NEW FINDINGS OF BODY AND TRACE FOSSILS IN THE ST. BRIDE'S AREA, CAPE ST. MARY'S PENINSULA, NEWFOUNDLAND

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ABSTRACT

The St Bride's area of the Avalon Peninsula, Newfoundland, is dominated by late Ediacaran and Lower Cambrian sedimentary rocks of the Musgravetown and Adeyton groups. Detailed 1:10 000 mapping of the St Bride's area has identified new trace fossil and trilobite localities. The trace fossils, found in abundance within the Bonavista Formation, are identified as Teichichnus rectus. *These trace fossils are recognized globally in Early Cambrian assemblages and are valuable contributors in constraining relative locations of the Precambrian–Cambrian boundary. Their presence here suggests that the host mudrocks were deposited in a marginal marine, reduced salinity environment.*

The trilobite fossils are found within a condensed 2- to 3-m-thick unit of the Brigus Formation; they are identified as belonging to the Strenuella sabulosa *Zone. These findings are consistent with comprehensive studies of trilobite taxonomy previously carried out in the area. The question as to why these fossils should be found in discrete, condensed fossiliferous horizons is beyond the scope of this study, but it is suggested that this observation might form the basis of future work.*

INTRODUCTION AND REGIONAL SETTING

This short paper provides an account of new fossil localities within Cambrian rocks of the Cape St. Mary's Peninsula. The sites discussed were mapped and described during a field-mapping course completed for the University of Durham, and assisted by the Geological Survey of Newfoundland and Labrador. The trace and body fossils encountered are known from some previous studies, but they merit additional discussion for several reasons.

St. Bride's is located along the western coast of the Cape St. Mary's Peninsula, which forms the southwestern portion of the Avalon Peninsula of Newfoundland; it lies within the eastern part of the Avalon Zone of the Appalachian Orogen (Williams, 1979; Fletcher, 2006; Figure 1). The area mapped is a predominantly coastal section stretching from Lear's Cove in the south to Cuslett in the north and encompasses some 20 km². The area is underlain by Neoproterozoic (Ediacaran) and Cambrian sedimentary rocks, disposed within a regional syncline, which is offset by large-scale normal faults that have predominantly sinistral strike-slip motions (Figure 2). The sedimentary rocks are cut by numerous diabase dykes presumed to be of Devonian age, although these remain undated.

Neoproterozoic sedimentary rocks are assigned to the Musgravetown Group (Hayes, 1948) and the Cambrian sedimentary rocks are assigned to the Adeyton and Harcourt groups (Jenness, 1963; Fletcher, 2006; Figure 3). The Cambrian succession found on the peninsula is of international importance due to the trilobite faunas found within it. Cambrian outer-shelf faunal assemblages are rarely preserved, but they are valuable for interregional correlation, and hence the region plays a key role in global biostratigraphy (Fletcher, 2006, p. 99). The Cambrian stratigraphy and paleontology of the area have been comprehensively studied by T. Fletcher (amongst others) since the 1950s; the area around Branch, on St. Mary's Bay, was the focus of much of this work. Here, we report on some previously undocumented fossil localities in the St. Bride's area, on the opposite side of the peninsula (Figure 2). These trilobite specimens are found within the lower Cambrian mudstones of the Brigus Formation (Adeyton Group of Jenness, 1963).

The trilobite taxonomy of the Cambrian succession has been extensively documented (Fletcher, 2006, and references therein), whereas ichnofossils have been comparatively less well researched. Of particular interest at St. Bride's is an intensely bioturbated *Teichichnus* ichnofabric within the Bonavista Formation (also within the Adeyton Group), which adds to the evidence for early evolution of infaunal
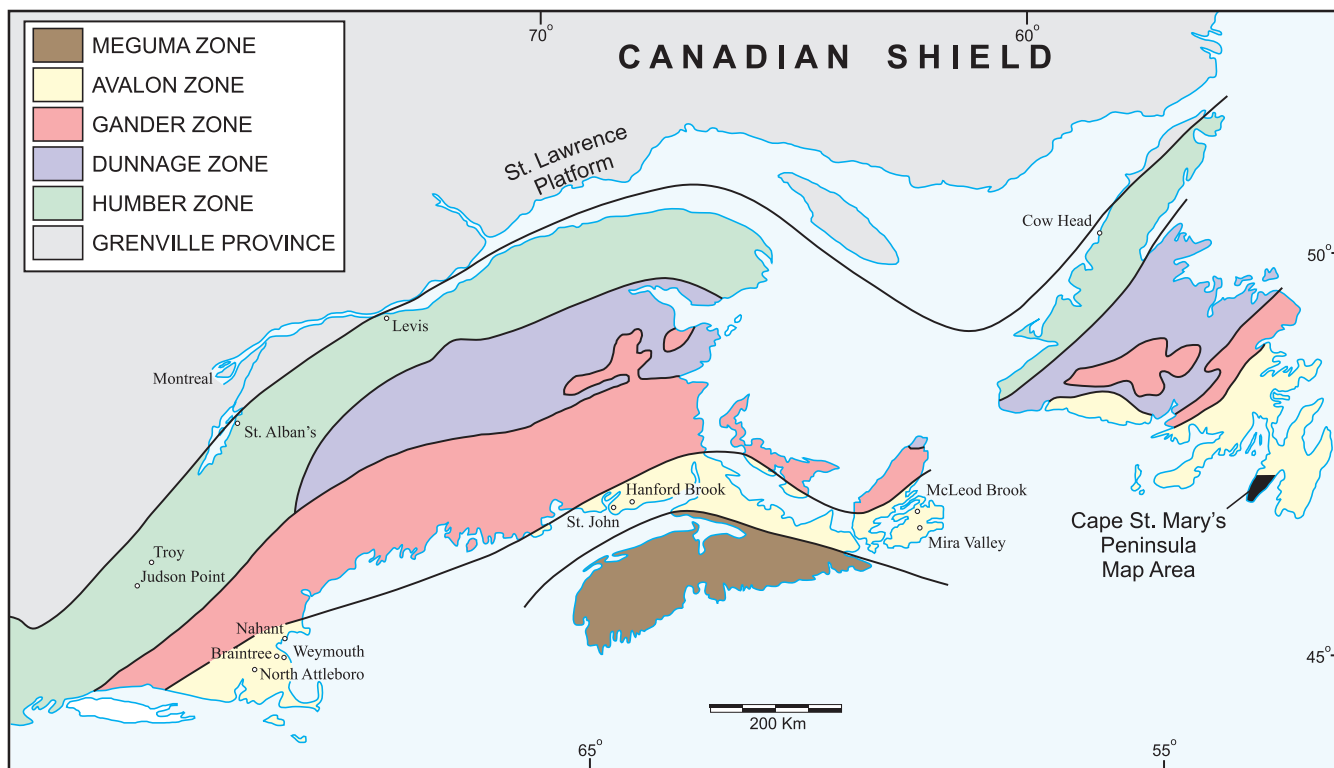
Figure 1. *Location and tectonic setting of Cape St. Mary's Peninsula (Fletcher, 2006).*

organisms during the early Cambrian (Loughlin and Hillier, 2010). These trace fossils predate the first trilobites in the Cambrian succession of Newfoundland. Although the presence of these traces has been noted prior to this study (*e.g.*, Landing, 1995; McIlroy and Logan, 1999), they have not been described in detail. The St. Bride's locality displays exceptional three-dimensional preservation of *Teichichnus*, and may therefore be important in understanding the nature of the organism(s) that created this record. This paper expands on previous observations and also discusses the importance of these trace fossils for correlation purposes. Since *Teichichnus* is unknown below the base of the Cambrian (*e.g.*, Crimes, 1992), it has played an important role in globally defining the Proterozoic–Cambrian boundary (McIlroy *et al.*, 1998).

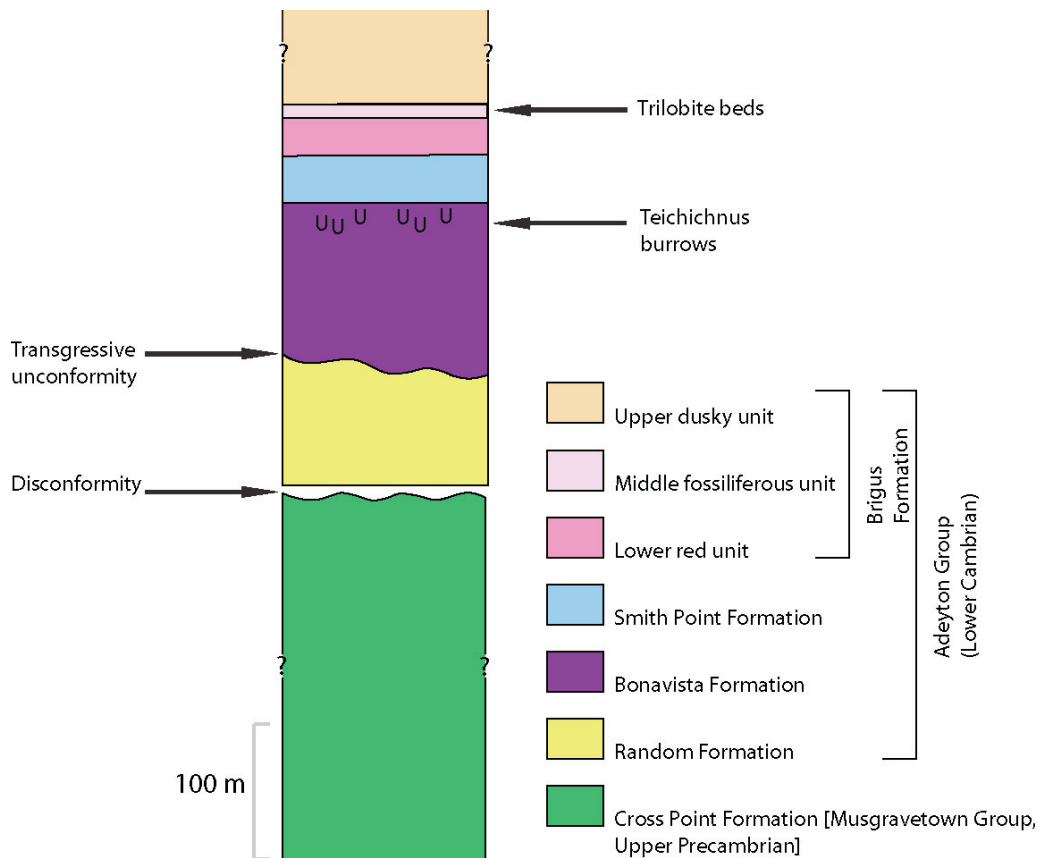## TRACE FOSSILS IN THE BONAVISTA FORMATION

MORPHOLOGY AND INTERPRETATION

The Bonavista Formation (van Ingen, 1914) represents sublittoral zone deposits of dusky purple, red and grey mudstone and siltstone. It lies uncomformably above the interbedded quartzites, sandstones, siltstones and mudstones of the Random Formation (Walcott, 1900) and is conformably overlain by the distinctive pink limestones of the

Smith Point Formation (Hutchinson, 1962; Figure 3). The mudstones are very fine grained (<50 μm) and well consolidated. Carbonate nodule banding is common, and green silty bands are also locally present. In addition, the formation contains intermittent, pink, stromatolitic limestone beds (<1 m thick), which are particularly well exhibited in Deadman's Cove (Figures 2 and 4). These are confined to the lower part of the formation (Fletcher, 2006, pp. 37-40) and are likely to represent either rhythmic shallowing cycles or brief clastic-sediment-starved intervals (Fletcher, 2006, pp. 37-41). The Bonavista Formation is restricted to the west side of the Cape St. Mary's Peninsula, and is absent in the east, where the Smith Point Formation sits directly upon quartzites of the Random Formation (Figure 2).

The best examples of trace fossils in the formation are seen in outcrops on the shore of Distress Cove (Figure 4), in St. Bride's, immediately north of the beach at Bird Island Resort. This location is easily accessed by a wooden staircase at the south end, or by a gravel track at the north end. Bioturbated bedding planes and cross-sectional views are continuously exposed for a distance of over 500 m, in essentially flat-lying to very gently folded strata. Identical burrows can also be observed within the upper parts of the Bonavista Formation at various locations all the way along the coast between St. Bride's and Cuslett (Figures 2 and 4), but access to these is more difficult. The traces can be

Figure 2. *Geological sketch map of the Cape St. Mary's Peninsula. Study area is indicated by red box. Modified from Fletcher (2006).*

Figure 3. *A simplified stratigraphic column of the units mapped in the St. Bride's area. Fossil horizons are indicated.*

rows and the host rock. Waslenschuk *et al.* (1983) discuss the importance of biological irrigation, the process whereby the organism inhabiting the burrow periodically flushes the water inside. From modern examples of shrimp burrows they conclude that such organisms do not flush the water within the burrows with sufficient frequency and vigour. As a result, the burrow waters become relatively enriched in nutrients, sulphides and dissolved organic carbon, causing the burrow waters to be reduced compared to the overlying seawater. The combination of these could explain the reduced burrow fill observed in the St. Bride's *Teichichnus* traces.

There is also a lateral convex-down texture within the burrows, illustrating the sediment filtering process conducted by the organism; such a burrow may be formed by a deposit feeder moving back and forth in a horizontal direction whilst continually shifting its burrow upward through the sediment (Ekdale and Berger, 1978). The burrows were identified as belonging to the *Teichichnus* ichnogenus (Häntzschel, 1975), and, more specifically, we propose that they are of the form *Teichichnus rectus* (Seilacher, 2007; Figure 5) due to their straight branches and changeable geometry.

observed as elongate grey features, up to 150 mm long, on red to purple bedding planes, and the traces have no preferred orientation (Plate 1A). On surfaces normal to bedding, they appear as vertical features, up to 50 mm in depth, that clearly crosscut bedding (Plate 1B). The width of the traces ranges from 8 to 20 mm. This is large in comparison to the majority of burrow trace fossils, but is comparable to the widths discussed by Seilacher (2007). In some places, the burrows comprise up to 40 percent of the rock. They are visually spectacular, and cover most of the bedding surfaces in the section.
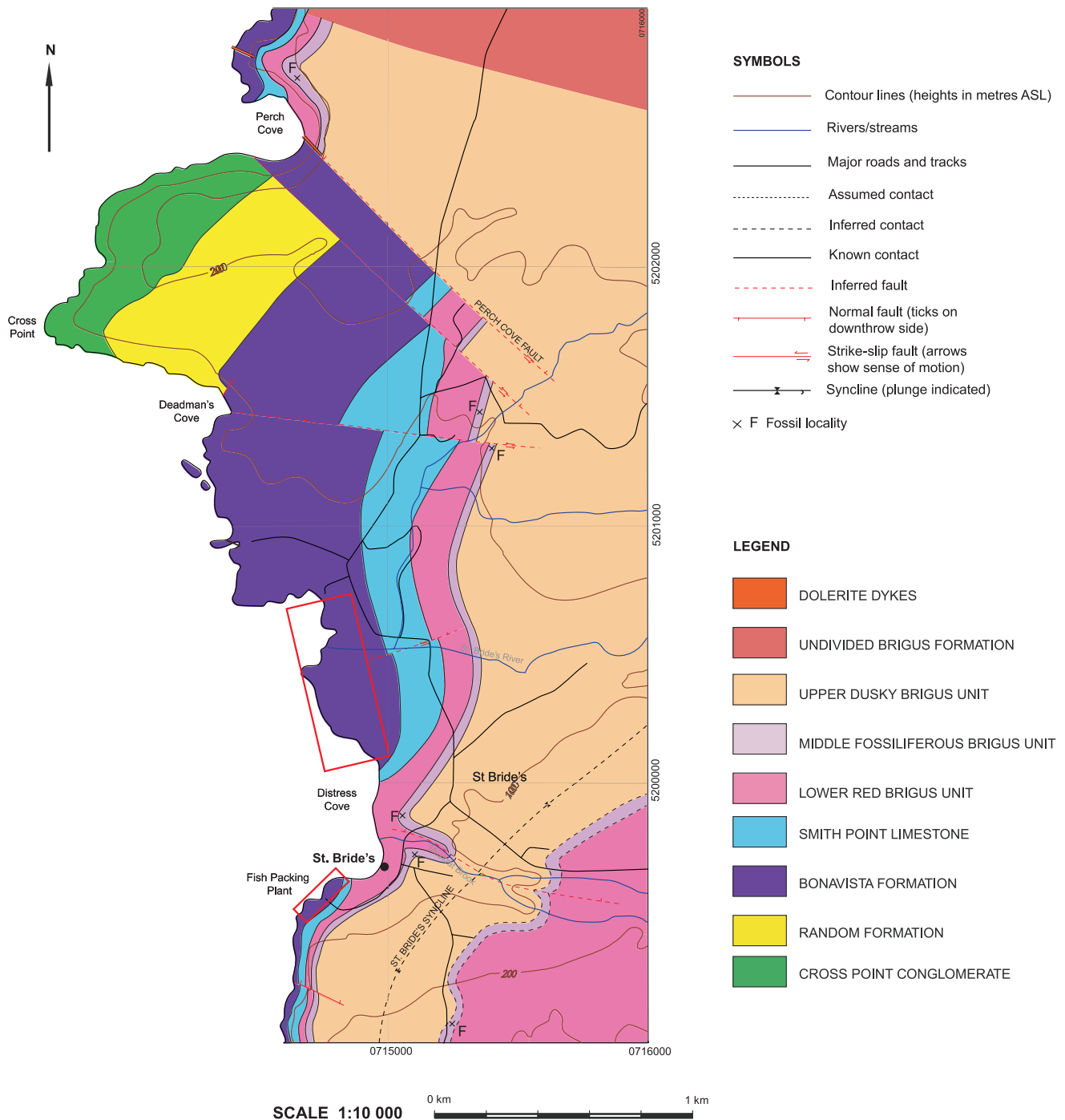
In the field, one can observe that there is a definite internal spreiten structure. The traces are defined by more than simple colour variations. They are filled with green-grey sandy sediment, slightly coarser than that of the surrounding mudstone, with a general downward progression from bedding planes (Plate 1B). The lithological contrast between the host sedimentary rock and the burrow fill suggests that sand has been brought down from an overlying bed. The change in porosity and permeability within the burrow fill may provide higher pore fluid volumes, resulting in variable reduction/oxidation conditions between the bur-

Local environmental factors were probably the primary control on trace-fossil distribution. Substrate and salinity are proposed as the main influences on ichnodiversity and size in the contemporaneous Caerfai Group of southwest Wales, UK (Loughlin and Hillier, 2010); *Teichichnus* burrows here generally have widths in the range of approximately 10 to 20 mm, although in the St. Non's Sandstone, where the traces are most abundant, the width of the burrows can be up to 31 mm. These widths are comparable to those within the Bonavista Formation (8 to 20 mm), suggesting that the producing organism was of a similar size in both locations. However, the depth of burrows in the St. Non's Sandstone reaches 93 mm, with lengths up to 720 mm, much greater than those observed in the Bonavista Formation. This sug-

SYMBOLS

————	Contour lines (heights in metres ASL)
————	Rivers/streams
————	Major roads and tracks
··············	Assumed contact
- - - - -	Inferred contact
————	Known contact
- - - - -	Inferred fault
——┬——┬——	Normal fault (ticks on downthrow side)
⇐	Strike-slip fault (arrows show sense of motion)
——×—▸	Syncline (plunge indicated)

× F Fossil locality

LEGEND

🟧	DOLERITE DYKES
🟥	UNDIVIDED BRIGUS FORMATION
🟧	UPPER DUSKY BRIGUS UNIT
🟪	MIDDLE FOSSILIFEROUS BRIGUS UNIT
🟪	LOWER RED BRIGUS UNIT
🟦	SMITH POINT LIMESTONE
🟪	BONAVISTA FORMATION
🟨	RANDOM FORMATION
🟩	CROSS POINT CONGLOMERATE

SCALE 1:10 000

0 km 1 km

Base map is © 1985. Her Majesty the Queen in right of Canada. Department of Energy, Mines and Resources.

Figure 4. *Geological sketch map of the St. Bride's area showing the main rock types and structural features and the trilobite fossil localities discussed in the text (marked with an F). The red boxes highlight the areas in St Bride's where the best* Teichichnus *exposures may be found. These trace fossils are abundant in the strata within Distress Cove, although they may be found elsewhere in the upper parts of the Bonavista Formation along the coast up toward Cuslett.*

Plate 1. *Photos of* Teichichnus rectus *burrows from outcrops on St. Bride's beach. A) shows the distribution of burrows across a bedding plane surface; B) shows cross-sections through burrow traces that display a stacked spreiten structure.*

gests that perhaps the depositional environment of the Caerfai Group was more enriched in nutrients relative to that of the Bonavista mudrocks.

The proposed depositional environment of the St. Non's Sandstone is the proximal reaches of a delta, which experienced reduced salinity and possibly higher oxygen levels (Loughlin and Hillier, 2010). Salinity is known as a critical factor for the majority of types of benthic life. Only euryhaline organisms of brackish and hypersaline environments are able to adjust to different osmotic pressures (Bromley, 1996). Trace-fossil assemblages from brackish paleoenvironments commonly show low diversity and are dominated by a single ichnotaxon, for example *Teichichnus,* as discussed by Bromley (1996). The association of *Teichichnus* and reduced salinity environments is persistent throughout the entire geological record (Buatois *et al.*, 2005).

During the lower Paleozoic, *Teichichnus* burrows are known to have formed within shallow level tiers (McIlroy and Logan, 1999) and are placed within the *Cruziana* ichnofacies for brackish, sublittoral paleoenvironments (*e.g.*, Pemberton *et al.*, 1992; Van Wagoner and Bertram, 1995). Several authors suggest marginal marine to marine conditions (*e.g.*, Taylor and Gawthorpe, 1993; Martin and Pollard, 1996). These indications as to the environment of deposition correlate with original interpretations that the Bonavista Formation was
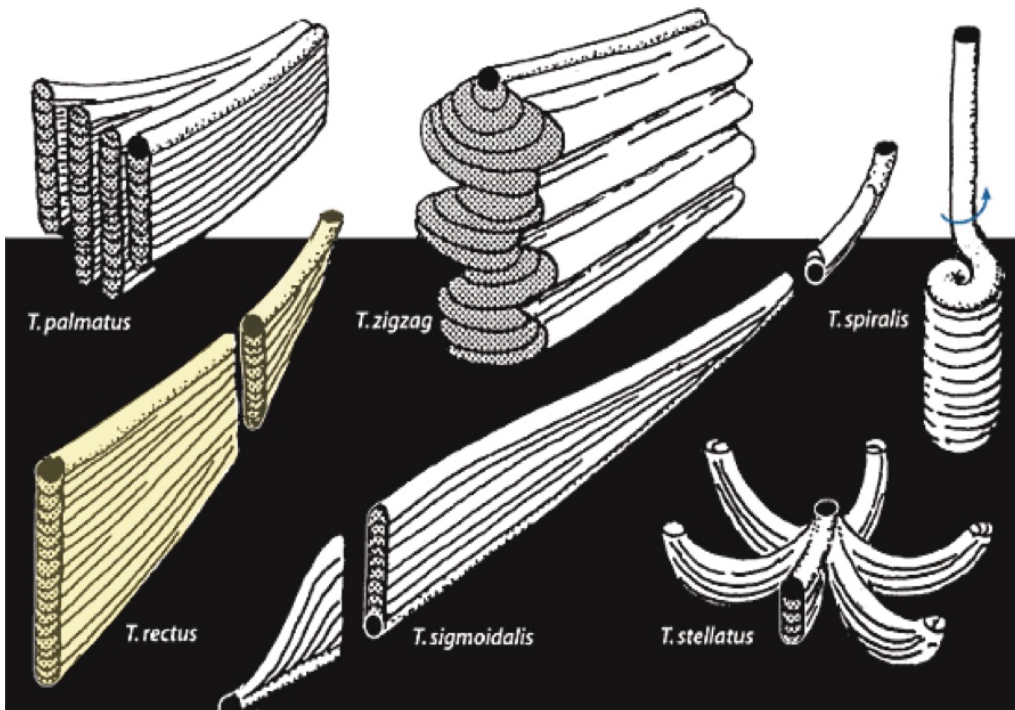
Figure 5. *The range of* Teichichnus *burrows described by Seilacher (2007). Due to the simple, straight branches observed in the field, we have classified our traces as* Teichichnus rectus *(highlighted). Modified from Seilacher (2007).*

laid down in a subtidal setting as a transgressive onlapping unit (*e.g.*, Fletcher, 2006, p. 37). From the fairly simple, straight branches of the traces we infer that the environment was relatively enriched in nutrients. However, one could also argue that as the traces are phobotactic, that is to say they do not overlap one another, the environment may have been depleted in nutrients (Seilacher, 2007).

No body fossils are identified at St. Bride's, or elsewhere, in the Bonavista Formation, that could pinpoint the organism responsible. Organisms that have previously been suggested as producers of *Teichichnus* include annelids (Buatois *et al.*, 2005; Farrow, 1966), arthropods (Buatois *et al.*, 2005) and crustaceans (Stanton and Dodd, 1984).

IMPORTANCE FOR CORRELATION PURPOSES

The appearance of *Teichichnus rectus* within the Bonavista Formation has been recorded elsewhere in Newfoundland, *e.g.*, by McIlroy and Logan (1999) and Landing *et al.* (1989). *Teichichnus* traces have also been identified in correlative units in parts of Nova Scotia (*e.g.*, Landing, 1995).

Perhaps of most significance is the potential for correlation across the Avalon Zone and correlative regions. As mentioned above, *Teichichnus* occurs in the Caerfai Group of southwest Wales, within which the St. Non's Sandstone appears to correlate temporally with the Bonavista Formation in Newfoundland (Loughlin and Hillier, 2010). McIlroy *et al.* (1998) also discuss the possibility of a correlation in their work, due to the presence of *Teichichnus* traces in the Early Cambrian Swithland Formation of the Charnian Supergroup in the English Midlands. In addition, *Teichichnus* has been documented in Early Cambrian rocks across Laurentia (*e.g.*, Landing and Bartowski, 1996; Desjardins *et al.*, 2010) and Baltica (*e.g.*, Clausen and Vilhjálmsson, 1986; McIlroy and Logan, 1999). Even farther afield, *Teichichnus rectus* may be found in Proterozoic–Cambrian boundary rocks in Pakistan (Seilacher, 2007). Thus it would seem that the organism forming the traces was widespread, maybe even more so than is recorded in the literature, since the lack of *Teichichnus*-dominated beds in certain locations may be due simply to a lack of suitable facies for preservation (McIlroy *et al.*, 1998).

The first appearance of *Teichichnus* in the Avalon terrane occurs in the *Rusophycus avalonensis* ichnozone in the upper half of Member 2 of the Cambrian Chapel Island Formation (*e.g.*, Narbonne *et al.*, 1987) but the trace does not become pervasive until the higher *Teichichnus* ichnozone of Newfoundland, which occurs within the Bonavista Formation (McIlroy *et al.*, 1998). *Teichichnus* is unknown below the base of the Cambrian and as such, McIlroy *et al.* (1998)

regard it as "unequivocal evidence for sediments laid down above the Precambrian–Cambrian boundary."

TRILOBITES IN THE BRIGUS FORMATION

The trilobitic fossil localities are found within the Brigus Formation (van Ingen, 1914), which consists of a series of very fine-grained (<50 μm) mudrocks of varying hues. The Brigus Formation has lithological similarities to the Bonavista Formation, and is inferred to have been deposited in a similar subtidal setting, although it was probably slightly deeper as a result of transgression. The rhythmic shallowing cycles of the Smith Point Formation, in which the first trilobites in the Cambrian of Newfoundland appear, separate these two subtidal sequences (Fletcher, 2006, pp. 42-45; Figure 3).

In the St. Bride's area, we have divided the Brigus Formation into three unnamed units. The lower unit is a deep red, well-consolidated mudstone. It is generally quite featureless, although at its base it contains carbonate nodules, similar to those seen in the Bonavista Formation. It also contains green reduction spots. The upper unit consists of well-consolidated beds of dusky red, purple, grey and orange mudstone. These two units likely correspond to Unit I and Unit III respectively of the Redland Cove Member of the Brigus Formation, as defined by Fletcher (2006, pp. 47-53).

The middle unit of the formation is fossiliferous. It is a thin unit of grey mudrock, with a maximum of approximately 6 m thick. Most notable is a 2- to 3-m-thick bed thought to correspond to the base of the Redland Cove Member Unit II of Fletcher (2006; T. Fletcher, personal communication, 2010). This is rich in fossils, mostly trilobites and brachiopod shells (Plate 2). The size of the trilobites ranges from <5 mm up to 5 cm. A pervasive, Acadian cleavage (Fletcher, 2006, p. 95) makes the rocks quite friable. As such, the fossils are usually preserved as fragments, but one nicely preserved death assemblage of articulated trilobites is found on St. Bride's beach (Figure 4; Plate 2). Other fossil localities include the cliffs above Perch Cove, the cliffs by the wharf in St. Bride's, and by a track that leads east from St. Bride's, from the road between St. Bride's and Cuslett (Foley Hill; Figure 4).

Due to the scattered nature and variable quality of the outcrops, it is difficult to ascertain whether all these localities represent the same fossiliferous horizon, but the differing nature of the specimens, in terms of size and preservation, could be explained by them belonging to different horizons within the unit. The locations are indicated in Figure 4, and some of the better specimens are shown in Plate 2. Fossils had previously been observed in the St. Bride's area by
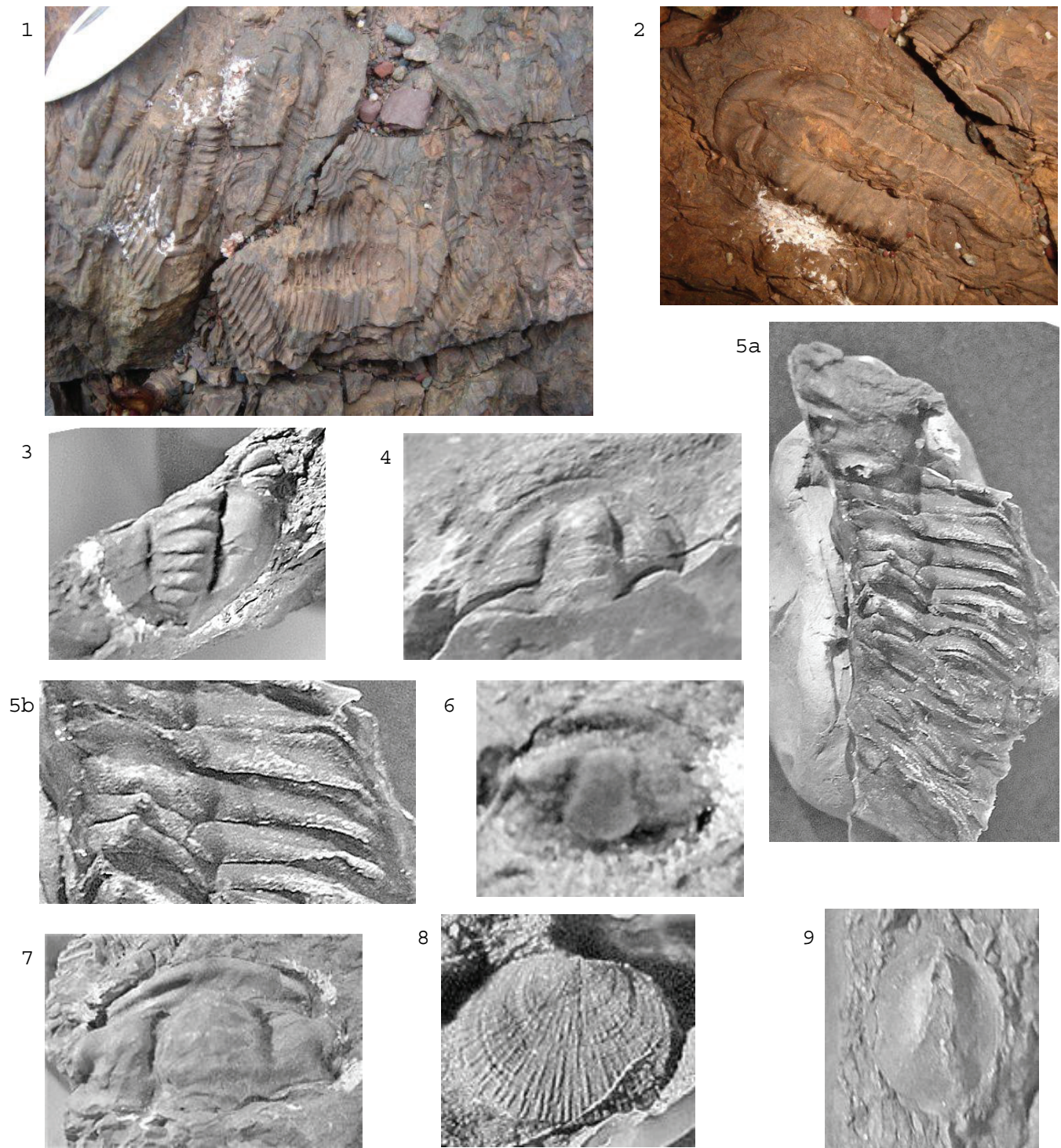
Plate 2. *Caption opposite page.*

T. Fletcher (personal communication, 2010) but not examined in detail or their localities depicted on maps.

The specimens were taken to the Natural History Museum, London, where they were identified by Adrian Rushton.

Plate 2 displays key identified specimens of both trilobites and brachiopods. *Strenuella sabulosa* Rushton, 1966 is, by far, the most abundant of the specimens observed and therefore the identified trilobites are referable to the *Strenuella sabulosa* Zone (Fletcher, 2006, p.52).

Plate 2. (opposite page) *A selection of trilobites and brachiopods from the middle fossiliferous unit of the Brigus Formation, St. Bride's. Localities include Distress Cove, Perch Cove and by the track leading east from St. Bride's, on Foley Hill. All the specimens are assigned to the* Strenuella sabulosa *Zone. All specimens, except for images 1 and 2, are housed in the Natural History Museum, London.*

Image 1. A field photo of an assemblage of numerous trilobite specimens observed in the field near the wharf, in the cliffside at St. Bride's beach. Fragmentary specimens visible with clear disturbance caused by cleavage planes. Pen knife for scale (approximately 1 cm width).

Image 2. Close up view. Length of central specimen = 38 mm.

Image 3. Serrodiscus bellimarginatus *Shaler and Foerste, 1988. Pygidium. Measurements as preserved: width = 7.5 mm; sagittal length (including articulating half-ring) = 5.7 mm. NHM8-0077.*

Image 4. A fragmentary cephalon of a Weymouthiid trilobite, possibly Cobboldites*. Maximum width = 9.2 mm. NHM7-0074.*

Image 5a. Strenuella sabulosa *Rushton, 1966. Latex cast of part of thorax with thoracic axial spines partially preserved. Width of axis = 6 mm; pleural width = 7 mm. NHM1-0082.*

Image 5b. Enlargement of part of the same specimen, showing the granulose sculpture. Estimated length of spines above thorax = <2 mm. NHM1-0083.

Image 6. Dipharus attleborensis *Shaler and Foerste, 1888. Cranidium. Axial length = 2.9 mm; width across eyes = 3.4 mm. NHM1-0072.*

Image 7. Strenuella sabulosa *Rushton, 1966. Cranidium, occipital spine missing. Width across eyes = 20.8 mm; sagittal length (as preserved) = 12.2 mm. NHM4-0080.*

Image 8. Alisina *cf.* atlantica *(?) Walcott, 1890. Latex cast of an external mould. The insertion of ribs is visible toward the anterior margin of the valve. Width = 4.5 mm; length = 3.4 mm; rib density of approximately 7 ribs per mm at the anterior margin. NHM2-0073.*

Image 9. A calcareous brachiopod doubtfully assigned to the Obolellidae. Length = 4.9 mm; width = 3.8 mm. NHM8-0079.

The collected fossils show clear evidence of tectonic deformation, with distortions to their geometries. Numerous cranidium and thoracic fragments of *Strenuella sabulosa* Rushton, 1966 are present. A rubber latex cast of the external surface of the thoracic segments shows the typical granular surface-sculpture of *S. sabulosa*. Other specimens observed include a pygidium and some small cephalon fragments of *Serrodiscus bellimarginatus* Shaler and Foerste, 1888, a cranidium and possible pygidium of *Dipharus attleborensis* Shaler and Foerste, 1888, and some Weymouthiids, *e.g.*, a fragmentary cephalon resembling *Cobboldites (?)*. Small, presumably immature, undetermined eodiscoid trilobites are also present.

Brachiopod specimens were collected from the same localities. Three taxa have been identified, including small *Lingulella* a possible Obolellid (?) (Walcott and Schuchert, 1908 [*in* Walcott, 1908]) and an external mould, resembling *Alisina cf. atlantica (?)* Walcott, 1890.

Although trilobites occur throughout the Brigus Formation across the Avalon Peninsula, it was clear that in our mapping area the fossils were concentrated only in a very distinct 2- to 3-m-thick bed. Speyer and Brett (1986) and Kidwell and Jablonski (1983) state that two sedimentary conditions may be responsible for condensed fossilized sequences:
1) low background rates of sedimentation, allowing fossils to accumulate in condensed beds without dilution, and
2) 'sediment bypassing', whereby persistent currents transport sediment away, preventing it from accumulating and diluting the shell pavement.

Rapid burial by subsequent deposits may then allow for the preservation of the fossil beds. Whereas current or storm wave agitation may be a suitable explanation for the fragmented beds, the more pristine death assemblage on St. Bride's beach has a far more ambiguous provenance due to a paucity of sedimentary structures in the overlying beds. It is presumed here that it must have been preserved due to a period of enhanced net sediment deposition in the water column in an area unaffected (at least temporarily) by current or wave action.

CONCLUSIONS

This report documents new trace fossil and trilobite localities in the St. Bride's area that may be of interest for further studies. Already mentioned is the use of *Teichichnus* in global constraints on the position of the Proterozoic–Cambrian boundary. However, the potential importance of the St. Bride's locality lies more in the abundance of the traces, and their exceptional preservation in three dimensions. This is a possible study area for statistical work aimed at better understanding the geometry, and perhaps origins, of these records of early motile organisms. Further study around the Cape St. Mary's Peninsula (and elsewhere in the Avalon Zone) could expand on our findings and provide a better indication of how common the *Teichichnus* burrows are within the Bonavista Formation on a regional scale, and whether they have value in terms of regional correlation.

The trilobite faunas are consistent with previous findings by T. Fletcher based mostly upon work in the Branch area. They are of interest due to the locally superb preservation of death assemblages, and also may have potential for sedimentological studies intended to better understand how such thin, intensely fossiliferous beds are developed.

Last, but not least, fossil localities are in easily accessible places within the community of St. Bride's, and may thus be of interest for geotourism and educational purposes, especially given their proximity to the Cape St. Mary's Ecological Reserve.

ACKNOWLEDGMENTS

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