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Dinosaur tracks from the Kilmaluag Formation (Bathonian, Middle Jurassic) of Score Bay, Isle of Skye, Scotland, U. K.

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Tracks of a juvenile theropod dinosaur with footprint lengths of between 2 and 9 cm as well as adults of the same ichnospecies with footprints of about 15–25 cm in length were found in the Bathonian (Middle Jurassic) Kilmaluag Formation of Score Bay, northwestern Trotternish Peninsula, Isle of Skye, Scotland, UK. Two footprint sizes occur together on the same bedding plane in the central portion of Score Bay, both *in situ* and on loose blocks. Another horizon containing footprints above this was also identified. The footprints from the lowest horizon were produced in a desiccated silty mud that was covered with sand. A close association of both adults and juveniles with similar travel direction indicated by the footprints may suggest post-hatching care in theropod dinosaurs. Other footprints, produced on a rippled sandy substrate, have been found on the slightly higher bedding plane at this locality. Loose blocks found 130 m to the northeast in the central part of Score Bay have not been correlated with any *in situ* sediments, but were preserved in a similar manner to those from the higher bedding plane. These tracks represent the youngest dinosaur remains yet found in Scotland.

Keywords Scotland, dinosaur, Middle Jurassic, post-hatching care, theropod, footprint
RRH: MID-JURASSIC DINOSAUR TRACKS, SCOTLAND
LRH: N. D. L. CLARK ET AL.

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INTRODUCTION

In late 2002, dinosaur footprints were discovered on loose blocks of sandstone, as well as *in situ,* on the foreshore at Lub Score, northwest Trotternish Peninsula, Isle of Skye, Scotland, UK (Fig. 1). The majority of these footprints were much smaller than any previously found in Scotland, and were closely associated with larger footprints of what seems likely to be the same species. These footprints are stratigraphically younger than any other dinosaur remains found in Scotland to date, and are different from those found elsewhere from the Middle Jurassic succession on the Isle of Skye (Fig. 2).

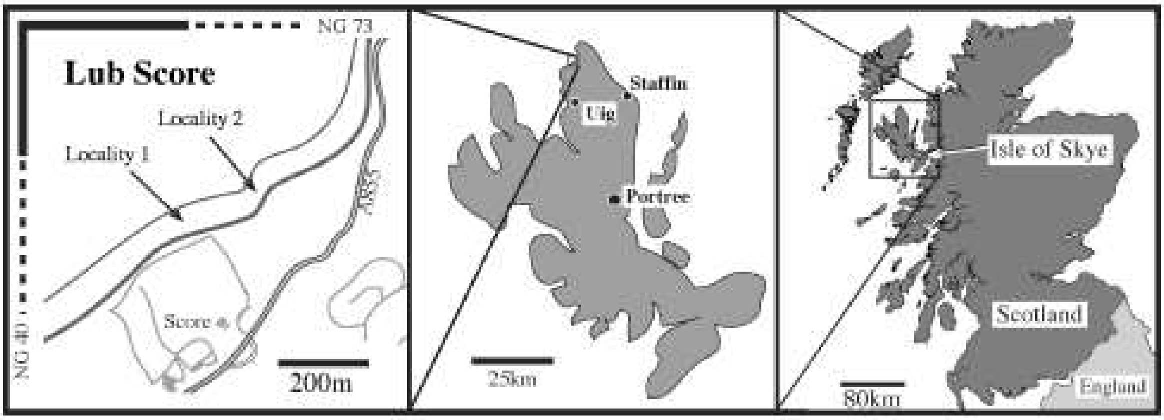

FIG. 1. Locality map of Lub Score, Isle of Skye, Scotland (British Ordinance Survey Grid figures (NG73 and NG40) and road number (A855) are given on the enlarged map of Lub Score).

The first dinosaur footprint to be found in Scotland was discovered on a loose block of muddy limestone from the Lonfearn Member of the Lealt Shale Formation at Rubha nam Brathairean in 1982. This 49cm long footprint is thought to have been made by an ornithopod (Andrews and Hudson, 1984; Delair and Sarjeant, 1985). Since then dinosaur footprints and trackways have been found in the Valtos Sandstone Formation (Bathonian) near Staffin at Dun Dearg and Kilt Rock (Clark and Barco Rodriguez, 1998; Clark, 2001a), and the Duntulm Formation (Bathonian) near Staffin at An Corran (Clark et al., 2004).

Small footprints of about 19.5cm in length, identified as belonging to the ichnogenus *Grallator* were found from the Valtos Sandstone Formation, also near Rubha nam Brathairean, associated with 28cm long *Eubrontes* footprints (Clark and Barco-Rodriguez, 1998). Other smaller footprints closer to 12cm in length have since been found as well as larger ornithopod footprints about 40cm long all from the Valtos Sandstone Formation near Kilt Rock, Trotternish Peninsula. More recently, very large (>50cm) *in situ* footprints from the Duntulm Formation at An Corran, Staffin Bay were found that appeared to be directed mostly towards the northeast (Clark et al., 2004).

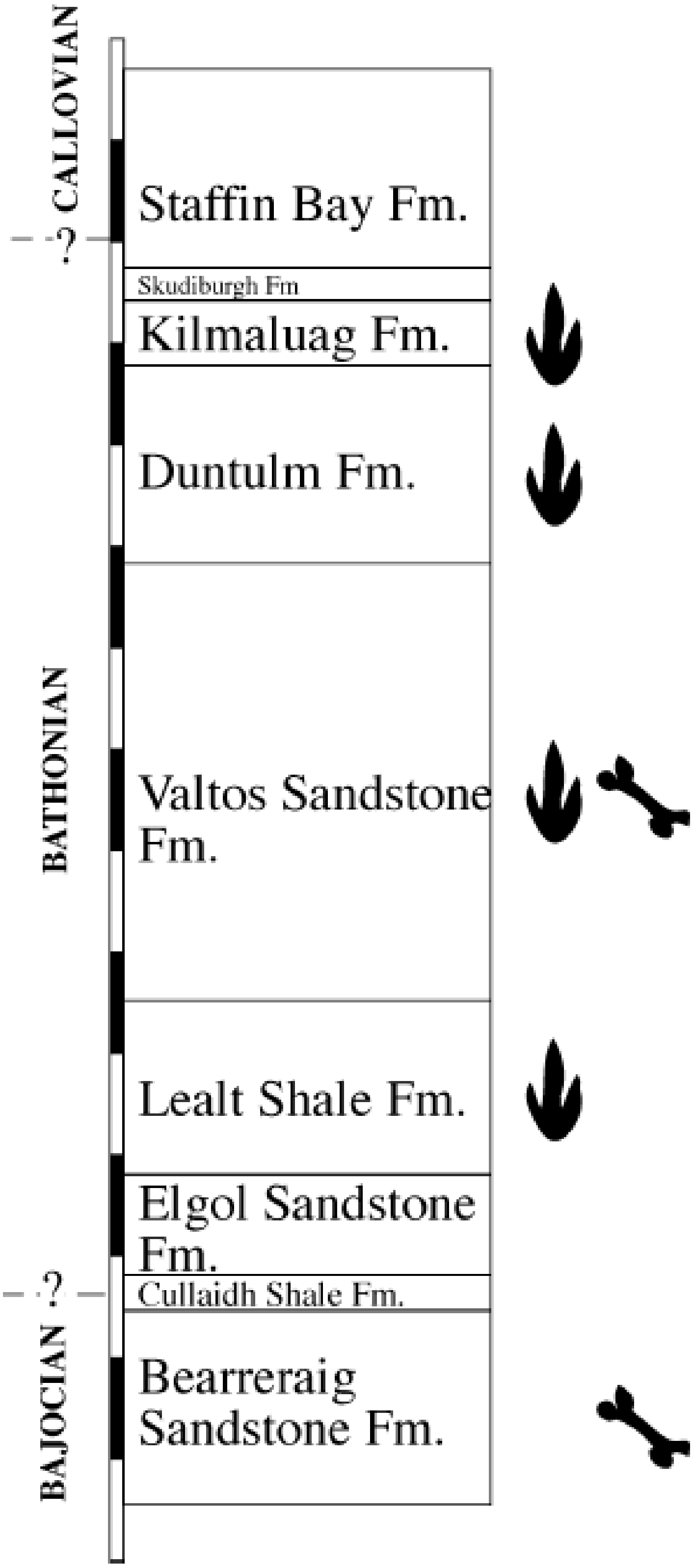

FIG. 2. Diagramatic representation of the Middle Jurassic stratigraphy of the north of the Isle of Skye, with approximate thicknesses, showing levels from which dinosaur bones and footprints have been found (based on Harris and Hudson, 1980; Andrews and Walton, 1990; and Cox, 2002). Vertical scale in 25 m sections.

Dinosaur bones are also known from Scotland. A theropod tibia was found in the Broadford Beds Formation (Hettangian) in the Strathaird Peninsula, southern Isle of Skye (Benton et al., 1995), a thyreophoran ulna and radius came from the Bearreraig Sandstone Formation (Bajocian) at Bearreraig Bay, northern Isle of Skye (Clark, 2001b), and cetiosaur bones and a coelophysid-like tail bone were discovered in the Valtos Sandstone Formation at Dun Dearg near Staffin (Clark et al., 1995; Clark et al., 2004).

The footprints described here are from the northwestern part of the Trotternish Peninsula, Isle of Skye at Lub Score (also known as Score Bay) (Fig. 1). A major block of sandstone containing 24 distinct footprints on one bedding surface was collected for the Staffin Museum, Isle of Skye. Further specimens have since been collected by the Staffin Museum and Hunterian Museum, Glasgow during 2003 and 2004. The footprints range in length from 1.8cm to 22.0cm (Figs. 3, 6).

METHODS

The footprints were described using the footlength (FL), as illustrated by Thulborn (1990, fig. 4.8c), and the angle between the tips of the digital nodes of digits II, III, and IV (α) (Fig. 4). The footprint span (Fs) was measured between the tips of digits II and IV. It is considered that this may provide a more reliable measurement for footprint comparisons, as interdigital angles are difficult to measure accurately, or consistently (Thulborn, 1990). The footprint span was used because footprint width is likely to be variable dependent on the consistency of the sediment and the weight and stance of the dinosaur. The paces were measured from the tip of digit III to the next tip of digit III of the alternate footprint and the stride was measured in a similar manner between subsequent footprints following the method of Thulborn (1990, Fig. 4.10).

A silicone rubber mould of the best surface was made using the room temperature vulcanising T28 silicone rubber with T6 catalyst, TW catalyst booster, DP 100 release agent, and heavy chopped strand-mat glass fibre from Alec Tiranti Ltd. following the method described by Clark et al. (2002). A fibreglass and polyurethane resin cast was made by The Quickening (Glasgow), from the mould and placed with the collections of the Hunterian Museum, University of Glasgow (GLAHM 114912).

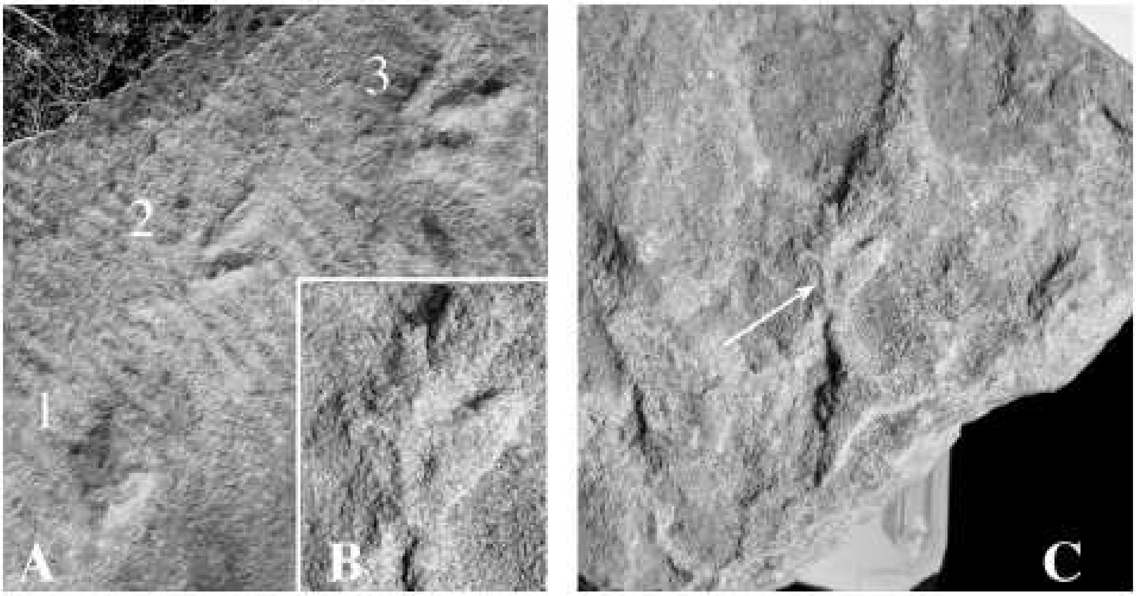

FIG. 3. *A*. set of footprints of dinosaur turning on rippled sandstone from upper level at locality 1 (see Table 1: Lmk 3.2 = 1; Lmk 3.3 = 2; Lmk 3.4 = 3 on figure; scale = x0.6), *B* and *C*. GLAHM 114913 with arrow pointing towards small footprint (enlarged in B) overprinting larger footprint, probably from upper level (B. scale = x1.9; C. scale = x1).

STRATIGRAPHY

Stratigraphic correlation within the Kilmaluag Formation in Trotternish is problematic due to the discontinuous nature of the sedimentary succession (Anderson and Dunham, 1966; Harris and Hudson, 1980). Although the type section in the Kilmartin River (Anderson, 1963; Anderson and Dunham, 1966) exhibits about 26m of succession, the strata are disturbed and broken by offshoots from a sill that underlies the Kilmaluag Formation in that area. The best and most easily accessible exposures of this formation are those in Kilmaluag Bay (Harris and Hudson, 1980; Morton and Hudson, 1995), although exposure is tidal and can vary depending on beach sediment cover. The section at Lub Score cannot be confidently correlated with any particular beds from these localities.

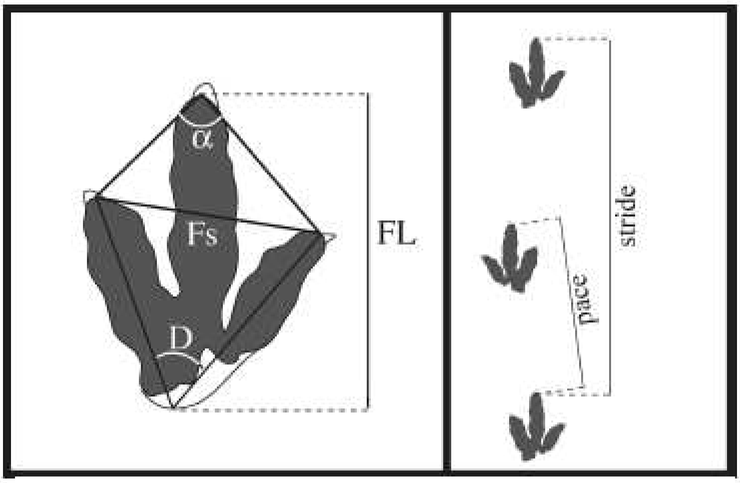

FIG. 4. Diagram to show the measurements of α (angle between tips of digital nodes of digits II, III, and IV), FL (footprint length), Fs (footprint spread between digits II and IV), D (divarication angle), pace and stride (partly based on Thulborn, 1990).

Anderson and Dunham (1966) suggest that the sandstones at Lub Score, from which the dinosaur footprints are found, are representative of the Duntulm Formation. In Anderson's field notes (GSE LSA 212) he records a light gray marly shale with ostracods (locality D16). These ostracods, and other associated fossils, are characteristic of the Kilmaluag Formation, however, indicating that Anderson and Dunham's interpretation may be incorrect. The abundant ostracods in the mudstones immediately above and below the main footprint-bearing sandstone as well as the presence of the conchostracan *Antronestheria kilmaluagensis* Chen and Hudson, 1991, strongly suggests that these sediments are of the Kilmaluag Formation and not the Duntulm Formation. The most abundant ostracods are *Theriosynoecum conopium* Wakefield and Athersuch, 1990, and *Darwinula cicatricosa* Wakefield, 1994, both of which are characteristic of the Kilmaluag Formation (Wakefield, 1994).

LITHOLOGIES

The sediments on the foreshore of Lub Score are best exposed at low tide. Boulders and cobbles on the beach obscure much of the exposure and have to be removed to gain access to the horizon of interest. The two locations from which dinosaur footprints have been obtained are about 120 metres apart. The footprints from the southern most locality 1 can be ascribed to two levels within a sandstone bed overlying grey-green silty mudstones (Fig. 5A). The lowest level is at the base of the sandstone where it interfaces with a grey-green silty mudstone. The silty mudstone contains an abundant fauna of conchostracans, ostracods, and fish scales. The higher level is 14cm above the interface surface on a rippled bedding plane. The footprints found at the northern most locality 2 may be from the upper level although no *in situ* footprints have been found at this location (Fig. 5). The sediments contain a fauna that is characteristic of a freshwater environment (Wakefield 1994, Cox 2002). Footprints are likely to have been preserved during a period of desiccation in sediments with moderate moisture content and where they were subject to high sedimentation rates (Ashley and Liutkus 2002). Mudcracks on the lower footprint bearing surface indicate a period of desiccation prior to being covered by sand.

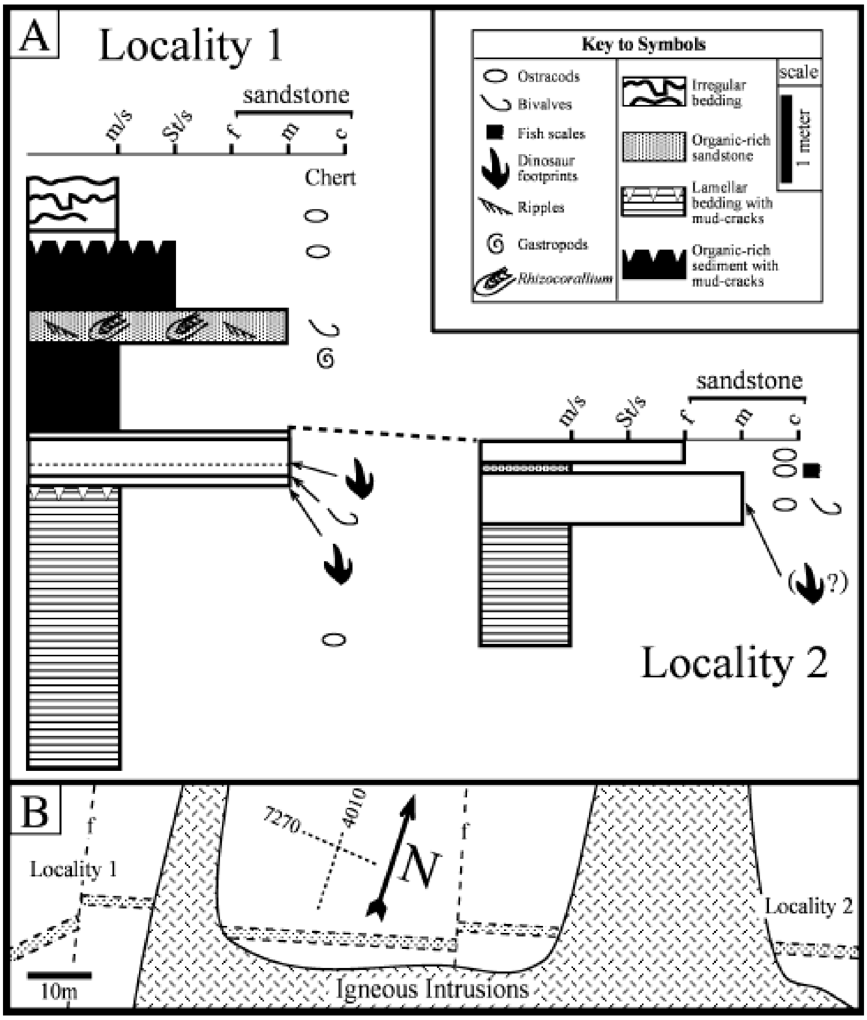

FIG. 5. A. Representation of the sediments exposed at localities 1 and 2 showing grain size, structures, and fossil content, *B.* Detailed map of the two localities at Lub Score showing the geology (f = fault, parallel dashed lines with stippling between represents the dinosaur footprint bearing sandstone, igneous intrusion is
cross-stippled).

Locality 1

The 36cm thick brown sandstone that contains the dinosaur footprints has a distinct bedding surface 7cm above the base. The base is the surface on which the most abundant dinosaur footprints occur. The footprint lengths range from 7.0-22.0cm with the majority being in the 7-15cm range and all are directed towards the southwest and west. All the footprints at this level are preserved as natural casts as the underlying mud is poorly consolidated and is easily removed by the action of the sea. The 7cm thickness of sandstone immediately above the footprint surface contains abundant and complete specimens of *Pleuromya* with both valves attached. The gray-green silty mudstones and gray silty laminated shales below the footprint horizon are poorly exposed. Where seen, the shales contain abundant ostracods as well as broken fragments of the conchostracan *Antronestheria kilmaluagensis* (Hitchcock, 1841), jet and pyrite nodules. Below these shales (about 16 metres) is a gray ripple bedded siltstone that contains abundant gastropods, ostracods, plant fragments and bivalves. About 14cm above the main footprint surface is a rippled bedding plane that also contains small dinosaur footprints from 1.8-12.5cm in length.

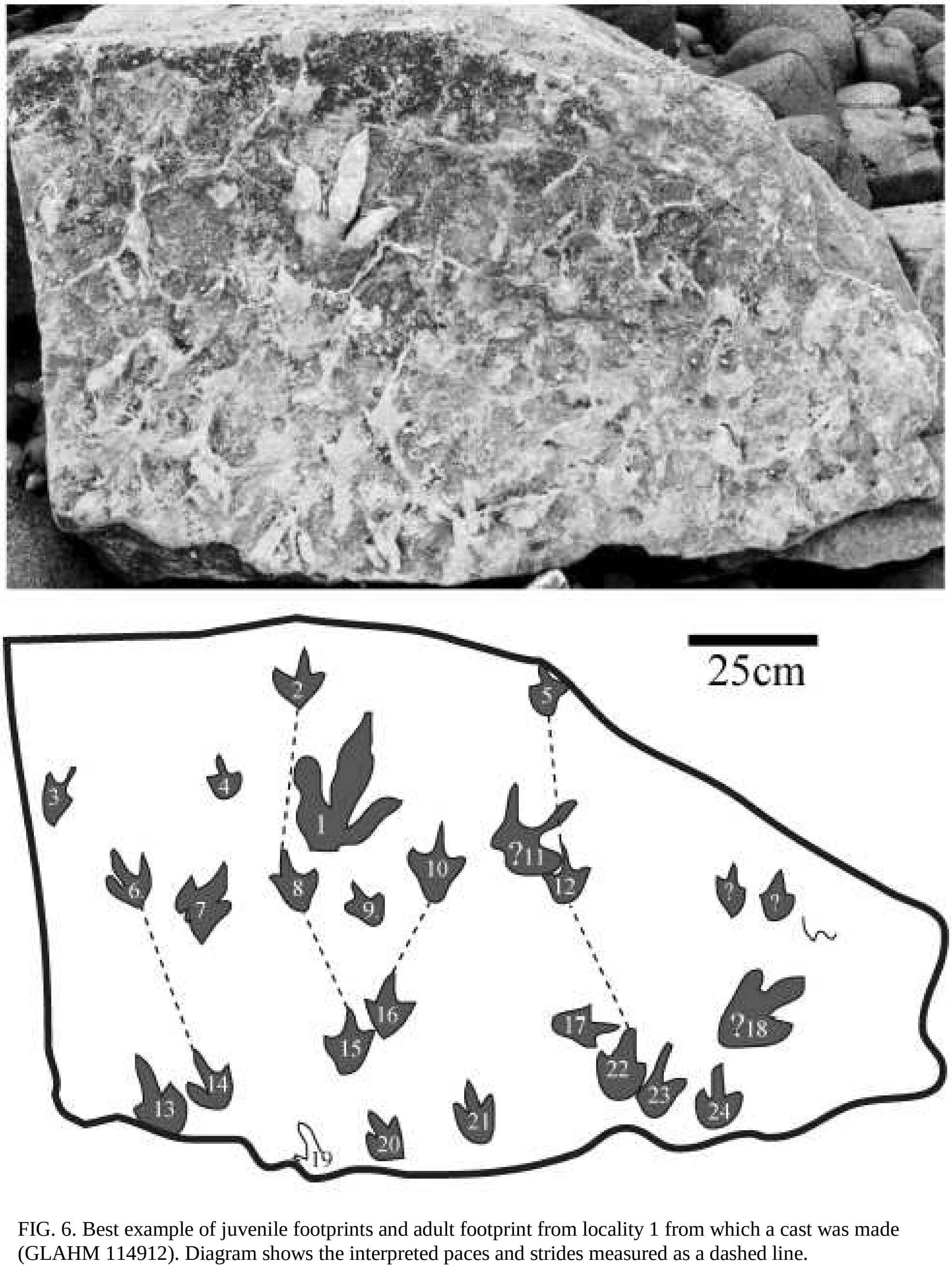

FIG. 6. Best example of juvenile footprints and adult footprint from locality 1 from which a cast was made (GLAHM 114912). Diagram shows the interpreted paces and strides measured as a dashed line.

Footprint number	FL (cm)	Fs (cm)	α	Pace (cm)	Stride (cm)	Fs/FL	D
(GLAHM 114912) 1	22.0	15.7	83			0.72	60
2	9.4	7.3	85	(8-2) 29.6		0.77	66
3	9.7	6.5	88			0.67	52
4	8.2	5.1	68			0.62	60
5	8.8	6.8	74	(12-5) 28.4	(22-12-5) 55.7	0.77	67
6	9.0	6.2	74	(14-6) 32.8		0.69	54
7	11.9	6.9	73			0.58	52
8	8.9	6.7	86	(15-8) 24.7	(2-8-15) 52.3	0.75	59
9	8.6	7.1	82			0.82	60
10	12.4	7.8	81			0.63	58
11	16.2	13.0	86			0.80	58
12	9.2	6.7	87	(22-12) 28.6		0.73	62
13	11.3	7.1	68			0.63	55
14	8.9	6.6	78			0.74	50
15	10.8	6.8	78			0.63	52
16	10.0	7.3	82	(16-10) 23.2		0.73	63
17	9.8	7.2	90			0.73	59
18	15.6	9.1	85			0.58	46
19			83			-	
20	8.6	5.2	66			0.61	47
21	11.3	5.2	79			0.47	36
22	10.4	7.1	62			0.68	55
23	10.9	6.0	80			0.55	52
24	10.0	7.3	83			0.72	57
GLAHM 114903	6.9	5.4	69			0.78	
GLAHM 114904	9.3	6.8	63			0.73	
GLAHM 114913	8.9	7.6	88			0.85	62
GLAHM 114913/1	1.78	1.16	98			0.65	59
GLAHM 114913/2	2.0	1.47	97			0.74	63
Field specimens Lmk 1.1	18.0	12.0	77			0.67	
Lmk 1.2	15.0	10.0	87			0.67	
Lmk 1.3	10.0	6.0	66			0.60	
Lmk 3.1	9.0	6.0	78			0.67	
Lmk 3.2	12.8	8.7	91			0.68	68
Lmk 3.3	12.8	8.8	87	(3.2-3.3) 28.0		0.69	64
Lmk 3.4	12.5	8.6	83	(3.3-3.4) 26.5	(3.2-3.3-3.4) 53.0	0.69	60
Lmk 5.1	19.0	9.8	65			0.52	
Lmk 5.2	7.0	4.2	76			0.60	
Lmk 5.3	7.3	4.3	74	(5.2-5.3) 24.3		0.60	

Table 1. Data obtained for the footprints recovered from the Kilmaluag Formation at Lub Score (FL=footprint length; Fs=footprint span; α=angle between tips of digital nodes of digits II, III and IV; numbers in brackets are individual footprints identified as part of a trackway; D=divarication angle).

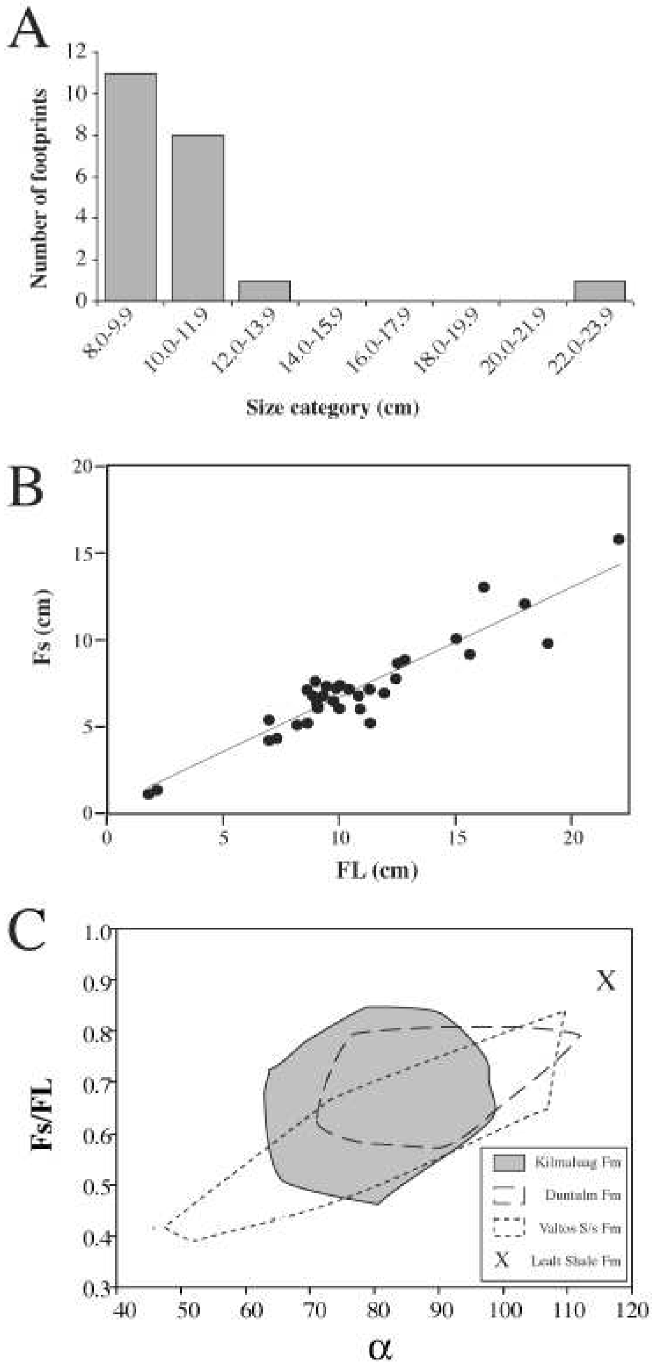

FIG. 7. *A*. Chart showing the size distribution of footprints on the lowest bedding plane surface with 22 associated footprints (GLAHM 114912). Two poorly defined footprints were removed from the data set (nos. 11 and 18), *B*. Graph showing the relationship between the footprint length (FL) to span (Fs) ratio and the angle *α* for footprints from the different Middle Jurassic formations represented on the Isle of Skye (Kilmaluag Formation (N=36), Duntulm Formation (N=10), Valtos Sandstone Formation, (N=10), Lealt Shale Formation (N=1)), *C*. Graph showing the relationship between the footprint span (Fs) and the footprint length (FL) of dinosaur footprints from the Kilmaluag Formation. R_2 =0.87; y = 0.63x + 0.46.

Between locality 1 and 2, the sediments are intruded by two dykes and a sill, and are cut by minor faulting (Fig. 5B). Above the sandstone that contains the dinosaur footprints is a sequence of fossiliferous mudstones, siltstones and sandstones, some of which have been altered by the igneous intrusions. One distinct rock type close to the intrusions is a light colored chert that appears to have disrupted bedding and mud cracks. It looks superficially similar to a sliver of Kilmaluag Formation that is baked in a sill above An Corran, Staffin Bay (Clark et al., 2004). Other horizons within this sequence contain *Rhizocorallium*, gastropods, abundant ostracods and conchostracans.

Locality 2

The footprints found at locality 2 are transmitted tracks or natural moulds within a sandstone containing darker organic laminae. These are found on worn loose blocks of sandstone. The precise level from which these footprints derive has not been identified at this location, but the sandstone and footprint preservation is similar in character to the upper footprint level of the sandstone from Locality 1. The sandstone contains abundant ostracods and fish scales characteristic of the Kilmaluag Formation. The footprints appear to be the same ichnospecies as those from locality 1. The topmost exposure at this locality is a >19cm thick white laminated sandstone above a 4cm light brown mudstone. It is considered that this sandstone may be the lateral equivalent of the footprint-bearing sandstone at locality 1, although no footprints have been found *in situ*. The only other exposed sediment at this locality is an unconsolidated siltstone containing abundant shell fragments and ostracods below the sandstone.

DESCRIPTION

The dinosaur footprints from Lub Score are all from small bipedal tridactyl dinosaurs. On the slab of the lower footprint-bearing surface that contains approximately 24 individual footprints (Fig. 6), the footprint lengths range from about 8cm to 22cm (Table 1 GLAHM 114912/1-24) with the majority being less than 12cm in length (Fig. 7A). Natural casts of the dinosaur footprints were made by medium-grained sand infilling a silty mudstone.

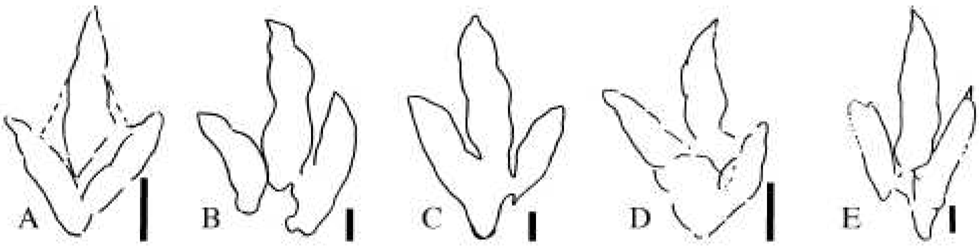

FIG. 8. Outline sketches of different sized footprints from the Kilmaluag Formation at Lub Score showing similarity of form despite size differences (scale bars= 2.5 cm). *A* = GLAHM 114912/16; *B* = field specimen; *C* = GLAHM 114912/1; *D* = GLAHM 114904; *E* = field specimen (field specimens not collected).

Formation	**FL (cm)**	**Fs (cm)**	**α**	**Fs/FL**
Duntulm Formation (DF)	49.0	31	70.5	0.63
(DF)	53.0	38.2	103	0.72
(DF)	52.0	30.2	89	0.58
(DF)	42.0	33.8	111	0.80
(DF)	42.0	30.4	98	0.72
(DF)	48.0	28.1	79	0.59
(DF)	41.0	27.5	90	0.67
(DF)	47.0	29.4	96	0.63
(DF)	42.0	29.1	78	0.69
(DF) B	24.3	20.0	76	0.82
Valtos Sandstone Formation (VSF)	18.9	8.4	50	0.44
(VSF)	18.9	7.7	52	0.41
(VSF)	24.0	11.9	76	0.50
(VSF)	17.5	11.9	72	0.68
(VSF)	24.0	14.7	70	0.61
(VSF)	19.6	9.1	50	0.46
(VSF)	19.6	8.4	47	0.43
(VSF)	22. 0	14. 9	100	0.68
(VSF)	17.0	14. 5	109	0.85
(VSF)	40.4	26.8	106	0.66
Lealt Shale Formation	49.0	44.6	115.0	0.91

Table 2. Data from other formations for comparison with data obtained from the Kilmaluag Formation (legend same as for table 1; (DF) B is the single footprint from level B at An Corran (Clark *et al.* 2004).

The footprints found at Lub Score have tightly confined dimensions of Fs/FL and α when compared to the same dimensions of footprints from other formations of the Middle Jurassic in Scotland (Table 2; Fig. 7B). The footprints from the Valtos Sandstone Formation have a broad distribution indicating that the faunal diversity is greatest in that Formation. The Duntulm Formation footprints are also quite well constrained plotting close to and amongst the Kilmaluag Formation footprints from Lub Score. The spread of α values of the Duntulm Formation footprints may be due to the coastal erosion at An Corran that has abraded many of the footprints making it difficult to confidently identify the tips of the digital nodes in some prints. The Lealt Shale Formation solitary footprint does not plot close to the Kilmaluag Formation footprints, thus it may represent a different type of dinosaur. The broad spatulate digits also support this interpretation and it has been suggested, by Delair and Sarjeant (1985), that it represents the footprint of a large ornithopod.

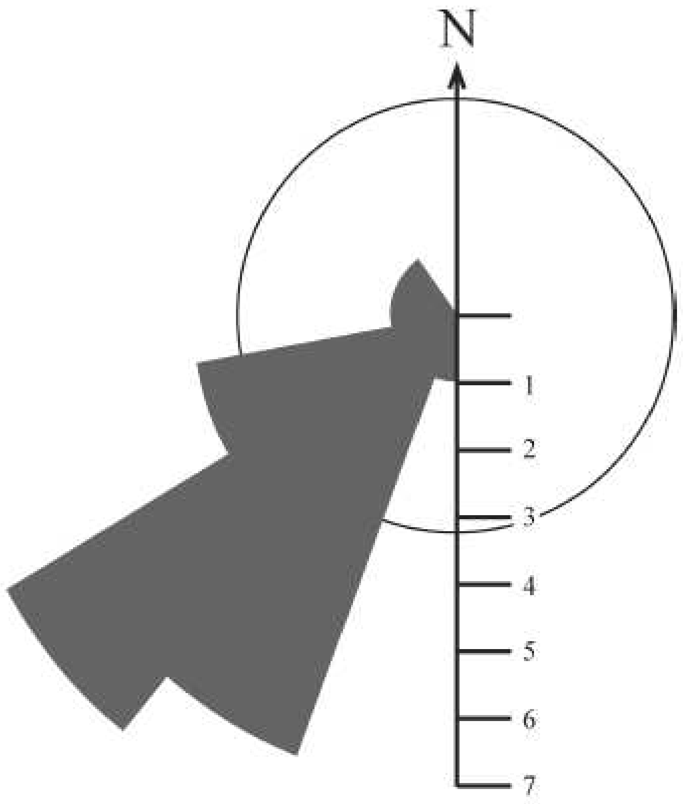

FIG. 9. Plot showing the probable direction taken by the trackmakers on the large loose block containing 24 footprints (GLAHM 114912).

The Kilmaluag Formation dinosaur footprints likely belong to the same ichnospecies as the gross morphology and the relative dimensions of the smallest footprints and the largest ones are similar and are found in close association (Figs. 7C, 8). In most of the footprints, the nodes are not easily seen, but the tips of the digital nodes and the claw impressions are more clearly observed allowing more accurate measurements to be taken.

The orientation of the footprints on the larger slab containing 24 footprints shows an alignment of the smaller footprints with the larger distinct footprint (GLAHM 114912). As this was a loose block of sandstone on the foreshore, the orientation relative to north is uncertain. By comparing the line of the most recent joint surface with the orientation of the joint plane in the exposed sediment, it is possible to provide an approximation to the direction of the trackmaker. It has been deduced that the trackmakers were all moving in a west to southwesterly direction (Fig. 9).

COMPARISONS

It is sometimes difficult to distinguish between tridactyl theropod footprints (Haubold, 1971). None of the footprints have the hallux impression diagnostic of *Anchisauripus*; however, this is only rarely seen as an impression because the hallux is held above the level of the other digits (Haubold, 1971). The genotype for *Eubrontes* (*E. giganteus* Hitchcock, 1845) has a divarication angle of just 32°, *Anchisauripus sillimani* (Hitchcock, 1841) is the same and *Grallator paralellus* Hitchcock, 1865, is between 22° and 29°. The relatively high divarication angle of about 55° for the Kilmaluag Formation footprints may be due to a different method having been employed to measure this angle thus rendering it useless for comparative purposes in this instance (Thulborn, 1990; Fig. 4.5). The footprints are slightly asymmetric with digit III convex outwards with digit IV being slightly longer than digit II. Digit IV is also broader than digit II. *Grallator* is distinguished from *Anchisauripus* by the lack of a hallux impression, a greater relative length of stride and the small size of the prints. The rediscovery and designation of type specimens for the ichnogenera *Grallator*, *Anchisauripus*, and *Eubrontes*, has not helped in recognizing diagnostic differences between them (Olsen et al., 1998). The projection of digits II and IV has been suggested as a possible means of differentiating between these ichnogenera, but this difference may relate more to the interaction of the foot with the substrate than any real difference (Olsen et al., 1998).

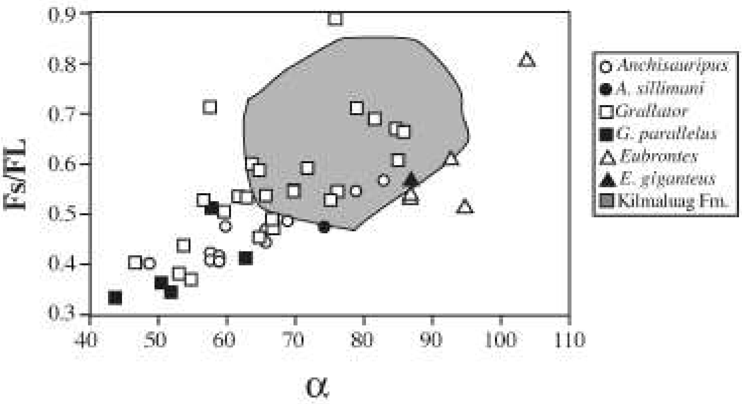

FIG. 10. Graph showing the relationship between the Fs/FL ratio and α of the Kilmaluag footprints imilarly measured dimensions and angles of similar and related ichnogenera based on data obtained from Haubold (1971; figs. 43 and 44) and type specimens from Olsen et al. (1998).

The data collected for this exercise appear to separate the three ichnogenera, but this may still represent variation within an ichnogenus, the end members being interpreted as different ichnogenera (Fig. 10). Certainly, *Anchisauripus* and *Grallator* appear almost indistinguishable based on the α data (measured using figures in Haubold, 1971, and Olsen et al., 1998). The box plots of α show more overlap of the footprints from the Kilmaluag Formation with *Grallator* and *Anchisauripus* than *Eubrontes* (Fig. 11A). The foot splay to length ratio (Fs/FL) plot (Fig. 11B) also shows substantial overlap between all three ichnogenera and the Kilmaluag footprints. The footprints from the Valtos Sandstone Formation have been interpreted as belonging to a mixed fauna including *Grallator* and *Eubrontes*. This can be shown by the spread of data overlapping data obtained for these ichnogenera (Fig. 11). Of the ichnospecies of *Grallator* recorded by Haubold (1971), three appear to be more closely allied to the footprints from the Kilmaluag Formation; *G. maximus* Lapparent and Montenat, 1967, *G. variabilis* Lapparent and Montenat, 1967, and *G. oloensis* Lapparent and Montenat, 1967, (Fig. 12). These three ichnospecies are from the Lower Jurassic of France. Of these three ichnospecies, *G. maximus* is reported to a maximum of 14cm long (Lapparent and Montenat, 1967; Haubold. 1971). More data are required to test whether using this method for ichnospecies identification is reliable.

The relative length of the stride and pace to the footprint length is quite small, with mean values of 0.37 for the FL/pace ratio in the Lub Score footprints compared to 0.44 for the Duntulm Formation footprints, and 0.25 for the Valtos Sandstone Formation footprints (Table 3). Based on diagrams presented by Haubold (1971), the two *Anchisauripus* trackways illustrated have FL/pace values of 0.29, compared with 0.18 for *Grallator*, and 0.31 for *Eubrontes*. The problem with using FL/pace and FL/stride measurements as diagnostic characters is that the measurement depends on how fast the animal was moving at the time it made the imprints. It is possible that some of the differences between the ichnogenera *Grallator*, *Anchisauripus* and *Eubrontes* are variations due to allometric growth within closely related species (Olsen et al. 1998). Despite the differences shown by the boxplots, it appears that the footprints from the Kilmaluag Formation at Lub Score can be assigned to any one of these three ichnogenera. Of these ichnogenera, *Eubrontes* has priority if future study shows that the differences are less than generic in importance.

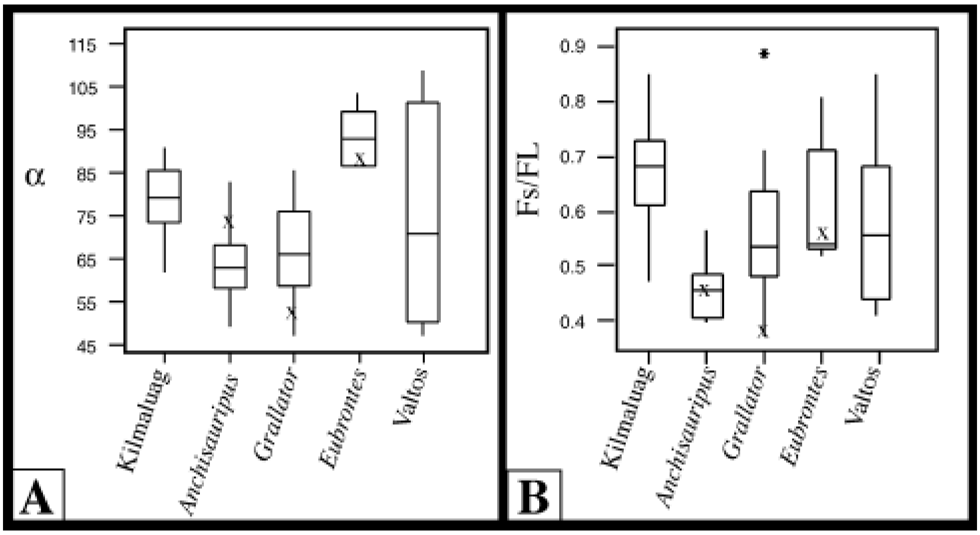

FIG. 11. Box plots of *A*. Fs/FL and *B*. α for the specimens from the Kilmaluag Formation, *Anchisauripus*, *Grallator*, and *Eubrontes*, as well as the mixed fauna from the Valtos Sandstone Formation for comparison (data obtained from same sources as Fig. 10; x = type specimens of ichnogenus).

The more abundant smaller footprints are not as well preserved on the large loose block collected in 2002 (GLAHM 114912), but measurements of the lengths and widths of the footprints suggest that they are of the same ichnospecies. The reason why the footprints are less well preserved is perhaps because the animals were lighter and not able to produce as deep an imprint in the sediment. It is thought that the casts were produced by infilling directly into the original impressions as there is no evidence of transmission from a higher level. There is no overlapping of the footprints and the state of preservation is similar for all the smaller footprints, suggesting that they were all made at about the same time.

INTERPRETATION

The footprints and trackways from the lower level at 1ocality 1 may represent the first evidence of post-hatching care of young theropod dinosaurs. The ichnogenera *Grallator*, *Eubrontes*, and *Anchisauripus* are closely related and have been interpreted as belonging to the theropod infraorder Coelurosauria (Haubold, 1971; Olsen et al., 1998). On one slab there are about twenty-four individual footprints ranging in size from 7-22cm in length, but the smallest individual footprint from this locality is under 2cm in length (GLAHM 114913; Fig. 3b, c). All footprints on the large loose block (GLAHM 114912) appear to be moving in a west to southwesterly direction and do not overprint. This suggests that the animals were moving together in the same direction at about the same time. The similarity in overall morphology and the footprints being on the same bedding plane suggests a monospecific ichnotaxon group of young and adult dinosaurs. Parallel trackways have been used as evidence of herding in ornithopods and sauropods (Lockley, 1994), but this may also be a result of a linear geographic feature such as a shoreline (Day et al., 2004). The presence of only one adult amongst a number of juveniles suggests that the grouping may be that of a family of theropod dinosaurs.

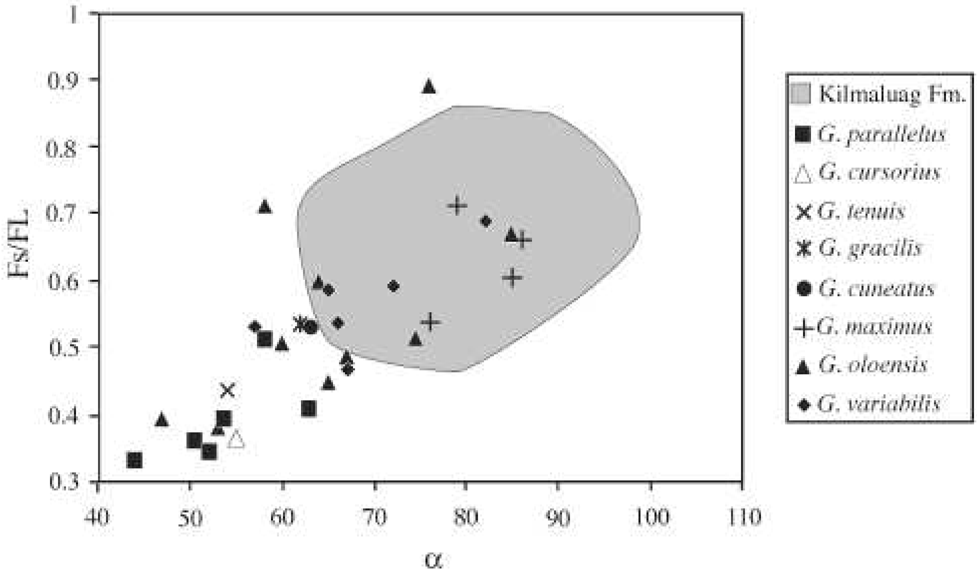

FIG. 12. Graph showing the relationship between the Kilmaluag Formation footprints and those of various species of *Grallator* (taken from Lapparent and Montenat (1967), Haubold (1971; figs. 41, 43 and 44) and Olsen et al. (1998) for the genotype: *G. parallelus*) using Fs/FL ratio and α.

The footprints of small juvenile dinosaurs are generally quite rare (Lockley, 1994). The footprints here suggest that most of the juveniles were over 1m in body length with at least one about 20cm in length.

Formation	FL/pace	FL/stride
Kilmaluag Formation	(8-2) 0.31	
	(12-5) 0.31	
	(14-6) 0.27	
	(15-8) 0.40	(2-8-15) 0.19
	(22-12) 0.34	(22-12-5) 0.17
	(16-10) 0.48	
	(5.2-5.3) 0.29	
	(3.2-3.3) 0.46	
	(3.3-3.4) 0.48	(3.2-3.3-3.4) 0.24
Duntulm Formation	0.47	0.26
	0.41	
Valtos S/s Formation	0.25	
	0.25	

Table 3. Data showing the ratios of the footprint lengths to the pace length and stride lengths; numbers in brackets are individual footprints identified as part of a trackway (see table 1).

Using the equation (hip height = $3.06FL^{1.14}$) for the hip height of coelurosaur dinosaurs (Thulborn, 1984; Thulborn and Wade, 1984), the size/age model of Horner (1992) (Lockley, 1994) and an approximate hip height to body length multiplier for *Coelophysis* of 1:5.4 suggests that the smaller footprints are of an animal that is between 100 and 200cm long and about a year old or younger, although the smallest footprint of 1.8cm on a loose block (probably from a level above the best multi-track surface) suggests a young hatchling of about 20cm in length. The larger adult footprint is of an animal that is about 340cm long and at least 3 years old (Lockley, 1994). From the strides, it is possible to deduce that the animals that produced the small footprints were moving between 6 and 15 km/h (speed = $0.25g^{0.5}$ X $\text{stride}^{1.67}$ X hip $\text{height}^{-1.17}$) (Alexander, 1976). This is thought to represent a walking or trotting speed (Thulborn and Wade, 1984).

It is unlikely that this association is due to small predators chasing larger prey, or a larger predator chasing smaller prey, as the smaller dinosaurs are not moving very fast and show no signs of scattering. There is a strong possibility that the close association of adult and juvenile dinosaurs is coincidental and that there was no relationship between the trackmakers. The timing of the footprint impacts is important to our interpretation of any potential interactions between the trackmakers. The similarity of preservation between the juvenile footprints does suggest that they were made at about the same time, however, the larger footprint is better defined and more difficult to ascertain its timing relative to the juveniles. Due to the lack of overlap, it seems likely to have been produced either at the same time, or after the passage of the juvenile dinosaurs. This would support a parental care hypothesis, a larger stalking predator hypothesis, or a coincidental association.

DISCUSSION

Herding has been recorded in ornithopod dinosaurs as well as sauropods (Lockley, 1994; Lockley and Meyer, 2000) and a dinosaur footprint ontogeny from hatchling to adult has been recorded for hadrosaurs (Carpenter 1992, Lockley 1994). The footprints from locality 1 at Lub Score represent the first recorded association, or family group, of juvenile and adult theropods from the same bedding plane.

Evidence suggests that in some dinosaurs, for example the hadrosaurs, hatchlings and young juveniles do not leave the nest until they have grown from about 30cm to at least 100-130cm in length and would therefore be unlikely to contribute to the footprint record (Lockley, 1994). Preservational and observational bias may also contribute to a paucity of recorded small footprints (Lockley, 1994).

Although it is difficult to identify the specific dinosaur responsible for producing a particular footprint, and because of the difficulty in showing conichnospecificity between footprints, the most likely data to represent a monospecific ichnotaxon association would come from a single bedding plane (Lockley, 1994). This is especially true where parallel trackways are present (Lockley, 1994). The assertion that the trackmakers are the same species for both the large and small footprints, and hence demonstrating a possible relationship between them, is therefore only tentative.

There are a number of track sites that record possible gregarious, or herding, behavior in dinosaurs. The Upper Jurassic sauropod footprint tracksites of Cabo Espichel, Portugal, and Lommiswil, Switzerland, as well as sites in the USA and Korea, demonstrate that the sauropods, at least, moved in herds (Lockley, 1994; Lockley and Meyer, 2000). There are also hadrosaur tracks where different growth stages are represented from hatchling to adult (Carpenter, 1992; Lockley, 1994). Many of these ornithopod trackways are from several stratigraphical horizons suggesting migration, but some multiple trackway sites, such as the Lower Cretaceous Valdebrajos site in Spain, have provided evidence of herding in bipedal ornithopods (Lockley, 1994; Lockley and Meyer, 2000).

Footprints of ornithopods from the Jindong Lake Basin (Cretaceous) of South Korea, where both adult and juvenile footprints have been recognized, suggests evidence of migratory behavior as such assemblages occur at multiple stratigraphic levels travelling towards the southwest (Lockley, 1994). This cannot be shown for the Lub Score prints as the association of large and small prints appears most abundantly on one bedding plane at locality 1. Although the best sample shows that the dinosaurs were mostly traveling in the same direction, it is not possible to say with confidence, what direction that was, as the sample was a loose block; Nor is it possible to say whether the direction was the same for the individual prints collected from locality 2.

Beyond recording the existence of dinosaur footprints from the Kilmaluag Formation, and interpreting the movement of some individual trackmakers, the interpretation of any relationship between trackmakers is speculation. The taxonomy of theropod dinosaur footprints needs further consideration, as it is clear from this study that there is substantial morphological overlap between different related ichnogenera and ichnospecies.

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