



## Early Cambrian *Teichichnus*-dominated ichnofabrics and palaeoenvironmental analysis of the Caerfai Group, Southwest Wales, UK

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### ABSTRACT

The early Cambrian Caerfai Group of Pembrokeshire in Southwest Wales yields an intensely bioturbated *Teichichnus*-dominated ichnofabric, and provides evidence for the early evolution of infaunal organisms. Three units of the Caerfai Group comprise the focus of this study in sections exposed at Caerfai Bay. In the St. Non's Sandstone few primary sedimentary structures are observed, bedding being predominantly massive with subordinate parallel and current ripple cross-lamination. The topmost St. Non's Sandstone contains common soft-sediment deformation phenomena, and collectively deposition is believed to have taken place in the proximal subaqueous reaches of a steep-fronted delta system. *Teichichnus* is the dominant trace, with subordinate *Planolites*, *Palaeophycus* and possible *Rhizocorallium*.

The overlying Caerfai Bay Shales were deposited from mass flows with evidence of downslope creep suggesting deposition on a steep delta front. Sandstone debrites are common, as are tuffaceous beds with evidence of reworking by bottom currents. Sandstone and tuff event beds contain common *Skolithos* and *Arenicolites* with less frequent *Planolites*. Interbedded mudstones contain infrequent *Teichichnus*.

The Caerfai Bay Shales coarsen and thicken-upwards into the Caerbwdy Sandstone. Debrite sandstone beds dominate, and bed thickening upsection indicates progradation of the delta system. The dominant trace fossil within the unit is *Teichichnus* which is constrained to the top few centimetres of individual sandstone beds. Less common are *Planolites* and *Palaeophycus*.

The size and abundance of *Teichichnus* in the Caerfai Group are similar to, or exceed those in contemporaneous sections in Avalonia and Baltica. 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 Caerfai Group. *Teichichnus* is most abundant in the St. Non's Sandstone, where the proximal reaches of the delta experienced reduced salinity and possibly higher oxygen levels. Burrow diameter progressively decreases upsection, and bioturbation becomes less pervasive in subsequent units of the Caerfai Group. This indicates that by the Cambrian Stage 2, significant advances into reduced salinity environments had occurred, along with the dispersal of the *Teichichnus* producer throughout the Avalonia-Baltica seaway. Correlation within Avalonia indicates that a transgression in the Cambrian Stage 2 initiated the deposition of the Caerfai Group marking the onset of the Welsh Basin.

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### 1. Introduction

Trace fossils are abundant before the first appearance of hard part macrofauna in the fossil record (Seilacher, 1956; Crimes, 1974, 1992) and have been used to correlate regional and global stratigraphy at the Proterozoic–Phanerozoic boundary (Crimes, 1975, 1987; Alpert, 1977; Narbonne et al., 1987; Seilacher et al., 1998; Jensen et al., 2000). Indeed, the Precambrian–Cambrian boundary is defined on the earliest appearance of *Trichophycus pedum* (Seilacher, 1955; Babcock and Peng, 2007) (or *Treptichnus pedum*, formally *Phycodes pedum*) in the Global

Standard Stratotype and Point (GSSP), located in the Chapel Island Formation of Newfoundland (Narbonne et al., 1987; Gehling et al., 2001). In this *T. pedum* Zone (Geyer and Uchman, 1995) an increase in complexity and diversity of biogenic structures has been recognised (Crimes, 1987, 1992), with the evolution of spreiten structures and more elaborate three-dimensional burrows associated with the development of diverse marine ecosystems, deeper infaunal penetration, and intricate tiering patterns. The onset of vertical bioturbation and associated mixground development led to a reduction in matground-based shallow water ecosystems during the “Cambrian Explosion” of phyla diversification (Crimes, 1992; Seilacher et al., 2005).

In this paper we document an “intermediate” example between simple and more complex burrow forms preserved in the Lower Cambrian of the St. David's Peninsula, southwest Wales, and speculate

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on its age. We also detail the palaeoenvironmental context, re-interpreting the previous depositional facies model of a siliciclastic shelf to that of a steep-fronted delta.

## 2. Geological and Palaeontological context

The early Cambrian Caerfai Group lies unconformably on the Precambrian Peibidian Volcanic Complex (Figs. 1 and 2; Hicks, 1877; Green, 1908; Cox et al., 1930; Williams and Stead, 1982). Radiometric dating of the St. David's Granophyre (which is the youngest Peibidian component) and has provided a U–Pb date of  $587 \pm 25/-14$  Ma (Patchett and Jocelyn, 1979) providing a minimum age for the Peibidian Supergroup (Fig. 2). The structure and stratigraphy of the section was initially described by Murchison (1839) and subsequently by Salter (1857), Harkness and Hicks (1871), Hicks (1877, 1878) and Geikie (1883). More recent work has focused on the sedimentology (Turner, 1979) and micropalaeontology (Siveter and Williams, 1995) of the Group, or constitutes a general overview (Crimes, 1970; Prigmore and Rushton, 1999) with no systematic description of ichnology. Sections described in this study are primarily those exposed on the east-side of Caerfai Bay, on the southern coastline of the St. David's peninsula (Fig. 1; Williams and Stead, 1982).

The Caerfai Group comprises a basal Conglomerate Division, the St. Non's Sandstone, Caerfai Bay Shales and Caerbwdy Sandstone (Fig. 2; Cowie et al., 1972; Williams and Stead, 1982), the latter three units forming the focus of this study. The base of the Random Formation in eastern Newfoundland contains conglomerates that have been related to several of the contemporaneous sections (McIlroy et al., 1998) and may therefore reasonably correlate with the basal Conglomerate Division of the Caerfai Group. If this is the case then a significant unconformity is present through the Ediacarian and Cambrian Stage 1 of Pembrokeshire (Fig. 2).

The boundary between the St. Non's Sandstone and Caerfai Bay Shales is consistently faulted throughout the St. David's peninsula, and in the study area the transition has been intruded by a dolerite dyke. Landing et al. (1998) suggested an unconformable contact separating the St. Non's Sandstone and Caerfai Bay Shales; this has not been confirmed in this study, although the presence of a paraconformity cannot be dismissed.

The Caerfai Bay Shales have yielded the oldest Cambrian body fossils in Pembrokeshire, though collections were made from localities other than Caerfai Bay (Siveter and Williams, 1995). The specimens comprise the bradoriid crustacean *Indiana? lentiformis* (Cobbold, 1921) as identified by Siveter and Williams (1995), with a probable trilobite fragment and a specimen of *Coleoloides? sp.* Fragments of

the brachiopod *Lingulella primaeva* were identified by Hicks (1871), though these were later redescribed as a cephalic fragment of *Olenellus* (see Hicks, 1892). Pringle (1908) identified the presence of a single hypostome of *Olenellus* (see discussion in Cox et al., 1930), conspecific with further specimens collected by Pringle and George (1948). Siveter and Williams (1995) studied new and previously collected material, identifying the bradoriid crustacean *I? lentiformis* that they consider equivalent to earlier described specimens of Pringle (Cox et al., 1930) and Pringle and George (1948). *I? lentiformis* is currently the only reliable biostratigraphic indicator in the section of interest, correlating with the Lower Comley Sandstone (Ac2) in Shropshire (Cobbold, 1921; Cobbold and Pocock, 1934) and provides a Cambrian Series 2 age for the Caerfai Bay Shales. Landing et al. (1998) used volcanic zircons from an ash layer in the Caerfai Bay Formation to give a U–Pb date of  $519 \pm 1$  Ma.

*Teichichnus* Seilacher (1955) are frequently observed within the Caerfai Group (Fig. 2), being the primary contributor to bioturbation in the St. Non's Sandstone, Caerfai Bay Shales and Caerbwdy Sandstone. *Teichichnus* is a spreiten structured trace fossil that first appears in the earliest Cambrian (Crimes, 1987, 1989, 1992) and represents the repetitive infaunal activity of a deposit-feeding organism. The presence of a *Teichichnus*-dominated ichnofauna places the Caerfai Group above the *Trichophycus pedum* Ichnozone, within either the *Rusophycus avalonensis* Ichnozone or the succeeding *Teichichnus* Interval (Landing, 1994)/*Cruziana tenella* Ichnozone (Macnaughton and Narbonne, 1999). It is comparable to the *Teichichnus*-bearing beds that occur throughout the latter ichnozones in south-east Newfoundland, the English Midlands and North Wales (Landing, 1992; Brasier, 1992; McIlroy and Logan, 1999). This therefore suggests that deposition of the St Non's Formation occurred within the Cambrian Stage 2. Evidence for a widespread Avalonian-Baltic *Teichichnus* ichnofabric is observed throughout the Early Cambrian (Table 1) aiding in the development of a unified regional stratigraphy.

## 3. Sedimentology and ichnology of the Caerfai Group

### 3.1. Basal Conglomerate Division

The oldest Cambrian unit of the St. David's peninsula is the basal Conglomerate Division consisting of cross-bedded and massive red/brown, granule to boulder-grade exotic clast conglomerates with subordinate sandstone interbeds (Green, 1908; Crimes, 1970). The Conglomerate Division has been interpreted as deposits of an alluvial fan, overlain by braided fluvial and finally transgressive shoreface sediments (A. Rees, personal communication 2007). In topmost beds

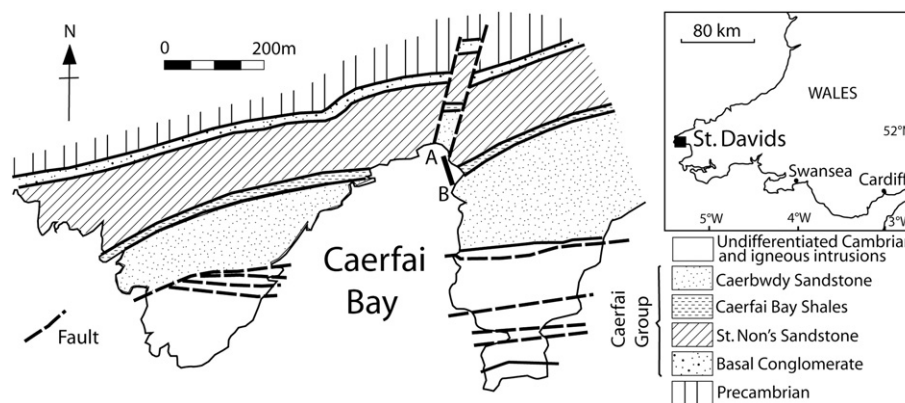


Fig. 1. Location map of the study area (UK National Grid Reference SM 762 243). A–B represents the logged section through the St. Non's Sandstone, Caerfai Bay Shales and Caerbwdy Sandstone.

Modified after Williams and Stead (1982).

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