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R.B. MacNaughton and K.M. Fallas

Geological Survey of Canada
Current Research 2019-2

2019

Canada

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ISSN 1701-4387
ISBN 978-0-660-30249-2
Catalogue No. M44-2019/2E-PDF
https://doi.org/10.4095/314518

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Recommended citation

MacNaughton, R.B. and Fallas, K.M., 2019. Eastern extent of the Risky Formation (Ediacaran), Mackenzie Mountains, Northwest Territories; Geological Survey of Canada, Current Research 2019-2, 15 p. https://doi.org/10.4095/314518

Critical review
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Abstract: Newly documented exposures of dolostone, sandy dolostone, and quartz arenite in the Natla structural panel, western Wrigley Lake map area (NTS 95-M; Mackenzie Mountains, Northwest Territories) are assigned to the Ediacaran Risky Formation. Similarities in lithology and stratigraphic succession with the type area of the formation (Sekwi Brook structural panel, Mackenzie Mountains) support the assignment. The newly recognized occurrence of Risky Formation is within an interval previously mapped as Backbone Ranges Formation and implies that the base of the Cambrian is much higher within that unit than is suggested by previous correlations. The Risky Formation forms an eastward-thinning tongue within the Backbone Ranges Formation and may extend as far east as the hanging wall of the Plateau Fault. Karst breccia within the Risky Formation hosts base-metal mineralization in the type area of the unit and in the Wernecke Mountains. Thus, there may be limited exploration potential in the eastward extension of the Risky Formation.

Résumé : Dans la partie ouest de la région cartographique de Wrigley Lake (SNRC 95-M; monts Mackenzie, Territoires du Nord-Ouest), au sein du panneau structural de Natla, des affleurements nouvellement documentés de dolomie, de dolomie gréseuse et de quartzarénite sont attribués à la Formation de Risky de l'Édiacarien. Cette attribution s'appuie sur les similitudes lithologiques et stratigraphiques avec la formation dans sa région type (panneau structural de Sekwi Brook, monts Mackenzie). Cette manifestation récemment identifiée de la Formation de Risky se situe à l'intérieur d'un intervalle attribué à la Formation de Backbone Ranges lors de levés cartographiques antérieurs, ce qui signifie que la base du Cambrien se trouve à un niveau plus élevé dans cette unité que ne le laissaient croire les corrélations précédentes. La Formation de Risky forme une langue qui s'amincit vers l'est au sein de la Formation de Backbone Ranges et pourrait se prolonger à l'est aussi loin qu'au toit de la faille de Plateau. Des brèches karstiques à l'intérieur de la Formation de Risky renferment des minéralisations de métaux communs dans la région type de l'unité et dans les monts Wernecke. Par conséquent, il pourrait exister un potentiel limité pour l'exploration dans le prolongement de la Formation de Risky vers l'est.

INTRODUCTION

The Risky Formation is the uppermost unit of the Cryogenian-Ediacaran Windermere Supergroup in the Mackenzie Mountains (Narbonne and Aitken, 1995) and was defined by Aitken (1989) based on exposures in the Sekwi Brook and June Lake regions (Fig. 1) of eastern NTS 105-P (Sekwi Mountain map area). Although the name also has been applied to strata well to the northwest, in the Wernecke Mountains in the eastern Yukon (e.g. Narbonne and Hofmann, 1987; Pyle et al., 2004; Macdonald et al., 2013), the unit has not been documented east of its type area near Sekwi Brook. Based on fieldwork conducted in August 2018, the present report documents likely occurrences of Risky Formation in the western part of NTS 95-M (Wrigley Lake map area), significantly increasing the known eastward extent of the unit. The occurrences are within a succession previously mapped as belonging to the Backbone Ranges Formation, and thus help to address the long-standing controversy regarding correlations between that unit and the Windermere Supergroup.

STRATIGRAPHIC CONTEXT

The Ediacaran-Cambrian lithostratigraphic framework of the Mackenzie Mountains (Fig. 2) is based on exposures in the hanging-wall panel of the Plateau Fault, where strata were deposited in relatively proximal settings, and on progressively more outboard successions in the Sekwi Brook and June Lake structural panels (Fig. 1; the latter panel is also referred to as the June Lake anticline). (For brevity, in the balance of this report the short form 'panel' is used synonymously with 'structural panel'.) In the Plateau Fault panel, the base of the Ediacaran is delineated by thin carbonate units belonging to the informal Ravensthroat and Hayhook formations (James et al., 2001), equivalent to the

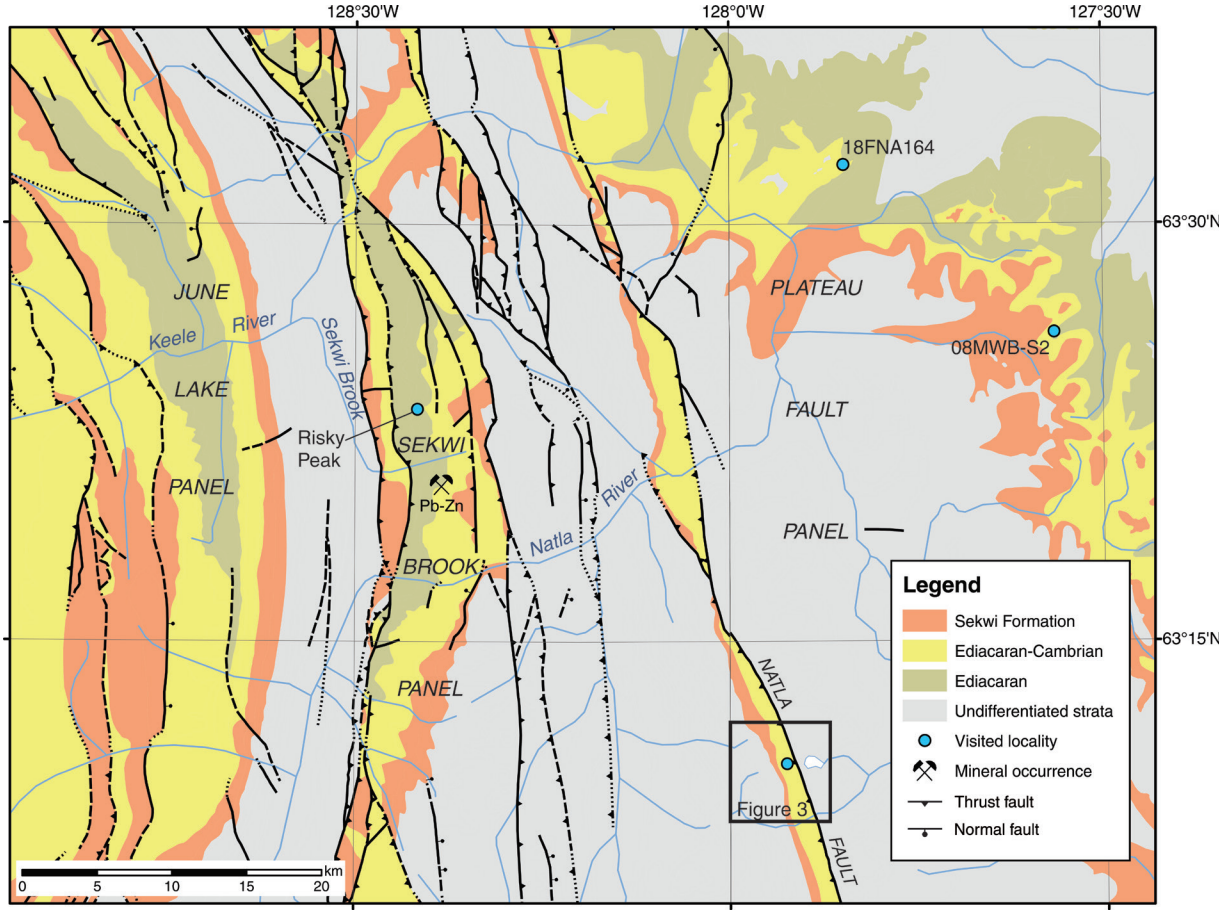

Figure 1. Location map, showing main areas referred to in text. Mineral locality south of Risky Peak corresponds to the DAR claims (Hitchins and Leary, 1975). Units grouped as 'Ediacaran-Cambrian' are dominantly of pre-trilobite Cambrian age, but may include Ediacaran strata at their base (*see* Fig. 2). Sekwi Formation is the oldest trilobite-bearing Cambrian unit in the Mackenzie Mountains (e.g. Fritz, 1972, 1979). Geology simplified after Blusson (1972) for areas west of 128° W, after Gabrielse et al. (1973c) for the eastern part of map that is south of 63°30'N, and after Fallas et al. (2011) for the northeast corner of the map. Inset box shows location of map in Figure 3.

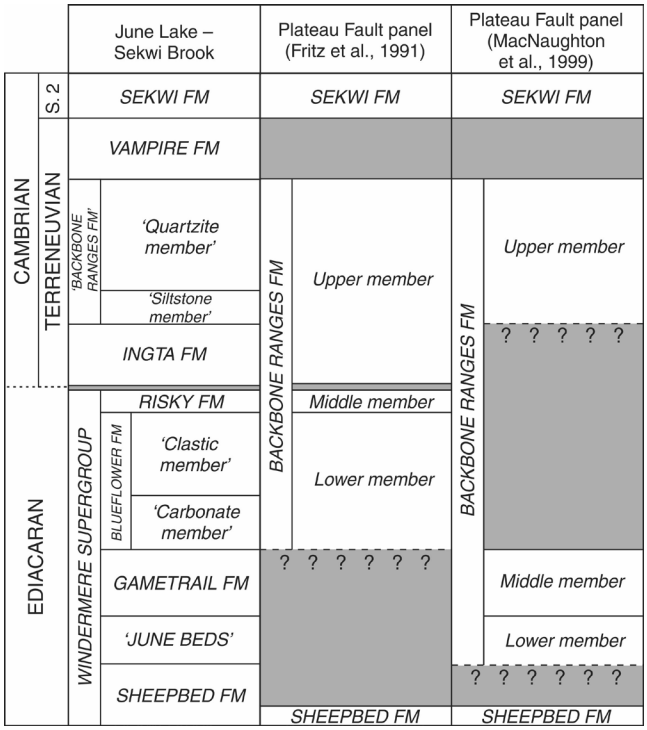

Figure 2. Stratigraphic chart for Ediacaran-Cambrian lithostratigraphy in the Mackenzie Mountains. For locations, *see* Figure 1. Combined stratigraphy for June Lake and Sekwi Brook panels is after Aitken (1989) and MacNaughton et al. (1997, 2000), with modifications from Macdonald et al. (2013) and the present work. Formation names for Plateau Fault panel follow Gabrielse et al. (1973a); two contrasting correlations are presented, with sources given in the table headings. FM = Formation; S.2 = Cambrian Series 2. Grey indicates unconformities.

"Tepee dolostone" of earlier usage (e.g. Eisbacher, 1981; Aitken, 1991). Above the carbonate units are several hundred metres of dark-weathering shale belonging to the Sheepbed Formation (Gabrielse et al., 1973a). A carbonate member of the Sheepbed Formation is locally preserved beneath the unconformable base of the overlying Backbone Ranges Formation (Eisbacher, 1981). Aitken (1989) considered this carbonate member to be a platformal expression of the Gametrail Formation (*see* below), but subsequent studies, including carbonate stable-isotope chemostratigraphy, have falsified that correlation and the member is currently referred to as the "Sheepbed carbonate" (Macdonald et al., 2013). The overlying Backbone Ranges Formation consists of three informal members: a lower member, dominated by sandstone with lesser mudrocks and minor carbonate; a middle member of brightly coloured carbonate; and an upper member dominated by thick-bedded quartz arenite (Gabrielse et al., 1973a). The upper surface of the middle member is a strongly developed karst surface (Fritz, 1982; MacNaughton et al., 1999) and potentially an important unconformity (Fritz et al., 1991; MacNaughton et al., 2000). Above the upper member, a package of carbonate and variegated mudstone originally was also assigned to the Backbone Ranges Formation (Gabrielse et al., 1973a), but was reassigned to the Sekwi Formation by Fritz (1981). In this area, trilobites of the *Bonnia-Olenellus* Zone are present near the base of the Sekwi Formation, providing definitive evidence of a Cambrian age (Gabrielse et al., 1973a; Fritz, 1981). The position of the Ediacaran-Cambrian boundary within the Backbone Ranges Formation is controversial (compare, e.g. Gabrielse et al., 1973a; Aitken, 1989, and Fritz et al., 1991; *see also* review by MacNaughton, 2011).

In the Sekwi Brook panel, the lowest exposed unit in the succession consists of dark-weathering shale assigned to the Sheepbed Formation (Aitken, 1989; Macdonald et al., 2013), but the stratigraphy above this unit is different from that seen in the Plateau Fault panel. In ascending order, the overlying Ediacaran units are: heterolithic, deep-water strata of the informal "June beds" (Macdonald et al., 2013); slope-deposited, well bedded carbonate of the Gametrail Formation (Aitken, 1989; MacNaughton et al., 2000); slope-deposited, dark-weathering shale with lesser sandstone and carbonate, referred to the Blueflower Formation (Aitken, 1989; MacNaughton et al., 2000); and shallow-water, interbedded dolostone and sandstone of the Risky Formation (Aitken, 1989). The June beds, Gametrail Formation, and Blueflower Formation have yielded Ediacaran fossils (Narbonne and Aitken, 1990; Narbonne, 1994; MacNaughton et al., 2000; Narbonne et al., 2014; Carbone et al., 2015). The upper surface of the Risky Formation is a karstic unconformity (Aitken, 1989; MacNaughton et al., 2000). Above this surface is a succession of quartz arenite and lesser mudrock, originally mapped as map unit 12 (Blusson, 1971, 1972) and subsequently assigned to the Backbone Ranges Formation (e.g. Aitken, 1989; MacNaughton et al., 1997, 2000). There is significant uncertainty regarding the detailed correlation of these strata with the Backbone Ranges Formation as it is expressed in the Plateau Fault panel (*see* review by MacNaughton, 2011). MacNaughton et al. (1997) subdivided these strata into informal lower and upper members. To avoid confusion with the member designations of the Backbone Ranges Formation in the Plateau Fault panel, these two members are referred to in the present report by names that reflect their lithology: a lower 'silty member' and an upper 'quartzite member'. Above these strata are dark-weathering siltstone and lesser sandstone, referred to in older reports as map unit 13 (Blusson, 1971, 1972; Fritz, 1979) and now considered to be a tongue of the Vampire Formation (Fritz, 1982). This package in turn is overlain by carbonate units of the Sekwi Formation. In this area and to the west, the basal interval of the Sekwi Formation preserves trilobites of the *Fallotaspis* Zone, two zones older than the base of that unit in the Plateau Fault panel (Fritz, 1972, 1979).

Still further west, in the June Lake panel, the stratigraphy is similar to that found in the Sekwi Brook panel, with two notable differences. First, the lowest beds exposed are carbonate units that probably belong to the uppermost part of the Gametrail Formation (Aitken, 1989). Second, an additional unit is present between the Risky and Backbone

Ranges formations: the Ingta Formation, a succession of variegated shale with a capping carbonate unit (Aitken, 1989; MacNaughton et al., 1997). The Ingta Formation contains Cambrian trace fossils, and the base of the Cambrian is within the unit or at its base (MacNaughton and Narbonne, 1999; Carbone and Narbonne, 2014). Based on this age constraint, the karstic surface that caps the Risky Formation is considered to be the sub-Cambrian unconformity in the June Lake and Sekwi Brook regions (Narbonne and Aitken, 1995; MacNaughton et al., 2000).

In the Sekwi Brook region (Aitken, 1989; MacNaughton et al., 2000), the Risky Formation is dominated by dolostone and sandy dolostone that tend to weather to a pale pinkish-orange; the dolostone is locally oolitic. Trough crossbedding, swaley cross-stratification, and upper flow-regime parallel bedding and/or lamination are present in these facies, as are stromatolites. Less common, but nonetheless volumetrically significant is quartz sandstone that contains trough and planar-tabular crossbedding, swaley and hummocky cross-stratification, and parallel lamination. In the east limb of the June Lake anticline, sandstone is more prevalent than carbonate, grey shale is locally present, and stromatolites are rare (Aitken, 1989). Aitken (1989) reported that the Risky Formation is not present in the west limb of the June Lake anticline and attributed this to downslope depositional pinchout; the possibility of sub-Cambrian erosion also cannot be ruled out at present.

RISKY FORMATION IN THE NATLA STRUCTURAL PANEL

New exposures of Risky Formation were documented in the southwestern corner of NTS 95-M. The rocks lie within a structurally coherent package that is bounded to the east by the Natla Fault (Gabrielse et al., 1973c), and so is referred to herein as the Natla structural panel (or Natla panel, for brevity). The Natla structural panel (Fig. 3) extends into the eastern part of NTS 105-P (Sekwi Mountain map area) and the northwestern part of NTS 95-L (Glacier Lake map area). Gabrielse et al. (1973c) mapped the oldest and structurally lowest rocks in the panel as Backbone Ranges Formation (undivided). The Natla panel extends southward into NTS 95-L (Glacier Lake map area), where these strata were assigned to the upper member of the Backbone Ranges Formation (Gabrielse et al., 1973b). This assignment is defensible in NTS 95-M as well, in light of the sandstone-rich character of much of the succession, and the apparent absence of the middle member. A measured section (Fig. 3) by Gabrielse et al. (1973a; their section 19) established that strata immediately above the Backbone Ranges Formation belong to the Sekwi Formation and preserve Cambrian trilobites (*Bonnia-Olenellus* Zone). Above the Sekwi Formation, the succession in the Natla panel extends upward to include rocks as young as Devonian.

Identification of Risky Formation in the Natla structural panel relies upon lithological similarity with exposures in the type area, and on recognition of a homotaxial stratigraphic correlation between the two areas. The succession assigned to Backbone Ranges Formation in the Natla panel is shown in Figure 4a. Here, the succession between the Natla Fault and the top of the Backbone Ranges Formation is estimated to be nearly 1 km thick and can be subdivided into six informal units, herein designated by letters. In ascending order, these packages consist of the following lithologies (thicknesses estimated): A) quartz sandstone with minor siltstone (250 m); B) siltstone with minor sandstone and accessory dolostone (200 m); C) dolostone with lesser quartz sandstone (70 m)—the probable correlative of the Risky Formation; D) quartz sandstone (70 m); E) siltstone and sandstone (90 m); and F) quartz sandstone (275 m).

The Natla panel succession can be compared to the stratigraphy exposed in the Sekwi Brook panel (Fig. 4b). There, the Risky Formation is up to 167 m thick and is underlain by a thick succession of Blueflower Formation consisting of mudrock with lesser amounts of interbedded sandstone and carbonate (Aitken, 1989), which likely correlates with unit B and possibly unit A in the Natla panel. (In the Natla panel, absence of an underlying carbonate correlative with the Gametrail Formation probably reflects the level at which the Natla Fault has cut through the stratigraphy.) In the Sekwi Brook panel, the succession between the Risky Formation and the Sekwi Formation can be subdivided as follows, in ascending order:

1. The basal part of the 'silty member' of the Backbone Ranges Formation consists of thick-bedded quartz arenite with abundant crossbedding; the first author of the present report has previously measured a thickness of 120 m for this interval at Risky Peak. This package corresponds with unit D in the Natla panel. The remainder of the 'silty member' consists of brown-weathering sandstone and siltstone, with an estimated thickness of 150 m at Risky Peak; this corresponds to unit E in the Natla panel.
2. The overlying strata, estimated to be 450 m thick at Risky Peak, form a second package dominated by quartz sandstone (the 'quartzite member'), corresponding to unit F in the Natla panel.
3. Between the second quartz sandstone package and the Sekwi Formation are dark-weathering, mudrock-dominated strata of the Vampire Formation. Vampire Formation is not present in the Natla panel. As noted above, the base of the Sekwi Formation is markedly older in the Sekwi Brook region, suggesting that the absence of the Vampire Formation in the Natla panel is due to an unconformity at the base of the Sekwi Formation in that area. Figure 5 illustrates the proposed correlation between the two areas.

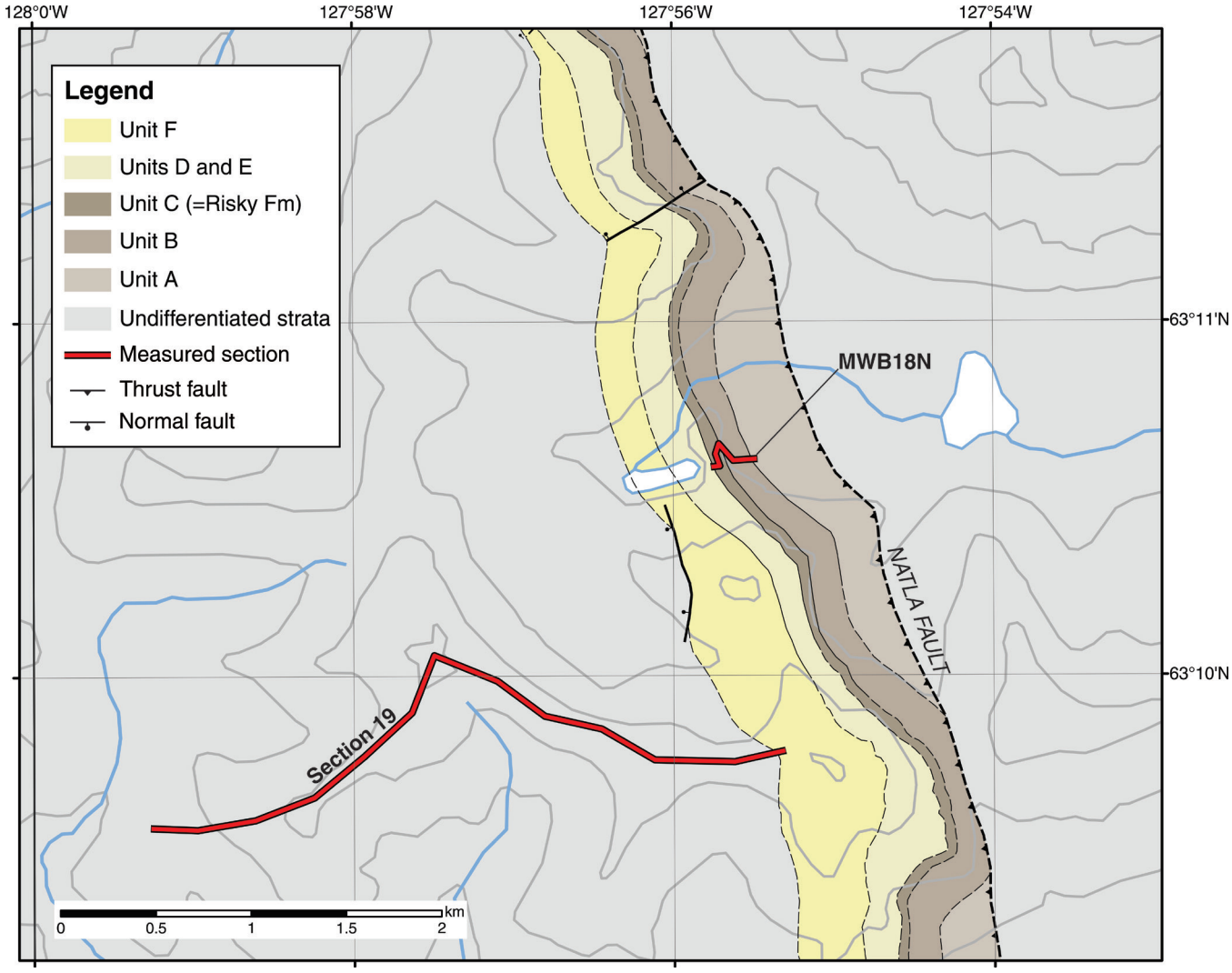

Figure 3. Ediacaran-Cambrian geology of the Natla panel, reinterpreted from Gabrielse et al. (1973c), based on observations by the present authors. Units A–F are subdivisions of the upper member of the Backbone Ranges Formation documented in the present report (Fig. 4). Measured section MWB18N is described herein. Measured section 19 is from Gabrielse et al. (1973a) and includes Sekwi Formation and younger units.

A stratigraphic section (MWB18N; Fig. 6) measured in the Natla panel includes the interval between the uppermost part of unit A and the lower part of unit D. The descriptive notes from the section are in the Appendix. Along the route of the measured section, the Risky Formation (Fig. 7) exposes 30 m of strata. This is less than half the thickness calculated graphically for exposures on the ridge immediately adjacent to the south; however, along the route of the section, the base of the Risky Formation is covered and may be within an underlying, 36 m covered interval. Alternatively, there may be unrecognized structural complications, or the change in thickness may be real, reflecting depositional thickness variations or karst or erosion of the carbonate rocks (Fig. 4a).

Along the route of section MWB18N (Fig. 6), the Risky Formation is dominated by dolostone, sandy dolostone, and dolomitic sandstone, that account for 24.5 m of the exposure. These facies are pale grey or pale tan on fresh surfaces and weather to shades of orange, orange-tan, or tan. Dolostone is fine to medium crystalline. Beds are 3–60 cm thick, and variously preserve parallel lamination, current-ripple crosslamination, trough crossbedding, and hummocky cross-stratification (Fig. 8a). Less common, accounting for 5.5 m of the thickness of the unit, is very fine- to fine-grained quartz sandstone (Fig. 8b) that is white, pale grey, or pale tan on fresh surfaces and weathers white, or pale shades of tan, grey, or orange. Bedding is 1–30 cm thick, with parallel lamination, trough crossbedding, and current ripple crosslamination. In the basal 7 m of the exposure, sandstone and dolostone intervals contain sporadic partings of green mudstone, which locally contain synaeresis cracks (Fig. 8c).

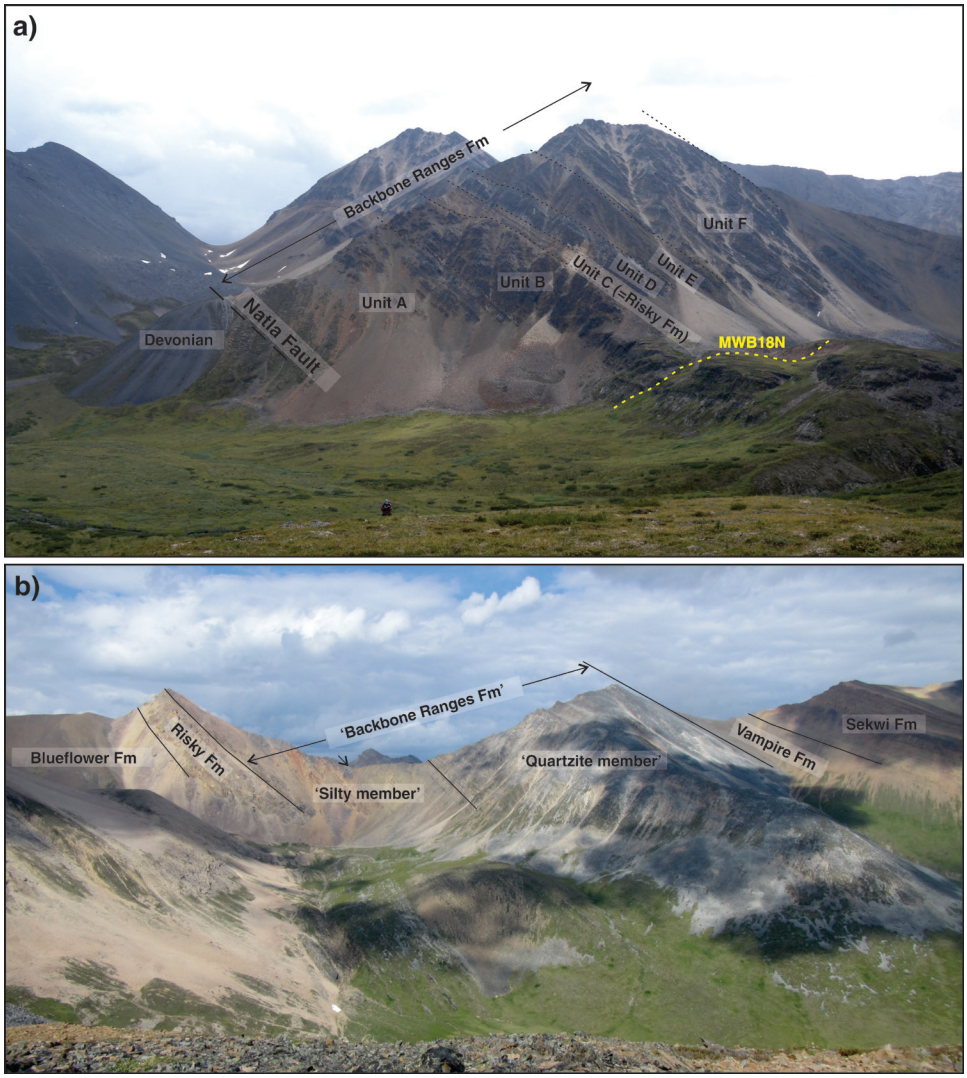

Figure 4. Ediacaran-Cambrian stratigraphy as viewed in outcrop. **a)** Succession exposed immediately above the Natla Fault (labelled) in the Natla panel. Subdivisions of Backbone Ranges Formation are described in the text. At this locality, strata above Backbone Ranges Formation belong to Sekwi Formation and younger units (Gabrielse et al., 1973a). Yellow dashed line shows approximate trace of measured section MWB18N (labelled) up to base of section unit 17 (hidden from view beyond low ridge). View is looking south from co-ordinates: 63.1847°N, 127.9224°W. Photograph by K.M. Fallas. NRCan photo 2019-009. **b)** Succession exposed at Risky Peak (prominent peak at left) in Sekwi Brook panel. See text for descriptions of units. Small arrow points to the level at which the 'silty member' of the interval assigned to the Backbone Ranges Formation can be subdivided into a lower sandstone unit and an upper siltstone-dominated unit. Photograph is looking north from co-ordinates: 63.3711°N, 128.3897°W. Photograph by R.B. MacNaughton. NRCan photo 2019-005

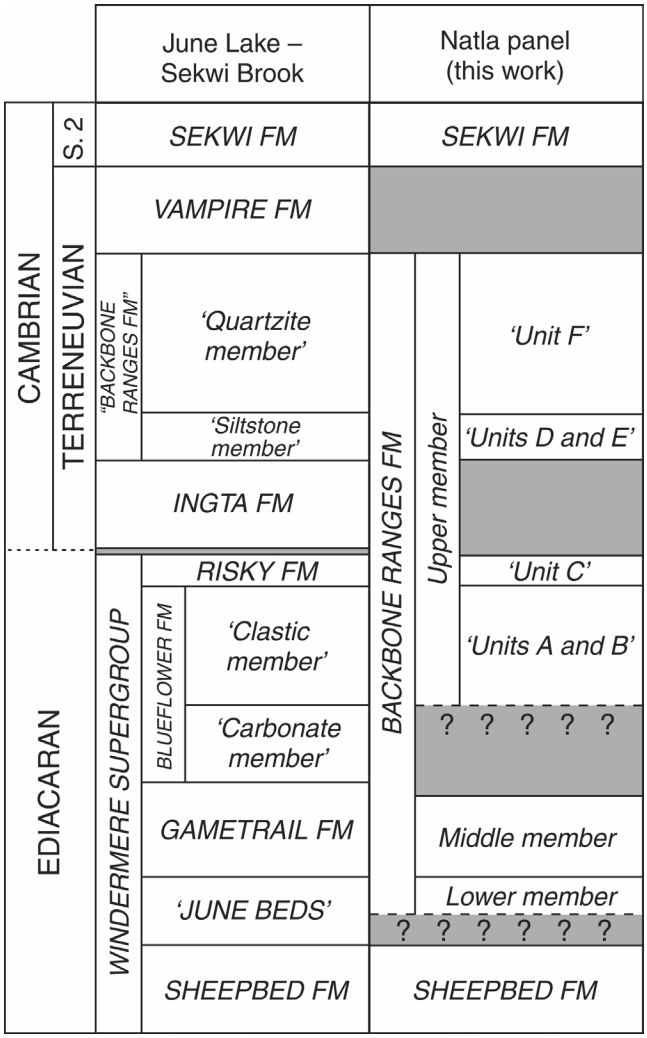

Figure 5. Proposed correlation of Ediacaran-Cambrian units between the Natla and Sekwi Brook panels. Sheepbed Formation and lower and middle members of Backbone Ranges Formation are not present in Natla panel; their correlation is inferred and follows MacNaughton et al. (1999, 2000). Note uncertainty around correlations of base of upper and lower members of Backbone Ranges Formation. FM = Formation; S.2 = Cambrian Series 2. Grey indicates unconformities.

The strata in measured section MWB18N strongly resemble the lithofacies found in the Risky Formation in the Sekwi Brook and June Lake panels (Aitken, 1989; MacNaughton et al., 2000). Similarities include the presence of dolostone and sandstone lithofacies, and a comparable range of weathering colours. The sedimentary structures found in the Natla and Sekwi Brook panels also are similar (trough crossbedding, hummocky and/or swaley cross-stratification, parallel lamination and/or bedding), suggesting that both successions were deposited in a relatively high-energy, shallow-marine setting (MacNaughton et al., 2000). The presence of hummocky cross-stratification suggests deposition in part on the lower shoreface (Brenchley, 1985), whereas the prevalence of trough crossbedding is more typical of the upper shoreface (Walker and Plint, 1992).

An alternative correlation is that the carbonate package in the Natla panel may correlate with the carbonate-dominated middle member of the Backbone Ranges Formation; however, the middle member typically consists of microcrystalline to very fine crystalline dolostone, contains abundant intraclast rudstone ('flat-pebble conglomerate') and maroon siltstone partings, and generally lacks discrete sandstone beds (MacNaughton et al., 1999, 2008). Since these characteristics do not apply to the Natla panel exposures, the present authors view this correlation as unlikely.

STRATIGRAPHIC IMPLICATIONS

As noted above, correlation of the Ediacaran-Cambrian interval between the Plateau Fault panel and structural panels to the west has been problematic. Controversy centres upon the age and correlation of the three members of the Backbone Ranges Formation, in particular the middle member. In one view, exemplified by Gabrielse et al. (1973a), the Backbone Ranges Formation is seen as entirely Cambrian. Aitken (1989) supported this view, albeit with reservations, and considered the succession between the Risky and Sekwi formations at Sekwi Brook to be correlative with the entirety of the Backbone Ranges Formation. A second view, expressed by Fritz et al. (1983, 1991; *see also* MacNaughton et al., 2008) correlates the Risky Formation with the middle member of the Backbone Ranges Formation. Aitken (1989) offered several lithostratigraphic objections to this view. MacNaughton et al. (1999, 2000) suggested a third alternative, correlating the middle member of the Backbone Ranges Formation with the Gametrail Formation. Biostratigraphic constraints on the succession are limited, and so all of these suggested lithostratigraphic correlations are homotaxial, and each correlation inherently assumes that the upper member of the Backbone Ranges Formation is entirely Cambrian.

By documenting the likely presence of a tongue of Risky Formation within the upper member of the Backbone Ranges Formation (Fig. 5), this work suggests that the upper member is not entirely Cambrian. As was discussed above, fossil data constrain the Risky Formation to be latest Ediacaran (e.g. Narbonne and Aitken, 1990; MacNaughton and Narbonne, 1999; Carbone and Narbonne, 2014; Carbone et al., 2015). Thus, its presence within the upper member implies that the lower part of the upper member, as well as the two underlying members, correlate with the Windermere Supergroup stratigraphy of the Sekwi Brook panel. Thus, only the upper part of the upper member (i.e. units D, E, and F described above) can be correlative with the basal Cambrian succession found further west in the Mackenzie Mountains.

In the Sekwi Brook and June Lake panels, the karstic upper surface of the Risky Formation probably corresponds to the sub-Cambrian unconformity (as noted above). Thus, the correlations proposed in the present report imply that the

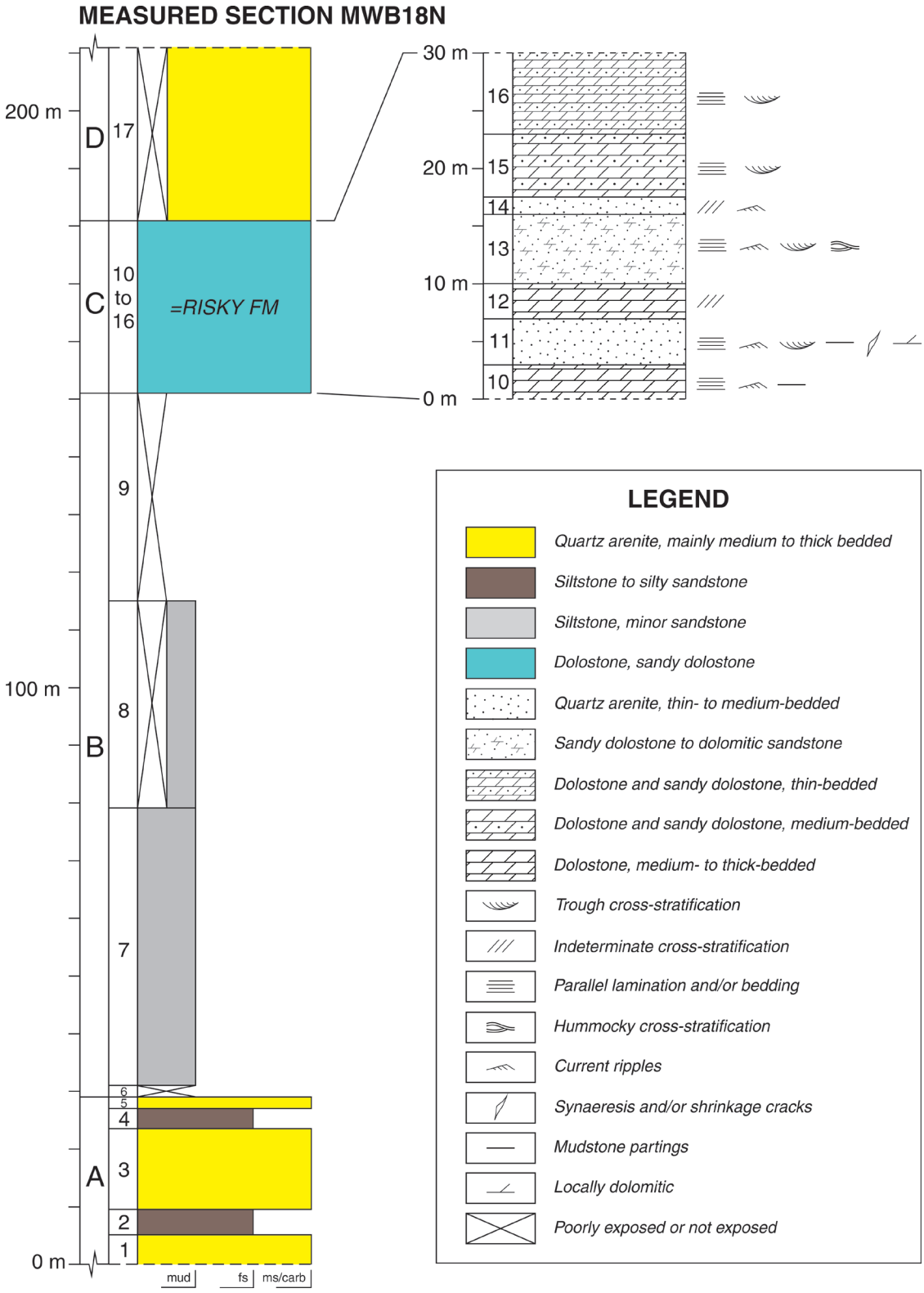

Figure 6. Simplified graphic log of measured section MWB18N (at left), with detailed log (at right) of the part of the section assigned to the Risky Formation (unit C). Interval numbers are given at left of each log; these are keyed to measured section provided in Appendix. Legend applies to both logs. Grain-size abbreviations below generalized graphic log (on left) are as follows: fs = fine sand; ms = medium sand; carb = carbonate.

Figure 7. Photograph of entire exposed thickness of Risky Formation in measured section MWB18N. Assistant in red shirt is 1.75 m tall; arrows indicate head and feet. Risky Formation may extend downward below base of exposure (*see* discussion in text). Co-ordinates: 63.1769°N, 127.9281°W. Photograph by R.B. MacNaughton. NRCan photo 2019-006

Figure 8. Sedimentary structures and bedding styles in Risky Formation, measured section MWB18N. All three photographs taken near co-ordinates: 63.1774°N, 127.9287°W. **a)** Dolostone and sandy dolostone with well developed physical sedimentary structures, including hummocky cross-stratification (upper two-thirds of image) and ripple crosslamination (to left of head of hammer). Unit 13 in section. Marks on hammer handle are 10 cm apart. Photograph by R.B. MacNaughton. NRCan photo 2019-011. **b)** Orange-weathering dolostone (unit 13 in section) at left, overlain by pale grey-weathering, well bedded quartz sandstone (unit 14 in section) at right. Hammer at contact between units is approximately 30 cm long. Photograph by R.B. MacNaughton. NRCan photo 2019-007. **c)** Synaeresis cracks in pale green mudstone parting, unit 11 in section. Marks on hammer handle are 10 cm apart. Photograph by R.B. MacNaughton. NRCan photo 2019-010

sub-Cambrian unconformity may lie within the upper member of the Backbone Ranges Formation. In combination with the karstic unconformity at the top of the middle member (Fritz, 1982; Fritz et al., 1991; MacNaughton et al., 1999, 2008), this would mean that there are at least two significant unconformities within the formation. In view of these issues around correlation and internal packaging, there is a clear need for stratigraphic review, and probably revision, of the Backbone Ranges Formation.

The Risky Formation also may be present east of the Natla panel. At several locations in the Plateau Fault panel, a marker unit of orange- to creamy-tan-weathering sandy dolostone is present near the middle of the upper member of the Backbone Ranges Formation (Fig. 9). This dolomitic marker is a few metres thick, as documented, e.g. in Figure 3.4.1-7 of MacNaughton (2011), which illustrates a section (08MWB-S2; *see* Fig. 1 for location) measured through the upper member by the present authors in 2008. Unit 16 in that section consists of 6 m of thin-bedded dolostone to dolomitic sandstone, which shares a number of features with the Risky Formation as documented in the Natla panel, including the presence of current ripples, parallel-lamination, and low-angle crosslamination (possible swaley cross-stratification), with green shale partings between some beds (R.B. MacNaughton, unpub. notes, 2008). These eastward occurrences eventually may be a useful marker for subdividing the upper member in the Plateau Fault panel.

Figure 9. Outcrop exposure of sandy dolostone and/or dolomitic sandstone, with lesser dolostone, in upper member of Backbone Ranges Formation in the Plateau Fault panel. This carbonate package is probably a thinned eastern extension of the Risky Formation; arrows mark top and bottom of unit. Person in red coat is approximately 1.75 m tall. Locality is shown as mapping station 18FNA164 on Figure 1. Co-ordinates: 63.5360°N, 127.8463°W. Photograph by K.M. Fallas. NRCan photo 2019-008.

ECONOMIC IMPLICATIONS

The Risky Formation hosts Mississippi Valley-type base-metal mineralization in at least two areas. In the Sekwi Brook panel, the DAR claims centre on the third ridge south from Risky Peak (Fig. 1) and comprise showings of galena-sphalerite-tetrahedrite in the upper part of the Risky Formation. Sulphides partially or completely fill solution cavities, breccia beneath the cavities, crackle breccia, and fractures (Hitchins and Leary, 1975). The origin of these cavities and related features is likely related, at least in part, to karst development (e.g. Aitken, 1989). A similar situation prevails in the GOZ zinc deposit and other nearby occurrences in the Wernecke Mountains, eastern Yukon (Reeve, 1977; Osborne et al., 1986). There, sphalerite, smithsonite, galena, and pyrite are associated with karstic breccia zones in thick-bedded dolostone assigned to the Risky Formation; note that Osborne et al. (1986) referred to the Risky Formation using the older, informal name, “map unit 11”.

Eastward extension of the Risky Formation from its type area may offer additional opportunities for base-metal exploration. The outcrop belt in the Natla panel has a strike length of approximately 52 km. Following along structural strike from the Natla panel, rocks assigned to the upper member of the Backbone Ranges Formation, and which might include strata correlative with the Risky Formation, extend northwest to the Arctic Red River, a distance of approximately 250 km. Caution is necessary in assessing the exploration potential of such strata. The presence of karst breccia appears to be a key control on mineralization in the Risky Formation (Osborne et al., 1986), and karst developed preferentially in the upper part of the unit in the Sekwi Brook panel (Hitchins and Leary, 1975; Aitken, 1989). Significant local thickness variations probably reflect erosion of the Risky Formation prior to deposition of overlying strata (Aitken, 1989; MacNaughton et al., 2000). The possibility that deeper erosion in more proximal (i.e. eastern) locations preferentially removed karst breccia may be a risk for mineral exploration. The absence of karst features from measured section MWB18N is consistent with this view; however, the present reconnaissance work cannot rule out the existence of karst features in the Risky Formation elsewhere in the Natla panel or to the east.

CONCLUSIONS

The present study increases the known geographic extent of the Ediacaran-aged Risky Formation well to the east of its type area, and potentially as far east as the hanging wall of the Plateau Fault. In these occurrences, the Risky Formation consists of orange- to tan-weathering dolostone, sandy dolostone, and dolomitic sandstone, with lesser pale-weathering quartz sandstone, and preserves sedimentary structures that

suggest deposition in high-energy, shallow-marine environments. Robust support for the correlation comes from lithological similarities with the Risky Formation in its type area and from homotaxial stratigraphic successions in the two areas, although additional constraints from fossils or stable-isotope chemostratigraphy would be valuable.

The newly recognized occurrences of the Risky Formation are within the upper member of the Backbone Ranges Formation. This falsifies previously suggested correlations between the Risky Formation and the middle member of the Backbone Ranges Formation. It also demonstrates that the lower part of the upper member is Ediacaran and thus is correlative with the uppermost part of the Windermere Supergroup, emphasizing the need for stratigraphic review and probably revision of the Backbone Ranges Formation.

East of its type area, the Risky Formation may have potential for base-metal exploration, by analogy with base-metal deposits hosted by the unit near its type section and in the Wernecke Mountains. Sub-Cambrian erosional removal of the karst breccia that hosts mineralization in the unit may be a significant exploration risk, however.

ACKNOWLEDGMENTS

I. Edgeworth assisted with measuring the section and T. Etchinelle was wildlife monitor. Sahtu Helicopters provided safe and reliable flying. Elliot Creek Investments provided crew accommodations in Norman Wells. MacNaughton previously visited the Sekwi Brook area in 1997 as a Postdoctoral Fellow funded by Lithoprobe and NSERC funding to G.M. Narbonne (Queen's University). MacNaughton and Fallas previously visited the Plateau Fault panel in 2008 as part of the Sekwi Mountain Project, a joint effort of the Northwest Territories Geoscience Office and the Geological Survey of Canada organized by E. Martel. C. Ozyer, M. Francis, P. Wozniak, and K. Clark assisted with field preparations. The manuscript was improved by critical comments from J. Dixon. This is a contribution to the second phase of the Geo-mapping for Energy and Minerals Program.

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Geological Survey of Canada Project 340544NU62

APPENDIX

Measured section MWB18N. Section through part of the upper member of the Backbone Ranges Formation, including a probable tongue of Risky Formation, measured in 'Natla panel' in western NTS 95M. Described by R.B. MacNaughton, assisted by I. Edgeworth. August 2, 2018. Base of section at 63.17688501° N, 127.92457833° W (station 18MWB063). Top of section at 63.17649501° N, 127.929345° W (station 18MWB064).

Unit	Description	Thickness (m)	Cumulative (m)
	Section is lost on a dip slope toward a tarn lake. Comparison with exposures in adjacent hillsides suggests that this is likely to be close to the top of unit 17, and thus very close to the transition between this quarzite package and the overlying siltstone.		
17	Base covered but abrupt. Exposure is mainly via spot outcrops. Quartz arenite, fine to medium grained, fresh surfaces white to pale tan, weathers white to light grey; very blocky and shattered outcrop; thick-bedded with possible trough cross-bedding and with 3D bedforms preserved on top surfaces.	30.0	221.0
	Top of unit 16 corresponds to top of Risky Formation tongue. Contact is covered along main line of section, but can be sighted/followed to the southwest toward a rising cliff, where it corresponds to the top of a succession of orange dolostone. Exposure at that point is good enough to constrain the position of the contact (i.e. the top of the Risky Formation) to a covered interval that is less than 1 m thick.		
16	Poorly exposed. Spot outcrops of dolostone to sandy dolostone; resembles unit 15 but beds are 10 cm or less in thickness. Uppermost 4.0 m of unit weathers to a darker orange tone.	7.0	191.0
15	Base sharp. Resistant. Dolostone to sandy dolostone, locally to dolomitic sandstone, fine to medium crystalline with fine sand grains; fresh surfaces pale tan, weathers pale tan and pale orange; beds 5–30 cm thick with well developed trough cross-bedding and parallel lamination.	5.5	184.0
14	Base sharp. Resistant. Quartz arenite, very fine to fine grained; fresh surfaces white or pale grey, weathers white, pale grey, or pale tan; beds 3–30 cm thick, with possible cross-bedding and current-rippled tops.	1.5	178.5
13	Base abrupt. Resistant. Sandy dolostone to dolomitic sandstone, fine to medium crystalline with fine sand grains; fresh surface light tan, weathers orange to medium tan; beds 5–30 cm thick with excellent parallel lamination, ripple cross-lamination, and small-scale trough cross-bedding.	6.0	177.0
12	Base gradational. Resistant. Dolostone, medium crystalline; fresh surfaces light tan, weathers light orange-tan; beds 20–60 cm thick, with a massive appearance, possibly with relict cross-bedding.	3.0	171.0

Unit	Description	Thickness (m)	Cumulative (m)
11	Base sharp. Resistant. Sandstone, very fine to fine grained; pale grey to pale tan on fresh surfaces, weathers grey, light grey, tan, and locally orange; cement variably silica or dolomite; beds 1–20 cm thick with well developed parallel lamination and current ripple cross-lamination; small-scale trough cross-bedding. Minor green shale partings. Tension or shrinkage cracks, some strongly aligned.	4.0	168.0
10	Base covered. Resistant. Dolostone, fine to medium crystalline; fresh surfaces pale tan, weathers orange; beds 10–30 cm thick, massive, parallel laminated, or current rippled; minor green mudstone partings.	3.0	164.0
	Base of Risky Formation tongue probably lies high in covered interval (unit 9).		
9	Covered.	36.0	161.0
8	Largely covered along route of section, but subcrop suggests lithologies like those in unit 7, as does the view along strike to the north.	36.0	125.0
7	Base covered. Semi-resistant. Siltstone, much as for unit 4. Siltstone is dark to medium grey on fresh surfaces, weathers grey to brown; layers 2–10 mm, with parallel lamination. Sandstone, very fine, locally to fine grained; fresh surfaces pale brown to pale grey, weathers brown or rusty; beds 1–10 cm thick (thicker is more common) with current ripples. Proportions of siltstone and sandstone variable. Near base is a 30 cm thick bed of parallel-laminated orange dolomitic sandstone.	48.0	79.0
6	Covered interval; base is sharp. Float is like sandstone and siltstone at the base of unit 4	2.0	31.0
5	Base sharp. Resistant. Quartz arenite, very fine to fine grained; fresh surfaces medium brownish grey, weathers light grey; beds 2–20 cm thick with current ripples and poorly developed trough cross-bedding.	2.0	29.0
4	Base sharp. Semi-resistant. Siltstone, locally to very fine-grained silty sandstone; fresh surfaces medium grey, weathers brown to rusty; platy, in layers 2–10 mm, parallel laminated. In basal 0.5 m, contains up to 20 percent quartz sandstone, very fine to coarse grained, in beds up to 1 cm thick with current ripples.	3.5	27.0
3	Base covered, but appears sharp here and along strike. Quartz arenite, fine to very coarse grained, in beds 5–60 cm thick with well developed cross-beds, including trough cross-bedding; fresh surfaces light grey with variably developed rusty spots, weathers light grey. Uppermost 3.0 m appears orange, is affected by bedding-parallel shear, and contains up to 10 percent siltstone that is light grey to grey on fresh surfaces, weathering brown.	14.0	23.5

Unit	Description	Thickness (m)	Cumulative (m)
2	Base gradational by introduction of siltstone over approximately 30 cm. Semi-resistant. Siltstone to very fine-grained silty sandstone, platy, parallel laminated, in layers 2–10 mm thick; fresh surfaces light to medium grey, weathers grey, brown, rusty.	4.5	9.5
1	Base covered. Resistant. Quartz arenite, medium to coarse grained, with well rounded grains; fresh surfaces light grey with rusty spots, weathers light grey; beds 1–5 cm thick with current ripple cross-lamination, or 13–30 cm thick with cross-bedding (possibly trough cross-bedding). Exposure of this unit is slightly thicker along strike to the north.	5.0	5.0
	Base of section is at base of exposure at bottom of the east side of a knoll on the south side of the cirque. Bedding: 154/50.		