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Life history information from tracks of domestic dogs *(Canis familiaris)* in ceramic building materials from a Roman bath-house at Vindolanda, Northumberland, England

DEB BENNETT

Equine Studies Institute. P.O. Box 411, Livingston, CA 95334 USA
office@equinestudies.org

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ABSTRACT: This report analyzes tracks impressed by dogs *(Canis familiaris)* into bricks and tiles later utilized in the construction of a first-century A.D. bath-house at Roman Vindolanda (Northumberland, England). Track sizes, trackway parameters, gait and morphology are described; measurements indicate three to five different size classes of dogs. Withers height cannot accurately be predicted from the size of individual tracks. Hair impressions visible in Vindolanda tiles are compared with hair impressions in tracks made by modern cats and dogs. The Vindolanda collection of pawprints on ceramic building materials is the largest known to date from any Romano-British site and among the largest known from any area or time period; in light of the valuable life-history information that animal tracks can give, more work in the area of ichno-archaeology is encouraged.

KEYWORDS: TRACK, TRACKWAY, *Canis familiaris,* DOMESTIC DOG, VINDOLANDA, CONFORMATION, GAIT ANALYSIS, BRACHYMEL DOG, ICHNOLOGY, ICHNO-ARCHAEOLOGY

RESUMEN: Este estudio analiza las pisadas de perros *(Canis familiaris)* conservadas en ladrillos y tejas usadas en la construcción de una terma romana de Vindolanda (Northumberland, Inglaterra) durante el primer siglo de nuestra era. Se describen los tamaños y características de las huellas caninas, así como los senderos que éstas definieron y los tipos de marcha a los que remiten. Las medidas indican la presencia de entre tres y cinco tipos diferentes de perros. No resulta posible predecir el tamaño del perro a partir del tamaño de una huella. Las improntas del pelaje detectadas en determinadas huellas se han comparado con otras registradas en perros y gatos actuales. La colección de huellas de animales domésticos de Vindolanda es la mayor jamás documentada en yacimientos británicos de época Romana y una de las mayores conocidas en el mundo hasta la fecha. A la vista de la valiosa información que aportan las huellas animales sobre la biología de las especies, el trabajo concluye animando al abordaje de nuevos trabajos en el área de la icnoarqueología.

PALABRAS CLAVE: PISADAS, RASTROS, *Canis familiaris*, PERRO DOMÉSTICO, VINDOLANDA, CONSTITUCIÓN, ANÁLISIS DE PASO, PERRO BRAQUIMÉLICO, ICNOLOGÍA, ICNOARQUEOLOGÍA

But Holmes! How did you come to find the footprints in the garden?
My dear Watson — because I was looking for them.
— A. Conan Doyle, «A Study in Scarlet»

INTRODUCTION

During the excavation in 2000 of a first-century A.D. military bath-house in the Roman fort-village complex at Vindolanda (Chesterholm, near Hexham, Northumberland, England), considerable quantities of brick, tile, and other ceramic building materials were uncovered (Birley, 2001). From these, a collection was made of 111 fragments which bear animal footprints. Some also carry human finger and palm-prints, and impressions made by tools, nails, textiles, and bits of wood. Animal species that made tracks at Vindolanda include domestic dog *(Canis familiaris)*, semi-feral cat *(Felis sylvestris),* domestic pig *(Sus scrofa),* sheep *(Ovis ammon),* goat *(Capra hircus),* and cattle *(Bos taurus)* (Higgs, 2001a, b). Over 80% of tracks identified by Higgs were made by dogs, and the present report focuses on these.

Much information of importance and interest can be derived from study of animal tracks and trackways preserved in an archaeological context (Cram, 1984; Roberts *et al*., 1996; Hunt & Lockley, 1997; Lockley, 1998). Since tracks are made by the living animal, they supply an independent line of observation and reasoning which may corroborate evidence from skeletal remains (Cram & Fulford, 1979). Tracks can supply data about foot morphology when foot-bones of the track-making animals are scarce or hard to assign (Lockley, 1998) as they are at Vindolanda. Fine detail preserved in some tracks gives information about hide, claws, and pelage which skeletal remains cannot supply. The distance between prints in a trackway gives an approximate idea of the shoulder or hip-height of the animal that made them (Heglund *et al*., 1974). Gait is indicated by the depth of impressions, the parts of the pawprint that are impressed most deeply, the distance between pawprints, and the spatial relationship of prints made by fore and hind feet (Halfpenny, 1986; Rezendes, 1992; Murie & Elbroch, 2005). Tracks may reflect not only morphology and gait but behavior (Rezendes, 1992).

The tracks of terrigenous quadrupeds, whether impressed in fired ceramics or in mud or sand which geological processes later turn to stone, are less often reported than skeletal remains (Lockley, 1998; McDonald *et al*., 2007). Published reports, especially of tracks made by domestic animals, are few. The Vindolanda collection of pawprints on ceramic building materials is the largest known to date from any Romano-British site and among the largest known from any area or time period. This study attempts to apply the principles of ichnological analysis to this important collection.

MATERIALS AND METHODS

Imprinted tiles were examined and a photograph made of all complete or nearly-complete pawprints. Horizontal lighting was used to bring out texture and depth (Higgs, 2001b). The surface of each tile was palpated and examined with a ten-power hand lens to locate the boundaries of those pawprints which were very lightly impressed, to facilitate measurement, and to detect fine detail. Tracks were measured with a vernier caliper, yielding the values in Table 1 and Figure 1.

Since the clay out of which many of the Vindolanda ceramics were made preserves even the whorls in human finger and palm-prints, all tracks were scrutinized for impressions made by fur growing on the animals' feet (Plates 6-10). Experiments performed by the author with modern dogs imprinting on clay indicate that we can be reasonably certain that where fur impressions are not present, the dog had a short or "smooth" coat with little or no long hair growing on the bottom of its feet (Figures 5 A, B).

The overprinting of the fore pawprint by that of the hind foot is termed "registration". Unregistered, partly-registered and registered pairs of prints were noted in order to determine gait (Table 2). Dogs' forefeet are wider than their hind feet with greater splaying of the toes, and these morphological differences, reflected in the shape of individual impressions, are the basis for differentiation of fore vs. hind prints (Bang & Dahlstrom, 1974). Although the structure of dogs' paws is more or less symmetrical about a line between digits III and IV, the toe pertaining to digit IV in both the fore and hind limbs is slightly longer than that pertaining to digit III, and in most cases this allows separation of prints made by the right vs. left paws (Evans, 1993). It should be noted that correct

FOREPAW TRACKS

Track No. (Higgs numbering)	Vindolanda Small Finds No. (SF) or other code	Tile No. (Higgs numbering)	Width of track in cm
25	7905	T-20	3.00
----	8071	T-42	3.0 est (Puppy?)
----	8122	T-104	3.12
99	7845	T-59	3.16
147	8109	T-96	3.22
75	8069	T-40	3.24
----	EXH 01	----	3.24
24	7905	T-20	3.27
83	7865	----	3.29
102	8002	62	3.36
71	7883	----	3.39
73	8069	----	3.53
17	XXX8	T-31	3.58
74	8069	T-40	3.66
----	V11-123A	----	3.66
66	7858	----	3.68
136	8102	T-87	3.80
92	7974	T-49	3.90
----	7892	----	3.96
----	8121	T-99	3.97
149	8107	T-97	3.97
77	8068	T-41	4.00
100	8117	T-60	4.09
----	8122	T-104	4.09
----	V11-123A	----	4.13
68	8033	T-35	4.15
----	EXH 01	----	4.20
----	EXH 01	----	4.25
----	8063	----	4.30
----	EXH 01	----	4.38
43	7894	T-17	4.40
46	7912	T-21	4.40
----	8073	T-64	4.47
09	7844	T-38	4.49
----	8073	T-66	4.50
146	8116	----	4.5 est
----	EXH 02	----	4.52
----	7890	----	4.55
38	7843	T-12	4.59
91	7895	T-47	4.60
22	XXX8	T-31	4.60
26	7905	T-20	4.62
----	7890	----	4.62
----	EXH 01	----	4.67
35	7831	T-9	4.7 est
----	8004	T-61	4.7 est
----	7975	T-67	4.83
----	7908	T-52	4.90
76	8068	T-41	5.31
----	7907	T-69	5.35
----	V11-137A	----	5.38
19	XXX8	T-31	5.43
87	7991	T-46	5.4 est
----	8128	T-108	5.44
80	8071	T-42	5.49
94	7891	T-50	5.54
----	8130	T-107	5.56
103	8016	T-63	5.57
42	7866	T-16	5.73
----	EXH 03	----	5.75
86	9911	T-45	5.97
----	7979	T-68	6.32
----	8077	T-73	6.45
----	8101	T-95	6.9 est
----	8094	----	6.9 est

HIND PAW TRACKS

Print No.	Vindolanda Small Finds No. (SF)	Tile No.	Width in cm
23	7905	T-20	2.57
16	XXX8	T-31	2.72
18	XXX8	T-31	2.75
148	8109	T-96	2.80
82	7865	----	2.97
49	7864	----	2.95
58	8006	T-28	3.05
101	8117	T-60	3.13
----	EXH 01	----	3.14
----	EXH 01	----	3.15
----	8124	T-105	3.18
79	8068	T-41	3.19
90	7895	T-47	3.23
----	EXH 01	----	3.24
----	8001	T-25	3.30
78	8068	T-41	3.31
72	7883	----	3.34
----	8074	T-65	3.35
----	EXH 01	----	3.36
----	7892	----	3.40
39	7843	T-12	3.42
65	7858	T-30	3.45
----	EXH 01	----	3.49
145	8116	----	3.6 est
95	7896	T-55	3.61
34	8027	T-5	3.73
----	8123	T-103	3.74
----	8063	----	3.9 est
45	7912	----	4.02
----	EXH 03	----	4.10
----	7901	T-51	4.14
143	8108	T-93	4.28
----	8089	T-78	4.41
----	V11-137A	----	4.50
87	9911	T-45	4.59
88	7991	T-46	4.59
----	7891	T-50	4.38
----	8078	T-74	4.80
----	7979	T-68	4.9 est

TABLE 1

Pawprint widths in cm. Tile and track numbers are after Higgs (2001b). Not all tiles have small finds (SF) numbers. Codes beginning with the letter "V" designate context in cases where tiles were found outside the first-century A.D. bath-house. "EXH" designates tiles currently on exhibit at the Vindolanda Museum, Chesterholm, Northumberland, England.

interpretation of gait, especially when the trackway consists of less than four tracks, depends upon correct identification of left and right tracks.

INTERACTION OF PAW AND SUBSTRATE

Properties of the substrate must be considered before tracks can be fully understood. Roman brick and tile was made by mining suitable clay, mixing it with water to the consistency of paste, and then pressing it into molds of various sizes (Figure 3). "Green" bricks or tiles were then dried in the open air until they attained "leather hardness". Brodribb (1987) states that Roman brick and tile was usually dried under a structure with a roof but no walls. In areas with arid climates today, bricks are dried in the open, and Higgs (2001b) notices that some impressions in the Vindolanda tiles may have been muted by rain (see isolated hind tracks in Plate 3, for example). Firing, of course, makes permanent any impressions made when the surface was in a soft state (Brodribb, 1987; Warry, 2010). Each day in the normal operation of a brickyard, as bricks reach the hardness necessary before firing, some are removed from the drying-ground while new ones are added (Figure 3). The whole expanse of

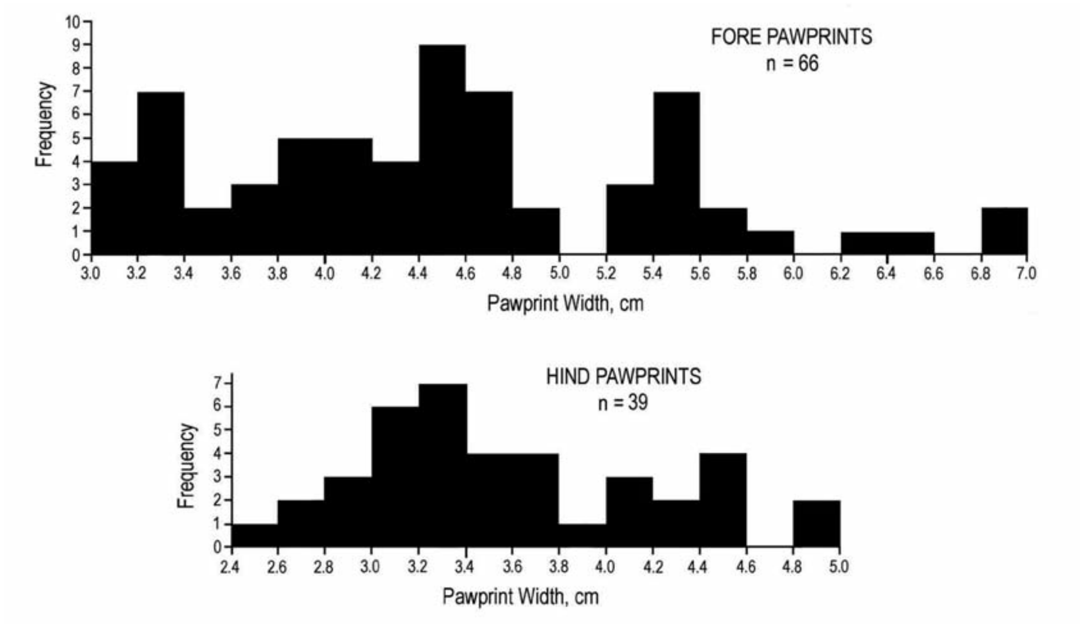

FIGURE 1

Histogram for Vindolanda hind and fore-track widths based on 2 cm size classes. Three to five peaks are evident for forepaw tracks. The hind-track histogram is aligned at the 80% point, representing the whole-sample average for hind:fore track width.

drying bricks usually, therefore, does not present a surface of uniform hardness, and an animal crossing the brickyard would therefore leave tracks of varying depth.

The depth of impressions is a function of several factors, including the shape of the animal's feet, its weight, the gait and speed at which it was moving, the composition of the substrate and its softness. Systematic investigations which control for these factors are few (Jackson *et al*., 2010), and none have been performed with animals in the weight-range of dogs moving on hardening tile or brick. The author's experience with potter's clay, wet cement, and ordinary farmyard mud shows that potter's clay is rather stiff so that dogs' footprints do not penetrate to any depth. However, potter's clay takes a fine impression. Ordinary mud will allow even a lightweight dog's paws to sink in, but fine detail is less likely to be recorded. This is even more true when the substrate is soggy or sandy [Figure 4, although see Elliott (1991: 225), illus. 2 of a brick from Newstead, Roxburghshire, England, which appears to bear the deeply-impressed pawprint of a rough-coated dog].

Potter's clay differs in composition from the material used to make brick, which is usually a mixture of clay and sand. Tile-clay and potter's clay are similarly fine-grained and are capable of recording the individual whorls in human fingerprints. In order to provide direct comparison with suspected hair marks evident in some Vindolanda tracks, the author made "tiles" of potter's clay and encouraged a cooperative 7 kg (14 lb.) Lhasa Apso (a long-haired brachymel dog breed) to walk on them. Pawprints made by the Lhasa Apso (Figure 5A) show hair marks of the same kind and pattern as those evident in Vindolanda tiles SF7883 and SF7865 (Plates 7, 8). Domestic dogs show several different types of hair ranging from coarse and wiry to fine and fuzzy (Ryder, 2000); dogs with coarse hair usually also have long hair. The red fox *(Vulpes vulpes)* has very hairy feet, but hair impressions in the pawprints of domestic dogs are distinctively different from those made by the red fox (Figures 6D, 8).

The experiment was repeated with a 25 kg (50-lb.) American Pitbull, a short-coated breed which has nearly hairless feet. This much heavier dog also did not sink far into potter's clay, rather the firmness of the substrate caused "squashing" of its toe-pads (Figure 5B). Photographs of a dog's feet show the toes in closed position, but when the dog stands on its feet and makes a pawprint, the toe-pads broaden as the feet are weighted. The toes also spread apart, even on a firm substrate, although they spread more when the substrate is soft (Cabrera, 2011). Pawprints therefore can be expected to measure wider than the same dog's closed and unweighted foot (Figure 7).

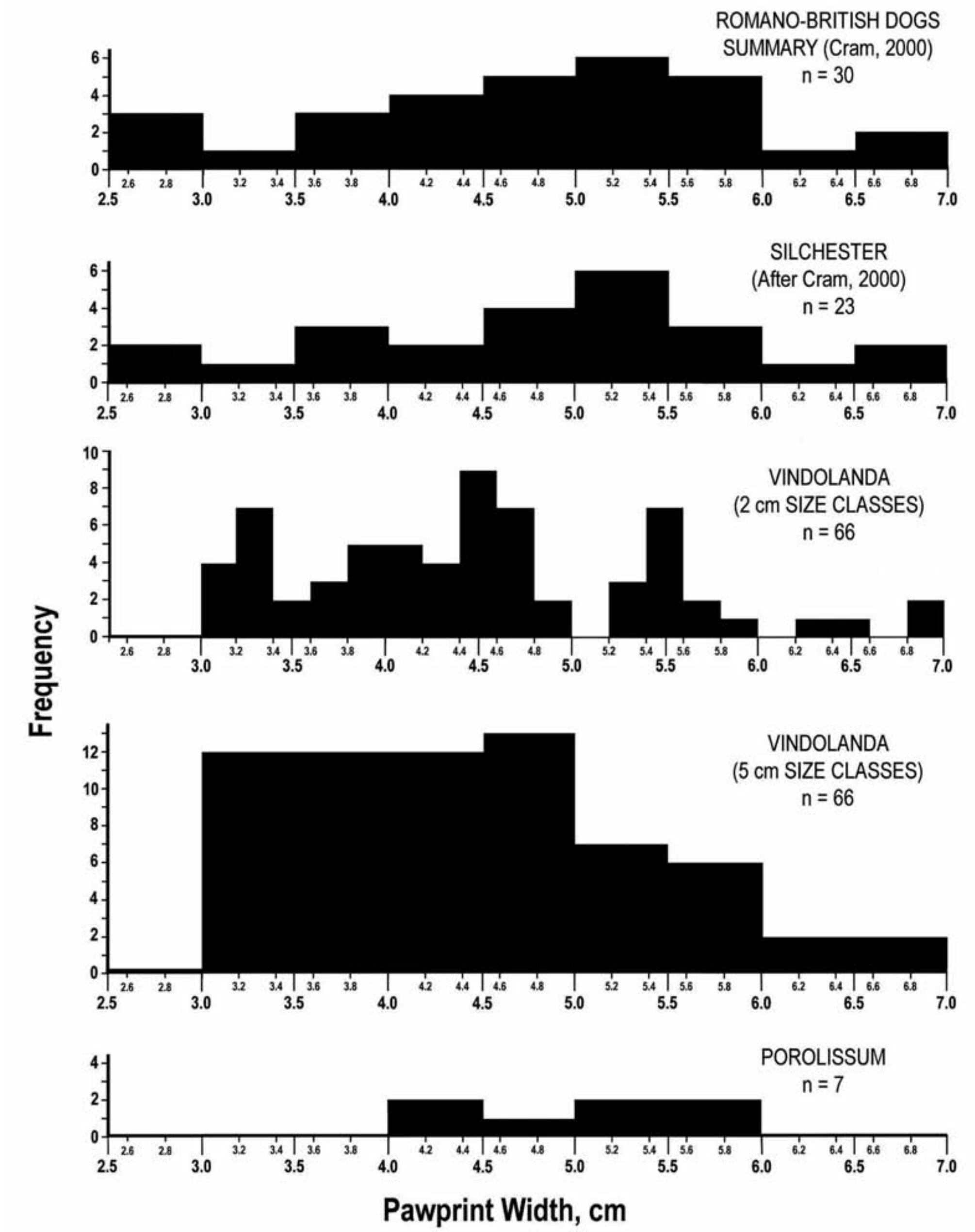

FIGURE 2

Histograms representing fore track widths based on arbitrary 5 cm size classes for Vindolanda, Silchester (Cram, 2000), Porolissum (Gudea, 2004), and Romano-British localities other than Silchester (Cram, 2000). The 2 cm Vindolanda histogram is presented at the same scale for ease of comparison. Average fore-track width is less at Vindolanda than at other localities.

Identification Codes and Plate Number	Measured Widths, In cm	Track relationship	Probable Gait	Remarks
T-60, P100LF and P101LH; SF 8117	4.09F 3.13H	Left hind entirely behind left fore; all parts of both feet impressed to about equal depth	Slow walk or standstill	Center axes of tracks are parallel and feet have normal anatomy
T-31, P22LF and P21LH; SF XXX8 Plate 1	4.60F	Left hind entirely behind left fore.	Slow walk	The dog appears to have walked over a rag lying upon the tile, pressing the texture of the rag into the substrate. The rag was later moved, creating a drag mark
T-51, unnumbered right hind and fore, SF 7901	4.14H	Right hind overprinting right fore. Heel pads deeply impressed, especially the hind foot	Slow walk	Oblique registration with a divergence of about 13 degrees
T-28, P56RF and P53RH, SF 8006	3.05H	Right hind over right fore	Slow walk	Directly aligned, but the hind toes are rather far behind the front toes
SF 8063, unnumbered right fore and hind prints	4.30F 3.90H	Right hind barely reaching right fore	Slow walk	Oblique registration with divergence of about 35 degrees
SF 8109, T-96, P147LF and P148LH.	3.22F 2.80H	Left hind barely reaching left fore	Slow walk	Oblique registration with inverted divergence of about 16 degrees, indicating bowlegged hindlimb conformation
T-12, P38RF and P39RH, SF 7843	4.59F 3.42H	Right hind overprinting right fore	Walk	Offset by ½ the width of the track
T-31, P16LH, P17LF, P18RH; SFXXX8 Plate 1	3.58F 2.72H 2.75H	Left hind overprinting left fore; print 18 is the right hind; the right fore is missing	Walk	Direct registration
P96LF, P95LH, SF 7896	3.61H	Left hind overprinting left fore	Walk	Oblique registration with a divergence of about 8 degrees

T-30, P64RH and P65RF, SF 7858	3.45H	Right hind overprinting right fore	Walk	Side-gaiting walk; twisted toes. Likely made by brachymel dog.
T-52, unnumbered left hind and fore, SF 7908	4.90	Left hind overprinting left fore	Walk	Direct registration
P45RH and an unnumbered fore track; SF 7912	4.02H	Right hind overprinting right fore	Walk	Direct registration
P92RF and P93RH, SF 7974	3.90F	Right hind overprinting right fore	Walk	Offset by ½ the width of the track
P83LF and P82LH, SF 7865 Plate 7	3.29F 2.97H	Left hind overprinting left fore	Walk	Offset by ½ the width of the track; hair marks; structurally normal feet
P71LF, P72LH, SF 7883 Plate 8	3.39F 3.34H	Left hind overprinting left fore	Walk	Offset by ½ the width of the track; hair marks; structurally normal feet
T-47, P91LF and P90LH, SF 7895 Plate 4	4.60F 3.23H	Left hind overprinting left fore	Walk	Direct registration
T-63, P103LF and P104LH, SF 8016	5.57F	Left hind over left fore	Walk	Oblique registration with divergence of about 35 degrees
T-40, P74RF and unnumbered associated hind print; P75LF and unnumbered associated hind print; SF 8069	3.66F 3.24H	Apparently the same dog going over its own tracks in opposite directions	Walk	Oblique registration with divergence of about 20 degrees. The hind print of the "northbound" set almost obliterated by the fore print of the "southbound" set
T-93, P143RF and unnumbered partial right hind print; SF 8108	4.28H	Right fore overtracked by right hind	Walk	Oblique registration, the hind track falling almost entirely clear of the fore print, with an angle of divergence of about 25 degrees

T-45, P86LF and P87LH; SF 9911	5.97F 4.59H	Left fore overprinted by left hind	Walk	Direct registration, although toes of hind foot do not come as far forward as those of the forefoot
V11-137A; unnumbered fore and hind prints	5.38F 4.50H	Left fore overtracked by left hind	Walk	Offset registration
Unnumbered and partial right hind and fore prints; SF 8077	6.45F	Right fore overprinted by right hind; hind toes almost level with fore toes	Vigorous walk or slow trot	Oblique registration with divergence of about 8 degrees
T-74, unnumbered right fore and hind prints; SF 8078	4.80H	Right hind overprinting right fore; hind toes level with fore toes	Vigorous walk or slow trot	Offset registration
T-69, unnumbered right hind and fore prints, SF 7907	5.35F	Right fore on top of right hind	Trot	Heel pad impression is present but light; toes impressed slightly more deeply. Offset by ½ the width of the track.
T-31, P19LF and P20LH; SF XXX8 Plate 1	5.43F	Left hind passing left fore; heel pads of both are barely visible	Trot	Straight alignment. The pad of medial digit II left no impression; the mark from lateral digit V may have been obliterated by subsequent tooling
Unnumbered and partial left hind and fore prints; SF 8074	3.35H	Left hind over left fore, with hind toes ahead of fore toes	Trot	Direct registration
T-68, unnumbered left hind and fore prints, SF 7979 Plate 5	6.32F 4.90H	Left hind overprinting left fore	Side-trot	Offset by almost the whole width of the track, and the hind toes are ahead of the toes of the forepaw.
T-20, P26RF and an unnumbered right hind print; SF 7905 Plate 2	4.62F	Right fore pawprint, partly obscured by P23LH and human finger-marks. The right hind print is overtracked by the fore	Side-trot	Toes impressed more deeply than heel; offset by 3/4ths the width of the fore track. The axes of the feet diverge about 33 degrees.

T-96, P147LF and P148LH	2.80H	Left fore passed by left hind	Side trot	The hind toes do not come as far forward as the fore toes. The angle of divergence between the centerlines of hind and fore prints is about 16 degrees
T-78, unnumbered right fore and hind prints, SF 8089	4.41H	Right fore passing right hind	Side trot	Offset registration
T-105, unnumbered right fore and hind prints, SF 8124	3.18H	Hind toes almost as far forward as fore toes; toes more deeply impressed than heels	Side trot	Divergence is about 8 degrees
P49RH, SF 7864 Plate 11	2.95H	Right hind with very light heel mark but toes deeply impressed.	Trot or canter	Toy-sized; structurally normal feet; rather long claws
T-20, P23LH, P24LF, and P25RH, and an unnumbered partial right fore pawprint (just the tips of the toes); SF 7905 Plate 2	3.27F 3.00F 2.57H	Fore tracks passed by hind tracks.	Canter	This trackway consists of four related prints. The left hind print is mostly obliterated by human finger-marks. Heel and toe-pads impressed to about equal depth.
P146LF and P145LH, SF 8116 Plate 15	4.50F 3.60H	Left fore passed by left hind. Hind impression very faint, but the fore print is quite deep, especially anteriorly	Canter	Straight trackway, axes of fore and hind prints parallel
T-41, P76LF, P77RH, and P78LH SF 8068 Plate 3	5.31F 4.00F 3.31H	Difficult to interpret because the three tracks are all of different sizes. Assumption is made that 76 and 77 are left and right hind of the same animal.	Gallop	This trackway consists of 3 related prints. Heel pads of the forepaw and right hind paw are impressed only lightly, while that of the left hind paw made a deep impression, as if the animal had suddenly decided to decelerate

T-87, P136RF and unnumbered partial hind print; SF 8102	3.80F	Fore print with deep toe impressions but fainter heel, and a related single toe of a hind print	Gallop	The dog was moving fast, with most of its weight on the forehand

TABLE 2

Description of Vindolanda dog tracks that are indicative of gait. Descriptions are grouped by gait. Plate numbers are given for ease of reference to Higgs' (2001b) catalog.

FIGURE 3

Brick-making by the ancient method being carried on in Mexico today. Note the lighter appearance of wet, freshly-formed bricks. An animal crossing the Vindolanda tileyard would also likely have found substrate of varying firmness.

Track size is affected by substrate in two ways. The wetter it is, the broader the track will be. On the other hand, the clay used for Roman brick and tile, as well as modern potter's clay, shrinks up to 10% as it dries and any surface impressions shrink in the same proportion (Cram & Fulford, 1979).

SPECIES IDENTIFICATION

Identification of track-making species is accomplished by morphological comparison, in a manner analogous to the identification of bony remains. Terminology for carnivore footpads is given in Figure 6.

During Roman times, six species of carnivores existed in the area of Vindolanda which could have left pawprints in unfired tiles and bricks:

1. Cat *(Felis sylvestris)* – semi-feral in Roman times, and often larger than modern domestic cats. Skeletal remains of cats are known from the Vindolanda bone collection (Hodgson, 1977; Bennett, 2005).
2. Dog *(Canis familiaris)* – Dogs of several sizes are known from skeletal remains to have existed at Roman Vindolanda (Hodgson, 1977; Hambleton, 2004; Bennett, 2005).
3. Red Fox *(Vulpes vulpes)* – Hodgson (1977) reported fox bones from Vindolanda.

FIGURE 4

Track made in wet silty loam by a 7 kg male Lhasa Apso. This is the print of the right forepaw. Note the weak impression of the medial toe-pad, the irregular depth, and the lack of fine detail. A track in this type of substrate preserves only the general shape of the dog's paw, and the track will measure wider than the paw.

FIGURE 5A

Track made on a smoothed «tile» made of potter's clay by the same Lhasa Apso as in Figure 4. This is the print of the left forepaw made at a standstill. The pattern of hair growing from between the dog's toes and on the bottom of its foot can clearly be seen. There are only two claw-marks; the animal had just had its toes clipped.

FIGURE 5B

Track made in potter's clay by a 25 kg American Pitbull, a breed with a very short coat. The bottoms of this dog's feet are nearly hairless; although the clay captures the texture of the animal's footpads, no hair marks are evident.

FIGURE 5C

Track made in potter's clay by a 6 kg domestic cat. This is the impression of the right forepaw. Note the short antero-posterior dimension of the track and the clearly trilobate posterior margin of the interdigital pad. The cat was standing still on the clay and not spreading its toes when it made this impression. Hair marks are evident especially along the anterior margin of the interdigital pad. Claw marks impressed for all four toes because this cat spends almost all of its time inside its owner's house and has rather long claws.

Breed	Shoulder Height, cm Male	Shoulder Height, cm Female	Track width, cm Forepaw	Track width, cm Hind paw	% track width, forepaw/ shoulder height X 100**
American Pit-Bulldog	44.0	----	6.2	----	14% male
*Chihuahua	13.0	13.0	2.3	2.2	18% male and female
*Jack Russell Terrier	31.5	29.0	4.5	4.0	14% male 14% female
*Bearded Collie	53.0-56.0	51.0-53.0	5.7	----	10-11% male
*Border Collie	53.0	53.0***	5.7	4.0	11% male 8% female
*Flat-Coated Retriever	58.0-61.0	56.0-59.0	7.6	6.5	13% male 11-12% female
*Lercher (puppy)		38.0	3.5	3.2	9% female puppy
*Lercher	----	56.0	5.4	----	10% female
*German Shepherd	62.5	57.5	6.5	5.6	10% male 10% female
*Greyhound	71.0-76.0	68.0-71.0	4.9	4.7	6-7% male 6-7% female
Lhasa Apso	18.0	----	3.8	----	21% male
*Wolf	70.0-80.0	----	10.0-11.0	7.0-8.0	12-16% male

*Data summarized from Cram (2000) and Bang and Dahlstrom (1974)
**Rounded to the nearest whole percentage
***Near estimate

TABLE 3
Measured track width and withers height for some modern dogs.

4. Wolf *(Canis lupus)* – Both Hodgson (1977) and Bennett (2005, 2007b) discuss the possible presence of wolf, for some very large doglike bones have come from the Vindolanda excavations, but wolf has not been definitely identified. Harcourt (1974) likewise assigns most large canid bones to *C. familiaris,* even though paleontologic and zoogeographic studies indicate that *C. lupus* was present in Britain during the centuries of Roman occupation (Kurtén, 1968).
5. Badger *(Meles meles)* – Bennett (2005) reported badger skeletal remains from Vindolanda.
6. Marten *(Martes* cf. *martes)* – Bennett (2005) reported skeletal remains of a large pine marten.

This paper also illustrates and compares the conformation of the feet and pawprint morphology of the coyote, *Canis latrans.* Although fissiped, the tracks of badger and marten are distinctive and none with that morphology have been noted in the Vindolanda collection, although badger tracks have been reported on tiles from another site of Roman age (Bar-Oz, 2010).

PAWPRINTS OF CATS AND "CAT-FOOTED" DOGS

Higgs (2001a, b) identifies 16 pawprints in the Vindolanda collection made by cats vs. 265 made by dogs. Cats represent only about 6% of total carnivore footprints, yet in morphology they are similar enough to those of dogs to merit discussion. Foot anatomy dictates not only the shape, but the range of potential variations in shape, of the track an animal can make (Spira, 2001; Anton *et al*., 2004). Cats' forefeet are wider relative to their length than those of canids; the outline of a cat's pawprint is nearly circular. Because cats can spread their toes much more than can dogs, the impressions made in the pawprint by the cat's individual toe-pads are often spaced widely apart. Cats tend to spread their toes when moving at speed, but also when they find themselves traversing wet or soft substrates (Bang & Dahlstrom, 1974; Higgs, 2001b).

The interdigital pad of the cat has a deeply multilobate form which often impresses a scalloped posterior edge (Figures 4C). Pawprints of domestic or semi-feral cats can be up to 7.5 cm wide (about 3 inches), overlapping the lower end of the size range for domestic dogs. Moreover, some dogs that have short, upright feet and round toe-pads —referred to as "cat-footed" by dog fanciers– leave tracks that are rounder in outline than those of dogs with other foot conformations (Spira, 2001) (Plate 12). However, since cats have retractable claws, where claw impressions are seen in the pawprint –particularly if the claw marks are broad or the tip-mark is far from the impression made by the toe-pad– the print is probably that of a dog (Rezendes, 1992). Cat claw-marks, when present, tend to be thin and deep (Bar-Oz, 2010; but see Figure 5C).

The canid interdigital pad has a smooth, narrowly U-shaped anterior margin that reaches well forward to a point between the lateral toe-pads. The rear border of the interdigital pad may be broadly U- or V-shaped and is shallowly divided into three lobes (Figures 5A, B and 6). Claw impressions are typically, but not inevitably, present in the pawprints of canids. They are more likely to be absent when made by a dog moving slowly (Bang & Dahlstrom, 1974; Murie & Elbroch, 2005). They may also be absent if the dog has had its nails clipped, or if one or more have been worn down or broken.

When the substrate in which the tracks are made is fine-grained, hair impressions are possible. Only hairs present on the bottoms of the feet, or long hairs hanging down around the margins of the foot, will leave impressions in a track (Figure 5).

DIFFERENTIATING PAWPRINTS OF WILD CANIDS *vs.* DOMESTIC DOGS

Pawprints of the four canids under consideration range *in toto* from about 3 cm (1 1/8 in) to

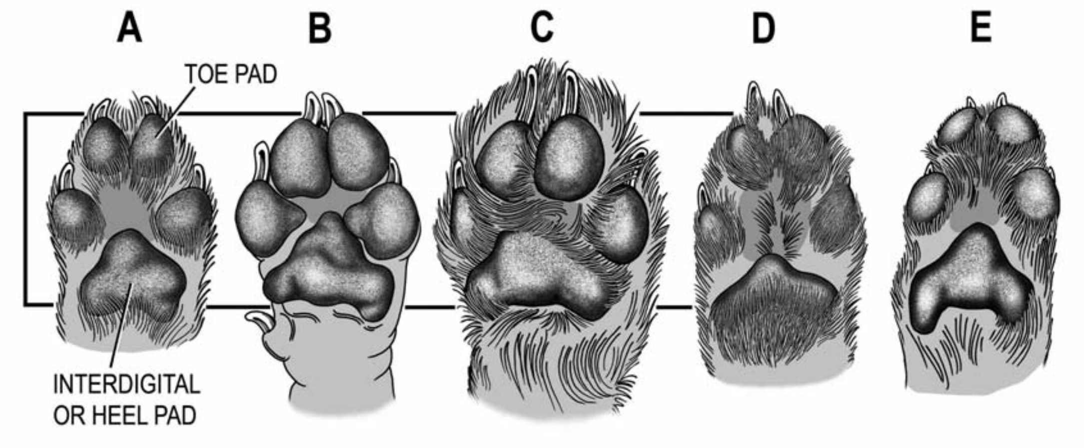

FIGURE 6

Forepaw proportions of five canids. The images are not to scale, but in order to make proportional differences stand out, they have been reduced to the same length from tip of digit IV to deepest indentation of interdigital pad. All have been drawn from field photographs with special attention to hair growth on the bottom of the foot. A, Wolf *(Canis lupus)*. B, American Pitbull *(Canis familiaris)*. C, Lhasa Apso *(Canis familiaris)*. D, Red Fox *(Vulpes vulpes)*. E, Coyote *(Canis latrans)*.

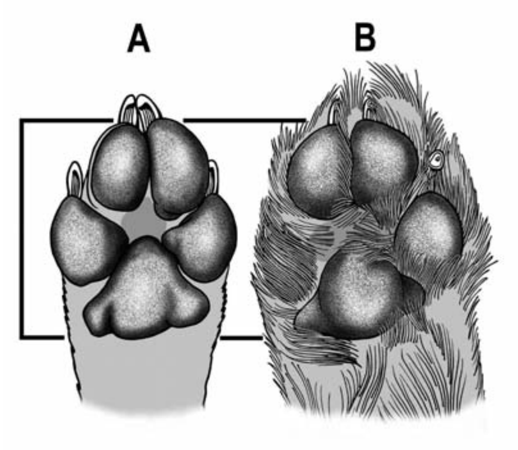

FIGURE 7

Hind paw proportions not to scale, as in Figure 6. A, American Pitbull (a skeletally normal dog). B, Lhasa Apso (a brachymel breed). As with the forepaw, the hind paw in the brachymel dog is noticeably wide for its antero-posterior length.

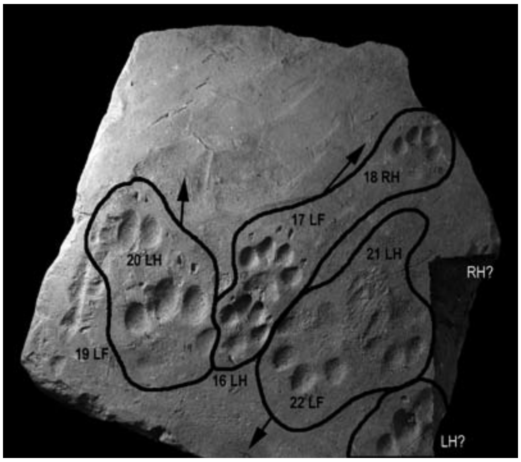

PLATE 1

SF XXX8, T-31. Corner tile preserving fragments of four trackways. Lines and arrows here and in Plates 2 and 3 have been supplied for ease of visualization, and numbering follows Higgs' system (Will Higgs, pers. comm.).

about 13 cm (5 1/2 in) wide (Rezendes, 1992). The length of canid forepaw prints is typically about 10% greater than their width, so that the track has an oval shape overall. Hind prints are narrower than those made by the forefoot (Table 1, Figure 7, and Plates 1-5, 7-8, 11, 14). At Porolissum in Romania, and also at Stonea Grange in England, hind prints average about 90% the width of the fore prints of the same animal (Legge, 1996; Gudea, 2004). Hind prints of dogs at Silchester average only 82% as wide as those of the forepaw (Cram & Fulford, 1979). The sample size for measured hind and forepaw prints combined at Porolissum is 7; for Silchester it is 34; for Stonea Grange, only 4. Vindolanda hind prints (n = 39) average 80% the width of forepaw prints (n = 66).

The red fox has feet covered with coarse hair. The hair grows not only from between the toes but also from the toe-pads and interdigital pad. Hair impressions are therefore characteristic of red fox pawprints (LeRue, 1968; Rezendes, 1992) (Figure 6D). In wet mud or snow, red fox foot-pads make impressions with distinct margins, but if the substrate is drier, the margins will be indistinct or "fuzzy"-looking due to the hair covering (Rezendes, 1992). The hair that grows from the red fox's interdigital pad tends to part along a chevron-shaped line paralleling its anterior margin. Hairs ahead of this line grow forward while those behind it grow backward. The line of parting itself is narrow, hairless, and prominent, and shows in the pawprint as a chevon-shaped "bar". Where present, this bar is diagnostic of the tracks of red fox (Rezendes, 1992) (Figure 6D, 10).

Long or "rough"-coated dogs have furry feet; short-coated dogs have feet that range from moderately hairy to nearly hairless (AKC Dog Handbook, 2005 and see the British Kennel Club website, 2011). Hair on dogs' feet grows only from between the toes and from the skin between the toe pads and interdigital pad – never from the pads themselves. This is true also of the feet of wolves and coyotes (LeRue, 1968; Rezendes, 1992) (Figure 6).

The forepaws of the coyote, and its pawprints, are noticeably longer and narrower than those of the wolf or dog; in both proportions and size, they resemble the red fox (Rezendes, 1992) (Figure 6D, E). The wolf and dog are morphologically almost indistinguishable (Figure 6A-C), but only the largest modern domestic dogs –those with humerus length of more than about 170 mm— overlap the size range of the wolf. Postcranial bones of a size to match small wolves have been reported from a number of Romano-British sites (Harcourt, 1974) including Vindolanda (Hodgson,

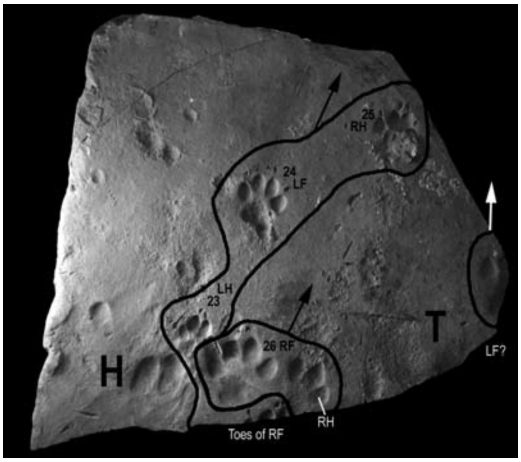

PLATE 2

SF 7905, T-20. Large fragment of a bipedalis preserving two partial trackways, one isolated forepaw track, human finger-prints (H) and textile marks (T).

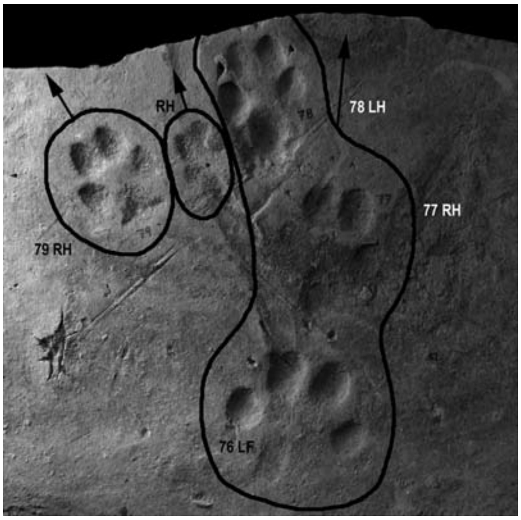

PLATE 3

SF 8068, T-41. Pedalis preserving one partial trackway and two isolated hind paw tracks, one made by a dog noticeably smaller than the others. The two isolated tracks might have been muted by rain (see Higgs, 2001b: 56).

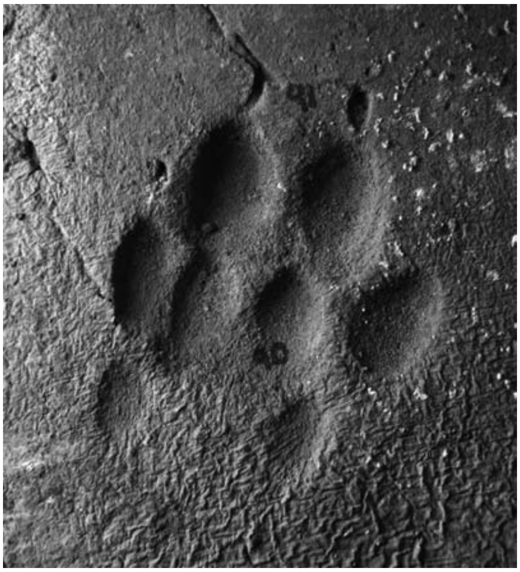

PLATE 4

SF 7895, T-47. An example of direct registration in a track made by a walking dog, left hind overprinting left fore. This track reflects normal foot conformation.

PLATE 5

SF 7979, T-68. Enlarged detail showing left hind overprinting left fore. The hind toes fall ahead of the fore toes, and the track is offset, indicating that the track-making animal was proceeding at a vigorous side-trot. Note the outward divergence of the axis of the hind track, suggesting normal hindlimb conformation.

1977), but postcranial remains of dogs are difficult to differentiate from those of wolves and so far no skeletal remains from Vindolanda can definitely be assigned to wolf (Bennett, 2005). The largest canid fore pawprint recorded from the Vindolanda collection (estimated 6.9 cm, about 2 ¾ in.) is,

PLATE 6

SF 7905, T-20. Enlarged detail of the hind track of a dog surrounded and partially obscured by human fingerprints. Tile clay is capable of preserving fine detail.

PLATE 7

SF 7865. Enlarged detail showing left hind tracking up to the rear margin of left fore. Impressions of the hair that grew from the bottom of the dog's foot are clearly visible. This dog had structurally normal feet.

moreover, too small to have been made by even the smallest adult wolf. All canid pawprints in Vindolanda tiles were made by domestic dogs (Higgs, 2001a, b).

DOG CONFORMATION AND TRACKWAY CHARACTERISTICS

The forefeet of a well-conformed dog face forward or turn slightly outward, but with defective conformation they turn considerably, either outward or inward. Likewise, defective conformation of the hindlimb causes the hind paws to orient excessively either outward or inward (Elliott, 2001; Spira, 2001).

"Breakover" subsumes the chain of events which occur in the short period of time during which the foot is picked up, between the last moment when it is fully planted and when it clears the ground (Goubaux & Barrier, 1892; Pollitt, 1995; Elliott, 2001; and see also the wider discussion in Peters, 2000). The "line of breakover" is the area of the foot which is last in contact with the ground; it is perpendicular to the direction in which breakover occurs.

The feet of skeletally normal or "wild type" dogs face forward, but those of brachymel dogs are sometimes more or less twisted outward [i.e. "east-west feet" or "fiddle-fronted" conformation; Teichert (1987), Spira (2001)], which causes breakover to occur over the medial digits. Conversely, the forepaws of broad-chested dogs may orient inward ["pigeon-toed" "bowed front", Spira (2001)], so that breakover occurs over the lateral digits. In a track, toe-marks on the side of the foot over which breakover occurs will be more deeply impressed. Likewise, habitual breakover that is far in either direction from the center toes will tend to twist the toenails in the opposite direction, and this too will show up in the animal's tracks. Three Vindolanda tiles, SF 7892, 8002 and V11-123A, show twisted pawprints (Plates 12, 13). The pair of

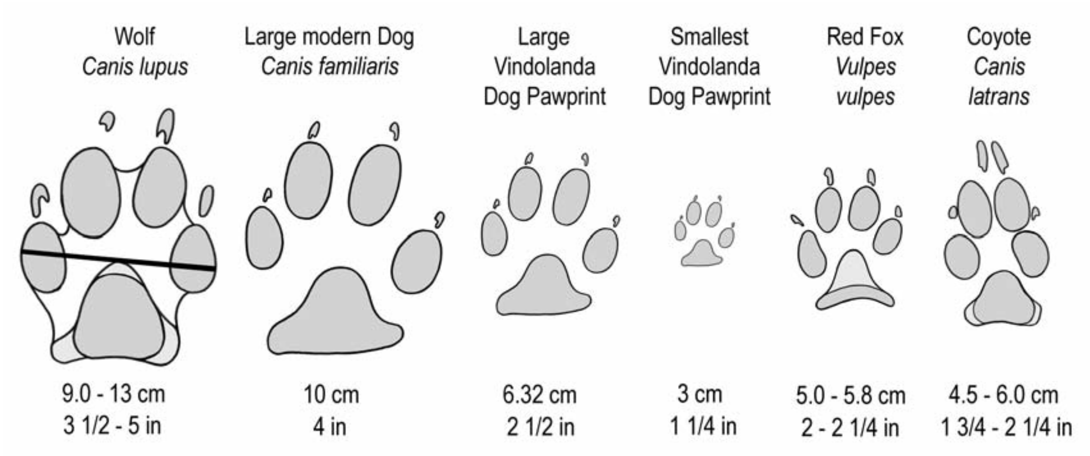

FIGURE 8

Track morphology for four species of canid, showing the size range of Vindolanda tracks. These images are to scale, with track widths given. Track widths measured as shown by the black bar across the wolf track.

forepaw prints on the tile from context V11-123A (Plate 13) are so strongly turned outward that the left forepaw appears to be a right, and vice-versa. Left and right prints on that tile measure 3.66 and 4.33 cm respectively, which is in the size range expected for brachymel dogs of the Roman era. Asymmetrical development of left and right limbs –which would produce different forepaw widths— has been documented in a brachymel dog from Vindolanda (Hambleton, 2004).

The hind limbs of all quadrupedal mammals are built so that the axial plane of the limb is oriented at an angle which diverges outward from the sagittal plane of the body. This allows the stifle joint (the anatomical knee joint) to clear the ribcage when the hindlimb is protracted (Figure 9A,B, 10B). The wider the rear part of the ribcage, the more the limb must orient outward (Bennett, 1989), although if the dog is long-backed or short-legged, this requirement is lessened (Elliott, 2001).

The orientation of the axis of the hind limb relative to the sagittal plane of the body is also the plane in which protraction occurs. Thus, when a normally-conformed dog protracts a hind limb, the toes orient and strike the ground in a plane oblique to the sagittal plane of the body. This causes the print of the hind foot to orient outward from the sagittal plane of the body about 10 to 35 degrees more than that of the forefoot, which is usually oriented more parallel to the body axis (Figure 9; Table 2; Plate 3). Breakover in the hind foot, particularly at slower gaits, is thus typically not over the central toes but medial to them, so that the medial side of the hind pawprint is often more deeply impressed than that of the lateral side (Plates 2,5,6,7,8).

Modern domestic dogs frequently present defective hindlimb conformation, and it is possible for a dog's hind feet to orient either too much outward ("cow hocks") or too much inward ("bandy behind" or bowlegged) (Spira, 2001). As with defective conformation of the forelimb, hindlimb conformation is reflected in tracks and trackways. Vindolanda tile SF 8109 preserves fore and hind pawprints of a dog that was apparently bowlegged behind, with its toes orienting toward rather than away from the axis of the fore print and the hind toenails twisted medially (Plate 14). Concomitantly, it is the lateral aspect of this track which is more deeply imprinted.

GAIT AND TRACKWAY CHARACTERISTICS

An excellent summary of gait characteristics as they relate to trackways of quadrupedal mammals can be found in Halfpenny (1986); the principles and biomechanics of gait, and methods of quantifying gait, have been set forth by Hildebrand (1965, 1974) and Biewener (1990). Trackway information in this section comes from Halfpenny (1986), Rezendes (1992) and Murie & Elbroch (2005). Dogs utilize numerous gaits, including walk, trot, pace, canter, transverse gallop, and rotatory gallop. Bennett (1992) reviewed footfall order and interaction between spinal and limb dynamics for the same gaits in horses. Using X-ray cinematography, Elliott (2001) gives extensive and insightful discussion of normal and faulty gait in dogs.

When the dog is standing, walking, slowly pacing or trotting slowly, the toes of the hind print do not fall as far forward as those of the fore print. The speed of the walk, but also the length of the dog's back relative to the length of its legs, dictate how far behind the fore print the hind print will fall (Elliott, 2001). Only when the dog accelerates into a vigorous pace, trot, canter, or gallop do the hind impressions fall level with or ahead of those made by the forefeet, and the faster the dog runs, the farther ahead the hind prints then appear.

Wolves, foxes and coyotes typically produce trot trackways in which the hind print directly registers on the fore print, and the trackway thus consists of a straight row of prints. Domestic dogs do not always produce registered trackways; much more frequently than wild canids, they use a variant style called "side trotting" in which the axis of the body is carried at an angle to the direction of travel. For example, if the dog carries its hindquarters to the left of its forequarters, depending upon how much the axis of the dog's body diverges from its line of progression, the print of the right hind may fall between, directly behind, or to the left of the print of the left forepaw. The oblique orientation of the body usually also prevents the hind print from coming as far forward as the fore print (Figure 9B).

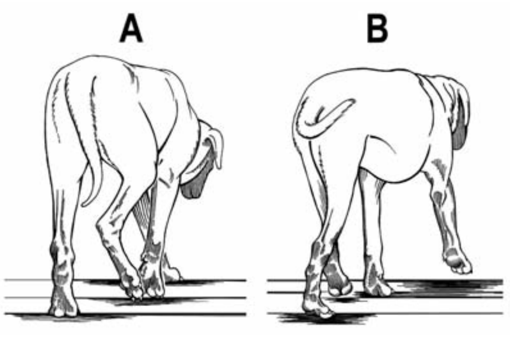

FIGURE 9

Rear views of moving dogs illustrating the reason for angled and offset track pairs. A, The moment of registration at a walk. B, Dog side-gaiting at a trot. The image captures the moment of push-off from the left diagonal pair (right hind and left fore), with the right diagonal pair protracting. Note the outward angulation of the protracting hind foot in both views. In B, the dog's hindquarters are carried about 20 degrees to the left of its line of progression. Because of this, its right hind track will fall directly behind the track of the left fore, while the left hind track will fall to the left of all other tracks (Images re-drawn after Muybridge, 1887).

Side-gaiting also causes the center axis of individual footprints, both fore and hind, to orient at an angle to the direction of travel. This detail is not evident in the diagrams presented in most track-identification handbooks (that by Rezendes (1992) is a refreshing exception), but close examination of actual trackways makes it plain. Thanks to the above-mentioned fact that the hind feet of mammals normally orient outward, if a dog side-gaits with its haunches to the left of its forequarters, the print made by the right hind leg will appear to deviate to the right considerably from the line of travel, while that made by the left hind leg will appear to orient nearly straight forward (Figure 9B).

Canids utilize two forms of gallop, transverse and rotatory. The rotatory gallop is the gait of wild carnivores, but only the more athletic breeds of domestic dog are capable of it. Long-backed, brachymel breeds typically find the rotatory gallop difficult, as do arthritic dogs (Elliott, 2001). While the canter and transverse gallop contain but a single period of suspension per stride, the rotatory gallop is sometimes called the "double-suspension gallop" because it contains two periods of suspension per stride. The first period of suspension in a rotatory gallop is longer than the second. As its speed increases, the dog may spend more total milliseconds in suspension than with feet in contact and thus almost literally flies over the ground (Elliott, 2001) (Figure 10).

Dogs flex their spines more when in rotatory gallop than when in canter or transverse gallop, enabling the prints of the hind paws to fall ahead of those of the forepaws (Hildebrand, 1974). The trackway pattern produced by a cantering dog (one using a transverse gallop) is distinctive: sets of four pawprints in offset diagonal rows in which impressions from fore and hind feet alternate (from back to front: fore-hind, fore-hind) (Plate 2). The rotatory gallop, by contrast, produces a shallowly "C"-shaped pattern in which the hind pawprints fall ahead of those made by the forepaws (from back to front, fore-fore hind-hind). The faster the dog runs in a rotatory gallop, the farther ahead of its foreprints the hind prints will fall (Figure 10). The gauge of the trackway will also become narrower thanks to lateral flexion of the spine in running (Carpenter, 2009), so that the normally "sloppy" trackway of a domestic dog will look almost as tidy as that made by the red fox or coyote.

Individual prints in the trackway of a dog moving at speed –whether cantering or using a rotatory gallop— are typically asymmetrical, with the foreparts of both fore and hind feet imprinting much more deeply than the heel; sometimes all of the interdigital pad is absent from the track. Claw marks of the central two toes of fore and hind feet will normally be clear, but the faster the dog runs, the less the side toes touch the ground, especially behind (Rezendes, 1992; Plates 11, 15).

TRACKWAYS IN TILE AND BRICK

Trackways consisting of more than two related pawprints are rare in collections of imprinted Roman ceramic building materials because, in the normal course of brickyard operation, moist "green" bricks are laid out every day but bricks that have hardened sufficiently for firing are removed (Figure 3). Although firing makes pawprints permanent, the chance of finding a long trackway is lessened because after firing the ceramics may then be utilized in different parts of a building, or in different buildings being built at the same time. Conversely, ceramics from more than one tilery or brickyard might be incorporated into a single building (Cram & Fulford, 1979). Ceramics may also be salvaged for re-use. This was the case with Vindolanda tiles coming from second-century A.D. contexts V11-123A and V11-137A, which were salvaged by Roman soldiers or villagers from the same first-century A.D. bathhouse from which the rest of the Vindolanda collection comes (Andrew Birley, pers.comm.).

Trackways of animals moving across a grid of hardening tiles at any gait above a walk must also be rare, because as speed increases so does the dis-

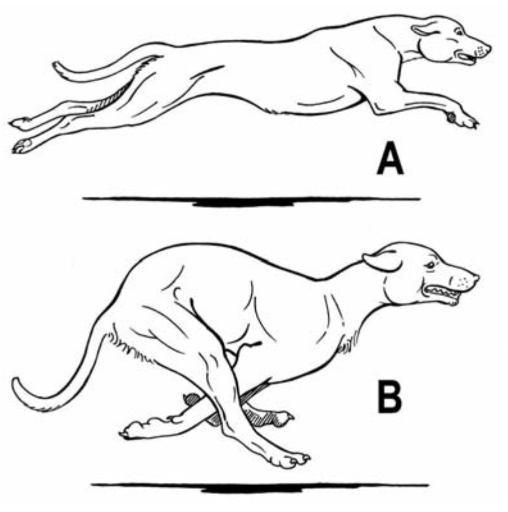

FIGURE 10

Dog moving at top speed. A, Female greyhound in the first period of suspension of a right-lead rotatory gallop. B, Same dog in the second period of suspension. The footfall order is: right hind, left hind (suspension), left fore, right fore (suspension). View B clearly shows why hind tracks fall ahead of the fore tracks in a rotatory gallop.

PLATE 8

SF 7883. Enlarged detail showing left hind tracking up to the rear margin of left fore. Hair impressions are clearly visible. This dog was walking, and had structurally normal feet.

PLATE 9

SF 7890, T-50. Enlarged detail of a track made by left fore which shows the texture of the dog's footpads. No hair marks are visible. At the top of the plate, there is an impression made by the head of a nail.

tance between related tracks in a trackway, lessening the chance that related prints will be impressed in bricks or tiles of the usual sizes. Exceptionally large tiles, such as were sometimes produced for use in the corners of a room, are more likely to capture multiple pawprints (Higgs, 2001b and Plates 1-3).

PLATE 10

SF XXX8, T-31. Enlarged detail of a left hind track. The dog walked slowly over a piece of woven cloth which was lying upon the wet surface of the tile, and in doing so pressed the texture of the cloth into the tile. Someone later pulled the rag away, creating a ridged drag-mark (Higgs, 2001b: 55).

TRACK DIMENSIONS AND WITHERS HEIGHT

Cram (2000) was the first to take the sensible step of measuring the withers height and pawprint width of some modern dogs. However, the data set (even with some additions) is very small (Table 3). What the limited data do make clear is that because of proportional variation, withers height cannot be predicted directly from pawprint dimensions. Cursorial dogs with gracile build have small feet for their height (Cram, 2000; Kemp *et a*l., 2005). Likewise, toy (midget) and especially brachymel (dwarf) dogs have paws that are wide in proportion both to their withers height and to the antero-posterior length of the paw (Table 3, Figure 6C). The pawprint made by a brachymel dog predicts a withers height greater than the animal actually presents, just as the footprint made by a dog with gracile build predicts a withers height less than the animal actually presents.

RESULTS AND DISCUSSION

SIzE DISTRIBUTION OF VINDOLANDA PAWPRINTS

When size classes of Vindolanda forepaw prints are defined at about the limit of measurement accuracy (2 mm) (Table 1, Figure 1A), five fairly distinct peaks appear. Three to five peaks are apparent when size classes are defined at 5 mm (Figure 2). Since the size range for brachymel dogs overlaps the range that subsumes structurally normal small to medium sized dogs, it is not possible to determine which size-class or classes contain them, because dogs with different build cannot be differentiated on the basis of pawprint width. Neither is more sophisticated statistical analysis of the Vindolanda pawprint widths a viable approach, due to the small population within each size class. The accompanying histogram (Figure 1) does indicate that dogs of different size (and thus most likely of different height, build, and weight) must have been present.

Skeletal remains provide direct evidence of the size and conformation of Vindolanda dogs. Postcranial bones scaling dogs with withers heights greater than 70 cm are present in the Vindolanda collection (Harcourt, 1974; Hodgson, 1977). On the basis of Cram's (2000) data, such dogs

–assuming that they were of normal rather than gracile build— can be expected to leave pawprints at least 6.5 cm wide. There are two fore pawprints in the Vindolanda collection that correspond to these dimensions; such pawprints appear at Vindolanda at about the same frequency as in other localities in Roman Britain. There are no dog bones from Vindolanda or any other Romano-British site large enough to suggest withers height over about 75 cm (Harcourt, 1974; Cram, 2000), although wolves may top 90 cm (Nowak, 1991). A 90-cm wolf would leave a pawprint about 13 cm wide (Murie & Elbroch, 2005).

When size classes of paw prints from Vindolanda are defined at arbitrary 5 mm intervals, a histogram emerges with a large block of instances between 3.0 and 5.0 mm, i.e. in the range that describes brachymel, small, and medium-sized dogs. The preponderance of dogs of these sizes at Vindolanda differs from Silchester (Cram, 2000) and other published Romano-British localities [summarized by (Cram, 2000)], which show five peaks and a more even frequency distribution (Figure 2). A small sample of pawprints from Porolissum in Romania (Gudea, 2004) likewise ranges from 4.0 to 6.0 cm in width. Fore pawprints less than 3.0 cm in width are absent from the Vindolanda collection. Several Romano-British sites have produced dog postcrania with miniature rather than brachymel morphology. Fore pawprints of these dogs might have been less than 3.0 cm in width (Harcourt, 1974; Baxter, 1997, 1998, 2010). Skeletal remains of miniature dogs from Vindolanda are currently under analysis (Bennett & Timm, in prep.).

While hind tracks average 80% the size of fore tracks in the Vindolanda collection, it should be remembered that the animal that made each trackway is an individual, and there is no such thing as an "average animal". The Vindolanda collection contains 35 sets of tracks that can reasonably be assumed to have been made by the same animal (Table 2). Among these, the hind pawprint averages 82% the width of the fore pawprint, but the range is large, from 62% to 99%. Because of this, it is difficult to decide where to place the histogram representing hind pawprint width relative to that for the fore pawprints. Figure 1 places it at the 80% point (the average for the whole population of tracks), which produces a reasonable but not perfect alignment of peaks. This can probably be accounted for by the fact that hind track width is more affected by the animal's speed and the firmness of substrate than is the width of the fore track.

HAIR AND CLAW IMPRESSIONS AND OTHER FINE DETAIL

Besides preserving the whorls in human fingerprints (Plate 6), Vindolanda tiles often preserve the texture of dogs' foot pads (Plate 9). Higgs (2001b) notes several textile impressions preserved in the tiles; in one instance, a dog evidently stood upon a rag spread upon a tile. The rag was later moved, creating a ridged drag mark that partially distorted the track (Plate 10).

Most dog tracks preserve claw-marks. Generally the claws are short and rather wide. Dog tracks with long claws (Plate 11) may indicate house-pets which did not roam very much. This track is the hind pawprint of a miniature dog measuring only 2.95 cm wide, one of the smallest in the collection.

PLATE 11

SF 7864. Enlarged detail of a right hind track. This small dog was probably moving at a trot or canter; tips of the central toes are deeply impressed but the interdigital and lateral toe-pads are very light. The dog had long claws.

PLATE 12

SF 8002, T-62. Enlarged detail of a "cat-footed" dog, that is one with a round track shape and round toe-pads. This animal's toenails are twisted laterally and the medial part of the track is more deeply impressed, suggesting "fiddle-fronted" conformation sometimes seen in brachymel dogs.

Two Vindolanda tiles, SF 7865 and SF 7883, preserve hair impressions on hind and fore pawprints (Plates 7, 8). Legge (1996: 513) notices hair impressions in the track of a dog or fox on a single tile from Stonea Grange. This is the only previous mention of hair impressions on Roman building ceramics found in the literature, but because tile-clay is usually fine-grained, this surely represents an oversight rather than the absence of long-haired dogs from the majority of Roman-era sites.

Roman writers described various breeds of dog (Anonymous, 1913; Alcock, 1996), and there are hundreds of intentionally representational contemporary images of Roman dogs [summarized by Toynbee (1973), but see also Bibliotheca Alexandrina (2011); Romano-British dog images are summarized by Alcock in Cram (2000)]. The author's own survey of Roman dog images suggests the existence of at least five different dog "morphologies", which may or may not equate to breeds in the modern sense (Bartosiewicz, 2000; DeGrossi Mazzarin & Tagliacozzo, 2000; Baxter, 2006).

The remains of brachymel dogs are distinctive and frequent from Romano-British sites (Teichert, 1987; Baxter, 1997, 1998, 2006, 2010; Cram, 2000), and Vindolanda is no exception (Hambleton, 2004).There were certainly long and short-coated brachymels – for example, in a mosaic from the Great Palace, Istanbul, where both long and short-coated terriers are shown together in a hunting scene (Bibliotheca Alexandrina, 2011). A well-known statuette of a long-haired brachymel dog comes from Coventina's Well at Carrawburgh (Roman Procolita or Brocolita) in Northumberland, less than 5 miles from Vindolanda (Toynbee, 1973).

There were probably also long-coated as well as short-coated coursers or deerhounds, and woolly-coated sheep-guarding dogs [see Bibliotheca Alexandrina (2011), image of a courser in a mosaic at the British Museum, and many images of the Turkish guard/hunting dog or "Kuvash" in Brewer *et al*. (2001)]. A single deep pawprint made on a brick from Newstead appears to be that of a "rough-coated" dog of moderately large size (Elliott, 1991: 225, illus. 2).

As mentioned above, size alone cannot differentiate pawprints made by brachymel vs. structurally normal dogs, but the tendency of brachymel dogs for "fiddle fronted" bandy-legged conformation, which moves the line of breakover toward the medial aspect of the forepaw and which tends to twist the toes and claws, is frequent among modern brachymel breeds. Vindolanda tiles SF 7858, SF 8002, and V11-123A evince fore pawprints with twisted claws (Plates 12, 13) while SF 8109 indicates a dog that was bowlegged behind (Plate 14). Interestingly,Vindolanda tracks that show hair-marks all reflect normal foot morphology.

PLATE 13

V11-123A. Enlarged detail of a pair of fore pawprints made by a bandy-legged dog with forepaws turned outward. The medial parts of both tracks are more deeply impressed, and both the claws and the toes are twisted laterally.

GAITS USED BY VINDOLANDA DOGS

Gait analysis has not been carried out for Silchester or any other Romano-British pawprint site except Stonea Grange. There, Legge (1996) records 13 tracks of walking dogs or 42% out of a total of 31 tracks from which gait could be gauged. Only 3 tracks in the Stonea Grange collection (10%) indicate that the dog was moving at a gait faster than a walk.

Vindolanda presents a larger sample size, with 35 sets of related tracks indicating gait. In three cases, gait could be either of two possibilities so these instances have been counted twice to give a total sample size of 38. At Vindolanda, 59% of track sets indicate that the animal was walking, 28% trotting and 13% cantering or galloping. Of a total of 12 impressions made by trotting dogs, 5 (45%) were using the side-gait variant.

PLATE 14

SF 8109, T-96. Enlarged detail of left hind coming forward to the posterior margin of left fore; only the claws and toe-tips of the hind foot overprint the forefoot. This dog's hind feet orient inward about 16 degrees compared to the axis of the forefoot, indicating bowlegged hindlimb conformation. Note the heavily impressed lateral aspect of the hind track, and the medial "twist" to the claws.

The average fore pawprint width of walking dogs at Vindolanda is 4.5 cm while the average hind pawprint width is 3.6 cm (i.e., the hind print measures on average 80% the width of the fore print). The figures for trotting dogs are 5.6 cm and 3.8 cm (H:F = 68%) respectively, while those for cantering or galloping dogs are 4.0 and 3.1 cm (H:F = 77%) respectively. The average width for all Vindolanda fore pawprints is 4.5 cm and the average width for hind pawprints is 3.6 cm (H:F = 80%). These figures suggest that dogs of all sizes were about equally likely to utilize walk, trot, or canter/gallop gaits when crossing the Vindolanda tileyard. This contrasts with cat pawprints analyzed by Higgs (1981a, b), most of which seem to show the animal bounding or running. The lower H:F percentages for trotting and cantering dogs suggest that when moving at speeds greater than a walk, the dogs tended to tilt their bodies somewhat forward, carrying relatively more weight upon the forepaws and less upon the hind paws. The forepaws then leave deeper and somewhat broader tracks, while the hindpaw tracks become shallower, narrower, and sometimes partial. The same phenomenon occurs, although to a lesser degree, in trotting and galloping horses (Goubaux & Barrier, 1892).

PAUCITY OF WILD ANIMAL TRACKS

Besides the tracks of dogs, Higgs (2001a, b) catalogs tracks made in Vindolanda tiles and bricks by cattle, sheep or goat, and pigs. Although this is a wider representation than at any Romano-British site other than Silchester (Cram & Fulford, 1979; Cram, 2000), it by no means represents all species known from skeletal material at Vindolanda (Bennett, 2007b).

Cram & Fulford (1979) suggest that the reason there are no tracks of wild animals in the Silchester collection is that the tileyard ground was fenced. However, the Silchester collection contains cattle tracks and even one made by a pony, so that if there was a fence, the gate must sometimes have been left open.

The location of the Vindolanda tileyard certainly influenced the likelihood of its being crossed by wild animals. Clay was mined from pits just south of the first-century A.D. bath house (Andrew Birley, pers. comm.). Geophysical survey of an area north of the Stanegate Road near the Vindolanda fort points up a strong anomaly which may represent the kiln used for production of bricks and tiles. The tileyard was probably located on nearby open ground to the north and west of the kiln (Andrew Birley, pers. comm.). This area lies within 200 m of the steep and wooded valley of the Chineley Burn (Birley, 2001). In the first century A.D., the stream-valleys surrounding Vindolanda certainly harbored deer, feral pigs, hares, badgers, foxes, pine martens, otters, voles and birds. However, logging was an ongoing enterprise, so that oak building beams utilized at Vindolanda in the second century A.D. likely had to be brought in from a considerable distance (Blake, 2007; Tyers, 2007).

Cram & Fulford (1979) suggest that a tilery operated by the Roman military, as that at Vindolanda certainly was (Birley, 2002), might have invited less trackmaking because human activity would have gone on there around the clock. The tile-yard, they suggest, would be guarded at night. Apparently, however, if night guards were present at Vindolanda, they were more concerned with protecting the army's valuable livestock than with shooing animals off the tiles (Birley, 2002). Soldiers on night duty likely patrolled a fairly large area, utilizing dogs to assist them in discouraging visits by wild animals — and cattle rustlers. It is not unreasonable to speculate that some of the pawprints on Vindolanda tiles may, in fact, be those of herd-guarding dogs.

PLATE 15

SF 8116. Enlarged detail showing left fore passed by left hind. The anterior parts of the fore track are deeply impressed while the whole of the hind track is very lightly impressed, indicating that the dog was cantering or galloping.

Cram & Fulford (1979) report chicken and crow tracks at Silchester. Chickens were kept by the wife of the first-century A.D. Vindolanda commandant (Birley, 2005, 2009) and there are chicken bones from Vindolanda contexts of all periods (Bennett, 2007a). In the first century, however, chickens were still considered a luxury food reserved for consumption by the social elite (Alcock, 2001), and the entire Vindolanda flock at that time was probably penned within the commandant's private compound inside the fort, rather than being permitted to run at large. The same may probably be said for domestic and semi-domestic ducks and geese (there is so far no record of these at Vindolanda until the second century A.D. (Bennett, 2007a), although some were probably present earlier). More problematic is the absence of peck-marks and tracks made by ravens, crows, and other wild birds which are known from the Vindolanda bone collection (Bennett, 2007a) and from nearby Birdoswald (Izard, 1997).

OVER-REPRESENTATION OF DOG TRACKS

Vindolanda's bone collection is one of the largest known from any Roman-era site (Stallibrass, 1995), with 14 species of mammals and 10 species of birds so far identified (Bennett, 2007a, b). The three species most frequently represented by bony remains, in descending order, are cattle *(Bos taurus),* domestic pig *(Sus scrofa),* and sheep or goat *(Ovis ammon* or *Capra hircus)* (Bennett, 2007b). Skeletal remains of dogs are known from every Vindolanda context, both within and outside of the fort, and from every time period (Bennett and Timm, in prep.). Dog bones are not rare (about 5% of the collection as opposed to about 60% cattle bones) but they do not compare in frequency to cattle. Dog tracks are therefore highly over-represented on Vindolanda tiles and bricks.

A modern joke holds that dogs are "magnetically attracted" to wet cement, and there may be some truth to this; perhaps different types of mud exude odors or have other characteristics that especially attract dogs. Apart from the possibility that soldiers on herd-guarding duty brought dogs into the vicinity of the tileyard, it is conceivable that villagers who owned dogs customarily let them loose in the evening to forage – and to bark at strangers. All Roman settlements, moreover, contained a population of un-owned camp and pariah dogs which were tolerated (as free-roaming pigs were also tolerated) because of their propensity to eat garbage (Brewer *et al*., 2001; Birley, 2002). There are frequent literary references as well to dogs that roamed tomb and sacred precincts, cleaning up any scraps they could find (Alcock, 2001; DeGrossi Mazzorin & Minniti, 2002; Smith, 2006).

SKELETAL VARIABILITY IN ROMAN-ERA DOGS

The total range of variability in the skulls of modern domestic dogs exceeds that of the entire Order Carnivora (Drake & Klingenberg, 2010). The postcranial skeleton in the domestic dog varies less but still considerably (Van Valkenburgh, 1980), and selection for different body morphology has produced dramatic differences in limb bone shapes and properties of modern dogs (Kemp *et al*., 2005). While dog skeletons of the Paleolithic, Neolithic, Bronze Age and early Iron Age vary little from a putative "primitive" morphology (for example, see Churcher, 1993), the Roman invasion of Britain marks the beginning of an era of much wider variability. Miniature or "toy" skeletons appear for the first time, brachymels become common, new skull types emerge, and the biggest dogs get bigger (Harcourt, 1974). Roman-era dogs in Italy, the Eastern empire, and North Africa reflect the same trends (Bökönyi, 1974; DeGrossi Mazzarin & Tagliacozzo, 2000; MacKinnon & Belanger, 2006). The Vindolanda collection contains skull and postcranial bones of a wide array of dogs, from fairly small (estimated 34 cm withers height) to almost as large as any previously reported from Roman Britain (estimated 71 cm withers height) (Bennett, 2005; Bennett & Timm, in prep.).

The Vindolanda pawprint collection probably does not represent either the smallest or the largest dogs that lived in the fort and village. Fore pawprints less than 3.0 cm wide have been recorded from other Romano-British sites (Cram & Fulford, 1974; Cram, 2000), and the biggest Vindolanda tracks are only half the size of pawprints expected from the biggest dogs indicated by skeletal remains. This anomaly may be explained by the fact that in first-century A.D. Britain, both very small and very large dogs were rare and valuable. Roman animal breeders understood perfectly well that in order to maintain consistent physical type in a bloodline, uncastrated males must be controlled and breeding-ready females must be sequestered (Anonymous, 1913; Hall, 1993). Valuable dogs –great and small— may thus have been chained up or kept in closed kennels.

CONCLUSIONS

Tracks and trackways preserved in an archaeological context are a valuable source of data which may illuminate aspects of soft-tissue anatomy, pelage characteristics, gait and behavior which skeletal remains usually cannot. Tracks supply data about foot morphology when foot-bones of the track-making animals are scarce or when most skeletal elements are not found in articulated relationship, as at Vindolanda.

Track morphology of dogs is different from that of cats, foxes, coyotes, wolves, and other carnivores. All carnivore tracks in the Vindolanda collection are those of cats or dogs, and all canid tracks are those of domestic dogs. Dog tracks are over-represented on Vindolanda tiles likely because dogs were brought into the tileyard by guards. Pariah dogs from the Vindolanda village may also have made tracks. The frequent and menacing presence of dogs may at least in part explain the absence on the Vindolanda tiles of tracks made by wild mammals and peck-marks or tracks made by wild birds.

The Roman invasion of Britain marks the beginning of an era of great variability in the body morphology of domestic dogs. Measurement of Vindolanda pawprints suggests that three to five different sizes of dogs left tracks. Forepaw tracks less than 3 cm wide are absent from the Vindolanda sample, as are tracks wider than 6.9 cm. The Vindolanda tile-track collection thus probably does not represent either the smallest or the largest dogs that lived at the site during the first century A.D. This anomaly may be explained by the fact that, at that time, both very small and very large dogs were considered valuable and were not permitted to roam.

For several reasons, trackways containing even one complete stride (four related pawprints) can be expected to be rare when impressed in tile or brick:

1. Yards typically contained tiles or bricks in various states of hardness.

2. When building ceramics containing tracks were removed for firing and utilization, no attempt was made to preserve the integrity of the trackway.
3. The distance between tracks made by trotting, cantering, and galloping dogs exceeds the dimensions of most individual tiles or bricks.

Dogs of all sizes appear to have been about equally likely to utilize walk, trot, or canter/gallop gaits when crossing the Vindolanda tileyard. Sidegaiting at the trot was common at Roman Vindolanda, as it is today.

Fine detail preserved in tracks indicates that some first-century A.D. Vindolanda dogs had long or "rough" coats and hairy feet. Comparative experiments conducted with modern dogs and cats show that hair impressions could have been recorded for long-haired dogs, red foxes, or cats. Hair impressions have been noted in only one other Roman-era tile-track collection, but this surely represents an oversight rather than the absence of long-haired dogs from the majority of Roman-era sites. Intentionally representational Roman artwork from every part of the empire shows both long and short-coated dogs. Future workers are encouraged to look at pawprints impressed in tile at 5X resolution or higher in order to detect hair marks.

Skeletal elements of brachymel dogs are frequent in the Vindolanda skeletal collection. Tracks with "twisted" morphology and concomitantly marked medial or lateral breakover suggest that brachymel dogs with "fiddle fronted" and bow-legged conformation existed at Vindolanda during the first century A.D.

Withers height cannot be predicted directly from track dimensions because both brachymel and gracile dogs' paws are disproportionate compared to "wild type" dogs. Nonetheless more data relating paw and track width to withers height, body weight, conformation, step length and stride length would increase understanding of dog trackway parameters and facilitate archaeo-ichnological analysis.

Cram & Fulford (1979) point out the necessity of comparing the frequency of pawprinted tiles with the total tile population. More data would help to define the total size range of dogs that made tracks, as well as the frequency of dog tracks compared to those made by other animals, especially wild species. The Vindolanda sample should be compared with track data from other Romano-British sites, sites located in other parts of the Roman empire, and from those both older and younger in age.

Many more pawprinted tiles undoubtedly exist than have been formally reported. Tracks in tile can be expected to occur, at least at low frequency, in any world area and at any time period where brick or tile construction was utilized. Future workers are encouraged to succeed as Sherlock Holmes did – by first appreciating the value of the information that tracks can give, and then by looking for tracks in places where it is reasonable to expect them.

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