

Teredolites longissimus Kelly & Bromley from the Miocene Grand Bay Formation of Carriacou, the Grenadines, Lesser Antilles

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Pickerill, R.K., Donovan, S.K. & Portell, R.W. *Teredolites longissimus* Kelly & Bromley from the Miocene Grand Bay Formation of Carriacou, the Grenadines, Lesser Antilles. *Scripta Geologica* 125: 1-9, 1 fig., 1 pl., 1 table, Leiden, May 2003.

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Key words – *Teredolites*, ichnology, Miocene, Lesser Antilles, systematics.

The ichnotaxon *Teredolites* Leymerie, 1842, represented by *T. longissimus* Kelly & Bromley, 1984, is documented for the first time from the Lesser Antilles. Its occurrence also represents the first record of the ichnotaxon from the Miocene of the Caribbean. Five specimens, each occurring in isolation without an enclosing xylic (wood) substrate, but merely calcite-lined tubes, occur in the Miocene Grand Bay Formation of Carriacou, the Grenadines, Lesser Antilles. Stratigraphic considerations suggest that following physical destruction or biological decomposition of their enclosing substrate(s), the tubes may have accumulated in relatively shallow water only to be subsequently resedimented into a deeper-water (> 150 m) environment.

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Introduction

In the summer of 2000, we retrieved a small assemblage of macroborings associated with molluscs and scleractinian corals from the Middle Miocene Grand Bay Formation of Carriacou in the Grenadines, Windward Islands, Lesser Antilles. Although these macroboring ichnotaxa were relatively rare, occurring in association with only 30 samples of the thousands of body fossils observed by us in the sequence, the overall assemblage was relatively diverse and included seven ichnogenera assigned to at least 12 ichnospecies, namely *Caulostreptis cretacea* (Voigt), *C. spiralis* Pickerill, Donovan and Portell, *C. taeniola* Clarke, *Entobia* isp. or isp., *Gastrochaenolites cluniformis* Kelly and Bromley, *G. dijugus* Kelly & Bromley, *G. torpedo* Kelly & Bromley, *Oichnus paraboloides* Bromley, *O. simplex* Bromley, *Petroxestes pera* Wilson & Palmer, cf. *Rogerella* isp., and *Trypanites solitarius* (Hagenow). These have been documented by

us in Pickerill *et al.* (2001, 2002a) and, particularly, Pickerill *et al.* (2002b).

We revisited Carriacou in 2001 and discovered five examples of an additional, but previously unrecorded, ichnotaxon from the same formation. This is *Teredolites longissimus* Kelly & Bromley, 1984, produced by teredinid bivalves. Whereas all other bioerosional ichnotaxa recorded by us were clearly associated with lithic substrates, *T. longissimus* is known to be produced in xylic (woody) substrates (Kelly & Bromley, 1984). Unlike most other reported examples of *Teredolites*, however, those from Carriacou did not occur as aggregations; instead, they were present as allochthonous and isolated specimens preserved only in the form of tube linings with their former xylic substrate(s) having been destroyed or decomposed prior to fossilization. We here document and describe the material in detail, and comment on its ichnotaxonomic importance and possible biostratinomic history.

General geology

Carriacou is located approximately 30 km northeast of Grenada, in the Grenadine chain of the Windward Islands, Lesser Antilles (Fig. 1). The island consists of an older Tertiary volcanic sequence with subsidiary sedimentary strata (to the west), overlain by Miocene siliciclastics and carbonates in the south, southeast and east (Martin-Kaye, 1958; Speed *et al.*, 1993). The latter strata have been subdivided, in

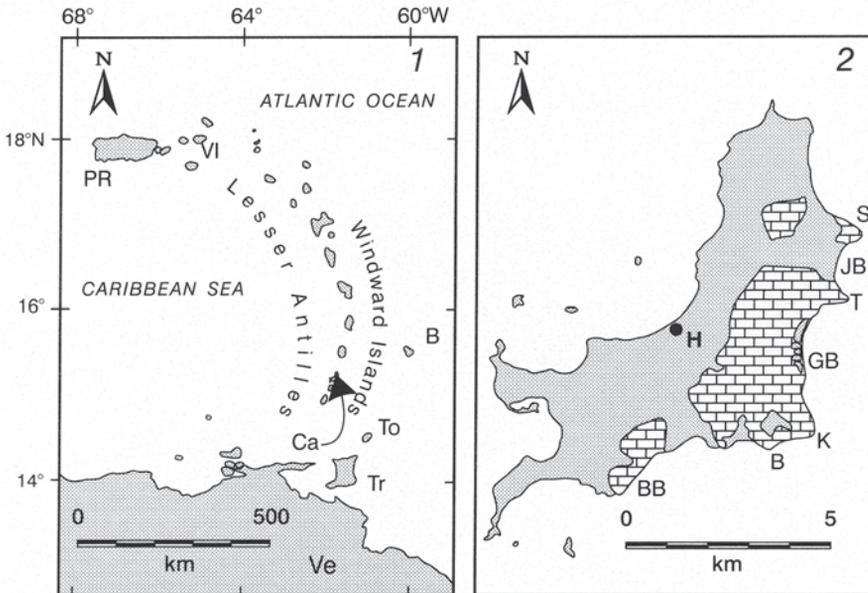


Fig. 1. (1) Geographic location of Carriacou (= Ca, arrow), Windward Islands, Lesser Antilles. PR = Puerto Rico, VI = Virgin Islands, B = Barbados, To = Tobago, Tr = Trinidad and Ve = Venezuela. (2) The island of Carriacou showing the capital Hillsborough (H), Point Saint Hillaire (S), Jews Bay (JB), Tarleton Point (T), Grand Bay (GB), Kendeace Point (K), Breteche Point (B) and Black Bay (BB). Key: stipple = older rocks; brick pattern = Middle Miocene strata (that is, Carriacou and Grand Bay formations). After Pickerill *et al.* (2002b, fig. 1).

ascending stratigraphic order, into the Lower Miocene? Belmont Formation, the Lower-Middle Miocene Kendeace Formation, the Middle Miocene Carriacou Formation and the Middle Miocene Grand Bay Formation (Robinson & Jung, 1972; Speed et al., 1993). Detailed studies on various aspects of the geology and palaeontology of these units have been undertaken by Trechmann (1935), Martin-Kaye (1958), Jung (1971), Robinson & Jung (1972), Speed et al. (1993), Donovan & Harper (1999, 2001), Donovan & Veltkamp (2001), Pickerill et al. (2001, 2002a, b) and Donovan et al. (2003).

Specimens described herein were collected from the Grand Bay Formation (Middle Miocene). This sequence comprises beige to light brown, deep-water turbiditic volcanoclastic sandstones (commonly amalgamated) with minor mudstone/marlstone intercalations, and sporadically developed pebbly sandstones, conglomerates and volcanic ash layers (Pickerill et al., 2002b; Donovan et al., 2003). The most detailed palaeontological study of the sequence is that by Jung who described 109 species of molluscs from numerous locations (1971, fig. 1, p. 150). Reference to two of the locations documented by Jung, those from which our material is collected, is included herein (see also Robinson & Jung, 1972). The bivalves described by Jung (1971) included no teredinids.

Systematic ichnology

***Ichnogenus Teredolites* Leymerie, 1842**

Type ichnospecies — *Teredolites clavatus* Leymerie, 1842, by monotypy.

Emended diagnosis — (Revised after Kelly & Bromley, 1984; Savrda & Smith, 1996). Clavate borings, commonly, though not exclusively, lined and primarily, though not universally, occurring in association with woody substrates; acutely turbinate, evenly tapered from aperture to base of the main chamber; neck region not separated from the main chamber; cross-sections at all levels more or less circular; elongate to short; branched or unbranched.

Remarks — Kelly & Bromley (1984) provided a useful diagnosis of the ichnotaxon, but did not include any reference to branching. Savrda & Smith (1996) noted that *Teredolites* could in fact be branched, most likely as a result of a response of the wood-boring bivalves to substrate overcrowding. Savrda & Smith (1996) thus regarded its presence or absence as an accessory ichnotaxonomic feature that had behavioural significance, but not necessarily a diagnostic feature worthy of the establishment of a new ichnospecies. However, Savrda & Smith (1996) did not emend the diagnosis of Kelly & Bromley (1984) to include branching. That proposed above therefore combines the original diagnosis of Kelly & Bromley (1984) and the subsequent observations of Savrda & Smith (1996).

***Teredolites longissimus* Kelly & Bromley, 1984**

P1. 1, figs. A-E.

Diagnosis – (After Kelly & Bromley, 1984, p. 806). Clavate *Teredolites* predominantly parallel to the grain in lignic substrates having length/width ratio usually greater than 5. Commonly sinuous to contorted.

Material and locality — Five specimens from the Middle Miocene Grand Bay Formation, east coast of Carriacou at Tarleton Point (Fig. 1). Specimens housed in the National Natuurhistorisch Museum, Leiden, (RGM 212401–212405). Specimens RGM 212402, 212403 (Pl. 1 B, C) from Naturhistorisches Museum Basel (NMB) locality 10708; remainder (Pl. 1 A, D, E) from NMB locality 10707 (Jung, 1971; Robinson & Jung, 1972). Specimens preserved on upper surfaces of turbiditic volcanoclastic layers.

Description — Specimens are preserved essentially in semi-relief as isolated, incompletely and variably preserved tubes each composed of a discrete and thin calcite lining. Size and additional data of each are presented in Table 1. RGM 212401 is the only example to exhibit a well-preserved cross-sectional view at one extremity; this is perfectly circular (diameter = 8 mm). Preserved bases on RGM 212403 and 212405 are round and turbinate; bases on other specimens not preserved. External surfaces of all tubes unsculptured.

Remarks — Wood-boring bivalves include the families Pholadidae (piddocks) and Teredinidae (shipworms or pileworms), both of which belong to the order Myoida (Turner, 1971; Turner & Johnson, 1971). Unlike the family Pholadidae, most teredinids line all or part of their borings with a thin or thick (see Grave, 1928) calcite tube. This provides an attachment site for retractor muscles of siphons and pallets, and shelters soft parts during occupation and, possibly, after destruction of xylic substrates (Savazzi, 1982; 1994; Savrda & Smith, 1996). Therefore, the Carriacou material was undoubtedly produced by teredinids, though, of course, their taxonomic affinities remain obscure.

Kelly & Bromley (1984) proposed that calcite linings associated with *Teredolites*, particularly those commonly occurring with *T. longissimus*, be disregarded in ichnotaxonomy, preferring to treat them as body fossils falling within the informal group name *Teredolithus* (non-italicized) as defined by Bartsch (1930). This latter collective name was suggested to include numerous indeterminate fossil species of well-known molluscan tubes of indeterminate specific affinity such as *Teredo* and *Kuphus*. However, Savrda & Smith (1996) argued for inclusion of linings in ichnoterminology pertaining to *Teredolites* despite their equivocal position with respect to body fossils and ichnofossils. They correctly pointed out that the presence and character of calcite linings, by themselves, provide little information regarding bivalve taxonomy below the familial level, and that the form and extent of linings may be more a reflection of varying organism behaviour than of taxonomy or ontogeny. As such, they intimated

Table 1. Summary of essential characteristics of *T. longissimus* from the Grand Bay Formation of Carriacou. Numbered locations refer to those of Jung (1971, fig. 1, p. 150); size dimensions (length, width, calcite linings) are in millimetres.

Repository	Location	Length	Width	L/W ratio	Course	Fill	Lining thickness
RGM 212401	10707	59	9	6.6	curved	calcite	0.3
RGM 212402	10708	23	6	3.9	straight	sst.	0.6
RGM 212403	10708	30	6	5.0	straight	sst.	0.5
RGM 212404	10707	32	6	5.4	sinuous	sst.	0.6
RGM 212405	10707	9	6	1.5	straight	sst.	0.3

that the presence of linings alone, as in the case herein and, indeed, in many other previously reported examples where little or no wood or even coalified material is preserved (e.g., Huggett & Gale, 1995; Savrda & Smith, 1996; Tewari *et al.*, 1998; Donovan *et al.*, 1998), is sufficient to assign material to *Teredolites*. While such calcareous linings to borings are undoubtedly body fossils, they are important in ichnology if regarded as biogenic moulds of the boring ichnotaxon (e.g., Donovan, 2002, table 2). Accordingly, we assign the five specimens documented herein to *Teredolites* with confidence. For further discussion of the ichnotaxonomic importance of the linings of bivalve borings, see Donovan (2002).

Teredolites currently includes two ichnospecies, namely the nomenclatural type *T. clavatus* Leymerie, 1842, and *T. longissimus* Kelly & Bromley, 1984. These are differentiated on length-to-width ratios, geometry and axial orientation with respect to the host xylic substrate. *Teredolites clavatus* is generally perpendicular to substrate grain, is characterized by relatively straight axes and typically has L/W ratios of less than five. In contrast, *T. longissimus* is primarily, though not universally (e.g., Tewari *et al.*, 1998; Wilson & Taylor, 2001), parallel to substrate grain, is typically sinuous or contorted (commonly a result of stenomorphism) and has L/W ratios greater than 5. Additionally, as noted above and unlike *T. clavatus*, *T. longissimus* is invariably partly or wholly lined by calcite. Because of their presence as isolated tubes, the xylic substrate(s) having been decomposed or physically destroyed prior to fossilization, it is impossible to comment on the primary orientation of the Carriacou material. Furthermore, the preserved L/W ratios are not totally realistic as all specimens are only partially preserved, particularly RGM 212402 and 212405 (Pl. 1 B, E). RGM 212405, in particular, is simply a small portion of the basal (posterior) tube. However, where more completely preserved the specimens have L/W ratios of five or above (Table 1) and two of these (RGM 212401 and 212404) are curved to slightly sinuous. Further, the basal terminations of *T. clavatus* tend to be distinctly more bulbous than those observed herein (RGM 212403 and 212405). Thus, these specimens compare well with previously reported examples of *Teredolites longissimus* to which we assign all RGM 212401-212405 with confidence.

Discussion

Although clearly allochthonous, an additional and intriguing consideration with respect to the material documented herein is its biostratigraphic history. Obviously, and by definition, the tubes were initially secreted in some form of wood substrate(s), the latter having subsequently been physically destroyed or biologically decomposed prior to their release and eventual fossilization. As noted, all specimens were collected occurring in isolation on the upper surfaces of turbiditic volcanoclastic sandstones. We therefore envisage two possible scenarios with respect to their biostratigraphy. First, following destruction or decomposition of their enclosing xylic substrate, they could have accumulated in a relatively shallow-water regime subsequently followed by re-sedimentation as components of sediment gravity flows into deeper water, in this particular case estimated by Jung (1971), Donovan & Veltkamp (2001), Donovan & Harper (2001), and Donovan *et al.* (2003) as greater than 150 m, probably more than 200 m. This is certainly true of the associated molluscan-dominated faunas within the

turbidites that include numerous, diverse and clearly allochthonous shallow water and non-marine species (see Jung, 1971) that were included as integral components of the sediment gravity flows (Pickerill *et al.*, 2002b). Secondly, the tubes could have been accumulated gravitationally following waterlogging or destruction of their enclosing xylic substrate(s) and not necessarily have been resedimented, instead simply accumulating at the sediment-water interface of previously deposited turbidites and not as components of the sediment gravity flows themselves.

Though somewhat equivocal, we favour the former scenario. In particular, four specimens possess a fill identical in composition and grain size to the enclosing turbiditic sandstone matrices, an unlikely situation for the latter hypothesis. Additionally, several are preserved oblique to stratification, a preservational style more consistent with inclusion as integral components of sediment gravity flows rather than gravitational settlement through the water column. Such an explanation is consistent with the preservational histories of other borings from this formation (Pickerill *et al.*, 2002b).

Finally, we note that the recording of *Teredolites* herein represents the first from Miocene strata in the Caribbean. Previous documentation of the ichnotaxon in this region has only formally been made from Jamaica from the late Paleocene?-Eocene turbidites of the Richmond Formation (Pickerill *et al.*, 1992), and Pliocene turbidites of the Bowden Formation (Pickerill *et al.*, 1996) and its basal unit referred to locally as the Bowden shell bed (Donovan *et al.*, 1998). The Richmond and Bowden formations contain, respectively, examples of *T. clavatus* and *T. longissimus* still preserved within their host xylic substrates, but clearly allochthonous. In contrast, the turbiditic Bowden shell bed of the Bowden Formation preserves *T. longissimus* as isolated and randomly distributed calcite tubes. These are similar, though smaller, to the material documented herein and Donovan *et al.* (1998) assumed the nomenclatural philosophy adopted by the present authors.

Acknowledgements

We thank Angel Gomez, Vivienne Robertson and Bob McCulloch for technical assistance, and the late Dr Roy Blackman, and Professors Dave Harper and Trevor Jackson for help in the field. This work was supported by National Geographic Society grant #6625-99, the National Sciences and Engineering Council of Canada and the McGinty Endowment of the Florida Museum of Natural History. Constructive reviews by Professor Mark Wilson (College of Wooster, Ohio) and Dr. Paul Taylor (The Natural History Museum, London) are gratefully acknowledged. This paper is a contribution to S.K.D.'s Nationaal Natuurhistorisch Museum projects "Trace fossil studies" and "Caribbean palaeontology," and is also University of Florida Contribution to Paleobiology 543.

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Manuscript received 28 June 2002.

Plate 1

Teredolites longissimus Kelly & Bromley, 1984, from the Middle Miocene Grand Bay Formation of Carriacou, Windward Islands, Lesser Antilles. All specimens are preserved in isolation on upper surfaces of volcanoclastic sandstones. All specimens are housed in the Nationaal Natuurhistorisch Museum, Leiden, The Netherlands (RGM). Scale bars represent 5 mm.

Fig. A. RGM 212401, curved tube.

Fig. B. RGM 212402, straight tube, abraded and showing infill of identical lithology to surrounding matrix.

Fig. C. RGM 212403, short, straight tube fragment.

Fig. D. RGM 212404, geniculate, J-shaped tube,

Fig. E. RGM212405, rounded tube termination.

