A Geologic Play Book for Utica Shale Appalachian Basin Exploration

Abstract

Inorganic Geochemistry

Bulk Mineralogy

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The research team used X-ray diffraction (XRD) and scanning electron microscopy (SEM) to evaluate the bulk mineralogy composition of Utica, Point Pleasant and Trenton samples from the Study area. X-ray powder diffraction aided in determining mineral compositions of these lithologies in drill cutting samples from five wells in New York, six wells in Ohio and 17 wells in Pennsylvania, as well as of Utica-equivalent rocks from 18 outcrops in central Pennsylvania, for a total of 930 samples. Semi-quantitative results made using the Rietveld method, a sophisticated technique that can take into account such factors as preferred orientation and peak shape, provided a level of precision sufficient for dividing the minerals into major categories for classifying the lithologies that were encountered. Data from interpreted XRD analyses fell into three broad categories: (1) quartz plus feldspar; (2) carbonates; and (3) clay minerals. Plots of these data for all wells in which more than three intervals were sampled (none of the outcrops had sufficient samples) reflect changes in mineralogy with depth. Displaying the mineralogy results in this manner facilitates the interpretation (or in many cases, confirmation of past interpretation) of Utica, Point Pleasant, Trenton and other formation and member boundaries. While XRD plots are based on drill cuttings obtained from specific intervals within each well, interpretations based on them without reference to geophysical logs of the same intervals may result in inconsistent or inaccurate correlations. A complete set of the data spreadsheets and plots is available in the final report.

SEM imaging was used in conjunction with energy-dispersive spectroscopy (EDS) techniques of nine samples of Utica and Point Pleasant drill cuttings from three wells in Pennsylvania. Analytical data for each sample included: (1) a high-resolution image; (2) an EDS spectrum, which includes a graph and a text file listing the percentages of the elements in the entire area shown in the high-resolution image; and (3) a set of element maps showing where the particular element was detected. A map for sulfur, for example, shows where pyrite grains exist, whereas a map for calcium probably indicates the distribution of carbonates. For each sample, separate maps for aluminum, calcium, iron, potassium, magnesium, sodium, sulfur, silicon and titanium were constructed. In addition, the research team prepared element maps that illustrate multiple elements in contrasting colors that can be used not only to show the distribution of elements, but also to verify the identity of grains in the SEM photomicrographs. For example, a map of silicon and calcium that has a high percentage of calcium but basically no silicon most likely indicates grains of carbonates rather than of plagioclase feldspars. Likewise, a three-color map of aluminum, silicon, and potassium showing an abundance of each element scattered across the map would suggest that the sample is composed mainly of potassium aluminum silicate, indicating probable clay minerals, k-feldspar or other silicate minerals. When used in conjunction with XRD analysis, this becomes a powerful tool to determine the most likely mineralogy.

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Carbonate Content

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The research team measured rock cuttings and core samples from approximately sixty wells in New York and Ohio in order to determine carbon content using an insoluble-residue analytical procedure. For each given sample, carbonate-content results and Total Carbon Content (TOC) were then plotted with geophysical logs. The results indicate that within the Utica/Point Pleasant interval, TOC does not directly correlate to any radioactive material, and that the gamma-ray (GR) log is primarily driven by carbonate and clay content instead of TOC. In fact, the carbonate content tracks the GR almost exactly.

Data collected and analyzed from four wells in Ohio indicate that reservoirs, in the absence of matrix porosity, containing high TOC and carbonate content may be the most successful. Higher carbonate content will consist of more brittle and "fracable" rock, whereas high TOC will provide the amount of organic matter needed for a productive reservoir. Some additional porosity can also be found between clay particles, suggesting that slightly higher clay content is indeed beneficial.

The organic-rich interval of the Utica is more carbonate-rich in the basal sections of the formation. The Ohio wells that were studied indicate that the organic-rich shale in the Utica had an average carbonate content of approximately 25% and a clay content of about 70%. The clay content in the Utica is incredibly high, likely too high for the rock to be fraced effectively. The Point Pleasant Formation contains an average clay content of about 50% within the organic-rich facies, and an even greater percentage in the limestone beds. The upper Lexington/Trenton and Logana members have carbonate content values that average approximately 70% in their organic-rich facies.

Carbon Isotopes

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Carbon isotopes can be used as a chronostratigraphic tool because the isotopic composition of the marine inorganic carbon reservoir ($\delta^{13}C_{DIC}$) changes synchronously across the ocean over time. There is little isotopic fractionation during carbonate precipitation so that $\delta^{13}C_{carb} \approx \delta^{13}C_{DIC}$. This allows researchers to use $\delta^{13}C_{carb}$ to temporally correlate spatially disparate strata. This Study used $\delta^{13}C_{carb}$ to set up a chemostratigraphic framework for the greater Appalachian basin. Similar to a previous study on coeval strata in New York, numerous $\delta^{13}C_{carb}$ trends were identified in the current Study region, and these $\delta^{13}C_{carb}$ trends were used to correlate strata across various lithologies. Organic-rich strata appear to be most abundant in a specific $\delta^{13}C_{carb}$ interval named TR-1, which occurs just after another $\delta^{13}C_{carb}$ interval, the Guttenberg isotopic carbon excursion (GICE), a global positive $\delta^{13}C_{carb}$ excursion. The GICE represents a major perturbation of the global biogeochemical carbon cycle, but its cause is unknown. Strata containing $\delta^{13}C_{carb}$ interval TR-1 are currently interpreted to have been deposited during a sea level rise, perhaps during post-GICE deglaciation; however, evidence for glacially-forced sea level change is indirect. Here the research team presents a sediment accumulation model where sea level is the only free variable controlling sedimentation locus. The driver of sea level change may be shifts in glacial ice abundance due to the short nature of a transgressive-regressive cycle (<500,000 years). Alternatively, the change in sedimentation locus could be tectonic in origin, or at least tectonically influenced as the study units were deposited during the end of the Taconic Orogeny, a period of heightened tectonism and explosive volcanism in the region.

While the true mechanism that drove changes in lithology and $\delta^{13}C_{carb}$ is still uncertain, it is apparent the carbon cycle was perturbed during the transition in depositional environment. Further, deposition of the most organic-rich strata appear to fall in the transitional argillaceous carbonates of the Trenton Group, deposited between the clean carbonates of the Black River Group and the calcareous shales of the Utica Shale. This suggests that organic matter production and/or preservation was enhanced during environmental transition rather than during periods of environmental stability. Numerical box models of the biogeochemical carbon cycle were used to explore the general magnitude and duration of the perturbations the global carbon cycle that drove the $\delta^{13}C_{carb}$ signal. Model results supply a broad, but important set of constraints changes on global organic carbon burial and weathering patterns.

Citation

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