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**Biostratigraphic evidence for incremental tectonic development of early Cambrian
deep-water environments in the Misty Creek embayment
(Selwyn basin, Northwest Territories, Canada)**

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Draft

Abstract

The early evolution of the Misty Creek embayment (MCE), a prominent, northwest-trending sub-basin of the economically important Selwyn basin, is poorly understood. The abrupt contact between Cambrian Stage 4 (traditional lower Cambrian) carbonate ramp strata of the Sekwi Formation and overlying Miaolingian (traditional middle Cambrian) deep-water, calciturbiditic strata of the Hess River Formation has been regarded as diachronous. This important transition, which marks the onset of long-lived, deep-water conditions in the MCE, remains unexplained. This study uses biostratigraphic data from a previously undescribed location in the MCE, existing biostratigraphic and lithostratigraphic data from the 1970s, and regional thickness patterns to characterise the sharp yet diachronous transition from lithofacies typical of the Sekwi Formation to those typical of the Hess River Formation. The dramatic change in depositional environments was diachronous yet non-gradational, precluding a eustatic cause. The change was geologically abrupt, probably through two extension-related subsidence events, with different geographic extents, which heralded the MCE's long life as a deep-water basin. The onset of deep-water conditions in the MCE occurred semi-contemporaneously with other extension-related events that are recorded in the northern Canadian Cordillera, demonstrating that Cambrian Series 2-Miaolingian was a time of widespread extension and subsidence along the western margin of Laurentia.

Keywords: Selwyn basin, Cambrian, Mackenzie Mountains, trilobite biostratigraphy, Cambrian Stage 4, Miaolingian

32 **Introduction**

33 The Selwyn basin is a complex, regionally deformed lower Paleozoic deep-water basin
34 along the northwestern margin of ancestral North America (Gordey and Anderson 1993).
35 Spanning from Alaska to British Columbia, the Selwyn basin contains past-producing
36 sedimentary exhalative/clastic-dominant (SEDEX/CD) base-metal deposits at several
37 stratigraphic levels and carbonate-hosted Zn and Au deposits in surrounding shallow-water
38 carbonate strata (Dewing et al. 2006; Ootes et al. 2013; Thiessen et al. 2016). The
39 stratigraphically lowest SEDEX/CD deposits in the Selwyn basin, belonging to the past-
40 producing Anvil district, were hosted by variably deformed and metamorphosed deep-water
41 Cambrian strata (Pigage 2004; Goodfellow 2007). The exact age of the Anvil district host rocks
42 and mineralisation are not well constrained (Pigage 2004; Turner 2015).

43 The Selwyn basin includes multiple second- and third-order sub-basins, including deep-
44 water embayments along its margins, the northernmost of which is the Misty Creek embayment
45 (MCE; Cecile 1982). Although the MCE (Fig. 1) is well exposed and stratigraphically intact in
46 many places, it is understudied and underexplored for mineral potential because of its
47 remoteness. Depositional ages of some of the lower Paleozoic deep-water units in the MCE are
48 poorly constrained because of a paucity of chronostratigraphic data. Cambrian strata in the MCE
49 exhibit characteristics associated with SEDEX/CD deposits, including evidence of anoxia,
50 synsedimentary tectonic instability, and elevated base metal content (Turner 2015). Refining the
51 depositional ages and conditions of lower Paleozoic deep-water units is necessary to illuminate
52 basin evolution processes and events that may have favoured the formation of base metal
53 deposits.

This study approaches the early tectonic development of the MCE using four types of information to illuminate the nature of the contact between Sekwi and Hess River formations (S-HR contact): (a) new biostratigraphic material from an unusually well exposed and well situated contact locality is identified and interpreted; (b) published biostratigraphic datasets (Fritz 1976, 1978, 1979; Cecile, 1982) are used to evaluate the age of the contact throughout the embayment; (c) the lithostratigraphic nature of the contact is characterised using published stratigraphic sections; and (d) published thickness datasets are compiled and compared to the biostratigraphic evidence. These four mutually informative types of information are used to develop a possible explanation for the abrupt, diachronous S-HR transition. Refining the chronology of tectonostratigraphic events in the various embayments and troughs of the northern Canadian Cordillera will facilitate comparison among sub-basins and development of a regional tectonic history that includes other basins.

Geological Background

Selwyn basin and Misty Creek embayment

The Selwyn basin was an elongate Paleozoic marine basin on the present-day western passive margin of ancestral North America from the latest Neoproterozoic to the Devonian, now preserved in eastern Yukon and western Northwest Territories (NWT) (Gordey and Anderson 1993). In the early to middle Cambrian, the northernmost Selwyn sub-basin was the northwest-trending Misty Creek embayment (MCE; Fig. 1A) in the present-day NWT. The MCE was connected to the Selwyn basin via a (present-day) southwest-facing opening (Cecile 1982), and was separated from a contemporaneous shallow-water carbonate and siliciclastic intracratonic basin to the northeast (Dixon, 1997; Dixon and Stasiuk, 1998; Maclean, 2011; Sommers et al., 2020) by the Mackenzie-Redstone arch (Fig. 1).

The current understanding of the stratigraphy, biostratigraphy, depositional evolution, and paleogeography of MCE deep-water units is based largely on reconnaissance work by Cecile (1982), who subdivided what had been previously known as the “Road River Group” into the Hess River, Rabbitkettle, Duo Lake, and Cloudy formations (Fig. 1B). The Cambro-Ordovician evolution of the MCE is known only superficially, and the biostratigraphy and depositional ages of its oldest stratigraphic units are not well constrained. The relationship between the tectonostratigraphic evolution of the MCE and the Selwyn basin proper remains an open question.

Sekwi Formation

Stratigraphy and Lithofacies

The Sekwi Formation (Fig. 2; Handfield 1968), is a 500- to 1300-m-thick (Fischer and Pope 2011) lower Cambrian (Cambrian Stage 3 and 4) carbonate ramp unit known for its impressive thickness, abundance of trilobites, and compositional heterogeneity. Initial lithostratigraphic studies of the unit (Handfield 1968; Aitken et al. 1973) were later followed by biostratigraphic (Fritz 1972, 1976, 1978, 1979) and sedimentological (Krause 1979) work. Dilliard et al. (2007, 2010) divided the formation into seven unconformity-bounded sequences (S0-S6; Fig. 2B). Sequences S0 and S1 (lower Sekwi Formation) consist of thirteen deeper-water ramp lithofacies influenced by normal faulting. Sequences S2 to S6 (upper Sekwi Formation) are shallower-water ramp cycles, each with basal shallow-subtidal carbonate lithofacies shallowing upward to peritidal carbonate caps.

The Sekwi Formation conformably overlies fine siliciclastic rocks of the Cambrian Vampire Formation in areas that are distal (west) to the Plateau fault (Fritz, 1979; Fischer and

Pope 2011; MacNaughton and Fallas 2019). In areas near the Plateau fault, the Sekwi Formation overlies rocks of the Ediacaran to Cambrian Backbone Ranges Formation, and the Vampire Formation is absent (Fritz, 1979; Fischer and Pope 2011; MacNaughton and Fallas 2019). The Hess River Formation overlies the Sekwi Formation, and at the S-HR contact, the uppermost Sekwi Formation is Cambrian Stage 4 (Fritz 1972, 1976, 1978, 1979).

The Sekwi Formation ramp faced and deepened southwest (present-day coordinates). Its maximum thickness (>800 m) is in a NW-trending zone in NTS 106C and 106B (Fig. 3A; Chan et al., 2019) that later became the MCE.

Biostratigraphy

Fritz (1972) used paleontological data gathered from the Sekwi Formation type section to establish a trilobite zonal scheme for the traditional lower Cambrian. The lowermost part of the Sekwi Formation (*sensu* Dilliard et al. 2007, 2010) was deposited during the latter part of the *Fallotaspis* Zone (Fig. 2), and most of the lower Sekwi Formation is in the *Nevadella* Zone. Lowermost *Bonnia-Olenellus* Zone fossils appear midway through S1 (Fig. 2B). Close to the Mackenzie-Redstone arch, *Fallotaspis* and *Nevadella* zones are absent, and *Bonnia-Olenellus* Zone trilobites are close to the base of the formation (Gabrielse et al. 1973). The upper Sekwi Formation (up to 500 m thick) is entirely within the *Bonnia-Olenellus* Zone (Cambrian Stage 4).

Chemostratigraphy

Dilliard et al. (2007) published a $\delta^{13}\text{C}$ curve for the Sekwi Formation (Fig. 2B); retrospectively, at least three carbon isotope excursions, which probably represent the Cambrian arthropod radiation isotope excursion (CARE), Mingxinsi carbon isotope excursion (MICE), and

archaeocyathan extinction isotope excursion (AECE), are identifiable in the Sekwi Formation (Fig. 2A; Geyer, 2019; Peng et al., 2020; Cramer and Jarvis, 2020). The redlichiid-olenellid extinction isotope excursion (ROECE) may be partly expressed in Section 4 of Dilliard et al. (2007), which, unlike the type section (section 10), has an intact upper contact that is not compromised by faulting or post-Sekwi exposure in the vicinity of the Mackenzie-Redstone arch [Dilliard et al. 2007 (fig. 2)]. Section 4 ends in sequence 6 of Dilliard et al. (2007) and therefore contains the youngest known Sekwi Formation strata that also have carbon isotope data. In the carbon isotope curve for section 4, a slight negative shift below the upper contact (Fig. 2B) may be the falling limb of the ROECE; if the ROECE is indeed present, the Sekwi Formation does not capture it completely.

Hess River Formation

Stratigraphy and Lithofacies

The contact between resistant Sekwi Formation carbonate strata and recessive, dark-weathering, thin-bedded, shale-rich, fossil-poor Hess River Formation strata is always abrupt and conspicuous, even when partly obscured by cover. The Hess River Formation type section (section 6 of Cecile 1982; Figs. 1A and 4A) consists of 60 m of poorly exposed interstratified calcareous and siliceous shale overlain by 360 m of interstratified calcareous shale and argillaceous limestone. This division into a lower shale-dominated unit and an upper lime-mudstone-dominated unit applies to many, but not all, Hess River Formation sections described in Cecile (1982). The Hess River Formation is 100 to 2530 m thick; isopach patterns indicate greater thickness towards the centre of the MCE (Fig. 3B; Cecile 1982). Thick Hess River

Formation sections (e.g., Cecile section 5, ~2100 m) commonly include a significant amount of sandstone.

The only detailed stratigraphic work on the Hess River Formation is that of Chevrier and Turner (2013a, b), from the centre of the MCE, where the formation is >1350 m thick and the base is unexposed (Fig. 4B). There, the formation is dominated by monotonously interlayered, thin-bedded calcareous siltstone and silty lime mudstone, but contains a conspicuous black shale unit low in the section. Black shale intervals in numerous Hess River Formation sections (Fritz 1976, 1978, 1979; Cecile 1982), may be of interest for their base-metal content (Turner 2015), and so their depositional age and correlation are concerns that require further research. The basal Hess River Formation contains floating clasts of what appear to be Sekwi Formation limestone in sandy matrix in at least one location, suggesting that the contact may be locally unconformable or reworked (Turner 2015).

Biostratigraphy

Basal strata of the Hess River Formation range from Cambrian Stage 4 to Wuliuan (Fritz 1976, 1978, 1979; Cecile 1982). Apparent variability in the S-HR contact age led previous authors to suggest that it may be diachronous (Fritz 1976; Cecile 1982). Biostratigraphically well-constrained S-HR formational contacts do not show a noticeable time gap between the deposition of the two units (Fritz 1976, 1978, 1979), and Cecile (1982) regarded the S-HR contact as conformable. On the MCE margins, the base of the Hess River Formation may be unconformable, and it is typically middle Cambrian (Fritz 1976, 1978, 1979; Cecile 1982).

Chemostratigraphy

The only available carbon isotope curve for the lower Hess River Formation is in the central MCE [section 9 of Cecile (1982); the lowermost Hess River Fm. is not exposed (Chevrier and Turner 2013a,b)]. The curve includes a negative $\delta^{13}\text{C}$ excursion that probably corresponds to the DICE in a black shale interval (Fig. 4B; Turner 2015); moderately negative $\delta^{13}\text{C}$ values at the base of the section may be evidence of the ROECE. The age of the S-HR contact at section C9 cannot be determined with certainty, either biostratigraphically or chemostratigraphically.

Lower Cambrian (Stages 3 and 4) biostratigraphy of Laurentia

Lower Cambrian biostratigraphy in Laurentia is based almost exclusively on trilobite assemblages. The current regional lower Cambrian trilobite biostratigraphic scheme for Laurentia consists of the *Fritzaspis*, *Fallotaspis*, *Nevadella*, and *Bonnia-Olenellus* zones (Fritz, 1972; Hollingsworth, 2007). These biozones are defined by trilobite genera and span Cambrian stages 3 and 4, comprising what was traditionally known as the trilobite-bearing lower Cambrian (e.g., Peng et al. 2020; Geyer 2019). Although the modern lower Cambrian trilobite biozones of Laurentia have been widely used for decades, there are issues with their utility. Among these is the comparatively long duration of the *Bonnia-Olenellus* Zone (Fig. 2A). Because of this long duration, strata deposited during *Bonnia-Olenellus* Zone time commonly span a substantial thickness. Therefore, the *Bonnia-Olenellus* Zone is problematic because it is too long to be useful for deciphering basin-evolution events of relatively short duration.

According to Fritz (1991), the *Bonnia-Olenellus* Zone can be divided into informal lower, middle, and upper sub-zones. Fritz (1972, 1991) did not explicitly define criteria for the lower part of the *Bonnia-Olenellus* Zone, although it is commonly represented by *Laudonia* and

Olenellus truemani Fritz 1972. Fritz (1991) thought that *Wanneria* occupied the middle *Bonnia-Olenellus* Zone, together with *Olenellus laxocules* Fritz 1972, *O. sequolamus* Fritz 1972, and *O. paraoculus* Fritz 1972. The upper sub-unit was defined as containing “abundant, small, relatively smooth ptychopariid trilobites” such as *Antagmus*, *Syspacephalus*, *Piaziella*, and *Onchocephalus*. *Zacanthopsis* and *Goldfieldia* also appear to be limited to the upper part of the zone. Species that are restricted to the upper *Bonnia-Olenellus* Zone include *Olenellus parvofrontatus* Fritz 1991, *O. puertoblancoensis* Lochman 1952, *O. romensis* Resser and Howell 1938, and *Bonnima semidiscoidea* Fritz 1991 (Fritz 1972, 1976, 1978, 1979, 1991). Lastly, the genus *Ogygopsis* occurs only in the upper *Bonnia-Olenellus* Zone (Palmer 1964, Fritz 1976, 1978, 1979; Table 1). Late in his career, Fritz contributed a summary table depicting his understanding of lower Cambrian genus ranges (Aitken 1997, Table 1).

More recently, finer-scale biozones have been proposed to augment or replace the *Bonnia-Olenellus* Zone. Webster (2011) proposed six new trilobite biozones in the upper *Bonnia-Olenellus* Zone based on data from the southern Great Basin (California and Nevada); it is unclear how applicable these zones are elsewhere in western Laurentia. Webster and Bohach (2014) proposed a provisional biostratigraphic framework for much of western North America (British Columbia, Nevada, and Sonora) characterised by *Lochmanolenellus pentagonalis* Webster and Bohach 2014, *Fritzolenellus truemani* Walcott 1913, and *Mummaspis muralensis* Fritz 1992 for the lower *Bonnia-Olenellus* Zone.

Materials and Methods

New trilobite collections come from a ~20-m-thick exposure across the Sekwi-Hess River formational contact in the north-central Misty Creek embayment (NTS 106B; Figs. 1A and 5).

208 The exposure consists of four units (Fig. 5), of which three contain trilobite fragments; a set of
209 fossiliferous, local to very local float slabs was collected from each. Of the 167 trilobite
210 fragments in the collection, 105 specimens were identifiable to genus- or species- level
211 (Appendices A-C). The basal unit (unit 1; carbonate-dominated) is considered to represent the
212 uppermost Sekwi Formation. Units 2-4 (shale-carbonate, carbonate, and shale-carbonate,
213 respectively, in ascending order) are considered to correspond to the lowermost Hess River
214 Formation because of their recessive weathering and significant shale content (Cecile, 1982).

215 Matrix was removed to prepare some fossil specimens using a Chicago Pneumatic 9160
216 engraver. Specimens were coated with India ink, dusted with NH_4Cl sublimate, and
217 photographed with a Canon EOS Mark IV equipped with a 100 mm f-2.8 lens. One Braun light
218 with a 20.3 cm (8 inch) snoot was used for lighting alongside reflectors placed around the
219 specimen. Photographs were processed in Adobe Lightroom and edited to alter brightness and
220 contrast in Adobe Photoshop.

221 Ages of the S-HR contact in 21 other MCE sections were assessed using biostratigraphic
222 data in Fritz (1976, 1978, 1979) and Cecile (1982) (Fig. 6; Table 1). Fritz's (1991) tripartite
223 informal subdivision of the *Bonnina-Olenellus* Zone was applied to estimate depositional age as
224 precisely as possible using existing taxonomy.

225 The S-HR formational contact is variably well constrained biostratigraphically
226 throughout the MCE. The contact has a "definite" age determination where strata are
227 unambiguously upper *Bonnina-Olenellus* Zone on both sides of the contact or middle *Bonnina-*
228 *Olenellus* Zone on both sides of the contact. However, the S-HR contact is commonly bracketed
229 by middle *Bonnina-Olenellus* Zone assemblages below and upper *Bonnina-Olenellus* Zone
230 assemblages above. In these cases, the age determination was extrapolated based on the

assemblage that is closest to the contact (Table 1). In other cases, the use of open nomenclature necessitates an extrapolated contact age. For example, in Fritz section 21, the trilobite closest to the S-HR contact in the Hess River Formation is cf. *Olenellus paraoculus*. *O. paraoculus* occurs in the middle *Bonnia-Olenellus* Zone, but Fritz's (1978) designation of cf. *O. paraoculus* makes the age determination less certain. In addition, three sections [Fritz sections 5, 22, and 23 (Fritz 1976, 1978)] were designated as having an S-HR formational contact in the middle *Bonnia-Olenellus* Zone despite upper *Bonnia-Olenellus* Zone trilobites found as float slightly closer to the contact. In these cases, because the upper *Bonnia-Olenellus* Zone trilobites were f float, it is assumed that their original stratigraphic position was somewhat higher, and a middle *Bonnia-Olenellus* Zone age was assigned instead.

New lithostratigraphic and biostratigraphic results

Lithological descriptions of the studied intervals (units 1-4) that span the S-HR contact are provided in Supplementary File A. The taxonomic contents of individual samples are documented in Supplementary File B, and the systematic taxonomy of the collections in Supplementary File C.

Unit 1 consists of pale grey-weathering, fine- to medium-grained, irregular or planar-layered, thin- to medium-bedded limestone, and contains a dorypygid-dominated trilobite assemblage consisting of *Bonnia?* sp., *Ogygopsis* sp., and other indeterminate dorypygid cranidia and pygidia (Figs. 5 and 7; Table 2; Appendices A- C). This assemblage is sparse and generally poorly preserved relative to the other intervals, making taxonomic identifications difficult.

Unit 2 consists of grey-brown-weathering, medium-grained, thickly laminated to very thin-bedded, parallel-laminated, bioturbated limestone interbedded with recessive, dark grey- to-

grey-brown-weathering, thickly laminated shale. It contains an olenellid- and dorypygid-dominated assemblage consisting of *Bonnia* sp., *Kootenia marcoui* Whitfield (1884), *Ogygopsis* cf. *O. batis* Walcott (1916), aff. *Olenellus parvofrontatus* Fritz (1991), *Olenellus* cf. *O. parvofrontatus* Fritz (1991), *Olenellus* sp., *Zacanthopsis*? sp., and other indeterminate olenellid fragments (Figs 5 and 7; Table 2; Appendices A- C).

Unit 3 consists of non-fossiliferous orange-brown-weathering slump-folded, medium-grained, thin-bedded dolostone (Fig. 5, Supplementary File A).

Unit 4 consists of recessive, dark grey, silty, thickly laminated to very thin-bedded, parallel-laminated lime mudstone and contains a dorypygid- and- ptychopariid-dominated assemblage consisting of dolichometopid sp. 1, *Kootenia marcoui*, *Ogygopsis* cf. *O. batis*, an indeterminate oryctocephalid, “*Syspacephalus*” sp., *Zacanthopsis*? sp., and *Zacanthopsis* cf. *Z. expansa* Fritz 1991 (Figs 5 and 7; Table 2; Appendices A- C).

Interpretation

Age determinations of S-HR contact at study locality

The faunas identified from the three fossiliferous units in this study all belong to the *Bonnia-Olenellus* Zone, placing them in Cambrian Stage 4 (Table 2). In units 3 and 4, *Zacanthopsis* cf. *Z. expansa* and numerous ptychopariid trilobites (“*Syspacephalus*”) indicate upper *Bonnia-Olenellus* Zone *sensu* Fritz (1972, 1991; also see Table 1 in Aitken 1997). Because *Ogygopsis* occurs only in the upper *Bonnia-Olenellus* Zone elsewhere in Laurentia (Palmer 1964, Fritz 1976, 1978, 1979; Aitken 1997). *Ogygopsis* sp. is present in unit 1, meaning that despite the relative sparseness of the unit 1 assemblage, all three fossiliferous units belong to the upper *Bonnia-Olenellus* Zone, which spans the S-HR contact at the study location.

Although all three units belong to the late *Bonnia-Olenellus* Zone, different trilobite taxa are present in each of the three fossiliferous units (Table 2). These differences are probably not temporally meaningful, and may reflect slight shifts in paleoenvironment such as water depth, euxinia, or salinity.

Little work has attempted to tie early Cambrian trilobite assemblages to specific depositional environments. Some workers (Tremblay 1996; Bohach 1997) documented biofacies that were probably a function of paleoenvironmental influences. In lower Cambrian strata of British Columbia, Nevada, and California, olenellids dominate inner-shelf deposits (Bohach 1997). Lochman (1952) and Fritz (1991) both suggested that uppermost lower Cambrian strata in Laurentia are dominated by abundant olenellid and ptychopariid trilobites, best substantiated in carbonate-shelf facies (Tremblay 1996). Based on sedimentology and interpreted depositional setting of the Hess River Formation (Chevrier and Turner, 2013a,b; Turner, 2015), most of the trilobites in this study were probably transported to the location in which they were preserved, meaning that if paleoenvironmental shifts were responsible for differences in faunal assemblages in units 1, 2, and 4, they occurred in the source area from which the trilobites and sediments were derived.

Geographic distribution of Sekwi-Hess River formational contact ages

The age of the S-HR contact (Figs. 6 and 8A; Table 1) varies geographically from the middle to upper *Bonnia-Olenellus* Zone (Cambrian Stage 4) *sensu* Fritz (1972, 1991; Table 1 of Aitken 1997). The geographic distribution of S-HR contact ages outlines elongate zones subparallel to the northwest-trending long axis of the MCE (Fig. 6). The oldest S-HR contacts (middle *Bonnia-Olenellus* Zone) cluster in an area offset slightly to the southwest of the embayment's long axis, particularly in the northwestern part of the MCE. Areas to the southwest

and northeast of this exhibit younger S-HR contacts, in the upper *Bonnia-Olenellus* Zone. In the east-central part of the embayment, the Sekwi Formation is unconformably overlain by the Hess River Formation or Rabbitkettle Formation (basal strata of Hess River and Rabbitkettle formations in this area are middle Cambrian and Ordovician, respectively). The pattern of elongate basin-floor zones parallel to the embayment's northwest-trending long axis is geographically consistent, with the exception of section 8 of Cecile (1982), a small, middle *Bonnia-Olenellus* Zone salient in the upper *Bonnia-Olenellus* Zone area. This anomaly may reflect the basin architecture of the MCE, or instead be an artifact caused by taxonomic uncertainty: the assignment to middle *Bonnia-Olenellus* Zone is based on the presence of *Wanneria?* sp. 1 m below the S-HR formational contact in float. The uncertainty of this taxonomic assignment renders the age assignment uncertain.

Other uncertainties associated with age determinations and the geographic distribution of S-HR formational contact ages include contact ages that were extrapolated (Table 1). Furthermore, some of the collections that were used to make age determinations were quite close to the formational contact, meaning that the boundary between the upper and middle *Bonnia-Olenellus* zones can be close to the contact, potentially compounding the error associated with extrapolating the contact age. Despite these issues, the geographic distribution of the age of the S-HR formational contact presented here is consistent with the existing data, is based on a number of sections that have reliable biostratigraphic data, and can be further tested with additional fossil collections and chemostratigraphy.

Sekwi Formation and Hess River Formation isopachs

The Sekwi Formation is interpreted as representing a southwest-facing carbonate ramp (Dilliard et al. 2007; 2010), and isopach patterns for the *Fallotaspis* and *Nevadella* Zones in the

Sekwi Formation are consistent with this interpretation - its thickness increases regionally to the southwest (Fig. 3A, Chan et al. 2019). *Fallotaspis* Zone strata thicken to the southwest, reaching maximum thickness in central NTS 105P, and from there thin southwestward. *Nevadella* Zone strata also thicken to the southwest, reaching maximum thickness in south-central NTS 105P and then thinning southwestward. Isopach patterns for the *Bonnina-Olenellus* Zone strata are also consistent with southwestward thickening, with one crucial exception: the *Bonnina-Olenellus* Zone reaches maximum thickness in north-central NTS 106B, and then thins southwestward (Chan et al. 2019). Hess River Formation isopachs also trend northwest, and the formation's thickness is greatest in an area parallel to, but offset to the southwest of, the MCE's long axis (Fig. 3). Comparison of Hess River Formation isopachs with *Bonnina-Olenellus* Zone isopachs in the Sekwi Formation (Fig. 3) reveals that the area of thickest *Bonnina-Olenellus* Zone in NTS106B coincides with the thickest part of the Hess River Formation in the MCE.

Discussion

Onset of deep-water deposition in the MCE

The newly documented field location provides an unusually well exposed and fossiliferous S-HR transition. Because the spacing of biostratigraphic material across the contact is denser than in any of the existing datasets, it also provides an especially detailed view of the transition. The S-HR contact represents the first appearance of regionally deep-water lower Paleozoic environments in the MCE. The nature of this contact, together with thickness and facies patterns, encodes important information about the tectonic development of part of Laurentia's ancestral passive margin. Although there are older deep-water stratigraphic units near the Proterozoic – Cambrian transition regionally, the Selwyn basin is regarded as a mainly Paleozoic phenomenon (e.g., Gordey and Roots, 2011). The origin of the S-HR contact may

therefore be relevant to the development of the continent's ancestral margin beyond the MCE and the Selwyn basin, and to the economic potential of deep-water Cambrian strata regionally.

Any interpretation of the S-HR contact must take into account the following characteristics: (a) lithostratigraphically abrupt transition from shallower-water lithofacies typical of upper Sekwi Formation to contrasting, deep-water lithofacies typical of Hess River Formation; (b) a biostratigraphically conformable contact at each location (no missing time); (c) variation in the timing of the onset of Hess River Formation (deep-water) deposition (possibly on a time-scale of millions of years); and (d) thickness patterns of *Bonnina-Olenellus* Zone strata in Sekwi and Hess River formations that appear similar in the area of the eventual MCE.

On passive margins that are unaffected by tectonic activity, regional changes in paleo-water-depth can be assumed to be geologically instantaneous and caused by eustasy. Paleobathymetric changes caused by eustatic sea-level rise commonly preserve evidence of gradual transgression, preserved lithostratigraphically as transgressive systems tracts (TST; Catuneanu, 2006). When a lithostratigraphic contact between an underlying shallow-water unit and an overlying deeper-water unit lacks a regionally identifiable and correlatable TST (i.e., records abrupt transition to deeper-water conditions), and the timing of the lithostratigraphic change is known to be variable, a eustatic origin for the transition is not defensible, and tectonic causes should be investigated.

The Selwyn basin was a long-lived deep-water environment that developed over older, shallower-water passive-margin environments, attesting to a substantial episode of regionally anomalous subsidence (Gordey and Anderson 1993; Moynihan et al. 2019). The northwestern margin of ancestral North America experienced two or three main episodes of extension in the early Paleozoic (Cecile et al. 1997), and Cecile (1982) invoked extension as an explanation for

the origin of the MCE. The S-HR contact's characteristics are difficult to reconcile with eustatic deepening, and therefore extension-related paleoenvironmental change should be re-evaluated as the mechanism behind the S-HR transition.

The combined lithostratigraphic, biostratigraphic, and thickness evidence highlighted by this study identifies three episodes in the MCE's evolution across the S-HR contact (Fig. 8B).

(1) During middle *Bonnia-Olenellus* Zone time, a narrow, northwest-trending axial area of extension-related subsidence developed through basin-floor normal faulting in what was to become the MCE. The new deep-water zone coincided geographically with both (a) the area in which the underlying *Bonnia-Olenellus* Zone in the Sekwi Formation is regionally thickest and (b) the area in which the Hess River Formation is thickest (Fig. 3). Deep-water lithofacies characteristic of the Hess River Formation began to accumulate in this axial zone, even as lithofacies typical of the Sekwi Formation continued to accumulate northeast and southwest of it. The fact that the Sekwi Formation's *Bonnia-Olenellus* Zone strata are thickest here (>800 m) suggests that subsidence had been taking place along this zone before the transition to Hess-River-like lithofacies, but was subtle and gradual enough during Sekwi Formation deposition that carbonate accumulation could keep up with the enhanced subsidence without a significant change in depositional environment.

(2) During upper *Bonnia-Olenellus* Zone time, an abrupt transition from Sekwi Formation lithofacies to Hess River Formation lithofacies occurred regionally in the MCE. Like the older S-HR contacts expressed only in the axial zone of the MCE, these transitions are lithostratigraphically abrupt (no TST), even though they are biostratigraphically

conformable, suggesting that a second abrupt deepening event took place during the upper *Bonnina-Olenellus* Zone, with a more regional effect than the first one.

(3) Eastern-most Sekwi Formation sections in the MCE have unconformable contacts with the overlying units; basal strata of the Hess River Formation are middle Cambrian in these locations (Table 1). These exposure surfaces may have resulted either from uplift along the Mackenzie-Redstone arch (perhaps coeval with and related to central-MCE subsidence events), or from eustatic sea-level changes expressed in the shallow-water setting at the eastern limit of the Sekwi Formation's depositional area. This complex subject is beyond the scope of the present study.

The combined evidence supports an incrementally diachronous transition from mainly shallow-water depositional environments with in situ carbonate production and accumulation in the upper Sekwi Formation (Krause 1979; Dilliard et al. 2007) to deep-water environments and the accumulation of transported carbonate affiliated with the Hess River Formation (fine-grained calciturbidites; Fig. 8b; Turner 2015). Sekwi Formation environments persisted in shallower settings even as enhanced subsidence, accommodated by seafloor normal faults, drowned other locations, producing a deep-water carbonate depositional environment characteristic of the Hess River Formation.

A tectonic interpretation for this suite of evidence (Fig. 8B) is compatible with the lithostratigraphic, biostratigraphic, and thickness evidence. It is also supported by structural evidence from recent regional mapping (MacNaughton et al., 2017) of syndepositional normal faults that were active during Hess River Formation deposition (Fig. 9). These faults produced mappable thickness changes in the Hess River Formation across the structures. The Hess River Formation's lithostratigraphy and map-patterns are understood only at a reconnaissance level,

and there is a lack of paleocurrent data or other information about the location of the predominant source area of the carbonate component. Furthermore, the nature and location of the transition zone between the Hess River Formation and its shallow-water lateral equivalent(s) is modified, and partially hidden, by Laramide (Cretaceous to Eocene) contractional deformation. This complicates the identification of embayment-boundary extensional faults and carbonate source area(s). It is, therefore, difficult at present to determine the location of all relevant extensional structures. The expected, predominantly southwest-side-down normal faults east of the early axial region of thickest Hess River Formation and oldest S-HR contact (east of the type section Cecile 6; Fig. 8A) and near the eastern boundary of the deep-water MCE area, are confirmed by the relationships shown in Fig. 9. Northeast-side-down structures might be expected west of the axial zone and west of the type section (Fig 8A,B), but have not yet been identified. These speculations can be further tested through lithostratigraphic and mapping data.

Conversely, a tectonic explanation for the abrupt contact is not strongly supported by the previously documented stratigraphy of the basal Hess River Formation, which seemingly lacks the abundant synsedimentary breccias and slump structures that would be expected with abrupt, fault-related subsidence. The S-HR contact and basal Hess River Formation are commonly recessive and covered; evidence for syn-sedimentary tectonism may be widely present but unexposed. Furthermore, no detailed study has been made of Hess River Formation lithostratigraphy other than Cecile's section 9 (Chevrier and Turner, 2013a,b; Turner 2015). An excavated S-HR contact at the Hess River Formation type section contains suspected Sekwi Formation clasts suspended in quartzose sandy sediment (Turner, 2015), which could be the result of mass wasting. Interestingly, where the type section (Cecile section 6) is presented in Cecile (1982), these clasts are depicted as carbonate nodules [shown similarly in numerous other

sections in Cecile (1982)]. Some sections of Fritz (1979) show conspicuous intraformational conglomerates and soft-sediment folds in the lower ~100 metres of the Hess River Formation. Carbonate-intraclast conglomerate beds are present in an interval 100-200 m above the base of the Hess River Formation 25 km northwest of the study location (lower 1/3 of the unit; K. Fallas, unpublished data). It is possible that evidence of synsedimentary tectonism and/or mass wasting is present in the basal Hess River Formation but has not been widely recognised owing to the typically poor exposure of the contact. Soft-sediment folds in unit 3 of the present study, where the contact interval is unusually well exposed, may in fact be typical of the basal Hess River Formation. Alternatively, depth-dependent stretching (Beranek 2017; Campbell et al. 2019) has been invoked to explain the apparent lack of sedimentary structures related to rifting elsewhere in the Canadian Cordillera (Aitken 1991), and could possibly explain the apparent dearth of syn-tectonic mass-flow deposits in the basal Hess River Formation.

Comparison with other basins in the northern Canadian Cordillera

Constraining the onset of subsidence and deep-water deposition in the MCE allows comparison with other depocentres in the northern Canadian Cordillera, many of which also preserve evidence for syn-sedimentary tectonism. Elsewhere in the Selwyn basin, the Gull Lake Formation contains evidence for tectonic subsidence (basal clast-supported conglomerate of angular to subangular carbonate clasts), low in its stratigraphy. This conglomerate contains archaeocyathans, implying a maximum depositional age of Cambrian Stage 4 (Gordey and Anderson, 1993; Abbot, 1997). The Mount Roosevelt Formation in the Kechika trough (British Columbia) contains unorganised conglomerate beds at several stratigraphic levels interpreted to have been sourced from fault scarps and deposited at faulted basin margins that formed because of rapid uplift/subsidence during Cambrian Stage 4 to earliest middle Cambrian. (Post and Long,

2008). In the Coal Creek inlier (Yukon), the Shell Creek Formation (Terreneuvian-Miaolingian) may have been deposited in a tectonically active basin, based on truncation of underlying Ediacaran strata and lateral thickness and facies variations (Busch et al., 2021), and has been tentatively correlated with the Illtyd, Slat Creek, and Sekwi formations. In the Richardson trough, the carbonate-dominated Illtyd Formation (Cambrian Stage 4) unconformably overlies Precambrian units, was deposited during the middle-late *Bonnina-Olenellus* Zone (Fritz 1997), and is conformably but diachronously overlain by recessive, deeper-water strata of the Slat Creek Formation and Road River Group (Cambrian Stage 4 to early middle Cambrian (Fritz 1997). The Slat Creek Formation was interpreted to record an extensional environment because of abrupt lateral thicknesses and facies changes (Fritz 1997, Busch et al. 2021). The stratigraphy and early history of the Richardson trough are strikingly similar to those of the MCE; it is generally regarded as having developed because of extension (Cecile 1997, Moynihan et al. 2019). Some of these basins may have had a common origin, in which the Cambrian Stage 4 to Wuliuan interval may represent a discrete episode of extension, allowing for deep-water deposition to begin contemporaneously in a variety of areas. Further work is needed to constrain the timing of these subsidence episodes, preferably with a synthesis of chemostratigraphic and biostratigraphic methods.

Conclusions

Trilobite assemblages in three lithological units closely spanning the abrupt contact of the lower Cambrian shallow-water Sekwi and deep-water Hess River formations in the Misty Creek embayment (Selwyn basin) at a new location all represent the upper *Bonnina-Olenellus* Zone. Based on existing biostratigraphic datasets, the Sekwi-Hess River formational contact is

diachronous, but is conformable in most areas, with an age ranging from middle to upper *Bonnina-Olenellus* Zone. Deposition of the Hess River Formation began during the middle *Bonnina-Olenellus* Zone along a northwest-trending axial zone in the MCE, but during the upper *Bonnina-Olenellus* Zone, it was deposited throughout most of the MCE. The transition from shallow-water Sekwi Formation carbonate lithofacies to deep-water Hess River Formation shale-carbonate lithofacies is biostratigraphically conformable at the scale of study, regardless of where it is positioned in the middle and upper *Bonnina-Olenellus* Zone. These results indicate a lithostratigraphically abrupt yet time-transgressive transition from shallow-water to deep-water lithofacies that may have developed sporadically over millions of years during Cambrian Stage 4. This hypothesis is consistent with the available isopach, biostratigraphic, lithostratigraphic, and map evidence, and suggests that anomalous subsidence was mediated by seafloor normal-faulting during regional extension. SEDEX/CD deposits are strongly associated with sub-basins caused by syn-sedimentary tectonism, because fault zones act as conduits for mineralising fluids (Wilkinson 2014). The regional subsidence event(s) that resulted in the deposition of the Hess River Formation in the MCE may, therefore, render the embayment an auspicious location for base-metal exploration.

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Figure Captions

Figure 1: (A) Misty Creek embayment (MCE) configuration, adapted from Cecile (1982) and Turner (2015), showing study location and relevant stratigraphic sections; cross-section A-A' is shown in Fig. 8A. Inset shows location in Canada. (B) Simplified MCE stratigraphy, adapted from Cecile (1982). No specific stratigraphic thicknesses are implied; maximum thickness of deep-water Cambrian – Silurian strata in MCE is >3000 m (Cecile, 1982).

Figure 2: (A) Chronology of Sekwi and Hess River formations, based on compilation of the standard genus-based biostratigraphic scheme for lower and middle Cambrian (Fritz, 1972; Hollingsworth, 2007), time-scale of Peng et al. (2020), and global isotope excursions adapted from Geyer (2019). The positions of some biozones and chemostratigraphic excursions against the global time-scale are not well established. (B) Sekwi Formation section 4 (Dilliard et al., 2007), showing general lithologies, trilobite biostratigraphy, carbon isotope chemostratigraphy, and sequence stratigraphy. The CARE, MICE, and AECE carbon isotope excursions are evident in the Sekwi Formation curve.

Figure 3: (A) Isopach map showing thickness of the *Bonnia-Olenellus* Zone in the Sekwi Formation, after Chan et al. (2019), with 1:250k NTS map-sheet numbers. Red square shows eventual location of Misty Creek embayment. (B) Isopach map of entire Hess River Formation in MCE, after Cecile (1982). Red square outlines same geographic area as red square in (A). Cambrian-Ordovician shallow- to deep-water facies boundary serves as a general outline of the MCE. Area of thickest Sekwi *Bonnia-Olenellus* Zone in NTS 106B (A) closely corresponds to deep-water axis of the MCE (B).

Figure 4: (A) Type section of Hess River Formation (section 6 of Cecile, 1982), adapted to demonstrate general lithologies, biostratigraphy, and stratigraphic context; basal contact is present, but covered. This is the previously documented Hess River Fm. section that is closest to the study location. (B) Detailed stratigraphy of Hess River Formation at Cecile's (1982) section 9 (Chevrier and Turner, 2013a,b). Carbon isotope stratigraphy from Turner (2015) provides chemostratigraphic context for the largely unfossiliferous succession. Note that basal strata of the Hess River Fm. are not exposed at this section, so the carbon isotope curve is incomplete.

Figure 5: Exposure at study location (64°35'35.178"N 130°46'19.218"E). Sekwi Formation (unit 1) is in foreground; Hess River Formation (units 2-4 and above) continues up-section into the distance. Graphic log at right shows estimated thicknesses and summary of rock types.

Figure 6: Map showing geographic variability in the age of the contact between the Sekwi and Hess River formations in the MCE, using informal subdivision of the *Bonnia-Olenellus* Zone. Based on information from Fritz (1976, 1978, 1979), Cecile (1982), and the present study.

Figure 7: Representative trilobites from units 1 (Sekwi Fm.), 2 (Hess River Fm.), and 4 (Hess River Fm.) demonstrate that all three units belong to the upper *Bonnia-Olenellus* Zone. All specimens are identified by a GSC location number ("C-number") followed by a reference number referring to the national collection of type and figured specimens at the GSC in Ottawa; suffix "a" indicates that the figured material is a cast or mould. (A) Indet. dorypygid Unit 1. GSC location C-625728, GSC 142649. Partial cranidium. Sample U1-F, specimen 1. (B) *Ogygopsis* sp. Unit 1. GSC location C-625728, GSC 142650. Pygidium. Sample U1-G, specimen 1. (C) *Ogygopsis* cf. *O. batis* Unit 4, GSC location C-625730, GSC 142651. Cranidium. Sample U4-E,

specimen 1. (D) *Ogygopsis* cf. *O. batis* Unit 4, GSC location C-625730, GSC 142652. Pygidium. Sample U4-G, specimen 1. (E) *Kootenia marcoui* Unit 2, GSC location C-625729, GSC 142653. Cranidium. Sample U2-H, specimen 3. (F) *Kootenia marcoui* Unit 2, GSC location C-625729, GSC 142654a. Silicone putty cast of external mould of pygidium. Sample U2-C, specimen 1. (G) *Olenellus* cf. *O. parvofrontatus* Unit 2, GSC location C-625729, GSC 142655a. Silicone putty cast of external cephalic mould. Sample U2-O, 1. (H) *Zacanthopsis*? sp. Unit 2, GSC location C-625729, GSC 142656. Cranidium. Sample U2-C, specimen 7. (I) *Zacanthopsis* cf. *Z. expansa* Unit 4, GSC location C-625730, GSC 142657a. Silicone putty cast of external mould of cranidium. Sample U4-R, specimen 8. (J) “*Syspacephalus*” sp. Unit 4, GSC location C-625730, GSC 142658. Sample U4-Q, specimen 4.

Figure 8: (A) Cross-section of the MCE (green line A-A’ in Fig. 1) compiled from sections in Fritz (1978) and Cecile (1982). Along the deep-water axis of the MCE, Sekwi-Hess formational contact is in middle *Bonnia-Olenellus* Zone, but in southwestern and northeastern MCE areas, the contact is in the upper *Bonnia-Olenellus* Zone. At the northeastern MCE margin, Sekwi-Hess River contact is unconformable (lowermost Hess River Fm. is middle Cambrian). Panel is hung from base of middle Cambrian. (B) Tectonic interpretation of the initiation of MCE deep-water sedimentation in the Cambrian through extension-related normal faulting, depicted along a hypothetical SW-NE cross-section. (0) Sekwi Formation was deposited on a west-facing carbonate ramp during *Fallotaspis*, *Nevadella*, and early *Bonnia-Olenellus* zones. (1) Normal faulting caused subsidence during middle *Bonnia-Olenellus* Zone, in the area where the contact age is in middle *Bonnia-Olenellus* Zone and Hess River Formation is thickest (Fig. 4). Deep-water Hess River Formation facies began to accumulate in the narrow, newly deepened axial area, but shallower-water Sekwi Formation deposition continued nearby. (2) Further extension and subsidence occurred more broadly during late *Bonnia-Olenellus* Zone, causing change to deep-water Hess River Formation depositional environments throughout most of the MCE. Uplift caused erosion of easternmost upper Sekwi Formation. (3) Continued regional subsidence or eustatic sea-level rise led to deposition of Hess River Formation lithofacies in middle Cambrian throughout the entire sub-basin. Sekwi-Hess River contact near embayment margin (Mackenzie-Redstone arch) is unconformable. Configuration of northwestern margin of MCE and northwestern extent of the area of middle *Bonnia-Olenellus* Zone Sekwi-Hess River contact age are not well known owing to exposure constraints.

Figure 9: Probable syndepositional normal fault in Hess River Formation in NTS 106-B between study location and section C10 (see Fig. 6). Hess River Formation thickens from approximately 40 m to 150 m across a normal fault offsetting strata of the Hess River and Sekwi formations. Overlying Rabbitkettle Formation and younger strata are unaffected. Down-dropped side of fault (southwest) indicated by symbol. Abbreviations: DL=Duo Lake Formation, HR=Hess River Formation, R=Rabbitkettle Formation, and Sk=Sekwi Formation. Topography from the Canadian Digital Elevation Model (2015), 20 m resolution, accessed April 2015. Map generated in ArcMap 10.7.1.

774 **Table captions:**

775 Table 1. Locations, age-diagnostic taxa, and age determinations of stratigraphic sections that
776 were used to determine the geographic variability of the Sekwi-Hess River formational contact.
777 “B-O Zone” = *Bonnina-Olenellus* Zone. Unit 3 is not shown because it is barren.

778 Table 2. Taxonomy and stratigraphic distribution of best-preserved material in units 1, 3, and 4,
779 in order of first appearance.

780

781 **Supplementary Files:**

782 Supplementary File A. Stratigraphic units bracketing Sekwi-Hess River formational contact at
783 new field locality and their taxonomic content.

784 Supplementary File B. Samples and their taxonomic content.

785 Supplementary File C. Systematic taxonomy and representative trilobite images.

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Section	Source	Latitude	Longitude	Sekwi Fm.- closest biostratigraphic determination below contact	Sekwi Fm.- taxa in closest biostratigraphically useful collection below contact	m below contact
Fritz 2	Fritz 1976	64.6167	-131.7167	middle <i>Bonnia</i> - <i>Olenellus</i> Zone	<i>Wanneria parvifrons</i> , <i>Olenellus laxoculus</i>	-29 m
Fritz 3	Fritz 1976	64.4333	-131.3667	upper <i>Bonnia</i> - <i>Olenellus</i> Zone	aff. <i>Olenellus puertoblancoensis</i> (Lochman)	-141 m
Fritz 4	Fritz 1976	64.3792	-129.7167	<i>Bonnia</i> - <i>Olenellus</i> Zone	<i>Olenellus</i> sp.	-202 m
Fritz 5	Fritz 1976	63.7042	-129.4875	middle <i>Bonnia</i> - <i>Olenellus</i> Zone	<i>Wanneria</i> sp., <i>Olenellus paraoculus</i>	-15 m
Fritz 6	Fritz 1976	63.8583	-130.4333	upper <i>Bonnia</i> - <i>Olenellus</i> Zone	<i>Olenellus puertoblancoensis</i>	-41 m
Fritz 10	Fritz 1976	63.5278	-128.6958	upper <i>Bonnia</i> - <i>Olenellus</i> Zone	<i>Syspacephalus vapidus</i> , <i>Piaziella? rara</i> , <i>Olenellus puertoblancoensis</i> , <i>Antagmus truncatus</i> , <i>Piaziella pia</i> (in Sekwi Fm)	0 m
Fritz 13	Fritz 1978	64.5125	-131.8917	upper <i>Bonnia</i> - <i>Olenellus</i> Zone	aff. <i>Olenellus puertoblancoensis</i> (Lochman)	-4 m
Fritz 15	Fritz 1978	64.3667	-131.8125	upper <i>Bonnia</i> - <i>Olenellus</i> Zone	<i>Syspacephalus</i> sp. (-266 m in Sekwi); <i>Ogygopsis</i> sp. at -165 m	-165 m
Fritz 18	Fritz 1978	64.5125	-130.7792	middle <i>Bonnia</i> - <i>Olenellus</i> Zone	<i>Olenellus sequomalus</i> , <i>Wanneria</i> sp.	-69 m
Fritz 20	Fritz 1978	64.2708	-131.3000	upper <i>Bonnia</i> - <i>Olenellus</i> Zone	<i>Olenellus puertoblancoensis</i>	-215 m
Fritz 21	Fritz 1978	63.6667	-128.9125	middle <i>Bonnia</i> - <i>Olenellus</i> Zone	<i>Wanneria logani</i>	-14 m
Fritz 22	Fritz 1978	63.6750	-129.1333	middle <i>Bonnia</i> - <i>Olenellus</i> Zone	<i>Wanneria parvifrons</i> , <i>Olenellus paraoculus</i>	-29 m
Fritz 23	Fritz 1978	63.6333	-129.2583	middle <i>Bonnia</i> - <i>Olenellus</i> Zone	<i>Wanneria logani</i> , <i>Olenellus paraoculus</i>	-10 m
Fritz 28	Fritz 1979	64.8417	-131.3125	upper <i>Bonnia</i> - <i>Olenellus</i> Zone	<i>Olenellus puertoblancoensis</i>	-15 to 0 m

Fritz 29	Fritz 1979	63.7292	-129.1083	middle <i>Bonnia</i> - <i>Olenellus</i> Zone	<i>Olenellus paraoculus</i>	-8 m
Fritz 30	Fritz 1979	63.6042	-128.8333	middle <i>Bonnia</i> - <i>Olenellus</i> Zone	<i>Wanneria logani</i> , <i>Olenellus paraoculus</i>	-9 m
Fritz 31	Fritz 1979	64.3792	-129.7167	<i>Bonnia</i> - <i>Olenellus</i> Zone	Same as Fritz Section 4 (Fritz, 1976)	-202 m
Cecile 5	Cecile 1982	64.7167	-131.7167	middle <i>Bonnia</i> - <i>Olenellus</i> Zone	<i>Olenellus paraoculus</i>	-61 m
Cecile 6	Cecile 1982	64.6667	-130.8167	n/a	n/a	n/a
Cecile 8	Cecile 1982	64.4667	-131.5667	middle <i>Bonnia</i> - <i>Olenellus</i> Zone	<i>Wanneria?</i> sp.	-1 m
Cecile 10	Cecile 1982	64.6000	-130.0333	n/a	n/a	n/a
Cecile 16	Cecile 1982	64.5333	-129.8083	n/a	n/a	n/a
Cecile 18	Cecile 1982	64.3167	-129.7000	n/a	n/a	n/a

Table 1. Locations, age-diagnostic taxa, and age determinations of stratigraphic sections that were u
formational contact. “B-O Zone” = *Bonnia*-*Olenellus* Zone. Unit 3 is not shown because it is barren

Hess River Fm.- closest biostatigraphic determination above contact	Hess River Fm.- taxa in closest biostratigraphically useful collection above contact	m above contact	Sekwi-Hess River formational contact age within <i>Bonnia- Olenellus</i> Zone
upper <i>Bonnia- Olenellus</i> Zone	<i>Olenellus puertoblancoensis</i> ?	104 m	middle (extrapolated)
upper <i>Bonnia- Olenellus</i> Zone	<i>Goldfieldia</i> sp. (<i>Helcionella</i> sp., <i>Onchocephalus</i> ? sp. at 187 m)	92 m	upper (definite)
Ordovician (Rabbitkettle)	<i>Hystericurus</i> ? sp., <i>Leiostrigium</i> ? sp.	21 m	unconformity
upper <i>Bonnia- Olenellus</i> Zone (lower part)?	<i>Goldfieldia</i> sp.	9 m	middle (extrapolated)
Ordovician	<i>Didymograptus</i> sp., <i>Phyllograptus</i> sp., <i>Tetragraptus</i> sp.	134 m	upper (extrapolated)
upper <i>Bonnia- Olenellus</i> Zone	<i>Syspacephalus vapidus</i> , <i>Piaziella</i> ? <i>rara</i> , <i>Zacanthopsis</i> <i>stribuccus</i> ?	3 m	upper (definite)
upper <i>Bonnia- Olenellus</i> Zone	<i>Onchocephalus</i> sp., <i>Piaziella</i> sp.	194 m	upper (definite)
upper <i>Bonnia- Olenellus</i> Zone	<i>Ogygopsis</i> ? sp.	12 m	upper (definite)
middle <i>Bonnia- Olenellus</i> Zone	<i>Wanneria</i> sp.	101 m	middle (definite)
<i>Bonnia-Olenellus</i> Zone	<i>Olenellus</i> sp.	42 m	upper (definite)
middle <i>Bonnia- Olenellus</i> Zone (overlain by upper Cambrian)	cf. <i>Olenellus paraoculus</i>	15 m	middle (extrapolated)
upper <i>Bonnia- Olenellus</i> Zone (lower part)?	<i>Goldfieldia</i> sp. (<i>Bathyriscus</i> sp. at 203 m)	9 m	middle (extrapolated)
upper <i>Bonnia- Olenellus</i> Zone (lower part)?	<i>Goldfieldia</i> sp.	13 m	middle (extrapolated)
<i>Bonnia-Olenellus</i> Zone	<i>Olenellus</i> sp., <i>Olenellus</i> <i>altifrontatus</i> ?	2 m	upper (definite)

upper <i>Bonnia</i> - <i>Olenellus</i> Zone	<i>Ogygopsis</i> sp., <i>Zacanthopsis</i> sp., aff. <i>Olenellus</i> <i>puertoblancoensis</i>	48 m	middle (extrapolated)
upper <i>Bonnia</i> - <i>Olenellus</i> Zone	<i>Zacanthopsis</i> sp.	1 m	upper (extrapolated)
Ordovician (Rabbitkettle Fm.)	<i>Hystericurus</i> ? sp., <i>Leiostridium</i> ? sp.	21 m	unconformity
upper <i>Bonnia</i> - <i>Olenellus</i> Zone	<i>Olenellus puertoblancoensis</i> (Lochman)	5 m	upper (extrapolated)
upper <i>Bonnia</i> - <i>Olenellus</i> Zone	<i>Olenellus puertoblancoensis</i> (Lochman)	50 m	inconclusive
upper <i>Bonnia</i> - <i>Olenellus</i> Zone	<i>Olenellus</i> sp., <i>Onchocephalus</i> ? sp.	100 m	middle (extrapolated)
middle Cambrian	<i>Poliella</i> sp.	53 m	unconformity
middle Cambrian	<i>Poliella</i> sp.	10 m	unconformity
Ordovician (Rabbitkettle Fm.)	<i>Protopliomerops</i> ? sp.	268 m	unconformity

used to determine the geographic variability of the Sekwi-Hess River

l.

taxon	Unit 1	Unit 2	Unit 4	group
	Sekwi Fm.	Hess River Fm.	Hess River Fm.	
<i>Ogygopsis</i> cf. <i>O. batis</i>		X	X	dorypygid
<i>Ogygopsis</i> sp.	X			dorypygid
<i>Bonnia</i> sp.	X	X		dorypygid
<i>Kootenia marcoui</i>		X	X	dorypygid
<i>Kootenia marcoui</i> ?			X	dorypygid
aff. <i>Olenellus parvofrontatus</i>		X		
<i>Olenellus</i> cf. <i>O. parvofrontatus</i>		X		olenellid
<i>Olenellus</i> sp.		X		olenellid
indet. olenellid material		X		olenellid
indet. oryctocephalid			X	oryctocephalid
<i>Zacanthopsis</i> ? sp.		X	X	zacanthoidid
<i>Zacanthopsis</i> cf. <i>Z. expansa</i>			X	zacanthoidid
" <i>Syspacephalus</i> " sp.			X	ptychopariid

Table 2. Taxonomy and stratigraphic distribution of best-preserved material in units 1, 3 order of first appearance.

(sub)biozone
upper B-O Zone
upper B-O Zone
B-O Zone
B-O Zone
B-O Zone
B-O Zone
B-O Zone
B-O Zone
B-O Zone
B-O Zone
B-O Zone
upper B-O Zone
upper B-O Zone

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