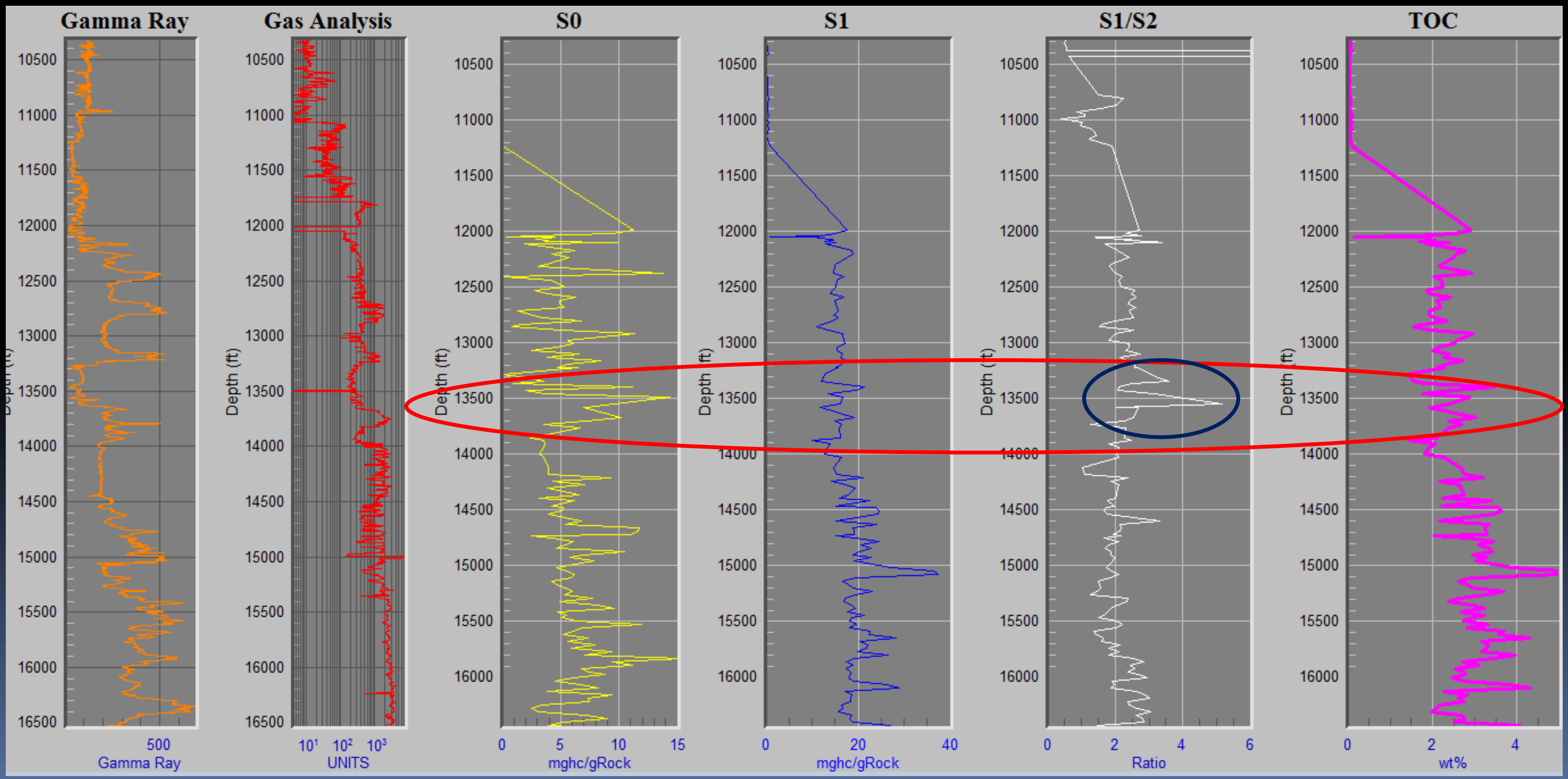
- Case A: 13,100 - 13,600
- Case B: 14,900 - 15,350
- Case C: 16,000 – 17,000



Case A: 13,100 - 13,600

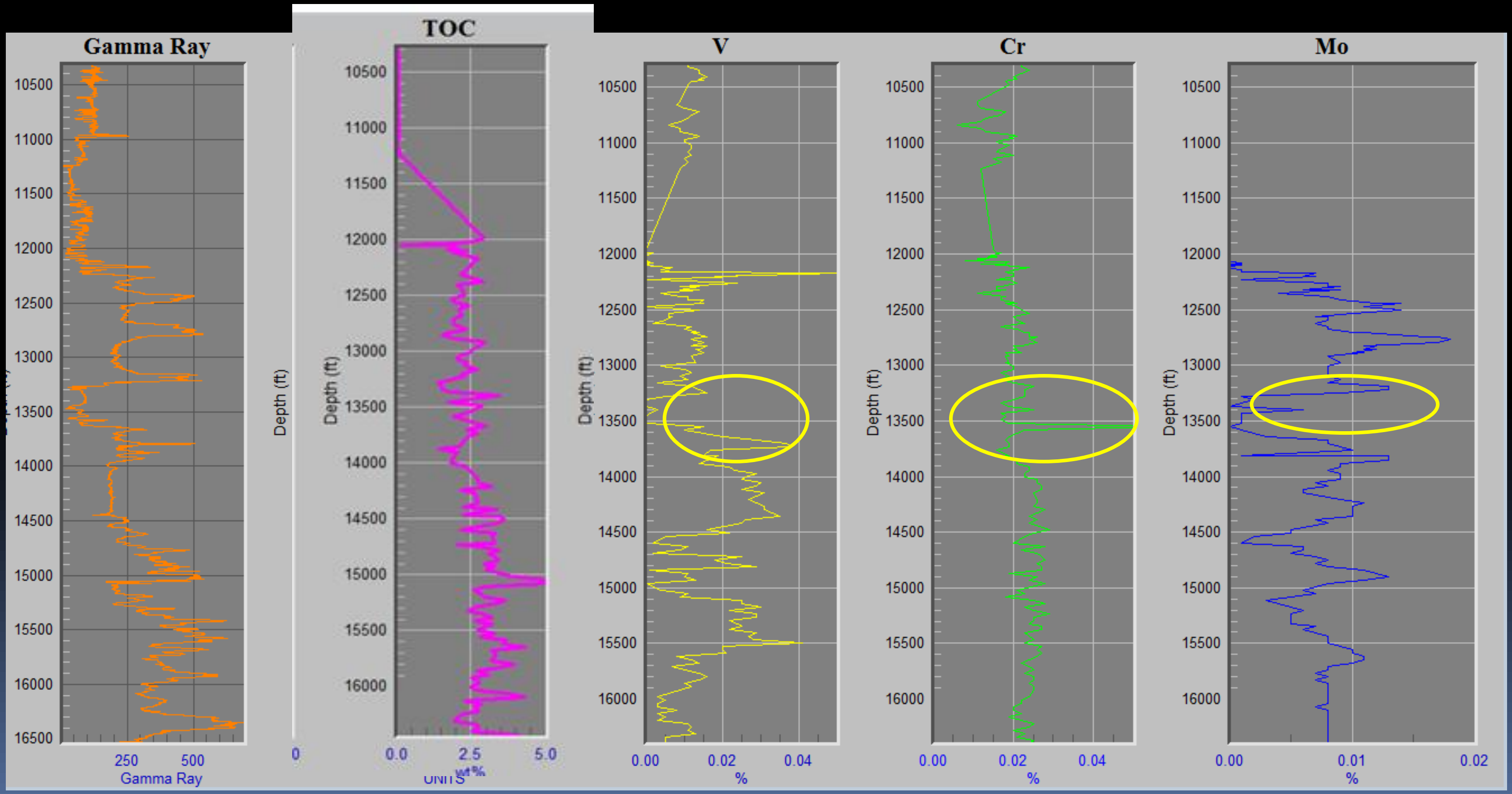
Rock Eval Pyrolysis 13100-13600

The upward trend of the S1/S2 ratio is a good indication of productive hydrocarbons in this interval. Note the TOC peak is slightly higher, around 13,400.

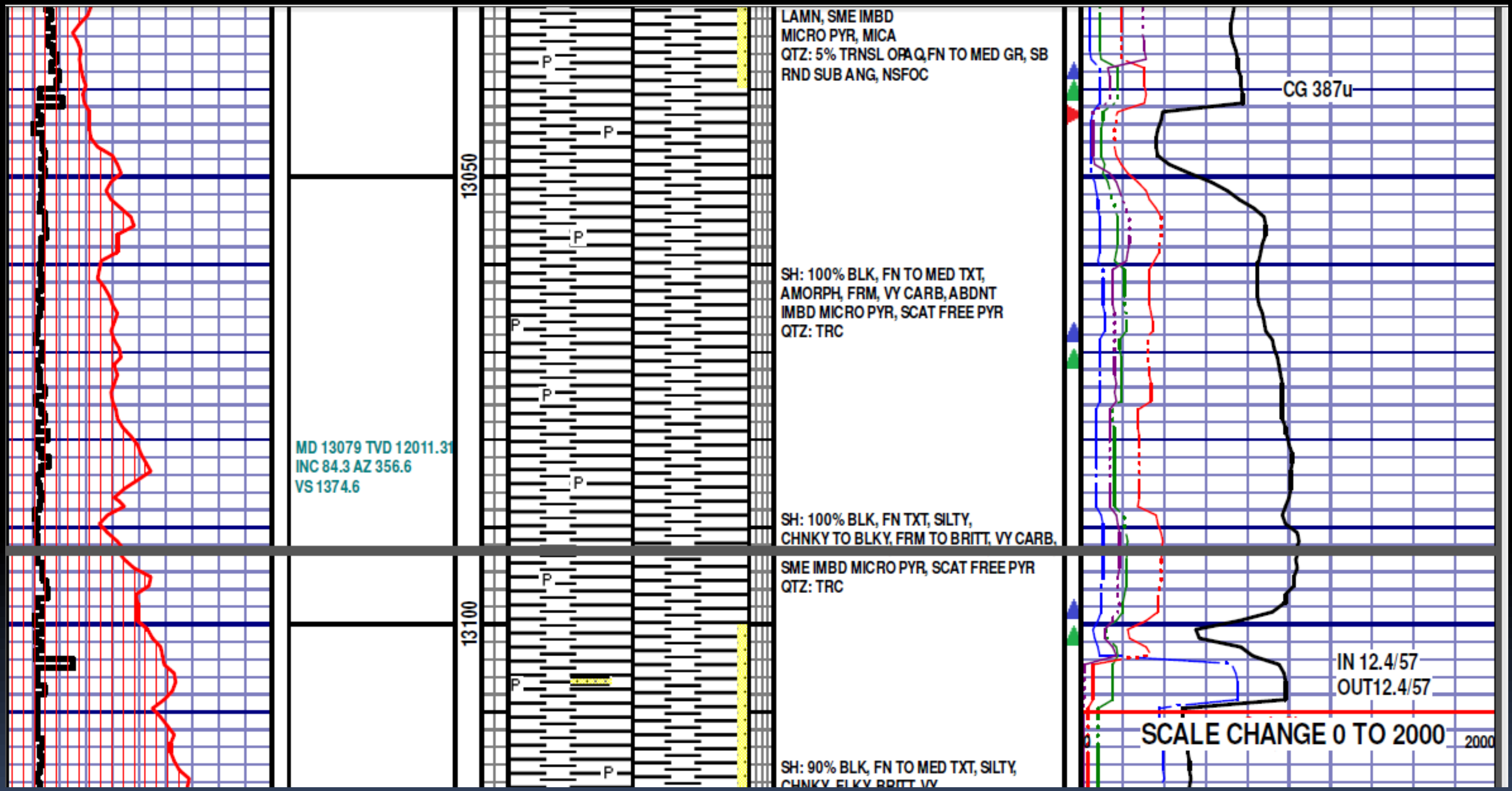


XRF Analysis 13100-13600

Peaks of these elements through this interval indicate a paleo-environment conducive of hydrocarbon generation.

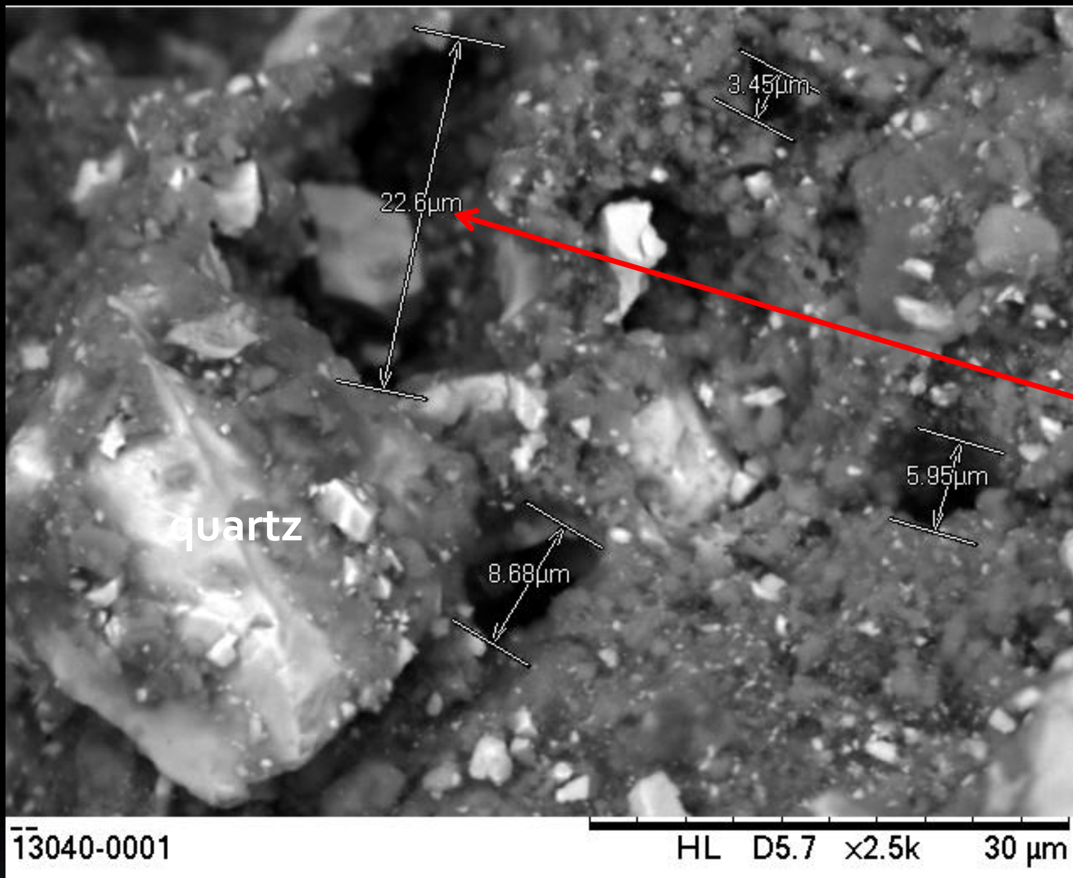


Mudlog Through Top of Case Area



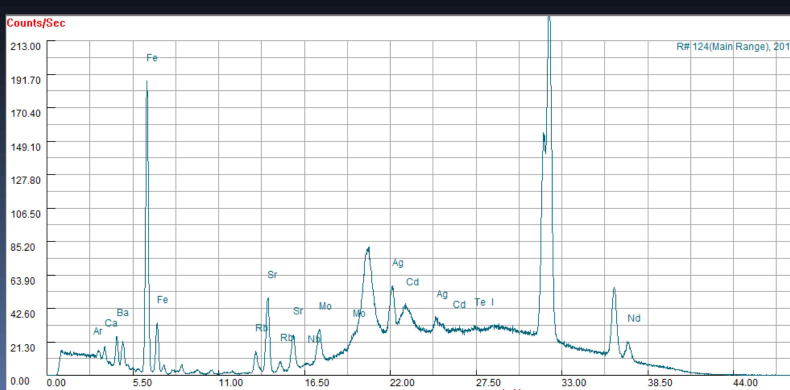
Background gas is lower from previous levels. Quartz is present in the sample along with mica. Pyrite is also visible.

13040

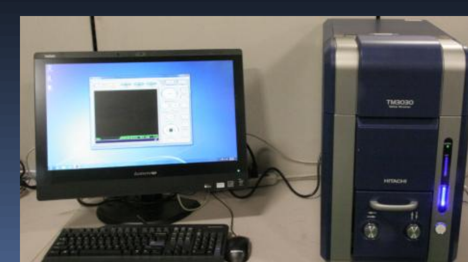


..less than a macropore at 30 micrometers, this large pore is still well within the mesopore range of 1-30.

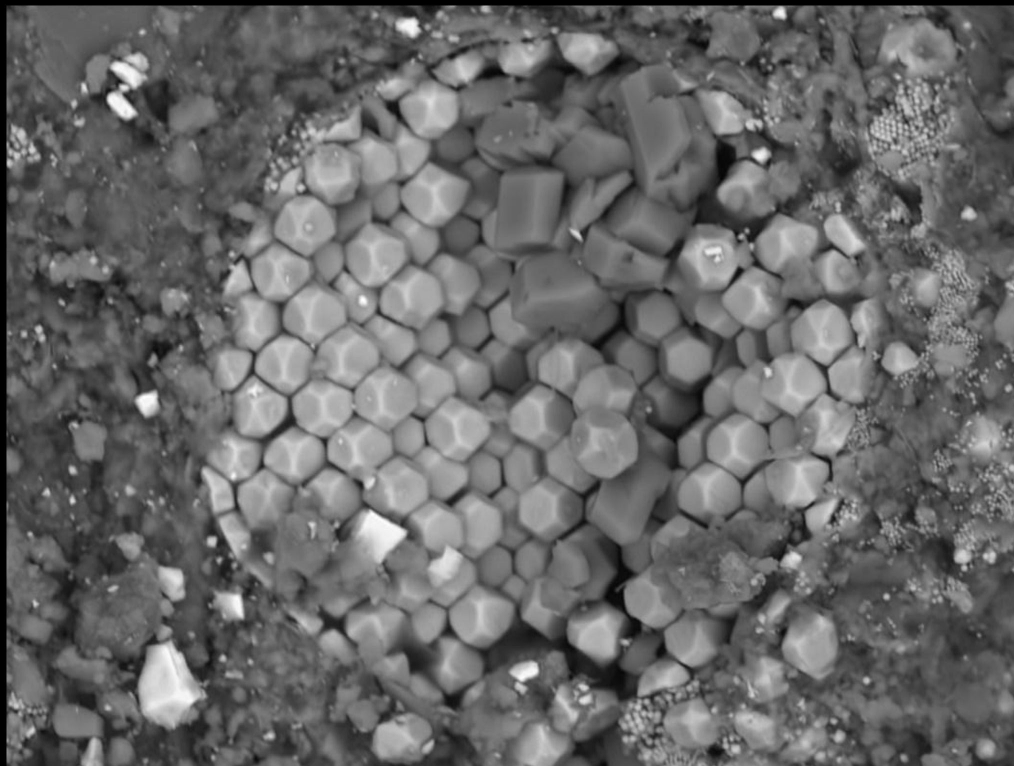
S1 indicates only a slight increase.



Large pores are present with an average size of 10.17 micrometers. Porosity appears very good through this interval.

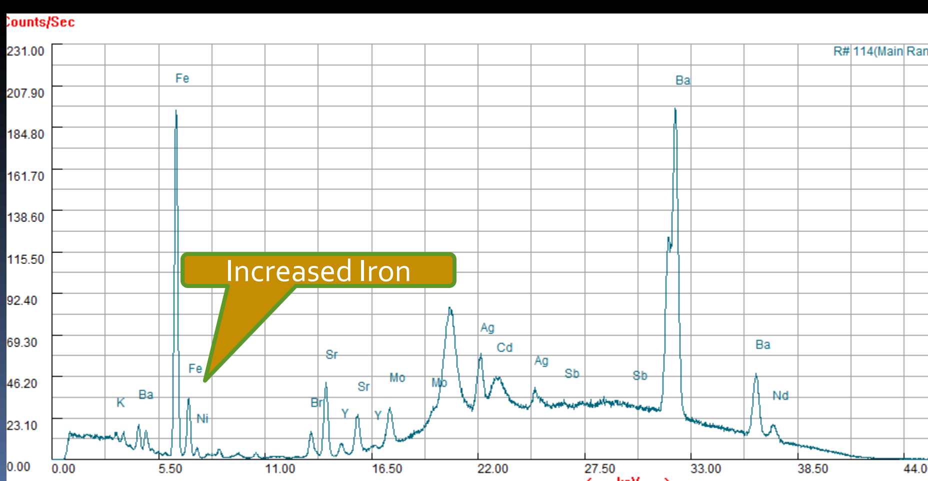


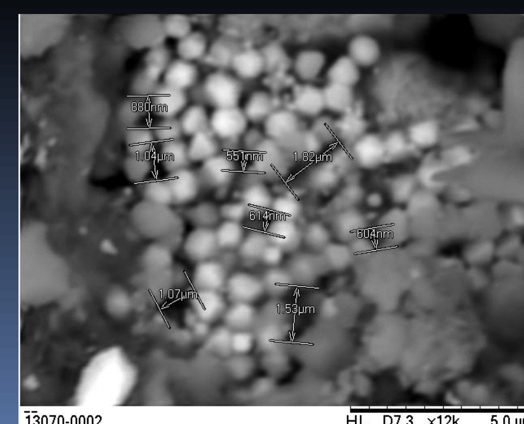
13070



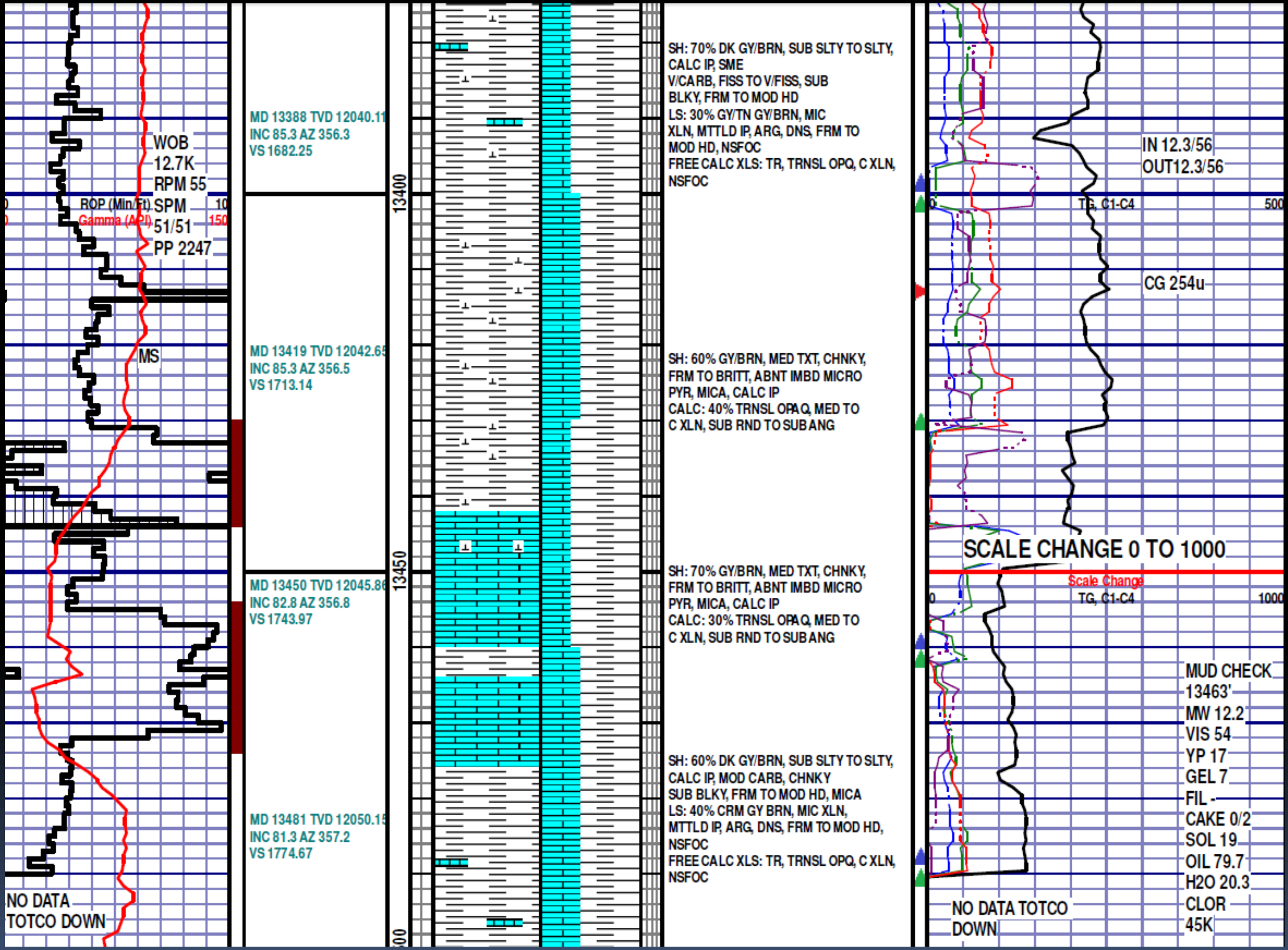
Pyrite Framboids with intraparticle pores

Porosity is low in this section of the case area. Those pores present average .9 micrometers.



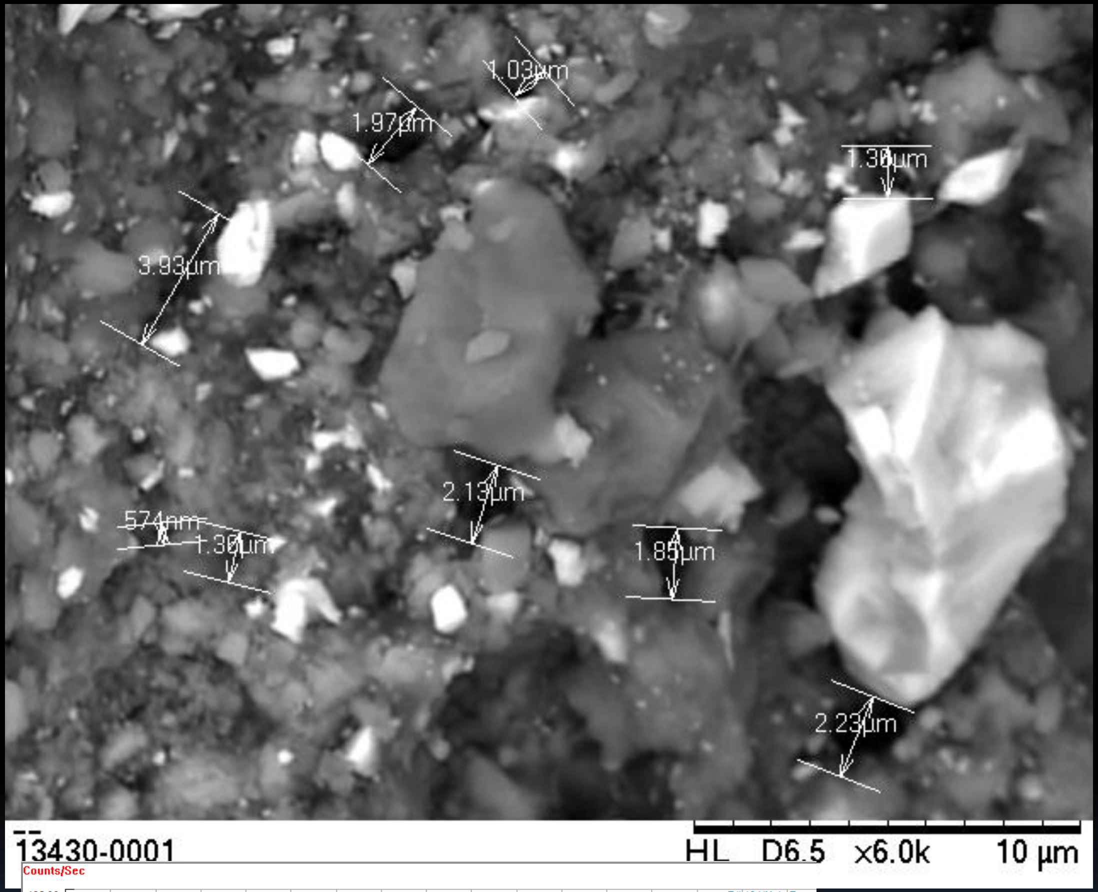


Mudlog for this Zone



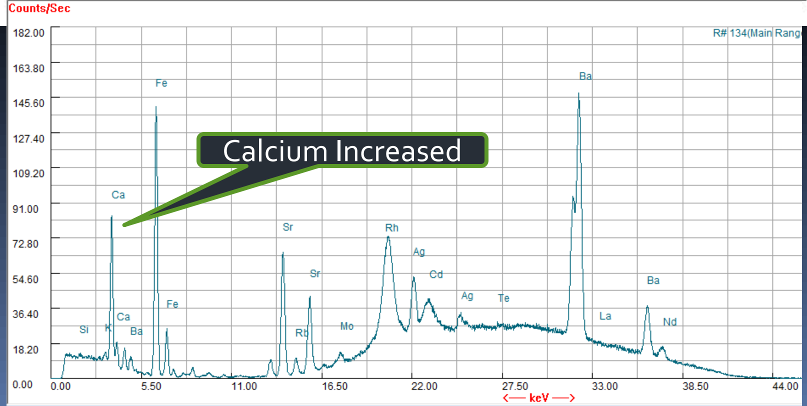
Calcite is in the sample along with limestone.

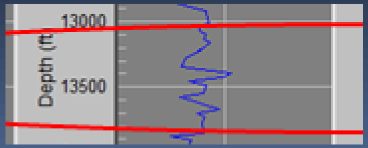
13430



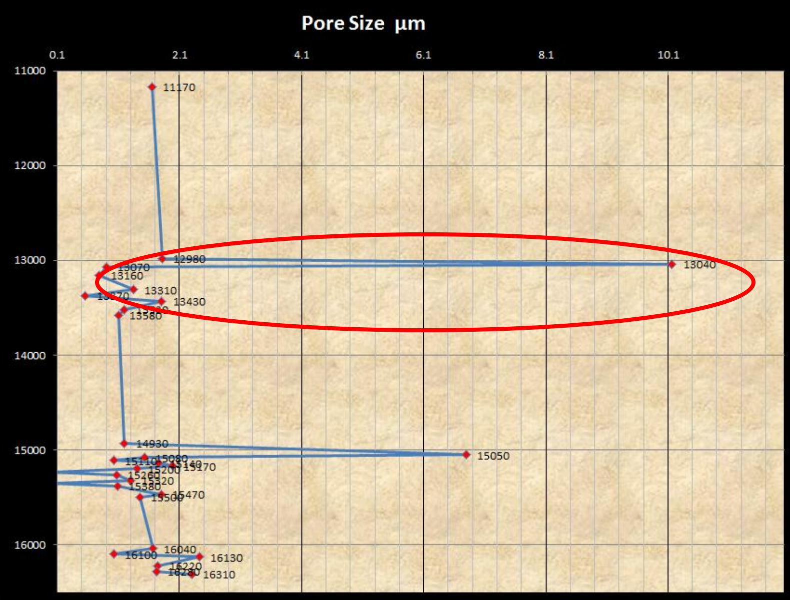
The porosity has increased slightly. The average pore size is 1.81 micrometers.

S1 has increased through this area indicating more free hydrocarbons.



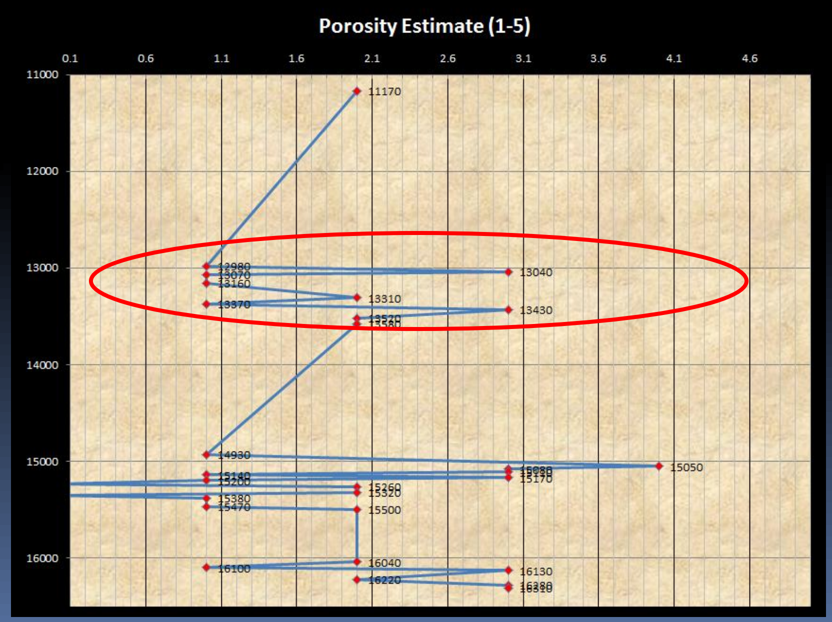


Porosity Analysis 13100-13600



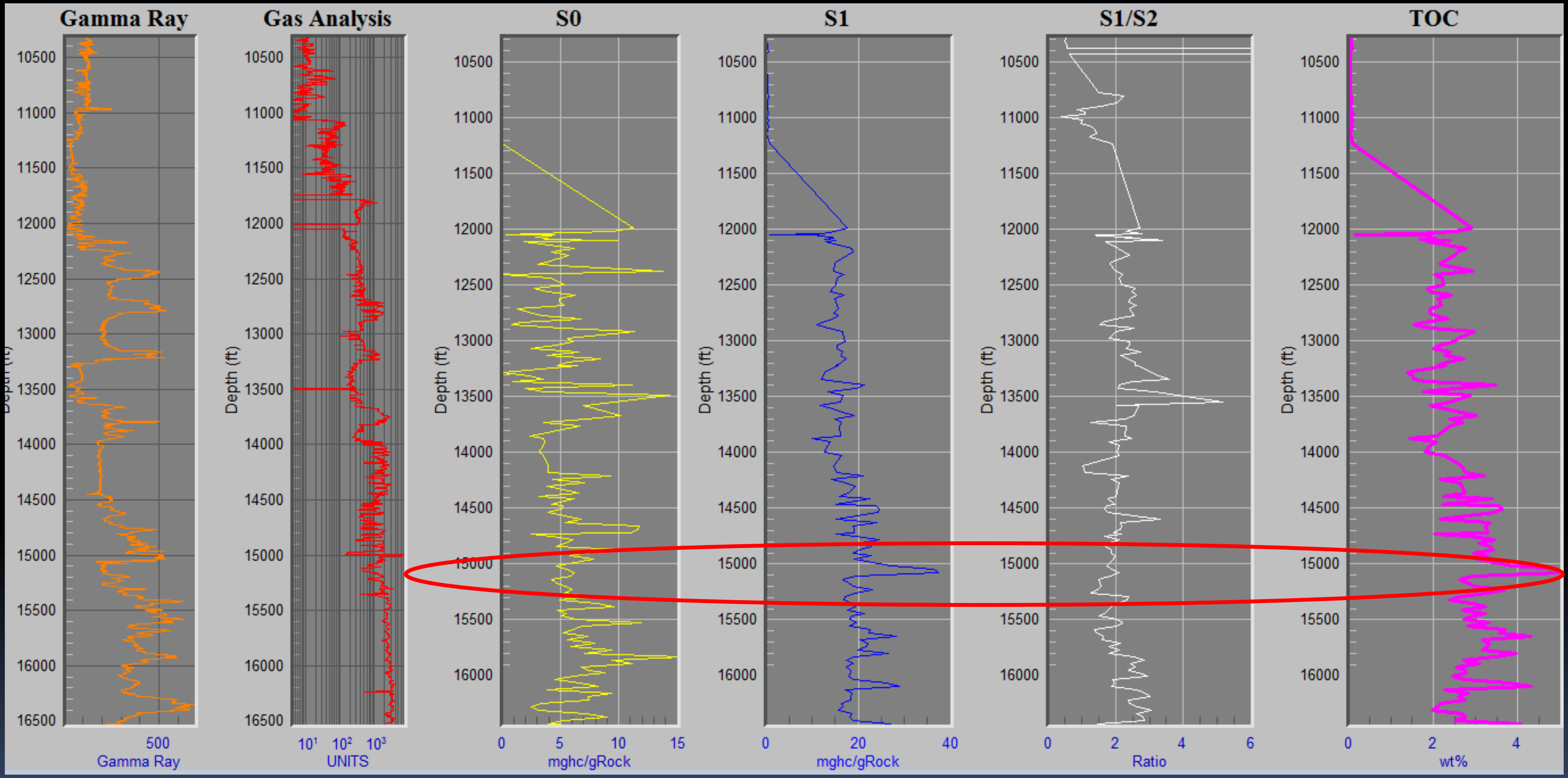
Larger pores were present at 13040 but were less frequent.

Although the pore sizes were small around 13430, they were numerous



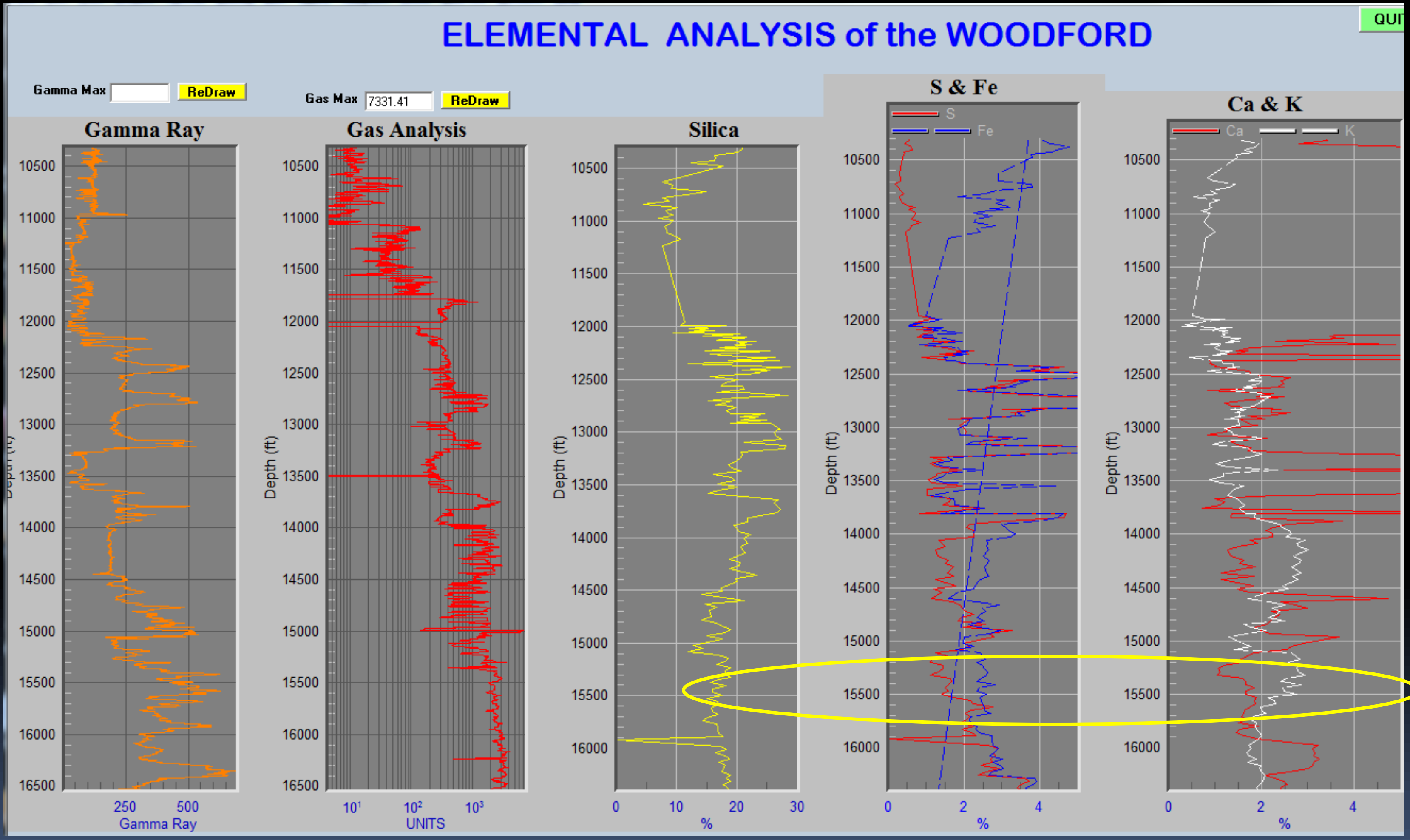
Case B: 14,900 – 15,300

Rock Eval Pyrolysis 14900-15300



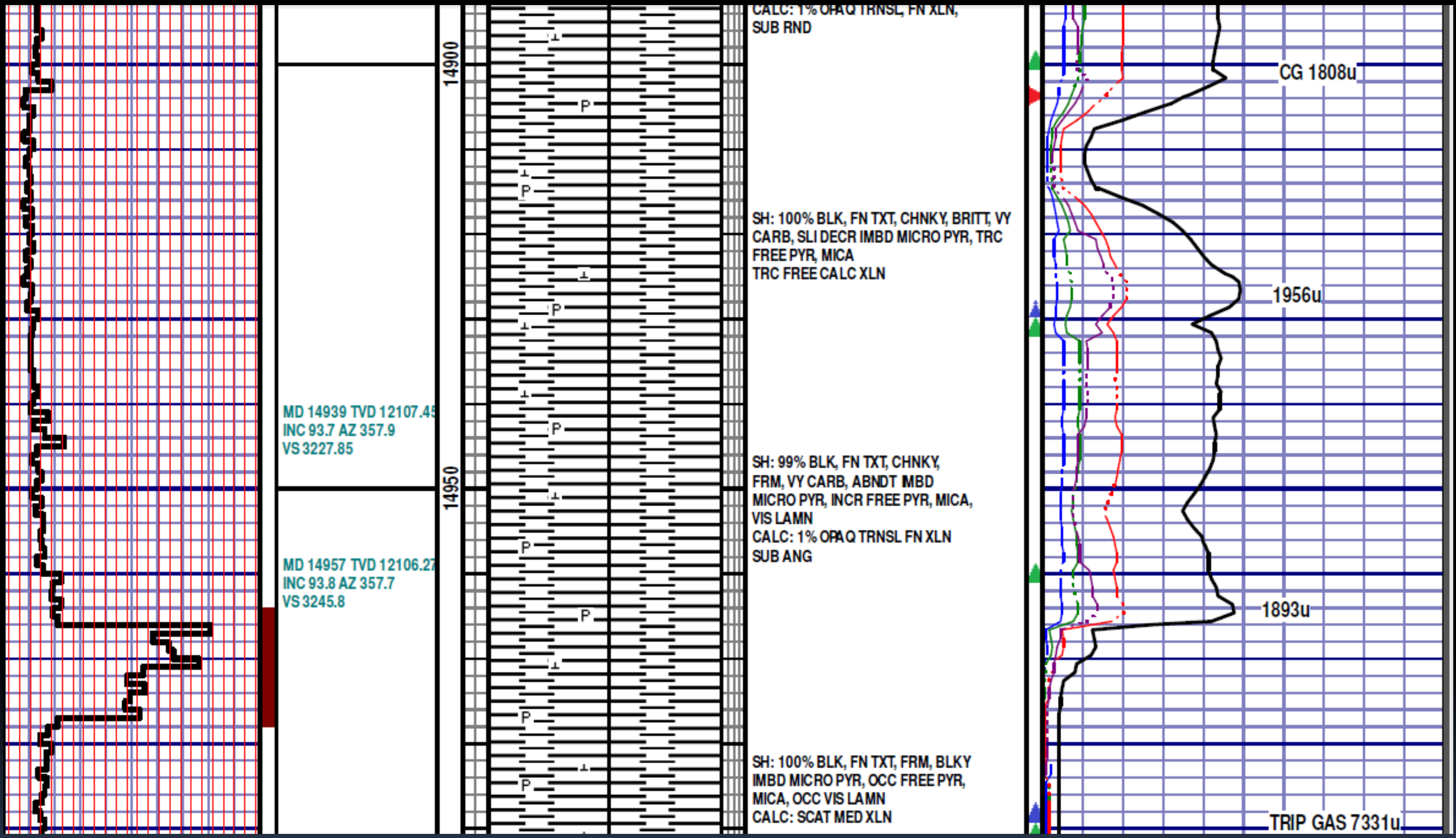
TOC is high, S1/S2 not impressive, S1 is high. The total gas is high and increasing.

XRF Analysis 14900-15300



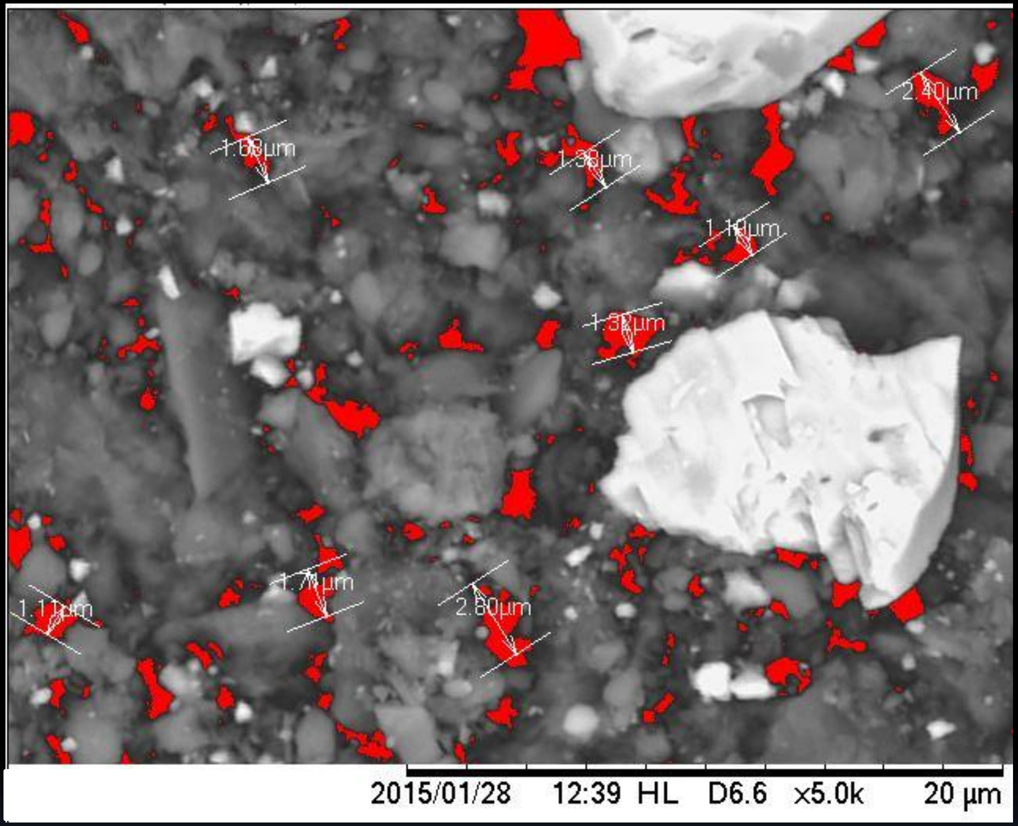
Silica is fairly strong for fracking, Fe & S are good indicating some pyrite, Ca & K are in a good range.

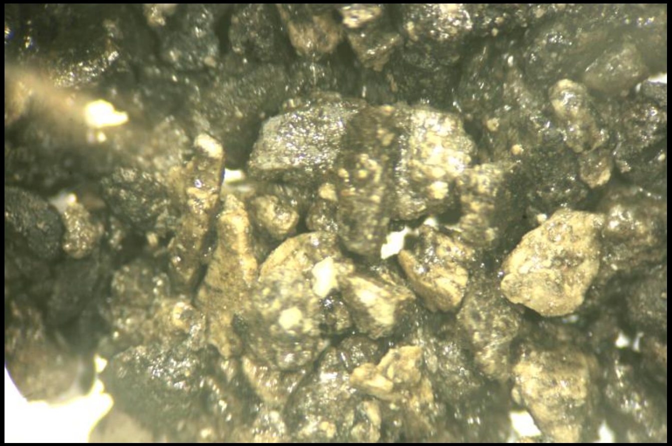
Top of Case 2 - 14900 +



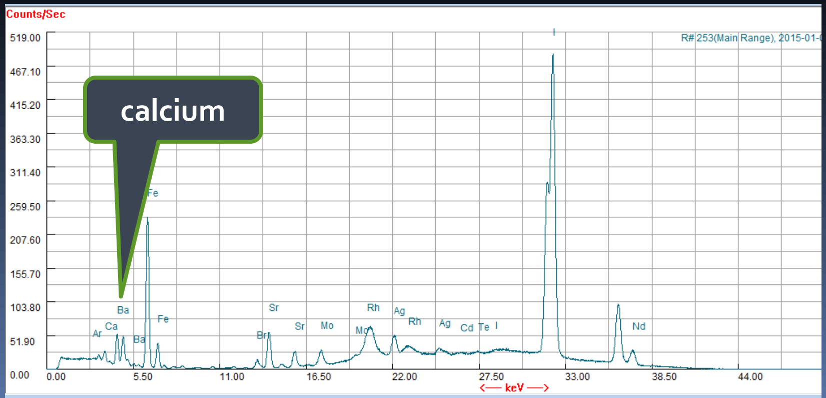
Background gas is slightly lower. Calcite is present in the cuttings.

14930

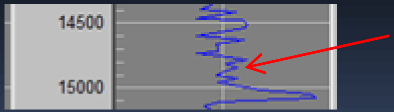




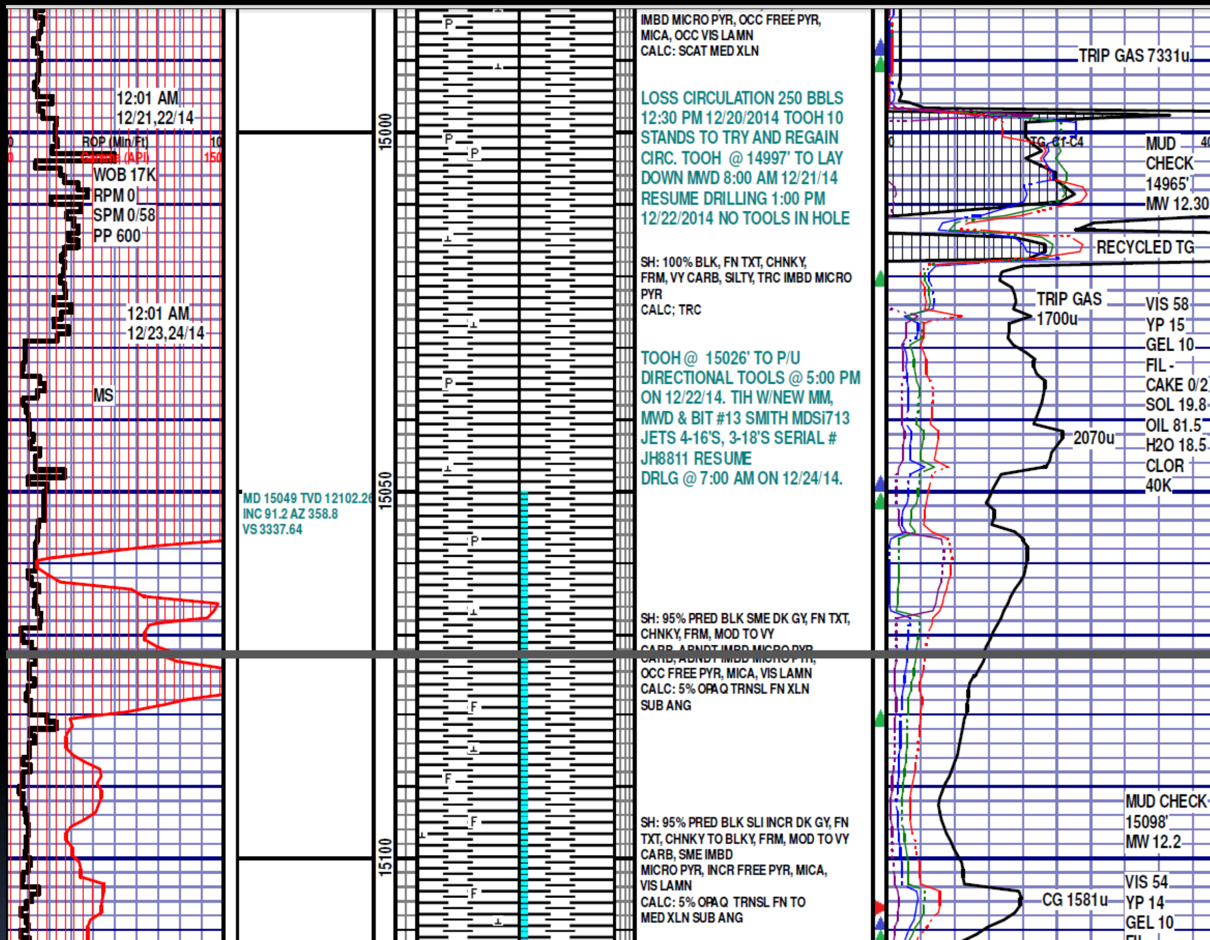
Small pores are visible with an average size of 1.9 micrometers.



S1 is slightly elevated

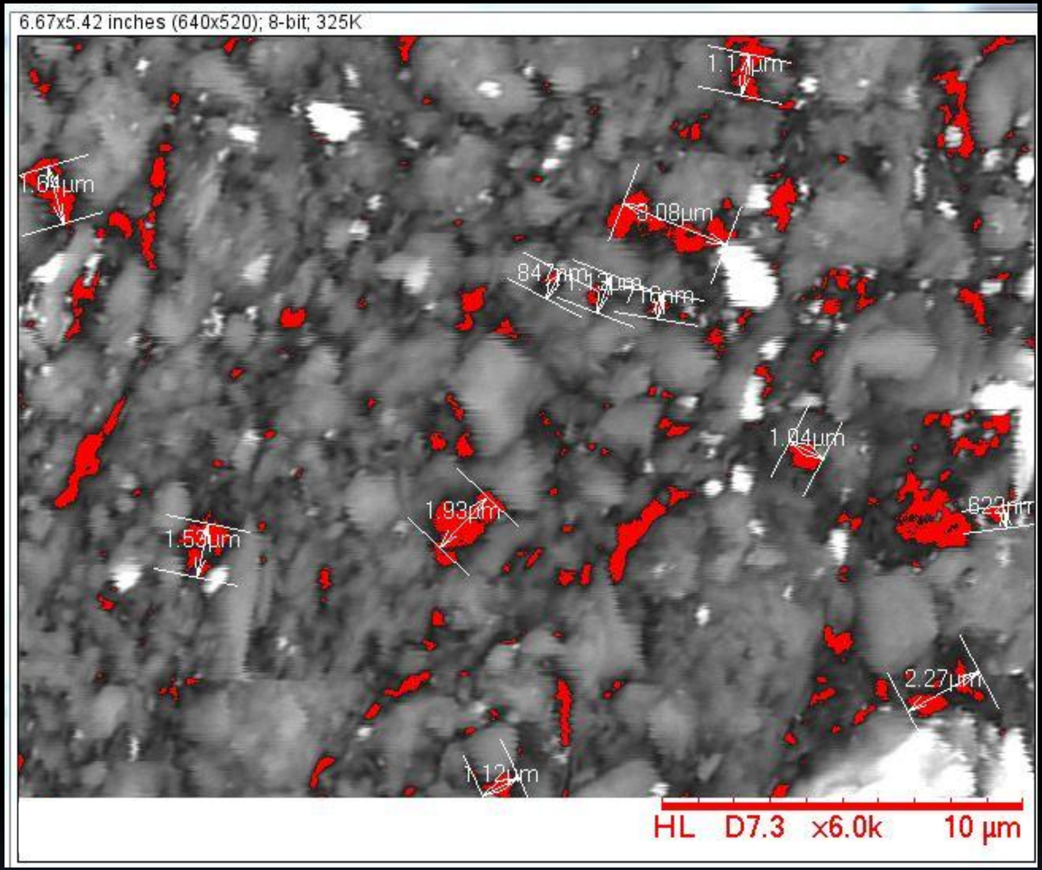


Area of 15050

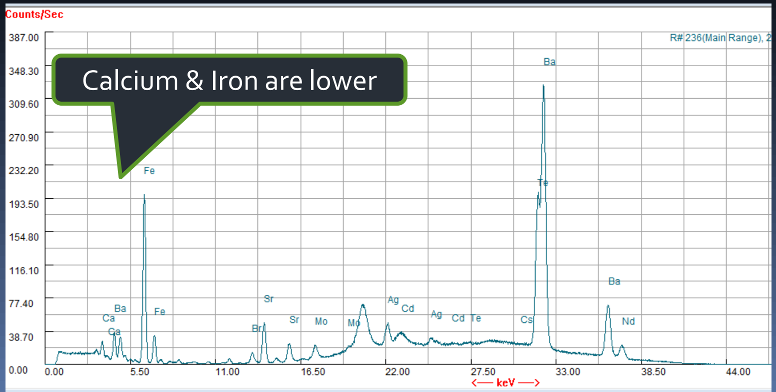


Gases have increased through this zone. Calcite, mica and pyrite are still visible in the sample.

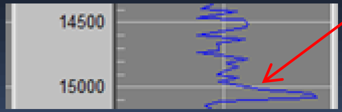
15050



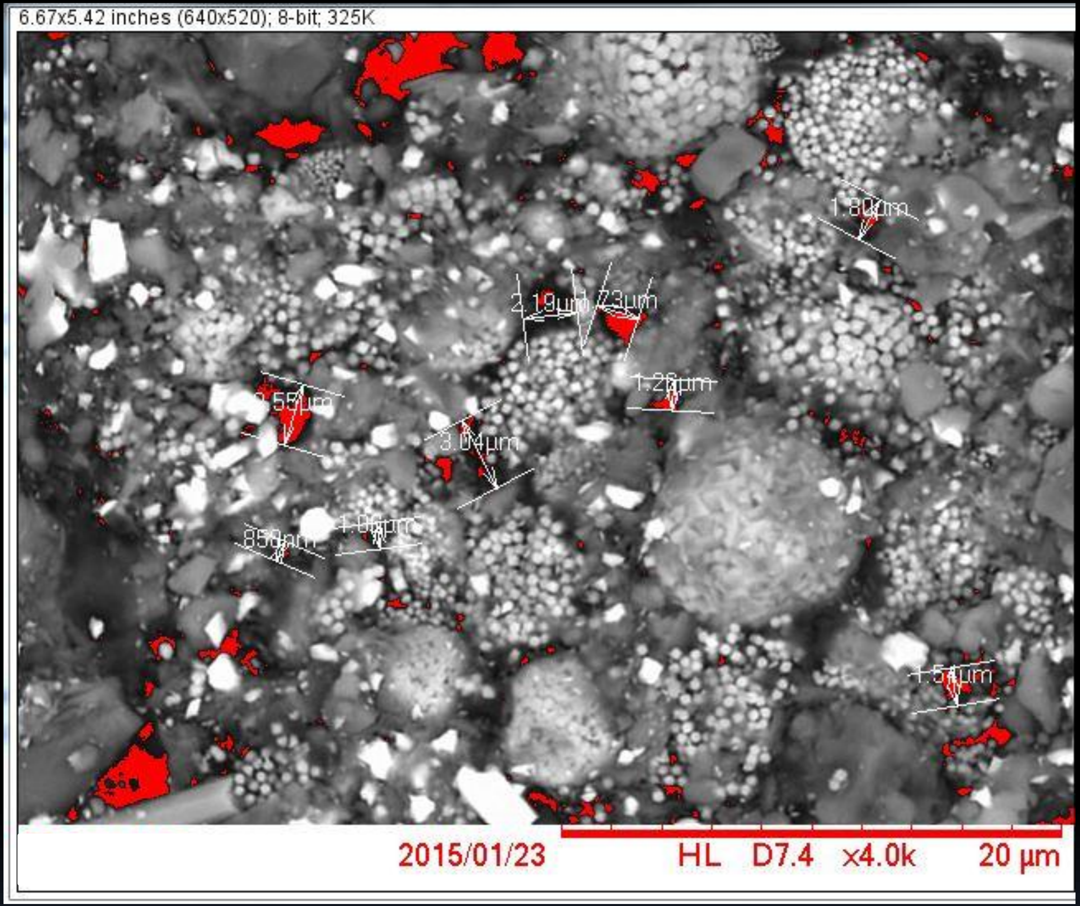
Porosity is increasing with an average size of 1.53 micrometers.



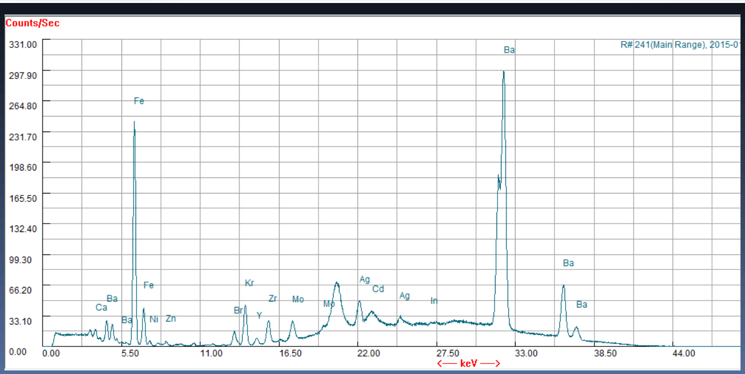
S1 is rising.



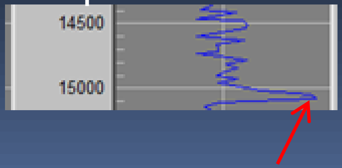
15080



A few pores are visible with an average size of 1.53 micrometers. The abundance of pyrite framboids has increased.

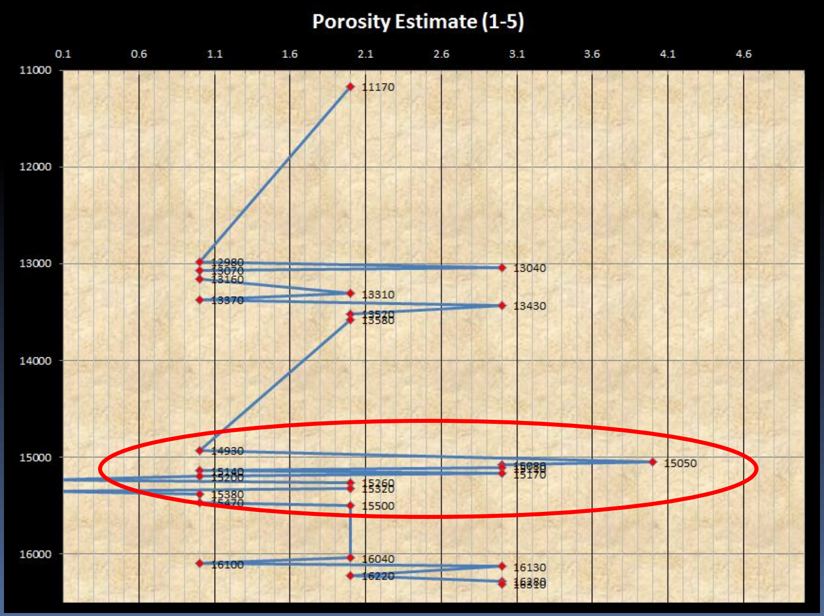


S1 peaks in this area.



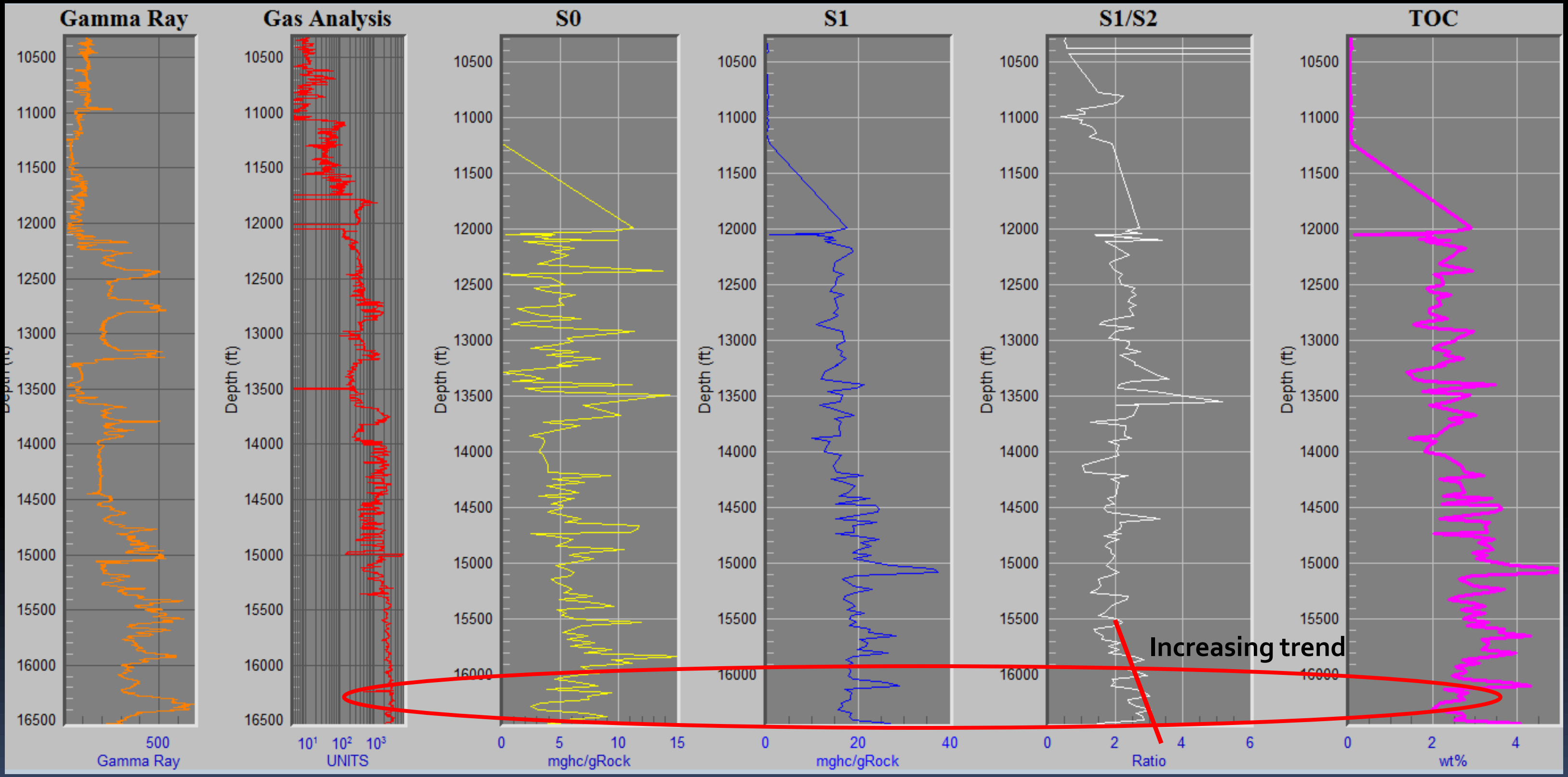
Porosity Analysis 14900-15300

This zone represents the best porosity seen throughout the lateral so far.



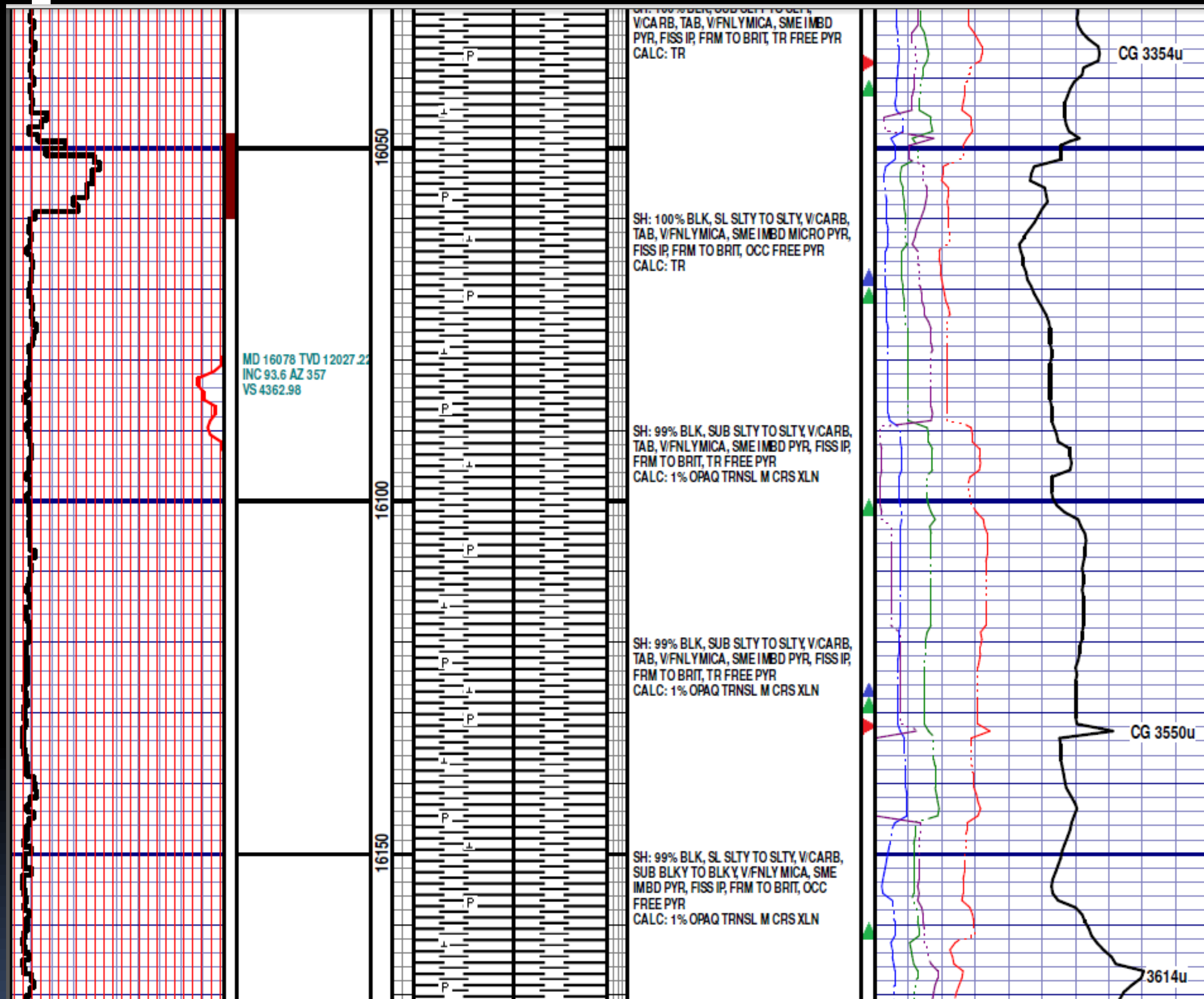
Case C: 16,000-17,000

Rock Eval Pyrolysis 16000-16500



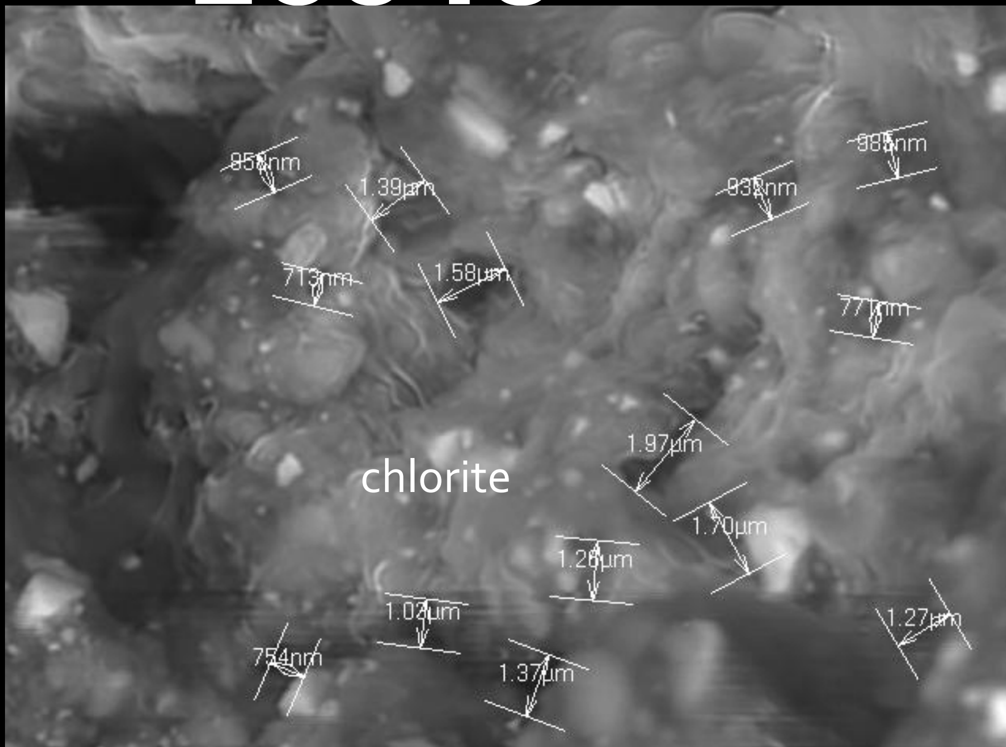
The increasing trend of S1/S2 is a good indicator of a productive zone.

Upper Zone of the Case Area

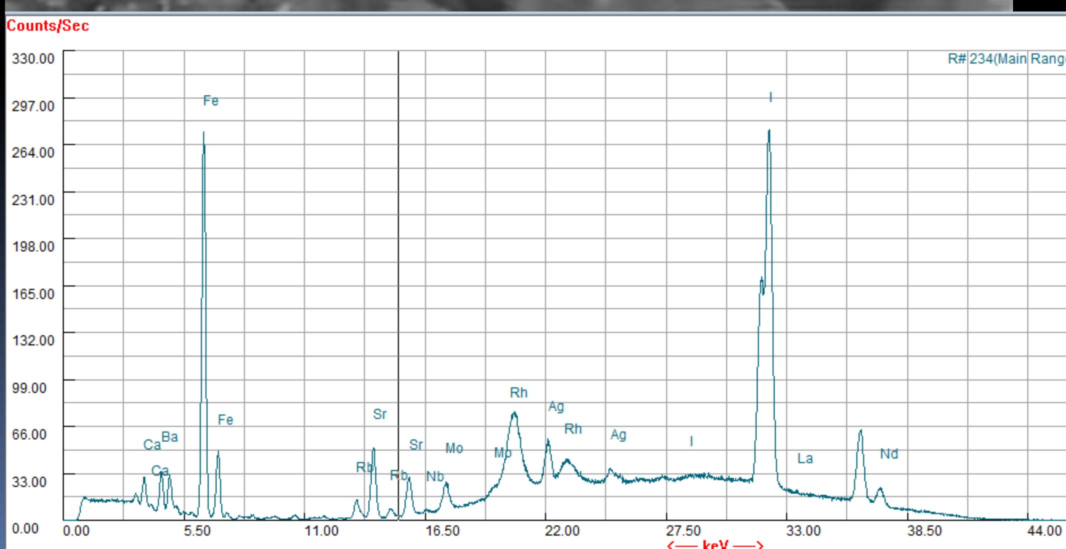


Gases remain high and constant. Calcite is present along with pyrite and quartz.

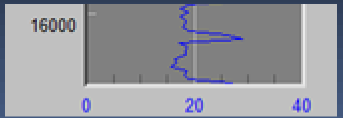
16040



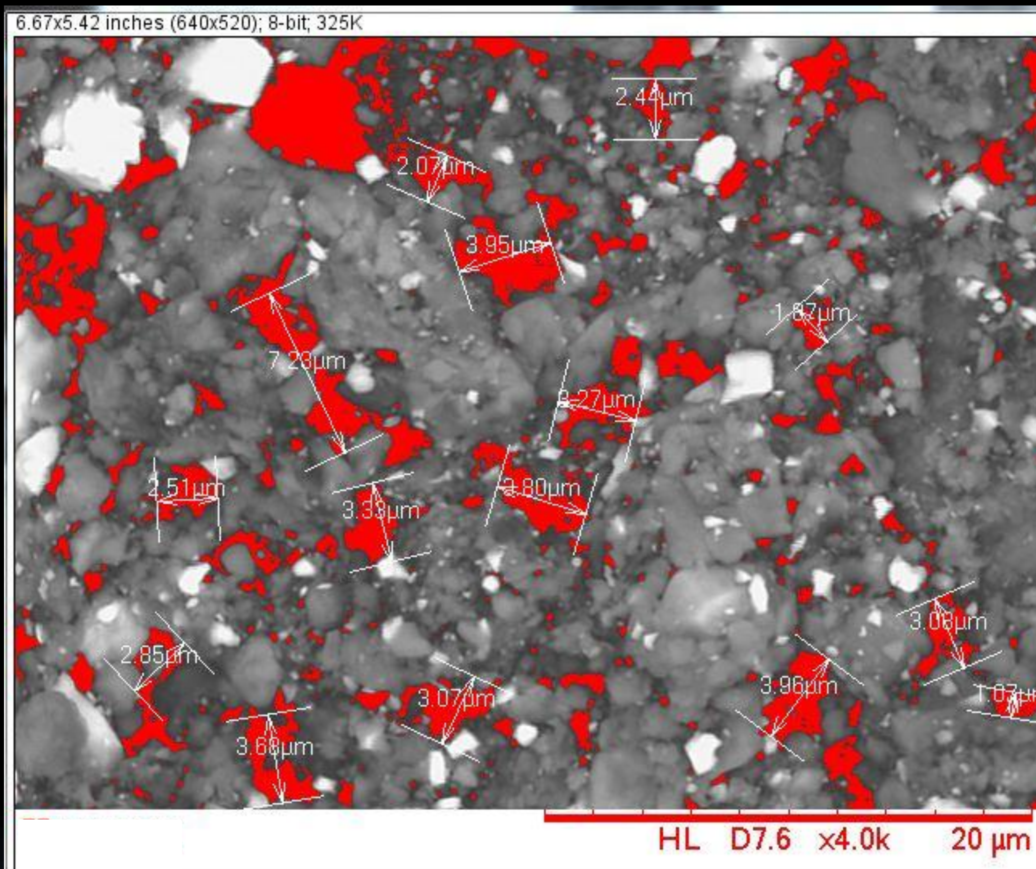
Increasing numbers of pores in many sizes. The average size seen is 1.67 micrometers. The visible porosity is moderate.



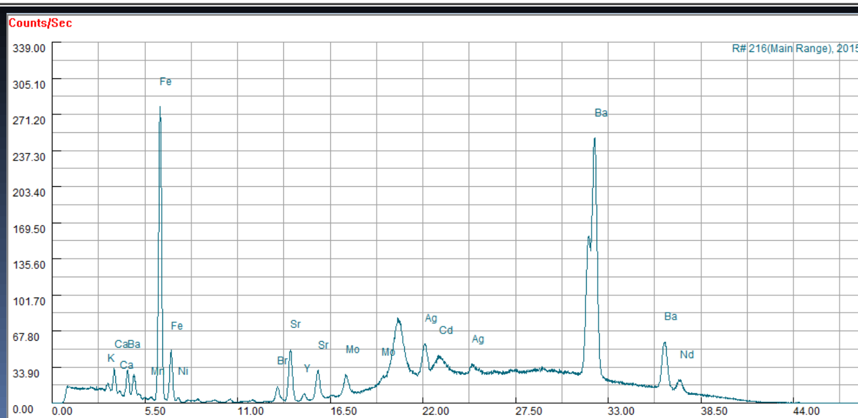
S1 low



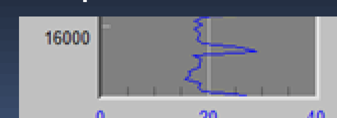
16130



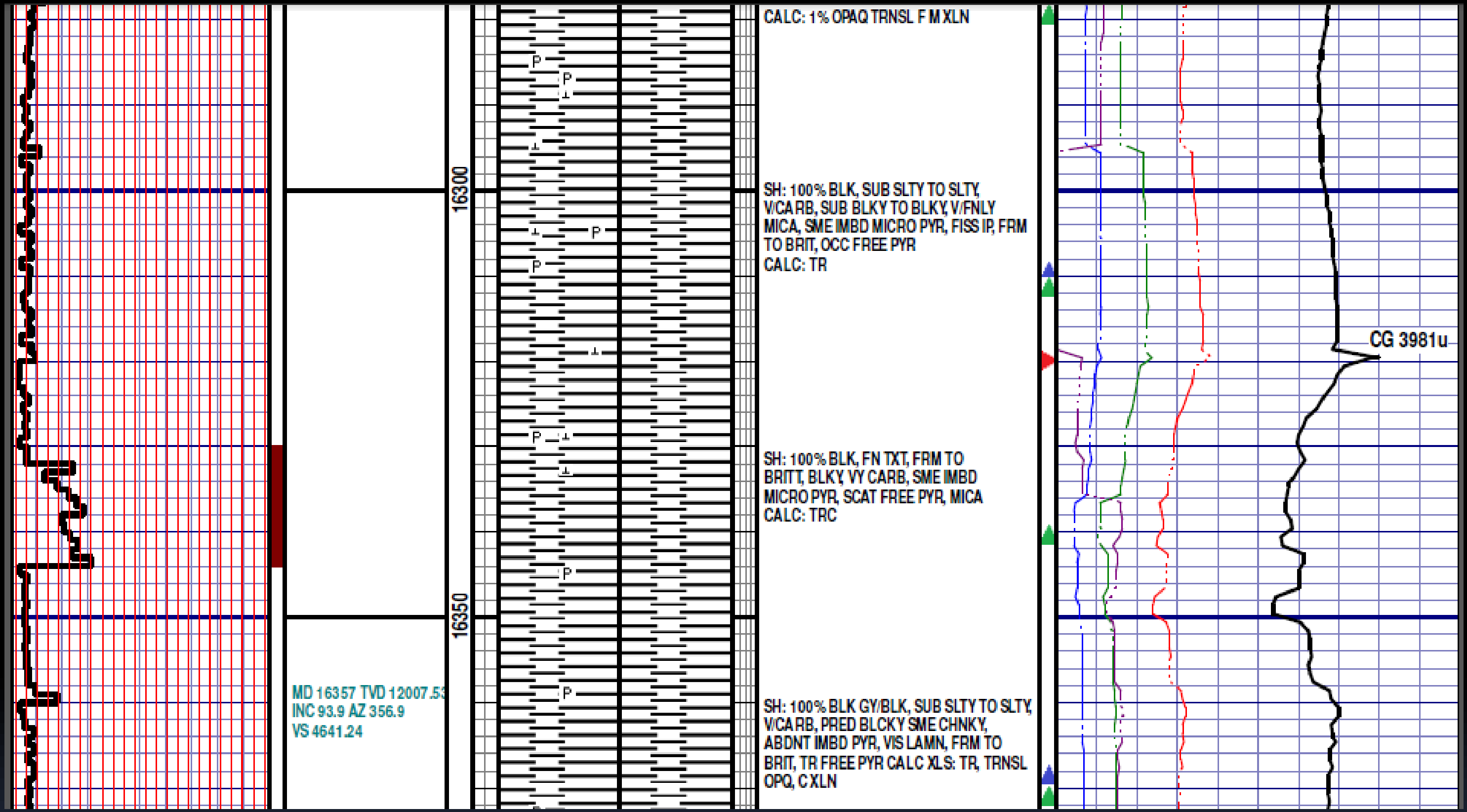
There are an increasing number of large pores with an average size of 2.43 micrometers. Porosity appears very good.



S1 peaks in this area.

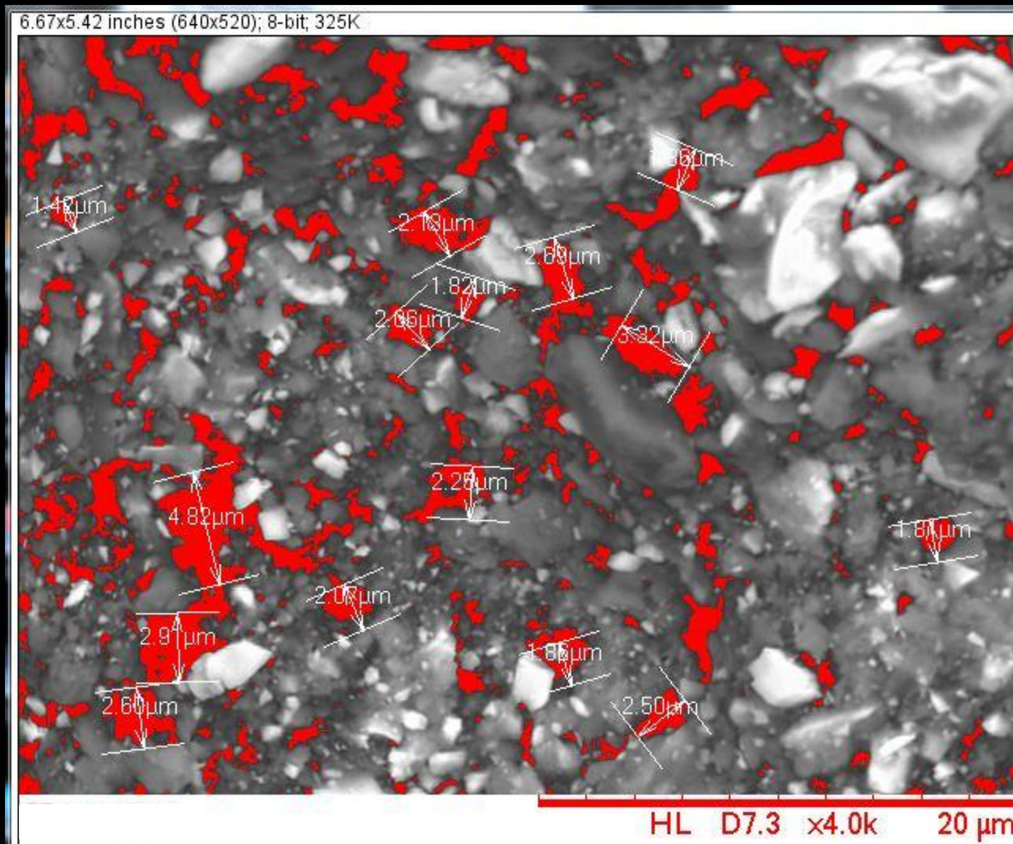


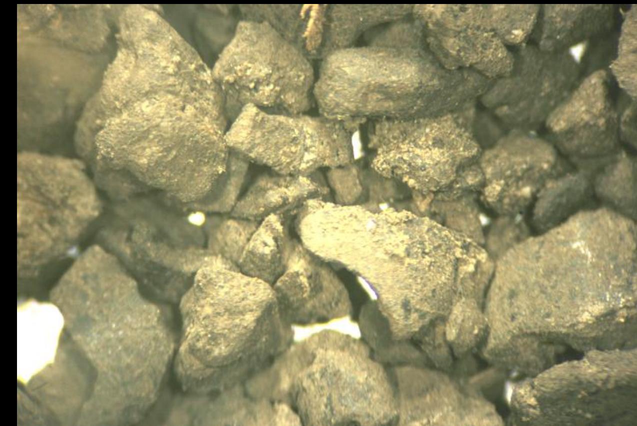
16310 Area



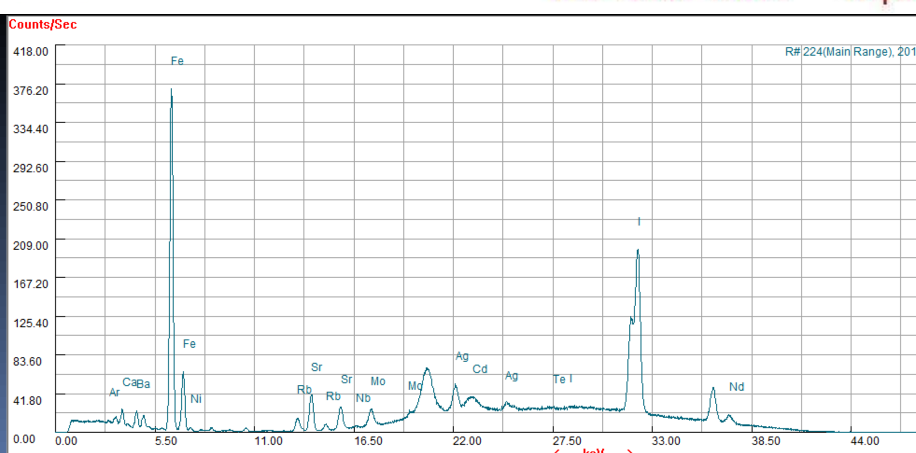
Mudlog appears unchanged through this zone.
Gasses are holding at high levels.

16310

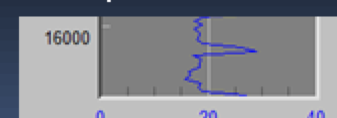




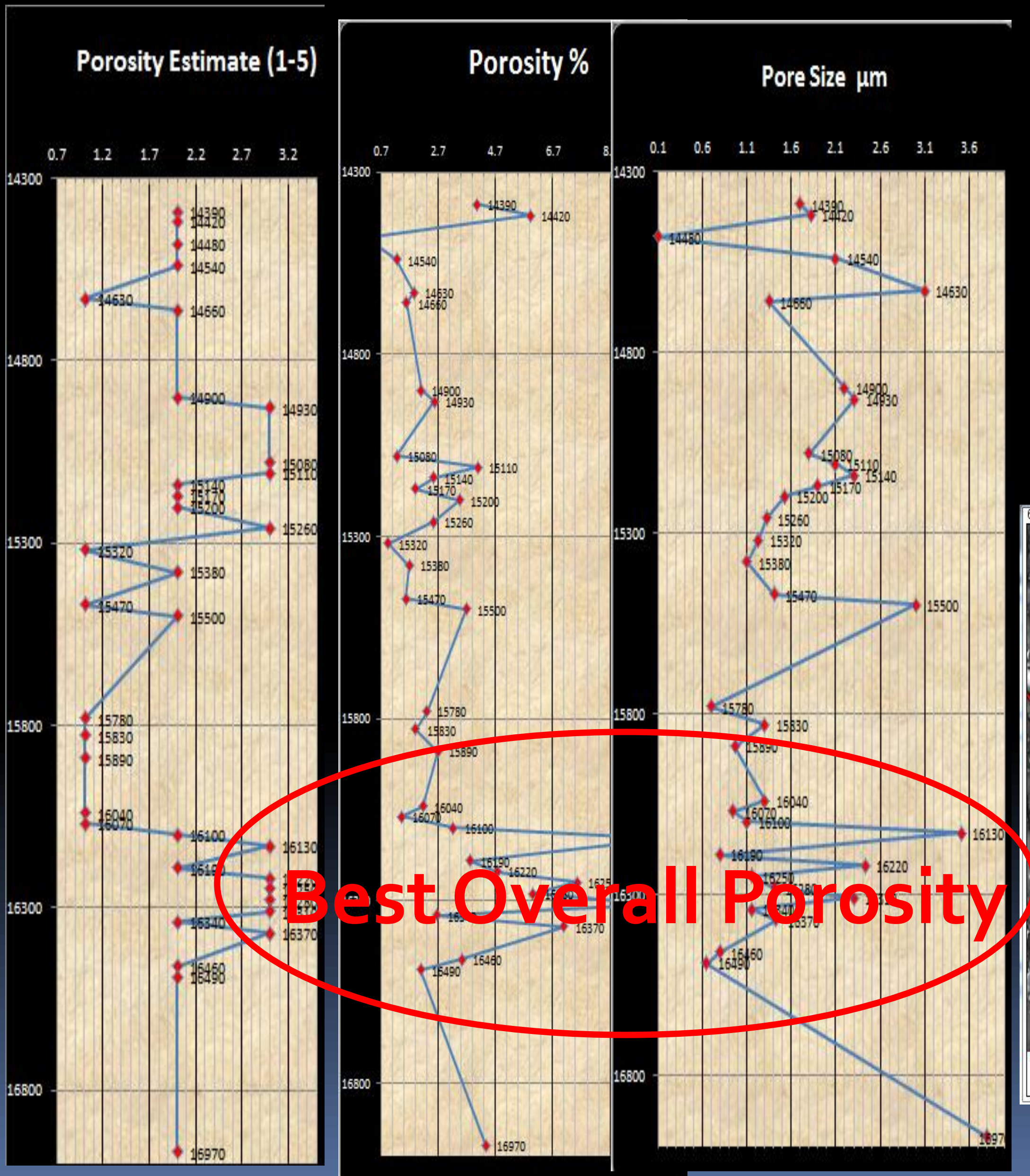
Large pores were very numerous even at low power on the SEM. The average size is 2.3 micrometers. The overall porosity is very good.

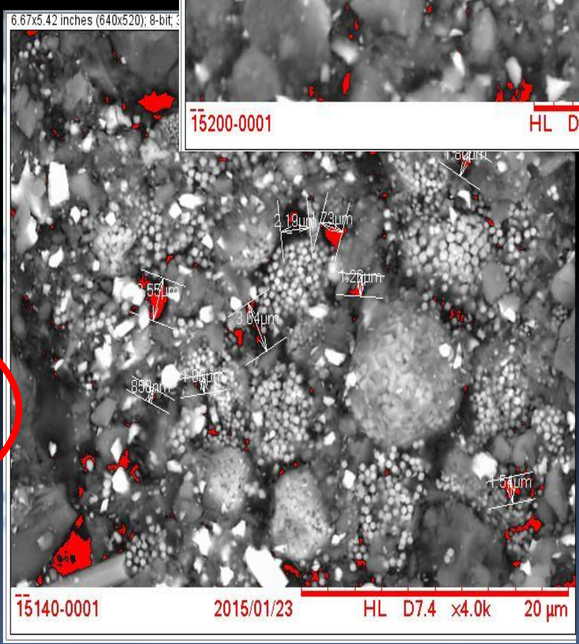


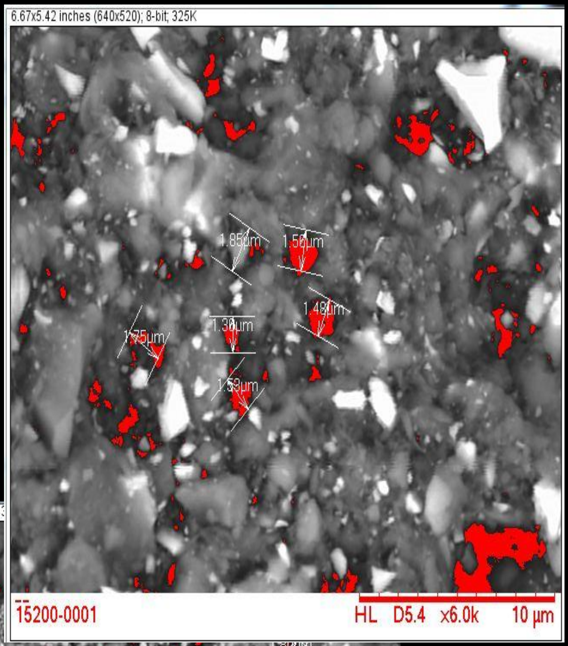
S1 is peaked here.



Overall SEM Porosity Analysis

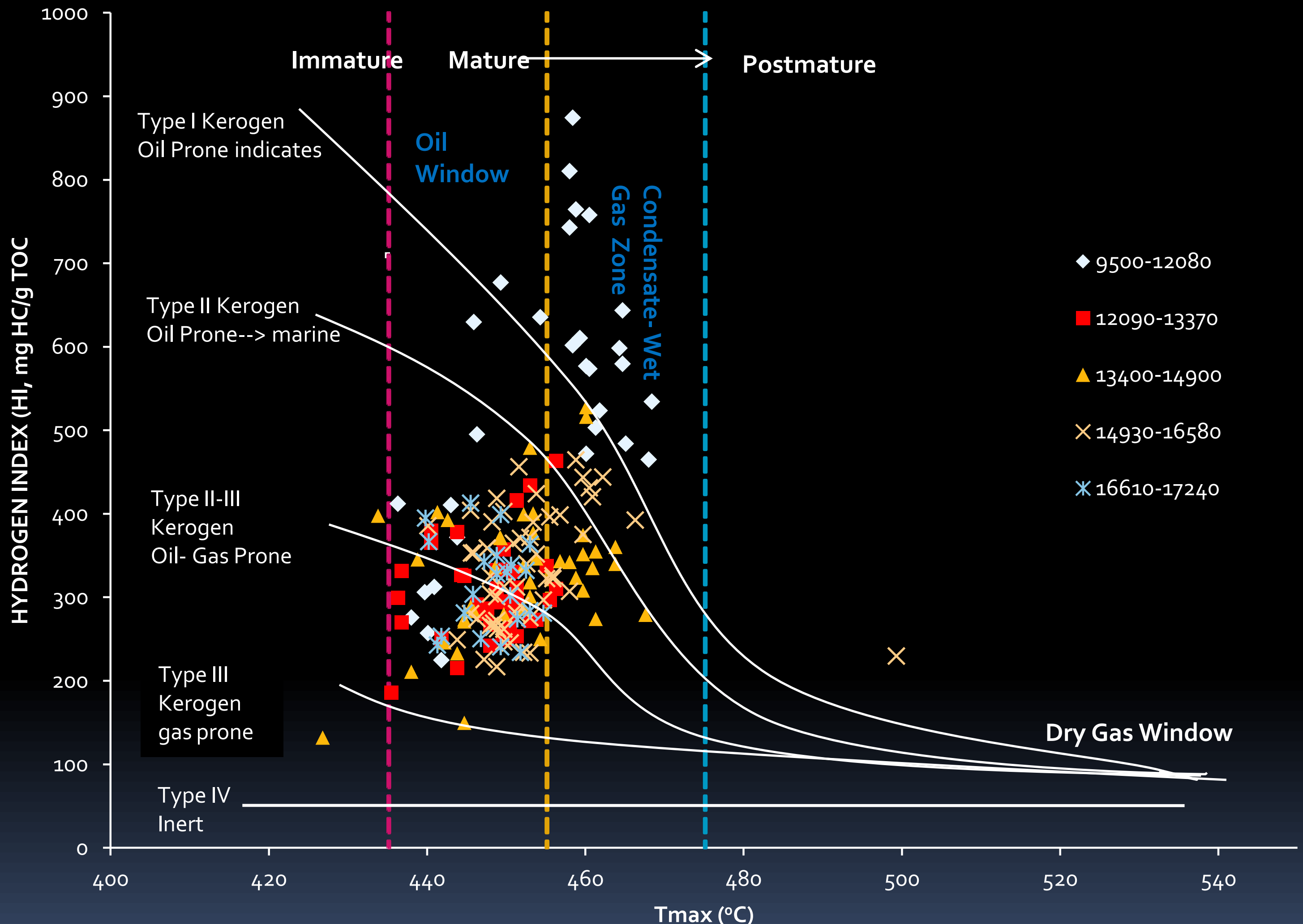






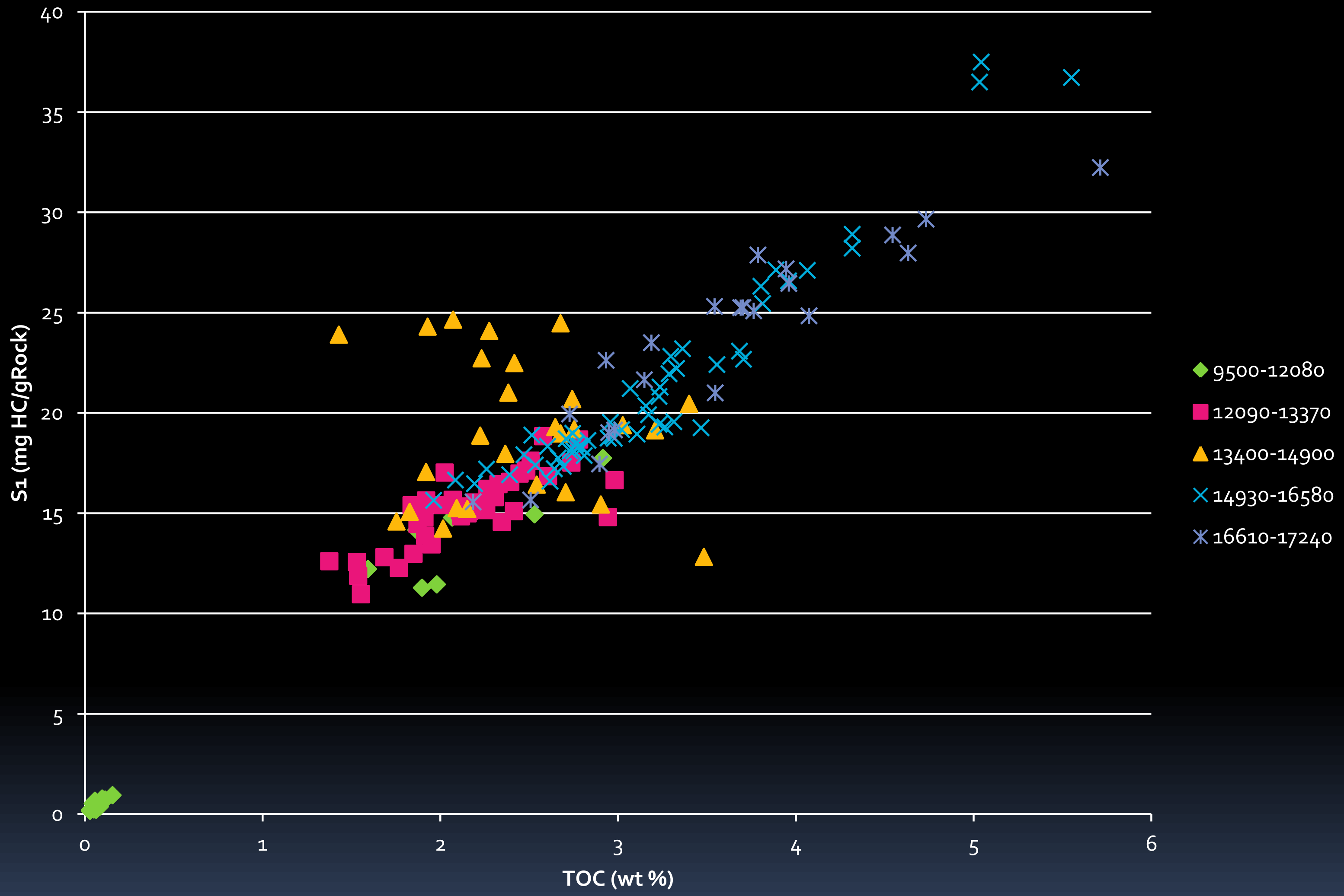
Rock Pyrolysis Results

Kerogen Type



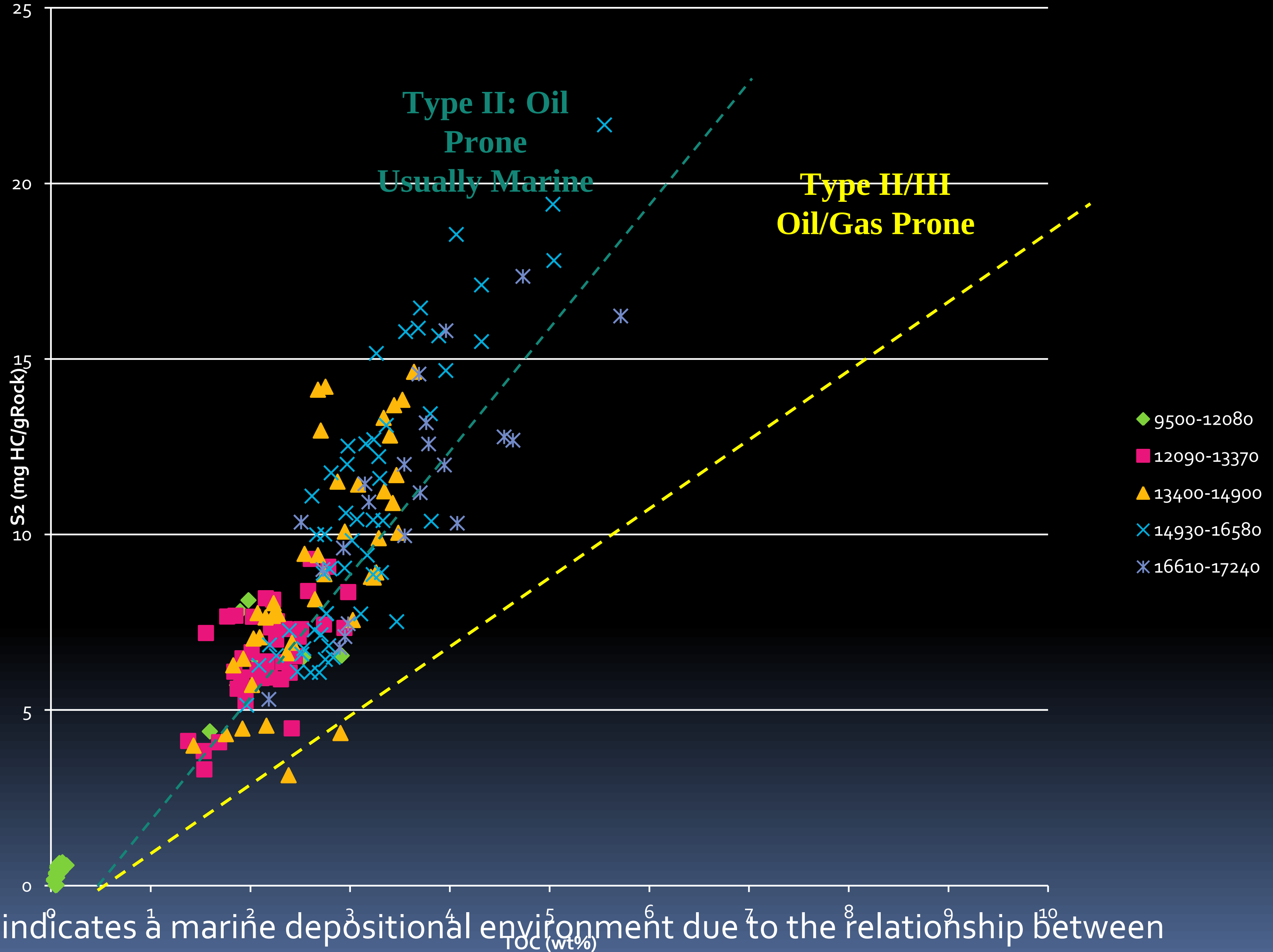
Location of the most mature and highest possible productivity are defined. The type of possible production is also identified. Note: HI is a measure of hydrogen richness given by HI=(S2/TOC)*100

TOC vs S1



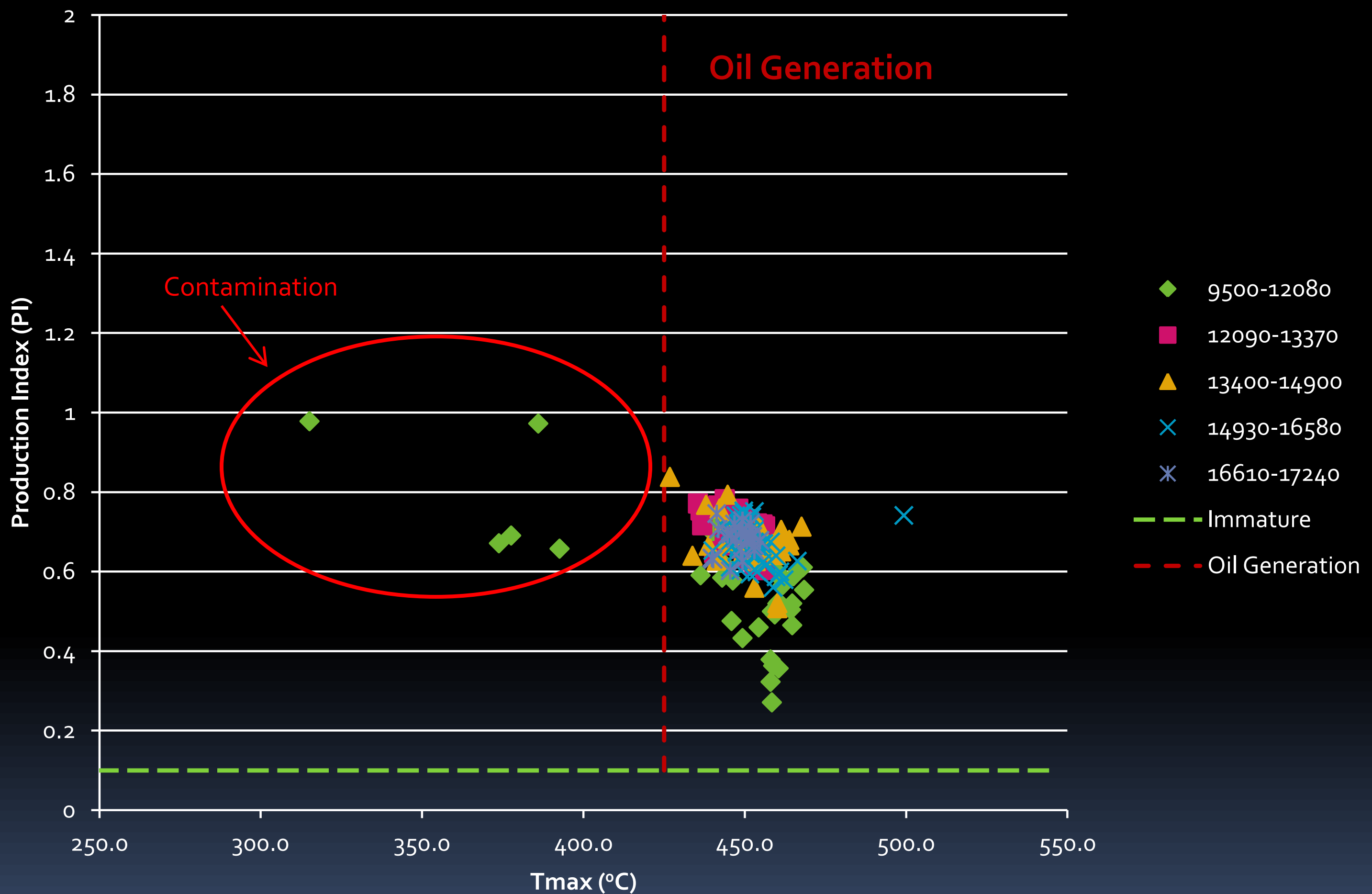
Plotting TOC vs S1 in a horizontal well, a linear trend is expected in the data. Had this been a vertical well, the data would look much different.

TOC vs S2



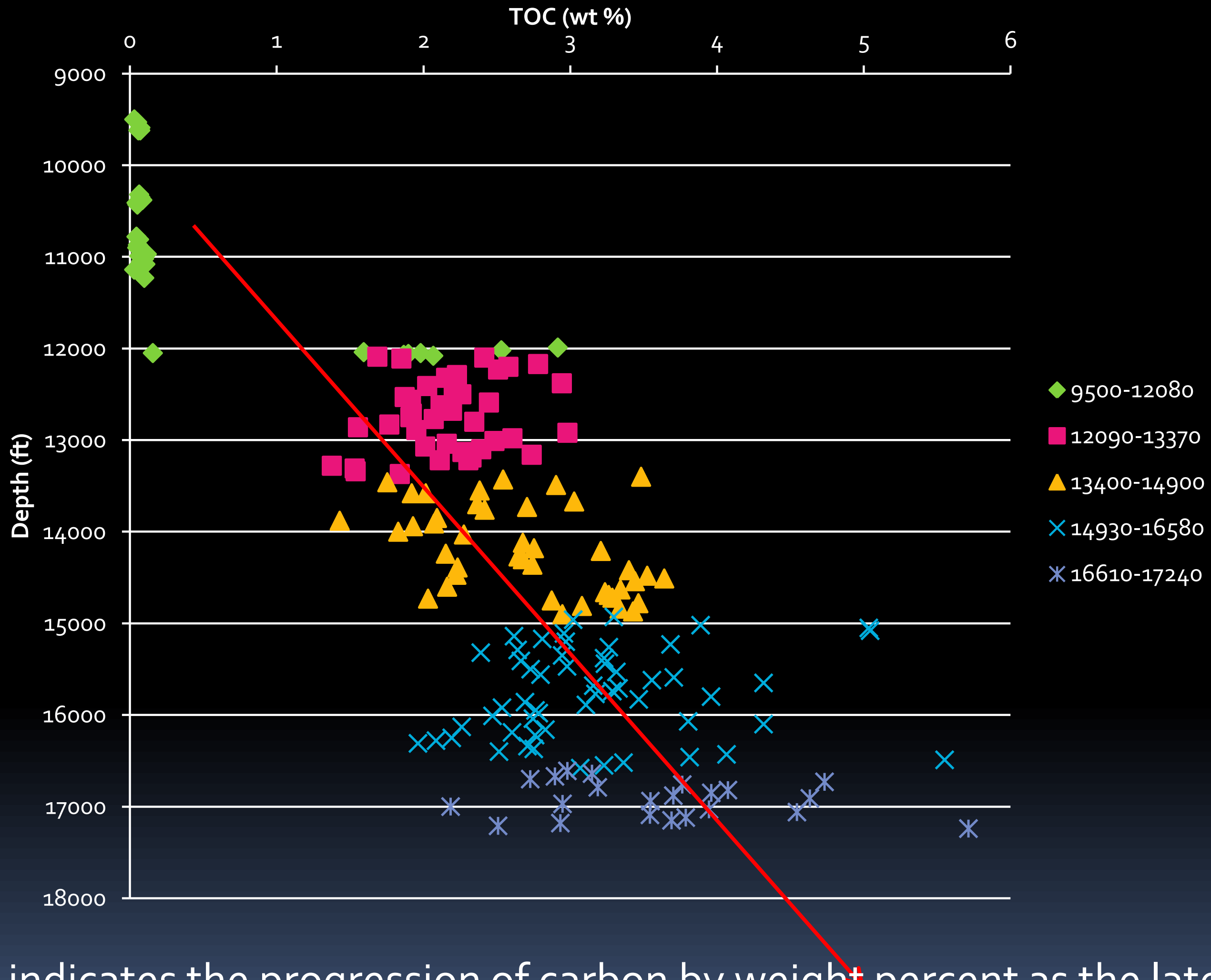
This indicates a marine depositional environment due to the relationship between the oil prone type II kerogen to the gas prone type III kerogen.

TMax vs PI



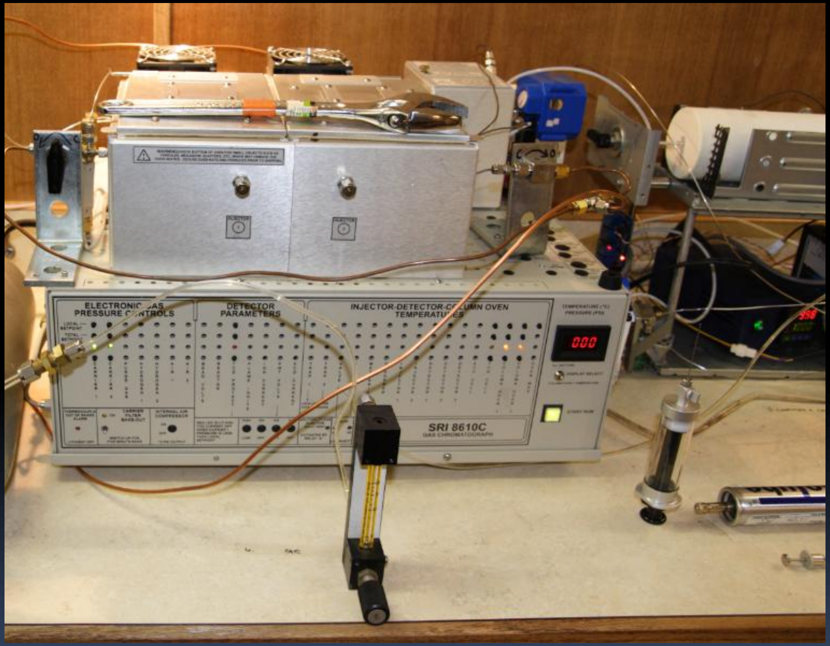
The relationship between hydrocarbon to the type identifies what type of production can be expected. **Production Index:** *This is derived from the pyrolysis of the first and second stage and defined as S1/(S1 + S2) (McCarthy et al., 2011) and is a function of maturity.*

TOC vs Depth



This figure indicates the progression of carbon by weight percent as the lateral is drilled. Clearly the concentration of carbon content increases as the wellbore penetrates deeper into the Woodford. In addition this could indicate different hydrocarbon compartments within the source rock.

Geochemical Analysis



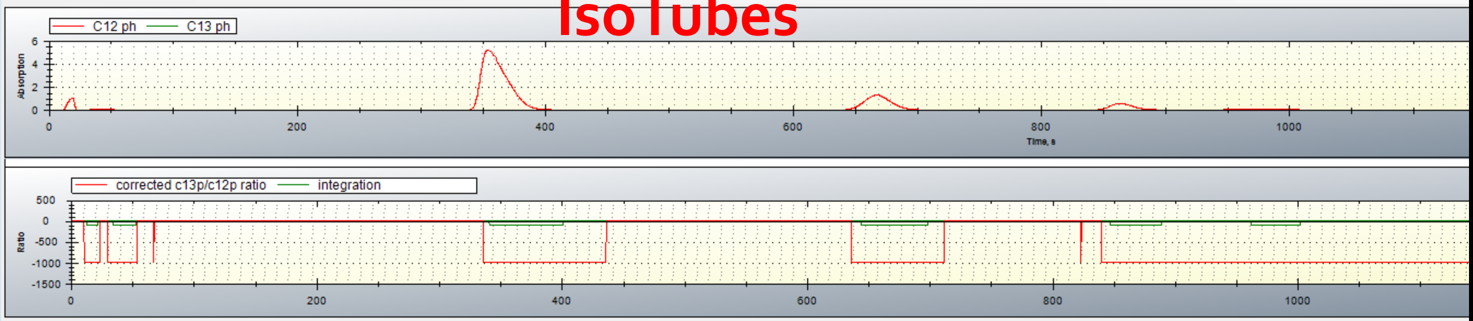
GC IR II

Tubes & Jars

Isotope Analysis - Jars $\delta^{13}C$ and Tubes: 16,970'~17,000'

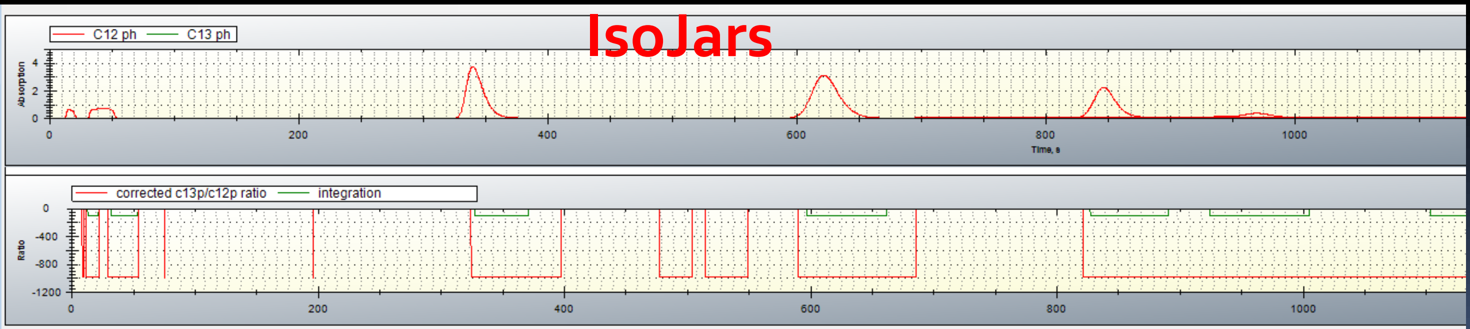
File Method Calibration

IsoTubes



#	Peak Start, s	Peak End, s	C12 LS int	C13 LS int	LS Ratio	Corrected LS Ratio	LS Delta	C12 PH int	C13 PH int	PH Ratio	Corrected PH Ratio	PH Delta
1	12.78	21.86	0.03827	0.02432	0.6355	1.032	-5.443	6.203	6.182	0.9966	1.035	-2.371
2	34.54	52.52	0.01027	0.006469	0.6296	1.023	-13.54	1.62	1.601	0.9885	1.026	-11
3	341.1	400.8	0.7688	0.4748	0.6176	0.9975	-38.4	128.3	124	0.966	1.004	-32.01
4	644.1	698.6	0.2106	0.1296	0.6157	0.9994	-36.55	34.06	32.89	0.9656	1.003	-33.11

IsoJars



#	Peak Start, s	Peak End, s	C12 LS int	C13 LS int	LS Ratio	Corrected LS Ratio	LS Delta	C12 PH int	C13 PH int	PH Ratio	Corrected PH Ratio	PH Delta
1	13.33	21.81	0.02492	0.01544	0.6195	1.002	-33.66	3.958	3.839	0.9699	1.006	-30.25
2	32.57	53.84	0.08253	0.05111	0.6193	1.002	-34.31	13.12	12.72	0.9693	1.005	-30.94
3	327.8	371.1	0.3683	0.2294	0.6229	1.001	-34.67	62.5	60.64	0.9702	1.003	-33.37
4	597.5	661.8	0.4928	0.307	0.623	1.004	-32.54	83.47	80.92	0.9694	1.004	-31.82

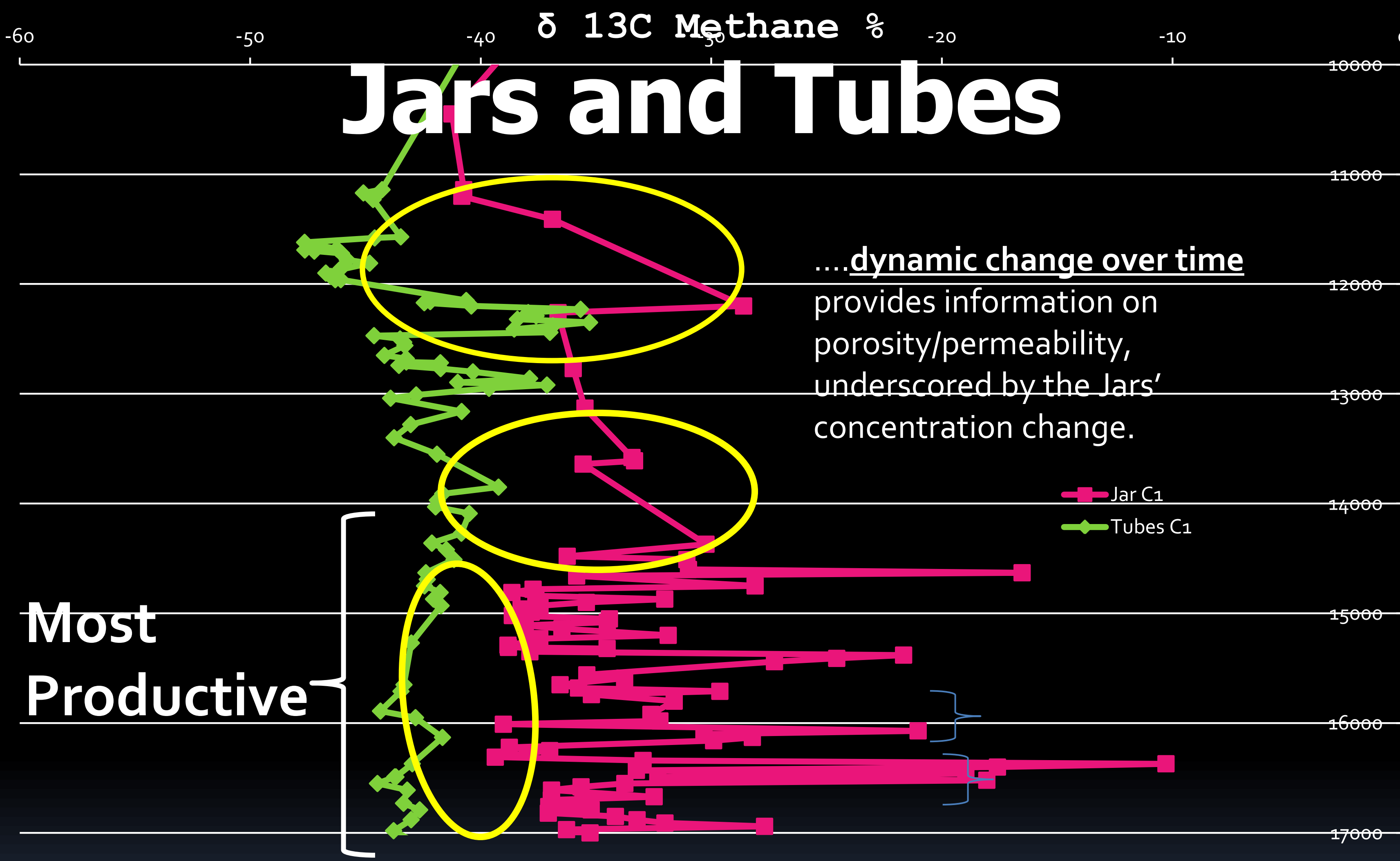
Jars $\delta^{13}C$ 16970~17000

- In 2 weeks, C_1 Doubled, $C_{2,3,4,5}$!
- $\delta^{13}C_1$ decreased from -32.01 to -33.37, ~1.3

MEANING…

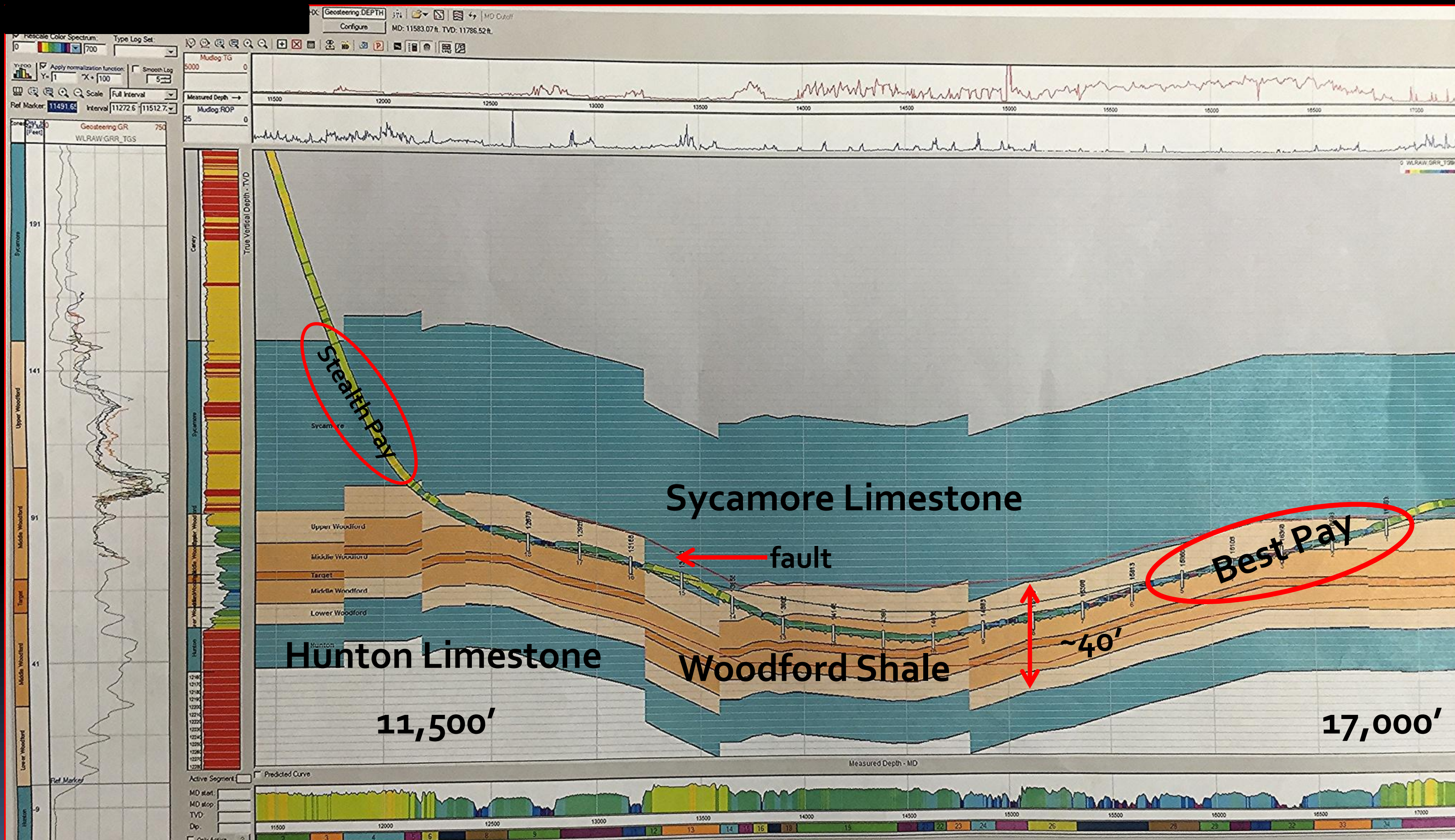
- Small decrease of $\delta^{13}C_1$ --- good porosity and permeability
- Large $C_{1,2,3,4}$ --- production potential high, especially favoring liquid

Jars and Tubes



When taken collectively, we find a large difference between isotubes and isojars. This data indicates that the potential for hydrocarbon recovery is very high and tending toward liquids. A large difference between Jars /Tubes and their dynamic change over time provides information on porosity/permeability, underscored by the Jars' concentration change. ***The large difference in C1, C2 & C3 between tubes and jars is the key!***

Horizontal Cross-Section



Conclusion

•GCIR tells C1-5+CO_2 isotope & composition static (tube) & dynamics (cuttings in jars), relates to hydrocarbon type, porosity & permeability. The analysis has provided strong indicators of the zones of best production and defined specific compartments within the reservoir.

•Rock Eval tells S0,1,2, TOC (liquid and potential) of the cuttings at given depth. The data corroborates the findings of the isotope analysis.

•XRF defined the elemental formation composition, characterized frackability , provided additional corroboration of other results.

•SEM provided direct visual characterization of porosity and corroborating the findings of the other procedures.

Thank You!