

**PALAEOENVIRONMENTAL INTERPRETATION OF THE TRIASSIC
SANDSTONES OF SCRABO, COUNTY DOWN, NORTHERN IRELAND:
ICHOLOGICAL AND SEDIMENTOLOGICAL STUDIES INDICATING A
MIXED FLUVIATILE–AEOLIAN SUCCESSION**

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Abstract

The Sherwood Sandstone Group at Scrabo, Co. Down, Northern Ireland, has been variously interpreted as aeolian or fluvial. The sedimentological and ichnological data show that these sandstone-dominated facies were deposited within a mixed fluvial–aeolian regime, in which fluvial processes were responsible for the majority of the preserved sedimentary sequence. The sequence contains a moderately diverse non-marine ichnofauna comprising the invertebrate trace fossils *Biformites*, *Cruziana/Rusophycus* (*Isopodichnus*), *Herpystezoum* (*Unisulcus*), *Planolites*, 'small arthropod trackways', 'large arthropod trackways' (cf. in part *Paleohelcura*), and the vertebrate trace fossil *Chirotherium?* (as well as a number of other, presently unnamed, vertebrate footprints). The recorded ichnofauna greatly increases that previously known from the Irish Triassic, compares favourably with that from the rest of Europe, and represents the only known Irish locality for reptilian trackways.

Introduction

The Sherwood Sandstone Group (Triassic) in north-east Ireland comprises part of a thick sequence of non-marine sediments, with a maximum thickness of 1850m (Parnell *et al.* 1992), which are rarely exposed and known mostly from borehole data. At Scrabo (Fig. 1) the Sherwood Sandstone Group occurs within a deep trough of Carboniferous to Triassic age (Parnell *et al.* 1992), which is developed on a structural high (the Longford–Down Massif). Approximately 37m of strata, which dip at 5°

north-east, are exposed at Scrabo Hill (Charlesworth 1963). Several Palaeogene dolerite dykes and sills are exposed at the southern end of the hill, and these form a resistant cap that has shielded the sandstones against removal by ice during the last glaciations.

Various environmental interpretations have been made of the Scrabo succession. The succession has been interpreted as representing aeolian conditions (Charlesworth 1953; 1963), with the caveat that some parts might have had a waterlain origin (Charlesworth 1953).

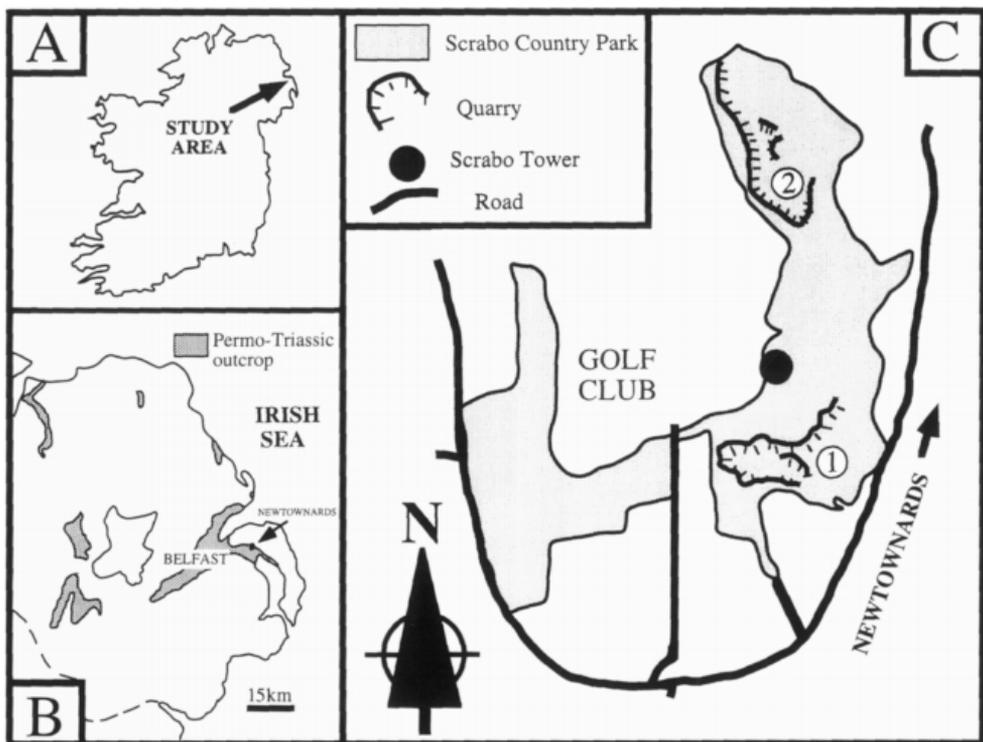


Fig. 1—Location maps: A. map of Ireland with approximate location of the study area indicated; B. map of Northern Ireland, showing the location of Scrabo, south-west of the town of Newtownards, and outcrop of Permo-Triassic sediments; C. detailed map, showing the positions of localities 1 and 2 respectively.

Opinions of other authors include: a shallow waterlain origin of deposition, although not elaborating on whether this is marine, fluvial or lacustrine (Wilson 1972); a river-channel environment, with no evidence for aeolian deposition (Parnell *et al.* 1992); and a shallow-water depositional environment of variable energy, with an additional aeolian influence increasing towards the top of the Sherwood Sandstone Group (Smith *et al.* 1991).

Trace fossils recorded in this investigation either occur in small quantities or are poorly preserved. However, they form an important component of the environmental interpretation. Although an increasing number of well preserved non-marine trace fossil assemblages have been described (Bromley and Asgaard 1979; Pollard 1981; Pickerill 1992), such is not usual for non-marine environments, and their

trace fossils are commonly overlooked, or mentioned only in a cursory fashion. We believe that it is important to document and consider the taxonomic and ethological position of ichnotaxa from less ideal situations, in order to maximise their potential in environmental interpretation.

This paper documents and describes the ichnofauna from the succession at Scrabo, places it within its sedimentological setting and discusses the environmental implications that lead to the present interpretation.

Systematic ichnology

Previously recorded trace fossils from the Scrabo succession include vertebrate footprints (Young 1883; Ashley 1946; Swinton 1960a; 1960b; Sarjeant 1974), worm-burrows (Ashley 1946; Charlesworth 1953; 1963) and shrimp-

burrows (Smith *et al.* 1991). New collections indicate a moderately diverse ichnofauna, with *Biformites* (the shrimp-burrows of Smith *et al.* 1991), *Chirotherium*?, *Cruziana/Rusophycus* (*Isopodichnus*), *Herpystezoum* (*Unisulcus*), *Planolites*, 'small arthropod trackways', 'large arthropod trackways' (cf. in part *Paleohelcura*), as well as other unassigned vertebrate footprints. All collected materials are deposited within the geological collections of the Ulster Museum, Belfast (BELUM). The invertebrate ichnogenera are typically closely associated with intercalated fluvialite mudstone-sandstone horizons, which display features of subaerial exposure, whereas vertebrate trackways occur in association with both fluvialite and aeolian depositional units. Ethologically, the Scrabo ichnotaxa represent an association of fodinichnia (?domichnia), repichnia and cubichnia, in which fodinichnia (?domichnia) are the most abundant in terms of total number of individuals, although repichnia are more diverse in terms of ichnotaxa present.

Ichnogenus *Biformites* Linck 1949

***Biformites* ichnosp.**

Figs 2 and 3b

Material and occurrence. K7997, K12527, K13553, K13554, K13555, with a total of several dozen specimens, from locality 1 (see Fig. 1).

Description. Horizontal endogenic full reliefs and convex hyporeliefs (within, and at the base of, sandstones), which are straight or curved in plan view, commonly cross-cut each other, run parallel or subparallel and occasionally appear to originate from the same locus. Burrows are 2–10mm wide by up to 75mm long and circular or ovoid in cross-section. The larger burrows are thickly lined (0.5–3mm thick), having a smooth inner surface with a pelleted outer ornament. Smaller burrows are apparently unlined and appear pellet stuffed. The pellets, circular or ovoid in shape and 1–3mm long, occur in a random, uniserial, or biserial manner and are occasionally observed to be composite in nature.

Discussion. Although previously described as 'shrimp-burrows' (Smith *et al.* 1991), Triassic material of this style is generally referred to *Biformites* (J.E. Pollard, pers. comm.). The *Ophiomorpha* of Kennedy and MacDougall (1969), from the Weald of southern England,



Fig. 2—Large block (BELUM K12527) containing a multitude of examples of *Biformites*, observed in convex hyporelief; specimens occur singularly and as groups originating from a common locus, and are either straight or variably curved (scale bar = 20mm).

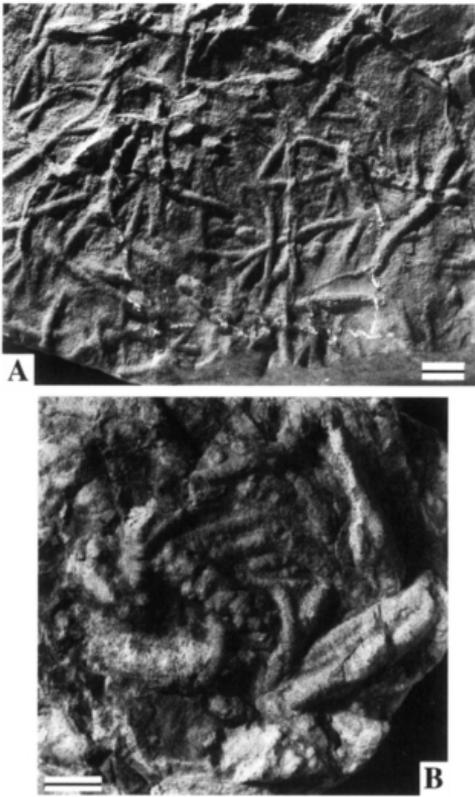


Fig. 3—A. *Planolites beverleyensis* (BELUM K13556), hyporelief (scale bar = 10mm); B. *Biformites* and *P. beverleyensis* (BELUM K7997), hyporelief (scale bar = 10mm). Note the composite nature of the pellets of the central *Biformites*.

may be conspecific with the Irish specimens, but according to Pollard *et al.* (1993) such should not be referred to *Ophiomorpha*. Additionally, both *Edaphichnium* and *Oligichnos*, from Eocene palaeosols (Bown and Kraus 1983) and Paleocene fluvial-lacustrine environments (Melchior and Erickson 1979), are similar in terms of burrow orientation and their pelleted morphology to the Scrabo material, although they lack a burrow lining and differ in the nature of their pellets. Pelleted burrow forms, from a range of different environments, would benefit from a comprehensive monographic treatment, although this is beyond the scope of the present work.



Fig. 4—Photograph of the vertebrate footprint *Chirotherium?*, indicating the presence of reptilian life within the Scrabo ecosystem; the tuberculated appearance of the print is of a secondary nature and does not represent hide markings (scale bar = 10mm).

Ichnogenus *Chirotherium* Kaup 1835 *Chirotherium?* ichnosp.

Fig. 4

Material and occurrence. K12282, two consecutive prints, from locality 1.

Description. Comprising two incomplete digitgrade prints (K12282), which occur one behind the other, overlapping. The front and rear prints comprise at least four and three digits respectively, with the prints 55mm wide and no longer than 39mm. The digits appear to bear the impressions of claws, and the surface of each print varies from smooth to tuberculated.

Discussion. Previously identified as *Chirotherium lomasi* (Swinton 1960b) but, given the lack of a 'thumb' impression and the minimal nature of the trackway, some doubt has been expressed as to this assignment (Delair and Sarjeant 1985, 152). This material is therefore only referred to *Chirotherium?* ichnosp.

Ichnogenus *Cruziana* d'Orbigny 1842 *Cruziana problematica* (Schindewolf 1921)

Fig. 5



Fig. 5—*Cruziana problematica* and *Rusophycus* (BELUM K13552), hyporelief view on a flat surface (scale bar = 10mm).

Material and occurrence. K13552 and K27211, two blocks with a number of specimens in variable states of preservation, from locality 1.

Description. Bedding-parallel, smooth, ribbon-shaped (straight to gently curved), bilobed convex hyporeliefs, with a weakly developed median groove (or lobes occasionally well separated). Observed range in width 1–3mm, although all individuals are consistent in width along their length, a maximum observed length of 13mm, and a relief of 2–3mm.

Discussion. Size and lack of lateral bevels distinguish this material from *Didymaulichnus*. *Isopodichnus* is commonly used for such small bilobed Devonian or Triassic red-bed trace fossils (see Trewin 1976; Pollard 1981). However, as neither environment nor age is a

valid taxonomic criterion, the Irish material is referred to *Cruziana* following Bromley and Asgaard (1979). For detailed discussion on the taxonomy and environmental implications of this type of trace fossil see Trewin (1976), Seilacher (1978), Bromley and Asgaard (1979), Pollard (1981; 1985) and Pickerill (1992). Devonian and Triassic red-bed examples of *C. problematica* (*Isopodichnus*) are commonly of non-marine freshwater or brackish origin (Trewin 1976; Bromley and Asgaard 1979; Pollard 1981; 1985). Although not all examples of *C. problematica* are necessarily indicators of non-marine regimes (Bromley and Asgaard 1979), their occurrence within red-beds can generally be taken as representing non-marine conditions, and in the case of Triassic examples they represent the product of branchiopods (Pollard 1985).

***Herpystezoum* Hitchcock 1848**
***Herpystezoum* ichnosp.**

Fig. 6

Material and occurrence. K13551, one block with four trails, from locality 1.

Description. Smooth, concave epirelief, surface trails, U- or V-shaped in cross-section, with or without lateral levées, which are commonly restricted to one side. Total width 3mm (lateral levées 0.5–1mm wide), height 2mm, and length 60mm (incomplete). Trails are bedding-parallel, cross-asymmetric ripples, and in plan view are straight or curved in morphology; with straighter sections exhibiting slight



Fig. 6—*Herpystezoum* (BELUM K13551), epirelief on a rippled surface (scale bar = 10mm).

sinuosity, or irregularity, in their path. Cross-cutting of trails is observed.

Discussion. These trace fossils are comparable with the 'looped trails' of Ireland *et al.* (1978). Such trace fossils could conceivably represent the product of a number of organisms, including gastropods, bivalves, crustaceans, insects and annelids (Schäfer 1972; Baldwin 1974; Buckman 1992a; 1992b), and occur over a wide range of environments from marine (Buckman 1992a; 1992b), through marginal-marine (Wright and Benton 1987), to non-marine (Ireland *et al.* 1978; Turner 1978).

Ichnogenus *Planolites* Nicholson 1873

***Planolites beverleyensis* (Billings 1862)**

Fig. 3a–b

Material and occurrence. K7997, K13556, several dozen specimens from localities 1 and 2.

Description. Horizontal endostratal burrows, comprising convex hyporeliefs on the base of sandstone beds above thin mudstone horizons. Burrow width 1–4mm, length 10–70mm. Burrows are smooth and consistent in width along their length, straight to variably recurved in the horizontal plane, and curve upwards at both ends. These burrows occur in dense masses, in which individuals commonly cross-cut each other, producing radiating interpenetrating structures, which give the impression of acute palmate branching.

Discussion. Triassic burrows of this general style, particularly where palmate branching is well developed, are commonly referred to *Phycodes curvipalmatum* (Pollard 1981). However, although the Irish specimens commonly run parallel to each other and appear to branch, this is predominantly a feature of cross-cutting caused by overcrowding. Therefore this material is assigned to *Planolites*, which can in some cases also be branched (Pemberton and Frey 1982), and is further assigned to *P. beverleyensis* by comparison with Pemberton and Frey (1982, pl. 5, fig. 2). Although *Planolites* is a common

marine trace fossil, this should not preclude its pertinent usage within non-marine strata.

A number of examples of *P. beverleyensis* appear to be slightly pelleted. Taken in conjunction with their co-occurrence with *Biformites* and other similarities to *Biformites*, this suggests that the two were produced by the same constructor. Variation within *Biformites* and similarity to *P. beverleyensis* can then be explained in terms of behaviour (ethology) and/or substrate consistency.

Ichnogenus *Rusophycus* Hall 1852

***Rusophycus* ichnosp.**

Fig. 5

Material and occurrence. K13552 and K27211, two blocks with a number of individuals in variable states of preservation, from locality 1.

Description. Smooth, bilobed convex hyporeliefs, maximum relief 2–3mm, width 3mm and length 6mm. Occurring in simple coffee-bean shaped form, or with slightly divergent lobes.

Discussion. The co-occurrence of *C. problematica* on the same hand specimen, separation from the same, and the clear coffee-bean shape of the ichnotaxon indicate assignment within *Rusophycus*.

'Small arthropod trackways'

Fig. 7

Material and occurrence. Three observed individuals, one from an unknown horizon at Scrabo (K11550), the others field specimens from locality 1.

Description. Biserial concave epireliefs, comprising indistinct scratch marks, or two parallel faintly impressed narrow grooves. Maximum width of trackway 4mm.

Discussion. It is likely that more than one ichnotaxon is included within this group of trace fossils, some possibly referable to *Diplichnites triassicus* (J.E. Pollard, pers. comm.); however, the nature of preservation precludes taxonomic assignment.

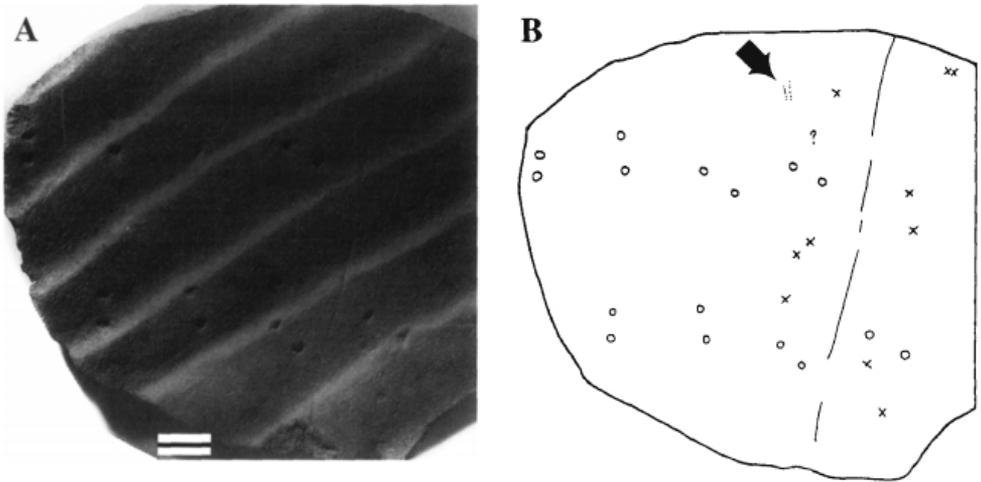


Fig. 7—'Large arthropod trackways' (BELUM K11550), viewed in epirelief (scale bar = 20mm): A. Photograph of specimen; B. explanatory sketch: open circles are imprints from the Type II trackway; crosses (and question mark) are imprints from the Type I trackway. Note that the latter are centred around a discontinuous sinuous groove. Arrow indicates the location of a much smaller, poorly preserved, biserial 'small arthropod trackway'.

'Large arthropod trackways'
Type I (cf. *Paleohelcura* Gilmore 1926)

Fig. 7

Material and occurrence. K11550, one observed specimen from Scrabo (no detailed locality data).

Description. A biserial trackway, comprising faint, elongate, dactyli imprints arranged about a discontinuous, lightly impressed, sinuous axial groove. Imprints occur in groups of two and three, with opposing groups arranged along the mid-line in a strongly offset V-shaped fashion. Total trackway width c. 35mm.

Discussion. By comparison with material illustrated by Brady (1947, fig. 1), this specimen can be tentatively compared to *Paleohelcura*. Such trackways represent the movements of arachnids, such as a scorpions or spiders. The presented material is likely to represent the movement of a scorpion.

'Large arthropod trackways'
Type II
Fig. 7

Material and occurrence. K11550, one observed specimen, locality as in Type I.

Description. A biserial trackway, comprising elongate, dactyli imprints in paired series. Each pair of imprints within a series is perpendicular or oblique to the mid-line, and pairs on opposing sides of the mid-line are arranged with the same disposition. Total trackway width 45–55mm.

Discussion. Consideration of dactyli number, spacing and stride length indicates that this trackway was produced by the same organism as the Type I trackway described above. This trackway could be an unusual variant of *Paleohelcura*, which is known to be morphologically plastic (see Brady 1947; 1961; Sadler 1993), but no formal designation is given here owing to the single occurrence and short length of the trackway (see recommendations in Trewin 1995). Although both trackways are likely to have been produced by the same organism, this does not necessarily imply that the same ichnogenic assignment should be made. The Type II trackways may have been produced by a scorpion moving in either a sideways or rotary fashion.

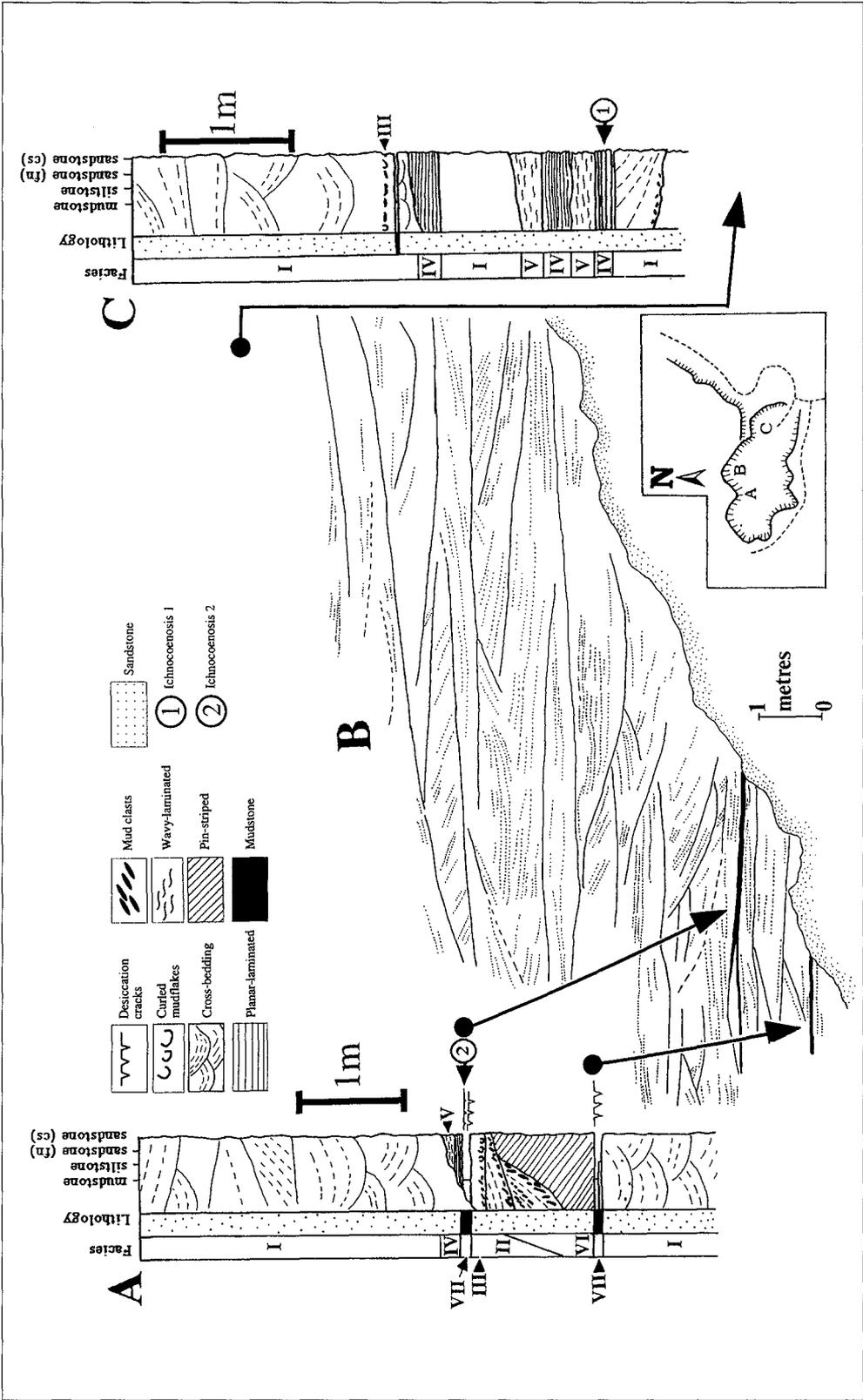


Fig. 8—Examples of observed vertical and lateral variations within the Scrabo facies, at locality 1: A, and C, sedimentary logs of facies; B, south-facing cliff section (traced from a series of transparencies), relative positions of A, B and C shown in insert, bottom right.

Sedimentological background

The Sherwood Sandstone Group at Scrabo, typically red or white, comprises fine- to medium-grained sandstones, with occasional interbedded chocolate-brown mudstones and mudflake conglomerates. The sandstones are highly feldspathic in nature (>25%), commonly contain a high clay content (mainly diagenetic, from the degradation of feldspar grains) and comprise grains that vary from relatively angular to well rounded and from elongate to highly spherical. Additionally, the sandstones can be highly porous, with a porosity of up to 50%, which includes much secondary porosity from the selective degradation of feldspar grains. The sequence of sediments is dominated by sandstones characterised by medium- to large-scale trough and planar cross-bedding, occurring in complex cross-cutting sets (Figs 8 and 9; also Parnell *et al.*

1992, fig. 4a), with the occurrence of smaller-scale features such as ripples (including climbing-ripples), rain-pits, desiccated surfaces and water-escape structures (Fig. 10). Detailed examination of the Sherwood Sandstone Group indicates a complex distribution of facies, with much lateral variability. A representative log of parts of the succession is given (Fig. 8), to illustrate temporal and spatial facies distributions, and seven distinct facies (Facies I–VII) are briefly characterised below.

Facies I: Cross-bedded sandstones

This facies forms the majority of the Scrabo sandstones and comprises fine- to medium-grained arenites, in the form of large-scale trough and planar cross-bedded sets, with a maximum foreset angle of dip no greater than 30°, and a set thickness typically in the range of 0.5–1m. This facies typically has an erosive channelised base. Water-escape structures, isolated mudflake clasts, thin, laterally-impersistent, horizontal mudstones, mud-draped symmetrical ripples, adhesion ripples, wind-scour structures and deflation surfaces have been recorded within this facies.

Facies II: Channelised conglomeratic sandstones

Small-scale channels (<0.5m thick), filled with planar cross-bedded medium-grained sandstones, with mudflake clasts as basal lags and along cross-bedding sets (Fig. 10e). The mudflake conglomerates are locally sourced and have clasts 5–50mm long arranged parallel to bedding, chaotically or in an imbricated fashion.

Facies III: Curled mudflake sandstones

White sandstones with *in situ* curled mudflakes along their base (Fig. 10d); occasionally developed along the upper surface of Facies II, or occurs in isolation within Facies I.

Facies IV: Thinly bedded sandstones

Thin planar-bedded, clean medium-grained and muddy fine-grained sandstones, which alternate on a millimetre to centimetre scale. Either planar-laminated or characterised by asymmetric, rippled sandstone beds, which



Fig. 9—An example of cross-bedding at Scrabo, within a massive arenaceous part of the quarry section (geologist for scale, c. 2m).

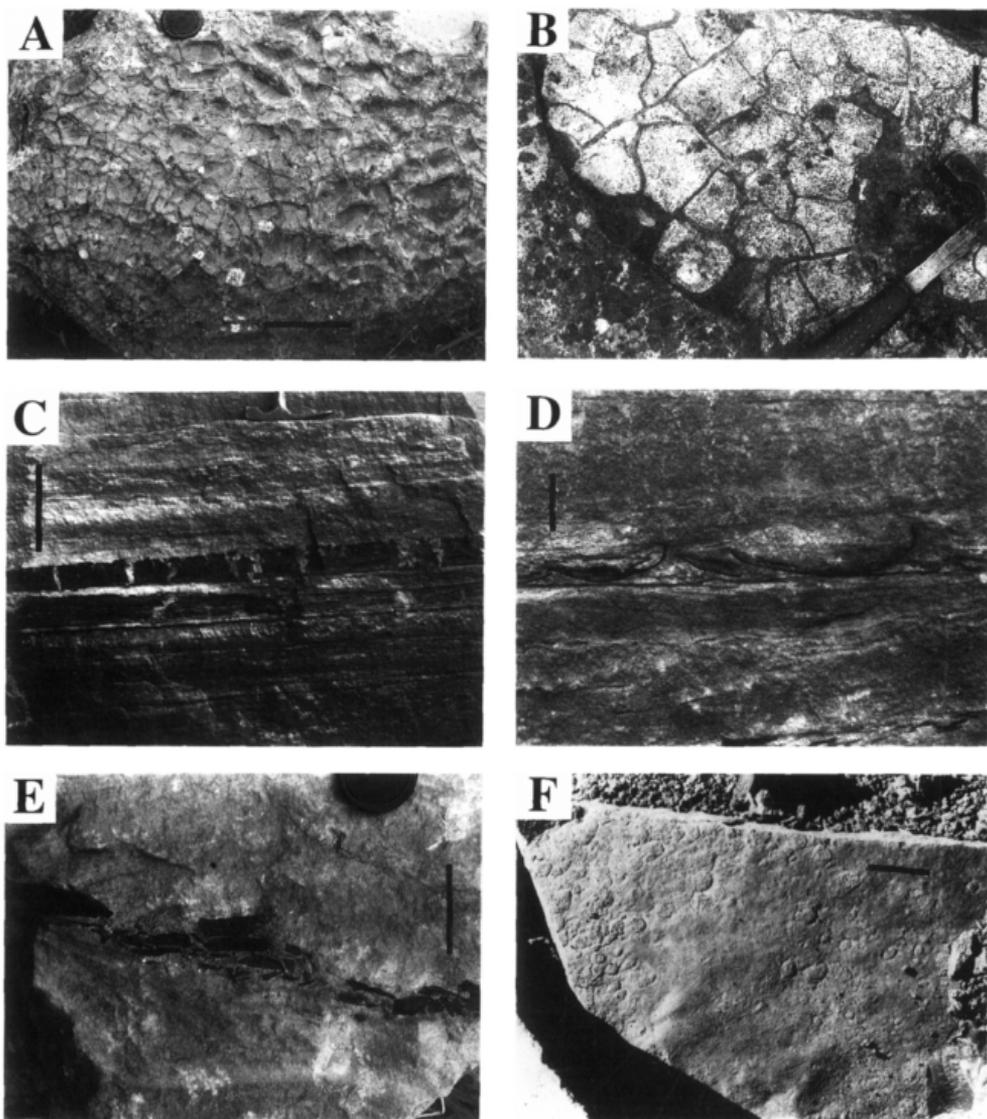


Fig. 10—Small-scale sedimentary structures from the Scrabo sandstone: A. bedding plane view of desiccation cracks (radiating from bottom left), also exhibiting irregular-crested, symmetrical ripples (scale bar = 110mm); B. bedding plane view of desiccation cracks, exhibiting typical polygonal pattern (scale bar = 40mm); C. vertical section through desiccated mudstone horizon (scale bar = 165mm); D. curled mud-flakes *in situ* (scale bar = 10mm); E. imbricated mudstone clasts (scale bar = 55mm); F. rain prints, observed along the sole of a sandstone bed (scale bar = 40mm).

sometimes have planar bases. Ripple wavelength is commonly highly variable within any given train, with observed variation of 40–50mm, 70–130mm and 35–90mm, with a ripple index (RI) of 5–26. Ripples typically

comprise a cleaner medium-grained base with 1–5mm-thick, fine-grained muddy sandstone top that conforms to the shape of the rippled surface. The trace fossils *Cruziana/Rusophycus*, *Herpystezoum*, 'large arthropod

TRACE FOSSILS	UNIT, AGE AND LOCALITY		
	SCRABO SST (SHERWOOD SST GROUP), SCRABO HILL	HELSEY SST FMT (SHERWOOD SST GROUP), CHESHIRE BASIN	WATERSTONES (MERCIA MDST GROUP), CHESHIRE BASIN
<i>Biformites</i>			
Assorted invertebrate trackways			
<i>Isopodichnus/Cruziana/Rusophycus</i>			
<i>Planolites/Phycodes curvipalmatum</i>			
<i>Herpystezoum</i> /'loop trails'			
Vertebrate footprints			
<i>Thalassinoides</i>			
Striated oblique burrows			
Small stuffed burrows			
<i>Lingulichnus</i>			
<i>Diplocraterion</i>			
<i>Arenicolites</i>			
<i>Palaeophycus triadicia</i>			

Fig. 11—Comparison of the Triassic ichnofaunas of the Cheshire Basin and Scrabo Hill; data on the Cheshire Basin from Pollard (1981), indicating the similarity between the Scrabo sandstone ichnofauna and that of the Helsby Sandstone Formation.

trackways' and 'small arthropod trackways' occur within this facies. Small-scale water-escape/liquefaction structures are occasionally observed within the cleaner sandstone fraction. Additionally rain-pits (maximum diameter 10mm) and pinhole cavities (1mm or less in diameter) are observed within this facies.

Facies V: Wavy-laminated sandstones

Lithologically similar to Facies IV, but differentiated on the basis of its irregular, wavy, discontinuous lamination/bedding; occurs directly above Facies IV, with a gradational boundary.

Facies VI: Pin-striped sandstones

This cross-bedded facies occurs as a sandstone unit up to 1m thick, which passes

laterally into Facies II. Pin-striping occurs on a millimetre scale, with alternation of medium- to fine-grained sandstone laminae. Highly porous, it weathers faster than the other observed sandstones.

Facies VII: Desiccated mudstones

The mudstones that typify this facies occur in beds, up to 100mm thick, that are laterally discontinuous, horizontal in nature, or occasionally drape small dune features. They commonly exhibit desiccation surfaces (Fig. 10a-c), and may have more than one desiccated surface within them. Sand-filled desiccation cracks commonly display pygmatic structure owing to compaction (Fig. 10c). Small lens- or dune-shaped sand bodies are occasionally developed within the

thicker mudstone horizons, which commonly exhibit asymmetric and symmetric rippled surfaces with superimposed sand-filled desiccation cracks. The latter sandstone bodies contain *Planolites*, *Biformites* and isolated vertebrate footprints.

Environment

Environmental interpretation is based mostly on the observed sedimentary structures, particularly the physical (inorganic) sedimentary structures, with supportive information gleaned from the associated trace fossils. None of the typical marine or marginal-marine ichnogenera recorded from other Triassic deposits, such as *Diplocraterion*, *Thalassinoides*, *Lingulichnus*, *Arenicolites* or *Palaeophycus striatus*, are known, precluding the possibility of a marginal-marine, estuarine or intertidal regime of deposition (J.E. Pollard, pers. comm.). The trace fossils at Scrabo are, however, similar to those of the Helsby Sandstone Formation (Sherwood Sandstone Group) described by Pollard (1981) (Fig. 11), which are of a fluvial origin (Pollard 1981).

Three major environmental settings can be recognised from the Scrabo succession: fluvial 'channel' (Facies I, II), overbank/'lacustrine' (Facies IV, VII) and aeolian/aeolian reworked (Facies III, V, VI), in which fluvial and ephemeral lacustrine environments of deposition are dominantly preserved, with minor aeolian elements. Aeolian processes may have been more common than evidenced within the preserved sedimentary record, as witnessed by the common occurrence of rounded quartz and feldspar grains. Although some of the latter may have been reworked from the underlying Permian (Parnell *et al.* 1992), they may also have been reworked by river systems flowing through contemporaneous aeolian dune fields.

Fluvial 'channel' environments

The cross-bedded sandstones of Facies I are interpreted as fluvial in origin, as they lack highly inclined cross-lamination typical of many but not all aeolian dunes. The occurrence of mud-drapes, occasional rip-up clasts, and

interbedded mudstone beds and lamellae indicates that these sandstones have a fluvial origin. The facies represents deposition within a major fluvial channel area—a conclusion that is supported by the commonly channelised base of the facies.

The channelised conglomeratic sandstones (Facies II) represent deposition within smaller-scale ephemeral channels (cf. Cowan 1993). That deposition was intermittent is evidenced by the associated occurrence of mud-drapes, desiccated surfaces and rip-up clasts.

The only trace fossils associated with either type of fluvial 'channel' deposit are vertebrate footprints. However, the latter are not restricted to fluvial facies, but are also recorded from elsewhere within aeolian deposits (see e.g. McKeever 1991; 1994), as well as intertidal settings (Pollard 1981). Such would be expected given the more mobile, non-facies-dependent nature of the reptilian producers of the trackways.

Overbank/'lacustrine' environments

The thinly bedded sandstones (Facies IV), with mostly tabular geometry, are interpreted as overbank floodplain deposits, with rippled horizons nearer to the active channels. The recorded RI of 5–26 is of interest, as it encompasses the recorded fields for both aeolian and aqueous current ripples (Tanner 1967; Selley 1992; Tucker 1993). At one measured section, ripples exhibit a progressive upward decrease in RI (14–26, 7–18, 5–6, 6–7), indicating a possible change from aeolian to aqueous current ripples. The latter is unlikely, however, given the association with *Cruziana/Rusophycus (Isopodichnus)*, indicating subaqueous deposition throughout. Additionally, the occurrence of *C. problematica* suggests that temporary freshwater-brackish ponds may have been developed. The transient inhospitable nature of these ponds is indicated by the restriction of the ichnofauna wholly to repichnia (*Cruziana/Rusophycus*, *Herpystezoum*, 'small arthropod trackways', 'large arthropod trackways'). Pinhole cavities (?after gypsum) recorded from this facies have also been noted by Thompson (1970b) from 'striped' facies within the Waterstones of the Cheshire Basin,

where they are recorded from river floodplain or lagoonal environments. The environment of deposition was, therefore, aqueous, but liable to periods of drying out with the possible production of minor amounts of evaporitic minerals. Temporary subaerial exposure is also indicated by the presence of trackways attributable to scorpions ('large arthropod trackways' types I and II), which are non-aquatic.

The desiccated mudstones (Facies VII) are hard to place in terms of a depositional model. The lateral discontinuity of these mudstones suggests that they may represent abandoned channel sections that have subsequently silted up. However, the mudstones lack the plug-shaped morphology typical of abandoned channel sections and their lateral discontinuity is a feature of cut-down by Facies I. It is more appropriate, therefore, to consider that this facies represents overbank deposits, with deposition during flood events, resulting in localised, shallow, ephemeral lakes, prone to drying out. The lakes were inhabited by the constructors of the feeding/habitation burrows *Planolites* and *Biformites* and crossed by reptiles that left distinctive trackways.

Aeolian environments

The occurrence of *in situ* curled mudflakes (Facies III) along the tops of Facies II and within Facies I indicates deposition under aeolian influence (Smith *et al.* 1991; N. Trewin, pers. comm.), since the delicate mudcurl structures can only be explained if they were buried by aeolian processes. This is important, as it indicates the intermittent nature of water flow within the river channel systems of the palaeo-Scrabo area.

The wavy-laminated sandstones (Facies V) appear to be identical to the sheetflood facies of Cowan (1993, fig. 9), from the Sherwood Sandstone Group of the East Irish Sea Basin, representing aeolian reworked fluvial deposits. The latter interpretation fits well with the Scrabo facies, which occurs directly above Facies IV, fluvial, sheetflood deposits.

The distinctive pin-stripped lamination of Facies VI, although not exclusively associated with aeolian depositional systems (Cowan

1993), can be taken to be indicative of aeolian dune deposition. Additionally, a lack of mudstone intraclasts within this facies suggests that it is likely to be of aeolian origin, as do its relatively high permeability and the degree of grain roundness and sorting (see criteria in Cowan 1993, 234). Differentiation of this facies from that of fluvial Facies I is often difficult owing to the nature of exposure at Scrabo. However, Facies VI appears to be subordinate.

Environmental summary

The Scrabo palaeo-environment can be interpreted as representing deposition within a small basin, comprising both fluvial (channel and overbank) and aeolian processes, in which aeolian activity may have been temporally dominant, but in which fluvial activity has produced the bulk of the preserved sedimentary record. By comparison with similar environments in the East Irish Sea Basin and the Cheshire Basin, it can be suggested that the river system was dominated by low to moderate sinuosity braided channels (see Thompson 1970a; Pollard 1981; Cowan 1993; Meadows and Beach 1993).

Substrate conditions

The trace fossils present in Facies VII (desiccated mudstones) and Facies IV (thinly bedded sandstones) can be used to extract additional information concerning changes in substrate consistency and to document subaerial exposure. *Planolites* and *Biformites* within Facies VII are closely associated, commonly display cross-cutting relationships, and are of a similar size and shape. As they differ mainly in the nature of their outer burrow ornament, and the presence or absence of a lining, these two burrow systems are likely to represent the work of the same constructor. Differences can be interpreted as reflecting a progressive change in the consistency (water-content) of the substrate, *Biformites* constructed within a soft substrate, and *Planolites* within a firmer substrate; reflecting a progressive drying out, culminating in the production of desiccation cracks. However, all

burrows were constructed within a subaqueous environment.

The trace fossils associated with Facies IV also provide additional information. *Cruziana/Rusophycus* (*Isopodichnus*) on the bases of the rippled sandstones represents the activities of branchiopods within an aqueous freshwater or brackish environment (see Pollard 1985). On the rippled upper surfaces, *Herpystezoum* may represent the locomotory efforts of a number of organisms within either an aqueous or sub-aerial environment (Buckman 1992; 1992b), but the occurrence of the 'large arthropod trackways' (the tracks of scorpions) indicates that the pools of water in which *Cruziana* were produced must have been ephemeral. The two 'large arthropod trackways' contrast in their sharpness of definition, which can chiefly be explained either as a factor of toponomy (surface track v. undertrack, see Goldring and Seilacher 1971) or sediment consistency. It is here postulated that the two styles of preservation represent different substrate conditions as the sediments dried out. The trace fossils of Facies IV indicate, therefore, repeated cycles of waterlain deposition in shallow ephemeral pools that intermittently dried out.

Comparison with other non-marine ichnoassemblages

A comparison of the ethological distribution of the Scrabo ichnofauna with other Triassic non-marine ichnofaunas from Germany, Greenland, the UK and India (Bromley and Asgaard 1979; Pollard 1981; Sarkar and Chaudhuri 1992) indicates that these do not possess pascichnia (or rarely so), as is also the case for the ichnofauna described from a Jurassic aeolian deposit (Ekdale and Picard 1985) and a number of Carboniferous fluvial sandstones (Buckman 1992b; Pickerill 1992, *Rusophycus* ichnocoenosis). These ichnofauna are otherwise of variable ethological and faunal composition. Although not all marine ichnofauna possess pascichnia (Buckman 1992b, fig. 2.3c), many do, particularly those within the *Cruziana*- or *Nereites*-ichnofacies. It is tempting, therefore, to draw the conclusion that a characteristic feature of non-marine

ichnofaunas, irrespective of age, is their lack of pascichnia (see Pollard 1981), which could be used in conjunction with the typical low diversity of non-marine ichnofaunas (Miller 1984), as well as type of ichnotaxa, to further differentiate non-marine from marine environments. Features such as the lack of pascichnia and low ichnodiversity may be used in conjunction with the ichnospecies present to identify non-marine facies from the European Triassic and possibly within a wider stratigraphic and geographic context. Nevertheless, some care must be taken with this approach, as it is often difficult to pigeon-hole ichnospecies in respect of their interpreted ethology. Additionally, ichnofauna cited as being from marginal-marine environments commonly also lack pascichnia, and may exhibit a marked restriction in ichnodiversity. Further, the non-marine *Mermia* ichnofacies, recently erected by Buatois and Mángano (1995), is characterised by the occurrence of pascichnia.

Ichnofacies/ichnocoenoses

Increased interest in non-marine ichnofaunas has considerably advanced the knowledge of such assemblages, with the examination of environments including aeolian, lacustrine, alluvial, fluvial and palaeosols (Bromley and Asgaard 1979; Retallack 1984; Ekdale and Picard 1985; Thoms and Berg 1985; Andrews 1991; Gierlowski-Kordesch 1991; Pickerill 1992; Sarkar and Chaudhuri 1992; Hasiotis *et al.* 1993; Genise and Bown 1994; Buatois and Mángano 1995). Pemberton *et al.* (1992) indicated the likelihood that a variety of non-marine ichnofacies had yet to be defined, in addition to the standard *Scoyenia* ichnofacies for such environments. Subsequently the *Termitichnus* and *Mermia* ichnofacies have been erected as additional non-marine ichnofacies (Smith *et al.* 1993; Buatois and Mángano 1995). The Irish material can be accommodated within the *Scoyenia* ichnofacies (see Buatois and Mángano 1995, table 2). In respect of non-marine environments, the ichnofauna can more usefully be thought of in terms of its constituent ichnocoenoses. A number of ichnocoenoses have been recognised

within non-marine ichnofacies (Bromley and Asgaard 1979; Pollard *et al.* 1982; Pickerill 1992), and it is possible to consider the Scrabo ichnofauna in terms of two distinct ichnocoenoses. Ichnocoenosis 1 is represented by *Cruziana/Rusophycus (Isopodichnus)*, *Herpystezoum*, 'large arthropod trackways' and 'small arthropod trackways' (repichnia dominated), within thinly bedded typically rippled facies (Facies IV), while ichnocoenosis 2 includes *Planolites*, *Biformites*, and minor *Chirotherium?* (fodinichnia dominated), within more thickly bedded sandstones containing well-defined mudstone horizons and desiccation cracks (see Fig. 8). Ichnocoenosis 1 represents a transient (overbank/'lacustrine') environment dominated by repichnia, which was occasionally subaerially exposed—an interpretation that is supported by the observed passage of the dominantly subaqueous Facies IV into the wind-reworked Facies V (Fig. 8). Ichnocoenoses a, b and d of Pollard *et al.* (1982) from ephemeral lacustrine deposits of the Middle Devonian Hornelen Basin of Norway are also dominated by repichnia, as is the *Isopodichnus* ichnocoenosis (Pollard 1981; 1985), and both are closely comparable to ichnocoenosis 1, with the exception that the former are wholly aquatic. Ichnocoenosis 2 represents an ephemeral fluvial environment dominated by fodinichnia (?domichnia), which was occasionally subaerially exposed, resulting in the production of desiccation cracks. Both ichnocoenoses were therefore initially aquatic, and subsequently subaerially exposed, although to differing degrees within different environmental/lithological settings.

Conclusions

1. The sedimentology and ichnofauna of the Sherwood Sandstone Group at Scrabo indicate mainly fluvial processes of deposition. This is confirmed by comparison with the Triassic of the Cheshire and East Irish Sea Basins.
2. Although most of the sequence is interpreted as representing fluvial channel and overbank floodplain/'lacustrine' deposits, aeolian processes are indicated

by the occurrence of aeolian dune facies (Facies VI), the preservation of curled mudflakes (Facies III), adhesion ripples and warts, and wind scours (within parts of Facies I), and reworked floodplain deposits (Facies V). Aeolian processes may have been temporally more important, but have a low preservation potential in comparison to their fluvial counterparts.

3. Trace fossils in the Scrabo area are mainly limited to fluvial units, and then typically only to those comprising a mixture of sandstone and mudstone (overbank/'lacustrine'). This limits the resolution of ichnology as an environmental tool in mixed fluvial-aeolian successions. However, *Biformites*, *Cruziana/Rusophycus* and *Planolites* clearly indicate subaqueous environments, whereas 'large arthropod trackways' (produced by scorpions) indicate subaerial exposure. The mode of preservation of a number of the recorded vertebrate trackways also indicates aeolian influence. In addition, trace fossils can determine environmental parameters such as substrate consistency.
4. As with many other non-marine *Scoyenia* ichnoassemblages, the limited diversity (in comparison to marine assemblages) and lack of pascichnia (dominance of fodinichnia and repichnia) may be useful as an indicator of non-marine conditions, but caution must be employed when trying to interpret the ethological significance of trace fossils within non-marine environments.

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