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Neoproterozoic–Cambrian stratigraphy of the Mackenzie Mountains, northwestern Canada, part I: Ediacaran measured sections and updated lithostratigraphy, NE Sekwi Mountain map area (NTS 105-P)

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ABSTRACT

This report updates Ediacaran stratigraphic assignments in the northeastern part of NTS map area 105-P (Sekwi Mountain map area). A previous report (MacNaughton et al., 2008) included graphic logs for three measured sections in this region. The sections were thought to encompass the uppermost part of the Sheepbed Formation, a platform facies of the Gametrail Formation, the lower and middle members of the Backbone Ranges Formation, and the basal part of the upper member of the Backbone Ranges Formation. The sections were considered to span much of the Ediacaran and possibly the basal Cambrian. Based on more recent bedrock mapping, as well as revisions to regional stratigraphic correlations, the measured sections from the earlier report are reassessed. An interval previously treated as a sandy, shallow-marine upper part of the otherwise shale-dominated Sheepbed Formation is reassigned to the lower member of the Backbone Ranges Formation. The contact between the two units corresponds to an upward change from dark grey to brown or rusty weathering colours. In the area where the sections were measured, the "Sheepbed carbonate" is not present at the Sheepbed-Backbone Ranges contact, nor is the shale-rich Nadaleen Formation (a.ka. "June beds"), although these units are commonly present at this level in other parts of the Mackenzie Mountains. A thick package of shallow-marine, grey sandy dolostone and dolomitic sandstone, previously assigned to the Gametrail Formation is also placed in the lower member of the Backbone Ranges Formation, based on comparison with other sections regionally. In light of recent studies, measured strata in the basal part of the upper member of the Backbone Ranges Formation probably are Ediacaran rather than Cambrian. Previously unpublished descriptive notes are provided for the three measured sections.

INTRODUCTION

From 2005-2008, the Northwest Territories Geoscience Office (now Northwest Territories Geological Survey) led a major bedrock mapping initiative in the Mackenzie Mountains, the Sekwi Mountain Project (Martel et al., 2011). Officers of the Geological Survey of Canada (GSC) were involved as bedrock mappers and as specialists on regional stratigraphy. In 2007, the present author and the late C.F. Roots measured three stratigraphic sections to clarify Ediacaran lithostratigraphy in northeastern NTS map area 105-P (Sekwi Mountain map area; Figure 1). The sections were presented as graphic logs in a subsequent report (MacNaughton et al., 2008). At the time, the Ediacaran and lower Cambrian stratigraphy of northeastern NTS 105-P had been documented only at a coarse scale (Blusson, 1971) and the new sections permitted the area's lithostratigraphy to be mapped in greater detail (Roots et al., 2011). Blusson (1971) had mapped the succession as consisting of a shale-dominated Proterozoic unit (map-unit 9) overlain by a quartzarenite-dominated unit considered to be Cambrian and/or Precambrian (map-unit 12). MacNaughton et al. (2008) demonstrated that this succession could be understood largely in terms of units formalized by Gabrielse et al. (1973), with map-unit 9 corresponding to the Sheepbed Formation (Ediacaran) and most of map-unit 12 to the Backbone Ranges Formation (Ediacaran-Cambrian). An intervening carbonate unit was assigned to the Gametrail Formation (Ediacaran) based on arguments presented by Aitken (1989).

The present report has two purposes. First, subsequent work on stable-isotope chemostratigraphy (Macdonald et al., 2013) and bedrock mapping (MacNaughton et al., 2018; MacNaughton and Fallas, 2019) has clarified aspects of Ediacaran stratigraphy in the Mackenzie Mountains, and stratigraphic assignments and correlations suggested by MacNaughton et al. (2008) are reassessed herein. Second, MacNaughton et al. (2008) did not include descriptive notes for their measured sections. Those notes are provided herein, along with updated graphic logs reflecting current knowledge of the lithostratigraphy.

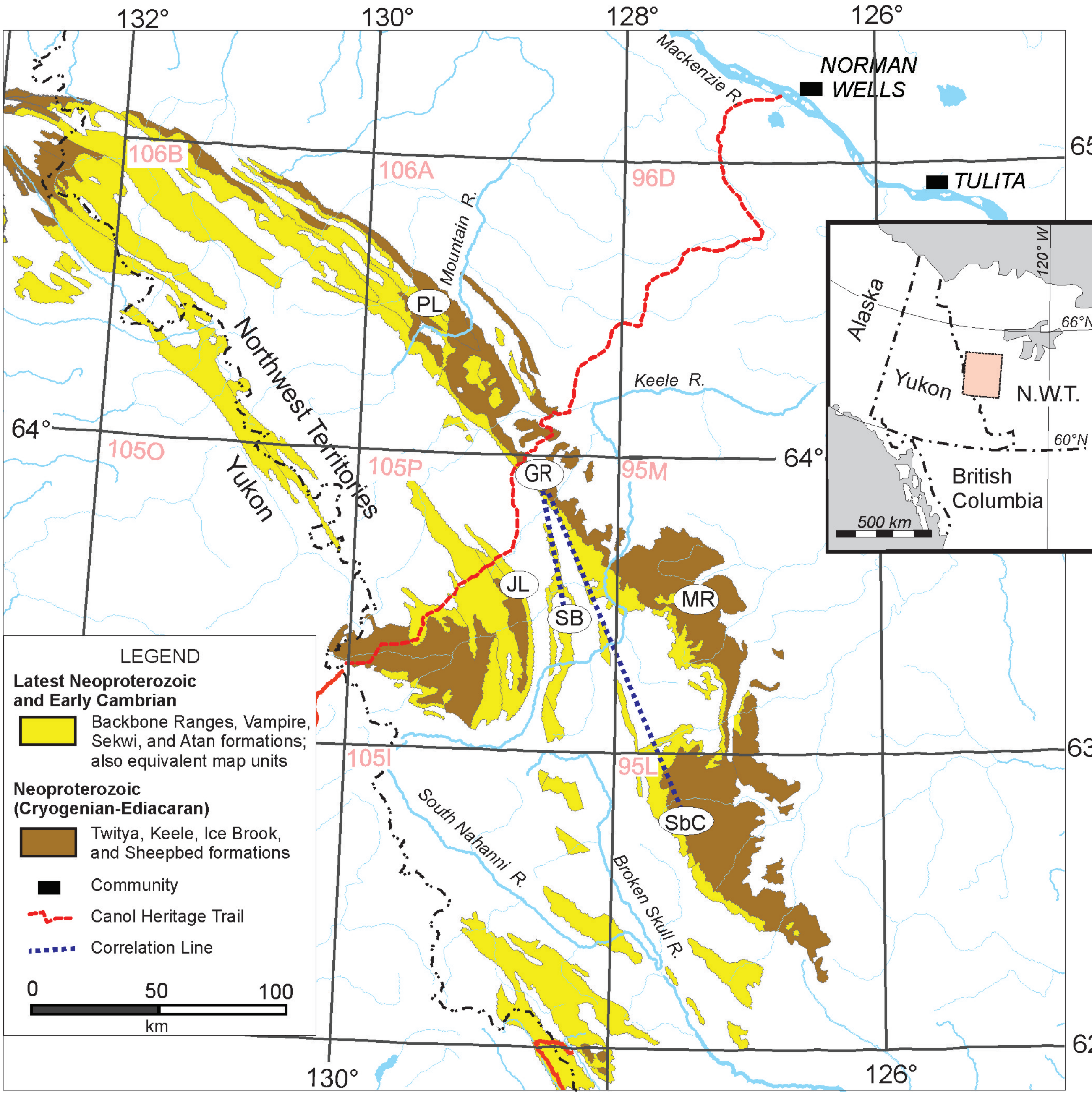


Figure 1. Location map, showing distribution of Ediacaran-Cambrian strata in Mackenzie Mountains. Locations of important reference localities are labelled as follows: SbC: Sheepbed Creek (type sections, Backbone Ranges and Sheepbed formations; Gabrielse et al., 1973); MR: Moose Horn River (reference section for "platformal Gametrail Formation", i.e., Sheepbed carbonate; Aitken, 1989); JL: June Lake structural panel (type section, Ingta Formation; Aitken, 1989); SB: Sekwi Brook (type sections, Gametrail, Blueflower, and Risky formations; Aitken, 1989); GR: Godlin River (this paper); PL: Palmer (also known as Shale) Lake (reference locality, "platformal Gametrail Formation", i.e., Sheepbed carbonate; Aitken, 1989). Map figure from MacNaughton et al. (2008). Black dotted line is for a correlation diagram in MacNaughton et al. (2008, their Fig. 12) that is not reproduced here.

STRATIGRAPHIC CONTEXT

Across much of the Mackenzie Mountains, Ediacaran-Cambrian stratigraphic correlation is hampered by strongly developed proximal-to-distal facies trends at high angle to structural trends. The result is that stratigraphic successions can be markedly different between structural panels, a situation further complicated by the effects of several unconformities.

The distal succession has been studied extensively in the Sekwi Brook and June Lake regions (Figure 1), where Aitken (1989) established formations that, with later revisions (MacNaughton and Narbonne, 1999; Macdonald et al., 2013; MacNaughton and Fallas, 2019), remain the basis for the Ediacaran lithostratigraphy of a wide region of western NWT and eastern Yukon (Macdonald et al., 2013; Moynihan, 2014; MacNaughton et al., 2017, 2018; Moynihan et al., 2019). The Ediacaran-Cambrian succession in this area (Figure 2) consists of the following units (ascending order): Sheepbed Formation (dark-weathering shale); Nadaleen Formation (a.k.a. “June beds”; heterolithic, but shale-dominated); Gametrail Formation (carbonate); Blueflower Formation (mixed carbonate-clastic lower member, shale-dominated upper member); Risky Formation (dolostone, locally with abundant oolite, and quartz arenite); Ingta Formation (variegated shale); Backbone Ranges Formation (a “silty member” overlain by a “quartzite member”); Vampire Formation (siltstone and sandstone); and Sekwi Formation (dominantly carbonate). (For reassignment of the informal “June beds” to the Nadaleen Formation, see Moynihan et al., 2019.) Strata below the uppermost part of the Blueflower Formation are of slope origin (Dalrymple and Narbonne, 1996; MacNaughton et al., 2000; Macdonald et al., 2013), whereas the uppermost beds of the Blueflower Formation and overlying units were deposited in shelf to non-marine settings (MacNaughton et al., 1997, 2000; Macdonald et al., 2013; Carbone et al., 2015). Ediacaran macrofossils are present from the Nadaleen Formation to the Blueflower Formation (Narbonne and Aitken, 1990; MacNaughton et al., 2000; Macdonald et al, 2013; Carbone et al., 2015). Based on trace fossil assemblages, the base of the Cambrian is within or at the base of the Ingta Formation (MacNaughton and Narbonne, 1999; Carbone and Narbonne, 2014). Early Cambrian trilobites are present throughout the Sekwi Formation, and locally in the uppermost beds of the Vampire Formation (Fritz et al., 1991).

Beginning with the work of Gabrielse et al. (1973), the proximal succession (Figure 2) has been studied at localities in NTS 95-L, 95-M, 105-P, and 106-A (Figure 1; see review in Turner et al., 2011). Recently, the succession has been studied in NTS 106-B and 106-C (MacNaughton et al., 2018). The base of the Ediacaran is constrained by a “cap carbonate” (informal Ravensthroat and Hayhook formations; James et al., 2001), which is overlain by dark-weathering shale of the Sheepbed Formation. The Sheepbed Formation locally is overlain by a unit of platformal carbonate, which was treated as part of the Sheepbed Formation by Eisbacher (1981) and currently is referred to as the “Sheepbed carbonate”, effectively a member of the formation (Aitken, 1984; Macdonald et al., 2013). The Sheepbed carbonate was considered by Aitken (1989) to be a platformal expression of the Gametrail Formation, but this view was later falsified based on stable-isotope chemostratigraphy (Macdonald et al., 2013). The Sheepbed carbonate is regionally mappable along the Plateau Fault (Roots et al., 2011) and should be (re)formalized as a new formation. The upper surface of the Sheepbed carbonate commonly is a karst surface (Turner et al., 2011). This surface locally is overlain by a thin, shale-dominated succession; near Palmer (Shale) Lake (Mount Eduni map area; NTS 106-A), Macdonald et al. (2013) assigned these strata to the “June beds”. These strata probably correlate with the Nadaleen Formation (Moynihan et al., 2019). Above this level, the Backbone Ranges Formation consists of three members that are regionally extensive from the type locality near Sheepbed Creek (NTS 95-L) northwest at least as far as NTS 106-C. The lower member consists of quartz arenite, mudrocks, and carbonate, the middle member of brightly weathering carbonate, and the upper member largely of thick-bedded quartz arenite. The top of the middle member is commonly a karst surface (Fritz, 1982; MacNaughton et al., 1999; MacNaughton et al., 2018). The Backbone Ranges Formation is overlain by the Sekwi Formation, which provides a tie to the distal succession.

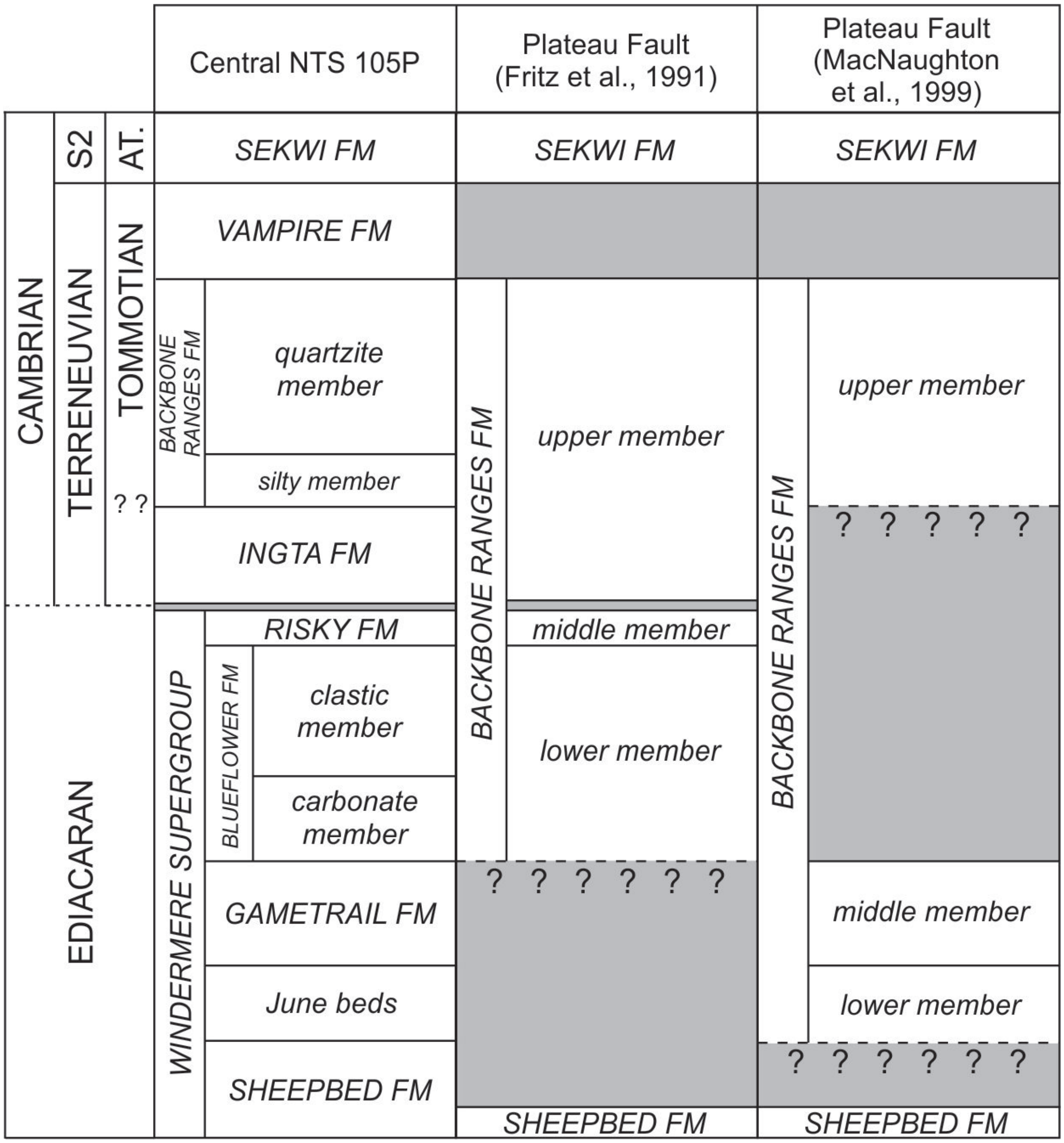


Figure 2. Ediacaran-Cambrian lithostratigraphy of the Mackenzie Mountains. At left is lithostratigraphy for central NTS 105-P, as displayed in June Lake and Sekwi Brook areas, based on Aitken (1989), MacNaughton et al. (1997), MacDonald et al. (2013), and MacNaughton and Fallas (2019). Columns for stratigraphy along Plateau Fault follow Gabrielse et al. (1973) for lithostratigraphy and show only regional extensive units. “Sheepbed carbonate” is included in Sheepbed Formation; “June beds” (probably equivalent to Nadaleen Formation; Moynihan et al., 2019) are present locally immediately beneath Backbone Ranges Formation (Macdonald et al., 2013). Two contrasting correlations are shown, based on references cited in the figure. Diagram modified from MacNaughton and Fallas (2019). (Abbreviations: FM = formation; S2 = Cambrian Series 2; AT. = Atdabanian.)

Due to limited fossil constraints, early efforts at correlating the two successions were primarily homotaxial. Particular issues arose around whether the strata assigned to the Backbone Ranges Formation in the distal succession were equivalent to the entire proximal Backbone Ranges Formation (Aitken, 1989) or only to the upper member (Fritz et al., 1991), but also around the correlation of carbonate units. Of particular note was the decision by Aitken (1989) to assign the Sheepbed carbonate to the Gametrail Formation as a platformal expression of that unit (see, e.g., reference localities at Palmer Lake and near Moose Horn River in Aitken, 1989). By contrast, MacNaughton et al. (1999) suggested a correlation between the middle member of the Backbone Ranges Formation and the (distal) Gametrail Formation. Another proposal was that of Fritz et al. (1991), which treated the middle member of the Backbone Ranges Formation as correlative with the Risky Formation. For a detailed overview of these correlation issues, see Turner et al. (2011).

More recently, Macdonald et al. (2013) used carbon-isotope chemostratigraphy to falsify the correlation between the Sheepbed carbonate and the (distal) Gametrail Formation, and argued that the Sheepbed carbonate was absent from the more distal succession. MacNaughton and Fallas (2019) mapped a probable tongue of the Risky Formation within the upper member of the Backbone Ranges Formation, casting doubt on a correlation between the Risky Formation and the middle member. In light of these developments, the Sheepbed carbonate may be present only in the proximal succession, the middle member of the Backbone Ranges Formation is likely a proximal equivalent of the Gametrail Formation, and the Risky Formation is present in both successions but thins proximally to a tongue. These correlations are being assessed as part of a regional restudy of the Backbone Ranges Formation (e.g., MacNaughton et al., 2018, *in press*).

UPDATES TO MACNAUGHTON ET AL. (2008)

MacNaughton et al. (2008) documented three overlapping stratigraphic sections along 15 km of depositional strike on the NE-facing flank of a ridge extending from Godlin River southeast to Ekwi River ("GR" on Figure 1). They assigned the stratigraphy to the following units (ascending order): Sheepbed Formation; Gametrail Formation; and lower, middle, and upper members of the Backbone Ranges Formation. Coverage included 190 m of strata assigned to the uppermost Sheepbed Formation, as well as the basal 28 m of the upper member of the Backbone Ranges Formation. Complete sections were obtained for intervening units.

As noted, several revisions to the stratigraphic decisions of MacNaughton et al. (2008) are required, reflecting more recent studies in the region. Figure 3 presents reinterpreted graphic logs of the measured sections. Descriptive notes presented later in the report also reflect these revisions. Figure 4 compares the interpretations of MacNaughton et al. (2008) with those presented herein.

MacNaughton et al. (2008) considered their section MWB07-02 to include the upper part of the Sheepbed Formation and the lower part of the Sheepbed carbonate (which they assigned to the Gametrail Formation). Intervals 1-17 in that section were assigned to the Sheepbed Formation. However, only intervals 1-3 match the regional character of the Sheepbed Formation, being dominated by dark-weathering shale and siltstone; herein, only those intervals are assigned to the Sheepbed Formation. In intervals 1-3, subordinate fine-grained sandstone preserves Bouma-type sedimentary structures, suggesting deposition from turbidity currents, consistent with a deep-marine origin. By contrast, intervals 4-17 comprise several brown to rusty-weathering upward-coarsening successions, each of which has a basal package of siltstone and sandstone that passes upward into sandstone and conglomeratic sandstone. Sandy facies contain sedimentary structures suggesting shoreface deposition (hummocky cross-stratification, trough cross-bedding). Herein, the base of the Backbone Ranges Formation is placed at the base of interval 4, which also corresponds to an upward

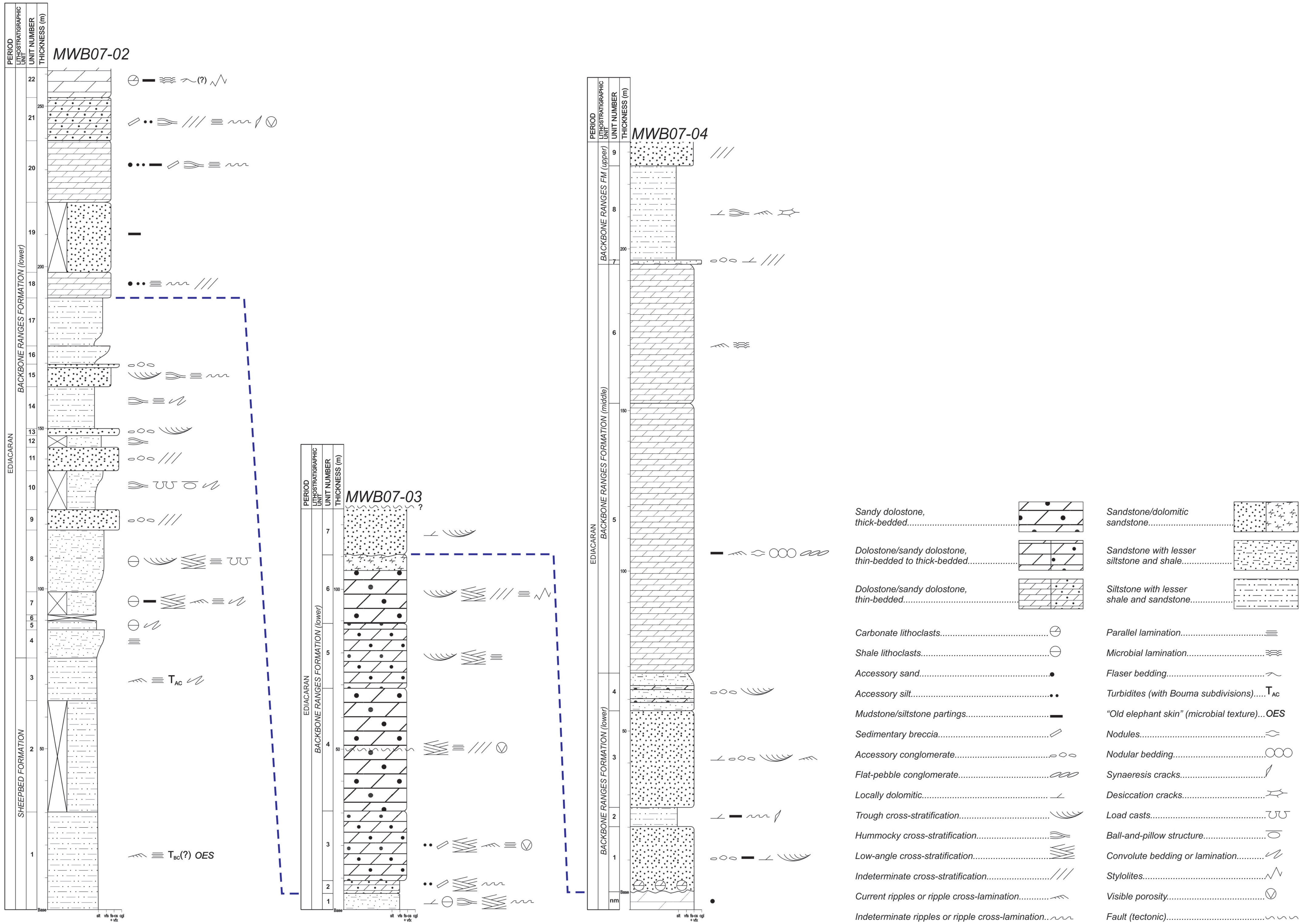


Figure 3. Graphic logs for the measured sections described in this report. These logs previously appeared in print as individual figures in MacNaughton et al. (2008) but are shown together here for ease of reference. Blue dashed lines show correlations between the sections. Abbreviations: nm = not measured; slt = silt; vfs = very fine sand; fs-cs = fine to coarse sand; cgl = conglomerate; vfx = very finely crystalline.

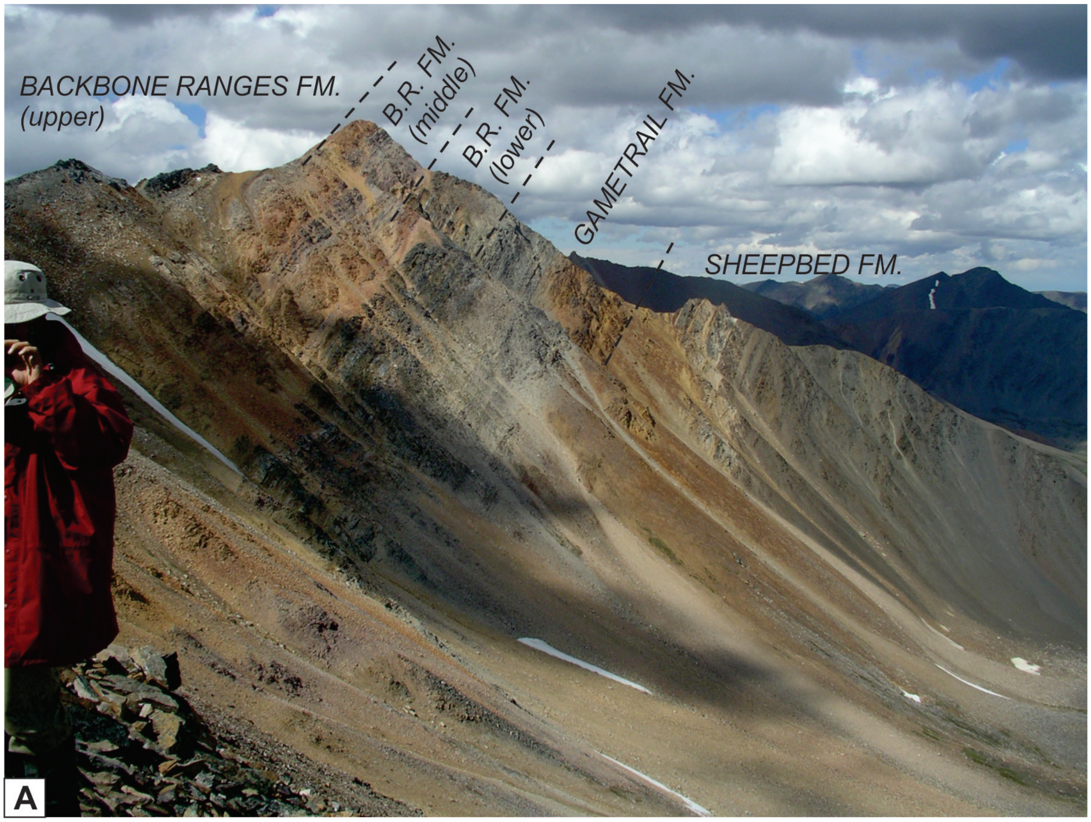
change in weathering character, from recessive to semi-resistant or resistant. In defining the Sheepbed Formation, Gabrielse et al. (1973, p. 29) noted that the formation regionally was recessive and dominated by "thin-bedded, locally platy, dark brown and black, noncalcareous shale and siltstone", but that in northwestern NTS 95-L the formation appeared to be capped by a relatively resistant, orange-weathering unit. Subsequent workers also noted the presence of a relatively resistant, shallow-marine upper interval of the Sheepbed Formation around the unit's type area in central NTS 95-L (Fritz, 1982; MacNaughton et al., 1999). However, regional observations during more recent bedrock mapping (K.M. Fallas and R.B. MacNaughton, work in progress) indicate that, where present, the Sheepbed carbonate separates dark grey, shale-dominated Sheepbed Formation from the overlying brown, orange, or rusty facies. Since the top of the Sheepbed carbonate regionally coincides with the base of the Backbone Ranges Formation, the regional colour change is adopted herein as a defining characteristic of the base of the Backbone Ranges Formation. This interpretation is also supported by the common presence of karst features atop the Sheepbed carbonate, indicating an unconformable contact.

It is relevant that strata assignable to the Nadaleen Formation ("June beds" of Macdonald et al., 2013) were not found at the contact between the Sheepbed and Backbone Ranges formations, suggesting that this unit is preserved only locally in the hanging wall of the Plateau Fault. Delineating its extent in the hanging wall of the Plateau Fault could be a valuable contribution to understanding the region's stratigraphic evolution.

Revision of the position of the base of the Backbone Ranges Formation implies that the lower member of that unit is significantly thicker in the study area than was previously reported. It also requires a reassessment of the carbonates in sections MWB07-02 and MWB07-03 that were assigned to the Gametrail Formation by MacNaughton et al. (2008). The revision places this thick package of sandy dolostone and dolomitic sandstone within the lower member of the Backbone Ranges Formation. In support of this reinterpretation, it should be noted that the quartz sand-dominated character of these carbonates is unlike other reported occurrences of the "platformal" Gametrail Formation (=Sheepbed carbonate), which are dominated by carbonate allochems (Aitken, 1989). By contrast, although carbonates are a minor component of the lower member of the Backbone Ranges Formation in its type area (Gabrielse et al., 1973; Fritz, 1982; MacNaughton et al., 1999), sandy carbonates of shallow-marine origin can make up a significant proportion of the lower member elsewhere (e.g., in northwest NTS 95-M; R.B. MacNaughton and K.M. Fallas, unpublished observations). The base of the carbonate package within the lower member is gradational in sections MWB07-02 and MWB07-03, although the gradational interval is thinner in the latter section. The upper contact of the carbonate package was observed in two sections. In MWB07-03, the contact is sharp and irregular, locally with a thin layer of Fe-stained sandstone adhering to the underlying carbonate. In MWB07-04, quartz arenite immediately above the contact contains large clasts of carbonate, apparently reworked from the underlying carbonate package. These features suggest that the upper contact is erosional and possibly disconformable.

The succession above the lower member's carbonate package was documented in section MWB07-04. The balance of the lower member is heterolithic, containing abundant grey quartz sandstone (locally to quartz pebble conglomerate), but also orange-weathering dolomitic facies and maroon to brown siltstone. Member assignments above the lower member are unchanged from MacNaughton et al. (2008). Above an abrupt basal contact, the middle member consists of thin-bedded dolostone and limestone that weathers pink, maroon, grey, cream, or orange at different levels. Intraclastic flat-pebble conglomerate and maroon-weathering siltstone partings are common at various levels; these are characteristic features of the unit in other localities, including the type section (MacNaughton et al., 1999).

The brightly coloured middle member is an excellent marker horizon for mapping, but its correlation into more distal settings has been controversial. It has been correlated with the Risky Formation (Fritz et al., 1991; MacNaughton et al., 2008) or with the Gametrail Formation *sensu stricto* (MacNaughton et al., 1999).



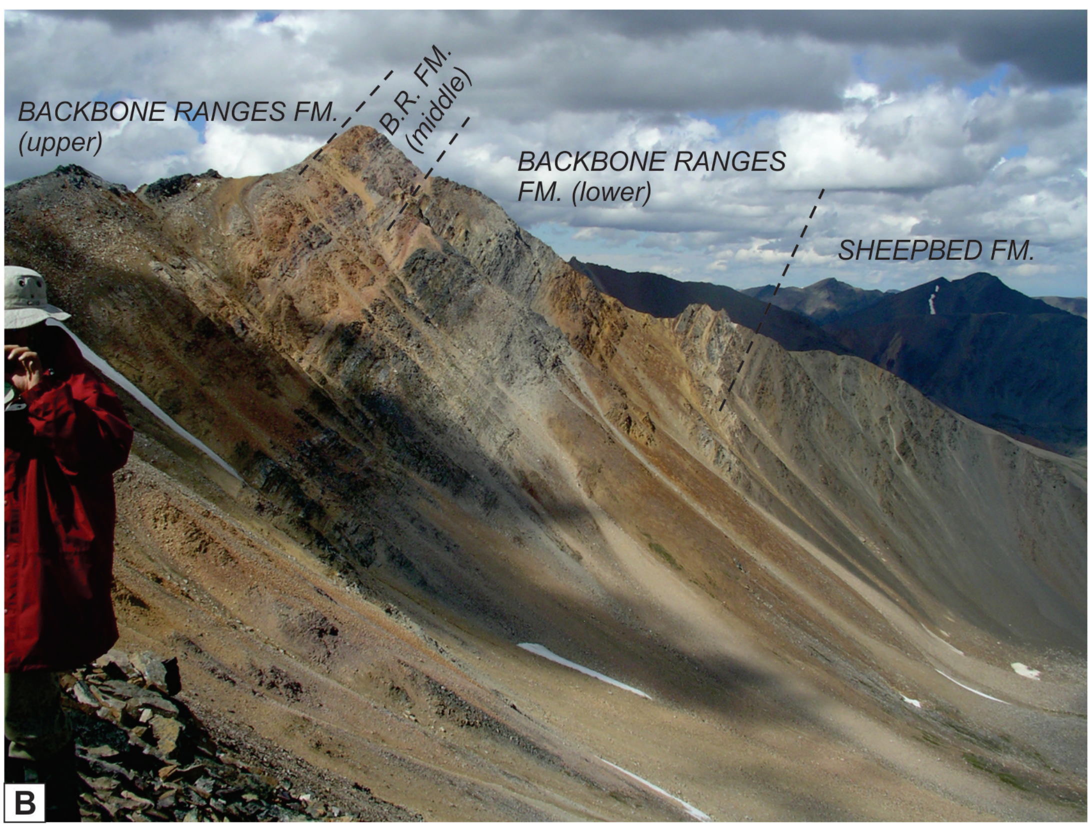


Figure 4. Ediacaran stratigraphy, exposed in first ridge spur north of measured section MWB07-04. (Abbreviations: FM. = formation; B.R. = Backbone Ranges.) Photographer (C.F. Roots) was standing near 63.8746˚ N; 128.580˚ W. NRCan photo 2020-356. A. Units labelled as interpreted by MacNaughton et al. (2008). B. Units as interpreted herein.

The recent recognition in NTS 95-M of a probable tongue of the Risky Formation within the upper member along the Plateau Fault (MacNaughton and Fallas, 2019) likely rules out a correlation between the middle member and the Risky Formation. By falsifying the correlation of the Gametrail Formation and Sheepbed carbonate proposed by Aitken (1989), Macdonald et al. (2013) removed a major objection to correlating the middle member with the type Gametrail Formation. At present, then, correlation between the Gametrail Formation and the middle member of the Backbone Ranges Formation appears to be the most defensible interpretation. This hypothesis is being tested using stable-isotope chemostratigraphy, in collaboration with E.C. Turner (Laurentian University) and K.M. Fallas (GSC).

The contact between the middle and upper members of the Backbone Ranges Formation is sharp, and irregular when seen from the air. It is overlain by 1 m of dolomitic sandstone and pebble conglomerate, above which is 27 m of maroon siltstone, with abundant polygonal mud cracks. The section ends in cross-bedded quartz arenite. Mapping traverses indicated that the upper member in this area is dominated by quartz sandstone, with lesser siltstone, shale, and dolostone. MacNaughton et al. (2008) thought the upper member likely to be early Cambrian, but the work of MacNaughton and Fallas (2019) suggests that the lower part of the upper member in the hanging wall of the Plateau Fault may be of late Ediacaran age.

CONCLUSIONS

The study by MacNaughton et al. (2008) permitted the strata assigned to map units 9 and 12 by Blusson (1971) in northeastern NTS 105-P to be assigned to formal lithostratigraphic units. These assignments were adopted on a new bedrock geology map for the area (Roots et al., 2011). However, more recent studies (Macdonald et al., 2013; MacNaughton and Fallas, 2019) necessitate revisions to the conclusions of MacNaughton et al. (2008) regarding the Ediacaran-Cambrian lithostratigraphy of the area, and will require updates to the published map in due course.

Dark, recessive-weathering siltstone, shale, and minor sandstone (map unit 9 of Blusson, 1971) can still be confidently placed in the Sheepbed Formation. An overlying, generally resistant-weathering package of strata (map unit 12 of Blusson, 1971) is reinterpreted as including only the Backbone Ranges Formation, which displays its characteristic tripartite subdivision: lower member of quartz arenite, siltstone, and dolostone to dolomitic sandstone; middle member of brightly coloured carbonate rocks; and upper member with abundant quartz arenite. Strata previously assigned to the Gametrail Formation (MacNaughton et al., 2008) are placed instead in the lower member of the Backbone Ranges Formation. The informal Sheepbed carbonate, which in many regions lies between the Sheepbed and Backbone Ranges formations, is thus not present in the study area. The Nadaleen Formation (a.k.a., “June beds”), documented elsewhere between the Sheepbed carbonate and the Backbone Ranges Formation (Macdonald et al., 2013), also is not found in this area.

Recent revisions to Ediacaran-Cambrian lithostratigraphy (Macdonald et al., 2013; MacNaughton and Fallas, 2019) also necessitate revisions to some suggestions by MacNaughton et al. (2008) regarding regional correlations. Notably, the middle member of the Backbone Ranges Formation is more likely to correlate with the Gametrail Formation than with the Risky Formation. Also, the basal part of the upper member of the Backbone Ranges Formation may be late Ediacaran rather than early Cambrian in age.

MEASURED SECTION DESCRIPTIONS

Coordinates in these notes use NAD83 as map datum. Bedding thickness terms follow Ingram (1954).

Measured Section MWB07-02: Section measured through upper part of Sheepbed Formation and basal part of lower member, Backbone Ranges Formation. Measured on July 17, 2007, in northeastern NTS 105-P (Sekwi Mountain map area). Documented by R.B. MacNaughton and C.F. Roots. Overcast, cool, with onset of rain during latter part of workday. Coordinates of base of section: 63.9238492 N˚; 128.6754822˚ W. Coordinates of top of section: 63.9220404˚ N; 128.6813342˚ W.

Unit	Description	Thickness (m)	Cumulative (m)
	Carbonate package continues upsection as grey-weathering dolostone that forms a precipitous cliff.		
22	Base covered. Resistant. Thicknesses for this interval are approximate. Basal 5 m is dolostone; light grey on fresh surface, weathers grey; thin to thick bedded; indeterminate cross-beds, intraclast horizons, stylolites, microbial lamination, mudstone drapes (flasers?). Overlain by 5 m of dolostone; tan weathering; cross-bedded. Then 5 m or more of dark grey dolostone.	15.0	267.5
	Measured to base of grey-weathering carbonate.		
21	Base covered, probably gradational. Resistant, but mainly felsenmeer. Mixture of very fine-grained quartz sandstone, dolomitic very fine-grained sandstone, and sandy dolostone; fresh colour not recorded, weathers orange to grey to tan; thin bedded; hummocky cross-stratification, indeterminate cross-bedding, parallel-lamination, ripple cross-lamination; synaeresis cracks in float; vugs up to several cm across, quartz and calcite lined, in float. Some carbonate breccia. Unit apparently is more dolomitic upsection.	13.5	252.5
20	Base covered. Basal 2 m of unit is resistant; balance is felsenmeer. Dolostone, very finely crystalline; grey to orange on fresh and weathered surfaces; thin bedded; hummocky cross-stratification, parallel-lamination, ripple cross-lamination. Includes significant amounts of dolomitic to calcareous siltstone and fine-grained sandstone. Local carbonate breccia. Some greenish-tan siltstone, siliceous.	19.0	239.0
19	Character of base not recorded. Felsenmeer. Sandstone, grain-size not recorded; fresh surface orange, weathers orange and green; very thin to thin bedded; mudstone partings.	21.9	220.0

18	Base covered, corresponds to first appearance of carbonate. Resistant. Dolostone, very finely crystalline; fresh surfaces light grey to tan, weathers cream to orange; locally sandy to silty; thin-bedded; parallel lamination, ripple cross-lamination, small-scale cross-stratification.	8.0	198.1
	Base of major carbonate package within lower member, Backbone Ranges Formation.		
17	Base covered but sharp. Recessive to semi-resistant. Basal 1.5 m is dominantly siltstone, weathering green to grey, with minor rusty-weathering sandstone, very fine grained. Passes upward into felsenmeer of green and maroon-brown siltstone and shattered brown sandstone, very fine-grained, micaceous, thin bedded.	15.0	190.1
16	Base sharp. Recessive to semi-resistant. Upward-coarsening package. Base of interval is siltstone, green on fresh and weathered surfaces. Top is sandstone, micaceous, very fine grained; red to brown on fresh and weathered surfaces. Top of unit very rusty.	6.4	175.1
15	Base covered. Mainly semi-resistant. Sandstone, brown weathering, mica-rich, as for underlying units; hummocky cross-stratification, ripple cross-lamination, parallel-bedding, soft-sediment deformation. Capped by 60 cm of quartz granule conglomerate, resistant, with trough cross-stratification.	7.0	169.7
14	Base sharp. Poorly exposed, recessive. Siltstone; red, purple-brown, maroon on fresh and weathered surfaces; laminated, weathers to chips. Shaly siltstone; fresh surface light grey, weathers pale green; laminated, chippy. Maroon and green silty facies appear to alternate on 0.5 m scale. Up to 10% of unit is sandstone, fine-grained; fresh surface greenish tan, weathers reddish brown; very thin to thin bedded; lamination, possible hummocky cross-stratification. Some soft-sediment deformation. Surfaces with slickensides are common. Quartz veins. Upper third of unit largely covered by blocks from unit 15, but unit 14 may become slightly sandier upward.	13.0	162.7
13	Base covered. Resistant. Quartz sandstone to quartz granule conglomerate, as for units 9 and 11; fresh surface white to tan, weathers white to light grey, with limonite spots; medium to thick bedded; trough cross-stratification, in some cases with granule layers emphasizing foresets. Capped by 20-30 cm of quartz granule conglomerate with some very small quartz pebbles; weathers deep, purplish red; trough cross-stratified, with possible relict bedforms on top surface.	1.7	149.7

12	Base sharp. Poorly exposed, semi-resistant. Sandstone, fine-grained, micaceous; brown on fresh and weathered surfaces; thin to thick bedded; trough cross-stratification, low-angle cross-lamination, parallel-lamination; resembles brown sandstone in underlying units but has no obvious soft-sediment deformation. Up to 50% of unit is siltstone, brown, which is common in float. Some greenish-weathering soft shale also present in float.	4.5	148.0
	Top of unit is top of a resistant rib.		
11	Base sharp. Resistant. Quartz sandstone and granule conglomerate, siliceous, as for unit 9. Top of unit weathers orange, rusty, red. At top of unit, sandstone has zones that weather out as pits up to 1.5 cm across; these weakly cemented zones could be weathered-out sand chips or sand clasts, but this is uncertain.	7.0	143.5
10	Base covered. Recessive to semi-resistant. Brown-weathering sandstone and siltstone, as for interval 8. Basal 7.5 m is largely covered, dominated by brownish-maroon siltstone and shale, with some very fine-grained sandstone that has been affected by soft-sediment deformation. Upper part of unit is dominated by sandstone with up to 20% siltstone; sandstone is quartzose with minor greenish clay, siliceous; hummocky cross-stratification; several horizons of soft-sediment deformation, including load casts, ball-and-pillow structure.	12.1	136.5
	Top of quartz arenites in unit 9 is at base of a recessive notch.		
9	Base covered, but apparently very sharp. Resistant. Quartz sandstone, coarse to very coarse grained, to granule conglomerate, siliceous; quartz grains clear to milky, pink, or opalescent, very well rounded; fresh surface white to tan, weathers white to light grey, locally weathers tan, especially near a small fault; limonite spotting; thick to very thick bedded; internal structure obscured by heavy lichen cover, but shows possible traces of cross-bedding.	6.4	124.4
8	Base gradational. Semi-resistant. Sandstone, fine-grained, micaceous, siliceous; fresh light brown, tan, weathers brown; up to thick bedded throughout, with some very thick beds in uppermost part of unit; blocky; trough cross-stratification, low-angle cross-lamination, parallel-lamination; bases of beds sharp, some loaded; some amalgamated beds. Up to 20% of exposure is sandy siltstone to silty sandstone, micaceous; colours as for the sandstone; laminated; weathers to chips.	19.0	118.0

7	Recessive notch continues. Base covered. Rocks very broken up, poorly exposed; upper 2/3 of interval much obscured by rock fallen from upsection. Sandstone, fine-grained, micaceous, locally calcareous or dolomitic; fresh surface tan to orange (limonite stain), weathers brown to orange; thin, medium, and (rarely) thick bedded, beds up to at least 60 cm thick; current-ripple cross-lamination, parallel-lamination, mud clasts, possible elephant-skin microbial texture; basal beds contorted by soft-sediment deformation, but upper part well-bedded with low-angle cross-lamination (possible hummocky cross-stratification). Beds in upper part of interval lack prominent limonite and are better indurated than those in lower part. Black mudstone partings common on bedding and lamination surfaces. By analogy with interval 8, this unit probably contains some siltstone, possibly as much as 50%.	7.5	99.0
6	Covered. Interval makes a prominent notch on ridge crest, covered mainly by talus from underlying units. Upper third of interval may be orange- to rusty-weathering, gossanous siltstone.	1.5	91.5
	Top of interval 5 is base of a recessive notch on ridge crest.		
5	Base sharp. Recessive to semi-resistant. Siltstone, micaceous; brown on fresh and weathered surfaces; laminated; platy fracture. Atop the unit is a single bed (30-60 cm thick) of sandstone, very fine-grained, micaceous; weathers brown; contains mud clasts; affected by soft-sediment deformation.	3.0	90.0
4	Base covered. Semi-resistant. Notable band (approximately 1 m thick) of rusty-weathering talus at base. Sandstone, very fine grained, some beds siliceous, some may be slightly dolomitic; micaceous; fresh surface brown with orange limonite spotting, weathers grey to orange to brown; very thin to thin bedded; some beds irregularly bedded, others flaggy with well-developed parallel lamination. Siltstone; fresh surface brown, weathers brown-grey, light brownish-grey, khaki; laminated; breaks into chips. Estimated percentage of sandstone increases upsection, from 40% at base to 80% at top.	9.0	87.0
	Base of lower member, Backbone Ranges Formation. Contact placed at the level where rusty weathering colours become prominent, associated with an upward change from recessive to semi-resistant weathering profile and the appearance of sandstone-rich, upward-coarsening packages.		

3	Base covered. Recessive. Siltstone (60-80 %); brown to grey on fresh surface, weathers khaki to brown; blockier, less muddy than in interval 1, weathers to small chips. Sandstone (20-40%), very fine grained, quartzose, with lithic fragments, mud clasts, haematite; fresh surface light brown, weathers khaki, greenish-khaki, maroon-brown; very thin to medium bedded (up to approx. 25 cm thick); beds sharp based, commonly parallel-laminated; thicker beds have a massive to faintly parallel-laminated lower division; tops display straight-crested, current ripples; sandstone characteristics consistent with T_{ac} turbidites. Rare silty shale, papery. Possible soft-sediment deformation in float.	13.0	78.0
2	Covered. Rock types in float are much as for Unit 1, including siltstone and very fine-grained sandstone, siliceous; some sandstone beds are up to 5 cm thick. Float weathers khaki, greenish-khaki, locally rusty to orange. Fractures to form chips.	35.0	65.0
1	Base arbitrary. Recessive. Dominated by siltstone to shaly siltstone (60-80 %) and very fine-grained sandstone to silty sandstone (20-40%), intimately interlaminated; fresh surface brown to grey, weathers khaki to brown, with a greenish-brown tone near top of interval; local rusty weathering spots, some associated with possible pyrite nodules; thin to thick laminated; platy fracture. Rare, very thin, sharp-based beds of sandstone, may be parallel-laminated, possibly with current rippled tops (T_{bc} turbidites?). Elephant-skin microbial texture on some surfaces. Rare horizons of papery, brown-weathering, silty shale to shale. Rocks cleaved, siliceous, micaceous. No obvious packaging of rock types. Debris from brecciated quartz vein in float at top of interval. Bedding in this interval: 146/43 SW Slickensides on bedding (azimuth/plunge): 165/20	30.0	30.0
	Beneath the base of the section, the Sheepbed Formation continues downward and consists of poorly exposed, monotonously dark grey-brown-weathering shale and siltstone.		

Measured Section MWB07-03: Section measured through carbonate interval of lower member, Backbone Ranges Formation. Measured on July 18, 2007, in northeastern NTS 105-P (Sekwi Mountain map area). Documented by R.B. MacNaughton and C.F. Roots. Clear, warm, with intermittent thunderstorm activity during the middle part of the day. Coordinates of base of section: 63.9520878˚ N; 128.7458558˚ W. Coordinates of top of section: 63.9518041˚ N; 128.7478585˚ W.

Unit	Description	Thickness (m)	Cumulative (m)
7	Base sharp, probably erosional; top of unit 6 is irregular; Fe-oxide stained quartz sandstone layer adheres locally to surface. Resistant. Quartz sandstone, fine grained; medium to thick bedded; well-developed trough cross-stratification. Several dolomitic sandstone layers (up to 10%? of unit). In float, dolomitic sandstone layers with possible sandstone intraclasts. Unit continues upsection to possible fault offset. Unit 7 in this section corresponds to the base of a dark grey band that is visible in cliffs along strike to south.	Not measured	
	Top of carbonate package within lower member, Backbone Ranges Formation.		
6	Base sharp at marked thickening of bedding, which corresponds to a change to a paler, creamier weathering tone. Resistant. Dolostone to sandy dolostone, very finely crystalline and very fine grained; fresh colour in basal 10 m is light grey to light greyish tan, whereas that of upper part of unit is finely mottled light grey to grey, possibly reflecting increasing percentage of quartz sand upsection; unit weathers light grey to light creamy grey; thin to very thick bedded, dominantly thick bedded (especially the lower end of thick range); abundant well preserved physical sedimentary structures, including trough cross-stratification, low-angle cross-lamination, parallel lamination; stylolites at some levels. Uppermost 5 m of unit is especially sandy, very close to being fine-grained dolomitic quartz sandstone, and weathers pale greyish-cream.	21.5	110.8
5	Base gradational at change in bedding thickness and weathering colour (i.e., unit 5 is slightly darker weathering and overall is thicker bedded than unit 4). Resistant. Dolostone to sandy dolostone, very finely crystalline and very fine grained; grey on fresh surface, weathers grey to light grey; dominantly thin to medium bedded, lesser thick bedded; some beds apparently massive, others have very well preserved physical sedimentary structures, especially trough cross-stratification of various scales, but also possible parallel-lamination or low-angle cross-lamination. Many "massive" beds also display possible relict cross-bedding (obscured by diagenesis?).	20.0	89.3

4	Base gradational. Resistant. Dolostone to sandy dolostone; very finely crystalline and very fine grained; light grey on fresh surface, weathers light grey or creamy grey to (less commonly) tan; medium to very thick bedded, dominantly thick bedded; stylolites on bedding planes; some beds apparently massive, other have diffuse internal layering, and others preserve clear cross-stratification, parallel-lamination, or low-angle cross-lamination; locally up to 10% vuggy porosity, possibly following old foreset surfaces. Rare dolomitic sandstone as very thin beds. A fault, probably of small offset, crosses section and affects dip 20 m above base of interval. Rocks near the fault are dolomitic, but have a limy yellow surface coating.	38.8	69.3
3	Base gradational. Resistant. Sandy dolostone to dolomitic sandstone (50%), very fine grained and very finely crystalline; grey on fresh surface, weathers pale grey to pale creamy grey; thin to thick bedded; abundant physical sedimentary structures, including low-angle cross-lamination, parallel lamination, and current-ripple cross-lamination; locally has minor, small pores. Dolostone (10-20%), microcrystalline to very finely crystalline; grey on fresh surface, weathers pale grey; medium to thick bedded, beds can vary noticeably in thickness across outcrop; massive. Sandstone, very fine grained, interbedded with siltstone (10-20%); light brown to brown on fresh surfaces, weathers grey, orange, tan; siltstone is laminated, sandstone is very thin to thin bedded; parallel-lamination, current-ripple cross-lamination; sandstone more prevalent than siltstone. Bed bases in all these facies are sharp. Up to 20% of unit is distorted/broken beds of dolostone or dolomitic sandstone to sandy dolostone facies; some beds are barely broken, with angular slabs still in place, whereas others contain well-rounded slabs; the more broken beds have a dolomitic sandstone matrix. Some beds have well-developed vuggy porosity, with vugs up to centimetre size.	21.5	30.5
2	Base gradational; placed at first true carbonate bed. Semi-resistant. Dolostone (50%), very finely crystalline; fresh surfaces grey, weathers light grey; beds very thin to thin with sharp bases, thickness variable along beds; massive, or possibly with physical lamination. Dolomitic sandstone to sandy dolostone (40%), quartzose, very fine grained and/or very finely crystalline; fresh surface grey, weathers brown to orange; very thin bedded; low angle cross-lamination, ripple cross-lamination; includes minor siliceous sandstone. Siltstone (10%); fresh surface brown, weathers tan, orange, brown; laminated; present mainly as interlaminations with dolomitic sandstone. Some dolostone beds show *in situ* brecciation. Percentage of dolostone beds increases upward within the unit.	4.3	9.0

1	Base of unit arbitrary; facies continue downsection. Semi-resistant. Sandstone to dolomitic sandstone, very fine to fine grained (70%); fresh surfaces light grey to light tan, weathers light brown, tan, orange; very thin to thin bedded; hummocky cross-stratification, low-angle cross-lamination, ripple cross-lamination; micaceous; mud chip layers. Siltstone (up to 30%), with some very fine sand; fresh surface tan, weathers orange to brown; laminated. Rocks more dolomitic upward in unit. Bedding at base of unit: 150/72 SW	4.7	4.7
	Base of section is in uppermost beds of the siliciclastic-dominated interval below major carbonate package in Backbone Ranges Formation, lower member.		

Measured Section MWB07-04: Section measured through upper part of lower member, entirety of middle member, and basal part of upper member, Backbone Ranges Formation. Measured on July 18, 2007, in northeastern NTS 105-P (Sekwi Mountain map area). Documented by R.B. MacNaughton and C.F. Roots. High broken overcast, cool. Section was measured quickly, and fresh colours of rock types were not consistently recorded as a result. Coordinates of base of section (NAD83): 63.8757182˚ N; 128.5772764˚ W. Coordinates of top of section: 63.8746412˚ N; 128.5803457˚ W.

Unit	Description	Thickness (m)	Cumulative (m)
	Base covered, apparently sharp at a marked change in rock type. Quartz sandstone, fine grained; weathers light grey, light creamy grey; thin to thick bedded; cross-stratification. Continues upsection.	Not measured	
8	Base covered but sharp. Recessive. Dominated by siltstone, micaceous; weathers maroon, khaki, brown; laminated, weathers to chips; layering irregular, suggesting presence of ripple cross-lamination. Minor (<10%) dolomitic sandstone, very fine grained; weathers orange; thin bedded, current-ripple cross-lamination, polygonal shrinkage cracks, possible hummocky cross-stratification.	27.0	225.5
7	Base covered but very sharp. Resistant. Quartzose dolomitic sandstone to dolomitic small pebble conglomerate; thin bedded; may contain poorly preserved cross-stratification.	1.0	196.5
	Base of upper member, Backbone Ranges Formation.		
6	Base gradational by colour change over 5 m. Resistant. Dolostone, very finely crystalline; fresh surfaces light tan, weathers orange to cream in lower part of unit, cream in upper part; very thin to thin bedded throughout, but up to medium bedded in upper part of unit; microbial lamination, current ripple cross-lamination.	43.0	195.5
5	Base covered. Resistant. Dolostone and limestone, microcrystalline to very finely crystalline; light grey to light pinkish grey on fresh surfaces, dolostone weathers pinkish grey, limestone weathers pale grey; very thin to thin bedded; bedding very regular, locally with suggestions of nodular to wavy bedding; maroon to orange mudstone/siltstone partings between beds; some flat-clast rudstone horizons; current-ripple cross-lamination, soft-sediment deformation. Intermittent levels of dolostone, orange weathering, as very thin beds, interlayered with thin beds of red siliciclastic mudstone. There may be a cyclic alternation between red/pink (muddier) and grey (cleaner) facies.	85.0	152.5
	Base of middle member, Backbone Ranges Formation.		

4	Base gradational. Resistant at base, more recessive upsection. Sandy dolostone to dolomitic quartz sandstone, fine to coarse grained, locally conglomeratic with quartz granules, small carbonate and sandstone pebbles; weathers tan, cream, orange; thin to medium bedded; trough cross-stratification. Mudstone to siltstone, weathering greenish-tan, is common in float, and is more prevalent in upper part of unit.	11.5	67.5
3	Base covered. Resistant but frost shattered. Dominated by quartz sandstone, very fine to very coarse grained; weathers white; thin to thick bedded; trough cross-stratification. Lesser dolomitic sandstone and conglomerate; weathers orange; conglomerate has clasts of cream dolostone, clasts of reworked quartz sandstone, and well-rounded quartz granules; trough cross-stratification. Shale, weathering maroon-red, is present 4 m above base of unit as a 15 cm-thick lens at base of a dolomitic conglomerate, and 22 m above base of unit as a 60 cm-thick interval. Minor dolostone, as described for unit 2.	30.0	56.0
2	Base abrupt. Semi-resistant. Dolostone to dolomitic siltstone (70%); weathers orange; thin to medium bedded; massive, parallel laminated, locally intraclastic. Quartz sandstone, very fine grained, to silty sandstone (30%); weathers white, light grey, brown; very thin to thin bedded; ripple cross-laminated, synaeresis cracks. Mudstone drapes on many of the sandstone bedding surfaces.	6.0	26.0
1	Base erosional, with large, semi-rounded clasts (large cobbles and small boulders) of dolostone reworked in basal quartz sandstone. Resistant but very shattered. Quartz sandstone, very fine to very coarse grained, with some granule-bearing beds; fresh surfaces light grey to white, weathers dominantly white, also light grey, light tan, but heavy lichen cover makes this interval look dark grey at a distance; thin to thick bedded; trough cross-stratification. Some red, khaki, tan siltstone drapes between beds. Minor amounts of orange-weathering dolomitic sandstone, dolomitic siltstone, and silty dolostone.	20.0	20.0
	Resistant. Dolostone; cream to light grey weathering; thick bedded; stylolites. Some very thin lenses and stringers of quartz sandstone. Continues downsection.	Not measured	
	Base of section is in uppermost beds of carbonate package within lower member, Backbone Ranges Formation.		

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