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Chirotherium barthii Kaup 1835 from the Triassic of the Isle of Arran, Scotland

CLARK, N.D.L.[1] ASPEN, P. [2] and CORRANCE, H. [3]

1. Hunterian Museum, University of Glasgow, University Avenue, GLASGOW, G12 8QQ
2. Department of Geology and Geophysics, University of Edinburgh, West Mains Road, EDINBURGH, EH9 3HT

[3.] 36 Bensley Avenue, Girdle Toll, IRVINE, KA11 1A5

ABSTRACT

The mould of a track from southern Arran, and several *in situ* trackways and individual tracks, as well as a partial trackway on a loose block of sandstone, from western Arran, represent the first verifiable fossil tracks of *Chirotherium* from the Triassic of Scotland and supports a Scythian (Lower Triassic) age for the base of the Auchenhew Beds. The grouping of the I-IV toes with toe V behind and lateral to the group is characteristic of *Chirotherium*-like tracks. A comparison with European and American Triassic trackways suggests that the tracks belong to the species *C. barthii* Kaup, 1835 first described from Hildburghausen, Germany.

INTRODUCTION

Carboniferous, Permian and Jurassic tracks and trackways are well known from the rocks of Scotland (Clark 2001, Clark and Jewkes 2000, Clark and Barco Rodriguez 1998, Hopkins 1999, McKeever 1994, McKeever and Haubold 1996). Tracks from the Triassic are, however, poorly represented in Scotland despite a number of tetrapod remains being found from the Lower Norian Lossiemouth Sandstone Formation (Benton and Walker 1985). Trackways from the Hopeman Sandstone Formation and the Cutties' Hillock Sandstone Formation of Morayshire were previously considered to be Triassic, but are now thought to be uppermost Permian in age (Clark 1999, Hopkins 1999).

It was in 1850 that Harkness (1850a, b) mentioned the existence of "footsteps of *Chirotherium* in relief" primarily from Corse Hill Quarry, Annan, Dumfriesshire. As there is a lack of any description or illustrations of these footprints noted by Harkness, and as the tracks are now lost, it is impossible to substantiate the claim of *Chirotherium* from the Triassic of Dumfriesshire. More recently, Delair (1969) provides us with the first description of poorly preserved Scottish Triassic tracks. These tracks, which were found by two schoolboys near Violet Bank, Annan, were presented to the Dumfries Museum, Dumfries, and subsequently named *Delairichnus annanensis* by Haubold (1971a). Since then, no report of Scottish Triassic tracks has been noted in the literature except for one record of "the fossil footprint of a large reptile (dinosaur?)" (McKerrow and Atkins 1985, p80) from the Triassic of south-eastern Arran on Levencorroch Hill. This specimen, now in the collections of Oxford University Museum, is described here and is the first verifiable record of *Chirotherium* from Scotland. The catalogue entry for this specimen (OUM (Oxford University Museum) G.53) indicates that it had been identified by M. King in 1992 as the left pes of *Chirotherium*. Other tracks on a loose block at the foot of a waterfall in the old sea cliffs 300m NE of Cleiteadh nan Sgarbh in western Arran NW of Blackwaterfoot (discovered by PA in 1993), form part of a trackway, consisting of two pedes and two manus (excursion 4, locality 12 of McKerrow and Atkins 1985). Since these discoveries, three *in situ* trackways and a number of individual tracks, giving a total of 36 tracks, were discovered about 400 metres north of Cleiteadh nan Sgarbh in August and November 2001 (figure 1). These occurrences of *Chirotherium* are described here.

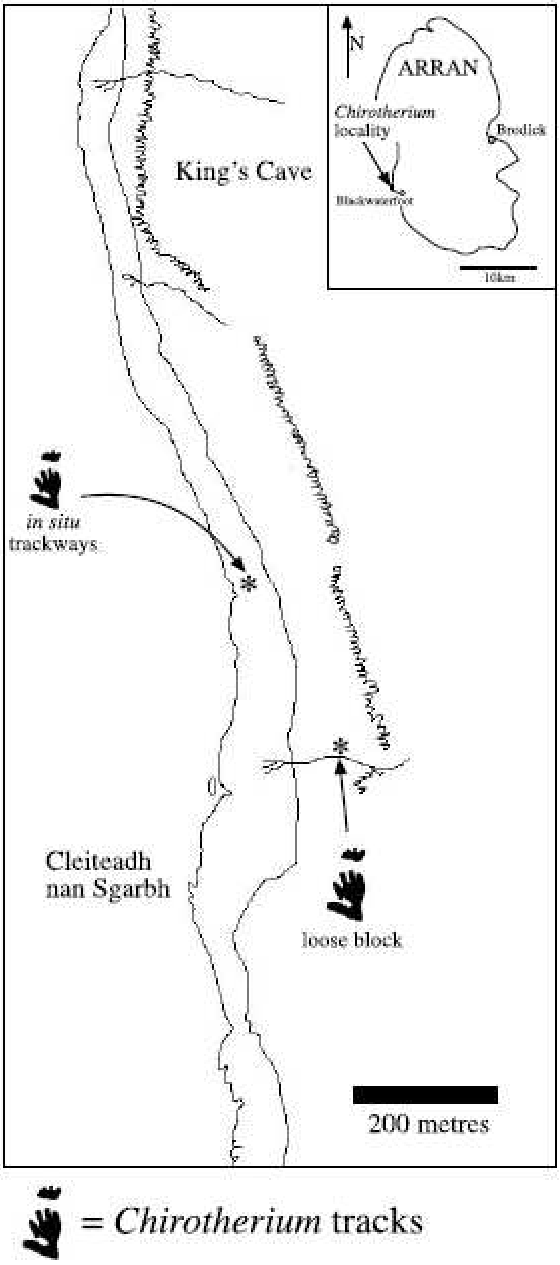

Figure 1. Map of the west of Arran immediately northwest of Blackwaterfoot showing the location of the Triassic tetrapod tracks and trackways.

SETTING

The Triassic rocks on Arran are divided into two main units; the Auchenhew Beds, and below them the Lamlash Beds. The older Lamlash Beds consist mostly of fluvial and aeolian sands with occasional caliche horizons (Pollard and Lovell 1976). It is from the younger Auchenhew Beds that trace fossils were first discovered in 1973 (Lovell 1981, Pollard and Lovell 1976, Pollard and Steel 1978, 1981). These consist of trace forms cf. "*Siphonites*", cf. *Cylindricum* and epichnial burrows produced by ephemeral invertebrates in shallow fluvial-lacustrine sediments. Occasional occurrence of halite pseudomorphs in these beds indicates a continuation of arid conditions into the Auchenhew Beds and perhaps a marine influence prior to the onset of the fully marine Rhaetic sediments above (Lovell 1981, Pollard and Steel 1978, 1981). The tracks are all from the Auchenhew Beds and probably from a horizon above the level from which the miospore assemblage was obtained by Warrington (1973), but the precise horizons from which the loose blocks were derived has not been determined. The age of the base of the Auchenhew Beds has been constrained by miospores to the late Scythian to Anisian (late Early to early Middle Triassic) (Warrington 1973). The existence of dinoflagellate-like acritarchs from the Auchenhew Beds suggests a marine influence but does not preclude a non-marine environment of deposition as there are fresh to brackish water dinoflagellate species recorded in the fossil record (Warrington 1973, Mao *et al.* 1999).

The *in situ* trackways occur in a 35cm thick brown medium-grained sandstone with two ripple-laminated levels (figure 2). Trackways I and II are found 3cm above the lower rippled surface, and trackway III was found 3cm above the upper rippled surface (which is 15cm above the lower rippled surface). The symmetrical ripples of the lower surface indicate a NE-SW flow orientation, whereas the upper surface symmetrical ripples suggest a NW-SE flow orientation.The top of the sandstone unit, which is equivalent to the top of bed D of Pollard and Steel (1978), has desiccation cracks and is about 60 cm above a horizon containing halite pseudomorphs. This has been interpreted as having been deposited in either a flood plain lake or a tidal flat area (Pollard and Steel 1978). The *Chirotherium* tracks occur at the top of unit D. Halite pseudomorphs have been previously recorded from the *Chirotherium*-bearing sediments of the Moenkopi Formation in Arizona, USA (Peabody 1948). The depositional environment of the Moenkopi Formation is interpreted as resulting from deposition in a standing body of brackish water with high evaporation. Most of the *Chirotherium* trackways are associated with dried and cracked mudflats related to fluvial deposition (Peabody 1948). The surfaces containing the tracks on the foreshore at Cleiteadh nan Sgarbh are associated with desiccation cracks as well as southward directed fluvial currents (Pollard and Steel 1978). The top 5cm of the red siltstone immediately below the track-bearing sandstone is discoloured to a grey-blue colouration and contains calcareous nodules and centimetre diameter quartz pebbles. This with the symmetrical ripples is suggestive of a similar depositional environment to that found in the Moenkopi Formation of Arizona.

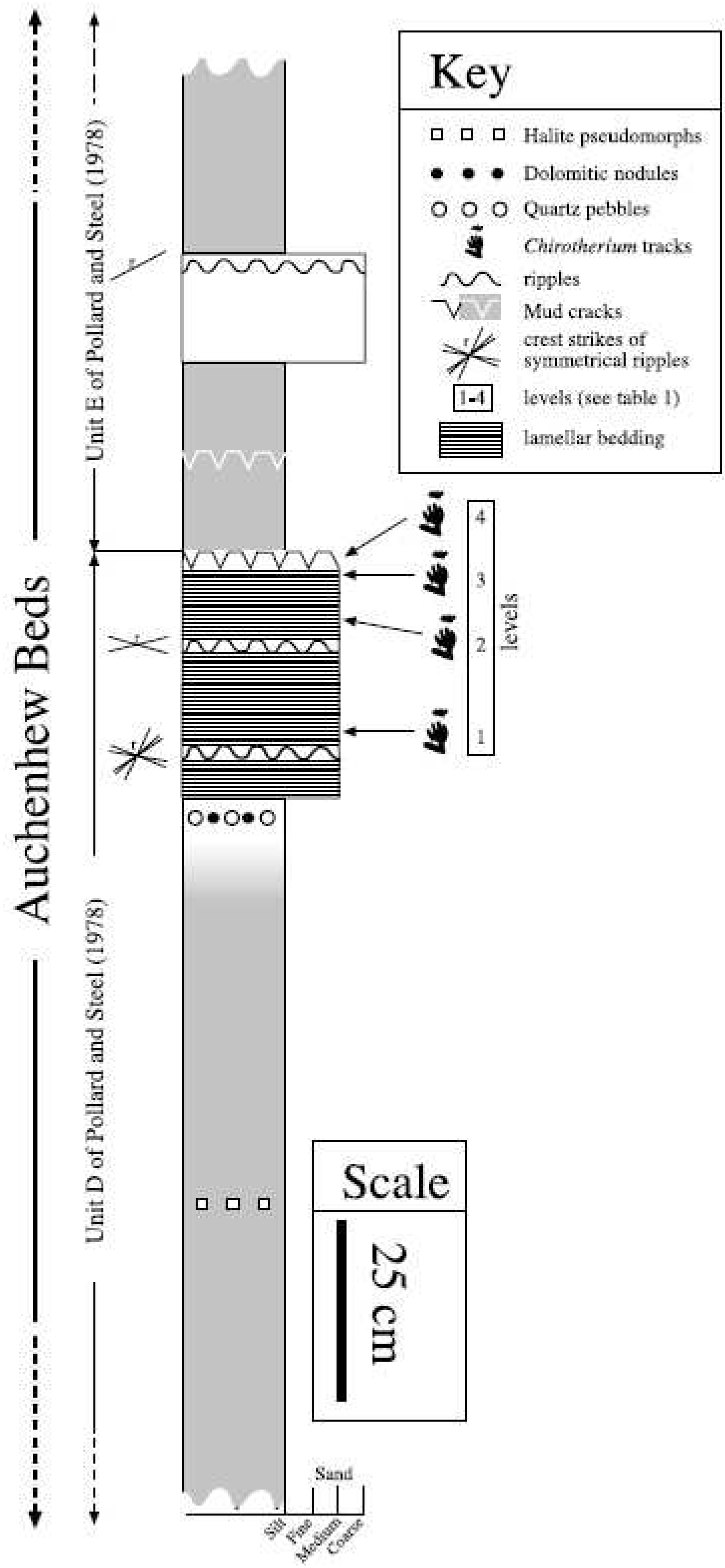

Figure 2. Stratigraphy and sedimentary features of the section of foreshore near Cleiteadh nan Sgarbh which contains the chirotheroid impressions.

METHOD

A silicone rubber mould of the tracks near King's Cave, western Arran, was used to make a cast of the tracks for the collections of the Hunterian Museum, Glasgow (GLAHM 114737). Silicone rubber T28

(15kg) with T6 catalyst, thixotropic additive, TW catalyst booster, heavy chopped strand mat glass fibre, and DP100 release agent (Tiranti) were used to produce a fast curing and rigid rubber mould. The T6 catalyst was mixed with the TW catalyst booster in a 5:1 ratio by weight for a cure time of about one hour. The catalyst mixture was mixed with the T28 rubber and the thixotropic additive was added until the rubber was thick enough to adhere to the near vertical sandstone block without slippage. This gave a working time of about half an hour. The sandstone containing the tracks was sprayed with the DP 100 release agent to prevent tears in the rubber on removal. The mould was used for photography and making a replica cast for the collections at the Hunterian Museum.

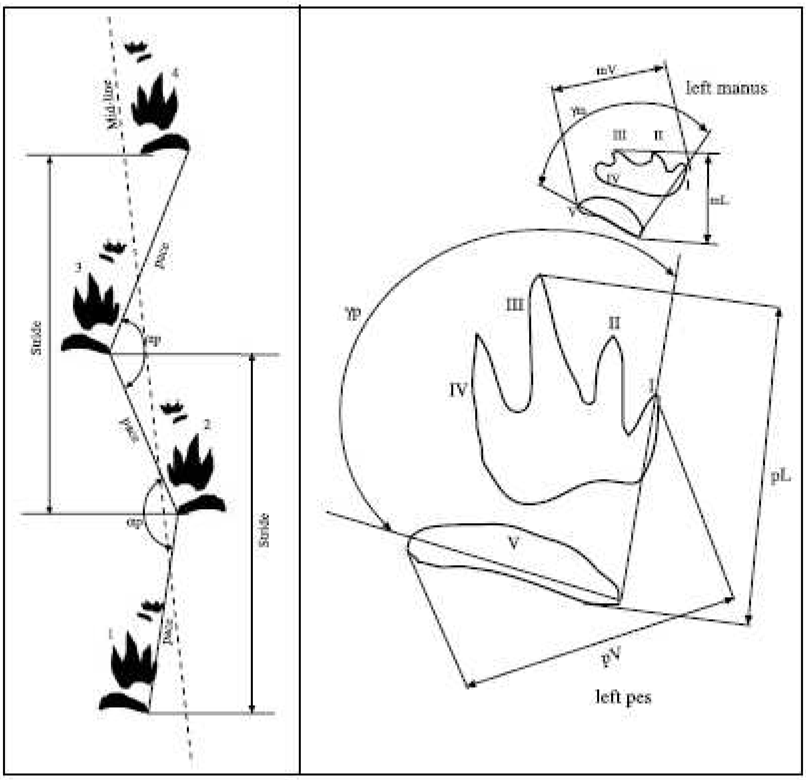

Figure 3. Scheme used for the measurements of the tracks and trackways after Peabody (1948), Haubold (1969, 1971a, b), and Karl and Haubold (1998).

Measurements of the *in situ* trackways (figure 3, table 1) were taken following the scheme of Peabody (1948) and Haubold (1969, 1971a, b) as preservation allowed, and more detailed analysis of the better preserved tracks follows the scheme of Karl and Haubold (1998).

DESCRIPTION

The specimen (OUM G.53) from Levencorroch Hill was collected in 1980 by Guy Plint and later donated to the Oxford University Museum by Brian Atkins (H. P. Powell *pers. comm.).* It is a relief cast of the left pes and includes digit V (figure 4). The anterior tips of the digits are broken making it difficult to compare their relative lengths crucial in specific diagnosis. Digit V is angled laterally to digits I-IV as is characteristic of chirotheroid tracks. A tentative identification of *Chirotherium* cf. *barthii* is based on digit III appearing to be longer than the other digits I-IV, and digit IV the next longest.

Figure 4. Single track from Levencorroch (OUM G.53); X0.3.

The better preserved pes of the trackway from near King's Cave, western Arran (figure 5, 6c), has the characteristic longer III digit with digits IV and II being shorter respectively (table 1). The relative lengths of the digits and the total length of the pes is consistent with the identification of *C. barthii* for this trackway. The preservation of the tracks from the four trackways (figures 6a, b, d; 7a-i, k-l) is very poor due to erosion by the sea and bioerosion. Despite the poor preservation, it is still possible in some tracks to see that digit III is longer than the other digits and that digit V is angled laterally to digits I-IV (figure 7 a-i, k-l). The largest tracks with an apparent pL of up to 400mm are much larger than any previous record of *C. barthii*. The measured length of these tracks of trackway IV may be long due to a mounding displacement of the sand around the impression (figure 7l). This would give a false measurement for pL and pV although the pace and stride lengths are not longer than for the other trackways on Arran (Table 1). This would suggest that the use of pL and pV in species determination in poorly preserved tracks of *Chirotherium* are unreliable as the sediment displacement may distort the true values.

Trackway number	Track number	Stride	Pace	pL	pV	p	p	pes direction	mL	mV	stride:pL ratio	Level
[1]	1	x	650	280	175	x	080	050	x	x	x	1
[1]	2	x	-	260	(165)	x	(090)	072	x	x	x	1
	3	x	x	330	230	x	088	338	x	x	x	1
[2]	4	x	620	260	(190)	x	082	262	80	120	x	1
[2]	5	x	-	260	(190)	x	(090)	270	x	x	x	1
IV	6	-	x	350	260	x	084	120	x	x	x	4
IV	7	1056	-	390	320	115	080	150	x	x	1:2.9	4
IV	36	1542	840	300	x	130	x	(124)	x	x	1:4.2	4
IV	8	1539	720	400	240	116	082	142	x	x	1:4.2	4
IV	9	-	850	400	280	-	x	128	x	x	x	4
IV	37	x	-	x	x	x	x	x	x	x	x	4
IV	38	x	x	x	x	x	x	x	x	x	x	4
[3]	10	x	540	250	160	x	080	058	x	x	x	1
[3]	11	x	-	260	130	x	080	040	x	x	x	1
III	12	-	-	300	(160)	-	082	(320)	x	x	x	2
III	13	1040	580	-	(170)	(178)	092	-	x	x	1:3.7	2
III	14	1054	550	270	180	(168)	104	(318)	x	x	1:3.8	2
III	15	1030	520	250	210	164	090	-	x	x	1:3.7	2
III	16	1184	680	280	x	162	x	350	x	x	1:4.2	2
III	17	-	-	290	x	-	x	324	x	x	x	2
III	18	x	x	(160)	x	x	x	352	x	x	x	2
([4])	19	x	(104)	320	215	x	085	212	x	x	x	3
([4])	20	x	-	(340)	(240)	x	x	212	x	x	x	3
[5]	21	x	540	330	250	x	082	264	x	x	x	1
[5]	22	x	-	320	210	x	082	230	x	x	x	1
I	23	-	840	290	x	-	x	280	x	x	x	1
I	24	1382	560	250	x	170	x	270	x	x	1:5.1	1
I	25	1396	850	280	220	170	073	280	x	x	1:5.1	1
I	26	1756	920	290	240	178	080	278	x	x	1:6.4	1
I	27	1768	870	250	245	162	080	296	x	x	1:6.5	1
I	28	-	-	280	x	-	x	-	x	x	x	1
	29	x		390	x	x	x	328	x	x	x	1
II	30	-	-	280	x	-	x	050	x	x	x	1
II	31	1008	520	260	(170)	162	x	068	x	x	1:3.6	1
II	32	1024	500	280	240	148	075	036	x	x	1:3.6	1
II	33	1034	570	290	235	162	075	070	x	x	1:3.7	1
II	34	-	520	300	240	-	060	-	x	x	x	1
	35	x	x	290	190	x	086	030	x	x	x	2
Levencorroch		x	x	250	212	x	080	x	x	x	x	?
Old sea-cliff	1	x	600	240	x	x	x	x	x	80	x	?
Old sea-cliff	2	x	-	255	137	x	069	x	137	70	x	?

Table 1. Data obtained from tracks near Cleiteadh nan Sgarbh and Levencorroch (all length measurements in mm where applicable; [1-5] = two tracks of same trackway; I-IV = multiple track trackways; - = na; x = not measured; ( ) = best estimate or incomplete track; for the stride:pL ratio, the mean pL for that trackway is used; m was not measured due to the poor preservation of the manus).

The manus is not well preserved in most tracks and has only been measured in three cases. The best preserved manus being that of track 4 (figure 7k, table 1) with a mL of 80mm and a mV of 120mm. Again the uncertainty of the accuracy of these measurements make it difficult for useful comparison with other species although the measurements do fall into the size range for *C. barthii* and *Isochirotherium herculis* (Haubold 1969).

The pace angulation (p) of 115-178 for the Arran trackways is close to 170, and the stride:pL ratio of 4.3:1 is close to the value of 5:1 used in the diagnosis for *C. barthii* suggested by Peabody (1948) (Haubold 1971b). For the same features, the diagnostic values used for *I. herculis* are 140-160 and 4.5:1 respectively. The only real difference between *C. barthii* and *I. herculis*, other than in the relative lengths of the pes digits, is in the length of the foot (pL) which is 250mm or less in *C. barthii* and over 300mm in *I. herculis* (Peabody 1948, Haubold 1971b).

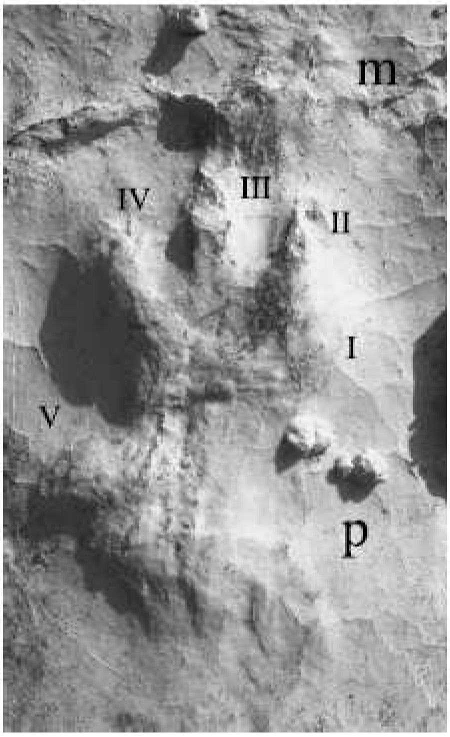

Figure 5. Single track from the loose block on the old sea-cliffs (loose block 2 of table 1) (GLAHM 114737). p = pes; m = manus; digits = I-V on pes; X0.3.

	mean pL	mean stride	mean pace	stride:pL
Arran	295	1272	634	4.3
Moenkopi	180	1010	510	5.6
Hildburghausen	207	1116	567	5.4

Table 2. Comparison between means of track data for *C. barthii* from Arran (this study), Moenkopi (Peabody 1948, N=2), and Hildburghausen (Haubold 1971b, N=15).

The track from Levencorroch and many of the tracks from trackways 1 (figure 7b) and 3 (figure 7d-h) are relief tracks. The other tracks from the loose block (figure 5) and trackways1 (figure 7a, c) and 2 (figure 7i) that appear as imprints are likely to be undertracks as these occur where the relief tracks have been removed. The trackway surface is therefore at the top of, or above, the relief tracks. This may account for the poor preservation of, or lack of, the manus imprints as the force applied to the manus was less than that of the pedes and so would not transmit as well. In the Levencorroch track, the anterior portion of digit IV shows distinct parallel striae that appear to have been caused by claw marks as it descended through the sediment (figure 7j).

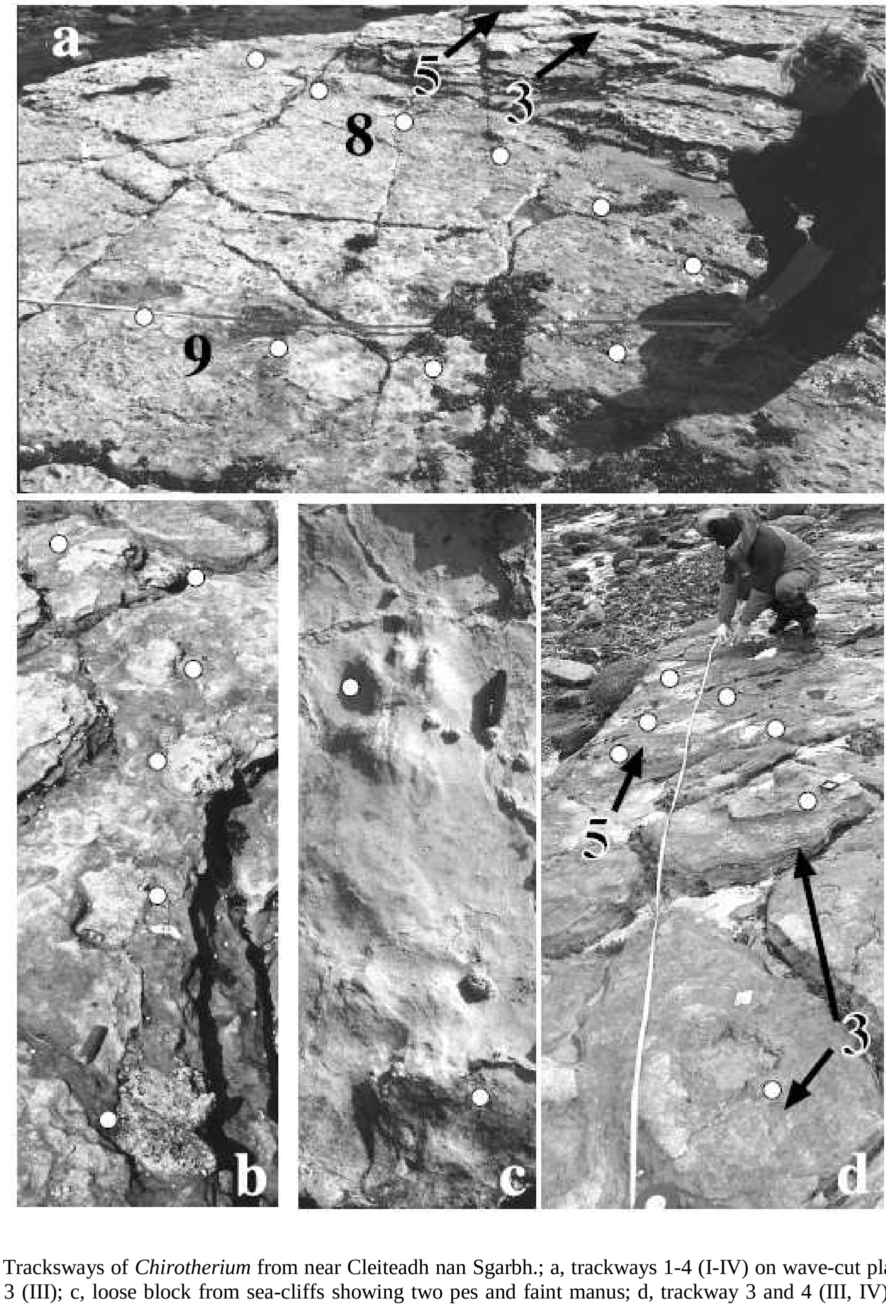

Figure 6. Tracksways of *Chirotherium* from near Cleiteadh nan Sgarbh.; a, trackways 1-4 (I-IV) on wave-cut platform; b, trackway 3 (III); c, loose block from sea-cliffs showing two pes and faint manus; d, trackway 3 and 4 (III, IV). Circles mark position of individual pes positions (pen-knife in b and c is 9cm long).

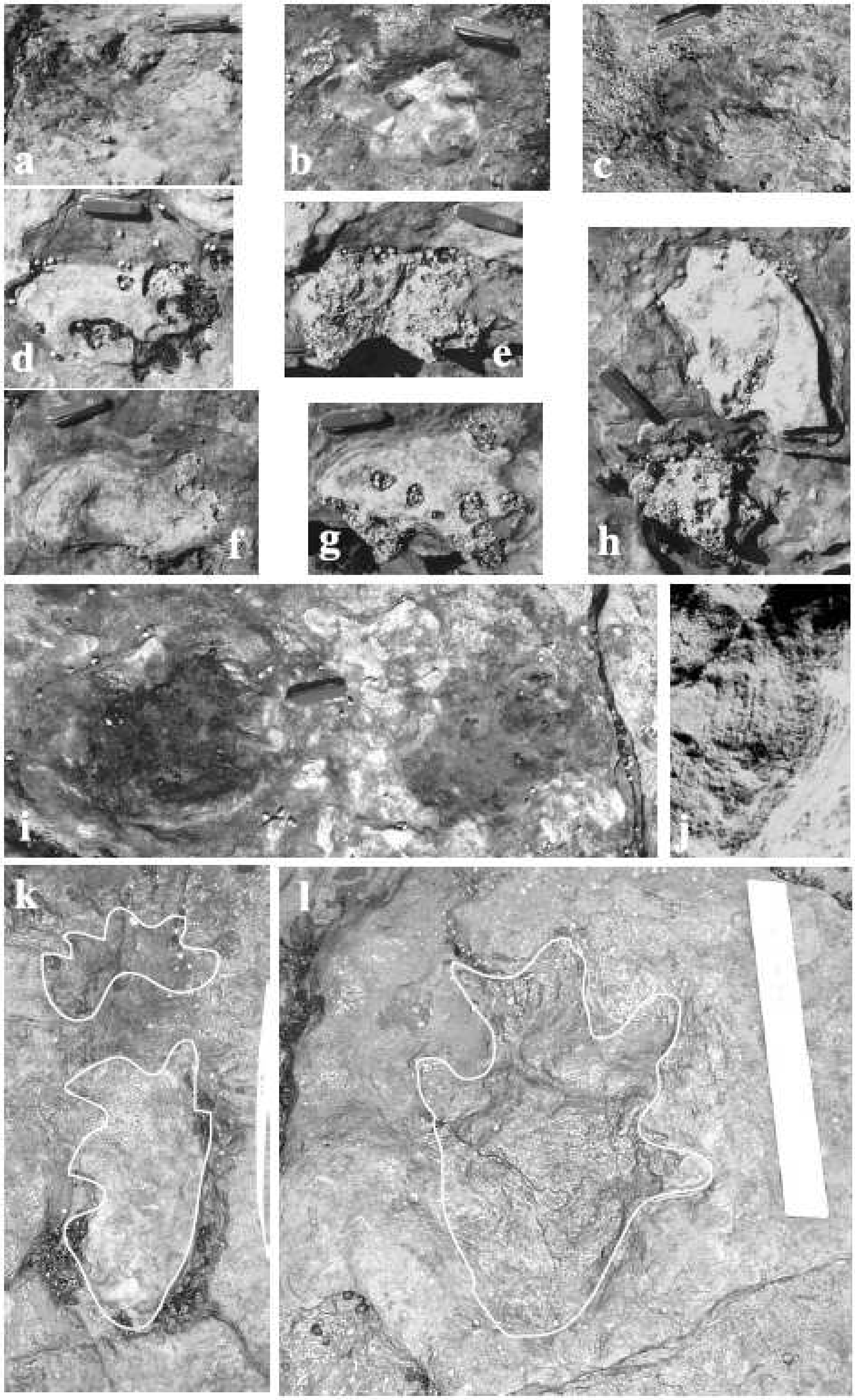

Figure 7. Individual pes tracks from trackways showing variation in preservation. a-c, from trackway 1 (I); d-h, from trackway 3 (III); i, from trackway 2 (II); j, the anterior of digit IV of the Levencorroch specimen (OUM G 53) showing ?scratch striae (X0.9); k, track 4 showing pes and manus outlined (X0.22; table 1); l, track 7 from trackway 4 outlined (X0.20; IV, table 1). All X0.14 except where otherwise stated.

C. barthii is a relatively widespread form of *Chirotherium* having been found in England as *C. stortonense* (now considered to be *C. barthii* (Haubold 1971b, Tresise and Sarjeant 1997)); Arizona, USA (Peabody 1948); Argentina as *C. higuerensis* (see Peabody 1955); Spain, France and Germany (Haubold 1971b). The data provided by Haubold (1971b) from the type locality at Hilburghausen, and also from Arizona (Peabody 1948), suggest that *C. barthii* has a shorter pes than the Arran specimens although the strides and paces are of the same order (table 2). Very few chirotheroids have a similarly long pes length. *Isochirotherium herculis, C. moquiensis* and *C. rex* all have pes lengths of about 300mm (Haubold 1971a, b, Peabody 1948). The tracks from Arran are not *Isochirotherium* due to toe III being the longest and toes II and IV being subequal in length. These lengths are characteristic of *C. barthii* although the pes length is much greater than the maximum length of 250mm quoted by Peabody (1948) in his diagnosis for that species. The claw marks on the Arran specimens are triangular like *C. moquienesis* rather than the spatulate like claw marks described by Peabody (1948) of *C. rex*. However, the Arran specimen differs from *C. moquienesis* in that the row of metatarsal-phalangeal joints form a transverse arch similar to that seen in *C. barthii*.

Beasley's A1 form was synonymised with *C. barthii* by Haubold (1971b) and it has been suggested by King and Thompson (2000) that Beasley's A2 form may also be *C. barthii*. Beasley himself had doubts over the validity of his A2, A3 and K forms (Tresise and Sarjeant 1997) although the A3 forms have since been given the ichnospecies name *Isochirotherium herculis* (Edgerton 1839).Although the Arran tracks are longer than the diagnostic value of pL, it is considered that the pes length is less conservative than the relative lengths of the digits. It is therefore considered that the Arran tracks represent large examples of *C. barthii* rather than *I. herculis*.

REGIONAL CORRELATION

Gregory (1915) placed the Levencorroch marls at the base of the Keuper (Middle Triassic) and the Auchenhew shales and sandstones in the Bunter Formation (Lower Triassic). This was supported by the work of Tyrrell (1928), and Craig (1965) adapted this to form the tripartate scheme of Lamalash Beds, Auchenhew Beds and Rhaetian black mudstone. The dating of the base of the Auchenhew Beds by Warrington (1973) to the late Scythian or Anisian age, is slightly younger than the age suggested by Gregory (1915). Lovell (1983) placed the horizons from which the trace fossils were studied (Pollard and Lovell 1976, Lovell 1981, Pollard and Steel 1978, 1981) at about the same level as the miospore assemblage studied by Warrington (1976). The base of the Mercia Mudstone Group in Arran may be isochronous with part of the Sherwood Sandstone Group in the Vale of Eden and Solway Firth (Lovell 1983). This is consistent with a northward migration of the St Bees Sandstone Formation (Jones and Ambrose 1994, Holliday *et al.* 2001). Correlation between the Triassic basins of Scotland, England and Ireland is very difficult due to the range in thicknesses and lack of continuity of lithological units (Taylor *et al.* 1971), however, Lovell (1983) showed the Rathlin, Arran and Ulster Basins as being interconnected. Some attempts have been made to correlate the Triassic of southern Scotland with the Cumberland rocks (Greig 1971, Horne and Gregory 1916), the latest being the study by Holliday *et al.* (2001) who proposed that a gamma-ray log high at the base of their ES3 unit (Eden Shale Formation) may be a useful chronostratigraphic marker to correlate as far as the East Irish Sea and North Sea. In Cumbria it appears as though this marker is close to the base of the St Bees Sandstone Formation. The Annanlea and Warmanbie Sandstones can be correlated with the St Bees Sandstone Formation of northern England (Horne and Gregory 1916) the top of which may be synchronous with part of the base of the Mercia Mudstone Group as represented on Arran. It is also possible, therefore, that the occurrence of tracks on Arran is approximately synchronous with the top of the Sherwood Sandstone Group of the Cheshire Basin as shown in Lovell (1983). Lower Triassic tracks are rare from the Cheshire Basin and East Irish Sea Basin although chirotheroid tracks are known from both these basins including possible examples of *C. barthii* (King and Thompson 2000). A chirotheroid track is also known from rocks of similar age from the top of the Sherwood Sandstone Formation of Scrabo, Northern Ireland (Buckman *et al.* 1998).

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REFERENCES

BENTON, M.J. and WALKER, A.D. 1985. Palaeoecology, taphonomy, and dating of Permo-Triassic reptiles from Elgin, North-East Scotland. *Palaeontology* **28,** 207-234.

BUCKMAN, J.O., DOUGHTY, P.S., BENTON, M.J. and JERAM, A.J. 1998. Palaeoenvironmental interpretation of the Triassic sandstones of Scrabo, County Down, Northern Ireland: ichnological and sedimentological studies indicating a mixed fluviatile-aeolian succession. *Irish Jour Earth Sciences.* **16,** 85-102.

CLARK, N.D.L. 1999. The Elgin Marvels (part 2). *Open University Geological Society Journal*. **20,** 1-3.

CLARK, N.D.L. 2001. Dinosaur tracks, helicopters, and broken bones. *Geological Curator*. **7,** 163-166.

CLARK, N.D.L. and BARCO RODRIGUEZ, J.L. 1998. The first dinosaur trackway from the Valtos Sandstone Formation (Bathonian, Jurassic) of the Isle of Skye, Scotland. *Geogaceta* **24,** 79-82.

CLARK, N.D.L. and JEWKES, M. 2000. Tetrapod trackways (*Matthewichnus* sp. and ?*Pseudobradypus* sp.) from the Coal Measures (Carboniferous) of Central Scotland. *Scottish Journal of Geology* **36,** 87-90.

CRAIG, G.Y. 1965. Permian and Triassic. *In* G. Y. Craig (ed.), *The Geology of Scotland*. Oliver and Boyd, Edinburgh, 383-400.

DELAIR, J. B. 1969. Preliminary notice of vertebrate footprints from the Trias of Dumfries-shire, in Addenda Antiquaria. *Trans Dumfries Galloway Nat Hist Antiq Soc* series 3. **46,** 178-179.

GREGORY, J.W. 1915. The Permian and Triassic rocks of Arran. *Trans Geol Soc Glasgow.* **15,** 174-87.

GREIG, D.C. 1971. The South of Scotland (3rd edition). *British Regional Geology*, HMSO, Edinburgh. 125pp.

HARKNESS, R. 1850a. On the New Red Sandstone of the southern portion of the Valley of the Nith. *Quart. Journal Geol Soc London*. **G,** 389-99.

HARKNESS, R. 1850b. On the position of the impressions of footsteps in the Bunter Sandstone of Dumfries-shire. *Ann Mag Nat Hist* series 2. **6,** 203-208.

HAUBOLD, H. 1969. *Chirotherium*-Fährten aus dem Buntsandstein im "Mauritianum" in Altenburg. *Abhandlungen u. Berlin Naturkundliche Museum "Mauritianum" Altenburg.* 21-36.

HAUBOLD, H. 1971a. Ichnia Amphibiorum et Reptiliorum fossilium. *In* KUHN, O. (ed.) *Encyclopedia of Paleoherpetology*. **Part 18**, Gustav Fischer Verlag, Stüttgart and Portland, USA. 124pp

HAUBOLD, H. 1971b. Die tetrapodenfährten des Buntsadsteins in der Deutschen Demokratischen Republik und in Westdeutschland und ihre Äquivalente in der gesamten Trias. *Paläontologische Abhandlungen, Ab A.* **4** (3)**,** 397-548.

HOLLIDAY, D.W., WARRINGTON, G., BROOKFIELD, M.E., MCMILLAN, A.A. and HOLLOWAY, S. 2001. Permo-Triassic rocks in boreholes in the Annan-Canonbie area, Dumfries and Galloway, southern Scotland. *Scottish Journal of Geology.* **37,** 97-113.

HOPKINS, C.A. 1999. Trackways in the sands of time. *Earth Heritage* **11,** 17-18.

HORNE, J. and GREGORY, J.W. 1916. The Annan Red Sandstone Series of Dumfriesshire. *Trans Geol Soc Glasgow.* **15,** 374-386.

JONES, N.S. and AMBROSE, K. 1994. Triassic sandy braidplain and aeolian sedimentation, the Sherwood Sandstone Group, west Cumbria. *Proceedings of the Yorkshire Geological Society.* **50,** 61-76.

KARL, C. and HAUBOLD, H. 1998. *Brachychirotherium* aus dem Coburger Sandstein (Mittlerer Keuper, Karn/Nor) in Nordbayern. *Hallesches Jahrbuch Geowissenschaft.* **20,** 33-58.

KING, M.J. and THOMPSON, D.B. 2000. Triassic vertebrate footprints from the Sherwood Sandstone Group, Hilbre, Wirral, northwest England. *Proc Geol Assoc*. **111,** 111-132.

LOVELL, J.P.B. 1981. Intertidal sediments in the Auchenhew Beds (Triassic) of Arran. *Scottish Journal of Geology* **17,** 223-224.

LOVELL, J.P.B. 1983. Permian and Triassic. *In* G. Y. Craig (ed.) *The Geology of Scotland* (2nd edition). Scottish Academic Press, Edinburgh, 325-342.

MAO, S.Z., WAN, C.B. and QIAO, X.Y. 1999. Cretaceous non-marine dinoflagellates from northeastern China. *Grana* **38,** 144-161.

MCKEEVER, P.J.A. 1994. A new vertebrate trackway from the Permian of Dumfries and Galloway. *Scottish Journal of Geology* **30,** 11-14.

MCKEEVER, P.J.A. and HAUBOLD, H. 1996. Reclassification of vertebrate trackways from the Permian of Scotland and related forms from Arizona and Germany. *Journal of Paleontology* **70,** 1011-1022.

MCKERROW, W.S. and ATKINS, F.B. 1985. *Geologists' Association Guide: Isle of Arran.* Geologists' Association, London. 96pp.

PEABODY, F.E. 1948. Reptile and amphibian trackways from the Lower Triassic Moekopi Formation of Arizona and Utah. *University of California Publications Bulletin of the Department of Geological Sciences* **27,** 295-468.

PEABODY, F. E. 1955. Occurrence of *Chirotherium* in South America. *Bulletin Geol Soc America.* **66,** 239-240.

POLLARD, J.E. and LOVELL, J.P.B. 1976. Trace fossils from the Permo-Triassic of Arran. *Scottish Journal of Geology* **12,** 209-225.

POLLARD, J.E. and STEEL, R.J., 1978. Intertidal sediments in the Auchenhew Beds (Triassic) of Arran. *Scottish Journal of Geology* **14,** 317-328.

POLLARD, J.E. and STEEL, R.J., 1981. Intertidal sediments in the Auchenhew Beds (Triassic) of Arran:reply. *Scottish Journal of Geology* **17,** 225-226.

TRESISE, G. and SARJEANT, W.A.S. 1997. *The Tracks of Triassic Vertebrates: Fossil Evidence from North-West England.* The Stationary Office, Norwich, 204pp.

TYRRELL, G.W. 1925. The geology of Arran. *Mem Geol Surv UK.*

WARRINGTON, G. 1973. Miospore of Triassic age and organic-walled microplankton from the Auchenhew Beds, south-east Arran. *Scottish Journal of Geology* **9,** 109-116.