

# A complex trace fossil from the Spitskop Member (terminal Ediacaran–? Lower Cambrian) of southern Namibia

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**Abstract** – *Streptichnus narbonnei* igen. et isp. nov., a new trace fossil from the upper part of the Spitskop Member of the Urusis Formation, southern Namibia, consists of clusters of unidirectionally curved radial elements, in which individual elements typically are composed of imbricated sickle-shaped segments somewhat comparable to those of *Treptichnus pedum*. Such complex trace fossils generally are found only in Cambrian or younger strata. This opens to question the position of the Ediacaran–Cambrian boundary in the Nama Group, suggesting that it may locally be within the uppermost part of the Urusis Formation, rather than at the base of the Nomtsas Formation.

Keywords: Ediacaran, Cambrian, Namibia, trace fossils.

## 1. Introduction

The global stratotype section and point (GSSP) for the base of the Cambrian system is located in the lower part of the Chapel Island Formation in a section on Fortune Head, Burin Peninsula, Newfoundland, and defined by the trace fossil *Treptichnus pedum* (Narbonne *et al.* 1987; Brasier, Cowie & Taylor, 1994). First described as *Phycodes pedum* (Seilacher, 1955), this ichnospecies has also been assigned to *Trichophycus* (Geyer & Uchman, 1995) or *Treptichnus* (Jensen, 1997). The principles by which trace fossils can be applied to Ediacaran–Cambrian boundary biostratigraphy were first concisely formulated by Seilacher (1956). Seilacher (1956) observed that Cambrian rocks in the Grand Canyon area of the western USA contained a wealth of diverse trace fossils, whereas the Proterozoic rocks there were barren except for a few simple forms. That the latter are now known not to be trace fossils but plant fossils or of inorganic origin does not matter; this remains a topical problem today. In the absence of obvious facies control, this suggested that the contrasting trace fossil records reflected the evolution of large benthic animals. Seilacher (1956) recognized that this dramatic shift makes trace fossils useful in recognizing the base of the Phanerozoic, particularly in areas dominated by siliciclastic sediments. The generality of this pattern was further substantiated by a great number of studies in sections worldwide (e.g. Alpert, 1977; Fedonkin, 1977; Paczeńska, 1986; Walter, Elphinstone & Heys, 1989). Then, some thirty years after Seilacher's paper, Crimes (1987) published a comprehensive overview and synthesis and recognized three latest Proterozoic–earliest Cambrian trace fossil

zones. At about the same time, Narbonne *et al.* (1987) erected the *Harlaniella podolica*, *Phycodes pedum* and *Rusophycus avalonensis* zones, in sections in Newfoundland, corresponding to each of the three zones of Crimes (1987). In addition to the eponymous taxa, the *Treptichnus pedum* Zone includes *Bergaueria*, *Conichnus*, *Gyrolithes* and *Monomorphichnus*, which appear a few metres up-section in the stratotype area (Narbonne *et al.* 1987; Narbonne & Myrow, 1988). The top of the *T. pedum* Zone is defined by the appearance of the bilobed arthropod-type trace fossil *Rusophycus*. A major defining feature of the *Treptichnus pedum* zone is that it includes the first branching burrow systems. Further studies on the stratotype section have extended the range of several of these taxa, including finds of *T. pedum* several metres down-section from the GSSP-defining occurrence of *T. pedum* (Gehling *et al.* 2001). The extended ranges do not challenge the general applicability of trace fossil-based correlation at this time in Earth history (e.g. Crimes, 1987; MacNaughton & Narbonne, 1999). However, together with finds of *Treptichnus*-type trace fossils in supposed terminal Ediacaran strata (Jensen *et al.* 2000), they suggest that some refinements may be needed to the definition of the base of the *T. pedum* Zone and its precise relation to the GSSP (cf. Gehling *et al.* 2001; Jensen, 2003). In this paper we address aspects of this topic by describing a new complex trace fossil from the upper part of the Urusis Formation, close to the Ediacaran–Cambrian boundary in the Nama Group, southern Namibia.

## 2. The Ediacaran–Cambrian boundary interval in the Nama Group

Siliciclastic and carbonate sedimentary rocks of the Nama Group, southern Namibia, were deposited in a

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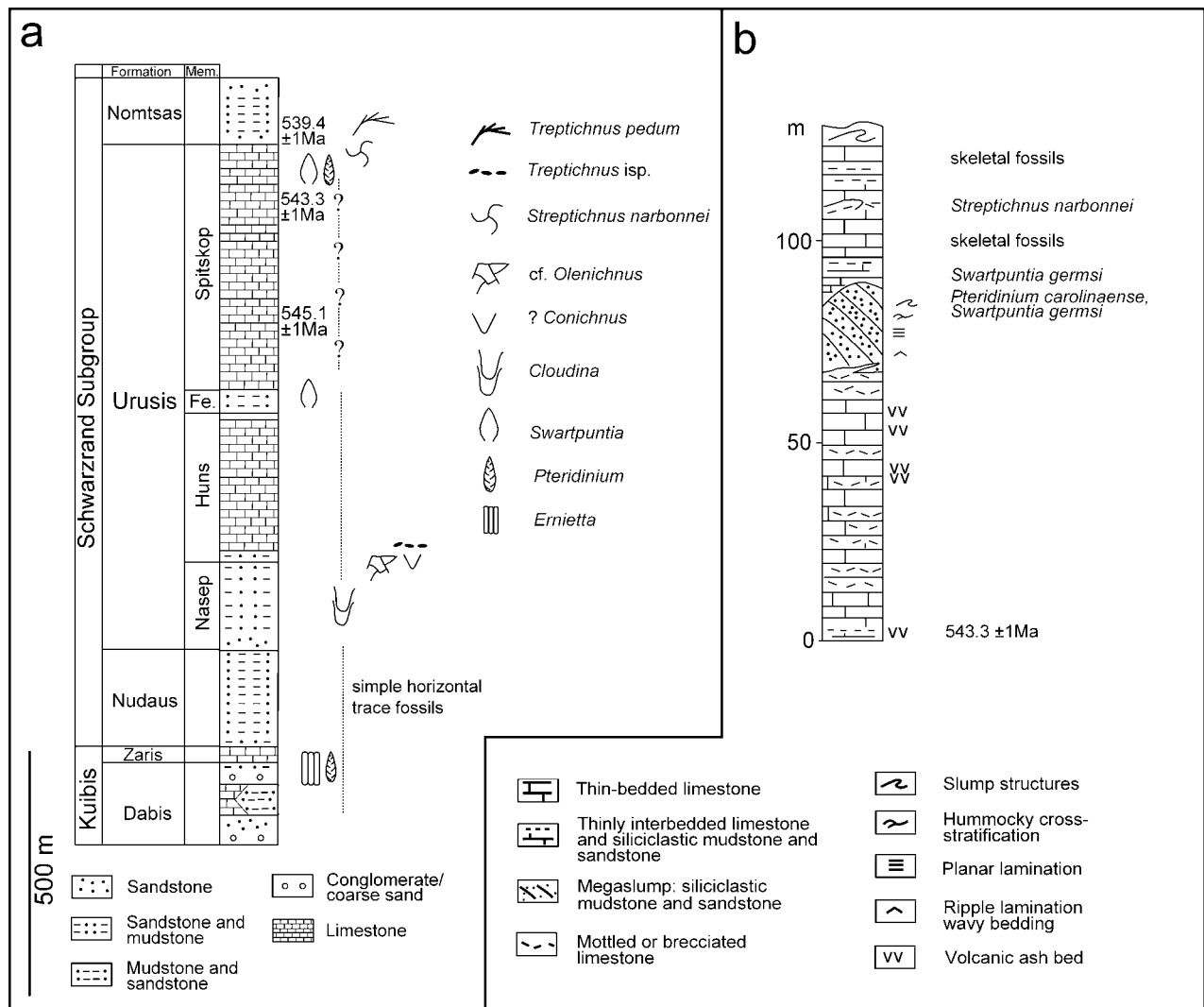


Figure 1. Stratigraphic setting of *Streptichnus* in the Nama Group, southern Namibia. (a) Generalized column for the stratigraphy of the Nama Group in the Witputs basin (simplified from Germs, 1983), showing the distribution of selected trace fossils and body fossils. Fe. – Feldschuhorn. (b) Stratigraphic log of the uppermost part of the Spitskop Member on Swartpunt farm. Modified from Narbonne, Saylor & Grotzinger (1997, fig. 3). Occurrence of unidentified skeletal fossils according to B. Z. Saylor (pers. comm. 2003).

foreland basin resulting from the Neoproterozoic assembly of Gondwanaland (e.g. Germs, 1995; Gresse & Germs, 1993; Saylor *et al.* 1998). Two sub-basins have been recognized, the Zaris sub-basin to the north, and the Witputs sub-basin to the south, divided by a central high, the Osis arch. Current consensus positions the Ediacaran–Cambrian boundary near the top of the Schwarzrand Subgroup, between the Urusic and Nomtsas formations (Fig. 1). The Nomtsas Formation locally fills palaeovalleys cut at least 30 metres deep into sediments of the Urusic Formation, suggesting a pronounced unconformity (Germs, 1983; Saylor, Grotzinger & Germs, 1995; Saylor & Grotzinger, 1996). Runnegar *et al.* (1995) suggested that it represents a global eustatic signal that can be recognized also at the base of the Sauk sequence in western North America. The Nomtsas Formation contains *Treptichnus pedum* (reported as *Phycodes pedum* or *Trichophycus pedum*) (Crimes & Germs, 1982; Geyer & Uchman,

1995; Grotzinger *et al.* 1995). Zircons recovered from close to the base of the Nomtsas Formation yielded a U–Pb age of  $539.4 \pm 1$  Ma (Grotzinger *et al.* 1995). Ediacara-type fossils, *Pteridinium carolinaense* and *Swartpuntia germsi*, occur close the top of the Urusic Formation, about 90 metres above a volcanic ash-bed with a U–Pb zircon age of  $543.3 \pm 1$  Ma (Grotzinger *et al.* 1995; Narbonne, Saylor & Grotzinger, 1997). The small shelly fossil *Cloudina*, generally regarded as restricted to the Ediacaran (Grant, 1990), is thought to range close to the top of the Urusic Formation (Germs, 1983; Grotzinger *et al.* 1995).

Recently,  $\delta^{13}\text{C}$  chemostratigraphy has become an important method of characterizing Neoproterozoic sections. In particular, a pronounced negative  $\delta^{13}\text{C}$  excursion has been ubiquitously recognized in carbonate-dominated sections close to the Ediacaran–Cambrian boundary (e.g. Narbonne, Kaufman & Knoll, 1994; Shields, 1999). Coincidence with ash layers in

Oman made it possible to date this excursion at  $542.0 \pm 0.3$  Ma (Amthor *et al.* 2003), which compares well to the currently favoured age of about 543 Ma for the base of the Cambrian as based on correlation of the GSSP with sections in Siberia and Namibia (see Grotzinger *et al.* 1995). Carbon isotope values for much of the Nama Group are about +2, and no pronounced negative excursion in  $\delta^{13}\text{C}$  has been recorded (Kaufman *et al.* 1991; Grotzinger *et al.* 1995). This has led to the suggestion that this interval of time is contained in the unconformity at the base of the Nomtsas Formation.

### 3. Description of new trace fossil

Ichnogenus *Streptichnus* *igen. nov.*

*Type and only ichnospecies.* *Streptichnus narbonnei* *isp. nov.*

*Diagnosis.* Complex trace fossil composed of clusters of more or less horizontal unidirectionally curved elements that radiate from a narrow central area. Individual radial elements are broadly cylindrical but typically consist of superimposed curved to sickle-shaped segments, which closely follow the axis of the radial elements.

*Etymology.* From the Greek *streptos*, meaning twisted.

*Streptichnus narbonnei* *isp. nov.*

Figures 2, 3

1995 Spiral burrow; Grotzinger *et al.*, fig. 2d.

*Diagnosis.* As for ichnogenus.

*Etymology.* In recognition of the contributions of Dr Guy M. Narbonne to Ediacaran–Lower Cambrian ichnology and stratigraphy.

*Material and stratigraphic setting.* Two adjoining slabs with three prominent specimens numbered F624–6, of which F626 is designated holotype, and additional fragmentary specimens. The trace fossils were recovered from the upper part of the Spitskop Member (Fig. 1b) of the Urusis Formation at farm Swartpunt, southern Namibia (close to ‘fossil locality’ of Narbonne, Saylor & Grotzinger, 1997, fig. 1), at about 795 metres in medium-scale sequence 18 of Saylor (2003, fig. 4). Here, thin-bedded sandstones are bracketed by thin-bedded limestone, representing deposition on the mid-shelf (see Saylor, 2003).

The trace fossils are preserved in positive relief on the base of a sandstone bed. The bed is about 4 cm thick; the basal two centimetres of this bed has planar lamination and towards the top has low-angle swaley lamination. The sole of the bed has generally aligned fine, needle-like, tool-marks. A further specimen (F627) is preserved on the base of a thin quartzite bed recovered in local float, suggesting a comparable stratigraphic

level. The material is housed with the Namibian Geological Survey, Windhoek.

*Description.* Clusters of curved, rarely straight, up to 8 cm long, 2–3 mm wide, largely horizontal elements that radiate from a narrow central area (Fig. 2a, b, c). The curvature of the radial elements along the bed sole is consistently dextral as viewed in hypichnial preservation. In three of the clusters the radial elements are concentrated in two opposing sectors. A precise count of the number of radial elements in each cluster is problematic; one specimen has at least 13 (Figs 2a, 4), but fragmentary clusters suggest a higher number in others. Sectioned material shows a vertical burrow at the centre of the clusters that extends into the sandstone bed for at least 9 mm; it has not been possible to establish if the burrows penetrate the full thickness of the beds.

Individual radial elements have a roughly circular cross-section, often with weak transverse corrugations. The radial elements rarely are simple cylinders but typically have a plaited appearance due to variously developed transverse elements. This includes superimposed elongate, gently curved, segments in which each more distal segment originates from below (in hypichnial view) the preceding one (Fig. 3b). Other parts of the radial elements have the appearance of a tightly coiled spiral (Fig. 3d), in places with an asymmetric zigzag shape (Fig. 3c). Still others have an intermediate appearance between these two types, consisting of short, asymmetric, sickle-shaped segments that appear to coil around a central burrow or with the appearance of a spiral pierced through the centre by a cylinder (Fig. 3a, b). In these, the proximal portions of the transverse elements are invariably positioned on the convex side of the burrow axis, then crossing to the concave side of the latter, where the transverse segment may form a slight protrusion (Fig. 3a, b). No consistent pattern of distribution of these different morphologies has been detected. None of the transverse elements extend significantly (< 1 mm) off the main axes of the radial elements. The direction of the spiral coil is dextral as viewed from the centre of the clusters, regardless of the type of plaited morphology.

*Discussion.* *Streptichnus narbonnei* was formed by an animal extending down through a sandy layer and performing radial excursions close to the sand–mud interface. The majority of the individual radial elements appear to have been pressed onto the base of the sandstone bed as seen by a slight depression of the sandstone sole along the contact with a radial element. This suggests that significant portions of the trace fossil were constructed within the muddy sediment and were subsequently pressed onto the sandstone during compaction. Any effect this may have had on trace fossil morphology is unclear, but some transverse segments may originally have had a more vertical

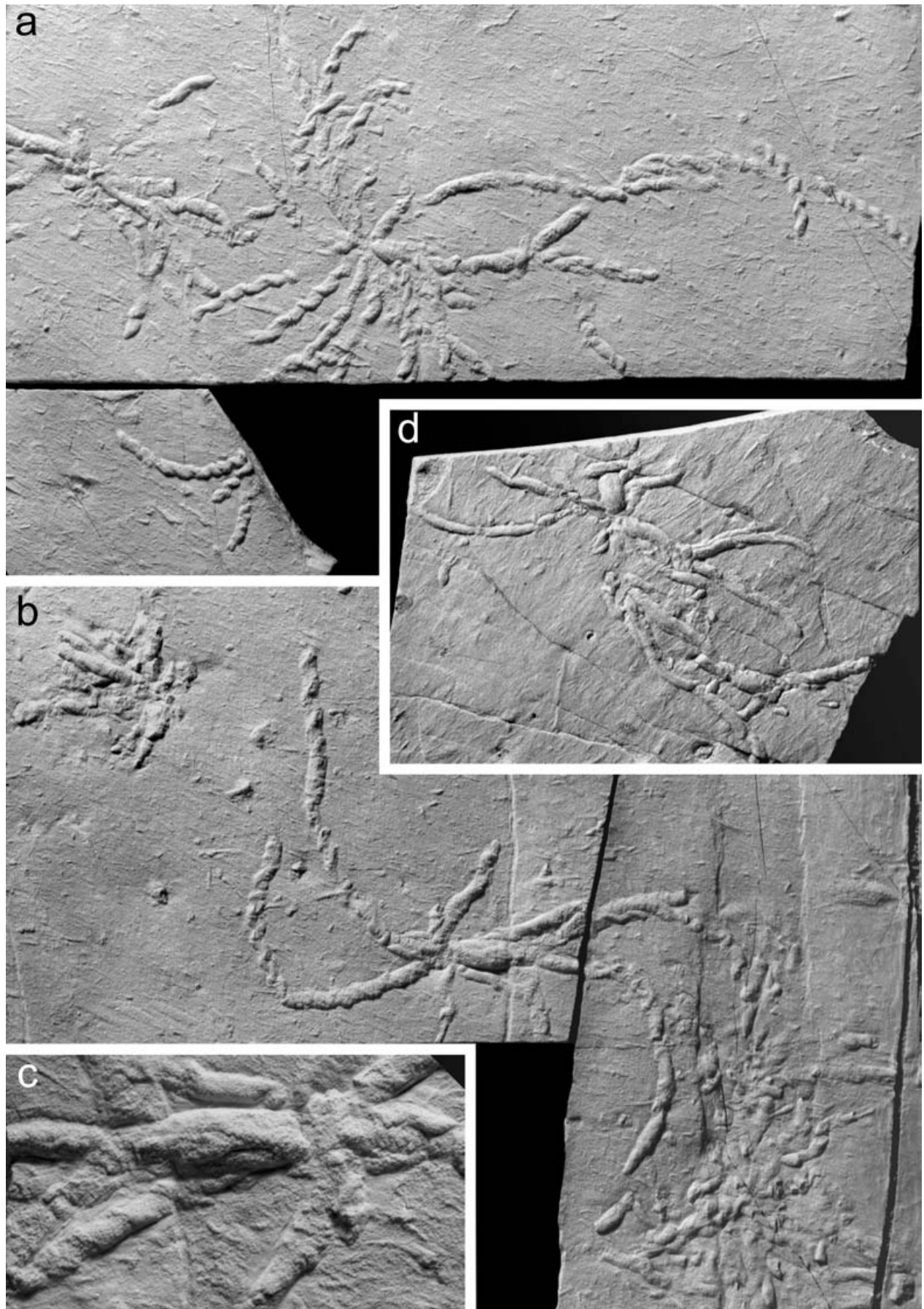


Figure 2. For legend see facing page.

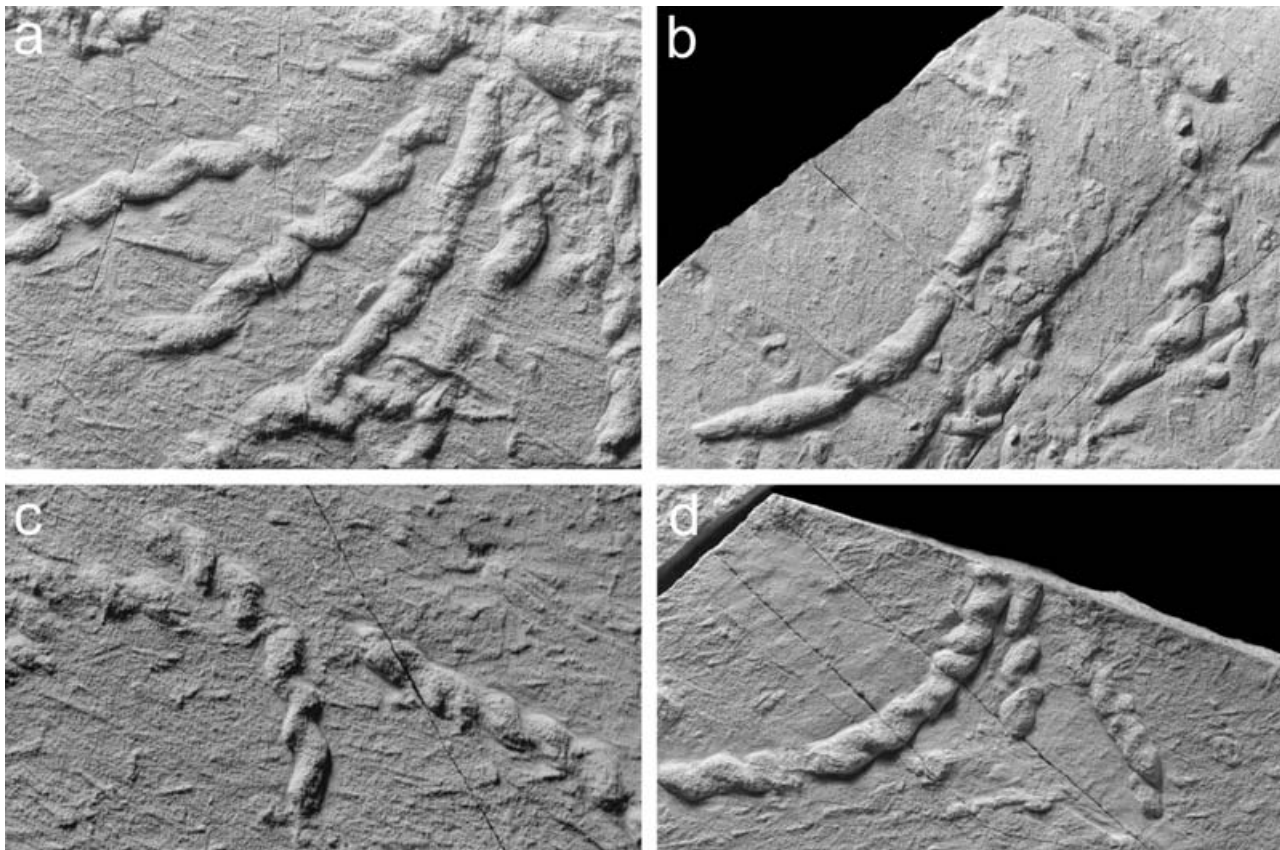


Figure 3. Close-ups of selected portions of the trace fossil in Figure 2. See Figure 4 for location of close-ups with respect to Figure 2. (a) Radial element with sickle-shaped transverse elements,  $\times 1.8$ . (b) The radial elements on the left half shows imbricate elongate gently curved probes. Radial element on right half shows sickle-shaped elements, above which are truncated nearly circular cross-sections of inclined probes,  $\times 1.3$ . (c) Radial element composed of transverse segments that renders a great similarity to a spiral coil,  $\times 1.8$ . (d) A further example of a radial element that resembles a spiral coil,  $\times 1.8$ .

orientation and become flattened during compaction (Fig. 3a).

Many of the radial elements, including the specimen figured by Grotzinger *et al.* (1995, fig. 2d), are strongly suggestive of horizontal spirally coiled trace fossils such as *Helicorhaphe* and *Helicolithus* (see e.g. Książkiewicz, 1977; Uchman, 1998). However, because there are intermediates between sections that clearly consist of imbricate elements and those that appear to consist of a continuous spiral coil, the latter likely are the result of closely spaced probes. The difference between essentially straight and zigzag-shaped portions of the trace fossil apparently resulted from the angle at which transverse segments are joined. It should be noted that this trace fossil is not unique in having a morphology that suggests both a continuous horizontal spiral as well as shorter probes. Uchman, Bromley & Leszczyński (1998) described

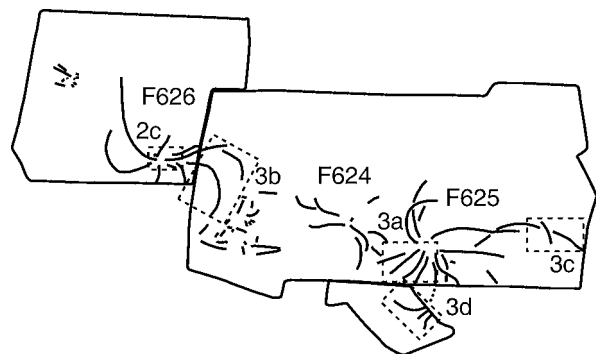


Figure 4. Sketch of *Streptichnus narbonnei*-bearing slabs showing the arrangement of clustered curved radial elements. Boxes show the location of close-ups in Figure 3.

*Treptichnus meandrinus* from the Eocene of Poland, which shows considerable similarity to *Helicolithus*. Indeed, Seilacher (1977) reconstructed *Helicolithus*

Figure 2. *Streptichnus narbonnei* igen. et isp. nov., from the Spitskop Member, southern Namibia. (a) Specimens F624 and F625 showing clusters of unidirectionally curved radial elements and the plaited, spiral appearance, of each individual element,  $\times 0.8$ . (b) Specimen F626, holotype of *Streptichnus narbonnei*, showing the spiral curvature of the radial elements and their spiral-like segmentation. A fragmentarily preserved specimen is in the upper left corner,  $\times 1.2$ . (c) Close-up of the central portion of specimen F626. Notice that the radial elements converge towards a narrow central area,  $\times 2.0$ . (d) Specimen F627, a cluster with few radial elements and with little development of segmentation,  $\times 0.8$ .

as having a spiral structure with multiple vertical shafts, suggesting that the development of spirals and vertical probes is not mutually exclusive. Because of the transitions from clearly imbricate elements, we assume that no horizontal helicoidal spiral was present in *Streptichnus*, though this possibility cannot be completely ruled out.

It has not been possible to observe directly the exact arrangement of the probes, and attempts to clarify the morphology further by serial sectioning on portions of the material did not provide useful results; however, inferences are possible based on the preserved morphology. The upper parts of the probes appear to have had a vertical or inclined orientation (e.g. Fig. 3b) and the proximal portions possibly joined to form what effectively became an axial cylinder (Fig. 3a). It is not possible to decide if distal portions of the transverse elements ended blindly or if they extended to the sediment–water interface. There is in any case no evidence for the latter, and the lack of any significantly laterally diverging probes also suggest that they were relatively short.

The Namibian trace shows certain general similarities to *Treptichnus pedum*. In Seilacher's (1955) model, sickle-shaped probes go down, around and up from what is effectively a main horizontal shaft. The distal portion of each probe probably reached the sediment–water interface (Seilacher, 1955; Geyer & Uchman, 1995; Jensen, 1997). *Streptichnus* differs from *Treptichnus pedum* in that the distal portions of the probes in the latter typically protrude from the convex side of the axial cylinder, whereas in *Streptichnus* the probes emerge on the concave side of the radial elements. In *Treptichnus pedum*, the probes may extend laterally for a considerable distance from the axis of the axial cylinder but closely follow it in *Streptichnus*. There is also no direct evidence that the distal portions of the probes in *Streptichnus* connected to the sediment–water interface. Another, and more basic, difference is that the Namibian material consists of radially arranged clusters in which the radial elements are curved in a uniform direction. Because of these differences we erect the new ichnogenus *Streptichnus*, rather than to assign the material to a new ichnospecies of *Treptichnus*. It should be noted that the differing opinions on the generic assignment of *Phycodes pedum* are relatively moot compared to the need to evaluate the different forms currently assigned to this ichnospecies (cf. Geyer & Uchman, 1995; Jensen, 1997).

#### 4. Trace fossils and the Ediacaran–Cambrian boundary in the Nama Group

Several ichnotaxa that are generally thought to be restricted to the Phanerozoic have been reported from the Ediacaran of the Nama Group (Germs, 1972; Crimes & Germs, 1982). Before discussing the stratigraphic

implications of *Streptichnus*, we will attempt an overview of the Nama Group trace fossil record in the course of which we present some additional new data.

##### 4.a. Trace fossils of the Ediacaran part of the Nama Group

Trace fossils are exceptionally rare in the Kuibis Subgroup and possibly restricted to rare, simple horizontal forms. Crimes & Fedonkin (1996) reinterpreted the *Skolithos* of Germs (1972) as more likely body fossils, and we concur that these are not trace fossils. *Bucholzbrunnichnus kroeneri*, originally described as a *Scolicia*-like trace fossil (Germs, 1973), more likely is a body fossil (J. G. B. Germs, pers. comm. 2004). The attribution to *Bergaueria* of minute pustulose structures from the Kuibis Subgroup (Crimes & Germs, 1982) is questionable. The lower part of the Schwarzrand Subgroup largely consists of fine shale and sandstone of the Nudaus Formation, yielding rare *Pteridinium* and *Rangaea*. Crimes & Germs (1982) reported the vertical spreite-burrow *Diplocraterion* from the Nudaus Formation in the northern sub-basin. This is of particular interest, as spreite-burrows are generally considered first to appear in the Early Cambrian. The Nudaus *Diplocraterion* consists of simple slits on the surface of beds. While this type of preservation is known in *Diplocraterion*, Grant's (1990) suggestion that these are more simple trace fossils seems equally probable in the absence of any documentation of the spreite. Also questionable is the identification as *Nereites* of paired epichnial ridges from the Nudaus Formation (Crimes & Germs, 1982). These can more likely be compared to a simple near-surface trace such as *Archaeonassa* (see Jensen, 2003), and the same may be true for the ?*Chondrites* of Crimes & Germs (1982), also reported from the Nudaus Formation. The Urusis Formation consists of two siliciclastic-dominated members (Nasep and Feldschuhorn) and two carbonate-dominated members (Huns and Spitskop). The Feldschuhorn and Spitskop members yield the Ediacara-type fossil *Swartpuntia germsi* (Narbonne, Saylor & Grotzinger, 1997). The lower part of the Huns Formation (*sensu* Saylor, Grotzinger & Germs, 1995), contains the first more diverse assemblage of trace fossils. Notable is the presence of forms that are discontinuous on bedding planes, and which may show a weakly developed three-lobed lower surface. The overall development of these burrows is of branching burrow systems and suggests assignment to *Treptichnus* isp. (Jensen *et al.* 2000). Geyer & Uchman (1995) reported on the occurrence of possible *Treptichnus pedum* (as cf. *Trichophycus pedum*) in the Urusis Formation, though this material was not figured. Other trace fossils that we observed low in the Huns Member at Arimas farm include *Cochlichnus*, *Helminthopsis* and simple conical forms suggestive of *Conichnus* (Fig. 5b). *Conichnus*, generally interpreted as a cnidarian resting

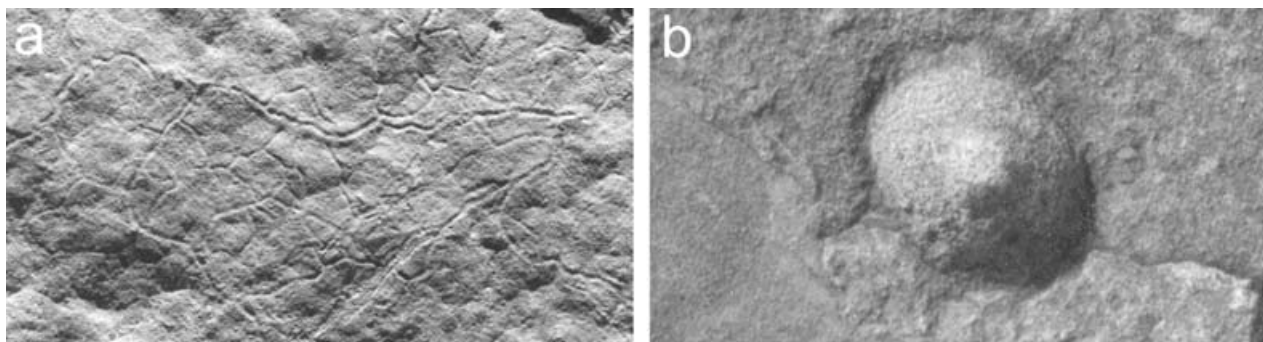


Figure 5. Trace fossils from the terminal Ediacaran of southern Namibia. (a) Field photograph of network-forming trace fossil, cf. *Olenichnus* isp., from lower part of Huns Member at Hoolog farm,  $\times 0.5$ . (b) Conical trace fossil, cf. *Conichnus* isp., on the base of sandstone bed, Huns Member at Arimas farm,  $\times 2$ .

structure, is one of the trace fossils that define the *Treptichnus pedum* Zone of Newfoundland (Narbonne *et al.* 1987). Because of the simple morphology we are doubtful about its diagnostic value. Structures similar to the ones figured here can form by sediment filling the flared (primarily or secondarily) upper portions of vertical tubes (see Jensen, 1997). Beds probably attributable to the Huns Member at Hoolog farm contain irregular networks on bedding planes (Fig. 5a). These are comparable to *Olenichnus irregularis* described from the Lower Cambrian Kessyusa Formation in the Olenek area, Siberia (Fedonkin, 1985). The presence of right-angle junctions makes it possible that these represent simple tunnel-networks (cf. Jensen, 1997), but the possibility that the Namibian material represents spatial coincidence of unbranched trace fossils cannot be excluded. Geyer & Uchman (1995) reported *Skolithos* isp. from the Nasep Member of the Urusis Formation. These, however, consist of short projections at the base of sandstone beds, and therefore might well represent partial preservation of *Planolites* or other moderately simple trace fossils. From the Nasep Member, Geyer & Uchman (1995) also reported *Torrowangea rosei*, a form widely reported from Ediacaran and lowermost Cambrian strata. There have been reports of undocumented *Monomorphichnus* from the Schwarzrand subgroup, but these have to be treated with caution, particularly considering the similarity of this trace fossil to toolmarks, which in the Nama Group include demonstrable examples where Ediacara-type organisms acted as tools (Runnegar, 1996).

#### 4.b. Discussion

Geyer & Uchman (1995) suggested that, based on the published record of Nama Group trace fossils, the Precambrian–Cambrian boundary be placed in the middle of Schwarzrand Subgroup, rather than at the base of the Nomtsas Formation. The above overview shows that most of the reported Phanerozoic-type trace fossils in the sub-Nomtsas Formation Schwarzrand

Subgroup are unconvincing, or need to be corroborated. The cf. *Olenichnus* and ?*Conichnus* reported here also do not present serious evidence for a Cambrian age. *Treptichnus* isp. low in the Urusis Formation shows the presence of branching trace fossils but these cannot be confirmed as *Treptichnus pedum*. Much of the siliciclastic sediments of the Nama Group were deposited in a high-energy fluvial to marginal marine environment (e.g. Germs, 1983), which likely presented unfavourable conditions for the preservation of trace fossils. There are, however, enough intervals with trace fossils in the Nama Group that facies constraints alone are not an obvious controlling factor. The simple branching trace fossils and possible networks may reflect a latest Ediacaran increase in trace fossil diversity (Jensen *et al.* 2000; Jensen, 2003).

We have argued above that the trace fossils described here should be assigned to a new ichnospecies and ichnogenus, but they are arguably not of lesser complexity than many specimens of *Treptichnus pedum* (e.g. MacNaughton & Narbonne, 1999, fig. 8). The basal Cambrian ichnozones of Crimes (1987) and Narbonne *et al.* (1987) are partly defined by the appearance of complex infaunal burrows. Comparable complexity of burrowing rather than precise ichnotaxonomic parity would thus be of importance. By this reasoning, *Streptichnus narbonnei* would suggest a Cambrian age for the upper part of the Spitskop Member. *Streptichnus narbonnei* occurs a few metres above limestones containing tubular fossils (B. Z. Saylor, pers. comm.), and about 20 to 30 metres above the occurrence of the Ediacara-type fossils *Swartpuntia germsi* and *Pteridinium carolinaense* (Narbonne, Saylor & Grotzinger, 1997). Unidentified tubular fossils also occur in a limestone a few metres above the trace fossil (Fig. 1b). *Cloudina* has been reported from the Spitskop Member (Germs, 1983), but the precise stratigraphic level or location has not been published. *Cloudina* and *Pteridinium carolinaense* are not known to range into the Cambrian (Grant, 1990; Grotzinger, Watters & Knoll, 2000), whereas *Swartpuntia* has been reported from the Lower

Cambrian of the Great Basin area, western USA (Hagadorn & Waggoner, 2000; Hagadorn, Fedo & Waggoner, 2000). The study of the skeletal fossils immediately above and below the *Streptichnus*-bearing level will be crucial in the effort to constrain further the biostratigraphy of the top of the Spitskop Member and for the further discussion on the definition and precision of Ediacaran–Cambrian trace fossil based correlation and zones.

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