Chapter 34

The Hula Hula Diamictite and Katakturuk Dolomite, Arctic Alaska

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Abstract: The Katakturuk Dolomite is a *c.* 2-km-thick Neoproterozoic carbonate succession (units K1–K4) exposed in the NE Brooks Range of Alaska. These strata were deposited on a south-facing (present coordinates), rifted passive margin on the North Slope subterrane (NSST) of the Arctic Alaska-Chukotka Plate (AACP). The glaciogenic Hula Hula diamictite rests below the Katakturuk Dolomite and consists of 2–50 m of diamictite that interfingers with the underlying Mt. Copleston volcanic rocks. Unit K1 of the Katakturuk Dolomite begins with less than 10 m of dark grey, finely laminated limestone with 'roll-up' structures, and continues upwards with nearly 500 m of recrystallized, ooid-dominated grainstone. The Nularvik dolomite (unit K2 of the Kataktruk Dolomite) rests on unit K1 with a knife-sharp contact on a heavily silicified surface. The Nularvik dolomite is composed predominantly of laminated micro-peloids hosting tubestone stromatolites and giant wave ripples, followed by decametres of dolomatized, pseudomorphosed former aragonite crystal fans.

Carbon-isotope chemostratigraphy suggests that the Hula Hula diamictite is an early Cryogenian glacial deposit, and that, despite the absence of directly underlying glacial deposits, the Nularvik dolomite is a basal Ediacaran cap carbonate. These correlations are supported by the characteristic sedimentological features in both the carbonate capping the Hula Hula diamictite and the Nularvik dolomite. Detrital zircon and Palaeozoic fauna provenance studies support the inference that much of the AACP is exotic to Laurentia; however, the pre-Mississipian relationship between the NSST and the rest of the AACP remains uncertain. Previous palaeomagnetic surveys have been hampered by pervasive Late Cretaceous overprints. Additional geological mapping, sequence stratigraphy and geochronological data are needed to correlate Neoproterozoic and Palaeozoic units across the AACP, and constrain relationships between subterranes in the AACP.

The Neoproterozoic Katakturuk Dolomite (units K1–K4) and the overlying Cambrian to Ordovician Nanook Limestone form the backbone of the northernmost ranges of the Arctic National Wildlife Reserve of Alaska (for a field guide and an introduction to the general geology of the region, see Molenaar *et al.* 1987). The pre-Mississippian stratigraphy of the NE Brooks Range has been described through geological mapping (Leffingwell 1919; Reed 1968; Reiser 1971; Sable 1977; Robinson *et al.* 1989), palaeontological reconnaissance (Dutro 1970) and sequence analysis (Clough & Goldhammer 2000). Recently, Macdonald *et al.* (2009*b*) conducted integrated chemo- and lithostratigraphic studies, identified two putative glacial horizons and suggested a late Neoproterozoic age for the Katakturuk Dolomite.

The Katakturuk Dolomite was named by Dutro (1970) for its exposure in the Katakturuk River canyon in the Sadlerochit Mountains. Katakturuk is an English derivation of the Inupiaq word *Qattaqtuuraq*, which translates to 'a wide open place' (Clough 1989). The Katakturuk Dolomite has only been positively identified in three localities: the Sadlerochit Mountains, the Shublik Mountains and on both sides of the Hula Hula River near Kikitak Mountain (Fig. 34.1). The succession attains its greatest thickness in the Sadlerochit Mountains, where it is composed of *c.* 2080 m of shallow-water dolomite, and progressively thins to the south in the Shublik Mountains and at Kikitak Mountain. Exposures in the NE Brooks Range capture the shelf–slope transition, facing to the south (present coordinates).

Macdonald *et al.* (2009*b*) identified the Hula Hula diamictite at the base of the Katakturuk Dolomite in the eastern Sadlerochit Mountains and along the Hula Hula River near Kikitak Mountain (Fig. 34.1). The type section of the Hula Hula diamictite is on the east side of the Hula Hula River along Eustik Creek (Figs 34.2 & 34.3a, section F621; 69°25.491′N, 144°23.216′W). At this locality, the diamictite is overlain by a 10-m-thick, dark, variably dolomitized limestone (unit K1 of the Katakturuk Dolomite) that contains microbial 'roll-up' structures (Hoffman *et al.* 1998; Pruss *et al.* 2010). This is one of only two limestone horizons within the Katakturuk Dolomite.

In the Sadlerochit Mountains, nearly 500 m higher in the sequence, a micro-peloidal dolostone containing tubestone stromatolites, giant wave ripples and decametres of pseudomorphosed former aragonite crystal fans rests on a silicified surface. The type section of the Nularvik dolomite (referred to as the Nularvik cap carbonate in Macdonald *et al.* 2009*b*) is on the west side of the Nularvik River (Figs 34.2 and 34.3b, section F601; 69°37.588′N, 145°05.451′W). The Nularvik dolomite is succeeded by a major transgression marked by shale and allodapic carbonate, and then an additional *c.* 1200 m of Ediacaran shallow-water dolomite (units K3–K4).

Exposure of the Katakturuk Dolomite is limited to the North Slope subterrane (NSST) of the Arctic Alaska-Chukotka Plate (AACP). The NSST is tied to the AACP by the Carboniferous Lisburne Group; however, the pre-Mississippian relationship between the NSST, the AACP and Laurentia remain uncertain. Dark-coloured limestones, potentially correlative to the lowermost unit of the Katakturuk Dolomite (K1), are present in the Third and Fourth Ranges of the NSST (Fig. 34.1), *c.* 10 km and 15 km south of the Shublik Mountains, respectively (Reiser 1971). However, the thickness of this unit is unknown as it is poorly exposed in the Third Range and structurally duplicated in the Fourth Range (Macdonald *et al.* 2009*b*). Precambrian dolomites dominated by stromatolites and coated grains, possibly correlative with the Katakturuk Dolomite, have been described on Seward Peninsula and near Snowden Mountain on the southern subterranes of the AACP (Dumoulin 1988; Dumoulin & Harris 1994), and in the Farewell Terrane (Babcock *et al.* 1994); however, no diamictites have been described at these localities. Terminal Neoproterozoic diamictites occur in the Upper Tindir Group of East-Central Alaska, but these were definitively deposited on Laurentia (Allison *et al.* 1981; Young 1982; Macdonald & Cohen 2011).

Structural framework

Present exposures of the Katakturuk Dolomite in the Sadlerochit, Shublik and Kikitak Mountains (Fig. 34.1) are the product of Palaeogene north-vergent thrusting (Wallace & Hanks 1990). These structures formed during a late-stage reactivation of the mostly Mesozoic Brookian orogeny (Moore *et al.* 1997), and are related to the piecemeal accretion of southern Alaska (Fuis *et al.* 2008). Pre-Mississippian strata in the NE Brooks Range also preserves Early to Middle Devonian SE-vergent structures associated

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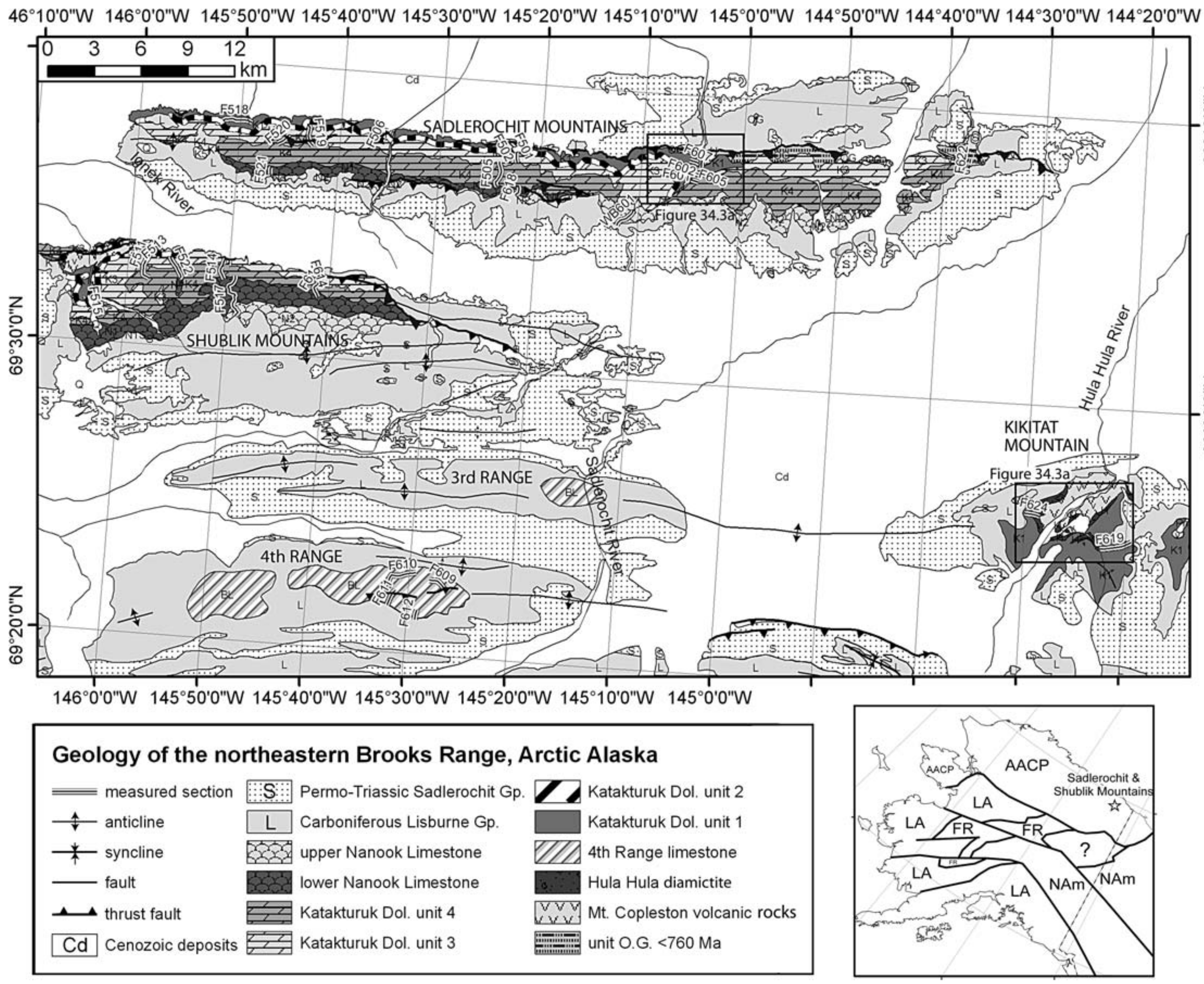

Fig. 34.1. Geological map of the Shublik, Sadlerochit and Kikitak Mountains, and the Fourth Range, with a simplified tectonic and location map inset. Post-Ordovician geology modified from Robinson *et al.* (1989) and Bader & Bird (1986). Tectonic map modified and simplified from Johnston (2001) and Colpron *et al.* (2007). Abbreviations for terranes: AACP, Arctic Alaska-Chukotka Plate; FR, Farewell-Ruby-Hammond Terranes; NAm, Ancestral North America; LA, Late Accreted Terranes; ?, poorly exposed and of uncertain affinity.

with the Romanzof orogeny (Oldow *et al.* 1987). These structures are thought to be distinct from those related to the Late Devonian Ellesmerian orogeny in the Yukon and Canadian Arctic Islands (Lane 2007).

Metamorphic grade generally increases from north to south with exposures of the Katakturuk Dolomite in the Shublik and Sadlerochit Mountains displaying little folding and simple block faults. In the NE Sadlerochit Mountains, the underlying Neoproterozoic rocks are tightly folded and chloritized; however, this apparent difference in deformation may be due entirely to lithology and rheology. The overlying Nanook Limestone contains conodonts with a Conodont Alteration Index (CAI) of 3.5 suggesting that at least these strata have experienced less than 300 °C (Harris *et al.* 1990). The Katakturuk Dolomite is heavily dolomitized and recrystallized; however, the age of the dolomitzation is unknown and, typically, primary sedimentary features are preserved. In the Kikitak Mountain area, small-scale folding is more common, and the basalts are pervasively chloritized. These modifications, coupled with incomplete exposures, make an exact determination of the thickness of the Hula Hula diamictite impossible.

Clough & Goldhammer (2000) inferred a NE–SW palaeo-strandline (present coordinates) from palaeo-current data measured in tabular cross-bedded grainstones, the orientation of elongated stromatolites, and from the thickening of outer-ramp to slope facies to the south. While readily measurable elongated stromatolites are not present in the lower kilometre of the Katakturuk Dolomite, facies changes are apparent between the Sadlerochit, Shublik and Kikitak Mountains, deepening from north to south (Macdonald *et al.* 2009*b*); deepening is not demonstrable in facies changes from west to east along the ranges. Consequently, for the lower kilometre of the Katakturuk Dolomite (the Hula Hula Diamictite and units K1–K3), Macdonald *et al.* (2009*b*) assumed an east–west palaeo-strandline. Balanced cross-sections from seismic data reveal a *c.* 30% Palaeogene north–south shortening in the NE Brooks Range (Molenaar *et al.* 1987; Moore *et al.* 1997). This results in a restored distance between the Sadlerochit and Shublik Mountains of *c.* 11 km, and an additional 10 km north–south and 50 km east–west between the Shublik and Kikitak Mountains. However, there are few constraints on the pre-Palaeogene tectonic movement between the two ranges, inhibiting confidence in three-dimensional basin reconstructions.

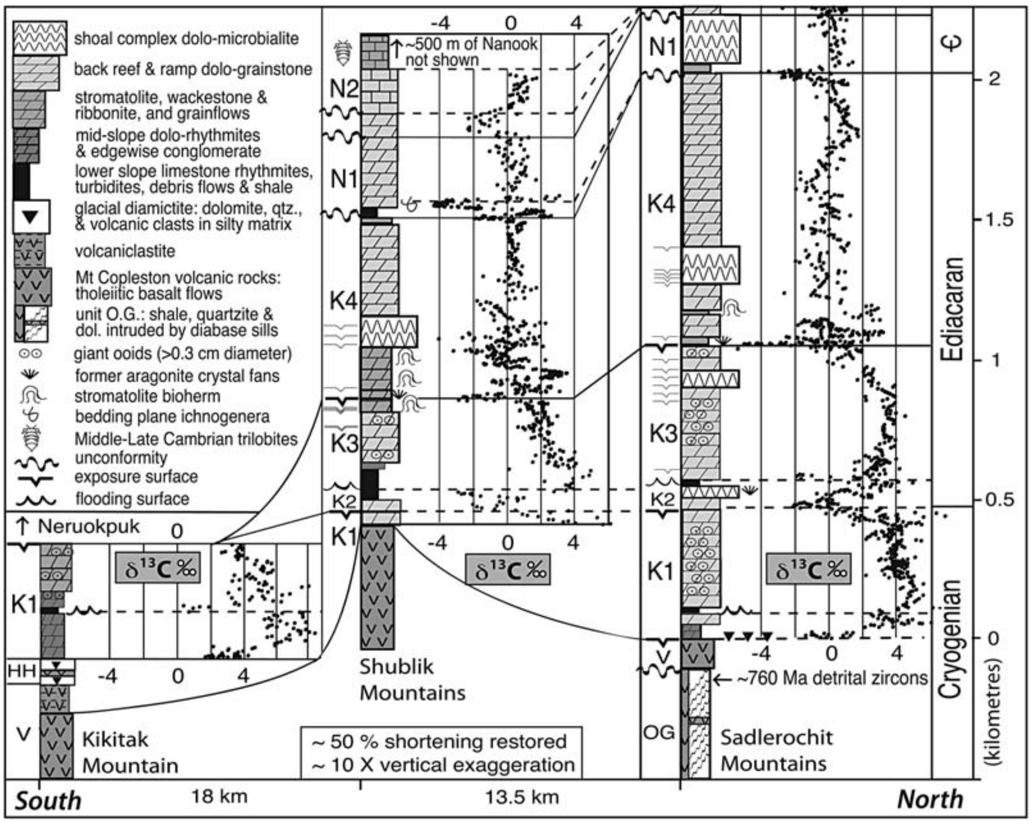

Fig. 34.2. Composite carbon chemo- and lithostratigraphy of the Katakturuk Dolomite (K1–K4) and the Nanook Limestone (N1, N2) in the NE Brooks Range. Sadlerochit data from measured sections F601, F602, F607, F501 and F505; Shublik data from measured sections F513, F514, F517, F613 and F614; Kikitak data from measured sections F619 and F624 (see Figs 34.1 & 34.3 for locations). All carbonate carbon measurements in ‰ notation. Depositional distance assumes *c.* 30% Palaeogene shortening (Molenaar *et al.* 1987; Moore *et al.* 1997). Time scale is inferred from the detrital zircon ages in the 'O.G.' (Macdonald *et al.* 2009*b*), Cambrian trilobites in the Nanook Limestone and the similarity of the chemostratigraphic profile and sedimentary structures in the intervening carbonates to other Neoproterozoic age successions (see text for discussion). HH, Hula Hula diamictite; V, Mt. Copleston volcanic rocks.

Stratigraphy

As much as 3 km of Neoproterozoic strata are exposed in the NE Brooks Range of Arctic Alaska. The oldest strata in the region are in map unit 'O. G.', which was previously mapped as the Neurokpuk Formation (Fm.) and consists of tightly folded, mixed siliciclastic and carbonate rocks (Reiser *et al.* 1980; Robinson *et al.* 1989; Macdonald *et al.* 2009*b*). The thickness of this unit is unknown and its base is not exposed. Map unit O. G. is succeeded by the Mt. Copleston volcanic rocks. Although this contact is structural in the Sadlerochit Mountains (Macdonald *et al.* 2009*b*), regionally it has been described as an unconformity (Reiser *et al.* 1980; Robinson *et al.* 1989). The Mt. Copleston volcanic rocks underlie and interfinger with the Hula Hula diamictite, which is in turn succeeded by the *c.* 2-km-thick Neoproterozoic Katakturuk Dolomite. Subsidence analysis suggests that these strata were accommodated by extension on the southern margin of the North Slope subterrane with units K1–K3 of the Katakturuk Dolomite deposited on a thermally subsiding passive margin (Macdonald *et al.* 2009*b*).

Mt. Copleston volcanic rocks

The Mt. Copleston volcanic rocks are rusty weathering, dark maroon to black and green tholeitic basalts with 5 mm chlorite, calcite, zeolite amygdales, and common native copper. In the western Shublik Mountains, the basalt is up to 450 m thick with metre-scale individual flows. Along the Hula Hula River, the Mt. Copleston volcanic rocks are *c.* 500 m thick with a true thickness difficult to determine due to structural complexities. The volcanic rocks are often greenstone, and dominated by volcaniclastic units in the upper *c.* 100 m. On the west flank of Kikitak Mountain, the basalts are over 100 m thick and metamorphosed to greenstone. In the eastern Sadlerochit Mountains, the basalts appear relatively low grade with minimal chlorite, 5–10 mm long plagioclase lathes, and intact, spherical amygdales. Exposures measure up to 105 m thick with an unconformable, often faulted basal contact with the underlying unit O. G. The Mt. Copleston volcanic rocks and the Katakturuk Dolomite are separated by the Hula Hula diamictite, which ranges in thickness from *c.* 2 m to 50 m.

Katakturuk Dolomite

In the Sadlerochit Mountains, the Katakturuk Dolomite is over 2000 m thick, whereas in the Shublik Mountains, it is only *c.* 1000 m thick. This is due both to internal thinning and a basal truncation (Macdonald *et al.* 2009*b*). Generally, the Katakturuk Dolomite is composed of massive, light-grey, shallow-water dolomite with common ooids and cement. However, further to the SE, along the Hula Hula River, the Katakturuk Dolomite is composed predominantly of allodapic carbonate of unit K1 and measures only 400 m thick, with the upper units of the Katakturuk Dolomite truncated under the sub-Mississippian unconformity (Figs 34.2 & 34.3b). To highlight the major unconformities and disconformities, and departing from Robinson *et al.*'s (1989) lithostratigraphic subdivision, Macdonald *et al.* (2009*b*) divided the Katakturuk Dolomite into four informal units (Fig. 34.2): the Cryogenian map unit K1, the basal Ediacaran Nularvik dolomite (map unit K2), the early–middle Ediacaran map unit K3 and the late Ediacaran map unit K4. The uppermost portion of the Katakturuk Dolomite in the Sadlerochit Mountains, as described by Clough & Goldhammer (2000) has been included with the lowermost Nanook Limestone (Macdonald *et al.* 2009*b*).

Nanook Limestone

The Katakturuk Dolomite is overlain by the Cambrian to Ordovician Nanook Limestone. Previous studies suggested an unconformity at this level (Clough & Goldhammer 2000; Macdonald *et al.* 2009*b*); however, this interpretation may have been complicated by cave breccias from a karstic surface higher in the succession (personal observations). The lower *c.* 250 m of the Nanook Limestone host bed-parallel ichnogenera and C-isotopic profiles that are consistent with an Early to Middle Cambrian age

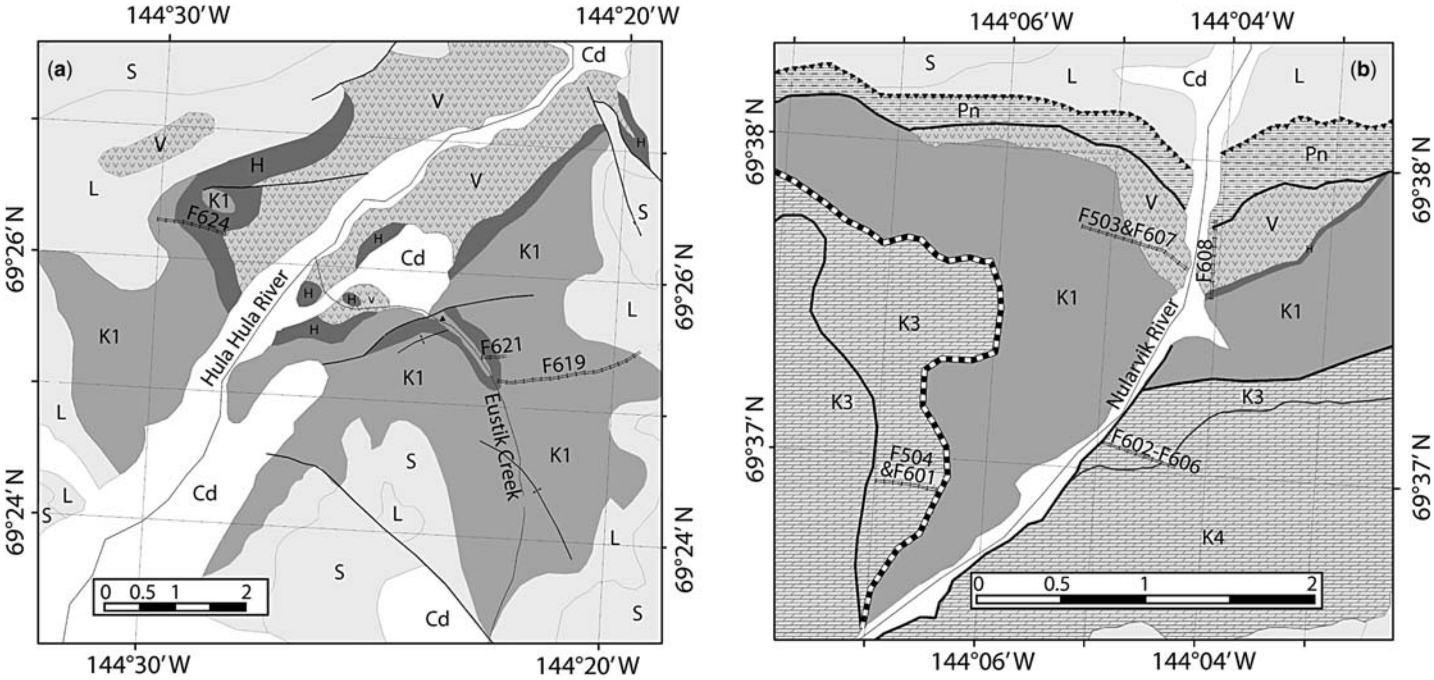

Fig. 34.3. (**a**) Geological map of the Kikitak Mountain area near the Hula Hula River. (**b**) Geological map of the eastern Sadlerochit Mountains along Nularvik Creek. See Figure 34.1 for locations and keys for both maps.

(Macdonald *et al.* 2009*b*). The upper Nanook Limestone contains Late Cambrian trilobites (Blodgett *et al.* 1986), and terminates with *c.* 160 m of Middle to Late Ordovician strata with the uppermost beds containing a diverse gastropod assemblage along with other molluscs, ostracods and brachiopods with a definitive Late Ordovician age (Blodgett *et al.* 1986) and a Siberian affinity (Blodgett *et al.* 2002).

Glaciogenic deposits and associated strata

Hula Hula diamictite

Reiser *et al.* (1970) described the orange weathering diamictite along the Hula Hula River as carbonate debris flows with clasts of basalt, and included these deposits with the Katakturuk Dolomite. Macdonald (2009) separated the Hula Hula diamictite from the Katakturuk Dolomite and suggested that sedimentation occurred under a glacial influence. On the east side of the Hula Hula River, along Eustik Creek, the Hula Hula diamictite is *c.* 50 m thick. Although incomplete exposure and structural repetition compromise the measurement of exact thicknesses, discrete thrust panels allow for confidence in the general stratigraphic relations. The lower 12 m of the diamictite is composed of cobble-sized clasts of orange dolomite and green to black basalt, together with quartzite pebbles, in a green to tan siltstone, and is interfingered with at least four basaltic flows that range in thickness from 0.2 to 2 m. This lower diamictite is overlain with *c.* 30 m of poorly exposed, fine millimetre-laminated siltstone with rare, gravel- and cobble-sized bedding-piercing outsized clasts and multiple orange allodapic carbonate beds. The upper 5 m of the Hula Hula diamictite is a massive, clast-supported diamict with boulders of dolomite and cobbles of basalt in a calcareous silt matrix. No striated clasts have been observed.

On the west side of the Hula Hula River near Kikitak Mountain (Figs 34.2 & 34.3b), the basal Hula Hula diamictite is composed of *c.* 10 m of diamictite with cobbles of dolomite and basalt in a siltstone matrix, and an additional *c.* 40 m of fine millimetre-laminated siltstone with rare outsized clasts and multiple beds of orange allodapic carbonate. The Hula Hula diamictite is also exposed in the eastern Sadlerochit Mountains along the Nularvik Creek, where the diamictite is only 2 m thick, and is composed of angular cobbles of dolomite, quartzite and basalt in a coarse, arkose grit (Fig. 34.4).

Katakturuk Dolomite

Near Kikitak Mountain and on both sides of the Hula Hula River, the basal unit of the Katakturuk Dolomite (K1) consists of *c.* 10 m of dark limestone, and an additional *c.* 75 m of rhythmite and allodopic carbonate. Near the Hula Hula River, on the north side of Eustik Creek, the basal 10 m limestone overlying the Hula Hula diamictite exhibits 'roll-up' microbial structures, reminiscent of the basal Rasthof Formation of northern Namibia (Hoffman *et al.* 1998; Pruss *et al.* 2010), whereas these are not present in the Sadlerochit Mountains. These shallow upwards to $<$500 m of massively bedded, often silicified, grainstone and packstone with poorly defined parasequences that are littered with giant ooids (*c.* 5 mm in diameter). Unit K1 culminates with *c.* 30 m of resistant, silicified grainstone and broken beds of recrystallized black chert that weather to a distinct black and white (the lower *zebra dolomite* of Robinson *et al.* 1989).

Nularvik dolomite

The Nularvik dolomite (K2) is equivalent to the upper portion of the zebra dolomite (Robinson *et al.* 1989; Clough & Goldhammer 2000). In the Sadlerochit Mountains, the Nularvik dolomite (K2) consists of 20–45 m of white to buff-coloured, recrystallized, finely laminated, micro-peloidal dolomite, overlain by tens of metres of former aragonite crystal fans (Macdonald *et al.* 2009*b*). Funnel-shaped calcite and silica cements are common in the lower 15 m of unit K2. In cross-section, the funnels are less than 5 cm tall, and up to 2 cm wide, taper downward, and are commonly linked at the top along bed parallel cements. The funnels are filled with isopacous, void-filling cements. In the western Shublik Mountains, these funnel-shaped cements are laterally equivalent with tubestone stromatolite bioherms (Corsetti & Grotzinger 2005). The peculiar tubestone stromatolites are distinguished by evenly distributed, *c.* 1-cm-diameter, cement-filled cylindrical tubes, and span as much as 8 m of stratigraphy.

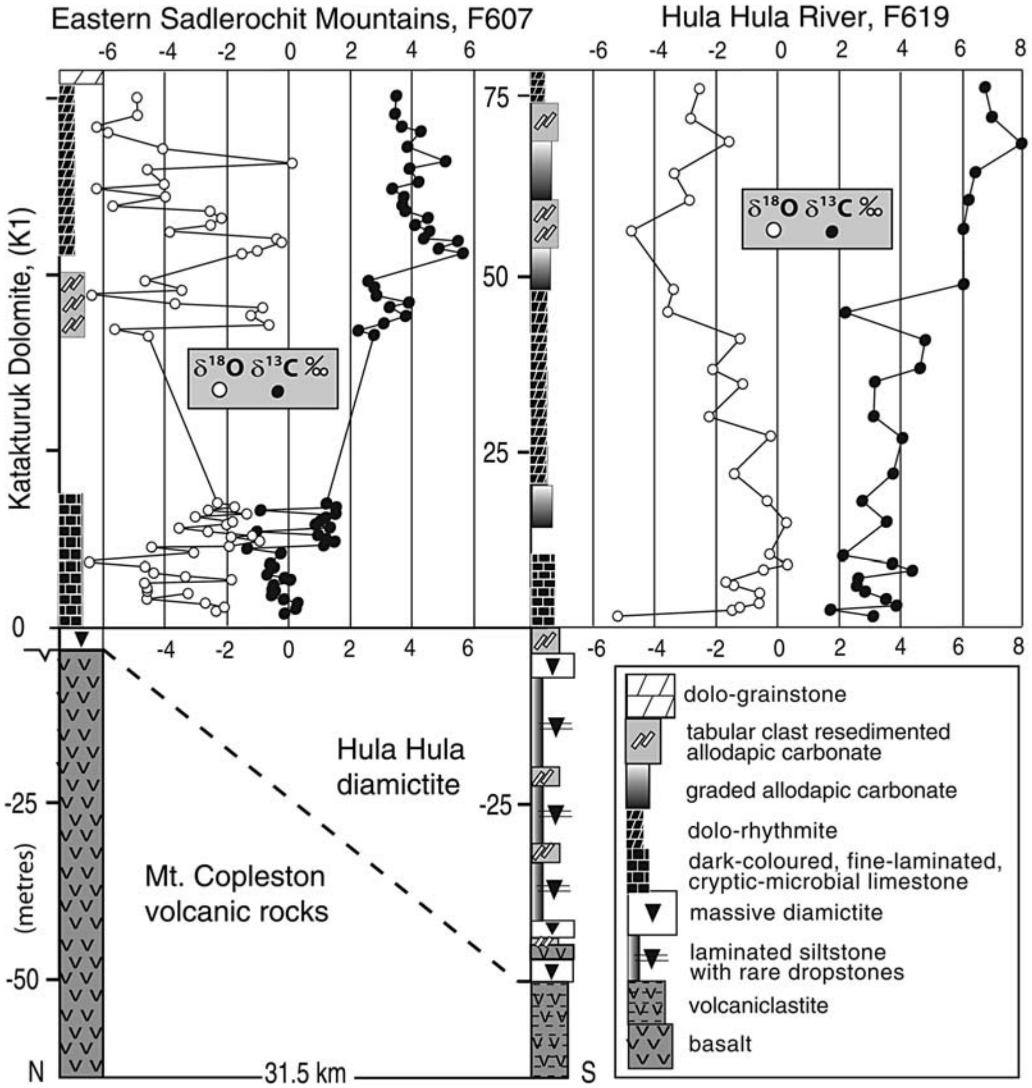

Fig. 34.4. C-isotope chemo- and lithostratigraphy of the Mt. Copleston volcanic rocks, the Hula Hula diamictite, and unit K1 along the Nularvik Creek in the eastern Sadlerochit Mountains (F607), and along the east side of the Hula Hula River (F619).

In the central and western Sadlerochit Mountains, giant wave ripples (Allen & Hoffman 2005) are also present in the Nularvik dolomite, at the top of the micro-peloidal dolomite. These are succeeded by breccia, and tens of metres of pseudomorphosed aragonite crystal fans, with individual fans measuring as tall as 60 cm (Clough & Goldhammer 2000; Macdonald *et al.* 2009*b*). The strata hosting the fans are dominated by grainstone and cement and are often broken, brecciated and recrystallized. Crystal fans are not present at this horizon in the Shublik Mountains.

In the Sadlerochit Mountains, unit K2 is succeeded by 2 m of shale and laterally discontinuous allodapic carbonate beds. In the Shublik Mountains, these deeper water facies expand to over 100 m of shale, rhythmite and allodapic carbonate. These are in turn overlain by an additional *c.* 1200 m of dolomite, primarily in grainstone, biolaminate and stromatolitic facies (units K3 and K4).

Boundary relations with overlying and underlying non-glacial units

In the eastern Sadlerochit Mountains, along the Nularvik Creek, the Hula Hula diamictite rests disconformably on pillow basalt of the Mt. Copleston volcanic rocks, with a basally erosive contact. In the Kikitak Mountain area, the Hula Hula diamictite also rests disconformably on the Mt. Copleston volcanic rocks; yet, the upper 50 m of the Mt. Copleston volcanic rocks consists of a volcaniclastic diamictite of outsized volcanic gravel and cobbles in matrix-supported volcanic grit. It is unclear if this deposit is a debris flow or a glacial diamictite formed of reprocessed volcanic rocks. Macdonald *et al.* (2009*b*) included this unit with the Mt. Copleston volcanic rocks rather than the Hula Hula diamictite because it lacks foreign clasts, shows no obvious evidence for a glacial origin, and because volcanic breccias occur at other horizons within the Mt. Copleston volcanic rocks.

Along the Nularvik Creek in the Sadlerochit Mountains the basal contact of the Katakturuk Dolomite (unit K1) is poorly exposed, whereas near Kikitak Mountain and on both sides of the Hula Hula River, the Hula Hula diamictite is overlain with a knife-sharp contact by *c.* 10 m of dark limestone. The Nularvik dolomite (K2) rests above unit K1 on a heavily silicified surface with a knife-sharp contact (Fig. 34.5).

Chemostratigraphy

High-resolution, carbonate C- and O-isotope chemostratigraphy through the Katakturuk Dolomite and Nanook Limestone were reported by Macdonald *et al.* (2009*b*). In the Sadlerochit Mountains, above the Hula Hula diamictite, in the basal 20 m of K1, C-isotope values rise from −2‰ to +6‰ (Fig. 34.4) where they hover between +3‰ and +6‰. In the Kikitak Mountain area, C-isotope values rise from +1‰ to +8‰, and also oscillate around +5‰ with slightly more variability. In the last parasequence of K1, values drop to 0‰.

C-isotope profiles of the Nularvik dolomite display an inverted S-shaped profile with a nadir at −2‰ (Fig. 34.5). In the Sadlerochit

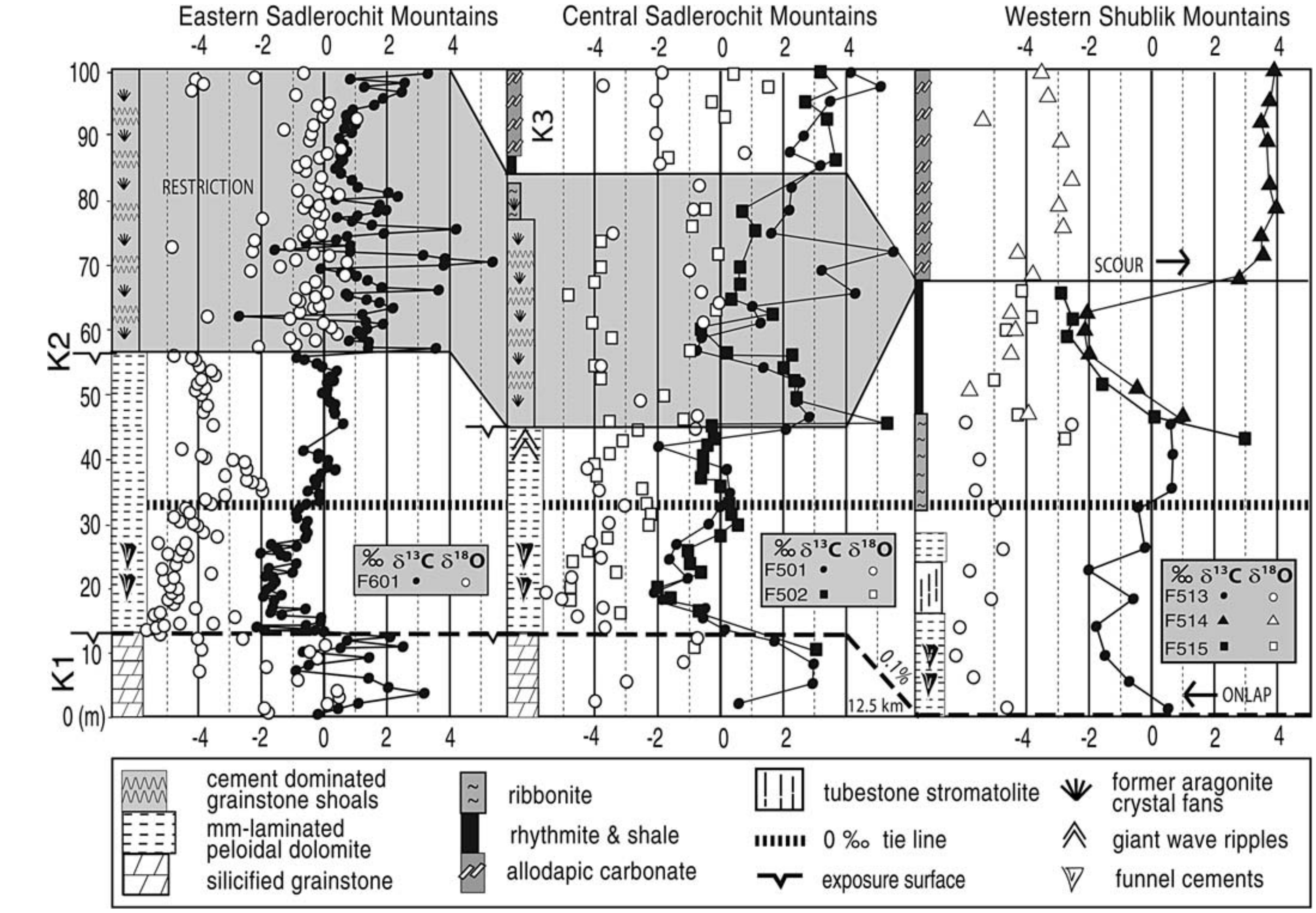

Fig. 34.5. Chemo- and lithostratigraphy of the Nularvik dolomite. See Figure 34.1 for locations of measured sections. All carbonate carbon (filled) and oxygen (hollow) data are in ‰ notation.

Mountains, above the Nularvik dolomite, C-isotope values are highly variable through the cement-dominated crystal fans. In the Shublik Mountains, no crystal fans are present, and instead the transgressive sequence progresses from grainstone, to ribbonite, to variably dolomitized limestone rhythmite and shale. C-isotope values bottom out at −3‰ in these rhythmites, then jump to +3‰ above a sharp surface below the overlying allodapic carbonate (Fig. 34.5).

Palaeolatitude and palaeogeography

The most popular model for the opening of the Arctic Ocean involves a *c.* 66° counterclockwise rotation of the AACP away from the Canadian Arctic islands about a pole in the Mackenzie Delta region (Carey 1955, 1958; Hamilton 1970; Grantz *et al.* 1979). Barring any earlier movement relative to Laurentia, this model would place the Neoproterozoic exposures in the NE Brooks Range offshore of what is now Banks Island. Lane (1997) pointed out multiple geological inconsistencies with the rotation model, including ages of deformation and deposition and proposed a model pinning Arctic Alaska to near its present position since Palaeozoic times. However, his 'fixed' Alaska model does not account for growing palaeontological evidence of Siberian and Baltican Palaeozoic fauna in Alaskan terranes (Blodgett *et al.* 2002; Dumoulin *et al.* 2002).

There are several modified versions of the rotation model that include differential motion within the AACP (Miller *et al.* 2006), and pre-rotation displacement relative to North America (Sweeney 1982). The Neoproterozoic stratigraphy and Palaeozoic palaeobiogeographic affinities of the AACP do not necessarily contradict the rotation model for the opening of the Arctic Ocean, but they do indicate that the pre-Devonian AACP was exotic to Laurentia (Macdonald *et al.* 2009*b*). These models are difficult to test directly because most palaeomagnetic studies in northern Alaska have been compromised by a pervasive Late Cretaceous overprint (Plumley *et al.* 1989; Stone 1989).

Geochronological constraints

A minimum age constraint on the Katakturuk Dolomite is provided by Late Cambrian trilobites in the upper portion of the overlying Nanook Limestone (Blodgett *et al.* 1986). A lower age constraint is provided by map unit O. G., which is stratigraphically below the Mt. Copleston volcanic rocks and the Hula Hula diamictite, and contains *c.* 760 Ma (^{206}Pb/^{207}Pb LA-ICPMS) detrital zircon grains (Macdonald *et al.* 2009*b*). A coarse, diabase sill within map unit O. G., previously assumed to be coeval with the Mt. Copleston volcanic rocks, yielded a whole rock Rb–Sr isochron age of 801 ± 20 Ma (Moore 1987; Clough & Goldhammer 2000); however, recent U–Pb dates of badellyite in these sills suggest they are Cretaceous in age (Macdonald 2009).

Discussion

A glacial origin of the Hula Hula diamictite is indicated by the presence of bed-penetrating outsized clasts interpreted as dropstones and the association with a geochemically and sedimentologically distinct overlying dark-coloured limestone. Although the bulk of the Mt. Copleston volcanic rocks are below the Hula Hula diamictite with a few small flows inter-fingering with the lowermost Hula Hula diamictite, it is not certain that the Mt. Copleston volcanic rocks mark the onset of glaciation, as there could have been glacial activity prior to the emplacement of the basalts that failed to leave a record. Nonetheless, a potential interpretation of the stratigraphy of the Hula Hula diamictite along Eustik Creek is that the basal *c.* 10 m of massive diamictite with interfingering basalts were deposited as glaciomarine deposits during the encroachment of sea ice; the middle *c.* 30 m of millimetre-laminated silts with occasional debris flows and rare dropstones formed under total ice cover; and the upper *c.* 5 m of massive diamictite represents the ice-retreat phase.

Above the Hula Hula diamictite, C-isotope values rise from $-2‰$ to $+6‰$ in the Sadlerochit Mountains and from $+1‰$ to $+8‰$ near Kikitak Mountain (Fig. 34.4). Although it is not clear why values are more enriched in the deeper-water sections, the positive, concave trend, and the extremely enriched values are typical of Cryogenian post-glacial carbonates (Halverson *et al.* 2005), and the basal negative anomaly is similar in magnitude to the basal Rasthof Formation (Yoshioka *et al.* 2003). An early Cryogenian age of the Hula Hula diamictite is also suggested by the presence of 'roll-up' microbial structures in the overlying dark limestones, which are reminiscent of the basal Rasthof cap carbonate of Northern Namibia (Hoffman *et al.* 1998).

C-isotope profiles of the Nularvik dolomite (K2) display an inverted S-shaped profile with a nadir at $-2‰$ (Fig. 34.5). Normalized for thickness (and excluding isotopic values of cements), this isotopic profile is similar to that of the Ediacaran basal Doushantuo in South China (Jiang *et al.* 2003; Zhou & Xiao 2007), which has been dated at 635.2 ± 0.6 Ma (Condon *et al.* 2005). The C-isotope profile is also reminiscent of slope sections of the Keilberg Fm. in northern Namibia, where underlying glacial deposits have been dated at 635 ± 0.5 Ma (Hoffmann *et al.* 2004), and shelf sections are 3–4‰ lighter than foreslope sections (Hoffman *et al.* 2007). Assuming that carbon is well-mixed in the oceans and on platforms, the relatively enriched values of the Nularvik dolomite suggest it was deposited early compared to shelf sections in northern Namibia, and then truncated by exposure surfaces before seawater reached extremely negative values.

Funnel-shaped calcite and silica cements in unit K2 are similar to those in the basal Ediacaran Ol cap carbonate of Mongolia (Macdonald *et al.* 2009*a*), in the Keilberg Fm. Of Northern Namibia, and in the basal Doushantuo in South China (Macdonald, unpublished data). As these are laterally equivalent with tubestone stromatolite bioherms and are reminiscent in plan view, they may be a related facies that is characteristic of basal Ediacaran cap carbonates.

The crystal fans in the Nularvik dolomite are formed in grainstone with multiple exposure surfaces, pervasive cements, and broken and brecciated beds (Clough & Goldhammer 2000; Macdonald *et al.* 2009*b*). Occasionally, individual fans are tipped over on their side from the buckling of teepees. C-isotope values are highly variable through this interval. Together, these data suggest the fans were formed in a restricted, lagoonal setting with multiple exposure surfaces (Macdonald *et al.* 2009*b*). This is a very different depositional environment than the settings for sea-floor precipitate crystal fan development in other basal Ediacaran cap carbonates (Peryt *et al.* 1990; James *et al.* 2001; Hoffman & Halverson 2008). Isotopic scatter, evidence of exposure and pervasive cementing is also a common feature in other basal Ediacaran cap carbonates that were deposited in basins lacking active stretching, such as the upper portion of the Doushantuo Fm. in South China (Jiang *et al.* 2003) and the Jbeliat dolostone in Mauritania (Hoffman & Schrag 2002; Shields *et al.* 2006). This pre-transgression shoaling could be a product of isostatic rebound outpacing passive subsidence and post-glacial eustatic sea-level rise.

Although no late Cryogenian glacial diamictites have been identified, the Nularvik dolostone contains an isotopic profile and sedimentary textures in a particular order that are both characteristic of basal Ediacaran cap carbonates globally (Allen & Hoffman 2005). The lack of glacial deposits can be attributed to poor preservation potential as the glacio-eustatic sea-level drop left the carbonate platform exposed or possibly covered with grounded ice until the post-glacial transgression. Glacial diamictites are also rare under the Keilberg cap carbonate on the Otavi platform in Northern Namibia (Hoffman & Halverson 2008). In the Sadlerochit and Shublik Mountains, a late Cryogenian glaciation may be contained in a silicified surface, with the overlying Nularvik dolomite representing the basal Ediacaran cap carbonate.

The Katakturuk Dolomite has previously been correlated with the early Neoproterozoic deposits of NW Laurentia (Rainbird *et al.* 1996), such as the Lower Tindir Group of the Yukon-Alaska border area (Young 1982; Macdonald *et al.* 2010*a*), the pre-717.4 Ma Fifteenmile Group in the Ogilvie Mountains (Macdonald *et al.* 2010*b*), the Little Dal Group in the Mackenzie Mountains (Aitken 1981) and the pre-716.3 Ma Shaler Supergroup of Victoria Island (Young 1981; Macdonald *et al.* 2010*b*). This correlation was based in large part on palaeogeographical reconstructions that tie the AACP to northwestern Laurentia. However, the Katakturk Dolomite is younger than *c.* 760 Ma and likely Cryogenian to Ediacaran in age (Macdonald *et al.* 2009*b*). Using the 801 ± 20 Ma Rb–Sr date, Clough & Goldhammer (2000) argued that the Mt. Copleston volcanic rocks represent a rifting episode coeval with the *c.* 780 Ma Gunbarrel Event (Park *et al.* 1995; Harlan *et al.* 2003), and that the Katakturuk Dolomite was deposited during the thermal subsidence stage on a passive carbonate ramp. Instead, the Mt. Copleston basalts could be correlative with the Franklin igneous event. However, NW Laurentia lacks potentially correlative Cryogenian to Ediacaran successions dominated by platformal carbonate rocks. At present, the origin and Neoproterozoic position of the NSST and AACP are unknown; however, the Neoproterozoic and Palaeozoic strata of the AACP potentially have features in common with peri-Siberian and Baltican terranes (Colpron & Nelson 2009; Macdonald *et al.* 2009*b*). Further work is necessary to test these correlations.

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