PALAEOENVIRONMENTAL INTERPRETATION OF THE TRIASSIC SANDSTONES OF SCRABO, COUNTY DOWN, NORTHERN IRELAND: ICHNOLOGICAL 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 fluviatile. The sedimentological and ichnological data show that these sandstone-dominated facies were deposited within a mixed fluviatile–aeolian regime, in which fluviatile 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).

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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 inter-penetrating 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 over-crowding. 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.

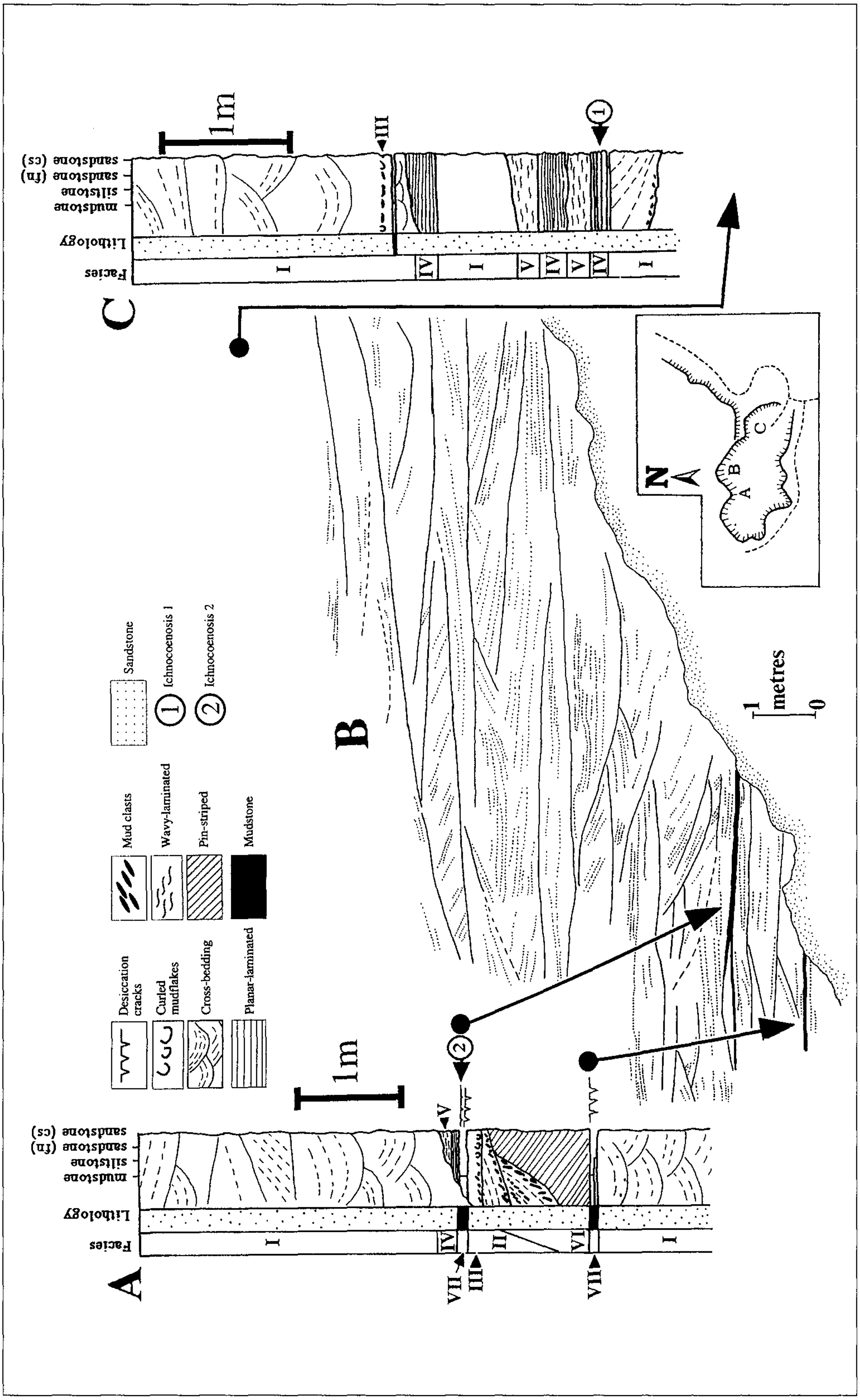

Fig. 8—Examples of observed vertical and lateral variations within the Scrabo facies, at locality 1: A, and C, sedimentary logs of facies; B, south-facing cliff section (traced from a series of transparencies), relative positions of A, B and C shown in insert, bottom right.

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

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 ptygmatic 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 fluviatile origin (Pollard 1981).

Three major environmental settings can be recognised from the Scrabo succession: fluviatile 'channel' (Facies I, II), overbank/'lacustrine' (Facies IV, VII) and aeolian/aeolian reworked (Facies III, V, VI), in which fluviatile 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.

Fluviatile 'channel' environments

The cross-bedded sandstones of Facies I are interpreted as fluviatile 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 fluviatile origin. The facies represents deposition within a major fluviatile 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 fluviatile 'channel' deposit are vertebrate footprints. However, the latter are not restricted to fluviatile 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 fluviatile deposits. The latter interpretation fits well with the Scrabo facies, which occurs directly above Facies IV, fluviatile, sheetflood deposits.

The distinctive pin-striped 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 fluviatile 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 fluviatile (channel and overbank) and aeolian processes, in which aeolian activity may have been temporally dominant, but in which fluviatile 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 (dessicated 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 subaerial 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 fluviatile 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 fluviatile 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 fluviatile 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 fluviatile 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 fluviatile counterparts.
3. Trace fossils in the Scrabo area are mainly limited to fluviatile 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 fluviatile–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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