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Trace Fossils in the Permian Rocks of English Riviera UNESCO Global Geopark

Malcolm B. Hart [1,*], Christopher W. Smart [1]

[1]School of Geography, Earth & Environmental Sciences, University of Plymouth, Drake Circus, Plymouth PL4 8AA, UK

Corresponding Author:
Malcolm B. Hart
School of Geography, Earth & Environmental Sciences, University of Plymouth, Drake Circus, Plymouth PL4 8AA, UK
Email: M.Hart@plymouth.ac.uk

Abstract

The Permian breccias, conglomerates and sandstones of the English Riviera UNESCO Global Geopark were deposited in quite harsh, desert environments just north of the Permian Equator. Body fossil evidence is completely lacking but rare trace fossils provide evidence of a land-based community. There is a variety of traces present, probably indicative of the presence of a range of unknown animals. Though these animals cannot be identified, their occurrence is important in the understanding of the biodiversity of these Permian environments.

Keywords: Trace fossils, Permian, Devon, Desert environments

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Introduction

The English Riviera UNESCO Global Geopark is located on the east-facing coastline of South Devon (Figs 1, 2). It lies within the Variscan Orogenic Belt, which crosses South-West England from west to east. The main tectonic events were in the Carboniferous, when the Rheic Ocean finally closed (Leveridge and Shail 2011 and references therein). At this time, South-West England was located just north of the Equator (Hart 2012, fig. 2), and included in the 'super-continent' of Pangaea. With a major southern-hemisphere glaciation in progress, sea levels were low, and much of Pangaea was terrestrial and subject to – at the palaeolatitude of the English Riviera – desert-like conditions. In the Torquay area (Figs 2, 3), the folded strata of the Devonian are overlain by the terrestrial deposits of the Permian, and this major unconformity is seen immediately south of Goodrington (Fig. 4A, B) and in Waterside Cove. The lowermost sediments are coarse breccias and conglomerates, with interbedded finer-grained sandstones and rare siltstones which can be traced along the coastline of Devon north of Torquay (Benton *et al*. 2002; Gallois and Mather 2016; Coram and Radley 2016). In the lower parts of the succession, west of the River Exe, most of the sediments were deposited intermittently during rare flooding events, such as those seen in modern Middle Eastern wadis (Hart 2012, fig. 17A, B). The breccias and conglomerates are dominated by rounded to sub-angular boulders and cobbles of the local Devonian limestones, occasional fragments of slate and rare igneous rocks (not including the Dartmoor granite, which was intruded close to the Carboniferous/Permian boundary; see Chesley *et al*. 1993). These are not encouraging environments in which to look for body fossils but, in a few places, trace fossils are known. These provide the only evidence of life-forms existing in the harsh environments of these Pangaea deserts and are, therefore, exceptionally important.

Location

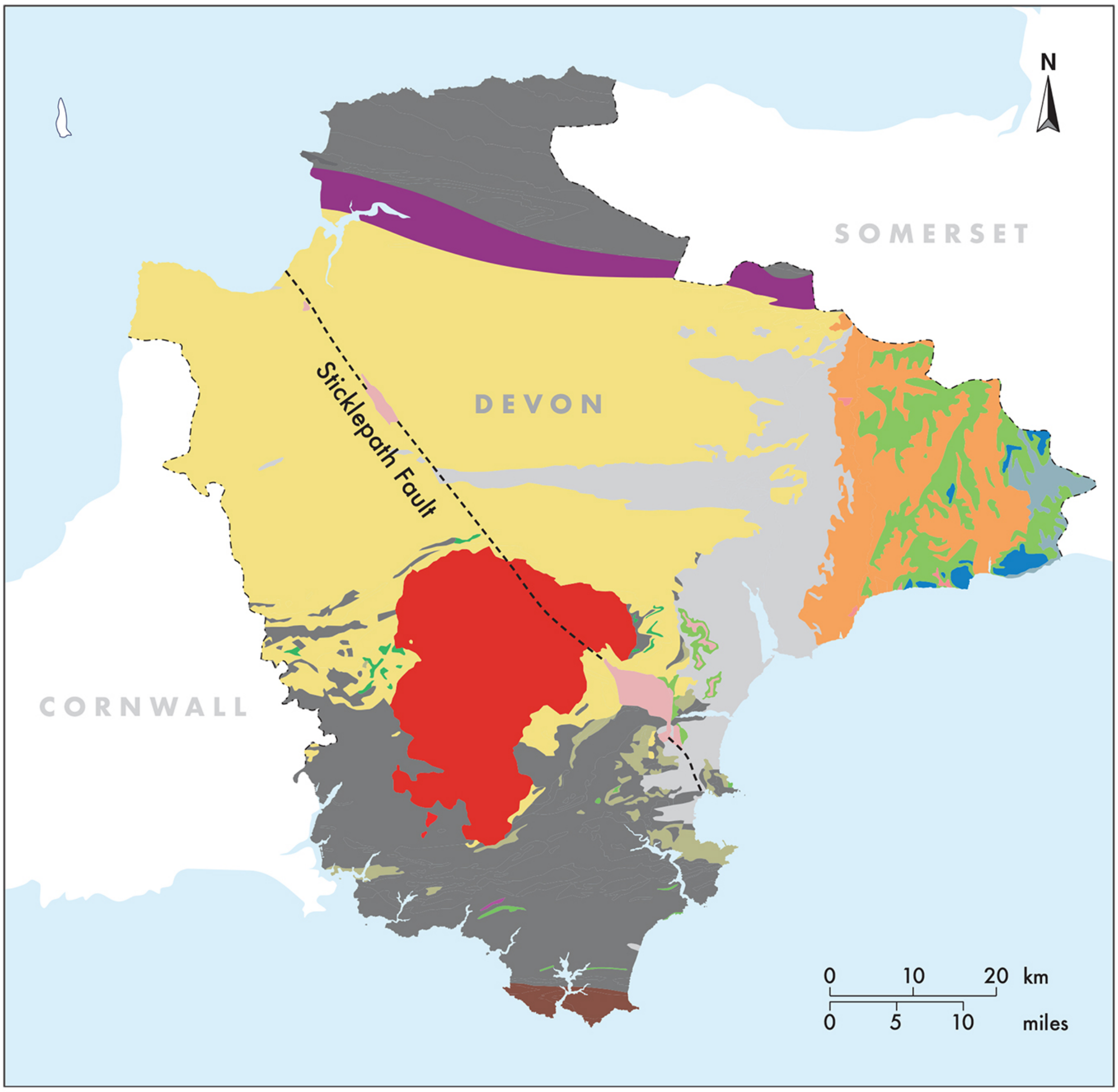
The English Riviera UNESCO Global Geopark is located on the eastern coastline of South Devon (Figs 1, 2). The boundary of the Geopark territory is that of the Torbay Unitary Authority and, as such, follows no geological or physical features. While the coastline provides the obvious access to the geological features, there are many inland quarries which are, unfortunately, either overgrown, built over, or infilled. In a few locations there are exposures in roadside cuttings.

The marine area of Tor Bay is enclosed between two, prominent headlands; Hope's Nose in the north and Berry Head in the south. These headlands are composed of resistant Devonian rocks, while the intervening area (forming the 'bay') is formed mainly of softer, Permian sandstones, conglomerates and breccias.

Trace Fossils

A trace fossil, or ichnofossil (Greek, *ikhnos*, trace, track) is any disturbance or modification of sediment caused by the activities of an animal (or, in some cases, plants). Traces can range from the obvious borings in shells, reptile footprints and worm burrows to pervasive mottling as a result of the complete mixing of sediment. Trace fossils are, therefore, a record of biological activity but can only rarely be linked to any specific animal. The International Commission on Zoological Nomenclature (ICZN) adjudicates on the names of trace fossils, and although many ichnologists consider structures formed by plants as trace fossils and have also given them names, these are not recognized as such by the International Code of Botanical Nomenclature (ICBN) which deals with plants (including algae and fungi).

There are several published classifications of trace fossils, most of which are based on their presumed mode of formation or their assumed purpose. For example, *domichnia* (dwellings), *repichnia* (creeping and crawling), *fodinichnia* (feeding by deposit feeders), *pasichnia* (surface feeding traces) and *cubichnia* resting traces) are all in wide usage and originate from work by Seilacher (1953). The simplest classifications refer only to



Clays and sands of the Bovey Basin (Eocene/Oligocene)
Chalk (upper Cretaceous)
Upper Greensand of S.E. Devon and Blackdown Hills(Cretaceous)
Jurassic of the Axe Vally and Uplyme
Sandstones and mudstones (Triassic)
Breccias and sandstones (Permian)
Dartmoor granite batholith
Culm measures of mid-Devon (Carboniferous)
Devonian strata of north and south Devon
Devonian limestones of Plymouth, Brixham, Torquay and Newton Abbot
Devonian strata of north and south Devon
Devonian rocks of the Start complex

Figure 1. Geological map of Devon, based on published data of the British Geological Survey.

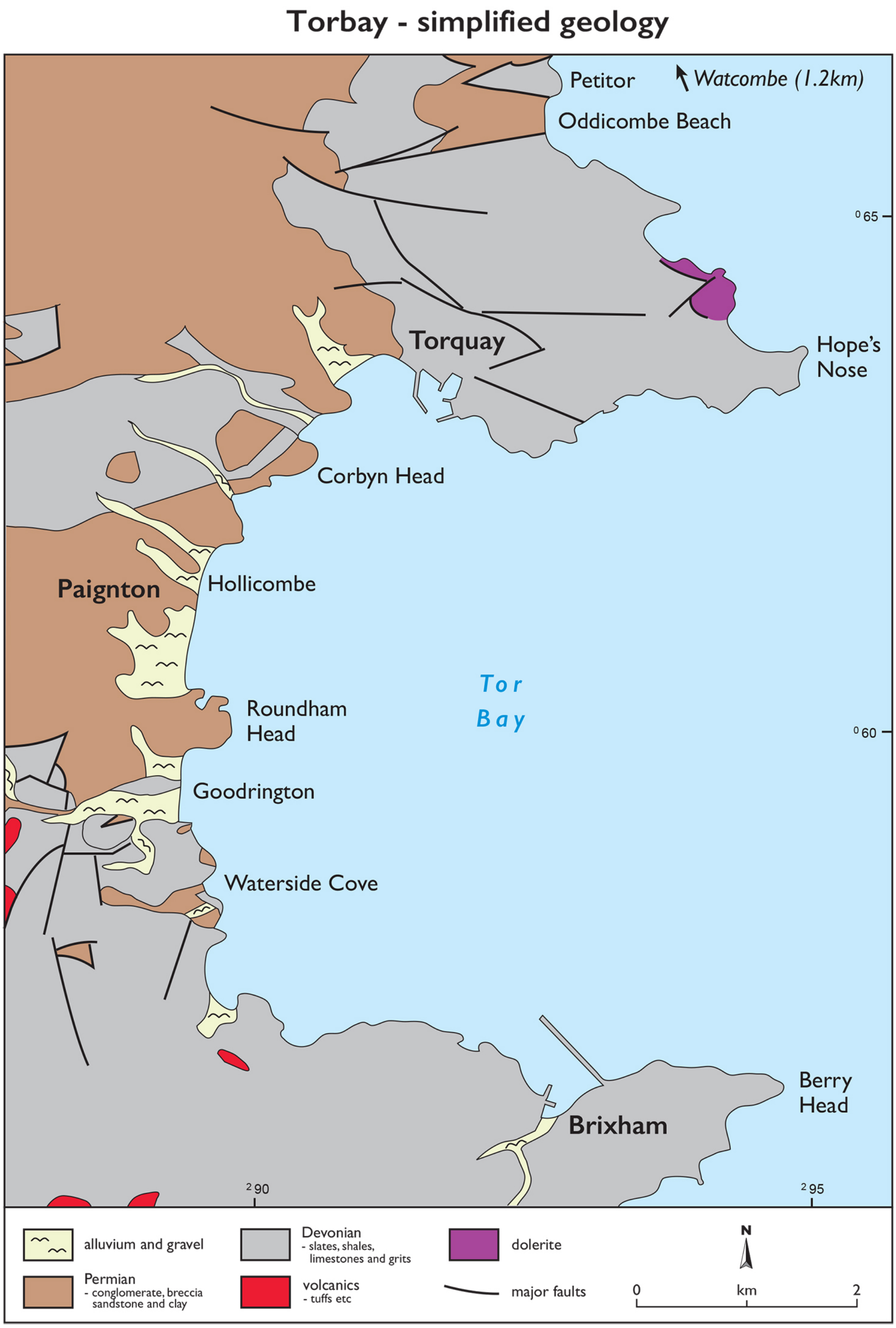


Figure 2. Simplified geological map of the English Riviera UNESCO Global Geopark.

the morphology and do not imply any direct mode of formation. Trace fossils from the Permian rocks of Devon can be classified as *endichnial*, a structure preserved within the sediment, or *exichnial* traces (on the sediment surface). The latter are crustacean trails (Shapter 1842) and reptile footprints (Clayden 1902) preserved on the surfaces of Permian sandstones in inland quarries.

Presumed annelid burrows were recorded by Pengelly (1864) in the Torbay Breccia at Goodrington, and Ussher (1877) observed the presence of 'numerous annelid tracks' in the Watcombe Formation above Watcombe Cove (Fig. 2). Henson (in Selwood *et al*. 1984) noted that 'thin burrows were common' in the tops of graded sedimentation units in the Watcombe Formation in outcrops in the Watcombe valley.

Some of the best-known examples of trace fossils are from the Goodrington area, especially in Waterside Cove. These have been described by Laming (1969), Henson (1971), Perkins (1971), Ridgeway (1974, 1976), Pollard (1976), Selwood *et al.* (1984), Gallois and Mather (2016), Coram and Radley (2016) and Falcon-Lang (2019).

Structures attributable to animal burrows are generally rare. They are, however, relatively abundant in a few thin (<0.5 m thick) beds immediately above the base of the Torbay Breccia Formation near Waterside Cove, Goodrington [UK Grid Reference SX 896 587], and in the Watcombe Formation at Petit Tor Beach [SX 926 664] and in Watcombe Cove [SX 926 763]. Trace fossils are especially common in almost all the fallen blocks of this material at Petit Tor Beach and at Watcombe Cove. Poorly preserved structures that might be attributable to animal burrows were recorded by Gallois and Mather (2016) in the Torbay Breccia at Paignton as well as in the Teignmouth Breccia at Maidencombe Beach [SX 928 684] and Ness Beach, Shaldon [SX 940 718]; both localities being just outside the Geopark.

Locations

While trace fossils are known from a few places within the English Riviera UNESCO Global Geopark, there are two significant locations in Waterside Cove and Watcombe Cove where such fossils are regularly encountered. These, and other locations outside the Geopark, have recently been described by Gallois and Mather (2016) and Coram and Radley (2016).

Waterside Cove

Endichnial burrows are relatively common at a few stratigraphical levels *in-situ* and in fallen blocks of the lowest part of the Torbay Breccia near Waterside Cove (Figs 2, 3), and in fallen blocks of Watcombe Formation at Watcombe Cove. They occur in sandstone interbeds within the predominantly breccia-rich successions.

At the southern end of Goodrington Sands, south of Paignton, is an outcrop of Meadfoot Group (Lower Devonian) sandstones and siltstones that are spectacularly folded into recumbent, north-ward verging, overfolds (Fig. 4A). These are stained red by the overlying Permian succession, with the unconformity visible by the railway bridge, as well as in Waterside Cove (Fig. 4B) to the south.

The burrows observed on the foreshore rock platforms are large (<150 mm diameter and commonly >1 m long), unbranched, both straight and sinuous, with well-developed meniscus fills (Fig. 5A). The Waterside Cove trace fossils have been illustrated by Laming (1969, fig. 3) and Perkins (1971, fig. 38). The latter suggested that the burrows had been created by a worm-like creature that could ingest small pebbles, though this appears to be rather unlikely. A detailed description of the burrows is provided by Henson (1971) who thought that they were most probably made by reptiles for occupation or in search of food. In the most complete description of the Waterside Cove burrows to date, Ridgeway (1974) concluded that the trace fossils were made by primitive burrowing

Age	Formation	Thickness m	Predominant lithologies: depositional environments	Localities with trace fossils and *possible trace fossils*
early Triassic	Exmouth Mudstone and Sandstone	250	red-brown mudstone with lenticular sandstones: playa lakes crossed by braided streams	Sandy Bay, Exmouth
-?-?-?-?	Dawlish Sandstone / Exe Breccia	> 150	sandstones and breccias: braided streams, sand dunes and fluvial fans	*Lympstone* Poltimore
late Permian (Lopingian)	Teignmouth Breccia	120	breccias with minor sandstone interbeds: fluvial fans	*Ness Cove, Shaldon* *Maidencombe*
	Oddicombe Breccia	130	breccias and sandstones: braided streams and fluvial fans	not exposed on the coast
	Watcombe Formation	100	breccias (Watcombe Breccia) passing down into sandstones (Petit Tor Member): fluvial fans and braidplains	Watcombe Cove Petit Tor Beach
	unconformity		*c.* 12Ma erosional gap	
early Permian (Cisuralian)	Torbay Breccia	200	breccias and sandstones: debris flows, fluvial fans and braided streams	Waterside Bay *Paignton*
	unconformity			
Devonian	Torquay Limestone and Nordon Formation		complexly folded limestones, mudstones and tuffs	

Figure 3. Generalised stratigraphy of the Permian rocks exposed on the south Devon coast between Torbay and Exmouth. All thicknesses and lithologies are, laterally, highly variable. After Gallois and Mather (2016) and reproduced with permission of the Ussher Society.

reptiles and that the variations in size were related to animal size. Pollard (1976) confirmed this interpretation and suggested that the burrows might have been formed by limbed amphibians or reptiles during aestivation rather than as dwelling or feeding burrows. Pollard (1976) concluded that the Waterside Cove examples could "probably be named" *Beaconites* cf. *antarcticus* (Vialov 1962) and the name *Beaconites* has often been used since that time.

The presence or absence of burrow linings and walls appears to be crucial and Gallois and Mather (2016) discussed the taxonomic separation of *Beaconites* and *Taenidium*. Pollard (1976) had named the Waterside Cove examples as *Beaconites* based on a comparison with the type material (photographs, not rock specimens) of Vialov's (1962) *B. antarcticus* from the Devonian part of the Beacon Supergroup in Antarctica. The burrows described here are much larger than those described by Vialov (1962) but are of a similar size range as those described by Bradshaw (1981). Similar, meniscus-filled traces have also been described as *Beaconites* from Devonian rocks in South Wales (Allen and Williams 1981; Morrissey and Braddy 2004) and from Carboniferous rocks in County Mayo, Ireland (Graham and Pollard 1982). D'Alessandro and Bromley (1987), in a comprehensive review of *Taenidium* and morphologically similar forms, drew attention to the close similarity between *Beaconites* and *Taenidium*. They concluded that, until the description of the former had been clarified, unbranched meniscus-filled fossils of the type described from Waterside Cove, should be referred to as *Taenidium* (Heer 1877).

The most comprehensive discussion of *Beaconites* and *Taenidium* is provided by Keighley and Pickerill (1994) who concluded that there had been inconsistent use of both names. *Taenidium*, it was suggested, should only be applied to un-lined, meniscate, back-filled burrows without a wall created by the occupant. Using the emended definition provided by Keighley and Pickerill (*op. cit.*) the Waterside Cove traces should be regarded as *Taenidium*; see Keighley and Pickerill (1994, text-fig. 2, plate 1).

In a brief description of these fossils, Falcon-Lang (2019, p. 78) suggests that they may have been formed by 'giant' arthropleurids, though there is little direct evidence for such animals being present in Devon at this time. None of the trace fossils associated with the *Taenidium* occurrences appear to be comparable to the suggested arthropleurid trace fossils described from the uppermost Carboniferous and lowermost Permian of New Mexico by Schneider *et al*. (2010).

Watcombe Cove and Adjacent Cliffs

At the very northern limit of the English Riviera UNESCO Global Geopark are Oddicombe Beach, Petitor, and Watcombe Cove (Fig. 2). Trace fossils are relatively abundant in fallen blocks of breccia and fine-grained sandstone in the Watcombe Formation (Fig. 3) at Watcombe Cove but less common at Petit Tor Beach, where they comprise straight to gently curved, unbranched, meniscus-filled burrows, mostly 4 to 8 mm in diameter, but with a maximum observed length of 400 mm. They often form complex networks in which burrows are superimposed on one another at angles of mostly 40° to 90° (Fig. 5C). Locally, many burrows coalesce to form irregular disturbed patches up to 90 x 200 mm which may have given access to the sediment-water interface (Fig. 5C). The burrow infillings are lithologically similar to the matrix with curved menisci picked out by grain-size variations in the sandstones. These burrow systems may be similar to those described as *Helminthopsis* isp. by Lima and Netto (2012) from the Permian of southern Brazil.

Exichnial Trace Fossils

Exichnial trace fossils have been described by Gallois and Mather (2016) from the Dawlish Sandstone Formation including crustacean trails (Shapter 1842) and reptile footprints. Clayden (1902) reported that trackways of the mammal-like synapsid reptile *Cheilichnus bucklandi* (Jardine) were relatively common on some of the sandstone bedding planes in an old quarry at Poltimore [SX 971 971] near Exeter (Edwards and Scrivener 1999, plate 3i). Gallois and Mather (*op. cit*.) also described rare occurrences of small trace fossils from the Torbay Breccia at Livermead and Corbyn Head (in Torbay) as well as from the Teign Breccia at Maidencombe Beach and at Ness Cove, Shaldon. They also report the presence of an irregular, star-shaped 'disturbance' with associated cementation in the Corbyn's Head Member of the Torquay Breccia at Corbyn Head, Torbay, which might be a partially lined trace fossil *c.f. Heliophycus* Miller and Dyer (1878), a burrow of unknown affinity or the result of plant action.

Figure 4. A) Folded sediments of the Meadfoot Group at the southern end of Goodrington Beach. Note that the red staining is the result of being overlain by the uncomformable conglomerates of the Permian succession (Figure 4B) that are exposed in Waterside Cove. The *'Taenidium'*-rich horizon lies just above the coarse-grained, basal conglomerate.

Geotourism

The Permian sites within the English Riviera UNESCO Global Geopark are generally accessible and much safer than some of the Devonian locations (see Hart and Smart *this volume*). Waterside Cove, Goodrington, Petitor/ Oddicombe and Watcombe are backed by cliffs and some (*e.g.*, Oddicombe) are most definitely unstable. All the coastal sections are subject to quite large tidal ranges and should be avoided on rising tides.

Trace fossils are generally rare, occasionally being found on rock surfaces that may, in the summer months, be algae covered. They may be interesting to the specialist, but general visitors may struggle to both find these fossils and understand their significance. As such, they are unlikely to be regarded as important tourist highlights, no matter their palaeontological significance.

Geosites that may, potentially be used for pre-university education are quite limited, but are described on-line in the Devon Register of Educational Sites.

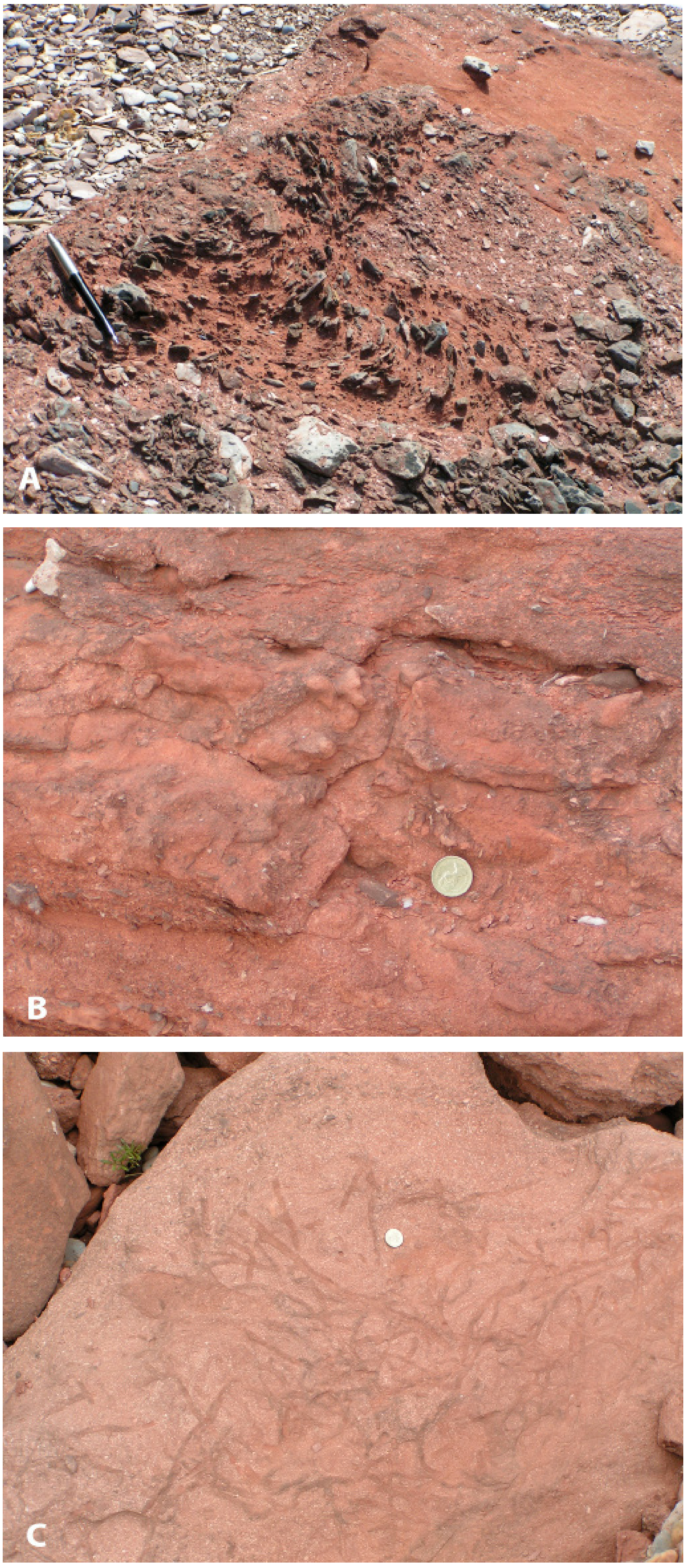


Figure 5. A) '*Taenidium*' meniscus-filled trace fossil from Waterside Cover, south of Goodrington. B) highly burrowed sandstones from Petitor Cove, north of Oddicombe Beach. C) intense bioturbation (?*Helminthopsis*) of sandstone from Watcombe Cove, north of Oddicombe Beach. In figures 5B and 5C the GB£1.00 coin provides the scale, while in figure 5A it is a pen.

Conservation

Many of the geological sites within the English Riviera UNESCO Global Geopark are recognized as nationally important. Many are on the Geological Conservation Review (GCR) Register, while others are Sites of Special Scientific Interest (SSSI) and National Nature Reserves (NNR); see Page (2004) for a review. While many are under local management, all are under statutory protection by Natural England. These processes have been described by Hart and Smart (*this volume*).

Summary

The presence of trace fossils in the Permian strata of the English Riviera UNESCO Global Geopark demonstrates that life existed in the harsh, desert conditions of the area at that time. These fossils are, the only evidence of such life and their presence can be both interesting, and useful, in debates on Permian palaeoenvironments in Devon.

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