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The Lower and Middle Triassic of Western Canada: Passive margin, Back-Arc or Fore-Arc geodynamic setting?

Sébastien Rohais, IFP Energies nouvelles, France
Vincent Crombez, IFP Energies nouvelles, ISTeP, France
Tristan Euzen, IFP Technologies (Canada) Inc., Canada
François Baudin, ISTeP, France

Summary

The Montney, Doig and Halfway Formations were deposited during the Triassic in the Western Canada Sedimentary Basin (WCSB). The palaeogeographic reconstruction and even the geodynamic setting of these formations are still a matter of debate. Passive margin, Back-Arc or Fore-Arc geodynamic settings have been proposed for the Triassic of WCSB during the last 30 years, nevertheless, no definitive clues have been recognized in the sedimentary records to propose the most likely solution. This debate is by itself of great scientific interest but also has major implications on the petroleum system (source rock distribution, heat flow, burial history).

In this paper, we present sedimentary, geochemical and stratigraphic evidences from Lower and Middle Triassic series in the WCSB (subsurface and outcrops) combined with a geodynamic analysis suggesting that a Fore-Arc geodynamic setting is in our opinion the best interpretation.

Introduction

The Canadian Rockies are very well known for their terranes and associated foreland basin initiated during the Mid-Jurassic. Nevertheless, the timing of the terrane amalgamation and mountain belt accretion are still debated (e.g. Oldow et al., 1989; Ricketts, 2008). Meanwhile, most of the publication indicates that an older passive margin was located in this area from the Proterozoic, Cambrian to the Late Triassic? (e.g. Dickinson, 1977; Monger and Price 1979; Coney et al., 1980; Price, 1994). Transition from one phase to the other should be recognized especially because passive margin and foreland are two extreme end-members of a basin evolution. This transition may involve complex scenarios and multiple interpretations have been proposed (e.g. Oldow et al., 1989; Nelson et al., 2006; Johnston and Borel, 2007; Miall and Blakey, 2008).

The Montney, Doig and Halfway Formations were deposited in the WCSB during this Triassic turn over phase and different interpretations are still debated about their geodynamic setting and paleogeographic reconstruction. For instance, the paleogeographic maps published by Miall and Blakey (2008) suggest a Back-Arc setting that is also supported by other studies (e.g. Zonneveld et al., 2010), while the new series of paleogeographic maps published by Blakey (2014) suggest a Fore-Arc setting based on the work of Nelson et al. (2006) and Colpron et al. (2007). Recently, Onoue et al. (2015) suggest that the Upper Triassic was deposited in a distal ramp environment on the passive western margin of the North American craton.

In this paper, we present results of a basin analysis, sedimentological, geochemical characterization and sequence stratigraphy studies to support the geodynamic setting of the Montney, Doig and Halfway Formations.

Stratigraphic architecture of the Montney-Doig-Halfway Fms

Four main sequences have been recognized in the Montney, Doig and Halfway Formations from the proximal to the most distal setting (Crombez et al. a, submitted). The first three sequences (1, 2 and 3) correspond to third order sequences that are equivalent to the Montney Formation as defined in British Columbia (BC), of Early Triassic age. These sequences are organized in a full second order cycles with sequence 1, 2 and 3 corresponding to TST-, HST- and FSST/LST-like packages respectively. Sequence 4 corresponds to a second order sequence that is equivalent to the Doig and Halfway Formations as defined in BC, of Middle Triassic age. It can be subdivided into three third order sequences 4a, 4b to 4c. Sequence Boundary 4 (SB4) is a main surface that recorded a major turn over in the basin dynamic. Other evidences from Sequence 3 suggest that this major turn over may have started as early as SB3.

The stratigraphic architecture of Sequences 1, 2 and 3 in Alberta suggests a margin setting that progressively tilted to the West. The distribution of turbiditic systems indicates that the basin floor was progressively deformed to create large depressions aligned along the future foreland basin axis. In most distal settings (Present day trust and fold belt in BC), Sequences 1, 2 and 3 were starved and organized in a shallowing upward trend.

Sequence 4 recorded a progressive increase of the Southern and Western sedimentary sources implying emerging land to the West and/or South West. The basin axis progressively shifted eastward. Meanwhile, the most distal setting (initially to the West) was rapidly uplifted (non deposition, possible erosion?).

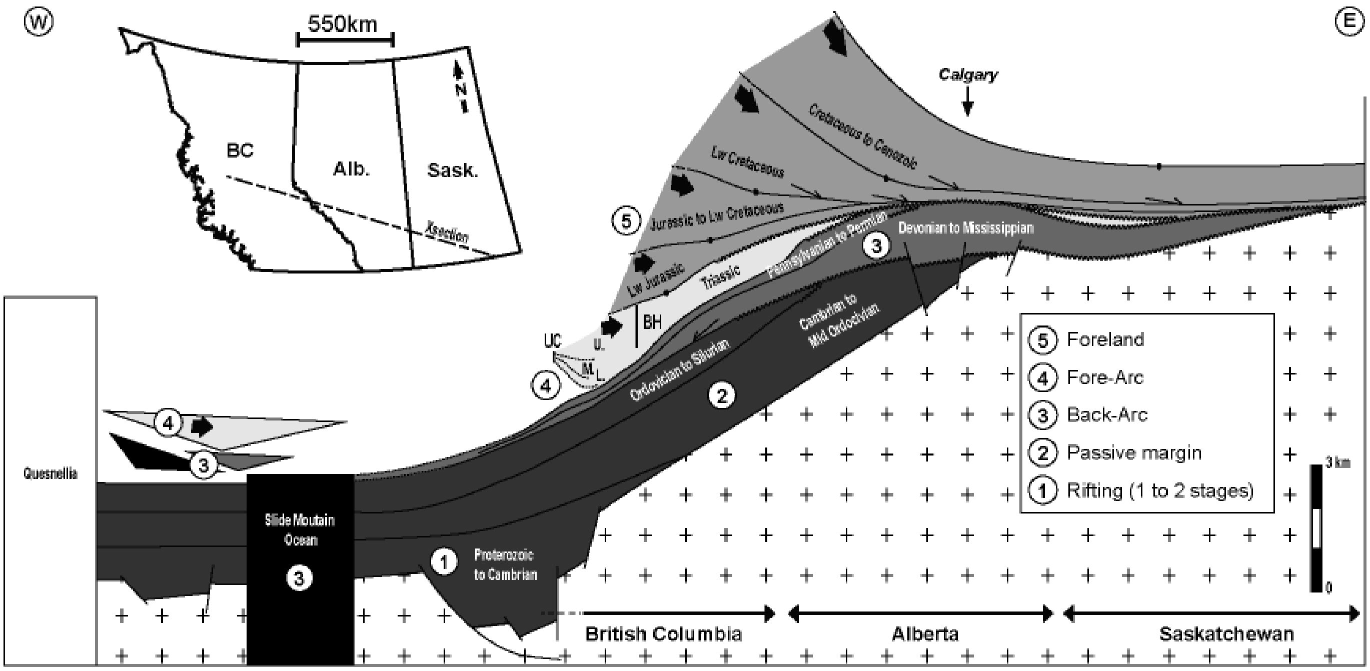

Figure 1: Simplified cross section across the Western Canada Sedimentary Basin. Thicknesses, timing and geometries are modified from Oldow et al. (1989), Price (1994), Nelson et al. (2006) and Colpron et al. (2007). Black arrows indicate the western sedimentary inputs starting in the Triassic in the WCSB and potentially as early as Late Permian along the accreted Arcs. Black dots indicate the basin axis. BH: Brown Hill section. UC: Ursula Creek section. L. Lower, M. Middle, U. Upper. (Rohais et al., in prep).

Basin dynamic

Several key elements can be highlighted:

Trace element and Rare Earth Element (REE) concentration were measured along severals sections from the most distal to the most proximal setting. Comparison with regional Triassic provenance geochemistry suggest that an arc provided sedimentary inputs from the western part of the basin. The relative proportion of arc derived sediment increase though time during the Triassic, which is consitent with previous studies in BC (Unterschutz et al., 2002).

Trace element combined with Rock-Eval analysis interpreted in terms of paleo-environmental conditions indicate that the basin was progressively disconnected from open marine conditions during the Early to Middle Triassic (Crombez et al. b, in prep). Sedimentological interpretation also confirms this trend as the Late Triassic is mainly characterized by restricted sabkhra deposits.

Subsidence and burial history analysis indicate that the basin was progressively tilted to the West during Early Triassic (Seq. 1, 2 and 3). A change in the subsidence regime (spatial and rate) was then recorded during the Middle Triassic (Seq. 4).

Discussion and conclusion

Basin analysis, sedimentological and stratigraphic correlation proposed in this paper indicate:

- A stratigraphic architecture of the lowermost part of Early Triassic (~Montney Fm, Giesbachian-Dienerian, Seq. 1) diagnostic of a “passive” margin setting;
- A basin floor progressively structured to form a large depression aligned with the future foreland axis (at least from Seq. 2);
- A progressive uplift of the westernmost part of the basin (present-day BC, distal setting during the Early Triassic) during Middle Triassic (Anisian-Ladinian), followed by another pulse of subsidence during Late Triassic (Carnian);
- Western sedimentary inputs from Middle Triassic (Seq. 4) and large-scale subsidence (shallow and flat basin) recorded by the Late Triassic (Carnian)
- Evidences for a progressive restriction and disconnection from the open marine setting from Early to Middle Triassic (potential sea water stratification?)

Although the eastern part of the basin shares many similarities with a passive margin setting, especially during Early Triassic, evidences from an active volcanic arc during sedimentation as well as basin deformation patterns are not consistent with such an interpretation.

Our analysis don’t support a back-arc basin interpretation either, because it is not compatible with a progressive uplift of the most distal part of the basin

All the evidences presented in this paper support the following East to West basin architecture: (1) a margin facing an open marine domain to the West that was progressively tilted and uplifted, (2) a basin axis structurally deformed during sedimentation along NW-SE trends, (3) a distal starved basin progressively uplifted during Lower to Middle Triassic that could be interpretated as a proto accressionary prisme, and (4) an active arc island and emerging lands feeding from West to East the western part of the basin. Concequently, a fore-arc basin is in our opinion the most likely interpretation for the geodynamic setting during the Triassic in the WCSB. It is consistent with the most recent series of palaeogeographic maps published by Blakey (2014). This work provides new constraints to document the timing of this Fore-Arc, just prior to the establishment of a foreland basin.

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