Correlation And Chronostratigraphy Of The Duvernay Formation: Elemental and Stable Carbon Isotope Stratigraphy

Sarah J. Porter, Gabriel Rotberg, Gemma Hildred, Barry Lees, Tim Pearce, James Griffiths
sarahporter@chemostrat.com

Chemostrat Ltd. and Chemostrat Inc.

Introduction to the Duvernay Formation

The Upper Devonian (Frasnian) Duvernay Formation of Alberta is a proven, areally extensive source rock and has become a major and active shale resource play. The Duvernay is conformably overlain by the Ireton Formation and conformably overlies platform carbonates of the Cooking Lake Formation in the East Shale Basin and the Majeau Lake Formation in the West Shale Basin, where the Cooking Lake Formation is absent (e.g. Stoakes and Creaney, 1984). Although productive, the Duvernay consists of a carbonate shale sequence characterised by significant lateral facies variations that produces exploration and development challenges when targeting sweet spots and modelling changes in mineralogy for frack optimisation. However, the lack of reliable biostratigraphy and variable log response, and lateral facies variation ensures that chronostratigraphic correlation is poor, which in turn hampers regional play fairway mapping. For example, the Duvernay is believed to be age equivalent to the Muskwa Formation, although these plays have different organic and mineralogical characteristics, which implies that more detailed time resolved palaeoenvironmental reconstructions of the Upper Devonian are required. This study demonstrates a proof of concept study of the application of C-isotope chronostratigraphy in combination with elemental chemostratigraphy to constrain the correlation of Duvernay both on a field to sub regional scale.

Carbon Isotope Stratigraphy And Elemental Chemostratigraphy

Carbon isotope stratigraphy ($\delta^{13}C$) of marine carbonate ($\delta^{13}C_{carb}$) and organic-rich ($\delta^{13}C_{org}$) rocks, exploits the variation of the $^{13}C/^{12}C$ ratio in the global oceans throughout geological time. These variations are the result of partitioning of carbon between the organic and carbonate reservoirs in the lithosphere (e.g. Shackleton and Hall, 1984; Berner, 1990). Trends and excursions observed in $\delta^{13}C$ curves in marine stratigraphy are therefore extremely valuable for stratigraphic characterisation and lateral correlation of rock units and packages. Further, with a high-resolution global database that extends from the Neoproterozoic through to the Cenozoic available for comparison (Saltzman and Thomas, 2012), carbon isotopes have enormous potential to be utilised as a chronostratigraphic tool. This is exceptionally valuable in barren stratigraphy where biostratigraphy is not viable.

Elemental Chemostratigraphy focuses on sedimentary units, which can exhibit variations in the constituent minerals, or the proportion of accessory phases (e.g. clay and heavy minerals), even within apparently uniform successions. These changes are reflected in the variations in the elemental composition of the sediments. The current study utilises inorganic geochemical data derived from inductively coupled plasma-optical emission spectrometry (ICP-OES) and inductively coupled plasma-mass spectrometry (ICP-MS), to recognise the subtle variations in the chemistry of the sediments in study intervals. Using these subtle variations, a geochemical fingerprint for an interval can be established, therefore allowing for correlations to be established between wells. Additionally, by linking the elements to the key mineral phases (using X-ray diffraction (XRD) data to calibrate), it is possible to establish the key controls (e.g. palaeoenvironment, provenance) on the elemental variations seen through the Duvernay Formation.

Correlation and Chronostratigraphy

From the cored intervals of ten Duvernay wells from the Kaybob and Willesden Green areas, carbon isotope stratigraphy has been utilised to define and laterally correlate package boundaries. These boundaries have been integrated into a chemostratigraphic correlation scheme established for these ten well sections (with a further eight wells having also had chemostratigraphic zonations defined). The zonations established using the carbon isotope stratigraphy are in agreement with those established using inorganic elemental data, thus demonstrating the ability of carbon isotope stratigraphy to perform as a viable stratigraphic correlation tool. This, in turn, acts as a validation tool for the chemostratigraphic zonations that have been developed, allowing for correlation of sequences between the Kaybob and Willesden Green areas. In addition, a marked positive $\delta^{13}C$ isotope excursion (~1.5-2 per mil) is observed in these wells within the same stratigraphic interval. Evidence from additional studies of middle Frasnian carbon isotope excursions, have demonstrated that a coeval positive isotope excursion of comparable magnitude is present in China during the *punctata* zone. On a preliminary level, the excursion within the Canadian Duvernay Formation wells therefore not only provides a regional correlative marker horizon as also recognised by the chemostratigraphic correlation scheme, but also provides chronostratigraphic constraint for this package within the Duvernay Formation. This is especially important for the Duvernay Formation, as biostratigraphy is not available.

Conclusions

The integrated approach to the correlation scheme, using both elemental chemostratigraphy and carbon isotope analysis, has enabled an increased understanding of the internal stratigraphy and lateral facies variations within the Duvernay Formation. The use of the carbon isotope analysis also has the benefit of providing an additional method for stratigraphic correlation. The identification of a pronounced isotopic excursion has allowed us to provide an age-constraint for a horizon within the Duvernay wells. This has permitted chronostratigraphic correlation between wells from two Duvernay fields (Kaybob and Willesden Green). Additionally, the carbon isotope data demonstrates the value in applying this technique to establish a regional framework for the Upper Devonian in Alberta. With a readily available well-constrained and high resolution global database spanning over 3000 Ma, this method also has wide applications to other shale plays worldwide, at the exploration and appraisal stage. This emphasises the importance of carbon isotope analysis in well and formation characterisation, and sub-regional scale prospectivity, and advocates its use as a viable and cost-effective alternative to biostratigraphy. By integrating the carbon isotope data with elemental chemostratigraphy it is possible to produce robust sub-regional chronostratigraphically calibrated correlation frameworks that are independent of lateral facies changes across the two sub-basins.

References

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