Palaeophycus bolbitermilus isp. nov. from the Lower Silurian Upsalquitch Formation of New Brunswick, eastern Canada

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Palaeophycus bolbitermilus, a new ichnospecies of *Palaeophycus* Hall, is described from turbiditic strata of the Lower Silurian Upsalquitch Formation of northern New Brunswick, eastern Canada. The ichnospecies is unbranched, thinly lined, smooth and unsculptured, and in contrast to previously defined ichnospecies of *Palaeophycus* is characterized by a consistently developed bulb-like termination at one extremity.

Le *Palaeophycus bolbitermilus*, une nouvelle ichnoespèce de *Palaeophycus* Hall, a été relevé dans des strates turbiditiques de la Formation du Silurien inférieur d'Upsalquitch dans le Nord du Nouveau-Brunswick, dans l'Est du Canada. Cette ichnoespèce est non ramifiée, elle est marquée de lignes fines, elle est unie et sans relief, et, par opposition aux ichnoespèces précédemment définies de *Palaeophycus*, elle se caractérise par une terminaison piriforme uniformément développée à une extrémité.

Traduit par la rédaction

INTRODUCTION

The ichnogenus *Palaeophycus* was first defined by Hall (1847, p. 7) as "Stem terete, simple or branched, cylindric or subcylindric; surface nearly smooth, without transverse ridges, apparently hollow". It was originally considered by Hall (1847) as the stem of a "fucoid" but later interpreted as a trace fossil (e.g., James 1885). Over the next century or so, numerous ichnospecies of *Palaeophycus* were defined, particularly during the years 1847 to 1883, but in a seminal and exhaustive review Pemberton and Frey (1982) reduced the then known 54 ichnospecies to a taxonomically recognizable 5. These were *P. tubularis* Hall, 1847, *P. striatus* Hall, 1852, *P. heberti* (Saporta, 1872), *P. sulcatus* (Miller and Dyer 1878) and *P. alternatus* Pemberton and Frey, 1982. Pemberton and Frey (1982) distinguished these on the nature of the burrow linings (thin or thick) and external surface characteristics (unornamented, striate, annulate or alternately striate and annulate). They regarded the remainder of historically defined forms as synonyms of the 5 they recognized, as *nomina oblita*, *nomina dubia*, *nomina nuda*, inorganic or assignable to alternative ichnogenera (Pemberton and Frey 1982, pp. 852 – 853). The simplified nomenclature proposed by Pemberton and Frey (1982) was, and continues to be, widely adopted by the ichnological fraternity. Nevertheless, it is clear that it cannot always be universally applied because several additional, apparently aberrant, ichnospecies have subsequently been formulated. These include *P. ferrovittatus* Hofmann, 1983; *P. subornatus* Ghare and Kulkarny, 1986; *P. annulatus* Badve, 1987; *P. anulatus* McCann and Pickerill, 1988; *P. canalis* Walter, Elphinstone and Heys, 1989; *P. serratus* McCann, 1993; *P. beifengwanensis* Luo, Tao and Gao, 1994 and *P. crenulatus* Buckman, 1995. In a review of most of these ichnospecies, Buckman (1995) regarded several as *nomina dubia (P. annulatus, P. anulatus, P. canalis, P. serratus)*, a conclusion with which we agree. Notwithstanding, herein we recognize and describe an additional ichnospecies, namely *P. bolbitermilus*, isp. nov. that we regard as ichnotaxonomically distinct.

LOCATION AND GEOLOGICAL SETTING

The material documented herein was collected from two inland locations within the Lower Silurian Upsalquitch Formation in the Upsalquitch Forks area of northern New Brunswick, eastern Canada (Fig. 1), specifically:

1. On a logging road adjacent to Cravens Gulch, 1.1 km west of the Northwest Upsalquitch River, 3.6 km southwest of Upsalquitch Forks; Lat. 47° 39' 15" N, Long. 66° 44' 54" W, and
2. On Dalhousie Road, 3.6 km northwest of the bridge over the Southeast Upsalquitch River, 2.7 km east-northeast of Upsalquitch Forks; Lat. 47° 40' 44" N, Long. 66° 40' 22" W.

In the Upsalquitch Forks area, the Upsalquitch Formation

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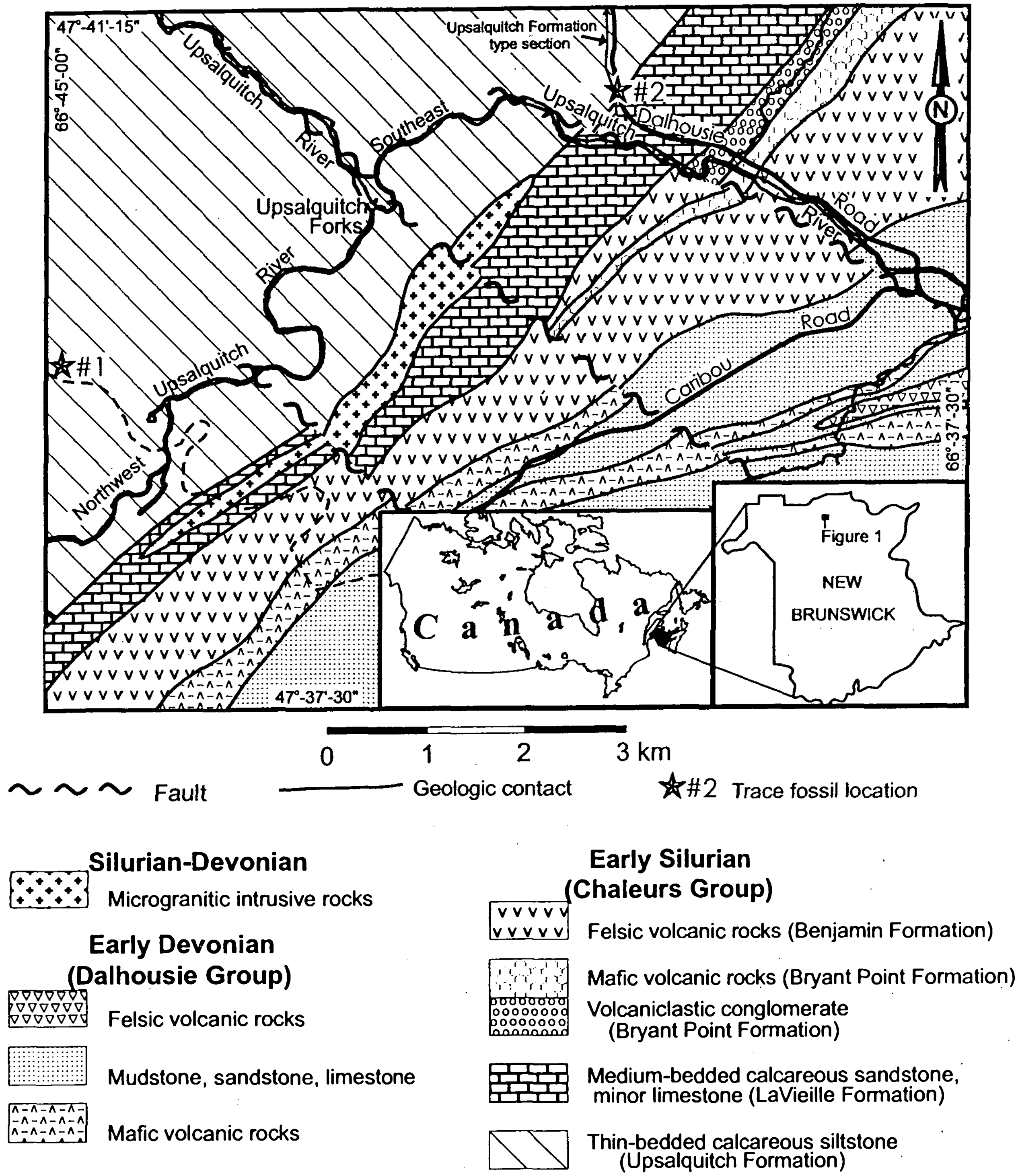

Fig. 1. Simplified geological map of the Upsalquitch Forks area, northern New Brunswick, eastern Canada (insets) and location of the two trace fossil localities (see text for details) of *P. bolbitermilus*.

is the oldest lithostratigraphic unit and forms the basal sequence of the Early Silurian Chaleurs Group (Fig. 1). The formation is approximately 1800 m in thickness (Wilson 2000). It is comprised of dominantly thin to very thin (10–40 mm) calcareous siltstones and shales, with interbeds of sporadically distributed and thicker (10–40+ mm) fine-grained sandstones and calcarenites (St. Peter 1978; Wilson 2000). Partial Bouma sequences in the siltstones and sandstones, several slump horizons and flutes and grooves on the soles of several layers collectively attest to its origin as a deep-water turbiditic sequence, most probably deposited on a slope.

Thirty ichnospecies have been recognized in the Upsalquitch Formation (Kim *et al.*, unpublished data). At the two aforementioned locations, *P. bolbitermilus* isp. nov. occurs in association with *Calycraterion* isp., *Cochlichnus anguineus* Hitchcock, 1858, *Didymaulichnus lyelli* (Rouault 1850), *Furculosus carpathicus* Roniewicz and Pieńkowski, 1977, *Helminthopsis hieroglyphica* Wetzel and Bromley, 1996, *Palaeophycus heberti*, *Planolites annularius* Walcott, 1890, *Planolites montanus* Richter, 1937, *Planolites*

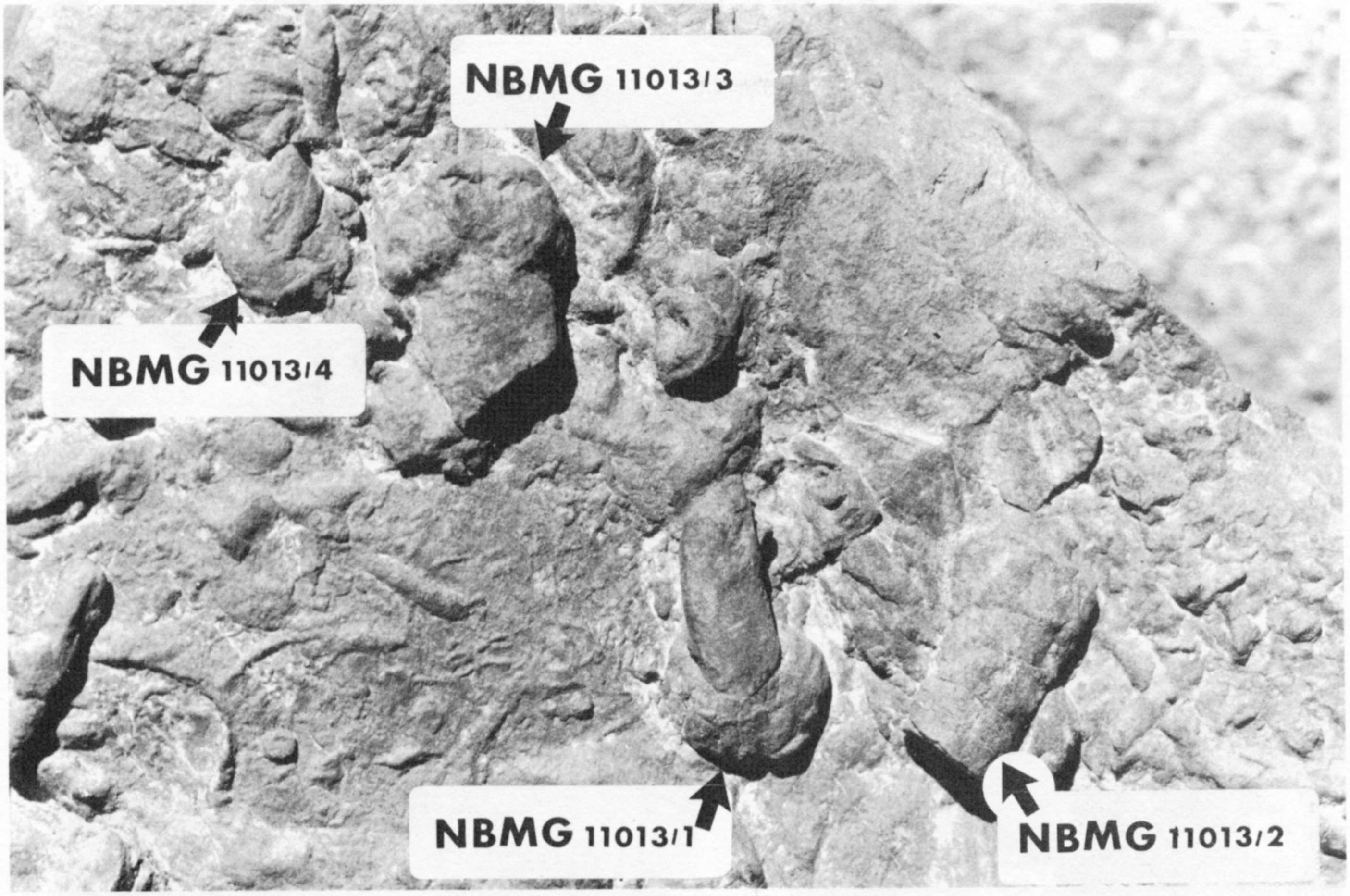

Fig. 2. Basal view of slab NBMG 10013, illustrating holotype of *P. bolbitermilus* (NBMG 11013/1) and paratypes NBMG 11013/2-4; scale bar = 1 cm.

terraenovae Fillion and Pickerill, 1990 and *Teichichnus rectus* Seilacher, 1955.

SYSTEMATIC ICHNOLOGY

The material described herein is housed in the New Brunswick Museum, Saint John, New Brunswick, Canada and is prefixed NBMG.

Ichnogenus *Palaeophycus Hall, 1847*

Type ichnospecies: *Palaeophycus tubularis* Hall, 1847, by subsequent designation (Miller 1889, p. 130).

Diagnosis: Branched or, more typically, unbranched, straight to curved to slightly undulose, smooth or ornamented, lined, predominantly horizontal cylindrical structures of variable diameter; fill typically structureless and similar to the host rock; when present bifurcation is not systematic, nor does it result in swelling at the site of the branching (after Pemberton and Frey 1982; Fillion and Pickerill 1990).

Discussion: Following several discussions with respect to differentiation of *Palaeophycus* from the morphologically similar ichnotaxon *Planolites* Nicholson (e.g., Osgood 1970; Pemberton and Frey 1982; Fillion 1989; Fillion and Pickerill 1990, Keighley and Pickerill 1995) there is now general agreement that the presence of a lining in the former and an absence in the latter is the significant ichnotaxobase (*sensu* Fürsich 1974) enabling ichnogeneric distinction. As noted by Keighley and Pickerill (1995) other ichnotaxobases and ethological considerations are, without exception, subordinate to this directive.

Palaeophycus bolbitermilus isp. nov.
Figs. 2, 3

Diagnosis: Horizontal to slightly oblique, thinly lined, unbranched, smooth and unsculptured, cylindrical burrow typically, though not exclusively, with a massive, structureless fill and characterized by a bulb-like termination at one extremity.

Etymology: Greek *bolbi* = bulb-like and Latin *termilus* = ending, in reference to the characteristic morphology of the ichnospecies.

Material: Sixteen specimens on 4 rock slabs, NBMG 11013 – 11016. Rock slabs NBMG 11013 – 11015 are from locality 2 of Fig. 1; NBMG 11016 is from locality 1.

Holotype: NBMG 11013/1

Paratypes: NBMG 11013/2 – 11

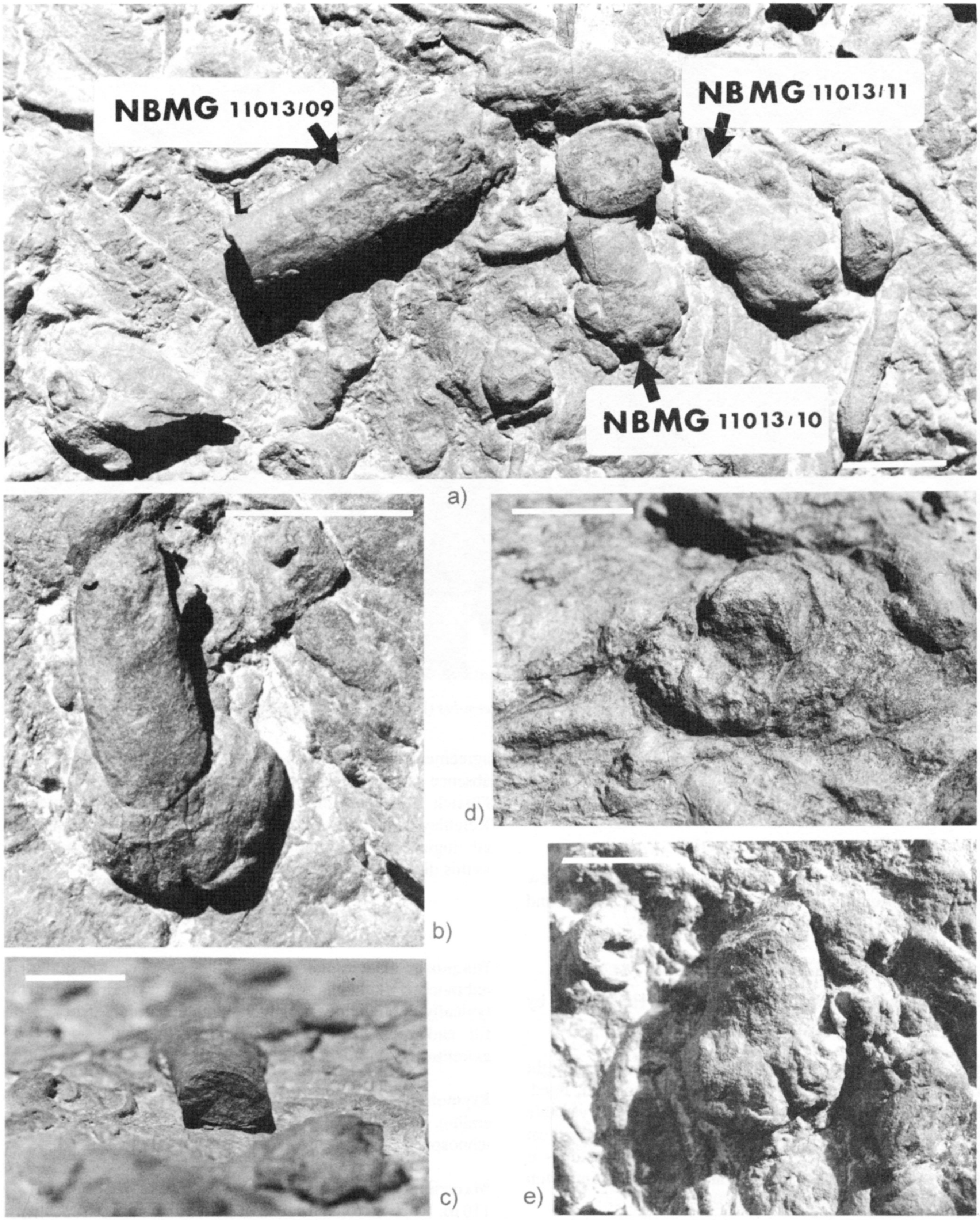

Fig. 3. *P. bolbitermilus* specimens. a) Slab NBMG 10013 exhibiting paratypes 11013/9-11; b) Holotype NBMG 10013/1; c) Lateral view of cylindrical, flattened, horizontal tube illustrating thin external lining, NBMG 11013/09; d) Obique specimen of *P. bolbitermilus* showing central tube invaginated into bulb-like termination, NBMG 11016; e) Short example of *P. bolbitermilus*, NBMG 11013/03. All specimens preserved in positive hyporelief, scale bars = 1 cm.

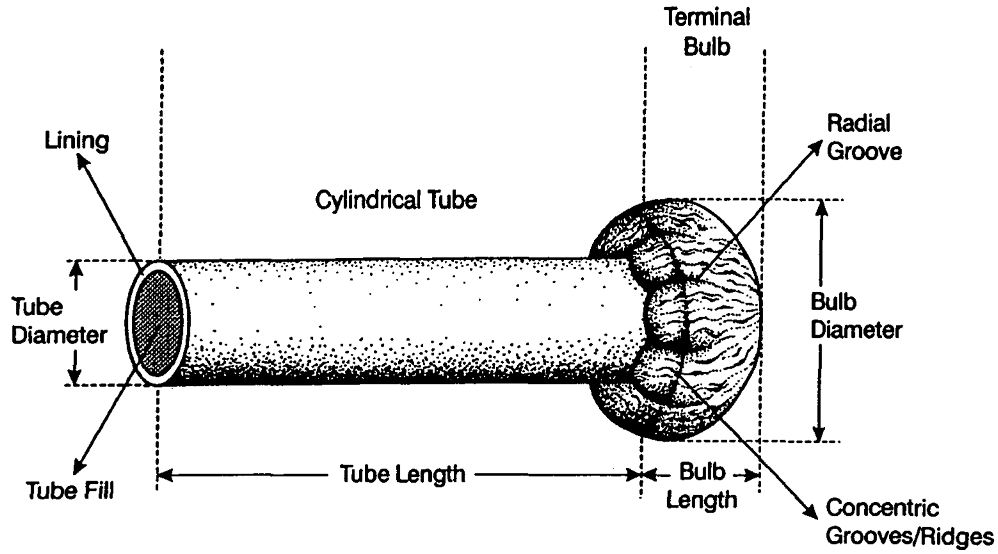

Fig. 4. Schematic representation of *P. bolbitermilus* illustrating terminology adopted herein. Tube length up to 20 mm, bulb length up to 8 mm. See text for details.

Additional specimens: NBMG 11014/1 – 2; NBMG 11015/1 – 2; NBMG 11016/1

Description: Descriptive terminology is illustrated schematically in Fig. 4, and size and morphological data for each specimen, where available, are indicated in Table 1. All specimens are preserved in convex hyporelief, more rarely in full relief, on the soles of 10–40 mm thick, parallel-to cross-laminated, fine-grained sandstone layers and comprise two basic elements, namely a horizontal cylindrical tube and a bulb-like termination at one extremity.

The cylindrical tubes are straight and typically parallel to stratification, although two specimens (NBMG 11015/1 and 11016/1) occur at 35–45° to bedding. They are up to 20 mm long but are typically truncated as a result of weathering and also invaginated into the terminal bulb; presumably, therefore, they were originally longer. Cross-sectional shape is elliptical, a result of compaction and/or deformation, with long axes varying from 5.4–10.5 mm and short axes from 3–9 mm; the resultant cross-sectional ratios (length/width) vary from 1.1–2.0. Tube-fill is either massive and structureless and similar in grain size to the host rock, or, less commonly (Table 1), possesses weakly developed concave-downward laminae at and towards the base of the tubes. Where observable, tubes possess a distinct but thin (approximately 0.1mm) mudstone lining. Outer surfaces of tubes are typically smooth; superficial and irregularly developed wrinkles/striations on NBMG 11014/1 – 2, 11016/1 are considered compactional and not primary features.

The terminal bulbs are typically hemispherical to hemielliptical and superficially resemble the cap of a button-shaped mushroom; they curve steeply at their lateral margins and then steeply inward within the host rock. Vertical sectioning of several examples indicated a structureless infill but no additional vertical or oblique continuity into the overlying substrate, though admittedly this is the typical situation with trace fossils preserved in semi-relief on turbidite soles. The obliquely preserved specimen 11016/1 (Fig. 3d) does, however, suggest that the bulbs were originally spheroidal or elliptical structures and had no such continuity, as also illustrated by us schematically in Fig. 4. Each bulb possesses at least 8, possibly up to 12, radial grooves; interspersed with these may be regular to irregular, less deeply impressed fine grooves. Several also possess concentric regular to irregular grooves or ridges. The bulbs are 4–8 mm in length and 8.5–24 mm in width (Table 1); width/tube diameter ratio is 1.1–2.5; width/length ratio is 1.6–3.0.

Discussion: It is tempting to equate *P. bolbitermilus*, as formulated and described herein, with several previously established ichnotaxa, particularly as the material is essentially preserved in semi-relief. The ichnogenera *Arthraria* Billings, *Bifungites* Desio and *Diplocraterion* Torell are obvious candidates in semi-relief preservation. However, these ichnogenera all possess expanded terminations at both extremities and the latter two have vertical components extending from these. *Arthraria*, although lacking vertical elements, is also characterized by a dumb-bell morphology, and as with *Bifungites* and *Diplocraterion* but unlike *P. bolbitermilus*, the expanded terminations are unsculptured (see Fillion and Pickerill 1984). Furthermore, these ichnotaxa consistently exhibit a dumb-bell morphology, a feature totally absent in *P. bolbitermilus*. Additionally, a minor consideration is that these ichnogenera are almost invariably associated with neritic and not turbiditic sequences. Superficially, the material described herein also closely resembles several ichnospecies of *Phycodes* Richter; however, these possess flabellate or broom-like (not bulb-like) terminations (see Han and Pickerill 1994). It also resembles several plug-shaped ichnotaxa (e.g., *Calycraterion* Karaszewski), as reviewed by Pemberton *et al.* (1988), but all these are vertical structures and clearly differ from the essentially horizontally oriented specimens of *P. bolbitermilus*. Specimens of the recently formulated *Sphaerichnus lobatus* Fürsich, 1998 are also broadly comparable in that this ichnotaxon is also essentially a horizontal tube that, at least schematically (Fürsich 1998, p. 269), possesses irregular spherical structures along its course. The latter does, however, differ substantially from the material described herein (see below).

Following the recommendations of Pickerill (1994), we

Table 1. Size and morphological data, in millimeters, for most specimens of *P. bolbitermilus* from the Lower Silurian Upsalquitch Formation of northern New Brunswick (see Fig. 4 for legend)

Sample	Tube length	Tube diameter (long/short)	Bulb length	Bulb diameter	Lining	Tube fill	Bulb ornament
NBMG 11013/1	14	6.7 / 5	7	14	n.o.	Massive	RG, CR
NBMG 11013/2	11	7 / 5.5	7	11.5	0.2	Laminate	RG, CR
NBMG 11013/3	9	10.5 / 6	8	15	n.o.	Massive	RG, CG
NBMG 11013/4	4	7 / 3.5	4	11.3	0.1	Massive	RG, CR
NBMG 11013/5	4	5 (?) / 3.5	5 (?)	10 (?)	0.1	Massive	n.o.
NBMG 11013/6	4	7.5 / 4.5	5	9.5	0.1	Laminate	RG
NBMG 11013/7	4	12 / 6.5	5	15	0.1	Massive	RG
NBMG 11013/8	2	7.5 / 4	5	8.5	0.1	Laminate	RG
NBMG 11013/9	21	9.4 / 5.8	8	13.5	0.1	Massive	RG
NBMG 11013/10	7	8 / 4 (?)	7	13	n.o.	n.o.	RG, CG
NBMG 11013/11	15	8.5 (?)	8	12	n.o.	n.o.	RG, CG
NBMG 11014/1	13	6.7 / 4 (?)	4.6	8.5	n.o.	Massive	n.o.
NBMG 11014/2	8 (?)	5.4 / 3 (?)	n.o.	10, 4	n.o.	Massive	n.o.
NBMG 11015/1	5	7.8 / 7	n.o.	12	0.1	Massive	RG, CG
NBMG 11015/2	7 (?)	8 / n.o.	5 (?)	10	n.o.	Massive	RG
NBMG 11016/1	7	9.5 / 9	n.o.	24	0.1	Laminate	CG

(?), approximate value; RG, radial grooves; CG, concentric grooves; CR, concentric ridges; n.o., not observed

consider the significant features (morphology related to distinct behaviour – *sensu* Fürsich 1974) of this material to be the presence of a generally horizontal, more rarely oblique, cylindrical and lined tube that typically possesses an internally structureless fill (see also Schlirf 2000). Accordingly, at the ichnogeneric level, it is best assigned to *Palaeophycus*, most commonly interpreted ethologically as a dwelling structure (domichnion), produced infaunally, and subsequently passively infilled (Pemberton and Frey 1982; Keighley and Pickerill 1995). That the tubes were in fact infaunal open structures and subsequently passively infilled is supported, respectively and collectively, by preservation of several specimens in full relief, the presence of (albeit thin) distinct linings and the occurrence in several examples of a basal concave-upward laminate fill. Indeed, had the material not possessed the bulb-like terminations, it could have easily been assigned to *P. tubularis*, itself characterized by a thin lining and smooth external surface.

We regard the bulb-like termination, although an integral component, as an accessory feature (minor variation of trace maker behaviour – *sensu* Fürsich 1974). Its presence distinguishes it not only from *P. tubularis* but also from all other previously documented ichnospecies of *Palaeophycus*, none of which possess such a feature. The origin and function of the bulb remain enigmatic. As noted above, however, *S. lobatus* also possesses bulb-or ball-like structures along its course. These differ from the bulb-like terminations of *P. bolbitermilus* in several respects. First, *S. lobatus* comprises irregularly spherical structures with radial lobes and cylindrical horizontal axial extensions; second, the lobes possess chevron-patterned external ridges; and, third, they possess a fill of faecal pellets. Nevertheless, as also suggested by Fürsich (1998) for his material, it seems likely that the terminal cavity of *P. bolbitermilus* served some specific purpose. Based on the presence of abundant faecal pellets in *S. lobatus*, Fürsich (1998) interpreted its bulb-like structures as refuse dumps. *P. bolbitermilus* bulbs contain no faecal pellets and, therefore, a similar origin is unlikely. Alternative functions could possibly be related to breeding, bacterial farming, or as "turn around" structures but there is no definitive evidence to substantiate any of these possibilities.

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