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Abstract: In the eastern Mackenzie Mountains, Northwest Territories, basal Cambrian quartz sandstone of Mount Clark Formation is present as a belt in the eastern limbs of the Stony and Foran anticlines. These strata were deposited in shallow water. To the northeast, in Macdougal anticline, correlative and therefore coeval strata in the basal part of Mount Cap Formation consist of sandstone, shale, limestone, and dolostone that were deposited in a somewhat deeper water shelf setting. These relationships define facies belts that record the influence of the ancient Mackenzie Arch on Lower to Middle Cambrian deposition. New and previously published biostratigraphic control based on trilobites suggests that Lower to Middle Cambrian strata in eastern Mackenzie Mountains record multiple transgressions. This may have implications for the distribution of prospective reservoir facies (e.g. shoreface sandstone) beneath the adjacent Mackenzie Plain exploration area.

Résumé : Dans la partie orientale des monts Mackenzie (Territoires du Nord-Ouest), le grès quartzeux basal du Cambrien de la Formation de Mount Clark forme une bande sur le flanc est des anticlinaux de Stony et de Foran. Ce grès s'est déposé en eau peu profonde. Au nord-est, dans l'anticlinal de Macdougal, des strates corrélatives et, par conséquent, contemporaines les unes des autres dans la partie basale de la Formation de Mount Cap sont constituées de grès, de shale, de calcaire et de dolomie qui se sont déposés dans un milieu de plate-forme continentale un peu plus profond. Ces relations permettent de définir des zones de faciès qui témoignent de l'influence de l'ancienne arche de Mackenzie sur le dépôt des strates du Cambrien inférieur et moyen. Les données récentes et déjà publiées sur le contrôle biostratigraphique fondé sur les trilobites donnent à penser que les strates du Cambrien inférieur et moyen dans l'est des monts Mackenzie rendent compte de multiples transgressions. Ces transgressions seraient susceptibles d'avoir eu des incidences sur la répartition des faciès de roches réservoirs potentielles (p. ex. grès d'avant-plage) dans les profondeurs de la région d'exploration adjacente de la plaine du Mackenzie.

INTRODUCTION

The last decade has seen a reconsideration of the Lower and Middle Cambrian stratigraphy of the eastern Mackenzie Mountains, Northwest Territories (Fig. 1), notably with respect to the distribution of the Lower Cambrian Mount Clark Formation (Fig. 2). Earlier reports (e.g. Aitken et al., 1973; Dixon and Stasiuk, 1998) considered Mount Clark Formation to be absent from the region but recent studies indicate that it is present (Serié et al., 2009; Pyle and Gal, 2009) and mappable (Fallas and MacNaughton, 2012). Mount Clark Formation is dominated by well sorted quartz arenite and is a reservoir for natural gas, condensate, and oil in the Colville Hills (Hamblin, 1990; Dixon and Stasiuk, 1998; Janicki, 2004; Price and Enachescu, 2009). Understanding its distribution in the Mackenzie Mountains will help to predict its extent beneath Mackenzie Plain, where it may be a target for exploration (MacLean, 2011).

Cambrian stratigraphy in the eastern Mackenzie Mountains has been studied as part of the Mackenzie Delta and Corridor Project (Geo-mapping for Energy and Minerals Program). A report based on fieldwork carried out in 2009 and 2010 (Fallas and MacNaughton, 2012) confirmed previous reports of a basal Paleozoic package of quartz sandstone in the eastern Mackenzie Mountains, demonstrated that these strata were regionally extensive and mappable, and provisionally assigned them to the Cambrian Mount Clark Formation. During the 2011 and 2012 field seasons, additional study was made of the distribution, lithology, and paleontology of Lower and Middle Cambrian strata. This report is a preliminary account of that work, which further clarifies the distribution and age of Mount Clark Formation and associated units.

GEOLOGIC SETTING AND LITHOSTRATIGRAPHY

Cambrian strata in the study region lie unconformably upon the Neoproterozoic Mackenzie Mountains Supergroup (Aitken et al., 1973; Aitken and Cook, 1974; Turner and Long, 2012; Long and Turner, 2012). Regional distribution and character of Lower and Middle Cambrian formations in the eastern Mackenzie Mountains and regions to the east and northeast have been addressed in a number of studies (Aitken et al., 1973; Dixon and Stasiuk, 1998; MacLean, 2011). In the eastern Mackenzie Mountains, Lower to Middle Cambrian stratigraphy encompasses, in ascending order, the Mount Clark, Mount Cap, and Saline River formations (Fig. 2) and has been documented in several publications (Aitken et al., 1973; Aitken and Cook, 1974; Serié et al., 2009; Fallas and MacNaughton, 2012).

Mount Clark Formation is dominated by quartz arenite. It locally contains conglomerate at its base and quartz wacke and minor siltstone or shale in its upper part (Serié et al., 2009; Fallas and MacNaughton, 2012). Trace fossils are common and many beds have been bioturbated intensely. Published biostratigraphic controls on the Mount Clark Formation are sparse. At the type section, near Cap Mountain (Franklin Mountains), fossils of the *Bonnia-Olenellus* Zone are present at or near the contact with the overlying Mount Cap Formation (Williams, 1923; Kobayashi, 1936).

Mount Cap Formation lies with gradational contact upon Mount Clark Formation but also passes laterally into it, particularly near paleo-highs (Dixon and Stasiuk, 1998; MacLean, 2011; this work). Where Mount Clark Formation is absent, Mount Cap Formation lies unconformably on Neoproterozoic strata. Mount Cap Formation is commonly dominated by dark-weathering (grey, black, or brown) shale and siltstone, but also contains limestone, sandstone, and dolostone, which are commonly glauconitic (Aitken et al., 1973; Dixon and Stasiuk, 1998; Serié et al., 2009; Fallas and MacNaughton, 2012). Trilobite faunas indicate that Mount Cap Formation ranges in age from late Early to Middle Cambrian age (*Bonnia-Olenellus* to *Glossopleura* zones; Kobayashi, 1936; Aitken et al., 1973; Fritz, 1970; Serié et al., 2009).

Mount Cap Formation is overlain sharply and likely unconformably by Saline River Formation, a unit of shale, dolostone, anhydrite, and salt (Aitken et al., 1973; Dixon and Stasiuk, 1998). Saline River Formation is unfossiliferous, but must be of Middle or early Late Cambrian age based on its stratigraphic position.

Distribution of Lower and Middle Cambrian formations was strongly controlled by paleogeographic highs and lows. The Mackenzie Arch defines the southwestern limit of the Mackenzie Plain depocentre, which underlies much of the Mackenzie Plain and Franklin Mountains. The Mackenzie Plain depocentre deepens locally to form the Mackenzie Trough (MacLean, 2011).

DISTRIBUTION OF LOWER AND MIDDLE CAMBRIAN FORMATIONS

Fallas and MacNaughton (2012) documented several sites in the eastern Mackenzie Mountains where quartz arenite at the base of the Cambrian succession is mappable. Aitken and Cook (1974) had recognized a sand-rich interval at the base of the Cambrian succession but considered it to be everywhere a basal facies of the Mount Cap Formation. Fallas and MacNaughton (2012) followed Serié et al. (2009) in assigning such strata provisionally to the Mount Clark Formation, basing this decision on stratigraphic position and dominance by quartz arenite.

Fieldwork by MacNaughton and Fallas in 2011 and 2012 has further clarified the distribution of basal Cambrian facies (Fig. 1). In the eastern Mackenzie Mountains, the structural culmination of the Stony and Foran anticlines

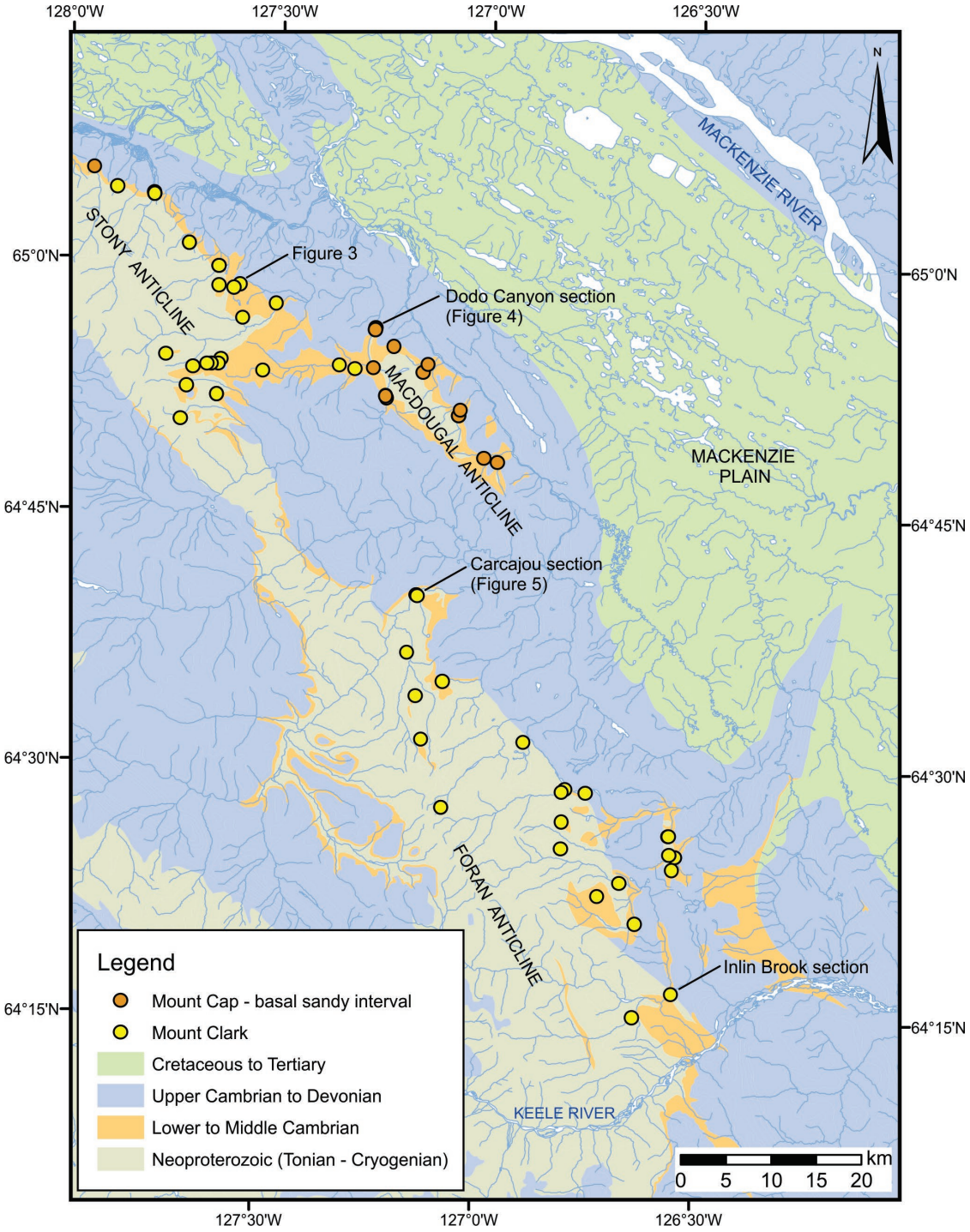

Figure 1. Map of eastern Mackenzie Mountains and adjacent Mackenzie Plain, showing distribution of Mount Clark Formation versus sandy basal interval of Mount Cap Formation. Key locations mentioned in the text are labelled, except for Cap Mountain (type section of Mount Clark Formation), which is in the Franklin Mountains, approximately 165 km east-southeast of the bottom right corner of the map. Eastern limit of Mackenzie Arch is delineated by Stony and Foran anticlines. Visited outcrop and section locations are shown by brown and yellow dots. Geology simplified after Aitken et al. (1974) and Aitken and Cook (1976).

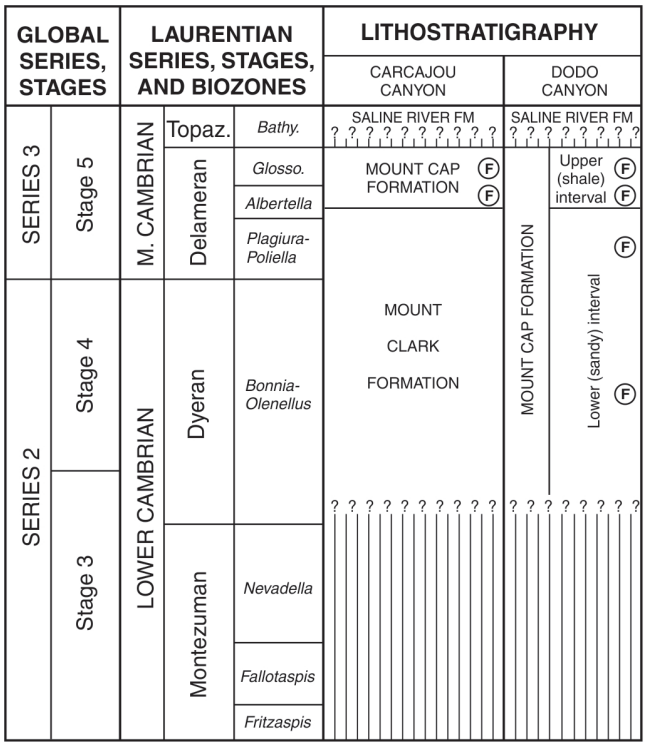

Figure 2. Chronostratigraphy of Mount Clark and Mount Cap formations in eastern Mackenzie Mountains. Age controls from fossils (Fritz, 1970; Aitken et al., 1973; Serié et al., 2009; and B.R. Pratt, work in progress) are indicated by the letter 'F' in a circle. Chronostratigraphic divisions follow Peng et al. (2012). Vertical line pattern indicates gaps recorded by unconformities; question marks indicate uncertainty as to age of basal Cambrian beds and base of Saline River Formation. In view of the long-standing use of Laurentian series, stages, and biozones in the study region, these are referred to in the text, but current global divisions of the Cambrian System are also shown. Abbreviations: M. = Middle; Topaz. = Topazan; Fm = Formation; *Bathy.* = *Bathyuriscus*; *Glosso.* = *Glossopleura*.

roughly delineates the eastern extent of the Mackenzie Arch (Aitken et al., 1974). In the eastern limbs of these anticlines (Fig. 1), the basal part of the Cambrian succession consists of several metres to tens of metres of resistant, pale-weathering, thin- to thick-bedded, well sorted, fine- to coarse-grained quartz arenite (Fig. 3). Common sedimentary structures include trough crossbedding, tabular bedding, and both plane lamination and ripple crosslamination. Bioturbation is common and locally intense. Horizontal burrows are most common, but locally there are beds with abundant vertical burrows giving rise to a 'pipe-rock' fabric (i.e. *Skolithos* ichnofacies). These lithofacies typify the strata provisionally assigned to Mount Clark Formation by Fallas and MacNaughton (2012). They are overlain by a dark-weathering succession of shale with lesser carbonates and sandstone, assigned to Mount Cap Formation (Fig. 3). At some locations, a transition interval of silty quartz arenite to quartz wacke is present at the top of the Mount Clark Formation.

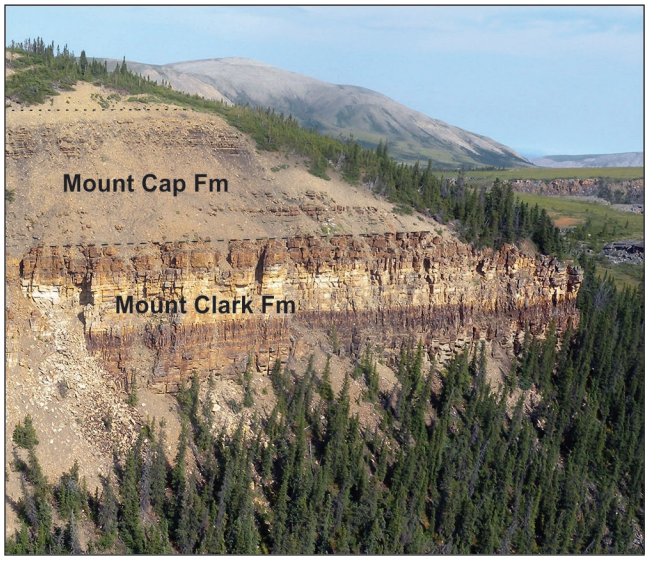

Figure 3. Cliff exposure of Mount Clark and Mount Cap Formations near eastern flank of Mackenzie Arch, eastern Mackenzie Mountains. Contact between these units (long-dashed line) is at relatively sharp upward transition from sandstone-dominated to shale-dominated strata. Base of Mount Clark Formation is probably just below base of cliff. Also shown (short-dashed line) is approximate contact between Mount Cap Formation and overlying Saline River Formation. Measured thickness of Mount Cap Formation in this cliff is almost 40 m (R.B. MacNaughton, unpub. data). Co-ordinates: 64°58′34.0″N, 127°36′22.9″W. Photograph by K.M. Fallas. 2013-110

Northeast of Stony and Foran anticlines, in exposures around the Macdougal anticline (Fig. 1), basal Cambrian strata are more heterolithic and darker weathering. Sandstone beds are well developed at some levels, locally including quartz arenite, but the sandstone generally is silty (i.e. a wacke rather than an arenite) and commonly contains glauconitic and dolomitic beds. Beds are very thin to thick; crossbedding and parallel lamination are common. Bioturbation by horizontal burrows can be pervasive, and includes simple horizontal traces (*Palaeophycus*, *Planolites*) and arthropod-produced traces (*Cruziana*, *Rusophycus*). Sandstone is interbedded with shale and carbonate lithofacies. Such heterolithic strata are better assigned to the Mount Cap Formation than to the Mount Clark Formation because the latter unit, by definition, is dominated by sandstone, mainly pure quartz arenite (Hamblin, 1990; Dixon and Stasiuk, 1998). The heterolithic basal interval is overlain by a shale-dominated succession like that assigned to Mount Cap Formation in exposures to the southwest. The well documented succession exposed in Dodo Canyon (Aitken et al., 1973) typifies Lower to Middle Cambrian stratigraphy in Macdougal Anticline (Fig. 4).

Thus, the Mount Clark Formation in the eastern Mackenzie Mountains appears to be restricted to a belt along the eastern flank of the Mackenzie Arch. New biostratigraphic results (*see* below) suggest that it passes northeastward into the heterolithic basal interval of the Mount Cap Formation.

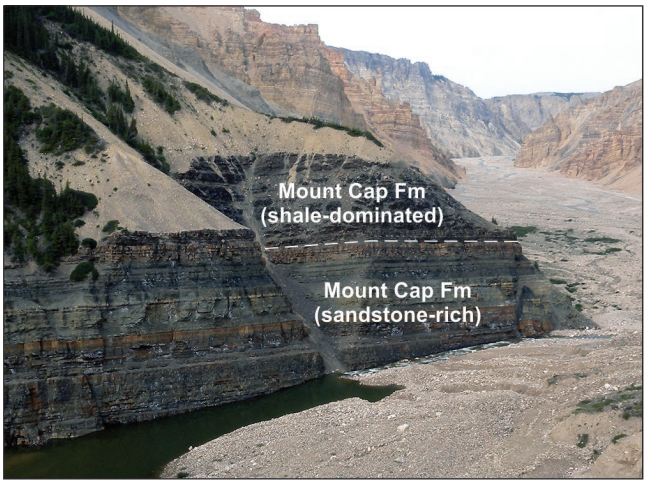

Figure 4. Cliff exposure of Mount Cap Formation in Dodo Canyon, eastern Mackenzie Mountains. Base of formation is just below base of cliff at bottom left. Dashed line shows contact between sandstone-rich, heterolithic basal interval and shale-dominated upper interval of formation. Thickness of sandstone-rich interval at this site is approximately 44 m (Aitken et al., 1973). Trilobites collected for the present work came from exposures just beyond the promontory formed by this cliff. Co-ordinates: 64°56′14.9″N, 127°15′57.6″W. Photograph by K.M. Fallas. 2013-109

EARLY AND MIDDLE CAMBRIAN BIOSTRATIGRAPHY

Current understanding of Early and Middle Cambrian biostratigraphy in the eastern Mackenzie Mountains is based mainly on material collected by the GSC during Operation Norman (1968–1970). In Dodo Canyon, the heterolithic basal interval of Mount Cap Formation yielded *Olenellus* sp., '*Paedumias*' sp., and *Onchocephalus* sp., indicating the late Early Cambrian *Bonnia-Olenellus* Zone (Fritz, 1970; Aitken et al., 1973). Above this, a progressively shalier succession yielded species belonging to the Middle Cambrian *Albertella* and *Glossopleura* zones. No species diagnostic of the early Middle Cambrian *Plagiura-Poliella* Zone or the early part of the *Albertella* Zone were collected and Fritz (1970) postulated that an unconformity was present in the section.

At localities in the eastern Mackenzie Mountains where Mount Clark Formation is present beneath Mount Cap Formation, biostratigraphy is less well constrained. Sparse published data suggest that the base of Mount Cap Formation at such localities generally is within the *Albertella* Zone (Aitken et al., 1973; Serié et al., 2009). An exception is at Inlin Brook, where Serié et al. (2009; their section 1) reported trilobites characteristic of *Bonnia-Olenellus* Zone (Lower Cambrian) from strata they assigned to the lower part of Mount Cap Formation, overlying the Mount Clark Formation. Mount Cap Formation extends into the *Glossopleura* Zone (Aitken et al., 1973; Serié et al., 2009).

During the 2011 field season, Pratt and MacNaughton visited sections exposed in Dodo Canyon and along the Carcajou River. At Dodo Canyon, they examined the basal, sandstone-rich, heterolithic interval of Mount Cap Formation, as well as the lower part of the overlying shale succession. The site studied was on the downstream end of a large streamcut (Fig. 4) that was documented previously by Aitken et al. (1973; *also* Fritz, 1970). No physical evidence was found for an unconformity within the Mount Cap Formation, which appears to be a conformable succession.

Preliminary study of new trilobite collections from Dodo Canyon confirms the presence of olenelloids (*Bonnia-Olenellus* Zone) in the heterolithic, sandstone-rich interval of Mount Cap Formation. Bioturbated sandstone at the top of the heterolithic interval contains abundant specimens of an early ptychoparioid trilobite, probably belonging to *Amecephalus*. These strata would likely be in the early Middle Cambrian *Plagiura-Poliella* Zone, providing an additional reason to doubt the presence of an unconformity within Mount Cap Formation. Trilobites that may represent the *Albertella* Zone were found as float from the overlying shale-dominated interval; strata higher in Mount Cap Formation were not collected at this site.

Along Carcajou River near Carcajou Falls, a well exposed section includes both Mount Clark and Mount Cap formations (Fig. 5). From this section, Serié et al. (2009; their Section 3) reported genera indicative of *Glossopleura* Zone (late Delameran Stage, Middle Cambrian) in the upper part of Mount Cap Formation. During the present work, Mount Clark Formation yielded no body fossils except indeterminate linguliform brachiopods. Trilobites collected from the basal shale beds of Mount Cap Formation (2.1–4.0 m above base of formation; Fig. 5) likely record the *Albertella* Zone. Overlying shale (10.2 m above base of formation, and upward) contains *Glossopleura*, which defines the *Glossopleura* Zone, co-occurring with what may be a new species of *Bathyuriscus.* Additional species of *Bathyuriscus* are present upsection; these strata could also be in the *Glossopleura* Zone but might record the overlying *Bathyuriscus-Elrathina* Zone. Study of these collections is underway by B.R. Pratt.

DISCUSSION OF STRATIGRAPHIC RELATIONSHIPS

Lower and Middle Cambrian strata in the eastern Mackenzie Mountains show a shallow to deeper water trend from west to east. On the eastern flank of Mackenzie Arch, well sorted, crossbedded quartz arenite records the action of moderate- to high-energy currents, alternating with quiescent periods during which organisms intensely bioturbated the substrate. 'Pipe-rock' beds record local development of the *Skolithos* ichnofacies, which suggests a shallow subtidal sandy setting, whereas horizontally burrowed beds probably originated under lower energy conditions flanking the

Figure 5. View upstream along Carcajou River showing Cambrian succession. Resistant beds of sandstone in the foreground belong to Mount Clark Formation and are overlain sharply by dark-weathering shale and limestone cliffs of Mount Cap Formation. Person standing right of centre provides scale. Yellow arrow points to position immediately beyond highest resistant sandstone bed where spot outcrops of Mount Cap Formation shale at the shoreline yielded *Albertella* Zone trilobites. Co-ordinates: 64°40′15.9″N, 127°09′25.6″W. Photograph by R.B. MacNaughton. 2013-108

main sand bodies (Desjardins et al., 2010). In Macdougal anticline, the more heterolithic succession contains both shale and carbonate, consistent with deeper water, lower energy conditions. Trace fossils record development of the *Cruziana* ichnofacies, characteristic of the open shelf below fair-weather wave-base (MacEachern et al., 2007). In both regions, the shale-dominated upper Mount Cap Formation records still deeper water deposition.

Published fossil data and preliminary identifications reported herein suggest that the top of Mount Clark Formation at Carcajou Canyon and top of sandy basal Mount Cap Formation at Dodo Canyon are correlative and define a flooding surface produced during *Albertella* Zone time. Thus, facies belts were present parallel to the eastern flank of Mackenzie Arch during and prior to the Middle Cambrian. This suggests that at least two episodes of transgression took place during the Early to Middle Cambrian in the eastern Mackenzie Mountains: Early to Middle Cambrian (pre-*Albertella* Zone) transgression established the facies belts, and Middle Cambrian (*Albertella* Zone) transgression led to regional deposition of the shale-dominated (upper) interval of Mount Cap Formation.

The report of *Bonnia-Olenellus* Zone trilobites from Mount Cap Formation at Inlin Brook (Serié et al., 2009) requires additional comment. At this locality, both Mount Clark and Mount Cap formations are present, but the report of Serié et al. (2009) suggests the contact between these units is older than elsewhere in the eastern Mackenzie Mountains. Instead, the age relationship is like that seen in the type section of the Mount Clark Formation at Cap Mountain (Williams, 1923; Aitken et al., 1973). Variation in the age of the contact between Mount Clark and Mount Cap formations reinforces the view that Mount Clark Formation is time-transgressive (Pugh, 1983) and the contact diachronous (Dixon and Stasiuk, 1998). Unfortunately, Serié et al. (2009) did not indicate the level within the Mount Cap Formation from which they collected trilobites. As result, the implications of their data for the history of Cambrian transgression in the eastern Mackenzie Mountains are unclear.

ECONOMIC IMPLICATIONS

Sandstone of Mount Clark Formation is a significant regional exploration target (Hannigan et al., 2011). Based on public-domain industry reflection-seismic data, MacLean (2011) suggested that an ancient depocentre beneath Mackenzie Plain may contain more than 100 m of Mount Clark Formation, which he ranked as a relatively low-risk exploration target. MacLean (2011; *also* Pugh, 1983) considered Mount Clark Formation to have been deposited on the flanks of high areas during Early Cambrian, pre-rift thermal subsidence, whereas Mount Cap Formation was deposited in deeper water during Middle Cambrian rifting (graben formation and subsidence) and transgression.

This work indicates that thick shoreline and shallow-marine facies of Mount Clark Formation also were deposited on the southwestern margin of Mackenzie Plain depocentre as the basin expanded during Early to Middle Cambrian transgression. If transgression was stepwise, there may be buried Cambrian shorelines beneath Mackenzie Plain that could constitute an exploration target. Such facies probably would be too thin to resolve on reflection-seismic profiles, an issue discussed by MacLean (2011). Presence of appropriate reservoir facies is an exploration risk for Cambrian plays beneath Mackenzie Plain. Detailed regional study of sedimentology, biostratigraphy, and sequence stratigraphy of Mount Clark and Mount Cap formations is needed to improve the assessment of hydrocarbon potential.

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