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Formal definition of the Neoproterozoic Mackenzie Mountains Supergroup (Northwest Territories), and formal stratigraphic nomenclature for its carbonate and evaporite formations

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TABLE OF CONTENTS

PREFACE

The Mackenzie Mountains Supergroup is long-standing lithostratigraphic unit that contains much of the Proterozoic depositional record of northwestern Canada. Despite its importance, neither it nor many of its internal subdivisions have been properly formalized. Geological Survey of Canada Open File Reports 7112 and 7113 are intended to correct this long-standing omission. The authors of these reports have extensive experience in the study of the Mackenzie Mountains Supergroup. The formalization that they propose will solidify the nomenclatural status of this important stratigraphic succession.

These reports were prepared so as to honour the spirit of the North American Code of Stratigraphic Nomenclature. They have been reviewed by two critical readers (R. Rainbird and R. MacNaughton) who are well-versed in Proterozoic stratigraphy. The typescript was copy-edited by R.B. MacNaughton, who has experience as Editor-in-Chief of an earth-science journal. Although these works are part of a series of “Open File Reports”, they are intended as final reports and a permanent record of the work. Publications by the Geological Survey of Canada are permanently archived online and in branches of the Natural Resources Canada Library and can be downloaded free of charge, ensuring their long-term availability.

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ABSTRACT

The Mackenzie Mountains Supergroup in NWT is formalised in this and a companion paper. The supergroup includes carbonate rocks of the Tabasco Formation (new), mudstones, sandstones and minor carbonate rocks of the Tsezotene Formation, sandstones, mudstones and carbonate rocks of the Katherine Group, and carbonate rocks, evaporite rocks and mudstones of the Little Dal Group. Descriptions and type sections are provided for eight new formations: the Tabasco Formation (formerly "H1 unit") and seven formations of the Little Dal Group (Dodo Creek, Stone Knife, Silverberry, Gayna, Ten Stone, Snail Spring, and Ram Head formations).

INTRODUCTION

Young et al. (1979, 1982) proposed that Proterozoic strata in western and northern Canada be divided into three major unconformity-bounded packages (sequences A, B, and C). These divisions correspond approximately to the Mesoproterozoic, early Neoproterozoic, and late Neoproterozoic, and are separated by unconformities dated at approximately 1000 Ma (A-B) and 750 Ma (B-C). Strata of sequence B that underlie the Coates Lake Group in the Mackenzie Mountains were informally named the Mackenzie Mountains supergroup (Young et al., 1979). This informal usage has been followed by subsequent authors (e.g., Young, 1992; Aitken, 1981; Narbonne and Aitken, 1995; Long et al., 2008; Turner and Long, 2008), without formal definition. The supergroup, as originally established, was constructed as follows, from oldest unit to youngest.

1) Shallow-water dolostone of the informal "map-unit H1" (Aitken et al., 1973, 1978a; Aitken and McMechan, 1991), here formally recognised as the Tabasco Formation. This formation's base is not exposed in the Mackenzie Mountains.

2) Progradational shelf deposits of the Tsezotene Formation (Gabrielse et al., 1973), that include a lower "grey member" consisting predominantly of dark grey to black mudstone, overlain by an upper "red member" including carbonate rocks, sandstones and varicoloured mudstone of shallow-water origin [Long, 1982, 1991; Long et al., 2008; see companion paper (Long and Turner, 2012].

3) Fluvial and marine sandstones, mudstones and minor carbonate rocks of the informal Katherine Group (Hume and Link, 1945). These strata were informally divided into seven formation-scale units, (K1 to K7; Aitken et al., 1978a; Long et al., 2008) that are formalised in a companion paper (Long and Turner, 2012) as the Eduni, Tawu, Grafe River, Etagochile, Shattered Range, McClure and Abraham Plains formations.

4) Carbonate rocks, evaporite rocks and minor fine-grained terrigenous clastic rocks of the

Little Dal Group (Gabrielse et al., 1973; Aitken et al., 1978a,b; Aitken, 1981), which are here divided into seven formations: the Dodo Creek, Stone Knife, Silverberry, Gayna, Ten Stone, Snail Spring, and Ram Head formations.

Strata of the Mackenzie Mountains Supergroup are overlain unconformably by a succession of locally preserved volcanic strata (the "Little Dal basalt") and siliciclastic and carbonate rocks of the Coates Lake Group. Jefferson (1983), and Jefferson and Ruelle (1986) included these latter units in the informal Mackenzie Mountains supergroup, whereas others (Aitken, 1981; Narbonne and Aitken, 1995; Thorkelson et al., 2005; Long et al., 2008; Turner and Long, 2008) considered them to be part of the overlying Windermere Supergroup. An alternate view presented by Jefferson and Parrish (1989), placed the "Little Dal basalt" in the Mackenzie Mountains supergroup, but excluded the Coates Lake Group from either supergroup, as did Jefferson and Colpron (1998). The present paper follows the usage of Narbonne and Aitken (1995), Thorkelson et al. (2005), Long et al. (2008) and Turner and Long (2008), in excluding the "Little Dal basalt" and Coates Lake Group from the Mackenzie Mountains Supergroup.

This paper presents a formal definition of the Mackenzie Mountains Supergroup, and eight new formations (with type sections): one at the base of the exposed succession in the Mackenzie Mountains, and seven in the Little Dal Group. It is the intent of this paper and its companion (Long and Turner, 2012) to establish a complete formal stratigraphic nomenclature for early Neoproterozoic strata in the Mackenzie Mountains, in order to facilitate future mapping and correlation of Neoproterozoic stata in northwestern Canada.

MACKENZIE MOUNTAINS SUPERGROUP

Definition

The Mackenzie Mountains Supergroup (new; Figs. 1 and 2) in the Mackenzie Mountains, Northwest Territories, is defined here and in a companion paper (Long and Turner, 2012) to include carbonate rocks of the Tabasco Formation, mudstones, sandstones and minor carbonate rocks of the Tsezotene Formation, sandstones, mudstones and carbonate rocks of the Katherine Group, and carbonate rocks, evaporite rocks and mudstones of the Little Dal Group. The Mackenzie Mountains Supergroup unconformably overlies weakly deformed strata of the Pinguicula Group in the Wernecke Mountains (Thorkelson, 2000; Thorkelson et al., 2005; Turner, 2011), but its base is not exposed in the Mackenzie Mountains. The supergroup underlies volcanic rocks known as the "Little Dal basalt" and strata of the Coates Lake Group in the Mackenzie Mountains. Structural studies (Aitken and Pugh, 1984; Cook, 1992; Cook and MacLean, 2004) indicate that the supergroup is underlain by several kilometres of older sedimentary rocks that may be equivalent to Sequence A (≈1.7-1.2 Ga) of Young et al. (1979), which, in turn, may be underlain by metamorphic and plutonic rocks similar to those exposed to the east in the Wopmay orogen (Hoffman and Bowring, 1984; Parrish, 1991). This interpretation is supported by analysis of zircon grains in granitic clasts recovered from an Ordovician diatreme near Coates Lake by Jefferson and Parrish (1989), which yielded an inherited age of at least 1.75 Ga. The Shaler Supergroup, exposed in the Minto Inlier of Victoria Island and adjacent parts of the northern mainland is directly correlative to the Mackenzie Mountains Supergroup (Rainbird et al., 1996; Long et al., 2008). The depositional age of Mackenzie Mountains Supergroup strata above the base of the Katherine Group is currently bracketed by a maximum age of 1005 Ma (youngest detrital zircon in Katherine Group unit K7; Leslie, 2009) and minimum age of 779 Ma (Rb-Sr on cross-cutting intrusive bodies; Armstrong et al., 1982; U-Pb on cross-cutting bodies; Jefferson and Parrish, 1989; Fig. 2).

Type Area

The Mackenzie Mountains Supergroup is exposed in the Mackenzie Mountains, Northwest Territories, from 62°20' to 65°30'N and 126°00' to 134'30'W (Fig. 1). Parts of the supergroup have been tentatively correlated with strata as far west as Alaska, and as far to the northeast as the Minto Inlier on Victoria Island (Fig. 1; Long et al., 2008). At least part of the Mackenzie Mountains Supergroup is presumed to be present in the subsurface west of the Plateau fault, and the basal contact of the supergroup and direct equivalents of its lowest strata are exposed in the Wernecke Mountains (YT; Turner, 2011) as units formerly included in the upper part of the Pinguicula Group (Eisbacher, 1981). Putative equivalents are exposed in the Ogilvie Mountains (Abbott, 1997; Thorkelson et al., 1998, 2001, 2005; Long et al., 2008). Seismic data indicate that equivalent rocks are locally present in the subsurface of the interior plains east of the Mackenzie Mountains (Cook and MacLean, 2004).

Composite Stratotype

No complete section of the Mackenzie Mountains Supergroup exists in the Mackenzie Mountains, and so a composite stratotype is proposed (Fig. 2), consisting of the type section of the Tabasco Formation in NTS 96D, the type section of the Tsezotene Formation in NTS 95M (63°24'N / 126°40'W; Gabrielse et al. 1973, section G1), the principal reference section of the Katherine Group in NTS 95L (62°38'N / 126°32'W; Gabrielse et al., 1973, Section G2), and the type sections of the seven formations of the Little Dal Group. Type sections for all of the hitherto unformalised formation-scale units in the Mackenzie Mountains Supergroup are presented in this and a companion paper (Long and Turner, 2012).

TABASCO FORMATION (New)

Description

The informal "H1 unit" was established during early mapping in the Mackenzie Mountains, when the Mackenzie Mountains Supergroup was divided into numbered Helikian (obsolete; equivalent to Mesoproterozoic and early Neoproterozoic) units. The H1 unit was first referred to by Usher (1970), and was later described as massive, pale grey, locally cherty, fenestral, microbially laminated and intraclastic dolostone (Aitken et al., 1973, 1978a,b). A later written description (Aitken and McMechan, 1991) indicated the presence of three members: a lower member, largely covered (thickness unstated), of muddy and quartz-sandy ripple-laminated dolostone and dolomitic mudstone, a middle member of dark grey dolostone dominated by coniform stromatolites with sandy cross-stratified dolostone at its top, and an upper member of cherty dolostone with abundant microbial lamination and stromatolites, tepee structures, channels, minor ripples and intraclast conglomerates.

The Tabasco Formation replaces the informal "H1 unit" of Aitken et al. (1973). It is named for a lake near the type section in NTS 106G. The Tabasco Formation is exposed in the Mackenzie Mountains at three widely spaced localities: in the core of the Tawu Anticline in NTS 106G; in the core of the Foran Anticline in the Carcajou map sheet (NTS 96D), and in the hanging-wall of the Tsezotene fault in the Tsezotene Range (NTS 95M). Only the first of these is a good exposure. The Tabasco Formation is thought to be equivalent to the Mikkelsen Islands Formation in the Shaler Supergroup (Rainbird et al., 1996; Long et al., 2008) and has been tentatively correlated with the Dolores Creek Formation in the Wernecke Mountains (YT; Turner, 2011), which lies close to the base of the exposed Mackenzie Mountains Supergroup.

Type Section

A full section through the Tabasco Formation has not been established because the base of the formation, and of the Mackenzie Mountains Supergroup, is not exposed in the Mackenzie Mountains. The type section of the Tabasco Formation (Figs. 3 and 4) was measured in the core of the Tawu Anticline as two overlapping segments in stream gullies on the east side of the Ramparts River (NTS 106G), for a total but incomplete thickness of approximately 480 m. No basal contact is exposed, and the upper contact is covered. Although a marked change in the slope's weathering profile reflects the contact with the overlying Tsezotene Formation, as much as 100 m of strata spanning the contact are covered, such that the uppermost part of the Tabasco Formation and the nature of its transition to the Tsezotene Formation cannot be documented. The exposed part of the Tabasco Formation contains five units; all are entirely dolomitic except for the lowest 10 m, and most are medium grey-weathering except for the uppermost 20 m, which contain black-weathering quartz-sandy dolostone and chert bands.

The lowest 10 m (unit 1) consist of centimetre-banded, alternating lime mudstone and dolomudstone, with sparse quartz silt and local ripple cross-lamination; its upper boundary is covered. The overlying 185 m (unit 2) consists of poorly bedded, very weakly and discontinuously laminated cuspate stromatolites and draping dolomudstone lacking shallow-water sedimentary structures. Cuspate structures are not columnar, but are laterally linked through swales that have either a streaky microstructure that is identical to that of the stromatolitic highs, or a non-stromatolitic microstructure. Relief on individual coniform stromatolite layers is up to 1 m, cusp diameters are typically 1-3 m, and individual stacks of inherited cuspate relief locally reach thicknesses of 3 m. Vertical and lateral density of cuspate stromatolites is fairly uniform and their distribution is seemingly random. This second unit is gradationally overlain by 15 m of low bioherms and biostromes (up to 4 m relief) of unbranched, columnar stromatolites (10-20 cm diameter) and interbiohermal lows filled with dolomudstone with sparse, fine quartz sand (unit 3). This biohermal interval is abruptly overlain by 210 metres (unit 4) of cortoid-intraclast grainstone–packstone (allochems generally invisible in outcrop). The lower 80 m of this interval is intermittently quartzose, with a 20 m-thick layer of tepees at its top. The upper contact of the cortoid-intraclast interval is not exposed. The uppermost ~55 m of the section (unit 5) is dominated by dolomitic quartz wacke with subangular quartz sand grains, cross-bedding, symmetrical and asymmetrical ripples, tepees, black chert, and weakly to conspicuously laminated dolomudstone. The true thickness of this unit is greater than indicated by this section, because similar rock is exposed above the level of the top of this section farther south along the cliff, where strata gently dip southward on the south limb of the Tawu Anticline. The contact with the overlying Tsezotene Formation is covered.

LITTLE DAL GROUP

Introduction

The uppermost part of the Mackenzie Mountains Supergroup consists of ~2.5 km of unmetamorphosed carbonate, fine terrigenous clastic, and evaporite strata that were originally named the Little Dal Formation by Gabrielse et al. (1973a), with a type section south at Coates Lake in NTS 95L at 62°35’N / 126°26’-126°38’W (equivalent to section 79-AC-2 of Aitken et al., 2011), directly overlying the proposed type section of the Katherine Group, and truncated above by strata of the Rapitan Group. The Little Dal Formation was raised to group status (Aitken et al., 1978a), with seven informal formation-scale units (Aitken, 1981) that had no type sections. The establishment of informal and formal stratigraphic names was hampered by uncertainty over stratigraphy and lateral correlation. In early mapping, the term "Little Dal Formation" was in some cases limited to what later became known as the Upper Carbonate formation of the Little Dal Group, whereas the underlying units (Mudcracked to Rusty Shale formations) were mapped together as the "H5 unit". This usage was soon abandoned once the relationships among stratigraphic units that predominate on either side of the Plateau fault were understood, and the group's stratigraphy informally established by Aitken (1981). It is the intent of this paper to provide formal type sections for the formations of the Little Dal Group, based on Aitken's original stratigraphic sections (Aitken et al., 2011) together with other sections documented since the 1970s.

Distribution and Correlation

Distribution of the Little Dal Group in the Mackenzie Mountains is shown in Figure 1; its estimated thickness is approximately 2.5 km. Although northeastward correlation and basin interpretations of the Little Dal Group and Shaler Supergroup are now well established (Long et al., 2008), correlating westward from the NWT into YT is complicated by a lack of strata equivalent to most of the Little Dal Group in the Wernecke Mountains (Turner, 2011) and a stratigraphic succession farther west in YT that does not lend itself to straightforward lithostratigraphic, sequence stratigraphic, or chemostratigraphic correlations. The Little Dal Group is correlative to the Boot Inlet, Fort Collinson, Jago Bay, Minto Inlet and Wynniatt formations in the Amundsen Basin of Victoria Island and northern mainland NWT (Rainbird et al., 1996; Long et al., 2008). The lower Little Dal Group (Dodo Creek Fm. to middle of Stone Knife Fm.) is equivalent to unit F of the (former) upper Pinguicula Group in the Wernecke Mountains (Thorkelson, 2000; Thorkelson et al., 2005; Turner, 2011). It is also probably equivalent to units D2 and D3 in the Hart River Inlier and unit F1a in the Coal Creek Inlier (Abbott, 1997).

Subdivision

Regional mapping indicates the presence of seven units worthy of formation status in the Little Dal Group (Aitken, 1981). These units are formally named below (in ascending order), the Dodo Creek Formation, Stone Knife Formation, Silverberry Formation, Gayna Formation, Ten Stone Formation, Snail Spring Formation and Ram Head Formation (Figs. 2 and 5; Table 1).

DODO CREEK FORMATION (New)

Definition and Type Area

The Dodo Creek Formation (Figs. 7 and 8) is named for good exposure along Dodo Creek (NTS 96D). It is present on the flanks of anticlines east of the Plateau fault, although in some eastern areas it is erosionally truncated beneath the Cambro-Ordovician Franklin Mountain Formation. The Dodo Creek Formation, as here defined, is equivalent to the Mudcracked formation of Aitken (1981) with minor modification to its upper contact. It is a thin (<60 m) terrigenous unit that overlies the Katherine Group conformably in northwestern parts of the Little Dal Group exposure area (Turner et al., 1997) but slightly unconformably in southeastern areas (Batten et al., 2004). Numerous sections have been measured through this formation (Aitken, 1981; Turner, 1999; Batten, 2002; Aitken et al., 2011). The Dodo Creek Formation is recognised as a stratigraphic unit that is distinct from the overlying Stone Knife and Silverberry formations because (1) it is regionally distinctive and mappable (unit between uppermost Katherine Group quartz arenite and oncolite at base of overlying formations); and (2) its scale is commensurate with that of similar, predominantly marine formations in the underlying Katherine Group (Tawu, Etagochile, and McClure formations). The Dodo Creek Formation is separate from the Katherine Group because of its greater stratigraphic affinity with the Little Dal Group: it is the transgressive unit at the base of a ~2.5 km-thick, entirely marine succession.

In the northwestern part of the Mackenzie Mountains, the lower conformable contact of the Dodo Creek Formation is where quartz arenite of the Abraham Plains Formation (uppermost Katherine Group) is overlain by interlayered, dark-weathering, decimetre- to metre-scale beds of grey, red and green siltstone and quartz sandstone. Shallow-marine features are ubiquitous in the lower half of the Dodo Creek Formation, including synaeresis cracks, halite casts, hummocky cross-stratification, gutter casts, tool marks, graded shale chips, trough cross-bedding, and asymmetrical and symmetrical ripple cross-lamination. Many bedding surfaces have a black veneer that is probably microbial mat residue. The irregular macroscopic carbonaceous compressions *Morania* and *Beltina* are locally abundant on bedding planes. The upper part of the formation contains less sandstone, fewer physical sedimentary structures, rare halite casts, and conspicuous, generally structureless carbonate mudstone layers in the central part of the exposure area. Strata resembling the Dodo Creek Formation cannot be identified in an exposure of the lower Little Dal Gp in Yukon (NTS 106C; Turner, 2011), where the basal Little Dal Group consists of a thin and monotonous interval of siltstone and mudstone (shale).

Southeastern exposures of the Dodo Creek Formation consist of a lower terrigenous mudstone-dominated unit with desiccation cracks, symmetrical ripples and halite casts, overlain by desiccation-cracked dolomudstone of roughly equal thickness (Batten, 2002; Batten et al., 2004; Aitken et al., 2011).

The upper contact of the Dodo Creek Formation is here revised from the use of Aitken (1981) for the Mudcracked formation. The contact was previously placed at the top of a widespread and distinctive oncoid grainstone, which acts as a conspicuous marker unit. Where the oncoid grainstone is absent, Aitken (1981) placed the contact at the top of the lowest desiccation-cracked carbonate interval above the Katherine Group. This definition is problematic, because the oncolite and desiccation-cracked dolomudstone are not temporally equivalent: the latter is a highstand deposit, but the former is a transgressive deposit belonging to the overlying cycle. It is preferable that formation contacts conform to regional transgressive - regressive cycles if practical, and so the top of the Dodo Creek Formation is henceforth defined as the base of the oncoid grainstone, or, where the oncoid grainstone is absent in the southeast, the top of the lowest desiccation-cracked carbonate interval.

Isopach mapping (Turner and Long, 2008) indicates subtle thickening to the southwest, which conforms to the general orientation of isopachs for the Mackenzie Mountains Supergroup (Turner and Long, 2008). Regional patterns in composition and thickness yield the following generalisations: (1) the formation thickens southwestward; (2) sandstone abundance increases westward, such that southeastern areas are poor in sand-grade quartz; and (3) the abundance of carbonate layers in the upper part of the formation decreases northwestward to negligible amounts in the northwestern one-third of the exposure area.

The Dodo Creek Formation is not currently equated with any lithologically obvious part of the Hematite Creek Group (sensu Turner, 2011) in the Wernecke Mountains (YT), although some hint of a stratigraphically equivalent unit is present. The formation is correlated with the lower part of the Boot Inlet Formation (Reynolds Point Group, Shaler Supergroup) in the Amundsen Basin (Rainbird et al., 1996; Long et al., 2008).

Type and Reference Sections

The type section of the Dodo Creek Formation is in a creek that flows into the Stone Knife River, below and between two exhumed reefs of the Stone Knife Formation in NTS 106A (Figs. 5 - 7). The section base is at approximately 64°48’05” N / 129°40’59” W. The succession is approximately 43 m thick, of which the lowermost ~5 m are not exposed. The lower 30 m of the formation is dominated by metre-scale alternations of siltstone and shale, in which synaeresis cracks, hummocky cross-stratification (HCS), symmetrical and asymmetrical ripples, halite casts, tool marks and siltstone clasts are abundant. At approximately 30 m is a ~6 m-thick unit of siltstone and mudstone, which is overlain by ~10 m of interlayered siltstone, dolomudstone and sandstone with asymmetrical ripple marks and tool marks, but no HCS.

A reference section for the Dodo Creek Formation is at the south end of Dodo Canyon (NTS 96D), where the base of the section is at approximately 64°59'20" N / 127°14'00" W (section 77-AC-14 of Aitken et al., 2011). This is a particularly well exposed and accessible location.

STONE KNIFE FORMATION (New)

Definition and Type Area

The Stone Knife Formation (Figs. 8 and 9) includes strata previously ascribed to the informal Basinal assemblage of Aitken (1981), Turner et al. (1997), Turner (1999), and Turner and Long (2008), with slight modification to the definition of its basal contact. The formation is named after the Stone Knife River, near the proposed type section in NTS 106A, where the formation reaches its thickest and deepest-water expression. This 143 to 622 m-thick unit is present east of the Plateau fault on the flanks of the Shattered Range, Tigonankweine and Tawu anticlines, and locally on the flanks of the Stony and Foran anticlines (Fig. 1). It is laterally equivalent to the Silverberry Formation (former Platformal assemblage) in locations northwest of a northeast-trending line that passes through approximately 63°55'N, 127°30'W (Aitken, 1981; Turner and Long, 2008). The formation generally is erosionally truncated and overlain by Paleozoic strata in all but the westernmost anticline (Shattered Range anticline). For thickness distribution, see Turner and Long (2008).

The Stone Knife Formation is an important and easily recognised stratigraphic marker east of the Plateau fault. Part of the formation (equivalent to members 1-3 of Turner et al., 1997 and Turner and Long, 2008) was once referred to informally as the "dead-end shale" in mineral exploration literature, whereas carbonate rocks of member 4 were referred to as the "lower limestone" (e.g., Hewton, 1982). In the Gayna River area (NTS 106B), carbonate rocks with molar-tooth structure in the uppermost Stone Knife Formation host minor amounts of Zn mineralisation (Hewton, 1982), and subtle deformation structures associated with the giant Little Dal reefs of the Stone Knife Formation have been proposed as a factor controlling metal distribution at a local scale (Turner, 2007).

The conformable basal contact of the Stone Knife Formation is placed at the base of a conspicuous, widespread, orange- to brown-weathering oncoid grainstone marker unit that sharply overlies the siltstone-dominated upper Dodo Creek Formation in the northwestern exposure area. In the southeastern exposure area, where the upper part of the underlying Dodo Creek Formation is dominated by desiccation-cracked dolomudstone and the oncolite is not always present, the contact is placed where the dolomudstone is sharply overlain by siltstone, mudstone, or intraclast grainstone. The upper contact with the Gayna Formation is conventionally placed where molar-tooth lime mudstone passes gradationally upward to dolomitic ooid-intraclast grainstone (Aitken, 1981), although such a contact does not conform to any sequence-stratigraphic boundary (Turner and Long, 2008).

The Stone Knife Formation includes four shale-to-carbonate cycles that define informal members (numbered 1 to 4 in Turner et al., 1997). Each of these cycles has a laterally variable thickness of between 16 and 400 m. The oncoid unit at the base of Member 1 is typically 1 - 10 m thick. The oncolite commonly contains sparse medium- to coarse-grained quartz particles, and locally contains abundant millimetric dolomudstone intraclasts. Patches of grey to black chert are common. Rare bioherms of branching columnar stromatolites are locally present. The oncolite is distinctive both for its weathering colour and the size of the coated grains (typically 2 mm or more in diameter), and is generally easy to distinguish from overlying ooid grainstones, where the Silverberry Formation overlies the Dodo Creek Formation. Above the oncolite marker, recessive, green-grey siltstone and mudstone are overlain by a distinctive, ubiquitous, resistantly weathering stromatolite biostrome that varies from one metre-thick isolated domes of columnar stromatolites to multi-storey biostromes >20 m thick. In most localities, the stromatolite unit is <10 m thick; thicker expressions are present (1) in northeastern (shoreward) locations, (2) near the transition to the Platformal assemblage, and (3) in the vicinity of giant deep-water reefs. Member 2 consists of red- to black-weathering mudstone, commonly with intraclast rudstone near the base, that is generally in part interlayered with nodular to medium-bedded, medium-grey-weathering lime mudstone (85-200 m thick), overlain by resistant, medium-bedded lime mudstone with no conspicuous sedimentary structures (12-300 m thick). Member 3 generally consists of recessive, medium-grey siltstone and shale or argillaceous lime mudstone (15–115 m thick) overlain by silty, argillaceous lime mudstone (20-110 m thick); rarely, the carbonate rock of upper Member 3 contains molar-tooth structure, stromatolites or desiccation cracks. Member 4 consists of grey to black shale (0–60 m thick) overlain by lime mudstone with molar-tooth structure (25–100 m thick). Rare but conspicuous carbonaceous macrofossils belonging to the *Tawuia-Chuaria* assemblage are locally present (Hofmann and Aitken, 1979; Hofmann, 1985), particularly in members 2 and 3. Hewton (1982) reported 15 m of magnetite-facies iron-formation among carbonate rocks of member 4, but this has not since been validated.

Throughout the entire thickness of the Stone Knife Formation, in locations along the flanks of the Shattered Range and Tawu anticlines between approximately 64°45’N, 129°30’W and 65°05’N, 131°00’W (NTS 106A, B and G), are isolated, giant reefs of calcimicrobial stromatolites that are up to

~500 m thick and several kilometres in diameter (Aitken, 1981, 1989; Turner et al., 1993, 1997, 2000a,b). The reefs are exposed as entire mountains or as mountainside exposures where creeks have incised massive reef facies. Reef exposures are grey-weathering when calcareous (common) and orange-brown when dolomitic (less common). Possible evidence of early metazoan-grade organisms has been reported from these reefs (Neuweiler et al., 2009).

Type and reference sections

The type section of the Stone Knife Formation is on the west flank of the Tigonankweine Range (NTS 96D) along a southwest-trending ridge, with the section base at approximately 64°03'45" N / 127°56'51" W (Figs. 5, 8 and 9). At this location, the Stone Knife Formation shows evidence for deposition in shallower water than it does in some other parts of its exposure area. The basal oncolite, 13 m thick, is overlain by 4.5 m of dolomudstone and siliciclastic mudstone (shale), followed by 32 m of lime mudstone with molar-tooth structure. This is capped by two stromatolite biostromes, each ~10 m thick, consisting of coalesced bioherms of branching columnar stromatolites. The biostromes represent the top of member 1, and are overlain by ~40 m of intraclast pack/rudstone, with a 1.5 m-thick layer of club-shaped bioherms of branching columnar stromatolites at 68 m above the base of the formation. From ~99 m stratigraphic height to ~173 m, lime mudstone nodules and layers are interlayered with terrigenous mudstone, here predominantly red. From 173 m to 239 m, dolomitic limestone is interlayered with grey siltstone / mudstone; some carbonate layers consist of intraclast floatstone debrites. Lime mudstone with few discernable sedimentary structures dominates from 239 m to 383 m, above which the carbonate rock is similar in structure but dolomitised; sparse HCS and cross-lamination are present in the interval between 260 m and 457 m. The 402 m-thick interval between 55 m and 457 m represents the second member of the Stone Knife Formation. The third member is marked by the abrupt appearance of terrigenous siltstone, which is interlayered with cross-laminated, silty lime mudstone from 457 m to 551 m. Molar-tooth structure and HCS appear at ~511 m. Molar-tooth dolomudstone contains interlayers of columnar stromatolite bioherms from 551 m to 574 m. A 20 m covered interval is then followed by ~40 m of dolomitic bioherms and biostromes of columnar stromatolites.

A reference section of the Stone Knife Formation is located on the west side of the Stone Knife River, on the south flank of Tawuia Reef (NTS 106A), with a section base at approximately 64°46'51" N / 129°39'54" W. This section was selected because it is in the area where the Stone Knife Formation reaches its thickest and deepest-water expression. Three of the four terrigenous mudstone (shale)-to-limestone members are well developed (member 1 is covered), and their relationships to phases of reef growth are well exposed.

The lower part of the Stone Knife Formation (members 1 and 2) has been equated with the highest known strata of the Hematite Creek Group in the Wernecke Mountains, YT (Thorkelson et al., 2005; Turner, 2011). The Stone Knife Formation is considered to be correlative to the Boot Inlet Formation in the Amundsen Basin (Morin et al., 1993; Rainbird et al., 1994, 1996; Narbonne et al., 2000; Long et al., 2008) which resembles it in both lithofacies and stratigraphic packaging.

SILVERBERRY FORMATION (New)

Definition and Type Area

The Silverberry Formation (Figs. 10 and 11) is equivalent to the informal Platformal assemblage of Aitken (1981), Batten et al. (2004), and Turner and Long (2008). It is named after the Silverberry River, near the type section in NTS 95L. This 301 to 812 m-thick formation is exposed on anticline flanks east of the Plateau fault, south of the Tigonankweine Range, and is laterally equivalent to the Stone Knife Formation. The boundary between areas in which are preserved the Stone Knife or Silverberry formations is a roughly northeast-trending zone at a high angle to the inferred paleo-shoreline and to paleobathymetric contours for the Little Dal Group, Katherine Group, and Mackenzie Mountains Supergroup as a whole (Aitken, 1981). For isopachs, see Turner and Long (2008), and for detailed sections, see Batten (2002, appendix) and Aitken et al. (2011).

Outcrops of the Silverberry Formation are limited to the southern one-third of the Mackenzie Mountain Supergroup exposure area; the northern two-thirds of the exposure area are occupied by the Silverberry Formation's deeper-water facies equivalent, the Stone Knife Formation. The basal contact of the Platformal assemblage was placed at the top of the oncoid marker unit of the former Mudcracked formation, or above the desiccation-cracked dolomudstone at the top of the Dodo Creek Formation in the southeast, where the oncoid unit is absent (Aitken, 1981). Here, however, the basal contact of the Silverberry Formation is placed at the base of the oncoid marker and top of the desiccation-cracked dolomudstone, as outlined for the Stone Knife Formation.

The Silverberry Formation is dominated by intraclastic, oolitic, stromatolitic and molar-tooth carbonate rocks. Like the Stone Knife Formation, it consists of four shallowing-upward cycles (Batten et al. 2004). The first is capped by a thick stromatolitic unit that is contiguous with the stromatolite biostrome of Stone Knife Formation member 1 and forms a basin-wide stratigraphic marker. The remaining cycles consist of transgressive intraclastic units overlain, with some lateral variation, by lime mudstone, shallowing up to molar-tooth dolomudstone, ooid grainstone and stromatolitic boundstone (Turner and Long 2008). The upper contact with the Grainstone formation (now Gayna Formation) was originally placed where desiccation-cracked dolomudstone appears in the fourth shallowing cycle, and although this stratigraphic position is within a cycle, it represents a fairly consistent stratigraphic level that is easily recognised for mapping purposes.

The Stone Knife and Silverberry formations are thought to be correlative to the Boot Inlet Formation in the Amundsen Basin (Rainbird et al., 1994, 1996). Strata equivalent to the lower Stone Knife/Silverberry interval have been identified in the Wernecke Mountains, YT (Turner, 2011).

Type section

The type section of the Silverberry Formation is on the east side of Thundercloud Ck., south-southeast of Coppercap Mountain and in the hanging-wall of the Plateau fault (NTS 95L), at approximately 62˚37'N /126˚35' W (Figs. 5, 10 and 11). As depicted in section 79-AC-2 of Aitken et al. (2011), the type section consists of four cycles in which the dominant rock type changes upward from lime mudstone through molar-tooth lime mudstone to intraclast ±ooid grainstone followed in some cases by a stromatolitic cap. The basal contact is where desiccation-cracked dolomudstone (Dodo Creek Fm.; ~30 m thick) is abruptly overlain by lime mudstone, ooid-intraclast grainstone and molar-tooth lime mudstone (~115 m), which is capped by a biostrome of columnar and domal stromatolites (~10 m thick). The biostrome probably correlates with the stromatolite unit that regionally caps the second cycle of the Little Dal Group. The biostrome is abruptly overlain by lime mudstone and intraclast grainstone (~85 m) followed by thin-bedded dolomitic lime mudstone (~22 m), interbedded lime mudstone, molar-tooth limestone, and intraclast grainstone (~88 m), and intraclast grainstone (~85 m). This succession is abruptly overlain by lime mudstone and molar-tooth lime mudstone (~138 m), and interbedded ooid grainstone and molar-tooth lime mudstone (28 m) that is capped by a thin succession of domal stromatolites and ooid grainstone (8 m) that forms the top of cycle 3. The stromatolite–ooid grainstone unit is abruptly overlain by argillaceous lime mudstone (85 m), and molar-tooth lime mudstone and intraclast grainstone (~105 m), forming cycle 4. The contact with the overlying Gayna Formation is where desiccation-cracked, quartz-sandy, intraclastic dolostone abruptly overlies the lime-mudstone-dominated interval. The Silverberry Formation is approximately 760 m thick at its type section.

GAYNA FORMATION (New)

Definition and Type Area

The Gayna Formation (Figs. 12 and 13) is named to acknowledge the importance of this unit as host of Zn-Pb mineralisation at Gayna River (NTS 106B; Hewton et al., 1982; Turner, 2007). The formation is equivalent to the informal Grainstone formation of Aitken, (1981), Hewton (1982), Batten (2002), Batten et al. (2004) and Aitken et al. (2011). It is up to 390 m thick, and is exposed east of the Plateau fault on the flanks of the Shattered Range and Tigonankweine anticlines. No complete sections with both contacts have been measured; an exposed upper contact is especially rare. For paleocurrent information, see Aitken (1981).

In most locations in the Little Dal exposure area, the lower contact of the formation is where molar-tooth-dominated carbonate mudstone of the uppermost Stone Knife and Silverberry formations, locally with siliciclastic mudstone partings, passes upwards into shallow-water oolitic, stromatolitic or desiccation-cracked dolostone. The upper contact is generally not exposed; the only documented exposure of the upper contact is near the Stone Knife River (Figs. 14 and 15), where desiccation-cracked, quartz-silty and shaly, thin-bedded dolostone is abruptly overlain by weakly banded, ripple cross-laminated gypsite.

All rocks of the Gayna Formation are dolomitic. The succession is dominated by buff-orange-weathering oolitic and intraclastic dolo-grainstone, yellow-buff-weathering, thin-bedded, quartz-silty, desiccation-cracked dolomudstone, and contains local stromatolitic, molar-tooth and cherty units. Sedimentary structures in the dolograinstones include hummocky cross stratification, ripple cross-lamination, trough cross-stratification, and grading. Fine quartz sand and silt are present in the upper dolostones.

Aitken (1981) divided the Grainstone formation into alternating massive oolite facies and platy dolomite facies, and identified distinct stratigraphic successions in northwestern versus southeastern areas (divided at Godlin River). Hewton (1982) divided the formation into four informal members for the Gayna River area (northeastern NTS 106B): lower host (dolo-oolite), argillaceous marker (argillaceous carbonate with molar-tooth structure), upper host (dolo-oolite), and platy dolostone (shaly dolostone with desiccation cracks). The last of these is the uppermost unit of the formation and underlies the contact with the Ten Stone Formation (Figs. 14 and 15). The type section conforms to Aitken's (1981) northwestern generalised stratigraphy for the Gayna Formation, as well as to the informal stratigraphic units used by industry at Gayna River (Hewton, 1982).

The Gayna Formation is thought to be correlative to the Fort Collinson and Jago Bay formations in the Amundsen Basin (Rainbird et al., 1996). There is no proposed equivalent in the Wernecke Mountains because the highest known exposures there are of the Stone Knife Formation.

Type Section

The type section of the Gayna Formation is through cliffs on the east side of the Keele River near Nidhe Brook (NTS 95M; Figs. 5, 12 and 13). The section's base is at approximately 63°56'56" N / 127°55'04" W, but the upper contact is not exposed.

Rocks of the Gayna Formation's type section are pervasively affected by fabric-destructive dolomite and this, together with the small grain size of the allochems, results in difficulty identifying primary lithofacies. In its type section, the basal contact of the Gayna Formation is drawn at a stratigraphic level where lime mudstone-dominated strata are overlain by dolostone containing shallow-water indicators such as HCS, cross-lamination, ooids, or desiccation cracks (Aitken, 1981). A lowest interval of dolostone with HCS, cross-bedding, ripple cross-lamination and desiccation cracks (44 m) is overlain by a covered interval (24 m) and a further 35 m of dolostone with HCS. A recessive, thin-bedded interval of quartz-silty dolostone with HCS, cross-lamination and trough cross-bedding, and rare centimetric layers containing graded, fine-grained quartz sand (111 m) grades upward into resistant, non-argillaceous dolostone with HCS, cross-bedding, and poorly preserved ooids (47 m). A further 43 m of oolitic dolograinstone that contains nodules and lenses of grey chert is abruptly overlain by a second recessive interval of argillaceous dolostone with sparse, thin layers of graded fine-grained quartz sand, ripple cross-lamination and desiccation cracks (~27 m).

The reference section of the Gayna Formation at Stone Knife River (64°46'45" / 129°42'15") is established owing to the rare exposure of the uppermost Gayna Formation and its contact with the overlying Ten Stone Formation (Figs. 14 and 15). Approximately 60 m of recessive, yellow-buff-weathering quartz-silty-to-sandy dolomudstone with abundant centimetric graded beds, ripple cross-lamination, planar mechanical lamination, and desiccation cracks overlie the second resistant unit of the Gayna Formation and are sharply overlain by white-weathering gypsite of the Ten Stone Formation.

TEN STONE FORMATION (New)

Definition and Type Area

The Ten Stone Formation (Figs. 5, 14 and 15) is named for extensive exposures in the hanging-wall of the Plateau Fault in the Ten Stone Range (NTS 106A). The formation, which is equivalent to the informal Gypsum formation of Aitken (1981) and Turner (2009) is poorly exposed and commonly tectonically deformed. It is locally exposed throughout the Mackenzie arc just east of the Plateau fault and in its immediate hanging-wall, and is locally >485 m thick. The Ten Stone Formation is of considerable importance: it hosts a major décollement surface for the Plateau fault, and may have contributed to the sulphur content of base-metal sulphides in spatially associated showings of the Mackenzie Mountains zinc district (Turner, 2009).

The lower contact of the Ten Stone Formation is placed where distinctive, recessive, peritidal dolostone of the uppermost Gayna Formation is abruptly overlain with possible disconformity by white-weathering, current-rippled, subtidal, sulphate-facies evaporites (see Gayna Formation, above). The upper contact is placed where white-weathering evaporites are abruptly overlain by siltstone or dolostone of the lower Snail Spring Formation, with seeming conformity. No section documented to date exposes both lower and upper contacts.

The formation possesses a distinctive though subtle stratigraphy that appears to be fairly consistent throughout the exposure area. The thick intervals of white-weathering evaporite rocks contain very minor interlayered dolostones as well as two distinctively pink-weathering argillaceous units of variable thickness. A ~5-10 m-thick, resistant, widespread carbonate member near the top of the formation locally contains molar-tooth structure.

The Ten Stone Formation is thought to be directly equivalent to the evaporitic Minto Inlet Formation of the Shaler Supergroup (Rainbird et al., 1994, 1996; Long et al., 2008). There is no proposed equivalent in the Wernecke Mountains, and correlation farther west in Yukon has not been established.

Type and Reference Sections

The type section of the Ten Stone Formation is on northeast-facing cliffs west of the Stone Knife River in NTS 106A (Figs. 5, 14 and 15). The base of the section is at approximately 64°46’46” N / 129°42’00” W. In this section, the uppermost part of the formation is absent owing to erosion at the sub-Cambrian unconformity. A reference section on south-facing cliffs between the Keele River and Nidhe Brook (NTS 95M) was chosen because it exposes the upper contact, although the base of the formation is not exposed. The base of the reference section is at approximately 63°57’54” N / 127°55’19” W.

In the type section, the basal contact is where pale grey- to white-weathering gypsite abruptly overlies yellow-buff-weathering ripple cross-laminated, desiccation-cracked quartz-silty dolomudstone of the Gayna Formation. This first white interval (~28 m thick) consists of slightly argillaceous gypsite, contains rare ripple cross-lamination and possible HCS, and has sparse, 1-5 cm-thick medium-brown-weathering dolomudstone bands and rare nodular gypsite. The overlying ~60 m of grey-weathering gypsite exhibits rare ripple cross-lamination and has recessive intervals of medium grey-weathering dolostone up to 7.5 m thick at its base and top; the dolostone has rare ripple cross-lamination. A second white-weathering interval (~50 m thick) has a 19 m-thick succession of dolostone-evaporite cycles at its base, each 1.5 to 3 m thick; carbonate layers are recessive and diminish in thickness upwards and eventually vanish. The remaining 24 m of the second pale grey to white gypsite interval includes rare nodular and enterolithically folded gypsite textures and sparse 1-40 cm-thick grey-brown dolostone interlayers. The second white-weathering interval is gradationally overlain by pink-weathering, argillaceous gypsite with rare ripple cross-lamination and centimetric dolostone interlayers. The brick-red colour intensifies upwards and then gradually diminishes; the full thickness of this first red interval is ~82 m. The third pale grey to white interval (~163 m thick) consists of sparsely ripple cross-laminated gypsite with several isolated ~0.5 m-thick dolostone bands and minor chicken-wire texture. A second, thin red interval (~ 7 m thick) has red siltstone interlayers and is overlain by a fourth pale-grey to white interval with ripple cross-lamination and rare chicken-wire texture. At 535 m above the basal contact is a conspicuous carbonate marker (14 m thick) that consists of weakly colour-banded, medium-grey-weathering dolomitic lime mudstone with cm-scale lime mudstone nodules. This is overlain by a 5 m-thick covered interval that consists of white gypsite along strike. Both this white gypsite and the marker limestone are truncated along strike along a subtly angular unconformity below red sandstone of the basal Franklin Mountain Formation (Cambrian).

The reference section, on south-facing cliffs between the Keele River and Nidhe Brook (NTS 95M), exposes the upper contact of the Ten Stone Formation (Figs. 14 and 15). The lowest Ten Stone Formation exposed there consists of tectonically deformed red and white gypsite above exposures of uppermost Gayna Formation desiccation-cracked quartz-silty to-sandy dolomudstone. Owing to an obvious loss of stratigraphic integrity at the base of the exposure, only the overlying, undeformed strata were measured. The lowest 101 m of exposed strata consist of intermittently plane-laminated, rarely ripple cross-laminated, slightly argillaceous, white-weathering gypsite with rare centimetric dolomudstone bands. This interval is overlain by 46 m of red-weathering gypsite, a covered interval (16 m thick) and a ~10 m-thick marker unit of weakly banded, pale brown-weathering dolomudstone with no discernable sedimentary structures. The marker unit is abruptly overlain by 62 m of pale grey-weathering gypsite with one 1-m-thick red interval, and a 4-m-thick covered interval. The base of the overlying Snail Spring Formation, in contrast to its composition at its type section, consists of green and red mudstone (0.4 m), red-, green- and grey-weathering dolomitic sandstone with desiccation cracks and ripple cross-lamination (4 m), interlayered sandstone, dolostone, and red mudstone (6 m). This transition interval then passes to yellow-buff-weathering, mechanically laminated and ripple cross-laminated dolostone more typical of the basal Snail Spring Formation.

SNAIL SPRING FORMATION (New)

Definition and Type Area

The Snail Spring Formation (Figs. 16 and 17) is here named for a spring on the north side of the Twitya River valley near the type section (NTS 106A). This unit was informally named the Rusty Shale formation (Aitken, 1981). It is a conspicuous, dark-brown-weathering, slightly recessive unit that is well exposed in the hanging-wall of the Plateau fault in NTS 106A, B and 95M, and locally in its footwall. For isopachs, see Aitken (1981).

The lower contact of the Snail Spring Formation is generally abrupt, where dolostone, or locally, thin siltstone or sandstone layers, overlie recessive evaporite rocks of the Gayna Formation. This contact is seldom well exposed. The upper contact is placed where resistant, buff-weathering, intraclastic, "molar-tooth", and stromatolitic dolostones of the Ram Head Formation gradationally overlie argillaceous carbonate rocks of the uppermost Snail Spring Formation.

As described and depicted by Aitken (1981), the Snail Spring Formation is typically ~200-250 m thick, and has five distinctive, regionally persistent, members. These begin with a lower, yellow-buff-weathering dolostone member (A), dominated by mechanical lamination, desiccation cracks, symmetrical and asymmetrical cross-lamination, minor molar-tooth structure, local chert, and quartzose sand to silt. This interval is overlain by locally ripple cross-laminated siltstone and laminated mudstone of member B, with rare stromatolites. The overlying member (C) includes interbedded quartz arenite and siltstone, with desiccation cracks, grading, and asymmetrical and symmetrical ripples. Member D is a grey laminated mudstone and siltstone, which is overlain by dolostone and limestone of member E, with muddy interlayers, molar-tooth structures, intraclasts, grading, and local stromatolites and oolite. The type section exhibits numerous, 4 to 25 m-thick shallowing cycles grouped into a larger-order cyclic pattern.

The Snail Spring Formation is thought to be correlative to the lower Wynniatt Formation of the Shaler Supergroup (Rainbird et al., 1996; Long et al., 2008).

Type Section

The type section of the Snail Spring Formation (Figs. 16 and 17) is on northeast-facing cliffs on the south side of the Twitya River, west of the Keele River junction; the section base is at approximately 64°06’28”N / 128°26’38” W. Although the underlying Ten Stone Formation is not exposed on the ridge, isolated exposures of pale-weathering gypsite are present along strike. The lowest unit of the Snail Spring Formation forms an abrupt change in slope and consists of dolostone with symmetrical and asymmetrical ripples, trough cross-bedding, gutter casts, intraclasts, poorly preserved stromatolites, rare laminae of normally graded quartz sand grains, and sparse grey chert nodules (14.5 m thick). A ~3.5-m-thick layer of desiccation-cracked siltstone with asymmetrical ripple marks is capped by ~1 m of desiccation-cracked, rippled, silty dolostone with siltstone chips. This unit is abruptly overlain by 8.7 m of strata in which dolomitic lime mudstone with molar-tooth structure is interlayered on a metre-scale with desiccation-cracked, rippled dolomudstone. Above this carbonate-dominated interval are 23 m of orange-brown-weathering desiccation-cracked siltstone with thin interlayers of very fine quartz sandstone. At 50 m stratigraphic elevation, the siltstone is punctuated by a 1-m-thick dolomitic limestone biostrome of branching columnar stromatolites (*Baicalia* and/or *Inzeria*). A further 53 m of orange-brown-weathering siltstone and mudstone with rare ripple cross-lamination, sparse thin bands of very fine quartz sandstone, and no desiccation cracks is gradationally overlain by ~36 m of interlayered siltstone/mudstone with desiccation cracks and symmetrical ripple marks (layers >5 m) and medium-grained quartz sandstone with mudstone clasts, cross-bedding, grading, desiccation cracks, and synaeresis cracks (layers 2.5-12.5 m thick). Above this sandstone-dominated interval is an intermittently exposed interval of plane-laminated, orange-grey- to yellow-brown-weathering siltstone (34 m). At the top of the formation is a carbonate-dominated interval (total ~17.5 m) consisting of ~10 m of quartz-silty cross-laminated molar-tooth limestone with HCS, quartz grains, and intraclasts, sharply overlain by 10 cm of red terrigenous mudstone, ~2 m of bioherms of columnar stromatolites with inter-bioherm ooid dolograinstone, 3 m of dolostone with HCS, and 2 m of molar-tooth limestone with intraclasts. This interval is then overlain by 0.3 m of red shale, and 15.5 m of strata in which dolostone and dolomitic limestone with HCS, intraclasts, and molar-tooth structure are interlayered with red and grey terrigenous mudstone and orange-buff-weathering siltstone with desiccation cracks. The top of the formation is placed where the last, 2.5-m-thick siltstone interval is overlain by graded intraclast dolostone of the lowermost Ram Head Formation. The total thickness of the Snail Spring Formation at its type section is approximately 197 m.

RAM HEAD FORMATION (New)

Definition and Type Area

The Ram Head Formation is here named for a lake near the type section in northwestern NTS 95M. This formation was previously referred to as the Upper Carbonate formation (Aitken, 1981;

Jefferson, 1983; Jefferson and Ruelle, 1986; Jefferson and Parrish, 1989). It is a thick (locally in excess of 850 m) cliff-forming dolostone exposed in the hanging-wall of the Plateau fault and in the hanging-walls of subsidiary faults immediately east of the Plateau fault. The formation was first described by Aitken (1981) with four members; Jefferson (1983) and Jefferson and Parrish (1989) subsequently recognised 13 informal members, of which the thirteenth is a volcanic unit (the "Little Dal basalt") now considered to be an entirely separate rock unit. Numerous sections have been measured through this formation (Jefferson, 1983; Aitken et al., 2011). For isopachs, see Aitken (1981), Jefferson (1983) and Jefferson and Parrish (1989).

The gradational basal contact with the Snail Spring Formation is placed above the uppermost of the thin shale interlayers present in the Snail Spring Formation's upper carbonate member according to the usage of Aitken (1981). The Ram Head Formation is unconformably overlain by a variety of middle Neoproterozoic to Paleozoic units. The oldest unit to overlie the Ram Head Formation is the "Little Dal basalt". Jefferson (1983) and Jefferson and Parrish (1989) note that this contact has very little stratigraphic variability: it is almost always at the level of unit UC12. Subtle angularity is evident at the contact in some locations. The unconformity separating Ram Head Formation strata from those of the Coates Lake Group is similarly subtle, cutting only as low as UC7 (Jefferson, 1983; Jefferson and Parrish, 1989). Evidence of significant karstification or subaerial exposure is not present at or near the upper contact of the Ram Head Formation; evidence of minor karstification and carbonate soil formation is, however, present at several levels within the formation.

The Ram Head Formation is almost exclusively carbonate and contains only minor intercalations of terrigenous mudstone. According to previous descriptions, the lower six members (UC 1-6 of Jefferson, 1983) are composed of grey and tan, poorly preserved stromatolitic to oolitic dolostone and limestone, whereas the upper six members (UC 7-12) are poorly preserved, discontinuous stromatolitic carbonate units separated by grey to brown nodular lime mudstone (see Jefferson (1983) for original descriptions of the 12 members of the Ram Head Formation). Minor siltstone and mudstone intervals are present.

Type Section

The type section of the Ram Head Formation (Figs. 18 and 19) follows a creek and northeast-facing slopes southeast of Boomerang Lake (NTS 95M); the section base is at approximately 63°47'04" N / 127°25'25" W. Among the previously documented sections, this section (#55 of Jefferson, 1983; 77-AC-40 of Aitken et al., 2011) exhibits the greatest number of typical attributes and serves as the type section. The rusty-weathering Snail Spring Formation is exposed in the lower part of a creek cutting through a vegetated hillside below slopes of mixed outcrop and talus of the Ram Head Formation. The upper Snail Spring Formation consists of siltstone (unmeasured) overlain by 47 m of interlayered siltstone, dolomitic limestone, dolostone, and rare sandstone, with a combination of features including ribbon limestone, HCS, molar-tooth structure, columnar stromatolites, intraclasts, cross-bedding, and synaeresis cracks; desiccation cracks are present in the uppermost ~9 m.

At the type section, the Ram Head Formation consists of sixteen shallowing-upward cycles (A-P; section has several significant convered intervals that may compromise this number). Each cycle has a lower, subtidal interval containing molar-tooth carbonate with HCS and/or mechanically laminated carbonate; some cycles, particularly in the upper one-third of the formation, have abrupt incursions of terrigenous siltstone at their bases. Uppermost parts of cycles are generally characterised by thin stromatolite biostromes, in one case accompanied by oolite; desiccation cracks are present near a few cycle tops, and several cycle tops have conspicuous evidence of subsurface karstic dissolution. The type section is 786 m thick, has an erosional upper contact, and is dominated by subtidal, non-stromatolitic carbonate lithofacies; columnar stromatolite lithofacies represent only 13% of the formation's thickness.

The base of the Ram Head Formation is placed above the last siltstone layer in desiccation-cracked dolostone of the uppermost Snail Spring Formation. The last siltstone layer (0.4 m thick) is sharply overlain by ~17.5 m of molar-tooth dolostone with intact and toppled columnar stromatolites at its base. This boundary differs slightly from that of Jefferson (1983) but conforms to that designated by Aitken (1981). A further 7 m of columnar-stromatolitic dolostone is overlain by 19 m of poorly preserved microbial dolostone that is at least in part thrombolitic or calcimicrobial. This microbial interval is gradationally overlain by ~7 m of molar-tooth dolostone followed by cover, and then 2.5 m of desiccation-cracked, orange-buff-weathering, banded dolomudstone (top of cycle A at ~64 m stratigraphic elevation above formation base). In cycle B (64 to 108 m stratigraphic elevation), dolomudstone of the top of cycle 1 is abruptly overlain by 18 m of medium grey-weathering molar-tooth dolostone with HCS, followed by cover. The middle of the cycle consists of microbial laminite interlayered with molar-tooth dolostone and minor columnar stromatolites, and the cycle top consists of 6 m of orange-weathering microbially laminated and stromatolitic dolostone cross-cut by metre-scale, siltstone-filled voids (karst cavities). Cycle C (108 to 130 m) consists of molar-tooth dolostone overlain by silty dolostone (a conspicuous, 6.5 m-thick orange marker unit) and then desiccation-cracked dolomudstone. Cycle D (130 to 153 m) consists of orange-weathering dolostone with mechanical lamination and HCS overlain by quartz-silty intraclast packstone and floatstone. Cycle E (153 to 208 m) begins abruptly with 4 m of metre-scale grey siltstone layers interlayered with cherty intraclastic dolostone, overlain by 50 m of interlayered mechanically laminated, microbially laminated, intraclastic and molar-tooth dolomudstone, capped by a 30 cm-thick biostrome of columnar stromatolites. Cycle F (208 to 302 m) consists of 50 m of mechanically laminated and molar-tooth dolostone overlain by 45 m of oolite grainstone/packstone with columnar stromatolites, microbial laminite and rare grey-black chert nodules; domal stromatolites are present in the uppermost 4 m. Cycle G (302 to 377 m) consists of mechanically laminated, locally intraclastic dolostone with grey chert nodules (54 m) gradationally overlain by 23 m of intraclastic, columnar-stromatolitic dolostone. Cycle H (377 to 427 m) consists of mechanically laminated dolostone with sparse microbial laminite and pale grey chert nodules, overlain by argillaceous dolostone with minor domal stromatolites and cross-cutting, metre-scale, siltstone-filled cavities; the top of the cycle is marked by a thin (~1 m; not exposed in the line of section) unusual floatstone – rudstone containing irregular, lobate pisoids intermixed with dark green siltstone. Cycle I (427 to 549 m) consists of millimetrically laminated, fissile orange dolostone with lime mudstone nodules (marker unit ~8 m thick), a 29 m-thick covered interval (Aitken et al. (2011) indicates shaly limestone and weakly laminated dolostone at this level), and massive cliffs (85 m thick) of vuggy, microbially laminated to vaguely columnar-stromatolitic, intraclastic dolostone. Cycle J (549 – 599 m) begins with 3 m of dark grey siltstone abruptly overlying massive dolostone of Cycle I, which is overlain by 16 m of vuggy dolostone with faint HCS and 18 m of interlayered dark grey siltstone and platy, yellow-weathering dolostone, capped by 3 m of pinkish-orange- and yellow-weathering columnar stromatolitic dolostone (a conspicuous marker unit). Cycle K (599 to 686 m) abruptly starts with ~3 m of dark grey siltstone followed by 27 m of tan dolostone with lime mudstone and grey dolomudstone nodules and minor siltstone interlayers (a conspicuous marker unit), and 2 m of conspicuously orange-weathering dolostone of the same lithofacies. This is followed by 40 m of faintly mechanically laminated buff-weathering dolostone with minor siltstone interlayers, and 14 m of massive intraclastic, laminated dolostone, capped by a thin biostrome of columnar stromatolites. Cycle L (686 to 718 m) consists of weakly mechanically laminated, faintly intraclastic pale grey dolostone overlain by 13 m of intermittently orange-weathering, intermittently quartz-sandy, locally columnar-stromatolitic dolostone, a 3.5 m-thick pink-weathering biostrome of columnar stromatolites, and 1.5 m of tan-weathering desiccation-cracked dolomudstone. Cycle M (718 to 747 m) abruptly begins with 10 m of olive-green and grey siltstone interlayered with orange-tan-weathering, weakly mechanically laminated dolomudstone, and grades up into 14 m of featureless dolostone capped by a 2 m-thick dolostone layer with frothy chert that is overlain by a 1.5 m-thick biostrome of columnar stromatolites with silicified laminae in the top 30 cm. Cycle N (747 to 754 m) consists of ~1 m of dark grey siltstone overlain by 6 m of mechanically laminated dolomudstone and

0.5 m of columnar stromatolites. Cycle O (754 to 774 m) consists of a basal siltstone (<1 m) overlain by 18 m of mechanically and microbially laminated buff dolostone with sparse, pale grey chert nodules overlain by 2 m of interlayered columnar stromatolites and microbial laminite. Cycle P (774 to 786 m) comprises 8 m of interlayered silty dolostone overlain by 6 m of columnar stromatolites interlayered with mechanically laminated dolostone. The upper part of the cycle is truncated by the basal contact of the "Little Dal basalt", which from a distance can be seen to truncate subtly the layering in the uppermost Ram Head Formation.

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FIGURE CAPTIONS

Figure 1. (A, B) Location and distribution of early Neoproterozoic strata in northwestern Canada. (C) Exposure area of the Mackenzie Mountains Supergroup in the Mackenzie Mountains (NWT; based on Turner and Long, 2008).

Figure 2. Generalised stratigraphy of the Mackenzie Mountains Supergroup.

Figure 3. Type section of the Tabasco Formation. Column width indicates weathering profile. Coloured fill indicates weathering colour.

Figure 4. Photograph of the type section of Tabasco Formation, composed of two overlapping segments (red lines). East side of Ramparts River; view to east (NTS 106G).

Figure 5. Map locations of type sections of formations of the Little Dal Group.

Figure 6. Type section of the Dodo Creek Formation. Column width indicates weathering profile. Coloured fill indicates weathering colour.

Figure 7. Type section of Dodo Creek Formation, west of Stone Knife River (northwestern NTS 106A). (A) Oblique aerial view to south (Knife Edge reefs at centre; Stone Knife River in upper left). Oncoid and stromatolite biostrome markers of overlying Stone Knife Formation are indicated. Pink line indicates line of measured section. (B) Semi-resistantly weathering lower Dodo Creek Formation (sandstone and siltstone) overlain by siltstone-dominated upper Dodo Creek Formation and oncoid marker of basal Stone Knife Formation. View to northeast.

Figure 8. Type section of the Stone Knife Formation. Column width indicates weathering profile. Coloured fill indicates weathering colour. Legend as in Fig. 6.

Figure 9. Type and reference section of the Stone Knife Formation. (A) Type section of Stone Knife Formation on west flank of Tigonankweine Range (northwestern NTS 95M). View to northwest. Line of section followed ridge-line. (B) Reference section of Stone Knife Formation west of Stone Knife River (northwestern NTS 106A). View to west. Pink line indicates line of measured section.

Figure 10. Type section of the Silverberry Formation, after section 79-AC-2 in Aitken et al. (2011). Column width indicates weathering profile. Coloured fill indicates weathering colour. Dashed lines indicate cycle contacts. Legend as in Fig. 6.

Figure 11. Photo of type section of Silverberry Formation (east-central NTS 95L). View to north. Pink line indicates line of measured section 79-AC-2 (Aitken et al., 2011). Although the oblique view gives an illusion of deformed bedding, the stratigraphy is continuous and layering dips steeply to the west (left).

Figure 12. Type section of the Gayna Formation. Column width indicates weathering profile. Coloured fill indicates weathering colour. Legend as in Fig. 6.

Figure 13. Photo of the type section of the Gayna Formation on east side of Keele River (northwestern NTS 95M). View to north. Line of section followed left side of valley in centre.

Figure 14. Type and reference sections of the Ten Stone Formation. Column width indicates weathering profile. Coloured fill indicates weathering colour. Legend as in Fig. 6.

Figure 15. Type and reference sections of the Ten Stone Formation. (A) Type section of Ten Stone Formation west of Stone Knife River (northwestern NTS 106A) includes basal contact with Gayna Fm. View to northwest. (B) Reference section of Ten Stone Formation near Nidhe Brook (northwestern NTS 95M) includes upper contact with Snail Spring Formation. View to north. Red lines indicate lines of measured sections.

Figure 16. Type section of the Snail Spring Formation. Column width indicates weathering profile. Coloured fill indicates weathering colour. Legend as in Fig. 6.

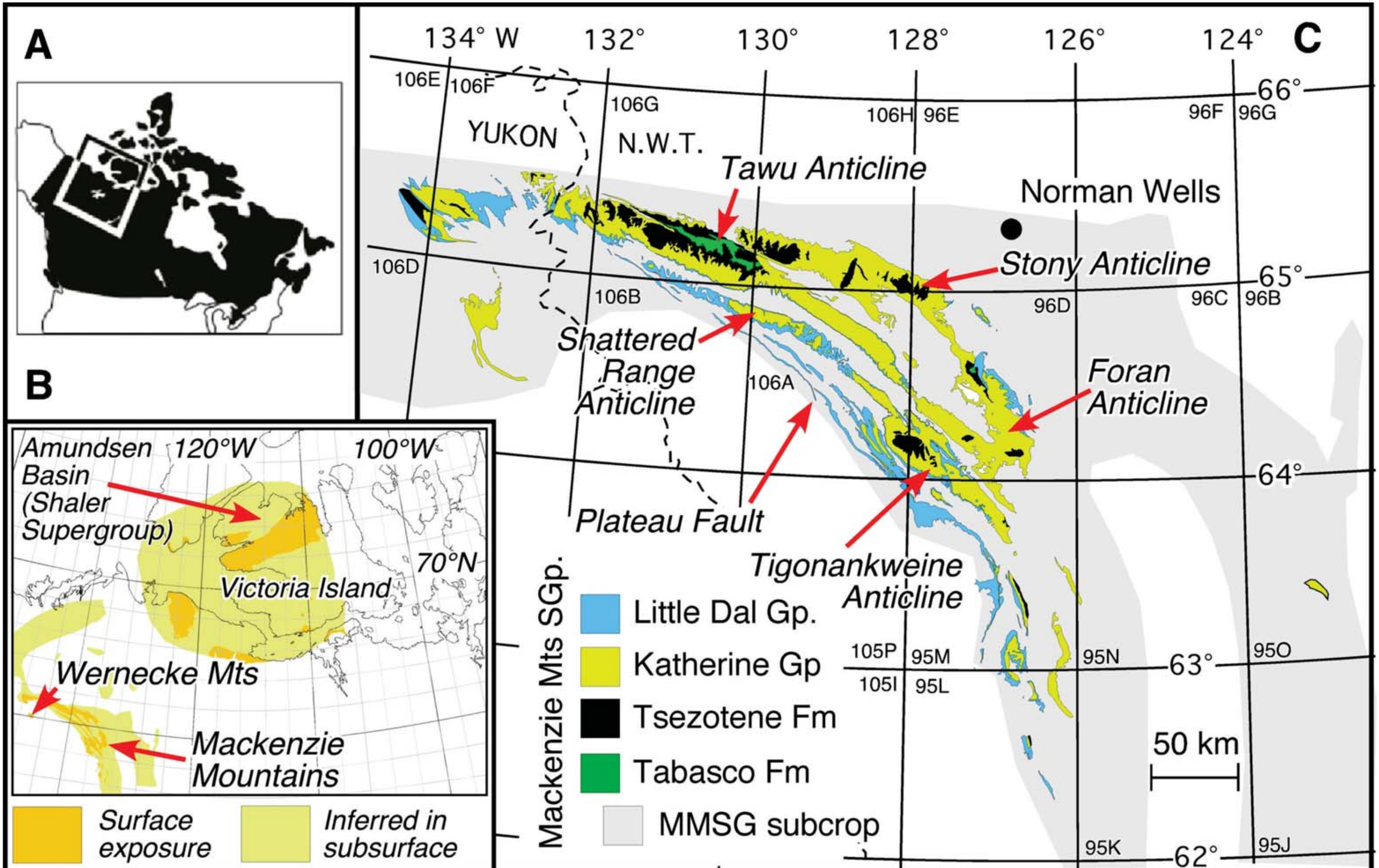
Figure 17. Photo of type section of the Snail Spring Formation on south side of Twitya River (southeastern NTS 106A). View to south. Pink line shows line of measured section.

Figure 18. Type section of the Ram Head Formation. Column width indicates weathering profile. Coloured fill indicates weathering colour. Legend as in Fig. 6.

Figure 19. Photos of the type section of the Ram Head Formation near Boomerang Lake (northwestern NTS 95M). (A) Type section of Ram Head Formation; view to west. (B) Middle part of type section of Ram Head Formation; view to south. Numbers indicate unit numbers in accompanying stratigraphic log (Fig. 18); coloured lines show line of measured section, which continues on a ridge to right of photo.

TABLE CAPTIONS

Table 1. Type section locations for Tabasco Formation and seven formations in the Little Dal Group.



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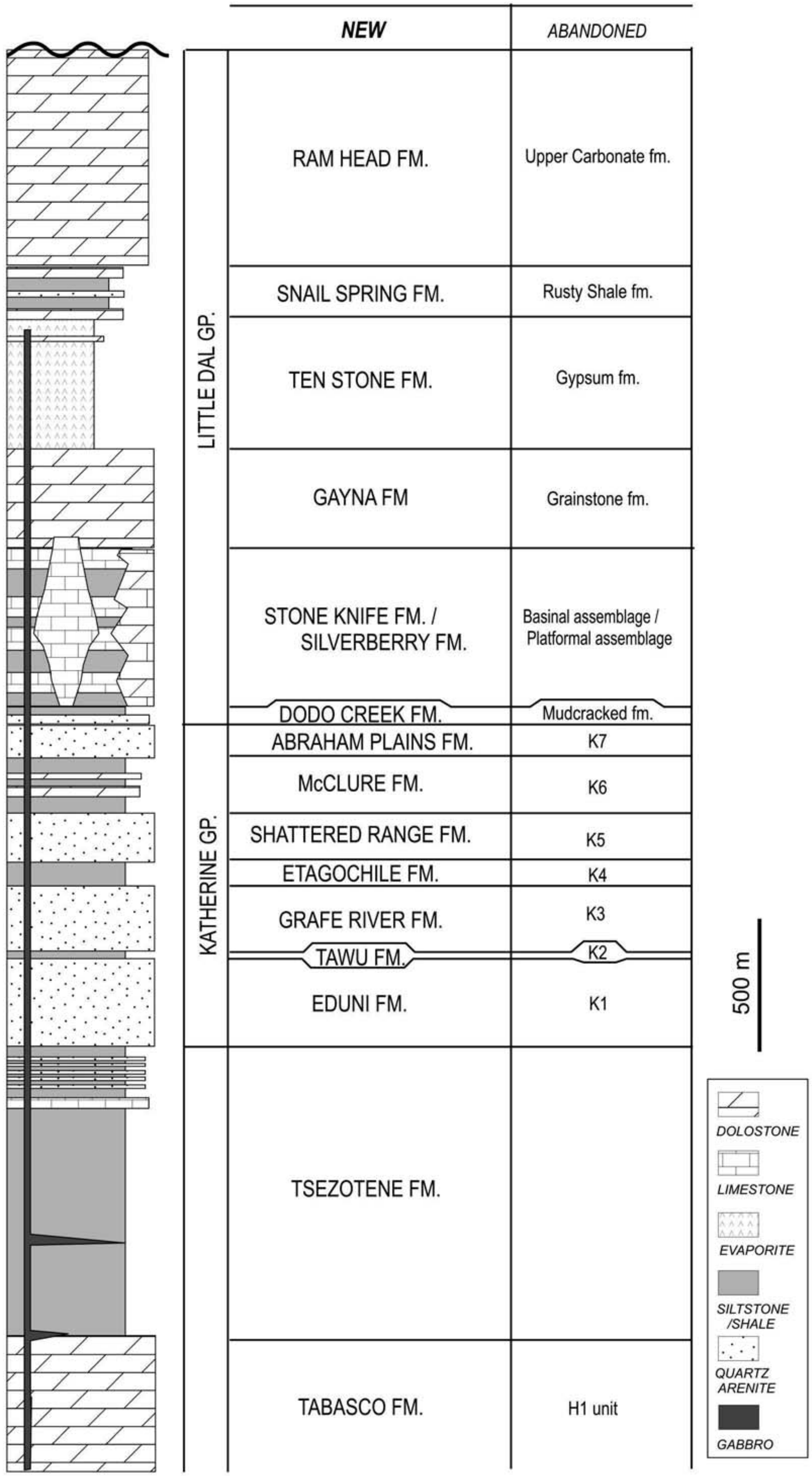

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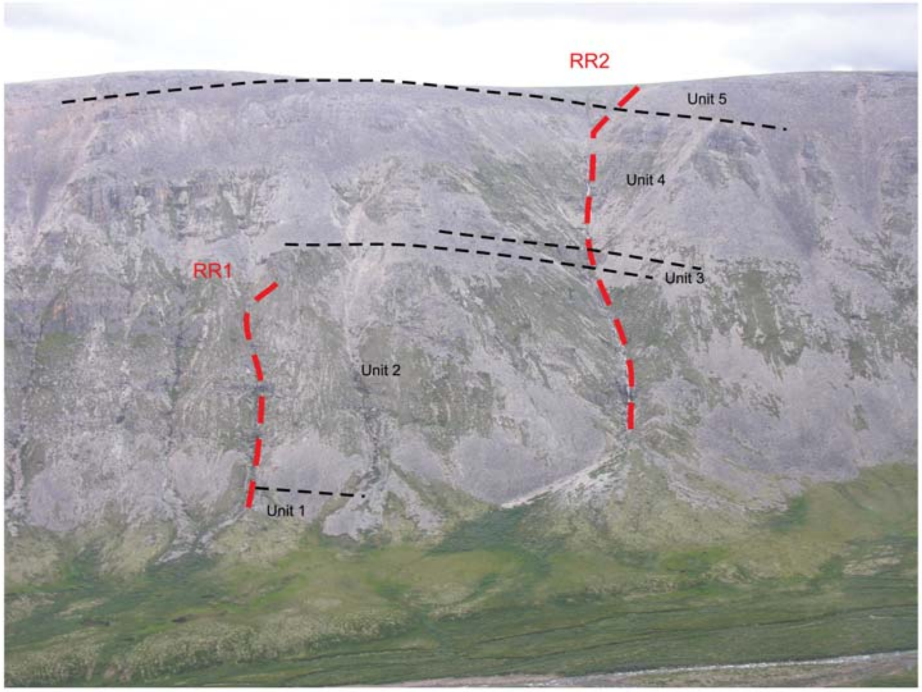


Figure 4. Photograph of the type section of Tabasco Formation, composed of two overlapping segments (red lines). East side of Ramparts River, view to east (NTS 106G).

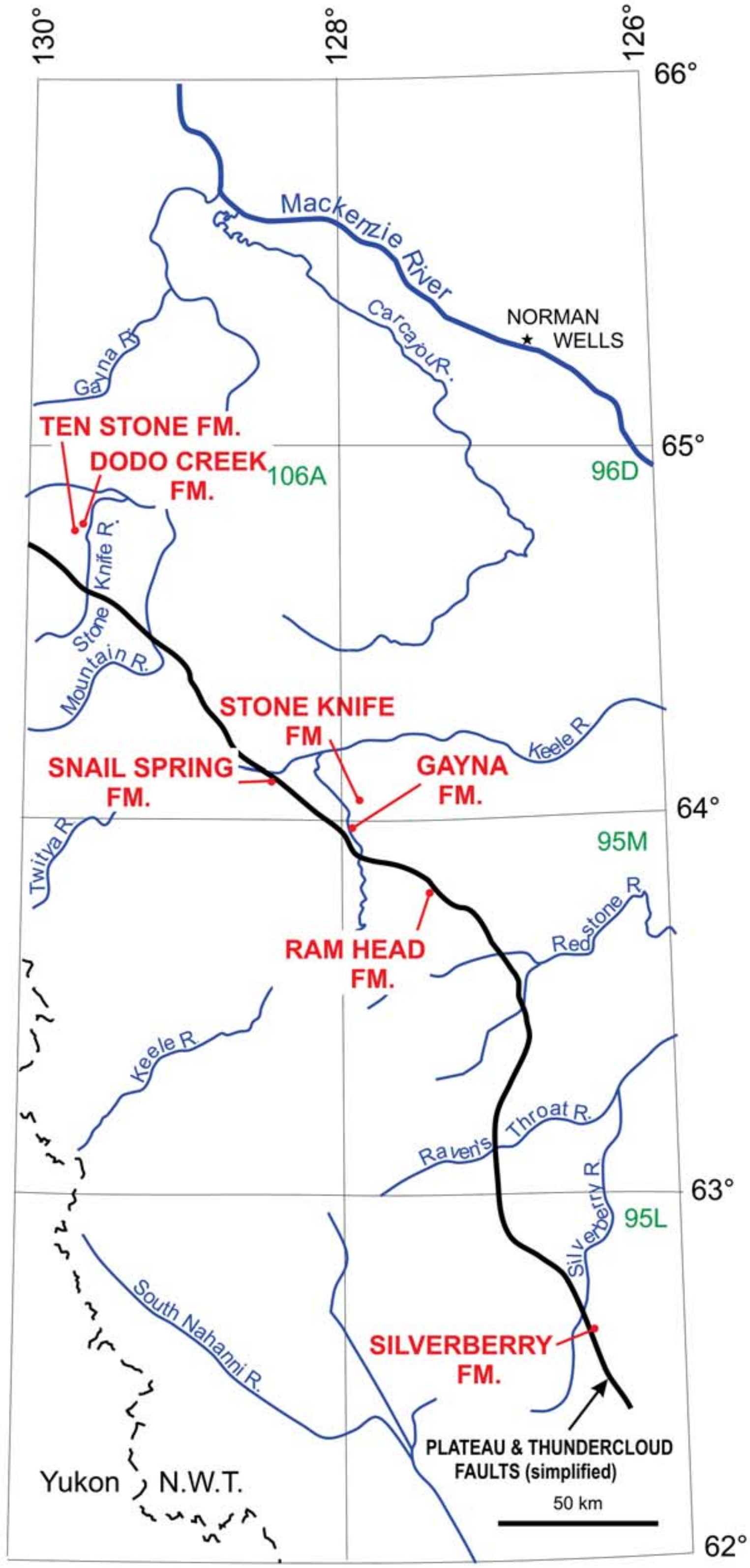


Figure 5. Map locations of type sections of formations of the Little Dal Group.

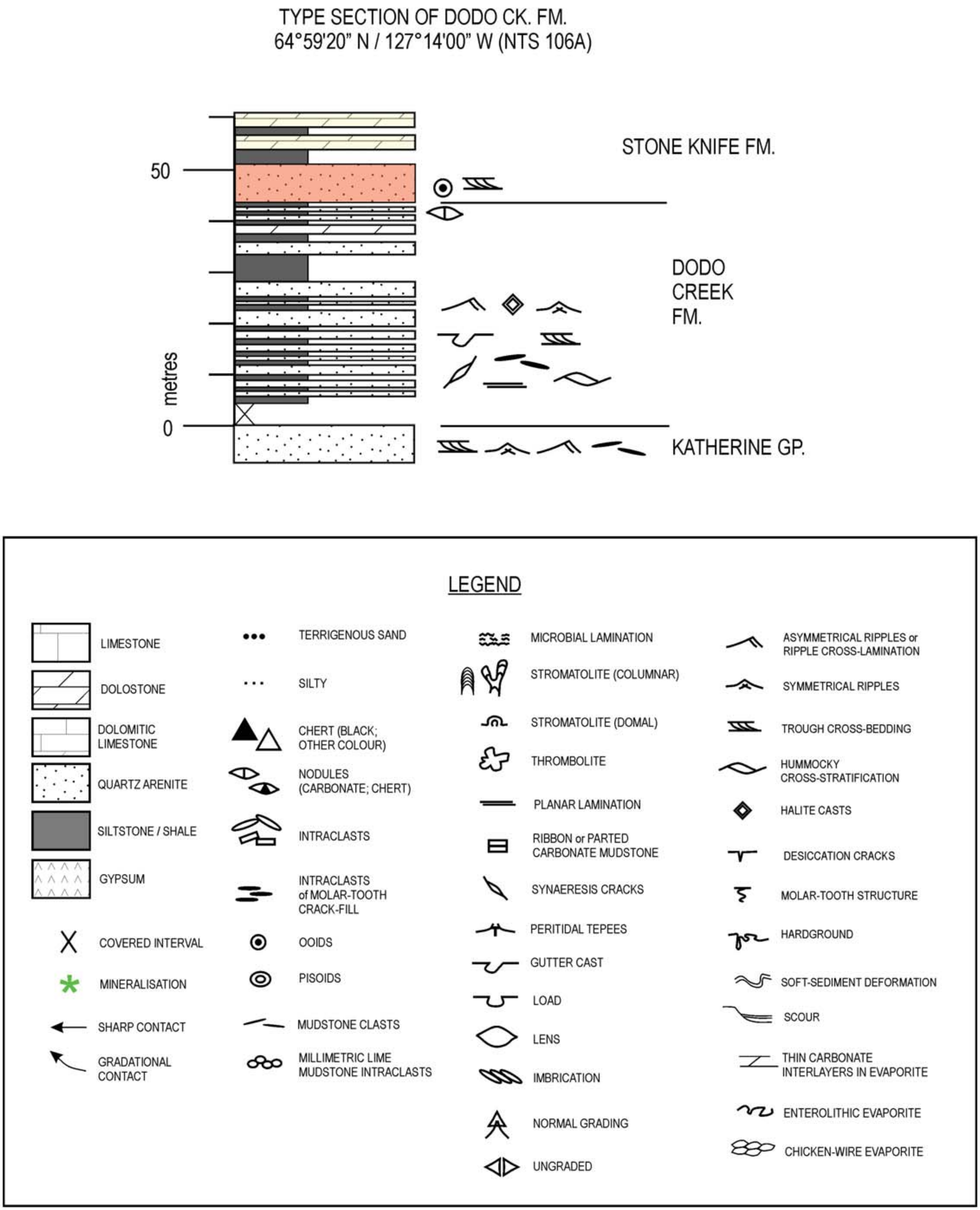


Figure 6. Type section of the Dodo Creek Formation. Column width indicates weathering profile. Coloured fill indicates weathering colour.

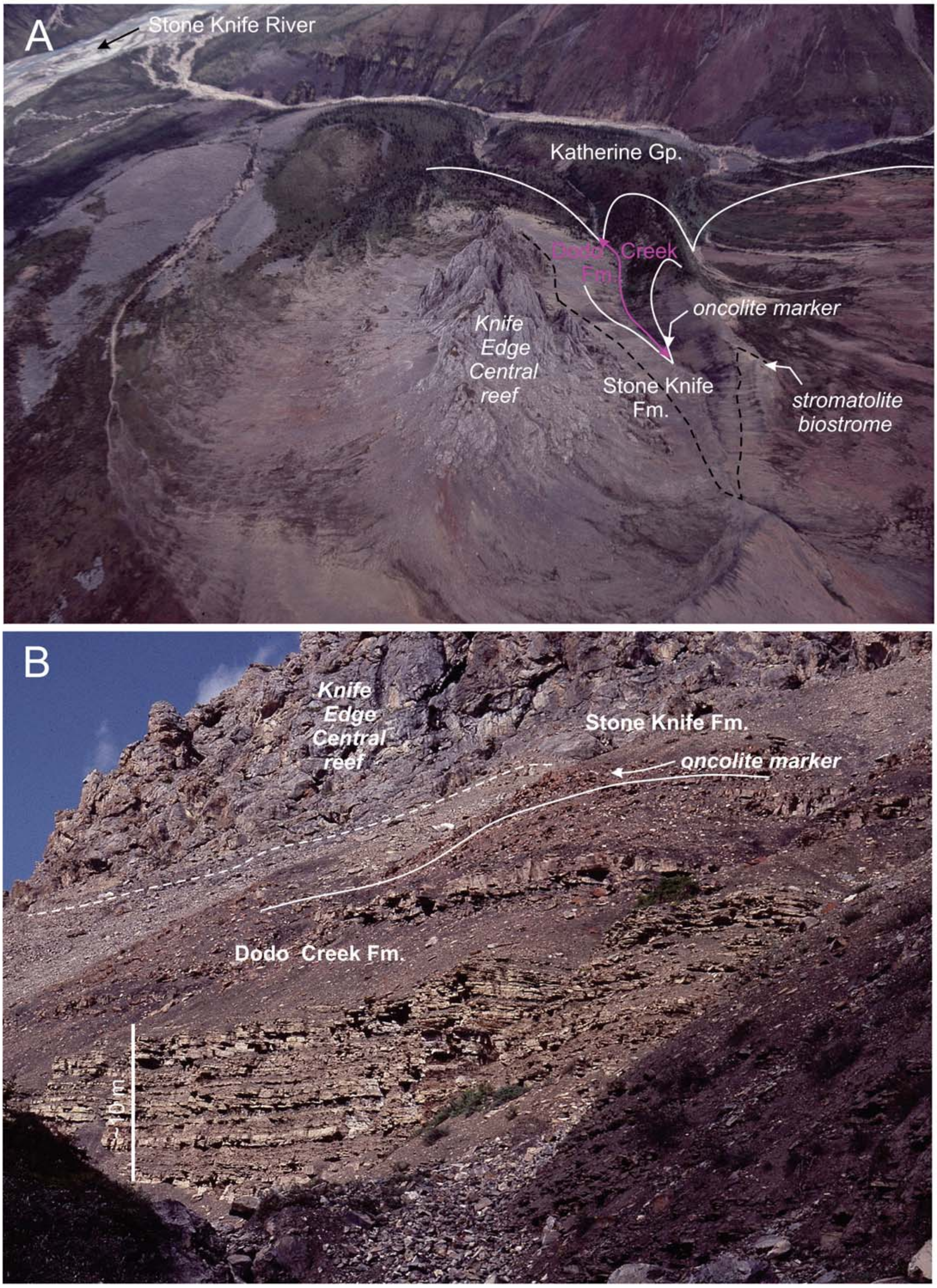
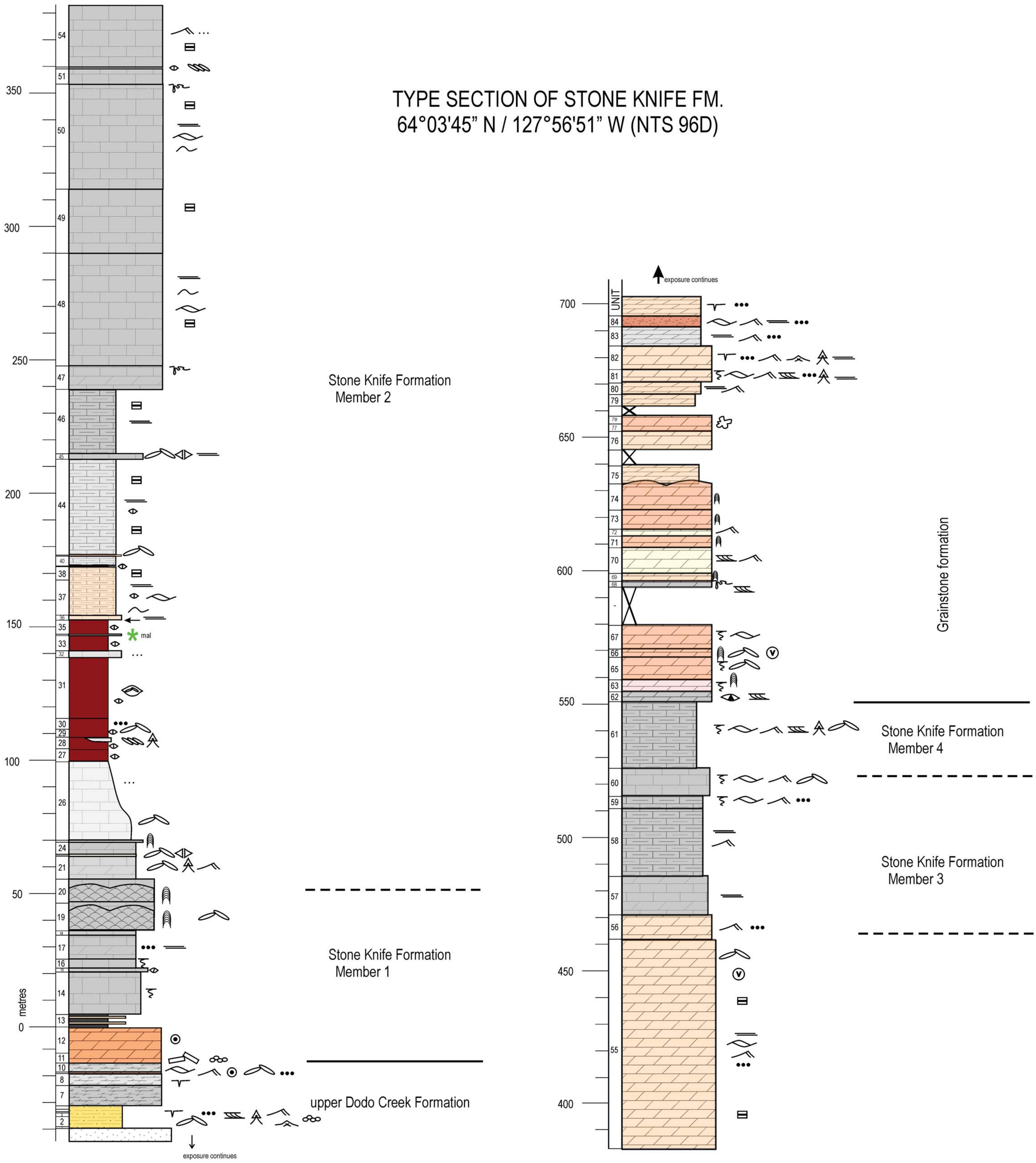


Figure 7. Type section of Dodo Creek Formation, west of Stone Knife River (northwestern NTS 106A). (A) Oblique aerial view to south (Knife Edge reefs at centre; Stone Knife River in upper left). Oncoid and stromatolite biostrome markers of overlying Stone Knife Formation are indicated. Pink line indicates line of measured section. (B) Semi-resistantly weathering lower Dodo Creek Formation (sandstone and siltstone) overlain by siltstone-dominated upper Dodo Creek Formation and oncoid marker of basal Stone Knife Formation. View to northeast.



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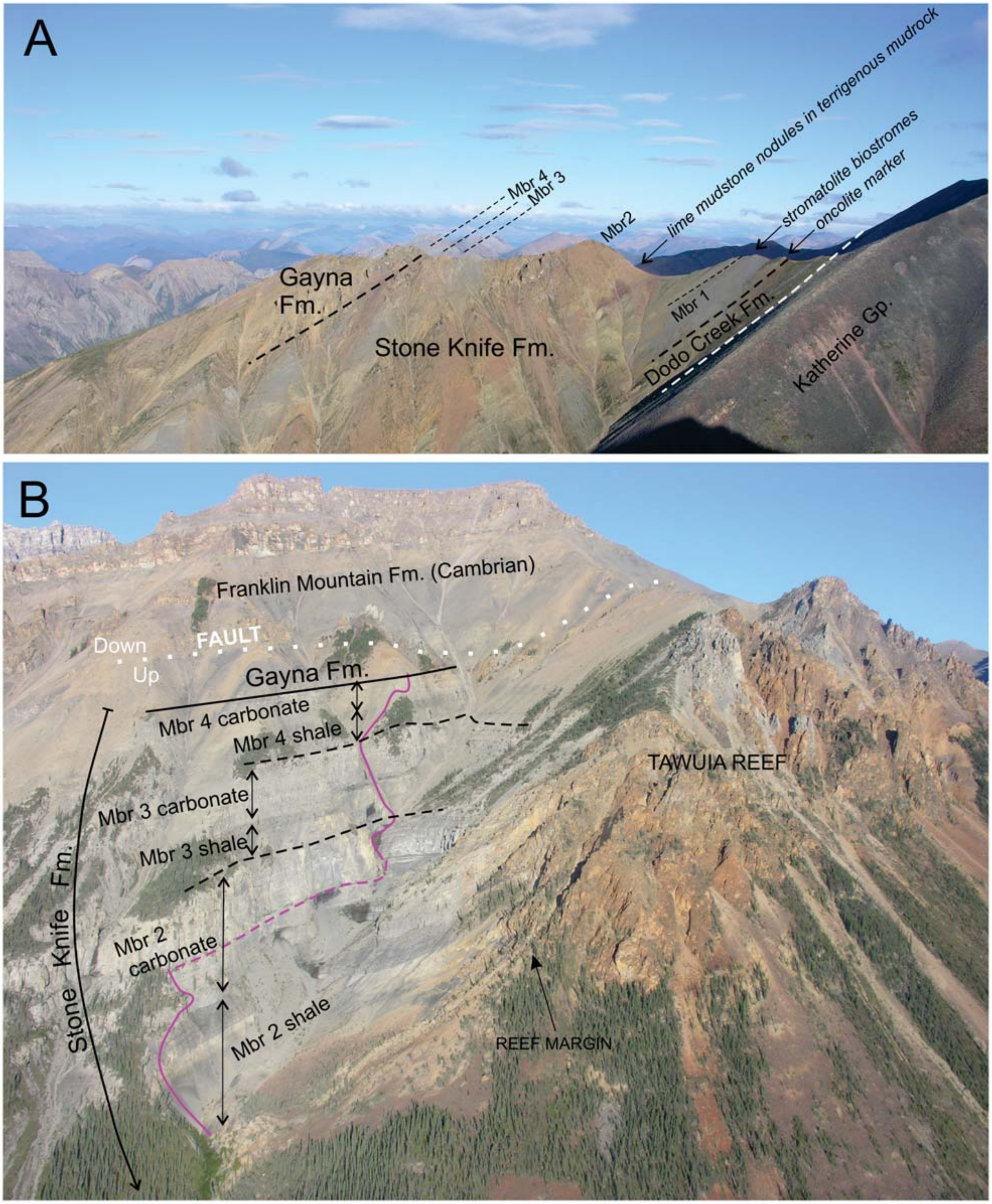


Figure 9. Type and reference section of the Stone Knife Formation. (A) Type section of Stone Knife Formation on west flank of Tigonankweine Range (northwestern NTS 95M). View to northwest. Line of section followed ridge-line. (B) Reference section of Stone Knife Formation west of Stone Knife River (northwestern NTS 106A). View to west. Pink line indicates line of measured section.

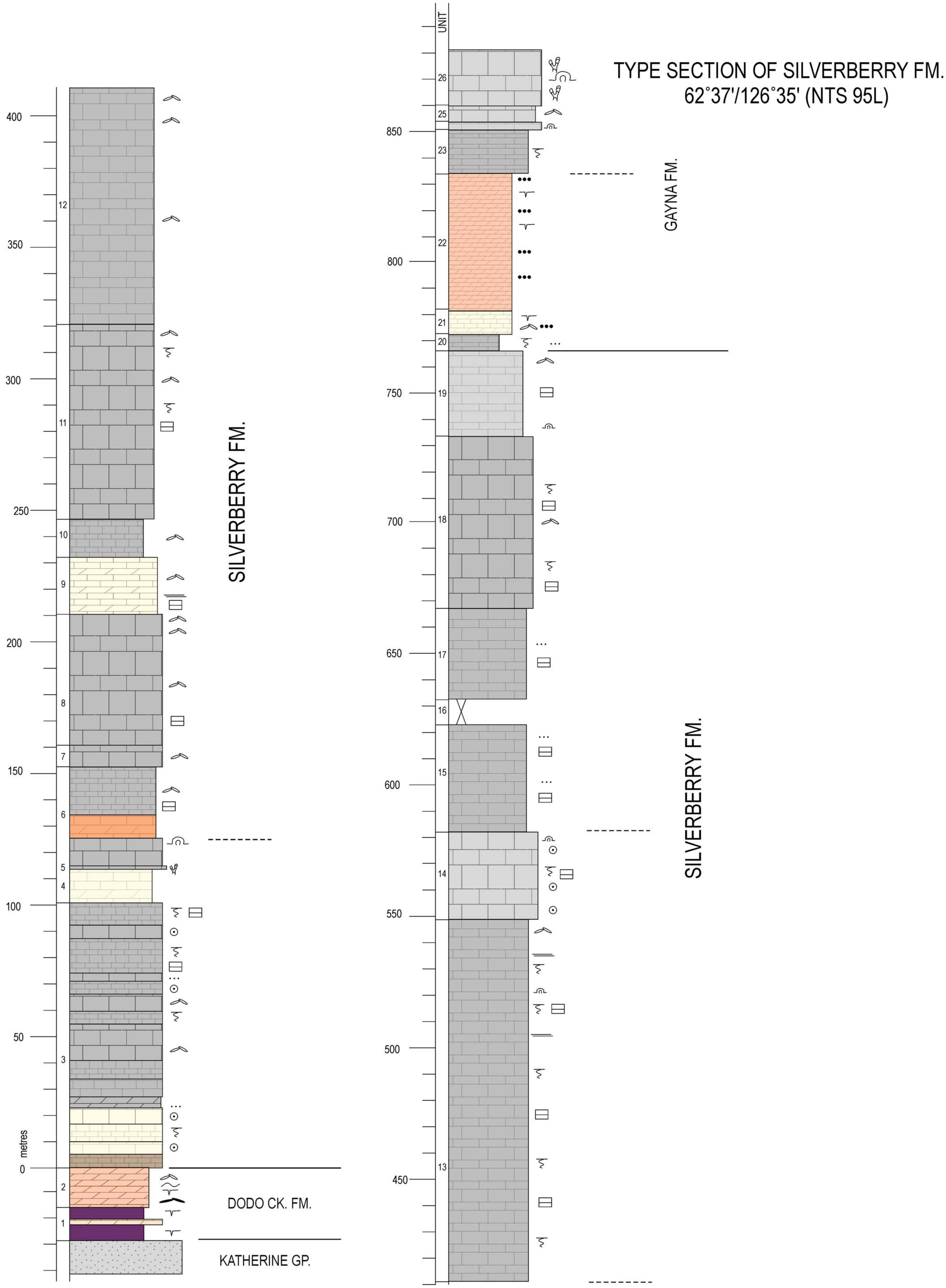


Figure 10. Type section of the Silverberry Formation, after section 79-AC-2 in Aitken et al. (2011). Column width indicates weathering profile. Coloured fill indicates weathering colour. Dashed lines indicate cycle contacts. Legend as in Fig. 6.

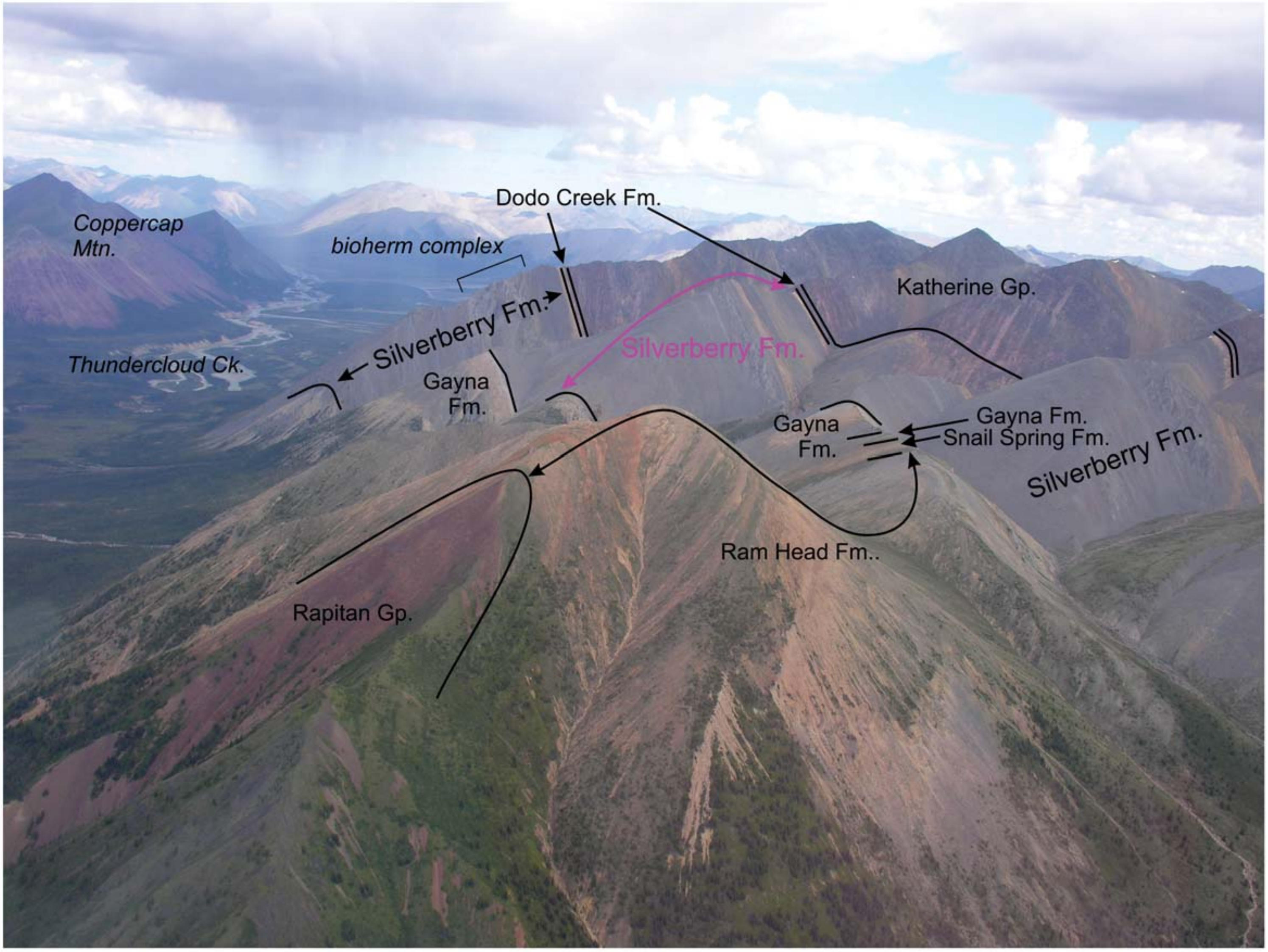


Figure 11. Photo of type section of Silverberry Formation (east-central NTS 95L). View to north. Pink line indicates line of measured section 79-AC-2 (Aitken et al., 2011). Although the oblique view gives an illusion of deformed bedding, the stratigraphy is continuous and layering dips steeply to the west (left).

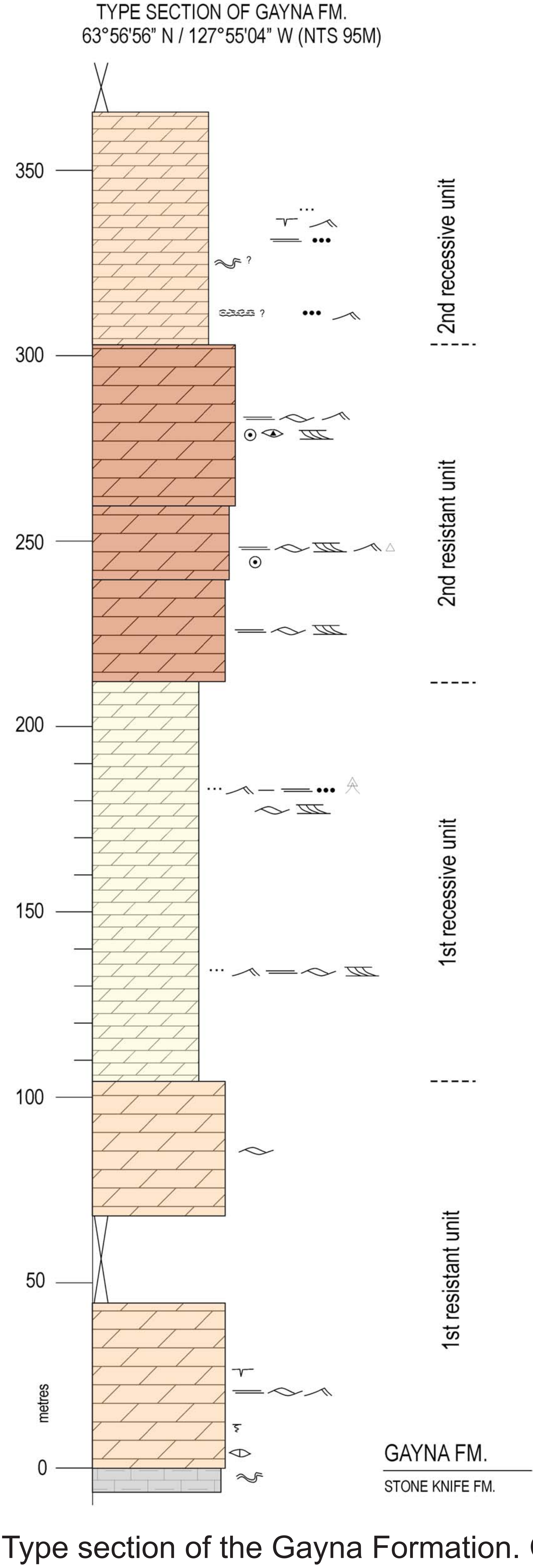


Figure 12. Type section of the Gayna Formation. Column width indicates weathering profile. Coloured fill indicates weathering colour. Legend as in Fig. 6.

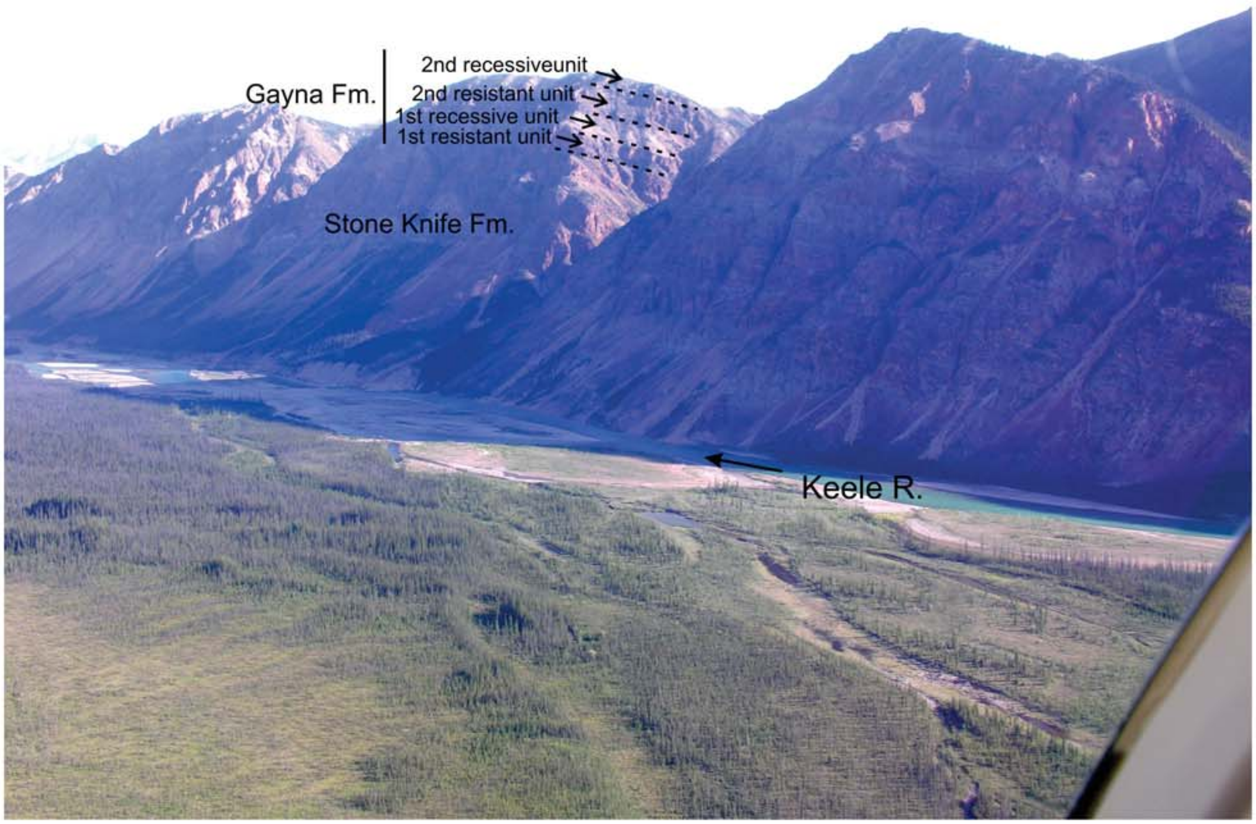


Figure 13. Photo of the type section of the Gayna Formation on east side of Keele River (northwestern NTS 95M). View to north. Line of section followed left side of valley in centre.

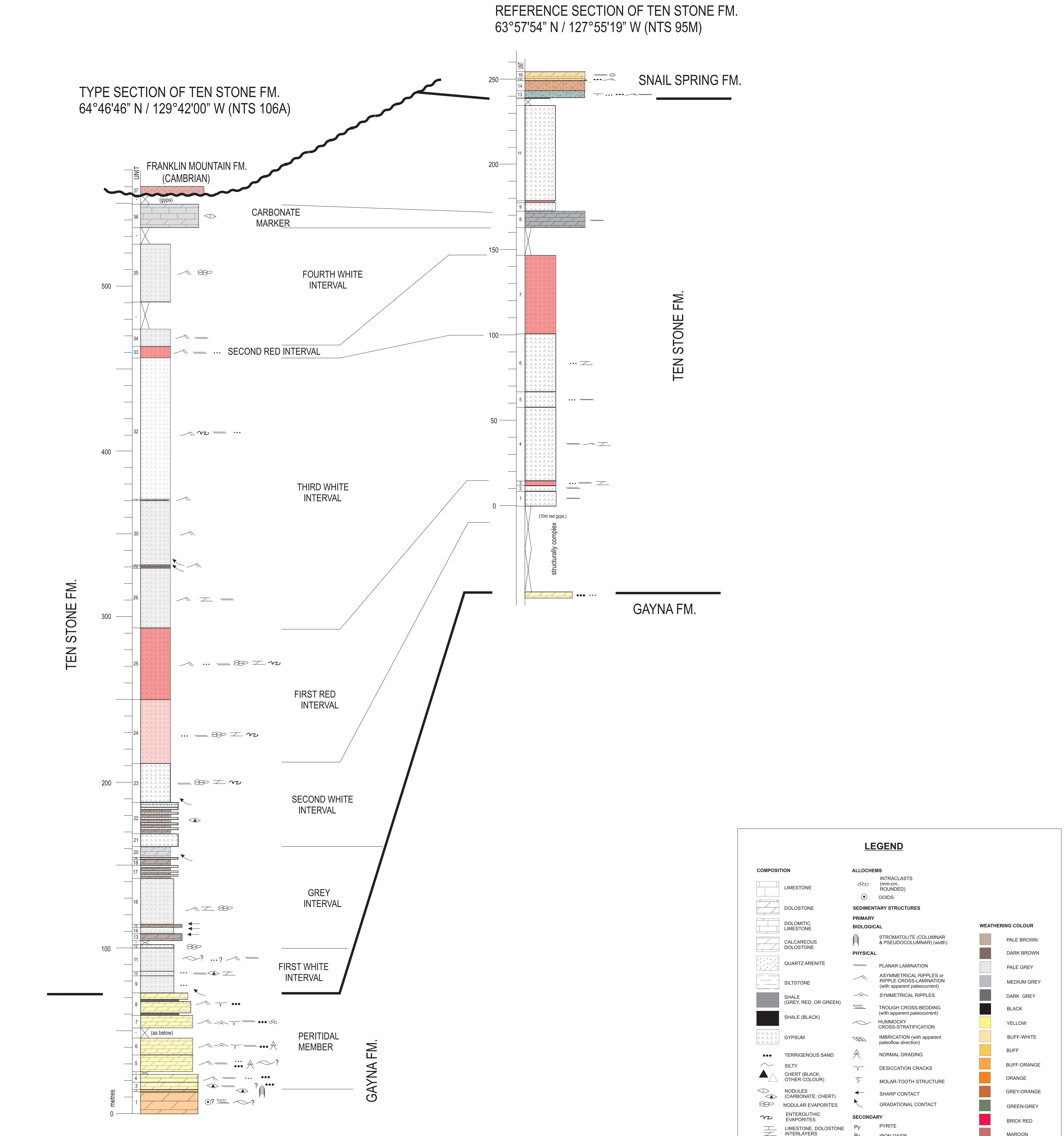


Figure 14. Type and reference sections of the Ten Stone Formation. Column width indicates weathering profile. Coloured fill indicates weathering colour. Legend as in Fig. 6.

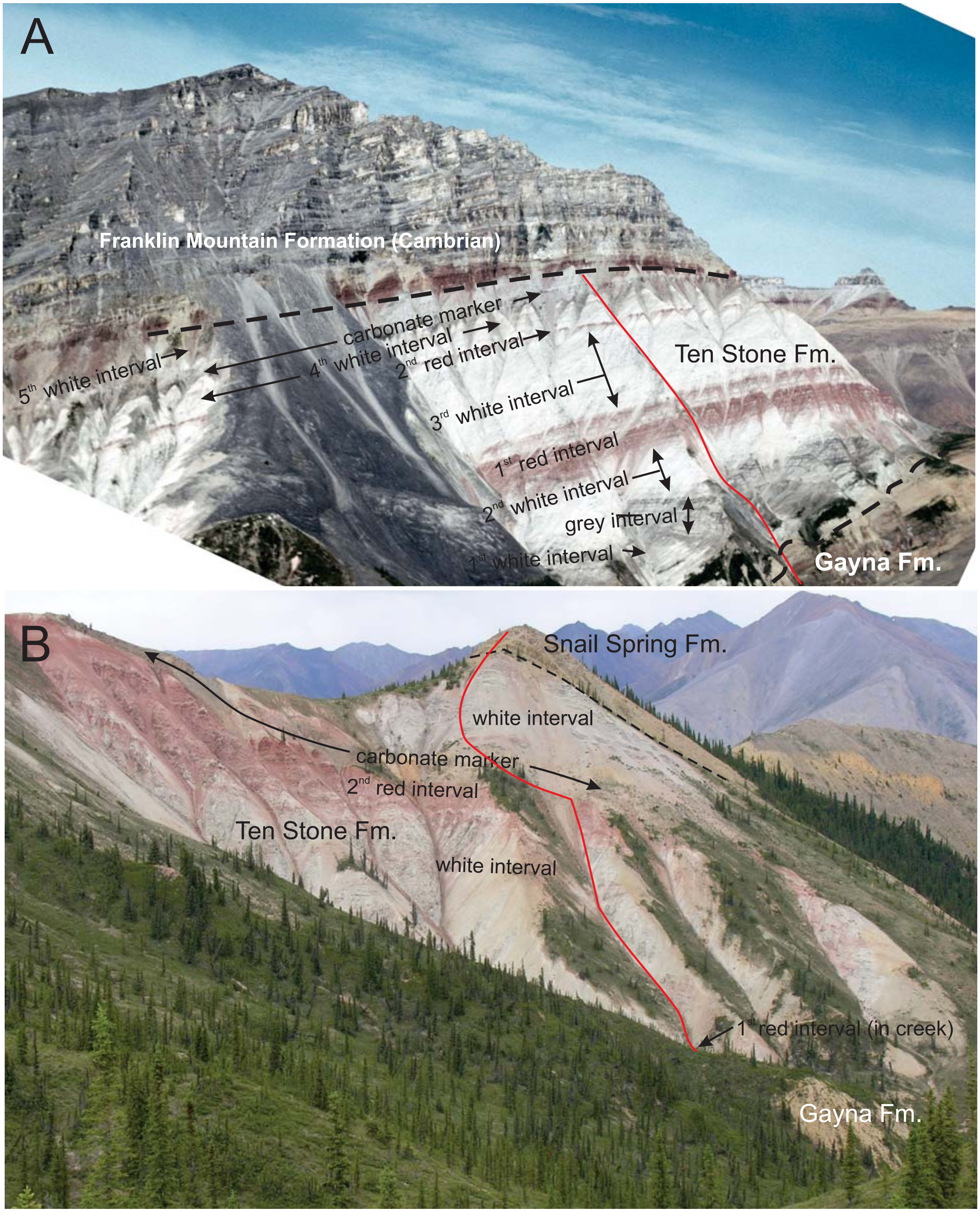
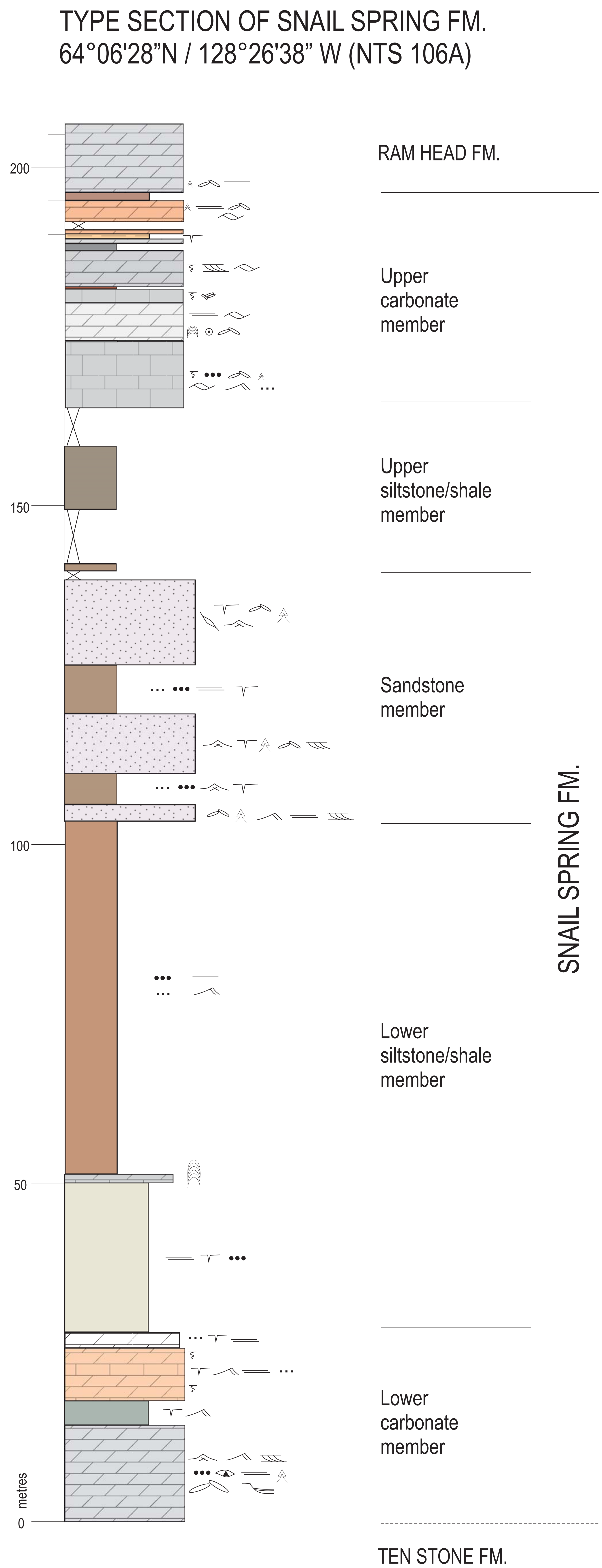


Figure 15. Type and reference sections of the Ten Stone Formation. (A) Type section of Ten Stone Formation west of Stone Knife River (northwestern NTS 106A) includes basal contact with Gayna Fm. View to northwest. (B) Reference section of Ten Stone Formation near Nidhe Brook (northwestern NTS 95M) includes upper contact with Snail Spring Formation. View to north. Red lines indicate lines of measured sections.



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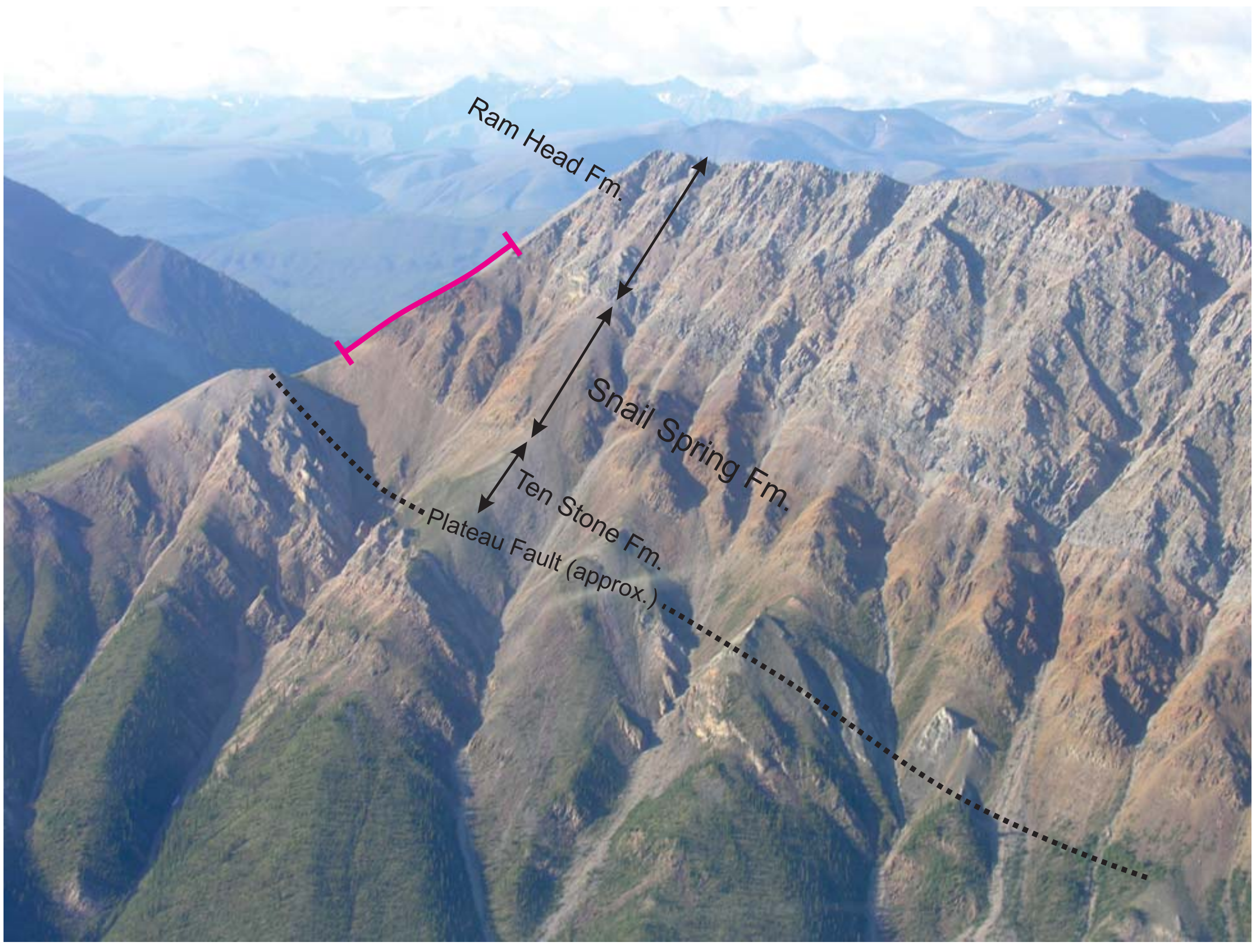


Figure 17. Photo of type section of the Snail Spring Formation on south side of Twitya River (southeastern NTS 106A). View to south. Pink line shows line of measured section.

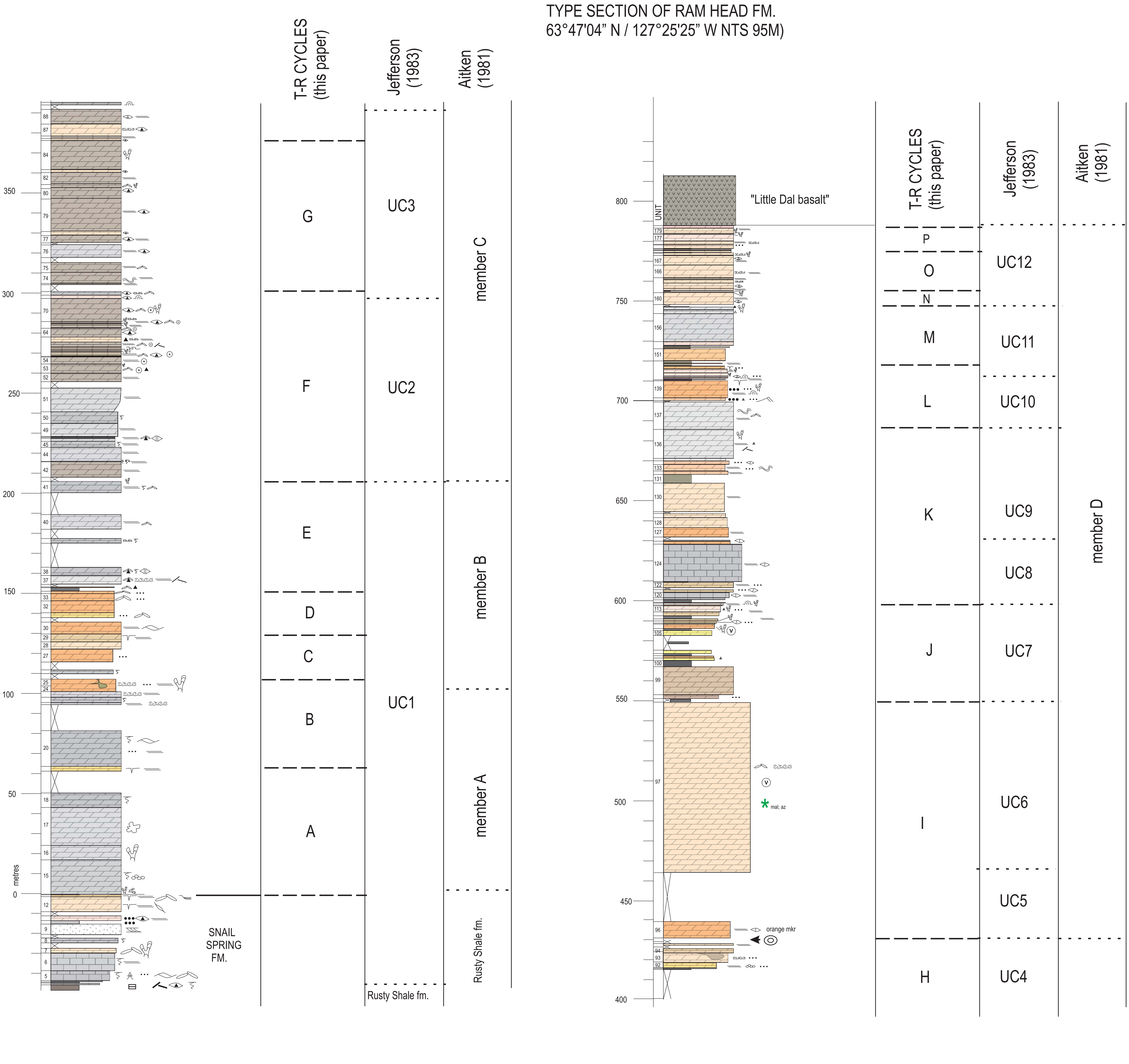
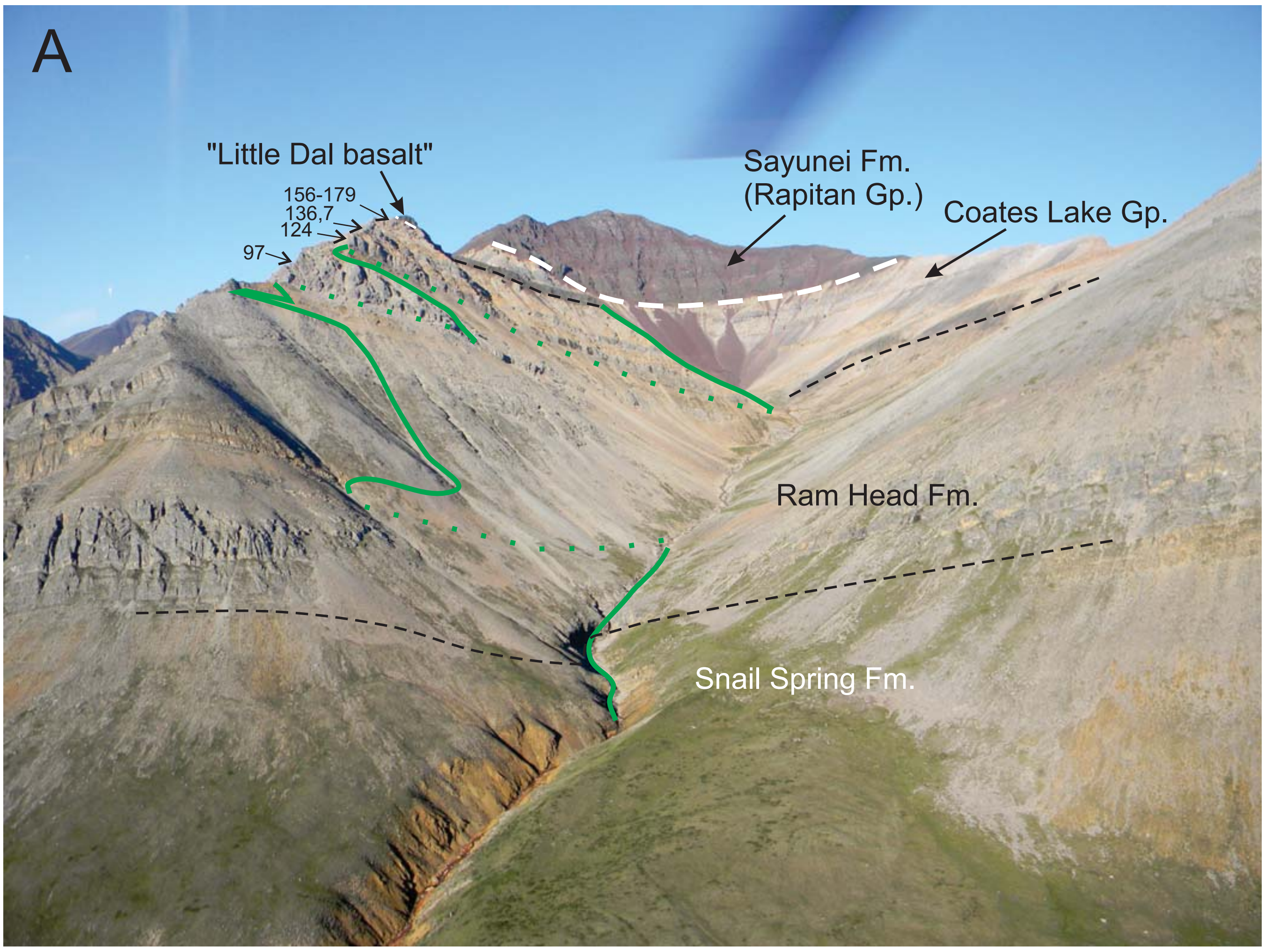


Figure 18. Type section of the Ram Head Formation. Column width indicates weathering profile. Coloured fill indicates weathering colour. Legend as in Fig. 6.



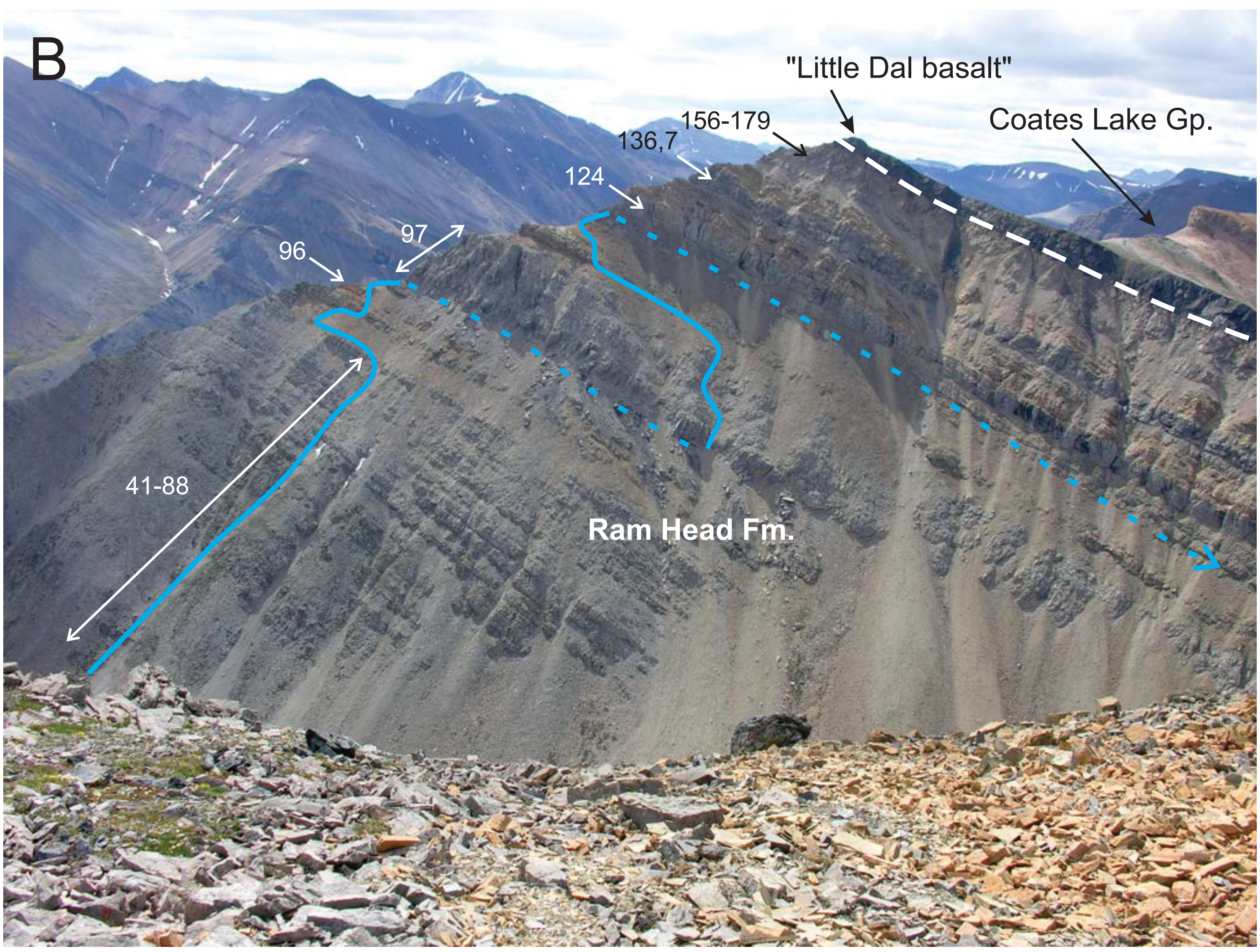


Figure 19. Photos of the type section of the Ram Head Formation near Boomerang Lake (northwestern NTS 95M). (A) Type section of Ram Head Formation; view to west. (B) Middle part of type section of Ram Head Formation; view to south. Numbers indicate unit numbers in accompanying stratigraphic log (Fig. 18); coloured lines show line of measured section, which continues on a ridge to right of photo.

Table 1. Type section locations for Tabasco Formation and seven formations in the Little Dal Group.

Formation Name	Abandoned informal name	Type section location	NTS sheet	Coordinates (base of t.s.) UTM z9	reference section(s)	previous references to type section
Tabasco Formation	"H1 unit"	Ramparts River	106G	420296 / 7232789	(none)	Usher, 1970; Aitken et a., 1973. 1978a, 1978b; Aitken and McMechan, 1991
Dodo Creek Formation	"Mudcracked formation"	Stone Knife River	106A	467550 / 7186500	Dodo Canyon	92-OC (Turner, 1999)
Stone Knife Formation	"Basinal assemblage"	Tigonankweine Range	96D	551365 / 7104400	Stone Knife River	79-AC-21 and 92-JS (Aitken, 1981, 1989; Turner et al., 1997, 2000a,b; Turner, 1999; Long et al., 2008; Aitken et al., 2011)
Silverberry Formation	"Platformal assemblage"	Silverberry River	95L	623990 / 6945202	(none)	79-2 (Aitken, 1981; Turner and Long, 2008; Aitken et al., 2011)
Gayna Formation	"Grainstone formation"	Keele River	95M	553032 / 7091762	Stone Knife River	77-AC-37 (Aitken, 1981; Aitken et al., 2011)
Ten Stone Formation	"Gypsum formation"	Stone Knife River	106A	466720 / 7184056	Nidhe Brook	07-SKR (Turner and Long, 2008)
Snail Spring Formation	"Rusty Shale formation"	Twitya River	106A	527097 / 7109128	(none)	77-AC-36 (Aitken, 1981; Aitken et al., 2011)
Ram Head Formation	"Upper Carbonate formation"	Boomerang Lake	95M	577693 / 7073952	(none)	section 55 (Jefferson, 1983; Jefferson and Parrish, 1989); 77-AC-40 (Aitken, 1981; Aitken et al., 2011)