Neoproterozoic and early Paleozoic correlations in the western Ogilvie Mountains, Yukon

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ABSTRACT

Continued investigations of sedimentary units in the Tatonduk and Coal Creek inliers of the western Ogilvie Mountains have resulted in a refinement of the regional Neoproterozoic and early Paleozoic stratigraphy. The proposed correlations simplify Yukon stratigraphic nomenclature and promote synthesis of geological data.

Strata of the Fifteenmile, Rapitan and Hay Creek groups, as well as the upper Windermere Supergroup are present in both inliers. Prominent unconformities within the Fifteenmile Group, and between the Windermere Supergroup and the variable overlying Paleozoic stratigraphy, represent at least three distinct tectonic events and basin-forming episodes.

We propose redefinition of the Fifteenmile Group, abandonment of the Tindir Group, and recognition of strata equivalent to the Coates Lake Group and Mackenzie Mountains supergroup. This refined nomenclature across the Ogilvie, Wernecke and Mackenzie mountains is a step toward enhanced regional correlation of exposures in the northern Cordillera and Proterozoic inliers of the western Arctic.

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INTRODUCTION

The Proterozoic stratigraphic record in the northwestern Canadian Cordillera is preserved in erosional windows through Phanerozoic strata (here termed 'inliers'; Fig. 1). Since early recognition of analogous sequences among these inliers (*e.g.,* Gabrielse, 1972; Eisbacher, 1978; Young *et al.*, 1979), correlation of units, particularly those with stratabound mineral potential, has been a principal goal in geological mapping and stratigraphic analysis. Correlations of early Neoproterozoic strata in the Ogilvie Mountains of the Yukon Territory (Abbott, 1997; Thorkelson *et al.*, 2005), the Mackenzie Mountains of the Northwest Territories (*e.g.*, Aitken, 1981; Eisbacher, 1981), and Victoria Island of Nunavut and Northwest Territories (Rainbird *et al.*, 1996; Young, 1981) were recently refined with chemo and litho-stratigraphy calibrated with U/Pb geochronology on zircons (Jones *et al.*, 2010; Macdonald *et al.*, 2010b; Medig *et al.*, 2010). We agree with previous researchers that the Lower Tindir and Fifteenmile groups are at least, in part, correlative with the Mackenzie Mountains supergroup (Abbott, 1997; Macdonald *et al.*, 2010b; Thorkelson *et al.*, 2005). We further extend stratigraphic correlations into the Cryogenian and Ediacaran periods and suggest that the Rapitan, Hay Creek and 'upper' groups of the Windermere Supergroup extend westward across Yukon.

In this paper, the Neoproterozoic and earliest Paleozoic strata are described based upon measured sections in the two western inliers (Coal Creek and Tatonduk; Fig. 2) of the western Ogilvie Mountains, about 100 km north of Dawson. Correlation of the Proterozoic strata has been challenging due to the paucity of age-defining fossils, the scarcity of isotopically dateable lithologies, and the unknown structural complications beneath broad valleys and between inliers that are 70 km apart. We systematically collected samples of carbonate rocks for stable isotope analysis, as well as igneous rocks for geochemistry and geochronology. Results will provide quantitative evidence to more conclusively determine the equivalency of regional units. Towards this goal, we herein describe the lithologic character of the many locally named units and seek to streamline the nomenclatures by using fewer and more wide-ranging stratigraphic terms.

THE COAL CREEK INLIER

Neoproterozoic strata in the Coal Creek inlier were separated from the Wernecke Supergroup by Norris (1981) and later mapped as the Mount Harper Group (Mustard and Roots, 1997) and the Fifteenmile Group (named after the headwaters of Fifteenmile River; Thompson *et al.*, 1987 and 1994). This latter informal unit was a provisional measure to distinguish older Neoproterozoic strata in the Coal Creek inlier from the Lower Tindir Group of the Tatonduk inlier and the Pinguicula Group in the Wernecke Mountains. The relationship of all these units to the Coates Lake Group and the Mackenzie Mountains supergroup of the Yukon-NWT border area was unclear. Our recent mapping, coupled with geochronologic and chemostratigraphic studies, provides a framework for correlating the Fifteenmile Group with other Neoproterozoic rocks throughout northwestern Canada (Macdonald and Roots, 2010; Macdonald *et al.*, 2010a).

Here we subdivide the Fifteenmile Group into two informal formations, the 'lower' assemblage and the Craggy dolostone. Overlying these is the Callison Lake dolostone (Abbott, 1997; Macdonald and Roots, 2010), which we propose should be grouped with the Lower Mount Harper Group and the Mount Harper volcanic complex. Furthermore, we believe the Upper Mount Harper Group (Mustard and Roots, 1997) should be dissolved and strata re-assigned to two existing groups (Rapitan, Hay Creek) and the 'upper' part of the Windermere Supergroup (James *et al.*, 2001).

FIFTEENMILE GROUP

The Fifteenmile Group was originally subdivided into upper and lower subgroups, containing three (PF1–PF3) and five (PR1–PR5) informally defined units, respectively (these units are shown on the regional map of Thompson *et al.*, 1994; suffix 'P' refers to Proterozoic). These authors suggested that the lower Fifteenmile Group was intruded by breccia equivalent to the *ca.* 1600 Ma Wernecke breccia (age reported in Abbott, 1997). However, Medig *et al.* (2010) demonstrated that PR1 overlies a regolith formed within the breccia, and that all of the lower subgroup is younger. Moreover, a tuff recovered within strata previously mapped as PR4 (revised to PF1a to reconcile inconsistencies of previous mapping) was dated at 811.51 ± 0.25 Ma (U/Pb ID-TIMS; Macdonald and Roots, 2010; Macdonald *et al.*, 2010b). Thus the lower Fifteenmile Group is considered much younger than the Wernecke breccia as noted by Thorkelson *et al.* (2005). Medig *et al.* (2010) suggested that PR1-PR2 are correlative with units A-C of the Pinguicula Group, however, this correlation remains to be tested with further mapping, geochemistry, and geochronology.

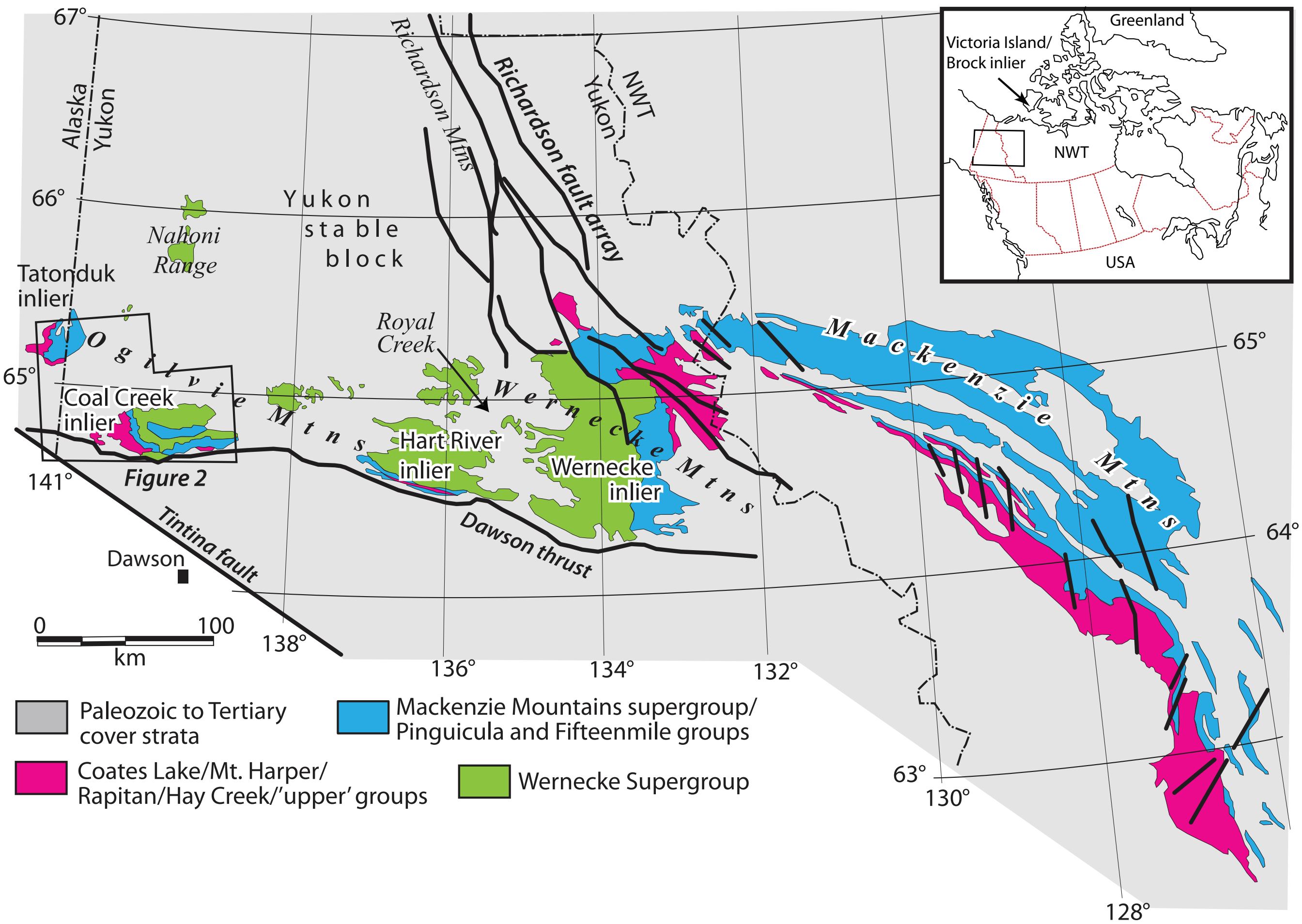

Figure 1. *Distribution of Proterozoic strata in the Ogilvie, Wernecke and Mackenzie Mountains. Modified from Abbott (1997) and Young et al. (1979).*

The former map units PR3-PR5, and PF1a are here discarded for two reasons. First, they represent a complex stratigraphic package with prominent lateral facies changes that are unsuited for lithostratigraphic correlation. Second, we have found them to be significantly mis-mapped throughout the Coal Creek inlier. Therefore we refer to this package, >1000 m of mixed carbonate and siliciclastic rocks, as the 'lower' assemblage of the Fifteenmile Group, pending resolution of its lowermost extent. A tuff within the upper portion of the 'lower' assemblage constrains its depositional age to 811.51 ± 0.25 Ma (Macdonald *et al*., 2010b). These strata are succeeded by the Craggy dolostone (informal term; formerly PF1), which is in turn unconformably overlain by the Callison Lake dolostone (Abbott (1997), correlated with former PF2 and PF3 by Macdonald and Roots (2010)). The Callison Lake dolostone consists of >300 m of microbially bound dolostone bracketed by intervals of shale.

In the 2008–2010 field seasons we measured ten detailed stratigraphic sections of the Fifteenmile Group. Our work outlined a network of stromatolitic buildups that occur between the inner shelf and upper slope facies on a northwest-facing (present coordinates) margin. In the south-central part of Coal Creek inlier, the lowermost unit of the 'lower' assemblage (formerly PR1) is exposed in a syncline to the northwest of Mt. Gibben, and in minor exposures occurring along strike to the west. On the north limb of the syncline, this lower siliciclastic unit is ~320 m thick (Fig. 4, section E1003), and consists primarily of weakly foliated, brown to grey-coloured siltstone and shale, as well as large carbonate blocks and conglomerates interpreted as olistostromes (Fig. 5a) and debris flows, respectively. Carbonate blocks are over 10 m in diameter and bedding is discordant to the supporting siliciclastic matrix. Deposition appears to be fault-controlled and the unit thickens along a syn-sedimentary northwest side-down fault (Roots and Thompson, 1992). This interpretation is

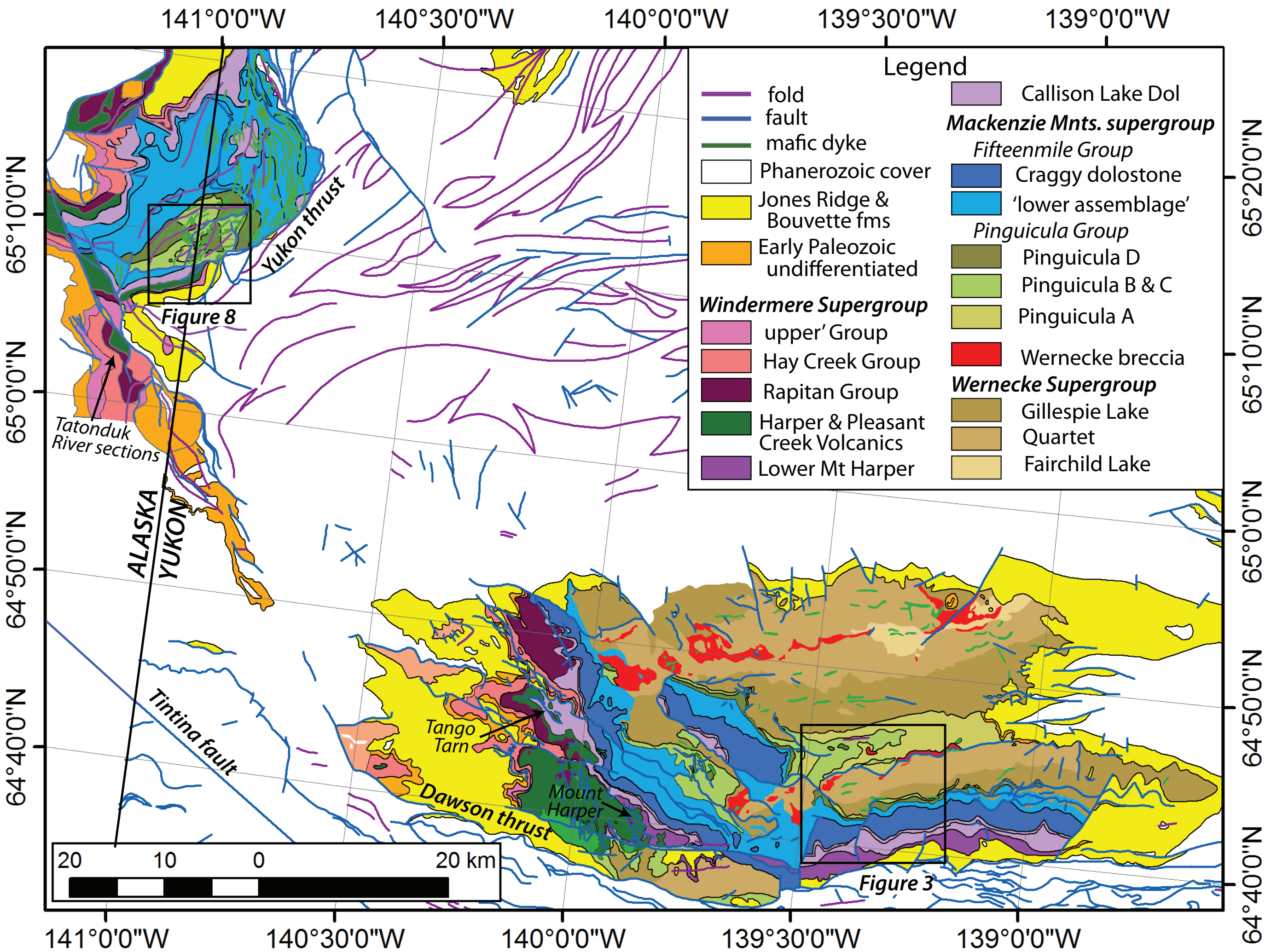

Figure 2. *Distribution of Neoproterozoic units in the Tatonduk and Coal Creek inliers of the southern Ogilvie Mountains. Map units are based on Thompson and et al. (1994) and Van Kooten et al. (1997), and revision and assignment of names are discussed in the text.*

supported by the abundance of larger olistostromes in the southernmost exposures. The olistostrome-bearing carbonates are overlain by >500 m of yellow to blue-grey weathering carbonate rocks (Fig. 5b). These strata were previously mapped as PR2 (Thompson *et al*., 1994) and correlated with the Pinguicula Group (Medig *et al.,* 2010), but it is unclear if they represent a distinct rock package or are facies change of the lower assemblage. Consequently, pending further study we herein map these units as 'Fifteenmile Group undifferentiated' (Figs. 2 and 3).

In the most proximal section (E1002; Fig. 5c), the 'lower' assemblage begins with ~100 m of blue-grey dolomite with oolitic grainstone and stromatolites. These are overlain by ~500 m of lilac to black-coloured shale and coarse clastic rocks, and an additional ~500 of carbonate mudstone, grainstone and stromatolites. The carbonate mudstone includes dark-coloured limestone and commonly contains molar tooth structures. The grainstone and stromatolite beds are typically light grey to buff-coloured dolostone. At the northwest end of the Coal Creek inlier, measured sections reveal symmetric transgressive-regressive sequences defined by the northwest progradation of stromatolitic buildups in low-stand sequence tracts.

These sequences culminate with the deposition of the Craggy dolostone (PF1), a regionally extensive, conspicuous white dolostone that is >500 m thick (Fig. 5c). The Craggy dolostone consists predominantly of massive, recrystallized and silicified grainstone. Occasionally, microbialaminites and low-relief stromatolites (up to 10 cm of relief) are visible. Recrystallized ooids, coated grains, brecciated teepee structures, flat-chip conglomerates, interclast breccias and low-angle crossbeds are also

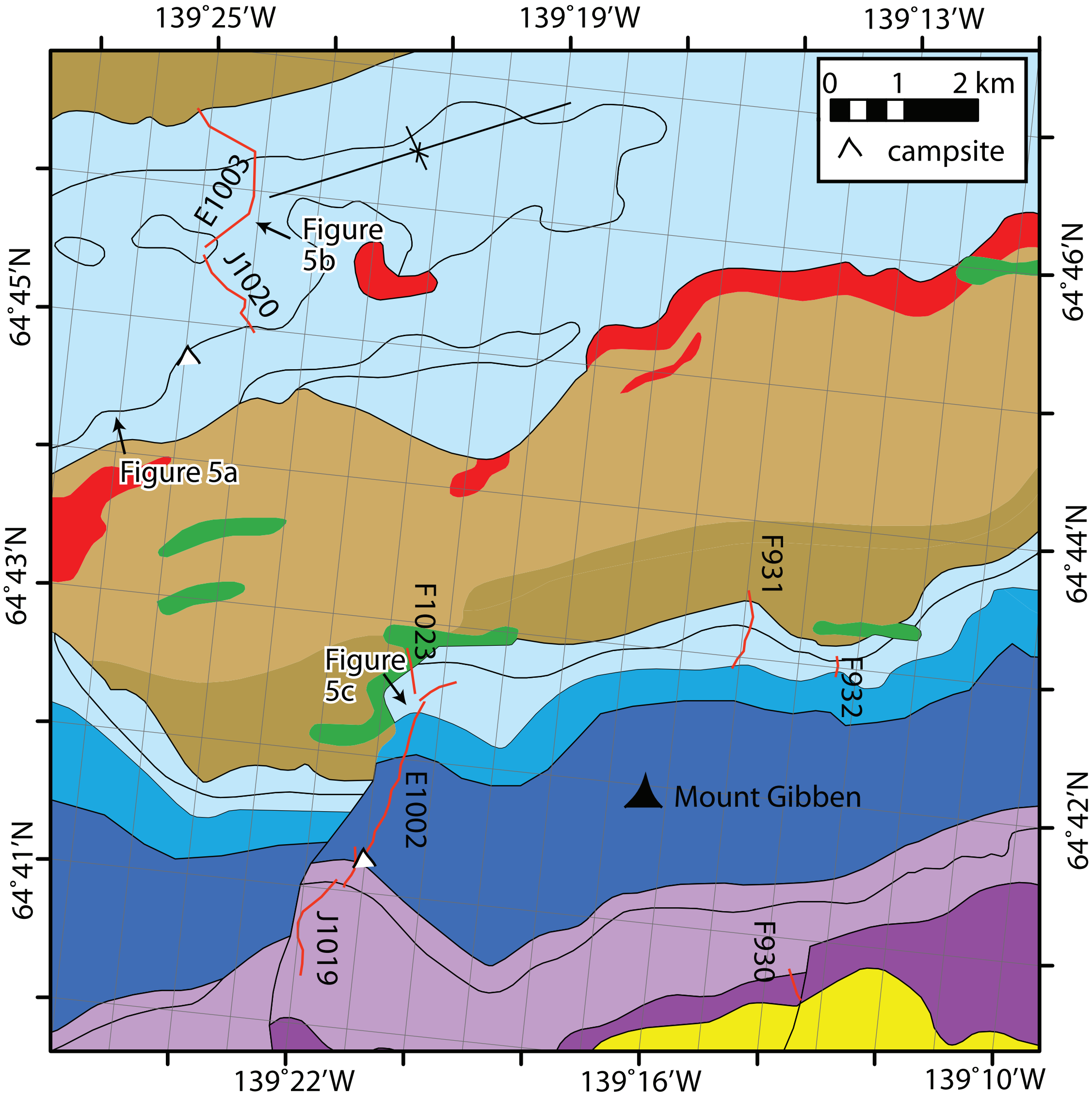

Figure 3. *Geological map of a part of the Coal Creek inlier, illustrating the locations of sections displayed in Figure 4. Modified from Thompson et al. (1994) with new mapping. Colour of units matches the legend in Figure 2.*

sometimes present. The Craggy dolostone does not contain any siltstone, mudstone, or shale, and its base is defined by the contact between the last black shale and the massive dolostone. This is an important point because in the most proximal sections, large, massive stromatolitic buildups in the overlying Callison Lake dolostone resemble the Craggy dolostone.

The Craggy dolostone is succeeded by the Callison Lake dolostone (previously part of the Upper Fifteenmile Group; Macdonald and Roots, 2010). Near Mt. Gibben, the Callison Lake dolostone is well exposed and measures over 500 m thick (Fig 4; section J1019). Here, the basal ~75 m consists of siltstone and shale with laterally discontinuous bioherms. The black shale has a peculiar waxy luster, which consists almost exclusively of sedimentary talc (Macdonald and Roots, 2010). The black shale also contains talc rip-up clasts supported in a nodular dolomicrite matrix and abundant black chert nodules. This shale was previously mapped as unit PF2 and is succeeded gradationally by over 400 m of silicified dolostone of PF3, which is characterized by stromatolites, microbialaminite and intraclast conglomerate. An additional ~25 m of interbedded black talc and dolomitic microbialite is present at the top of these strata. We consider the entire shale-carbonate sequence as the Callison Lake dolostone

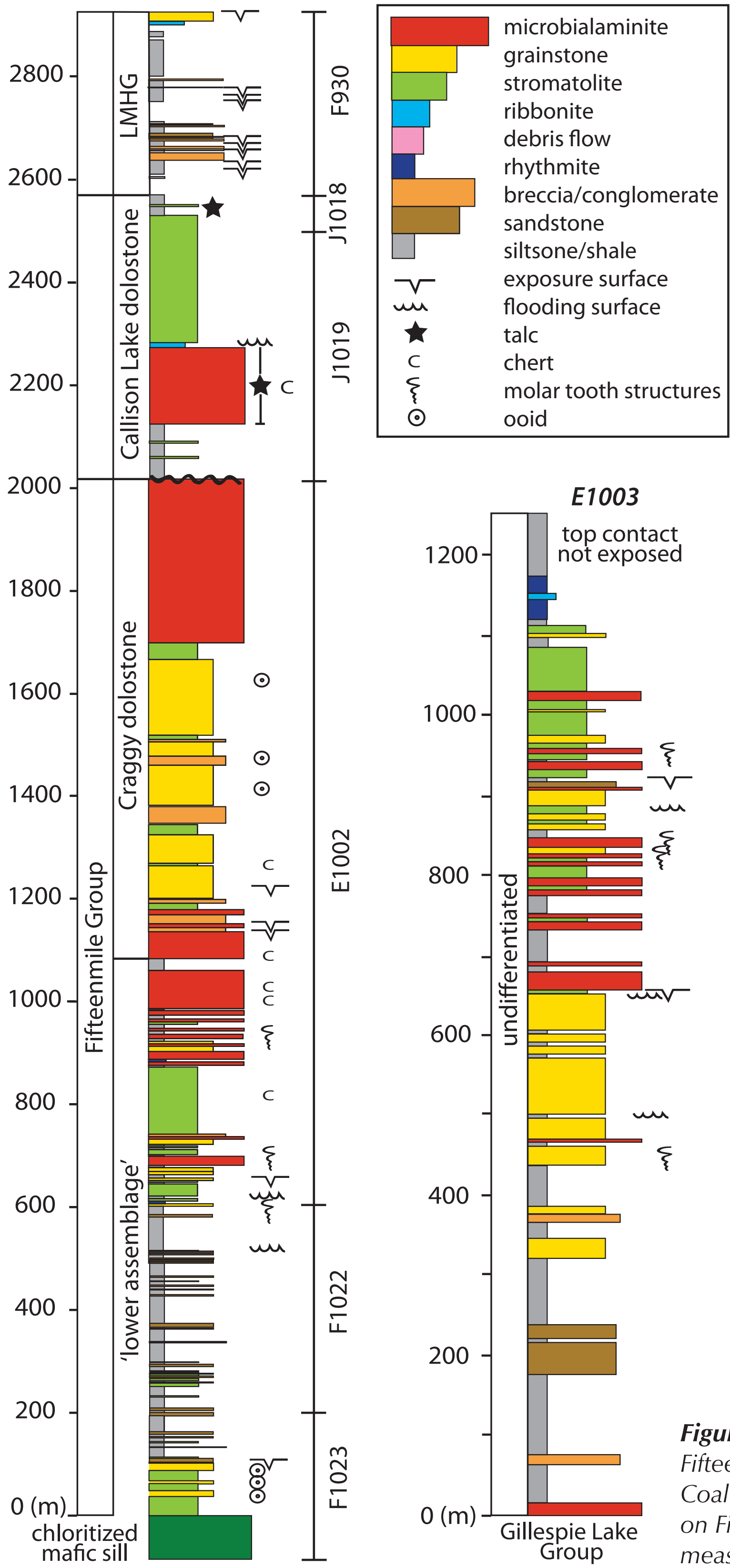

Figure 4. *Measured stratigraphic sections of the Fifteenmile Group west, and south of Mt. Gibben, in the Coal Creek inlier. Locations of the sections are shown on Figure 3. Section on the left is a composite of six measured sections indicated to the right of the column. LMHG: Lower Mount Harper Group*

because we interpret them to be genetically related. This nomenclature minimizes new terminology and allows straightforward stratigraphic correlations between the Coal Creek and Hart River inliers.

The low-angle unconformity at the base of the Callison Lake dolostone in the Hart River inlier (Abbott, 1997; Macdonald and Roots, 2010) suggests the commencement of an additional basin-forming episode. It is at an equivalent stratigraphic position, and possibly analogous to, the Coates Lake Group of the Mackenzie Mountains. Stratigraphic sections measured through this map unit in the Ogilvie Mountains reveal significant thickness and facies variations. Furthermore, in the western Coal Creek inlier, a wedge of proximal conglomerate and hematitic siltstone were deposited atop the Callison Lake dolostone by an adjacent normal fault, which was overstepped by subaqueous to subaerial volcanism (Lower Mount Harper Group and volcanic complex of Mustard and Roots, 1997; see below).

LOWER MOUNT HARPER GROUP

The Lower Mount Harper Group (LMHG) conformably overlies the Callison Lake dolostone. Near Mount Harper it is exposed on the north side of a syn-depositional fault scarp (the Mount Harper fault; Mustard and Roots, 1997) where it consists of up to 1100 m of talus breccia and debris flow conglomerate interpreted to represent coalescing alluvial fans (Mustard, 1991; Mustard and Donaldson, 1990). To the east, in the Mt. Gibben area, the LMHG is as thick as 300 m and consists predominantly of red beds commonly containing mudcracks, and conglomerate interbedded with minor carbonate rocks that were deposited in a distal fan environment (Fig. 4; Section F930).

THE MOUNT HARPER VOLCANIC COMPLEX

The Mount Harper volcanic complex (MHVC) is divided into six informal units that are defined both stratigraphically and compositionally (Mustard and Roots, 1997; Roots, 1987). A lower suite, constituting members A–C, are basaltic and comprise several hundreds of metres of pillowed and massive flows in both subaqueous and subaerial breccia. The lower flows overlie sandstone, siltstone and cobble conglomerate north of the Harper fault (Fig. 5d), a pre-volcanic, north side-down scarp. Soft-sediment roll-ups, dolostone rip-ups and spiracles (steam-generated cavities) attest to the soft, damp substrate encountered by the initial lava flow (Fig. 5d). The basal flows on the south side of the Harper fault disconformably overlie thickly bedded dolostone of Pinguicula unit B or C, attesting to uplift and erosion of the fault block prior to volcanism.

Volcanic members A and B formed an edifice up to 1200 m thick. Some of the later eruptions were subaerial, producing agglutinate spatter cones and hematitic, autobrecciated massive flows. Holocene erosion has provided cross sectional views of the edifice in which outward dipping paleo-slopes and tapering eruption units are discernible. Other steep exposures reveal that the edifice was unevenly dissected during, or shortly after, members A and B were extruded, resulting in overlaps by tuff-breccia, lapilli tuff, and block-and-ash breccia deposits of member C. The clasts are either primary basaltic, or derived from erosion.

Member A has the highest Mg/Fe ratio and is considered the most primitive magma although its high large-ion lithophile (LIL) concentrations suggest some crustal contamination. Subsequent flows and sheeted intrusions within member B have decreased Mg/Fe and more uniform composition. Incompatible element abundance diagrams yield patterns that approximate those of typical ocean island volcanic suites, such as Hawaii (Mustard and Roots, 1997).

The Upper suite consists of three members: D (rhyolite), E (andesite) and F (andesite). They are three distinct units, but their relative timing and original distribution remain unclear. In different places, each unit unconformably overlies members A–C. Despite their different rock types, members D and E are similarly enriched in large-ion lithophile elements and may have erupted from a compositionally differentiated magma chamber. The rhyolite is exposed as thick flows and probable domes. Member E forms cliff exposures of columnar-jointed and shattered massive flows; these prograde over an apron of angular flow shards ('hydroclastic breccia') that is extensive atop the older edifice. Epiclastic sedimentary units preserved as erosional outliers in the complex contain abundant clasts derived from members D and E.

Member F andesites form pillowed flows, breccias, tuffs and invasive flows that interfinger with, and intrude into, diamictites of the Rapitan Group. The scarcity of mafic minerals and relatively high concentration of most incompatible elements could have resulted from mixing a relatively primitive magma pulse with an evolved andesite such as member E. Sedimentary strata that overlie the western and northwestern part of the volcanic complex contain thin flows believed to be compositionally related to member F (*e.g.,* Green Shelter section; Fig. 7). In summary, a period of unknown duration separates the lower from the upper suite, during which time a fractionated magma evolved, and the last phase of volcanism was sporadic. Member D was dated at 717.43 ± 0.14 Ma (U/Pb ID-TIMS; Macdonald *et al.*, 2010b), but the age of the lower members of the MHVC is unknown.

RAPITAN GROUP

At Tango Tarn and on the south flank of Mount Harper (Macdonald *et al.*, 2010a, supplementary online material at www.sciencemag.org/content/327/5970/1241/suppl/DC1), a maroon-coloured mudstone with pebble to cobble-sized lonestones of dolomite and volcanic rocks forms the base of the Rapitan Group (formerly PH1; Thompson *et al.*, 1987; Mustard and Roots, 1997). These strata resemble, in colour, texture and stratigraphic position, the glacially influenced Sayunei Formation of the Rapitan Group in the Mackenzie Mountains (Eisbacher, 1978; Yeo, 1984). An ~1 m-thick, green to pink, brecciated tuff that is above the maroon stratified diamictite yielded a 716.47 ± 0.24 Ma U/Pb ID-TIMS zircon age (Macdonald *et al.*, 2010b). The tuff interfingers with a massive diamictite unit that is >10 m thick and consists of dolomite and volcanic boulder clasts suspended in a carbonate matrix. Above the massive diamictite is an additional ~10 m of fine-laminated, yellow-weathering carbonate mudstone with bed-penetrating dropstones that are interpreted as glacial in origin (Fig. 5e). Approximately 10 km north of Tango Tarn, ice till pellets (Fig. 5e) and striated clasts were also identified (Fig. 5f), further supporting a glacial origin for this deposit. In both the Coal Creek and Hart River inliers, plow structures and highly convoluted soft-sedimentary deformation suggest the presence of grounded ice (Macdonald *et al.*, 2010b). Furthermore, a granitic clast was discovered in the Rapitan Group in the Coal Creek inlier testifying to an exotic origin of some clasts.

Figure 5. *Field photos from the Coal Creek inlier. Figures 5a-c are from localities near Mt. Gibben with locations shown in Figure 3.* ***(a)*** *Large carbonate olistostromes (outlined in red) in siltstone of the 'lower' assemblage of the Fifteenmile Group; view is to the north.* ***(b)*** *Measured section E1003 through the undifferentiated Fifteenmile Group; view is to the west.* ***(c)*** *Measured section E1003 through the 'lower' assemblage; view is to the south; students for scale.* ***(d)*** *The lowest flow of the Mount Harper volcanic complex directly overlies (at scale card in circle) red and tan siltstone and sandstone beds of the Lower Mount Harper Group. Contact is conformable and exposed in north-facing gully 1 km north of Mount Harper.* ***(e)*** *Carbonate dropstone and grit in laminated orange dolomicrite matrix. Note the till pellet in the top right corner of the sample. This sample was extracted from outcrop of the Rapitan Group ~12 km north of Tango Tarn.* ***(f)*** *Striated clasts of the Rapitan Group, from subcrop ~10 km north of Tango Tarn. Coin is 2.5 cm across.*

HAY CREEK GROUP

The Hay Creek Group (Yeo, 1978; Young *et al.*, 1979) was proposed to encompass the Twitya and Keele formations in the Mackenzie Mountains. In its original usage, it was essentially a clastic to carbonate grand cycle. Later studies in the region defined the Icebrook Formation (Aitken, 1991) and documented 'cap carbonate' lithologies that were first referred to as the Tepee dolostone (Eisbacher, 1985) and later as the informal Hayhook and Ravensthroat formations (James *et al.*, 2001). All of these units should be included in a contemporary definition of the Hay Creek Group (R. MacNaughton, pers. comm., 2010).

In the Coal Creek inlier, the Rapitan Group is succeeded by <100 m of poorly exposed siltstone and limestone (formerly PH2) herein assigned to the Hay Creek Group. This unit commences with <10 m of dolomite breccia. While a genetic interpretation of this breccia is unclear, it is overlain by a white to buff-coloured, fine-laminated dolostone with abundant bed-parallel cements (sheet-crack) that shares textural and geochemical similarities with the Hayhook formation (James *et al.*, 2001) and basal Ediacaran cap carbonates world-wide (Hoffman *et al.*, 2007).

THE 'UPPER' GROUP

In the Mackenzie Mountains, the Sheepbed, Gametrail, Blueflower and Risky formations (*e.g.,* Aitken, 1989; Dalrymple and Narbonne, 1996; MacNaughton *et al.*, 2000; MacNaughton *et al.*, 2008) have provisionally been considered to comprise the informal 'upper' group of the Windermere Supergroup. Although details of correlation are controversial (see summary in MacNaughton *et al.*, 2008), these units have been considered to form two clastic-carbonate grand cycles that predate the deposition of Cambrian sandstone (Backbone Ranges Formation). This group completes Windermere Supergroup sedimentation.

In the Coal Creek inlier, the 'upper' group (formerly PH3-PH5) is exposed along the ridge and saddle due north of Tango Tarn (Fig 6; section F838) where it begins with ~250 m of black shale that directly overlie brecciated dolomite beds. The thick shale succession is succeeded by ~25 m of massive white to buff-coloured dolostone and an additional ~100 m of thinly bedded, pink dolo-rhythmite, ribbonite and grainstone with hummocky cross-stratification. The 'upper' group culminates with ~10 m of dark-coloured, nodular, organic-rich limestone. These carbonate beds are overlain disconformably by as much as 170 m of siliciclastic rocks (formerly PH5) that include simple trace fossils such as *Cruziana* and *Rusophycus*, thought to be early Cambrian in age (Mustard *et al*., 1988); in some instances, the beds are unconformably overlain by the Cambrian-Devonian Bouvette Formation.

BOUVETTE FORMATION

The Bouvette Formation was formally named by Morrow (1999) to describe a thick sequence of Cambrian to Devonian dolostone and limestone that outcrops extensively throughout central and northern Yukon. These strata characterize the geographic limits of the Yukon Stable Block (YSB) and encompass all strata mapped as unit CDb of Operation Porcupine (Norris, 1997; Morrow, 1999) and Unit 8 of the Nash and Larsen Creek map areas (Green, 1972). The Bouvette Formation commonly overlies a variety of Proterozoic strata in the southwestern parts of the YSB and conformably overlies the Cambrian Taiga Formation (or its equivalents) in the southeastern parts of the YSB (Morrow, 1999). The Ordovician to Silurian Road River Formation commonly succeeds Bouvette Formation and is laterally equivalent to parts of it, except in the Dave Lord region (Morrow, 1999). The type section of the Bouvette Formation was chosen by Morrow (1999; MTA-86-11; #36) 80 km north of Mount Harper in the northern Ogilvie Mountains.

Only two stratigraphic sections of the Bouvette Formation have been measured in the southern Ogilvie Mountains (Morrow, 1999, sections MTA-86-5 (4) and MTA-86-25 (7)). These strata unconformably overlie variable Proterozoic strata and record incomplete thicknesses ranging from 432 to 987 m. They predominantly consist of highly silicified, thick-bedded, very light grey dolomitic grainstone with abundant vugs and occasional microbial fabrics. Revisional mapping and preliminary descriptions of various outcrops of the Bouvette Formation in the Coal Creek inlier and further north in the Nahoni Ranges was carried out in 2010. However, the lack of significant relief and characteristic blocky weathering of the Bouvette Formation precluded logging detailed stratigraphic sections. Future study near Morrow's type section and near Royal Creek in northeastern Ogilvie Mountains will establish the sedimentological and chemostratigraphic characteristics of this map unit.

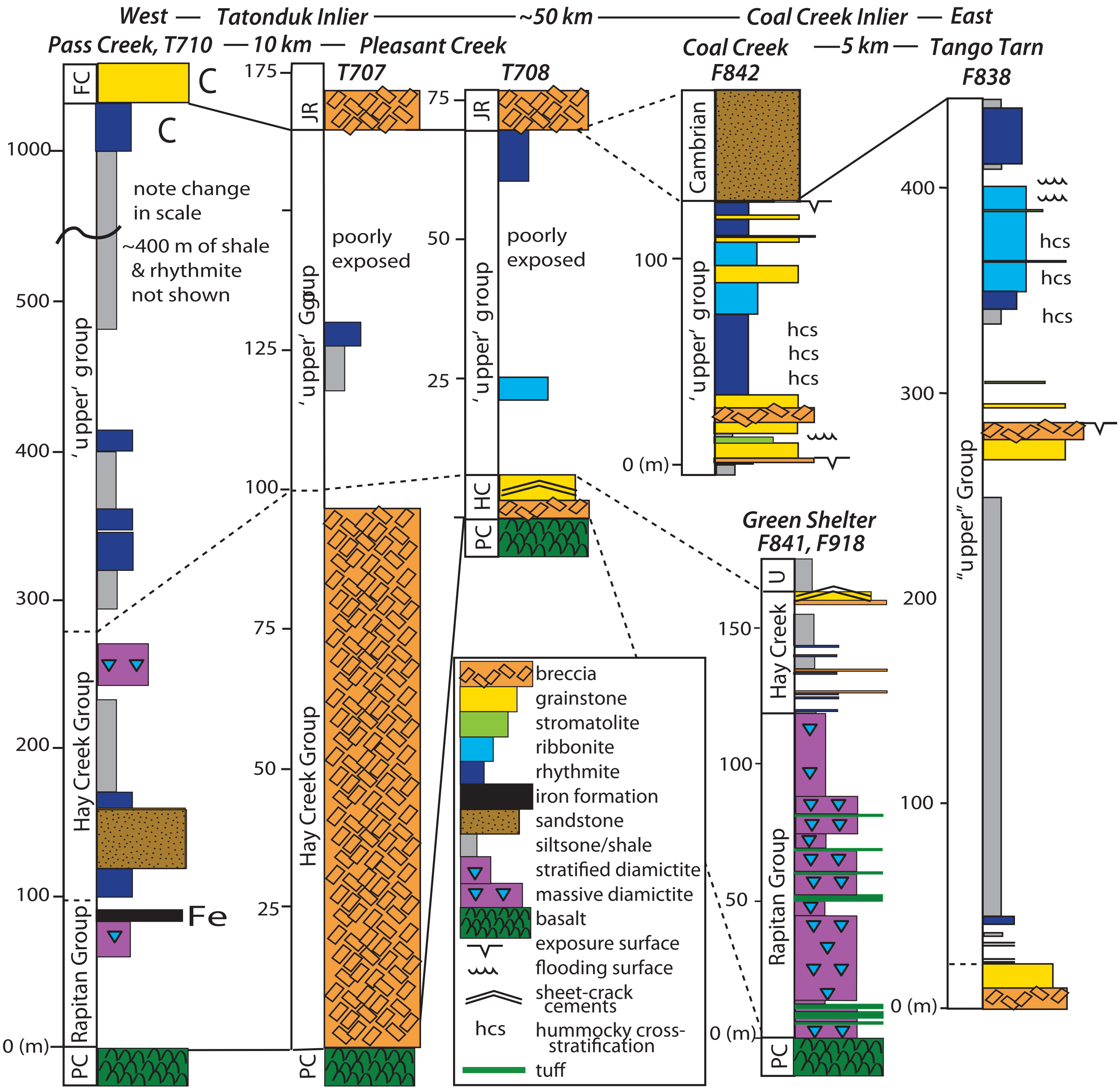

Figure 6. *Measured stratigraphic sections of the Rapitan Group, Hay Creek Group and 'upper' group. Locations are shown on Figures 3 and 8, and in Macdonald et al. (2010a,b). Vertical scale varies. 'FC' = Funnel Creek limestone; 'JR' = Jones Ridge limestone; 'PC' = Pleasant Creek volcanics.*

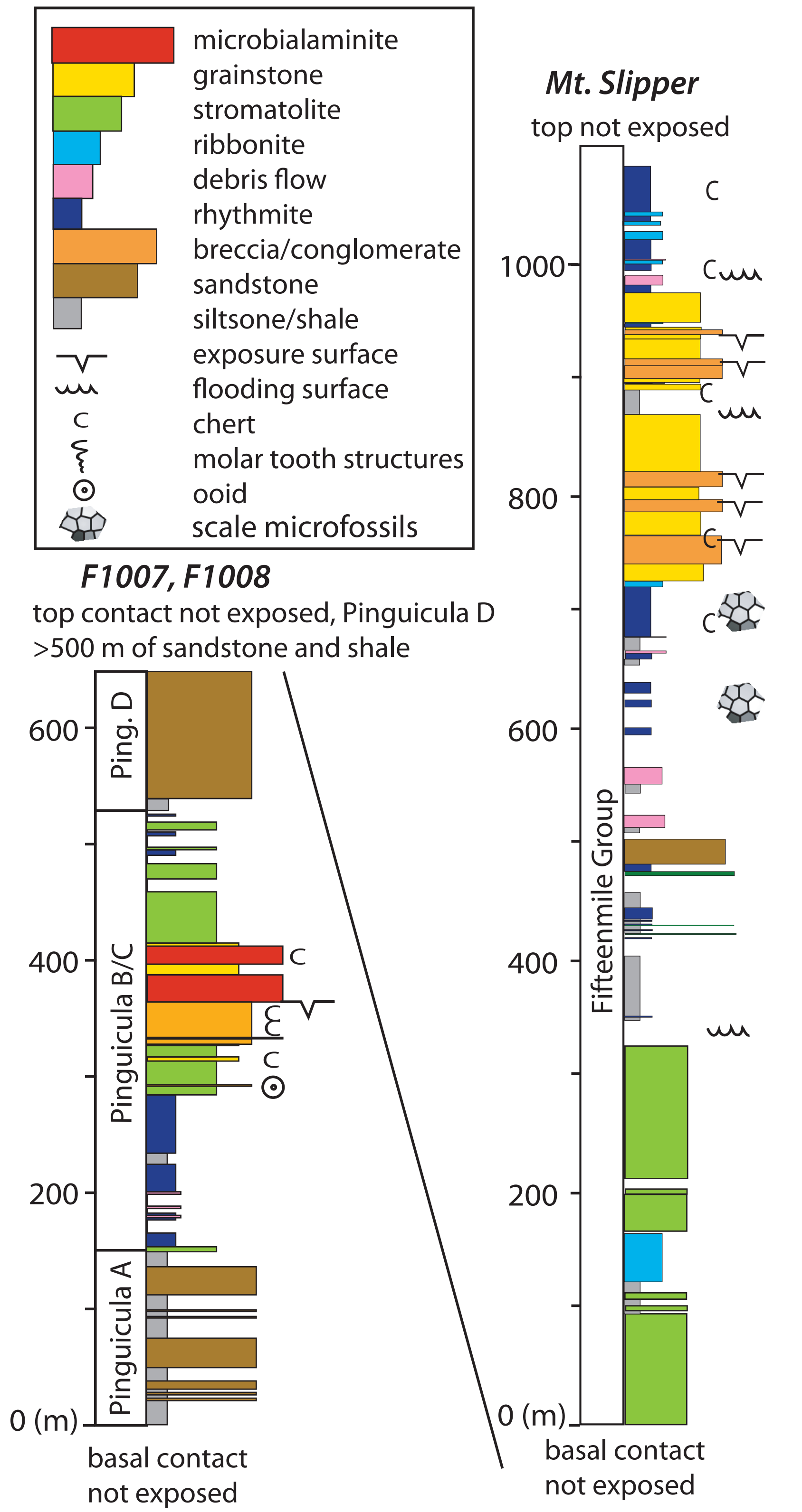

Figure 7. Measured stratigraphic sections of the Pinguicula Group near Pleasant Creek and at Mt. Slipper in the Tatonduk inlier. Locations are shown on Figure 8 and coordinates for the base are in Appendix 1.

THE TATONDUK INLIER

Cairnes (1915) referred to Precambrian stratigraphy exposed along the international border as the Tindir Group. Mertie (1930 and 1933) described the stratigraphy (and natural history) of the region in remarkable detail and recognized seven units in the Tindir Group. Brabb and Churkin (1969) produced a detailed geologic map of the Tindir Group on the Alaskan side of the border. The same stratigraphy was mapped on the Yukon side by Norris (1979). However, exact correlations of specific units of the Tindir Group across the border remained ambiguous until the completion of more recent mapping and compilation (Van Kooten *et al.*, 1997) and integrated litho and chemostratigraphy (Macdonald *et al.*, 2010a,b).

The informal division of the Tindir Group into the Upper and Lower Tindir groups was first distinguished by Payne and Allison (1981), despite the fact that no unconformable contacts had been observed between them. Young (1982) extended their work by separating the Lower Tindir Group into six informal units and the Upper Tindir Group into five informal units. The Lower Tindir Group units of Young (1982) were further modified by Van Kooten *et al.* (1997) and Macdonald *et al.* (2010a). Importantly, Van Kooten *et al.* (1997) identified an angular unconformity within the Lower Tindir Group. We have examined these units in part of the inlier drained by Pleasant Creek, on the Alaska-Yukon border (Fig. 8). Here we correlate and redefine individual units of the Lower Tindir Group below the unconformity, with units of the Pinguicula Group and units above the unconformity, with the Fifteenmile Group.

PINGUICULA GROUP

The Pinguicula Group was originally defined in the Wernecke Mountains near Pinguicula Lake and separated into

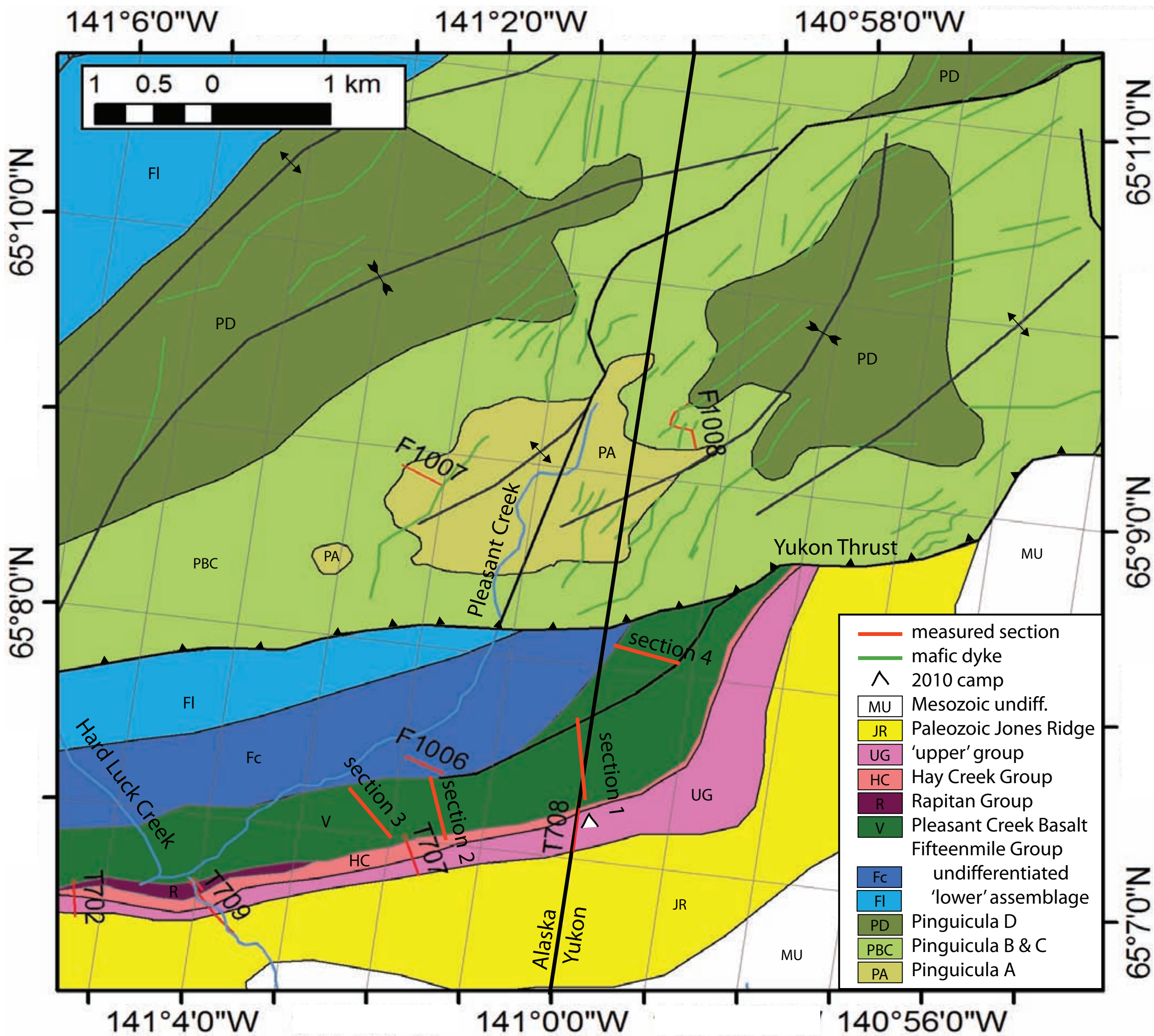

Figure 8. *Geological map of the Pleasant Creek area of the Tatonduk inlier.*

units A-F (Eisbacher, 1981). Although precise correlations were uncertain, Aitken and McMechan (1991) suggested the Pinguicula Group was in part correlative with the Mackenzie Mountains supergroup (MMSG). Abbott (1997) later described Proterozoic strata in the Hart River inlier of the eastern Ogilvie Mountains, correlating them with units A-D of the Pinguicula Group in the Wernecke Mountains. Furthermore, he recognized that unit D included strata equivalent to both the Tsezotene Formation and Katherine Group of the MMSG. Refining earlier work in the Wernecke Mountains, Thorkelson (2000) upheld units A-C in the Pinguicula Group, but reassigned units D-F to the Hematite Creek Group. The more restricted definition of Pinguicula Group allowed for its correlation with the pre-1270 Ma Dismal Lake Group in the Coppermine homocline. This correlation stemmed from the identification of a dyke assigned to the *ca.* 1380 Ma Hart River Sills that cuts fine-grained clastic strata assigned to Pinguicula A in the Wernecke Mountains (Thorkelson, 2000). However, the intruded strata were later reassigned to the Wernecke Supergroup (Medig *et al.*, 2010), which raised the possibility that Pinguicula A-C is younger than 1380 Ma.

In the Tatonduk inlier the Pinguicula Group (formerly the lower portion of the Lower Tindir Group) is exposed in a faulted anticline oblique to the international border. The base of the Pinguicula Group and underlying Wernecke Supergroup are not exposed. The stratigraphically lowest outcrop, ~150 m of grey to dark brown shale, siltstone and sandstone ('mudstone' unit of Young, 1982), is assigned to unit A of the Pinguicula Group. The units are succeeded by ~375 m of carbonate ('cherty-stromatolitic dolostone' and 'dolostone-shale' units of Young, 1982) that we recognize as equivalent to unit B/C of the Pinguicula Group (we choose to group units B and C of the Pinguicula Group together because laterally these buildups occur at different positions and represent facies changes, rather than a distinct temporal progression). In the F1008 measured section (Fig. 7), unit B/C begins with ~100 m of thinly bedded orange to light blue coloured dolomicrite, followed by ~275 m of shallow-water carbonates dominated by stromatolitic buildups (Figs. 9a,b). Again, Unit B/C is overlain by black shale and an additional >500 m of interbedded sandstone and shale that is correlated with Pinguicula unit D.

FIFTEENMILE GROUP

In the Tatonduk inlier, the Pinguicula Group is unconformably overlain by the Fifteenmile Group (formerly the upper part of the Lower Tindir Group), which is exposed near the international border at Mt. Slipper and along Pleasant Creek (Fig. 8). The exposures at Mt. Slipper, previously mapped as the Cambrian Jones Ridge limestone (Morrow, 1999; Norris, 1979; Young, 1982) are reinterpreted, based upon new mapping and carbon and strontium chemostratigraphy, as Tonian in age, lying stratigraphically below the Rapitan Group (Macdonald *et al*., 2010a; Van Kooten *et al*., 1997). The pre-Rapitan stratigraphy, including the exposures at Mt. Slipper, is intruded by numerous dykes (Fig. 9a), whereas the Rapitan Group and overlying stratigraphy are not (Macdonald *et al*., 2010a). The 'lower' assemblage of the Fifteenmile Group at Mount Slipper consists of >350 m of carbonate, dominated by branching to massive domal stromatolites and an additional ~500 m of fissile black shale with interbedded quartzite and carbonate (Fig. 6). Microfossils were located within the top 10 m of the 'lower' assemblage at Mt. Slipper (Macdonald *et al*., 2010a). These strata are succeeded by a yellow-weathering dolostone with common intraclast breccias, black chert nodules, and green shale interbeds that are tentatively assigned to the Callison Lake dolostone.

PLEASANT CREEK VOLCANICS AND TINDIR DYKE SWARM

The Pleasant Creek volcanics (formerly Upper Tindir unit 1) are a series of pillowed and massive basalt lava flows (Fig. 9c) along with substantial volcaniclastic breccia (Fig. 9d). Maximum thickness of the volcanic pile is ~330 m (Fig. 10). Stratigraphically, the volcanics are comformably on top of shallow-water carbonates and have a sharp, but comformable, upper contact with either carbonate or ironstone correlated with the Rapitan Group. The sub-vertical dykes are mapped throughout an area extending 15 km to the north and constitute a swarm. A direct relationship between the dykes and volcanics was not observed in the field, but preliminary geochemical analyses are consistent with a co-magmatic relationship. Trace element analyses are currently being carried out to determine the tectonic setting of these volcanic rocks and assess petrogenetic similarities to the Mount Harper Volcanic Complex, the Little Dal basalt, the sills within the Tsezotene Formation of the Mackenzie Mountains and/or the Natkusiak basalts of Victoria Island.

RAPITAN GROUP

The Rapitan Group (formerly Upper Tindir unit 2) is exposed near the international border along Pleasant Creek and in outcrops close to the Tatonduk River (Macdonald *et al*., 2010a). The stratigraphy of the Rapitan Group in this region was reviewed by Allison *et al*. (1981) and described in detail by Young (1982). The basal contact of the Rapitan Group was not seen; however, volcanic fragments similar in composition to the underlying Pleasant Creek Volcanics are common in the lower half of the massive diamictite. These strata are chiefly composed of fine-laminated, purple and red mudstone and siltstone speckled with dolomite gravel lonestones. These layers also contain faceted clasts and boulders with striations (Young, 1982), also indicating a glacial origin. The upper ~15 m of the Rapitan Group hosts multiple ~10 cm-thick beds of iron formation, which are interbedded with a laminated diamictite containing bed-penetrating, outsized clasts (Macdonald *et al.,* 2010a,b). The majority of clasts in the Rapitan Group consist of dolomite derived from the Fifteenmile Group. Where the upper contact is exposed, it is overlain by a well sorted carbonate matrix diamictite including abundant dolostone clasts of variable size, interpreted as a debris flow. This is overlain by a parallel-laminated siltstone and sandstone of the Hay Creek Group. Samples of the hematitic section of the Rapitan Group were systematically collected for further study and

Figure 9. *Field photos from the Tatonduk inlier.* ***(a)*** *Measured stratigraphic section F1008 of Pinguicula B/C looking north. Stratigraphic log shown in Figure 4. Arrows mark dykes of the Tindir dyke swarm.* ***(b)*** *Discrete columnar stromatolites from Pinguicula B/C in section F1008 at 160 m (see Fig. 4).* ***(c)*** *Massive and columnar jointed basalt flow, near the top of the volcanics exposure in Pleasant Creek. The flows dip 65° to the southeast, similar to the overlying ironstone.* ***(d)*** *Angular to subrounded, pebble to cobble-sized basaltic fragments with glassy texture, stratigraphically above massive lava flow at the top of Section 1, Pleasant Creek volcanics (see Fig. 8).* ***(e)*** *Measured section of the Jones Ridge limestone along the international border, looking east.*

comparison with other Neoproterozoic iron formation. The thickness of the Rapitan Group varies greatly from <50 m near Pleasant Creek, to >700 m, ~20 km to the northwest (Young, 1982). Paleocurrent measurements in the interbedded siltstone suggest a west-facing margin (present coordinates; Young, 1982).

HAY CREEK GROUP

Along the Tatonduk River, the Hay Creek Group (formerly unit 3 and a part of unit 4 of the Upper Tindir Group, Young, 1982) consists of >100 m of flat-bedded, graded siltstone and sandstone interbedded with minor dolomitic mudstone, and overlain by a massive dolomite-matrix diamictite and dolo-grainstone (Fig. 7; section T707). On the Yukon side of the international border, the diamictite is either absent or represented by a dolomite clast breccia suspended in a fine-grained dolomite matrix. No foreign clasts were noted with the exception of some clasts of the Pleasant Creek volcanics near the base. The breccia is overlain by another massive dolomite that is <5 m thick and is disconformably on units of the Hay Creek Group as well as the Pleasant Creek volcanics and Rapitan Group strata. It is a white to buff-coloured dolostone with bed-parallel cements and pseudo-teepee structures (Young, 1982). These pseudo-teepees do not show a polygonal plan-form or a concentration of cements along the broken pieces, as is typical of teepees that form as a result of sub-aerial exposure (Kendall and Warren, 1987). Instead, cements are isopachous and bed-parallel and the geometry of the beds are contorted and irregularly buckled, suggesting intraformational detachment during deposition. Similar 'sheet-crack' cements are globally present in basal Ediacaran cap carbonates (Hoffman and Macdonald, 2010).

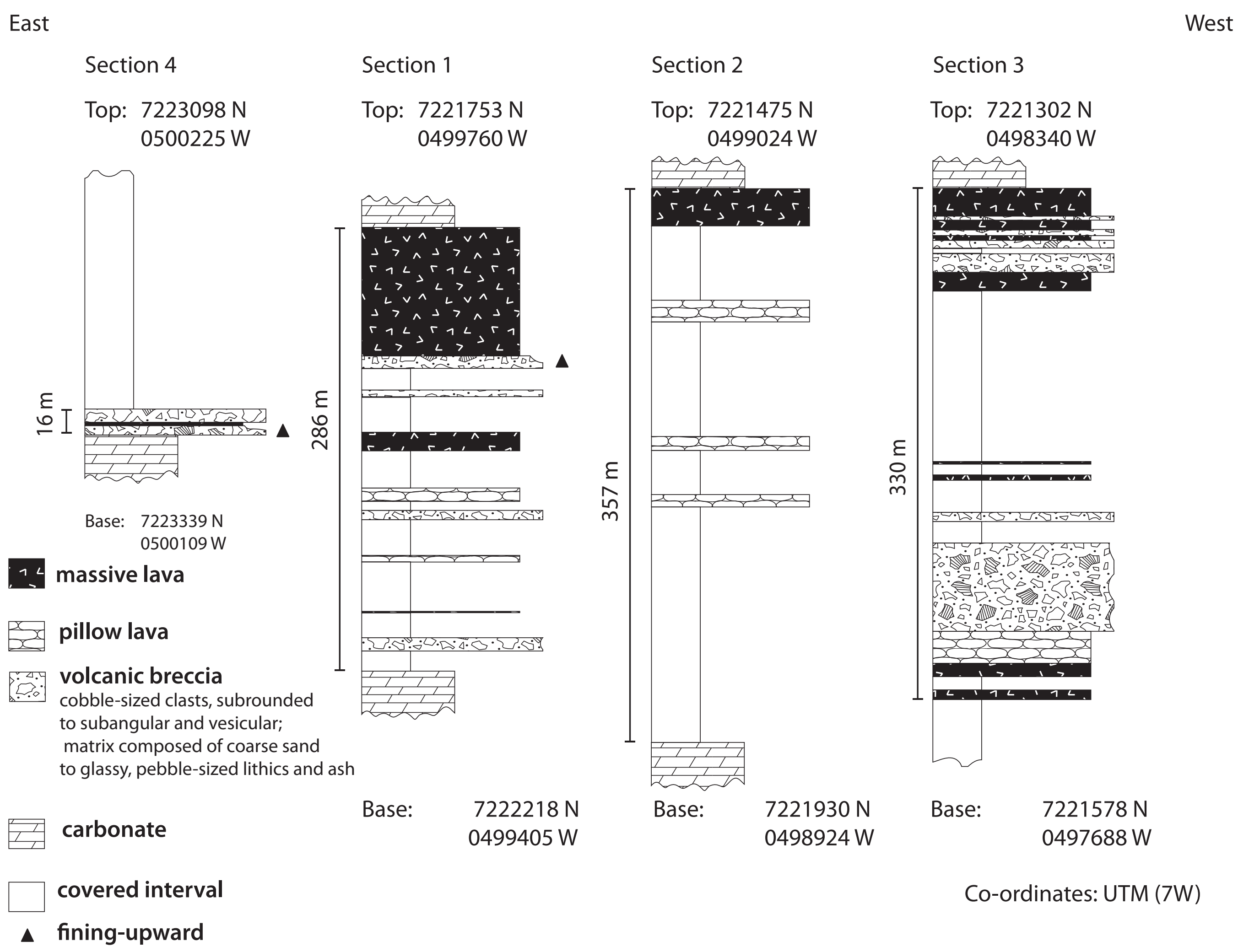

Figure 10. *Measured sections of the Pleasant Creek basalt. Locations of sections are shown in Figure 8.*

THE 'UPPER' GROUP

The Hay Creek Group is overlain by the 'upper' group (formerly units 4b and 5 of the Upper Tindir Group), which consists of <50 m of parallel-laminated siltstone, sandstone and dolomitic marl, and an additional sequence of black shale interbedded with minor organic-rich limestone (Fig. 7; section T707). Like the underlying units, the 'Upper' group displays a major stratigraphic expansion to the southwest ranging from 40 to 75 m thick in Yukon, to ~700 m thick along the Tatonduk River in Alaska (Macdonald *et al*., 2010a). Both the Hay Creek and 'upper' group strata are consistent with deposition along a southwesterly facing margin (present coordinates).

JONES RIDGE LIMESTONE

The type locality of the Jones Ridge Limestone is the Jones Ridge-Squaw Mountain area of the Tatonduk inlier of eastern Alaska, adjacent to the border with Yukon (Brabb, 1967). It is also exposed in the southwest corner of the Ogilvie River map area where it has been mapped as a lateral equivalent to the Bouvette Formation (CDb map unit of Norris, 1982). The Jones Ridge Limestone contains archeocyathids, trilobites, brachiopods, sphinctozoan sponges and conodonts which indicate an age-span of the Early Cambrian to Late Ordovician, with prominent hiatuses in the Middle Cambrian and Middle Ordovician (Brabb, 1967; Palmer, 1968; Blodgett *et al*., 1984; Rigby *et al*., 1988; Allison, 1988; Harris *et al*., 1995). Coeval but deeper water equivalents to the Jones Ridge Limestone are variably exposed to the southwest of the Jones Ridge-Squaw Mountain area and consist of the Funnel Creek limestone, Adams argillite and Hillard limestone. Diachronous Early Ordovician to Silurian (middle Wenlock) siltstone and shale of the Road River Formation unconformably or disconformably overlie the Jones Ridge limestone and its local equivalents (Blodgett *et al*., 1984; Harris *et al*., 1995).

We examined the Jones Ridge Limestone in the Ogilvie River map area north of the Yukon thrust at Mt. Slipper (Morrow, 1999; his section 21) and south of the Yukon thrust along the Jones Ridge. The Mt. Slipper section is cut by multiple dykes of unknown age, which is inconsistent with other outcrops of Jones Ridge Limestone in which intrusive bodies are absent. Therefore, along with geochemical argument, Macdonald *et al*. (2010a) reassigned these strata to the Fifteenmile Group. Along the Jones Ridge, the Jones Ridge Limestone is certainly age-equivalent in part to Cambrian-Ordovician strata of the Yukon Stable Block (Bouvette Fm, Taiga Fm, Slats Creek Fm and Illtyd Fm), Richardson Trough (Illtyd Fm, Slats Creek Fm, Rabbitkettle Fm and Vunta Fm), and parts of the Mackenzie-Peel Shelf (Backbone Ranges Fm, Sekwi Fm and Franklin Mountain Fm). In 2010, three detailed stratigraphic sections were measured near the type section of the Jones Ridge Limestone, spanning the lower and upper members (Fig. 9e). These sections were sampled at 1–2 m intervals for carbon isotope chemostratigraphy and approximately 30 bulk-rock samples were collected to search for conodonts. Five separate trilobite collections were also made.

DISCUSSION

The stratigraphic observations outlined above have allowed refinement and expansion of Neoproterozoic correlations presented in Macdonald and Roots (2010) and the development of consistent nomenclature within Yukon (Fig. 11). These correlations facilitate the synthesis of geological data throughout northwest Canada.

In the western Ogilvie Mountains we have reassigned the lower part of the Lower Tindir Group to the Pinguicula Group. We have included a part of the Lower Tindir Group, and units PR4, PR5 and PF1a of the Coal Creek inlier to the 'lower' assemblage of the Fifteenmile Group. The distribution of the 'lower' assemblage of the Fifteenmile Group in the western Ogilvie Mountains is consistent with deposition along northwest side-down normal faults. Detailed correlations between the Fifteenmile Group and the MMSG in the Mackenzie Mountains await further stratigraphic and chemostratigraphic description.

Additional detailed stratigraphic sections of the Callison Lake dolostone will provide better constraints on the depositional environment of this unit and its relationship with the metalliferous Coates Lake Group. The Callison Lake dolostone should possibly be separated from the underlying Fifteenmile Group because it appears more closely related to the overlying Lower Mt. Harper Group. One option is that the Callison Lake dolostone, Lower Mt. Harper Group and the Mt. Harper Volcanic Complex could be included in a separate group in recognition of possible correlation with the Coates Lake Group in the Mackenzie Mountains.

The Pleasant Creek Volcanics are geochemically and petrographically similar to members A-C of the Mount Harper Volcanic Complex. Whether these volcanics and the potentially correlative Tindir dyke swarm are coeval

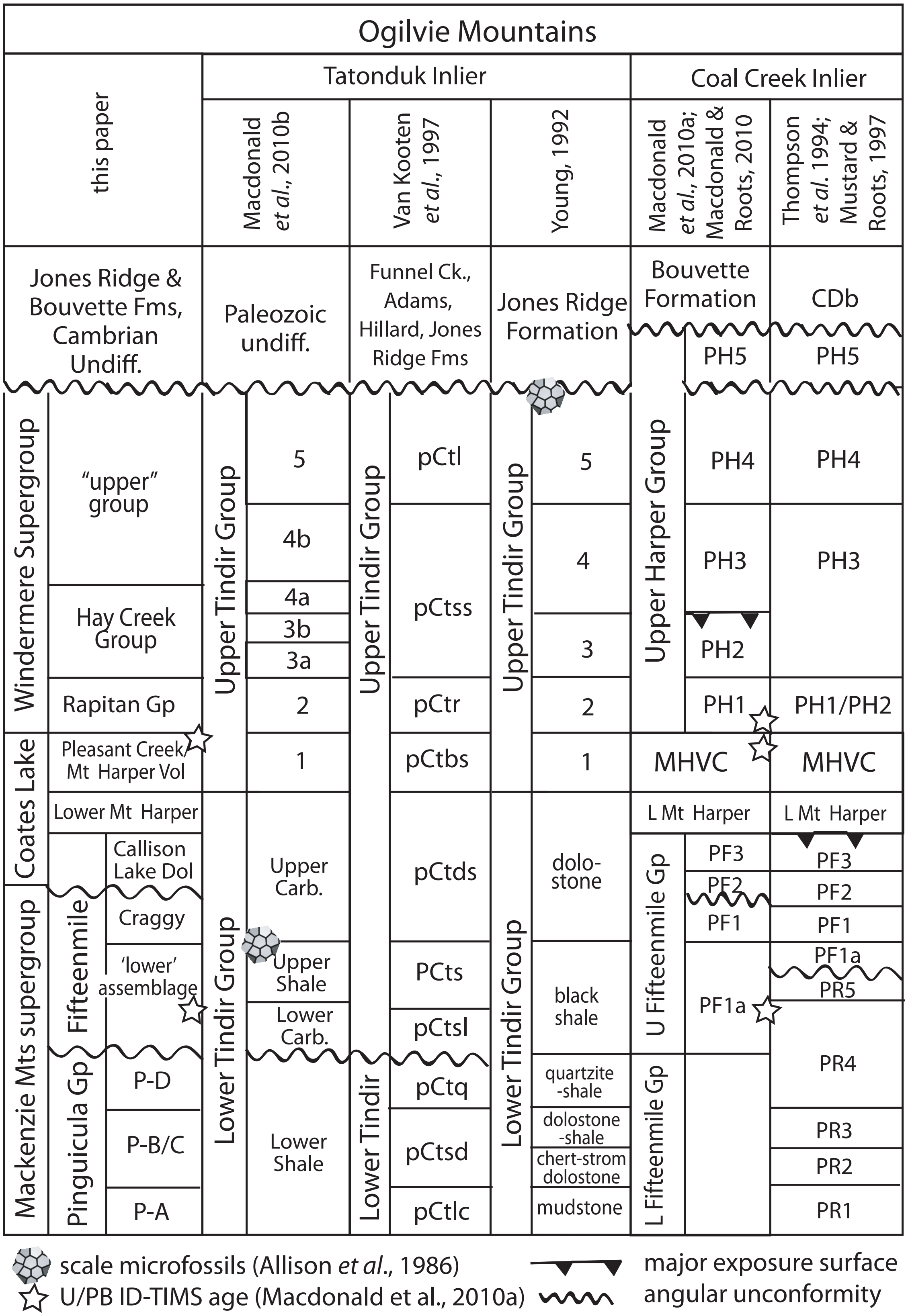

Figure 11. *Correlation of nomenclature and stratigraphic units previously used to describe the Tatonduk and Coal Creek inliers. Regionally consistent units proposed in this publication are shown in the left column.*

with the *ca.* 717 Ma members D-F of the Mount Harper Volcanic Complex and the Franklin Large Igneous Province (Macdonald *et al*., 2010b), the Little Dal basalt (Dudás and Lustwerk, 1997), and/or the *ca.* 778 Ma Gunbarrel event (Harlan *et al*., 2003) remains to be tested with further geochemical and geochronological analyses.

The Rapitan Group in the Tatonduk inlier consists of clast-poor siltstone and iron formation (Yeo, 1984; Young, 1976), reminiscent of the Sayunei Formation of the Rapitan Group in the Mackenzie Mountains. A glaciomarine depositional setting for the Rapitan Group in the Ogilvie Mountains is confirmed by the presence of faceted and striated clasts, bed-penetrating dropstones, common outsized and exotic clasts, and glacial push structures, along with evidence for subaqueous slumping in the form of graded grain and chaotic debris flows. A 716.47 ± 0.24 Ma U/Pb ID-TIMS zircon age (Macdonald *et al*., 2010b) from a tuff near the base of the Rapitan Group in the Coal Creek inlier provides a direct age constraint on deposition.

Above the Rapitan Group, the Cryogenian stratigraphy of the Hay Creek Group is very condensed and commonly absent in the western Ogilvie Mountains. The diamictite and breccia at the top of Hay Creek Group may be correlative with the Ice Brook Formation in the Mackenzie Mountains. A discontinuously exposed dolostone above the Hay Creek Group in both the Coal Creek and Tatonduk inliers shares sedimentological and isotopic characteristics with the Ravensthroat dolomite in the Mackenzie Mountains (Aitken, 1991; James *et al*., 2001) and with basal Ediacaran cap carbonates globally (Hoffman *et al*., 2002; Kennedy, 1996). The Ice Brook Formation has long been correlated with the Marinoan glaciation in Australia, (Eisbacher, 1985; Halverson *et al*., 2005). If this correlation is confirmed, the overlying black shale of the Hay Creek Group in Tatondul inlier is most likely correlative with the Sheepbed Formation in the Mackenzie Mountains.

This development and expansion of the stratigraphic framework for correlating Neoproterozoic strata in the Ogilvie Mountains will facilitate correlations with the Wernecke and Mackenzie Mountains and will aid in giving context to future geochemical, geochronological, paleontological, paleomagnetic and tectonic studies.

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Appendix 1. *Locations of the base of stratigraphic sections described in text.*

Section	Latitude	Longitude
E1002	64.708	139.340
E1003	64.705	139.341
E1006	65.123	141.033
F1007	64.149	141.034
F1008	65.152	140.989
F1022	64.712	139.325
F1023	64.714	139.346
F838	64.726	140.040
F841	64.756	140.115
F842	64.693	140.113
F918	64.762	140.107
F930	64.682	139.232
F931	64.725	139.249
F932	64.718	139.225
J1018	64.663	139.397
J1019	64.689	139.353
Section 1	65.119	141.005
Section 2	65.116	141.020
Section 3	65.115	141.035
Section 4	65.131	140.995
T708	65.119	141.004
T710	65.051	141.174