GEOLOGIC RESERVOIR CHARACTERIZATION METHODS AND FRAMEWORK

Emre Cankut Kondakcı | Senior Geologist

Engineering. Wellsite Operations.
Environmental Sustainability.

SEISMIC INTERPRETATION

Seismic interpretation is one of the most important steps in characterizing areas that hold hydrocarbon resources. Understanding of the structural geology and seismic stratigraphy of an area through seismic interpretation helps locate reservoirs accurately. Structural trapping mechanisms can be understood via seismic, as well as seal quality. Nature and distribution of faults, areal extent and geometry of folded structures can be resolved on seismic sections. Therefore, the risks associated with complex structural elements of an area will be reduced in order to design efficient projects.

Seismic also produces subsurface maps of geologic horizons which helps determine the areas with better reservoir thickness and structure. Well ties improve seismic subsurface models. Certain attributes can be applied to enhance the interpretations to show locations with hydrocarbon accumulations and ultimately help with volumetric calculations.

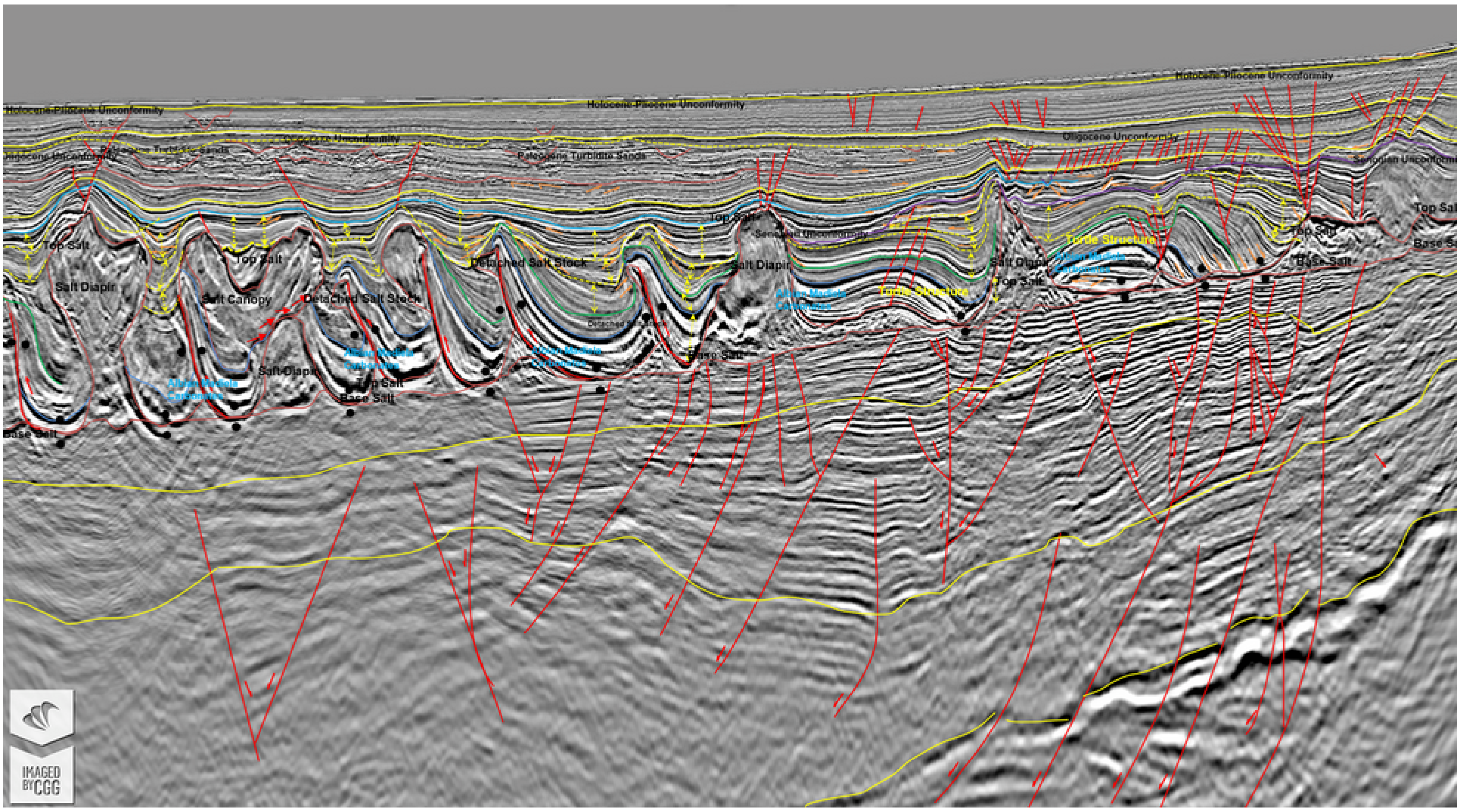


Figure 1. Seismic interpretation of an area with complex structural history

COMPUTER APPLICATIONS

Computer applications have been proven to be a vital element of any petroleum exploration investigation, yielding positive results in both the upstream and downstream side of the industry. Common uses include collection and interpretation of seismic data, well-log correlation, subsurface mapping, evaluation of quantitative data, development of quantitative geologic and mathematical models and simulations regarding behavior of petroleum in subsurface conditions, and core/outcrop descriptions. Data mining has been gaining popularity as a way for establishing database information in a relatively quick return time.

The construction of 3-dimensional models from 2-dimensional attributes/datasets have been made possible via computer applications. Visualization of geologic features has been observed to bridge the communication gap between the management, engineering and science teams.

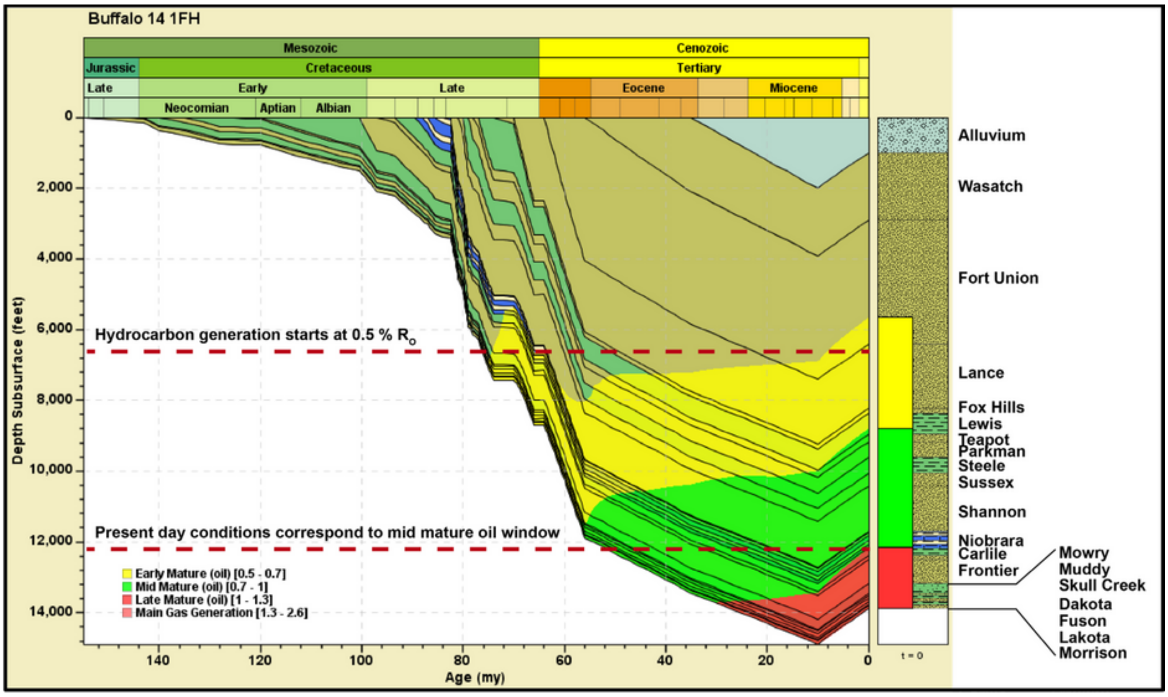


Figure 1. Burial and thermal history modeling of the Niobrara Formation.

WELL LOG INTEPRETATIONS, SUBSURFACE MAPPING AND CORRELATION

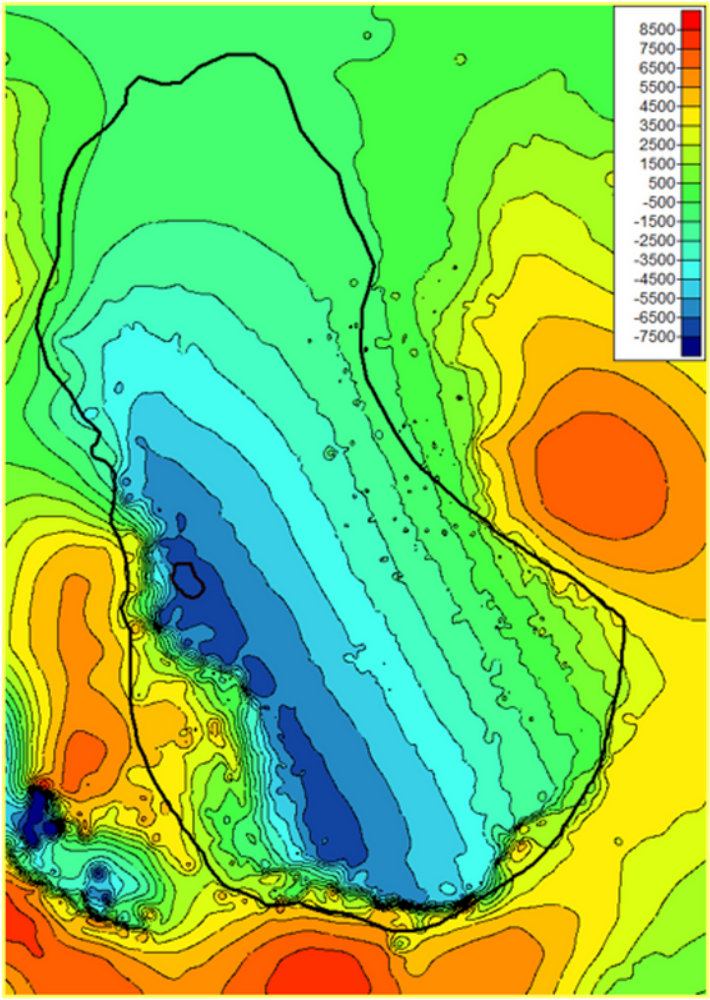
The use of well-logs in geologic reservoir characterization is a common practice. Well-logs help model lithology, fluid properties, and porosity that form the basis of reservoir characterization through conventional log analyses while more recent logging tools can help make higher resolution interpretations.

Geologic units can be mapped and correlated in the subsurface via picking formation tops from well-logs, mudlogs, and cores. Subsurface correlation of geologic formations provides valuable information on the depth changes, structural geometry, nature of trap mechanism, etc. from structural cross-sections, and the lateral/vertical continuity of rock units, and identification of pinchouts and stratigraphic traps from stratigraphic cross-sections. Geologic cross-sections are important in identifying the depth and geolocation of subsurface units in oil and gas exploration.

In addition to correlation of geologic formations in the subsurface, formation tops can be used to generate subsurface structure maps to show the areal extent, and the nature of formation dips that are important to understand in vertical, directional, and horizontal drilling plans. Calculating formation thicknesses from formation tops and generating isopach thickness maps for geologic formations that might be reservoir units, help identify where adequate formation thickness and continuity are found.

If reservoir is known, thickness of the formation can be optimized by applying cufoff values to specifically show areas of elevated reservoir potential. Common cutoffs are applied on the gamma-ray logs to better delineate intervals with higher sand and/or carbonate content, resistivity logs to identify zones with hydrocarbons, and porosity logs to show intervals with higher pore volumes. Moreover, well-logs can be used to generate petrophysical models to estimate organic carbon content, fluid saturation, permeability, and geomechanical properties.

Figure 2 Structure on top of the Niobrara Formation (MD) in the Powder River Basin.



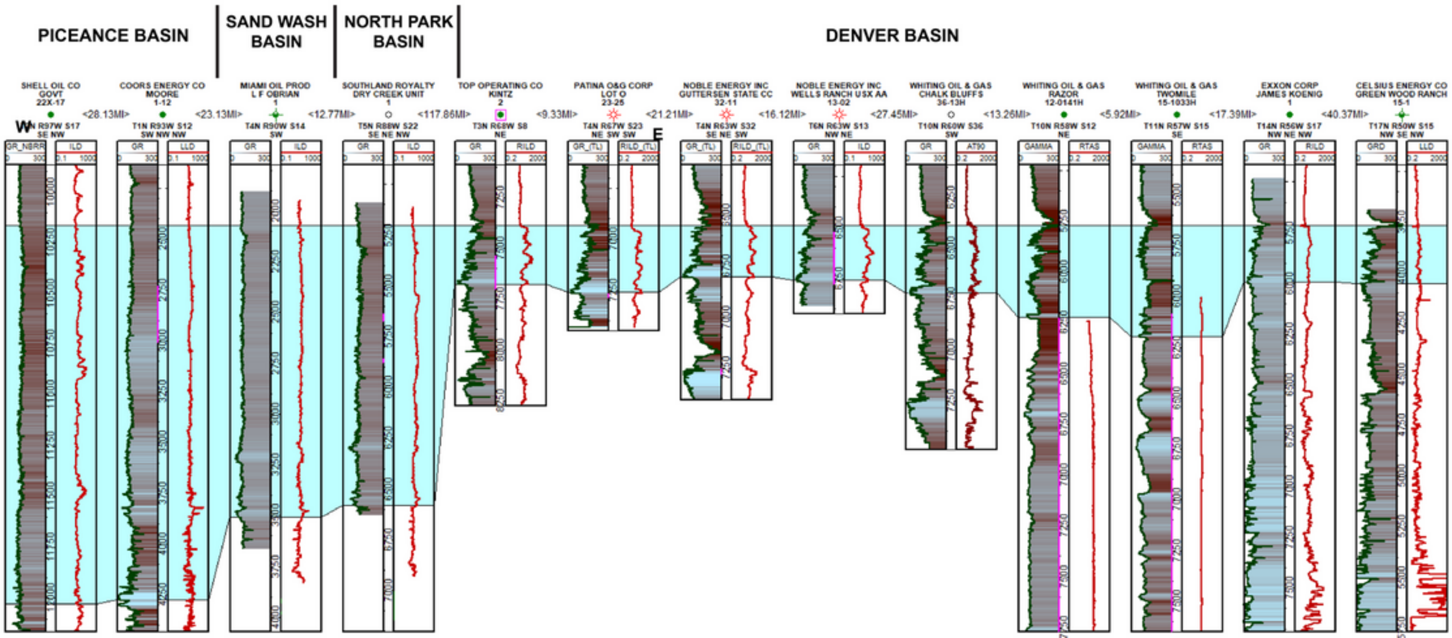


Figure 3 West – east (W – E) stratigraphic cross-section (Datum: Top Niobrara) of the Niobrara Formation across Colorado.

CORE DESCRIPTIONS AND CORE ANALYSES

Geologic analyses from cores have always been one of the first steps in investigations to understand the nature and distribution of reservoir facies and dynamics in an area of interest. Carefully studied cores, n a continuous manner, can provide information on the lithology, stratigraphy, depositional environment, thickness of facies, presence of natural fractures, and allow well-log calibration where data discrepancies exist.

Geologic information obtained from core descriptions can be used for regional/local stratigraphic/structural correlations to understand the geologic continuity of any rock group. Cores also permit further sampling, commonly in the form of plugs or grounded samples, which can be used to measure porosity, permeability, and gas/oil/water saturation.

Cores usually possess certain advantages over outcrops. Cores, although more expensive, are easier to locate, since cores do not require a specific geolocation like outcrops. Cores commonly exhibit better preserved features/boundaries as well as more complete sections compared to heavily weathered outcrop sections. Cores also provide better preserved samples of mudrocks, since mudrocks are highly prone to alterations on outcrops resulting in change of original attributes. Moreover, ichnofacies and body fossils are commonly better preserved in cores. In addition, due to being water-wet under subsurface conditions, sample quality is enhanced in cores. However, larger scale lateral and vertical variations and structures are not easily recognized due to limited coverage.

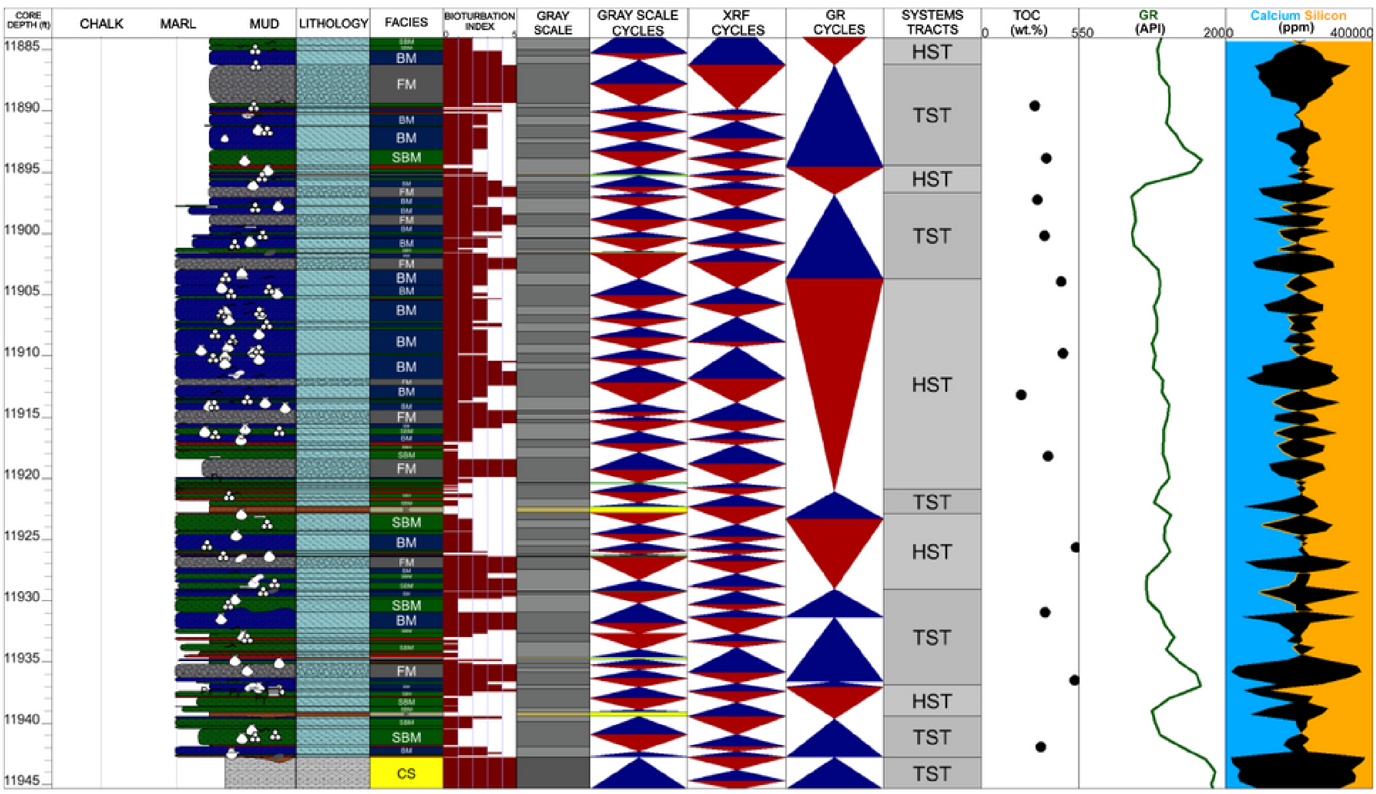


Figure 4 Core description framework of the Niobrara Formation in the Powder River Basin.

OUTCROP STUDIES

Outcrop analyses has been the most efficient method for investigation of in-situ geological conditions of rocks. Outcrop studies are useful for providing a better resolution for understanding bigger scale structural and depositional influences. Outcrops also allow geologic mapping in extensive areas. Surface geologic aspects of rock units, such as lithology, lateral and vertical continuity of facies, fractures, etc. can be correlated to subsurface and can help optimize subsurface geologic models.

Compositional and structural variations can be studied both vertically and horizontally as the availability of outcrop extent permits. Outcrop studies also allow additional sampling for further studying geologic aspects at a smaller scale, such as thin section, laboratory analyses, etc. In petroleum exploration, outcrops provide reservoir, source, seal, etc. analogies, which provides valuable information of petroleum system quality and elements that make up the internal architecture.

Figure 5 Outcrop section of the Green River Formation in Douglas Creek Arch area. The outcrop section offers the study of lacustrine depositional environments in great detail and helps understand the geology of an important oil shale deposit.

THIN SECTION STUDIES

Thin section studies are fundamental in the understanding of petrographic nature of rocks. Thin sections are useful for identifying composition and texture, diagenesis, pore structures of conventional reservoirs, and directly relate to reservoir quality and reservoir heterogeneity. Interpretations from thin section studies can influence decisions in exploration, production and appraisal of petroleum reservoirs.

Thin sections are one of the most efficient methods to characterize rock fabric and texture. Thin sections also provide adequate information on pore character of siliciclastic and carbonate rocks, as well as implications on porosity of mudrocks. Reservoir fluid properties associated reservoir pressure profile and geomechanical attributes can also be delineated via thin section studies. Overall, thin sections provide essential information on sediment source, diagenetic features, pore character and ultimately reservoir quality.

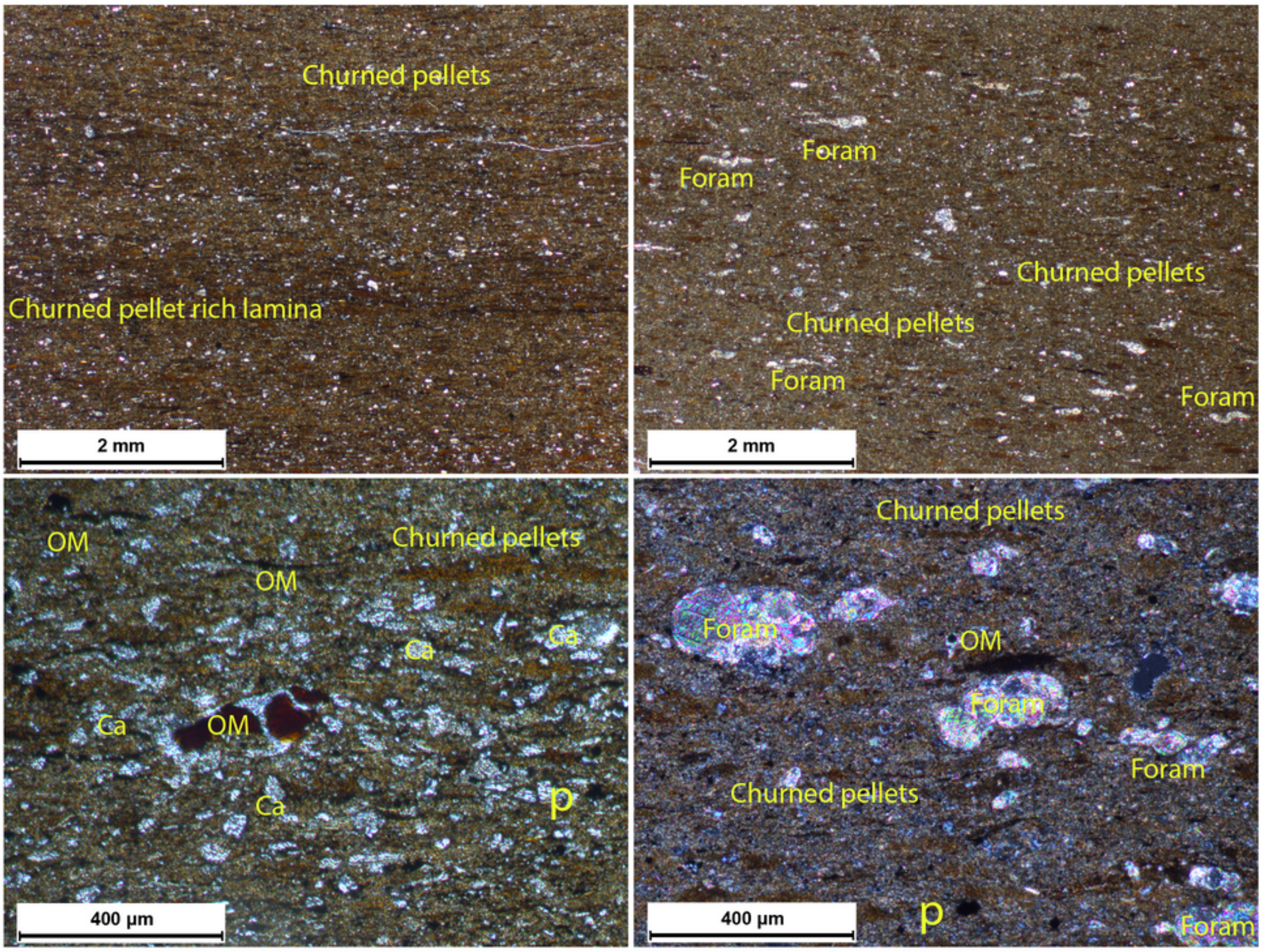


Figure 6 Thin section photomicrograph examples from a mudrock showing microscale heterogeneities on the mineralogy.

SCANNING ELECTRON MICROSCOPY (SEM)

SEM (Scanning-electron microscope) is a technique that permits higher magnification for imaging and therefore better resolution for geologic interpretations. SEM photomicrographs are taken as emitted electron beams interact with sample surface and recorded as raster. The spot size of created electron beam (probe) determines the response of different compositional elements.

SEM analyses provide high-resolution understanding on clay characterization and mineral composition in high magnification, in nanometer scale, which help establish a better foundation for geologic investigations. SEM results can be combined with other available data to understand the compositional and depositional features. Low- resistivity pays can be identified on SEM images, rather than well-logs, which is potentially insufficient to locate LRLC (Low resistivity-low conductivity) pays due to its limitations in well log scale. Combination of mineralogy and elemental information from x-ray diffraction (XRD) and x-ray fluorescence (XRF) analyses, SEM produces better lithologic and depositional interpretations.

SEM provides better resolution for imaging and monitoring geologic interactions under nanometer scale. SEM allows for the interpretation of the nature and distribution of pores in 3 dimensions. Elemental mapping of minerals is also possible which provides vital knowledge on productivity and formation damage. Understanding of variable distribution of productive intervals is important for locating “sweet-spots and hot-spots” in unconventional petroleum exploration.

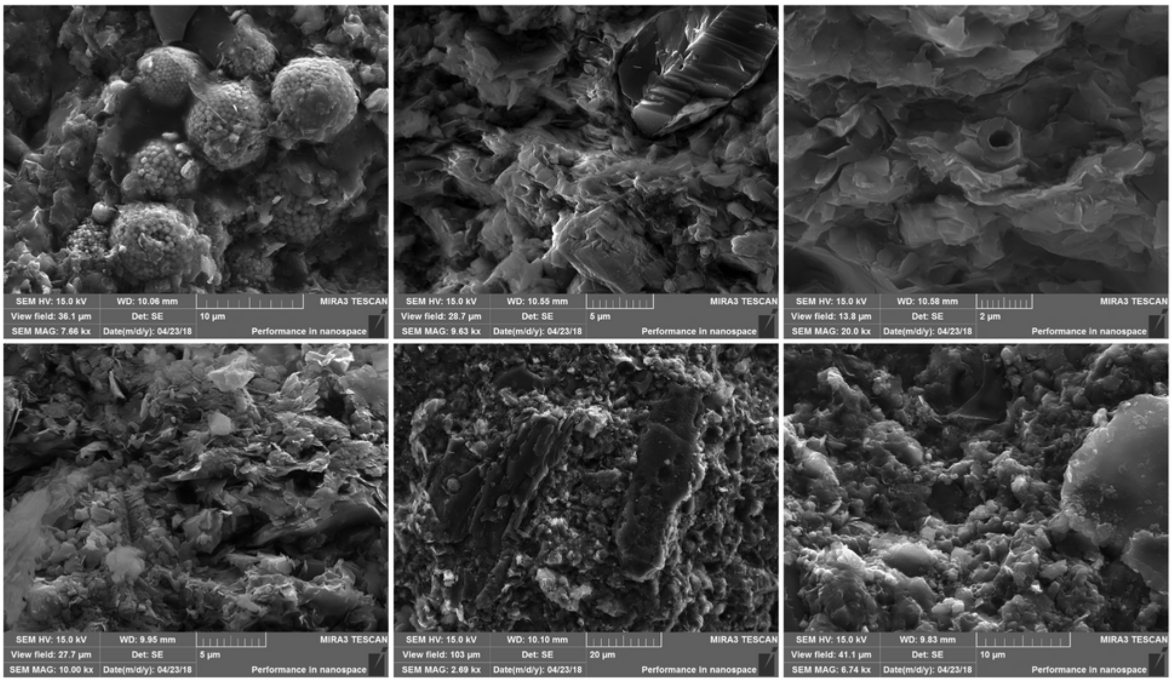


Figure 7 SEM photomicrographs of a calcareous mudstone illustrating the nanoscale mineralogical variations.

X-RAY DIFFRACTION (XRD) ANALYSIS

XRD (X-ray diffraction) is a mineralogical analysis providing semi-quantitative data on rock mineralogy by measuring peaks resulted by the diffraction of x-rays from the sample surface.Peaks created indicate both composition and attitude of crystallographic nature of samples. Each different mineral reflects unique x-ray diffraction peaks. However, the intensity and distribution of diffraction peaks depend strongly on sample quality and orientation of sample with respect to emitted x-rays. Detailed clay characterization can be performed with XRD analyses, as well as bulk mineralogical composition delineation.

With the application of XRD analyses, higher resolution geologic assessments with detailed mineral models are possible, which ultimately provide valuable information that can be used for drilling, completion and stimulation operations. In unconventional exploration, zones with enhanced fracability are easily identified. In addition, results of XRD analyses are useful in log calibration, since they provide information on grain density and clay type.

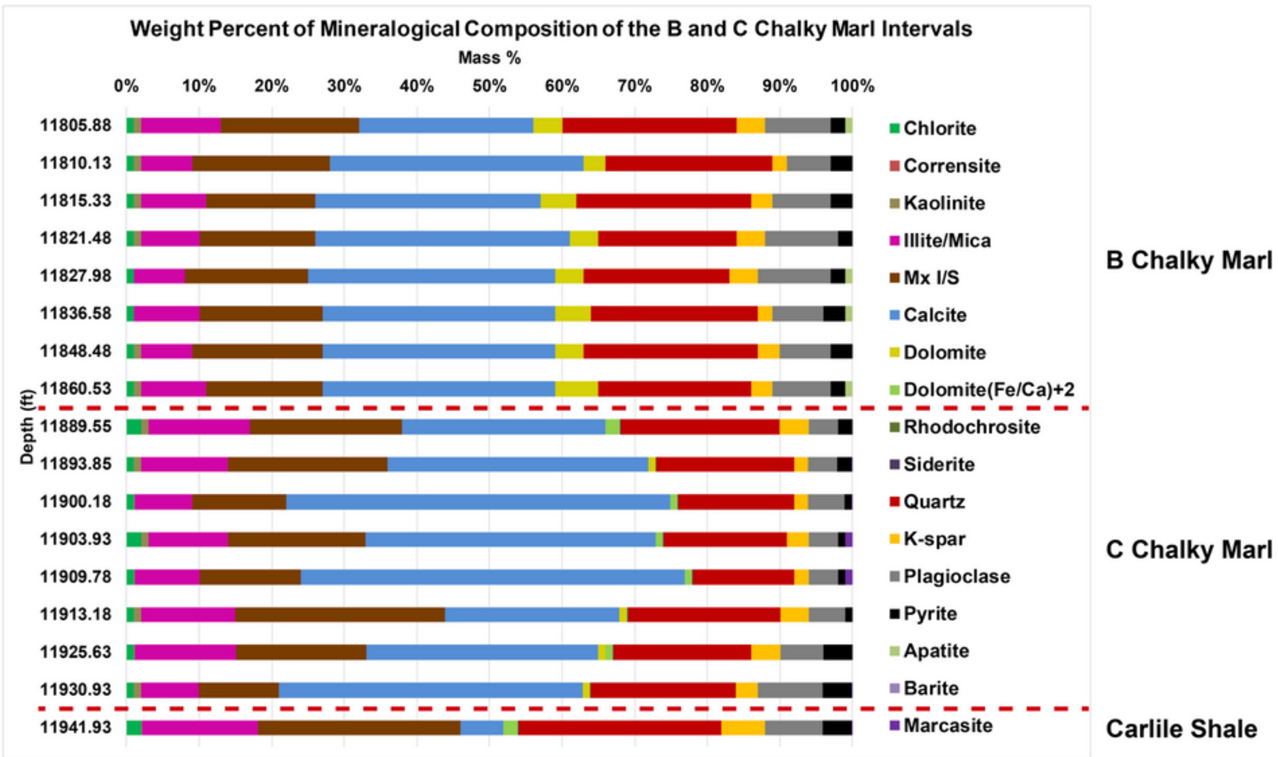


Figure 8 XRD bulk compositional analysis of the Niobrara Formation in the western Powder River Basin.

X-RAY FLUORESCENCE (XRF) ANALYSIS

Results of XRF (X-ray fluorescence) analyses reveal the characteristic response of elements producing unique fluorescence patterns with respect to being subjected to x-rays. XRF analyses improve the geologic interpretations, thus providing a better understanding of reservoir architecture. Compared to the semiquantitative XRD method, XRF offers fast results that are cost efficient. Elemental results from XRF can be modeled and converted to mineralogy. XRF analyses produce results that help discern the nature of sediment source areas based on trends of terrestrial and authigenic elements. The results can help differentiate detrital vs. biogenic silica, delineate the intensity of terrigenous influx, delineation of maximum flooding and maximum regression surfaces, understanding the intensity of organic matter influx and basin restriction/redox conditions, and paleoproductivity.

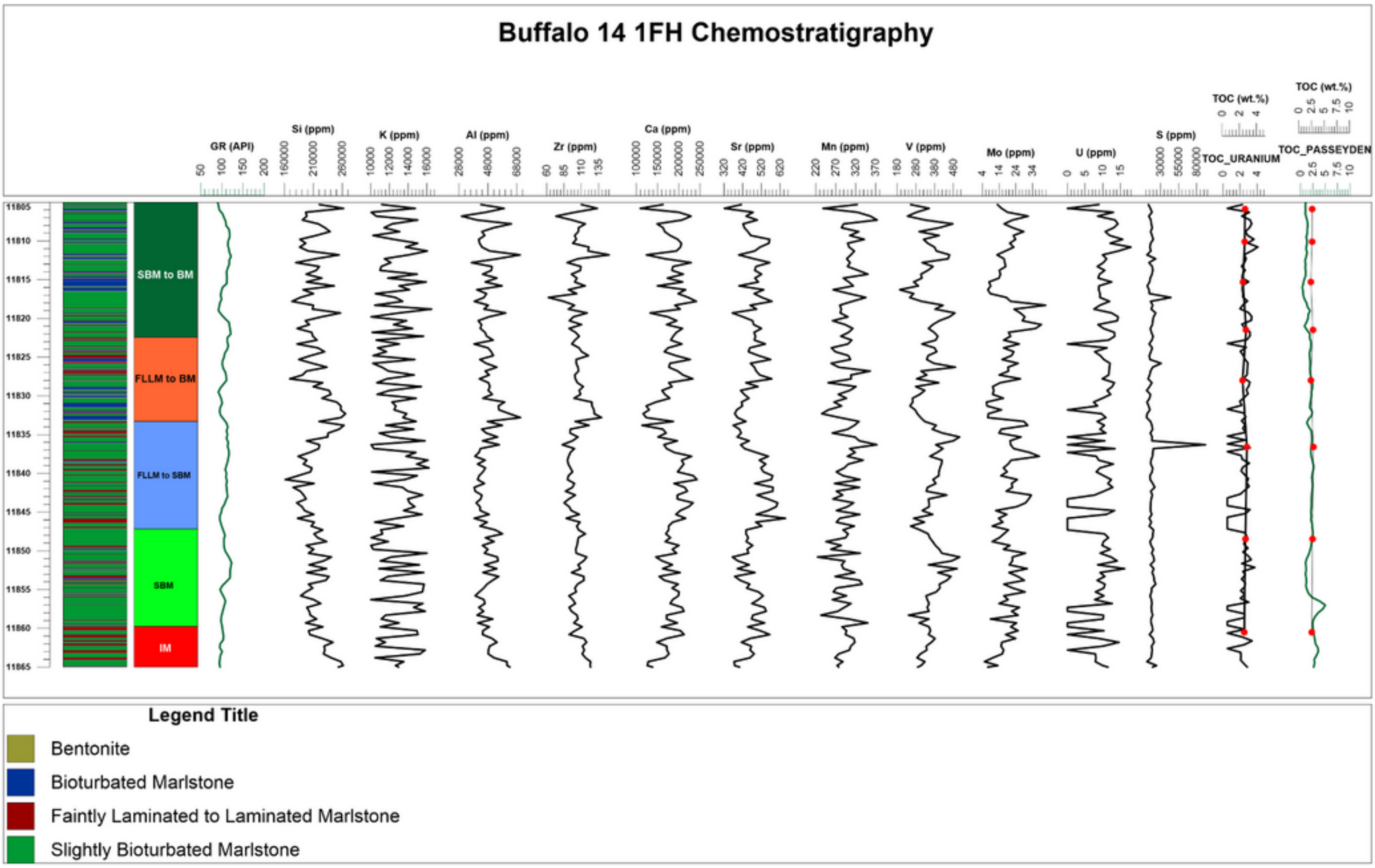


Figure 9 XRF elemental framework helps visualize lithological and geochemical changes.

SOURCE ROCK ANALYSIS

Source rock analyses conducted by pyrolysis of source rock samples provide fundamental information on quality, quantity and maturity of organic matter. Source rock analyses produce quantitative knowledge on the amount of readily producible hydrocarbons (S1), hydrocarbons produced by thermal cracking of kerogen (S2), amount of CO2 generated from kerogen during pyrolysis (S3), temperature at which hydrocarbon generation is the most intense (Tmax), total organic carbon (TOC), hydrogen index (HI), oxygen index (OI), production index (PI) and residual oil/contamination (S1/TOC). Combined analysis of source rock parameters (HI vs. OI, HI vs. Tmax, PI vs. depth, etc.)is a fundamental step in the investigation of all aspects of petroleum geology in the industry.

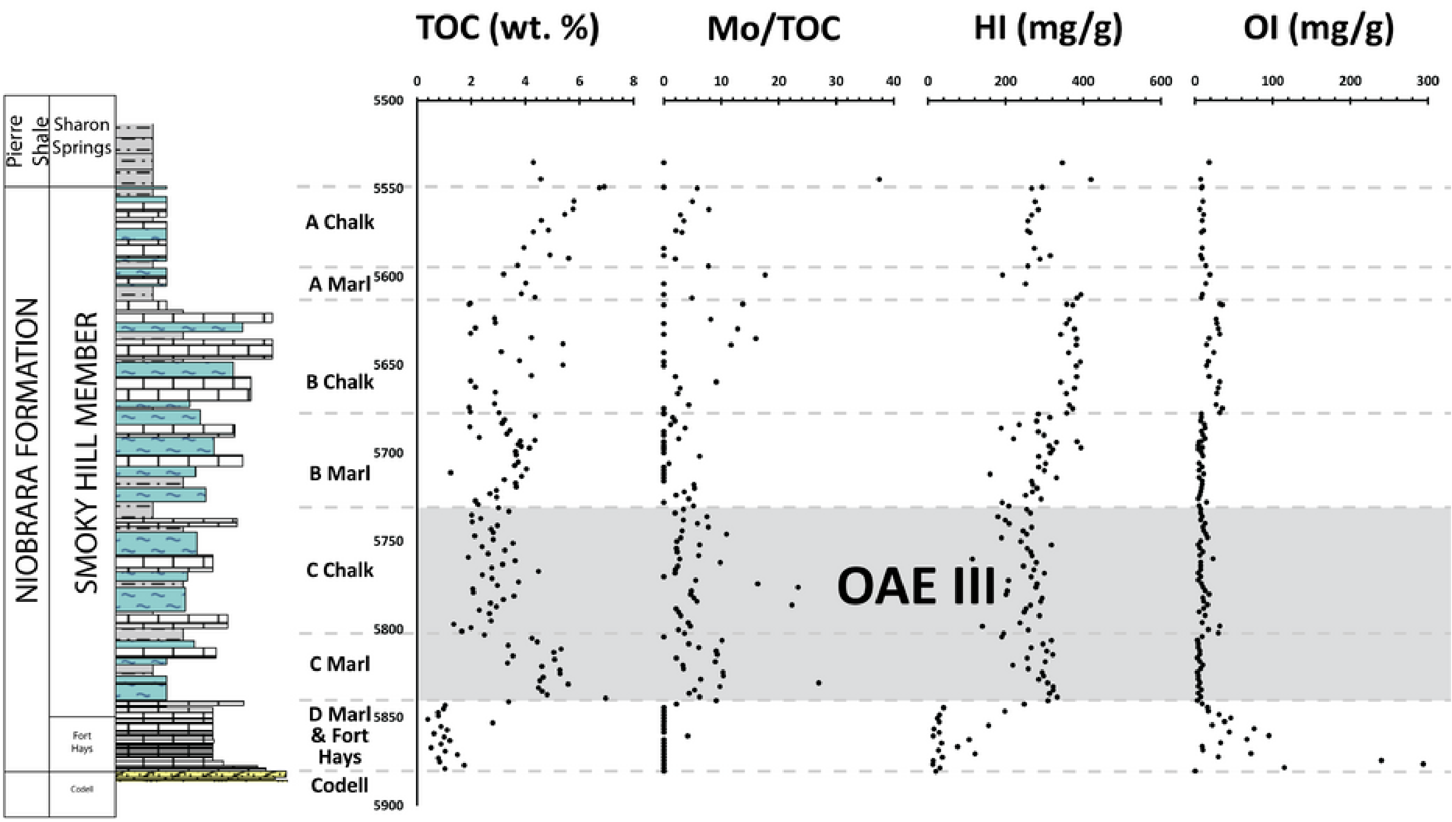


Figure 10 Source-rock analysis results and Molybdenum readings of the Niobrara Formation indicating elevated source rock potential.

CARBON & OXYGEN STABLE ISOTOPE ANALYSES

Stable isotope analyses of carbon and oxygen, although historically not common, have become a standard geochemical approach to define and characterize both liquid and gas hydrocarbons. Most common carbon isotopes used are the ratio of δ13C/δ12C, while the most common and useful oxygen isotope ratio is δ18O/δ16O.The trends reflect changes related to geochemistry, paleoclimatology and paleoceanography.

In fluid hydrocarbons, stable isotope analysis yield correlation of oil, bitumen and kerogen, delineation of multiple sources of oil, marine versus terrigenous influence on organic matter, paleoenvironmental reconstruction, source rock distribution and particular compound specific isotope analyses for correlation. Moreover, applications of stable isotope analyses in natural gases provide an understanding of the origin and thermal maturity of natural gas. Source- reservoir correlation, lateral-vertical reservoir continuity, compartmentalization of reservoirs, sorptive nature of coal and fine-grained rocks, presence of gas leakage and origin and nature of non- hydrocarbon gases.

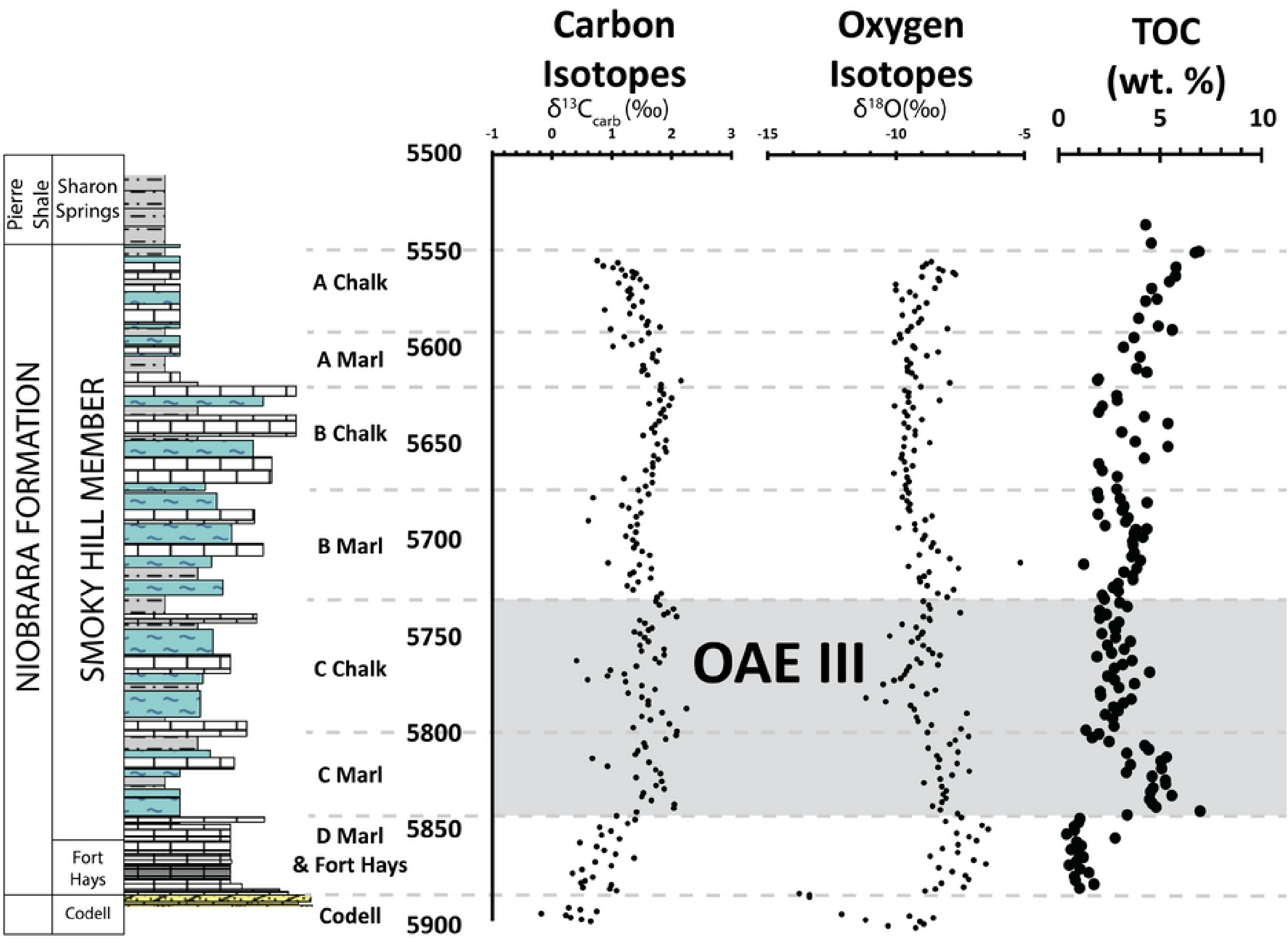


Figure 11 Stable carbon and oxygen isotope trends from the Niobrara Formation. Geochemical trends indicate variations in marine geochemistry, paleoclimate and paleoproductivity.

PETROPHYSICAL MODELS

Petrophysical models are common practices in reservoir evaluation. Petrophysical models derived from well logs can provide valuable information on the porosity, water saturation, organic richness, and geomechanical properties of rock units. When lab measured data is available, petrophysical models can be optimized through curve matching. Porosity obtained from well-logs can help determine the storage capacity of reservoirs. Water saturation modeling depends on the target formation. Archie's model used in conventional reservoirs can be substituted with the Indonesian Model for unconventional shale resources. Each method provides information that directly relates to reservoir quality. Total organic carbon estimates made from well-logs can often times show positive correlation with lab measurements and therefore can be used to estimate the level of organic richness in geologic units. Sonic and bulk density log based elastic moduli calculations help with geomechanical modeling where fracture closure pressures and other parameters can be estimated. With the availability of multiple log suits, petrophysical models can be improved for reservoirs and increase the chance of success in future operations.

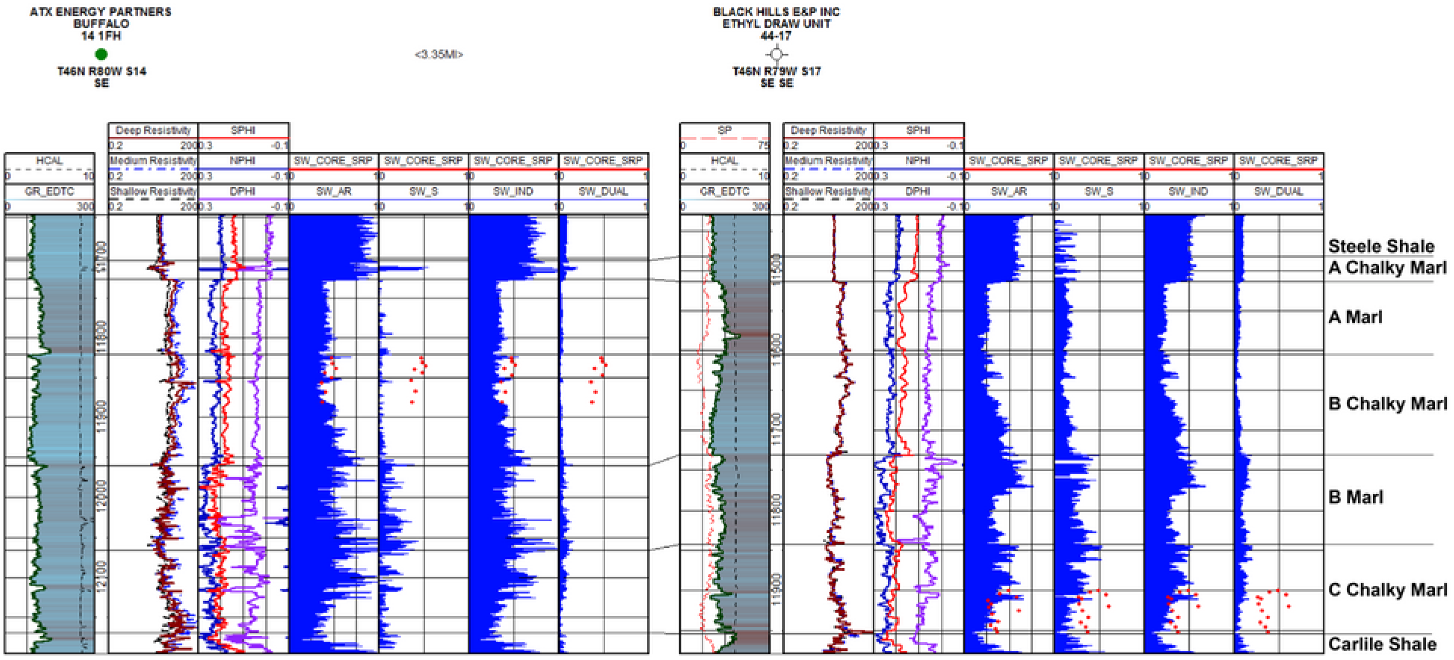


Figure 12 Water saturation modeling performed in the Niobrara Formation indicates economically viable hydrocarbon concentrations.

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