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The Use of Elemental and Stable Isotope Chemostratigraphy for Regional Correlation of the Duvernay Formation, Western Canada

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Abstract

The Duvernay Formation in the Western Canadian Sedimentary Basin (WCSB) is a highly prospective oil and gas play, with potential reserves of up to 443 trillion cubic feet of natural gas, 11.3 billion barrels of natural gas liquids and 61.7 billion barrels of oil (mid-point estimate of the Alberta Geological Survey, Rokosh et al., 2012).

The Duvernay Formation underlies an area of ~100,000km^2 in central Alberta, and has a maximum thickness of 250m (average 35-60m). In terms of lithology it consists of laminated bituminous shale, calcareous shale and dense argillaceous limestone (Rokosh et al., 2012). Disseminated pyrite is common in the Duvernay Formation, as is calcarenite (detrital limestone) and coral-rich mudstone. In terms of chronostratigraphy, the Duvernay Formation is of Frasnian age (Late Devonian, ~372-383 Ma) (Śliwiński et al. 2011). The key to exploration and exploitation of any regionally extensive shale play is understanding the temporal and geographic distribution of high TOC shales.

Here, we demonstrate the efficacy of using a combined elemental chemostratigraphy and stable isotope stratigraphy (SIS) approach to identify key trends in paleoenvironmental change; and to place each well within a robust chronostratigraphic framework based on published global stable isotope data.

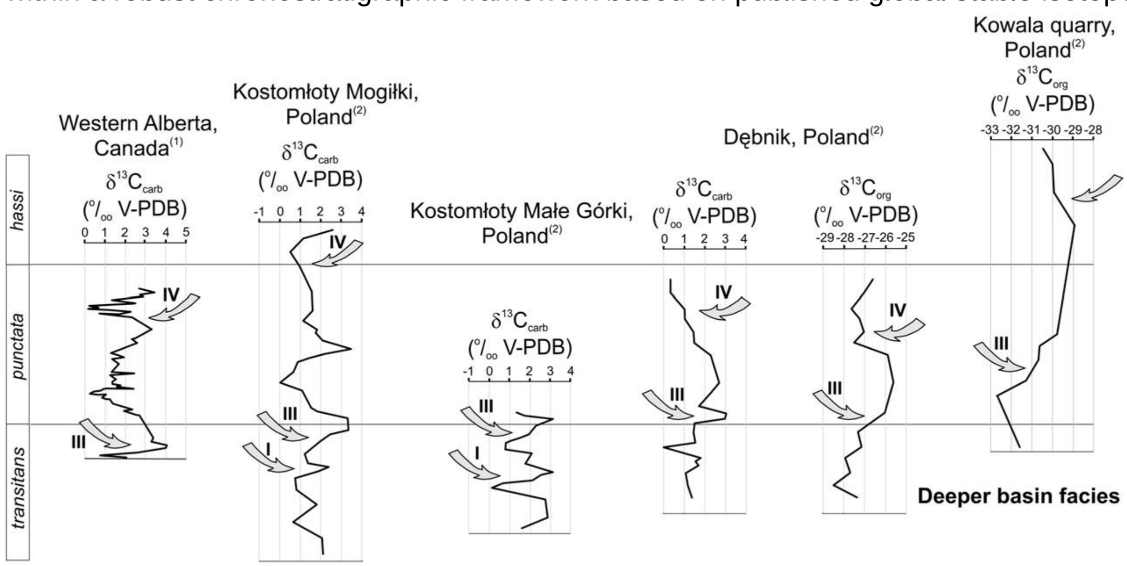

Fig. 1 – High resolution stable carbonate carbon isotope ($\delta^{13}C_{carb}$) and stable organic carbon isotope ($\delta^{13}C_{org}$) for locations in Canada and Poland (Pisarzowska & Racki, 2012). Data on the left (1) from the WCSB is from Śliwiński et al. 2011)

The *punctata* Event (described below) has been recorded from Frasnian successions in the WCSB (Duvernay Formation equivalents), which during the Frasnian stage consisted of isolated carbonate platforms on the western margin of the Devonian supercontinent Laurussia (Śliwiński et al. 2011). The stable carbon isotope record from the Frasnian stage displays an abrupt and high-amplitude global negative excursion, termed the '*punctata* Event', after the conodont biozone *Palmatolepis punctata* (Pisarzowska *et al*. 2006, Yans *et al*., 2007; Ma *et al*. 2008, Morrow *et al*. 2009). The *punctata* Event was short-lived (0.5-1 Ma); with a maximum variation of 5-6 ‰ recorded in the stable isotopic composition of calcium carbonate ($\delta^{13}C_{carb}$). The *punctata* Event has been recorded in a number of other locations globally, including central-west China (Zheng & Liu, 1997), the Czech Republic (Geršl & Hladil, 2004), Belgium (Yans et al., 2007) and Poland (Yans et al., 2007).

Carbon isotope data from the WCSB can be seen on the left of Figure 1 (data of Śliwiński et al. 2011), which clearly shows the major positive excursion at the top of the *P. transitans* conodont biozone termed 'Event III'. This isotopic excursion corresponds to a positive shift in eustatic sea level and basin anoxia, and has been identified in stable isotope records from Europe (Yans et al, 2007) to South China (Ma et al, 2008), the western U.S. (Morrow et al., 2009) and western Canada (Śliwiński et al. 2011).

Near the top of the *P. punctata* biozone a major negative carbon isotope excursion occurs, termed 'Event IV'. This excursion corresponded to another significant deepening of eustatic sea level, and is associated with a reduction in taxonomic diversity and overall abundance of reef biota (Pisarzowska & Racki, 2012).

Event III and Event IV were firstly identified in the stable organic carbon isotope ($\delta^{13}C_{org}$) data generated here for the Duvernay Formation. The position of the isotopic excursions were then used to identify the *P. punctata* and *P. transitans* conodont biozones, and hence provide relative age constraints for each well; thereby allowing a 16 well chronostratigraphic correlation to be defined over a distance of ~400km.

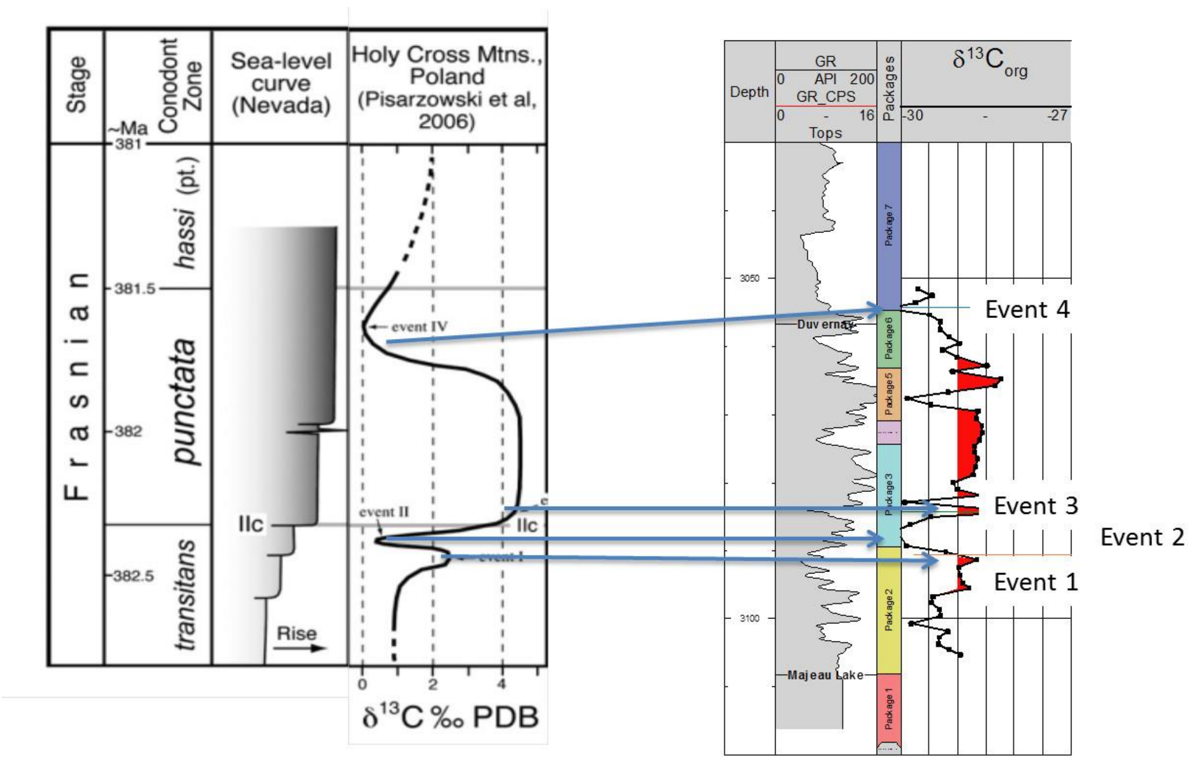

Fig. 2 – Stable carbon isotope correlation between the generalised $\delta^{13}C_{carb}$ curve from the Holy Cross Mountains in Poland (Pisarzowska et al., 2006) on the left, to $\delta^{13}C_{org}$ data from the Duvernay Formation in this study on the right; showing Event III and Event IV

In addition, this study combined the SIS data with TOC (Total Organic Carbon) data and a comprehensive elemental dataset for each well. Placing these data into the context of a regional model indicates:

- The oldest TOC shale seen in the Duvernay Formation developed in the deeper, more northerly basins, with the southerly basin experiencing oxic conditions in shallower water.
- As sea level rose during the Middle Frasnian, anoxic conditions developed across the entire region (seen in the data as the middle high-TOC shale).
- At the time of the youngest high-TOC shale, orogenic uplift to the north of the Duvernay Basin led to increased terrigenous input into the north east of the basin, which diluted the organic matter in the northerly wells. This restricted the most significant organic matter preservation to the southerly part of the basin.

This study therefore demonstrates how an integrated elemental chemostratigraphy and SIS approach can place palaeoenvironmental interpretations into a time constrained basin model. The methods and approaches used here for the Duvernay Formation are readily applicable to any shale basin and provide valuable information in exploratory drilling for the economic recovery of hydrocarbons; not only from the Duvernay Formation but from any shale play.

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