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ABSTRACT

The mid-Neoproterozoic Ram Head Formation is the uppermost formation of the Little Dal Group and Mackenzie Mountains Supergroup and records epicratonic sedimentation in northeastern Laurentia immediately preceding the dispersal of supercontinent Rodinia. The Ram Head Formation can be broadly divided into two members: a lower and an upper member. The lower member comprises abundant metre-scale shallowing upwards cycles composed of below wave-base molar-tooth dolomudstone, mechanically laminated dolomudstone and very rare and thin siltstone beds; and shallower water ooid-intraclast grainstones and stromatolites. The upper member begins with a pisolitic unit - interpreted to be a caliche representing a significant period of exposure – and a deepening upwards cycle before the resumption of shallowing-upwards cycles. The upper member contains no molar-tooth dolomudstone, and has significantly more and thicker siltstone units as well as terrigenous mudstone. A number of putative sedimentological evidences for synsedimentary tectonism are present throughout the formation and include: a sudden deepening-upwards cycle at the base of the upper member, locally abundant debrites in the lower member, common soft-sediment deformation and local brittle deformation, and possible toppled stromatolites at the base of the Ram Head Formation. No synsedimentary faults have been observed.

INTRODUCTION

This report is a detailed compendium of lithofacies in the type section of the Ram Head Formation in the Mackenzie Mountains near Boomerang Lake, NWT. The Ram Head Formation (Turner and Long, 2012) is the uppermost formation in the Little Dal Group, part of the Mackenzie Mountains Supergroup, a 3 km thick epicratonic succession of siliciclastic, evaporite, and carbonate rocks deposited in Laurentia's interior during the (Meso- to) Neoproterozoic (Gabrielse et al., 1973; Aitken, 1978, 1981; Aitken et al., 2011). The depositional age of the Ram Head Formation is indicated by the presence of the Bitter Springs negative carbon isotope excursion near the base of the formation, which has been dated at ~811 Ma (Macdonald et al., 2010). The Ram Head Formation is of interest for numerous reasons: it is the final sedimentary unit in northwestern Laurentia deposited before the dispersal of Rodinia; it forms the basement of the Coates Lake Group and associated sedimentary-rock-hosted copper mineralisation; it is temporally equivalent to strata containing some of the earliest testate eukaryotes in the nearby Ogilvie Mountains (Macdonald et al., 2010; Cohen and Knoll, 2012); it contains a record of the enigmatic Bitter Springs negative carbon isotope excursion that is uncomplicated by bathymetric variability (Halverson, 2006; Thompson et al., 2015); and was deposited during the poorly understood Neoproterozoic oxygenation event.

GEOLOGICAL BACKGROUND

The Ram Head Formation records epicratonic sedimentation near the northwestern margin of Laurentia during its residence in supercontinent Rodinia in the mid-Neoproterozoic. A marine transgression at the base of the Ram Head Formation was responsible for cutoff of the terrigenous sediment supply that was dominant through deposition of the underlying Snail Spring Formation, and a switch to littoral through subtidal carbonate deposition and development of a carbonate system (Aitken, 1981). The Ram Head Formation is exposed in a NW-trending belt in the hanging-wall (SW) of the Plateau fault, and locally in the footwall (Fig. 1). It is generally absent north and east of the fault owing to sub-Rapitan and later unconformities (Aitken, 1977). Where the Coates Lake Group overlies the Ram Head Formation, the unconformity at the base of the Coates Lake Group removed up to 150 m of strata, except for one anomalous locality where the entire Ram Head Formation was removed (Jefferson, 1983; Jefferson and Parrish, 1989). The Ram Head Formation (referred to at the time as the Little Dal Formation *sensu stricto*) was originally thought to be laterally equivalent to other carbonate units of the Little Dal Group (notably the Gayna Formation) before being recognised as a stratigraphically distinct formation overlying the rest of the Little Dal Group (Gabrielese, 1973; Aitken, 1977). The Ram Head Formation has been described by Aitken (1981), Jefferson (1983), Aitken et al. (2011), and Turner and Long (2012).

Aitken (1981) divided the Ram Head Formation into four informal members (A-D) based on cyclicity and lithofacies. The position of these subdivisions in the type section are shown in Figure 2 along with a comparison of the later subdivisions of Jefferson (1983), Turner and Long (2012), and this report. Aitken (1981) placed the base of the Ram Head Formation at the top of the last shale interval in the uppermost desiccated dolostone of the Snail Spring Formation. Member A is described as thickly bedded, massive, resistant dolostone with abundant molar-tooth structure, thick stromatolite biostromes, and common grainstone and microbial laminite. Member B is slightly recessive and highly cyclic; cycles are 1-6 m thick and made up of ooid grainstone, muddy dolostone, and microbial laminite. Member C dolostone contains massive, resistant bioherms, biostromes, and microbial laminite, and abundant secondary chert. Member D is dominated by stromatolitic units separated by colourful siltstones and shales. Small-scale shallowing-upwards cycles, similar to those of member B, are common. The base of member D is an oncolitic floatstone (here referred to as the pisoid unit), possibly recording a depositional hiatus. Aitken (1981) did not include the overlying "Little Dal basalt" in the Ram Head Formation, despite describing the basalt's lower contact as conformable, and noted that in the Thundercloud Range, carbonate deposition briefly resumed during a volcanic hiatus. Aitken (1981) also noted that increases in thickness of the Coates Lake Group are matched by subtle increases in thickness of the underlying Ram Head and Snail Springs Formations, which suggests that the vertical displacement attributed to faulting during deposition of the Coates Lake Group began with subtle subsidence variation along strike during deposition of the upper Little Dal Group.

Jefferson (1983) divided the Ram Head Formation into thirteen members (UC 1-13, including the overlying "Little Dal basalt"), as well as lower (UC 1-6) and upper (UC 7-13) parts of the formation (Fig. 2). The base of the Ram Head Formation was placed at the top of a prominent shale interval, some 40 m below Aitken's (1981) contact. The first member (UC 1) corresponds to Aitken's (1981) member A. Jefferson's UC 2 is equivalent to Aitken's (1981) member B, and UC 3 and 4 are equivalent to Aitken's (1981) member C. Members 1-6 (UC 1-6) are composed generally of grey- and tan-weathering stromatolitic and oolitic dolostones in metre-scale shallowing-upwards cycles. Jefferson's (1983) UC 5 is the base of Aitken's (1981) member D, and begins with the same pisolitic marker unit. The pisolitic unit is described as caliche-like (formed by in-situ growth). Above UC 5, UC 6 is a prominent cliff-forming, massive, dolomitised unit with local, faintly visible columnar stromatolites and minor chalcopyrite mineralisation. The carbonate members of the upper Ram Head Formation (UC 7-12) are composed of more recessive units than those of the lower Ram Head Formation, and are arranged in cycles roughly 10 m thick. Cycles are composed largely of colourful-weathering stromatolite layers and are separated by brightly coloured shales. The final member, UC 13, is the "Little Dal basalt", not considered to be part of the Ram Head Formation by Aitken (1981), but included by Jefferson (1983). The basal contact of the basalt is described as conformable in all locations by Jefferson (1983). The thickness variations noted by Aitken (1981) were elaborated on by Jefferson (1983) who, through more detailed isopach work, determined that the preservational thickness changes in the lower Ram Head Formation depicted, at least in part, depositional embayments, but did not speculate on the cause of such embayments.

Turner and Long (2012) formalised the Ram Head Formation, renaming it from Aitken's (1978) Upper Carbonate formation. The type section was divided into transgressive-regressive cycles A-P (16 cycles; though this number is probably a minimum because of a number of covered intervals; see Fig. 2). Cycles generally begin with subtidal carbonate lithofacies, though some cycles in the upper part of the formation have terrigenous material at their bases. Cycle tops are composed of thin stromatolite biostromes, locally have desiccation features, and locally show evidence of karst development. Cycles A and B are equivalent to Aitken's (1981) member A. Cycles C, D, and E are equivalent to Aitken's (1981) member B. Cycles F, G, and H are equivalent to Aitken's (1981) member C, and cycles I through P are equivalent to Aitken's (1981) member D. The "Little Dal basalt" is not included by Turner and Long (2012) as part of the Ram Head Formation, and it is noted that the "Little Dal basalt" subtly truncates layering in the uppermost cycle of the formation at its type section.

LITHOSTRATIGRAPHY

The type section of the Ram Head Formation (northwestern NTS 95M) (Fig. 1**)** was re-measured and documented in detail, approximately along the line of section documented by Turner and Long (2012) (Fig. 3). This stratigraphic section was also previously documented by Aitken (1981; section 77-40), Jefferson (1983; section 55), and Aitken et al. (2011; section 77-AC-40). The lower part of the section (upper Snail Spring Formation and Ram Head Formation units 1-52) was documented along a creek (base of section: UTM zone 9 NAD 83 577708E 7073971N ±10 m); Ram Head Formation units 53-123 were documented up a gulley and the side of a mountain adjacent to (south of) the creek (base of section: UTM zone 9 NAD 83 577512E 7073674N ±10 m); Ram Head Formation units 124-142 were documented up and along a ridge south of the main creek (base of section: UTM zone 9 NAD 83 577474E 7073402N ±10 m); units 143-215 were documented in a cirque at the head of the creek (base of section: UTM zone 9 NAD 83 576841E 7073667N ±10 m). A small auxiliary section detailing equivalents of units 115 to 122 was documented farther up the creek from the lower part of the section because of its good exposure, particularly of recessive units (base of section: UTM zone 9 NAD 83 577003E 7073743N ±10 m) (Fig. 3). All sections measured are within ~1 km of each other and units in common are easily correlated in the field. Graphic logs of the section are illustrated in figures 4, 5, and 6.

The section of the Ram Head Formation near Boomerang Lake is the type section as defined by Turner and Long (2012). Both the lower contact with the Snail Spring Formation and the upper contact (base of the "Little Dal basalt") are exposed. The formation is ~700 m thick. The underlying Snail Spring Formation is composed of peritidal siltstone, carbonate, and sandstone. The upper part of the Snail Spring Formation is predominantly carbonate with some siltstone units, and the contact between the Snail Spring and Ram Head formations is placed above the last siltstone unit in the transitional zone between the two formations in keeping with Aitken (1981) and Turner and Long (2012). The lower contact is conformable. The upper contact of the Ram Head Formation is at the base of the "Little Dal basalt". Strata dip between 12° and 46° to the SW and are locally disrupted by very minor faults with up to 15 m of offset. Individual beds can easily be matched across these faults.

The lowest Ram Head Formation unit is a 10 cm thick featureless, grey-weathering dolomudstone (unit 1 of Ram Head Formation in Fig. 5 and detailed section #1 in Fig. 6), followed by a 0.8 m thick mechanically laminated brown-weathering dolomudstone with scour marks (unit 2) (Fig. 7A). The contact between unit 2 and unit 3, a 35 cm thick recessive, fissile, argillaceous dolomudstone, is unconformable and laminations are truncated at the top of unit 2 (Fig. 7B). Unit 3 is overlain by one 10 cm bed of pale grey-weathering dolomudstone (unit 4). Unit 4 has erosional relief at its upper contact and pinches out erosionally over ~10 m. Unit 4 is overlain by 20 cm of resistant-weathering, massive stromatolitic dolostone (unit 5) that contains unwalled columnar stromatolites (~4 cm wide), some of which appear to be lying on their sides. Because of extensive dolomitisation and minimal access in a cliff face, it is difficult to assess the configuration of these stromatolites; they may be either toppled stromatolites or very large oncoids. This unit has an undulatory upper contact. Overlying the stromatolitic grainstone are 1.5 m of massive, unbedded intraclast rudstone with ooid dolograinstone matrix (unit 6). Intraclasts are dolomitic, 1-3 cm long, and generally rounded. Above unit 6 are 17.35 m of interbedded molar-tooth dolomudstone (unit 7) (Fig. 7C) with local 15-40 cm beds of dolomitised intraclast rudstone with intraclast dolograinstone matrix. Unit 7 contains intraclasts of reworked molar-tooth crack-fill and local ooid dolograinstone (one bed 1 m thick). The dolomitic molar-tooth structures appear as white crack-fills in a pale grey-weathering dolomudstone. Molar-tooth crack-fills are less than 5 cm long and constitute little (~10-15%) of the rock. Local faint ripple marks are present (Fig. 7D).

Overlying the thick molar-tooth interval is another thin stromatolitic unit (unit 8), a 0.1-0.6 m thick bioherm of domical stromatolites and branching vertical to inclined digitate stromatolites. The spaces among the stromatolites are filled by superficial-ooid and aggregate grain dolorudstone with dolograinstone matrix (Fig. 7E); superficial ooids are nucleated on intraclasts up to a few centimetres long. Above the bioherm is 10.2 m of molar-tooth dolomudstone similar to unit 5 (unit 9), followed by 1.4 m of layered ooid dolograinstone and intraclast dolograinstone (unit 10).

Units 11 and 12 consist of 29.5 m of dolomitic microbialite: stromatolites of unit 11 grade upwards into thrombolites of unit 12 after 5 m. The stromatolites are branching and columnar at the base of the unit and grade up-section into less columnar (Fig. 7F), domical to clotted shapes with cement-rich interstices (Fig. 8A). Laminae are undulatory and discontinuous and defined by pale cement. At the base of the unit, stromatolite clasts are present among columns. The thrombolites have a muddy internal texture and no interstitial intraclasts.

Above the microbial units is a thick succession (63.7 m) of alternating molar-tooth dolomudstone and dolomitised intraclast packstone to rudstone with dolomudstone matrix (units 13-19 with local decimetric ooid dolograinstone intervals. Units 14 and 16 contain dolomudstone clasts from underlying lithified beds. Desiccation cracks are present in units 13, 17, and 19, as well as pinch-and-swell in units 15 and 17. Unit 19 shows undulatory to lamination distorted around molar-tooth crack fill (Fig. 8B) and black bedding-plane veneers.

The overlying unit (unit 20) is mechanically laminated, buff-weathering dolomudstone, containing a metre-scale siltstone-filled cavern and associated clasts (see detailed section #2 in Fig. 6). The host dolomudstone is cross-cut by curved surfaces that cross-cut lamination in the host dolostone and depict former voids extending down as far as 1 m from the upper surface of the dolomudstone. The voids are occupied by medium green-grey-weathering siltstone in a pocket approximately 1 m x 1 m (Fig. 8C) as well as solution-widened vertical fissures and discontinuous bedding-plane fissures (Fig. 8D); the pocket- and fissure-filling siltstone locally contains floating, rounded centimetric clasts of the host dolostone (Fig. 8E). The dolomudstone of unit 20, together with its cross-cutting, enclosed siltstone, is truncated and overlain by a slightly different dolomudstone (still within unit 20), with at least 5 dm of relief. Where the overlying dolostone fills lows along the truncation surface (truncated siltstone pocket), centimetric subrounded clast-supported siltstone clasts are present in the dolostone, and are individually overgrown by columnar stromatolites (Figs. 8F and 9A), which coalesce upwards into a domal stromatolite (Fig. 9B). Siltstone clasts are present lower in the stratigraphy than the base of the siltstone cavern. Away from the exposed siltstone pocket (paleo-cave) in the same unit, siltstone occupying space along enlarged bedding-planes contains host dolomudstone clasts. Rare black chert nodules are locally present in the siltstone.

Overlying the dolomudstone with siltstone cavern unit are 11.1 m of orange-weathering nodular argillaceous dolomudstone interbedded with centimetric pale green to brown siltstone intervals (Fig. 9C) (unit 21). This unit is cross-cut by a small fault with approximately 15 m of E-side down offset, which repeats stratigraphy. The centimetric dolomudstone nodules are in siltstone interbeds the same green-grey colour as the siltstone in the underlying unit. The dolomudstone in unit 21 unit is bedded on a 5-20 cm scale and grades upwards into buff-weathering, wave-rippled dolomudstone (Fig. 9D) with local sub-centimetric intraclasts (Fig. 9E) and no siltstone interbeds (unit 22). Ripple crests are approximately west- to southwest-trending (after rotation to horizontal; n=2).

Unit 23 is composed of three debrites (Fig. 9F) totaling 1.3 m in thickness. Each debrite contains both rounded (up to 7 cm) and tabular (up to 4 cm) monomictic dolomudstone intraclasts floating in dolomudstone matrix. The debrites are structureless, and the contacts between debrite layers are sharp. Debrites one and two are nearly clast-supported and clasts are subangular (Fig. 10A). Debrite three is composed of smaller (mainly sub-centimetric) clasts that are generally more rounded than those in the lower two beds, and is matrix-supported (Fig. 10B) (unit 23). The contact between debrites 2 and 3 is sheared. The third debrite is overlain by 3 m of dark green siltstone (unit 24) that interfingers in some areas with the upper 20 cm of the underlying third debrite as well as interfingering with the overlying 20 cm thick dolomudstone (see detailed section #3 in Fig. 6). The overlying dolomudstone also contains randomly oriented clasts of the underlying siltstone. Still in unit 24, overlying the 3 m thick siltstone and 20 cm thick dolomudstone is another siltstone overlain by dolomudstone containing siltstone clasts (Fig. 10C).

Overlying the first three debrite units are four more debrites (units 26, 30, 32, and 33) as well as mechanically laminated dolomudstone, siltstone and argillaceous dolomudstone layers (units 25-33). All four of the debrites are similar to the lowest debrite in unit 23, with large, tabular, subangular intraclasts and dolomudstone matrix. In unit 32, the intraclasts have been dissolved away and are filled with geopetal sediment and cement (Fig. 10D).

Overlying the interval of four debrites is an 83.7 m thick interval of mechanically laminated dolomudstone layers with local intraclast dolorudstone beds and ooid dolograinstone beds, some molar-tooth dolomudstone, and local metre-scale stromatolite bioherms (units 34-52). Dolomudstone and molar-tooth dolomudstone units are pale grey-weathering with white centimetric dolomitic intraclasts (some of which is molar-tooth crack-fill). Unit 41 contains rare fracture coating malachite. Starting at unit 46, small amounts of black chert are present in the dolomudstone as nodules. Unit 49 contains convoluted lamination and displays black bedding-plane veneers.

Units 53-96 consist of alternating mechanically laminated dolomudstone, ooid-intraclast rudstone, and stromatolitic dolomudstone arranged in metre-scale cycles (see detailed section #4 in Fig. 6). Individual units are between 0.4 and 3.2 m thick (typically 1 m thick). The lithofacies at the base of each cycle is pale grey-weathering, mechanically laminated dolomudstone with 5-15 cm thick beds (Fig. 10E). The second lithofacies of each cycle is ooid-intraclast grainstone to rudstone with grainstone matrix and shows no internal organisation. Intraclasts are dark grey-black, rounded, and generally between 0.5 and 1 cm long (Fig. 10F). The final lithofacies in each cycle is stromatolitic dolomudstone that is buff-orange-weathering, massive, and composed of stromatolites of uncertain (probably columnar) morphology (Fig. 11A). One unit appears to have both columnar (~2-3 cm wide) and cabbage-shaped stromatolites. One other stromatolite unit contains ooid dolograinstone among stromatolite columns. The tops of stromatolitic units are always undulatory (~5 cm of relief). The contact between stromatolites and the base of the next cycle is always sharp. The mechanically laminated dolomudstones and stromatolitic mudstones are slightly more resistant-weathering than the ooid-intraclast dolorudstone. Throughout the cycles, undulatory lamination is locally present; black bedding-plane veneers are present mainly in dolomudstone units; grey-black-weathering chert replaces all three lithofacies in the form of stromatolite silicification, thin layers (Fig. 11B), and nodules. Small amounts of malachite, azurite and copper sulphides are present in a few units. This cyclic interval ends with a 4.7 m thick unit of stromatolitic dolomudstone with columnar stromatolites up to 10 cm wide (Fig. 11C), local ooids and dark intraclasts, and some grey chert.

Overlying the previous cyclic interval is 32.9 m of mechanically laminated and banded dolomudstone (units 97-101) with strongly convoluted lamination (Fig. 11D) that becomes more weakly convoluted up stratigraphy. Unit 97 contains convoluted lamination as well as micro faults (Fig. 11E). Later units (units 100-101) contain intraclasts, molar tooth structure, and an abundance of grey and black chert as nodules. Above unit 101 are 66.5 m of alternating stromatolitic dolomudstone, molar tooth dolomudstone (Fig. 11F), and mechanically laminated +/- banded dolomudstone with large covered intervals (44.5% covered) (units 102-116).

Stromatolites are both cabbage-shaped and columnar. Bioherms reach nearly a metre in width, and columnar stromatolites are around 2 cm in width. Molar-tooth cracks in dolomudstone are generally sparse (compose only ~10% of the rock). Units have locally been partly replaced with chert nodules (white, grey, and black).

Above the uppermost of the stromatolitic dolomudstone units is a recessive siltstone unit 0.8 m thick (unit 117) below 1.3 m of undulatory bedded nodular dolomudstone (unit 118) similar to unit 21 above the siltstone cavern unit. Dolomudstone nodules up to 10 cm long are embedded in centimetric green siltstone interlayers. This unit grades into 3.1 m of dolomudstone, again with undulatory bedding (unit 119). The next 13 m of outcrop consists of nodular dolomudstone with silty interlayers as in unit 118, but with varying mudstone and nodule proportions. The lower 4 m are composed of dolomudstone matrix with dolomudstone nodules (unit 120), followed by 3 m of lime mudstone matrix with lime mudstone nodules (unit 121), and finally, 6 m of dolomudstone matrix with lime mudstone nodules (unit 122) (Fig. 12A). All of the matrices are mechanically laminated with the same siltstone interbeds. The dolomitic matrices weather bright orange and the unit is known as the 'orange marker unit' (Fig. 12B). Views of the hillside scree, together with very poor exposure in the creek and excavated pits above the orange marker indicate that the overlying covered interval consists in large part of very dark siltstone/shale with minor thin carbonate beds.

The orange marker units and approximately 15 m of underlying strata were also documented in detail at a second, better-exposed location along a creek in addition to the one already described (see auxiliary section #5 in Fig. 6; see also Fig. 12C). The more detailed section, which begins at unit 116 with 3.7 m of stromatolitic dolomudstone, overlain by symmetrically rippled dolomudstone with undulatory parallel lamination, 4.1 m of molar-tooth dolomudstone, and 1.2 m of banded dolomudstone with an undulatory upper contact. Above these units is a thin, recessive layer of black siltstone ranging from 0.05 m to 0.45 m thick, followed by recessive, 0 to 0.5 m thick pisoid floatstone-rudstone with a silicified peloidal carbonate matrix (Fig. 12D) (equivalent to unit 117). The contact between silicified siltstone and pisoid rudstone is gradational over 15 cm (Figs. 12D, 12E). Pisoids are 0.5 cm to 2 cm in diameter. The pisoids' internal texture contains irregular, faint, approximately concentric lamination and encloses millimetric peloids. The siliceous matrix is dark green-brown (Fig. 12F). The pisoid unit is overlain by 1.9 m of resistant, mechanically laminated dolomudstone, 2 m of cover, followed by nodular lime and dolomudstone units (Fig. 13A). The nodular units start with orange-weathering dolomudstone nodules embedded in undulatory green siltstone interbeds in an orange-weathering dolomudstone matrix for 4.4 m (Fig. 13B) that grades into to a slightly more recessive, medium grey-weathering lime mudstone unit with no nodules or interbeds for 0.3 m. The lime mudstone grades upwards into 0.6 m of more resistant lime mudstone with lime mudstone nodules again in silty interbeds. The matrix then grades into orange-weathering dolomudstone with grey lime mudstone nodules 4.4 m (Fig. 13C) before returning to lime mudstone matrix and lime mudstone nodules for 0.2 m. At the top of this section, the nodules and siltstone interbeds decrease in size and abundance gradationally over 0.8 m before disappearing in slightly recessive lime mudstone beneath 23 m of cover, which on the mountainside veneers a recessive interval of dark grey siltstone-shale scree. Above the covered interval is the beginning of unit 123.

In the main line of section, a covered interval of 13.9 m (Fig. 13D) with dark-coloured siltstone scree overlies the nodular dolomitic and calcitic units (120-122), followed by 74.6 m of massive, generally featureless buff-weathering dolostone (unit 123). The dolostone is very resistant, of variable crystal size, exceptionally massive, and shows almost no internal structure except for a few locations exposing faint laminations or banding. The unit is variably vuggy and porous and is variably mineralised with void-filling malachite, azurite and copper sulphides (Fig. 13E). Rarely, the lowermost few metres of dolostone unit 123 exhibit microbial clots and interstitial cement similar to those of unit 12 (Fig. 13F). Because of poor access in cliff faces and fabric-destructive dolomitisation, it is unclear if the thrombolitic lithofacies is representative of the entire unit, or only a small component.

Overlying the microbial unit are three dolomudstone units (units 124-126 (Fig. 14A)). Unit 124 is present in outcrop and is mechanically laminated. Units 125 and 126 are felsenmeer. Unit 127, above 3.2 m of cover, is an undulatory bedded dolomudstone with ~5 cm argillaceous interbeds containing convoluted lamination, and possibly a slump fold. Unit 127 is similar to units 18 and 120. The argillaceous dolomudstone is overlain by a 4.4 m thick mechanically laminated dolomudstone with convoluted lamination and poorly preserved stromatolites near the top (unit 128); 4.7 m of dolomudstone containing dolomudstone lenses up to 6 cm long and stromatolites at the top (unit 129); and a 0.2 m thick stromatolitic dolomudstone (unit 130).

Above the dolomudstone interval is a 2.4 m thick, dark grey, fissile siltstone (unit 131). This siltstone is notably thicker than most underlying siltstone intervals, and marks the start of generally thicker and more numerous siliciclastic units in the upper Ram Head Formation, as compared to the thin, sparse siliciclastic units in the lower Ram Head Formation. Above unit 131 are two additional thin dolomudstone units, the first present only as felsenmeer, and the second partly replaced with blobby dark grey-black chert (units 132-133). The two dolostones are overlain by dark grey siltstone and dolomudstone layers totaling 6.5 m that are present only as scree at the top of a ridge (units 134-136). Above a covered interval of 2.7 m, are 0.4 m of yellow-weathering, recessive, laminated dolomudstone (unit 137) and 9.2 m of pink-weathering, massive dolomudstone (units 138-141) (Fig. 14B) with columnar stromatolites towards the bottom and possibly near the top, blobby black chert towards the bottom and top, and dolomudstone nodules, siltstone seams, and wavy bedding in the middle. These units weather pink to red and grade upwards into a 1.9 m thick pale grey-weathering lime mudstone with 30 cm thick bedding (unit 142).

Above the lime mudstone unit is a thin (1.3 m) dark grey siltstone unit (unit 143), followed by 15.9 m of nodular, mechanically laminated, 5-30-cm-bedded, lime mudstone (unit 144). Nodules are composed of lime mudstone and are smaller (<10 cm) near the bottom of the unit, and become larger (>10 cm) above 3 m (Fig. 14C). The unit has patchy dolomitisation denoted by a more orange weathering colour and dolomitisation becomes more prevalent towards the top of the unit. The overlying unit is an 11.2 m thick orange-weathering, nodular, mechanically laminated dolomudstone (Fig. 14D) with a gradational lower contact; dolomudstone nodules are visible only on close inspection (unit 145). Nodules are dolomudstone, <5 cm long, and are present only in the bottom few metres of the unit, which grades upwards into mechanically laminated dolomudstone overlain by 0.6 m of markedly orange-weathering, massive, featureless dolomudstone (unit 146).

Overlying 1.1 m of cover are 6.8 m of pale grey-weathering dolomudstone with an undulatory upper contact (unit 147), overlain by 2.8 m of fissile, pale green-weathering siltstone with locally rusty weathering (unit 148) (Fig. 14E). Right above the siltstone's lower contact are lenses of fine-grained quartz sandstone (Fig. 14F). Following the siltstone are 6 m of alternating mechanically laminated or banded orange dolomudstone with mechanically laminated, orange-weathering, recessive, argillaceous dolomudstone (Fig. 15A) (units 149-153). The uppermost dolomudstone is nodular (1-5 cm dolomudstone nodules), and mechanical lamination is undulatory. The overlying unit is 13.9 m of undulatory, pale grey-weathering mechanically laminated dolomudstone (Fig. 15B) that is generally bedded on a 5-15 cm scale except around the 6-8 m mark, where it is massive, with possible columnar stromatolites (unit 154). Unit 154 also contains layers of intraclast dolopackstone.

Overlying the dolomudstones is a succession (units 155-159) of resistant-weathering, vuggy, medium grey-weathering banded dolomudstone alternating with pale grey-weathering intraclast dolograinstone (Fig. 15C). Intraclast dolograinstone exhibits possible inverse grading. Intraclasts are dark grey and sub-centimetric. Above 20 cm of cover is a series of alternating recessive, argillaceous dolomudstones and more resistant-weathering dolomudstones of varying character totaling 8.7 m (units 160-172). The seven recessive argillaceous mudstone units in this interval are generally fissile and buff-coloured, and are locally banded. The eight resistant dolostone units range from bottom to top from mechanically laminated with cross-bedded quartz sand, to biohermal with 20-cm-long dolomudstone intraclasts, to biohermal (Fig. 15D), to banded and rippled.

Above unit 172 are interbedded siltstone and dolomudstone (units 173-179). Four thin, recessive siltstone layers weather a very distinctive dark purple-maroon, and are interbedded with orange-weathering dolomudstone (Fig. 15E). All of the dolomudstone units are banded, and the third contains tilted laminae produced by soft-sediment deformation (Fig. 15F); the second siltstone unit contains desiccation cracks. Overlying the interbedded siltstone and dolomudstone is a resistant, mechanically laminated intraclast dolofloatstone in 30 cm thick beds with grey chert nodules (unit 180). Intraclasts are composed of stromatolite fragments, are between 1 and 3 cm wide, and are oriented randomly (Fig. 16A). Overlying the stromatolite intraclast floatstone is a thin-bedded (2-10 cm) dolomudstone with undulatory lamination followed by large cabbage-shaped stromatolite bioherms, consisting of columns around 2 cm wide that grade upwards to dome-shaped bioherms roughly 30 cm in diameter (units 181-182).

Overlying the biohermal unit is a less resistant, mechanically laminated dolomudstone with laminations bending upwards around a fluid pathway in a fluid-escape structure, followed by a nodular, banded dolomudstone (units 183-184). The dolomudstone is overlain by another series of alternating terrigenous mudstone-to-siltstone (Fig. 16B) and featureless dolomudstone-to-argillaceous dolomudstone (units 185-193). The first three recessive units are either siliciclastic mudstone or siltstone, and the last two recessive units are siltstone. The bottom three siliciclastic mudstones weather dark green-brown, and the siltstones weather pale grey. The four intervening dolomudstone layers are all orange-weathering and very thinly bedded (<3 cm) to fissile. Two of the four dolomudstone layers are argillaceous.

The alternating siltstones and dolostones underlie 2 m of cover and another 10 m of featureless dolomudstone (Fig. 16C) that grades upwards into stromatolitic dolomudstone with partly silicified columnar stromatolites ~2 cm wide (Fig. 16D) (units 194-195). Above unit 195 is a 20 cm thick dark grey siltstone (unit 196) overlain by a series of alternating microbial and non-microbial dolomudstones: 1.1 m of dolomudstone with 30-cm-wide domical bioherms and dolomudstone lenses between bioherms; 3.2 m of interbedded microbial laminite and banded dolomudstone; 2.1 m of stromatolitic dolomudstone with columnar stromatolites 2-4 cm wide and grey chert nodules; 0.6 m of banded argillaceous dolomudstone; and 4.5 m of stromatolitic dolomudstone with stromatolite columns ~2 cm wide (units 197-201). Unit 201 grades upwards into a microbial laminite with crinkly lamination (Fig. 16E) (unit 202) and a sharp upper contact with 0.5 m of non-microbial, mechanically laminated dolomudstone (unit 203) that grades into nodular, undulatory-laminated and grey chert-bearing dolomudstone (unit 204).

Overlying unit 204 is a 4 m thick, banded, pale grey-weathering dolomudstone with grey chert nodules and 1-cm-wide stromatolite columns in the top 10 cm (units 205-206). Above unit 206 is 20 cm of brown-weathering argillaceous dolomudstone followed by 30 cm of microbial laminite and 60 cm of stromatolitic dolomudstone; columns are ~3 cm wide (unit 207). The overlying, discontinuous, 10 cm thick, green-weathering argillaceous dolomudstone (unit 208) is in turn overlain by 2.7 m of dolomudstone with possible stromatolites and microbial lamination (unit 209).

Unit 209 is overlain by 0.1 m of recessive, brown-weathering argillaceous dolomudstone (unit 210), passing upwards into banded, possibly microbial, pale grey to yellow-weathering dolomudstone (unit 211) and a possibly microbially laminated dolomudstone with white chert nodules (unit 212). Overlying the microbial dolomudstone are 2.6 m of symmetrically rippled, mechanically laminated dolomudstone (unit 213) and 0.6 m of columnar stromatolite dolomudstone (unit 214). The next unit upwards is another stromatolitic dolomudstone with white chert nodules and faint banding (unit 215). The uppermost carbonate unit, buff-weathering, featureless dolomudstone 1 m thick (unit 216), is discontinuously overlain by lenses of quartz sandstone up to 3 cm thick (unit 217).

The carbonate succession is sharply overlain by dark green to black-weathering basalt (the "Little Dal basalt"; unit 1 of the overlying Coates Lake Group) (Fig. 16F). The contact between strata of the Ram Head Formation and the basalt is undulatory on both an outcrop scale (Fig. 17A) and a sub-metre scale (Fig. 17B), with relief of up to 2 m evident from a distance and lamination in the uppermost Ram Head Formation subtly truncated. Discontinous quartzose sand lenses up to 5 cm thick are present at the contact (Fig. 17C). The lowest 1 m of basalt contains isolated, floating, rounded, bright orange-weathering fragments of dolostone (Fig. 17D). Amygdules are dispersed evenly throughout the lowest part of the basalt.

STRATIGRAPHIC PACKAGING IN THE RAM HEAD FORMATION

The Ram Head Formation is characterised by abundant shallowing-upwards cycles metres to tens of metres thick. Cycles in the lower and upper parts of the formation differ markedly, such that the formation can be divided into two members; a lower member and an upper member, separated by the pisoid unit (unit I and its equivalent, unit 117). In the lower Ram Head Formation, cycles begin with subtidal dolomudstone, generally mechanically laminated and commonly overlain by molar-tooth dolomudstone. In the upper Ram Head Formation, cycles commonly begin with an incursion of terrigenous silt or mud. Siltstone or subtidal carbonates are overlain by ooid and/or intraclast grainstone to rudstone and stromatolitic dolostone. The uppermost units of cycles have desiccation features. Cycles are not always complete or consistent, and one or more lithofacies is commonly absent. Cycle bases commonly rest on minor erosional surfaces. The most striking examples of cyclicity are units 53-96, which are repeated metre-scale mechanically laminated dolomudstone, ooid and intraclast dolorudstone, and stromatolitic dolostone cycles. Cycles throughout the rest of the formation are between 10 and 100 m thick and cycles in the upper member are generally thinner than those of the lower member. The one notable exception to the general trend of shallowing upwards cycles is a deepening upwards cycle (from units 117 to 123) beginning at the pisoid marker unit (unit I in detailed section 5 of Fig. 6). The pisoid marker records an extended interval of exposure and caliche development followed by: nodular dolomudstone interpreted to be lagoonal by Aitken

(1981); deeper water siltstone scree in the covered interval between units 122 and 123; and a large, muddy, deep water microbial buildup (unit 123). These units represent a deepening-upwards cycle beginning with an exposure surface and progressing through to deep-water environments.

Lithofacies also vary between the lower and upper Ram Head Formation. The lower member contains abundant molar-tooth dolomudstone towards the base of shallowing-upwards cycles and very little siltstone (less than 1% of the lower member's thickness). In contrast, the upper part of the formation contains no molar-tooth dolomudstone and siltstone forms nearly 7% of the upper member's thickness. Individual carbonate units are also generally thinner in the upper Ram Head Formation than in the lower part of the formation, though siltstone and terrigenous mudstone units are notably thicker in the upper member than in the lower member (units 131, 136, and 146 are above 1 m in thickness, thicker than any terrigenous unit in the lower member).

DEPOSITIONAL ENVIRONMENTS

The Ram Head Formation is composed predominantly of shallow-water carbonate rocks. The main lithofacies include molar-tooth dolomudstone with local intraclast beds, microbial dolomudstone (mainly stromatolitic, but locally thrombolitic), mechanically laminated dolomudstone, ooid and intraclast grainstone to rudstone, and nodular dolomudstone. Recurring dessication features suggest common intervals of exposure and semi-arid conditions.

Molar-tooth carbonate forms at depths above storm wave-base in shallow platform and mid- to inner ramp settings (James et. al, 1998), typically above storm wave-base but below fairweather wave-base. Locally, intraclasts of molar tooth crack fill are present in intraclast beds within molar-tooth dolomudstone units indicating periodic rip-up during high-energy events in shallower waters.

Mechanically laminated dolomudstone suggests deposition below fairweather wave-base. The dearth of other sedimentary structures such as cross-bedding, ripples, and flaser bedding suggests no influence of wave activity. The presence of molar-tooth structure in many mechanically laminated units also suggests a paleo depth of below fairweather wave-base. The mechanical lamination may be the result of currents or very thin tempestites. In thin section, all carbonate mud has been completely recrystallised to xenotopic dolomite, making it difficult to determine the mechanism of formation of the lamination.

Stromatolites of diverse shapes and sizes are present throughout the Ram Head Formation. They are predominantly columnar, unwalled, non-branching and a few centimetres wide. They are generally present in low-energy lithofacies near cycle tops, but evidence of higher-energy environments is present in the form of ooids, superficial ooids, aggregate grains, and stromatolite clasts present in some stromatolitic units. Units 11 and 12 display a gradational contact between stromatolites and thrombolites. The stromatolites of unit 11 display evidence of a high-energy environment as described above, whereas abundant mud is present in the thrombolitic unit (unit 12) and there are no coated or aggregate grains or intraclasts, suggesting a gradational shift towards a lower energy environment of deposition, possibly deepening, through these two intervals.

The possibility of synsedimentary tectonism during deposition of the Ram Head Formation was put forward by Aitken (1981) who suggested that thickness variations in the Snail Spring and Ram Head Formations were presaging the faulting that occurred during deposition of the Coates Lake Group, while Jefferson and Parrish (1989) argued for faulting before and after deposition of the Ram Head Formation. Both suggestions were based on isopach data, and not on sedimentological-stratigraphic evidence. A close examination of the sedimentology of the Ram Head Formation reveals multiple lines of evidence for the possibility of synsedimentary tectonism during deposition. (1) Abrupt deepening above the pisoid marker unit at the start of the upper Ram Head Formation followed by the 85 m thick microbial dolostone. This deepening is in sharp contrast to the cyclic shallowing-upward cycles that characterise the rest of the formation and may be explained by normal faulting. The 85 m thick monotonous microbial unit (unit 123) that accumulated during this deepening episode is anomalously thicker than any other unit in the formation. (2) Debrites are present in one interval in the lower part of the formation. These debrites are the first indication of any significant slope in the basin, possibly the result of tectonic-induced topography. (3) Convoluted lamination is common in the upper Ram Head Formation, representative of soft-sediment deformation. Local brittle deformation (healed microfaults) is also locally present. Both soft-sediment deformation and brittle deformation suggest sediment instability, possibly related to tectonism. (4) A layer containing possible toppled stromatolites is present at the base of the Ram Head Formation.

All above lines of evidence for syndepositional tectonism are indirect evidences for synsedimentary tectonism and are present at different stratigraphic levels of the Ram Head Formation. No syndepositional faults have been observed.

All previous descriptions of rocks now identified as the Ram Head Formation (Aitken, 1981; Jefferson, 1983; and Turner and Long, 2012) have noted the cyclic nature of the formation; subdivision of the formation into members by Aitken (1981) and Jefferson (1983) was based mostly on lithological variations, whereas Turner and Long (2012) focused on cyclicity. A focus on cyclicity is perhaps advisable as lithofacies vary subtly between sections and the comparison of cycles between sections may allow for study of possible synsedimentary tectonic activity. A general division between the lower and upper Ram Head Formations is also useful because of distinct differences in lithofacies, the nature of cycles, and cycle thickness. The changes from lower to upper Ram Head Formation indicate a shift to a more active and rapidly changing environment after a significant interval of exposure and carbonate soil development.

SUMMARY

The Ram Head Formation was documented at its type section near Boomerang Lake, Northwest Territories, in decimetric detail along four different but easily correlatable section segments within a few hundred metres of each other. The section at Boomerang Lake is found in the middle of the Ram Head Formation's narrow, N- trending exposure area in the Plateau fault hanging-wall in the Mackenzie Mountains, and is one of its most continuous and complete exposures. This work builds upon previous work by Aitken (1981), Jefferson (1983), and Turner and Long (2012). The basal contact of the Ram Head Formation with the underlying Snail Spring Formation is placed above the uppermost siltstone unit in the transitional zone between the two formations.

The Ram Head Formation can be subdivided into a lower and an upper member, each with distinct characteristics, divided at the base of a pisoid marker unit, a caliche representing an interval of exposure. The lower Ram Head Formation is composed of generally thicker pale grey-weathering mechanically laminated molar-tooth dolomudstone, buff-orange-weathering microbial (stromatolitic and thrombolitic) dolostone, orange-weathering nodular dolomudstone, and pale- to -medium grey-weathering ooid grainstone or intraclast grainstone with only minor (1%) siliciclastic intervals. The upper Ram Head Formation is composed of numerous thin (typically 1 to 5 m thick) units of pale grey-weathering mechanically laminated dolomudstone (no molar-tooth structure), buff-orange-red-weathering microbial dolostone, orange-weathering nodular dolomudstone, and variably coloured siltstone and mudstone (composing 6.7% of the thickness of the upper Ram Head Formation).

Nearly all lithofacies present show evidence of deposition in a shallow-marine setting, save for a few units deposited in a subaerial environment. Aside from the shale and microbial units near the base of the upper Ram Head Formation, of the common lithofacies, molar-tooth dolomudstone and mechanically laminated (variably nodular) dolomudstone represent the deepest depositional environments in the Ram Head Formation (below fairweather wave-base), whereas stromatolites represent a shallower environment above fairweather wave-base, commonly further supported by the presence of ooids and intraclasts and a lack of mud–grade material. Cyclic relative sea-level changes can be identified throughout most of the formation using detailed lithostratigraphy. The lower parts of the T-R cycles are defined by comparatively deeper-water lithofacies, which are mechanically laminated or molar-tooth dolomudstones. Cycle tops are defined by evidence of exposure such as desiccation cracks, nodular caliche development; or by shallow-water lithofacies such as stromatolites or ooid-intraclast dolograinstone.

Evidence indicating possible synsedimentary tectonism in the Ram Head Formation is putative and no synsedimentary faults have been observed. Examining other sections of the Ram Head Formation in search of sedimentological features suggesting tectonism and syndepositional faults would help clarify the nature of the tectonic environment at the time of Ram Head Formation deposition.

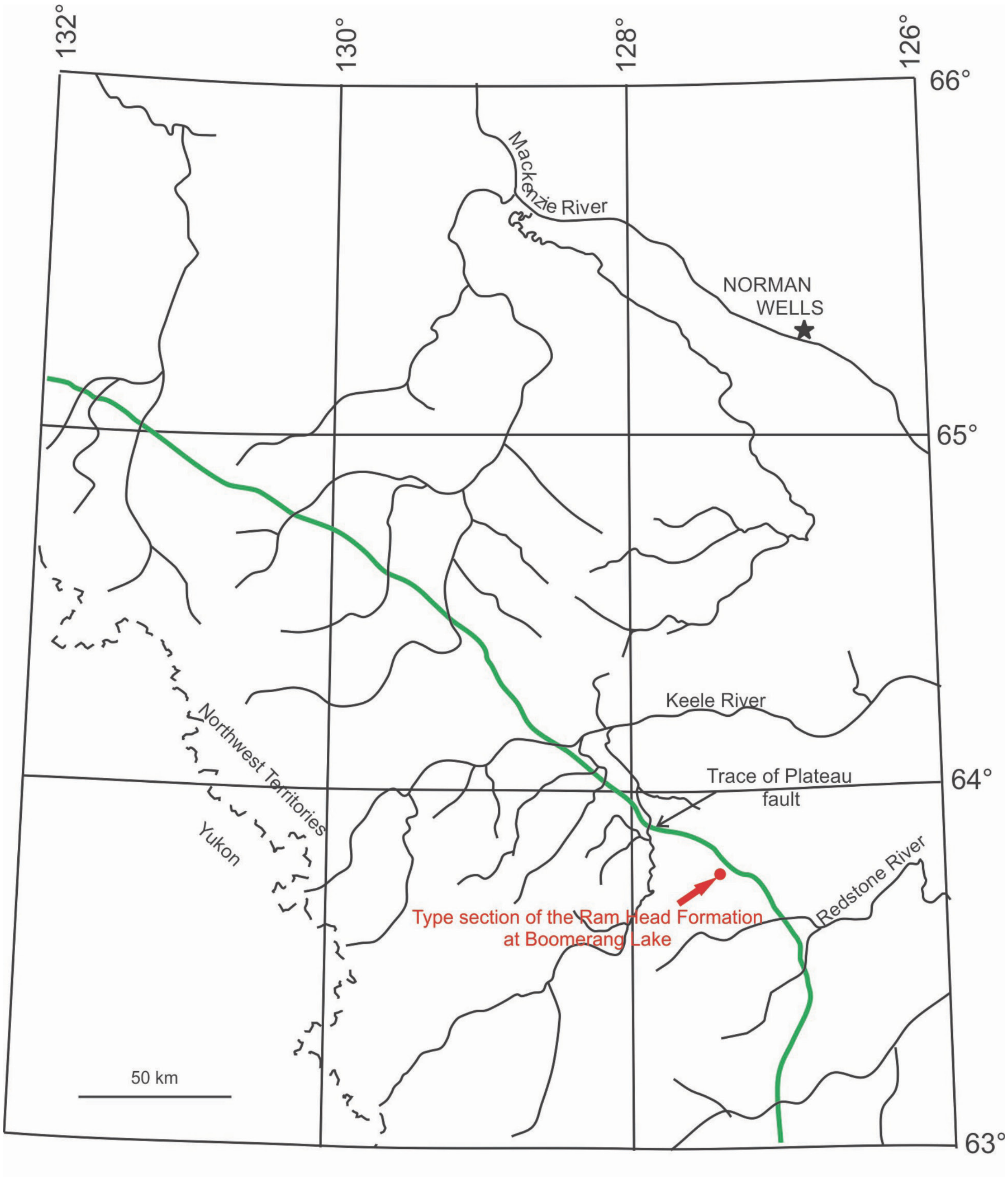

Figure 1. Location map of the type section of the Ram Head Formation at Boomerang Lake.

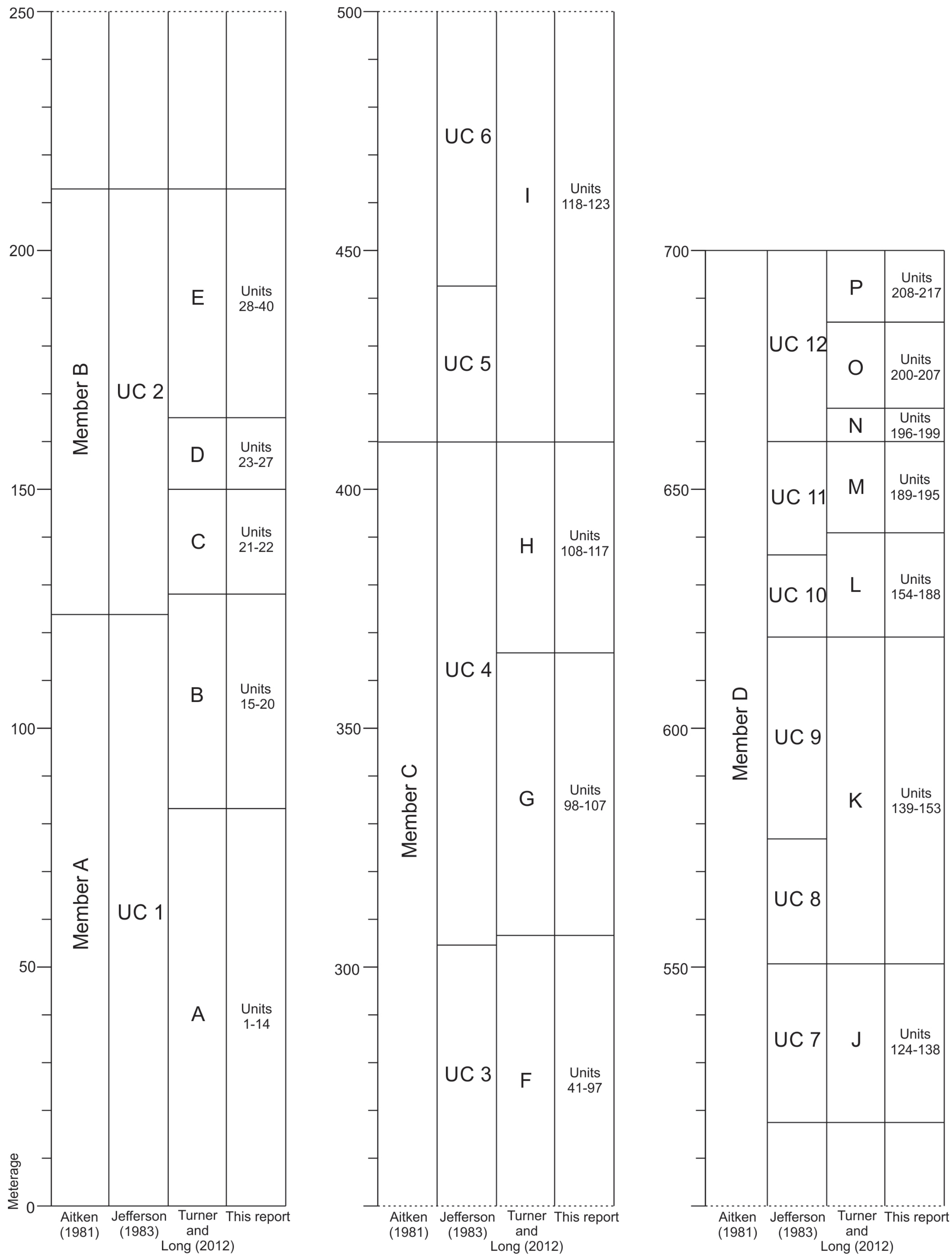

Figure 2. Comparison of subdivisions of the Ram Head Formation by Aitken (1981), Jefferson (1983), Turner and Long (2012), and this report.

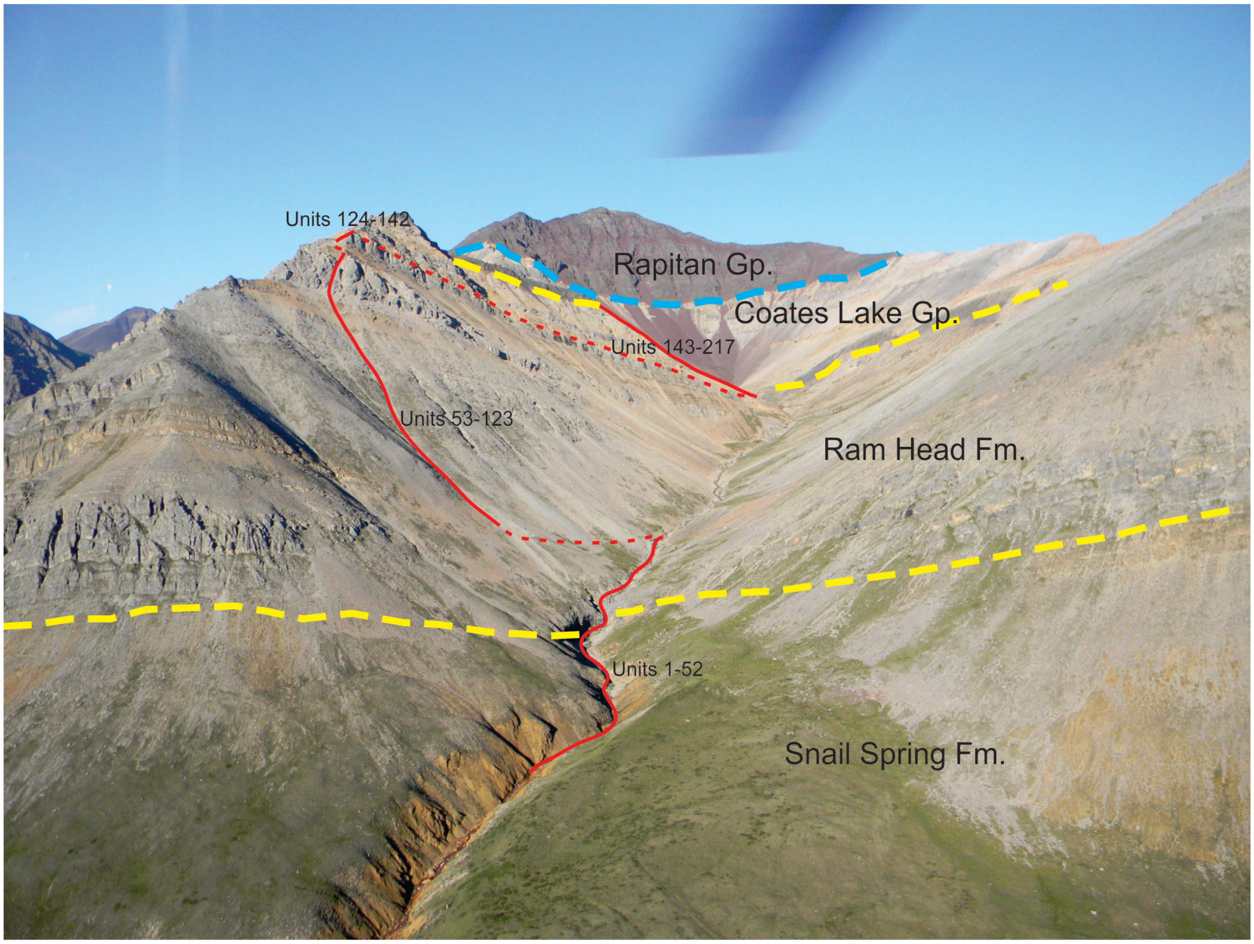

Figure 3. Type section of the Ram Head Formation (see Figure 1 for location). Red lines show the path measured; yellow dashed lines mark the lower and upper contacts of the Ram Head Formation. The apparent shift in the position of the upper contact of the Ram Head Formation across the gully is a function of perspective only. Blue dashed line marks the contact between the Coates Lake and Rapitan groups; numbers refer to units in the section log.

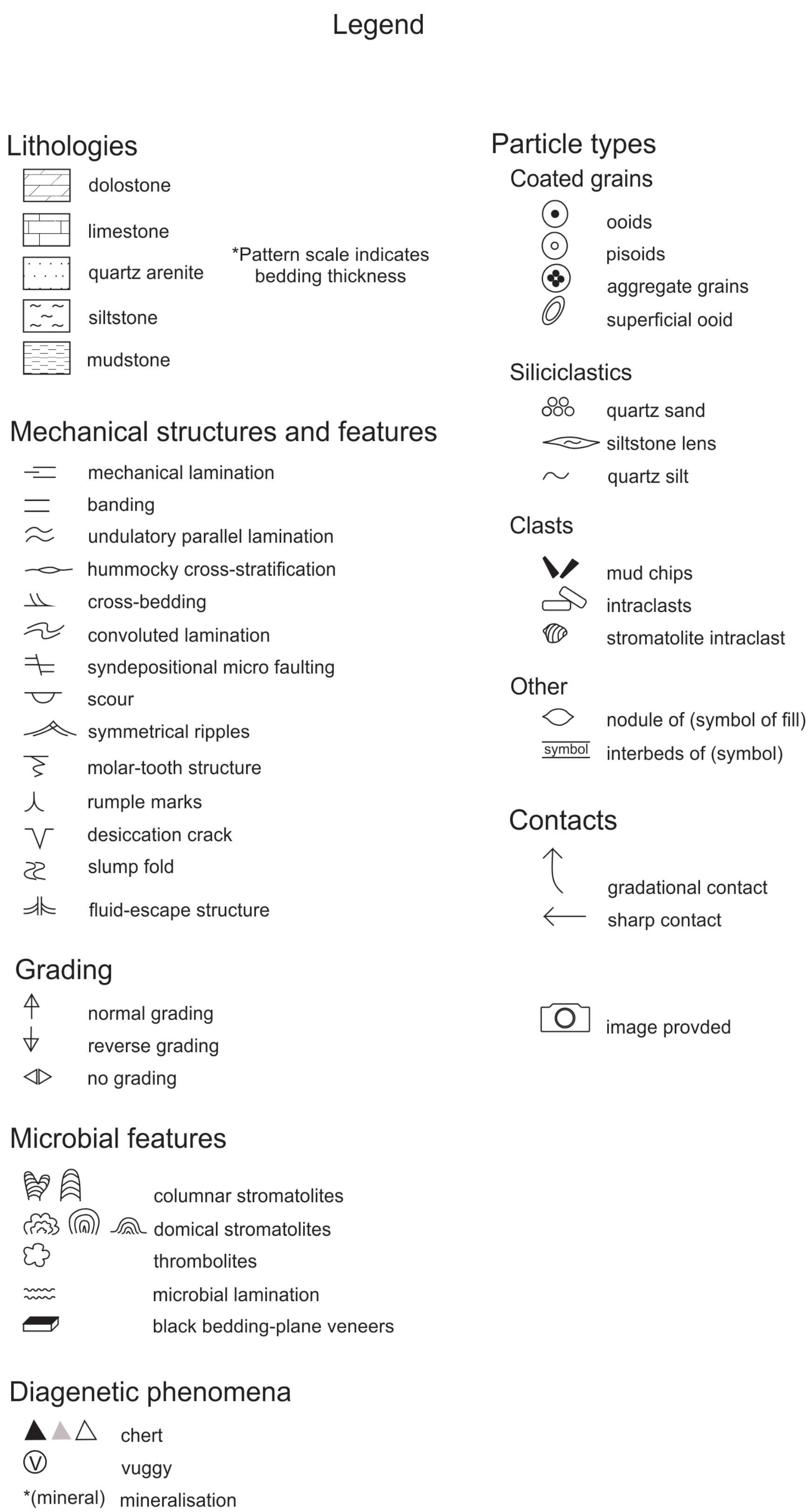

Figure 4. Legend of symbols used for graphic logs in figures 5 and 6.

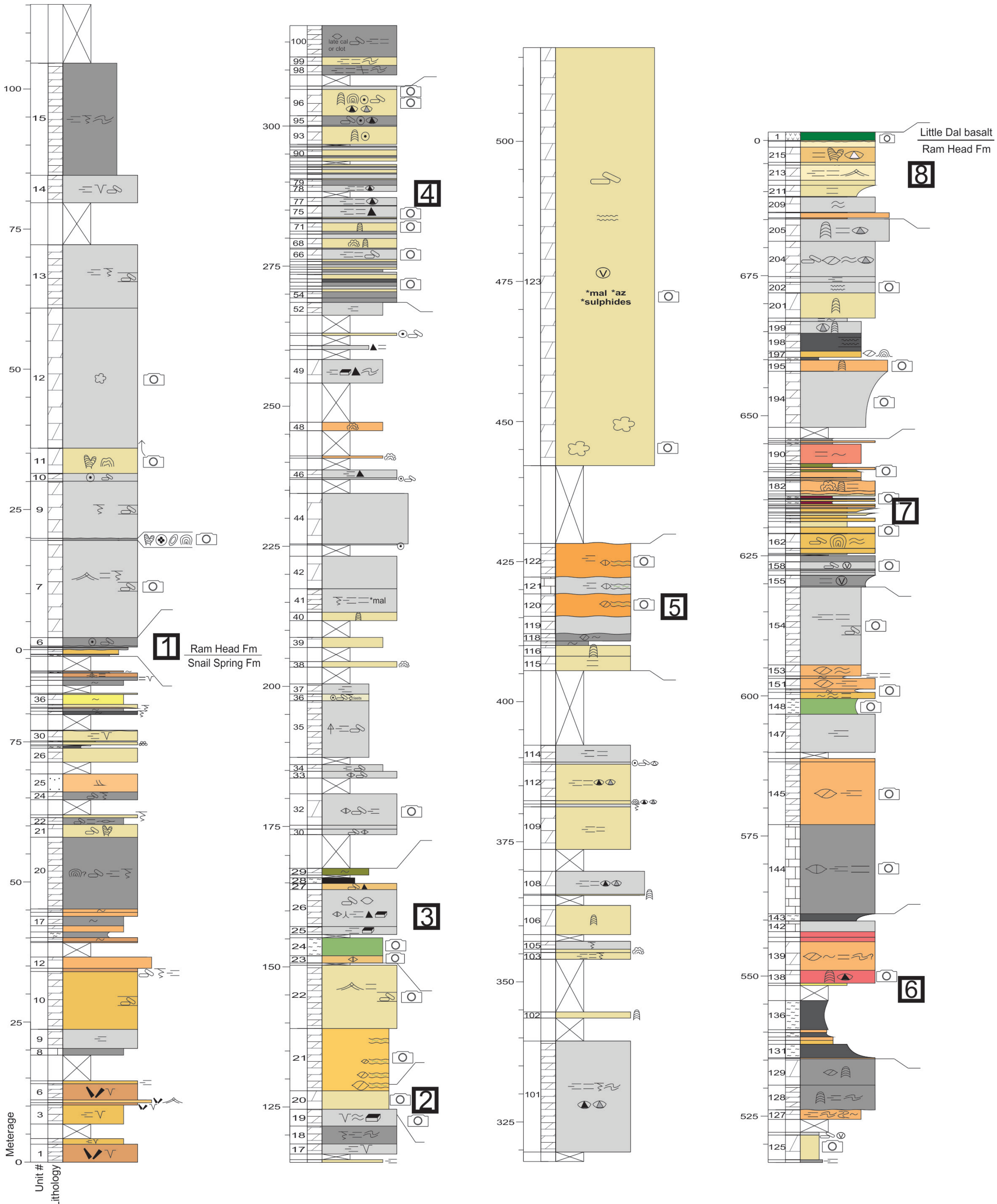

Figure 5. Stratigraphic log of the type section of the Ram Head Formation at Boomerang Lake, NWT. Column width indicates weathering profile; colour reflects weathering colour of each unit. See Figure 4 for symbol legend. Boxed number indicates detailed or auxiliary sections in Figure 6.

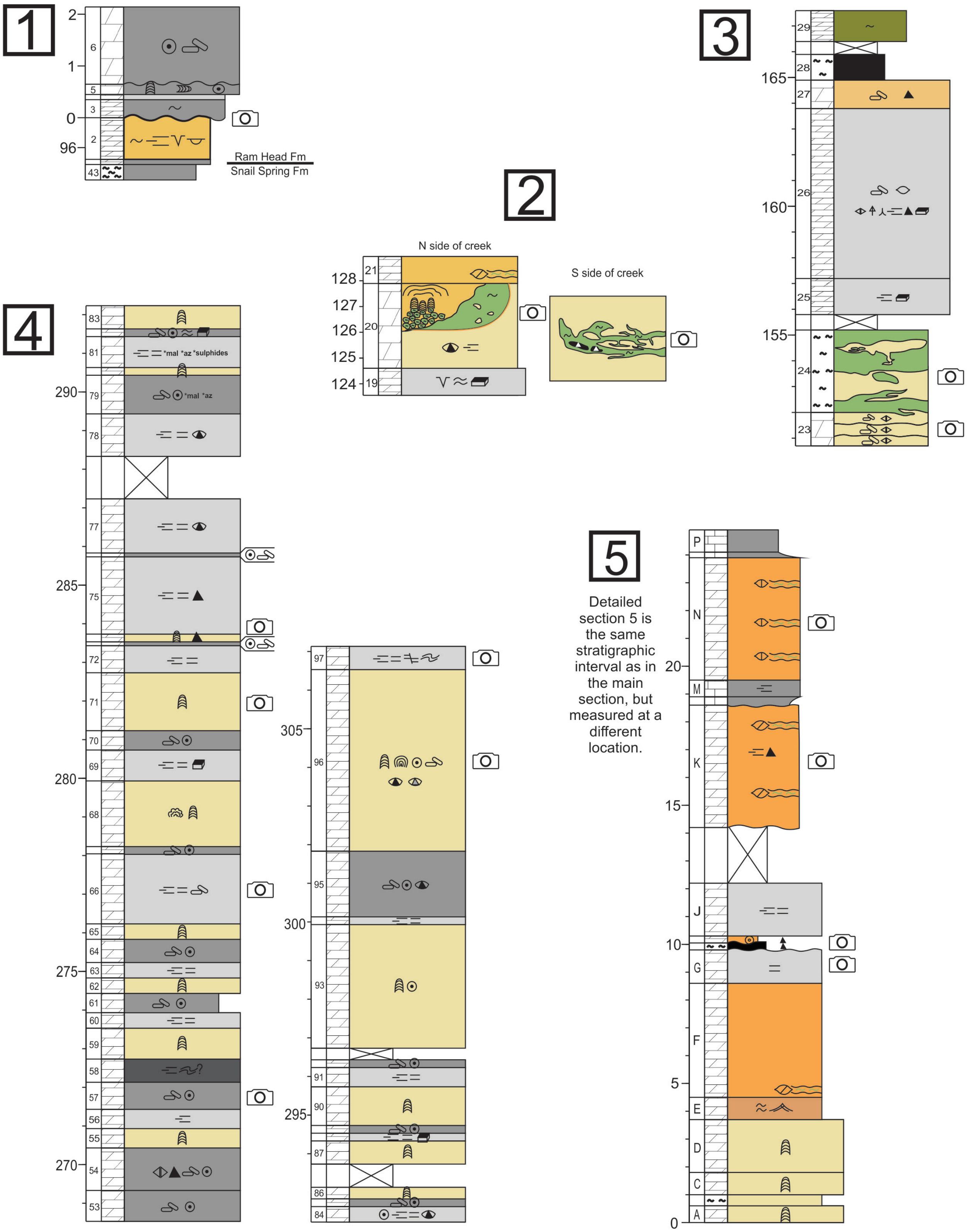

Figure 6. Detailed and auxiliary sections 1 through 5 numbered as in Figure 5. Symbol legend in Figure 4.

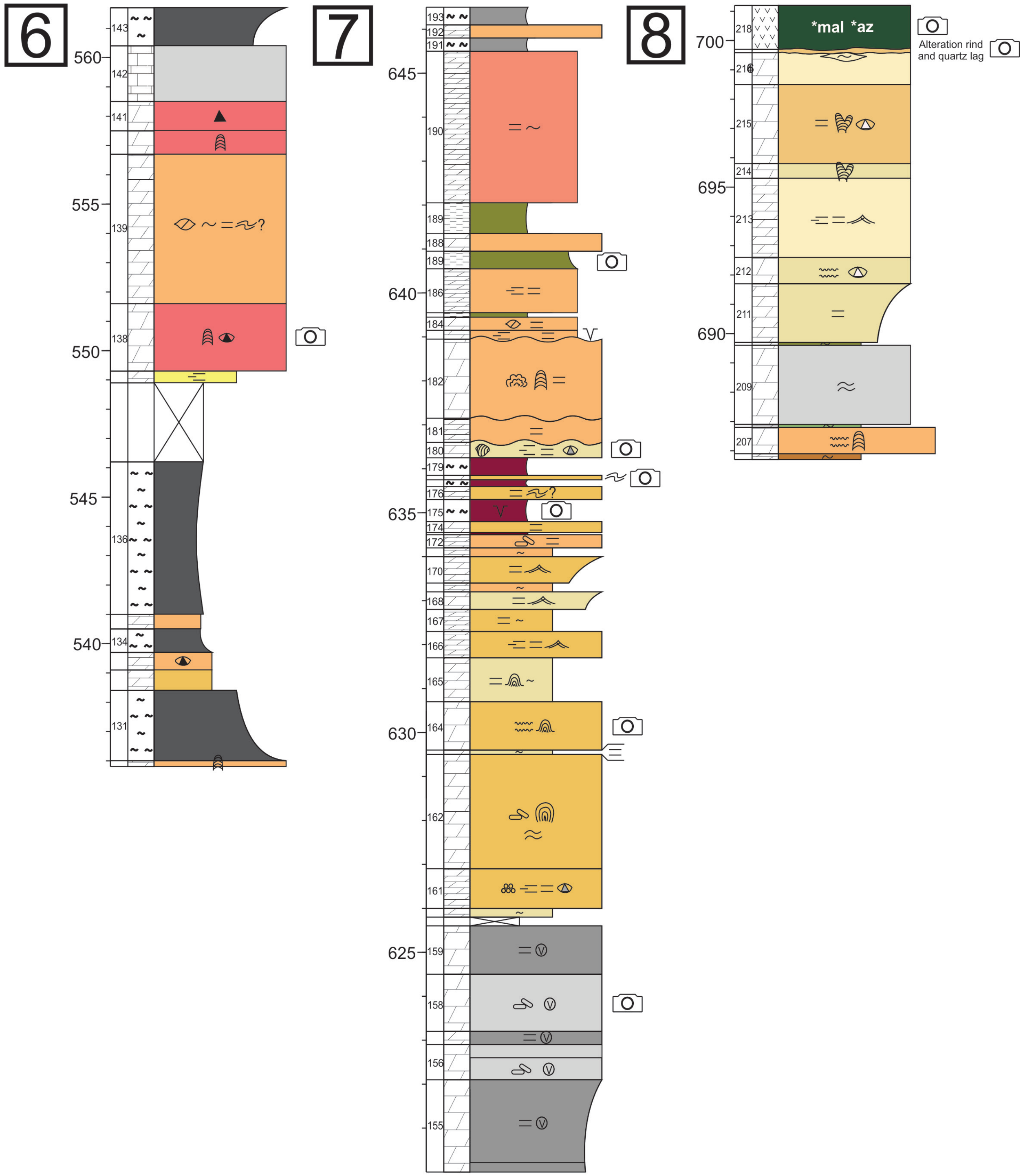

Figure 6, continued. Detailed and auxiliary sections 6 through 8 numbered as in Figure 5. Symbol legend in Figure 3.

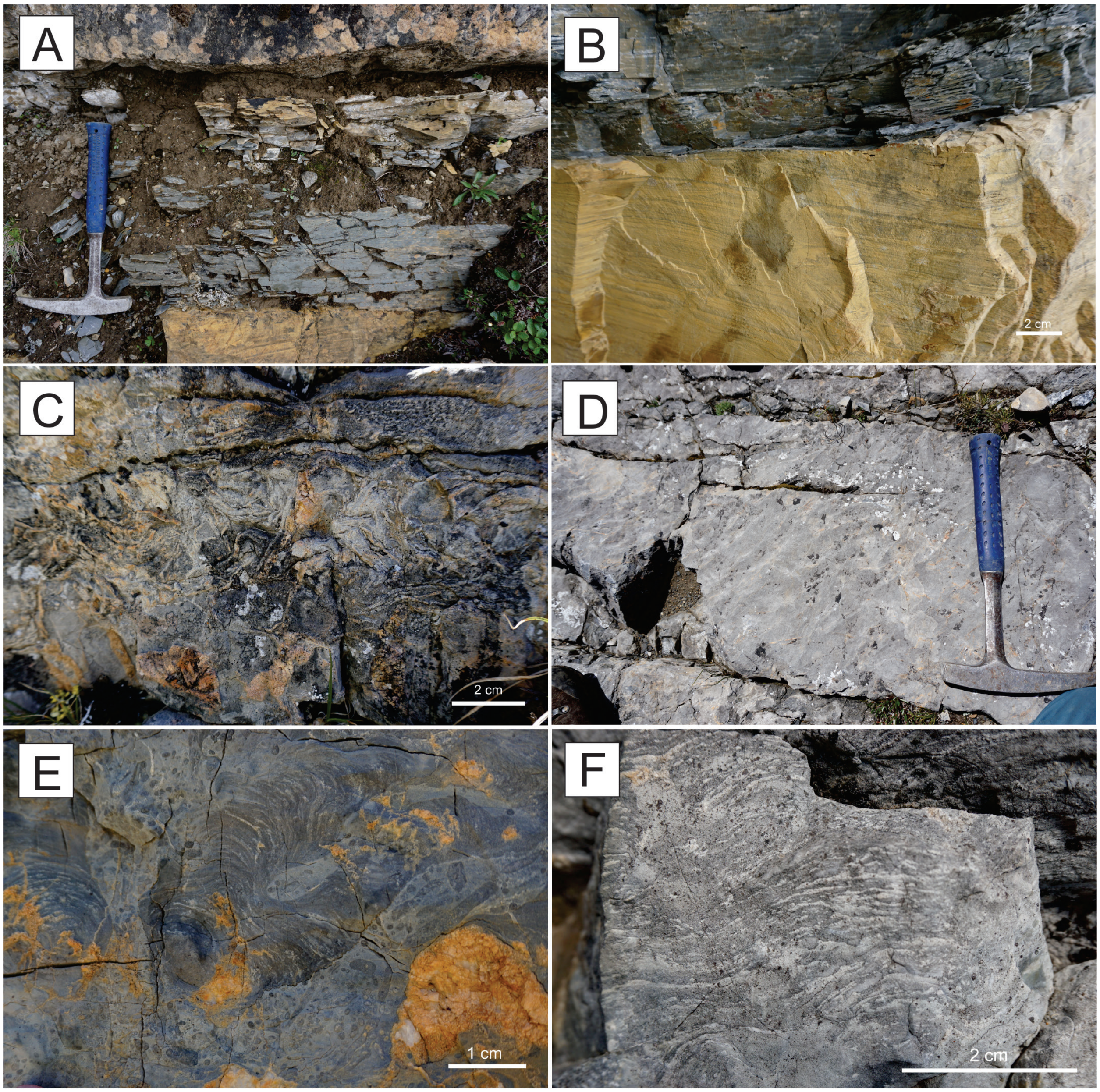

Figure 7. Typical carbonate lithofacies of the lower Ram Head Formation. (A) Contrast in weathering colour between units 2 and 3 in the lower Ram Head Formation. Hammer for scale is 30 cm long. (B) Close-up of erosional contact between units 2 and 3. (C) Molar-tooth dolomudstone with a relatively high abundance of molar-tooth crack fill (<25%). Unit 7. (D) Bedding surface showing symmetrical ripples in dolomudstone. Unit 7. Hammer for scale is 30 cm long. (E) Branching, columnar, unwalled stromatolites typical of the lower Ram Head Formation with coated grains and intraclasts between columns. Unit 8. (F) Atypical cement-rich stromatolites in large columns. Unit 11.

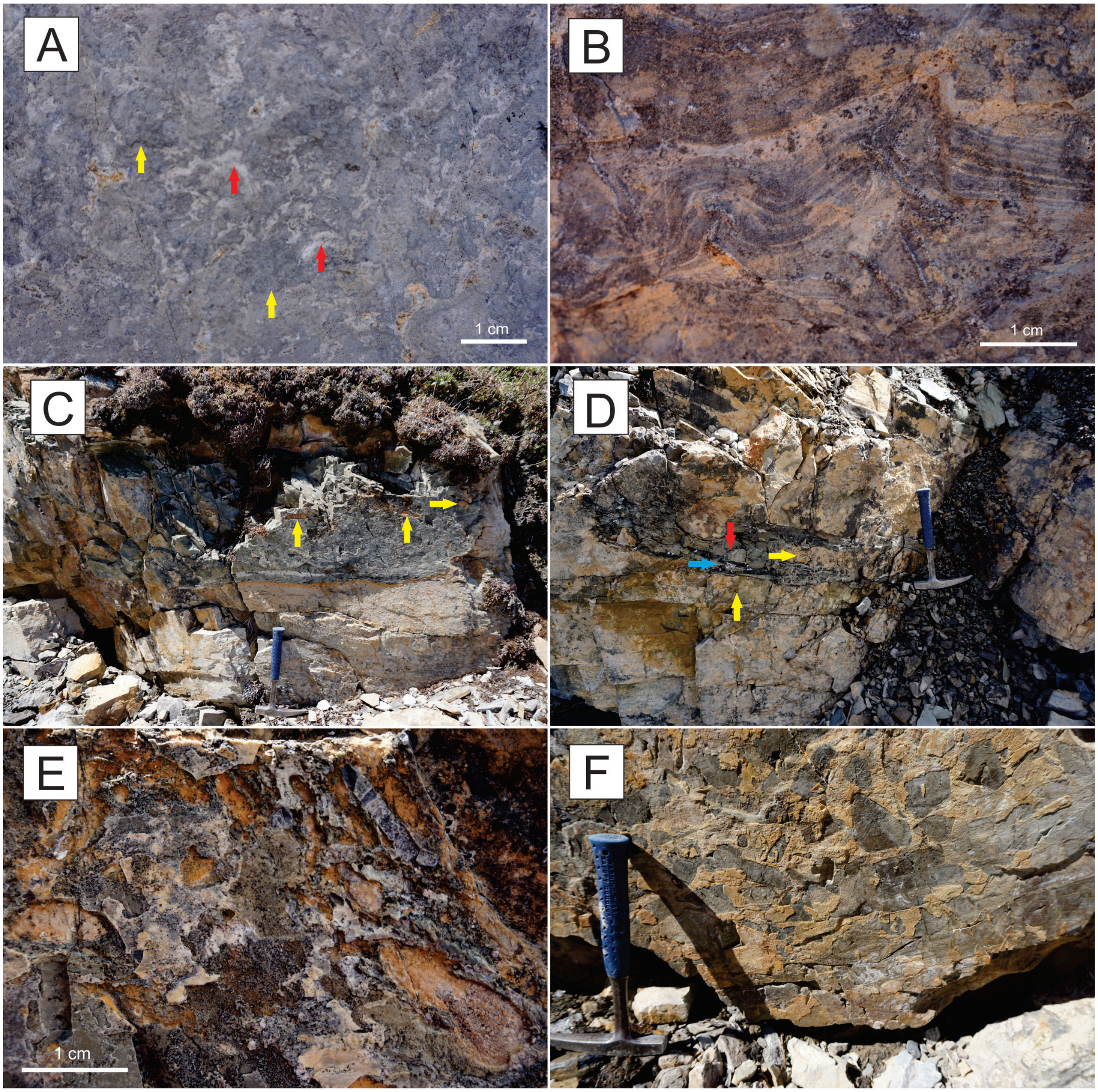

Figure 8. (A) Microbial clots in dolomudstone with cement-filled framework voids. Yellow arrows point to clots; red arrows point to cement-filled framework voids. Unit 12. (B) Mechanical lamination deflected around molar-tooth crack fill. Unit 19. (C) Green-grey siltstone 'cavern' cross-cutting buff-orange dolomudstone. Arrows point to dolomudstone clasts in siltstone. Unit 20; hammer for scale is 30 cm long. (D) Solution-widened joints and fractures in dolomudstone (orange) filled by siltstone with dolomudstone clasts and later partly silicified. Yellow arrows point to dolomudstone and dolomudstone clast in siltstone; red arrow points to siltstone filling joints and fractures; blue arrow points to chert in siltstone. Unit 20; hammer for scale is 30 cm long. (E) Numerous dolomudstone clasts (orange) in siltstone 'cavern'. Unit 20. (F) Sub-rounded siltstone clasts found below the base of the 'cavern' owing to erosion of the cavern and its fill. Unit 20. Hammer for scale is 30 cm long.

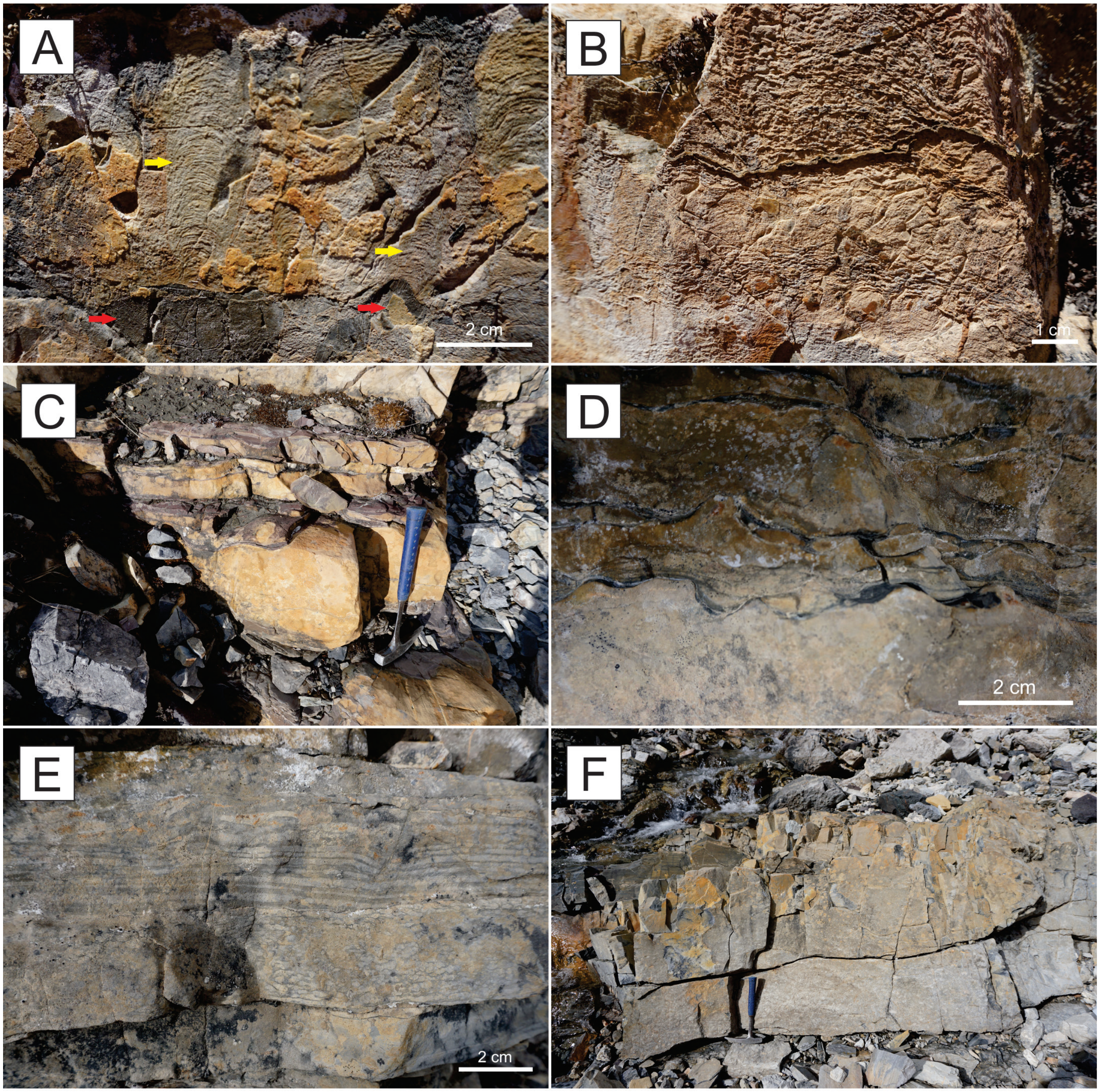

Figure 9. (A) Unbranching, unwalled, columnar stromatolites nucleated on siltstone clasts. Yellow arrows point to stromatolites; red arrows point to siltstone clasts on which stromatolites are nucleated. Unit 20. (B) Stromatolite bioherm overgrowing columnar stromatolites on siltstone clasts. Unit 20. (C) Typical recurring orange dolomudstone with silty interbeds containing dolomudstone nodules. Unit 21. Hammer for scale is 30 cm long. (D) Symmetrical wave ripples at the top of a dolomudstone bed. Unit 22. (E) Intraclasts dolorudstone bed overlain by a bed of mechanically laminated dolomudstone. Unit 21. (F) Outcrop view of three monomictic debrites overlain by green siltstone (top left). Unit 23. Hamer for scale is 30 cm long.

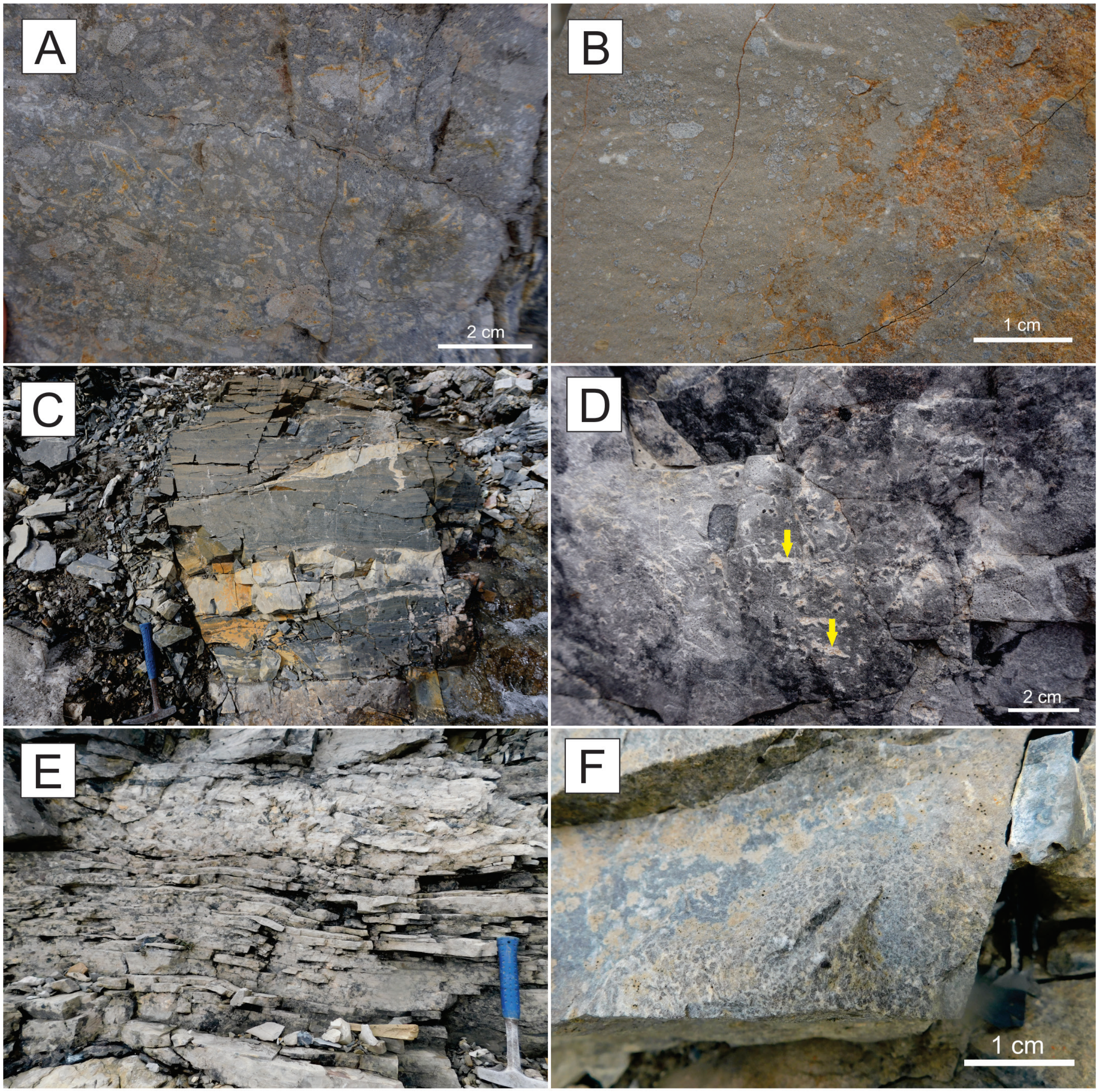

Figure 10. (A) Lowest debrite containing randomly oriented, centimetric, subrounded, tabular to irregular dolomudstone clasts in a matrix of dolomudstone. Unit 23. (B) Third debrite containing randomly oriented, mainly sub-centimetric clasts of dolomudstone in dolomudstone matrix. (C) Siltstone overlying the three debrites with dolomudstone-filled fractures. Unit 24. Hammer for scale is 30 cm long. (D) Intraclasts in a debrite dissolved and filled with geopetal cement. Arrows point to cement. Unit 32. (E) Thinly bedded, mechanically laminated dolomudstone typically found at the base of metre-scale shallowing-up cycles in the lower Ram Head Formation. Unit 66. Hammer for scale is 30 cm long. (F) Ooid-intraclast dolograinstone typical of the middle facies in metre-scale cycles of the lower Ram Head Formation. Unit 57.

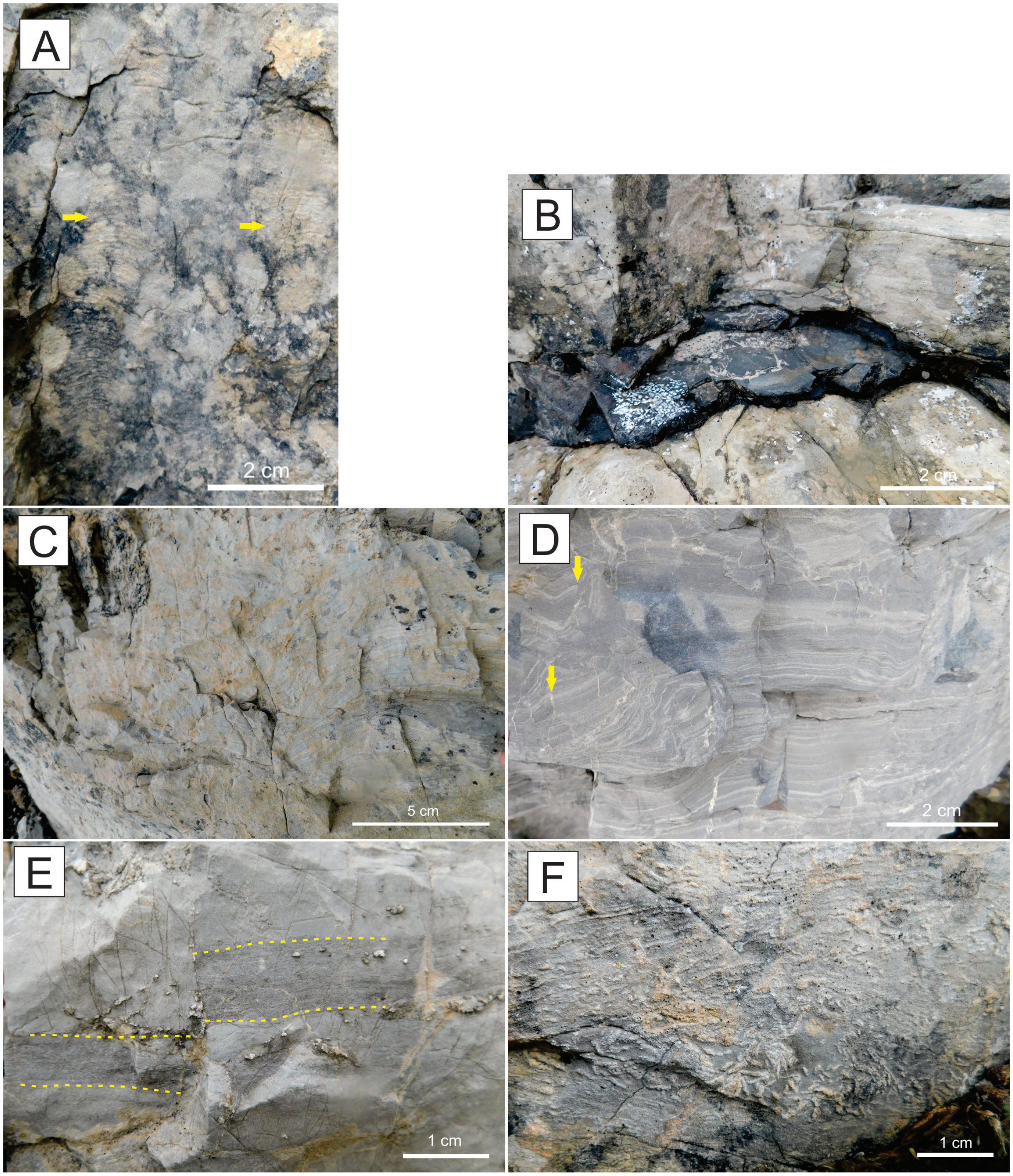

Figure 11. (A) Non-branching, columnar, unwalled stromatolites typical of the uppermost lithofacies in metre-scale shallowing upwards cycles in the Ram Head Formation. Yellow arrows point to stromatolite columns. Unit 71. (B) A layer of dark grey chert at the contact between stromatolitic dolomudstone and mechanically laminated dolomudstone. Units 74 and 75. (C) Large columnar unwalled stromatolites 10 cm wide. Unit 96. (D) Convoluted laminae and healed microfaults in mechanically laminated dolomudstone. Arrows point to healed microfault and broken laminae. Unit 97. (E) A healed microfault in mechanically laminated dolomudstone. Yellow dashed lines highlight offset of layer. Unit 97. (F) Molar-tooth dolomudstone with a relatively high amount of molar-tooth crack fill. Unit 105.

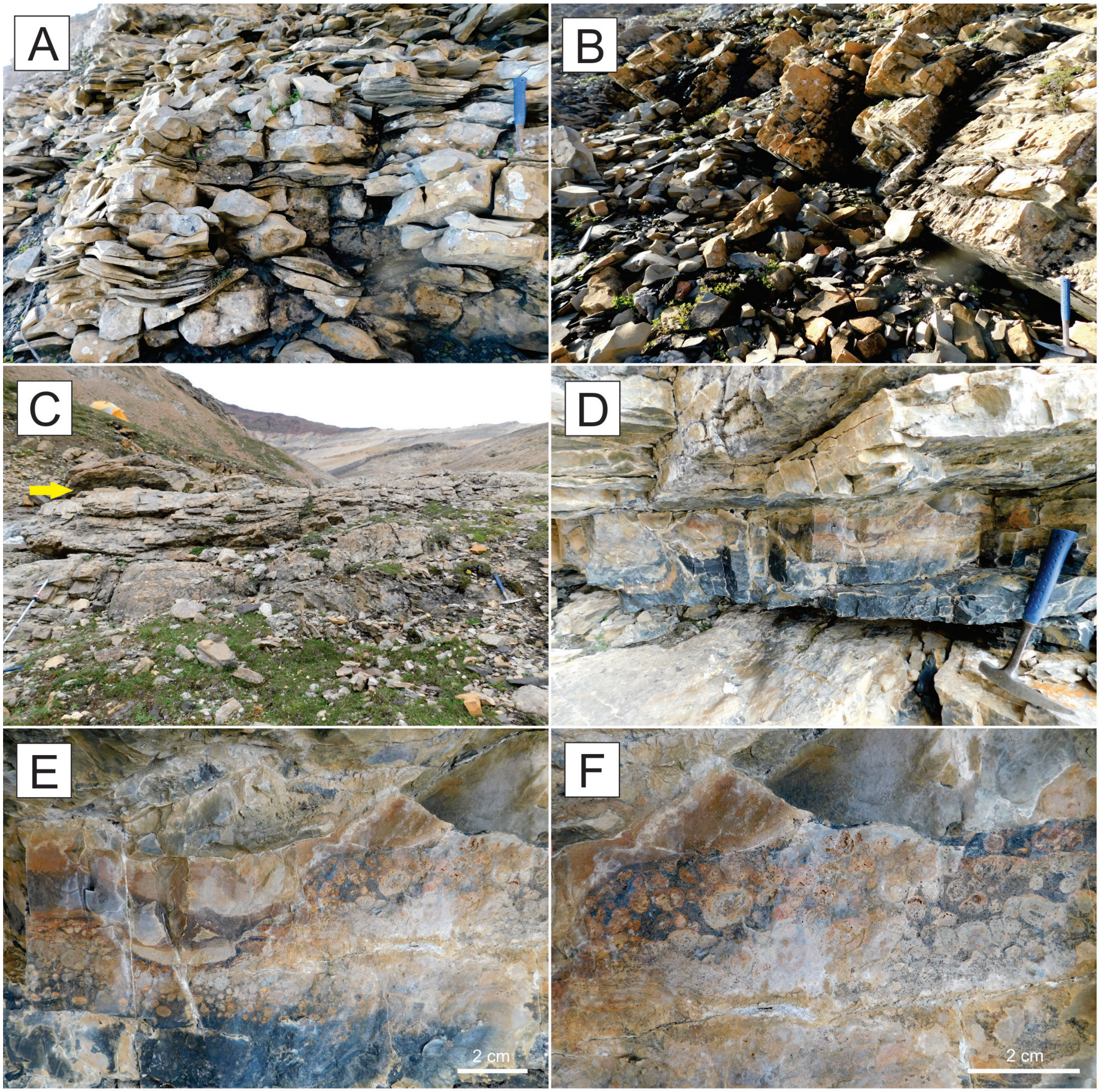

Figure 12. (A) Nodular, orange-weathering dolomudstone with centimetric silty interbeds containing grey-weathering lime mudstone nodules. Unit 122; hammer for scale is 30 cm long. (B) Bright orange-weathering colour of the 'orange marker unit', a dolomudstone with dolomudstone nodules in silty interbeds. Unit 120; hammer for scale is 30 cm long. (C) Outcrop view of auxiliary section #5 (see Figure 6) containing the orange marker and pisoid units (equivalent to units 115-122 in the main section). The yellow arrow points to the recessive interval containing the pisoid unit. Hammer for scale is 30 cm long. (D) Undulatory contact between dolomudstone (lowest unit; unit G in the auxiliary section) and silicified base of the pisoid unit (unit H in the auxiliary section). Gradational contact between the silicified base and the pisoid unit (units H and I). (E) Pisoids floating in silicified matrix at the contact between units H and I. (F) Pisoids range from <1 cm to nearly 2 cm in diameter. Unit I.

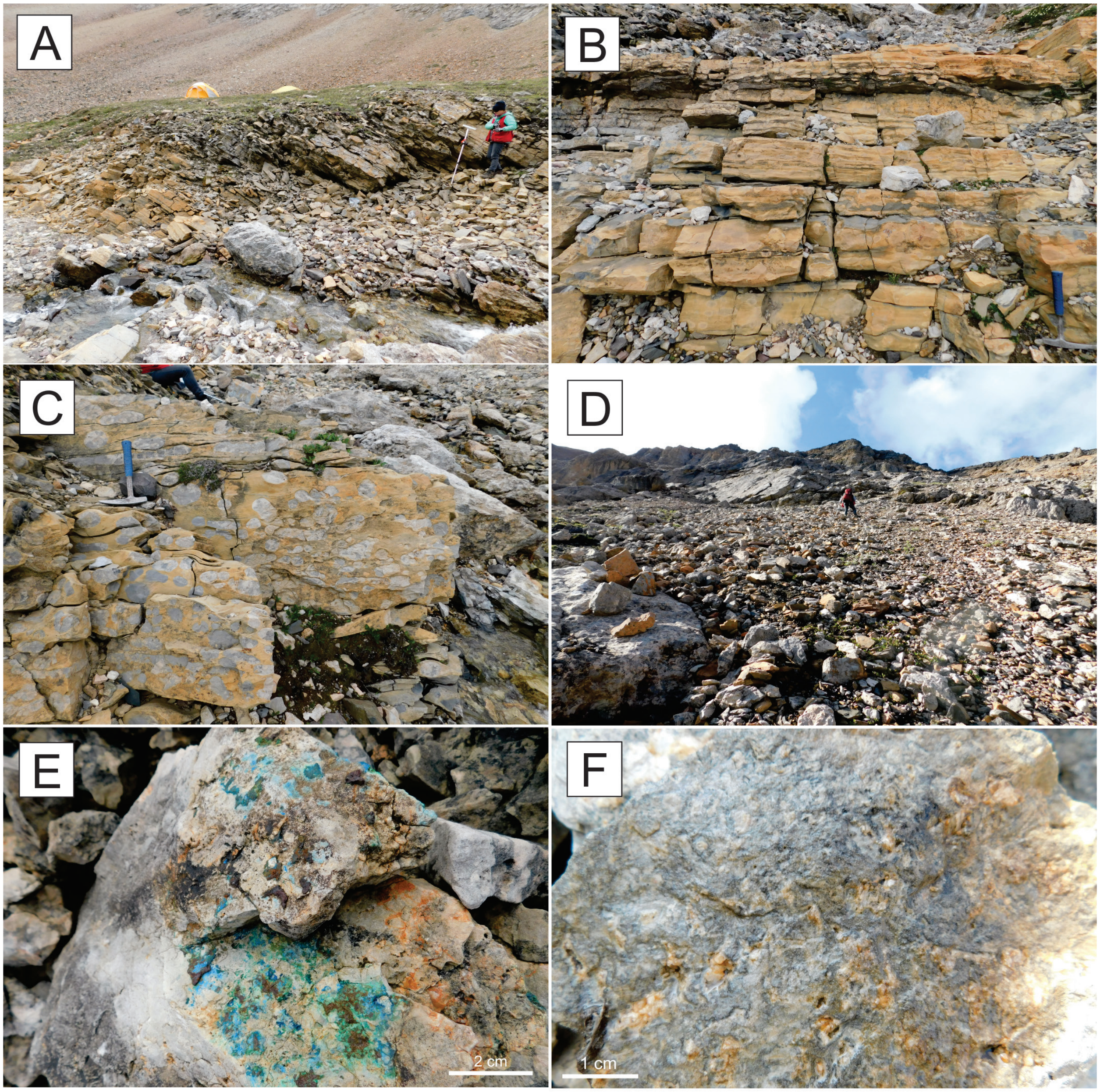

Figure 13. (A) Outcrop view of the upper part of the auxiliary section (#5 in Figure 6) from the orange marker unit (unit K) to the end of the section. (B) Outcrop view of the orange marker unit, orange-weathering dolomudstone and orange-weathering dolomudstone nodules in silty interbeds. Unit K. Hammer for scale is 30 cm long. (C) Orange-weathering dolomudstone with grey-weathering lime mudstone nodules. Unit N; hammer for scale is 30 cm long. (D) View looking up through covered interval to cliff-forming unit 123. (E) Malachite, azurite, and copper sulphide mineralisation in unit 123. (F) Microbial clots and cemented interstices at base of unit 123, similar to those of unit 12.

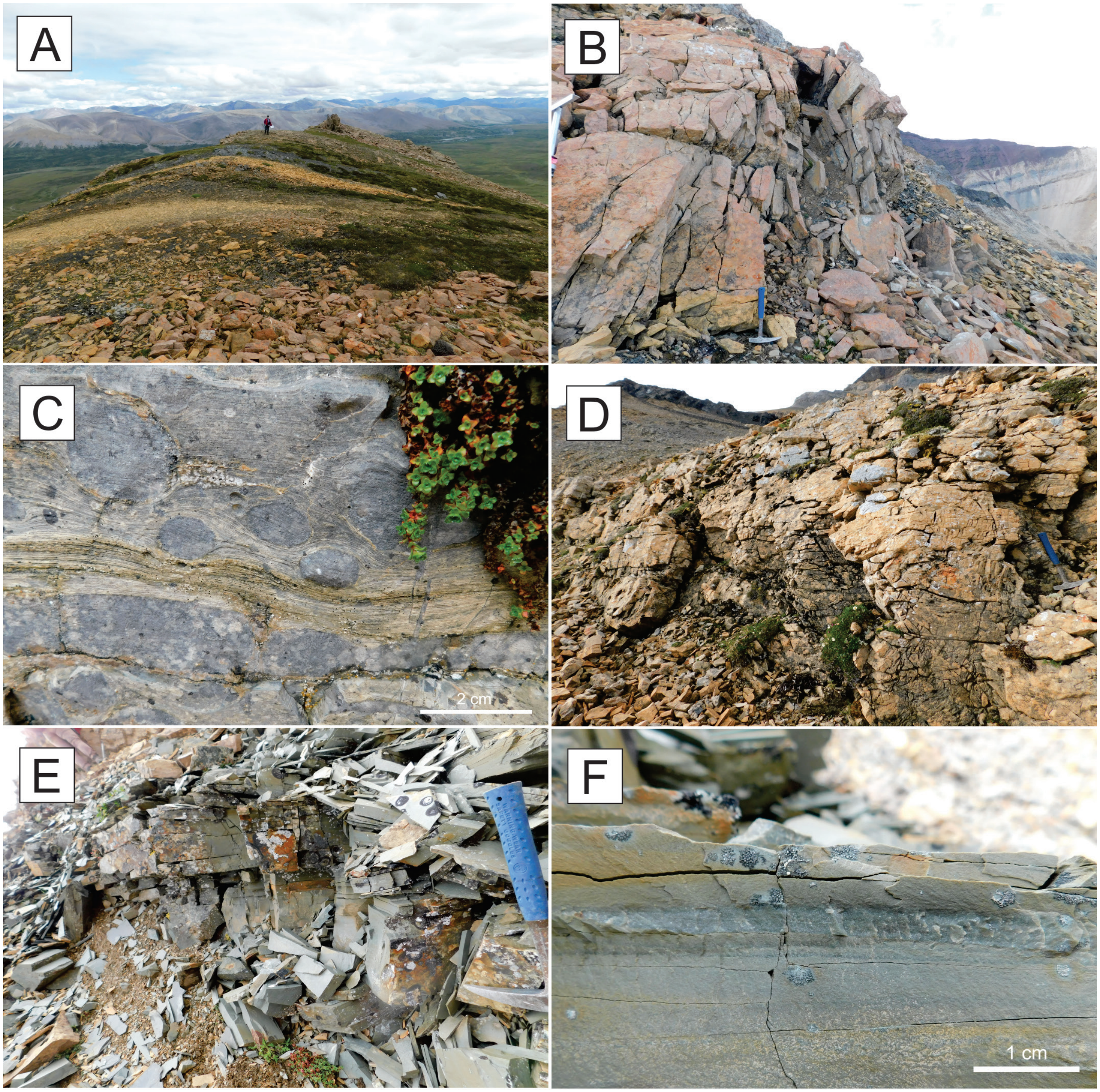

Figure 14. (A) Stratigraphic units 124 and 125 present only as felsenmeer on ridge, person is standing at the top of unit 123. (B) Pink-weathering dolomudstone typical of the more colourful units of the upper Ram Head Formation. Unit 138. Hammer for scale is 30 cm long. (C) Lime mudstone with lime mudstone nodules. Unit 144. (D) Orange-weathering nodular dolomudstone similar to nodular mudstones in the lower Ram Head Formation. Unit 145. Hammer for scale is 30 cm long. (E) A 2.8 m thick siltstone interval (the thickest in the Ram Head Formation), with local rusty weathering. Unit 148. Hammer for scale is 30 cm long. (F) Discontinuous quartz sand lenses at the top of unit 148.

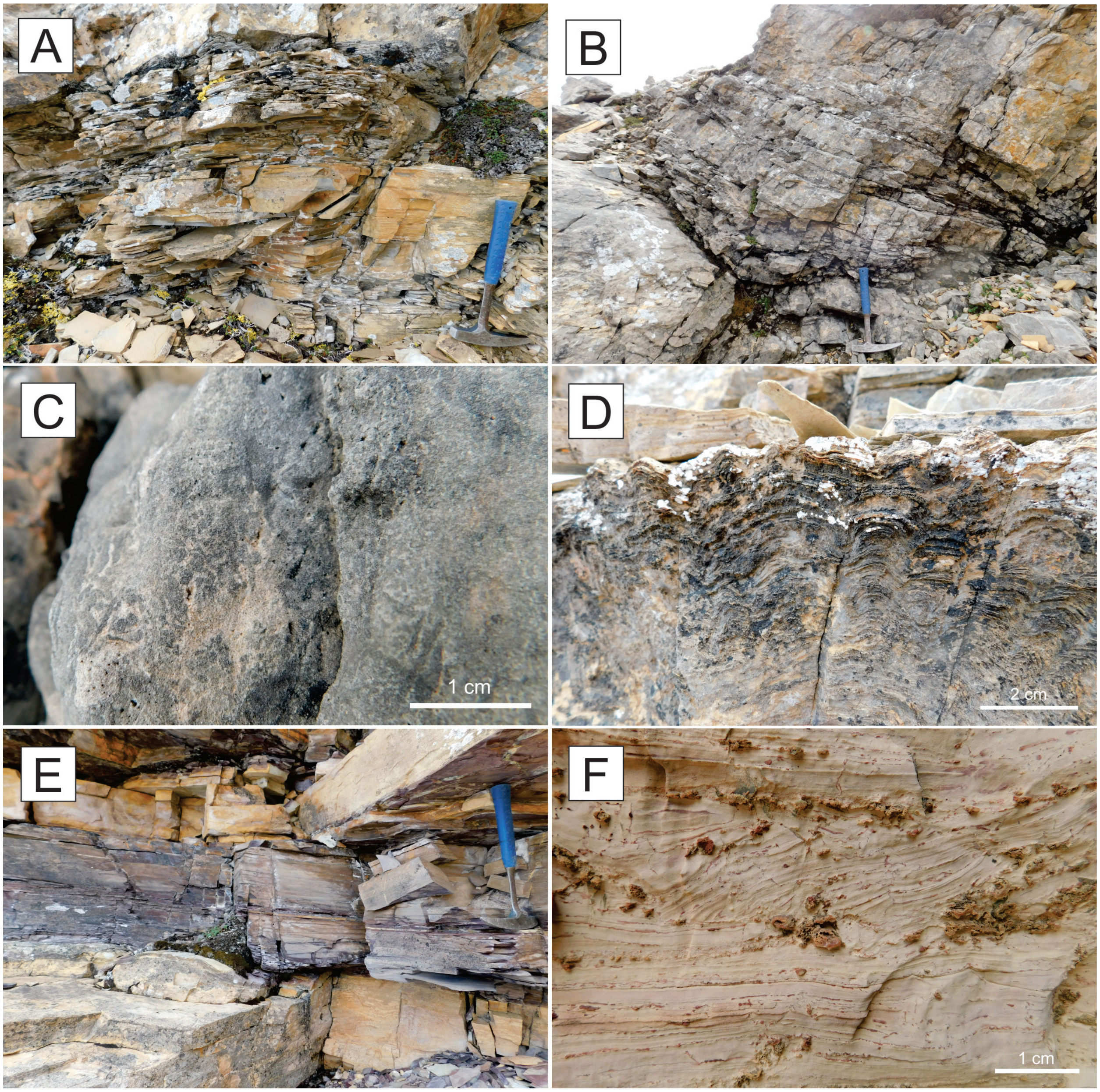

Figure 15. (A) Alternating recessive argillaceous dolomudstone and resistant dolomudstone. Units 149-151. Hammer for scale is 30 cm long. (B) Thin-bedded mechanically laminated dolomudstone typical of both the lower and upper Ram Head Formation. Unit 154. Hammer for scale is 30 cm long. (C) Rare ooid-intraclast dolograinstone of the lower and upper Ram Head Formation. Unit 158. (D) Stromatolite bioherm with surface relief and silicified laminae. Unit 164. (E) Dark purple siltstone of the upper Ram Head Formation. Unit 175. Hammer for scale is 30 cm long. (F) Tilted laminae (soft-sediment deformation) in mechanically laminated dolomudstone. Unit 178.

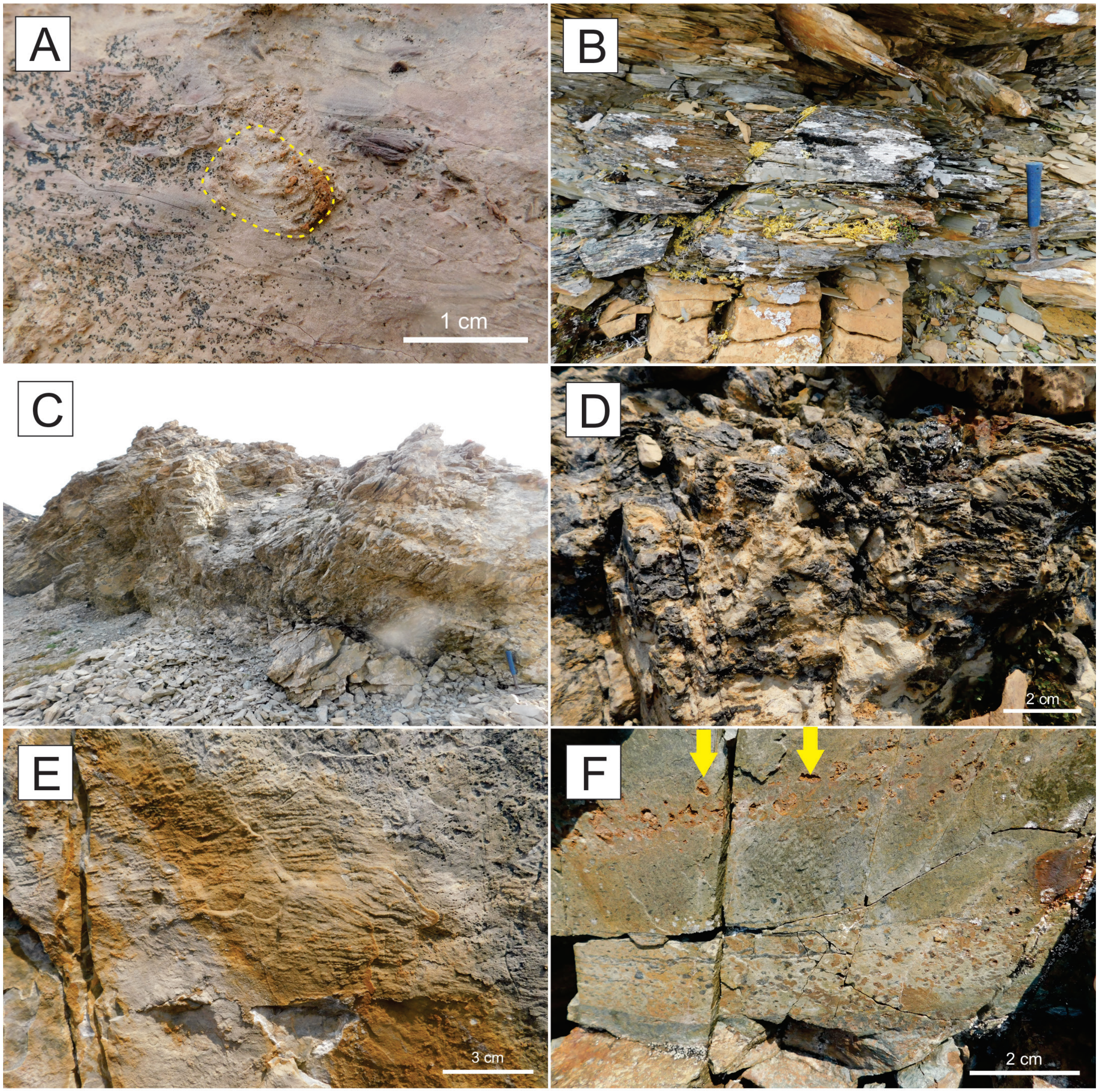

Figure 16. (A) Randomly oriented intraclasts composed of stromatolitic dolomudstone. Intraclast outlined in yellow. Unit 180. (B) Terrigenous mudstone found in the upper Ram Head Formation. Unit 187. Hammer for scale is 30 cm long. (C) A thick interval (10 m) of featureless dolomudstone. Unit 194. Hammer for scale is 30 cm long. (D) Silicified stromatolitic dolomudstone. Chert replaces stromatolite laminae and forms blobs. Unit 195. (E) Microbial laminate with crinkled laminations found in the upper Ram Head Formation. Bedding plane view. Unit 202. (F) “Little Dal basalt” near its lower contact. Arrows point to dolomudstone clasts. Unit 218.

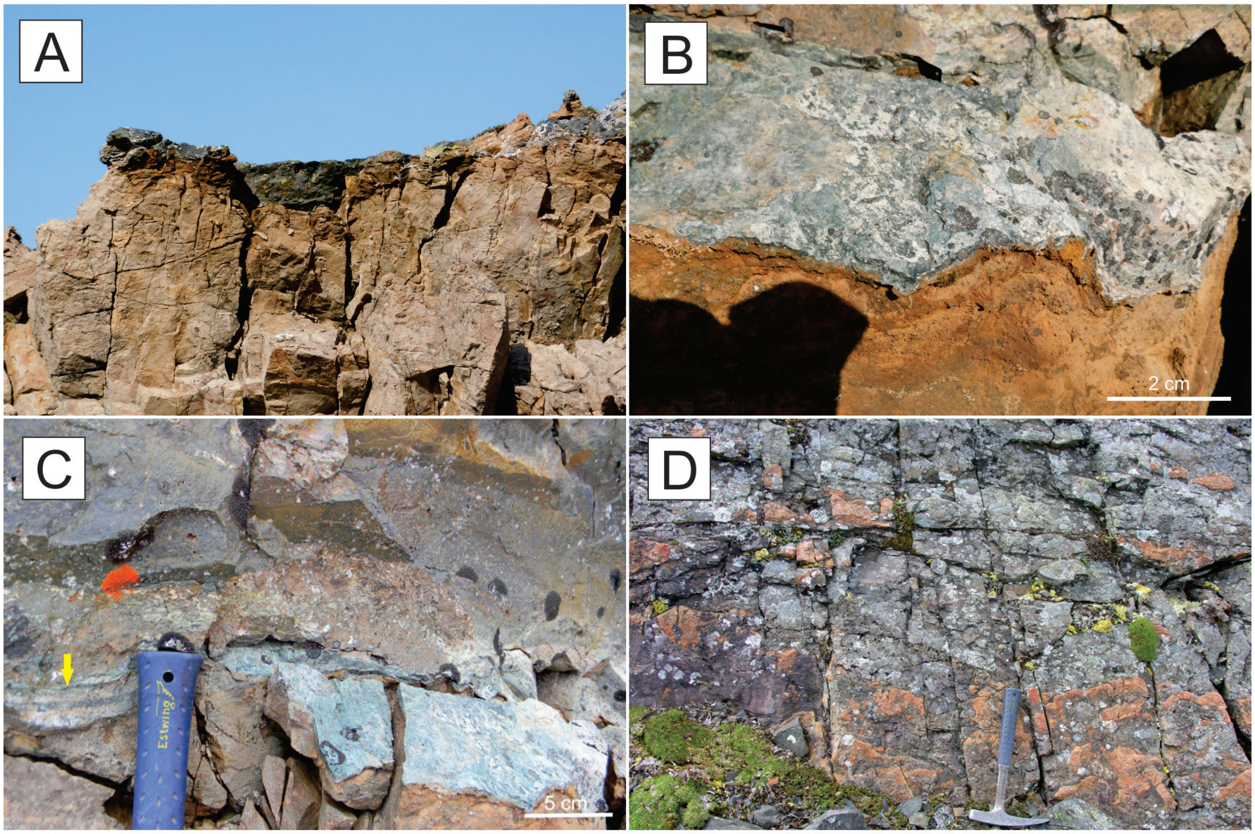

Figure 17. (A) Uppermost Ram Head Formation and the undulatory contact with the “Little Dal basalt”. (B) Sub-metric scale undulations on the contact between the uppermost Ram Head Formation and the “Little Dal basalt”. (C) Discontinuous sand lens at the contact between uppermost Ram Head Formation and “Little Dal basalt”. Yellow arrow points to sand lens. Unit 217. (D) Orange-weathering dolomudstone clasts floating in the bottom 1 m of the “Little Dal basalt”. Hammer for scale is 30 cm long.

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