The paleoenvironmental significance of trace fossils in Devonian sediments (Taylor Group), Darwin Mountains to the Dry Valleys, southern Victoria Land

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Summary A review of trace fossils in the Taylor Group from the Britannia Range to the MacKay Glacier indicates that they varied significantly both spatially and temporarily within the Devonian basin. New studies in the south provide a better understanding of ichnofaunas in the Junction Sandstone (570m) and Hatherton Sandstone (450m), with new information on very large burrows in the well-dated Aztec Siltstone. The burrow *Heimdallia chatwini* occurs in dense populations only in the northern part of the basin (Dry Valleys), but are not found above the Heimdall Erosion Surface. This surface is followed by thick horizons of dense *Skolithos linearis* burrows that indicate a change of environment. The *Skolithos* zone can be traced into the southern part of the basin (Darwin Glacier region) beyond the extent of the erosion surface. The *Skolithos* burrows suggest that the Devonian basin was subjected to a widespread marine incursion sometime during the Early to Middle Devonian.

Citation: Bradshaw, M.A. and F. J. Harmsen (2007), The paleoenvironmental significance of trace fossils in Devonian sediments (Taylor Group), Darwin Mountains to the Dry Valleys, southern Victoria Land, in Antarctica: A Keystone in a Changing World – Online Proceedings of the 10th ISAES X, edited by A. K. Cooper and C. R. Raymond et al., USGS Open-File Report 2007-1047, Extended Abstract 133, 5 p.

Introduction

In the Devonian, the Hatherton Glacier to Skelton Glacier region was part of the southern Victoria Land sedimentary basin in which 1500m of Taylor Group sediments were deposited. There was variation in sedimentation within this basin, especially in the lowermost units in the north, but it was entirely siliclastic. An unknown thickness of Devonian sediments was eroded during the onset of Permo-Carboniferous glaciation.

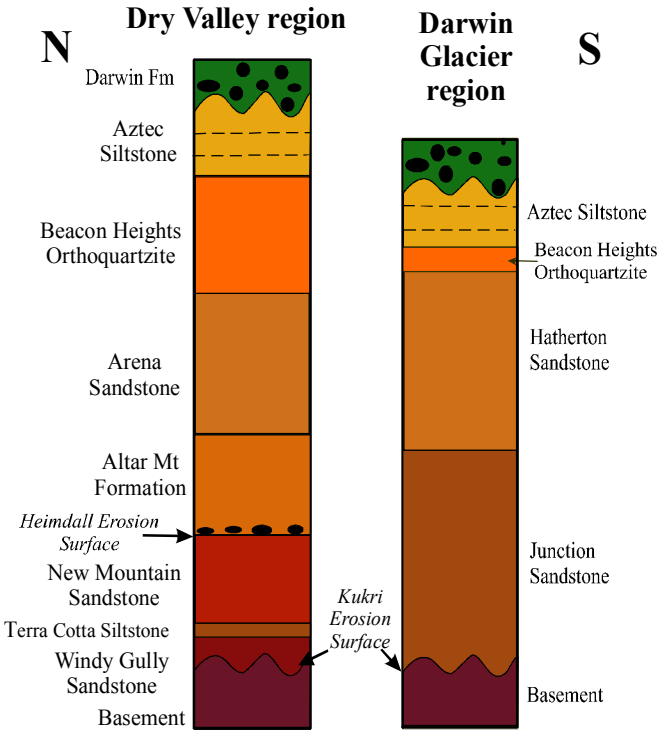

Figure 1. Taylor Group sequences in the Dry Valley region (left and the Darwin Glacier region (right).

The standard sequence in the Dry Valley region (northern part of basin) is subdivided by the Heimdall Erosion Surface, which separates the initial sediments (Windy Gully Sandstone, Terra Cotta Siltstone and New Mountain Sandstone) from the overlying Altar Mountain Formation, Arena Sandstone and Beacon Heights Orthoquartzite. The sequence ends with the fish-bearing sediments of the Aztec Siltstone. Apart from sparse Emsian spores in the Terra Cotta Siltstone (Kyle 1977), the Aztec Siltstone is the only formation to have body fossils that provide a reliable late Middle–Late Devonian age for this part of the sequence (Young 1988).

Three hundred kilometres to the south in the Britannia Range and Darwin Mountains, the Taylor Group comprises two very thick units; The Junction Sandstone (570 m) and the Hatherton Sandstone (450 m). In the Cook Mountains north of the Darwin Glacier the two units are followed by two thinner formations that correlate to the Dry Valley region. These are the Beacon Heights Orthoquartzite (40-50 m), which is markedly thinner than its correlative in the north (Beacon Heights, 284 m), and the Aztec Siltstone (minimum 135 m).

As the Heimdall Erosion Surface has not been recognised south of Knobhead, it is difficult to correlate the Dry Valleys lower Taylor Group sequence with that to the south. The combined thickness of Beacon sediments below the Beacon Heights Orthoquartzite in the Cook Mountains (1020 m) is therefore equivalent to 980 m in the north. Because of its position immediately below the Beacon Heights Orthoquartzite, the Hatherton Sandstone south of the Muluck Glacier is generally regarded as equivalent to the Arena Sandstone in the north, which would make the Junction Sandstone equivalent, at least in part, to the Altar Mountain Formation, New Mountain sandstone, Terra Cotta and Windy Gully Sandstone (Fig 1).

Junction Sandstone Formation

The Junction Sandstone is predominantly cross-bedded coarse sandstones and granule to pebble conglomerates, with a basal conglomerate (Brown Hills Conglomerate) up to 17 m that contains granitic and metasedimentary clasts. The formation is feldspathic and poorly sorted near its base of the formation, with influxes of coarse material at intervals. The formation becomes more quartzose and better sorted up section. Deposition was in broad shallow channels, and thin shales with dessication cracks indicate periods of exposure. The formation is best exposed in the Darwin Mountains and southern Cook Mountains. Coarse, conglomeratic, cross-bedded feldspathic sediments on Skua Ridge in the northern Cook Mountains should probably be included in this formation. Interbedded finely interlaminated maroon mud and white sandstones are reminiscent of parts of the Altar Mountain Formation on Mount Handsley in the north. These beds show flaser bedding, ripples with mud drapes, and numerous U-shaped burrows and escape structures. The coarse, feldspathic sediments at Swartz Nunatak north of the Muluck Glacier, which contain 3-4m of pebble/cobble conglomerate with clasts of vein quartz and lithic material (possible acid volcanics), may also be part of the Junction Sandstone.

Hatherton Sandstone Formation

The Hatherton Sandstone is predominantly well-sorted, medium grained quartzose sandstones, with coarser beds mainly in the lower part. Contact with the Junction Sandstone is gradational, with the base placed at the first substantial black shale horizon (40cm), a level that coincides with the first appearance of the large sinuous burrow, *Beaconites barretti*. The Formation exhibits large-scale planar and bi-modal trough cross-bedding, horizons of hummocky cross-stratification and horizontally laminated sediments. Trace fossils are particularly common.

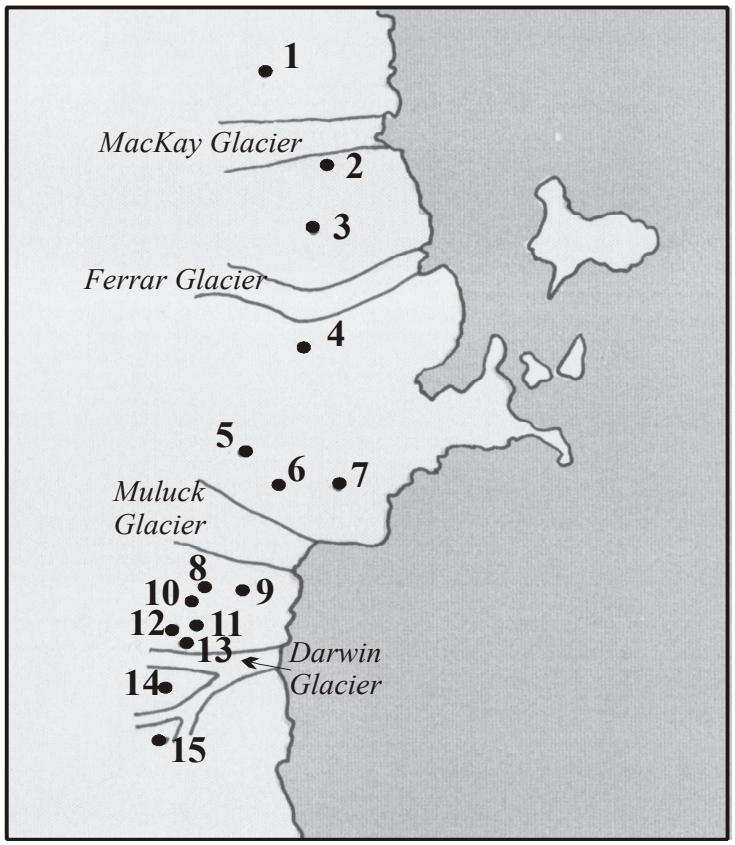

Figure 2. Southern Victoria Land localities: 1-Convoy Range, 2-Sperm Bluff, 3-Dry Valleys, 4-Rotunda, 5-Boomerang Range, 6-Swartz Nunatak, 7-Worcester Range, 8-Mt Gudmundson, 9-Skua Ridge, 10-Sliver Nunatak, 11-Fish Hotel, 12-Fault Bluff,13-Gorgons Head, 14-Darwin Mts, 15-Britannia Range.

The Hatherton Sandstone is well exposed in the Darwin Mountains and Britannia Range. It is remarkably uniform in lithology, and can be traced northward through the Cook Mountains to the Skelton Glacier névé outcrops, where it has been referred to as the Arena Sandstone.

Beacon Heights Orthoquartzite Formation

The Beacon Heights Orthoquartzite comprises well-sorted, well-cemented medium to coarse grained trough cross-bedded quartzose sandstones, sometimes containing impressions of *Haplostigma irregulare*. In the Cook Mountains the formation crops-out on Gorgons Head, Mt Gudmundson and Sliver Nunatak. Where visible, the basal contact is sharp but irregular on burrowed Hatherton Sandstone, with rare lithic cobble/pebble lenses in the lowest metre of sandstone. The formation is not present south of the Darwin Glacier.

Aztec Siltstone Formation

The Aztec Siltstone was unknown south of the Muluck Glacier until Woolfe et al (1990) recorded fish-bearing beds on Gorgons Head near the Darwin Glacier. A transect through the Cook Mountains resulted in the discovery of several new outcrops of Aztec Siltstone (Fault Bluff, Fish Hotel, Sliver Nunatak, Mt Gudmundson) from which important new fish collections have been made (Long & Young, 1995). Gorgons Head remains the most southerly known outcrop of the Aztec Formation with a minimum thickness of 135m.

The Aztec Siltstone comprises repetitions of coarse sandstones and finer siltstones/mudstones. Wide (up to 12m) shallow channels have lags rich in fish debris, and the very coarse, cross-bedded channel fill may contain scattered fish plates on foresets. Large dewatering structures were observed at several localities. Ripple laminated mudstone and siltstone horizons (maroon, green and grey) are more common than in any of the underlying formations, with vein networks representing soil horizons. Desiccation cracks are common. Small roots are prolific

at many horizons, while larger roots have been replaced by calcite. Horizons of scattered plant material (psilophytes, lycopod stems and small logs) also occur.

Trace fossils

There is significant variation in trace fossils within the Taylor Group, both spatially and temporally, and these probably reflect changes in environmental conditions across the Victoria Land basin.

Dry Valley area

In the Dry Valley region, a *Heimdallia-Diplichnites* ichnocoenosis is found in the Windy Gully Sandstone and New Mountain Sandstone Formations. Thick, densely bioturbated horizontal or low angle cross-bedded sandstones full of the burrow *Heimdallia chatwini* produce striking outcrops. The burrowed horizons represent periods of non-deposition and intense animal activity. A small crustacean is a likely producer (Bradshaw, 1981). The burrowed horizons are interbedded with low angle, flaggy cross-sets, whose foresets are often rippled or crossed by arthropod trackways, the most common of which is *Diplichnites*. The trackways indicate that a varied fauna of arthropods travelled across the dune foresets before the next layer was deposited. Thin interbedded layers of *Heimdallia* burrows indicate that sometimes the pause in sedimentation was longer than at others. Large circular infilled depressions with a better-cemented rim also occur.

Heimdallia burrows in similar profusion also occur to the north in well-sorted sandstones near the top of the Sperm Bluff Formation on Sperm Bluff and Gargoyle Turrets. Thick conglomerates in this formation indicate that these localities lay close to the north eastern margins of the sedimentary basin (Savage et al., 2005). The *Heimdallia-Diplichnites* association can be traced southwards as far as Table Mountain, and at about the same latitude, the Heimdall Erosion Surface also dies out. Further to the south *Heimdallia* burrows are unknown.

An abrupt change to coarse, feldspathic sandstones crowded with the deep burrow *Skolithos linearis* occurs immediately above the Heimdall Erosion Surface (Odin Arkose Member, Altar Mountain Formation) and this horizon can be traced throughout the Olympus and Asgard Ranges to just south of the Ferrar Glacier. Where the Heimdall Erosion surface disappears, the *Skolithos*-rich horizons occur in the top of the New Mountain Sandstone (eg. at Table mountain).

Britannia Range to Skelton Névé

Dense zones of *Skolithos linearis* occur in more than 100 m thickness in the upper part of the Junction Sandstone on Junction Spur, Tentacle Ridge and Skua Peak, and are associated with coarser lithologies (Fig. 4). Below these zones, only indeterminate vertical burrows, the funnel opening *Tigillites*, narrow *Beaconites antarcticus* and rare *Diplichnites* and *Helminthoidea* occur.

Figure 3. Dense *Skolithos* burrows in Junction Sandstone, Darwin Glacier.

In the overlying, better sorted and more quartzose Hatherton Sandstone, trace fossils become abundant and diverse. The lithology and ichnofauna of the formation is remarkably uniform across a vast distance from the Byrd Glacier (Sabrina Ridge section) to the most northerly exposure studied at Soowee Ridge in the Boomerang range. Successive forests show a variety of vertical and horizontal burrows as well many different sized arthropod trackways. The largest trackway observed at Escalade Peak reached a width of 91cm, while another nearby was 41cm across. The great variety of trackways indicates that the basin was inhabited by a range of arthropod animals, some of which were very large and likely to have needed water to support them.

Skolithos linearis burrows occur in the Hatherton Sandstone but never in the density observed in the Junction Sandstone. They often penetrate down from bounding surfaces truncating cross-beds but were also observed concentrated in the swales between burrowed sand hummocks. Horizontally laminated sandstones which overlie truncated cross-sets are frequently burrowed by *Beaconites barretti,* and smaller, straighter *B. antarcticus*. In the Hatherton Sandstone *B. barretti* varies in width from 2-13 cm (average between 6-8 cm), and can be traced horizontally for 1.7 m. Vertical sections show that the animal was capable of burrowing deeply into the sediment. Horizontal burrows often end in circular bosses or depressions, and occasionally an exposed burrow has an irregular appearance as if composed of a series of these circular depressions (Fig. 4). At several localities isolated groups of two or more similar circular depressions occur on bedding surfaces, some as large as 19 cm diameter. Although probably made by the same animal, the form of these depressions is different from the horizontal burrow *B. barretti*, and they are best described under the ichnogenus *Metaichna.* In contrast, *B. antarcticus* are narrow

burrows, between 0.5 and 2.6 cm in width that can be remarkably straight, traceable for up to 3 m along bedding. Occasionally they are subparallel to each other as if controlled by current direction. They appear to be shallow burrows, not penetrating far into the sediment like *B. barretti*. In rare instances they were observed to branch. It is likely that the two species of *Beaconites* were created by different types of arthropods.

No ichnofauna was observed in the Beacon Heights Orthoquartzite, and 'Skolithos' burrows reported in the overlying Aztec Siltstone (Woolfe et al., 1990) are, in reality, small root horizons. However, certain sandstones in the Aztec Siltstone contain very large *B. barretti* burrows as well as associated or isolated *Metaichna*. With widths of up to 23 cm and seldom less than 10 cm, these burrows and depressions must have been made by a large animal. They predate the development of horizontal and vertical roots in sandstone beds. Unlike the Hatherton forms, the burrow infill is frequently poorly meniscate or amorphous. The burrows are present in all the southern Aztec outcrops but are particularly spectacular on Mt Gudmundson. An isolated *Metaichna* on a bedding plane at Mt Gudmundson that measured 15 cm by 16 cm, appears to have faintly preserved the underside impression of a subcircular crab-like arthropod. North of the Mulock Glacier, a single large *B. barretti* only was observed in the Aztec Siltstone on Mt Kohn. Trackways are extremely rare in the Aztec Siltstone, but a partial trackway left by a very large arthropod has individual 'footprints' that are up to 6.5 cm in length.

Figure 4. *Beaconites barretti* in the Hatherton Sandstone, Darwin Mountains

The Lower Taylor Group sedimentary basin

The northern and southern limits of this basin are uncertain**.** The Sperm Bluff Formation near the MacKay Glacier appears to be the most northerly outcrop of the older part of the Taylor (Savage et al, 2005). Taylor Group outcrops on the north side of the MacKay Glacier are limited to the Convoy Range, where 60 m of Beacon Heights Orthoquartzite overlies 150 m of Arena Sandstone (Pocknall et al, 1994). In the south, the Hatherton Sandstone ends abruptly at the Byrd Glacier and its exact relationship to Beacon sediments that overlie the deeply eroded Cambrian Shackleton Limestone in the Churchill Mountains further south, is uncertain (Anderson, 1979).

Sedimentation in the Darwin part of the initial basin appears to have been more uniform and arenaceous than in the north, where a thick mudstone unit, the Terra Cotta Siltstone, accumulated north of the Muluck Glacier (max 82 m Mt Harmsworth), thining north and dying out near the Wright Valley. Above and below this mudstone, sandstones contain the *Heimdallia* ichnofauna that is unknown in the southern part of the basin. This ichnofauna occurs below the development an erosion surface (Heimdall erosion Surface) that precedes the appearance of dense 'colonies' of *Skolithos linearis* burrows at the base of the Altar Mountain Formation. Where the Heimdall erosion surface is absent, the *Skolithos* zone occurs within the top of the New Mountain Sandstone and the contact with the overlying Altar Mountain is gradational (Bradshaw, 1981).

Dense occurrences of *Skolithos linearis* burrows are generally associated with marine conditions and there are many examples of thick sandstone sequences that are crowded with this trace fossil at the exclusion of everything else, and all of these sequences are accepted as marine. This is not the case in the Taylor Group, where a debate on the non-marine versus marine origin of the Taylor Group remains unresolved. The fact that there are *Skolithos* rich zones, or 'pipe rock' that can be traced from the Dry Valley region to the Darwin Glacier supports a prolonged and widespread marine incursion.

Summary

This extended abstract summarises work in progress on the trace fossils of the Britannia Range/Skelton Névé region, and also incorporates information from the Dry Valleys region.

Acknowledgments. We thank co-editor W.R. Hammer for handling this abstract and also John Bradshaw for his helpful discussions and for checking the manuscript. Our thanks as well to Martin Kirkbride, Ray Waters, Brian Staite and John Long for their companionship in Antarctica over two field seasons in the Darwin-Cook Mountains area.

References

Anderson, J. M. (1979), The geology of the Taylor Group, Beacon Supergroup, Byrd Glacier area, Antarctica, New Zealand Antarctic Record, 2, 6-10.

Bradshaw, M.A. (1981), Paleoenvironmental interpretations and systematics of Devonian trace fossils from the Taylor Group (lower Beacon Supergroup), Antarctica. New Zealand J Geol. Geophys., 24, 615-652.

Kyle, R. A. (1977), Devonian palynomorphs from the basal Beacon Supergroup of South Victoria Land, Antarctica (note). New Zealand J Geol. Geophys., 20, 1147-1150.

Long, J. A. and G. C.Young, (1995), Sharks from the Middle-Late Devonian Aztec Siltstone, southern Victoria Land, Antarctica, Records of the Western Australian Museum, 17, 287-308.

Pocknall, D. T., T. J. Chinn, R,. Sykes, and D.N. B. Skinner (1994), Geology of the Convoy Range area, southern Victoria Land, Antarctica, 1:50 000 , Inst. Geol. & Nuc. Sciences geological map 11, 1 sheet & 36 p.

Savage, J, M. A. Bradshaw and K. Bassett (2005), Provenance of Devonian Supergroup sediments in southern Victoria Land, Antarctica, Geological Society New Zealand Miscellaneous pub. 119A, 76-77.

Woolfe, K, J., J. A. Long, M. A. Bradshaw, F. J. Harmsen and M. P. Kirkbride (1990), Fish-bearing Aztec Siltstone (Devonian) in the Cook Mountains, Antarctica, New Zealand J Geol. Geophys., 33, 511-514.