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1 **Subsidence dynamics of the Montney Formation (Early Triassic, Western Canada**
2 **Sedimentary Basin): insights for its geodynamic setting and wider implications**

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15 **ABSTRACT**

16 This study presents the first published subsidence analysis during the deposition

17 of the Montney Formation. It was deposited during the Early Triassic (ca. 252.2-

18 245 Ma) in the Western Canadian Sedimentary Basin (WCSB) located along the

19 western margin of the North American craton. Subsidence analyses of six

20 representative wells and two outcrop sections along a proximal to distal transect

21 are presented using a backstripping method integrating recent high-resolution

22 stratigraphic correlations for the Montney Formation. The entire Paleozoic to

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23 Cenozoic sedimentary column of the WCSB was backstripped to put the
24 deposition of the Montney Formation into a broader context and provide results
25 regarding the type of subsidence and geodynamic setting for the Montney
26 Formation.

27 The spatial and temporal evolution of the subsidence during the deposition of the
28 Montney Formation indicates that the most likely basin setting is a foreland. The
29 tectonic subsidence during the Triassic is herein interpreted as a combination of
30 the topographic loading of the orogenic wedge (flexure) and the sublithospheric
31 “loading” caused by slab load-driven subsidence (dynamic subsidence). This
32 suggests that the retro-foreland basin setting was associated with an eastward
33 dipping subduction during the deposition of the Montney Fm.

34 Three foreland stages are thus recorded in the whole WCSB, with evidence for (1)
35 a Late Permian (fore-arc) pro-foreland setting, then (2) a Triassic collisional retro-
36 foreland basin prior to the well-known (3) Jurassic-Cenozoic collisional retro-
37 foreland.

38 INTRODUCTION

39 The Canadian Cordillera is very well known for their terranes and the associated
40 collisional retro-foreland traditionally interpreted to be initiated during the Mid-
41 Jurassic. Two main stages are classically inferred to describe their tectonic
42 evolution (Price, 1994 and reference herein) with a first (1) Late Proterozoic to
43 Jurassic “miogeocline-platform” stage where the Western Canada Sedimentary
44 Basin (WCSB) is described as a “passive margin”, and a subsequent (2) Jurassic to
45 Eocene collisional foreland stage. Transition from one stage to the other should
46 be easily recognized especially because passive margin and foreland are two

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47 extreme end-members of basin evolution. This transition may involve complex
48 scenarios. Multiple interpretations have been proposed and debated for the
49 Permian to Triassic periods in Canada during which the Montney Formation (Early
50 Triassic) was deposited. For instance, the paleogeographic maps published by
51 Miall and Blakey (2008) suggest a back-arc setting that is also supported by other
52 studies (e.g. Zonneveld et al., 2010). Controversy, the new series of
53 paleogeographic maps published by Blakey (2014) suggest a pro-foreland in a
54 fore-arc setting based on the work of Nelson et al. (2006), Colpron et al. (2007)
55 and Mortensen et al. (2007). Recently, Onoue et al. (2015) suggest that the Upper
56 Triassic was deposited in a distal ramp environment on the passive western
57 margin of the North American craton. The debate about the geodynamic setting is
58 mainly related to three key issues for the entire North American Cordillera
59 orogen: 1) what was the exact location of the different terranes including island
60 arcs, oceanic crust and small cratonic masses during the Paleozoic (e.g. Monger
61 and Price, 1979; Coney et al., 1980, Monger et al., 1982; Johnston and Borel,
62 2007; Beranek and Mortensen, 2011; Colpron et al., 2015) ? 2) What was the type
63 and timing of initial accretion and was the margin cylindrical, i.e. could we export
64 the Antler-Sonoma orogeny evolution from North America to the Canadian
65 Cordillera (e.g. Speed and Sleep, 1982; Oldow et al., 1989; Barclay, 2000;
66 Mortensen et al., 2007; Fuentes et al., 2009; Sigloch and Mihalynuk, 2013) ? 3)
67 What was the timing and amplitude of post-Triassic large oblique-slip
68 displacement (e.g. Gabrielse, 1985; Irving et al., 1985; Engebretson et al., 1985;
69 Saleeby and Busby-Spera, 1992; Dickinson, 2004) ?
70 While most of these scenarios are based on geological mapping, volcanic and
71 magmatic occurrences, structural restoration and geodynamic reconstruction of
72 exotic terranes, little evidence has been derived from the sedimentary record in

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73 the WCSB to document and constrain the timing of deformation. Beranek and
74 Mortensen (2007, 2011) and Colpron et al. (2015) published geological mapping
75 and sediment provenance analysis using detrital zircons to infer compressional
76 setting in Yukon during the Triassic. The geodynamic and basin setting during the
77 deposition of the Montney Formation thus becomes an issue (Ferri and
78 Zonneveld, 2008). Recent provenance analyses using detrital zircon of Triassic
79 sedimentary rocks in British Columbia and Alberta indicate an active sedimentary
80 source to the west (Golding et al., 2016), providing additional evidence to support
81 a westward emerging land (Tozer, 1982; Gibson and Barclay, 1989). Nevertheless,
82 it is still unclear whether the Triassic succession, including the Montney Fm., was
83 deposited in an early retro-foreland setting, as the Jurassic setting, or pro-
84 foreland setting, or even during a renewed rapid extensional event in a back-arc
85 setting along the inherited Paleozoic passive margin. A fundamental difference
86 between these types of basins is that the subsidence evolution shows uniqueness
87 in its temporal and spatial trends (Fig. 1, e.g. Naylor and Sinclair, 2008; Sinclair
88 and Naylor, 2012 and references herein). For example, additional accommodation
89 to flexural tectonics may be created by the superimposed effects of dynamic
90 subsidence in retro-foreland (slab-related), a mechanism not possible in pro-
91 foreland basins (Fig. 1). Likewise, passive margin and back-arc setting are primarily
92 dominated by increasing subsidence when going seaward in response to thermal
93 cooling and no processes could account for an entire inversion and uplift of the
94 most distal environments (Fig. 1).

95 Detailed subsidence analyses have been published for the early stage of the WCSB
96 basin evolution, thus illustrating its thermal subsidence dynamics during the Early
97 Paleozoic (Bond and Kominz 1984). The subsidence evolution of the Jurassic
98 collisional foreland basin has also been addressed and characterized in several

1 99 studies (Price, 1994; McCartney, 2012). However, the subsidence dynamic of the
2 100 Triassic in the WCSB has not previously been characterized. Here, we present
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4 101 subsidence analyses using a backstripping method integrating recent high-
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6 102 resolution stratigraphic correlations for the Montney Formation (Crombez, 2016;
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8 103 Crombez et al., 2016; Euzen et al., this volume). Backstripping the sediment and
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10 104 water fill allows the effects of sediment and water loading to be quantitatively
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12 105 determined, thus isolating the remaining effect of the tectonic driving forces
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14 106 (Watts and Ryan, 1976). We backstripped six wells and two outcrop sections along
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16 107 a proximal to distal transect (approx. NE to SW) to quantify the spatial and
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18 108 temporal evolution of the subsidence during deposition of the Montney Fm.. In
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20 109 order to constrain the driving forces for subsidence, the overall basin evolution,
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22 110 from the Early Paleozoic to recent, was taken into account. Subsequently, we
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24 111 analyzed the entire backstripped subsidence to quantify the relative influence of
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26 112 thermal, flexure and sediment loading. Sediment fluxes were also discussed using
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28 113 solid siliciclastic accumulation rates to constrain uplift dynamics. Finally, by
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30 114 integrating the proposed evolution into the evolution of the Canadian Cordillera,
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32 115 we can discuss a geological scenario to constrain the geodynamic evolution during
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34 116 Montney Formation deposition.
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43 **DATA AND METHOD**

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46 118 The tectonic subsidence curves were generated using GENEX software for six
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48 119 subsurface wells and two outcrop sections (Fig.2, Table 1). These curves
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50 120 document basin dynamics during Montney Formation deposition. GENEX is a
51
52 121 numerical simulation program developed by IFPEN (IFP Energies nouvelles) during
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54 122 the 1980's that integrates subsidence, thermal and pressure reconstruction,
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56 123 maturity and compositional petroleum generation and expulsion. The full
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124 workflow and concepts in GENEX to backstrip wells, have been detailed in
125 Ungerer et al. (1990) and Forbes et al. (1991). GENEX has been widely used in
126 various types of basin and petroleum systems (Faure et al., 2004; Rudkiewicz et
127 al., 2007; Rohais and Moretti, 2017). In the present study, we took benefit of the
128 work of Ness (2001) that already carried out 1D basin analysis on sixteen wells in
129 the WCSB to understand when hydrocarbons in WCSB Triassic reservoirs were
130 generated and expelled from their sources. By matching burial and thermal
131 history with available vitrinite reflectance datasets, Tmax (determined by Rock-
132 Eval pyrolysis), bottom-hole temperatures, pressure profiles, and apatite fission
133 track analyses, Ness (1991) achieved a well-constrained basin analysis and
134 restored a geologically reasonable basin dynamic scenario. Based on the work of
135 Ness (1991), we used here a selection of six wells (Table 1) from the westernmost
136 part of the WCSB (autochthonous foreland) and adjacent allochthonous units of
137 the foreland-and-thrust belts and processed these wells in GENEX to compute the
138 tectonic subsidence.

139 Total subsidence and tectonic subsidence after sediment decompaction were
140 restored through time, by integrating porosity-to-depth laws for each lithology,
141 paleobathymetry, eustatic variations and erosion values (Airy type model such as
142 in Steckler and Watts (1978)). The paleobathymetry values are derived from
143 geometrical restorations based on sedimentological and sequence stratigraphy
144 studies (Crombez, 2016; Crombez et al., 2016). The most important source of
145 error when backstripping well sections is uncertainty in paleobathymetry. Thus,
146 we chose to explore a large range in paleobathymetry (+/- 50% of the mean
147 estimated paleo-water depth value, see Table 1).

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148 To discuss the potential influence of post-rift thermal subsidence, we estimated
149 the stretching with the Beta factor (β) (i.e. ratio between the initial crustal and the
150 final crustal thickness; McKenzie, 1978) using the Lithoprobe section interpreted
151 by Monger and Price (2002) that is presented in Fig. 2. The values are presented in
152 Table 1.

153 The full data set for backstripping is available as supplementary material in the
154 appendix (two outcrop sections and six wells). Fig.3 presents the formations and
155 their tops, the groups derived from the Alberta Geological Survey (2015) and the
156 age model used for the present study. Ages were adjusted using the most recent
157 reference (Cohen et al., 2013 updated). Triassic and Montney tops (Fig. 4) have
158 been updated using recent stratigraphic correlations (Crombez, 2016).

159 The stratigraphic architecture contains an indirect, yet quantifiable, record of
160 regional uplift that is the sediment supply. Indeed, sediment supply through time
161 can be related to uplift and denudation of the sediment source regions (e.g.
162 Bonnet and Crave, 2003; Rohais et al., 2012). Likewise, we extracted from the
163 modeled wells and outcrops solid (porosity corrected) sedimentation rates
164 (m/Myr) resulting from the siliciclastic component (sandstone, siltstone, shale)
165 that can be discussed in terms of sediment supply dynamics. These values are
166 directly available from the GENEX results.

167 **GEOLOGICAL SETTING**

168 **THE CORDILLERA: TERRANES, BELTS AND EVOLUTION**

169 The Canadian segment of the Cordillera is commonly subdivided into five
170 approximately N-S belts (Fig.2, e.g. Coney et al., 1980). Each belt is oriented
171 parallel to the overall tectonic trend and has been identified by its distinctive

172 bedrock geology, ages, physiography, metallogeny and deep-seismic expression
173 (Fig.2) (Wheeler and Gabrielse, 1972; Monger et al., 1972, 1982; Tipper et al.,
174 1981; Gabrielse et al., 1991; Hammer and Clowes, 1997; Clowes et al., 2002).

175 These belts correspond to two superterrane (Insular and Intermontane), two
176 intervening swaths of dominantly plutonic and metamorphic rocks (Omineca belt
177 and Coast belt), and the easternmost retro-foreland belt (including the WCSB)
178 that overlies and thins over the stable North American craton (Fig. 2).

179 The Intermontane superterrane includes from west to east the Stikinia (ST), Cache
180 Creek (CC), Quesnellia (Q), Yukon-Tanana (YT) and Slide Mountain (SM) terranes
181 (Fig. 2). The Omineca belt corresponds to the suture zone between the
182 Intermontane superterrane and the North American ancestral craton (Price,
183 1994). Over much of its length, the Omineca belt is bounded both side by fold-
184 and-thrust belts (Fig. 2). The Yukon-Tanana and Quesnellia terranes were
185 connected during Mid-Paleozoic times (Murphy et al., 2006; Nelson et al., 2006;
186 Colpron and Nelson, 2009; Beranek and Mortensen, 2011).

187 The timing of terrane amalgamation, as well as the timing of accretion of the
188 resulting superterrane to the western margin of ancestral North America in
189 Canada are still debated, but the most recent works provide a well-constrained
190 and consistent geological scenario that is briefly summarized hereafter.

191 The Yukon-Tanana terrane detached from western ancestral North America
192 during the latest Devonian to Early Mississippian initiation and growth of the Slide
193 Mountain Ocean (e.g. Mihalynuk et al., 1999; Nelson et al., 2006; Colpron and
194 Nelson, 2009; Beranek and Mortensen, 2011), in response to rollback of the
195 downgoing slab generating an extending back-arc region (Gabrielse, 1991; Piercey
196 et al., 2004). Persistent east-dipping subduction and expansion of the Slide

197 Mountain ocean were documented from Early Mississippian to Early Permian time
198 (e.g. Nelson et al., 2006; Colpron and Nelson, 2009; Beranek and Mortensen,
199 2011). By the Early to Middle Permian, the geodynamic setting changed when the
200 polarity of subduction reversed below the Yukon-Tanana terrane, and Slide
201 Mountain ocean lithosphere began to be consumed (Murphy et al., 2006; Nelson
202 et al., 2006; Beranek and Mortensen, 2011). The causal factor of subduction
203 reversal during the Permian remains unknown. A fore-arc setting associated with
204 a Late Permian west-dipping subduction is indicated by the presence of arc
205 magmatic, blueschist and eclogite clasts along the eastern part of the Yukon-
206 Tanana terrane (Mortensen et al., 1999). Evidence indicates that arc-continent
207 collision, and accretion of the Yukon-Tanana terrane along the ancestral North
208 American continental margin, occurred during Late Permian (Beranek and
209 Mortensen, 2011). East verging structures of latest Permian to earliest Triassic age
210 have also been described in the Slide Mountain terrane (Monger et al., 1991;
211 Saleeby and Busby-Spera, 1992). The timing for its thrusting was constrained by
212 Late Permian intrusives which cross-cut the bounding thrust fault in British
213 Columbia (Harms, 1985; Gabrielse et al., 1993). This suggests that the Slide
214 Mountain terrane most likely accreted to the autochthon during the Late
215 Permian-Early Triassic (Beranek and Mortensen, 2011), earlier than the commonly
216 inferred Middle Jurassic obduction age for Slide Mountain oceanic crust (e.g.
217 Harms, 1989; Struik et al., 1992, Murphy et al., 1995; Ferri, 1997; Ash, 2001). This
218 event in the Canadian Cordillera occurred approximately synchronous with the
219 Sonoma orogeny (Siberling, 1973) in the US Cordillera (Mortensen et al., 2007).

220 Geological thought on the Mesozoic-Cenozoic evolution of the Canadian
221 Cordillera has traditionally invoked accretion of island arcs, and their related
222 basement terranes to the western ancestral North America continental margin

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223 (Monger et al., 1982, 1991; Mihalynuk et al., 1992; 1994; Ash, 2001). In these
224 terrane accretion models, the Cache Creek terrane is interpreted as a composite
225 of Late Triassic accretionary prisms or subduction-related accretionary complex
226 associated with the Stikinia terrane, generated by Middle Triassic to Early Jurassic
227 destruction of the late Paleozoic ocean lithosphere (Cache Creek, e.g. Colpron et
228 al., 2015). Upper Paleozoic seamounts preserved in the Cache Creek terrane
229 indicate that it originated on the opposite side of Panthalassa from the Cordilleran
230 accretionary orogeny (Monger and Ross, 1971; Johnson and Borel, 2007). In the
231 late Rhaetian (late Triassic), renewed subduction beneath Stikinia was indicated
232 by sedimentary deposits in British Columbia (e.g. Barresi et al., 2015) and
233 emplacement of ca. 204–195 Ma plutons (Rhaetian-Sinemurian, Colpron et al.,
234 2015). At that time, subduction is inferred to have occurred on both sides of
235 Stikinia (ST) (Marsden and Thorkelson, 1992). The main east-dipping subduction
236 along the entire western margin of Ancestral North America was thus re-
237 established by the Middle to Late Triassic (Ferri, 1997; Colpron and Nelson 2009).
238 Crustal thickening, followed by regional exhumation of the Yukon-Tanana terrane,
239 suggests that convergence and thrusting between Stikinia, Cache Creek,
240 Quesnellia, and the North American margin had begun by the Sinemurian–
241 Pliensbachian (Early Jurassic, Colpron et al., 2015). The northern Whitehorse
242 Trough in the Yukon is thus interpreted to be a piggyback or wedge-top basin
243 during the initial stages of development of the northern Cordilleran orogeny (Early
244 Jurassic, Colpron et al., 2015).

245 The model presented herein has strong geodynamic implications. Assuming a
246 wide Slide Mountain ocean, such a model infers transition from a west-dipping
247 subduction (back-arc closure of the Slide Mountain ocean), slab detachment, and
248 east-dipping subduction from the Late Permian to the Late Triassic (e.g. Ferri,

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249 1997; Tardy et al., 2003), a time slot earlier than the Jurassic foreland evolution.

250 Assuming a narrow Slide Mountain ocean back-arc, a simple shortening by
251 imbrication would have been enough to consume the oceanic crust, associated
252 with a main “stable” east-dipping subduction.

253 By the Early to Middle Jurassic, the Insular Terrane was interacting with western
254 North America (McClelland and Gehrels, 1990; van der Heyden, 1992), and a
255 Cordillera-long continental arc developed (Gehrels et al., 2009) with a tectonic
256 regime that persisted until the early Cenozoic. The growth of the Cordilleran
257 orogeny was then accompanied by the development of Western Canada
258 Sedimentary Basin (collisional retro-foreland).

259 **WESTERN CANADA SEDIMENTARY BASIN**

260 The Western Canada Sedimentary Basin (WCSB) forms a very large sedimentary
261 wedge over Precambrian crystalline basement (Fig. 2). This wedge has a maximum
262 thickness of about 5,500 m along the edge of the Rocky Mountain Foothills, and
263 thins northeastward to a zero-edge along the basin margin. It includes the Alberta
264 Basin and the Williston Basin, which are separated by the Sweetgrass Arch (Fig. 2).

265 *Architecture of the “Paleozoic miogeocline-platform”*

266 The western margin of the WCSB, now preserved in the Cordillera, has had a long
267 tectonic history dominated by major episodes of extension from the Proterozoic
268 to the Paleozoic (Fig. 3). Two km-thick Proterozoic to Cambrian sequences in the
269 Cordilleran fold-and-thrust belt are generally absent in the undeformed WCSB to
270 the east. These sequences record two proterozoic stages of continental rifting and
271 extension around 1500-1400 Ma and 770-730 Ma (Hein and McMechan, 1994).
272 An age of 555 to 600 Ma (Neo-Proterozoic) for the breakup of the continental

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273 ancestral North American craton and initiation of drift along the early Paleozoic
274 passive margin has been established using the tectonic subsidence backstripping
275 method (Bond and Kominz, 1984). Following a long period characterized mainly by
276 erosion / non-deposition in the WCSB, sedimentation resumed during the
277 Devonian.

278 The Devonian (Granite Wash, Slave Point, Beaverhill Lake-BHL, Duvernay, Ireton,
279 Winterburn, Wabamun and lower Exshaw Formations) was deposited primarily
280 within a carbonate platform setting facing open marine conditions to the west
281 (see Mossop and Shetsen, 1994 and reference herein). The Devonian-
282 Carboniferous boundary occurs in the black shale of the lower Exshaw and Bakken
283 Formations (Fig. 3).

284 The Carboniferous (upper Exshaw / Bakken, Banff, Rundle Group, Golata,
285 Kiskatinaw, Taylor Flat, Ksituan Formations) includes proximal carbonate
286 platforms and ramps, and sandstone-dominated siliciclastic facies that were
287 deposited in slope to continental settings, as well as to basinward shale, spiculite
288 and bedded chert of basin to slope origin (Barclay et al., 1990; Richards et al.,
289 1994). Active extensional tectonism with high subsidence rates are documented in
290 the Peace River Embayment area as well as in the Prophet Trough (e.g. O'Connell,
291 1990; Barclay et al., 1990).

292 The Permian (Belloy and Fantasque formations) consists mainly of marine
293 siliciclastics and silty to sandy carbonates that are commonly silicified (Henderson,
294 1989; Henderson et al., 1994). Deposits are relatively thin and preserved only in a
295 narrow belt throughout most of the eastern Cordillera fold-and-thrust belt and,
296 locally, on the Interior Platform in the Peace River area. Thicker deposits are
297 preserved in the Ishbel Trough, which corresponds to an extensive structure

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298 developed on the down-warped and down-faulted ancestral western margin of
299 the North American plate (Fig. 2; Henderson et al., 1994). Numerous lines of field
300 evidence including geological mapping, biostratigraphic and diagenetic studies,
301 structural analysis suggest active tectonism during sedimentation and a potential
302 compressive setting with a large peripheral bulge (e.g. Fossenier, 2002;
303 Henderson et al., 2010; Zubin-Stathopoulos et al., 2011).

304 *Jurassic to Eocene foreland stage*

305 The classic indicators of foreland basin initiation such as basin geometry,
306 depositional setting, subsidence backstripping results and sedimentary
307 provenance suggest that the collisional retro-foreland phase began during the
308 Mid- to Late Jurassic (e.g. Poulton, 1989; Gillespie and Heller, 1995; Fuentes et al.,
309 2009; McCartney, 2012). The foreland phase then culminated in the Middle
310 Eocene at the end of the Laramide Orogeny. Using subsidence backstripping,
311 McCartney (2012) proposed that the basal series (Sinemurian–Toarcian, Nordegg
312 Fm.) of the Fernie Fm. was deposited in a backbulge depozone (sensus DeCelles
313 and Giles, 1996) and thus record initial low subsidence related to earliest
314 development of the foreland phase (Fig. 3). Eastward migration of the forebulge
315 occurred during the Middle Jurassic as recorded by the sub–upper Fernie
316 unconformity (Oxfordian–Kimmeridgian; Poulton, 1989). During the
317 Kimmeridgian, the upper Fernie Fm. (Nikanassin Fm.) was deposited in a rapidly
318 subsiding foredeep that received the first influx of westerly-derived detritus from
319 the Cordilleran orogen (Poulton, 1989). These formations are mainly fluvial,
320 deltaic and shallow marine siliciclastics to fine-grained condensed and starved
321 shelf successions (Poulton et al., 1994).

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322 The Cretaceous (Cadomin, Bluesky/Gething, Wilrich, Falher, Notikewin, Harmon,
323 Cadotte, Paddy, Shaffesbury, Dunvegan, Kaskapau, Cardium, Muskiki,
324 Marshybank, Puskwaskau and Wapiti formations) was dominated by
325 conglomeratic to fine-grained siliclastic deposits derived primarily from the rising
326 Cordillera to the west and deposited within the retro-foreland basin (see Mossop
327 and Shetsen, 1994).

328 **STRATIGRAPHIC ARCHITECTURE OF THE WCSB TRIASSIC SERIES AND**
329 **MONTNEY FM.**

330 WCSB triassic stratigraphy and nomenclature (Fig. 4) are mainly based on McLearn
331 and Kindle (1950), Hunt and Ratcliffe (1959), Armitage (1962), Barss et al. (1964),
332 Stewart (1984), Tozer (1984), Gibson and Barclay (1989), Gibson and Edwards
333 (1990a, b), Glass (1990) and many others. In the British Columbia foothills outcrop
334 belt, Triassic rocks are subdivided into the Grayling, Toad, Liard, Charlie Lake,
335 Baldonnel, Pardonet and Bocock formations (Edwards et al., 1994). In the
336 subsurface of the Peace River area, six main formations are present (Fig. 4). In
337 ascending order these are the Montney, Doig, Halfway, Charlie Lake, Baldonnel,
338 and Pardonet formations.

339 The main unconformities are located at the base of the Triassic (Permian-Triassic
340 Unconformity), at the base of the Doig/Halfway cycle (Sequence Boundary SB4,
341 Barss et al., 1964, Crombez 2016; Crombez et al., 2016), within the middle Charlie
342 Lake Fm. (Coplin Unconformity; Aukes and Webb, 1986; Campbell et al., 1989),
343 and at the top of the Triassic with the sub-Jurassic Erosion (Fig. 4).

344 The Montney Fm. consists primarily of fine-grained dolomitic sandstone and
345 siltstone with subordinate amounts of shale and a moderate to low clay content,

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346 locally high organic content (Davies, 1997; Zonneveld et al., 2010; Chalmers and
347 Bustin, 2012; Crombez, 2016). Recent biostratigraphic works (Orchard and
348 Zonneveld, 2009; Golding et al., 2014a, 2014b, 2015, 2016) indicate that the
349 Montney Fm. is early Triassic in age. Three main sequences have been recognized
350 in the Montney Fm., with proximal to distal settings (e.g. Davies et al., 1997;
351 Zonneveld et al., 2011; Crombez, 2016; Crombez et al., 2016). These sequences
352 are organized in complete second order cycles with sequence 1, 2 and 3
353 corresponding to Transgressive System Tract (TST), Highstand System Tract (HST)
354 and Falling Stage to Lowstand System Tract (FSST/LST) like packages respectively
355 (Fig. 4). Biostratigraphic data (Orchard and Zonneveld, 2009; Golding et al., 2014a,
356 2014b, 2015, 2016) were integrated into the most recent stratigraphic
357 architecture subdivision (e.g. Crombez, 2016) and indicate that the boundary
358 between sequences 1 and 2 is close to the Induan-Olenekian boundary (SB2), and
359 the boundary between sequence 2 and 3 corresponds to the Smithian-Spathian
360 boundary (SB3). The top of the Montney Fm. relates to earliest Anisian times (Fig.
361 4).

362 The Montney Fm. reaches a maximum thickness of ca. 350m in British Columbia
363 and thins toward the eastern subcrop edge (Fig. 5). Detailed sequence analysis
364 (Crombez, 2016) shows that each individual third order sequence can reach a
365 maximum thickness close to 225m and that the depocenters of these sequences
366 moved toward the west suggesting a filling of the basin primarily by eastern
367 sources (Fig. 6). Regarding the paleobathymetry, Crombez et al. (2016) and
368 Crombez (2016) suggest that the deposition of the Montney Fm. took place on a
369 shelf rather than in a deep abyssal basin (bathymetry < 250m, Table 1).

370 **SUBSIDENCE AND BASIN DEFORMATION**

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371 **TRIASSIC DYNAMICS**

372 *Results*

373 Along the ca. 500-km long proximal to distal transect, we used tops derived from
374 our high resolution stratigraphic correlations (Crombez, 2016; Crombez et al.,
375 2016) to compute tectonic subsidence for the six wells and two outcrop sections
376 (Fig. 7). Average, minimum and maximum subsidence rate during the deposition
377 of the Montney Fm. for each sequence are spatially presented in Fig. 8. Solid
378 (porosity corrected) siliciclastic sedimentation rates were quantified to evaluate
379 the sediment supply dynamic (Fig. 9).

380 Late Permian (Belloy and Fantasque formations) was characterized by very low
381 tectonic subsidence as well as minor local uplift in comparison with preceding
382 Carboniferous times (Fig. 7). The Permian-Triassic unconformity recorded the
383 initiation of tectonic subsidence and basin margin tilting with up to 100-110
384 m/Myr of tectonic subsidence in the deepest part of the basin (sections #1 and 2,
385 see Table 1 and Fig. 2 for location) and 5-10 m/Myr along the basin edge (wells #7
386 and 8) (Fig. 7). Sequence 1 (252-249.7 Ma) was then characterized by decreasing
387 tectonic subsidence in comparison with Late Permian-Earliest Triassic (Fig. 8),
388 from ca. 25-30 m/Myr in the deepest part of the basin (sections #1 and 2), to ca.
389 50 m/Myr in the main depocentre (well #4) and ca. 15-20 m/Myr along the basin
390 edge (wells #6, 7 and 8). It indicates an overall westward tilting of the basin
391 superimposed with maximal tectonic subsidence localized in the main depocentre
392 east to the present day limit of the fold-and-thrust belt. Sediment supply was
393 relatively low and increased rapidly after sequence 1 (Fig.9).

394 Sequence 2 (249.7-248 Ma) was characterized by tectonic inversion with evidence
395 of uplift in the western (deepest) part of the basin (Fig. 8; sections #1 and 2). A

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396 subsiding depocentre (ca. 10-20 m/Myr) was localized in the vicinity of wells #5 to
397 #6 (Fig. 7, Fig. 8). Sequence 3 (248-247 Ma) was characterized by the same trend
398 initiated during deposition of Sequence 2 (Fig. 7, Fig. 8). The subsiding depocentre
399 (wells #5 to 6) was then characterized by very low tectonic subsidence rates, ca. 2-
400 5 m/Myr (Fig.8). The uplift trends steadied along the basin eastern edge and
401 coevally, sediment supply increased to reach its maximum of the Triassic times
402 (Fig. 9).

403 During the development of sequence boundary SB4 (i.e. Montney-Doig contact),
404 the entire basin was uplifted (Fig. 8). The entire basin was then characterized by
405 very low tectonic subsidence during the Middle Triassic (Fig. 7). A second pulse,
406 less intense than during SB4, of increasing sediment supply was recorded up to
407 the Coplin unconformity (Fig. 9).

408 During the Triassic, sediment supply was characterized by a rapid (ca. 2-6 Myr-
409 long) increase (Sequence 1, 2 and 3) followed by a progressive (ca. 20-30 Myr-
410 long) decrease down to very low value during the Late Triassic (Fig. 9). Two pulses
411 can be identified within this Triassic-scale trend, with the first one (Sequence 1 to
412 3, Montney Fm.) corresponding to a maximum, and a second one (approximately
413 Middle Triassic prior to the Coplin Unconformity) recording a more gentle
414 sediment supply increase (Fig. 9). These two pulses are separated by a major
415 unconformity (SB4), followed by a sharp decrease of the sediment supply
416 (corresponding to the basal Doig Fm.).

417 *Interpretation*

418 The tectonic subsidence evolution with basin margin tilting, early inversion of the
419 deepest part of the basin (West) and landward migration of subsiding
420 depocentres share many similarities with the dynamic of a foreland basin and its

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421 four discrete depozones (Fig. 1; wedge-top: WT, foredeep: FD, forebulge: FB and
422 backbulge: BB, *sensu* DeCelles and Giles, 1996).

423 The deepest part of the basin (section #1) was characterized by the most distal
424 and starved depositional systems and was the first to be inverted following overall
425 tilting (Fig. 7). The initial overall basin tilting may be interpreted as a flexure of the
426 basin margin in response to tectonic loading. As the section #1 is mainly
427 characterized by starved and distal deposits, the uplift trend initiated at the
428 transition between sequences 1 and 2 could have occurred in the wedge-top or
429 forebulge (*sensu* DeCelles and Giles, 1996). The section #1 records continuous
430 deposition from the Late Permian into the Early Triassic (Henderson, 2011). This
431 section was located on the down-faulted eastern margin of the Prophet Ishbel
432 Trough (Fig. 2; Henderson et al., 2012). A wedge-top setting would imply that the
433 Prophet Ishbel Trough was fully filled at the end of the Permian, inverted and
434 back-thrusted in front of the Kootenay terrane (Fig. 2) to form a wedge-top during
435 the Triassic. Although inversion was documented (Henderson et al., 2010), the
436 preserved Permian facies support neither an overfilled configuration (Henderson
437 et al., 2012), nor an important tectonic uplift of the trough at the end of the
438 Permian. Additionally, the subsidence rates from section #1 to well #3 suggest
439 that this entire region evolved as a whole from sequence 1 to 3 (Fig. 8).
440 Consequently, the most likely interpretation is that Ursula Creek was sitting on
441 the edge of a large peripheral forebulge and the entire WCSB interpreted as
442 backbulge basin during the Triassic. The forebulge to backbulge area could then
443 be fault-bounded, as shown by Henderson et al. (2012) and Zonneveld et al.
444 (2011), hosting half graben-like structures similar to the Karoo foreland basin of
445 Africa (Catuneanu, 2004).

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446 The eastward migration of the subsiding depocentre from sequence 1 to 3 can be
447 interpreted as a backbulge to forebulge migration with the eastern edge of the
448 forebulge initially localized at the present day transition between the fold-and-
449 thrust belt and the undeformed WCSB (well #3). The tectonic subsidence
450 evolution during SB4 and the Middle Triassic suggests that the entire WCSB
451 behaved as a large and slowly subsiding basin just prior to the Coplin
452 unconformity (Fig. 7). Following the Coplin unconformity, a renewal of tectonic
453 subsidence associated with new basin margin tilting was then recorded during
454 Late Triassic (Fig. 7).

455 Sediment supply dynamics during the Triassic also supports a major uplift in the
456 catchment area, potentially related to overall basin margin tilting during the
457 Permian-Triassic boundary (Fig. 9). The progressive decrease of sediment supply
458 suggests that the uplift rate in the catchments was not permanent but transient at
459 the scale of the Triassic (Rohais et al., 2012). The decrease in sediment supply
460 following SB4 could correspond to a re-adjustment in the catchment potentially
461 related to backbulge - forebulge inboard migration.

462 The tectonic subsidence values quantified in the subsidence backstripping are
463 strongly dependent on paleobathymetry estimations. However, error bars on
464 Figure 8 show that uncertainties on paleobathymetry do not affect significantly
465 the overall trends and basin dynamic proposed in this study.

466 **INTEGRATION WITHIN WCSB EVOLUTION**

467 To constrain the driving forces for subsidence as well as to define the main
468 depozones during the deposition of the Montney Fm., the overall basin evolution
469 from the Early Paleozoic to Recent needed to be taken into account. We
470 computed the entire backstripped subsidence for the six wells and two outcrop

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471 sections (Fig. 10) to quantify the relative influence of thermal, flexure and
472 sediment loading-induced subsidence. Additionally, sediment fluxes were also
473 analyzed using solid siliciclastic sedimentation rates to constrain uplift dynamics.

474 *Key pre-Triassic events*

475 The very first Mid-Ocean Ridge basalt (MORB) evidence in the Slide Mountain
476 ocean (SM) occurred during Cycle II of Nelson et al. (2006), ca. 365-357 Ma (Late
477 Devonian-Earliest Mississippian). The backstripped tectonic subsidence curves
478 that we calculated were then compared with post-rift tectonic subsidence curves
479 initiated at 365 Ma (Fig. 10) and calculated from the stretching model of McKenzie
480 (1978) for different amounts of stretching, using the beta stretching values
481 defined from the Lithoprobe cross-section results (Table 1). There is a very good
482 match for all the backstripped curves with the theoretical post-rift tectonic
483 subsidence evolution from 365 Ma to ca. 320-330 Ma (end Mississippian-
484 Pennsylvanian boundary). We thus propose that thermal processes typical of a
485 passive margin evolution mainly controlled tectonic subsidence during the Latest
486 Devonian to Mississippian. Subsequently, all of the wells and sections included
487 herein indicate a deficit in cumulative tectonic subsidence compared to the
488 thermal model (Fig. 10), suggesting that the driving forces controlling thermal
489 subsidence were no longer active during the Carboniferous. This interpretation is
490 consistent with Cycle V of Nelson et al. (2006), ca. 314-269 Ma (Pennsylvanian-
491 Early Permian) that recorded the fore-arc initiation on the eastern part of the
492 Yukon-Tanana terrane (Klinkit arc). Potentially, the Devonian slab retreat stopped
493 in response to the over-steepening of the subducted slab, to a slab break-off or
494 even to an arc-arc collision. From ca. 300 Ma to 252 Ma (Permian), the most
495 inboard wells (#5, 6, 7 and 8) were gently uplifted, while the most distal ones

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496 were characterized by very low tectonic subsidence (Fig. 10). Combined with
497 sedimentological evidence such as the sediment provenance and the distribution
498 of depositional environments (Richards et al., 1994; Henderson et al., 1994), this
499 suggests a forebulge to backbulge dynamic, which is very consistent with the
500 paleogeographic reconstruction for Late Carboniferous and Permian with a
501 narrow and very deep Prophet Trough, Ishbel Trough, their associated peripheral
502 bulges and poorly preserved backbulge deposits (Henderson et al., 2010, 2012;
503 Zubin-Stathopoulos et al., 2011). Consequently, it is clear that the very oldest
504 deposits of the Montney Fm. were deposited in a peripheral forebulge to
505 backbulge setting in the WCSB.

506 *Key post-Triassic events*

507 The Late Triassic was characterized by low tectonic subsidence rates (Fig. 7, Fig.
508 10). The hinge line between subsiding versus uplifted depozones occurred
509 between wells #5 and #6 as well as uplifted zones in the deepest part of the basin
510 (section #1, Fig. 10). The basin was sediment-starved and/or fully bypassed as
511 indicated by a very low sediment accumulation rate (Fig. 9). Depositional systems
512 summarized by Gibson and Barclay (1989), Gibson (1993) and Edwards et al.
513 (1994) consist of restricted and protected settings throughout the WCSB, mainly
514 shallow marine environments across the previously identified peripheral
515 forebulge and open marine setting to the west. The paleogeography of Late
516 Triassic, combined with the spatial and temporal evolution of tectonic subsidence,
517 are consistent with a late underfilled stage to early filled stage in the evolution of
518 a foreland system, with temporary dominance of flexural tectonics such as in the
519 Karoo model of Catuneanu (2004).

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520 During the Early Jurassic, prevailing low tectonic subsidence rates (Fig. 10), and
521 paleogeographic restoration suggest a peripheral forebulge to backbulge setting
522 for the WCSB. The hinge line between subsiding versus uplifted depozones was
523 localized between wells #3 and #4 (Fig.10). The Late Jurassic (ca. 145-150 Ma)
524 recorded the rapid increase of tectonic subsidence in the deepest part of the
525 WCSB (section #1 to well #3), combined with a slowly subsiding depozone (wells
526 #4 to #6) and an uplifted depozone inboard (wells #7 and #8) (Fig. 10). This can be
527 interpreted as a foredeep - forebulge inboard migration during Late Jurassic. In
528 this framework, Lower to Middle Jurassic can also be interpreted as forebulge –
529 backbulge inboard migration. Amplitude, timing and basin-scale distribution of
530 tectonic subsidence during early collisional retro-foreland evolution (Late Jurassic-
531 Early Cretaceous) are very similar with Triassic trends (Fig. 10). The tilting of the
532 margin, followed by pulse of uplift during Late Jurassic to Early Cretaceous can be
533 interpreted as early, underfilled to filled phases of foreland basin evolution *sensu*
534 Catuneanu (2004). The relative balance between dynamic subsidence and flexure
535 may account for such an evolution. It implies that the “true foredeep” inboard
536 migration and arrival in the WCSB occurred at ca. 110-120 Ma (possibly the sub-
537 Cadomin).

538 During the Cretaceous and Cenozoic, the WCSB was characterized by a typical
539 forebulge – foredeep – fold-and-thrust belt evolution (McCartney, 2012; Pana and
540 van der Pluijm, 2015) with a final isostatic rebound (Fig. 10). Several pulses within
541 the backstripped subsidence curves can be correlated with the well-known
542 terrane accretion in the North American Cordillera orogen (Pana and van der
543 Pluijm, 2015).

544 **DISCUSSION**

545 **STRUCTURAL SETTING OF THE MONTNEY FM.: EXTENSION VERSUS COMPRESSION**

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3 546 Field and analytical studies including geological mapping, structural studies,
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5 547 tectonostratigraphic analysis, U-Pb zircon dating and detrital zircon studies in
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7 548 western Canada have reported compelling evidence for Late Permian-Early
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9 549 Triassic (ca. 250 Ma) collision (e.g. Mortensen et al., 2007; Beranek and
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11 550 Mortensen, 2011; Henderson et al., 2012). The accretion of terranes is well
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13 551 documented from Early to Middle Jurassic time because intense deformation and
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15 552 stitching plutons of that age occur in the southern Canadian Cordillera (e.g.
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17 553 Gabrielse and Yorath, 1989; Murphy et al., 1995). Therefore; the Triassic period
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19 554 should thus be viewed as part of an overall compressive setting continuum, or
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21 555 conversely as part of renewed extension within a back-arc system. Reactivation of
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23 556 inherited extensional structures is documented during the Triassic (Cant, 1986;
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25 557 Edwards et al., 1994; Zonneveld et al., 2011), however driving forces were neither
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27 558 documented nor quantified in these studies with investigated backstripped wells
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29 559 and outcrop sections.
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37 560 The spatial and temporal evolution of backstripped tectonic subsidence (Figs. 7, 8,
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39 561 and 10) during the Triassic can be interpreted as a continuum evolving from (1)
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41 562 Late Permian: a narrow foredeep, peripheral forebulge, and associated backbulge
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43 563 with poorly preserved deposits, diagnostic of an early underfilled stage of
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45 564 foreland basin evolution where flexural uplift overtakes dynamic subsidence, to
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47 565 (2) Early Triassic (Montney Fm.): a foredeep – forebulge – backbulge with thick
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49 566 clastic deposits diagnostic of a late underfilled stage of foreland basin evolution
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51 567 where dynamic subsidence overtakes flexural uplift, to finally (3) Middle to Late
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53 568 Triassic: a forebulge – backbulge configuration with shallow marine to restricted
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55 569 deposits across the entire WCSB, diagnostic of an early filled phase during which
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570 dynamic subsidence overtook flexural uplift but progressively decreased, as
571 suggested by the overall uplift of the forebulge depozone. In this context,
572 extensional faulting is interpreted as local rejuvenation of inherited structures
573 across a large forebulge flexure, as well documented in other foreland basins (e.g.
574 Karoo foreland basin of Africa; Catuneanu, 2004).

575 **GEODYNAMIC SETTING OF THE MONTNEY FM.: RETRO-FORELAND BASIN VERSUS COLLISIONAL**
576 **PRO-FORELAND BASIN**

577 Several works suggest that subsidence rates from the sedimentary record within
578 foreland basins may be key for differentiating the type of foreland basin (Fig. 1;
579 DeCelles and Giles, 1996; Ziegler et al., 2002; Sinclair and Naylor, 2012). As
580 previously discussed, the Montney Fm. can be considered to be a textbook
581 example that records the entire basin evolution from the earliest underfilled to
582 the intermediate filled stage of foreland basin evolution. The configuration of the
583 basin during Late Carboniferous to Permian (narrow and deep foredeep,
584 important forebulge erosion, poorly preserved backbulge), combined with the
585 subsidence evolution presented in this work, indicate that this period of time was
586 characterized primarily by a flexural uplift that overtook dynamic subsidence, if
587 any dynamic subsidence occurred. Collisional pro-forelands lack a mechanism for
588 dynamic subsidence (DeCelles and Giles, 1996; Ziegler et al., 2002), so we propose
589 that the Late Carboniferous to Permian period was characterized by a collisional
590 pro-foreland setting.

591 Furthermore, we show spatial and temporal subsidence changes that suggest
592 dynamic subsidence during deposition of the Montney Fm. The trends presented
593 and discussed in our study are valid even using the lowest estimations for
594 paleobathymetry (Fig. 8). Additional flexure in retro-foreland basins is caused by

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595 dynamic subsidence induced by the subducting slab (Beaumont, 1981; DeCelles
596 and Giles, 1996). Thus, we proposed that the Early Triassic (Montney Fm.) was
597 deposited in a retro-foreland basin setting. Data from worldwide foreland basins
598 suggest that forebulge and backbulge depozones are best preserved in retro-arc
599 settings (Catuneanu, 2004; DeCelles, 2012), which renders our interpretation even
600 more consistent. A retro-foreland setting is also inferred for the Jurassic-
601 Cretaceous western Canadian foreland basin.

602 Following the Late Permian, which is characterized by the lack of eastward
603 subduction on the western part of the Yukon-Tanana and Quesnellia terranes and
604 the shortening of the Slide Mountain ocean by imbrication or west-dipping
605 subduction (e.g. Ferri, 1997; Nelson et al., 2006), the Montney Fm. recorded the
606 reactivation of eastward subduction below the ancestral North American craton.
607 The size and configuration of the Slide Mountain ocean have been the subject of
608 much discussion, probably because of its south to north gradient from marginal
609 sea to large oceanic basin merging together with others oceans to the North
610 (Shephard et al., 2013). Assuming a large ca. 1300 to 3000 km-wide Slide
611 Mountain ocean (e.g. Snyder and Brueckner 1985; Nokleberg et al., 2000; Nelson
612 et al., 2006), only west-dipping subduction could have consumed the ocean during
613 the Late Permian. This interpretation is supported by direct evidences for an
614 active west-dipping subduction during the Late Permian found in blueschist and
615 eclogite rocks in the Anvil Allocthton in the southern Yukon (Erdmer, 1987;
616 Erdmer and Armstrong 1988). As we demonstrate the occurrence of an east-
617 dipping subduction below the WCSB during Early Triassic, this suggests a potential
618 slab break-off and related isostatic rebound to have occurred during Late Permian
619 – earliest Triassic transition. Nevertheless, the north to south extension of the
620 Late Permian west-dipping subduction can be debated since the lack of high-

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621 pressure assemblages elsewhere in the Cordillera suggests that Slide Mountain
622 ocean shortening may have occurred without substantial subduction (Ferri, 1997).

623 **WIDER IMPLICATIONS FOR CORDILLERA EVOLUTION**

624 The main east-dipping subduction along the entire western margin of Ancestral
625 North America was re-established as early as Middle to Late Triassic based on
626 volcanic-arc assemblages in Quesnellia terrane (Monger et al., 1991; Ferri, 1997;
627 Colpron and Nelson 2009). Thus, our findings suggest an earlier timing than Jura-
628 Cretaceous, or possibly an additional event, during the birth of the North
629 American Cordilleran orogen. The simplest interpretation would be to propose a
630 lag time (ca. 5-10 Myr) between evidence for subduction activity recorded in the
631 dynamic subsidence of a retro-foreland basin versus volcanic-arc emplacement.

632 We also show that the evolution of the WCSB from the Early Triassic (Montney
633 Fm.) to the Middle and Late Triassic did not follow the traditional backbulge –
634 forebulge - foredeep sequence. Conversely, the Middle to Late Triassic was
635 characterized in the WCSB by uplift and large scale flexure. This suggests that
636 dynamic subsidence did not drive tectonic subsidence anymore, which could be
637 interpreted in terms of decreasing influence of underlying slab forces. This
638 interpretation is corroborated by the end of activity of the east-dipping
639 subduction in the late Triassic, followed by the entrapment and final collapse of
640 the Cache Creek terrane between Quesnellia and Stikinia terranes (Mihalynuk et
641 al., 1994; Colpron et al., 2015). During the latest Triassic, renewed east-dipping
642 subduction beneath Stikinia was recorded by sedimentary deposits (e.g. Barresi et
643 al., 2015) and emplacement of ca. 204–195 Ma plutons (Marsden and Thorkelson,
644 1992). Subsequent exhumation was recorded in the Yukon Territory (Early
645 Jurassic; Colpron et al., 2015) that may correspond to isostatic rebound induced

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646 by slab break-off of the Cache Creek terrane. Basins, such as the Whitehorse
647 Trough, were characterized by rapid subsidence that was initiated in the
648 Sinemurian (Early Jurassic), and therefore may be interpreted as wedge-top
649 depozones recording some of the early stages of development of the North
650 America Cordilleran orogeny (Colpron et al., 2015).

651 The backstripped subsidence curves of the WCSB (Fig. 10) provide a record of the
652 evolution of the entire northern Cordillera, from its Cambrian-Silurian rifting,
653 passive margin (Fig. 11-a and 11-b) and Devonian back-arc development (Fig. 11-c)
654 through three distinct foreland stages resulting in the final orogeny (Fig. 11-d to
655 11-j) that is consistent with the most recent advances in the understanding of the
656 Cordilleran orogeny (e.g. Monger and Price, 2002; Nelson et al., 2006; Murphy et
657 al., 2006; Colpron et al., 2015):

- 658 1. Devonian extension and subsequent continental terrane (e.g. Yukon-Tanana,
659 Kootenay) rifting in response to back-arc initiation driven by slab retreat
660 (eastward dipping subduction) (Fig. 11c).
- 661 2. Late Devonian-Earliest Carboniferous post-rift subsidence with ocean sea-
662 floor spreading (Mid-Ocean Ridge basalt) recorded in the Slide Mountain
663 terrane (Fig. 11d).
- 664 3. Convergence recorded by a subsidence deficit during the Pennsylvanian to
665 Early Permian that may be related to a switch off of the initial eastward
666 dipping subsidence during the Late Carboniferous-Early Permian (Fig. 11e).
- 667 4. 1st foreland (collisional pro-foreland). Flexure and uplift recording the
668 progressive shortening and slicing of the Slide Mountain ocean below the
669 Yukon-Tanana and Quesnellia terranes (Late Permian) and potential isostatic

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2 670 rebound induced by slab break of the west-dipping subduction (at least in the
3 671 Yukon Territory) (Fig. 11f).

4 672 5. 2nd foreland (retro-foreland associated with short-lived Cache Creek
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6 673 subduction). Renewed eastward-dipping subduction during deposition of the
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8 674 Montney Fm. (Early Triassic) that could correspond to the Cache Creek
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10 675 subduction below the Ancestral North America margin (Fig. 11g).

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13 676 6. Termination of dynamic subsidence during the Middle to Late Triassic,
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15 677 recording the Cache Creek entrapment, slab break off and sinking, followed by
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17 678 isostatic rebound and exhumation (Fig. 11h)

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21 679 7. 3rd foreland (retro-foreland associated with long-lived subduction).
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23 680 Rejuvenating eastward-dipping subduction during the latest Triassic – earliest
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25 681 Jurassic and initiation of the wedge-top and foredeep depozones (e.g.
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27 682 Whitehorse Trough) (Fig. 11i).

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30 683 8. Multi-pulsed retro-foreland evolution (Jurassic-Cretaceous), recorded by the
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32 684 stacking of the island arcs in the Cordillera (Fig. 11j).

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35 685 9. Isostatic rebound during the Late Cenozoic.

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38 686 This model of WCSB evolution has additional implications regarding large scale
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40 687 geodynamic evolution of the western margin of North American ancestral craton. It
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42 688 challenges the large geodynamic model proposed by Sigloch and Mihalynuk
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44 689 (2013) in two ways. First, the process to form a large slab wall could be related to
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46 690 mixing slabs from different origins that were detached during several subduction
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48 691 reversals (Slide Mountain ocean and Cache Creek). This is an alternative proposal
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50 692 to forming massive slab walls to an invoked stationary trench and an associated
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52 693 slab buckling model (Sigloch and Mihalynuk, 2013). Second, the relative timing
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54 694 between the arc-continent collision (Intermontane - ancestral North American
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56 695 margin) and the induced foreland basin should be revisited. The very first arc-

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696 continent collision (Yukon-Tanana - Quesnellia) recorded by the Montney retro-
697 foreland basin (Early Triassic) was not responsible for the large slab break off. It is
698 the second main arc-continent collision during Late Triassic (Stikina) that accounts
699 for the large slab wall.

700 **FEEDBACK ON FORELAND INITIATION**

701 Traditionally the initiation of a foreland basin is defined using a combination of
702 the sediment provenance (Poulton, 1989; Leckie and Smith, 1992), the
703 distribution of depositional environments (Beaumont, 1981), the development of
704 a narrow basin fill parallel to the axis of the thrust belt (Jordan, 1981), and the
705 onset of rapid subsidence (Angevine et al., 1990; Xie and Heller, 2009; McCartney,
706 2012). Our study using subsidence analysis of the entire basin fill shows that the
707 WCSB and its associated Cordilleran orogen records three main foreland stages
708 with distinctive subduction configurations: a first one during the Permian, a
709 second one during the Early Triassic and a last one during the Jurassic to Cenozoic.
710 The common point, regardless of the basin and plate configuration, is the very
711 first forebulge uplift associated with the foredeep development in response to the
712 onset of thrusting and flexural loading. While foredeep data are often inaccessible
713 or not preserved, the best approach to identifying foreland initiation is to
714 characterize and quantify uplift dynamics at the basin scale through backstripping
715 to illustrate forebulge - backbulge depozones.

716 **CONCLUSIONS**

717 Our paper contributes to the characterization of the geodynamic setting for the
718 Montney Formation (Early Triassic). Backstripping tectonic subsidence curves
719 were quantified for six wells and two outcrop sections along a proximal to distal

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720 transect that is representative of the entire Western Canada Sedimentary Basin. It
721 proved necessary to analyze the entire sedimentary column to put the Montney
722 Formation into a broader context and provide consistent interpretations
723 regarding the type of subsidence and geodynamic setting for the Montney
724 Formation.

725 The tectonic subsidence evolution during the deposition of the Montney Fm. is
726 herein interpreted as a combination of the topographic loading of the orogenic
727 wedge (flexure) and the sublithospheric “loading” caused by slab load-driven
728 subsidence (dynamic subsidence). This suggests that the retro-foreland basin
729 setting was associated with an eastward dipping subduction during the deposition
730 of the Montney Fm..

731 We also show that the entire dynamic evolution of terrane interaction and the
732 Canadian Cordillera development can be interpreted in the light of backstripped
733 subsidence curves from multiple wells across the WCSB. Three main foreland
734 basin stages, associated with different basin-subduction configurations, were
735 identified. The first one (Permian) was coeval with the development of Late
736 Paleozoic anorogenic highland referred to as the Ancestral Rockies (cf. Miall and
737 Blakey, 2008 for review). The final foreland phase was initiated during the Late
738 Triassic-Early Jurassic and was coeval with the breakup of Pangaea. The Early
739 Triassic, amongst with the Montney Fm., recorded an additional foreland phase in
740 between these two main geodynamic events.

741 As a perspective for future work, the backstripping subsidence data set can be
742 interpreted to produce idealized flexural profiles, from which flexural properties
743 of the lithosphere might be derived (DeCelles, 2012). They can also be used to
744 estimate the velocity of migration of the flexural wave through the evolution for

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745 the three foreland systems. Finally, the integrated interpretation could be used as
746 a guideline to address some of the debates and challenges dealing with the Antler
747 and Sonoma orogenies in the western United States and Ancestral Rockies.

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1225 Fig.1: a. Idealized cross-section showing the main morphological elements and
1226 depozones of Passive margin, Pro-foreland and Retro-foreland basins. WT:
1227 Wedge-top, FD: Foredeep, FB: Forebulge, BB: Backbulge, BE: Basin edge. Oceanic
1228 crust is represented in black, and cratonic masses in white. b1, b2 and b3 illustrate
1229 the theoretical tectonic subsidence curves for these three basin types,
1230 respectively. c. Theoretical distribution of the tectonic subsidence across the
1231 three basin types, with uplifted versus subsiding depozones (up/down arrows
1232 respectively).

1233 Fig. 2: a. Geological map of the Canadian segment of the Cordillera including the
1234 main belts and terranes, and the Western Canada Sedimentary Basin (WCSB,
1235 Alberta and Williston basins). The black dash line shows the subcrop area where
1236 Triassic deposits are still preserved. Numbers refer to outcrop sections and wells
1237 presented in our study (see Table 1). Principal characteristics of allochthonous and
1238 pericratonic terranes in the Canadian Cordillera are from Monger et al. (1982),
1239 Gabrielse et al. (1991), Edwards et al. (1994), Price (1994), Wright et al. (1994),
1240 Clowes et al. (2002). Terranes: ST: Stikinia, CC: Cache Creek, Q: Quesnellia, YT:
1241 Yukon-Tanana, SM: Slide Mountain, K: Kootenay, NAC: North American Craton. b.
1242 Interpreted Lithoprobe profile showing the crustal geometry of the Cordillera
1243 orogeny (modified from Monger and Price, 2002).

1244 Fig. 3: Simplified stratigraphic scheme for the Western Canada Sedimentary Basin
1245 – WCSB and age model used for backstripping subsidence curves. The stratigraphy
1246 is compiled from the Atlas of the Western Canada Sedimentary Basin (Mossop
1247 and Shetsen, 1994) and the Alberta Table of Formations (Alberta Geological
1248 Survey, 2015). The age boundaries are assigned from more recent sources (Cohen
1249 et al., 2013 updated).

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1250 Fig. 4: Triassic stratigraphic framework in the fold-and-thrust belt of British
1251 Columbia and the subsurface of Alberta (modified from Gibson, 1974, 1975;
1252 Gibson and Barclay, 1989; Davies, 1997; Golding et al., 2015; Crombez, 2016). The
1253 three 3rd order sequences of the Montney Fm. are highlighted in color. The age
1254 boundaries are assigned from more recent sources (Cohen et al., 2013 updated).

1255 Fig. 5: Correlation panel of the Triassic and Montney Fm. from the two outcrops
1256 section in the fold-and-thrust belt of British Columbia (West) to the six wells from
1257 the subsurface of Alberta (East).

1258 Fig. 6: Thickness map for the three 3rd order sequences of the Montney Fm. in the
1259 subsurface of British Columbia and Alberta (modified from Crombez, 2016). The
1260 migration of the maximum thickness in depocenter illustrate the progradation of
1261 the sluggish depositional wedge profile from proximal setting to the east to distal
1262 setting to the west.

1263 Fig. 7: Backstripped tectonic subsidence curves for the two outcrops sections (1,
1264 2) and six wells (3-8) during Early to Middle Triassic. Curves are presented in a
1265 relative position along the cumulative tectonic subsidence axis for legibility. The
1266 thickness of the black curves illustrates the error bar induced by uncertainty on
1267 paleobathymetry estimation. The thin white dash line correspond to the average
1268 evolution. See Table 1 and Fig. 2 for well location.

1269 Fig. 8: Spatial and temporal evolution of the tectonic subsidence rate (m/Myr)
1270 during the deposition of the Montney Fm. Mean values are represented as well as
1271 the error bar (paleo-bathymetry uncertainties) for each sequences. Uplifted
1272 versus subsiding depozones are highlighted using arrows and colors (up/down
1273 arrows respectively, as well as unfilled/filled colors). Color code refers to the three
1274 main sequences. See Fig. 1 for keys.

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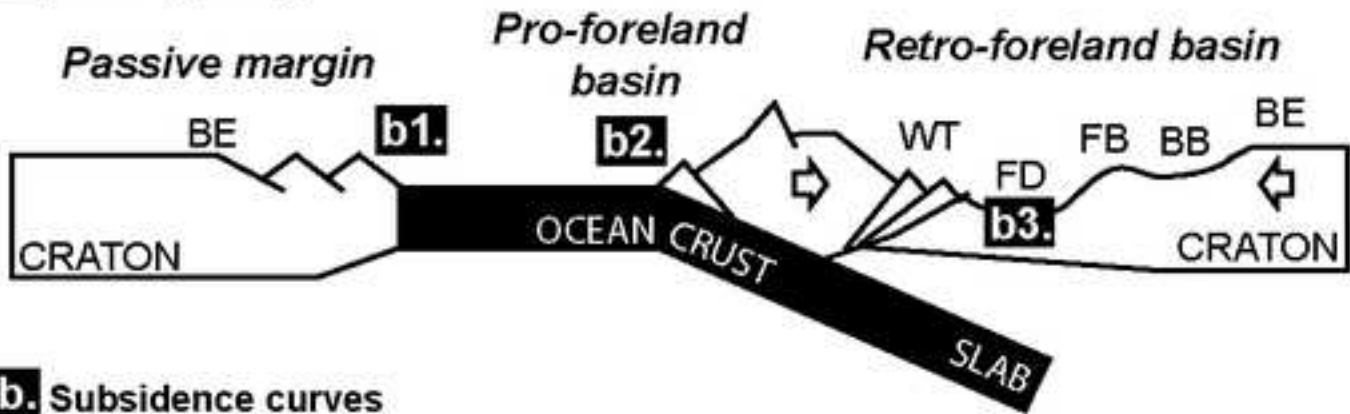
1275 Fig. 9: Solid (porosity corrected) siliciclastic sediment rate (sandstone, siltstone
1276 and shale) for the two outcrops sections (1, 2) and six wells (3-8) during Early to
1277 Middle Triassic. Following Late Permian very low value (by-pass and starved
1278 basin), the Montney Fm. recorded a major pulse in sediment supply in the same
1279 order of magnitude than the Jurassic collisional foreland initiation. See Table 1
1280 and Fig. 2 for well location.

1281 Fig. 10: Backstripped tectonic subsidence curves for the two outcrops sections (1,
1282 2) and six wells (3-8) from Late Devonian to Recent. Curves are presented in a
1283 relative position along the cumulative tectonic subsidence axis for legibility. The
1284 thickness of the black curves illustrates the error bar induced by uncertainty on
1285 paleobathymetry estimation. Orange lines correspond to the theoretical evolution
1286 using a post-rift thermal subsidence with the Beta value based on the model of
1287 McKenzie (1978). See Table 1 and Fig. 2 for well location.

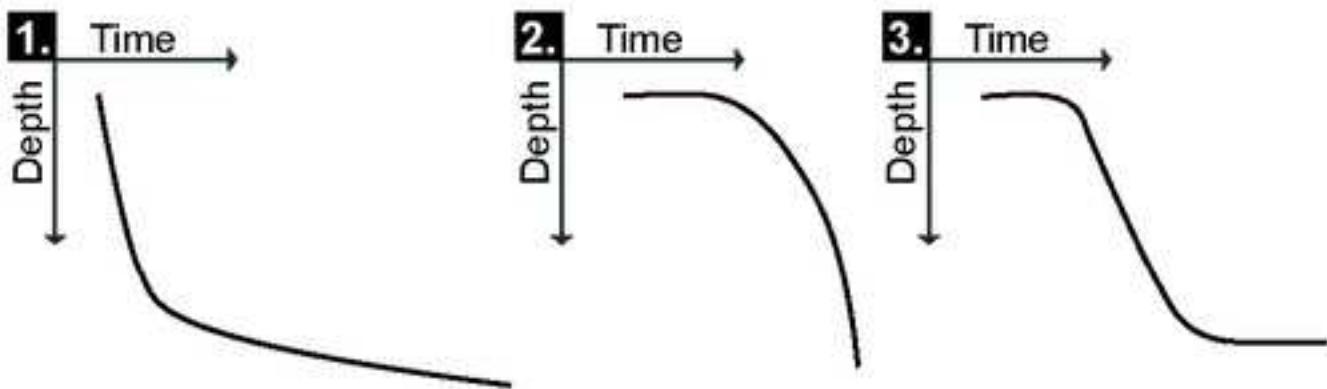
1288 Fig. 11: Simple evolution scheme for the WCSB and associated north American
1289 margin in Canada before, during and after the deposition of the Montney
1290 Formation. See text for detailed description. Dashed rectangle shows the location
1291 of the WCSB. The colored interval corresponds to the Triassic. Arrows indicate
1292 uplift versus subsidence (vertical), as well as extension versus compression
1293 (horizontal). Terranes: ST: Stikinia, CC: Cache Creek, Q- YT: Yukon-Tanana and
1294 Quesnellia, SM: Slide Mountain, K: Kootenay, NAC: North American Craton.

1295
1296 Table 1: Outcrops and wells used in the present study. The sequence thicknesses
1297 are from Crombez (2016) and the paleobathymetries are from geometrical
1298 reconstruction in Crombez (2016). See Figures 2 and 6 for location.

a. Basin typology

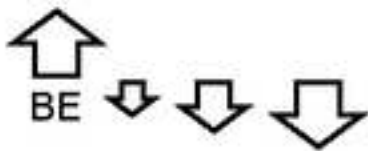


b. Subsidence curves



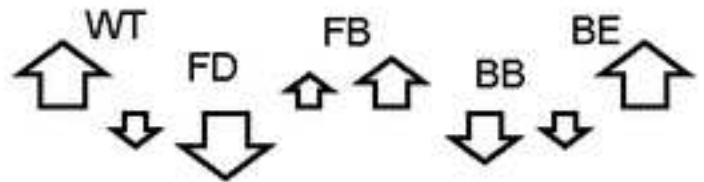
c. Tectonic subsidence distribution

Passive margin

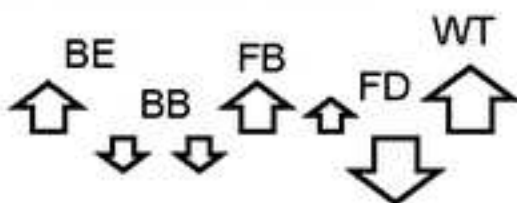


Retro-foreland basin

Flexural tectonic dominated

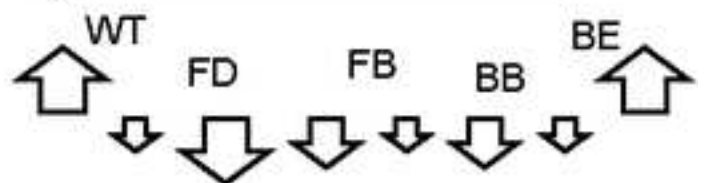


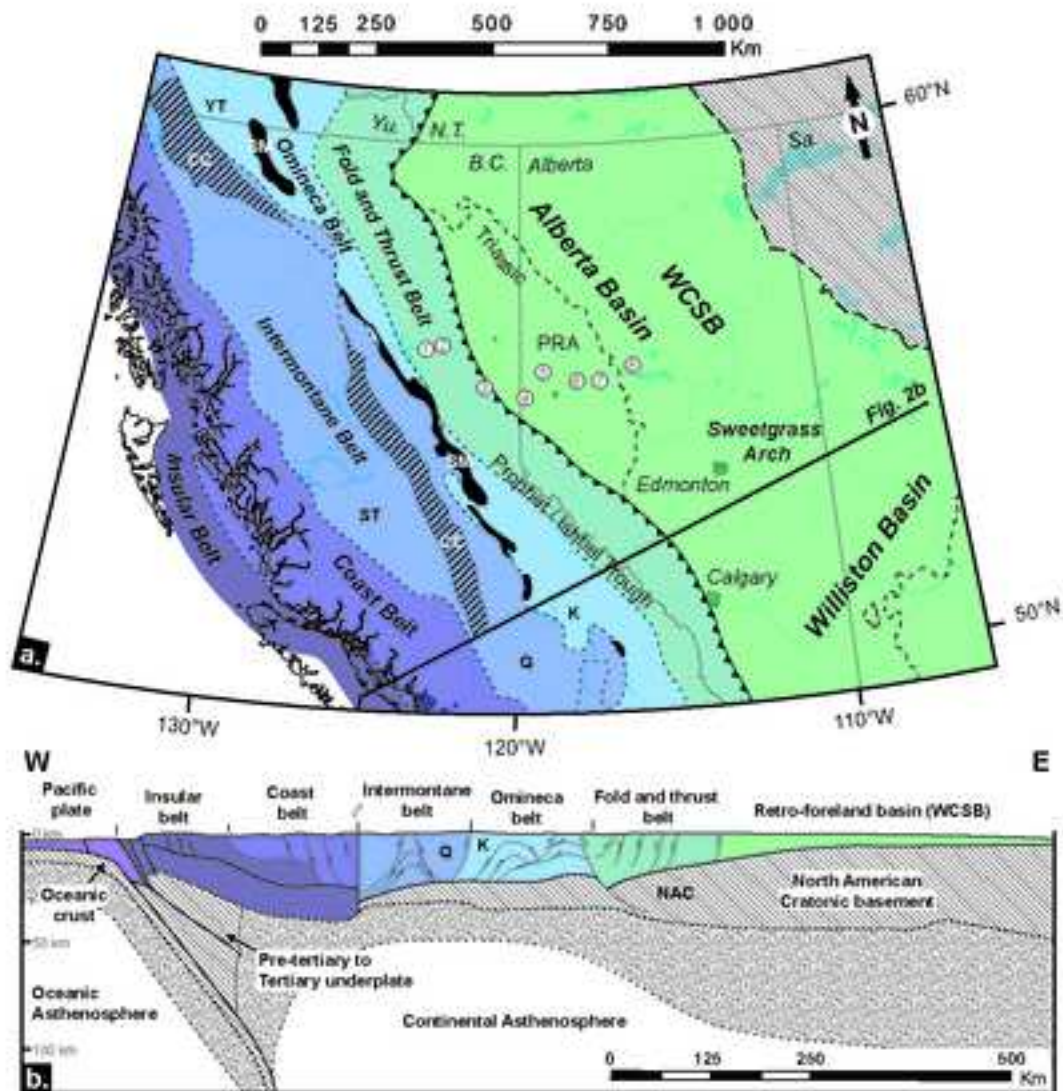
Pro-foreland basin

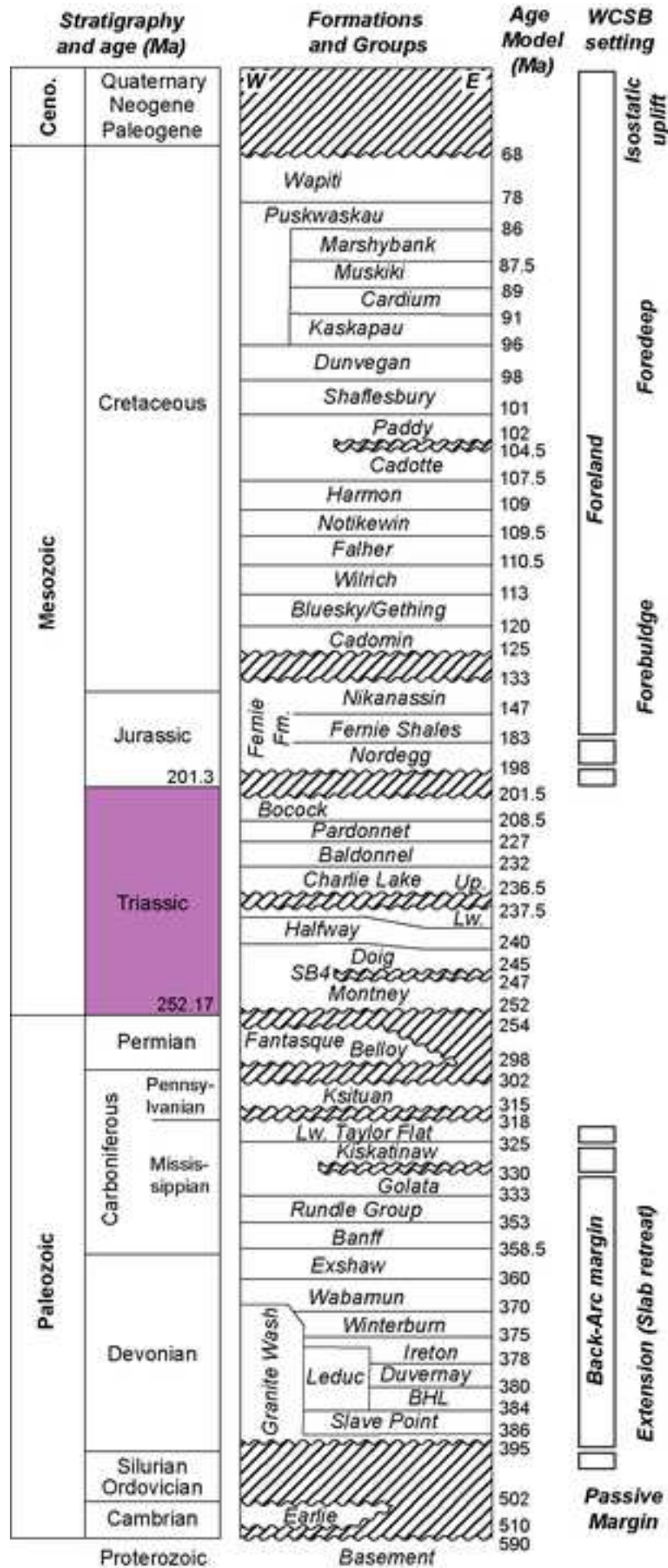


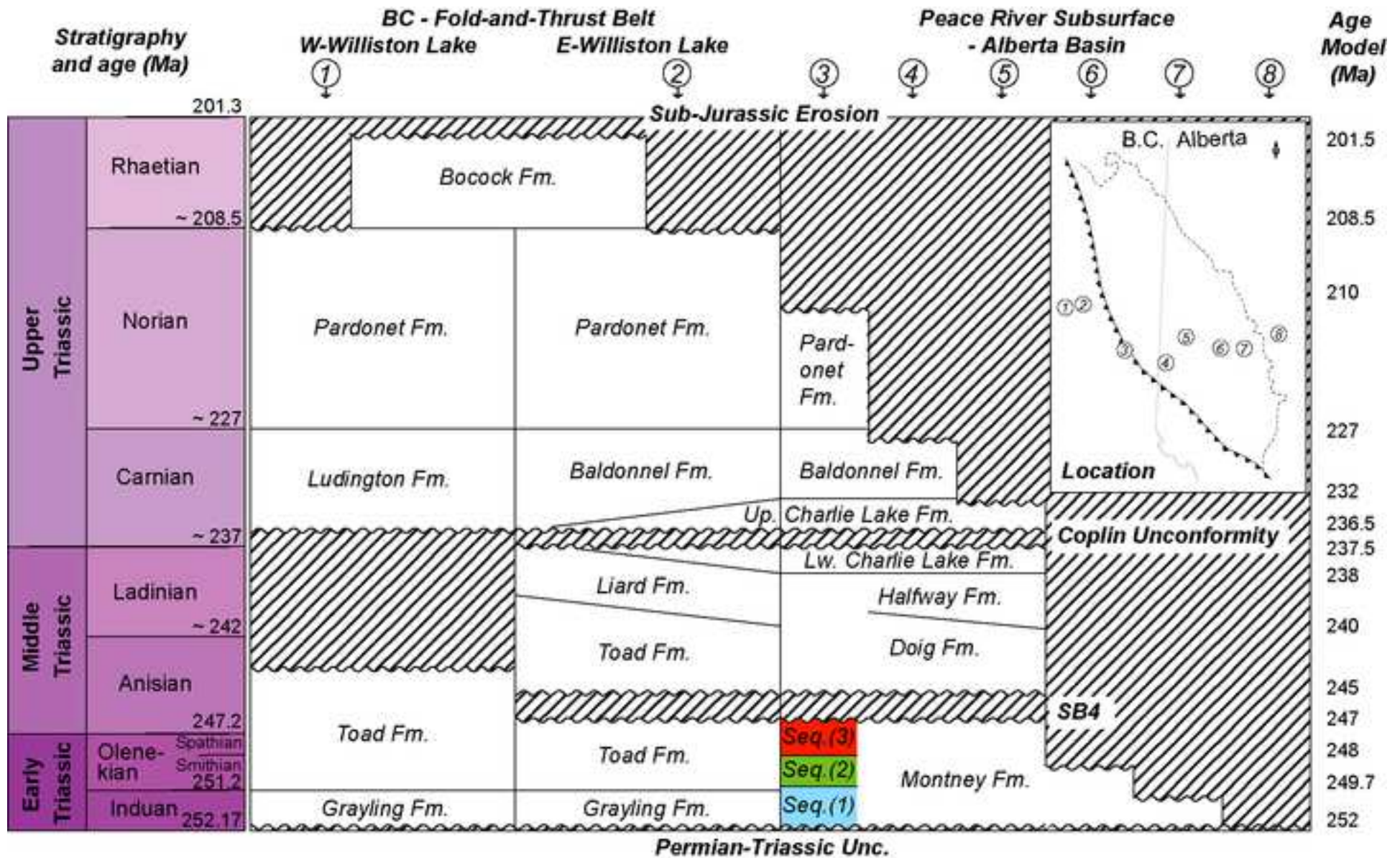
Retro-foreland basin

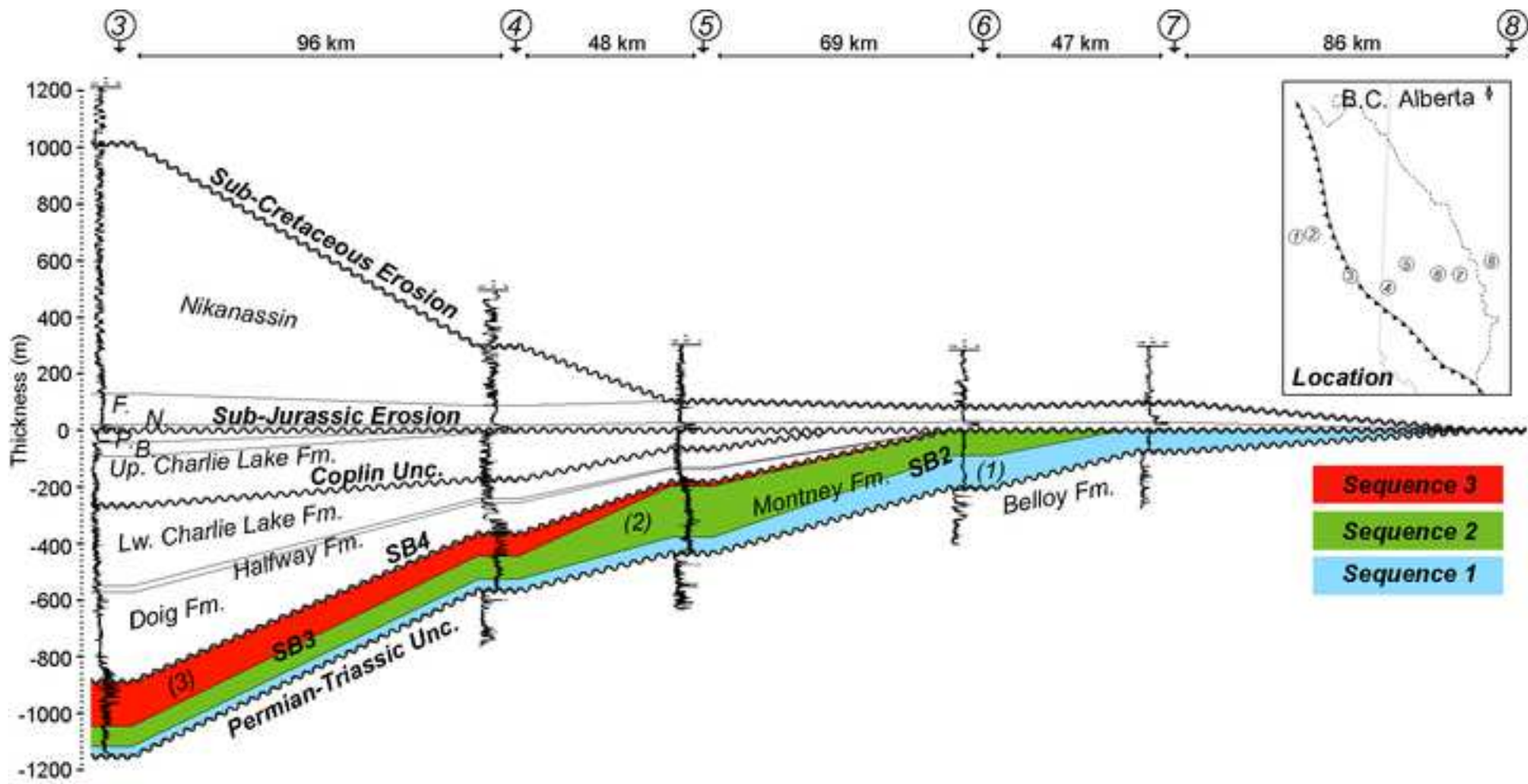
Dynamic subsidence dominated

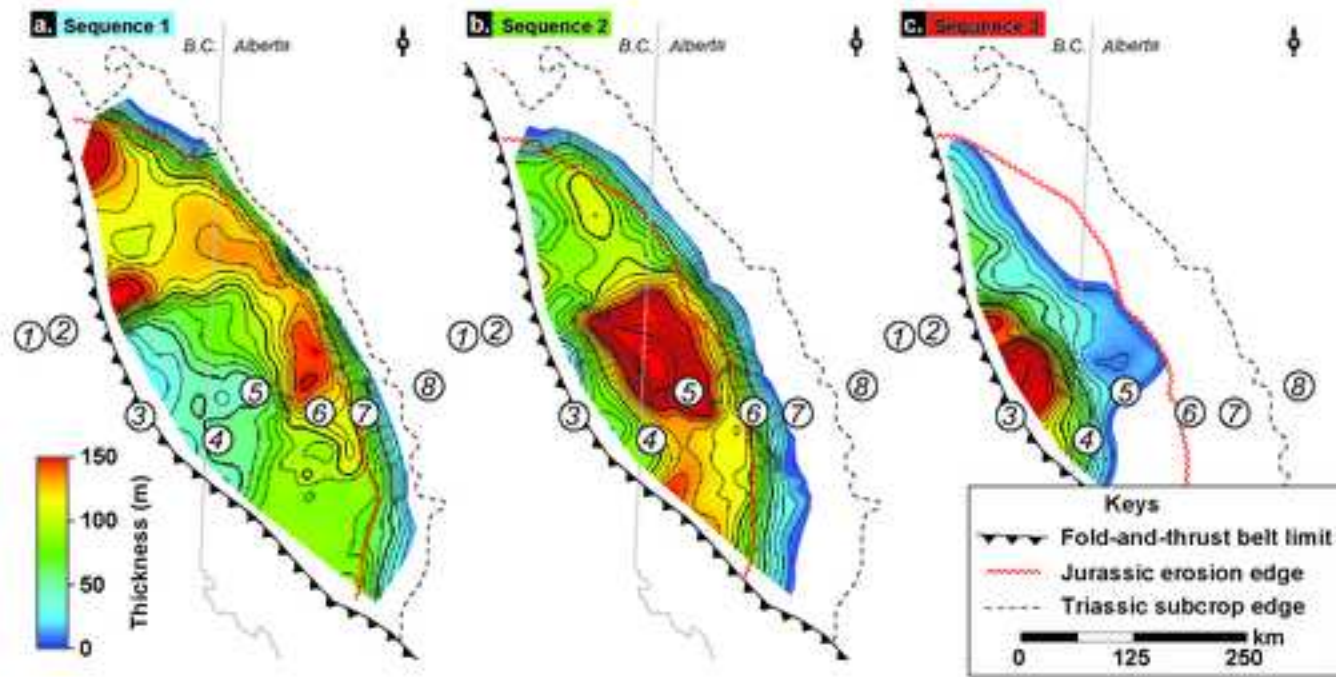


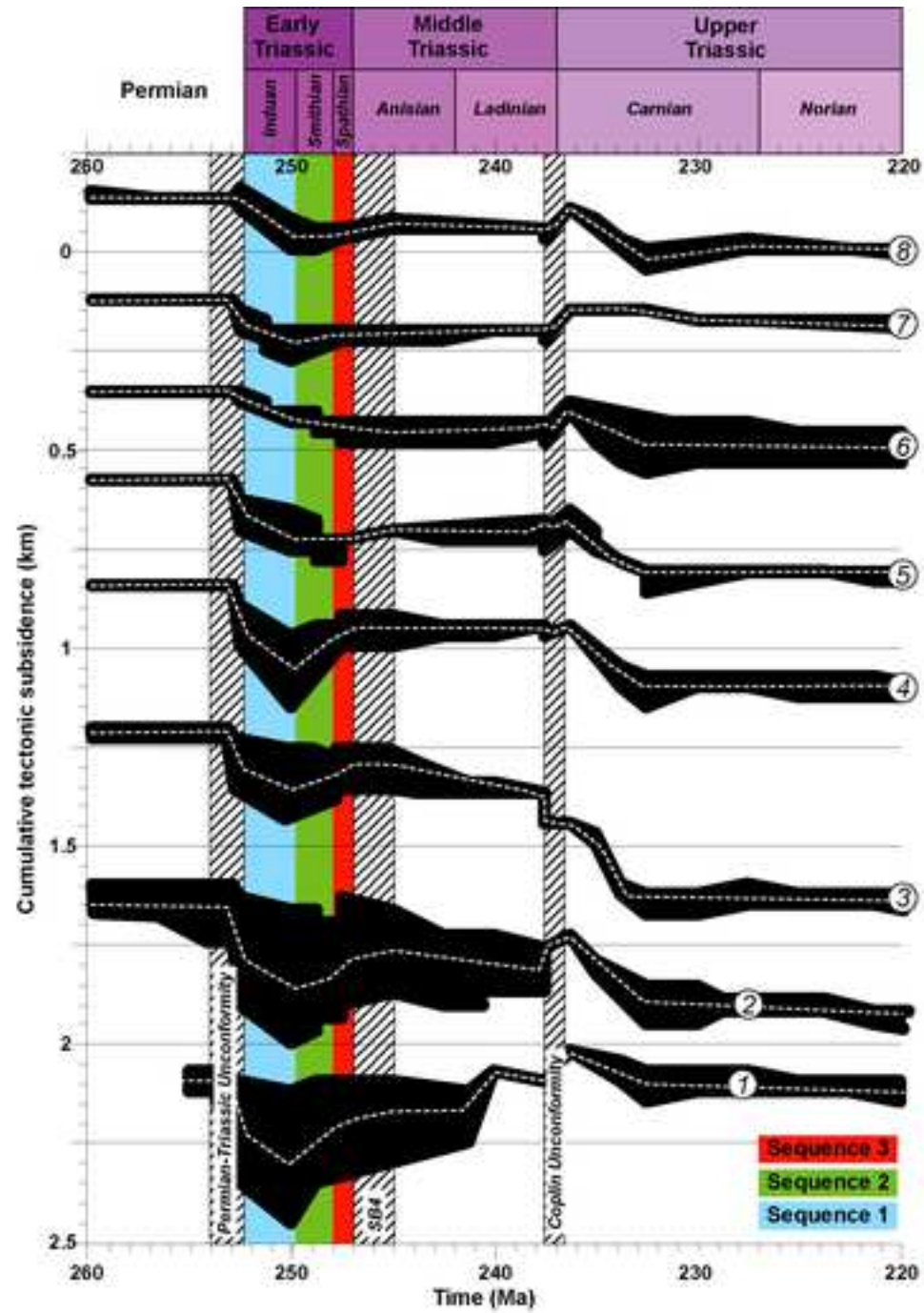












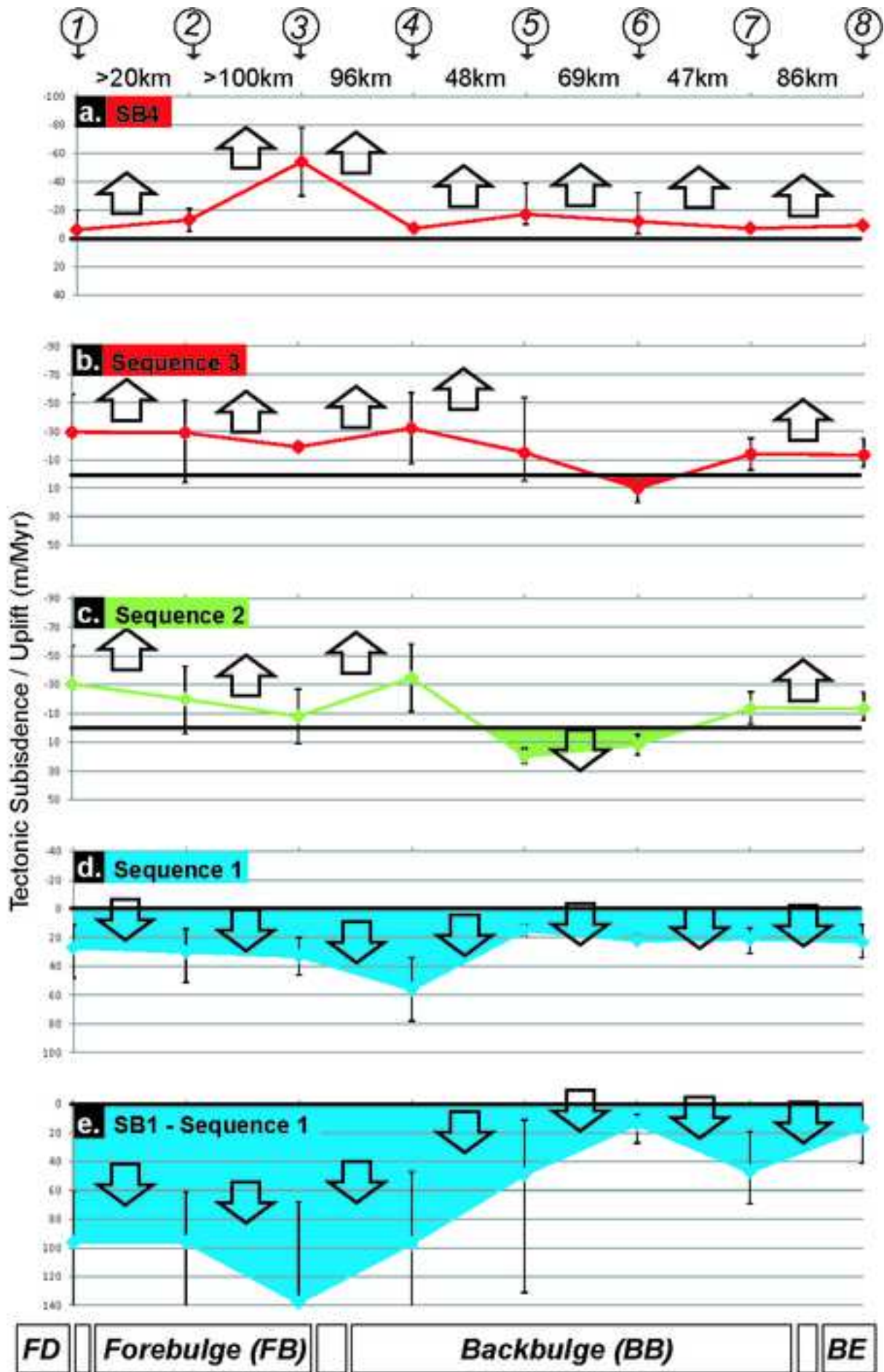
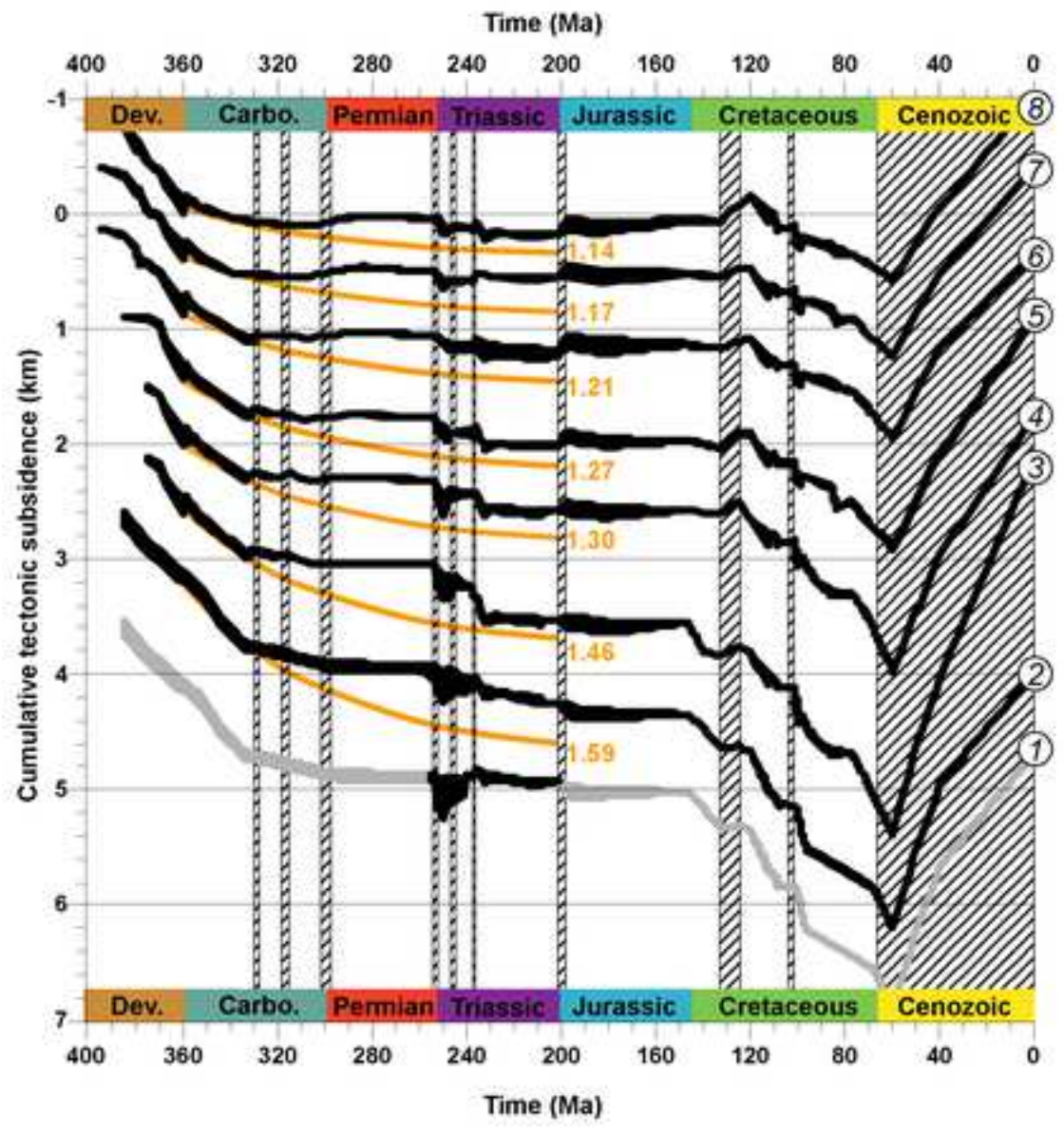
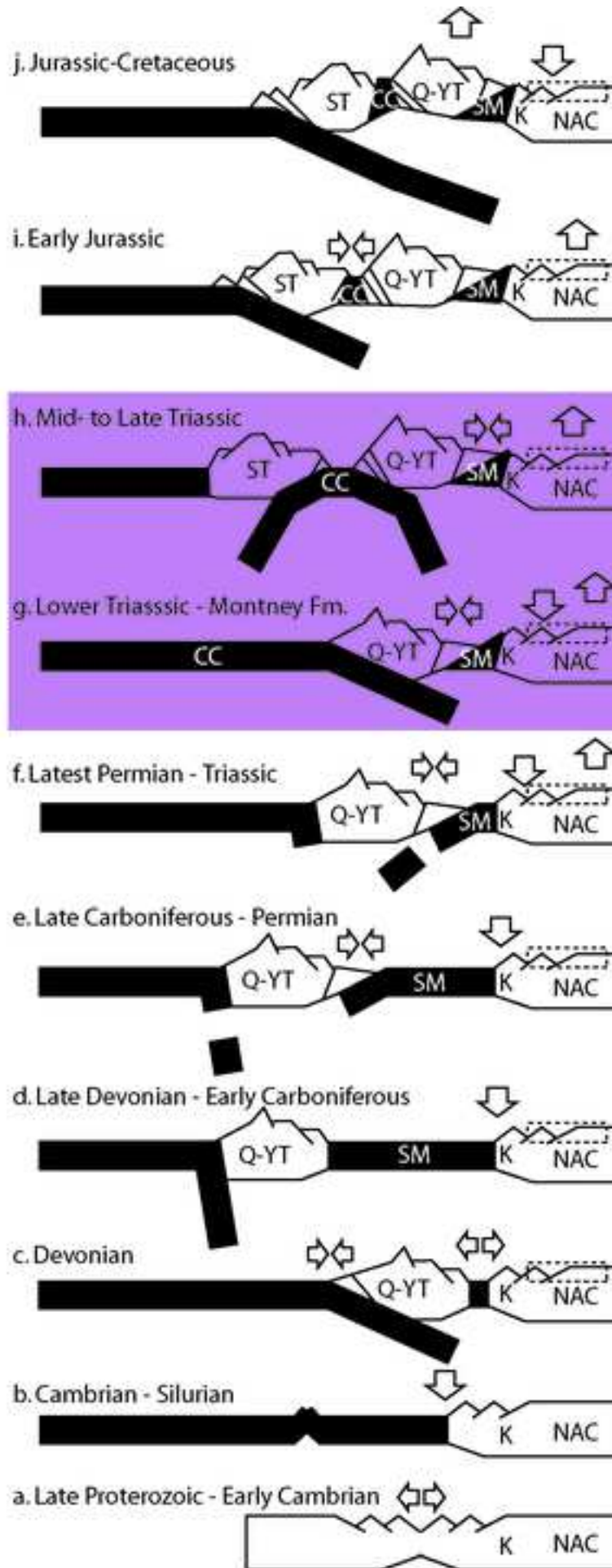


Figure10





FORMATIONS TYPE	PERIOD		DEPTH		THICKNESS	
	End (M.a)	Start	Top (m)	Bottom	(m)	
Section 1						
	U	0	0.1			
	U	0.1	40			
Erosion1	U	40	60			
Deposition1	M	60	68			
Wapiti2Kaska	M	68	96			
Dunvegan	F	96	98	0	276	276
Shaftesburry	F	98	101	276	1117	841
BoulderCreek	F	101	107.5	1117	1222	105
Hulcross	F	107.5	109	1222	1353	131
Gates	F	109	110.5	1353	1537	184
Moosebar	F	110.5	113	1537	1787	250
Gething	F	113	120	1787	2575	788
Cadomin	F	120	125	2575	2667	92
SubKErosion	U	125	128			
SubKDepositic	M	128	133			
Mont2Bick	F	133	147	2667	3784	1117
FernieShale	F	147	198	3784	4099	315
SubJurErosion	U	198	201			
SubJurDeposit	M	201	207			
BockcokDepo	F	207	208.5	4099	4160	61
PardonnetDe	F	208.5	227	4160	4293	133
Baldonnel	F	227	232	4293	4400	107
UpperCharlie	F	232	236.5	4400	4600	200
CoplinErosion	U	236.5	237.5			
LowerCharlie	M	237.5	240			
MontneyS4Er	M	240	241			
MontneyS4	F	241	245	4219	4271.5	52.5
MontneyS3	F	245	248	4271.5	4296.5	25
MontneyS2	F	248	249.7	4296.5	4318.3	21.8
MontneyS1	F	249.7	252	4318.3	4340.8	22.5
BelloyErosion	U	252	254			
BelloyDeposit	M	254	255			
Belloy	F	255	298	4340.8	4511.8	171
Stoddart	F	298	333	4511.8	5141.8	630
Debolt	F	333	353	5141.8	5850.8	709
BesaRiver	F	353	384	5850.8	6756.8	906
Section 2						
	U	0	0.1			
	U	0.1	40			
Erosion1	U	40	60			
Deposition1	M	60	68			
Wapiti2Kaska	M	68	96			

Dunvegan	F	96	98	0	276	276
Shaftesbury	F	98	101	276	1117	841
BoulderCreek	F	101	107.5	1117	1222	105
Hulcross	F	107.5	109	1222	1353	131
Gates	F	109	110.5	1353	1537	184
Moosebar	F	110.5	113	1537	1787	250
Gething	F	113	120	1787	2575	788
Cadomin	F	120	125	2575	2667	92
SubKErosion	U	125	128			0
SubKDeposit	M	128	133			0
Mont2Bick	F	133	147	2667	3784	1117
FernieShale	F	147	198	3784	4099	315
SubJurErosion	U	198	201			
SubJurDeposit	M	201	207			
BockcokDepo:	F	207	208.5	4099	4160	61
PardonnetDeç	F	208.5	227	4160	4293	133
Baldonnel	F	227	232	4293	4400	107
UpperCharlie	F	232	236.5	4400	4600	200
CoplinErosion	U	236.5	237.5			
LowerCharlie	M	237.5	237.75			
LowerCharlie	F	237.75	238	4600	4668	68
MontneyS4	F	238	245	4668	4923	255
SB4	U	245	247			
S3Depo	M	247	247.6			
MontneyS3	F	247.6	248	4923	4925	2
MontneyS2	F	248	249.7	4925	5077	152
MontneyS1	F	249.7	252	5077	5125	48
BelloyErosion	U	252	254			
BelloyDeposit	M	254	255			
Belloy	F	255	298	5125	5296	171
Stoddart	F	298	333	5296	5926	630
Debolt	F	333	353	5926	6635	709
BesaRiver	F	353	384	6635	7541	906

Well 3

	U	0	0.1			
	U	0.1	40			
Erosion1	U	40	60			
Deposition1	M	60	70			
Wapiti	M	70	78			
Puskwaskau	M	78	86			
Marshybank	M	86	87.5			
Muskiki	M	87.5	89			
Cardium zone	M	89	90			
Cardium	M	90	91			
Kaskapau	F	91	96	0	526	526
Dunvegan	F	96	98	526	756	230

Shaftesbury	F	98	100	756	1167	411
BFS	F	100	101	1167	1490	323
Paddy	F	101	102	1490	1576	86
MidAlbianEro:	U	102	104.5			
MidAlbianDeç	M	104.5	105			
Cadotte	F	105	107.5	1576	1613	37
Harmon	F	107.5	109	1613	1706	93
Notikewin	F	109	109.5	1706	1774	68
Falher	F	109.5	110.5	1774	1908	134
Wilrich	F	110.5	113	1908	2124	216
BlueSky/Gethi	F	113	120	2124	2455	331
Cadomin	F	120	125	2455	2508	53
SubKErosion	U	125	133			0
SubKDepositic	M	133	140			0
NikanassinDeç	F	140	147	2508	3391	883
FernieShale	F	147	183	3391	3501	110
Nordegg	F	183	198	3501	3521	20
SubJurErosion	U	198	201.5			
SubJurDeposit	M	201.5	207			
BockcokDepo:	M	207	208.5			
PardonnetDeç	F	208.5	227	3521	3564	43
Baldonnel	F	227	232	3564	3628	64
UpperCharlie	F	232	236.5	3628	3790	162
CoplinErosion	U	236.5	237.5			
LowerCharlie	M	237.5	237.75			
LowerCharlie	F	237.75	238	3790	4071	281
MontneyS4	F	238	245	4071	4421	350
SB4	U	245	247			
S3Depo	M	247	247.6			
MontneyS3	F	247.6	248	4421	4571	150
MontneyS2	F	248	249.7	4571	4641	70
MontneyS1	F	249.7	252	4641	4671	30
BelloyErosion	U	252	254			
UpperBelloy	M	254	269			
KsituanErosioi	U	269	302			
MUKsituanDe	M	302	306			
MidUpKsituan	F	306	312	4671	4821	150
LwKsituan	F	312	315	4821	4890	69
MissErosion	U	315	318			
MissDepositio	M	318	321			
LwTaylorFlat	F	321	325	4890	5018	128
Kiskatinaw	F	325	330	5018	5108	90
GolataErosion	U	330	331			
GolataDeposit	M	331	332			
Golata	F	332	333	5108	5118	10
Rundle	F	333	353	5118	5638	520
Banff	F	353	358.5	5638	5868	230

Exshaw	F	358.5	360	5868	5871	3
Wabamun	F	360	370	5871	6071	200
Winterburn	F	370	375	6071	6111	40
Well 4						
	U	0	0.1			
	U	0.1	40			
Erosion1	U	40	60			
Deposition1	M	60	70			
Wapiti Deposi	M	70	73			
Wapiti	F	73	78	0	430	430
Puskwaskau	F	78	86	430	616	186
Marshybank	F	86	87.5	616	637	21
Muskiki	F	87.5	89	637	663	26
Cardium zone	F	89	90	663	675	12
Cardium	F	90	91	675	707	32
Kaskapau	F	91	96	707	1212	505
Dunvegan	F	96	98	1212	1446	234
Shaftesbury	F	98	100	1446	1612	166
BFS	F	100	101	1612	1780	168
Paddy	F	101	102	1780	1810	30
MidAlbianEro:	U	102	104.5			0
MidAlbianDep	M	104.5	105			0
Cadotte	F	105	107.5	1810	1834	24
Harmon	F	107.5	109	1834	1867	33
Notikewin	F	109	109.5	1867	1929	62
Falher	F	109.5	110.5	1929	2059	130
Wilrich	F	110.5	113	2059	2190	131
BlueSky/Gethi	F	113	120	2190	2347	157
Cadomin	F	120	125	2347	2567	220
SubKErosion	U	125	133			
SubKDepositic	M	133	140			
NikanassinDej	M	140	147			
FernieShale	F	147	183	2567	2636	69
Nordegg	F	183	198	2636	2654	18
SubJurErosion	U	198	201.5			
SubJurDeposil	M	201.5	207			
BockcokDepo:	M	207	208.5			
PardonnetDej	M	208.5	227			
BaldonnelDep	M	227	230			
Baldonnel	F	230	232	2654	2665	11
UpperCharlie	F	232	236.5	2665	2828	163
CoplinErosion	U	236.5	237.5			
LowerCharlie	M	237.5	237.75			
LowerCharlie	F	237.75	238	2828	2896	68
MontneyS4	F	238	245	2896	3010	114
SB4	U	245	247			

S3Depo	M	247	247.6			
MontneyS3	F	247.6	248	3010	3073	63
MontneyS2	F	248	249.7	3073	3173	100
MontneyS1	F	249.7	252	3173	3223	50
BelloyErosion	U	252	254			
BelloyDeposit	M	254	256			
UpperBelloy	F	256	269	3223	3233	10
MidBelloy	F	269	294	3233	3257	24
KsituanErosioi	U	294	302			
MUKsituanDe	M	302	306			
LwKsituan	F	306	315	3257	3355	98
MissErosion	U	315	318			
MissDepositio	M	318	321			
LwTaylorFl	F	321	325	3355	3380	25
Kiskatinaw	F	325	330	3380	3454	74
GolataErosion	U	330	331			
GolataDeposit	M	331	333			
Rundle	F	333	353	3454	3929	475
Banff	F	353	358.5	3929	4139	210
Exshaw	F	358.5	360	4139	4143	4
Wabamun	F	360	370	4143	4343	200
Winterburn	F	370	375	4343	4403	60

Well5

	U	0	0.1			
	U	0.1	40			
Erosion1	U	40	60			
Deposition1	M	60	70			
WapitiDeposit	M	70	78			
PuskwaskauD	M	78	84			
Puskwaskau	F	84	86	0	591	591
Dunvegan	F	86	98	591	788	197
Shaftesbury	F	98	99.5	788	917	129
BFS	F	99.5	101	917	1066	149
Paddy	F	101	102	1066	1088	22
CadotteErosio	U	102	104.5			
CadotteDepos	M	104.5	106.5			
Cadotte	F	106.5	107.5	1088	1123	35
Harmon	F	107.5	109	1123	1147	24
Notikewin	F	109	109.5	1147	1209	62
Falher	F	109.5	110.5	1209	1382	173
Wilrich	F	110.5	113	1382	1503	121
Bluesky/Gethi	F	113	120	1503	1625	122
Cadomin	F	120	125	1625	1638	13
SubKErosion	U	125	133			
SubKdepositic	M	133	140			
Nikanassin	M	140	147			

Fernie	F	147	183	1638	1714	76
Nordegg	F	183	198	1714	1740	26
SubJurErosion	U	198	201.5			
Pardonnet	M	201.5	227			
Baldonnel	M	227	232			
UpperCharlie	M	232	235			
UpperCharlie	F	235	236.5	1740	1805	65
CoplinErosion	U	236.5	237.5			
LowerCharlie	M	237.5	237.75			
LowerCharlie	F	237.75	238	1805	1872	67
MontneyS4	F	238	245	1872	1922	50
SB4	U	245	247			
S3Depo	M	247	247.6			
MontneyS3	F	247.6	248	1922	1937	15
MontneyS2	F	248	249.7	1937	2119	182
MontneyS1	F	249.7	252.2	2119	2176	57
BelloyErosion	U	252.2	254			
BelloyDeposit	M	254	255			
MidBelloy	F	255	269	2176	2181	5
LwBelloy	F	269	284	2181	2219	38
Kistuan	U	284	308			
MUKsituan	M	308	312			
LwKsituan	F	312	315	2219	2283	64
LwTaylorFla	F	315	325	2283	2392	109
Kiskatinaw	F	325	328	2392	2492	100
GolataErosion	U	328	330			
GolataDeposit	M	330	331			
Golata	F	331	333	2492	2511	19
Runlde	F	333	353	2511	2985	474
Banff	F	353	358.5	2985	3227	242
Exshaw	F	358.5	360	3227	3233	6
Wabamun	F	360	370	3233	3486	253
Winterburn	F	370	375	3486	3524	38
GraniteWash	F	375	385	3524	3538	14
Well 6						
	U	0	0.1			
	U	0.1	40			
Erosion1	U	40	60			
Deposition1	M	60	70			
WapitiDeposit	M	70	77			
Wapiti	F	77	78	0	10	10
Puskwaskau	F	78	86	10	433	423
Dunvegan	F	86	98	433	546	113
Shaftesbury	F	98	99.5	546	643	97
BFS	F	99.5	101	643	742	99
Paddy	F	101	102	742	749	7

CadotteErosio U		102	104.5			
CadotteDepos M		104.5	106.5			
Cadotte F		106.5	107.5	749	780	31
Harmon F		107.5	109	780	800	20
Notikewin F		109	109.5	800	853	53
Falher F		109.5	110.5	853	1006	153
Wilrich F		110.5	113	1006	1131	125
Bluesky/Gethi F		113	120	1131	1223	92
SubKErosion U		120	133			
SubKDepositic M		133	140			
Nikanassin M		140	147			
Fernie F		147	183	1223	1275	52
Nordegg F		183	198	1275	1305	30
SubJurErosion U		198	201.5			
Bocock M		201.5	208.5			
Pardonnet M		208.5	227			
Baldonnel M		227	232			
UpperCharlie M		232	236.5			
CoplinErosion U		236.5	237.5			
LowCharlieDe M		237.5	237.75			
MontneyS4 M		237.75	245			
SB4 U		245	247			
S3Deposition M		247	247.6			
MontneyS3 M		247.6	248			
MontneyS2 M		248	248.4			
MontneyS2 F		248.4	249.7	1305	1397	92
MontneyS1 F		249.7	252.2	1397	1511	114
BelloyErosion U		252.2	254			
BelloyDeposit M		254	255			
MidBelloy F		255	269	1511	1521	10
LwBelloy F		269	284	1521	1542	21
Kistuan U		284	308			
MUKsituan M		308	312			
LwKsituan F		312	315	1542	1569	27
Kiskatinaw F		315	328	1569	1597	28
GolataErosion U		328	330			
GolataDeposit M		330	331			
Golata F		331	333	1597	1620	23
Runlde F		333	353	1620	2078	458
Banff F		353	358.5	2078	2310	232
Exshaw F		358.5	360	2310	2313	3
Wabamun F		360	370	2313	2538	225
Winterburn F		370	375	2538	2665	127
Ireton F		375	378	2665	2679	14
Leduc F		378	380	2679	2833	154
BHL F		380	384	2833	2911	78
GraniteWash F		384	395	2911	2957	46

Well 7

	U	0	0.1			
	U	0.1	40			
Erosion1	U	40	60			
Deposition1	M	60	70			
WapitiDeposit	M	70	78			
PuskwaskauD	M	78	84			
Puskwaskau	F	84	86	0	326	326
Dunvegan	F	86	98	326	451	125
Shaftesbury	F	98	99.5	451	532	81
BFS	F	99.5	101	532	613	81
Paddy	F	101	102	613	620	7
CadotteErosio	U	102	104.5			
CadotteDepos	M	104.5	107			
Cadotte	F	107	107.5	620	634	14
Harmon	F	107.5	109	634	665	31
Notikewin	F	109	109.5	665	710	45
Falher	F	109.5	110.5	710	861	151
Wilrich	F	110.5	113	861	971	110
Bluesky/Gethi	F	113	120	971	1100	129
Cadomin	F	120	125	1100	1106	6
SubKErosion	U	125	133			
SubKdepositic	M	133	140			
Nikanassin	M	140	147			
Fernie	F	147	183	1106	1174	68
Nordegg	F	183	198	1174	1202	28
SubJurErosion	U	198	201.5			
Bocock	M	201.5	208.5			
Pardonnet	M	208.5	227			
Baldonnel	M	227	232			
UpperCharlie	M	232	236.5			
CoplinErosion	U	236.5	237.5			
LowerCharlie	M	237.5	238			
MontneyS4	M	238	245			
SB4	U	245	247			
S3Deposition	M	247	247.6			
MontneyS3	M	247.6	248			
MontneyS2	M	248	249.7			
MontneyS1	F	249.7	252.2	1202	1287	85
BelloyErosion	U	252.2	254			
BelloyDeposit	M	254	255			
MidBelloy	F	255	269	1287	1306	19
LwBelloy	F	269	284	1306	1338	32
Kistuan	U	284	308			
MUKsituan	M	308	312			
Rundle2LKsitu	M	312	338			

Runlde	F	338	353	1338	1743	405
Banff	F	353	358.5	1743	1984	241
Exshaw	F	358.5	360	1984	1988	4
Wabamun	F	360	370	1988	2234	246
Winterburn	F	370	375	2234	2348	114
Ireton	F	375	378	2348	2590	242
Duvernay	F	378	380	2590	2608	18
BHL	F	380	384	2608	2670	62
SlavePoint	F	384	386	2670	2684	14
GraniteWash	F	386	395	2684	2719	35

Well 8

	U	0	0.1			
	U	0.1	40			
Erosion1	U	40	60			
Deposition1	M	60	70			
WapitiDeposit	M	70	78			
PuskwaskauD	M	78	84			
Puskwaskau	F	84	86	0	88	88
Dunvegan	F	86	98	88	243	155
Shaftesbury	F	98	99.5	243	323	80
BFS	F	99.5	101	323	403	80
Paddy	F	101	102	403	419	16
CadotteErosio	U	102	104.5			
CadotteDepos	M	104.5	107.5			
Harmon	F	107.5	109	419	444	25
Notikewin	F	109	109.5	444	476	32
Falher	F	109.5	110.5	476	623	147
Wilrich	F	110.5	113	623	702	79
Bluesky/Gethi	F	113	120	702	770	68
SubKErosion	U	120	133			
SubKdepositic	M	133	140			
Nikanassin	M	140	147			
Fernie	M	147	183			
Nordegg	M	183	198			
SubJurErosion	U	198	201.5			
Bocock	M	201.5	208.5			
Pardonnet	M	208.5	227			
Baldonnel	M	227	232			
UpperCharlie	M	232	236.5			
CoplinErosion	U	236.5	237.5			
LowerCharlie	M	237.5	238			
MontneyS4	M	238	245			
SB4	U	245	247			
S3Deposition	M	247	247.6			
MontneyS3	M	247.6	248			
MontneyS2	M	248	249.7			

MontneyS1	M	249.7	252.2			
BelloyErosion	U	252.2	254			
BelloyDeposit	M	254	255			
MidBelloy	M	255	269			
LwBelloy	M	269	284			
Kistuan	U	284	308			
MUKsituan	M	308	312			
Rundle2LKsitu	M	312	338			
Runlde	F	338	353	770	1028	258
Banff	F	353	358.5	1028	1281	253
Exshaw	F	358.5	360	1281	1286	5
Wabamun	F	360	370	1286	1566	280
Winterburn	F	370	375	1566	1695	129
Ireton	F	375	378	1695	1937	242
Duvernay	F	378	380	1937	1969	32
BHL	F	380	384	1969	2029	60
SlavePoint	F	384	386	2029	2061	32
GraniteWash	F	386	395	2061	2068	7

AMOUNT ERODED (m)	AMOUNT MISSING (m)	SANDSTONE %	SILTSTONE %	SHALE %	LIMESTONE %	DOLOMITE %
0						
0						
2700						
	1500	30	30	30	10	
	1200	28	30	25	2	3
		30	30	30	10	
		30	30	30	10	
		50	50			
		3	10	85		2
		30	30	30	3	3
		4	25	65		5
		30	25	35	1	4
		71	8	5		1
50						
	50	40	17	34		3
		40	17	34		3
		2	8	88	1	1
20						
	20	55	5		5	35
					100	
			35	15	20	30
				15		85
		16	30	12	3	23
100						
	85	16	30	12	3	23
	15		45	55		
			45	55		
		30	60	5		5
		30	60	5		5
		12	46	33	2	7
2						
	2	20	5			75
		20	5			75
		30	30		30	10
					90	10
			50	50		
0						
0						
2700						
	1500	30	30	30	10	
	1200	28	30	25	2	3

		30	30	30	10	
		30	30	30	10	
		50	50			
		3	10	85		2
		30	30	30	3	3
		4	25	65		5
		30	25	35	1	4
		71	8	5		1
50						
	50	40	17	34		3
		40	17	34		3
		2	8	88	1	1
50						
	50	55	5		5	35
					100	
			35	15	20	30
				15		85
		16	30	12	3	23
50						
	50	16	30	12	3	23
		16	30	12	3	23
			45	55		
50						
	50	30	60	5		5
		30	60	5		5
		30	60	5		5
		12	46	33	2	7
2						
	2	20	5			75
		20	5			75
		30	30		30	10
					90	10
			50	50		
0						
0						
3000						
	1633	30	30	30	10	
	1100	28	30	25	2	3
	180	3	10	85		2
	20	36	35	20		
	25	3	10	85		2
	10	46	25	15		3
	32	71	3	5		1
		3	10	85		2
		44	25	20		

		4	15	80		
		19	35	35	1	2
		30	30	30	10	
15						
	15	64	10	5	5	
		64	10	5	5	
		3	10	85		2
		41	15	25	2	3
		24	30	33		5
		4	25	65		5
		30	24	34	1	3
		70	3	5		2
150						
	150	40	17	34		3
		40	17	34		3
		2	8	88	1	1
		1	1	80	15	2
110						
	50	55	5		5	35
	60				100	
			35	15	20	30
				15		85
		16	30	12	3	23
10						
	10	16	30	12	3	23
		16	30	12	3	23
			45	55		
1						
	1	30	60	5		5
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0						
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