

The Devonian of Western Canada Sedimentary Basin: enormous yet underused archive of outcrops and exploration wells for fundamental research

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Abstract. In its new expanded definition, the Western Canada Sedimentary Basin (WCSB) is the vastest intracratonic sedimentary basin in the World. Over 620,000 exploration wells, the majority drilled in Alberta and Saskatchewan, provide enormous archive of cores, geophysical logs, and cutting samples available at provincial and federal oil-and-gas regulator facilities. The Devonian succession is particularly thick and economic. This subsurface archive is supplemented by outcrops of the fringing Cordilleran ranges. This paper highlights recent developments in fundamental research made on the Devonian cores and outcrops, just to emphasize how much more can be done to expand our knowledge on the Earth-surface processes of the middle Paleozoic.

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INTRODUCTION

The Western Canada Sedimentary Basin (WCSB) has been historically defined from Montana and South Dakota on the south to the southern Northwest Territories (NWT) at its northern edge. It tapers to zero against the Canadian Shield on the east, and westward it laps onto the eastern Cordillera (the Rocky Mountains and the Foothills) where the sedimentary basin fill attains its greatest thickness in the excess of 7 km (MacKay and Pedersen, 2022). In this geographic definition, the WCSB was the second largest sedimentary basin

in the World by area (1.4 million km²), also one of the most prolific hydrocarbon provinces with the third largest oil reserves (171 billion barrels as of 2019). A recently launched national initiative “WCSB Atlas 2027” extends the geographic definition by including the northern interior plains in the NWT up to the Mackenzie River Delta (Lynch *et al.*, 2023). Whereas inclusion or exclusion of the Cordillera westward to the preserved margin of Paleozoic-time Laurentia is under debate (*ibid.*), the new definition of the WCSB as the Paleozoic–Mesozoic sedimentary basin and the fringing mountain ranges all along the Cana-

dian portion of western Laurentia (Fig. 1a) makes it the vastest intra-continental sedimentary basin in the world. More than 620,000 exploration wells have been drilled in WCSB within Canadian jurisdictions. All provincial governments require that data associated with wells (cores, analyses, well

logs, test and production data) be provided to the government. Exploration wells drilled in territorial jurisdictions are similarly curated by the Geological Survey of Canada – Calgary, part of the federal agency Natural Resources Canada. This regulated curation of subsurface materials, amplified by

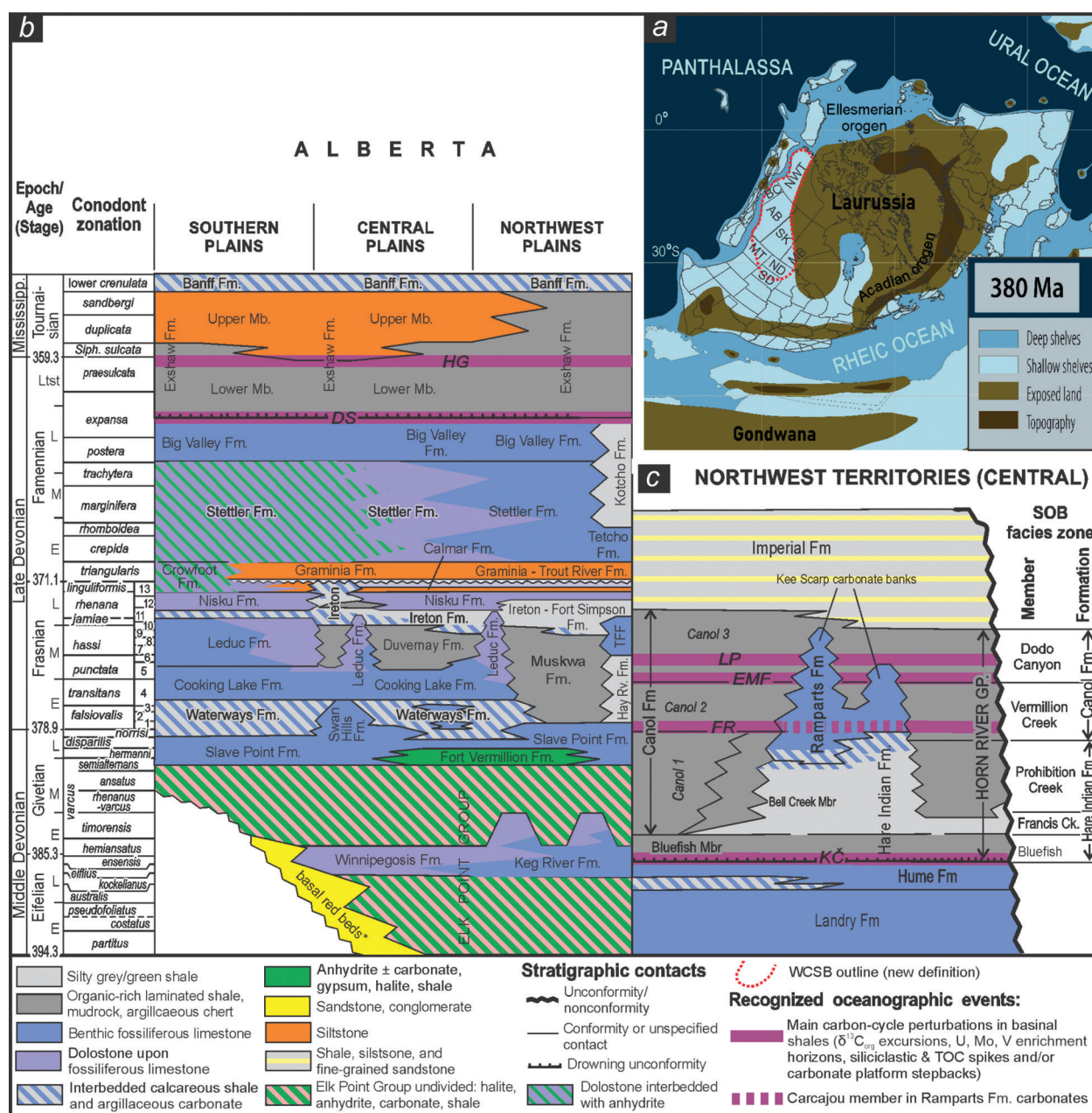


Fig. 1. *a*) Paleogeography of WCSB during the Late Devonian (courtesy of Chloé Markussen Marcilly / PHAB (Centre for Planetary Habitability), University of Oslo). Main jurisdictions within the WCSB: NWT = Northwest Territories; BC = British Columbia; AB = Alberta; SK = Saskatchewan; MB = Manitoba; MT = Montana; ND = North Dakota; SD = South Dakota. *b*, *c*) Middle–Late Devonian chronostratigraphic charts for Alberta (*b*) and the central Northwest Territories (*c*). Time calibration from Geologic Time Scale 2020; only main conodont zones are shown; numbered are Montagne Nour (MN) conodont zones. TFF = Twin Falls Formation.

availability of outcrops, opens opportunities to set up and conduct a broad range of fundamental research.

The Devonian succession is thick (>1.0 km in WCSB depocenters) and has manifold economic utility at its shallow to intermediate burial (~0–3000 m) over much of its expanse to the east of the Cordillera. Thus, it hosts major sourcerocks (basinal organic-rich shales) and a diversity of conventional hydrocarbon reservoirs in carbonate buildups and hydrothermal dolostones. The southeastern WCSB is also world's leading producer of potash, making up to 40% of world supply from the sylvitic-carnallitic salts of Saskatchewan (SK). The historical usage of this enormous sedimentary archive contributed to fundamentals of carbonate sedimentary geology and recognition of biotic-paleoenvironmental perturbations of the middle Paleozoic in the 1960s–1990s. A lot of R&D activity is currently underway, including projects on geothermal energy, Li extraction from brines, underground CO₂ burial and clean energy storage. Devonian saline aquifers, sills, depleted hydrocarbon reservoirs, and salt formations are widely prospected for these applications. Recent usage of the Devonian sedimentary archive for enquiries into then-time Earth-surface processes, biotic evolution, and refining the Geologic Time Scale, on the other hand, is admittedly timid. A few most recent developments are highlighted below.

GEOTECTONIC REGIME

The geotectonic regime of the western continental margin of Laurentia is usually described as a passive margin since Neoproterozoic–Cambrian rifting and until the Famennian, although such interpretation is not devoid of conjecture due to heavy overprint of Late Mesozoic–Early Cenozoic orogenic tectonism and associated igneous processes. During the Devonian–Mississippian, the vast expanse of the WCSB (Fig. 1) was a contiguity of basins/depocenters separated by arches in antecedent topography. Over the Middle–Late Devonian, these arches became buried under shallow-water sediments.

DEVONIAN SOUTH OF 60°N

In the Provinces (south of 60°N), the basal Devonian succession (the Elk Point Group) is dominated by evaporites (Fig. 1b, 2), including thick salt units of manifold economic use (Hauck, 2020; Kabanov *et al.*, in press). The age of the Elk Point Group is poorly constrained due to a lack of biostratigraphic data

from basal evaporites. The oldest Devonian beds can be Emsian or Lochkovian (Hauck, 2020). The Elk Point Group is succeeded by an assemblage of open-marine platform carbonates and the shale basins hosting isolated carbonate banks and pinnacles (time-specific bank-and-trough facies architecture; Kabanov *et al.*, 2023a, b). An advanced sequence stratigraphic framework supported by conodont ages is available for these strata in Alberta (Wong *et al.*, 2017). The Famennian succession mostly represents a geographically extensive carbonate platform with evaporites in its interior (Fig. 1b). A regional switch to anoxic sedimentation occurred in the late Famennian in the early–middle *expansa* conodont Zone in Alberta (Hedhli *et al.*, 2023), but locally (Williston Basin, southeastern WCSB) earlier in the middle Famennian (Sahoo *et al.*, 2023). Hedhli *et al.* (2023) discuss association of this major facies shift with the Dasberg anoxic event and the role of activated tectonism and the encroachment of the volcanic arc at the western margin of Laurentia, although the euxinic model of these authors may not withstand scrutiny.

DEVONIAN NORTH OF 60°N

The Early Devonian in the NWT and adjoining regions of eastern Yukon is dominated by peritidal carbonates and, locally, evaporites. This succession is generally more complete and more offshore than south of 60°N, with more conodont ages available (Gouwy, 2022). Evaporitic and peritidal deposits of the Early Devonian–early Eifelian are succeeded by fossiliferous benthic carbonates of middle to late Eifelian age (Kabanov, 2022). A major step-back of benthic carbonates and switch to anoxic sedimentation occurred during the latest Eifelian *ensensis* Zone (Fig. 1c), making it a time match with the global Kačák event, although our $\delta^{13}\text{C}(\text{org})$ data do not reveal isotopic excursions characterizing this event in other world regions (Kabanov *et al.*, 2023b). In northeastern Yukon, this surface is traced as a condensed section hyper-enriched in barite and Ni–Mo–Zn–Pt–Pd–Au–Re, which is seen as a result of metal drawdown from an anoxic water column in combination with the extreme sediment starvation (Gadd *et al.*, 2020). During the Middle Devonian, a belt of aggrading carbonates called Presqu'île Barrier formed across the present-day triple junction of NWT, Alberta and British Columbia in the Eifelian–Givetian (Fig. 2b). This belt acted as an effective water-exchange barrier between the Elk Point evaporitic basin and the Horn River open-ma-

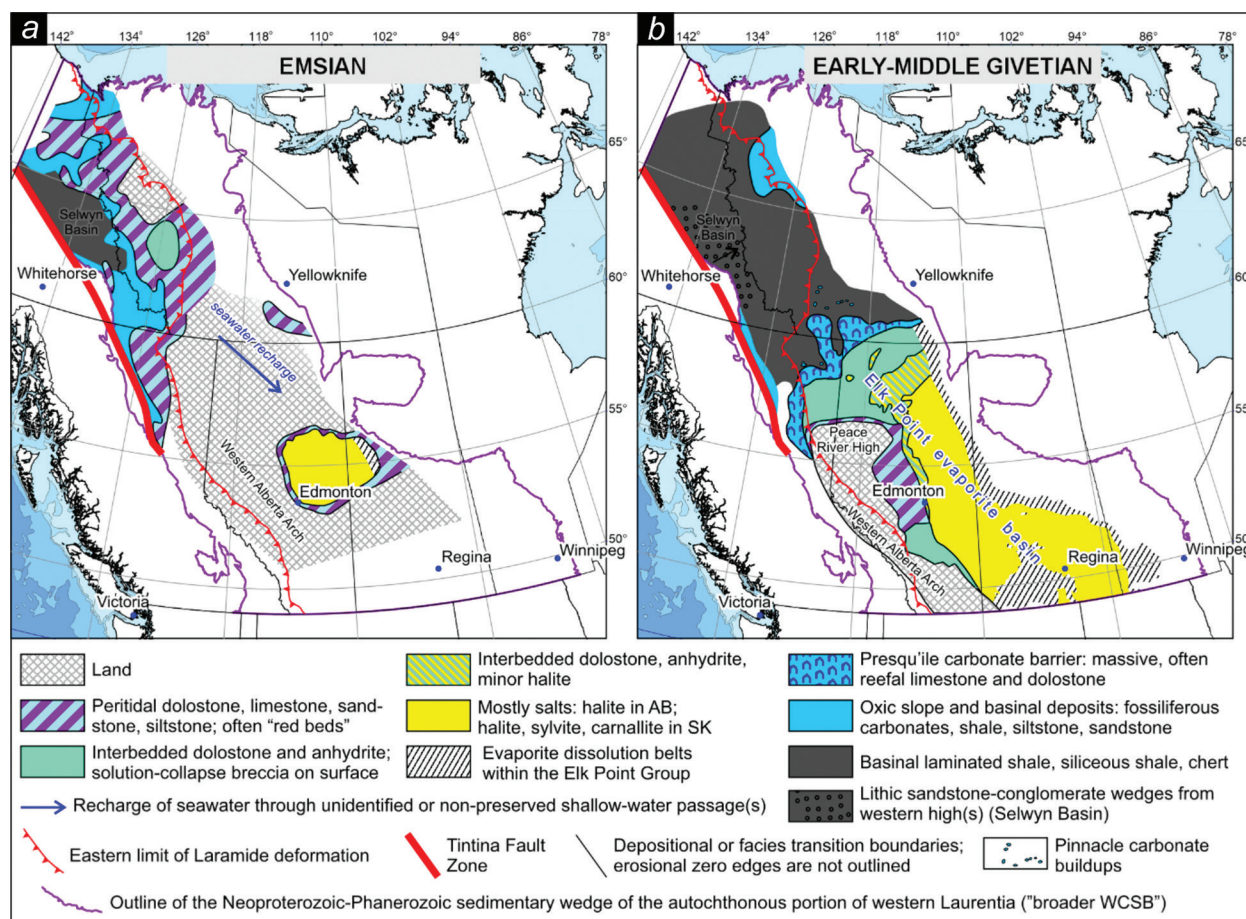


Fig. 2. Paleogeography of western Laurentia (Canadian part) during the deposition of basal Devonian evaporites (Kabanov *et al.*, in press): a) Emsian–early Eifelian; b) early–middle Givetian. Note semi-landlocked character of the Elk Point evaporite basin with Western Alberta – Peace River landmass on the west and seawater recharge passage through northwest.

rine basin with anoxic bottom condition (Fig. 2b). The black-shale strata, wedges of gray shale-siltstone, and isolated carbonate banks bundled in the Horn River Group are the latest Eifelian to middle Frasnian in age (Fig. 1c; Kabanov *et al.*, 2023a, b). The laminated, siliciclastic-lean shales and cherts of the Horn River Group grade upward into a thick succession of foreland clastics bundled in the Imperial and Tuttle formations (Fig. 1c). Recent $\delta^{13}\text{C}(\text{org})$, trace-metal, and gamma spectrometry data from the Horn River Group reveal fine records of multiple carbon-cycle perturbations that are matched with conodont ages to the Frasnian, basal *punctata* (i.e., early–middle Frasnian), and late *punctata* global events (Kabanov *et al.*, 2023a, b).

Finally, strong presence of trimethyl aryl isoprenoids and isorenieratane in organic extracts from black shales of the Horn River Group indicates photic-zone euxinic condition. Based on lit-

erature review and our new unpublished data, same biomarkers are invariably present in less thermally mature ($T_{\text{max}} \leq \sim 440\text{--}450\text{ }^{\circ}\text{C}$) drill cores from the Duvernay, Muskwa, and Exshaw/Bakken anoxic sediments of the southern WCSB (Fig. 1b). In combination with facies observations, these findings suggest that intermittent photic-zone euxinia was a persistent condition of the stratified yet oceanographically open-shelf basin of western Laurentia during the second half of the Devonian, as well as in many coeval shelf basins of the world (Kabanov *et al.*, 2023b).

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