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**RAPID COMMUNICATION**

# Burrowing below the basal Cambrian GSSP, Fortune Head, Newfoundland

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**Abstract**

The range of *Treptichnus pedum*, the index trace fossil for the *Treptichnus pedum* Zone, extends some 4 m below the Global Standard Stratotype-section and Point for the base of the Cambrian Period at Fortune Head on the Burin Peninsula in southeastern Newfoundland. The identification of zigzag traces of *Treptichnus* isp., even further below the GSSP than *T. pedum* in the Fortune Head section, and in other terminal Proterozoic successions around the globe, supports the concept of a gradational onset of three-dimensional burrowing across the Proterozoic–Cambrian boundary. Although *T. pedum* remains a reasonable indicator for the base of the Cambrian Period, greater precision in the stratotype section can be achieved by a detailed re-evaluation of the stratigraphic ranges and the morphological variation of ichnotaxa included in the *T. pedum* Zone.

## 1. Introduction

The Global Standard Stratotype-section and Point (GSSP) for the Proterozoic–Cambrian boundary in the Chapel Island Formation at Fortune Head, on the Burin Peninsula of southeastern Newfoundland, at an horizon marking the top of the *Harlaniella podolica* (ichnofossil) Zone and the base of the *Phycodes pedum* (ichnofossil) Zone (Narbonne *et al.* 1987), was ratified by the International Union of Geological Sciences in 1992 (Brasier, Cowie & Taylor, 1994; Landing, 1994). As pointed out by Osgood (1970), *Phycodes pedum* does not fit well into the concept of *Phycodes* as defined by its type ichnospecies. Maples & Archer (1987) showed that the restriction of *Treptichnus* to zigzag forms does not reflect the type material of this genus. Subsequently, Jensen (S. Jensen, unpub. Ph.D. thesis, Univ. Uppsala, 1993; 1997) and Jensen & Grant (1992, 1998) re-assigned *Phycodes pedum* to the ichnogenus *Treptichnus.* (Geyer & Uchman (1995) advocated assignment to *Trichophycus pedum*, but see Seilacher (1997).) The ichnofossil zones spanning the boundary correspond to assemblages first described by Crimes (1987) from Proterozoic–Cambrian successions around the globe. The GSSP was positioned at the first occurrence of *Treptichnus* (*Phycodes*) *pedum*, 2.4 m above the base of Member 2 in the Chapel Island Formation (Narbonne *et al.* 1987).

The Chapel Island Formation is a remarkably thick succession of siliciclastic sediment (approximately 1000 m) that spans the Proterozoic–Cambrian boundary up to and including the '*Ladatheca*' *cylindrica* and the *Watsonella crosbyi* small shelly fossil assemblage zones (Narbonne *et al.* 1987; Landing *et al.* 1989; Landing & Westrop, 1997). On the Avalon Peninsula, to the east, Ediacaran body fossils range through 2000–4000 m of the Conception and St. John's groups (Anderson & Misra, 1968; Misra, 1969; Gehling, Narbonne & Anderson, 2000), separated from Cambrian strata by some 7000 m of the Signal Hill Group (Williams & King, 1979). The Chapel Island Formation conformably overlies the terrestrial to paralic sequence of the Rencontre Formation that is, in turn, correlated with the top of the Signal Hill Group on the Avalon Peninsula (Strong, 1979; Smith & Hiscott, 1984). The definition of the GSSP within the Chapel Island Formation using ichnofossil zones as the principal biostratigraphic criteria, rather than small shelly or other body-fossil zones, reflects the fact that a consistent order of appearance of trace fossils has been observed in numerous siliciclastic sections spanning the Proterozoic–Cambrian boundary around the globe. Small shelly fossils, although mainly confined to thin carbonate units, concretions and grey (dysaerobic) mudstone units within the upper members of the Chapel Island Formation (Narbonne *et al.* 1987; Landing *et al.* 1989; Myrow & Landing, 1992), provide a means of correlation with Lower Cambrian carbonate successions on other continents. However, the sole use of small shelly fossils for identifying the Proterozoic–Cambrian boundary in carbonate successions is limited by their inconsistent order of appearance from one region to another (Bengtson, 1988).

Paradoxically, while the apparently abrupt appearance of several genera of Cambrian-type trace fossils in the Fortune Head stratotype represented a distinct advantage in correlation, the reasons for this jump in diversity are problematic and have not been adequately addressed. The absence of evidence of either a facies change or a major hiatus underlining the boundary (Narbonne *et al.* 1987) suggested near synchronous expression of many new animal behaviours. Our

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detailed observations in the summer of 1999 revealed that some of the complex trace fossils formerly known only from the Cambrian occur a few metres below the boundary, and below the last appearance of *Harlaniella podolica* and *Palaeopascichnus delicata*, from the latest terminal Proterozoic zone. This poses possible problems in recognizing and correlating the basal Cambrian boundary, and requires some qualification to the biostratigraphic application of trace fossils in this interval.

## 2. New observations

An investigation of the evolution of ichnofabrics in siliciclastic successions spanning the Proterozoic–Cambrian boundary has been undertaken recently in South Australia (Droser, Gehling & Jensen, 1999) and on the Burin Peninsula of Newfoundland. As part of this ichnofabric project, detailed logs were made of the Global Stratotype Section at Fortune Head and the subsidiary section at Grand Bank Head (7 km north of Fortune Head), based on and keyed into the labelled, measured sections of Myrow (P. M. Myrow, unpub. Ph.D. Thesis, Memorial Univ. of Newfoundland, 1987), Landing *et al.* (1988, fig. 20) and Myrow & Hiscott (1993). Working at centimetre scale, the ichnofabrics and the associated trace fossil taxa were described in relationship to the sedimentary facies.

Previously unrecorded specimens of *T. pedum* were discovered in the top of Member 1 of the Chapel Island Formation at Fortune Head in the designated Global Standard Stratotype-section, at 16.25 m and 17.55 m, respectively 4.41 m and 3.11 m below the GSSP at 20.66 m (Figs 1, 2a). The specimen at 17.55 m consists of a series of four closely spaced probes that join a straight, seemingly horizontal, 5 mm wide, segment at a right angle (Fig. 2b). The probes are orientated laterally to the overall direction of the trace, have a strong vertical curvature, and at least the second probe displays curvature in a horizontal plane. Because of the truncation by successive probes, only two probes approach completeness, with a width comparable to that of the straight segment. Due to slab size the specimen is truncated on two sides. Additional sampling would be desirable to obtain more complete specimens. However, despite the fragmentary preservation of this specimen the morphology is characteristic and fits within the range of forms currently included in *T. pedum* (cf. Geyer & Uchman 1995, fig. 6). *T. pedum* is, nevertheless, in need of a comprehensive study which, perhaps, would reveal a temporal signal among the morphologies currently included in *T. pedum.*

The section at Fortune Head is cut by a fault just below the 15 m level within Member 1 (P. M. Myrow, unpub. Ph.D. Thesis, Memorial Univ. of Newfoundland, 1987, p. 497) (Fig. 1). However, by comparison with the equivalent section at Grand Bank, it appears that there was relatively little displacement on this fault, and the top of Member 1 is largely intact above a series of faults with more significant displacement at the base of this measured section. In addition to ichnospecies of *Planolites*, a number of examples of *Treptichnus* isp. (Fig. 2) were observed between 7 m and 15 m in the upper part of Member 1 (Fig. 1). These traces differ from *T. pedum* in that the probes are more strongly aligned and lateral probes are only rarely visible. However, it is clear that they are three-dimensional burrow systems of the same basic form as *T. pedum.* Although both desiccation cracks and synaeresis cracks are present in beds within this part of Member 1, the traces fossils are clearly distinguishable. *Treptichnus* isp. has also been reported recently from the latest Neoproterozoic of Namibia, Spain, central Australia and Nevada, suggesting that it is a precursor to the behaviour that produced *T. pedum* (Jensen *et al.* 2000). Vendotaenids and tubes of *Sabellidites cambriensis* are common in certain darker coloured beds at levels close to where treptichnid trace fossils first appear, 9 m below the GSSP at Fortune Head (Narbonne *et al.* 1987).

In addition to the new horizons for *T. pedum*, vertical tubes of *Skolithos annulatus*, an ichnotaxon included in the *T. pedum* (ichnofossil) Zone (Narbonne *et al.* 1987), and the vertical spiral trace fossil *Gyrolithes polonicus*, were recorded also, 2.5 m below the GSSP. The discovery of this new material represents the fruits of concentrated observation aided either by increased erosion of outcrop within the stratotype section or by the more favourable seasonal incidence of sunlight onto otherwise shaded outcrop.

Two specimens of *T. pedum*, that in Figure 2b, from the 17.55 m level (3.11 m below the GSSP) in Member 1, and the specimen at the GSSP (Narbonne *et al.* 1987, fig. 6E), 2.4 m above the base of Member 2, in the Chapel Island Formation at Fortune Head, being loose in the outcrop, were collected and are now in the repository of the National Type Collection of Fossil Invertebrates and Plants, Geological Survey of Canada (Ottawa), under accession numbers GSC 116870 and GSC 116871, respectively.

## 3. Discussion

It is clear that the interval close to the GSSP was a time of faunal change. Considering the stage in the evolution of megascopic organisms, terminal Proterozoic–Early Cambrian assemblage zones must necessarily be based on a more limited range of taxa than expected thereafter. None the less, a number of significant ecological events are recorded at the base of the Cambrian. There is an increase in diversity and complexity of ichnotaxa coincident with: the first identifiable ichnofabrics in siliciclastic successions (Droser, Gehling & Jensen, 1999); depletion in microbial-mat textures (Seilacher & Pflüger, 1994; Hagadorn & Bottjer, 1997, 1999); and closure of a taphonomic window for preservation of Ediacaran soft-bodied organisms in coarse siliciclastics (Gehling, 1999). A marked negative carbon isotope excursion occurs just below the first known trace fossils of the *T. pedum* Zone and above the last diverse assemblages of Ediacaran fossils, in some successions (Narbonne, Kaufman & Knoll, 1994; Brasier *et al.* 1996; Kimura *et al.* 1997; Shields, 1999; Corsetti & Hagadorn, 2000). When identified at the end of a long $\delta^{13}C$ plateau, this negative excursion may prove to be an important proxy for identifying the Proterozoic–Cambrian boundary in successions where the trace fossil record is poor. In so far as preservational windows allow us to judge, the explosion in diversity of small shelly fossils in carbonate successions (Rozanov & Zhuravlev, 1992) and mixed carbonate–siliciclastic successions (Landing *et al.* 1989; Mount & Signor, 1992), appears to have closely followed the diversification of trace fossils. The concerted use of two or more sets of independent criteria for recognizing the boundary level might allow correlation between successions where index ichnofossil evidence is absent.

Since the Fortune Head GSSP was first proposed, it has proved its utility in recognizing the base of the Cambrian in Namibia (Grotzinger *et al.* 1995; Geyer & Uchman, 1995; Narbonne, Saylor & Grotzinger, 1997), South Australia (Jensen, Gehling & Droser, 1998; Droser, Gehling & Jensen, 1999), central Australia (Walter *et al.* 1995), California and

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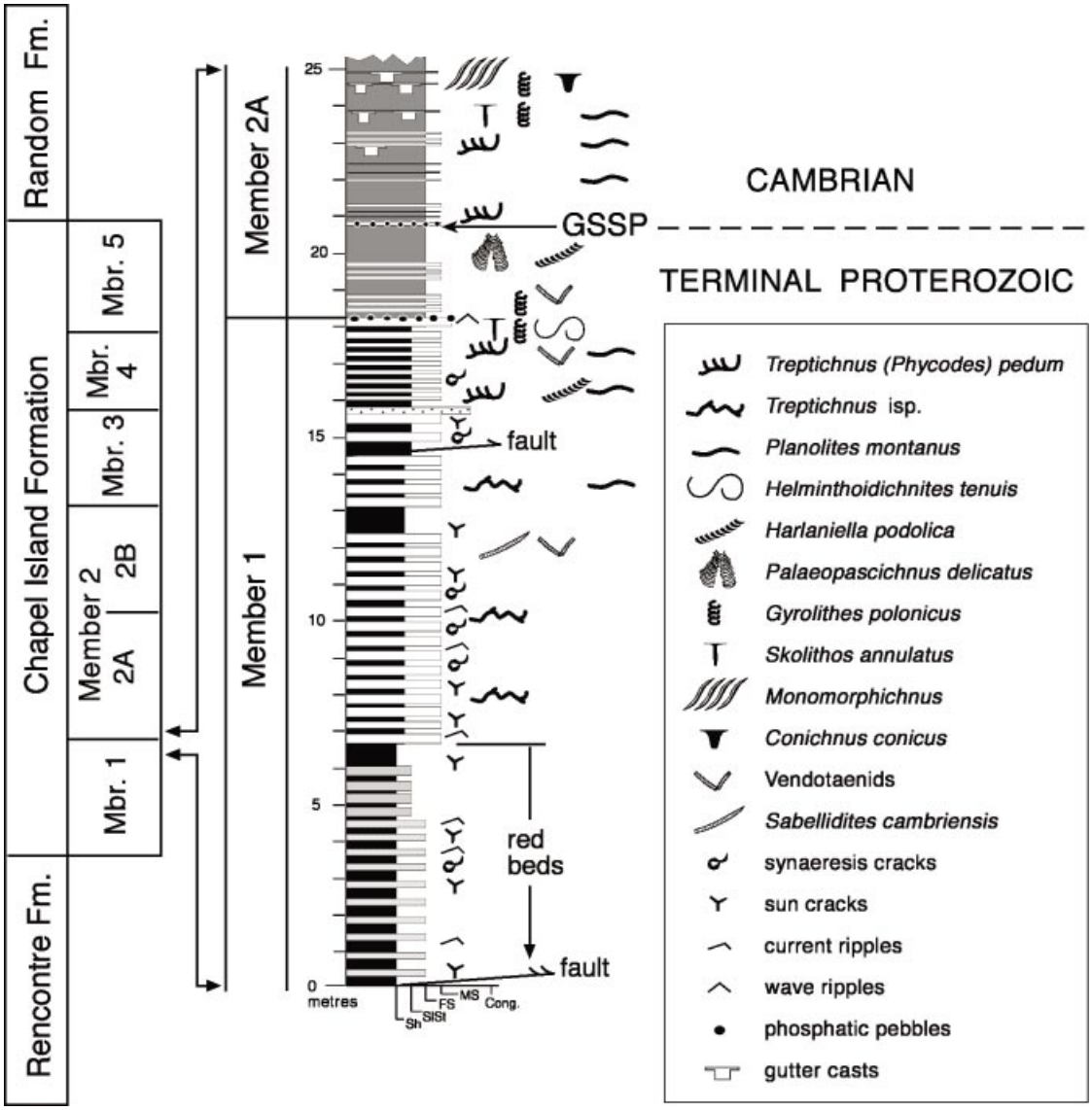



Figure 1. Stratigraphic section spanning the Proterozoic–Cambrian GSSP in the Chapel Island Formation at Fortune Head, Burin Peninsula, Newfoundland. Modified from Myrow (P. M. Myrow, unpub. Ph.D. Thesis, Memorial Univ. of Newfoundland, 1987), Narbonne *et al.* (1987, fig.5), and Myrow & Hiscott (1993, fig. 8).

Nevada (Runnegar *et al.* 1995; Runnegar, 1998; Corsetti & Hagadorn, 2000), central England (Bland & Goldring, 1995), China (Zhu, 1997), northwestern Canada (MacNaughton & Narbonne, 1999), and for bracketing terminal Proterozoic successions worldwide (Shields, 1999; Gehling *et al.* 1999). However, this is not to say that all sections show a clear sequential relationship of index fossils in strata above Ediacaran body fossils. Lindsay *et al.* (1996), and Goldring & Jensen (1996), demonstrated some of the difficulties in using *T. pedum* Zone ichnotaxa for correlating Proterozoic–Cambrian boundary-related events between basins where the successions differ in composition and sedimentary tectonics. Lindsay *et al.* (1996) argued that the order of occurrence of small shelly fossils and trace fossils near the boundary depends on the depositional regime within any particular basin as much as rates of evolution and migration. Jensen *et al.* (2000) discussed the occurrence of treptichnid-type trace fossils from latest terminal Proterozoic strata in Namibia, central Australia, Spain and Nevada. In Namibia, *Treptichnus* isp. is found in the lower Huns Member of the Urusis Formation in the Schwarzrand Subgroup (Nama Group) (Jensen *et al.* 2000). The youngest Ediacaran body fossils occur some 450 m stratigraphically above, in the Spitskop Member, near the top of the Urusis Formation (Grotzinger *et al.* 1995; Narbonne, Saylor & Grotzinger, 1997). The oldest known specimens of *T. pedum* in Namibia are in a suite of trace fossils in the lower Nomtsas Formation, separated from the Urusis Formation by a major disconformity (Grotzinger *et al.* 1995).

Of the relatively common specimens of *Treptichnus* isp., on certain horizons in the uppermost part of Member 1 (Fig. 1, 7–15 m), some are regarded as *Treptichnus* aff. *T. pedum* (Fig. 2f). The exact level at which treptichnids in general begin cannot be determined in the underlying part of the section due to faulting (Fig. 1, 14–15 m; approx. 6.5 m below the GSSP) and the presence of unfossiliferous red beds (Facies Association 1 of Myrow, Narbonne & Hiscott (1988)), 14 m below the GSSP (Fig. 1, 0–6.5 m). Considering that there is a different facies below this faulted part of the section in the top of Member 1, it cannot be excluded that

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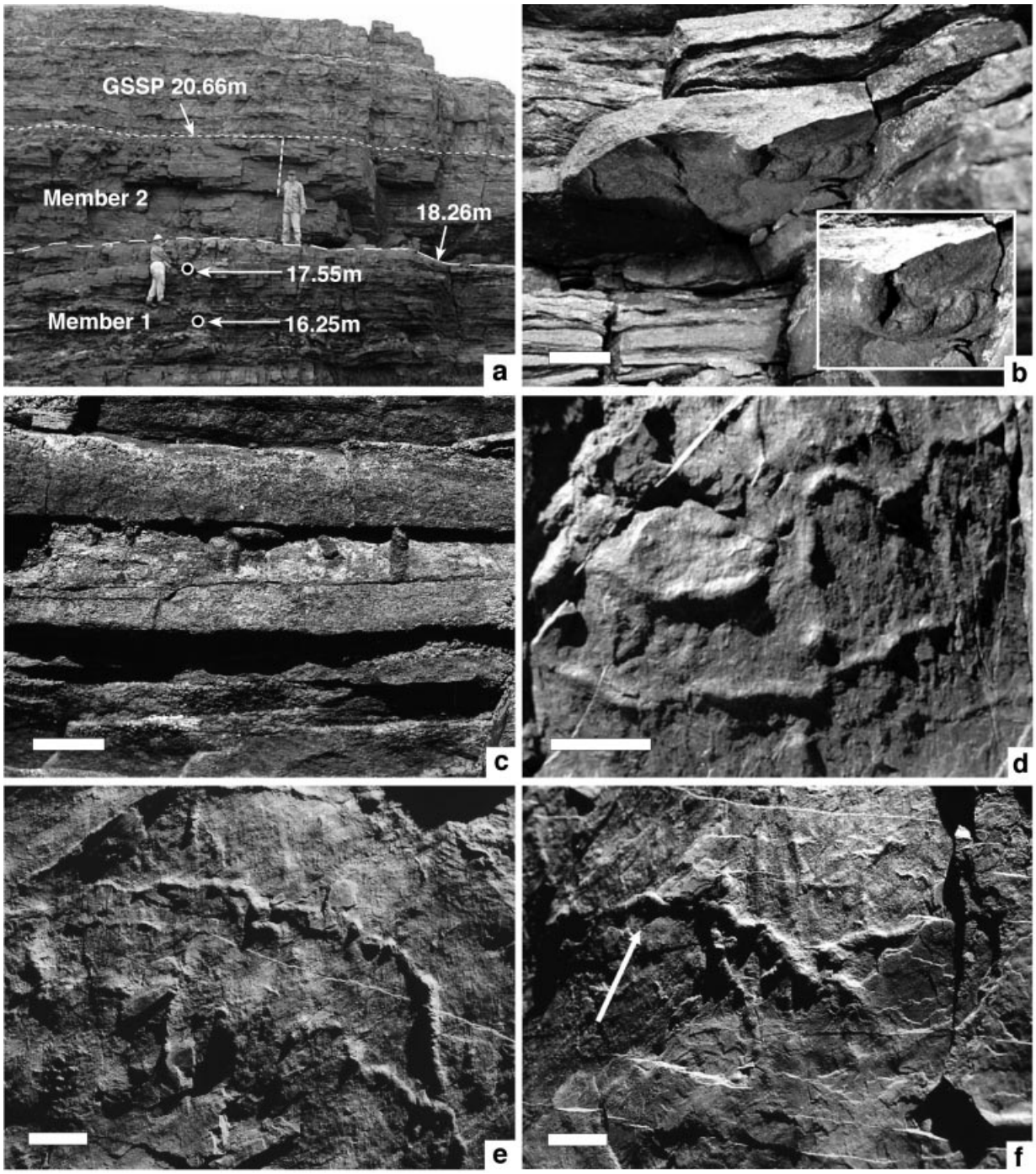



Figure 2. (a) Proterozoic–Cambrian GSSP at Fortune Head, Burin Peninsula, Newfoundland, 2.4 m above Member 1 – Member 2 boundary in the Chapel Island Formation. Newly discovered specimens of *Treptichnus pedum*, at 17.55 m and 16.25 m, respectively (see Fig. 1), 3.11 m and 4.41 m below the GSSP; rod scale, 1.5 m. (b) Specimen of *T. pedum* (GSC 116870) at 17.55 m level; insert of same specimen with different lighting. (c) *Skolithos annulatus* (right) and *Gyrolithes polonicus* (left) at 18.15 m, 2.51 m below the GSSP. (d, e) *Treptichnus* isp. burrows in positive hyporelief between 11 m and 13 m below the GSSP, within Member 1. (f) *Treptichnus* aff. *T. pedum*; arrow at site of branching. (b–f) bar scale 10 mm.

*T. pedum* ranged more than the 4.41 m below the GSSP, recorded here. On the other hand, if the influence of different facies is minor and if future research will confirm the status of the trace fossils as *Treptichnus*, but not *T. pedum*, the Proterozoic–Cambrian boundary GSSP provides further support for a late Neoproterozoic ichnofossil zone characterized by *Treptichnus* isp. and a lower diversity of trace fossils (cf. Jensen *et al.* 2000).

*Harlaniella podolica* and *Palaeopascichnus delicatus* make their last confirmed appearance in the section immediately below the GSSP. As described above, *Gyrolithes* and *Skolithos*, previously considered to first appear in the *T. pedum* Zone, like *T. pedum*, also range below the GSSP at Fortune Head. Ichnotaxa with ranges that begin within the first 3 m of section above the GSSP include *Arenicolites*, *Cochlichnus, Monomorphichnus* and *Didymaulichnus*, *Conichnus,* and

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*Helminthopsis* (Narbonne *et al.* 1987; Landing & Westrop, 1997). Of these, *Cochlichnus, Didymaulichnus,* and *Helminthopsis* range into the Proterozoic in sections elsewhere. *Arenicolites, Monomorphichnus and Conichnus* have not been convincingly described from Proterozoic strata. However, care is required with identification of these taxa in order to distinguish them from other taxa and from inorganic sedimentary features. In practice, it would be as well if all descriptions of Proterozoic trace fossils were confined to cases where the ichnotaxon was based on a number of specimens of consistent geometric form. Isolated or fragmentary specimens tendered as Proterozoic ichnotaxa should be subject to careful scrutiny in view of their potential significance for animal evolution.

Until now, there were no recorded cases where the ranges of *T. pedum* and *Harlaniella podolica* overlapped. Subsequent to the field study of Narbonne *et al.* (1987), a method for determining confidence intervals on stratigraphic ranges was proposed by Strauss & Saddler (1989), with modifications by Marshall (1990). Given the sparse number of fossil-bearing horizons recorded for each of these ichnotaxa, this statistical analysis of stratigraphic ranges of the ichnotaxa involved might have predicted the overlap that we now document at Fortune Head. In the future, determination of confidence intervals, requiring detailed field documentation of the number of horizons as well as the maximum recorded ranges of taxa used as zone fossils, might be advisable or even mandatory for any GSSP. Although the GSSP at Fortune Head does not coincide with the first known occurrence of *T. pedum*, it does mark a point above the last appearance of *H. podolica* and below the inception of a marked diversification of ichnotaxa and, by implication, new strategies in animal behaviour. This still allows correlation with Proterozoic–Cambrian successions bearing assemblages of trace fossils such as those in northwestern Canada, western USA, Mongolia, southern Namibia, Poland, south and central Australia.

In summary, the new finds of *T. pedum* below the GSSP show the characteristics currently attributed to this taxon (Seilacher, 1955; Geyer & Uchman, 1995; Jensen, 1997). However, the relationships of *T. pedum* to similar morphological forms should be assessed for stratigraphic purposes. A re-evaluation of stratigraphic ranges and taxonomic assignment of ichnotaxa in the Fortune Head section is warranted.

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