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TRACE FOSSILS IN THE MUSEUM

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TRACE FOSSILS IN THE MUSEUM

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TRACE FOSSILS IN THE MUSEUM: GUEST EDITOR'S PREFACE

by Stephen K. Donovan

"Modern ichnology continues to draw interest and expertise from traditional fields in sedimentary geology, yet it also benefits from numerous allied disciplines such as benthic ecology, ethology, functional morphology, comparative anatomy, and biogeochemistry. The spectrum of traces and tracemakers is broad, spanning all five major kingdoms of organisms, and substrates affected by them include virtually all siliciclastic sediments and skeletal or other organic constituents, the three classes of rock, and even artificial substances such as steel, glass, and concrete" (Frey and Pemberton 1990, p. 1).

Trace fossils are the 'orphans' of many museum collections. They are organic in origin, but classified outside the true Linnean system of classification, despite having binomial names like true organisms; however, they are sedimentary structures. Some trace fossils can confidently be related to the activities of a particular group of organisms, although assignment to a known producing species is rare, except where the two are preserved in close association, but most are of uncertain affinity and it may even be equivocal as to whether the were due to the activities of animals or plants. In consequence, their situation in most museum collections is unclear. If exhibited, only the dinosaur footprint or trackway are guaranteed to excite interest, the way all things dinosaurian do. Thus, for the museum curator, the basic questions about almost any and all trace fossil in their collection are many. What is it? What made it and why? Where should I put it? Should it be displayed and how?

This thematic issue of *The Geological Curator*, with its focus on trace fossils in museum collections, will, I trust, educate, entertain and inspire the membership of the Geological Curators' Group. Not many members are ichnologists, but, by harnessing the expertise of some of these few, and enticing other experts on trace fossils to make appropriate contributions, the present volume has come to fruition.

Two subjects which may be problematic for the uninitiated, and that I had hoped to see covered by specialist contributions in the present volume, are invertebrate ichnotaxonomy and vertebrate coprolites. Unfortunately, although I had expert and willing volunteers to write both of these papers, pressure of work meant that they were unfortunately unable to meet the deadline for submission of contributions. However, in their absence, I recommend the relevant reviews of Pickerill (1994) and Hunt *et al*. (1994), respectively, to any interested reader.

I thank Patrick Wyse Jackson for making *The Geological Curator* available for the publication of this thematic issue. I also thank my contributing authors, who responded uncomplainingly to my relentless encouragement by e-mail. The following referees, spread evenly between both sides of the Atlantic Ocean, are thanked for their critical input to this project: Loren E. Babcock (The Ohio State University, Columbus); Markus Bertling (Geologisch-Paläontologisches Institut und Museum, Münster); Neil D.L. Clark (Hunterian Museum, Glasgow); Joseph T. Hannibal (Cleveland Museum of Natural History, Ohio); Stephen T. Hasiotis (University of Kansas, Lawrence); John W.M. Jagt (Natuurhistorisch Museum Maastricht); David G. Keighley (University of New Brunswick, Fredericton); Spencer G. Lucas (New Mexico Museum of Natural History, Albuquerque); Phillip L. Manning (The Manchester Museum); Randall F. Miller (New Brunswick Museum, St. John); Patrick J. Orr (University College Dublin); and Roger W. Portell (Florida Museum of Natural History, Gainesville).

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HUNT, A.P., CHIN, K. and LOCKLEY, M.G. 1994. The palaeobiology of vertebrate coprolites. *In* Donovan, S.K. (ed.). *The Palaeobiology of Trace Fossils*. John Wiley & Sons, Chichester, 221-240.

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COLLECTING INVERTEBRATE TRACE FOSSILS

by Stephen K. Donovan, Ron K. Pickerill and Donovan J. Blissett

Donovan, S.K., Pickerill, R.K. and Blissett, D.J. 2006. Collecting invertebrate trace fossils. *The Geological Curator* 8(5): 205-210.

Trace fossils result from the behavioural activities between organisms and variable substrates. They form an integral part of the collections of many natural history museums, providing exciting specimens for display and important material for scientific research. Ichnofossils preserved parallel to stratification in sedimentary rocks can be collected in large slabs either from float or liberated by hammering or rock saw. Laterally extensive specimens commonly have a repetitive morphology, so a fragment may provide ample data for identification and description. The morphology of an ichnofossil that cross-cuts stratification will be more difficult to recognise in the field and may require laboratory preparation of slabs using a rock saw. Bioerosive structures in or on litho- or bioclasts may be easy to collect, but care must be taken to collect data relating to provenance, that is, whether the clasts are autochthonous or allochthonous.

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Introduction

Why collect trace fossils? After all, they are not fossils in the 'true' sense, but sedimentary structures of one sort or another, generated by organic activity. Nevertheless, they are treated as palaeontological objects and have a scientific value equivalent to that of other geological specimens. Natural history museums should acquire specimens of trace fossils for all the reasons that they want body fossils (Knell 1999; Allmon 2005), including the accumulation of exceptional examples for display and the preservation of name-bearing types (see also Pickerill 1994; International Commission on Zoological Nomenclature 1999).

The trace fossils considered in this contribution are those macroscopic structures generated by invertebrates and not, for example, microscopic arthropod coprolites (e.g., Blau *et al.* 1997) or microborings (e.g., Radtke 1991). The specimens of interest are those that are commonly formed either at or subsequent to the time of sedimentary deposition or lithification, either parallel to (trails, tracks, some burrows) or cross-cutting stratification (many burrows); and borings and other bioerosive structures in hard substrates (commonly rock (particularly limestone), shells and bones).

Invertebrate trace fossils, as discussed herein, can be divided into two broad groups: those preserved in what was originally 'soft' (unlithified) sediment (or, rarely, weathered rock; P.J. Orr, written communication), but which is now a lithified sedimentary rock, such as burrows, tracks and trails; and bioerosive structures in what were hard substrates at the time of trace formation, principally borings into limestones, shells and bones. Both groups can include trace fossils preserved in analogous spatial relationships to substrate, such as tracks, trails and burrows parallel to bedding, and borings on or within ancient hardgrounds or other lithic substrates, such as unconformities. Herein, we adopt the artificial 'convention' of considering trace fossils with respect to their orientation to stratification, parallel and non parallel, to which is added bioerosive structures in litho- and bioclasts.

Useful general references for understanding the terminology of trace fossils include Häntzschel (1975), Frey (1975), Maples and West (1992), Donovan (1994), Bromley (1996) and McIlroy (2004). Terminology of trace fossil morphology used herein follows these references and generally accepted descriptive criteria used throughout palaeontology. We do not discuss the many methodologies that are generally applicable to palaeontological and

Figure 1. Field photograph of an outcrop in the Miocene Pelleu Island Formation, White Limestone Group, Jamaica depicting pronounced overhang of bedding plane surfaces (see Blissett and Pickerill 2004 for details on the ichnotaxa).

geological collecting, and which are adequately described elsewhere (e.g., Rixon 1976). Further, we recommend Feldmann *et al*. (1989) for techniques of preparation, which are not discussed herein. Illustrated specimens are deposited in the collections of the Nationaal Natuurhistorisch Museum, Leiden, The Netherlands (RGM), and the Geology Museum, University of the West Indies, Mona, Kingston, Jamaica (UWIGM).

Collecting specimens oriented parallel or near-parallel to stratification

This group embraces surface tracks and trails, certain burrows and burrow systems, and surface etchings, borings, *etc*., on hardground surfaces. It also includes open infaunal burrow systems cast on the sole of the succeeding bed in turbidites and tempestites, commonly found in, for example, *Paleodictyon*. Such traces are best seen at sites where extensive bedding planes are exposed (tops of beds, except where they have been inverted by tectonic activity) or in extensive vertical sections with more or less pronounced overhangs (e.g., Figure 1). In many cases these are the easiest of trace fossils to recognise, yet they are not necessarily the easiest to collect, such as where the trace fossil is situated in the centre of a surface or the bed is more than a few tens of mm in thickness. An extensive bedding surface (e.g., Figure 2) with a variety of traces and other sedimentary structures can be a spectacular display specimen, even if it has to be collected as a jigsaw of separate fragments for re-assembly, broken up in the field by heavy hammering or perhaps even a rock saw; a less destructive methodology would be to cast the surface in the field. Important data, apart from that normally collected in the field (Tucker 1982), includes labelling the top and bottom of the slab(s) (there may be different assemblages of traces on each surface), compass orientation, and numbering the separate pieces of a 'jigsaw' that can be related to an explanatory sketch (for suggestions of how to glue a rock 'jigsaw' back together, see Wolberg 1989). The parts of a 'jigsaw' may include pieces of burrow infill which have 'popped off' of a bedding plane.

Collecting *in situ* specimens from bedding planes is likely to involve intensive labour, using a heavy hammer and/or a rocksaw. It is easier (and less destructive to an exposure) to look for loose slabs at

Figure 2. Large slab collected from talus of the early Pleistocene Old Pera Beds, Pera Point, parish of St. Thomas, Jamaica (see Donovan *et al*. 1997 for details), depicting the manpower that may have to be employed in retrieving important samples. The slab, preserving the ichnospecies *Bichordites monasteriensis* Plaziat and Mahmoudi, is on display in the UWIGM.

the particular exposure preserving trace fossils in the nearby talus (Figure 2), ensuring that the particular slab is not extraneous. Such collecting is facilitated by the morphology of most invertebrate trace fossils to be either discrete and of limited size (such as the resting trace *Rusophycus*), or more extensive yet showing a repetition of morphology, so the entire specimen does not necessarily have to be collected for accurate identification or attractive display (a well-known example is the distinctive trail *Scolicia*). Collecting involves the accumulation of robust slabs of bedded sedimentary rocks (Figure 2), which are difficult to transport unless the field vehicle is easily accessible to the exposure.

Collecting specimens oriented obliquely to stratification

This is not just 'more of the same' after the previous section. Sedimentary rocks typically separate naturally along bedding surfaces, exposing their secrets readily, but trace fossils that penetrate an individual layer are less likely to be exposed, and are less easy to recognise and interpret. Such traces may or may not intersect bedding planes, joints and any other surfaces through a bed; they could be well exposed or cryptic. A surface orientated perpendicular or otherwise to bedding, such as a joint, along which a bed fortuitously separates, may 'cut' through a rock preserving, for example, numerous vertical burrows (such as the Lower Cambrian Piperock of northwest Scotland; e.g., Hallam and Swett 1966; McIlroy and Garton 2004). Such a specimen may give up its secrets readily, but what of rarer and more complex burrows? There may be difficulties of interpretation in the field and, unless sections through beds are

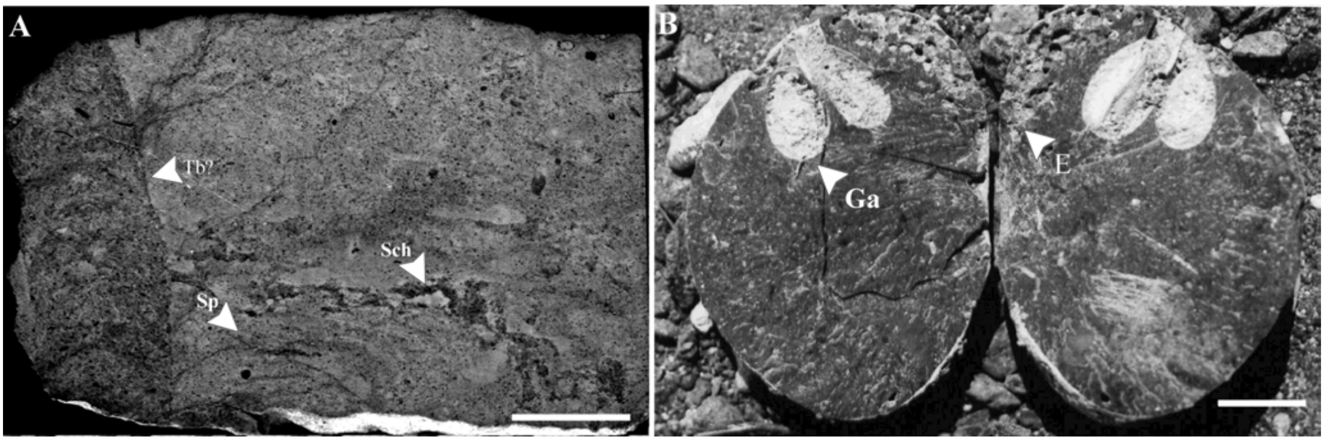

Figure 3. Vertical sections. (A) Vertical section through a slab collected from the outcrop in Figure 1 (RGM 283 561.1-3). For details of the ichnotaxa, see Blissett and Pickerill (2004). (B) Vertical section through a pebble from the Upper Pliocene Bowden shell bed of southeast Jamaica (UWIGM 1997.9a-b). For details on the borings, see Mitchell *et al*. (1998). Key: Sch=*Schaubcylindrichnus coronus* Frey and Howard; Sp=*Scolicia prisca* Quatrefages; Tb?=cf. *Taenidium barretti* (Bradshaw); Ga=*Gastrochaenolites* isp. cf. *G. cluniformis* Kelly and Bromley; and E=*Entobia* isp. Scale bar is 10 mm.

Figure 4. *Teredolites longissimus* Kelly and Bromley (RGM 212 403) as a discrete, isolated tube from the Middle Miocene Grand Bay Formation, Carriacou, the Grenadines, Lesser Antilles. For details on this ichnospecies, see Pickerill *et al*. (2003). Scale bar is 5 mm.

particularly luckily situated and arrayed, large blocks that are 'suspect' will have to be collected for prospecting by rock saw in the laboratory (Figure 3). However, given sufficiently randomly oriented samples in the field, the three dimensional morphology should be broadly determinable. As one example among many of how complex such a trace might be, see Bromley *et al*. (2003). The problems of adequately displaying such a specimen are immediately apparent, but an associated illustration or model in three dimensions should assist interpretation.

Collecting borings and other bioerosive structures in clasts

Burrows are by their nature autochthonous, except in the rare cases in which a burrow-bearing clast is incorporated into a conglomerate or a lithified burrow is exhumed and reworked as a clast. Bioerosive structures (hereafter, for simplicity, lumped together as borings) are a different kettle of fish. Borings preserved in or on an *in situ* surface, such as a hardground or unconformity, can be treated the same way as other structures with a simple relationship to stratification (see above). However, most traces on or within hard substrates that are encountered in the rock record – such as borings, but also including gnaw marks, grazing traces and surface embedments, amongst others – are found in clasts, particularly calcareous lithoclasts and bioclasts, and bones. These clasts may be transported (allochthonous), even though the relationship between the bioerosive trace and the clast is intimate. Thus, the orientation at which the shell, bone or cobble is preserved may not reflect their original attitude at which boring occurred; a clast may be bored before and/or during and/or after transport. It is therefore important to record the orientation and context of any clasts collected. What is important is to determine whether the geological context of the clast suggests transport and, if so, what is the likely environment from which it is derived.

To give but one example as an illustration, consider the rare borings found in clasts within the Middle Miocene Grand Bay Formation of Carriacou in The Grenadines, Lesser Antilles. Multiple lines of sedimentological, palaeontological and ichnological evidence have demonstrated that this unit was deposited in a deeper water turbidite basin, in perhaps 150 to 200 m of water or more (Donovan *et al*., 2003). Its trace fossils (ichnofossils) include both bioerosional and soft-sediment ichnotaxa (burrows). Borings are represented by a relatively diverse assemblage of at least eight ichnogenera and 13 ichnospecies that reflect bioerosional activities of a wide variety of organisms including gastropods, bivalves, clionid sponges, acrothoracian cirripedes and polychaete annelids. These macroborings occur mainly in association with a variety of originally shallow-water molluscan and, more rarely, scleractinian coral substrates. The exception is *Teredolites longissimus* Kelly and Bromley, 1984, that originally inhabited xylic substrates (not preserved), but which occur as discrete and isolated tubes filled with sedimentary rock and, more rarely, as calcite-filled tubes (Figure 4).

Allochthonous non-marine and autochthonous deeper water marine shells never exhibit macroborings, suggesting that bioerosion was restricted to available substrates in only shallow-water regimes. Although relatively diverse, the borings are uncommon components of the abundant substrates originally available for bioerosive activities, a reflection of taphonomic loss of bored material by selective mechanical (high energy waves, tides and/or currents) and/or biomechanical fragmentation (particularly by fish and arthropods), and destruction prior to re-sedimentation and final burial of surviving faunal elements actually containing borings. The existence of such processes is supported by the presence in the sequence of numerous examples of fragmented and abraded molluscan and coral clasts.

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CONTINENTAL TRACE FOSSILS AND MUSEUM EXHIBITS: DISPLAYING ORGANISM BEHAVIOUR FROZEN IN TIME

by Stephen T. Hasiotis and Mary C. Bourke

Hasiotis, S.T. and Bourke, M.C. 2006. Continental trace fossils and museum exhibits: displaying organism behaviour frozen in time. *The Geological Curator*, 8 (5):211-226.

This paper introduces continental trace fossils, and suggests ways in which modern and ancient traces can be used in museum exhibits. Burrows, tracks, trails, nests, borings, excrement and root patterns represent organism-substratum interactions of terrestrial and aquatic plants, invertebrates and vertebrates, and are preserved in the geologic record as continental trace fossils. Trace fossils are important because they are analogous to behaviour frozen in time and preserve information about organisms not recorded by body fossils. They can be used also as fossil evidence of organisms in the geologic record; an organism can make tens to millions of traces in a lifetime. Trace fossils represent hidden biodiversity; they preserve *in situ* evidence of food-web relations between fossorial, terrestrial and aquatic communities, and are useful for interpreting palaeoenvironmental, palaeohydrologic and palaeoclimatic settings.

Public education on the importance of continental trace fossils to palaeontology and the study of Earth history can be accomplished with side-by-side displays of casts of modern traces and trace fossils, which represent homologs or analogues to modern behaviours. Such displays allow the public to see how scientists study and interpret the significance of trace fossils as behaviour. This kind of exhibit demonstrates also that modern organisms and their behaviours have an evolutionary history through deep geologic time as recorded by the record of body and trace fossils. Several examples of modern traces and ancient trace fossils presented here illustrate ways to produce museum exhibits to educate the public on continental trace fossils.

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Introduction

The purpose of this paper is to introduce continental trace fossils to curators unfamiliar with the discipline of ichnology, and to suggest ways in which modern and ancient traces can be used in museum exhibits. Exhibits of modern and ancient traces allow the public to see how scientists study and interpret the significance of terrestrial and aquatic trace fossils as behaviour. These types of exhibits illustrate also that modern organisms and their behaviours are the product of evolutionary history as related by the record of body and trace fossils through geologic time.

Organism-substratum interactions of terrestrial and aquatic plants, invertebrates and vertebrates manifest themselves as burrows, tracks, trails, nests, borings, excrement and root patterns (e.g., Ekdale *et al*., 1984; Hasiotis 2002, 2003). These are preserved in the geologic record as continental trace fossils, and are now recognized as diverse and abundant in many late Palaeozoic, Mesozoic and Cainozoic deposits (e.g., Bromley and Asgaard 1979, Bown and Kraus 1983, Retallack 1984, Smith 1987, Gierlowski-Kordesch 1991, Lockley 1991, Sarkar and Chaudhuri 1992, Hasiotis *et al*. 1994, Donovan 1994, Genise 1995, Bown *et al*. 1997, Varricchio *et al*. 1997, Buatois *et al*. 1998, Groenewald *et al*. 2001; Miller *et al*. 2001).

Trace fossils are important because they are analogous to behaviour 'frozen in time' that can be used as evidence of organisms in the geologic record (e.g., Ekdale *et al*. 1984, Elliot and Nations 1998, Scott 1991, 1992, Hasiotis and Bown 1992, Hasiotis 2003, 2004). Terrestrial and freshwater organisms are not preserved often as body fossils in continental deposits because of oxidizing conditions, consumption of the remains by other organisms and the reworking of near-surface, body-bearing sediments (e.g., Behrensmeyer and Hill 1980, Behrensmeyer *et al*. 1992, Hasiotis and Bown 1992). These factors make it difficult for an organism to pass through the taphonomic barrier. When they are preserved, continental body fossils are deposited often outside their original environmental context. Any one organism, however, can make tens to millions of traces in a lifetime that may leave some record of its existence (Lockley 1991, Lockley and Hunt 1995, Hasiotis 2002, 2003). Thus, trace fossils make excellent proxies for the presence of organisms in terrestrial and aquatic deposits, and represent hidden biodiversity. They also preserve *in situ* evidence of food-web relations between fossorial, terrestrial and aquatic communities. Trace fossils are useful for interpreting such palaeoenvironmental variables as soil moisture and water-table levels, as well as precipitation and its seasonality for a specific climatic setting (e.g., Hasiotis and Dubiel 1994, Hasiotis 2004).

How trace fossils represent continental organisms and their behaviour

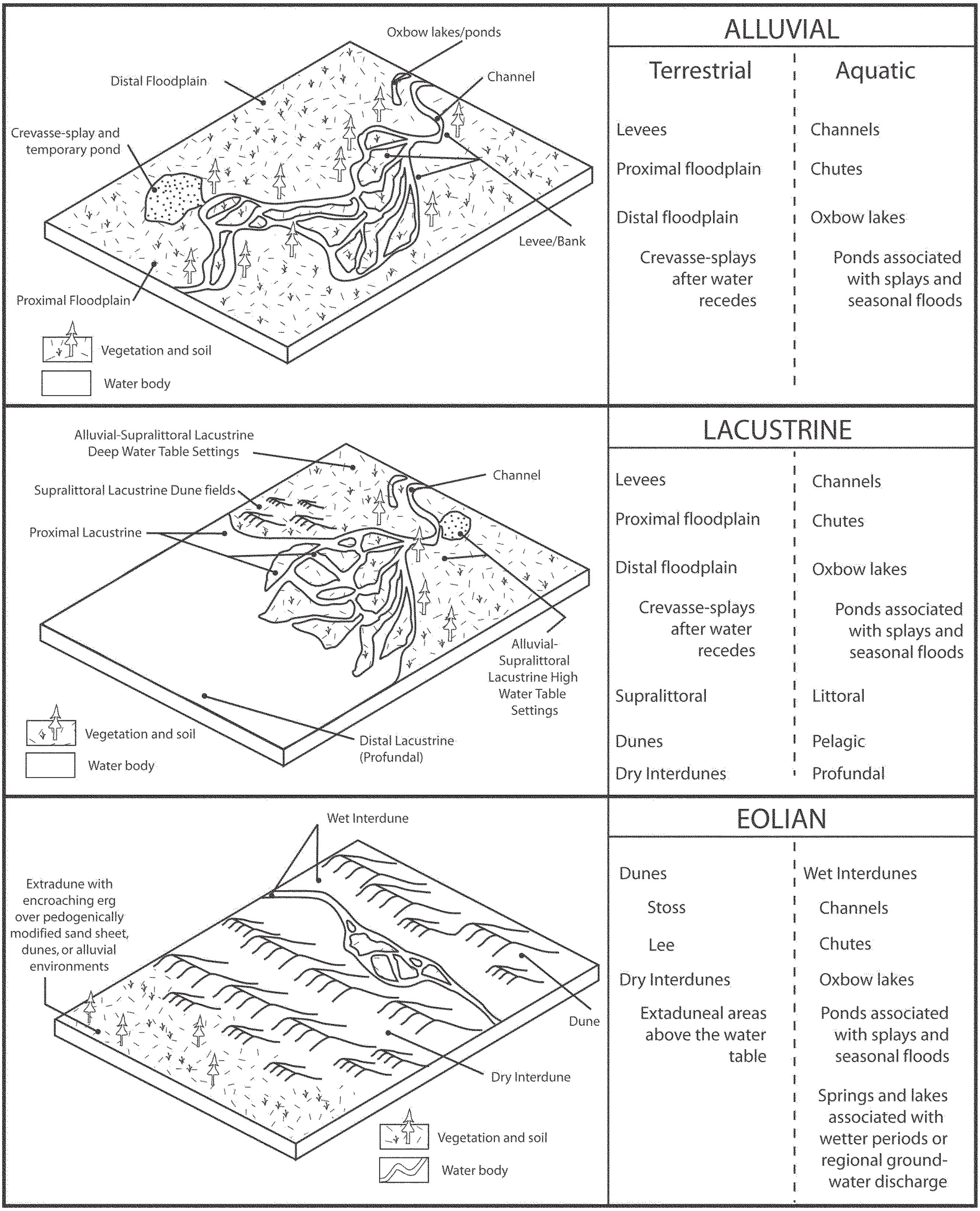
Organisms are distributed vertically and laterally in modern continental environments (Figure 1) with respect to their physiological needs or tolerance to water, soil moisture, salinity, temperature and ecological associations with other organisms, all of which are controlled by climate (Wallwork 1970, Whittaker 1975, Hasiotis and Bown 1992, Hasiotis 2000, 2002, 2004). Terrestrial and aquatic organisms have different requirements for water or soil moisture, substrate consistency at the water-substrate interface, and the degree of ionic concentration and salinity within the water or substrate. Organisms may be terrestrial in habitat, living above, on and below the soil surface to the depth of the top of the saturated zone or water table. Other organisms are amphibious and live in areas restricted to shorelines of water bodies spending time in and out of a water body, considered as semi-terrestrial or semi-aquatic in habitat. Still others are aquatic, and live in rivers, lakes and swamps, as well as below the water table in soil where the pore space is saturated with water. Organisms living in these environments have different tolerances to the degree of ionic concentration and salinity, and are classified as oligohaline, stenohaline, euryhaline, or mixohaline (e.g., Wallwork 1970, Perkins 1974, Hasiotis and Bown 1992, Ward, 1992). River water mixes with ocean water where the continental realm meets the marine realm to produce oligohaline, mesohaline, polyhaline and euhaline salinity zones in estuaries, bays and probably also groundwater (Perkins 1974). Water bodies and groundwater within the continental realm may be fresh, saline-alkaline and hypersaline, and controlled by the concentration of cations and anions (Hutchinson 1957, Wetzel 1983).

The traces of plants, invertebrates and vertebrates record in one or more ways the body size, presence in and effect on a substrate, habitat preference and type of activity of the organism (e.g., Wallwork 1970, Hasiotis 2000). With the exception of the Brachiopoda, Cnidaria, and Echinodermata, most phyla have species that spend some part of their life cycle in association with the continental substratum. Locomotion, feeding and reproduction are the major types of activities of all organisms (e.g., Evans and Eberhard 1970, Ratcliffe and Fagerstrom 1980, Evans 1991). These activities result in structures used for dwelling, concealment, gardening and predation, similar in some respects to behaviours of marine organisms (Bromley 1996).

Many animals have only minimal involvement with the substratum because their presence is temporary, occurrence is localized and effects are minimal (e.g., Wallwork 1970, Hasiotis 2000, 2002). For instance, many reptiles, mammals and birds nest, dwell or wallow in the substratum, but spend most of their time above the soil surface and produce millions of tracks and trackways in a lifetime.

Plants use root systems to anchor themselves to the substratum, retrieve minerals and water from the soil, and, in some cases, move laterally from one place to another. These root systems will most likely be the only *in situ* evidence of plants and their impact on the substratum (Sarjeant 1975, Pfefferkorn and Fuchs 1991, Hasiotis 2002).

Organisms spend various amounts of time interacting with the substratum throughout their life cycle as epigeon, geophiles or geobionts (Figure 2). The presence and amount of activity of animals within the substratum can be transient, temporary, periodic or permanent (Wallwork 1970, Hasiotis 2000). Organisms that are transient to the substrate have their complete life cycle above ground, but construct burrows for shelter for brief periods to escape temperature extremes or predation. Adult tiger beetles (Coleoptera: Cincidelidae) and stink beetles (Coleoptera: Tenebrionidae) construct burrows of a transient nature on floodplains, pointbars and sand bars (e.g., Chamberlain 1975, Stanley and Fagerstrom 1974, Ratcliffe and Fagerstrom 1980). Organisms that are temporary to the substratum spend their adult lives above ground, but have their egg and juvenile stages below ground in nests or burrows. For instance, dung beetles (Coleoptera: Scarabaeidae) spend much of their lives above ground, but excavate nests into the substratum to lay eggs in the dung in which they bury. These eggs hatch and the juveniles grow as larvae underground, pupate within the nest or in its proximity and burrow to the surface as adults (Halffter



ALLUVIAL

Terrestrial	Aquatic
Levees	Channels
Proximal floodplain	Chutes
Distal floodplain	Oxbow lakes
Crevasse-splays after water recedes	Ponds associated with splays and seasonal floods

LACUSTRINE

Levees	Channels
Proximal floodplain	Chutes
Distal floodplain	Oxbow lakes
Crevasse-splays after water recedes	Ponds associated with splays and seasonal floods
Supralittoral	Littoral
Dunes	Pelagic
Dry Interdunes	Profundal

EOLIAN

Dunes	Wet Interdunes
Stoss	Channels
Lee	Chutes
Dry Interdunes	Oxbow lakes
Extadunеal areas above the water table	Ponds associated with splays and seasonal floods
	Springs and lakes associated with wetter periods or regional groundwater discharge

Figure 1. Continental environments. Major components of alluvial, lacustrine and aeolian depositional environments; palustrine and volcanoclastic environments are minor and not illustrated here. Palustrine environments occur where the water table is at, below or just above the ground surface. Volcanoclastic deposition is mostly by air fall and the deposits are further modified by water (i.e., rivers or lakes) or wind (aeolian processes).

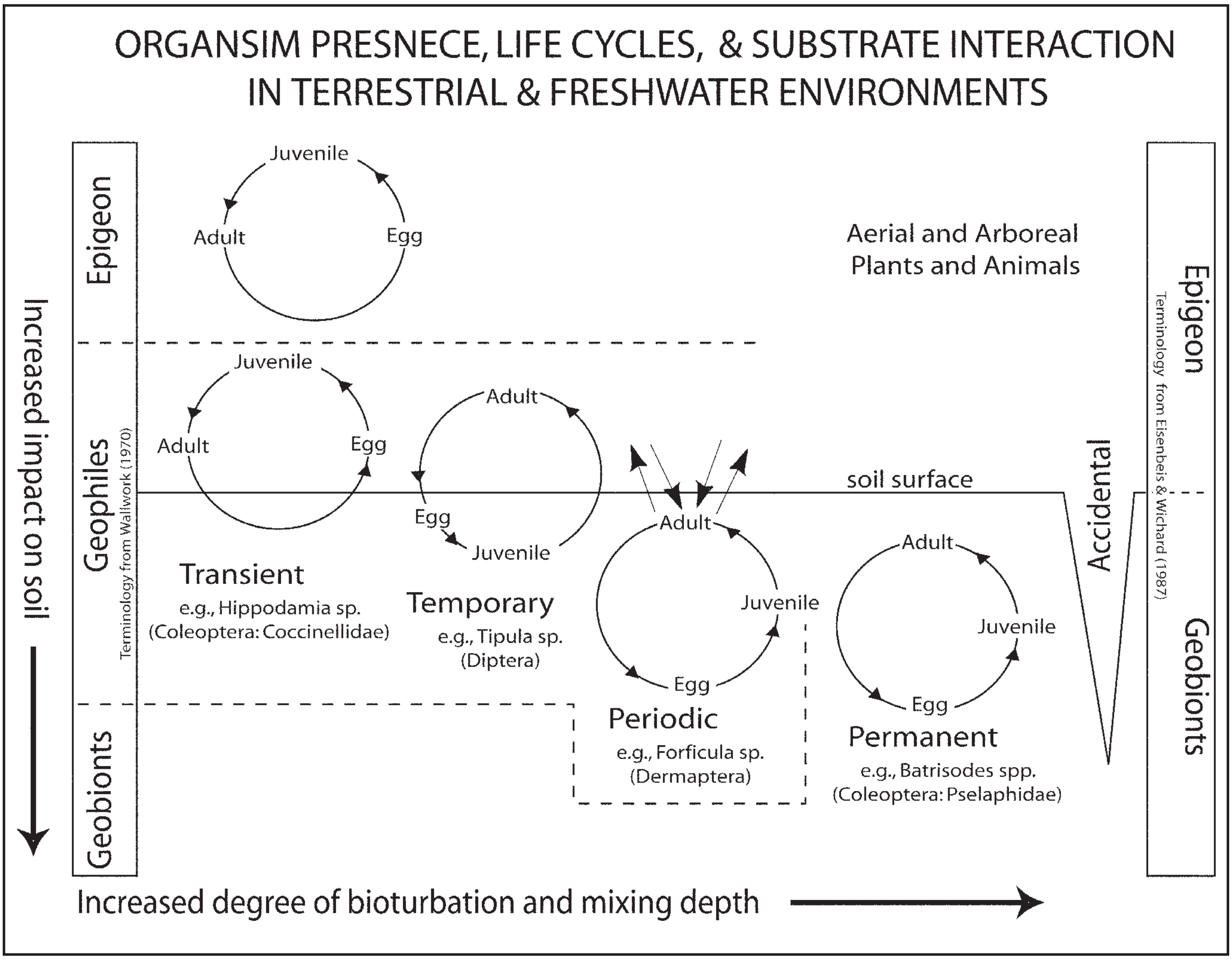


Figure 2. Organism presence, life cycles and substrate interaction in terrestrial and freshwater environments. Organisms are categorized as epigeon, geophiles or geobionts (terminology from Wallwork 1970, Eisenbeis and Wichard 1987), depending on how much time of their lives they spend in the subsurface. In general, the more time spent in the subsurface, the greater degree of bioturbation, sediment mixing and impact on soil formation. Modified from Hasiotis (2000).

and Matthews 1966). In this example, a series of traces is created by the adult and its offspring as larvae and as emergent adults. Organisms that are periodic to the substrate spend their complete life cycle underground, but emerge as adults to mate and begin the cycle again. Cicadas (Insecta: Hemiptera: Homoptera: Cicadidae) and termites (Insecta: Isoptera) represent two examples of periodic organisms. Cicadas mate and lay eggs in the branches of trees or on the ground. The eggs hatch and enter the ground as 1st instars (earliest juveniles), spending most of their lives underground feeding and growing. The mature juveniles emerge eventually, shedding their skin, take flight and mate to begin the cycle again (Gullan and Cranston 1994). Termites spend most of their lives below ground as part of small to large colonies collecting plant remains, maintaining and defending the nest, tending eggs and rearing the young, in some instances growing fungal gardens for food and to regulate the nest atmosphere (e.g., Wilson 1971). In many cases, when foraging for plant materials above ground, termites will build tunnels to bring the subsurface environment with them. Special winged adults emerge from the nest to take to the air in nuptial flights, mate and begin new nests (e.g., Wilson 1971, Hasiotis 2003). Such organisms with the complete life cycle underground as some rove beetles (Coleoptera: Staphylinidae) and most mold beetles (Coleoptera: Pselaphidae) have a permanent presence underground (Wallwork 1970).

Under suitable conditions, landscapes and their transient to permanent organisms are buried sooner or later by successive depositional events through time, particularly in aggradational systems. The bodies of plants, invertebrates and vertebrates are likely to be destroyed in many of these deposits. In some cases organism remains are transported and buried in various stages of mechanical and chemical degradation, in time becoming fossils (e.g., Behrensmeyer and Hill 1980). Burrows, nests, tracks, trails and rooting patterns, however, will have the highest preservation potential, and will record the presence and behaviour of these organisms in the geologic record as trace fossils (Hasiotis and Mitchell 1993, Genise and Bown 1994, Hasiotis 2002, 2003).

Behavioural categories for continental trace fossils

Water availability and its relationship with the substratum is the major limiting factor in the distribution of organisms (Wallwork 1970, Whittaker 1975). It controls the depth to which organisms burrow as well as the ecological relationships between organisms in the substratum. The majority of terrestrial organisms and biodiversity lives in the continental realm, and these organisms live mostly above the water table in well-drained terrestrial settings (e.g., Wallwork 1976, Aber and Melillo 1991, Wilson 1992). Continental aquatic environments are occupied by considerably fewer organisms and are depauperate in diversity compared to floodplains, because aquatic environments are geologically short lived and thus, are evolutionary dead ends (Hasiotis 2002, 2004). For example, lakes are evolutionary dead ends because organisms that evolve unique feeding or dwelling behaviours go extinct when the lake fills in through time (Hasiotis 2004). If the lake eventually filled and became a river or swamp (palustrine), the organisms adapted to benthic sedentary lifestyles could not compete with aquatic organisms adapted to the fluvial or palustrine environments. The high depositional energy and shifting substrates in fluvial systems precludes the occurrence of burrowing organisms, except for those living along or above the water line. The variation in water levels in palustrine systems would also preclude any specialized feeding behaviours evolved in relatively more stable deep-water habitats.

The groundwater profile controls the diversity of burrowing organisms, and the depth and morphology of burrows, nests, tracks, trails and rooting patterns (Figure 3). The groundwater profile is divided into two major components, the unsaturated and saturated zones. These are also known as the vadose and phreatic zones, separated by a surface where the two zones meet called the water table (Driscoll 1986). The vadose or unsaturated zone can be divided into the upper vadose zone (including the soil-water zone) and the intermediate vadose zone. The capillary fringe rises above the phreatic zone to a height relative to the grain size and porosity of the soil media. The capillary fringe is water-saturated pore space and is often associated directly with the saturated zone.

Trace fossils of continental organisms can be grouped into one of four behavioural categories (Figure 3) based on moisture zones of the groundwater profile as well as different space and trophic use (Hasiotis

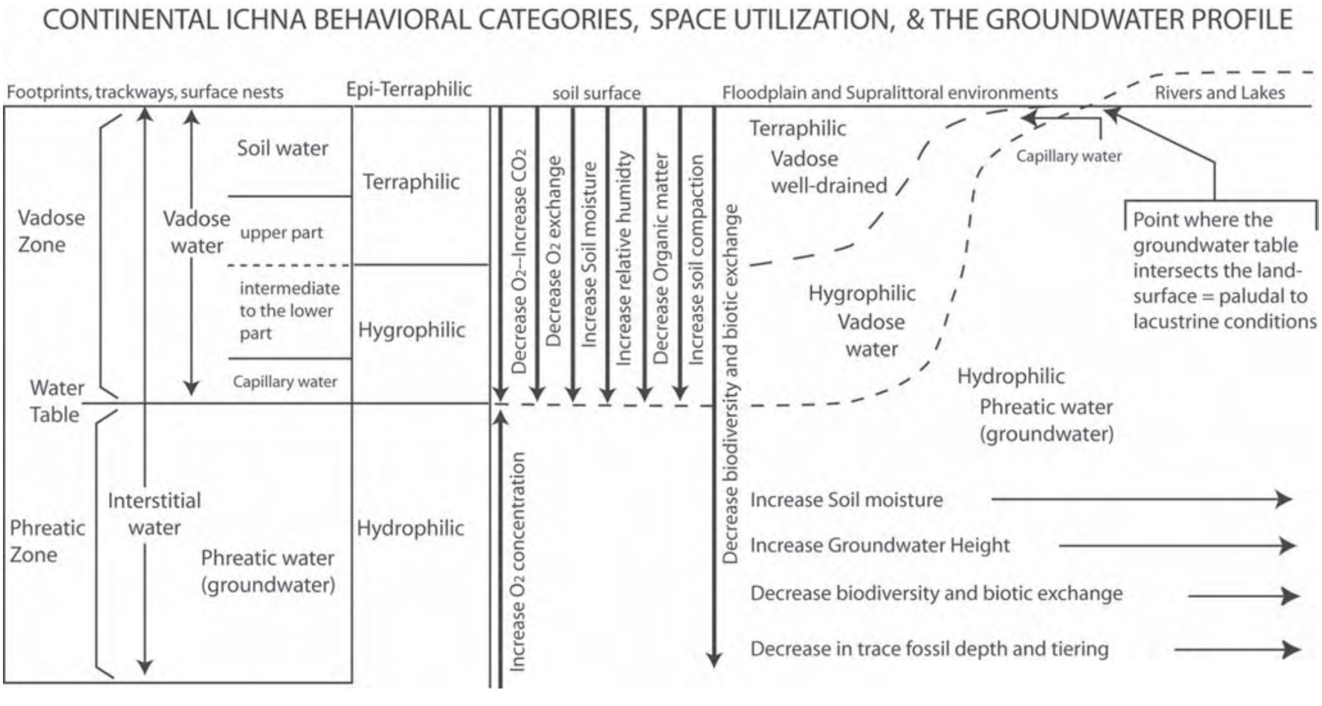


Figure 3. Continental ichna behavioural categories, space utilization and the groundwater profile. A four-part division of burrowing behaviour represented by continental ichnofossils or ichna that reflects the space utilization, trophic associations and moisture zones of the groundwater profile occupied by burrowing organisms in terrestrial and freshwater environments. Modified from Hasiotis (2004).

2000, 2004). These categories are based on the distribution of extant organisms and their physiological requirements for water (e.g., Kevan 1962, Wallwork 1970, Hasiotis and Mitchell 1993, Hasiotis 2000), as well as the distribution of ichnofossils, sedimentary structures and pedogenic features exhibited in outcrop and core (e.g., Stanley and Fagerstrom, 1974, Bown and Kraus, 1983, Hasiotis and Mitchell 1993, Hasiotis and Dubiel 1994, Hasiotis and Honey 2000). Organisms living above the water table in the well-drained, uppermost parts of the vadose zone construct terraphilic traces. These organisms have low tolerance for areas of prolonged high moisture levels, tolerate short periods of 100 % soil moisture and live in areas with relatively little available water. Surface-dwelling, trackway-making, shallow-nesting organisms construct surface tracks, trails and traces, and are termed epiterraphilic. Epiterraphilic tracemakers and their traces can co-occur with other behavioural categories at ground level during periods of elevated moisture levels. Organisms living within the intermediate and lower parts of the vadose zone construct hygrophilic traces. This category includes organisms that live above ground, but burrow to higher moisture levels in the substratum for reproduction. They obtain their oxygen from the soil atmosphere and above-ground atmosphere via the main shaft or tunnel of the burrow or nest. Hydrophilic traces are constructed by organisms that live below the water table within a soil and within the substratum in open bodies of water where the water table intersects the land surface or water is perched above the surface by an impermeable layer, such as clay, to form rivers, swamps and lakes. These organisms obtain oxygen from the water, but can also use high levels of soil moisture to keep their gills wet for short periods of time (e.g., Horwitz and Richardson 1986, Hasiotis and Mitchell 1993). This category includes organisms that burrow to a position below the water table and maintain the whole burrow, including the entrance at the surface.

The depth and cross-cutting relationships of continental traces, also known as tiering, can be used to approximate the position and fluctuation of the unsaturated and saturated zones of the palaeo-groundwater profile (Hasiotis and Dubiel 1994). These interpretations are verified independently by examining the association of primary and secondary sedimentary structures, and the development of such pedogenic features as mottling, ped structures, colouration, micromorphology, texture and geochemistry (e.g., Retallack 1990, 1997). In several cases in the Willwood Formation in the Bighorn Basin, Wyoming, red palaeosols interpreted as representing a well-drained environment contain relatively deep, penetrating rhizoliths consisting of grey, iron-depletion zones with red rims, indicating haematite accumulation. Powdery calcium carbonate is present locally within the grey depletion zones. These features indicate surface water gley (i.e., standing water on the surface) processes that caused iron and manganese to move from the root channel outward to the soil matrix and carbonate precipitation in the channel as the soil dried. Burrows are diverse, abundant and distributed deeply in these palaeosols. Purple palaeosols interpreted as representing more poorly-drained environments have rhizoliths consisting of iron depletion zones surrounded by yellow-brown rims composed of goethite, indicating surface water gley processes. Burrows are less diverse, but abundant in these palaeosols to shallower depths. Palaeosols that are even more poorly drained contain rhizoliths preserved in jarosite, which is an oxidation product of pyrite, and are associated with very few and shallow penetrating trace fossils. Very poorly drained, low chroma palaeosols contain sparse rhizoliths that do not penetrate deeply and burrows are very rare to absent. In all of these palaeosols, the position of the water table is marked by the place where the primary sedimentary structures and nearly original sedimentary layering is still preserved (Kraus and Hasiotis 2006, Hasiotis and Kraus unpublished data).

Trace fossils record *in situ* evidence of food-web and other ecological relations between fossorial, terrestrial and aquatic communities. For example, borings on dinosaur bones suggests scavenging by dermestid beetles of the postmortem dinosaur carcass (Hasiotis *et al.* 1999, Hasiotis 2004). Modern forensic studies have demonstrated that there is a succession of necrophilous (dead-flesh eating) and saprophagous (feeding on dead or decaying material) insects throughout the stages of decay on carcasses (Smith 1986). An ecological succession of insects results from changes in the attractive nature of a carcass leading to the complete decomposition of the animal (e.g., Reed 1958, Payne 1965). The dermestids are one of the last arthropods to arrive to a carcass during the dry stage where they feed on skin, fur and horns, and sometimes bore into bone to pupate. The trace fossils of dermestid feeding and pupation are the only evidence of this type of detritivore recycling during the Late Jurassic (Hasiotis *et al.* 1999, Hasiotis 2004). In other examples, trace fossils interpreted as those of dung beetles suggest strongly the presence of herbivores and edible plants, and their interactions (e.g., Chin and Gill 1996, Hasiotis 2002, 2004, Radies *et al.* 2005).

Continental environments and their trace-fossil associations can be classified as the behavioural proxies of biological community assemblages or ichnocoenoses (Figure 4), rather than archetypal ichnofacies. The redefined *Scoyenia* ichnofacies (Frey *et al*. 1984) and the purported *Mermia*, *Coprinisphaera* and *Termitichnus* ichnofacies (e.g., Genise *et al*. 2000, 2004, Buatois and Mángano 2004), are merely large lists of trace fossils that occur in a substratum that is largely ignored, not integrated into the facies scheme and too broad to be of any use (e.g., Hasiotis, 2004). Construction of ichnocoenoses properly incorporates patterns in bioturbation with the biophysicochemical controls and processes that operate in the continental realm, and correspond to characteristic environmental conditions. Localized remnants of above- and below-ground, trace-making, ecological communities are preserved as trace-fossil associations or ichnocoenoses. An ichnocoenoses can contain tiered traces of arboreal, epigeal and fossorial organisms that lived together, and had transient, temporary, periodic or permanent relationships with the substratum (geophiles and geobionts).

An ichnocoenoses would be named for the most abundant or significant pedological and ecological-modifying behaviour in that ichnocoenosis and subenvironment. For example, if crayfish burrows are the dominant trace fossils of an ichnocoenosis and environment, then the trace-fossil association is termed the *Camborygma* ichnocoenosis. If spherical termite nests are the dominant trace fossils of an ichnocoenosis and environment, then the trace-fossil association is termed the *Termitichnus* ichnocoenosis.

All things considered, continental trace fossils provide a vast amount of information when studied carefully with respect to the deposits in which they are found. Traces preserve evidence of differing amounts of soil moisture and the position of the palaeo-water table, and their fluctuations through time. Trace fossils indicate the presence of large numbers of plants, invertebrates and vertebrates, and record biodiversity and palaeoecologic relations that otherwise are overlooked when body fossils are absent or underrepresented in sedimentary deposits. Inferences can be made about the palaeoclimatic setting of an area in terms of precipitation and its seasonality when ichnologic data and interpretations are combined with other palaeontologic, sedimentologic and geochemical field and laboratory data. All of these aspects of continental trace fossils and the study of ichnology can be related to the public using museum exhibits.

Trace fossils as museum exhibits

The best way to teach the public about the importance and utility of continental trace fossils is to display them alongside casts of modern traces that represent homologs or analogues to those ancient behaviours. Some museums already have exhibits of dinosaur or reptilian trackways displayed with the trackmaker's skeleton or its restoration (Hannibal and Lucas 2006), however, there is much more to continental trace fossils than trackways. Side-by-side displays of modern and ancient behaviour allow the public to see how scientists study and interpret the significance of trace fossils. This kind of exhibit demonstrates that modern organisms and their behaviours have an evolutionary history through deep geologic time as recorded by the record of body and trace fossils.

Casts of modern traces can be made by pouring fibreglass, epoxy, concrete or dental plaster down into the burrow, nest or track-bearing surface (e.g., Shinn 1968, Farrow 1975, Hasiotis and Mitchell 1993). The burrows and nests should be cast so that the casting material forms a horizontal plane at the entrance-ground surface interface so that the cast can be mounted properly with respect to its original orientation in the subsurface. The constructors of the modern traces can be removed prior to casting or they can be entombed within the casting medium itself. Specimens of the tracemaker can also be retrieved from similar traces via excavation and capture, and displayed alongside the cast or actual trace examples. Genuine pieces of such nests as those constructed by dung beetles, termites, wasps, bees and ants can also be displayed alongside their constructors. Photographs of the burrow entrances in which the casting material was poured or the nest itself can be displayed with the trace and its constructor. Most people have no idea what kind of three-dimensional structure lies below a burrow entrance, seen only as an open hole in the ground. Such displays link the opening to the burrow and its constructor(s).

The exhibit is complete when the modern organism(s) and their biogenic structure are displayed together with an ancient continental trace fossil that represents their homologous or analogous behaviour. In the case of ancient trackways, a display is completed with the trackmaker's skeleton or its restoration, and complemented with the trackway and body of an extant organism with analogous behaviour. The ancient trace fossils can be displayed in or out of their surrounding matrix, depending on how complicated the three-dimensional structure is and the ease with which they can be removed from the matrix. In rare cases, the constructor of the ancient trace fossil is

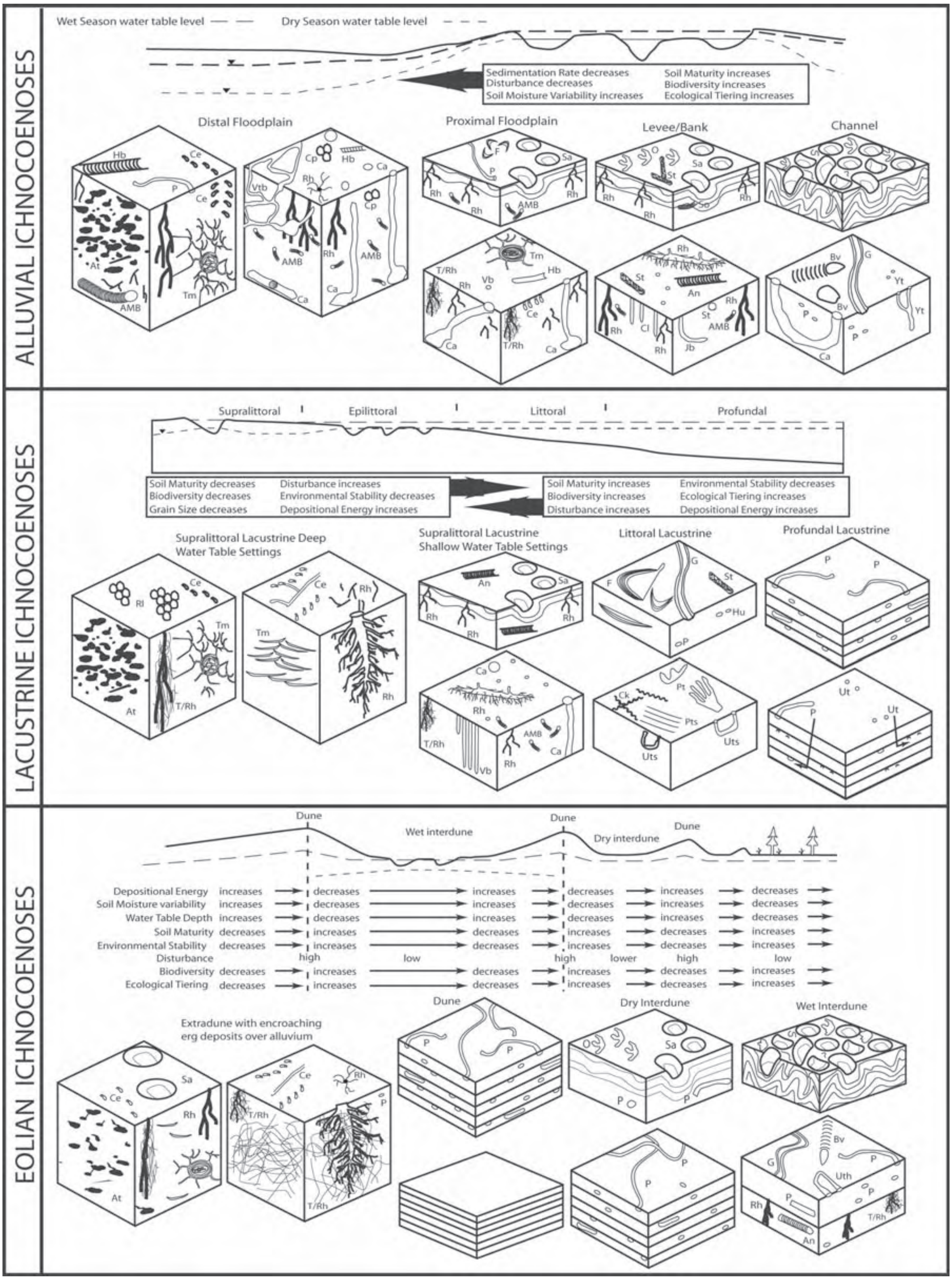


Figure 4. Continental ichnocoenoses. Examples of ichnocoenoses found in subenvironments of alluvial, lacustrine, and aeolian environments and deposits. Tiering and distribution in each subenvironment is controlled by the behaviour (Fig. 1), groundwater profile (see Fig. 2) and depositional processes (Fig. 3 and this figure). Abbreviations: **AMB**-adhesive meniscate burrows, **An**-*Ancorichnus*, **At**-ant nests, **Bv**-bivalve traces, **Ca**-*Camborygma*, **Ce**-*Celliforma*, **Ck**-*Cochlichnus*, **Cl**-*Cylindrichum*, **Co**-*Conichnus*, **Cp**-*Coprinisphaera*, **F**-*Fuersichnus*, **G**-gastropod trail, **Hb**-horizontal burrows, **Hu**-horizontal U-shaped burrow, **O**-ornithopod and theropod tracks, **P**-*Planolites*, **Rh**-rhizoliths, **Pt**-*Pteraichnus*, **Pts**-pterosaur scratch marks, **Sa**-sauropod tracks, **So**-*Scoyenia*, **St**-*Steinichnus*, **Tm**-termite nest, **T/Rh**-termite nests in rhizoliths, **Ut**-ghost U-shaped tubes, **Uts**-shallow U-shaped tubes, **Vb**-quasivertical burrows, **Vtb**-vertebrate burrows, **Wp**-wasp nest/cocoons, **Yt**-Y-shaped vertical burrow. Trace fossil illustrations and box diagrams are not to scale.

entombed within the trace itself (e.g., Hasiotis and Mitchell 1993, Hembree *et al*. 2004).

In the following sections we illustrate examples of ways in which traces can be used in educational exhibits on continental trace fossils, incorporating modern and ancient examples of organism behaviour frozen in time.

Crayfish burrow

Crayfish (Decapoda: Astacoidea and Parastacoidea) burrows are simple to elaborate in morphology and their depth of penetration is based on the depth of the saturated zone (e.g., Hobbs 1981, Hasiotis and Mitchell 1993). Burrows can be horizontal and just below the sediment-water interface or reach depths of up to 9 m below the sediment-air interface (Hasiotis and Mitchell 1993, Hasiotis and Honey 2000, Hasiotis 2004). Simple crayfish burrows are composed of a single shaft with one or more openings that terminate in a single chamber or as tunnels that branch laterally at the shaft terminus. More elaborate crayfish burrows have one or more openings, chambers and tunnels that originate or occur within a central shaft (Figures 5A, B). The burrow entrance is circular and often marked by a chimney composed of pellets of soil excavated from the burrow (Figures 5C, D). The surficial morphology of the burrow walls contain mm-scale clusters of scratch marks, cm-scale transverse scrape marks, mm-scale rounded striations, knobby and hummocky texture, and discontinuous sediment linings composed of excavated soil matrix (Hasiotis and Mitchell 1993).

The architectural and surficial morphologies of crayfish burrows appear to have changed little over their 280-million-year history (Hasiotis and Mitchell 1993, Hasiotis *et al*. 1993, Hasiotis 1999, 2002). Examples of crayfish burrows from the Upper Triassic Chinle Formation (Colorado Plateau, USA) and Paleocene Fort Union Formation (Wyoming, USA) illustrate how similar their morphologies are to each other, as well as to the burrows of modern crayfish (Figures 5E, F). The burrow morphologies demonstrate that the chelae were used to construct and maintain the burrows, and that the burrows were constantly modified during the life of the crayfish as well as by other members of the same species that inhabited the burrow after it was abandoned or after the original owner died.

The exhibit of crayfish burrows could contain actual casts of the modern and ancient burrows, as well as photographs of the outcrop and the fossil specimens associated with the burrows. Live specimens burrowing in an aquarium set-up would allow the

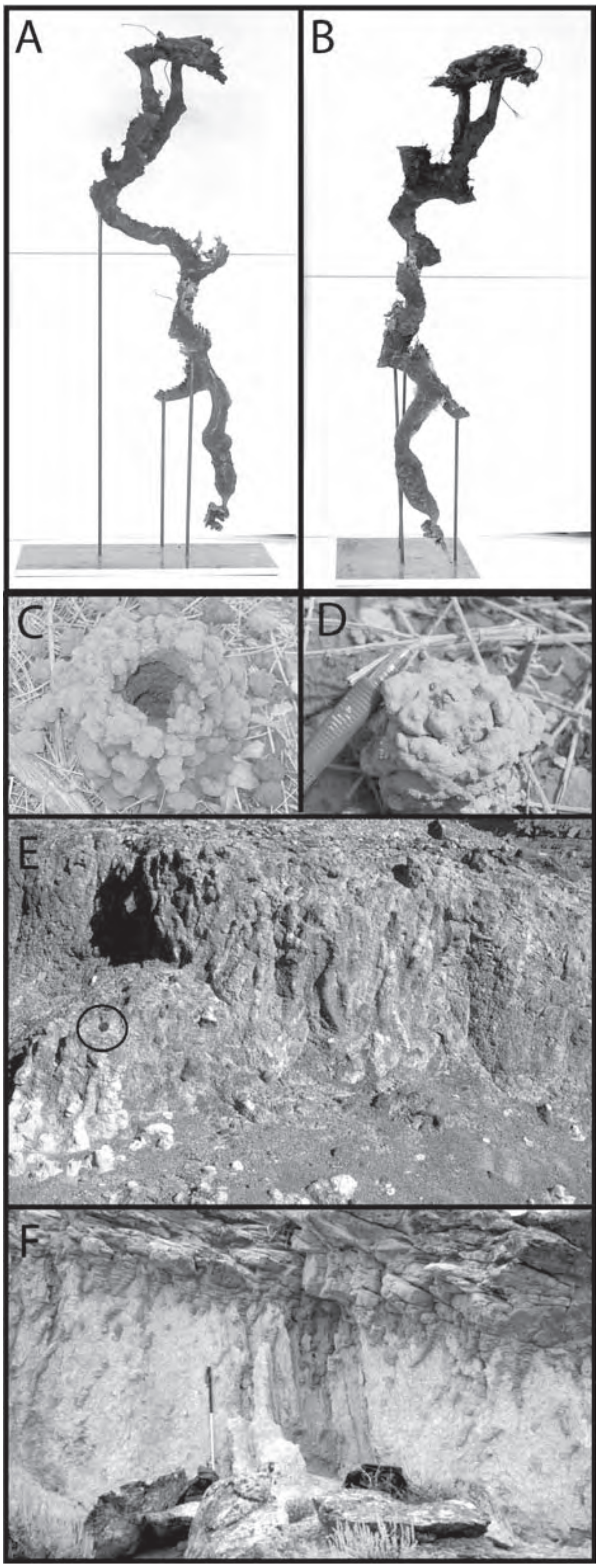


Figure 5. Crayfish burrows. (A-B) Cast of a modern crayfish burrow from the University of Kansas Ecological Research Station; burrow is 720 mm tall. (C-D) An open (C) and closed (D) chimney of a crayfish burrow, composed of soil pellets; (C) is 120 mm wide, (D) is 80 mm wide. (E-F) Triassic Chinle Formation (E) and Paleocene Fort Union Formation (F) crayfish burrows in outcrop; lens cap in left side of photograph in (E) = 50 mm, Jacob staff in (F) is 1.5 m tall.

public to see how crayfish construct and maintain their burrows.

Scorpion Burrow

Scorpion (Arachnida: Scorpiones) burrows are unique in morphology because they produce a spiral, flattened tunnel with several whorls that are well constrained in construction with respect to the tunnel angle and radius of coiling (Figures 6A, B). The burrow is composed of a single entrance, spiral tunnel and terminal chamber. The terminal chamber is slightly wider in diameter than the spiraled tunnel. The position of the chamber is directly under or away from the direction of the burrow opening. The burrow entrance is distinctively crescent shaped with the terminations of the crescent pointing upwards (Figures 6C, D). The morphology of the opening indicates the upward, ready position of the scorpion's chelae as it exits the burrow.

Although scorpion burrows have not been described from the geologic record, their terrestrial body-fossil record occurs at least as early as the Carboniferous (Petrunkevitch 1953), and possibly the Silurian (Kjellesvig-Waering 1986). Scorpion burrow morphology is so distinct that it should be easy to identify the presence of scorpion burrows in the rock record.

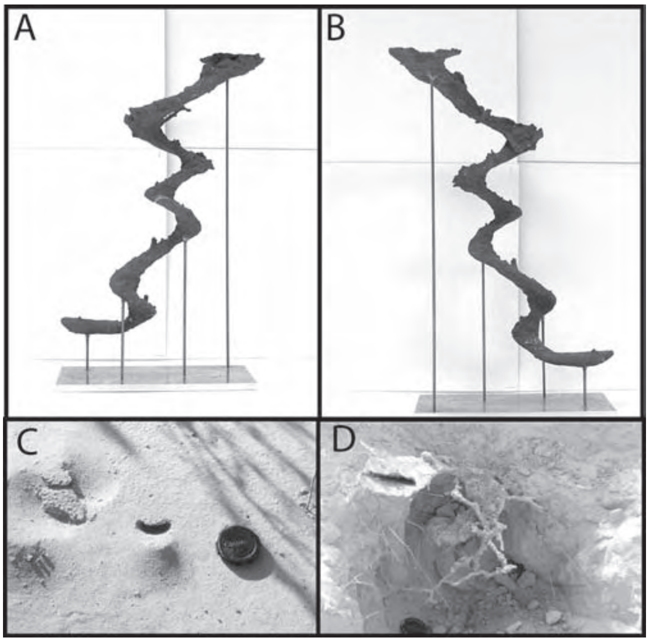


Figure 6. Scorpion burrows. (A-B) Cast of a modern scorpion burrow from the Simpson Desert about 80 km south of Alice Springs, Northern Territory, Australia; cast is 550 mm tall. (C-D) Crescent-shaped entrance of a scorpion burrow (C) prior to pouring the fiberglass into the burrow and excavation of a cast (D); lens cap is 50 mm wide.

Scorpion burrow casts can be displayed alongside the trace fossil *Gyrolithes* (e.g., Pemberton *et al*. 1992) or *Xenohelix* (Mansfield 1927), described from various marine deposits. The purpose of this exhibit would be to illustrate the subtle, but significant, difference in morphology between these types of spiral burrows that would indicate the difference in anatomy of the constructors that made them, as well as the environments they occur in.

Skink burrow

Skink (Squamata: Scincidae) burrows are composed of a main tunnel that slopes downward gently between 15° and 30° from horizontal (Figures 7A, B). The main tunnel may have one or more branches which form nearly identical, parallel tunnels. An inverted, flattened U-shaped cross section to these tunnels is produced by a weak to robust, longitudinal, medial groove on the floor. Several upward branching tunnels are used to evade predators and begin from the main tunnels. These escape tunnels are composed of short tunnel segments connected to each other and switchback on them in an upward direction, forming a crude pseudospiral. The burrow entrance is delineated by a dome shape with a flat floor and arched ceiling. In some cases the flattened, inverted U-shape of the tunnel can be seen.

Small and large diameter burrows of the Lower Triassic Fremouw Formation, Antarctica (Figures 7C, D), have similar burrow morphologies to those of modern skinks, which were used to help interpret the burrows as constructed by tetrapods (Hasiotis *et al*. 2004). The larger diameter burrows were interpreted as tetrapod in origin; however, the smaller diameter burrows were interpreted as being excavated by crayfish (Miller *et al*. 2001). The reinterpretation of these small diameter Triassic burrows was based on several key morphological features found in skink burrows. The overall architecture is not much different from the Triassic burrows, including the inverted U-shape of the cross-section. The Antarctic burrows are also similar to therapsid burrows described from Permian and Triassic continental rocks of the southwestern part of the Karoo basin in South Africa (Smith 1987, Groenewald *et al*. 2001). The longitudinal median groove in the modern skink and ancient burrows was produced by the sprawling stance of the lizard, and the locomotion of the front and rear limbs on either side of the body that formed the groove. The longitudinal scratches on the outside of the burrow and along the median groove were produced by the predominantly lateral digging motion used by these lizards.

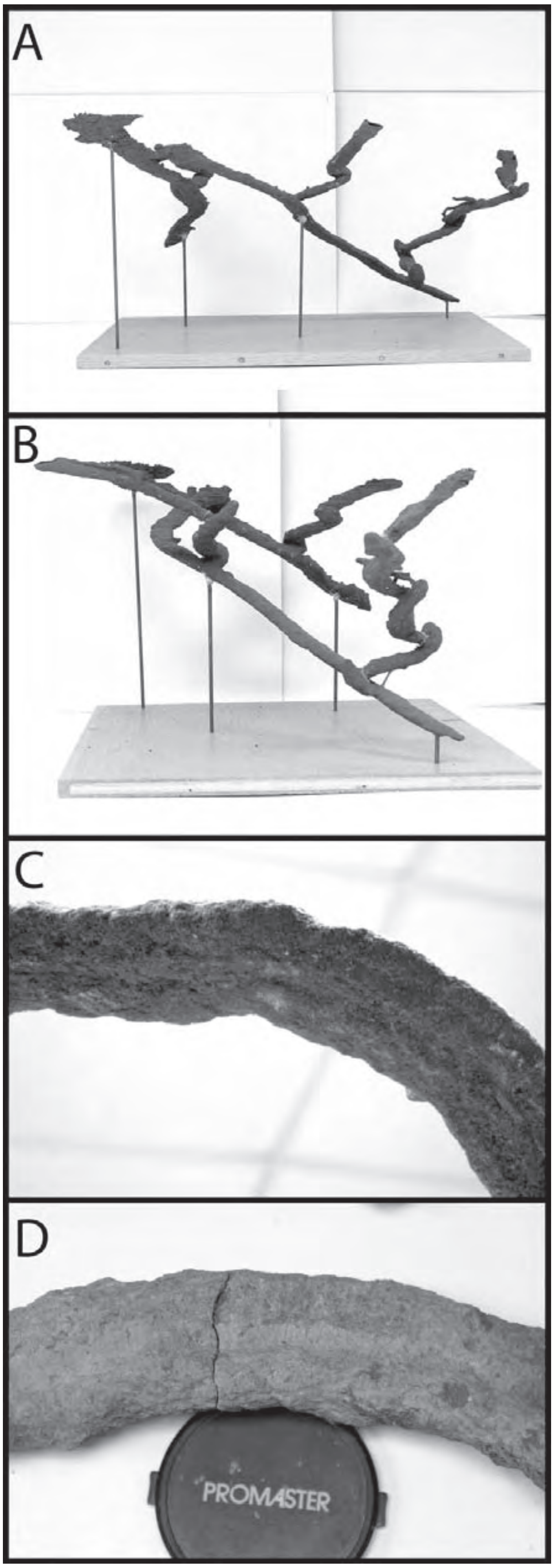


Figure 7. Skink burrows. (A-B) Cast of a modern skink burrow from the Simpson Desert about 80 km south of Alice Springs, Northern Territory, Australia; cast is 330 mm tall. (C-D) Inverted U-shaped groove in the floor of a modern skink burrow (C) compared to that of a burrow interpreted as vertebrate in origin (D) from the Triassic Fremouw Formation, Collinson Ridge, Antarctica. Burrow in (C) is 40 mm wide, lens cap in (D) is 62 mm wide.

The exhibit of skink burrows could be complemented with late Palaeozoic or early Mesozoic vertebrate burrows with similar cross-sectional morphology (Smith 1987, Groenewald *et al*. 2001). To make such an exhibit interactive, spiral burrows constructed by late Palaeozoic mammal-like reptiles of South Africa, with a cross-sectional morphology similar to that of skink and other lizard burrows, could be used and the question asked, "How or why are these burrows different?" One answer could be that the spiral morphology of the Palaeozoic burrows from South Africa indicates a mammalian burrow constructor.

Wolf spider

Wolf spider (Araneae: Lycosidae) burrow casts are relatively simple in morphology, composed of a vertical shaft and a slightly expanded termination that serves as a chamber (Figures 8A, B). The burrow entrance is circular and may contain an enclosure made of sediment woven with strands of silk or may be lined with an elevated rim of silk (Figures 8C, D).

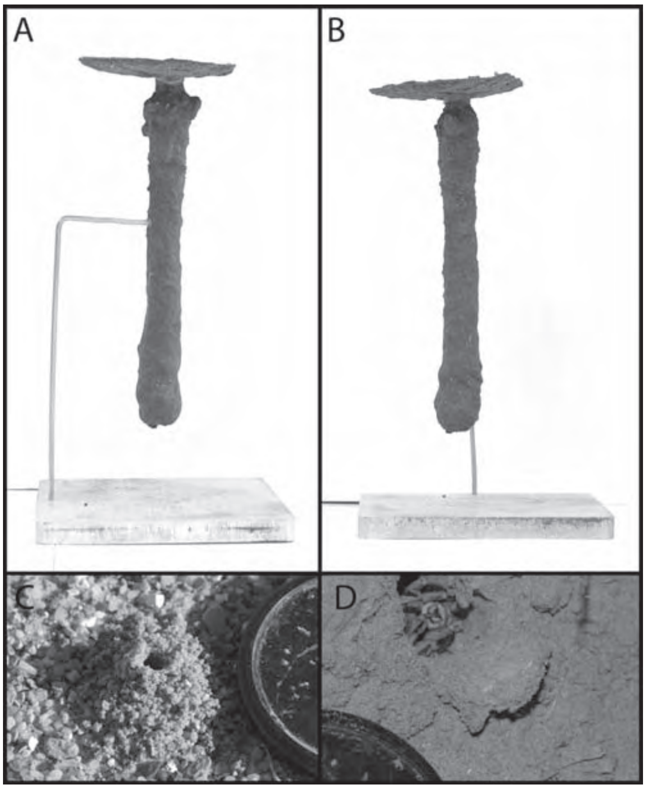


Figure 8. Wolf spider burrows. (A-B) Cast of a modern wolf spider burrow from the Simpson Desert about 80 km south of Alice Springs, Northern Territory, Australia; cast is 220 mm tall. (C-D) Wolf spider burrow entrances from the Umbum Creek near Lake Eyre, Australia. Chimney of a wolf spider burrow held in place by silk that can be seen at the entrance (C); a wolf spider burrow enclosure similar to a door composed sediment bound by abundant strands of silk (D). Lens cap in (C) is 60 mm tall and 250 mm tall in (D)

Similar burrows have been identified from Pleistocene aeolian deposits in the Bahamas (Curran and White 1991, Curran 1992) and from Jurassic aeolian deposits in South Africa (Hasiotis and Bumby unpublished data).

These types of burrows were used by spiders for dwelling, feeding and reproducing. The spiders ambushed prey from the opening of their burrows or would hunt at night and return to their burrows before dawn. The burrows were also used to raise the offspring, where the mother and her brood would be safe until the young spiders were old enough to leave the burrow (e.g., Chinery 1993). Such a burrow had multiple purposes despite its simple architecture.

An exhibit of spider burrows could contain casts of several types of modern spider burrows and Cainozoic trace fossils interpreted to have been constructed by spiders (e.g., Curran and White 1991, Curran 1992). This exhibit could be complemented with an aquarium containing a trap door spider or a burrowing tarantula or wolf spider. Live specimens would allow the public to see how spiders construct and maintain their burrows as well as hunt for such prey as crickets and grasshoppers.

Solitary wasp nest

A solitary wasp (Aculeata: Sphecidae) burrow is simple, composed of a gently sloping, subhorizontal tunnel terminating in an elliptical chamber (Figures 9A, B). Spiders, caterpillars and other insects are found typically within such chambers as food stores for an egg laid by the female wasp. The egg will hatch into a larva that will feed on its food supply. The larva will eventually pupate by spinning a cocoon of silk around itself within the chamber (Figure 9C). An adult wasp will emerge from the nest once pupation is complete; however, in many cases the larva or the pupa will die and the cycle will not be completed.

The trace fossil record of burrows and nests attributed to these organisms is poor, and is mostly limited to cocoons interpreted as those constructed by wasp larvae (e.g., Bown *et al*. 1997, Hasiotis 2002, 2003). A cocoon constructed by a wasp larva is the only likely part of the nest to be preserved because it is constructed with organic material. The nest is merely excavated in loose to firm soil and not reinforced by any other materials. Trace fossils of cocoons have been described from Mesozoic and Cainozoic continental deposits in the southwestern United States (Figures 9D, E). The best preserved cocoons show a pattern of silk on the outside and exit holes produced by the adult wasp or by a smaller parasitoid wasp, whose egg was laid on the prey as it was placed into the nest by the female wasp.

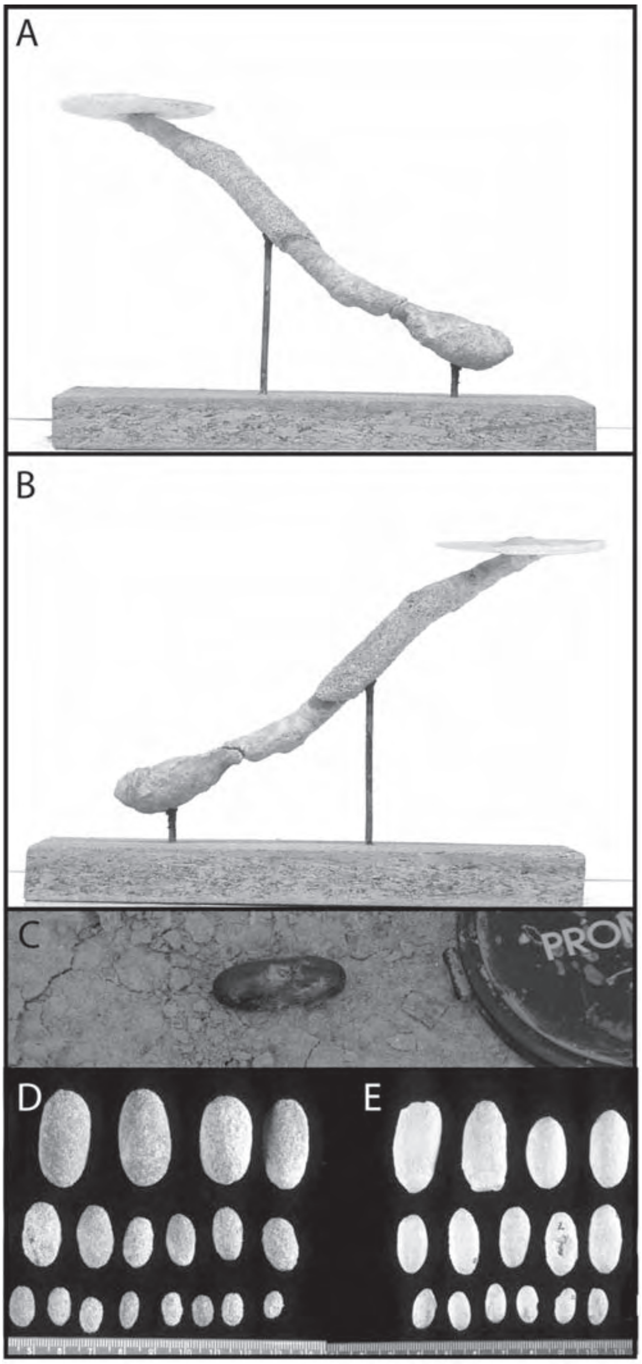


Figure 9. Wasp burrows and cocoons. (A-B) Cast of a modern wasp burrow from Argentina; cast is 105 mm tall. (C) Cocoon from a solitary wasp burrow from the Neales River area near Lake Eyre, Australia; lens cap is 35 mm tall. (D-E) Trace fossils interpreted as wasp cocoons from the Triassic Chinle Formation, Arizona (D), and the Palaeogene Claron Formation, Utah (E); scale in each photograph is in mm.

An exhibit could contain casts of several types of modern solitary wasp nests and cocoons, and Mesozoic and Cainozoic ichnofossils of cocoons interpreted to have been constructed by wasps. This exhibit could be complemented with casts of many types of solitary wasp nests as well as the actual nests of more social advanced wasps (Sphecidae and Vespidae), which have a variety of shapes and sizes. Live exhibits of wasps that build large nests are not advisable because of their aggressive nature (e.g., Evans and Eberhard 1970).

Summary

One of the most interesting things that can be done with continental trace fossils in museum exhibits is to display them alongside casts of modern traces that represent homologs or analogues to these ancient behaviours. Side-by-side displays of modern and ancient traces educate the public about how ichnologists, palaeobiologists and sedimentologists study and interpret the significance of trace fossils with respect to behaviour, organism anatomy, phylogeny, environment and ecology. These types of exhibits will help the public understand that modern organisms and their behaviours have counterparts in rocks preserved as body fossils and trace fossils, and that those fossils are used to interpret the evolutionary history of organisms and their behaviour through geologic time.

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DINOSAUR TRACKS FROM DORSET: A TWENTY-FIVE YEAR RETROSPECTIVE

by Paul C. Ensom

Ensom, P.C. 2006. Dinosaur tracks from Dorset: A twenty-five year retrospective. *The Geological Curator* 8(5): 227-241.

The practicalities of and issues connected with the collection of dinosaur tracks are considered in the light of the writers experience while Assistant Curator at the Dorset County Museum from 1978-1989, and subsequently. A number of short case histories are given.

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Introduction

This article is based on a talk, 'Dinosaur tracks from Dorset (A twenty year retrospective)', given at the GCG Seminar meeting held at the Yorkshire Museum on December 4th 2000. My brief was to review my experience of dinosaur tracks in Dorset and the impact they had on both the Dorset County Museum (DORCM), and, by extrapolation, could have on other museums. The seminar was divided into two parts. Firstly I offered a cautionary introduction under six headings which looked at how such material had been collected and the impact such specimens may have on the recipient institution, before giving 'A twenty year retrospective' of my Dorset experiences with dinosaur, and other, tracks. This article broadly follows the same format, with the addition of sections considering why dinosaur tracks are important and why we should consider their collection. In view of the lapse of over five years since the GCG seminar, I have expanded the retrospective's time-span to 25 years.

Catalogue numbers (Cat. No.) given in the text are those used by me (Ensom 1995a) when I reviewed the majority of Purbeck Limestone Group track discoveries, published and unpublished, and provided a comprehensive indexed catalogue of them. The indexes covered stratigraphy, locations, persons, repositories/institutions, palaeontology, and others – which included load-casts and water-hole.

The importance of dinosaur tracks

Before considering the practicalities of collecting dinosaur trackways, why are dinosaur tracks of such interest? Trackways (two or more tracks) or an *in situ* track (an individual print) provide unequivocal evidence for the presence of a dinosaur at that locality when the sediments had recently been laid down. Dinosaur bones found in sedimentary rocks may be derived from older strata or be parts of 'recently dead' animals washed down by a river. Complete carcasses may have drifted down a river and out to sea, before sinking to the sea-floor and being buried by sediment. The presence of the bones and even skin of scelidosaurs in the marine shales and clays of the Lower Lias of west Dorset is a good example of a dinosaur being found in a fully marine environment (Norman 1985). Tracks may be made in shallow water and there are well documented examples of swimming traces (Whyte and Romano 2001), which at least indicate the close proximity of land. Dinosaur tracks may provide useful information about the environments in which they were made and the state of sediments when walked on (Ensom 1995a, Romano and Whyte 2003). Dinosaur tracks have the potential to provide valuable information on the distribution, social groupings, behaviour, biomechanics and locomotion of these extinct creatures (Alexander 1989, Thulborn 1990, Romano and Whyte 2003).

Why collect them?

Any museum confronted with the opportunity to collect dinosaur tracks should be asking some searching questions before doing so. Some of these considerations are raised under the 'Practicalities of collection' heading below. Fundamentally, before a decision to collect them is made, thought must be given as to whether the trackways or individual track would be better left where they are. Do they represent something new, either ichnotaxonomically (preservational considerations are likely to be relevant in this context) or stratigraphically? Do they have display potential? While in Dorset, I was responsible for publishing a number of short accounts recording the discovery of dinosaur tracks which were recorded *in situ* and not collected (Ensom 1995a, b).

In working quarries, there will almost certainly be financial reasons why the destruction of trackways will be inevitable if they are not collected. Either that or they will be broken up and sold off piecemeal to the curious. The collection of pavements of any size will cause some disruption to an industry which relies on extraction taking place primarily during the 'dry' summer season, so that stone can dry and 'cure' before the winter months. Delay to stone extraction has an economic impact; the heavy plant, hired to dig the stone, once on site costs money regardless of whether or not it is working! Exceptionally (see 'Kevin Keates Quarry', below) there may be agreement to sacrifice reserves of valuable stone in order to leave a pavement *in situ*. Coastal sections are likely to be under constant attack from the sea and with the reality of rising sea levels this will become increasingly so. Can representative prints or sections of a track be lifted and preserved which allow the relationship of the different tracks to be studied, especially if the track is new to science or shows features not previously observed? Collecting representative tracks of a large quadupedal dinosaur will be a significant challenge in itself! The case for preserving large parts of multiple trackway sites (see 'Townsend Road' and 'Sunnydown Farm Quarry', below) may be compelling.

Practicalities of collection

Any prospective collector would do well to remember that there are not many geological specimens which come bigger and heavier than dinosaur tracks. They should consider very carefully a number of issues before embarking on their collection. They include the following:

- The ownership of the site. Permission to investigate a site, then to excavate and collect, must be obtained from the landowner(s). Issues of ownership and where any specimens collected will go should be addressed as soon as practicable, unless the exercise is seen as purely an opportunity to record and publish the occurrence. The owner's agreement that the information will be published and/or placed in a public archive should be obtained.
- Legislation and planning. Not only should permission from the owners of a site be obtained, but consideration should also be given to whether local or national laws might be infringed, e.g., National Park and/or National Trust Byelaws, and restrictions pertaining to a site's designation as an SSSI. Consulting representatives of English Nature or their equivalents in Wales and Scotland (both countries have trackway sites), or the local Minerals Officer with the County or District Councils, may be informative. Large-scale excavations may require planning permission if such a consent does not already cover the site.
- The accessibility of the site. Access to remote or inaccessible sites can present huge problems, both during the excavation phase and, critically, during the recovery operation. While quarries will normally have reasonable vehicular access, there may be restrictions on the number of vehicle movements which can take place each day. Coastal locations usually present most of the difficulties confronted at the worst inland venue, with the additional hazards of rocky shores, and tides which can inundate sites and cut-off the unwary. Access by sea could be an advantage. An alternative is collection by helicopter (Figure 1). Access rights will at least need to be checked and may need to be cleared with the owners of adjacent land or land crossed to reach the site.
- Manpower and equipment. Trackway sites will often require several very fit and suitably equipped individuals with appropriate skills in handling heavy blocks of stone with weights up to, and sometimes more than, a tonne. Access to equipment to lift and position such material may be possible through contacts in the local quarrying industry (see also 'Risk assessment', below). Angle grinders were used at a site in 1981 (Figure 2) and can still be hired, though I understand that fitting the blade is a process for which the user should have received training. These are highly dangerous machines, but very effective for isolating and thinning slabs of rock with trackways preserved.
- Costs. Recovering a trackway site will often involve a considerable amount of time. If salaried staff are involved or temporary labour is being contracted, salary costs with attendant overheads should be taken into account. Travel to and from the site will also need to be factored in along with subsistence costs, and, possibly, overnight accommodation. In the absence of friendly support from local industry, the full costs of equipment hire and transport will also have to be taken into account. In the case of the Sunnydown Farm excavation in 1986/87, the Dorset Natural History

& Archaeological Society paid for the cost of the removal of over 300 tonnes of overburden.

- Impact on work. In a world where so much of the working year is mapped out in great detail at an early stage, the serendipitous discovery of important fossil sites may have a significant impact on how that work schedule will then develop. Modification of forward job plans is likely to be essential.

Risk assessment

While I believe that there is a real danger of staff in institutions becoming bogged down with increasingly elaborate and convoluted risk assessments, there is no doubt that a simple and effective process of risk identification is essential before undertaking fieldwork. This is especially so in quarries, whether they are working or not. Coastal locations bring their own set of hazards. Examples of issues which need to be considered are as follows:

- The physical hazards of quarries; unstable faces, falling rocks, trip hazards, unstable and slippery surfaces, the weight of blocks of stone, slurry lagoons and deep water.

- The quarrying process and any linked activity, e.g., waste disposal site, generates large numbers of vehicle movements and many of the vehicles are of such a size that being visible is crucial. In addition, shot-firing may be carried out and the levels of noise encountered in such places is often considerable.

- Environmental factors. The weather can cause considerable discomfort and in extreme cases may result in the need for medical attention. Ill-equipped individuals may suffer from hypothermia or sun stroke and the glare from a large expanse of pale sedimentary rocks is not much different to that from snow.

Actions should be taken to mitigate risks. Of course, this may all seem very obvious and in a sense it is, but there is still no harm in thinking through the issues, and making sure that the correct kit and attitudes are taken into the field.

Collections impact

When I gave the seminar in 2000, the expression 'collections impact' was not something which could be ignored. In the intervening 5 years, a former colleague of mine, Dr Paul Davis, who is the Registrar at the Natural History Museum, London (NHM), has coined the expression 'collections enhancement' as a substitute and, in my opinion, it is a great improvement! A good analogy is the question of whether a half-drunk glass of beer or wine is best described as half empty or half full. Certainly, I have always felt that there is something inherently negative about the word 'impact'. The cynic will accuse Paul Davis and myself of playing word-games, and put it all down to management-speak, and in any case, there is no difference, is there? Well, I think there is. Curators are not just the custodians of a museum's collections on behalf of a society, local authority or the nation, neither is their job solely concerned with the acquisition and preservation of knowledge on those collections. From my days as a curator, I recall a significant part of my job was having the responsibility for enhancing the museum's collection. Of course, collecting enhances the coverage a collection has or, if you like, its excellence. Often there is a consequent increase in understanding of the rest of the collection. All these areas of responsibility have seemed increasingly under threat over the last few years, so I have taken some comfort from some of the articles on aspects of collections and those that care for them published in the June 2005 issue of *Museums Journal*. Having said my bit on this, I can admit that while dinosaur tracks have certainly enhanced collections I have been responsible for, there is no denying that they have had an impact as well!

Collections impact can be considered under the following headings:

- Long term storage and handling. Is the surface to be stored in 'one piece' or as palletised sections on suitable heavy duty racking? Mechanical handling equipment may be essential. Avoid having to handle collections like this more than is absolutely necessary and take into account the requirements for research. The sauropod trackways discovered at Kevin Keates Quarry in 1997 (Figure 3), on land owned by the National Trust, were exposed, recorded and reburied with protective layers on top. Arguably this approach has solved several issues at a stroke, particularly long term storage, and access for research – there is none!

- Access for research. This may influence the long term storage method adopted. A pavement spread out has advantages in providing easy access, but this may not be practicable and racked storage may provide the most space-efficient solution. Reassembling palletised sections for study requires space, is invariably time consuming and potentially damaging for the specimens.

- How a museum displays such material. Single tracks are more readily displayed than rock pavements with trackways preserved over their surface. The latter can provide a spectacular display and several museums have gone down this road, e.g., Hunterian Museum, Royal Scottish Museum (now Museum of Scotland), DORCM and NHM. In the latter case, trackways are stored/ displayed outside the Palaeontology Building. In any display situation, good lighting is essential, with low light raking the surface of the slab to show off the moulds or casts of the tracks to best effect; trackways going in a variety of directions present their own problems!

Responsibilities

With the discovery of trackway sites comes a responsibility to record and, if appropriate, publish accounts of them, bringing the discoveries to wider audiences. The data from such sites must not be lost. Writing up a site for publication is time consuming, but such activity falls within the remit of scholarship, a quality espoused by Johnson (2005), who commented that there is a need to redress the balance in museums between 'edutaining' and the 'in-depth understanding of collections'. The responsible pursuit of scholarship is a great opportunity to forge links with local, regional and even national learned societies, universities and other museums.

The big pluses

My experience in Dorset has shown that there are a number of very valuable spin-offs from the discovery of dinosaur tracks.

- Networking. The forging of strong or stronger links with the local quarrying community and with statutory/non statutory organisations, *etc*., can bring on-going benefits at many levels, e.g., being alerted to rediscoveries, new discoveries, early warnings of new excavations, publicity for your museum (see below), access to sites and support when in the field.

- Scientific potential. This may include the publication of papers, new research and the attraction of experts to your museum, benefiting the discovery and existing collections. There is also the potential for day symposia and conferences.

- Display potential. Though challenging (Figures 4-6), as has already been noted, trackways can provide the basis for displays. These have the potential to be spectacular, allowing reconstruction of habitats and the animals which lived in them, and providing an opportunity for visitors to make the connection between an extinct animal and something which actually lived – and left the evidence.

- Potential for a PR goldmine. Dinosaurs have always the potential to capture the interest of the press. What follows is a summary of the 'media-circus' attracted by the Townsend Road discovery in 1981, happening as it did in that period of the summer when Parliament was in recess, and what had become known as the 'Scilly Season', despite a change of occupancy at No.10, was in full swing! The story broke on Thursday 20th August with an article in the *SwanageTimes*, by which time we had been on site for approximately 4 weeks. The author of that article, a local journalist, Andrew Wyllie, was what I think in the trade is called a 'stringer' and a very effective one at that. His story was widely circulated. BBC Radio was quick to enter the arena along with BBC Southern (TV) (Figure 7). Interviews were carried on Radio Solent, Radio 4 (The World Tonight) and Southern Television's 'Nationwide'. The main early evening Radio 4 news (18.00 – 18.30) mentioned the discovery as had an earlier bulletin during the afternoon. Independent Television also gave coverage at this early stage. An active interest throughout was taken by 2 Counties Radio with several broadcasts. Later, Radio 2 carried a live interview on the John Dunn Show, Monday September 14th. Reports indicated that Eire television gave coverage and that the New Zealand press also carried a note. Reports are known to have appeared in Australia and Canada. Local and national press coverage was good, though the accuracy of some of the reports left much to be desired; 'Builder digs up giant lizard fight' and 'Dinosaurs' graveyard discovered' were two of the more entertaining ones in nationals! *The Times*, *Daily Telegraph*, *Daily Mail*, *Daily Express* and latterly *The Sunday Times* all carried articles. In most cases the DORCM and/or the Dorset Natural History & Archaeological Society (DNH&AS), which owned and ran the museum, were mentioned. Similar publicity continued during the lifting of the site and the transport of the pavement back to Dorchester. Purchasing such publicity, much of a high profile nature, would have cost a small fortune and was way outside the DORCM's pocket. Dr David Norman, who visited the site while on holiday, recorded an interview for BBC's 'The Living World' which was broadcast on 30th August and repeated on 3rd September. This demonstrates nicely the potential for involving researchers in such discoveries.


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Figure 1. A Westland Wessex helicopter landing dinosaur track casts (DORCM G 866) at Tyneham, Dorset, 1981.

Figure 2. The author uses an angle grinder to cut the trackway pavement (DORCM G 11047) at Townsend Road, Swanage, in preparation for its lifting. (Copyright of Mr S. Price.)

Figure 3. Sauropod tracks at Keates' Quarry, 1997. The broom provides a crude scale.

Figure 4. The Geology Gallery with polythene plans laid on the floor to indicate the position of the pavement blocks as they are brought in from the store.

Figure 5. A breather is taken as a section of the pavement from Townsend Road, Swanage, is carried from the ground floor to first floor Geology Gallery at the Dorset County Museum, March 1983.

Figure 6. The Townsend Road trackway blocks being reassembled.

Of course there were those who would spurn such publicity, seeing it as an inappropriate place for science to be. However, the DORCM took publicity very seriously, seeing it as an essential part of its armoury for getting noticed by local and not so local politicians, the residents of the county and the considerable numbers of tourists who visited Dorset each year. There is a valuable lesson here – being noticed helps you survive.

Alternatives to collection

There are alternatives to the collection of tracks. As happens in one of the cases below (Keates' Quarry), reburial is an option, provided that in a quarry the underlying strata are not required or can be sacrificed. The trackways can be mapped though, in that context, remember that casts on an underside will require turning over before the extent of the trackways can be seen and plans drawn. Another is to take moulds/casts of the tracks which may be particularly attractive where recovery of the blocks from isolated coastal sections, for example, is impracticable. Latex may provide one particularly useful option. Provided the environmental conditions allow the latex to cure, the suitably strengthened mould can be lifted and rolled up before being carried off-site. A draw-back of this non-rigid medium is that taking a cast from the mould will require a former to permit the original shape of an irregular surface to be restored and held rigid while the cast is taken.

A twenty five year retrospective

When I took up my post as Assistant Curator at the DORCM in 1978, there were several individual dinosaur tracks preserved as either 'moulds' or 'casts', all from the Early Cretaceous Purbeck Limestone Group and Wealden Group. The challenge with these specimens was to see to their curation, linking together the various documentary records. They remained visual reminders of what was becoming clear from the scientific literature, that is, Dorset, and specifically the Isle of Purbeck, was what could be termed a mega-dinosaur trackway site (Ensom 1995a). In 1978, the NHM, Hunterian and Royal Scottish Museums all had displays of trackways collected during the 1960s and 1970s. Over the next eleven years the DORCM would see its own collections enhanced by new discoveries of trackway sites.

Townsend Road – 1981 (Cat. No. 50): The first of these new sites was a chance discovery of dinosaur tracks while digging the footings for a new property at 21 Townsend Road, Swanage, Dorset. It was reported via Mr David Lewer, a local historian and member of the DNH&AS, to the Curator of the DORCM. This led to an excavation carried out by staff and volunteers of the DORCM and members of the DNH&AS, which owned and ran the museum. This was by kind permission of the owner and developer, Mr Dave Selby and his wife Joy. Four horizons with >170 prints were revealed. The tracks were preserved as moulds, casts, transmitted moulds and transmitted casts (for an explanation of these terms, see Ensom 1995a, p. 78). Plans were drawn of the site and eventually the main surface, with a covering of dessication cracks and more than twelve trackways, made on at least two different occasions in the history of the site, was lifted and transported back to Dorchester. The discovery attracted a great deal of public (Figure 8) and media interest, the latter noted above.

This site brought home to me the importance of dedicated volunteer support. Without the help of so many people with different skills we could not have achieved all we did. The tracks and other features were drawn onto Kodatrace by an archaeological draughtsman (Figure 9), forming the basis of Ensom (2002, text-fig. 1). The DORCM's Conservator cast the most important tracks as keyed, multi-part Plaster of Paris slabs (Figure 10) and masterminded the production of archival plaster casts of each individual print before the site was lifted. These were marked with an identifying alphanumeric code and magnetic north. Each print was drawn and measured. A Dyeline of the detailed site-plan was used to plan which, and how, the tracks would be lifted, and to mark out the lines for the cuts to be made with the angle grinder (Figure 11). All joints and incipient fractures were marked with small lines or symbols in black emulsion paint, and zinc-tape numbers which linked to the plans were attached (Figure 12); this helped relocate and assemble pieces of a very heavy and intricate, 3-dimensional 'jig-saw puzzle' at a later stage. The first use of 1:1 polythene plans, in reality tracings of the joint surfaces with numbers written on in spirit felt tip, was made here and proved to be of considerable value. Some parts of the site, where the tracks were more readily separated on slabs only a few centimetres thick and, as a result, were more fragile, were recovered in advance of the main lift (Figure 13). English China Clay Quarries Ltd kindly provided a couple of sacks of locally produced Tertiary ball-clay to help hold fragmentary pieces of the pavement together or support slabs which had lost some of their original thickness. These sections of pavement were stacked on old doors to be lifted onto a flat-bed lorry in due course.

The remaining areas of the site were lifted and recovered using some of the volunteers who had

Figure 7. A BBC Southern TV crew filming on site at Townsend Road, August 1981.

Figure 8. Outreach. Members of the public and parties of schoolchildren, as seen here, were given impromptu lectures! (Copyright of Mr S. Price.)

Figure 9. Townsend Road with volunteers in the background and Derek Moody, the archaeological draftsman, mapping the site in the foreground.

Figure 10. Rodney Alcock, Archaeological Conservator, works with dental plaster to produce a keyed, multi-piece, plaster cast of one of the trackways.

Figure 11. The dyeline plan with cutting lines, block numbers and joints, *etc*., all marked on it in preparation for the lifting of the site.

worked on the site, but also, and most importantly, an enthusiastic band of young offenders from Portland Borstal. The weather, which had been hot and dry throughout the excavation and preparation for removal, broke the night before with strong winds and rain. Fortunately, the day was essentially dry, though the overnight rain had made everything rather greasy underfoot. Remaining slabs were lifted, and either loaded directly onto the lorry or placed on pallets and then loaded. The flat-bed lorry with driver was on loan from Mr Bill Jesty, a local watercress grower and a member of the DNH&AS. Driven to an overnight location for safe-keeping, the lorry arrived in Dorchester on the Saturday morning. With the help of a fork-lift and several trusted, enthusiastic and jemmy wielding(!) inmates from H.M.Prison in Dorchester, and colleagues from the Museum, the pavement was reassembled in a range of outbuildings owned by the DORCM. The plans of the pavement, which had been prepared on-site, proved invaluable, both in the calculation of how the large slabs would need to be orientated to get them to fit into these confined spaces, and when it came to the re-assembly of the pavements. The mission was accomplished with minimum fuss.

Approximately one year later, on a Sunday, with the Museum closed to the public, a team of six, composed of staff and friends, transported one section of the pavement to the first floor Geology Gallery (Figures 4-6). Floor loading had been discussed with a structural engineer beforehand. In the course of a long day, the slabs were brought from the store, about 200 m away, and reassembled. Arranging the lighting was carried out at leisure. Experimentation showed that fluorescent tubes down one side provided a wash of light across the surface to show-off the tracks to best effect (Figure 15). The tracks have been on display since March 1983. In the summer of 2005 the gallery closed in order to start work on the new and enlarged *Jurassic Coast Gallery*, and after 22 years the tracks will be taken off-display.

Worbarrow Tout – 1981: While excavations were proceeding at Swanage, Trev Haysom, a local quarry owner, spotted a fallen block of limestone with two well preserved casts of a dinosaur track on one surface (Cat. No. 59). The Army use this section of coast as a gunnery range and became involved. Through their good offices, the specimen was collected from Worbarrow Tout using an helicopter and flown to the deserted village of Tyneham (Figure 1), a short distance inland. Accessioned into the DORCM's collection, the specimen was loaned to the Army and put on display in the old schoolroom at Tyneham.

The discovery of this single specimen led to a thorough investigation and logging of the strata at Worbarrow Tout in order to ascertain the exact horizon from which it had fallen. Worbarrow Tout had already one documented dinosaur track horizon described first in the 1960s (West *et al*. 1969). In the course of this work, the source of the 1981 track was discovered along with a further eight track-bearing horizons (Ensom 1995b). A published section of the Tout (Ensom 1985) was a valuable spin-off from the initial discovery. Additional specimens were added to the collections of the DORCM including a spectacular block with a pair of superimposed casts of tridactyl tracks (Cat. No.114; Figure 14).

Durlston Bay – 1982: Dr Simon Kelly reported fallen blocks (Figure 16) with tracks in December 1981. Following up these reports in the spring of 1982 I discovered that Durlston Bay, like Worbarrow Tout, had many track producing horizons. Previously, there had been a tendency to correlate discoveries in quarries inland with the section in Durlston Bay. The literature recorded no tracks from Durlston Bay with any accuracy. Fieldwork identified nine track-producing horizons at this locality (Ensom 1995b).

***Purbeckopus pentadactylus* Delair: The holotype rescued and a figured specimen rediscovered - 1983-1985:** In 1963 Justin Delair described a block of limestone with a series of curious tracks over the surface (Cat. No. 12). The specimen, belonging to Mr W. J. Haysom, became the holotype of *Purbeckopus pentadactylus*. The specimen remained in the possesion of Mr Haysom, forming part of his garage drive. Despite this, the surface remained remarkably intact, which says much for the quality of this Purbeck stone! In 1983, Mr Haysom donated the slab to the DORCM. The slab was put on display in the geology gallery.

When Delair described the specimen, he also figured a second slab (Cat. No. 23) bearing further examples of these tracks. The photograph had been taken in a quarry yard. The specimen had then disappeared and attempts to relocate it, as revealed in correspondence in the DORCM, had failed. The author made several attempts to relocate this specimen, including spending some time tramping around a garden in Swanage looking at crazy-paving slabs in the forlorn hope that this important specimen might be there! Some time later, a visit to the DORCM by Mr A. Kirk and his daughter led to a discussion on dinosaur tracks. During that conversation we suddenly realised that a slab of limestone in their garden at Church Knowle might be the missing specimen. Armed with photocopies of the original plate, the Kirks returned to their home and were able to confirm the rediscovery

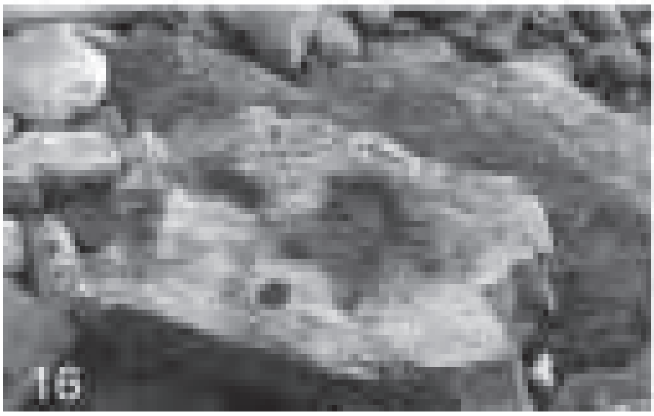


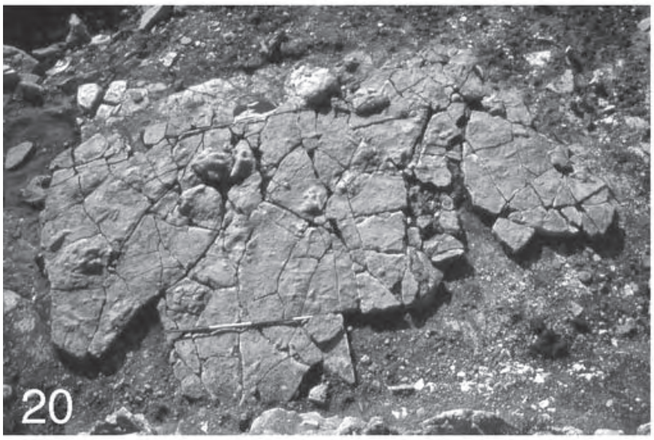
Figure 12. In the foreground, volunteers are marking the blocks and the fractures onto a plan and the pavement at Townsend Road, to allow reassembly.
Figure 13. Sheila Gowers and Rodney Alcock lifting part of the limestone pavement.
Figure 14. Two superimposed tridactyl track casts from the shore at Worbarrow Tout (DORCM G 11374).
Figure 15. Fluorescent tubes throw a wash of light across the reassembled pavement.
Figure 16. A fallen block of limestone with tracks in Durlston Bay, Swanage, Dorset.
Figure 17. Overburden is removed at Sunnydown Farm Quarry, autumn 1986.

of a long lost specimen. Bonuses included the discovery of a further print on the surface of that specimen and the recovery of an hitherto unrecorded slab (Cat. No. 130) with yet another track on the surface, also in their garden. Both specimens were presented to the DORCM. A full account of the discovery of these specimens is given by Ensom (1984, 1986). Subsequently, Wright *et al*. (1997) re-described all these specimens and assigned the assemblage of tracks to pterosaurs.

Sunnydown Farm Quarry – 1986-87: In the summer of 1986 I was asked if I was interested in having a look at a small quarry near Worth Matravers where the geology was not turning out to be quite as expected. There was a carrot in all this; soil-like horizons were present. The Purbeck Limestone Group had become especially famous during the 19th century as an important source of mammals (e.g., Owen 1871); searches made in the following 130 years had produced very little new material, so a chance to examine deposits laid down in conditions where mammals may have lived would always be very attractive. The site proved even more extraordinary than could have been imagined. A second quarry at the same location, slightly higher in the sequence, provided an horizon within the Cherty Freshwater Member. This bed went on to yield a diverse range of tracks including those made by a sauropod or ankylosaur, preserved as casts, some of colossal size, on the underside of the bed of limestone (Cat. No. 125). Permission was granted by the owner of the site for the DNH&AS to fund the removal of the overburden (Figure 17) in order to investigate these unusual trackways. This took the best part of a week, providing a clean top surface of the bed which had to be lifted and turned over to expose the casts of the tracks on its underside. Polythene plans were drawn of each section of the site to be lifted, marking the block joints with spirit based felt tip (Figure 18). The limestone pavement, later estimated to weigh in the order of 34 tonnes, was gradually turned over rather like the page of a book, but thankfully in lots of pieces. The polythene plan when turned over provided the 'template' upon which the blocks could be reassembled. We had hoped to take the blocks straight out of the quarry to lay out on the field above. The weight of the blocks made this impracticable and initially half the site was used as a laying-out space. Of course, the smallest error in the repositioning of one or more blocks ensured that our very heavy 3-dimensional jigsaw showed what resembled the effects of continental drift (Figures 19, 20). The elements eventually intervened and we withdrew for the remaining winter months. On our return, the first half of lifted pavement was removed with the aid of the owner of the site by tractor and trailer. Once this had been completed, the remainder of the site was lifted section by section onto a trailer and removed to join the previously lifted sections.

The limestone pavement on the surface of the field adjacent to the quarry provided the centre of attraction for several open-days organised jointly by the DORCM and the owners of the site. When not on show a large tarpaulin, sponsored by the Curry Fund of the Geologists' Association, covered the overturned blocks. Such was the success of these that the then owners of the site negotiated with the Museum for the use of the pavement as the centre-piece for a dinosaur visitor attraction at Sunnydown Farm. The tracks were placed in a concrete pit where they could be viewed from the raised surround and a purpose-built building was erected around them. The transfer of the pavement to the new venue was a major feat carried out over one week and requiring precision placement of the blocks in order to fit them into a very tight space (Figures 21-23). Sadly, the venture proved unviable and the property was sold with the tracks, which are part of the DORCM collection, still in place. A removable floor has now been placed over the trackways so that at a later stage they can be removed. Discussions have taken place about their use as part of an accessible public display, but nothing has yet come to fruition. While presenting a significant access problem at present, the very fact that this extraordinary site is still extant, under cover and can at some later date be accessed is most fortunate.

Sedimentary rock samples collected from this site require a mention. Their collection and subsequent processing had both short and long-term implications for the DORCM, as well as scientific repercussions. Following the discovery of a small (*c*. 0.05m long) tooth of a theropod dinosaur, the writer became aware of the potential for the recovery of a range of microvertebrate remains, including mammals, one of the reasons the site had been so attractive in the first place. A small test sample of the poorly consolidated sedimentary rock was removed from an upturned block, processed at home and almost immediately yielded an incomplete tooth of a multituberculate mammal. Further sieving yielded more mammal teeth. From then on, after each slab was lifted, the top *c*. 0.02 m of the clay in which the dinosaur tracks were made was collected. Fertiliser sacks were donated by a sympathetic farmer, thoroughly washed and then filled with around 15 – 23 kg of sedimentary rock. Each carried the number of the block(s) from under which the sample had been taken. An important lesson learnt was that plastic plant pins, with the number penciled or marked with indelible ink and inserted inside the sacks, would have been more reliable than numbers applied on the sometimes damp,



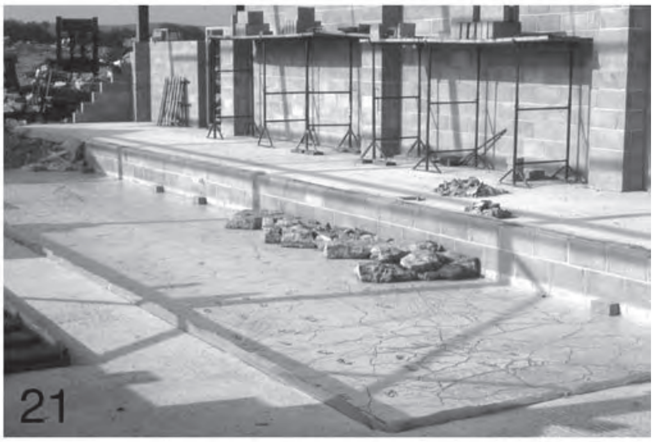


Figure 18. The exposed surface of the trackway bed at Sunnydown Farm Quarry. Note the polythene sheet at the right-hand end. Steve Etches is the figure on the right.

Figure 19. The lifted pavement, autumn 1986; note the ‘continental drift’ effect (see text) which has resulted in gaps opening-up between the blocks in the foreground.

Figure 20. The pavement has been ‘juggled’ back into position, winter 1987.

Figure 21. The concrete pit in which the trackway pavement was reassembled. Note the polythene plan on the floor which was used to get the best fit. The first pieces have been positioned.

Figure 22. The pit is gradually filled.

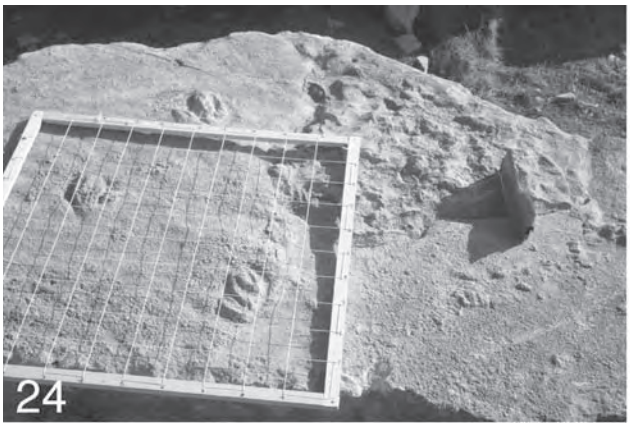
Figure 23. The *c*. 34 tonne pavement (DORCM G 11050) now occupies the whole of the pit.

and often grubby, surfaces of the sacks. This, combined with the abrasive effect of sack-upon-sack as they were moved around over the weeks before their contents were emptied and sieved, ensured that some numbers were lost. The total sedimentary rock sample amounted to approximately 3 tonnes. The samples were dried and then processed by wet sieving. Initially, this was carried out manually, working from home where the author had a dedicated space for processing sediment. The scale of the operation was such that a bulk sieving machine (Ward 1981) was commissioned from Steve Etches, known principally in geological circles for his internationally important collection of Kimmeridge Clay fossils. This labour-saving system greatly increased the rate at which samples could be reduced to 5% of their original weight. Picking the residues was enormously time-consuming and carried on outside museum working hours. The rewards were great, with new species of amphibian (Evans and McGowan 2002), the first from the Dorset Purbeck Limestone Group, and mammal being recovered and described, and a review of both the lepidosaurian reptiles and mammals being undertaken, leading to taxonomic revisions (see papers by Evans & Searle and Sigogneau-Russell & Kielan-Jaworowska *in* Milner & Batten 2002a). The significance of the mammal fauna recovered from Sunnydown Farm and other sites has been acknowledged by Kielan-Jaworowska *et al.* (2004, p. 45).

The discovery of the rich microvertebrate fauna highlights the serendipitous nature of field collection. Such discoveries were not predicted when the excavations began and I have often wondered what other organisation would have wished to, or could have become involved and been so willing to, provide the resources for this work. Yet, without the commitment of the DORCM/DNH&AS, their staff and volunteers, and research workers in other institutions, science would have remained blissfully unaware of the remarkable range of new vertebrates and other material, including eggshells, yielded by these strata. These new collections, combined with the already substantial collections from these strata, led Milner and Batten (2002b, p. 6) to say "….. no other vertebrate fauna from before the Campanian of North America approaches this diversity". The resurgence of interest in these strata stimulated by these discoveries led to a well attended symposium, 'Life and Environments in Purbeck Times' held at the DORCM in March 1999, and supported by Amerada Hess and The Palaeontological Association. The latter published many of the papers in *Special Papers in Palaeontology* (Milner and Batten 2002a). The initial implications for the DORCM were what would happen to the trackways, if present, once recovered. Then, unexpectedly, it was compounded by the question of how the museum would, in the longer term, deal with the substantial collection of microvertebrates and the inevitable research interest they would generate. Collections of tiny fragile teeth mounted on pins in glass tubes, and other picked residues also stored in small glass tubes, present significant collections management issues especially in museums where resources are stretched.

Acknowledgement of this as an issue brings me back to the matter of 'collections impact' and 'collections enhancement', and in this case the unquestionable enhancement of our knowledge of these extraordinary strata and the filling of gaps in the 'Tree of Life'. What should the attitude of the museums' profession be to collection on such a scale? What is the purpose of museums? Should the woeful lack of resources to support collections in so many, and the Nationals are not immune (Morris 2005), mean that opportunities for serious collection and preservation to underpin long-term research be passed by? Wilkinson (2005, pp. 5, 15), in the potentially influential report of the Museums Association Inquiry into collections, acknowledges the lack of 'vibrancy and rigour' in the development of collections. There is a real danger that the 'bean-counter mentality' which has developed and then driven so many museums over the last 15 or so years with targets for this and for that, along with the growth in 'edutainment' (Johnson 2005), is having an increasingly serious effect on their ability to reach out at a scholarly level, interacting with local extractive industries, members of the public, local societies, local authorities, civil engineering contractors, *etc*. I do not speak for the DORCM, but I would be surprised if in 2006 they would let themselves become involved in another Sunnydown Farm site, and the potential loss to communities, both local and national, both public and academic, and to that august museum of over 150 years standing, is plain to see.

Kevin Keates' Quarry – 1997: In 1997, Trev Haysom, who had spotted the fallenWorbarrow Tout block in 1981, was walking with his family through that area peppered by quarries around the Langton Matravers and Acton areas of the Isle of Purbeck. One of the family noticed some large (maximum diameter seen was 1.14 m) oval to circular, shallow depressions across a recently cleared area of limestone in a quarry being worked by Kevin Keates. These strongly suggested dinosaur track moulds of a rather different sort to those found before.



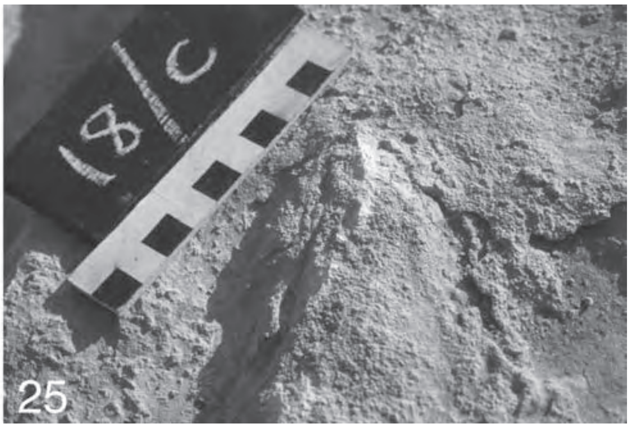


Figure 24. The 1 m^2 stringed grid being used to measure and draw the track surfaces. The large feature on the far side of the block is a sauropod track.

Figure 25. A mini-blackboard with block number and feature number. The scale bar is 0.1 m.

I was fortunate enough to be on holiday in the area soon after their discovery and was able to visit the site. Armed with brushes, the features were swept clear of debris revealing a considerable number of tracks (Figure 3).

The University of Portsmouth visited the site early on and carried out some recording. The National Trust (whose land was leased by Kevin Keates) involved the University of Bristol and, as a result, Dr Jo Wright, then based at Bristol, was commissioned to document the site. A short report was published (Wright 1998). Once recorded, and after an open day when the public could view the discovery, the site was reburied *in situ* in order to preserve it for the future.

Belle Vue Quarry – 1997 to date: The discovery of identical prints to those seen at Keates' Quarry at the same horizon heralded the start of what continues to be a fascinating opportunity to watch a quarry develop, exposing a succession of bedding planes through the 'Middle Purbeck Beds' with tracks preserved as moulds or casts, and other features including microvertebrate horizons. Through the kindness of the owners, Mr and Mrs W. T. Haysom, access has been freely given and research at this site is ongoing. Track-bearing pavements have been recovered and are being held by the Haysoms.

The Isle of Portland dinosaur tracks – 2002 to date: During 2002, tipped blocks of Purbeck limestone from the 'Thick Slatt' were observed to have dinosaur tracks on one of their lower surface. The author, then employed by the NHM, was invited by Richard Edmonds, on behalf of Dorset County Council, to assist with the recording and decision making process which would lead to the recovery of these specimens. The recording was carried out in 2003/04 and priority lists made for the recovery of the blocks. The recording process started with a check of the numbering of the blocks identified as having tracks preserved on their lower surface. Some blocks had been numbered with a spray can, as used in the stone industry, as they were lifted from the heaps of tipped stone where they had first been spotted. Those that had been omitted at this stage were added to the sequence and, as an insurance, the numbers were carved with hammer and chisel into the sides of the blocks. The recording of the track surfaces was carried out using a 1 m^2 stringed grid which was laid on the surface with data being transferred to squared paper at a scale of 1:10 (Figure 24). Polythene plans were made of each block; these are available as templates in planning displays in the future. Photography was carried out when the sun was low in the sky to provide a raking light, showing the features to best effect. With only a short period of time with optimum lighting, and over 100 features to record, this required considerable speed, and a method for identifying each feature and the block it was on. To achieve this, a set of tiny black-boards (0.045 x 0.09 m) were made. These had the block number and feature reference denoted by a letter, as previously allocated on the plans of the blocks, written in blackboard chalk. A general oblique view was taken of each block before individual features were recorded (Figure 25). A 0.1 m scale bar with cm gradations was included in each picture. The blackboards could be wiped clean with a damp cloth and recycled very quickly.

The tracks are preserved as 'casts' on the base of a thick bed of limestone. Unfortunately, only a small percentage of the original blocks of limestone from this bed were preserved at the time of extraction, sometime before their discovery! Trying to make sense of the remaining pieces can be likened to having a 100 piece jigsaw, throwing away 95 pieces, and then trying to work out what is going on with the remaining five. Despite this, the site is fascinating, providing only the second recorded occurrence of dinosaur tracks from the basal part of the Purbeck sequence; both these are from the Isle of Portland. Their discovery fills a gap in our knowledge of the distribution of dinosaurs in Dorset successions deposited during the Late Jurassic - Early Cretaceous, a gap which the writer had been attempting to fill. A footnote to this story was the discovery of a metatarsal of a sauropod from the same part of the succession in a neighbouring quarry, shortly after the recording work had been carried out and, during which process, the presence of a substantial sauropod track was recognised (Figure 24). These tracks are currently owned by the quarry company whose land they are from. They are involved in discussions to ensure their long-term preservation.

Isolated discoveries and donations – 1981 to date: As was noted in the introductory paragraphs, an active interest with a network of contacts can be very rewarding for one's institution. The collections of the DORCM have benefited from a number of what can be best described as isolated discoveries and donations which largely came about through such contacts. In 1984, Mr P. A. Brown presented the DORCM with a very curious specimen consisting of what appeared to be the pad of a foot with several toes arranged around it (Cat. No. 106). In 1985, a small excavation for Purbeck Marble near Harman's Cross to the west of Swanage yielded a substantial 'mould and cast' (Cat. No. 124) of a tridactyl print. The slab with the cast on the base was sectioned parallel to the bedding plane and then polished by Trev Haysom, providing a spectacular view of burrows and other sedimentary structures. In 1992, two intriguing sets of tracks (Cat. Nos 131, 132) were spotted by Trev Haysom on limestone slabs from the 'Downs Vein' of the Intermarine Member. They have been ascribed to a small quadruped. These and the 'Purbeck Marble track' were all presented to the DORCM by W. T. Haysom.

Conclusion

The above serves to show that the investigation and collection of tracks is both feasible and potentially invigorating for both museums and science. While enhancement should certainly be seen as a key aim, the impact of such large specimens on a museum, on the storage and display space available, and on the staff who have to manage them, both currently in post and in the future, cannot be ignored.

Acknowledgements

I take this opportunity to thank all those that have assisted over many years with the excavation, planning, recovery and display of these extraordinary records of life that once existed in what is now Dorset. There are too many to thank them all by name, but a few must be mentioned. Firstly, the owners of the sites whose willingness to grant access has made so much of the above possible. Dave and Joy Selby who presented the Townsend Road pavement to the DORCM; Richard and the late Mary Notley; Trev and Sue Haysom, who have reported so many unusual finds, given specimens and much support; Hanson Bath and Portland Stone; and the Commandant of the Royal Armoured Corps at the West Lulworth Gunnery School. The DORCM and its parent body the DNH&AS, the Yorkshire Museum and latterly the NHM have all been supportive of my involvement. Derek Moody and Diana Lill both made a very important contribution to the drawing of the plans of the Townsend Road site in 1981. Bill Jesty was hugely supportive with the provision of transport and organising a forklift truck to help with the unloading. Sheila Gowers, who helped with much of the track lifting on site, Rob and Ian Curtis, and Tim Batty gave up a Sunday to install one section of the Townsend Road pavement in the Geology Gallery – an amazing achievement!

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TRACE FOSSIL COLLECTIONS AT THE UNIVERSITY OF MANCHESTER

by Amanda L. Edwards and John E. Pollard

Edwards, A.L. and Pollard, J.E. 2006. Trace fossil collections at the University of Manchester. *The Geological Curator* 8(5): 243-246.

The University of Manchester collections of trace fossils are located on two sites. The Manchester Museum houses type, figured and reference specimens, including Triassic vertebrate footprints from Cheshire collected in the 19th century, and invertebrate trace fossils from Silesian rocks of the Pennines, Lancashire and Avon collected during the past three decades. Collections in the School of Earth, Atmospheric and Environmental Sciences comprise teaching, research and reference specimens built up since 1970. The specimens from teaching collections (about 200 items) are regularly used by undergraduates, further education students and schools for study and project work. The research collections (*c*. 1800 specimens) result from the work of academic staff and postgraduate students. They consist of specimens from local Carboniferous rocks, British Triassic sequences countrywide and photographs of ichnofabrics in cores from Jurassic rocks of North Sea oilfields.

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Introduction

Trace fossil collections are housed in two locations within the University of Manchester, the Manchester Museum and the School of Earth, Atmospheric and Environmental Sciences (SEAES) (formerly Department of Earth Sciences and previously the Department of Geology). The collections in the Manchester Museum include type and figured specimens collected over a period of 150 years, while those in the SEAES result from ichnological research over the past thirty years by academic staff and postgraduate students. It is intended that these collections will ultimately be amalgamated with those of the Manchester Museum as this is the designated Regional Collection Centre, stemming from the Earth Sciences Review of 1988. At present, a combination of lack of resources, rebuilding projects and changes of curatorial policy have prevented these objectives being fulfilled. The trace fossils in both collections relate principally to studies of local Carboniferous and Triassic rocks that were published in a variety of journals, mostly since 1970.

Collections in the Manchester Museum

Many trace fossils in the Manchester Museum collection date back to the nineteenth century, especially Triassic reptilian footprints (Tresise and Sarjeant 1997) and others from Carboniferous strata (Binney 1856; Williamson 1887; Sarjeant 1974). Type, figured and referred specimens are listed in published catalogues (Jackson 1952; Nudds 1992, 2005) and are indexed with prefixes L or LL.

Prominent in the Triassic collections are chirotheroid and rhynchosauroid footprints from the Helsby Sandstone and the Tarporley Siltstones (Anisian) of Storeton, Runcorn and Lymm in Cheshire (Tresise and Sarjeant 1997). The Carboniferous collections contain a variety of invertebrate trace fossils, predominantly from non-marine environments. They include specimens collected from Silesian deltaic sedimentary rocks of the Pennines (Eagar *et al*. 1985), Westphalian rocks of Lancashire (Anderson *et al*. 1997) and Radstock, Avon (Pollard and Hardy 1991). Other trace fossils held in the collections are Mesozoic, including a Kimmeridge Clay ichnofauna (Wignall 1991) and Wealden burrows (Goldring and Pollard 1995).

Collections in the School of Earth, Atmospheric and Environmental Sciences

These collections comprise teaching, research and reference material, built up post-1970 by J.E. Pollard, F.M. Broadhurst and their Ph.D students. The extensive systematic, stratigraphical and palaeoenvironmental teaching collection of trace fossils is well organised and conserved. There are

Figure 1. The display and storage cabinets that were installed in 2004.

approximately 200 specimens in this teaching collection, which are augmented by photographs and teaching notes. The teaching collection is housed in modern, metal drawer cabinets situated in the main Palaeontology teaching laboratory of SEAES (Figure 1). It is used extensively for undergraduate and taught postgraduate courses within the school, and for evening classes, day schools and other projects with the public.

A recent example of external use of the collection was an art project carried out with Key Stage 3 pupils of the Grange School, Runcorn. The pupils were asked to paint and model a creature that could have made the locally quarried *Chirotherium* tracks, and to paint and draw the Triassic landscape (Figure 2). Over the course of the project the pupils had to learn how to use the evidence provided by the fossils and to use their imagination. Access to the specimens was provided by the loan of trace fossil material. The use of interactive classroom facilities then allowed the school to dynamically link with university staff. Collections of trace fossils work particularly well as a basis for projects which engage the public, as it becomes necessary for participants to interpret what they see, and allows them to express ideas and opinions within the constraints of the evidence provided by the fossils.

The research and reference collections comprise some 1800 specimens. The collections are housed in mobile drawer stacks in wooden drawers with fitted wooden lids. Published material is indexed with prefix MGSF. To date the Research Collection holds 131 type, figured and referred specimens. It includes Carboniferous specimens from the Pennines (Hardy 1970a; Broadhurst *et al*. 1980; Eagar *et al*. 1985; Miller 1988; Pollard 1988; Anderson 1996; Mangano *et al*. 2002), Triassic specimens from Arran (Pollard and Lovell 1976; Pollard and Steel 1978), from Annan (Pollard 1985) and Cheshire. A significant part of the Cheshire material is the unique diverse marginal marine ichnofauna from the Tarporley Siltstones of Daresbury (Ireland *et al*. 1978; Pollard 1981).

Other collections relating to published work include trace fossils from the Jurassic (Goldring *et al*. 1991), Cretaceous (Pollard *et al*. 1993) and Eocene (Siggerud *et al*. 2000). Specimens from unpublished theses include examples from the Devonian of the Midland Valley of Scotland (Walker 1985), the Carboniferous of the North Pennines (Lees 1991), Westphalian of Lancashire (Hardy 1970b) and the Eocene of the Suez Rift, Egypt (Malpas 2003). The research and reference collections also include incompletely characterised trace fossils of Triassic age from Gruinard Bay, northwest Scotland, Arran, Annan,

Figure 2. Life size reconstruction of the "Cheshire Beast" and associated art works by Year 9 pupils of the Grange School, Runcorn on display in the School of Earth, Atmospheric and Environmental Sciences, University of Manchester.

Cumbria, Cheshire, the Midlands, Somerset and south Devon, all of which are conserved, and await future research. A large database of photographs of Jurassic ichnofabrics (core samples) from North Sea oilfields also exists in departmental Ph.D. theses (e.g., Taylor 1991; Martin 1993; Blight 1998; Burns 1998).

Visitors are welcome to access the collections. This can be arranged by contacting the curator, Mandy Edwards, at the address above.

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TRACE FOSSILS: A SMALLER MUSEUM'S PERSPECTIVE

by Jonathan D. Radley

Radley, J.D. 2006. Trace fossils: a smaller museum's perspective. *The Geological Curator* 8(5): 247-254.

The Warwickshire Natural History and Archaeological Society, who amassed many specimens, including Triassic reptile tracks, initiated Warwickshire Museum's trace fossil collection during the nineteenth century. In recent decades, renewed interest in the trace fossil specimens has enhanced their value as a repository of scientific and historic data. Warwickshire's geological sites still have considerable potential for yielding trace fossils and, in particular, Jurassic sections have furnished new records in recent years. Triassic reptile tracks were first displayed at the Warwick Market Hall during the nineteenth century; notes are provided on a rediscovered, previously exhibited *Chirotherium* specimen from Preston Bagot, western Warwickshire. The Warwickshire Museum continues to display a small number of trace fossils.

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Introduction

The palaeobiological significance of certain trace fossils, notably vertebrate tracks, was known during the nineteenth century (Lockley and Gillette 1989), affording them long-term popular appeal. In contrast, the palaeobiological and sedimentological significance of many invertebrate burrows, tracks, resting traces, grazing sculptures and borings remained largely unrealised until the latter half of the twentieth century (Osgood 1975; Donovan 1994). Underlining this, as recently as the 1940s, certain invertebrate trace fossils were being referred to in the geological literature as 'fucoids', that is, fossilised remains of marine algae (Häntzschel 1975).

As a consequence, trace fossils, especially those attributable to invertebrates, are under-represented in the collections of smaller museums. Many collectors and generalist curators still lack the specialist knowledge and experience to identify and differentiate trace fossils in the field, and it is undeniable that these can be difficult entities to collect, classify, document, store and interpret. Nevertheless, in terms of balanced collecting, they vouch for biogenic activity and animal behaviour through time in a way that 'dead' body fossils can never achieve (e.g., Donovan 1994). Furthermore, they can be attractive and emotive display objects in their own right, more so in the present age of digital technology, the worldwide web and 'virtual museums'. This paper examines the status of ichnology in the Warwickshire Museum, a county museum in central England with a history of geological collecting, interpretation and display spanning 170 years.

Warwickshire ichnology: a summary

Warwickshire's 'solid' geology ranges in age from Neoproterozoic up to Middle Jurassic. Northern Warwickshire's Nuneaton inlier preserves Cambrian (Comley Series) sandstones (Hartshill Sandstone Formation) that are currently well exposed within Jee's Quarry, Hartshill (Bridge *et al*. 1998). There, the Park Hill, Tuttle Hill and Jee's members have yielded well-preserved trace fossils that indicate shallow-marine environments. Ichnotaxa recorded by Brasier and Hewitt (1979) include *Arenicolites*, *Didymaulichnus*, *Gordia* and *Planolites*. Records of simple burrows and 'trails' in the Mancetter and Outwoods Shale formations (Taylor and Rushton 1971) indicate trace fossils in the overlying Cambrian-Ordovician Stockingford Shale Group. Burrows have been recorded from the alluvial and marginal-marine Devonian Oldbury Farm Sandstone Formation, and the Westphalian Middle Coal Measures (Taylor and Rushton 1971; Bridge *et al*. 1998).

Developed largely as continental red-beds, the overlying Carboniferous up to Permian Warwickshire Group of the Warwickshire coalfield yields rootlet traces (Bridge *et al*. 1998). The widespread Triassic Sherwood Sandstone and Mercia Mudstone groups are also developed largely as clastic sedimentary rocks of non-marine semi-arid to arid origin, that

Figure 1. The 'Murchison and Strickland' slab (Warwickshire Museum specimen G10872). Shrewley Common, Warwickshire (Arden Sandstone, Late Triassic). Ruler is 300 mm long.

Figure 2. Enlarged view of part of the 'Murchison and Strickland' slab (Warwickshire Museum specimen G10872) showing reptile tracks (*Rhynchosauroides rectipes* Maidwell). Scale provided by ruler (graduated in centimetres).

have yielded reptile tracks as well as invertebrate traces (Old *et al*. 1991; Benton *et al*. 2002 and references therein). In southern and eastern Warwickshire, Rhaetian (uppermost Triassic) Langport Member ('White Lias') limestones contain a shallow-marine ichnofauna that includes arthropod burrows (*Thalassinoides*), U-shaped burrows (*Arenicolites*) and bioerosion traces (Radley 2002).

The overlying Lower and Middle Jurassic strata of southern and eastern Warwickshire are of essentially shallow-marine origin and rich in trace fossils (Radley 2004). In particular, the Lower Jurassic 'Blue Lias' limestones, marls and mudstones of the Rugby Limestone Member (Blue Lias Formation) yield the 'classic' Blue Lias ichnofauna (Moghadam and Paul 2000) that includes *Chondrites*, *Diplocraterion*, *Kulindrichnus* and *Thalassinoides*. Additionally, bioerosion traces are common throughout the Lower Jurassic succession (Radley and Barker 2001; Radley 2003).

Past collecting

The Warwickshire Natural History and Archaeological Society (WNHAS) was established in 1836 and remained active until the latter part of the nineteenth century. One of the principal aims was to initiate a geological collection for display at the Market Hall, Warwick. The museum collections soon grew, incorporating locally discovered material as well as acquisitions from further afield. Establishment of the Warwickshire Naturalists' and Archaeologists' Field Club in the mid-1850s added further impetus. The Natural History and Archaeological Society's published annual reports (1837-1892) confirm acquisition of many trace fossil specimens throughout that period.

The Triassic (Carnian) Arden Sandstone at Shrewley Common, west of Warwick, was the source of the first English Triassic reptile footprint finds, upon a large sandstone slab discovered by Hugh Strickland and acquired by the WNHAS in 1837 (Tresise and Radley 2000). Originally attributed to an amphibian, the tracks are now assigned to the ichnospecies *Rhynchosauroides rectipes* Maidwell, generated possibly by sphenodont lizards (Tresise and Radley 2000; Tresise 2003). The specimen was first figured by Murchison and Strickland (1840) and is preserved in Warwickshire Museum's collection (Figures 1, 2). The WNHAS subsequently acquired further *Rhynchosauroides*-bearing slabs from a quarry adjacent to the canal at Shrewley; many of these were collected by the Rev. Peter Bellinger Brodie, founder of the Field Club (see above) and long-term Honorary Curator of Geology for the Natural History and Archaeological Society's museum. Larger tracks were also discovered in local Triassic strata (Brodie 1859, 1887; Brodie and Kirshaw 1872; see Appendix) and acquired for the museum. Additionally, Triassic tracks from Shropshire, Staffordshire and Cheshire were collected from 1840 onwards. Significantly, the annual reports also confirm acquisition of invertebrate trace fossil specimens, chiefly obvious burrows and borings, but also 'fucoids'.

The WNHAS gradually declined through the late nineteenth and early twentieth centuries, and in 1932 the collections were transferred to the Warwickshire County Council. A public museum was re-opened at the Warwick Market Hall in 1951, where the council-run Warwickshire Museum has been located to the present day. The geological collection retains numerous trace fossil specimens, most notably Triassic track slabs acquired by the WNHAS.

Recent and current museum collecting

Several important trace fossils, notably bioturbated sandstone and limestone specimens from the local Triassic Arden Sandstone Formation and Langport Member, and *Rhynchosauroides* tracks from the Triassic sandstones of Grinshill, Shropshire, were acquired during the 1980s by Tristram Besterman, a former Keeper of Geology at the museum. Most recently (2000-present), the author has collected a number of trace fossils including Britain's oldest (Rhaetian; latest Triassic) grazing traces of regular echinoids (*Gnathichnus pentax* Bromley) discovered in eastern Warwickshire (Radley 2002), previously unrecognised suites of Early Jurassic (Lias Group) shallow-tier bioerosion traces (Radley 2003), and undescribed arthropod traces from the Saltford Shale Member (Blue Lias Formation) at Southam Cement Works quarry, eastern Warwickshire (Radley 2004). Additionally, voucher specimens of Langport Member (Rhaetian), Rugby Limestone and Marlstone Rock Formation (Lower Jurassic) ichnotaxa have been collected.

Future collecting

Important gaps remain within the museum's trace fossil collection. Notably, the rich assemblage of the Cambrian Hartshill Sandstone Formation (see above) is currently represented by just a handful of specimens. Additionally, the Triassic Arden Sandstone Formation at Shrewley and Rowington has yielded several invertebrate ichnotaxa (e.g., *Planolites montanus* Richter, *Treptichnus bifurcus* Miller; J.E. Pollard, personal communication) and new material could be collected. Investigation of Upper Bajocian-Lower Bathonian (Middle Jurassic) limestone at Cross Hands Quarry, at the county's southern tip, has revealed abundant burrows and bioerosion traces. These are largely unrepresented in the museum collections and would provide interesting comparison with those of the Lower Jurassic Lias Group (see above).

Fieldwork

The author's recent investigations of Early Jurassic bioerosion traces (see above) have involved bulk collection of calcitic fossil shells (principally oysters), belemnite rostra and lithoclasts from quarries, road cuttings, temporary exposures and ploughed fields in Warwickshire and adjacent counties. Within the Saltford Shale Member at Southam (see above), trace fossils are preserved on and within limestone and siltstone nodules, some representing scour casts (Radley 2002). Several nodules have been recovered *in situ*, revealing significant differentiation of traces on upper and lower surfaces, necessitating field orientation and marking.

Rugby Limestone trace fossils at the Southam site are conspicuous within bands of hard argillaceous limestone (Clements 1975), demanding a degree of field preparation to remove excessive amounts of matrix. Warwickshire's trace fossils occur largely within non-pyritic sandstone and carbonate lithologies (Clements 1975; Brasier and Hewitt 1979; Old *et al*. 1991; Bridge *et al*. 1998), robust fossil shells and other skeletal remains (Radley and Barker 2001). These substrates normally require little preparation other than washing and drying, prior to documentation and storage. Small amounts of pyrite are associated with Langport Member and Saltford Shale trace fossils from Southam, but museum specimens have not as yet shown signs of oxidation and deterioration.

The current collection

A large proportion of the existing trace fossil collection of the museum (numbering approximately 125 specimens) was amassed during the nineteenth century by the WNHAS. Some are identifiable amongst lists within the Society's annual reports (see below), Henry Beasley's 1906 account, and photographs contained in the Beasley Archive of the Liverpool Museum (personal observations). Museum geologists have collected further trace fossil specimens in recent decades. At present, Cambrian, Rhaetian and some Lower Jurassic invertebrate trace fossils are stored in drawers as part of the stratigraphically arranged lithological collections within the museum's main geology store at The Butts, Warwick. Smaller slabs bearing Triassic tracks

Figure 3. Smaller Triassic reptile track specimens in a drawer at The Butts store, Warwick.

and invertebrate traces, other than those mentioned above, are housed in drawers amongst the stratigraphically and taxonomically ordered palaeontological collections at The Butts store, and also the Market Hall Museum (Figure 3).

The largest Triassic specimen, the ‘Murchison and Strickland’ slab (Figures 1, 2), is housed in a wooden box within the store at The Butts, Warwick. Since it was first figured (Murchison and Strickland 1840), the specimen has suffered slight superficial abrasion, dust impregnation and a major crack (Figure 1). It is hoped that funding will be obtained to conserve and re-house this important specimen in the near future. Other large sandstone slabs are stored in wooden boxes with lids or on purpose-built trolleys. Oversized Lower Jurassic specimens (including burrowed limestone blocks from the Rugby Limestone Member; Figure 4) are housed within purpose-built wooden boxes. Specimens in boxes and drawers in both stores were recently re-packed as part of a volunteer project, implementing acid-free card trays and plastazote foam ‘cushions’ (Figure 3).

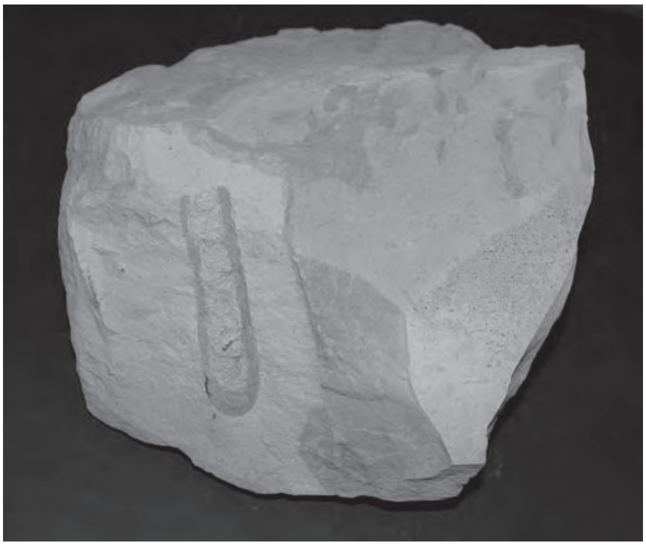

Figure 4. Limestone block preserving *Diplocraterion* burrows (Warwickshire Museum specimen G15521), Southam Cement Works quarry, Warwickshire (Rugby Limestone Member, Blue Lias Formation, Lower Jurassic). Block is 250 mm wide.

Figure 5. Beasley Archive photograph 365, showing Triassic sandstone slabs preserving reptile tracks, on display at the Market Hall Museum, Warwick. The photograph is attributed to ‘J. Harriott, 15 High Street, Warwick’. An identical photograph (Beasley Archive 28) is dated April 1902.

Display

An account by Hugh Miller (see Sarjeant 1974) indicated that Triassic reptile tracks were a feature of the WNHAS museum at the Market Hall in 1845. Subsequent accounts (e.g., Brodie and Kirshaw 1872; Beasley 1898, 1906) confirm the continued display of such specimens through the latter part of the nineteenth and early twentieth centuries. Importantly, the Beasley Archive (Tresise and Sarjeant 1997; personal observations) includes photographs of such specimens at the museum during the 1900s (Figure 5). The museum’s current geology gallery, dating back to the 1970s, displays several WNHAS slabs within the contexts of Triassic palaeontology and palaeoenvironments, and the Rev. Peter Bellinger Brodie’s contributions to geology. Two specimens are on open display (Figure 6).

Recent research

John Pollard (University of Manchester) researched the Triassic vertebrate track collections in the early 1980s, providing up-to-date identifications and notes on associated invertebrate trace fossils (also see Appendix). During the late 1990s, Geoffrey Tresise (Liverpool Museum) realised the status of the ‘Murchison and Strickland’ slab (Figures 1, 2) as preserving the first recorded Triassic footprints from England (Tresise and Radley 2000; Tresise 2003). More recently, King *et al*. (2005) have revised the status of Triassic vertebrate footprints attributed to *Chirotherium*, drawing upon Brodie’s records of larger tracks from Warwickshire (see above and Appendix). The present author’s research into Late Triassic and Jurassic bioerosion has been reported in recent issues of the *Proceedings of the Cotteswold*

Figure 6. Two Triassic sandstone slabs preserving reptile tracks on display at the Market Hall Museum, Warwick, 2005. The smaller specimen, preserving a *Chirotherium* footcast (Warwickshire Museum specimen G1156), is from Lymm, Cheshire. Below, the rippled sandstone slab (Warwickshire Museum specimen G1145) preserves deformed rhynchosauroid tracks and is from Shrewley, Warwickshire.

Naturalists' Field Club (e.g., Radley 2003; Radley and Barker 2001). Additionally, Late Triassic–Early Jurassic trace fossil specimens held by the Warwickshire Museum have featured in recent undergraduate projects at The University of Birmingham.

Trace fossils and the public

Invertebrate trace fossils enter the Warwickshire Museum as enquiries with surprising frequency. Most common are Cretaceous flint nodules from local Pleistocene deposits or English coastal sites. Often perceived by enquirers to be fossilised teeth or bones, many represent partial casts of arthropod burrows (*Thalassinoides* isp.).

Cut slabs of shelly ooidal ironstone, quarried from the Lower Jurassic Marlstone Rock Formation at Edgehill, southern Warwickshire, have been used as facings on several buildings around the market square in the town centre of Warwick, close to the Warwickshire Museum at the Market Hall. The slabs display cross-sections through a variety of well-defined burrows including 'dumb-bell' shaped *Diplocraterion* and/or *Rhizocorallium*, and *Thalassinoides* (Figure 7). These afford opportunities

Figure 7 (below). Bioturbated Hornton Stone (Lower Jurassic ooidal ironstone) used as a facing on a modern building, Warwick Market Place. The dumb-bell shaped structures (arrowed) are cross-sections through *Diplocraterion* or *Rhizocorallium* burrows. Slab is 590 mm across.

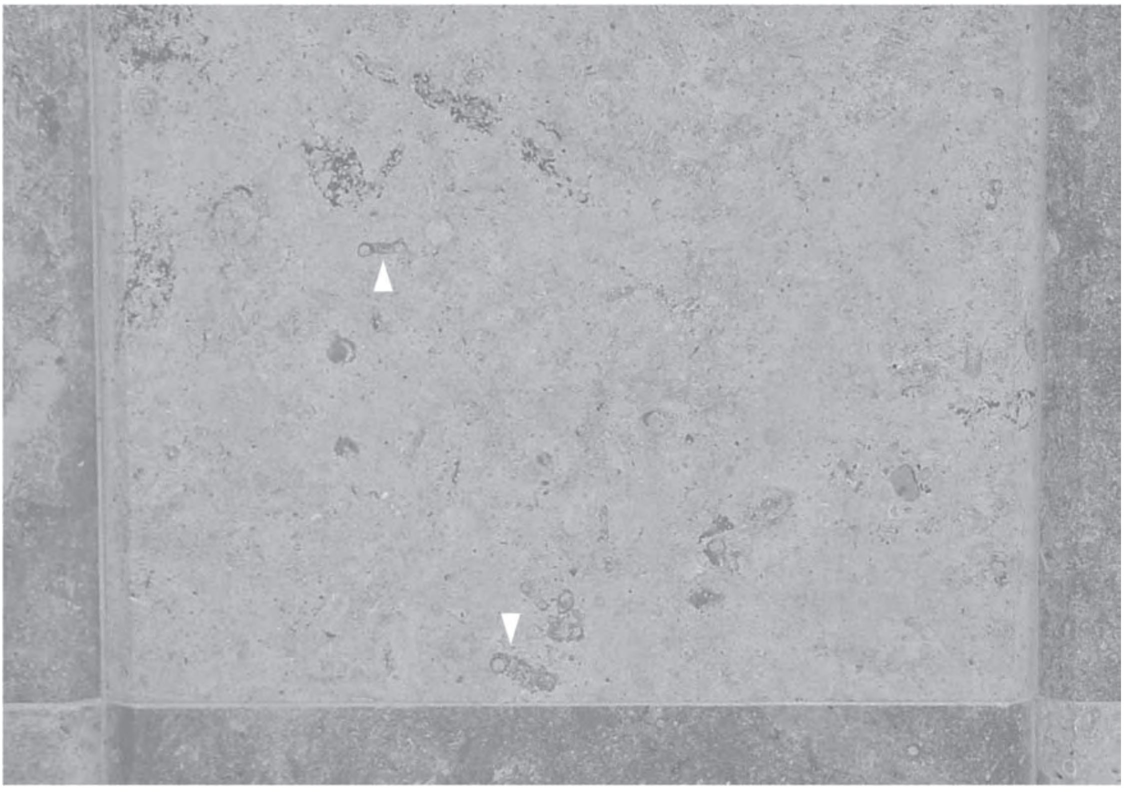

Figure 8. Sandstone slab preserving manus and pes casts (*Brachychirotherium* isp.) (Warwickshire Museum specimen G1143), Witley [Whitley] Green, Preston Bagot, Warwickshire (Arden Sandstone, Late Triassic). This specimen can also be seen in Beasley Archive photographs 28 and 365 (Figure 5). Specimen is 310 mm long.

to study body fossils and trace fossils in a highly accessible setting, and have featured in a number of museum-led geological walks. With further reference to field studies, Middle Jurassic burrow casts are figured within the identification and interpretative materials for Warwickshire Museum's school and holiday fossil-collecting trips to Cross Hands Quarry, near Little Compton.

Discussion and conclusions

The WNHAS acquired trace fossil specimens throughout much of the nineteenth century. This legacy is evident amongst the strengths of the modern collection, most notably the Triassic track-bearing sandstone slabs. Many of these specimens are from localities that are no longer productive (Benton *et al*. 2002), and represent irreplaceable repositories of palaeontological and sedimentological data. As such, they have attracted the attention of researchers in recent decades. Nevertheless, the potential for collecting new trace fossil material in Warwickshire remains considerable, and several new records have been established from Triassic and Jurassic strata in recent years.

Improved and more accessible storage conditions for larger specimens, though desirable, would demand increased space that is not at present available. However, current storage conditions are more than adequate and smaller trace fossil specimens have recently benefited from repacking as part of a major volunteer project. The Market Hall Museum continues to display Triassic vertebrate tracks more than 150 years since such material was first exhibited by the WNHAS, as well as representative invertebrate traces.

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APPENDIX

CHIROTHERIUM FOOTPRINTS IN WARWICKSHIRE: THE PRESTON BAGOT SLAB REDISCOVERED

by Jonathan D. Radley and John E. Pollard[1]

In 1859, the Rev. P.B. Brodie reported the discovery of a Triassic ('Upper Keuper') sandstone slab in a ploughed field at Witley Green, near Preston Bagot, western Warwickshire, preserving two casts of large footprints that he attributed to '*Cheirotherium*' (Brodie 1859, 1860). This specimen was purchased by the WNHAS and the locality was corrected to 'Whitley' in the society's annual report for 1859 (Anon 1860). Today, Whitley House and Whitley Farm lie roughly halfway between Preston Bagot and Henley-in-Arden. Subsequent reports (e.g., Brodie and Kirshaw 1872) confirmed the presence of this specimen within the society's collection.

King *et al*. (2005) have documented occurrences of *Chirotherium* prints in the UK, drawing upon the specimens collected during the nineteenth century that are now widespread amongst museum collections. They noted that the only track specimen formally provenanced to Preston Bagot in the present-day Warwickshire Museum collection (Warwickshire Museum specimen G11543) does not match Brodie's (1859) description and therefore concluded that Brodie's specimen is lost or mislabelled.

Tresise and Sarjeant (1997) drew attention to the Beasley Archive of Triassic footprint notes and photographs, held by the National Museums and Galleries on Merseyside. Henry Beasley, vertebrate ichnologist and long-term member of the Liverpool Geological Society, was familiar with the Warwickshire Museum collection (Beasley 1898, 1906) and several photographs of the Triassic track collection occur within the archive (Tresise and Sarjeant 1997). Photographs 28 and 365 (Figure 5), the former dated 1902 and both attributed to 'J. Harriott, 15 High Street, Warwick', exhibit a block of sandstone showing two footcasts of *Chirotherium* type provenanced in photograph 28 to Preston Bagot (largest of the three specimens at top left). Significantly, this specimen still exists within Warwickshire Museum's collection (Warwickshire Museum specimen G1143; Figure 8). The associated hand-written label cannot be attributed to a known curator or volunteer, but is certainly not the original. It reads 'Single positive foot impression of Labyrinthodon in grey sandstone. Upper Keuper, Shrewley, Brodie Collection'. Accordingly, the specimen was figured in the British Geological Survey's Redditch sheet memoir published in 1991, amongst a plate of Arden Sandstone (Carnian, Late Triassic) fossils chiefly from Shrewley, several kilometres northeast of Preston Bagot (Old *et al*. 1991, pl. 11k).

The junior author documented G1143 (Figure 8) as part of a Triassic trace fossil survey during the early 1980s. The lithology is medium/coarse-grained white sandstone with a crudely rippled, loaded and burrowed top, and a mudcracked and burrowed base. The latter preserves large, deep manus and pes casts of *Chirotherium* type (*Brachychirotherium* isp.; G. Demathieu, personal communication to J.E. Pollard, 1983).

In his original description of the Preston Bagot find, Brodie (1859) provided dimensions for both the rock matrix and individual footcasts. These match G1143 perfectly. Additionally, Brodie noted the presence of plough marks upon the surface of the specimen and G1143 accordingly preserves incised linear scratches consistent with such damage. We conclude that G1143, erroneously provenanced to Shrewley, is Brodie's Preston Bagot slab.

Brodie (1859) attributed the specimen to the 'Upper Keuper' sandstone, now classified as the Arden Sandstone division of the Mercia Mudstone Group that outcrops widely in the Preston Bagot - Henley-in-Arden area (British Geological Survey 1989). The lithology is consistent with those recorded from the local Arden Sandstone (Old *et al*. 1991).

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TRACE FOSSILS – THE POOR RELATIONS OF MUSEUM PALAEONTOLOGICAL COLLECTIONS?

by David N. Lewis and Stephen K. Donovan

Lewis, D.N. and Donovan, S.K. 2006. Trace fossils – the poor relations of museum palaeontological collections? *The Geological Curator* 8(5): 255-259.

Collections of fossil invertebrates in museums are dominated by certain taxa, such as molluscs, whereas other minor groups are ‘Cinderella’ taxa, of little general interest. Invertebrate trace fossils belong to this latter group, rarely utilised for museum displays and of scientific interest to only a small audience of experts. Organisation of such collections may be alphabetical, stratigraphical, geographical, ethological or a combination of these, but should not be ‘biological’. As illustrations, two national collections are discussed, those of the Natural History Museum, London, and the Nationaal Natuurhistorisch Museum, Leiden.

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Introduction

The palaeontological collections of most museums, both national and provincial, are primarily composed of recognisable and nominally easily identifiable and classifiable fossils, such as molluscs, echinoderms, trilobites, plants and so on. These are the groups which the majority of collectors have gathered since such things attracted attention, and which people like to collect, own and work on; when displayed in the public galleries they attract the attention of a broad spectrum of public visitors. Molluscs are a good example; they include a wide variety of attractive taxa, are commonly well-preserved, can be easily identified and are widely distributed. The most popular palaeontological exhibitions which draw people into natural history museums are, most probably, those which have dinosaurs, large mammals and fossil hominids.

However, there are other parts of palaeontological collections that are much less popular with the professional and public for a variety of reasons, including their aesthetic appeal, the difficulties and vagaries of classification, the overall shortage of expertise and, importantly, the amount of space they can take up when stored. These ‘Cinderella’ groups include such invertebrates as tentaculitids, scolecodonts and machaeridians. They also include collections of trace fossils, notorious for the amount of storage space they consume. Only occasionally do trace fossils manage to capture the public imagination, such as when dinosaur trackways are displayed (Ensom 2006). However, that is because they were made by dinosaurs, a major visitor attraction with or without trackways. Exhibitions of trails made by, say, gastropods or worms will not have the same impact, or indeed, any impact at all, although we recognise that, for example, large arthropod trackways can make exciting public displays (Briggs and Rolfe 1983).

The study of invertebrate trace fossils (principally their tracks, trails, burrows and bioerosive structures) is not very active in the UK at present, though there are some enthusiasts; in The Netherlands, S.K.D. and associates are the only active proponents. As a consequence of their relative lack of popularity and a usually corresponding lack of resources, the collections themselves may also suffer from a lack of curatorial care, such that at best they are put on a mere care-and-maintenance level, if that. This in time leads to a general disorganisation and even deterioration of the collections, which in turn leads to them being ignored, forgotten and, perhaps, ultimately being thrown out as ‘rubbish’.

Even in national museum collections trace fossils may be ignored when, because of a lack of resources and expertise, the presence of important material is 'forgotten'. The Natural History Museum in London (BMNH) has a good collection of trace fossils and yet for years these specimens were in a state which was less than user-friendly. Only when resources were available, in the form of unpaid volunteers supervised by hard-pressed museum staff, did the curatorial level of the collection rise and improve to a more usable state. The collection is small relative to many other taxa in the department, only occupying about 1.6 % of the storage area of one floor, not including larger traces like dinosaur tracks/trackways which have to be stored elsewhere within the Museum complex, nor other smaller traces which are kept alongside their known and recognised forming organisms.

A further consequence of 'Cinderella' groups like trace fossils is that a good collection made by an enthusiast is unlikely to be received with much enthusiasm by a museum whose storage space is limited. This may lead to the collection being lost to science.

However, trace fossils, especially when placed in their sedimentological and palaeobiological context, are important environmental and ecological indicators. They are useful for trying to determine such things as the mode of life, even if the organism itself was either not preserved or unknown. For example, the carpoid *Rhenocystis* from the Devonian of Bundenbach in Germany belongs to a group that have been the subject of debate concerning their functional morphology and mode of life; even such basic characteristics as life orientation are contended. Jefferies (1984) provided detailed descriptions of his interpretation of the movement of the organism that is now supported by the discovery of several specimens of *Rhenocystis* at the end of their trails (Sutcliffe *et al*. 2000). Even when the ichnotaxa are well documented and their relationships are known, e.g., the *Diplichnites-Cruziana-Rusophycus* sequence, the evidence of the actual producers is scanty. Although the producing organism may be found at the end of the trail (for example, a trilobite), there are other organisms in entirely separate taxonomic groups that produce very similar trace fossils (see discussion in Whittington 1992, p. 39). Correlating the two is very difficult, but the interest and benefits of doing so are great. So why is there only limited interest in trace fossils? The reasons might include any or all of the following.

- Collections failure - people do not recognise them or they cannot be extracted from their localities (Donovan *et al*. 2006).
- Too big to collect and/or store.
- Not aesthetic - trace fossils are generally considered unattractive, although ichnotaxa such as *Zoophycos* and *Paleodictyon*, for example, are nonetheless pleasing to the eye.
- Not identifiable - they require a good deal of expertise to appreciate their importance (although this may be said for many fossil groups).

Suggestions for organising trace fossil collections

Trace fossils are morphological and functional entities with the overlay of a Linnean style of classification, distinguished from true biological taxonomy by the prefix 'ichno' - ichnogenus or ichnospecies. They are not body fossils in the biological sense, but are the traces produced by the organisms in the course of living, that is, sedimentary structures. In order that a collection can be useful some form of organisation needs to be imposed upon the specimens. Various alternatives are possible.

- Alphabetical (commonly by ichnogenus) – The simplest organisation and one that enables a constant layout to be made of ichnogenera. Revision of the interpretation of the traces would not lead to major problems of reorganisation for curators, unless an ichnogenus is 'split' or synonymised. This is currently the way in which specimens are organised in the BMNH. It has the advantage of not requiring constant re-organisation according to differing interpretations, and is usable by expert and novice alike.
- Stratigraphical – Trace fossils can be restricted to certain stratigraphic levels, so that a stratigraphical organisation will reflect their different morphologies and likely producers, or may occur at many horizons (some taxa occur throughout the Phanerozoic).
- Geographical – Organisation according to location will show similarities and groupings over large areas, may help to correlate stratigraphic horizons and will support ichnofaunal studies.
- Ethological – Organisation follows a functional interpretation of ichnotaxa. Similar modes of production are grouped together, such as feeding traces, dwelling traces, locomotion traces, *etc*. Problems may arise when interpretations of behaviour change, which will probably give a curator problems of reorganisation.
- Combination – An assembly of these can also be used, though this will inevitably increase the

amount of space needed to accommodate the collection if it is not to be cluttered, cramped or confusing. Thus, the following organisation could be followed throughout the collection, each drawer bearing a label showing:

1. Geographical location - e.g., Isle of Wight, British Isles, North America.
2. Stratigraphical level - how old is it?
3. Ichnotaxon - its classification within the system.
4. Alphabetical - arranged within the ichnotaxonomic organisation.

Such a scheme of organisation is used by the Nationaal Natuurhistorisch Museum, Leiden (NNHM), a primary stratigraphic organisation being secondarily grouped into geographic areas, e.g., Devonian – Germany, Devonian – France; Upper Cretaceous – The Netherlands, Upper Cretaceous – Germany.

Ichnofossils should not be classified according to their perceived producing organism. Any given ichnofossil morphology may potentially have been produced by more than one biological species, which may belong to different phyla (Pickerill 1994). Only in cases where the producing organism is preserved in intimate juxtaposition with the trace can such an identity be established with confidence.

Whichever style the institution or curator chooses to follow is not so important as long as specimens can be located. There may also be a necessity to divide the collection into large and small components, whereby large slabs requiring shelf space have to be separated off from small 'hand specimens' which can be stored in drawers. If this has to be done, the standard layout should be followed as far as possible.

Two national collections

The evolution of a collection of items in a museum can tell a lot about the development of the museum as an institution of scientific excellence. Some of the older museums throughout the world may have started life as simple displays of curios without any particular regard to order. As scientific experience grew, better methods of display developed. Storage methods soon followed suit, for the collections began to grow as interest was fired amongst the population, and not everything could be put on show. Some museums were set up around a core collection, such as that of Hans Sloane for the British Museum, whose natural history collection was the core which eventually led to the founding of the daughter institution, the British Museum (Natural History), as the Natural History Museum (BMNH) in London was known until recently. The BMNH is now completely independent of the parent museum.

The Natural History Museum, London

The trace fossil collection in the Department of Palaeontology at the BMNH is modest in size and represents collections made from the nineteenth century onwards. In the past it contained pretty much anything that was not readily identifiable, with artifacts (including lumps of concrete with the impression of the sacking that had once contained it), curiously shaped stones, wind-polished rocks from deserts and lumps of rock with strange markings, including mineral dendrites resembling plants. In amongst these were to be found true trace fossils - the remains of the lifestyles of organisms. It also contained, and indeed still does, the Problematica, that is, body fossils of unknown identity.

Eventually, the whole mixed collection was sorted out and, with some exceptions, the non-trace fossil component was removed from the collection and transferred to the correct locations elsewhere in the museum. The exceptions include plaster models of Beringer's iconoliths (Taylor 2004) and curiously shaped flints that have a fanciful resemblance to various animals (see Lewis 2000). Other non-biological specimens are also retained for the purpose of illustrating to interested parties the pitfalls for the unwary. One fine example of these, amongst many, is an object which resembles an eviscerated stomach and which is actually a ceramic bottle that collapsed during firing.

The remaining true trace fossils are now stored in their own part of the storage system of the Department of Palaeontology. They occupy 125 drawers in three and a half cabinets, six shelves in two cabinets and a few slots in the roller storage set aside for large slabs (for a description of the storage units see Owen *et al*. 1982). These do not include the trace fossils whose producers are well known and which are stored with the relevant taxa in other parts of the collections, including the dinosaur tracks stored with fossil reptiles, most of the *Gastrochaenolites* specimens stored with the molluscs and *Gnathichnus* which are kept with the fossil echinoids.

Material from the Ediacara Formation of Australia is also kept together rather than being distributed alphabetically, with the rock specimens being supplemented by plaster casts of the originals held in Australian museums. These fossils also come into the category of 'problematica', a mixture of trace and body fossils preserved as natural moulds and casts. Even though some of these remains may eventually prove to be nothing more that sedimentary structures and not biologically produced entities, they should be kept together for contextual and historical reasons. This may seem to be returning to the earlier days of keeping together everything that was not identifiable, but now there is the difference of experience and new knowledge rather than ignorance and not knowing what to do with them. Research into another part of the problematica collections, the so-called 'Muschia' from the Devonian Gogo Formation of Australia, reveal that parts can be re-distributed to fossil fishes and crustaceans. The name 'Muschia', an unofficial one, indicates the general state of the preservation, a generalised mush.

The arrangement of the collection in a user-friendly state was non-existent for many years, with everything mixed in together. This made finding a specimen extremely difficult and time consuming, such that the whole collection had to be trawled through in order to locate something required. In the early 1990s a start was made to re-organise the trace fossils collections into something more user-friendly. Volunteers, including several from the Museum front-of-house staff (as part of their training to see how the Science Departments worked), carried out an initial sort through the material, firstly to re-box and re-label specimens, and then to sort roughly into similar items. Later on, another volunteer, a non-member of the staff who had an interest in trace fossils, again sorted through the collections, identifying as best as possible the ichnotaxa present. It was then very much easier to re-organise the collection, doing so alphabetically for the most part, but with certain discrete parts kept together, usually because they were cited in various scientific papers.

When the re-arrangement was complete, the drawers were re-labelled and location indexes were constructed so that specimens could be extracted easily and quickly. Furthermore, both the drawer labels and index can be updated easily.

The next phase of the operation will be to sort out and re-organise the material on the shelf units. This will be rather more tricky as some of the specimens are large and heavy, so that placing them in their correct alphabetic location may not be possible without endangering those who may want to look at them and remove them from the collections. Heavy specimens on a high shelf can be a problem without specialist handling equipment.

Currently, the trace fossil collections are used only occasionally by external visitors (e.g., Donovan 2002) and, more often, by internal staff. With pressure on the storage capacity of the Department of Palaeontology there is a possibility that the whole collection will be removed from the South Kensington site to the outstation at Wandsworth, where storage is much less cramped and environmental conditions are the equal of the main museum. However, access is less immediate and transport to the site is more difficult.

Nationaal Natuurhistorisch Museum, Leiden

The trace fossil collection of the NNHM is small, reflecting a previous lack of interest in ichnology in The Netherlands and the museum. There are currently about 60 drawers of ichnofossils, ranging throughout the Phanerozoic. The collection is richest in specimens from northwest Europe and Spain, particularly the Devonian and Mesozoic. Many specimens are awaiting identification or re-identification. Type and figured specimens are few. However, S.K.D. and co-workers are currently actively researching the ichnology of the Upper Cretaceous of northern Europe (e.g., Donovan and Jagt 2005) and the Cenozoic of the Antilles (e.g., Pickerill *et al*. 2003), resulting in a current steady influx of new, correctly identified specimens. Contributions concerning significant donated material are being encouraged to the museum's journal, *Scripta Geologica* (e.g., Blissett and Pickerill 2004).

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BOOK REVIEWS

Pellant, Chris & Pellant, Helen. 2004. *A Guide to Common Fossils*. Field Studies Council Publications, Preston Montford, Montford Bridge, Shrewsbury, 12 pp. Pocket guide. ISBN 1-85153-288-9. Price: £3-25.

Pellant, Chris & Pellant, Helen. 2004. *Guide to Common Minerals*. Field Studies Council Publications, Preston Montford, Montford Bridge, Shrewsbury, 12 pp. Pocket guide. ISBN 1-85153-897-6. Price: £3-25.

Following the success of the earlier *A Guide to Rocks* by the same authors, the Field Studies Council has published a further two pocket geological guides in its AIDGAP series. AIDGAP, or 'Aids to Identification in Difficult Groups of Animals and Plants', is obviously moving out of its own defined parameters when considering rocks and minerals, but this should surely be welcomed. However, there is the question of scope and what is attainable in 12 fold out pages, divided evenly between text and illustrations. On my shelf I have specialist AIDGAP guides on, for example, shieldbugs and the 'top 50' garden birds of the British Isles. A worthwhile guide to common rock types or common minerals is achievable, but, frankly, trying to cover even common fossils in such a limited space was always going to be impossible. My comments in this review will focus mainly on some of the shortcomings that I perceive of *A Guide to Common Fossils* (*GCF*).

I appreciate that introducing fossils and palaeontology in such a limited space is problematic and probably impossible. Nevertheless, the text would have benefited from more critical review before publication. There are some errors, such as referring to the trivial name of a Linnean taxon as its specific name, but my main criticism is that it could have been written so much better. For example, the two paragraphs on fossil corals are poorly structured, even given the limitations of space. The four entires under 'Further reading' will not help the novice, including as it does one volume from 1985 (good, but presumably out of print) and three guides by the authors, two of which are not concerned with fossil. Reference to, say, the three guides to British fossils published by the Natural History Museum in London and an up to date textbook would have served the reader rather better.

A stratigraphic distribution chart in the text is inaccurate in places. For example, there are entries for my beloved 'crinoids' (Lower Ordovician to Recent) and, ambiguously, 'echinoderms' (Ordovician to Recent); crinoids are echinoderms, too. If truly 'echinoderms', then the oldest examples from the British Isles are Lower Cambrian (Comley, Shropshire); if echinoderms is used in error for echinoids, then the oldest British occurrences are from near the top of the Ordovician (Lady Burn starfish beds, Girvan), not the base. Are there really British Lower Ordovician corals or Triassic scleractinians? And why are belemnites shown to range from the Lower Carboniferous to Upper Eocene?

There are 71 photographs of diverse fossils in colour, each with an informative caption. The photographs are generally fine, although the novice might be confused by obvious differences in orientation; for example, the five echinoids illustrated are shown in five different orientations. The stratigraphic coverage is dominated by Carboniferous (15) and, particularly, Jurassic taxa (33 entries, although seven range beyond the Jurassic). Some of my favourite groups with a good fossil record are not covered, such as the crabs, barnacles and borings. There is one Cambrian trilobite and one Bartonian gastropod. The Gault Clay, London Clay and East Anglian crags, to name three personal favourites, are ignored.

My criticisms of *GCF* are unfortunate as, in principal, I can only welcome such a guide. Part of the problem is the impossibility of dealing with such a broad subject area in such a limited space. Guides to particular groups (e.g., British ammonites) or stratigraphic divisions (e.g., British Lower Carboniferous fossils or fossils of the Chalk), which still couldn't pretend to the depth attained in the shieldbug guide mentioned above, would nevertheless be potentially far more worthy contributions. The *Guide to Common Minerals*, dealing with a far less diverse subject area, and with a three page table of properties of all 71 illustrated examples, appears to succeed where the *GCF* could not.

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TRACE FOSSILS IN TWO NORTH AMERICAN MUSEUMS: THE CLEVELAND MUSEUM OF NATURAL HISTORY AND THE NEW MEXICO MUSEUM OF NATURAL HISTORY AND SCIENCE

by Joseph T. Hannibal and Spencer G. Lucas

Hannibal, J.T. and Lucas, S.G. 2006. Trace fossils in two North American museums: the Cleveland Museum of Natural History and the New Mexico Museum of Natural History and Science. *The Geological Curator* 8(5): 261-268.

Ohio and New Mexico are rich in trace fossils (ichnofossils), and both states have longstanding traditions of ichnological research. The Cleveland Museum of Natural History, founded in 1920, has a substantial collection of ichnofossils that includes figured specimens from Ohio, West Virginia and New Jersey. Donations and intensive collecting of trace fossils followed the founding of the New Mexico Museum of Natural History and Science in 1986. This has resulted in North America's largest collection of Permian trace fossils, as well as important collections of trace fossils from several other geological systems. Trace fossils are on exhibit at both museums; both have exhibits showing a model of a large trace maker (a tetrapod in the case of the Cleveland Museum; *Arthropleura* in the case of the New Mexico Museum), either on or juxtaposed with a real fossil trackway. Among specimens brought to these museums for identification by members of the general public are trace fossils, although not usually identified as such, as well as concretions, which are erroneously thought to be fossil eggs. Trace fossils are also encountered and discussed during urban geological field trips in Cleveland.

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Introduction

Trace fossils are important components of the collections of a number of North American museums. In this paper we discuss two such examples, the Cleveland Museum of Natural History in Cleveland, Ohio, and the New Mexico Museum of Natural History and Science in Albuquerque, New Mexico. Our discussion uses 'trace fossil' in a broad sense, encompassing trackways, burrows and other evidence of movement of an organism (Jackson 1997, p. 672), as well as eggs, nests and coprolites. This broader sense of the term has been used by a number of workers (e.g., Gillette and Lockley 1989). This contribution is intended to give the perspectives of two museums in different regions of the United States and to serve as a complementary work to the other papers in this volume that discuss trace fossils in museums elsewhere.

Ohio and New Mexico are states that are both rich in trace fossils (ichnofossils) and that have longstanding traditions of ichnological studies. Invertebrate trace fossils are especially abundant in the Ordovician, Devonian and Carboniferous rocks of Ohio. Early work on invertebrate trace fossils in Ohio was undertaken by Joseph F. James and Samuel A. Miller in the late 1800s (Osgood 1975). James (e.g., 1892) was an early advocate of the animal origin of what we now know as invertebrate ichnofossils, while others, including Miller (1889, 1892), favoured the dominant late 1800s view of these fossils as plants ('fucoids'). Later, Richard Osgood's (1970) work on the ichnofossils of the Cincinnati region, published during the modern flowering of ichnological studies, was to become one of the most important North American contributions of its time to the field. Vertebrate trackways from the Upper Palaeozoic rocks of Ohio have also attracted some attention (e.g., Carman 1927; Mitchell 1931). Examples of Ohio trace fossils have been depicted in *Fossils of Ohio* (Hannibal 1997; Hansen 1997).

The Cleveland Museum of Natural History was founded in 1920. Some fossil trackways were collected or otherwise obtained during the first five decades of the Museum's existence, mainly those of tetrapods from the Upper Palaeozoic of Ohio or dinosaur trackways from western North American and the Connecticut Valley. Major collecting and donation of invertebrate ichnofossils has occurred only in the last few decades.

New Mexico is extremely rich in trace fossils, and has a history of ichnological discovery and research that goes back to Degenhardt's (1840) report of "grosse Fuss-Tritte von Vögeln" (large footprints of birds) in red sandstone near Socorro, New Mexico. Scientific study of New Mexico's trace fossils has intensified in the last few decades (e.g., Lucas and Heckert 1995, Lucas *et al*. 1998, 2005b), largely because the New Mexico Museum of Natural History and Science acts as a centre for this research.

The New Mexico Museum of Natural History and Science opened its doors in 1986, with essentially no collection at that time. The last two decades have seen its fossil collections grow to more than 50,000 catalogued specimens. In 1987, a private citizen, Jerry Paul MacDonald, discovered an exceptionally rich Permian footprint site in the Robledo Mountains near Las Cruces, New Mexico (MacDonald 1992, 1995). MacDonald's collections from this and nearby sites were subsequently donated to the New Mexico Museum of Natural History and became the nucleus of North America's largest collection of Permian trace fossils, which numbers nearly 2,000 catalogued slabs with traces. During the last decade, Museum scientists Adrian Hunt and Spencer Lucas, and Museum Research Associate Allan Lerner, have been very active in collecting and studying nonmarine (that is, continental) trace fossils, especially of Carboniferous, Permian and Triassic age, so that the Museum's trace fossil collection continues to grow in numbers and scientific importance.

Cleveland Museum of Natural History

Trace fossil collection

The Invertebrate Paleontology Collection of the Cleveland Museum of Natural History contains numerous invertebrate trace fossils, mostly from Ohio and nearby (but also not so nearby) states. This includes suites of figured and cited specimens from Ohio (e.g., Stukel 1987, Hannibal 1997), West Virginia (Bjerstedt 1989) and New Jersey (Gierlowski-Kordesch 1991). Most of the trace fossils are housed in metal cabinets. This collection is crowded, one reason being the large size of some trace fossils. The figured and cited specimens are segregated from the other trace fossils to make them more accessible. The Vertebrate Paleontology Collection contains a number of fossil footprints of dinosaurs, most from the Triassic of Massachusetts, but also a number of trackways from the Pennsylvanian of Ohio and the Permian of Arizona. Coprolites from various geological periods, including specimens from local Devonian rocks, as well as some Pennsylvanian, Permian and Triassic coprolites, are also included in the collection.

Trace fossil identification for the public

The Cleveland area is rich in trace fossils. The uppermost bedrock unit of much of northeastern Ohio is the Famennian Chagrin Shale, a rock unit in which trace fossils are, in most locales, more abundant than body fossils. Thus, trace fossils are some of the most common types of fossils brought to the Museum for identification. However, most are not originally identified as trace fossils by members of the public. They are typically identified as body fossils of plants or animals. The confusion with animals is understandable, as some forms do resemble animal imprints. *Planolites*, *Cochlichnus*? (Figure 1) and some other trace fossils may resemble a snake. Indeed, such a 'fossil snake' was included in an exhibit of rocks and fossils in one of J.T.H.'s elementary school classrooms. The confusion with plants is also understandable as, historically, many trace fossils were initially described as plants ('fucoids'). *Bifungites* is one taxon that has been brought in to the Museum several times as a fossil plant to be identified.

Figure 1. Sinusoidal invertebrate trace fossil *Cochlichnus*?, Cleveland Museum of Natural History (CMNH) 1314. Such elongate, sinuous ichnofossils are commonly confused with body fossils by the general public. Scale bar equals 10 mm.

One time was by a biology student whose professor at a local college insisted it was a plant!

Because trace fossils are not known to the general public, it typically takes some time to explain to the layperson exactly what it is that they have brought in for identification. Indeed, it helps to show them illustrations in a book that includes trace fossils, as some people find it difficult to change their opinion on something's identity despite the opinion of the museum curator. Feldmann and Hackathorn's *Fossils of Ohio* (1997) has been tremendously helpful in this regard.

'Fossil eggs' are a common type of pseudofossil brought in to the Museum for identification. These invariably turn out to be concretions, most derived from the Mississippian rocks exposed south of Cleveland. Some of these concretions have yellow clay interiors, making them appear even more egglike. Before they visit, some people call the Museum to ask if someone could look at their finds. These callers frequently identify the specimens as dinosaur eggs. Because Ohio has no Mesozoic rocks, we inform the people who call about 'dinosaur eggs' which they found in Ohio that they almost certainly do not have a dinosaur egg. Hope springs eternal, however, and almost all of those who call still come in—only to have their specimen identified as a concretion.

Trace fossils on exhibit

Trace fossils have been on exhibit for many years at the Cleveland Museum of Natural History. Most of these have been vertebrate footprints. The most prominent are two slabs of fossil tetrapod trackways, *Anomoeichnus ohioensis* Carman, 1927 (Figure 2), and *Baropus hainesi* Carman, 1927. They have been on exhibit in the Museum's Kirtland Hall, a gallery featuring fossils, for several decades. The slabs are on exhibit on a small island (about 80 cm high) immediately adjacent to a full-size reconstruction of a Pennsylvanian amphibian on a faux set of tracks (Figure 3). This exhibit has proved to be attractive. Children, and their parents, typically rub their hands over the reconstructed animal. Visitors were once able to do the same with the trackways. Parts of the trackways began to take on a polish over the years, however. Because the trackways are type material they were covered with plexiglass in the 1980s after a new curator recognized their importance. The trackways, however, have proved to be much hardier than the model, which has been damaged over the years and has had to be rehabilitated several times.

Several slabs of the famous Connecticut Valley dinosaur footprints are also on exhibit. Until a mounted *Coelophysis* was recently added to the gallery, these tracks were the only Triassic dinosaur fossils exhibited in the Museum. Currently, one large (97 by 173 cm) and several smaller slabs of footprints are on exhibit, and faux footprints are modelled into

Figure 2. The tetrapod trackway *Anomoeichnus ohioensis* Carman, 1927, CMNH 11899/Ohio State University 15329. The slab shown here is almost 170 cm long. The scale bar equals 0.5 m.

Figure 3. Oblique view of *Anomoeichnus ohioensis* (the same specimen seen in Figure 2), along with a reconstruction of the presumed trace maker, a tetrapod. The trackway *Baropus hainesi* Carman, 1927, is located behind *A. ohioensis* and the tetrapod model.

the base of a mounted *Allosaurus*. The Museum has also periodically placed dinosaur eggs on exhibit. These are placed in the permanent exhibit galleries or used to supplement traveling exhibits dealing with dinosaurs.

Invertebrate trace fossils have also been on exhibit for several decades, including a specimen misidentified as fossil plant material (some staff, apparently still members of the 'fucoid school', believing these to be of plant origin and refusing to let the label be changed). More recently, two ichnofossil specimens were integrated into exhibits in the Reinberger Hall of Earth and Planetary Exploration, which opened in autumn 1997 (Hannibal 1998a, b). These specimens were put on exhibit to illustrate the diversity of the fossil record, and to show examples of trace fossils that are encountered in the field and brought into the Museum for identification by the public. The trace fossil *Zoophycos* (Figure 4) was integrated into a time-line exhibit, and, like most of the specimens on the time line, is real and touchable. It is located on a tilted panel to make touching easier. A wall painting behind the *Zoophycos* specimen shows a cut-away view of the trace on the seafloor, together with contemporary marine organisms. The *Zoophycos* specimen is preserved in siltstone and the raised striae of the specimen have been polished some since being put on exhibit, but it has held up well over eight years. And no one seems to have tried to pry it up and purloin it as they have with touchable trilobites along the same time line!

Another trace, *Cochlichnus*?, found in the local Chagrin Shale, is located in another part of Reinberger Hall alongside a composite core and a faux rock wall representing Ohio's rocks. The specimen is placed high up and in correct stratigraphical position, next to the Upper Devonian part of the core. Several Mississippian concretions, similar to those that many people bring in to the Museum as supposed fossil

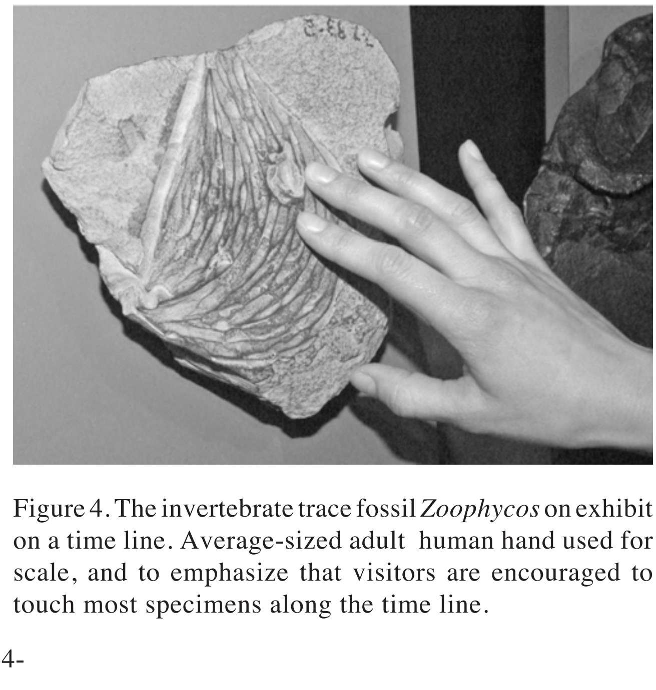

Figure 4. The invertebrate trace fossil *Zoophycos* on exhibit on a time line. Average-sized adult human hand used for scale, and to emphasize that visitors are encouraged to touch most specimens along the time line.

eggs, are displayed just above, next to the Mississippian core. The core is near a 'rock video' monitor which uses songs with catchy lyrics to explain that Ohio is not like it used to be in the prehistoric past (Hannibal 1998a). The songs and accompanying video do not include a discussion of trace fossils, but they do provide context for Ohio's fossils.

The Museum's Smead Discovery Center is a large room designed for young people to visit in order to examine and, when appropriate, play with materials. It contains one real dinosaur foot impression, a large specimen that was placed there because it had no accompanying data and was not scientifically important. Several replicas of dinosaur trackways are also included in this hands-on area. Dinosaur footprints also appear on a bronze sundial, designed by sculptor Walter Matia in 2004. The sundial, representing the evolution of life over time, is located outside of the Museum.

Trace fossils and urban field trips

Trace fossils have been part of field trips and classes for the general public, teachers and students at the Cleveland Museum of Natural History for many years. Trace fossils are readily encountered in visits to local stream outcrops. In the urban setting, trace fossils are also encountered in slabs of the Lower Carboniferous Salem Limestone, which is also known by the commercial name of Indiana limestone, as it has long been quarried in south-central Indiana. The most visually striking of these urban ichnofossils is '*Margaritichnus*', an elongate form marked in part with partitions. This trace fossil, noted by other designations, including worm castings (Shrock 1935), has long been known from the Salem Limestone. '*Margaritichnus*' is found in stone used for a number of buildings in Cleveland, including Saint John's Cathedral downtown and, closer to the Museum, the Veteran's Administration Hospital and buildings on the Case Western Reserve University campus (Hannibal and Schmidt 1991, figure 2). The ichnofossil is also found in Indiana limestone used for structures in many other cities in the United States.

New Mexico Museum of Natural History and Science

Trace fossil collection

As noted above, the New Mexico Museum of Natural History and Science (NMMNH) houses North America's most extensive collection of Permian vertebrate footprints (Figure 5). This collection has been extensively documented (see articles in Lucas and Heckert 1995, Lucas *et al*. 2005). Numerous invertebrate trackways and other traces of Permian age are also part of this collection. Furthermore, the Museum has a large collection of Triassic vertebrate tracks (Figures 6, 7) and invertebrate trails from New Mexico, as well as smaller collections of Jurassic, Cretaceous and Cenozoic vertebrate and invertebrate traces from New Mexico. The emphasis of the collection is on nonmarine trace fossils from fluvial and lacustrine palaeoenvironments. The traces are housed on open shelving in an approximately 1,000 square-foot area within the Museum's Geoscience Collection. However, plans are underway to move the collection into a newly remodelled, larger space, so that the trace fossil collection will have its own separate area with much room for expansion. The Museum also has large holdings of Permian and Triassic vertebrate coprolites (fossil faeces) (Hunt *et al*. 1998). The coprolites are housed in metal cabinets together with other fossils, mostly bones and teeth, from the same or nearby sites.

Figure 5. A characteristic Early Permian vertebrate footprint from New Mexico, NMMNH P-2459, assigned to *Ichniotherium*, the track of a diadectomorph 'amphibian'. Scale is in centimetres.

Figure 6. A typical Late Triassic dinosaur footprint from near Tucumcari, New Mexico, NMMNH P-44218, assigned to *Grallator*, the track of a small theropod. Scale is in centimetres.

Figure 7. *Brachychirotherium* (probably aetosaur) tracks from Upper Triassic Redonda Formation near Tucumcari, New Mexico, NMMNH P-44193. Scale is in centimetres.

Trace fossil identification for the public

The geology of New Mexico is diverse, with rocks of virtually every time period since the Proterozoic exposed at the surface in some part of the state. This, and the arid and rugged landscape, make fossil discovery by members of the public common.

Each year, New Mexico residents bring hundreds of fossils and would-be fossils that they have found to the NMMNH to be identified. Many of these objects are concretions or other rounded rocks thought to be dinosaur eggs. Only once has an actual dinosaur egg been brought to the Museum, in 1995, when a father came in with his three-year-old son who had picked up pieces of Jurassic dinosaur eggshell on a hike west of Albuquerque, New Mexico. Only a few kinds of trace fossils are usually brought in by members of the public, mostly crustacean burrows assigned to *Ophiomorpha* and *Thalassinoides*, which are common in Cretaceous shoreline sandstones in northern New Mexico.

Trace fossils on exhibit

Several Museum exhibits, past, present and planned, have or will feature trace fossils. An exhibit devoted to the Robledo Mountains Permian footprints ran for about a decade and was recently dismantled. The Museum will open a Triassic Hall in 2007, and Late Triassic tracks of dinosaurs and other archosaurs from the Tucumcari area in eastern New Mexico (Figures 6-7) will be featured. The fragments of dinosaur eggshell, found by the three-year-old boy just west of Albuquerque (Bray and Lucas 1997), are now on display in the Museum's renovated Jurassic Hall, which opened in August 2004. The Museum's Cretaceous exhibit, called 'New Mexico's seacoast', begins with the world-famous dinosaur tracks from a 100-million year old seashore now exposed at Clayton Lake State Park in northeastern New Mexico (Figure 8). These are mostly tracks of early ornithopod dinosaurs that browsed vegetation along the Early Cretaceous coastline (Lockley *et al*. 2000).

In the summer of 2004, a large trackway belonging to the ichnospecies *Diplichnites cuithensis* was discovered in Upper Pennsylvanian strata in a rugged, remote canyon in northern New Mexico (Lucas *et al*. 2005a). This trackway is attributable to the gigantic myriapod *Arthropleura*. The specimen, preserved on a thick bed of sandstone, was loaded onto a truck and transported to the New Mexico Museum of Natural History and Science in the spring of 2005. The Museum also purchased a life-size plastic model of *Arthropleura* to accompany the trace fossil. Most very large specimens of *Diplichnites cuithensis* are known from field localities, and only casts or replicas

Figure 8. This Early Cretaceous track surface at Clayton Lake, New Mexico, preserves more than 800 individual footprints, mostly of ornithopod dinosaurs, assigned to *Caririchnium*. Hammer is 280 mm long.

of large arthropod trackways are typically placed on exhibit. An exception to this is the huge Mississippian arthropod (?eurypterid) trackway described by Briggs and Rolfe (1983) that was formerly on exhibit at the Carnegie Museum of Natural History for many years. The exhibit at the New Mexico Museum of Natural History and Science (Figure 9) features the actual trackway and the model of *Arthropleura*. This exhibit is slated to become a permanent part of the Museum's new Paleozoic Hall, planned to open in 2009.

Figure 9. Exhibit in the New Mexico Museum of Natural History and Science of a plastic model of the giant millipede-like myriapod *Arthropleura*, NMMNH C-4635, on an actual arthropleurid trackway, NMMNH P-45287, collected in northern New Mexico. The trackway, from northern New Mexico, is a little more than 2 m long and its width ranges from 320 to 380 mm. It is assigned to the ichnospecies *Diplichnites cuithensis* Briggs, Rolfe and Brannan, 1979.

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