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The Canol shale basin of NW Canada: New outlook on lithostratigraphy and paleoceanographic control of a Devonian shale-hydrocarbon prospect

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Introduction

The Middle-Upper Devonian strata of the interior platform of northern mainland N.W.T. and adjacent Yukon were in the research focus for the last decade owing to major occurrence of basinal mudrocks prospective for high-quality shale hydrocarbons (Fig. 1). Two main pay horizons as recognized by NTGS in the Mackenzie Plain project area (Pyle et al., 2014; Pyle and Gal, 2016) are the thinner Bluefish Shale with estimated 46 billion barrels of oil-in-place and the thicker Canol Shale with expected 145 billion barrels of oil-in-place (NEB-NTGS, 2015), which will likely be subject to change with new data. This paper reports on the progress in stratigraphic correlations, paleogeographic zonation, and understanding of the depositional system through elemental and organic geochemistry conductive for paradigm-changing insight into the depositional systems of Devonian sourcerocks.

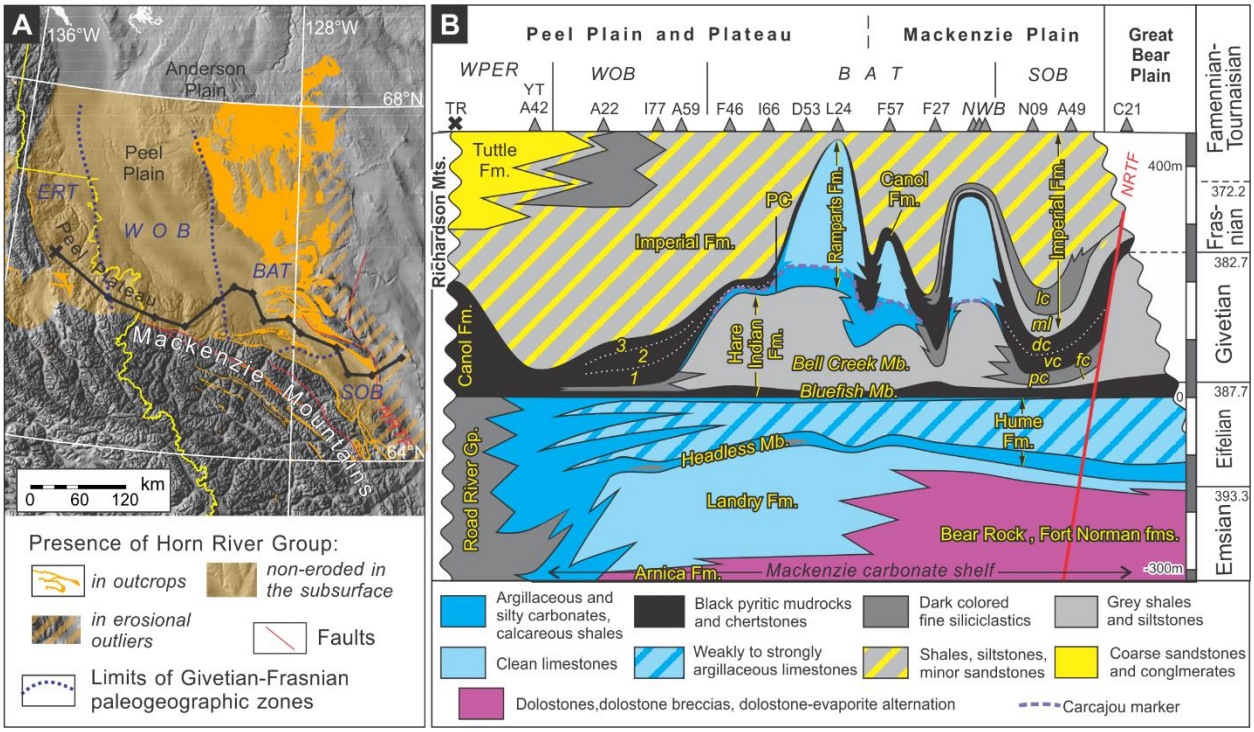

Figure 1. (A) Geographic spread of the Horn River Group between 64 and 68°N (Kabanov, 2019, modified). Palaeogeographic zones: (ERT) – eastern Richardson Trough and western Peel Shelf, (WOB) western off-bank area, (BAT) bank-and-trough area, (SOB) southern off-bank area. (B) Cross-section (black line on A);

top of Hume Formation as datum; wells from W to E: Cranswick YT A-42, Cranswick A-22, S. Ramparts I-77, N. Ramparts A-59, Ramparts River F-46, Hume River I-66, Hume River D-53, Carcajou L-24, Maida Creek F-57, Hoosier F-27, NWB is Norman Wells oilfield, Little Bear N-09, Bluefish A-49, and Bracket Lake C-21; Stratigraphic members in SOB: (fc) Francis Creek, (ps) Prohibition Creek, (vs) Vermillion Creek; (dc) Dodo Canyon, (ml) Mirror Lake, and (lc) Loon Creek. NRTF is Norman Range thrust fault (other tectonic elements are not shown). The Canol Formation in WOB area is subdivided into (1) lower, (2) middle, and (3) upper informal members.

Lithostratigraphic framework and facies zones

The Eifelian-Frasnian strata in the subsurface of Peel Plain and Plateau, Anderson Plain, and Mackenzie Valley north of 64.5ºN (Keele Arch is the southern limit of the study area) are being studied to update the stratigraphic framework (Fig.1), including borehole-outcrop correlations, chemostratigraphy, biostratigraphic age, and, in part of the study area, XRF surveys of cutting samples in legacy wells. This upgrade includes revised tops in 126 exploration wells in NTS areas 96 and 106 and establishment of formal and informal members within the Hume, Hare Indian, Ramparts, Canol formations, and the basal beds of the Imperial Formation (Kabanov and Gouwy, 2017; Kabanov et al., 2019). The core coverage is scarce except for 5 recently drilled wells in central Mackenzie Valley. This succession was measured in several reference outcrops of the adjacent ranges of the northern Mackenzies and Franklin Mountains with surface-subsurface correlation achieved through spectral gamma-ray (SGR) surveys of outcrops. The lateral facies changes in these strata are described as four facies zones, each having a separate layout of member-rank units mappable in the subsurface with legacy borehole logs, sample descriptions, and XRF surveys of cutting samples (Fig. 1; Kabanov et al., 2019). The resultant novelty is quite significant. For example, the top of Canol picked in 101 historical wells in NWT has 46 entries that are different in more than 3 m from tops of Hogue and Gal (2008). Thirty-five out of 55 wells are in likewise disagreement with the Canol tops of Pyle et al. (2014). Major change in excess of 15 m occurs in 32 out of 101 Canol tops of Hogue and Gal (2008) and 26 out of 55 tops of Pyle et al. (2014).

Paleoceanographic control

At least four horizons of enhanced anoxia (AHs) are recognized in the uppermost Eifelian – Middle Frasnian mudrock-dominated strata of the Mackenzie Valley and Peel area of NW Canada. Aluminum-normalized Mo and U logs in two cored sections reveal the AH-I at the Eifelian/Givetian boundary, AH-II in basal Frasnian, and AH-III and AH-IV bundled in the Middle Frasnian interval (Kabanov, 2019). These four horizons are characterized by reduced siliciclastic components. K+Th and U components from SGR are the best tools to trace these horizons in wells and outcrops. Updated conodont biostratigraphy correlates AHs a with “black-shale events” in several basins of the world (Fig. 2). The depositional environment is depicted as a stratified, relatively shallow-water basin with photic-zone euxinia, where the water-column chemocline defined co-sedimentation of anoxic mudrocks in topographic lows and oxic grey shales and carbonate banks on elevated areas of the seafloors. Based on ICP elemental data from 1687 samples, siliciclastics-lean basinal mudrock units that host AHs are strongly enriched in Mo compared to siliciclastic-rich units and show strong U/Mo covariation ($r \approx 0.8$ in Canol Formation and Bluefish Member). Supported by a lack of geological evidence for an oceanographic barrier, this enrichment indicates unrestricted water exchange with Panthalassa. At the same time, oligotrophy is indicated by a lack of P enrichment through the entire black-shale succession. These features can be reconciled through the model of Kidder & Worsley

(2010), which involves a global shift to a warm greenhouse mode with slowed oceanic convection, expanded oxygen-minimum zones, and no nutrient resupply from upwelling. The onset of mass degassing in continental LIPs represents a potential trigger for these mid-Devonian shifts (Fig. 2). Devonian black-shale events in this scenario represent genuine oceanic anoxic events marking hothouse episodes in their nascent form (Kabanov, 2019).

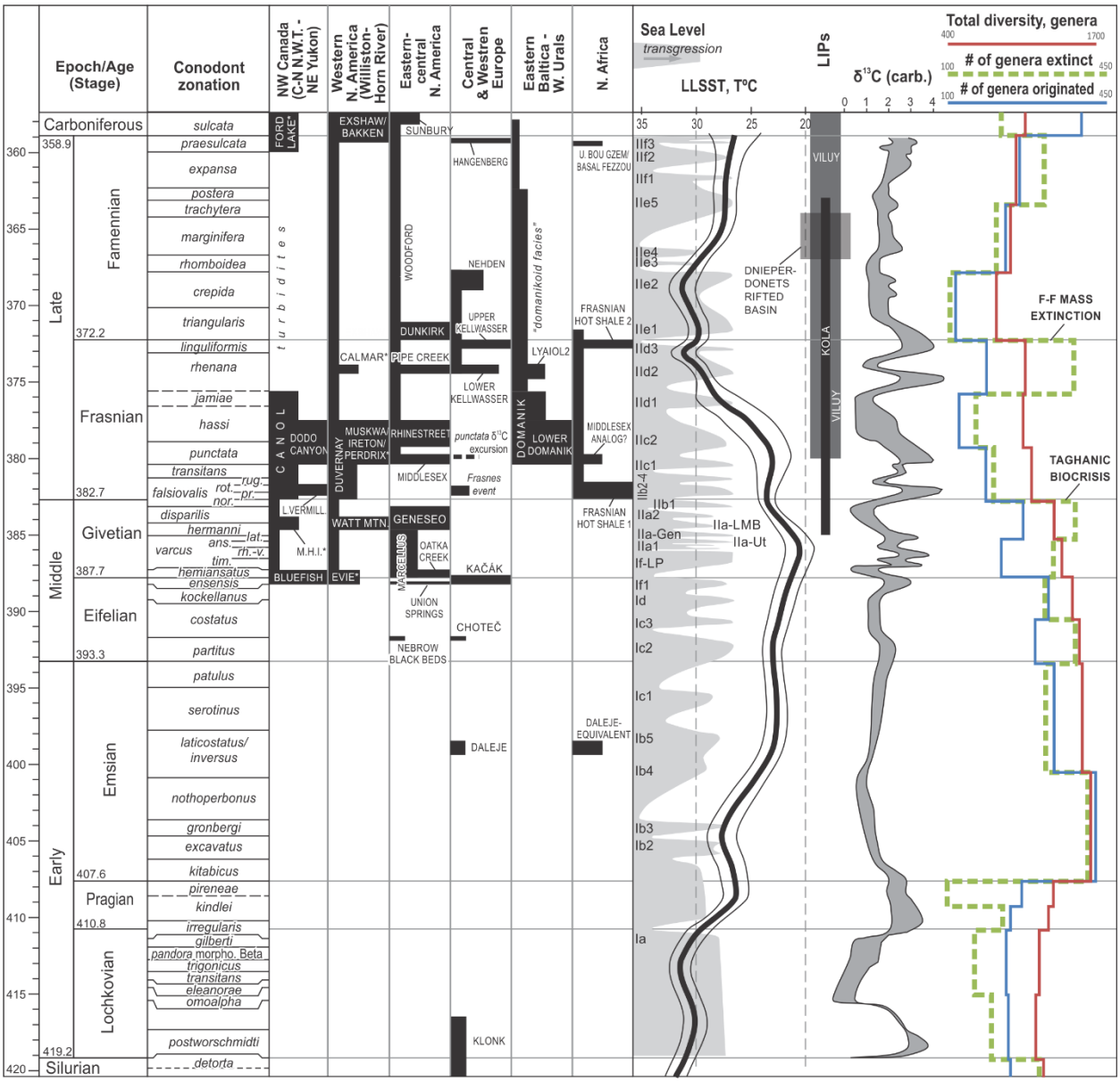

Figure 2. Occurrence of anoxic black shales in six global regions plotted against sea level curve, $\delta^{13}C$ curve from skeletal carbonate, low-latitude sea-surface temperatures (LLSST) from $\delta^{18}O$ of conodont apatite, extinction-origination curves for marine fauna (Paleobiology Database), and age ranges of Large Igneous Provinces (LIPs). Calibration of radiometric ages from GTS 2012. Extended figure caption with references is available in (Kabanov, 2019).

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