DINOSAUR TRACKSITES OF THE PALUXY RIVER VALLEY (GLEN ROSE FORMATION, LOWER CRETACEOUS), DINOSAUR VALLEY STATE PARK, SOMERVELL COUNTY, TEXAS

James O. Farlow[1], Mike O'Brien[2], Glen J, Kuban[3], Benjamin F. Dattilo[1], Karl T. Bates[4], Peter L. Falkingham[5], Laura Piñuela[6], Amanda Rose[1], Austin Freels[7], Cory Kumagai[1], Courtney Libben[1], Justin Smith[1], and James Whitcraft[1]

[1]Indiana-Purdue University, 2101 East Coliseum Boulevard, Fort Wayne, IN 46805 USA

[2]Texas Parks and Wildlife Department, 4200 Smith School Road, Austin, TX USA

[3]Strongsville, OH 44136 USA

[4]University of Liverpool, L69 3GE England

[5]University of Manchester, M13 9PL England

[6]Museo del Jurásico de Asturias, Colunga, Asturias, España

[7]Manchester College, North Manchester, IN 46962 USA

Abstract–In 1940 R.T. Bird of the American Museum of Natural History collected segments of a sauropod and a theropod trackway from a site in the bed (Glen Rose Formation; Lower Cretaceous) of the Paluxy River, in what is now Dinosaur Valley State Park (Glen Rose, Texas, USA). However, Bird left undocumented thousands of other dinosaur footprints this and other Paluxy tracksites. In 2008 and 2009 our international team carried out fieldwork to create detailed photomosaics of extant Paluxy tracksites, using GIS technology to combine these with historic maps and photographs. We also made photographs, tracings, LiDAR images, and

measurements of individual footprints and trackways. Paluxy dinosaur tracksites occur in more than one tracklayer, but the largest and most spectacular footprints occur in the Main Tracklayer, a 20-30 cm thick, homogeneous dolomudstone that is thickly riddled with vertical invertebrate burrows (*Skolithos*). There are two dinosaur footprint morphotypes in the Main Tracklayer: spectacular sauropod trackways (*Brontopodus*) and the far more numerous tridactyl footprints, most or all of which were made by large theropods (possible ornithopod prints occur in a tracklayer stratigraphically higher than the Main Tracklayer). Tridactyl footprints are highly variable in quality; Paluxy tracksites collectively constitute a natural laboratory for investigating how trackmaker-substrate interactions create extensive extramorphological variability from a single foot morphology. Trackways of bipedal dinosaurs show a "mirror-image" distribution, suggesting movement of animals back and forth along a shoreline. In contrast, most sauropod trackways head in roughly the same direction, suggesting passage of a group of dinosaurs. The trackways collected by R.T. Bird suggest that at least one theropod was following a sauropod.

INTRODUCTION

Although Native Americans (cf. Mayor, 2005), Spanish explorers, and early Anglo-American settlers may have observed them, the first person known to have seen dinosaur footprints in the carbonate bedrock of the Paluxy River or its tributary streams was a truant schoolboy, George Adams, at the beginning of the 20th Century (Farlow, 1987; Jasinski, 2009). Young Adams called the tridactyl footprints to the attention of his teacher, who recognized them as dinosaur tracks. Brief descriptions of these trace fossils were published by Ellis W. Shuler (1917, 1935, 1937), who created two ichnotaxa, *Eubrontes (?) glenrosensis* and *E.*

titanopelopatidus, to accommodate them (regrettably, the type specimen of *Eubrontes (?) glenrosensis* was incorporated into the wall of an outdoor bandstand, where it has suffered due to weathering; Adams et al. 2010). Subsequently tridactyl tracks were found to be common throughout the area of outcrop of the Glen Rose Fm and other Lower Cretaceous units across central Texas (Wrather, 1922; Gould, 1929; Albritton, 1942; Langston, 1974, 1979; Skinner and Blome, 1975; Farlow, 1981; 1987; Sams ,1982; Pittman, 1989; Hawthorne et al., 2002; Rogers, 2002; Farlow et al., 2006).

But the Paluxy hid even bigger ichnological secrets. By the mid-1930s local residents were aware of enormous footprints of quadrupedal animals that their discoverers assumed were elephants (Jasinski, 2009). These ichnites were made known to science by Roland T. Bird, a fossil collecter for Barnum Brown of New York's American Museum of Natural History (AMNH) (Bird, 1985). Visiting an Indian trading post in Gallup, New Mexico on his way home from the field, Bird saw putative footprints of a tridactyl dinosaur and a gigantic human in loose slabs of rock. Upon inquiry he learned that they had come from Glen Rose, Texas, and so he stopped there for a look. Although the "tracks" Bird had seen in Gallup turned out to be forgeries carved by a local entrepreneur (George Adams himself) for sale to unsuspecting tourists, Bird discovered that the tridactyl footprints were based on authentic originals in the bed of the Paluxy River. He was also shown indistinct, elongate, "mystery" prints in the riverbed that the locals called "man tracks" or "moccasin tracks." Most importantly, Bird learned of the huge "elephant" footprints, which he immediately recognized as having been made by sauropods.

Bird described the tridactyl and sauropod footprints in a brief popular article (Bird, 1939), in which he also talked about the mysterious "man tracks." The last were mentioned in the hope of amusing oil magnate Harry Sinclair, an important patron of Barnum Brown's dinosaur-hunting forays (Farlow, 1985).

Bird returned to Texas in 1940, with federal support in the form of a Works Progress Administration work crew, to collect portions of trackways of a sauropod and an apparently following theropod (Bird, 1941, 1944, 1953, 1985). The footprints and the surrounding rock were quarried out in pieces, and eventually reassembled behind the skeleton of an *Apatosaurus* at the AMNH. A second segment of the two trackways was assembled in an outbuilding of the Texas Memorial Museum (TMM) in Austin, and individual footprints were collected for other institutions.

Unfortunately, Bird's 1939 exercise in grantsmanship resulted in dramatic "blowback." Religious fundamentalists who literally interpreted the events of the biblical book of Genesis concluded that Bird's "man tracks" were genuine, particularly large examples of which had been made by the giants (*Nephilim*) of Genesis 6:1-4 (Attridge, 2006). The co-occurrence of human and dinosaur footprints in the Glen Rose Formation was further cited as evidence against both the antiquity of the earth and scientific descriptions of the evolution of life (Numbers, 2006). The "man tracks" figured prominently in creationist publications, most notably Stanley Taylor's 1970 film *Footprints in Stone* and Morris' (1980) book. However, some creationists were skeptical of the "man track" claims (Neufeld, 1975), and in the 1980s, the scientific community also responded, providing evidence that those human prints that were not out-and-out fakes or the caprices of weathering were in fact preservational variants of tridactyl dinosaur footprints, particularly of prints made during an unusual style of locomotion for the huge reptiles (see Milne and Schafersman, 1983; Cole and Godfrey 1985; Hastings, 1986, 1987; Kuban, 1986, 1989a, b; Farlow, 1987 and references cited therein), an interpretation that will be further documented in this paper.

At the same time, interest in the dinosaur footprints of the Glen Rose Formation in and of themselves, and not in the context of the "man track" controversy, was renewed (Farlow, 1987, 1993; Farlow and Hawthorne, 1989; Pittman, 1989; Hawthorne et al. 2002; Rogers, 2002; Farlow et al., 2006), as part of revived worldwide interest in dinosaur trace fossils more generally (e.g. Gillette and Lockley, 1989; Thulborn, 1990; Lockley, 1991; Leonardi, 1994; Lockley et al., 1994; Gierlinski, 1995; Lockley and Hunt, 1995; Sanz et al., 1997; Leonardi and Mietto, 2000; Lockley and Meyer, 2000; Colectivo Arqueológico y Paleontológico de Salas, 2001, 2006, 2009; Pérez-Lorente et al., 2001; Lockley, 2002; Moreno and Pino, 2002; Huh et al., 2003; Pérez-Lorente, 2003; García-Ramos et al., 2004; Whyte et al., 2010). The Paluxy River sauropod tracks were formally named *Brontopodus birdi* by Farlow et al. (1989), and recognized as the prime example of "wide-gauge" sauropod trackways (Farlow, 1992b; Wilson and Carrano, 1999; Romano et al., 2007; Marty et al., 2010).

Dinosaur Valley State Park (DVSP) was created in 1970 to protect the dinosaur tracks of the Paluxy River and surrounding natural areas (Jasinski, 2009). Although the park hosts thousands of visitors each year, paleontologists who have not seen the park may not be aware that Bird's collecting activities merely scratched the surface of DVSP's ichnological riches. During the 1980s and 1990s Kuban (sometimes working with one or more associates) mapped dozens of trails on several sites. In the same period Farlow repeatedly visited the park to carry out field work, but was overwhelmed by the enormity of the task that adequate documentation of the Paluxy's tracksites would entail. In 2008 and 2009, however, a serendipitous coming together of financial support, technological resources, and manpower made possible intensive documentation of several major tracksites exposed in the bed of the Paluxy in DVSP by an international team of workers. The present paper summarizes the goals of this work, describes our field and laboratory activities, and presents our preliminary findings.

METHODS AND GOALS

Supported by grants from funding agencies in the U.S., Spain, and the U.K., we assembled an international team to document thoroughly dinosaur tracksites within the boundaries of DVSP that still preserved significant footprint assemblages, and that also were not covered by gravel and sand river deposits so large as to be impossible, or too disruptive to the park's aquatic and riparian ecosystems, to clean. Additional Paluxy tracksites than those described here are known to exist or have existed (Kuban, 1986; Farlow, 1987; Hawthorne, 1990), but will not be discussed in this paper.

Our project has several long-term goals, which have only partly been accomplished thus far:

1) to create an updatable database of footprint and tracksite information;

2) to determine the number of kinds of footprint morphotypes and the number of individual animals responsible for the tracksites;

3) to document the range of variability of footprint shapes within each morphotype, and the sediment factors responsible for that variability;

4) to determine the appropriate nomenclature to apply to the tridactyl footprints;

5) if possible, to determine the interval of time over which tracklayers accumulated footprints;

6) to determine what the animals were doing as they made the tracks.

Our efforts were aided by drought conditions in 2008 and 2009 that either exposed tracksites that are normally underwater, or at least lowered water levels covering the footprints enough to make photography possible. Even so, working conditions were not always ideal. By late morning breezes usually became strong enough to create ripples in the water surface, reducing visibility of submerged footprints. In 2009 a strong thunderstorm moved along the valley of the Paluxy, dumping enough rain onto the watershed to create a river rise high and powerful enough to shut us down for a few days, and submerging for the duration of our fieldwork some important sites that had hitherto been dry. R.T. Bird (1985) experienced similar frustrations.

Field methods included both low-tech and high-tech approaches. Often assisted by volunteers from across the state of Texas, we began by cleaning sediment off tracksites, using brushes, push brooms, power hoses, shovels, and wheelbarrows. Once a site was cleaned, if the tracksite surface was above water we drew a meter-square chalk grid over it. We then used a Trimble GeoXh GPS system with Trimble Hurricane antenna to georeference footprints and other features of tracksite surfaces, and photographed overlapping sections of tracksites that were then stitched together using Arcview 9.3 to create photomosaics of tracksite surfaces. We also took thousands of photographs of individual footprints and trackways, both at ground level and from an elevated platform. Where possible, we traced the surface outlines of individual footprints or trackways on sheets of plastic, and directly measured footprint and step lengths and individual footprint bearings. Casts were made of some of the better preserved tridactyl dinosaur footprints. In order to characterize vertical burrows in the Main Tracklayer, an oriented sample, about 20 cm thick and 40 cm by 30 cm wide, was collected in place as it was in the process of eroding from the edge of the Main Tracklayer in the Blue Hole Parlor site. This sample was cut into two perpendicular vertical slabs and into 8 horizontal slabs, each 2 cm thick, with the exception of the bottom and top slab, which were cut a little thicker.

For comparison with previous stratigraphic studies (e.g. Hawthorne, 1990), a stratigraphic section was measured along the river bank outside the eastern boundaries of the park. It was measured to centimeter precision by marking 10 cm intervals on the exposure. Beds were observed, photographed, described, and sketched in the field from this framework.

To document the AMNH-TMM footprint slabs, the fully portable RIEGL LMS-Z420i 3D laser scanner was chosen for its ability to rapidly acquire spatial data (12,000 x, y, z and intensity points per second). A 6.1 megapixel Nikon D100 digital camera was mounted on the scanner and, once calibrated, provided images that were used to extract an RGB colour channel and reflection intensity information for the point cloud, to texture map the final model, and to produce a photorealistic representation of the track blocks (e.g. Bates et al., 2008). Both track blocks were scanned from multiple perspectives to provide more detailed 3D shape information by eliminating “shadows” (areas not visible to the laser) caused by irregularities in the exposure surface. Both perpendicular and oblique scan perspectives were necessary to eliminate shadows occurring in the tracks themselves. Point clouds captured from different perspectives were aligned using PolyWorks (Bates et al., 2008) to form a merged network of scans of aligned to extremely high precision (standard deviation less than 10^{-7}). Merged point clouds of the two separate track blocks were then surfaced using Geomagic to produce high-resolution triangulated meshes, which were contoured and shaded according to topography. The polygonal meshes of the AMNH and TMM blocks were imported into Maya (a CAD package) and rotated until they matched R.T. Bird’s 1940 maps and photographs of the two dinosaur trackways.

GEOGRAPHIC AND GEOLOGIC SETTING OF TRACKSITES

The dinosaur tracksites described in this study (Fig. 1) occur within DVSP, where the Paluxy River flows to the north before making a hairpin turn southward. The river has cut its way through overlying strata to expose track-bearing layers in and just above its bed. The local stratigraphic section comprises the lower and middle (Thorp Spring) members of the Glen Rose Formation (Nagle, 1968; Perkins et al., 1987; Pittman, 1989; Winkler et al., 1989; Hawthorne, 1990). Detailed stratigraphic sections (Fig. 2 and Hawthorne, 1990) indicate that tracklayers occur at four horizons, two of which are described in this paper.

Most of the dinosaur tracksites in the park (Figs. 3-11) occur in the Main Tracklayer, a ca. 20-30 cm-thick, sandy, homogeneous dolomitic wackestone (cf. Shelton et al., 1993). In addition to containing dinosaur footprints, the Main Tracklayer is thickly riddled with openings for vertical invertebrate burrows (Fig. 12A-C). Similar long, unbranched, tubular trace fossils are commonly assigned to the ichnogenus *Skolithos* (cf. Alpert, 1974; Droser, 1991; Schlirf and Uchman, 2005), and indicate an intertidal to shallow subtidal depositional environment (Seilacher, 1967; Curran, 1984; Droser, 1991; Vossler and Pemberton, 1988; Skoog et al., 1994), consistent with the presence of dinosaur tracks. *Skolithos* is also associated with dinosaur footprints in a shallow-water, carbonate setting in the Middle Jurassic Sundance Fm of Wyoming (Kvale et al., 2001).

A second kind of possible trace fossil (or tool mark?) was observed only once, at the Blue Hole Ballroom. This was a large, horizontal, somewhat linear feature in the surface of the bed, composed of repeated shallow depressions separated by short gaps (Fig. 12D). Similar features were observed at another site in the Glen Rose Fm (Farlow et al., 2006), where they were provisionally attributed to large gastropods.

Dinosaur tracks in the Main Tracklayer are preserved as concave epireliefs with distinct outlines. They are often quite deep, with sauropod prints sometimes punching through the bed to reach the underlying silt layer. Tridactyl footprints nearly always show some collapse or roofing over of toe marks, or other features suggestive of rather plastic substrate conditions at the time footprints were emplaced.

The Taylor Site (Figs. 2, 13) Tracklayer is a grainstone, strongly laminated at its base and bioturbated at its top. Preservation of tracks is very different from that in the Main Tracklayer. The Taylor Site contains numerous trails of elongate footprints with metatarsal impressions, most of which are largely filled in with a bluish-gray sedimentary rock. This reduces their topographic relief with respect to the surrounding rock, and contributes to the human-like shapes that creationists have identified as human tracks. However, when well cleaned the infilled prints clearly show tridactyl digital patterns. Cores taken at the margin of the fillings show that the original footprints were several centimeters deep before sediment filled them. Moreover, with repeated exposure due to low river levels during droughts, the iron-rich infilling sediment has in places oxidized to a reddish-brown color, making print outlines even more distinct (Kuban, 1986, 1989b; Farlow, 1987). Some of the Taylor Site prints presently occur as convex epireliefs that are topographically somewhat higher than the surrounding rock. One of the Taylor site trackways contains more than two hundred individual footprints.

DINOSAUR FOOTPRINT MORPHOTYPES

Remarkably, despite the large areal extent of tracksite exposures along the Paluxy, only two distinct dinosaur footprint morphotypes have been recognized, making this a low-diversity vertebrate ichnological assemblage.

Sauropods (Figs. 3A, 4B, C, 5-7, 11A, B, 14)

The sauropod footprints are of course what captured R.T. Bird's attention, and are among the world's best-preserved sauropod trace fossils (Farlow et al., 1989). Well-preserved manus prints (Fig. 14F) are rather horseshoe-shaped, being deepest along the anterior margin and shallowest at the center and rear of the print. Digits II-IV seem to have been bound together and separated from digits I and V. There is no indication of a claw on digit I. However, manus prints are often squashed from the rear, or even obliterated by pes prints (Figs. 3A, 4C, 11A-E).

Sauropod pes prints are much larger (commonly about a meter in length) than manus prints, and somewhat triangular in shape. Well-preserved pes prints (Fig. 14F) show three large, laterally directed clawmarks. The footprint is deepest along its medial margin, particularly at the front and rear edges of the print, and shallowest toward its lateral margin. Pes prints are as deep as, or deeper than, associated manus prints.

Both manus and pes prints are usually well offset from the trackway midline (Figs. 3B, 4C, 6B, 14A, B, D, E), manus impressions more so than pes impressions, making *Brontopodus* the paradigm of "wide-gauge" sauropod trackways (Farlow, et al., 1989; Farlow, 1992b; Wilson and Carrano, 1999; Wright, 2005; cf. Romano et al., 2007; Marty et al., 2010). Both manus and pes prints are rotated outward with respect to the trackmaker's direction of travel. The pace angulation of pes prints is about 100-120^{o}.

A plausible candidate for the *Brontopodus*-maker is *Paluxysaurus* (previously assigned to

Pleurocoelus), known from skeletal (including pedal) material from stratigraphic units of about the same age, from the same region (Langston, 1974; Gallup, 1989; Rose, 2007). Another candidate is *Sauroposeidon* (Wedel et al., 2000), but nothing is known of its pedal skeleton.

Tridactyl Footprints (Figs. 4C, 7D, 8, 9C, 11C, 13, 15-17)

With regard to three-toed footprints of bipedal dinosaurs, Paluxy River tracksites collectively constitute a natural laboratory for investigating extramorphological effects of substrate conditions and trackmaker movements in creating a variety of footprint shapes from a uniform foot shape. Although some tridactyl prints in the Main Tracklayer are beautifully preserved, even showing traces of digital pads in the toemarks (Fig. 15B, F), most show some toe tip pinching, toemark collapse, or other plastic deformation. Toemarks are often roofed over, such that their lengths in surface expression are considerably less than their lengths as toe tunnels beneath the rock surface (Fig. 16J; when the river level is up, it is amusing to watch small fishes swim in and out of such dinosaur toe tunnels). Sometimes toemarks are indicated by little more than gashes extending forward from the footprint (Fig. 16, 17E). In some trackways the animal impressed portions of the metatarsal region of the foot (Fig. 16E, F, K; 17), either deliberately or inadvertently as the foot interacted with substrate conditions, making “elongate” footprints (Kuban 1986, 1989a; cf. Pérez-Lorente, 1993; Lockley et al., 2003; Romero-Molina et al., 2003; Romano and Whyte, 2003; Boutakiout et al., 2009; Gierlinski et al., 2009). These extramorphological features complicate anatomical interpretation of tridactyl prints. For example, toemark pinching, collapse, or roofing make toe marks in surface expression look shorter and blunter than they really are (Fig. 16H, L).

Those of the alleged Paluxy River “man tracks” that are not erosional markings or human carvings are elongate metatarsal tracks in which the digit impressions are subdued by one or more factors (infilling, erosion, toemark collapse), causing the remaining metatarsal portion to appear more human-like (Kuban, 1986,1989a, b; Hastings, 1987); arguably such prints might be considered to be a footprint morphotype different from the more typical tridactyl prints. Although topographic expression of the toemarks is nearly lost in the "man tracks", they nonetheless show triangular distal ends that suggest a tridactyl shape (Fig. 17C). Furthermore, as already noted, the toemarks of some Taylor Site prints are accentuated by color differences between infilling material and the surrounding rock (Kuban, 1989b). Some color-delimited tridactyl prints at this site have positive relief relative to the surrounding rock (Fig. 16M; also see Fig. 15A, B for color differences between a well-preserved footprint and surrounding rock in the Main Tracklayer).

The best-preserved Paluxy tridactyls have long, narrow, pointed toemarks, with a slightly S-shaped digit III impression whose terminal end is medially directed (Fig. 15B, C, F). Typically they are 45-60 cm in total length. Footprints of this size and shape are consistent with having been made by a large theropod (Langston, 1974; Farlow, 1987, 2001; Pittman, 1989; Farlow et al., 2006). A plausible candidate is *Acrocanthosaurus*, known from Lower Cretaceous rocks of Oklahoma and Texas (Stovall and Langston, 1950; Harris, 1998; Currie and Carpenter, 2000).

The skeletal fauna of the Trinity Group includes other bipedal dinosaurs (Winkler et al., 1989). Conceivably some of the smallest Paluxy tridactyls could have been made by gracile ornithopods. Although some large tridactyls in the Main Tracklayer look look ornithopod-like in surface expression (Fig. 16H), the complicating effects of sediment-foot interactions mean that at present there are no Main Tracklayer prints that can unambiguously be identified as having been made by large ornithopods. However, the A Trail of the Taylor Site (Fig. 13A), preserved at a higher stratigraphic level than the Main Tracklayer, shows distinctly ornithopod-like prints over several steps, and may well have been made by an ornithopod.

Possible (but questionable) large ornithopod prints occur in the Upper Glen Rose Fm at a site in south Texas (Farlow et al., 2006). Huge footprints possibly made by enormous ornithopods occur in clastic sedimentary rocks correlative to the Glen Rose Fm at a site in Comanche County (Farlow and Hawthorne, 1989).

Large theropod footprints from the Glen Rose Fm are generally similar to those of large theropods from other ichnofaunas around the world (Lull, 1953; Langston, 1974; Thulborn, 1990; Sanz et al., 1997; Olsen et al., 1998; Lockley et al., 1998a, b; Lockley and Meyer, 2000; Farlow, 2001; Pérez-Lorente et al., 2001; Lockley, 2002; Farlow and Galton, 2003; Moratalla et al., 2003; Mossman et al., 2003; Pérez-Lorente, 2003; Weems, 2003; Day et al., 2004; Farlow et al., 2006; Rainforth, 2007; Lockley et al., 2008). Shuler (1935, 1937) tentatively assigned the Paluxy River tridactyls to two species of the Early Jurassic Connecticut Valley ichnogenus *Eubrontes*; Langston (1974) suggested that the Early Cretaceous ichnogenus *Irenesauripus* might be more appropriate. Evaluating the ichnotaxonomy of Glen Rose Fm tridactyls is one of the long-term goals of the present project.

WHAT WERE THE DINOSAURS DOING? PALEOECOLOGICAL AND BEHAVIORAL INTERPRETATIONS

The joint occurrence of sauropod and theropod footprints, particularly in coastal carbonate rocks, is a recurrent feature of dinosaur trace fossil assemblages (cf. Lockley et al., 1994; Pittman and Lockley, 1994; Dalla Vecchia et al., 2000, 2001; Moreno and Pino, 2002; Marty et al., 2003; Hunt and Lucas, 2007; Lockley, 2007; Marty, 2008; Petti et al., 2008). However, given the huge sizes of the trackmakers, and the carnivorous diet of the theropod, it is unlikely that any of Paluxy trackmakers was restricted to the shoreline habitat in which their prints are preserved (Farlow, 1992, 2001; Meyer and Pittman, 1994; cf. Dalla Vecchia et al., 2000), and skeletal fossils of the likely trackmakers are known from more inland clastic facies (Stovall and Langston, 1950; Harris, 1998; Currie and Carpenter, 2000; Rose, 2007; cf. Wright, 2005; Mannion and Upchurch, 2010).

The homogeneous character of the Main Tracklayer suggests that it was deposited in a single event. The density of *Skolithos* burrows might provide a clue as to how long the muddy deposit that became the Main Tracklayer was exposed before burial. If the ichnofabric proves to have little sign of second-generation burrowing (e.g. vertical burrows that cut across older burrows), this will support the interpretation that the dinosaur track-making event(s) occurred over a relatively short time interval. In that event, the number of dinosaur trackways as a function of the size of tracklayer exposures might serve as a proxy for the local abundance of dinosaurs on the landscape (cf. Farlow et al., 2010).

The Paluxy tridactyl prints and trackways show a mirror-image pattern of abundance, with most heading generally northward or southward, in approximately equal numbers (Farlow, 1987), a commonly observed dinosaur tracksite pattern that suggests that trackmakers were moving back and forth along the local coastline (Lockley, 1991; Farlow et al., 2006). This pattern provides no information about whether the theropod trackmakers were travelling singly or in groups. In marked contrast, the Paluxy sauropod trackways show a strong preference for moving southward (Fig. 18). This suggests that the sauropods were moving through the area as herd (Farlow, 1987). The total number of animals in the hypothetical herd would have been greater than the number of sauropod trackways exposed in the riverbed, because modern lateral river erosion continually exposes new trackways, and how far away from the river valley dinosaur trackways occur in the Main Tracklayer (cf. Fig. 7) is unknown. If the sauropods were travelling in a group, at least some of them were not walking side-by-side, because some of the sauropod trackways cross each other (Figs. 5, 11, 14D, 18).

R.T. Bird (1954, 1985) believed that one or more of the large theropods was pursuing the sauropod herd, and that the theropod in the AMNH-TMM trackway slab actually attacked the fleeing sauropod (Farlow, 1987; Thomas and Farlow, 1997). The theropod clearly walked across the site after the sauropod did, because the big carnivore's footprints are repeatedly impressed into the margins of the sauropod tracks (Fig. 19), as also occurs in other sauropod-theropod footprint associations at the Bird Site (Fig. 6C). Equally interesting, over much of the exposure of the two trackways, both the sauropod and the theropod trackway follow the same curving path, with the theropod trackway hugging the left edge of the sauropod trackway (Fig. 19).

Bird's imagination was captured by a missing left footprint (which would have borne the label C1K) of the theropod that coincides with the shortest stride involving the right feet (from C1J [whose toemarks are only partially impressed in the front margin of sauropod pes print S2R] to C1L; Fig. 19) of the big carnivore. Bird concluded–and the late paleoartist David Thomas concurred–that at this point in the trackway the theropod had actually attacked the sauropod, only to be dragged off its feet by the forward motion of the much bigger herbivore (Bird, 1985:173; Thomas and Farlow, 1997). As the meat-eater took an involuntary forward hop, its left foot was unable to touch the ground, and so print C1K was never made.

Although we think it quite possible that the theropod was indeed closely following the sauropod, we are skeptical that Bird's putative hop actually occurred. Had the carnivore been pulled off its feet after partly impressing right print C1J, to come down on the same right foot to make print C1L, we would expect footprint C1L to be very unusual. There might be a spectacular skid mark as the theropod's right foot contacted the substrate as it swung forward. Given the weight of the theropod (Bates et al., 2009b), print C1L would likely have been particularly deep, probably passing completely through the Main Tracklayer as many of the sauropod footprints do. Unfortunately, there seems to be nothing unusual about footprint C1L.

FOOTPRINT CONSERVATION

Once uncovered by the river, the footprints are ephemeral features. Exposures of the Main Tracklayer adjacent to Bird's 1940 quarry have been greatly reduced in size (Fig. 5); this and routine erosion have blurred or destroyed many of the footprints that Bird saw. Footprints that O'Brien, Kuban, and Farlow saw at the Main Tracksite in the 1980s have been lost (Fig. 4B). The Park Overlook site (which was positioned along the river between the Main Tracksite and Denio Branch Mouth Site), which in the 1980s contained a beautiful theropod trackway, is essentially gone.

Although river erosion contributes to footprint destruction, an even greater threat is freezing of the rock surface during the winter time, if water levels are so low that the prints are exposed. At such times, the footprints shatter (Farlow, 1992a). As long as the river flows freely, there is a rough balance between the rate at which "old" tracks are effaced by erosion, and "new" tracks are exposed by river action. A proposal in the 1980s to dam the Paluxy upstream from DVSP would have threatened this balance (Farlow, 1992a), but fortunately came to naught. For now, then, the dinosaur footprint resource at DVSP seems safe. However, the continued erosional loss of presently exposed footprints adds impetus to our goal of creating a database of tracksite information that can continually be updated.

Ironically, even some of the footprints collected by Bird are under threat. The portion of the "chase sequence" that Bird collected for the TMM (part of the type trackway of *Brontopodus birdi*; Farlow et al., 1989) was not assembled inside the museum, but rather inside a small outbuilding on the museum grounds. The rock slabs were placed over a sand layer atop a concrete slab lying on the ground, with the building built around them. Since Bird's time the porous rock of the Main Tracklayer has allowed moisture to seep up from below, causing weathering of the tracklayer surface, and gradual effacement of the footprints (Shelton et al., 1993). Indeed, some of the footprints in this specimen that were still clear in the 1980s (Farlow, 1987) have now become indistinct. The cost of moving the huge specimen indoors is great enough to have made the TMM reluctant to do this. Furthermore, the little outbuilding has itself been designated a national historic landmark, causing some to regard the building as more significant than the dinosaur tracks it was erected to protect.

ACKNOWLEDGMENTS

We thank the U.S. National Natural Landmarks Program, Texas Parks and Wildlife, Indiana University, the University of Oviedo (Protocolo CN-040226, Principado de Asturias, Spain), the Jurassic Foundation, the Palaeontological Association Sylvester-Bradley Award (UK), and the National Environmental Research Council doctoral dissertation grants (UK) for financial support of our field work. The Basins Studies Group of the University of Manchester is thanked for use of laser scanner equipment. The AMNH permitted us to reproduce an archival photograph, and the AMNH and TMM kindly allowed LiDAR scanning of the chase sequence trackway slabs. Collis Park provided aerial photos of DVSP. Park staff Jason Sanchez, Shannon Blalock, Michael Hale, Nate Gold, Kathy Lenz, Jim Bader, and Yvette Vaughn assisted our field work in innumerable ways. Faculty and students of Baylor University, and volunteers Laurie and Larry Jasinski, helped with site preparation and other aspects of field work. This paper is dedicated to the memory of Billy Paul Baker, long-time Superintendent of Dinosaur Valley State Park, for his friendship, support and encouragement of this project.

REFERENCES

Adams, T.L., Strganac, C., Polcyn, M.J., Jacobs, L.L. (2010): High resolution three-dimensional laser-scanning of the type specimen of *Eubrontes (?) glenrosensis* Shuler 1935, from the Comanchean (Lower Cretaceous) of Texas: implications for digital archiving and preservation. *Palaeontologia Electronica* (13 [3]); http://palaeo-electronica.org/2010_3/226/index.html.

Albritton, C.C. (1942): Dinosaur tracks near Comanche, Texas. *Field and Laboratory* (10), 160-181.

Alpert, S.P. (1974): Systematic review of the genus *Skolithos*. *Journal of Paleontology* (48), 661-669.

Attridge, H.W. (2006): *The HarperCollins Study Bible (New Revised Standard Version),* Revised Edition. HarperSanFrancisco, San Francisco, CA, 1-2204.

Bates, K.T., Falkingham, P.L., Hodgetts, D., Farlow, J.O., Breithaupt, B.H., O'Brien, M., Matthews, N., Sellers, W.I., Manning, P.L. (2009a): Digital imaging and public engagement in paleontology. *Geology Today* (25), 134-139.

Bates, K.T., Manning, P.L., Hodgetts, Sellers, W.I. (2009b): Estimating mass properties of dinosaurs using laser imaging and 3D computer modeling. *PloS One* (4[2]), e4532. doi:10.1371/journal.pone.0004532.

Bates, K.T., Rarity, F., Manning, P.L., Hodgetts, D., Vila, B., Oms, O., Galobart, Á., Gawthorpe, R.L. (2008): High-resolution LiDAR and photogrammetric survey of the Fumanya dinosaur tracksites (Catalonia): implications for the conservation and interpretation of geological heritage sites. *Journal of the Geological Society* (165), 115-127.

Bird, R.T. (1939): Thunder in his footsteps. *Natural History* (43), 254-261.

Bird, R.T. (1941): A dinosaur walks into the museum. *Natural History* (47), 74-81.

Bird, R.T. (1944): Did *Brontosaurus* ever walk on land? *Natural History* (53), 61-67.

Bird, R.T. (1954): We captured a "live" brontosaur. *National Geographic* (105), 707-722.

Bird, R.T. (1985): *Bones for Barnum Brown: Adventures of a Dinosaur Hunter* (edited by Schreiber, V.T.). Texas Christian University Press, Fort Worth, TX, 1-225.

Boutakiout, M., Ladel, L., Díaz-Martínez, I., Pérez-Lorente, F. (2009): Prospecciones paleoicnológicas en el sinclinal de Iouaridène (Alto Atlas, Marruecos). 2: Parte oriental. *Geogaceta* (47), 33-36.

Cole, J.R, Godfrey, L.R., Eds. (1985): The Paluxy River footprint mystery-solved. *Creation/Evolution* (15:1), 1-6.

Colectivo de Arqueológico y Paleontológico de Salas, Eds. (2001): *Actas de las I Jornadas Internacionales Sobre Paleontología de Dinosaurios y Su Entorno*. Salas de los Infantes, Burgos, España, 1-434.

Colectivo de Arqueológico y Paleontológico de Salas, Eds. (2006): *Actas de las III Jornadas Internacionales Sobre Paleontología de Dinosaurios y Su Entorno*. Salas de los Infantes, Burgos, España, 1-378.

Colectivo de Arqueológico y Paleontológico de Salas, Eds. (2009): *Actas de las IV Jornadas Internacionales Sobre Paleontología de Dinosaurios y Su Entorno*. Salas de los Infantes, Burgos, España, 1-330.

Curran, H.A. (1984): Ichnology of Pleistocene carbonates on San Salvador. *Journal of Paleontology* (58), 312-321.

Currie, P.J., Carpenter, K. (2000): A new specimen of *Acrocanthosaurus atokensis* (Theropoda, Dinosauria) from the Lower Cretaceous Antlers Formation (Lower Cretaceous, Aptian) of Oklahoma, USA. *Geodiversitas* (22), 207-246.

Dalla Vecchia, F.M., Tarlao, A., Tunis, G., Venturini, S. (2000): New dinosaur track sites in the Albian (Early Cretaceous) of the Istrian Peninsula (Croatia). *Memorie di Scienze Geologiche* (52), 193-292.

Dalla Vecchia, F.M., Tunis, G., Venturini, S., Tarlao, A. (2001): Dinosaur track sites in the upper Cenomanian (Late Cretaceous) of Istrian Peninsula (Croatia). *Bolletino della Società Italiana* (40), 25-53.

Day, J.J., Norman, D.B., Gale, A.S., Upchurch, P., Powell, H.P. (2004): A Middle Jurassic dinosaur trackway site from Oxfordshire, UK. *Palaeontology* (47), 319-348.

Droser, M.L. (1991): Ichnofabric of the Paleozoic *Skolithos* ichnofacies and the nature and distribution of *Skolithos* piperock. *Palaios* (6), 316-325.

Farlow, J.O. (1981): Estimates of dinosaur speeds from a new trackway site in Texas. *Nature* (294), 747-748.

Farlow, J.O. (1985): Introduction and annotations to Bird, R.T. (1985), *Bones for Barnum Brown: Adventures of a Dinosaur Hunter*. Texas Christian University Press, Fort Worth, TX, 1-15, 208-219.

Farlow, J.O. (1987): *Lower Cretaceous Dinosaur Tracks, Paluxy River Valley, Texas*. Field Trip Guidebook, South Central Section, Geological Society of America, Baylor University, Waco, TX, 1-50.

Farlow, J.O. (1992a): Of tracks and the river. In: (Shore, W.H., Ed.). *Mysteries of Life and the Universe*. Harcourt, Brace, and Company, San Diego, 63-84.

Farlow, J.O. (1992b): Sauropod tracks and trackmakers: integrating the ichnological and skeletal records. *Zubía* (10), 89-138.

Farlow, J.O. (1993): *The Dinosaurs of Dinosaur Valley State Park*. Texas Parks and Wildlife Press, Austin, TX, 1-32.

Farlow, J.O. (2001): *Acrocanthosaurus* and the maker of Comanchean large-theropod footprints. In: (Tanke, D.H., Carpenter, K., Eds.). *Mesozoic Vertebrate Life*, Indiana University Press, Bloomington, IN, 408-427.

Farlow, J.O., Coroian, I.D., Foster, J.R. (2010): Giants on the landscape: modelling the abundance of megaherbivorous dinosaurs of the Morrison Formation. *Historical Biology* (22), 403-429.

Farlow, J.O., Galton, P.E. (2003): Dinosaur trackways of Dinosaur State Park, Rocky Hill, Connecticut. In: (Letourneau, P.M., Olsen, P.E., Eds.). *The Great Rift Valleys of Pangea* *in eastern North America, Volume Two: Sedimentology, Stratigraphy, and Paleontology*. Columbia University Press, NY, 248-263.

Farlow, J.O., Hawthorne, J.M. (1989): Comanchean dinosaur footprints. In: (Winkler, D.A., Murry, P.A., Jacobs, L.L., Eds.). *Field Guide to the Vertebrate Paleontology of the Trinity Group, Lower Cretaceous of Texas*. Institute for the Study of Earth and Man, Southern Methodist University, Dallas, TX, 23-30.

Farlow, J.O., Pittman, J.G., Hawthorne, J.M. 1989. *Brontopodus birdi*, Lower Cretaceous sauropod footprints from the U.S. Gulf Coastal Plain. In: (Gillette, D.D., Lockley, M.G., Eds.). *Dinosaur Tracks and Traces*, Cambridge University Press, Cambridge, U.K., 371-394.

Farlow, J.O., Langston, W., Jr., Deschner, E.E., Solis, R., Ward, W., Kirkland, B.L., Hovorka, S., Reece, T.L., Whitcraft, J. (2006): *Texas Giants: Dinosaurs of the Heritage Museum of the Texas Hill Country*. Heritage Museum of the Texas Hill Country, Canyon Lake, TX, 1-105.

Gallup, M.R. (1989): Functional morphology of the hindfoot of the Texas sauropod *Pleurocoelus sp. indet.* In: (Farlow, J.O., Ed.). *Paleobiology of the Dinosaurs*, Special Paper 238, Geological Society of America, 71-74.

García-Ramos, J., Piñuela, L., Lires, J. (2004): *Guía del Jurásico de Asturias*. Zinco Comunicación, Gijón, Asturias, España, 1-117.

Gierlinski, G. 1995. *Śladami Polskich Dinozaurów*. Polska Oficyna Wydawnicza, Warsaw, 1-88.

Gierlinski, G.., Lockley, M.G., Niedźwiedzki, G. (2009): A distinctive crouching theropod trace from the Lower Jurassic of Poland. *Geological Quarterly* (53), 471-476.

Gillette, D.D., Lockley, M.G., Eds. (1989): *Dinosaur Tracks and Traces*. Cambridge University Press, Cambridge, U.K., 1-454.

Gould, C.N. (1929): Comanchean reptiles from Kansas, Oklahoma, and Texas. *Bulletin of the Geological Society of America* (40), 457-462.

Harris, J.D. (1998): A reanalysis of *Acrocanthosaurus atokensis*, its phylogenetic status, and paleobiogeographic status, based on a new specimen from Texas. Bulletin 13, New Mexico Museum of Natural History, Albuquerque, NM, 1-75.

Hastings, R.J. (1986): Tracking those incredible creationists–the trail continues. *Creation/Evolution* (6:1), 19-27.

Hastings, R.J. (1987): New observations on Paluxy tracks confirm their dinosaurian origin. *Journal of Geoscience Education* (35:4), 4-15.

Hawthorne, J.M. (1990): Dinosaur track-bearing strata of the Lampasas Cut Plain and Edwards Plateau, Texas. *Baylor Geological Studies* Bulletin 49, 1-47.

Hawthorne, J.M., Bonem, R.M., Farlow, J.O., Jones, J.O. (2002): Ichnology, stratigraphy and paleoenvironment of the Boerne Lake spillway dinosaur tracksite, south-central Texas. *Texas Journal of Science* (54), 309-324.

Huh, M., Hwang, K.G., Paik, I.S., Chung, C.H., Kim, B.S. (2003): Dinosaur tracks from the Cretaceous of South Korea: distribution, occurrences and paleobiological significance.

The Island Arc (2003), 132-144.

Hunt, A.P., Lucas, S.G. (2007): Tetrapod ichnofacies: a new paradigm. *Ichnos* (14), 59-68.

Jasinski, L.E. (2009): *Dinosaur Highway: A History of Dinosaur Valley State Park*. Texas Christian University Press, Fort Worth, TX, 1-212.

Kuban, G.J. (1986): A summary of the Taylor Site evidence. *Creation/Evolution* (6:1), 10-18.

Kuban, G.J. (1989a): Elongate dinosaur tracks. In: (Gillette, D.D., M.G. Lockley, M.G., Eds.). *Dinosaur Tracks and Traces*, Cambridge University Press, Cambridge, U.K., 57-72.

Kuban, G.J. (1989b): Color distinctions and other curious features of dinosaur tracks near Glen Rose, Texas. In: (Gillette, D.D., Lockley, M.G., Eds.). *Dinosaur Tracks and Traces*, Cambridge University Press, Cambridge, U.K., 427-440.

Kvale, E.P., Johnson, G.D., Mickelson, D.L., Keller, K., Furer, L.C., Archer, A.W. (2001): Middle Jurassic (Bajocian and Bathonian) dinosaur megatracksites, Bighorn Basin, Wyoming. *Palaios* (16), 233-254.

Langston, W., Jr. (1974): Nonmammalian Comanchean tetrapods. *Geoscience and Man* (8), 77-102.

Langston, W., Jr. (1979): Lower Cretaceous dinosaur tracks near Glen Rose, Texas. In: (Perkins, B.F., Langston, W., Jr., Eds.). *Lower Cretaceous Shallow Marine Environments in the Glen Rose Formation: Dinosaur Tracks and Plants*, Field Trip Guidebook, American Association of Stratigraphic Palynologists, 12th annual meeting, Dallas, TX (revised 1983), 39-61.

Leonardi, G. 1994. *Annotated Atlas of South America Tetrapod Footprints (Devonian to Holocene)*. Ministério de Minas e Energia, República Federativa do Brasil, Brasília, 1-247.

Leonardi, G., Mietto, P., Eds. (2000): *Dinosauri in Italia: Le Ormi Giurassiche dei Lavini di Marco (Trentino) e gli altri Resti Fossili Italiani*. Accademia Editoriale, Pisa, Italy, 1-494.

Lockley, M.G. (1991): *Tracking Dinosaurs: A New Look at an Ancient World*. Cambridge University Press, New York, 1-238.

Lockley, M. (2002): *A Guide to the Fossil Footprints of the World*. Lockley-Peterson Publications, Denver, CO, 1-124.

Lockley, M.G. (2007): A tale of two ichnologies: the different goals and potentials of invertebrate and vertebrate (tetrapod) ichnotaxonomy and how they relate to ichnofacies analysis. *Ichnos* (14), 39-57.

Lockley, M.G., Garcia-Ramos, J.C., Piñuela, L., Avanzini, M. (2008): A review of vertebrate track assemblages from the Late Jurassic of Asturias, Spain with comparative notes on coeval ichnofaunas from the western USA: implications for faunal diversity in siliciclastic facies assemblages. *Oryctos* (8), 53-70.

Lockley, M., Hunt, A.P. (1995): *Dinosaur Tracks and Other Fossil Footprints of the Western United States.* Columbia University Press, New York, 1-338.

Lockley, M.G., Hunt, A.P., Meyer, C. 1994. Vertebrate tracks and the ichnofacies concept:

implications for paleoecology and palichnostratigraphy. In: (Donovan, S., Ed.). *The Paleobiology of Trace Fossils*. John Wiley and Sons, NY, 241-268.

Lockley, M.G., Matsukawa, M., Li J. (2003): Crouching theropods in taxonomic jungles: ichnological and ichnotaxonomic investigations of footprints with metatarsal and ischial impressions. *Ichnos* (10): 169-177.

Lockley, M.G., Meyer, C. 2000. *Dinosaur Tracks and Other Fossil Footprints of Europe*. Columbia University Press, New York, 1-323.

Lockley, M.G., Meyer, C., Moratalla, J.J. (1998a): *Therangospodus*: trackway evidence for the widespread distribution of a Late Jurassic theropod with well-padded feet. *Gaia* (15), 339-353.

Lockley, M.G., Meyer, C.A., dos Santos, V.F. (1998b): *Megalosauripus* and the problematic concept of megalosaur footprints. *Gaia* (15), 313-337.

Lockley, M.G., dos Santos, V.F, Meyer, C.A., Hunt, A., Eds. (1994): *Aspects of Sauropod Paleobiology*. *Gaia* (10), 1-279.

Lull, R.S. (1953): *Triassic Life of the Connecticut Valley*. State of Connecticut State Geological and Natural History Survey Bulletin 81, Hartford, CT, 1-331.

Mannion, P.D., Upchurch, P. (2010): A quantitative analysis of environmental associations in sauropod dinosaurs. *Paleobiology* (36), 253-282.

Marty. D. 2008. Sedimentology, taphonomy, and ichnology of Late Jurassic dinosaur tracks from the Jura carbonate platform (Chevenez-Combe Ronde tracksite, NW Switzerland):

insights into the tidal-flat palaeoenvironment and dinosaur diversity, locomotion, and palaeoecology. *GeoFocus* (University of Fribourg, Switzerland) (21), 113-236.

Marty, D., Belvedere, M., Meyer, C.A., Mietto, P., Paratte, G., Lovis, C., Thüring, B. (2010): Comparative analysis of Late Jurassic sauropod trackways from the Jura Mountains (NW Switzerland) and the central High Atlas Mountains (Morocco): implications for sauropod ichnotaxonomy. *Historical Biology* (22), 109-133.

Marty, D., Hug, W.A., Iberg, A., Cavin, L., Meyer, C.A., Lockley, M.G. (2003): Preliminary report on the Courtedoux dinosaur tracksite from the Kimmeridgian of Switzerland. *Ichnos* (10), 209-219.

Mayor, A. (2005): *Fossil Legends of the First Americans*. Princeton University Press, Princeton, NJ, 1-446.

Meyer, C.A., Pittman, J.G. (1994): A comparison between the *Brontopodus* ichnofacies of Portugal, Switzerland, and Texas. *Gaia* (10), 125-133.

Milne, D,H., Schafersman, S.D. (1983): Dinosaur tracks, erosion marks and midnight chisel work (but no human footprints) in the Cretaceous limestone of the Paluxy River bed, Texas. *Journal of Geological Education* (31), 111-123.

Moratalla, J.J. (2009): Sauropod tracks of the Cameros Basin (Spain): identification, trackway patterns and changes over the Jurassic-Cretaceous. *Geobios* (42), 797-811.

Moratalla, J.J., Hernán, J., Jiménez, S. (2003): Los Cayos Dinosaur Tracksite: an overview on the Lower Cretaceous ichno-diversity of the Cameros Basin (Cornago, La Rioja

Province, Spain). *Ichnos* (10), 229-240.

Moreno, K., Pino, M. (2002): Huellas de dinosaurios en la Formación Baños del Flaco (Titoniano-Jurásico Superior), VI Región, Chile: paleoetología y paleoambiente. *Revista Geológica de Chile* (29), 151-165.

Morris, J.D. (1980): *Tracking Those Incredible Dinosaurs...and the People Who Knew Them*. Creation Life Publishers, San Diego, 1-240.

Mossman, D.J., Brüning, R., Powell, H.P. (2003): Anatomy of a Jurassic trackway from Ardley, , Oxfordshire, U.K. *Ichnos* (10), 195-207.

Nagle, J.S. (1968): Glen Rose cycles and facies, Paluxy River Valley, Somervell County, Texas. Bureau of Economic Geology, University of Texas, Austin, TX, 1-25.

Neufeld, B. (1975): Dinosaur tracks and giant men. *Origins* 2(2), 64-76.

Numbers, R.L. (2006): *The Creationists: From Scientific Creationism to Intelligent Design* (expanded edition). Harvard University Press, Cambridge, MA, 1-606.

Olsen, P.E., Smith, J.B., McDonald, N.G. (1998): Type material of the type species of the classic theropod footprint genera *Eubrontes*, *Anchisauripus*, and *Grallator* (Early Jurassic, Hartford and Deerfield Basins, Connecticut and Massachusetts, U.S.A. *Journal of Vertebrate Paleontology* (18), 586-601.

Perkins, B.F., Langston, W., Jr., Clarke, R.T., Eds. (1987): *Lower Cretaceous Shallow Marine Environments in the Glen Rose Formation: Dinosaur Tracks and Plants*. Field Trip Guidebook, Southwest Section American Association of Petroleum Geologists, Dallas, TX, 1-69.

Pérez-Lorente, F. (1993): Dinosaurios plantígrados en La Rioja. *Zubía* (5), 189-228.

Pérez-Lorente, F., Ed. (2003). *Dinosaurios y Otros Reptiles Mesozoicos en España*. Instituto de Estudios Riojanos, Logroño, España, 1-444.

Pérez-Lorente, F., Romero-Molina, Ma.M., Requeta, E., Blanco, M., Caro, S. 2001. *Dinosaurios. Introducción y Análisis de Algunos Yacimientos de Sus Huellas en La Rioja*. Instituto de Estudios Riojanos, Logroño, España, 1-102.

Perkins, B.G., Langston, W., Jr., Clarke, R.T., Hastings, R.J., Pittman, J.G., Bergan, G. (1987): *Lower Cretaceous Shallow Marine Environments in the Glen Rose Formation: Dinosaurs and Plants*. Field Trip Guidebook 1, Southwest Section AAPG Convention, Dallas, TX, 1-69.

Petti, F.M., D'Orazi Porchetti, S., Conti, M.A., Nicosia, U., Perugini, G., Sacchi, E. 2008. Theropod and sauropod footprints in the Early Cretaceous (Aptian) Apennic Carbonate Platform (Esperia, Central Italy): a further constraint on the palaeogeography of the Central-Mediterranean area. *Studi Trentini di Scienze Naturali, Acta Geologica* (83), 323-334.

Pittman, J.G. (1989): Stratigraphy, lithology, depositional environment, and track type of dinosaur track-bearing beds of the Gulf Coastal Plain. In: (Gillette, D.D., Lockley, M.G., Eds.). *Dinosaur Tracks and Traces*, Cambridge University Press, Cambridge, U.K., 135-153.

Pittman, J.G., Lockley, M.G. (1994): A review of sauropod dinosaur tracksites of the Gulf of Mexico Basin. *Gaia* (10), 95-108.

Rainforth, E.C. (2007): Ichnotaxonomic updates from the Newark Supergroup. In: (Rainforth, E.C., Ed.). *Contributions to the Paleontology of New Jersey (II), Field Guide and Proceedings*. Geological Association of New Jersey XXIV Annual Conference and Field Trip, East Stroudsburg University, East Stroudsburg, PA, 49-59.

Rogers, J.V., II. (2002): Theropod dinosaur trackways in the Lower Cretaceous (Albian) Glen Rose Formation, Kinney, County, Texas. *Texas Journal of Science* (54), 133-142.

Romano, M., Whyte, M.A. (2003): Jurassic dinosaur tracks and trackways of the Cleveland Basin, Yorkshire: preservation, diversity and distribution. *Proceedings of the Yorkshire Geological Society* (54), 185-215.

Romano, M., Whyte, M.A., Jackson, S.J. (2007): Trackway ratio: a new look at trackway gauge in the analysis of quadrupedal dinosaur trackways and its implications for ichnotaxonomy. *Ichnos* (14), 257-270.

Romera-Molina, M.M., Sarjeant, W.A.S., Pérez-Lorente, F., López, A., Requeta, E. (2003): Orientation and characteristics of theropod trackways from the Las Losas Palaeoichnological Site (La Rioja, Spain). *Ichnos* (10), 241-254.

Rose, P.J. (2007): A new titanosauriform sauropod (Dinosauria: Saurischia) from the Early Cretaceous of central Texas and its phylogenetic relationships. *Palaeontologia Electronica* (10:2), http://palaeo-electronica.org/paleo/2007_2/00063/index.html.

Sams, R.H. (1982): Newly discovered dinosaur tracks, Comal County, Texas. *Bulletin of the South Texas Geological Society* (23), 19-23.

Sanz, J.L., Moratalla, J.J., Rubio, J.L., Fuentes, C., Meijde, M. (1997): *Huellas de Dinosaurios de Castilla y León, Burgos y Soria*. Junta de Castilla y León, España, 1-87.

Schlirf, M., Uchman, A. (2005): Revision of the ichnogenus *Sabellarifex* Richter, 1921 and its relationship to *Skolithos* Haldeman, 1840 and *Polykladichnus* Fürsich, 1981. *Journal of Systematic Paleontology* (3), 115-131.

Seilacher, A. (1967): Bathymetry of trace fossils. *Marine Geology* (5), 413-428.

Shelton, S.Y., Barnett, R.C., Magruder, M.D. (1993): Conservation of a dinosaur trackway exhibit. *Collection Forum* (9[1]), 17-26.

Shuler, E.W. (1917): Dinosaur tracks in the Glen Rose Limestone near Glen Rose, Texas. *American Journal of Science* (44), 294-298.

Shuler, E.W. (1935): Dinosaur track mounted in the band stand at Glen Rose, Texas. *Field and Laboratory* (4), 9-13.

Shuler, E.W. (1937): Dinosaur tracks at the fourth crossing of the Paluxy River near Glen Rose, Texas. *Field and Laboratory* (5), 33-36.

Skinner, S.A., Blome, C. (1975): *Dinosaur Track Discovery at Comanche Peak Steam Electric Station, Somervell County, Texas*. Privately published, 1-16.

Skoog, S.Y., Venn, C., Simpson, E.L. (1994): Distribution of *Diopatra cuprea* across modern tidal flats: implications for *Skolithos*. *Palaios* (9), 188-201.

Stovall, J.W., Langston, W., Jr. (1950): *Acrocanthosaurus atokensis*, a new genus and species of Lower Cretaceous Theropoda from Oklahoma. *American Midland Naturalist* (43), 696-728.

Thomas, D.A., Farlow, J.O. (1997): Tracking a dinosaur attack. *Scientific American* (277:6), 48-53.

Thulborn, T. (1990): *Dinosaur Tracks*. Chapman and Hall, London,1-410.

Vossler, S.M., Pemberton, S.G. (1988): *Skolithos* in the Upper Cretaceous Cardium Formation: an ichnofossil example of opportunistic ecology. *Lethaia* (21), 351-362.

Wedel, M.J., Cifelli, R.L., Sanders, R.K. (2000): *Sauroposeidon proteles*, a new sauropod from the Early Cretaceous of Oklahoma. *Journal of Vertebrate Paleontology* (20), 109-114.

Weems, R.E. (2003): *Plateosaurus* foot structure suggests a single trackmaker for *Eubrontes* and *Gigandipus* footprints. In: (Letourneau, P.M., Olsen, P.E., Eds.). *The Great Rift Valleys of Pangea in eastern North America, Volume Two: Sedimentology, Stratigraphy, and Paleontology*. Columbia University Press, NY, 293-313.

Whyte, M.A., Romano, M., Watts, W. (2010): Yorkshire dinosaurs: a history in two parts. In: (Moody, R.T.J., Buffetaut, E., Naish, D., Martill, D.M., Eds.). *Dinosaurs and Other Extinct Saurians: A Historical Perspective*. Geological Society, London, Special Publications (343), 189-207.

Wilson, J.A., Carrano, M.T. 1999. Titanosaurs and the origin of “wide-gauge” trackways: a biomechanical and systematic perspective on sauropod locomotion. *Paleobiology* (25), 252-267.

Winkler, D.A., Murry, P.A., Jacobs, L.L. (1989): *Field Guide to the Vertebrate Paleontology of the Trinity Group, Lower Cretaceous of Texas*. Institute for the Study of Earth and Man, Southern Methodist University, Dallas, TX, 1-33.

Wrather, W.E. (1922): Dinosaur tracks in Hamilton County, Texas. *Journal of Geology* (30), 354-360.

Wright, J.G. (2005): Steps in understanding sauropod biology: the importance of sauropod tracks. In: (Curry Rogers, K.A., Wilson, J.A., Eds.). *The Sauropods: Evolution and Paleobiology*. University of California Press, Berkeley, CA, 252-284.

FIGURE 1. Digital elevation map of the Paluxy River valley in and around Dinosaur Valley State Park (Somervell County, Texas), indicating the major tracksites documented in this study, other track occurrences known to have existed (unlabeled), and a test excavation dug in 1974, away from exposures in the river bed, through overlying strata, to reach the Main Tracklayer.

FIGURE 2. Stratigraphic section of the lower Glen Rose Formation in and around Dinosaur Valley State Park, based on our observations, and comparisons with Hawthorne (1990); also see Pittman (1989). Bed lithologies are labeled by shading / pattern, and (particularly for different kinds of limestone [wackestone / packstone / grainstone) by horizontal distance to the right of the vertical axis of the section. Most of the park's tracksites are in the Main Tracklayer, a dolomitic wackestone. The Taylor Site is stratigraphically higher. Hawthorne (1990) identified two additional track horizons in the Paluxy River section.

FIGURE 3. Denio Branch Mouth Tracksite. A) View from an elevated platform across the site, looking upstream (northward). Most of the site was under shallow water at the time this photograph was taken, but a dry portion of the site, containing several tridactyl prints, is visible at the top of the photograph. A sauropod trackway (black arrow) marked only by poorly preserved pes prints heads southward (?) across the site, while a trackway composed mainly of "elongate" footprints (white arrow) heads in the opposite direction. B) Photomosaic detail of the northmost edge of the site; one of several tridactyl footprints is indicated by an arrow.

FIGURE 4. The Main Tracksite (so named because it contains the footprint exposures most easily seen by the casual observer). A) Aerial view, looking northward. Exposures of the

Main Tracklayer (1, 2, 3) peek out from beneath an overlying hard limestone shelf. B) Footprints in the three exposures of the Main Tracklayer; north to the top of the map. Extensive change in the footprint surface, due to erosion of previously exposed tracks, and uncovering of new tracks, has occurred over the last two decades; note the changing position of the shelf layer in exposure area 1 between the 1980s (small arrow) and the present (large arrow). The final footprint in the trackway of a small sauropod in exposure area 2 is indicated by a heavy black area. Exposure area 3 is contiguous with the West Bank of the Bird Site. Additional theropod footprints that do not appear in the map were documented here in 2008. The locations of the beginnings of two of the sauropod trackways mapped by Bird in 1940 (S1 and S2) are plotted on the map. C) Photomosaic (1-m grid) of exposure area 3. South to the top of the image. Note the well-preserved sauropod trackway from panel B; a white arrow labels the final exposed footprint in this trackway. Tridactyl prints are also scattered across this exposure.

FIGURE 5. The Bird Site. A) Aerial view of the Bird Site and exposure area 3 of the Main Tracksite (left edge of photograph), with Bird's and our trackway maps superimposed. Note erosional destruction of a significant part of the Main Tracklayer between 1940 and 2009-2010. B) Oblique vew of East Bank sauropod trackways from an elevated platform on the West Bank.

FIGURE 6. West Bank of the Bird Site. A) Photomosaic of the tracksite surface. Many individual sauropod and theropod footprints are outlined in black. B) Ground-level oblique view of a sauropod trackway; the animal was moving southward and away from the viewer. Tape measure exposes 1 m of tape. C) Sauropod footprint with a theropod

print impressed into its margin; scale in photograph marked in cm and inches.

FIGURE 7. Footprints discovered during a 1974 test excavation in a field well away from the river bed. A) Digging the pit. B-D) Footprints exposed, probably in the Main Tracklayer. B) Map and C) photograph of the uncovered track surface. Several footprints are identified by number in both panels. D) Tridactyl footprint (print 6 in panels B and C).

FIGURE 8. The Opossum Branch tracksite, exposed in the bed of a small tributary of the Paluxy River. The tracklayer is either the Main Tracklayer itself, or stratigraphically very close to it. A) Photomosaic of much of the tracksite surface. B) Map of footprints superimposed on the photomosaic.

FIGURE 9. The Blue Hole, a popular swimming area at DVSP. A) Aerial photograph; upstream (south) toward the viewer. Black arrow indicates a ledge exposing the Main Tracklayer along the downstream side of the Blue Hole. B) Photomosaic and map (north to the top) of several dinosaur tracks exposed in the main tracklayer indicated by the arrow in panel A. C) Ground level oblique view of several typical Blue Hole Site tridactyl footprints.

FIGURE 10. Aerial photograph showing location of the Blue Hole Ballroom and Blue Hole Parlor, two extensive exposures of the Main Tracklayer.

FIGURE 11. The Blue Hole Ballroom. A) Map of the tracksite; north to the top of the page. Black arrow indicates the beginning of the trackway of a large sauropod. A distinct trackway of a smaller sauropod (dark fill) crosses the trail of the bigger dinosaur near the end of the latter trackway, moving from east to west across the site. A second, less distinct trackway of a small sauropod crosses the trail of the large sauropod about

midway along the latter's length. B and C) Details from a site photomosaic, marked off in a meter grid. B) Portion of the tracksite emphasizing the trail of the large sauropod. C) Southwest portion of the tracksite featuring numerous tridactyl footprints.

FIGURE 12. Sedimentary features associated with the Main Tracklayer. A and B) Vertical invertebrate burrows (cf. *Skolithos*). A) Tracklayer surface densely marked by burrow openings adjacent to tridactyl footprints, Bird Site; scale marked in cm. B) Vertical section through a sample of the Main Tracklayer (top of the layer upward), Blue Hole Parlor; 1-cm bar indicated in the lower right-hand portion of the photograph. Numerous vertical burrows (darker than the surrounding sediment) snake in and out of the plane of the cut. The left-hand portion of the section shows some distortion of bedding, possibly due to a dinosaur footprint. C) Contact between the Main Tracklayer and overlying beds, Main Tracksite; scale marked in cm. A tridactyl print is emerging from the riverbank. Note numerous pinprick vertical burrow openings dotting the tracklayer surface. D) Horizontal surface trace of a large invertebrate, or possibly a tool mark, Blue Hole Ballroom; a meter stick provides the scale.

FIGURE 13. The Taylor Site, a footprint exposure stratigraphically several meters higher than the Main Tracklayer. A) Map of the site by Glen Kuban, with labels for individual footprints. C) Photomosaic of that portion of the tracksite recognized in 2009; numerous footprints mapped by Kuban in previous years were not seen. Some individual prints beyond the limits of the 2009 exposure, mapped by Kuban, are superimposed on the image. Footprint labels from Kuban's map are added to the photomosaic, which in this view is rotated about 30 degrees counterclockwise from Kuban's map.

FIGURE 14. Sauropod footprints and trackways. A) Trackway of the large sauropod, Blue Hole Ballroom; meter stick provides scale. The animal was moving from left to right, with pes prints obliterating manus prints. B, C) Portions of the more distinct small sauropod trackway from the Blue Hole Ballroom; meter stick provides scale. B) Ground-level oblique view of the last several footprints in the sequence. C) Overhead view of the final right pes print (and possible deformed manus impression ahead of it?). D) View from an elevated platform of three sauropod footprints in the East Bank of the Bird Site (Fig. 5). White arrows indicate direction of travel of trackmakers. From left to right these are the "East" (mean pes print length 76.5 cm), "Middle" (mean pes print length 62.0 cm), and "Wet" (mean pes print length 90.0 cm) sauropod trackways of Farlow et al. (1989). Manus prints occur in the East and Middle trackways, but not the Wet trackway. E) Overhead view of left manus-pes set, West Bank Bird Site; tape exposes 1 m. F) Overhead and oblique LiDAR images of right manus-pes set S2M from the American Museum trackway slab collected by R.T. Bird; pes print length about 87 cm. Shading indicates print depth, with darker shading indicating greater depth.

FIGURE 15. Well-preserved tridactyl footprints. A, B) Particularly well-preserved trackway, Blue Hole Ballroom A) Ground-level oblique view; meter stick provides scale. B) Overhead view of the splendid left print seen in the foreground of panel A; meter stick marked in 1-cm intervals. Note distinctly darker color of rock inside than outside the print. C) Print from Opossum Branch; scale marked in centimeter and inch intervals. D) Footprint with distinct hallux impression, south end of exposure area 3 of Main Tracksite. E) Large tridactyl, Blue Hole. F) Two very nice tridactyls, Opossum Branch.

G, H) Somewhat distorted tridactyls, West Bank Bird Site.

FIGURE 16. A-L), Moderately to greatly distorted tridactyl footprints, Main Tracklayer; scale in most panels provided by portions of a meter stick or tape marked in 1-cm intervals, or by a small scale marked in centimeter and inch, or only in centimeter, intervals. In all of these prints there is at least some pinching off or collapse of toe impressions. Some of the prints also show probable impressions of the metatarsal region of the trackmaker's foot. Footprints from Denio Branch (A, B, E, F, K), the Blue Hole (C, D, H, L), Opossum Branch (G), West Bank Bird Site (I), Main Tracksite (J). M). Tridactyl print from the Taylor Site. In contrast to prints from the Main Tracklayer, which are preserved as concave epireliefs, this print is preserved as a convex epirelief delimited from surrounding rock by darker color.

FIGURE 17. Trackways of "elongate" footprints. A-D) Trackway IIS, Taylor Site (Fig. 13). A) Photomosaic of the trackway; black arrow indicates print IIS,-3). B) Ground-level oblique view of print IIS,-3 and the following footprint in sequence, IIS,-2; meter stick provides scale. C) Overhead view of print IIS,-3. D) Ground-level oblique view further along the IIS trackway (IIS,-1 to IIS,+1); the 2 m of exposed tape are adjacent to print IIS,+1). E) Print from the Blue Hole Ballroom. F) Final portion of elongate trackway from Denio Branch Site (Fig. 3A); human figure provides scale. Most of the footprints in this trackway show little indication of toe marks in the prints, but the final print (black arrow) is clearly tridactyl, as seen (inset) in the photograph from an elevated platform.

FIGURE 18. Direction of travel of sauropods, Main Tracksite and Bird Site (Figs. 4-6, 14D). A) Composite map of sauropod movements from Bird's 1942 Rye Chart (Farlow et al.,

1989) and our observations. Main Tracksite trackways are at the top, the West Bank of the Bird Site is in the middle, and the East Bank of the Bird Site is at the lower right. B) Sauropod movements summarized as arrows. Information is provided for the sauropod trails illustrated in panel A, and also for trackways further to the south (upstream). Trackway labels S1-S5 were assigned to the sauropod trails on the Rye chart by Farlow (1987) and Farlow et al. (1989). Note the strong preference for southward movement by the sauropods. C) View of the Bird site, looking south (upstream). Location of Bird's 1940 trackway quarry in the immediate foreground.

FIGURE 19. The AMNH-TMM theropod-sauropod chase sequence. A) Portion of the 1942 Rye chart showing the chase sequence, the two main trackway blocks collected for the AMNH and the TMM, and individual prints collected for other institutions. Selected key footprints of theropod C1 and sauropod S2 are labeled for comparison with other panels of this figure. B) One of Bird's photographs of the chase sequence; image used by permission of the AMNH. C) Composite LiDAR image of the American Museum (AMNH FARB 3065; cf. Bates et al., 2009a) and Texas Memorial Museum (TMM 40638-1) trackway blocks.