Stratigraphy of the Mackenzie Mountains supergroup in the Wernecke Mountains, Yukon

Elizabeth C. Turner[1]
Laurentian University

Turner, E.C., 2011. Stratigraphy of the Mackenzie Mountains supergroup in the Wernecke Mountains, Yukon. *In:* Yukon Exploration and Geology 2010, K.E. MacFarlane, L.H. Weston and C. Relf (eds.), Yukon Geological Survey, p. 207-231.

ABSTRACT

Mackenzie Mountains supergroup (MMSG) strata in the Wernecke Mountains are described in detail. Three new formations are assigned to the revised and formalized Hematite Creek Group, which forms the base of the MMSG. The Dolores Creek Formation (black mudrocks and microbial dolostone) is the basal unit of the MMSG. The Black Canyon Creek Formation (cyclic peritidal dolostone) and Tarn Lake Formation (desiccation-cracked, shallow-marine siltstone and sandstone) are probably equivalent to the 'H1 unit' and Tsezotene Formation in NWT, respectively. The Hematite Creek Group is overlain by the Katherine Group (thick quartz arenite-dominated succession). The highest MMSG strata documented belong to the Basinal assemblage (Little Dal Group). Regional thickness and lithofacies variations in two of the new formations suggest that the basin had considerable paleobathymetric variation that is not consistent with patterns established in NWT. The economic potential of the succession is unknown.

---

[1] *eturner@laurentian.ca*

INTRODUCTION

Although suggested correlation schemes for Neoproterozoic stratigraphic units in northwestern Canada are numerous, a lack of detailed stratigraphic knowledge of units in the Wernecke Mountains and other locations in Yukon has precluded both definitive correlations and interpretation of basin evolution. Rainbird *et al.* (1996, 1997), Abbott (1997), Cook and MacLean (2004), Thorkelson *et al.* (2005) and Long *et al.* (2008) proposed that stratigraphic units originally assigned to the upper part of the Proterozoic Pinguicula Group (Eisbacher, 1978, 1981) in the Wernecke Mountains are equivalent to some part of the Mackenzie Mountains supergroup (MMSG; Young *et al.*, 1979). The present project was undertaken to ascertain whether this is valid, to determine what parts of the MMSG have stratigraphic equivalents in the Wernecke Mountains, and to establish preliminary interpretations of basin evolution for the MMSG west of known exposures in Northwest Territories (NWT). Four units that form much of the MMSG were examined in the Dolores Creek – Pinguicula Lake area, and are here compared to their equivalents in NWT. Strata of the MMSG were examined in detail on the flanks of an un-named mountain near the junction of 'Dolores Creek' with the Bonnet Plume River (Fig. 1), and on a ridge approximately 7 km south-southwest of Mount Profeit (both locations in NTS 106C).

HEMATITE CREEK GROUP (REVISED)

The entire succession described here (including Katherine Group and Little Dal Group strata) was at one point named Hematite Creek Group (Thorkelson, 2000), a term that was subsequently abandoned (Thorkelson *et al.*, 2005). This stratigraphic name is here re-introduced, and revised to refer only to the basal three formations of the MMSG (Fig. 2). These three formations form an internally conformable succession that appears to lie unconformably on Pinguicula Group unit 'C' and to underlie the Katherine Group conformably. The MMSG in the Wernecke Mountains consists, therefore, of three groups: the Hematite Creek Group (comprising three new formations), the Katherine Group, and at least part of the Little Dal Group (Fig. 3). The revised Hematite Creek Group is widespread in the Pinguicula Lake – Dolores Creek area. Three representative sections are presented below. It is proposed that the Dolores Creek Formation and Black Canyon Creek Formation measured sections become their type sections, but that the measured section of the Tarn Lake Formation be considered a reference section until a stratigraphically complete type section can be documented.

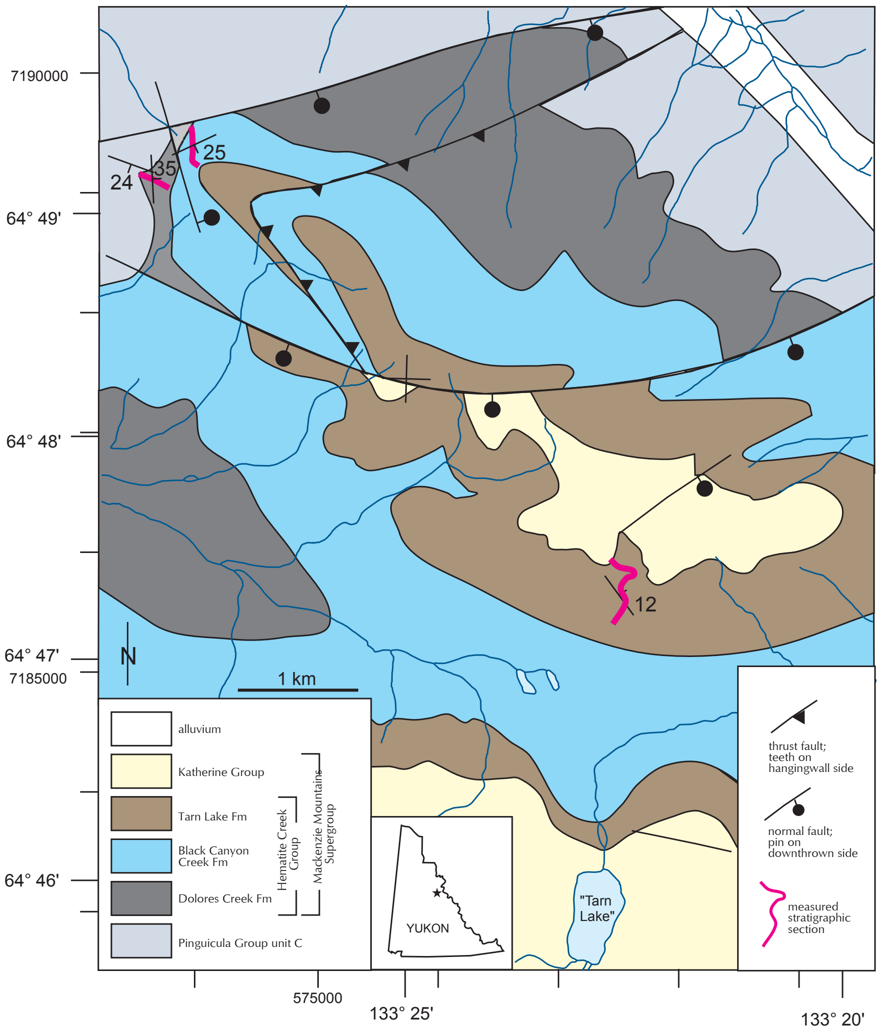


Figure 1. *Geologic map of a mountain exposing strata of the lower MMSG near the junction of 'Dolores Creek' and Bonnet Plume River. The locations of type sections of three new formations in the (revised) Hematite Creek Group (=basal MMSG) are indicated.*

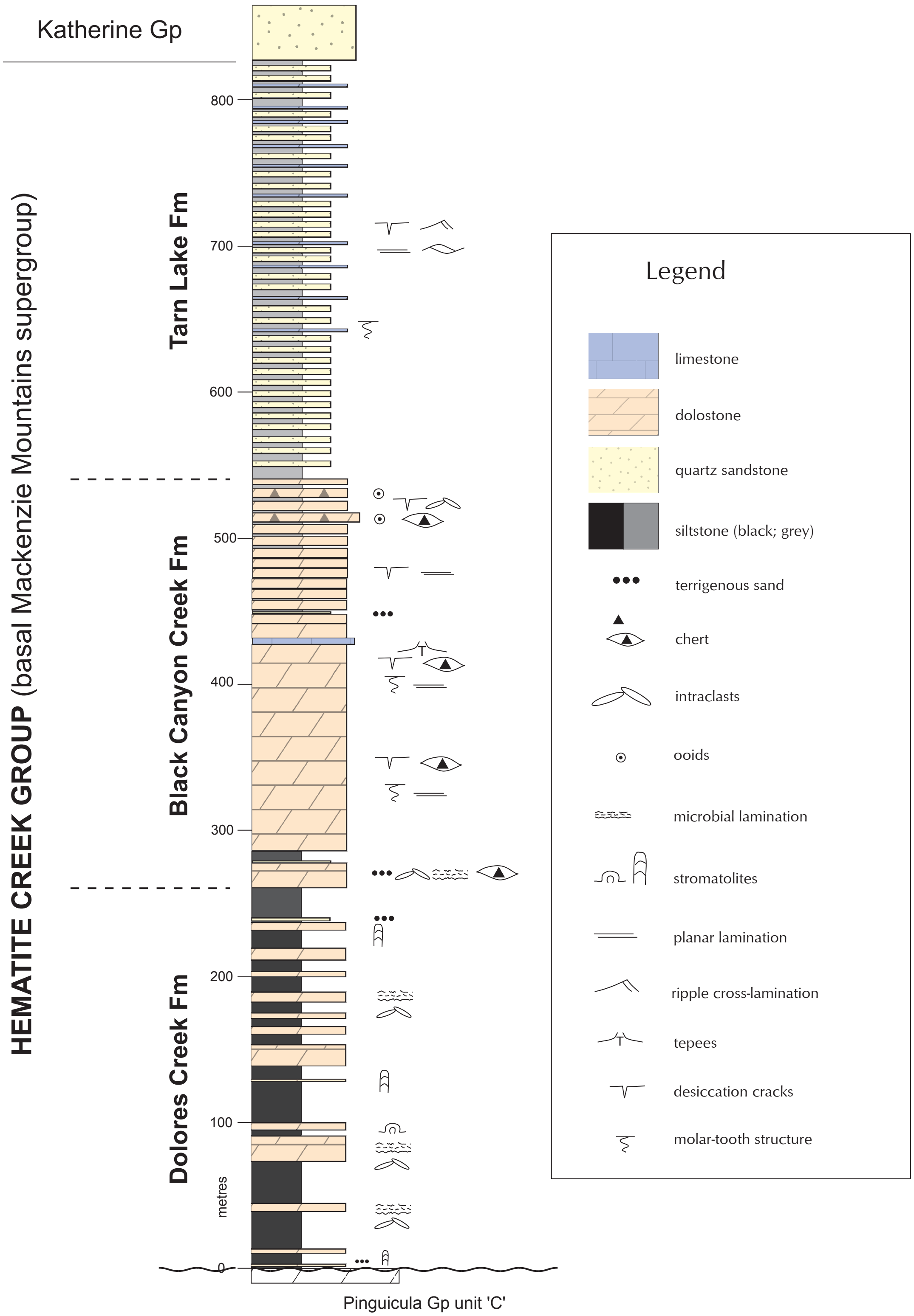
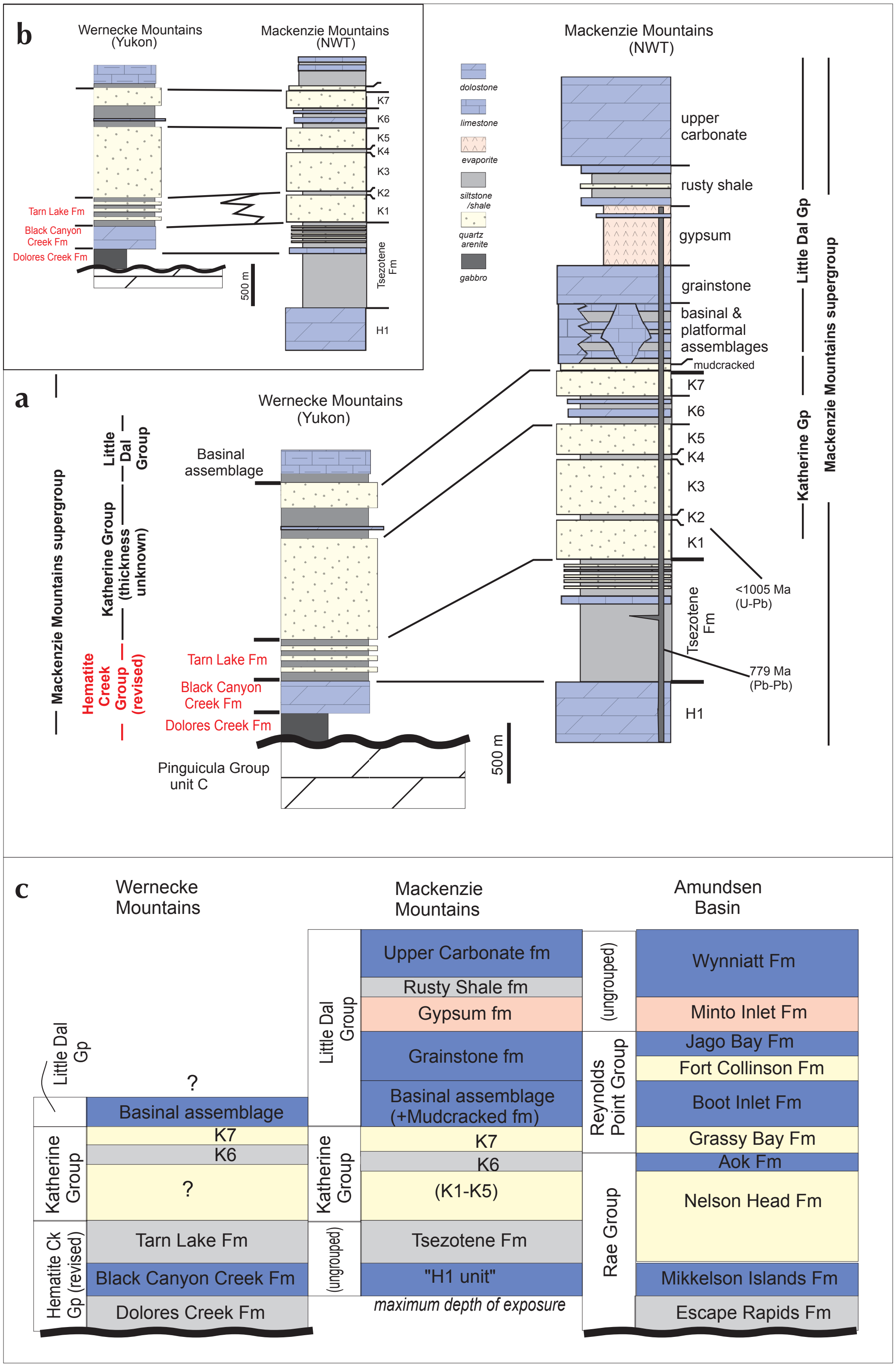


Figure 2. *Schematic stratigraphy for the (revised) Hematite Creek Group in the Dolores Creek – Pinguicula Lake area. Basal contact is an unconformity with dolostone of Pinguicula Group unit 'C'. Contacts between formations of the Hematite Creek Group are conformable and gradational.*

Figure 3. (a) *Proposed correlation of Hematite Creek Group, Katherine Group and Little Dal Group strata of the Wernecke Mountains. Radiometric bracketing dates are from Jefferson and Parrish (1989), Heaman et al. (1992), and Leslie (2009).* ***(b)*** *A less probable alternative correlation.* ***(c)*** *Revised correlation of MMSG units in the Mackenzie Mountains and Wernecke Mountains inlier, with Shaler Supergroup units (Amundsen Basin, after Rainbird et al., 1996 and Long et al., 2008).*



DOLORES CREEK FORMATION (NEW)

The basal unit of the MMSG is extensively exposed east of the Bonnet Plume River in north-central NTS 106C (Nadaleen River map sheet). A detailed section was measured on an un-named, 15 km-long mountain ridge, at a location approximately 12 km east of the Bonnet Plume River and 6 km south of 'Dolores Creek' (Thorkelson and Wallace, 1998), an informally named west-flowing tributary of the Bonnet Plume River, after which the formation is named. The ridge section measured in this study (Figs. 4 and 5; ~260 m thick) is the best of the generally recessive exposures of this formation in the Dolores Creek area, and is proposed as the type section of the Dolores Creek Formation. Much of the section consists of stratigraphically intact rubble along the ridge-line.

The Dolores Creek Formation is dominated by recessive dark grey to black-weathering, variably pyritic siltstone and mudstone with conspicuous, commonly bright orange-weathering microbial carbonate intervals. Covered intervals are numerous, but most can be inferred to be underlain by grey to black siltstone or mudstone based on the composition of ridge-line scree. Minor quartz sandstone units are present in the upper one-third of the formation.

The basal contact of the Dolores Creek Formation appears to be an angular unconformity at the top of massive, pale grey-weathering, laminated to thinly layered dolostone of unit 'C' of the Pinguicula Group (Figs. 1 and 6a). Strata of Pinguicula Group 'unit C' at this location exhibit no obvious evidence of meteoric alteration or geomorphic structures that would be consistent with karstification. No evidence of faulting is present at the contact. Less well-exposed sections of this formation on other flanks of the same large mountain (Fig. 7) exhibit the same stratigraphic

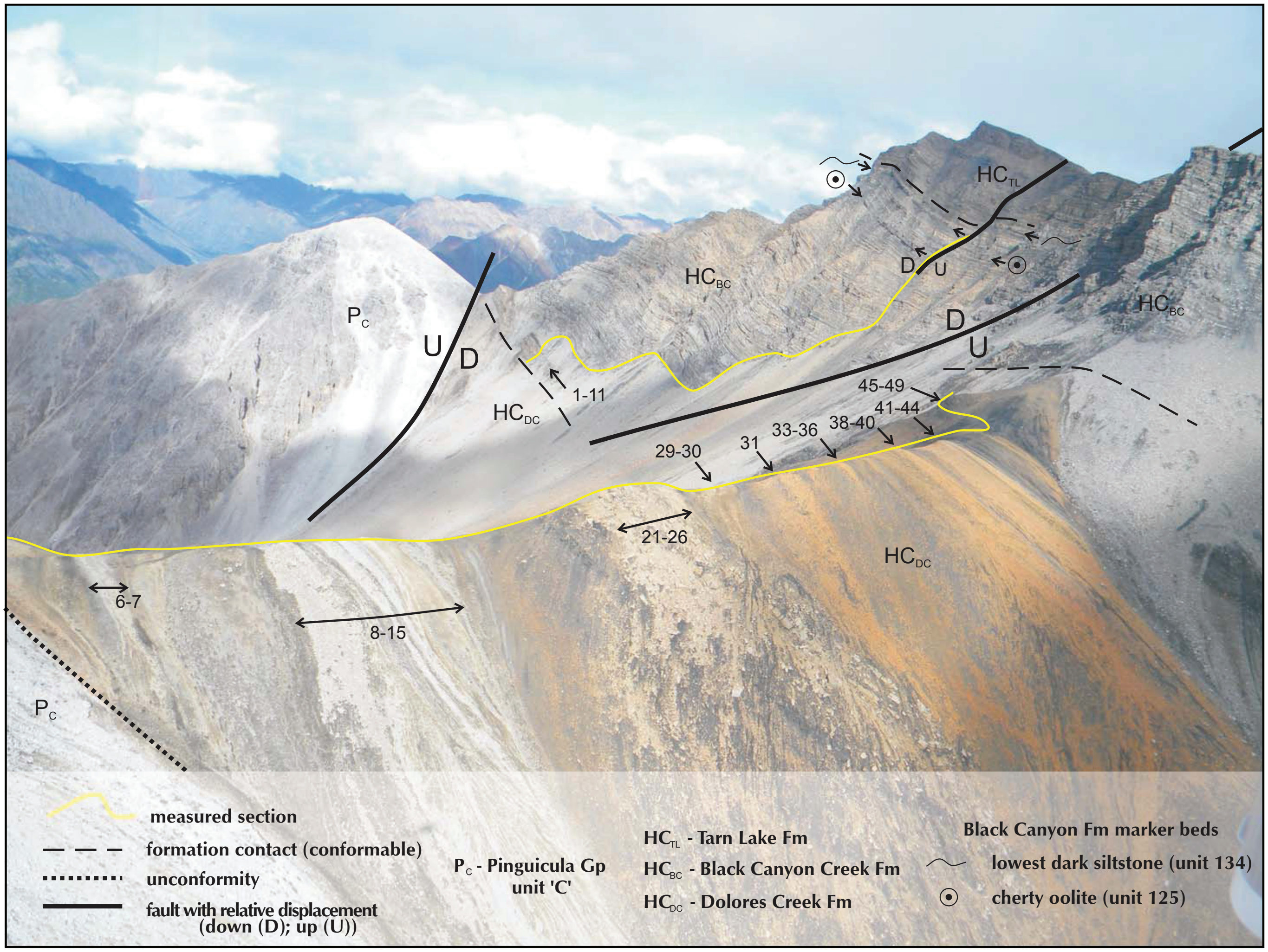


Figure 4. *Type sections of the Dolores Creek and Black Canyon Creek formations. Unit numbers for prominent layers in the measured sections are indicated.*

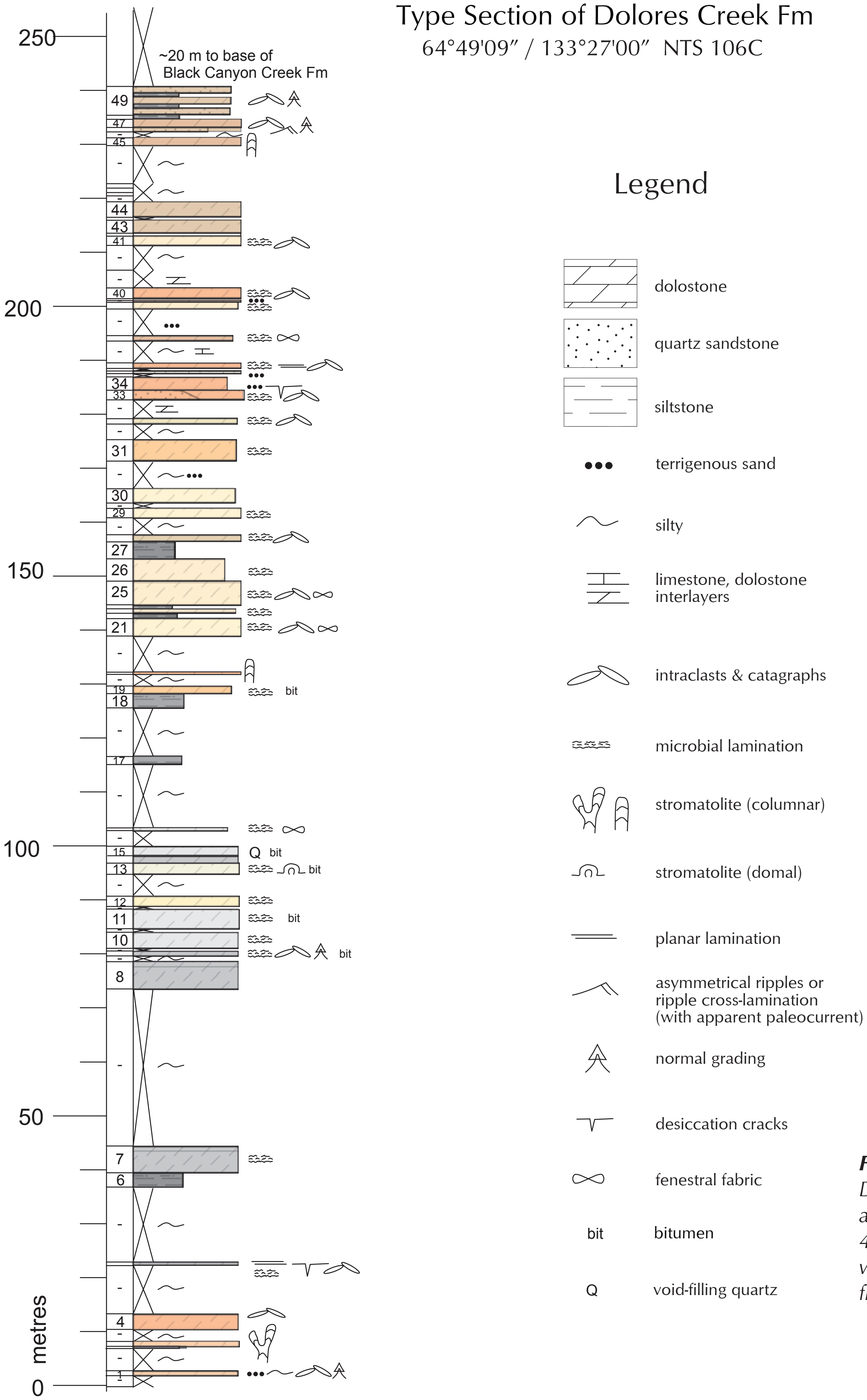


Figure 5. *Type section of the Dolores Creek Formation, as shown in Figures 1 and 4. Column width indicates weathering profile. Coloured fills indicate weathering colour.*

colour pattern in the disposition of distinctive, orange-weathering dolostones above the contact with Pinguicula unit 'C', supporting the inference that the contact at the measured section is structurally intact.

The upper contact with the Black Canyon Creek Formation (new) is at the top of a covered interval underlain by black siltstone and fissile mudstone (shale; Fig. 6b). The contact is probably conformable, based on the presence in the lowermost Black Canyon Creek Formation of microbial carbonate rocks identical to those that predominate in the Dolores Creek Formation, and the gradual loss of quartz sandy and silty interlayers across the transition into the basal Black Canyon Creek Formation.

The lowest 2 m of the Dolores Creek Formation are covered, but ridgeline scree indicates that they consist of dark grey siltstone. The lowest exposed unit (0.6 m) is bright orange-weathering microbially laminated dolostone with millimetric intraclasts and minor quartz silt. After another covered interval (siltstone), a 1 m-thick orange-weathering stromatolitic dolostone contains robust, branching, unwalled columnar stromatolites (form genus *Baicalia*). From 10 m to 132 m, the succession consists of thick (1 to 30 m) covered intervals of dark grey to black siltstone (70% of the interval's total thickness) with interlayered pale grey to yellow-buff-weathering microbial intraclastic dolostone (30%) identical to those below. Dolostones in this interval contain conspicuous intercrystalline and pore-filling bitumen. A 0.2 m-thick, bright orange-weathering unwalled, unbranching stromatolite (form genus *Colonella*; Fig. 6c) is conspicuous at 132 m. The stromatolite is overlain by a further 98 m of interlayered dark grey to black siltstone (60%) with orange-yellow, grey or brown–weathering, microbially laminated, intraclastic dolostone layers (40%); each typically 1 to 5 m thick (Fig. 6d,e). In this 98 m-thick interval from 132 to 230 m, thin, sparse quartz sandstone layers first appear 168 m above the formation's base, increasing over the next 30 m and then disappearing (Fig. 6f). This 98 m-thick interval has 10 m of black-weathering siltstone at its top. The overlying 11.5 m consist of ripple cross-laminated medium brown-weathering quartz sandstone with dark grey-weathering siltstone interbeds and sparse, graded intraclastic dolostone. A 1.6 m-thick unit of orange-brown-weathering, non-branching, unwalled columnar stromatolite (form genus *Boxonia*) occurs at the base of this interval (~230 m). The sandstone and siltstone of the uppermost exposure of the Dolores Creek Formation is overlain by approximately 20 m of cover (Fig. 6b), but appears to consist predominantly of black siltstone and fissile mudstone.

A preliminary stratigraphic survey of the metal composition of the black mudrocks was conducted using a portable, hand-held x-ray fluorescence (XRF) analyser (Thermo Scientific Niton® XL3t), in the analyser's "soils" software mode. Metals such as Zn, Pb and Ni show concentrations at some stratigraphic levels that are elevated above post-Archean average shale values (PAAS; Taylor and McLennan, 1985).

INTERPRETATION

The basal contact of the measured section appears to be a pronounced angular unconformity with massive strata of the underlying unit 'C' of the Pinguicula Group. It is possible, however, that the angularity of the unconformity is an artifact caused by differential strain in the weak, mudrock-dominated Dolores Creek Formation relative to that of rigid, massive dolostone of Pinguicula Group unit 'C'. A proper understanding of the configuration and implications of this important contact will require further investigation.

Inundation of the unconformity surface of the Pinguicula Group was not accompanied by deposition of high-energy facies. Although the unconformity surface may have been irregular, in this section there is no evidence for pronounced topography or syndepositional faulting that would have been reflected in marked lateral lithofacies variation and local shedding of coarse detritus from topographic highs. Strongly evaporative conditions are not indicated, and the microbial and intraclastic carbonate lithofacies record comparatively shallow-water to possibly emergent conditions (although no desiccation cracks were evident). At the same time, however, the black siltstone and mudstone that dominate this formation suggest that the shallow water of the incipient MMSG basin was anoxic and restricted from circulation with the open ocean. The black colour may reflect a high organic content, which probably accounts for the conspicuous bitumen in some of the formation's carbonate rocks. These attributes would be consistent with an incipient extensional basin that may not have been well connected to the global ocean. Three subtle transgressive intervals are suggested by the three columnar stromatolitic carbonates (at 7.4, 132.1, and 230.2 m), which differ markedly from the intraclastic, microbial dolomudstone that characterizes the remainder of the carbonate units.

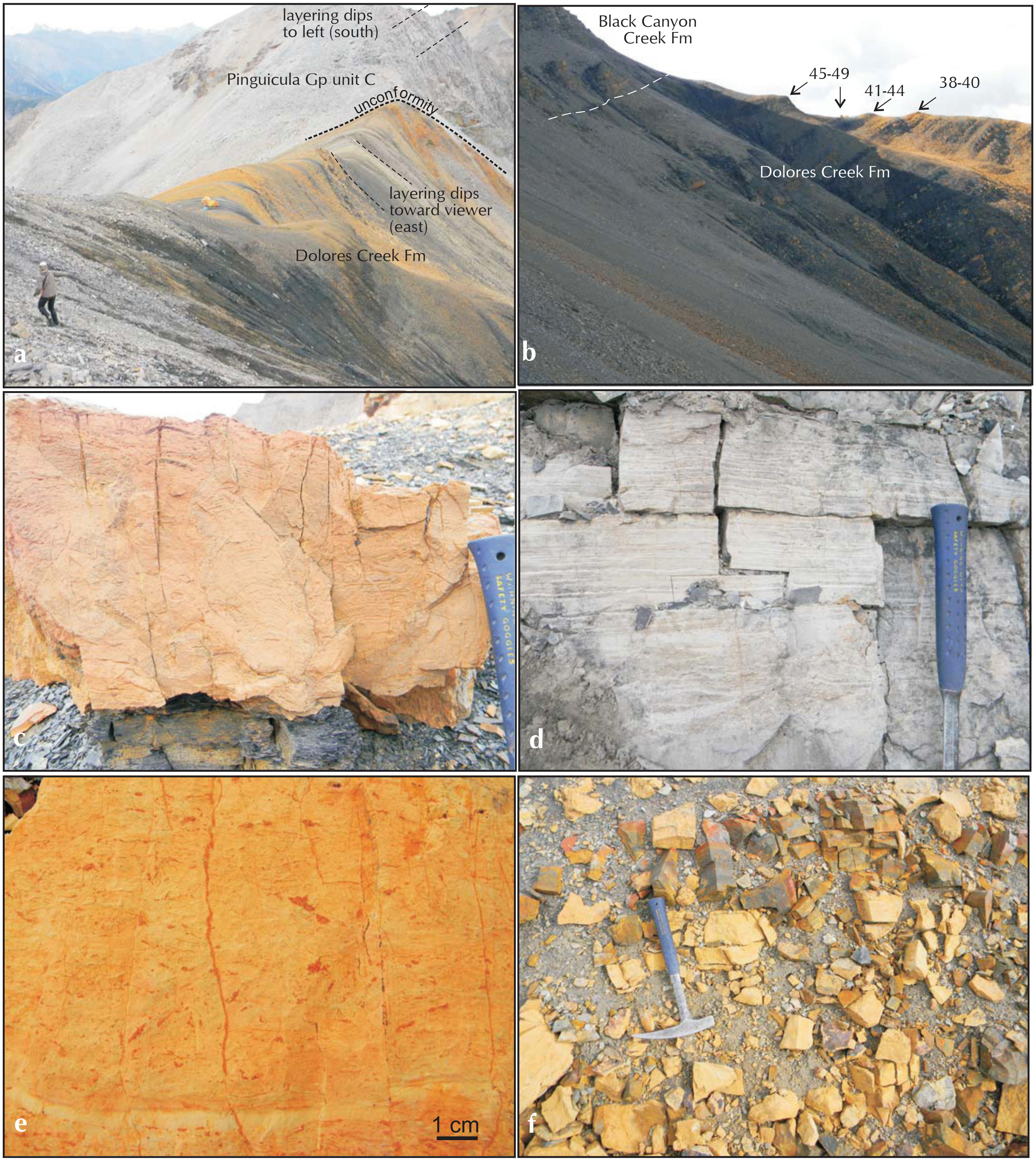


Figure 6. *Exposures and typical lithofacies of the Dolores Creek Formation.* ***(a)*** *View to west from top of Dolores Creek Formation, showing conspicuous black and orange weathering colours, and angular relationship between bedding in Pinguicula Group unit 'C' and that of the Dolores Creek Formation.* ***(b)*** *Gradational upper contact of Dolores Creek Formation and Black Canyon Creek Formation. Two 1 m-high tents on ridge (arrow) give scale.* ***(c)*** *Orange-weathering columnar stromatolite (unit 20) overlies grey-weathering siltstone (unit 19).* ***(d)*** *Planar-laminated (above) and intraclastic (below) grey-weathering dolostone of unit 28.* ***(e)*** *Bright orange-weathering microbial, intraclastic dolostone of unit 31.* ***(f)*** *Units 38 (orange-weathering dolomudstone) and 39 (rusty brown-weathering quartz sandstone).*

DISTRIBUTION AND MAPPING

The Dolores Creek Formation is easily recognized in the Dolores Creek-Pinguicula Lake area owing to its bright orange dolostones and dark grey to black, recessive mudrocks. It forms slopes and poorly exposed ridges beneath the evenly bedded, grey-weathering carbonate succession of the Black Canyon Creek Formation, and overlies massive, pale grey-weathering dolostone of Pinguicula Group unit 'C'. The extent of exposure beyond this area is unknown.

CORRELATION

The Dolores Creek Formation is equivalent to the lower part of abandoned Pinguicula Group unit 'D' of Eisbacher (1978). It is the basal unit of the MMSG, and has never before been described in detail. Equivalent strata are not exposed in the Mackenzie Mountains because that area is not as deeply exhumed. Basal strata of the Shaler Supergroup (Amundsen Basin, Arctic coastal NWT and Victoria Island) consist of the Escape Rapids Formation (Fig. 3c), which comprises a variety of storm-dominated marine to supratidal terrigenous siliciclastic facies (Long *et al*., 2008). From this description, it appears that, although the Dolores Creek Formation and Escape Rapids Formation may be in part time-equivalents, they appear to represent different environmental and tectonic settings (isolated rift basin(s) for Dolores Creek Fm; storm-dominated, stable, open-marine shelf for Escape Rapids Fm; Long *et al*., 2008). If the Dolores Creek Formation can be demonstrated to be the regional base of the MMSG, and it is accepted that the overlying Black Canyon Creek Formation (described below) is equivalent to the 'H1 unit', interpretations of seismic data from the interior plains of NWT (Cook and MacLean, 2004) that invoke approximately 2.3 km of MMSG-related strata beneath the inferred 'H1' unit may require revision.

ECONOMIC POTENTIAL

The economic potential of the Dolores Creek Formation is unknown. No economic mineral occurrences have been reported from these strata. Bitumen and quartz are locally present in carbonate porosity in the measured section, indicating migration of heated fluids at some time after sediment lithification.

BLACK CANYON CREEK FORMATION (NEW)

In the Dolores Creek - Pinguicula Lake area, the Black Canyon Creek Formation (~285 m thick) forms recessive hillsides and consists of evenly bedded, intermittently cherty, pale grey dolostone with silty interbeds, between more recessive siliciclastic strata of the Dolores Creek and Tarn Lake formations (Fig. 7). Although most exposures are extensively rubble-covered, exposure in cliffs above the type section of the Dolores Creek Formation (5 km south of Dolores Creek; 12.5 km east of Bonnet Plume River; Figs. 4 and 8) is almost complete, though complicated by numerous small normal faults. The section measured here (Fig. 8) is complete except for the uppermost ~10 m, which record the transition to the overlying Tarn Lake Formation; this upper part of the formation was deemed too dangerous to measure at the type locality. The Black Canyon Creek Formation is named for a tributary of Hematite Creek in NTS 106C.

The base of the Black Canyon Creek Formation is placed above the 20 m-thick covered interval at the top of the underlying Dolores Creek Formation (Figs. 4 and 6b), at the base of the lowest resistantly weathering interval of orange-buff and grey-weathering dolostone. Dolostones in the lowermost 17.3 m-thick interval are microbially laminated, mechanically plane-laminated, or intraclastic (mm to cm-scale), and have graded centimetric layers of quartz-rich, sandy to silty dolostone, and local, minor black chert nodules. This dolostone interval is overlain by 1.1 m of quartz sandstone and a 6.8 m-thick covered interval inferred to consist of fissile mudstone or siltstone similar to that of the underlying Dolores Creek Formation. The next ~148 m of the formation consist of approximately 11 decametre-scale cycles, each typically consisting of molar-tooth dolomudstone (MTS; generally <1 m thick; Fig. 9a), overlain by mechanically laminated to banded, desiccation-cracked and tepeed dolomudstone (Fig. 9b), locally with thin interlayers of intraclast dolopackstone. Chert nodules are locally common in the upper parts of cycles (Fig. 9b). MTS is not evident in the upper ~35 m of this interval, although cyclicity persists. From 140 to 144 m is the only calcareous interval in the succession: slightly argillaceous dolostone riddled with calcareous MTS crack-fills. The succession from 144 to 220 m consists of metre-scale cycles, each with siltstone or argillaceous dolostone (with MTS in the lower 30 m) overlain by mechanically laminated, desiccation-cracked and tepeed, locally intraclastic dolomudstone (Fig. 9c). At ~220 m is a prominent 3.5 m-thick marker bed of massive, dark-weathering, partly silicified, cross-bedded oolite (Figs. 9d-f). Above the oolite are 22 m of variably argillaceous dolostone with ooids and chert. The measured section ends at a conspicuous, 1.2 m-thick marker bed

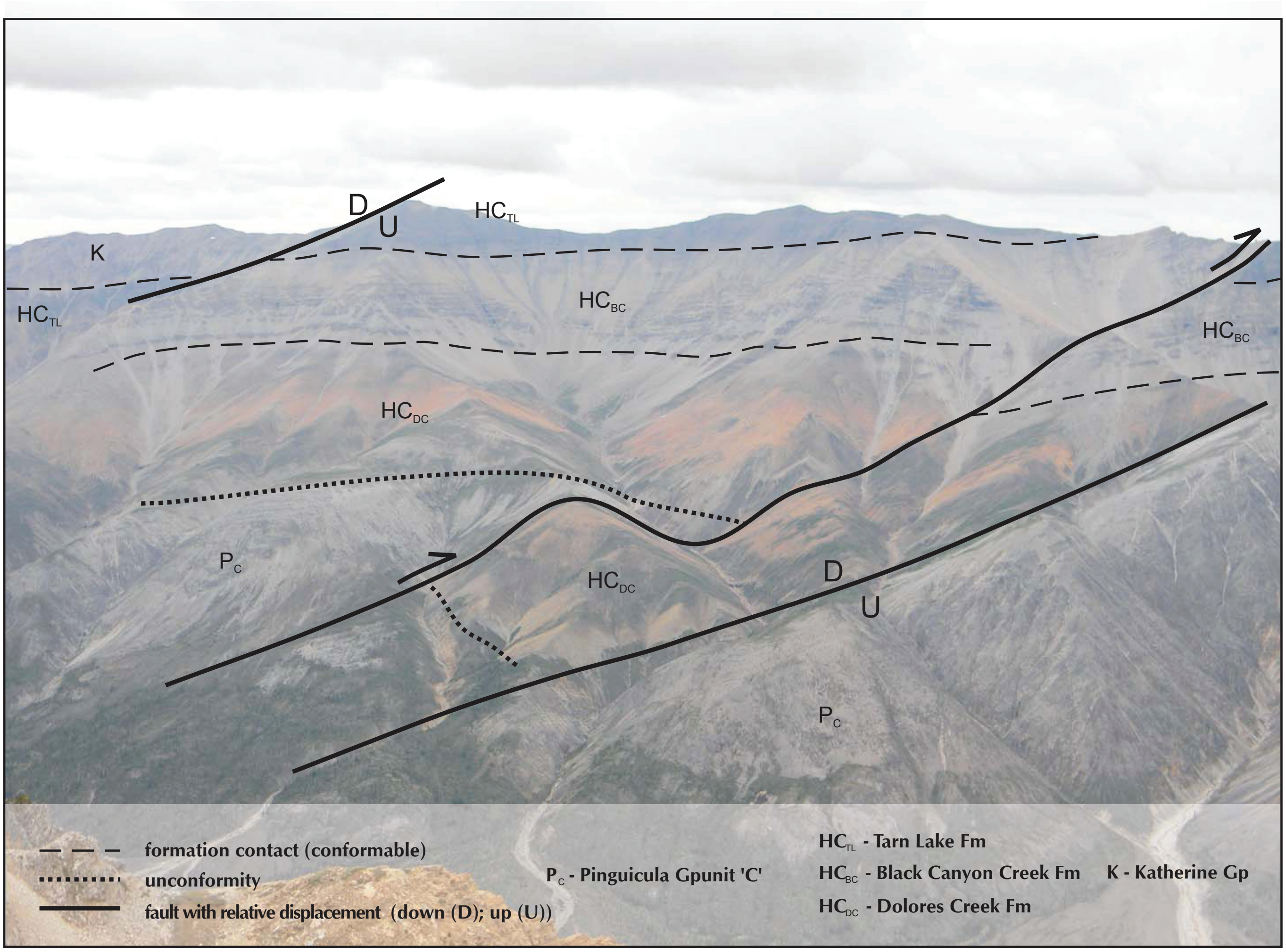


Figure 7. *A typical exposure of the Hematite Creek Group, here on the northeastern flank of the un-named mountain on which the type sections were measured (type sections not seen in this view).*

of dark grey-weathering siltstone (Figs. 9e,f). Although the remaining few metres of the formation were not measured, they are estimated from photos (Figs. 9e,f) to be about 10 m thick, and consist of interlayered siltstone/sandstone and dolostone, and represent a gradational zone between the Black Canyon Creek Formation and Tarn Lake Formation.

INTERPRETATION

The Black Canyon Creek Formation is markedly cyclic. Decametric cycles in the lower part of the formation record normal-marine subtidal conditions (molar-tooth dolostone) repeatedly shallowing to arid supratidal environments. This regime is then gradually superseded by silty-based supratidal cycles an order of magnitude thinner (metre-scale). Both cyclic intervals exhibit stability throughout many tens of metres of section, reflecting depositional equilibrium with subsidence, yet they differ markedly in composition and paleoenvironment: lower, normal-marine cycles are followed by upper, argillaceous, supratidal cycles. The change in cyclicity appears to reflect an adjustment in the subsidence regime that was coeval with the introduction of terrigenous silt. Abrupt transgression recorded by the oolite marker did not significantly alter the depositional regime and may not be part of the eustatic signal that is reflected in the rest of the formation. Although its lateral extent is not known, the marker unit is present in other exposures up to at least 5 km away. The transition to the overlying Tarn Lake Formation is a change from carbonate-dominated to terrigenous-clastic-dominated composition, but the depositional environment remains very shallow marine to supratidal through the entire Tarn Lake Formation. Apparently, this transition reflects a change in terrigenous source dynamics, which had been presaged by introduction of terrigenous silt in the upper Black Canyon Creek Formation.

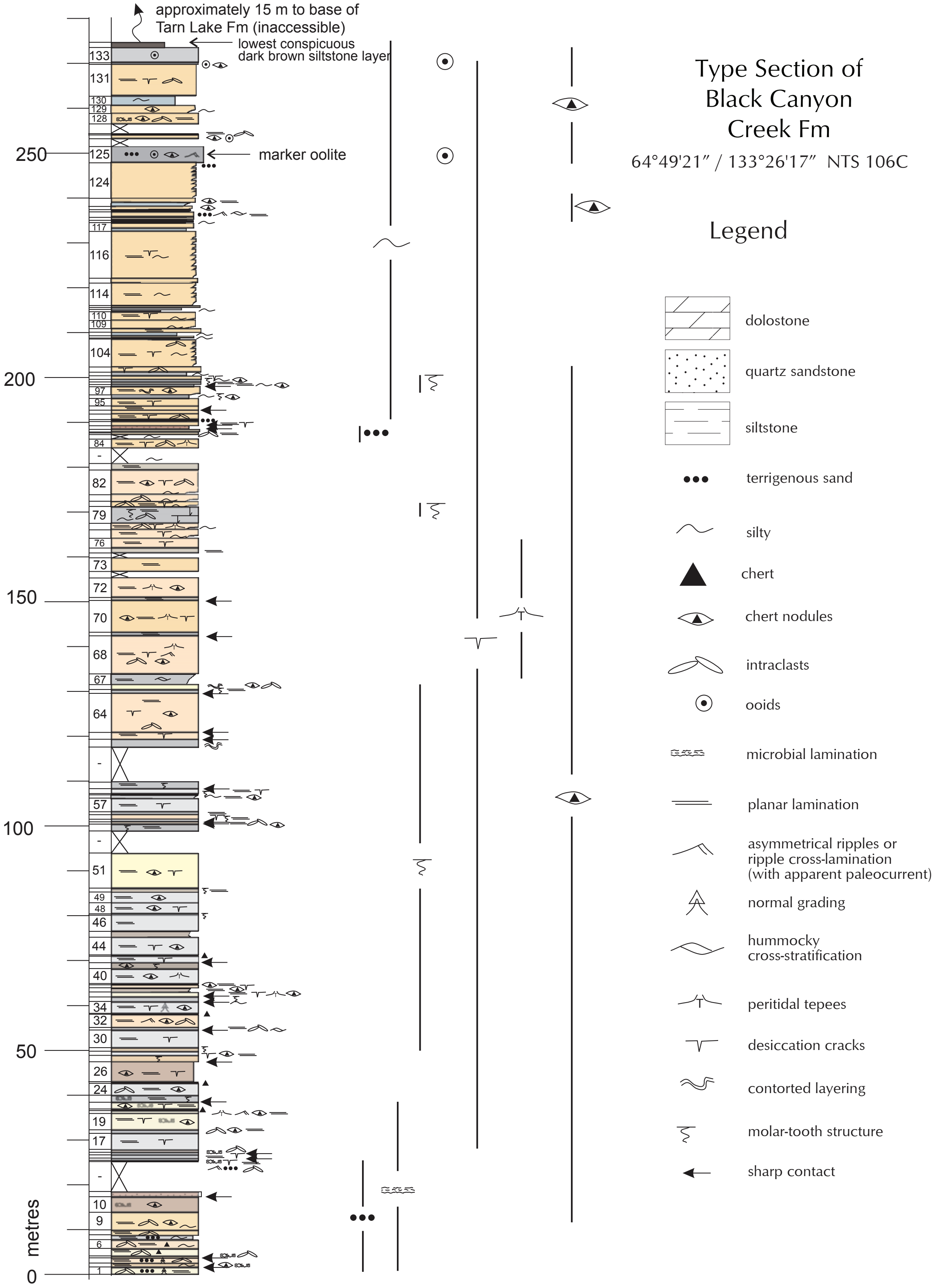


Figure 8. Type section of the Black Canyon Creek Formation, as shown in Figures 1 and 4. Column width indicates weathering profile. Coloured fills indicate weathering colour. Range bars to right of section summarize stratigraphic distribution of paleoenvironmentally significant sedimentary components and structures.

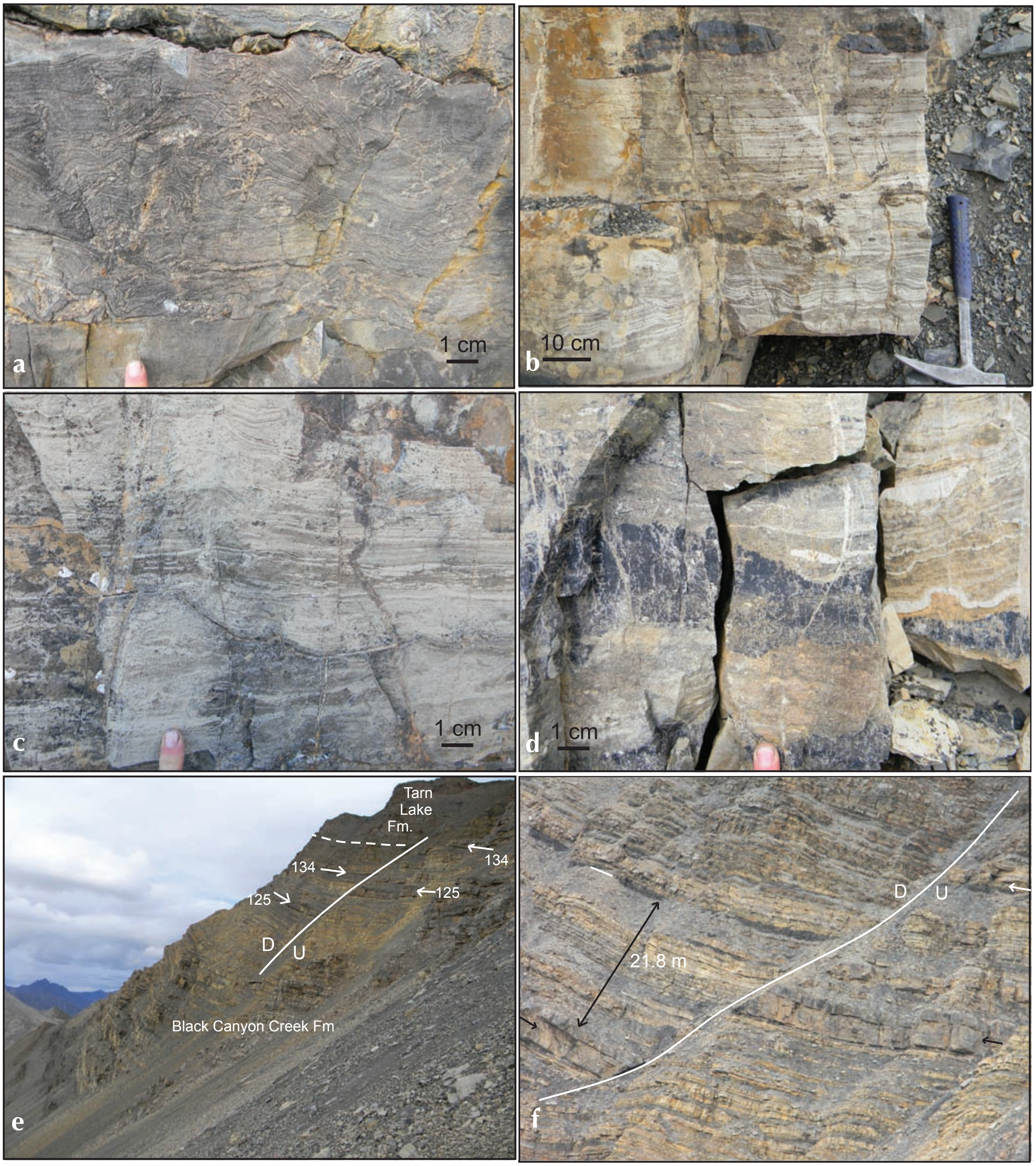


Figure 9. *Typical exposures, lithofacies, and marker units of the Black Canyon Creek Formation.* ***(a)*** *Recrystallized molar-tooth structure (unit 29).* ***(b)*** *Cherty, laminated supratidal dolostone (unit 68).* ***(c)*** *Laminated, tepeed supratidal dolomudstone (unit 78).* ***(d)*** *Interlayered cherty oolite and dolomudstone of marker bed 128.* ***(e)*** *Upper part of the Black Canyon Creek Formation, with marker beds 125 (oolite) and 134 (dark siltstone), just below transition to Tarn Lake Formation.* ***(f)*** *Close-up view of transition interval in (e), illustrating gradational nature of contact. Marker units 125 and 134 are indicated with black and white arrows, respectively.*

DISTRIBUTION AND MAPPING

The Black Canyon Creek Formation is widespread in the Dolores Creek-Pinguicula Lake area, where it is easily distinguished from other formations in the MMSG (and Pinguicula Group) by its conspicuous, regular layering and pale grey to buff colour, and by its stratigraphic position between the black and orange-weathering Dolores Creek Formation and the dark brown-weathering Tarn Lake Formation. No other unit in this area contains abundant chert nodules. Uppermost strata of the Black Canyon Creek Formation are commonly yellow-orange-weathering from a distance. The extent of exposure beyond this area has not been ascertained.

CORRELATION

The Black Canyon Creek Formation is equivalent to the upper part of Pinguicula Group unit 'D' of Eisbacher (1978). It may be stratigraphically equivalent to the Mikkelson Islands Formation of the Shaler Supergroup (Rainbird *et al.*, 1996) and is probably equivalent to the 'H1 unit' in the Mackenzie Mountains, NWT (Fig. 3c; Turner, in press a). Neither the Black Canyon Creek Formation nor the 'H1' unit exhibits any similarity to strata of Pinguicula Group unit 'C', other than their dolomitic composition.

This proposed correlation of the Black Canyon Creek Formation and 'H1 unit' is made despite pronounced differences in the lithofacies and stratigraphic expression of the carbonate successions in the two areas, which are separated by about 150 km (oblique to strike, and not palinspastically restored). The 'H1 unit', the lowest part of the MMSG exposed in the Mackenzie Mountains is known in only three localities in NWT, of which two are of poor quality or negligible thickness. At the third locality, in NTS 106G, the uppermost ~480 m of the formation are exposed (Turner, in press a), but what lies beneath is unknown. The 'H1 unit' is strikingly non-cyclic and is not peritidal throughout most of its thickness (Turner, in press a). It does not contain a significant amount of terrigenous silt. Nonetheless, some similarities with the Black Canyon Creek Formation are present, including the presence of chert (upper 'H1 unit'; throughout Black Canyon Creek Formation). The Black Canyon Creek Formation may be a shallow-water equivalent to the 'H1 unit'. Their apparent lateral equivalence but stratigraphic and sedimentologic dissimilarity suggest that they are best considered to be different formations. The 'H1' will be formalized in a separate publication.

An alternative correlation of the Hematite Creek Group is that the entire group consists of lateral facies equivalents of the Tsezotene Formation and lowermost Katherine Group (Thorkelson *et al.*, 2003; 2005; Fig. 3b). The Dolores Creek Formation would be equivalent to the lower 'Grey member' of the Tsezotene Formation (Long *et al.*, 2008; Turner and Long, 2008), the Black Canyon Creek Formation would be a shallower-water equivalent of carbonate rocks in the lower part of the upper 'Red member' of the Tsezotene Formation, and the Tarn Lake Formation would be a shallow-marine facies equivalent of the lowermost fluvial unit (K1) of the Katherine Group (Long, in press a). If the lower two formations of the Hematite Creek Group were correlated with the Tsezotene Formation in NWT, the westward thinning of time-equivalent units would be significantly less marked than in the correlation scheme that is favoured here.

ECONOMIC POTENTIAL

No occurrences of economic minerals are known from this unit, and the economic potential of the Black Canyon Creek Formation is unknown. Minor occurrences of copper minerals and fluorite are present in the 'H1 unit' in the Mackenzie Mountains approximately 150 km to the east-northeast (personal observation).

TARN LAKE FORMATION (NEW)

A terrigenous-clastic-dominated unit that lies stratigraphically between the Black Canyon Creek Formation and quartz arenite of the Katherine Group was measured up a creek incised into the south flank of an unnamed mountain about 10 km south of Dolores Creek and 16 km east of the Bonnet Plume River (Fig. 10). The name for this stratigraphic unit is after the informal name given by hunters to a small lake 2.5 km south of the type section.

The lower contact with the Black Canyon Creek Formation is covered at this location, and probably occurs a few tens of metres below the lowest exposed strata, based on Black Canyon Creek Formation exposures elsewhere in the valley, a negligible dip angle, and the geomorphology of the broad valley in which the section is based (Fig. 10). Lowermost Tarn Lake Formation strata are exposed above the Black Canyon Creek Formation where the latter was measured on a ridge on the northwestern part of the same mountain. The uppermost ~10 m of strata of the Black Canyon Creek Formation were not measured, but the excellent exposure of this inaccessible transitional interval clearly demonstrates a gradational contact through interlayering of dolostone, siltstone, and sandstone.

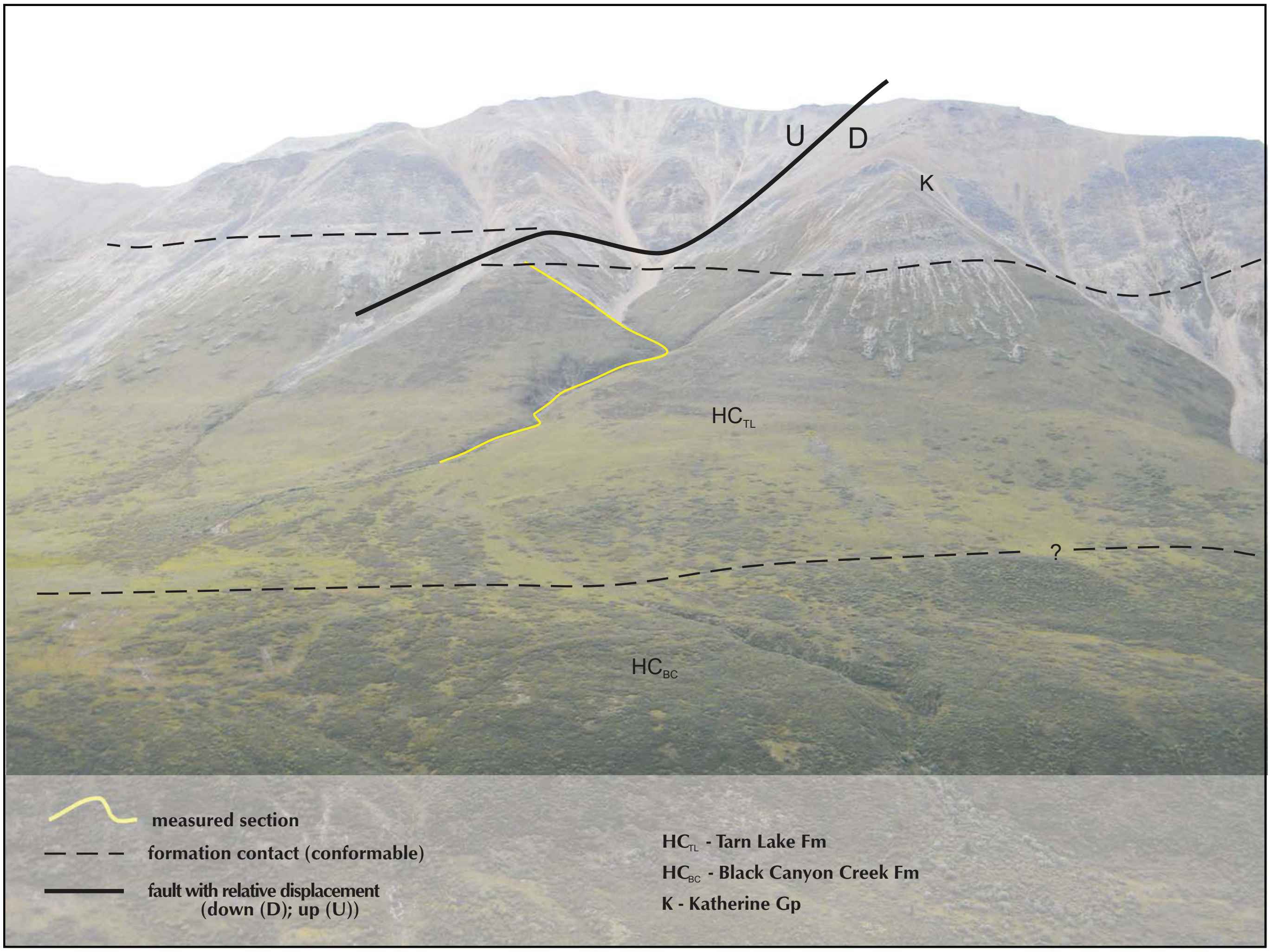


Figure 10. *Measured section of the Tarn Lake Formation on the south flank of the un-named mountain where all Hematite Creek Group sections were measured. To right (east) of marked fault, the lowest marine interval of the Katherine Group is down-faulted against the lowest fluvial interval.*

The measured section of the Tarn Lake Formation is approximately 265 m thick, and the full thickness of the formation in this area is probably approximately 300 m. The upper contact with resistant, white-weathering, massive quartz arenite of the Katherine Group is covered, but appears to be abrupt (Figs. 10 and 11).

The Tarn Lake Formation consists of generally medium-bedded quartz sandstone interlayered with siltstone (Figs. 12a,b). Sedimentary structures in sandstone and siltstone throughout most of the succession include hummocky cross-stratification (HCS), desiccation cracks, plane lamination and parting lineations, wave and current-ripple cross-lamination, trough cross-bedding, and less commonly, synaeresis cracks, scour structures, and gutter casts (Fig. 12c). Centimetric to millimetric siltstone clasts locally form lags at bed bases. Orange-brown-weathering dolostone interlayers first appear approximately one-fifth of the way through the exposed part of the succession. Although the lowest of these dolostone units contains recrystallized molar-tooth structure (Fig. 12d), all other dolostone units consist of millimetric to centimetric layers of dolomudstone to dolosiltstone (Fig. 12e), locally with desiccation cracks, wave-ripples, contorted layering, or grading expressed in quartzose silt to very fine sand. One carbonate unit two-thirds of the way through the exposed succession exhibits two layers of centimetric nodules of medium grey chert. The uppermost 50 m of the formation (Fig. 12f) are slightly more recessive and contain a lower proportion of quartz sandstone, although carbonate interbeds persist. Sedimentary structures are difficult to discern in this upper interval of dark grey-weathering

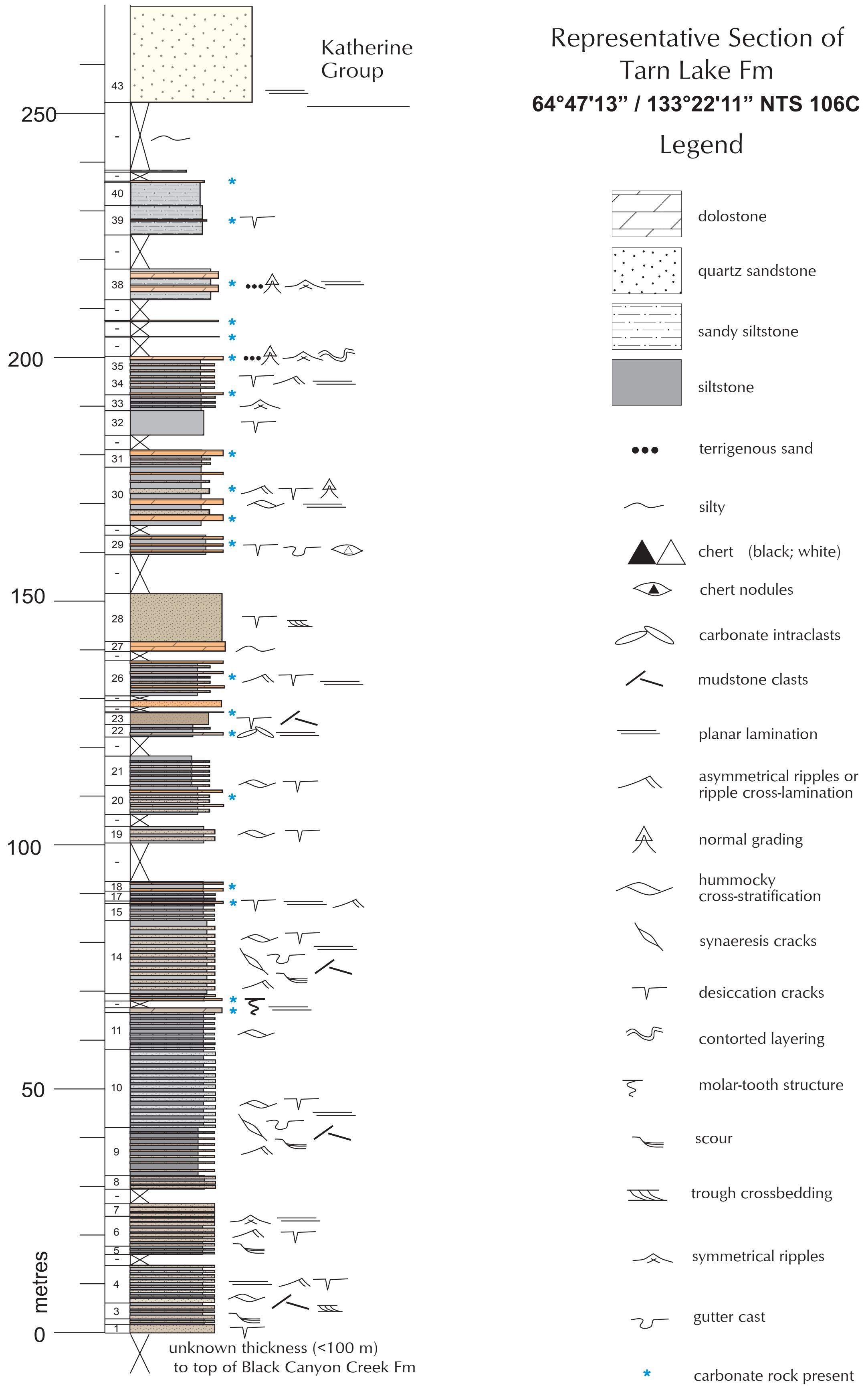


Figure 11. *Measured section of the Tarn Lake Formation, as shown in Figure 1. Column width indicates weathering profile. Coloured fills indicate weathering colour.*

Figure 12. *Exposure and typical lithofacies of the Tarn Lake Formation.* ***(a)*** *and* ***(b)*** *Typical exposures of sandstone and siltstone interlayers, from sandstone-dominated intervals.* ***(c)*** *Gutter cast (unit 8).* ***(d)*** *The only molar-tooth interval in the section is 1 m thick (unit 12).* ***(e)*** *Interlayered wave-rippled sandstone and dolomudstone (unit 38).* ***(f)*** *Uppermost ~120 m of the Tarn Lake Formation, and its abrupt upper contact with the Katherine Group.*

siltstone, but there is some suggestion of desiccation cracks. Cyclicity is not well developed in this formation, but may be expressed in decametre-scale variation in the relative proportions of siltstone to sandstone. A detailed study of paleocurrent indicators was not undertaken, but sparse measurements of wave-ripple crests suggest a north-trending shoreline, and ripple cross-lamination and gutter casts in tempestites are oriented roughly south-southwest, suggestive of shore-parallel geostrophic currents.

The maximum depositional age of the Tarn Lake Formation in the Wernecke Mountains is constrained by the age of youngest detrital muscovite (1033 ± 9 Ma Ar-Ar; Thorkelson, 2000; Thorkelson *et al.*, 2005). This concurs with detrital zircon ages for the Katherine Group in the Mackenzie Mountains: Rainbird *et al.* (1996) reported a youngest detrital zircon age of 1083 Ma, and Leslie (2009) obtained a 1005 Ma youngest zircon.

INTERPRETATION

The Tarn Lake Formation in the study area contains abundant sedimentary structures indicative of deposition in a very shallow-water, storm-dominated marine environment. Desiccation cracks are ubiquitous, indicating that the bathymetric differential between the sea-floor, where subaqueous deposition of storm-influenced sand (HCS; gutter casts) took place, and subaerial zones (desiccation cracks) was minimal (perhaps less than a metre), or that sediment deposition took place predominantly during storm surge over surfaces that were subaerially exposed during calm weather. The presence of one thin interval of molar-tooth structure indicates that the environment was, at least for a brief time, a geochemically normal (unrestricted) subaqueous setting. The combination of dominant attributes, however, depicts a very near-shore to subaerial environment in an arid or semi-arid environment strongly affected by storms. For storm waves to persist across shallow-water areas such as this, a strong fetch is required, which implies a large area of open water over which storm winds could build.

DISTRIBUTION AND MAPPING

Although strata of the Tarn Lake Formation are readily recognized as a recessive, medium brown-weathering interval beneath resistant quartz arenite of the Katherine Group and are widespread on recessive slopes of the Pinguicula Lake – Dolores Creek area, the full exposure area has not been demonstrated by mapping. Tarn Lake Formation strata superficially resemble silty marine intervals in the Katherine Group, and care should be taken that the two are not mistaken for one another.

CORRELATION

The Tarn Lake Formation consists of recessive siliciclastic rocks between the abandoned units 'D' and 'E' of the Pinguicula Group (Eisbacher, 1978, 1981). Although this unit appears to be stratigraphically equivalent to the Tsezotene Formation of NWT (Fig. 3c), and has been mapped as such in NTS 106E and 106F (Norris, 1982a,b; Thorkelson *et al.*, 2003), strata described here are similar to the Tsezotene Formation of NWT only in their terrigenous clastic composition. The comparatively thin, shallow-water Tarn Lake Formation in the Pinguicula Lake – Dolores Creek area contrasts markedly with the thick, deep-water mudstone and siltstone succession of the Tsezotene Formation of the Mackenzie Mountains, and for this reason, the shallow-water unit in the Wernecke Mountains requires a distinct formation name. The Tsezotene Formation in the Mackenzie Mountains (Gabrielse *et al.*, 1973; Long *et al.*, 2008; Long in press b), is interpreted to have been deposited in a sub-storm-wave-base, distal shelf environment dominated by siliciclastic mud (Long *et al.*, 2008). Thickness of the Tsezotene Formation in the Mackenzie Mountains is typically in excess of 1 km (Long, in press b); the type section, in the Tsezotene Range in NTS 95L (Glacier Lake) is approximately 1100 m thick (Gabrielse *et al.*, 1973).

There are no distinctive stratigraphic units in the measured section with which to correlate this formation locally or regionally. The only stratigraphically distinctive variability in the formation is the appearance of sparse carbonate interlayers in the upper three-quarters of the measured section.

The lower contact of the Tsezotene Formation is covered at the three known localities where the underlying 'H1 unit' is exposed in the Mackenzie Mountains, but exposure patterns and lithostratigraphy at these locations suggest that the transition is abrupt (major flooding surface; Long *et al.*, 2008; Turner and Long, 2008) and possibly unconformable (Turner, in press a). In the Wernecke Mountains, however, the lower contact of the Tarn Lake Formation is compositionally gradational (from carbonate-dominated to quartz sandstone-dominated), and depositional environments appear to be consistently shallow water to emergent. The Tsezotene Formation consists of grey mudrocks in the thick, lower 'grey member', and red-weathering mudrocks and subordinate carbonates and sandstones of the thinner, upper 'red member' (Long, in press b). The Tarn Lake Formation cannot be subdivided into meaningful, informal members, although the sparse carbonate layers are limited to the upper three-quarters of the exposed section.

Sediment grain size of the Tarn Lake Formation is markedly coarser than that of the Tsezotene Formation, and all sedimentary structures in the former point to extremely shallow-water deposition. In the context of paleotectonic conditions inferred by Turner and Long (2008), this suggests that, during deposition of the Tsezotene Formation, the MMSG basin may have deepened westward from a basin margin somewhere beneath the Mackenzie Plain to an area of maximum depth somewhere in the Mackenzie Mountains, then shallowed westward into the present-day area of the Wernecke Mountains. A different sediment supply and dispersal regime than that of the Tsezotene Formation in the Mackenzie Mountains would be necessary, and it is possible that the study area represents the western side of the early MMSG basin. Further work is required to establish the basin configuration at that time and determine the implications for tectonostratigraphic evolution of the basin and for inter-regional correlation.

Interpretation of the Tarn Lake Formation in a regional context is complicated by identification of strata that are clearly its equivalent in nearby NTS 106E and 106F as Tsezotene Formation (Norris 1982a,b; Thorkelson *et al.*, 2003). Norris (1982a,b) described the rocks as being of marine and non-marine origin, perhaps owing to the prevalence of desiccation cracks, and Thorkelson *et al.* (2003) described abundant indications of subaerial exposure. Although the lithofacies described for 'Tsezotene Formation' strata in NTS 106E by Thorkelson *et al.* (2003) are of a shallow-marine to subaerial origin that agrees with the Tarn Lake Formation, the unit's thickness is reported to be >1.2 km, which is roughly three times the inferred thickness of the Tarn Lake Formation exposed in this NTS 106C. Validation of marked thickening in the Tarn Lake – 'Tsezotene Formation' interval between NTS 106C and NTS 106E would imply a very significant geographic variation in subsidence rate that would support previous interpretations of basin segmentation in the MMSG (Turner and Long, 2008).

For proposed correlations to inliers west of the Wernecke Mountains, the reader is referred to Rainbird *et al.* (1996, 1997), Abbott (1997), Cook and MacLean (2004), Thorkelson *et al.* (2005), Long *et al.* (2008), and Macdonald and Roots (2009).

ECONOMIC POTENTIAL

No mineral occurrences are known from the Tarn Lake Formation or its equivalent in NWT (Tsezotene Formation). This is the first documentation of this unit, and so its regional economic potential is unknown.

KATHERINE GROUP

Thick strata of the Katherine Group are extensively exposed in the Dolores Creek - Pinguicula Lake area, where these quartz arenites were known for a time as unit E of the Pinguicula Group (Eisbacher, 1978), and the 'Corn Creek quartz arenite' or 'Corn Creek quartzite' (Eisbacher, 1981; Thorkelson, 2000). No sections were measured in this unit for this study, but some general characteristics can be established.

In the Mackenzie Mountains, the Katherine Group comprises seven formation-scale units (K1 to K7). Odd-numbered units are white, pink- and purple-weathering fluvial-dominated quartz arenite, whereas even-numbered units consist of dull brown marine siltstone and sandstone with minor orange-brown-weathering carbonate rock. The recessive marine intervals are commonly covered by blocky quartz arenite talus, but the uppermost marine interval, unit K6, is commonly conspicuous. Unit K6 siltstone is marked by an orange-weathering stromatolitic dolostone throughout the exposure area of the Katherine Group in the Mackenzie Mountains, and indeed in correlative strata of the Shaler Supergroup (Jefferson and Young, 1989; Long *et al.*, 2008).

This general description also applies to the Katherine Group in the Wernecke Mountains. Although it has not been ascertained that seven units are expressed, thick marine and fluvial units clearly alternate (Figs. 13a,b,c), and units K6 (including its characteristic stromatolite; Fig. 13d) and K7 clearly underlie strata of the lower Little Dal Group where they were documented 15 km east of Pinguicula Lake near a tributary of Corn Creek (Figs. 14 and 15a).

The Katherine Group is correlated with the Nelson Head, Aok and Grassy Bay formations in the Shaler Supergroup, Amundsen Basin (Fig. 3c; Rainbird *et al.*, 1996). Unit K6 is directly equivalent to the Aok Formation of the Shaler Supergroup (Jefferson and Young, 1989; Rainbird *et al.*, 1996; Long *et al.*, 2008). For suggested correlations westward to other Proterozoic inliers in the Yukon, the reader is referred to Rainbird *et al.* (1996, 1997), Abbott (1997), Cook and MacLean (2004), Thorkelson *et al.* (2005), Long *et al.* (2008), and Macdonald and Roots (2009).

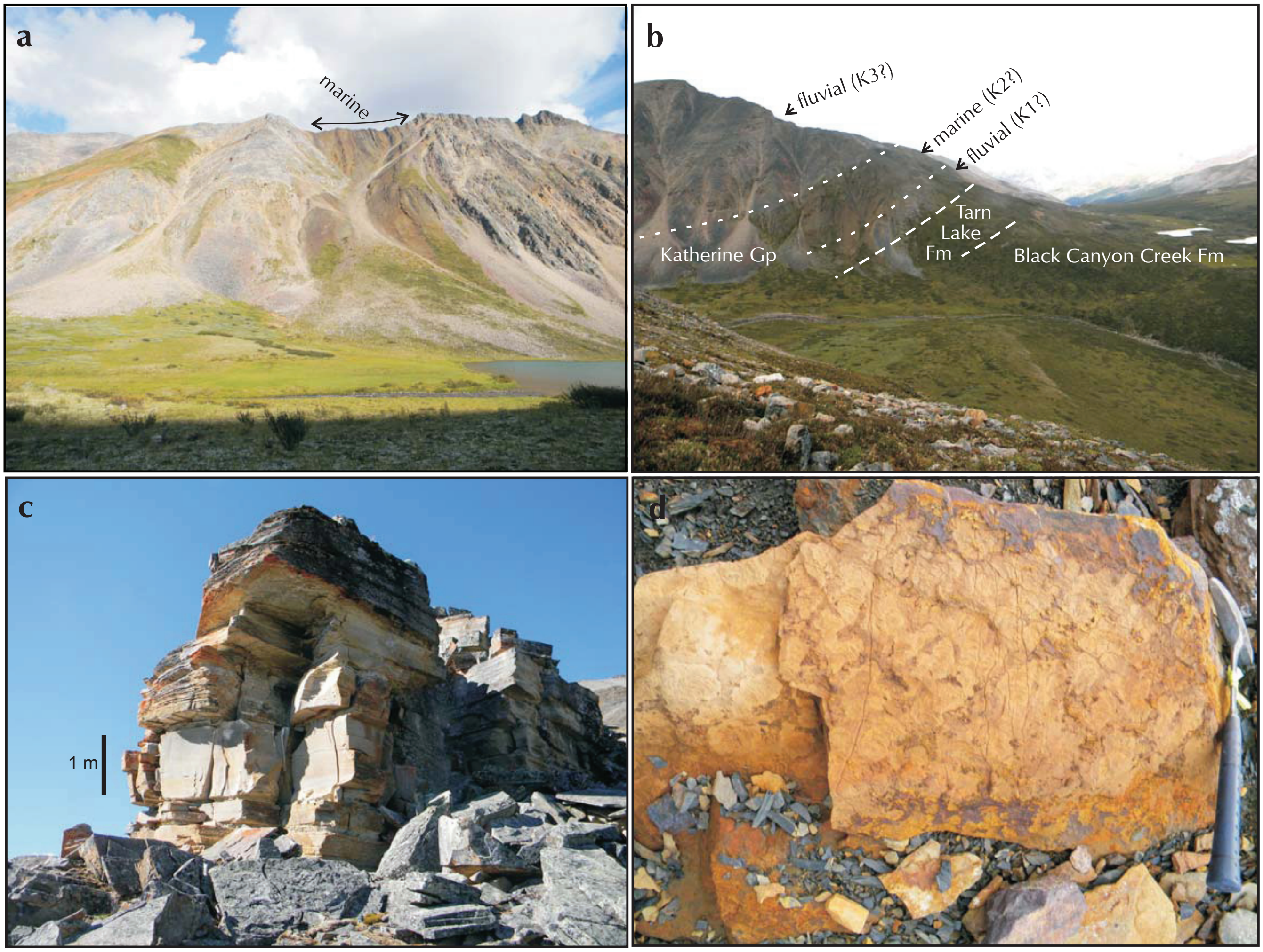


Figure 13. *Katherine Group.* ***(a)*** *Interlayered fluvial quartz arenite (pale purplish-grey) and marine siltstone – mudstone. It is unknown which of the marine intervals is depicted here.* ***(b)*** *Fluvial and marine intervals of the Katherine Group overlie strata of the Hematite Creek Group. If no structural features are present, this exposure would suggest that unit K1 is thin in this area.* ***(c)*** *Massive, cross-bedded and planar-bedded quartz arenite of the basal Katherine Group (marine) above Tarn Lake Formation type section (see Fig. 12f).* ***(d)*** *Orange-weathering stromatolite (Inzeria) is a widespread marker in unit K6 and equivalent unit of the Shaler Supergroup. This exposure is in upper Katherine Group near Mount Profeit.*

The abrupt base of the Katherine Group in the Wernecke Mountains resembles the same contact in the Mackenzie Mountains. The contact's abruptness is a function of the contrasting depositional processes and sediment grain sizes in marine (Tarn Lake/Tsezotene) versus fluvial (Katherine) systems, and reflects the progradation of a fluvial-dominated system over a near shore marine system at the beginning of Katherine Group deposition. The volumetric importance of quartz sand in the Tarn Lake Formation (and indeed the minor influxes of quartz sand that are intermittently present all the way to the base of the Hematite Creek Group) also emphasizes the similarity in source material in the two formations and the conformable nature of the transition between the two stratigraphic units, in spite of marked differences in structure and composition associated with their contrasting marine and fluvial environments.

LITTLE DAL GROUP – BASINAL ASSEMBLAGE

Strata of the lower Little Dal Group were examined on a ridge near Corn Creek, approximately 15 km east of Pinguicula Lake and 7 km south-southwest of Mount Profeit (Fig. 14). The abrupt basal contact with Katherine Group quartz arenite is overlain by approximately 20 m of poorly exposed, dark grey to black siltstone and shale followed by three metres of interlayered siltstone and

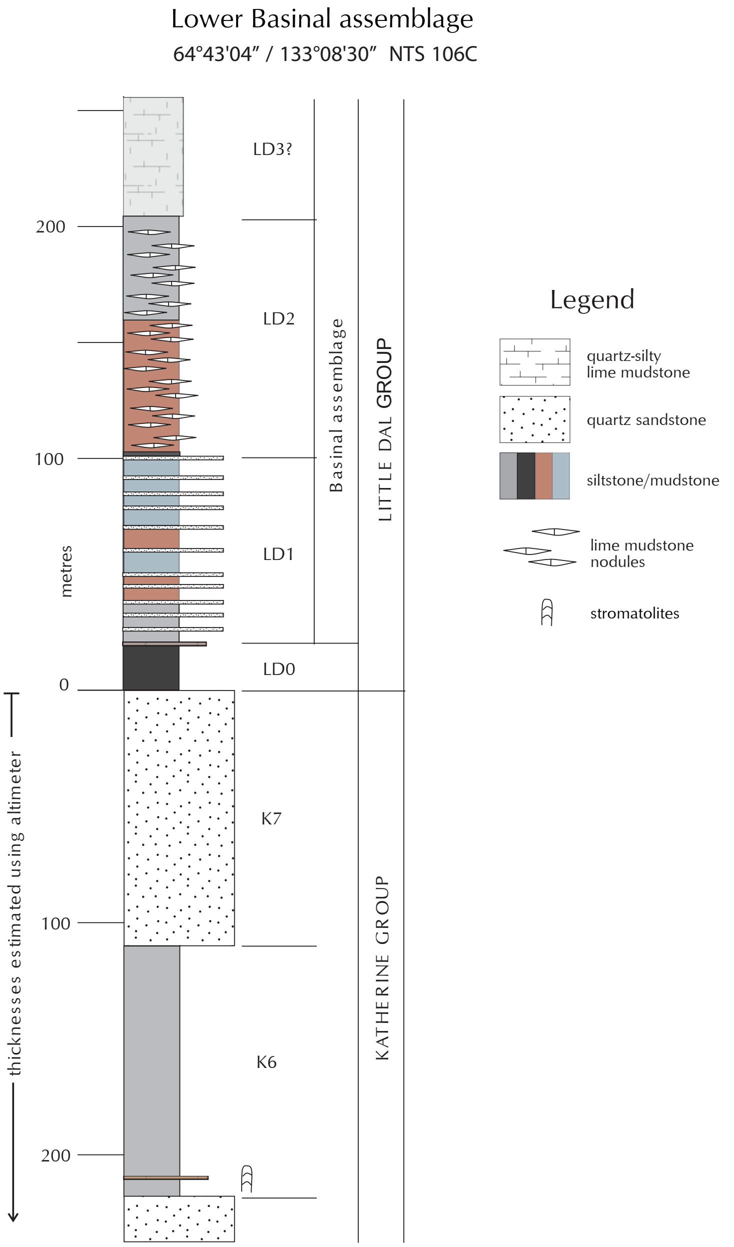


Figure 14. *Measured section of the lower part of the Basinal assemblage at a ridge location 7 km south-southwest of Mount Profeit. Column width indicates weathering profile. Coloured fills indicate weathering colour. Sequence-stratigraphic interpretations are based on the strikingly similar stratigraphy of the Basinal assemblage in the NWT (Turner and Long, 2008). Katherine Group talus below the ridge was crudely measured using an altimeter. Rough position of orange-weathering stromatolite (Fig. 13d) in unit K6 is indicated.*

quartz sandstone, capped by a thin, medium brown-weathering dolomudstone. The interval from 23 to 102 m consists of dark grey, brown, maroon, green, and tan-weathering siltstone (Fig. 15b) with subordinate ripple cross-laminated quartz sandstone. At 102 m is a thin but conspicuous (<1 m) black shale, which is then overlain by 102 m of maroon and greenish-tan-weathering siltstone with abundant lime mudstone nodules and local thin lime mudstone layers (Fig. 15c-e). This is overlain gradationally over 3 m by 50 m of platy, fissile, calcareous siltstone (Fig. 15f). The section (254 m total thickness) ends at a mountain peak.

INTERPRETATION

This succession is strikingly similar to the lower Basinal assemblage of the Little Dal Group (probably up to the middle of Basinal member 3; Turner *et al.*, 1997; Turner and Long, 2008; Turner, in press b). Like the underlying Katherine Group strata in this area, but unlike the units below the Katherine Group, paleoenvironments and stratigraphic expression closely resemble those of equivalent units in the Mackenzie Mountains. The Basinal assemblage consists of deeper-water carbonate rocks and terrigenous mudrocks. Deposition took place below the photic zone and below storm wave-base. The silt and clay-grade terrigenous material represents hemipelagic deposition and possibly very weak turbidity currents, whereas much of the carbonate mudstone was probably contributed by the settling of carbonate mud that precipitated in the overlying water column (Turner *et al.*, 1997).

The lowermost 23 m are interpreted as the first third-order stratigraphic cycle of the Little Dal Group (LD0; Turner and Long, 2008), and are equivalent to the Mudcracked formation. These siltstones lack the abundant shallow-water sedimentary structures of the Mudcracked formation, and the capping carbonate, so conspicuously developed as a marker oolite in NWT, is here limited to a ferruginous dolomudstone. The overlying 79 m-thick interval of siltstone and sandstone is equivalent to the second third-order cycle in the Little Dal Group (LD1; Basinal assemblage member 1); the stromatolitic carbonate that punctuates the top of this unit in NWT is absent. Multi-coloured siltstone with nodular lime mudstone (103 m) is characteristic of the third Little Dal cycle (LD2; Basinal assemblage member 2). It is unclear whether platy-weathering silty limestone of the uppermost exposed unit belongs to Basinal assemblage member 2 or member 3.

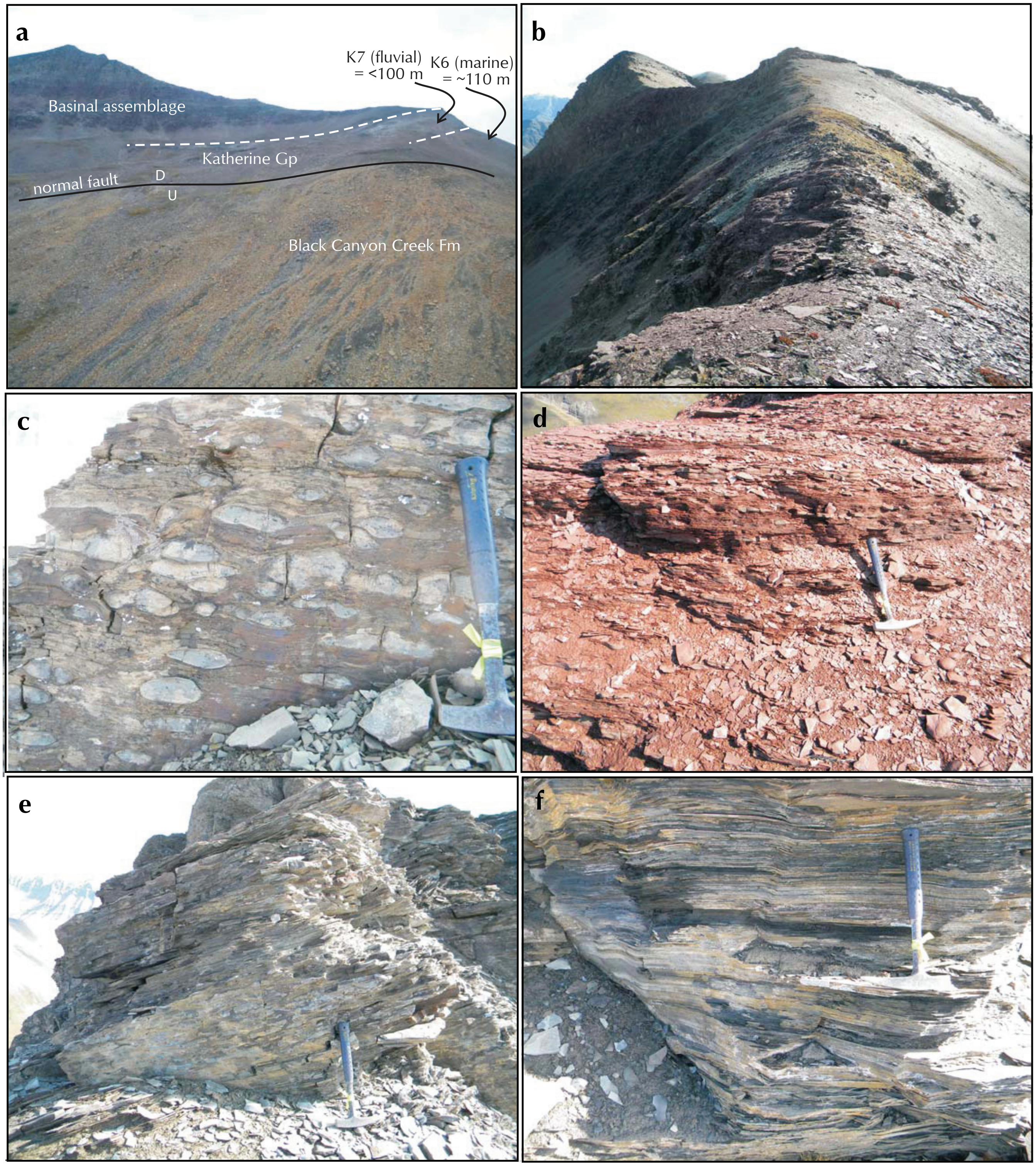


Figure 15. *Exposures and typical lithofacies of the Basinal assemblage of the Little Dal Group at location of measured section (Fig. 14).* ***(a)*** *Basal Little Dal Group overlies Katherine Group talus south of a normal fault, in the only Little Dal Group exposure in the Wernecke Mountains that has been documented to date (view to south).* ***(b)*** *View up-section from 50 m above section base shows maroon siltstone-dominated interval of lower Basinal assemblage.* ***(c)*** *Lime mudstone nodules in grey-weathering siltstone at 100 m stratigraphic elevation.* ***(d)*** *Maroon siltstone with thin beds and nodules of lime mudstone at 150 m stratigraphic elevation.* ***(e)*** *Lime mudstone nodules become less abundant at about 200 m stratigraphic elevation.* ***(f)*** *Uppermost ~50 m of the measured section consist of fissile, argillaceous limestone.*

Thorkelson *et al.* (2003) described Little Dal Group strata from NTS 106E as consisting of approximately 500 m of carbonate mudstone and black shale. Such a composition is typical of the deepest-water areas of the Basinal assemblage of the Little Dal Group in NWT (Aitken, 1981; Turner *et al.*, 1997; Turner and Long 2008). Previous interpretations of the basin configuration during this time interval were based on sections from NWT, with the northwestern-most section in NTS 106F just east of the Yukon-NWT border, where there exists indications of westward-shallowing and an absence of the deep-water black shale facies. The presence in the Basinal assemblage of black shale in NTS 106E, but of red and grey-weathering siltstone in NTS 106C (this study) points to a complex basin-floor paleotopography that lay at a variety of depths below a water column that was redox-stratified (Turner and Long, 2008).

CORRELATION

The Basinal assemblage is equivalent to abandoned Pinguicula Group unit 'F' (Eisbacher, 1981). It correlates northeastward from the Mackenzie Mountains to the Boot Inlet Formation of the Shaler Supergroup of Victoria Island and adjacent mainland (Fig. 3c). For proposed correlations to inliers west of the Wernecke Mountains, the reader is referred to Rainbird *et al.* (1996, 1997), Abbott (1997), Cook and MacLean (2004), Thorkelson *et al.* (2005), Long *et al.* (2008), and Macdonald and Roots (2009).

DISTRIBUTION AND MAPPING

The lack of detailed mapping in the MMSG in the Wernecke Mountains precludes assessment of the areal extent of this unit, or determination of the highest Little Dal Group stratigraphic unit present in the area.

ECONOMIC POTENTIAL

The economic potential of the lower Little Dal Group in the Wernecke Mountains is unknown. In NWT, part of the Basinal assemblage (equivalent to lower part of the nodular lime mudstone and siltstone interval) consists of black shale that probably accumulated under euxinic basin water. Although black shale is limited in the measured section of this study to <1 m in thickness, strata of the same interval to the northwest (NTS 106E; Thorkelson *et al.*, 2003) are reported to contain black shale, which may reflect the development of deep-water euxinia in more than one area of the basin. The extent and cause of basin extension and excessive subsidence during this time is as yet unknown, and the composition and origin of black shale of this interval in NWT are currently being studied. It remains unknown whether the black shale may have economic potential on its own, or whether it may have contributed metals to known showings in associated carbonate strata in NWT.

Parts of the Gayna River deposit in NWT (Hewton, 1982; Turner, 2007) are hosted by the upper Basinal assemblage, and vein-filling sphalerite is known in reefs of the Basinal assemblage away from the Gayna River deposit (personal observation). It is not known whether any of the four thick formations that overlie the Basinal assemblage may be present somewhere in the Wernecke Mountains. A superficial assessment of the economic potential of the Little Dal Group in Yukon is not possible without knowledge of its full stratigraphic expression and areal extent.

FUTURE WORK

This project has identified numerous aspects of the MMSG in the Wernecke Mountains that merit further investigation. Among these, the nature of the basal contact is critical; this is the long-sought interface between two major intervals in the Proterozoic evolution of northwestern Laurentia. Is this contact truly an angular unconformity, and does it exhibit evidence of extensive exposure, erosion, or tectonism? Is there facies variation in the basal Dolores Creek Formation that would reflect paleotopographic variation associated with rifting? The lateral continuity of the Dolores Creek Formation's stratigraphy requires investigation, to determine whether extensional basin segmentation took place.

The proposed correlation of the Black Canyon Creek Formation with the 'H1 unit' in NWT should be tested using stable isotope stratigraphy. A full section of the Tarn Lake Formation needs to be documented in detail. Perplexing thickness and facies patterns in the Tarn Lake Formation suggest significant syndepositional tectonic activity, and require documentation to establish the location of sedimentary depocentres and possible synsedimentary faults.

The Katherine Group remains undescribed; its basic stratigraphy needs to be established to determine whether its 7 formation-scale units are expressed in Yukon. Paleocurrent and isopach studies in the Katherine Group will help to establish basin deepening directions, which will reflect the regional basin configuration and add to the growing understanding of this tectonostratigraphically complex succession.

Areas south of Pinguicula Lake need to be examined to determine whether Little Dal Group strata younger than the Basinal assemblage may be present. All of these future endeavours will be fundamental to both understanding how the MMSG strata in the Wernecke Mountains correlate eastward to NWT and westward to other inliers in Yukon, and to evaluating the economic potential of the MMSG.

SUMMARY

Strata of the MMSG were examined in detail on the flanks of an un-named mountain near the junction of 'Dolores Creek' with the Bonnet Plume River, in NTS 106C (Fig. 1) and on a ridge approximately 7 km south-southwest of Mount Profeit. The Dolores Creek Formation (~260 m thick; Fig. 2) represents the basal strata of the MMSG, which have remained hitherto unknown. This unit is conformably overlain by a carbonate succession (Black Canyon Creek Formation; ~285 m thick) that is probably stratigraphically equivalent to the 'H1 unit' in the Mackenzie Mountains. Gradationally overlying the Black Canyon Creek Formation is a siltstone-dominated unit (Tarn Lake Formation; >265 m thick) and a thick succession dominated by quartz arenite (Katherine Group; unmeasured). The highest MMSG unit discovered to date in this area belongs to the Basinal assemblage of the lower Little Dal Group (>250 m). It is unknown how much of the upper part of the MMSG may be present in the Wernecke Mountains (Little Dal Group is 2-3 km thick in the Mackenzie Mountains). The economic potential of the MMSG in the Wernecke Mountains is unknown and requires further investigation.

ACKNOWLEDGEMENTS

The Yukon Geological Survey is gratefully acknowledged for supporting field activities. This work was also supported in part by an NSERC Discovery Grant. Kirsti Medig and Geoff Baldwin were stoic companions in the field in 2010 and 2009, respectively. Derek Thorkelson and Darrel Long provided invaluable advice on this manuscript. This work would not have been possible without the extensive previous work and generous advice of Derek Thorkelson.

REFERENCES

Abbott, G., 1997. Geology of the upper Hart River area, eastern Ogilvie Mountains, Yukon Territory (116A/10, 116A/11). Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada, Bulletin 9, 91 p.

Aitken, J.D., 1981. Stratigraphy and sedimentology of the Upper Proterozoic Little Dal Group, Mackenzie Mountains, Northwest Territories. *In*: Proterozoic Basins of Canada, F.H.A. Campbell (ed.), Geological Survey of Canada, Paper 81-10, p. 47-71.

Cook, D.G. and MacLean, B.C., 2004. Subsurface Proterozoic stratigraphy and tectonics of the western plains of the Northwest Territories. Geological Survey of Canada, Bulletin 575, 91 p.

Eisbacher, G.H., 1978. Two major Proterozoic unconformities, northern Cordillera. Geological Survey of Canada, Paper 78-1A, p. 53-58.

Eisbacher, G.H., 1981. Sedimentary tectonics and glacial record in the Windermere Supergroup, Mackenzie Mountains, northwestern Canada. Geological Survey of Canada, Paper 80-27, 40 p.

Gabrielse, H., Blusson, S.L. and Roddick, J.A., 1973. Flat River, Glacier Lake, and Wrigley Lake map areas (95E, L, M), District of Mackenzie and Yukon Territory. Geological Survey of Canada, Memoir 366, 153 p. and 3 maps.

Heaman, L.M., LeCheminant, A.N. and Rainbird, R.H., 1992. Nature and timing of Franklin igneous events, Canada: Implications for a late Proterozoic mantle plume and the break-up of Laurentia. Earth and Planetary Science Letters, vol. 109, p. 117-131.

Hewton, R.S., 1982. Gayna River: A Proterozoic Mississippi Valley-type zinc-lead deposit. *In:* Precambrian Sulphide Deposits, R.W. Hutchinson, C.D. Spence and J.M. Franklin (eds.), Geological Association of Canada, Special Paper 25, p. 667-700.

Jefferson, C.W. and Parrish, R.R., 1989. Late Proterozoic stratigraphy, U-Pb zircon ages, and rift tectonics, Mackenzie Mountains, northwestern Canada. Canadian Journal of Earth Sciences vol. 26, p. 1784-1801.

Jefferson, C.W. and Young, G.M., 1989. Late Proterozoic orange-weathering stromatolite biostrome, Mackenzie Mountains and western Arctic Canada. *In:* Reefs, Canada and adjacent area, H.H.J. Geldsetzer, N.P. James and G.E. Tebbut (eds.), Canadian Society of Petroleum Geologists, Memoir 13, p. 72-80.

Leslie, C.D., 2009. Detrital zircon geochronology and rift-related magmatism: central Mackenzie Mountains, Northwest Territories. Unpublished MSc thesis, University of British Columbia, Vancouver, BC, 236 p.

Long, D.G.F., *in press* a. Katherine Group. *In:* Geology of the Northern Cordillera, central Mackenzie Mountains; Sekwi Mountain (105P), Mount Eduni (106A), and northwestern Wrigley (95M) Lake map areas, Northwest Territories; Northwest Territories Geoscience Office, NWT Open File, 2011.

Long, D.G.F., *in press* b. Tsezotene Fm. *In:* Geology of the Northern Cordillera, central Mackenzie Mountains; Sekwi Mountain (105P), Mount Eduni (106A), and northwestern Wrigley (95M) Lake map areas, Northwest Territories, Northwest Territories Geoscience Office, NWT Open File, 2011.

Long, D.G.F., Rainbird, R.H., Turner, E.C. and MacNaughton, R.B., 2008. Early Neoproterozoic strata (Sequence B) of mainland northern Canada and Victoria and Banks islands: a contribution to the Geological Atlas of the Northern Canadian Mainland Sedimentary Basin. Geological Survey of Canada, Open File 5700, 27 p.

Macdonald, F.A. and Roots, C.F., 2009. Upper Fifteenmile Group in the Ogilvie Mountains and correlations of early Neoproterozoic strata in the northern Cordillera. *In:* Yukon Exploration and Geology 2009, K.E. MacFarlane, L.H. Weston and L.R. Blackburn (eds.), Yukon Geological Survey, p. 237-252.

Norris, D.K., 1982a. Geology, Wind River, Yukon Territory. Geological Survey of Canada, Map 1528A, scale 1:250 000.

Norris, D.K., 1982b. Geology, Snake River, Yukon-Northwest Territories. Geological Survey of Canada, Map 1529A, scale 1:250 000.

Rainbird, R.H., Jefferson, C.W. and Young, G.M., 1996. The early Neoproterozoic sedimentary Succession B of northwestern Laurentia: correlations and paleogeographic significance. Geological Society of America Bulletin, vol. 108, p. 454-470.

Rainbird, R.H., McNicoll, V.J., Thériault, R.J., Heaman, L.M., Abbot, J.G., Long, D.G.F. and Thorkelson, D.J., 1997. Pan-continental river system draining Grenville Orogen recorded by U-Pb and Sm-Nd geochronology of Neoproterozoic quartz arenites and mudrocks, northwestern Canada. Journal of Geology, vol. 105, p. 1-17.

Taylor, S. and McLennan, S.M., 1985. The Continental Crust: Its Composition and Evolution. Blackwell Scientific Publications, 312 p.

Thorkelson, D.J., 2000. Geology and mineral occurrences of the Slats Creek, Fairchild Lake and 'Dolores Creek' areas, Wernecke Mountains (106D/16, 106C/13, 106C/14), Yukon Territory. Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada, Bulletin 10, 73 p.

Thorkelson, D.J. and Wallace, C.A., 1998. Geological map of 'Dolores Creek' map area (106C/14), Wernecke Mountains, Yukon. Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada Geoscience Map 1998-11, scale 1:50 000.

Thorkelson, D.J., Laughton, J.R., Hunt, J.A. and Baker, T., 2003. Geology and mineral occurrences of the Quartet Lakes map area (NTS 106E/1), Wernecke and Mackenzie mountains, Yukon. *In:* Yukon Exploration and Geology 2002, D.S. Emond and L.L. Lewis (eds.), Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada, p. 223-239.

Thorkelson, D.J., Abbott, J.G., Mortensen, J.K., Creaser, R.A., Villeneuve, M.E., McNicoll, V.J. and Layer, P.W., 2005. Early and Middle Proterozoic evolution of Yukon, Canada. Canadian Journal of Earth Sciences, vol. 42, p. 1045-1071.

Turner, E.C., 2007. Lithofacies and structural controls on Zn-Pb mineralization at Gayna River, NWT. GAC-MAC Joint meeting 32, May 23-25, 2007.

Turner, E.C., *in press* a. 'H1 unit'. *In:* Geology of the Northern Cordillera, central Mackenzie Mountains; Sekwi Mountain (105P), Mount Eduni (106A), and northwestern Wrigley (95M) Lake map areas, Northwest Territories Geoscience Office, NWT Open File, 2011.

Turner, E.C., *in press* b. Little Dal Group. *In:* Geology of the Northern Cordillera, central Mackenzie Mountains; Sekwi Mountain (105P), Mount Eduni (106A), and northwestern Wrigley (95M) Lake map areas, Northwest Territories Geoscience Office, NWT Open File, 2011.

Turner, E.C. and Long, D.G.F., 2008. Basin architecture and syndepositional fault activity during deposition of the Neoproterozoic Mackenzie Mountains supergroup, N.W.T., Canada. Canadian Journal of Earth Sciences, vol. 45, p. 1159-1184.

Turner, E.C., James, N.P. and Narbonne, G.M., 1997. Growth dynamics of Neoproterozoic calcimicrobial reefs, Mackenzie Mountains, northwest Canada. Journal of Sedimentary Research, vol. 67, p. 437-450.

Young, G.M., Jefferson, C.W., Delaney, G.D. and Yeo, G.M., 1979. Middle and Upper Proterozoic evolution of the northern Canadian Cordillera and Shield. Geology, vol. 7, p. 125– 128.