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THE STORY OF THE ST. GEORGE DINOSAUR DISCOVERY SITE AT JOHNSON FARM: AN IMPORTANT NEW LOWER JURASSIC DINOSAUR TRACKSITE FROM THE MOENAVE FORMATION OF SOUTHWESTERN UTAH

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Abstract—Well-preserved theropod tracks from a newly discovered Lower Jurassic, Moenave Formation site in St. George Utah, are mostly assigned to the dinosaurian ichnogenera *Eubrontes* and *Grallator*, with some assigned to cf. *Gigandipus*, cf. *Kayentapus*, and *Anomoepus*. The non-dinosaurian ichnogenera *Batrachopus* and cf. *Selenichnus* are also reported. The ichnofauna is very similar to others from the region of southern Utah and other classic ichnofaunas of the same age from the eastern United States and elsewhere. However, their excellent preservation as deep natural casts, some with skin impressions, sheds new light on the configuration of the metatarsus and hallux of the *Eubrontes* trackmaker. One dinosaurian trackway (cf. *Gigandipus*) also reveals tail and squatting traces. The deep tracks also shed light on the mode of foot emplacement and withdrawal of the *Grallator* trackmaker, and the potential for theropods to produce undertracks with unusual morphologies that are not obviously theropodan.

Parallel scrape or slide marks, usually in sets of three, and sometimes terminating in *Grallator*-like tracks, suggest dinosaurs that were slipping and sliding in the mud, or partially buoyed up by water. Although such traces are common at this site, they are essentially unique: i.e., similar examples are not known from other, contemporary sites.

The paleogeographic and stratigraphic setting of the tracks suggests multiple track-making episodes in a marginal lacustrine setting. Body fossils include dinosaur teeth, a variety of fishes, ostracodes, and conchostracans. Sedimentary structures include abundant mud cracks, evaporite sulfate salt crystal casts, swales, miscellaneous ripple, scour, and flute marks, suggesting a NNE-SSW shoreline trend, perpendicular to paleo-depositional dip. Some tracks follow this trend, but many others are more or less randomly oriented.

Following its discovery in early 2000, the site has generated extraordinary public and media interest, attracting more than 100,000 visitors annually, as well as significant funding from federal and state sources. As a result, by 2001, a non-profit organization – the "DinosaurAh!Torium" – was founded to help develop the site as a public education resource, and by 2005, the St. George Dinosaur Discovery Site at Johnson Farm (SGDS) was established as an interpretive site, complete with a protective, museum-style building constructed over the main track discovery site. Since the initial discovery, dozens of other nearby sites have also been found as a result of ongoing excavation and development. Many hundreds of large and small specimens from more than two dozen stratigraphic levels have been recovered and cataloged. In fewer than five years, the SGDS has become one of the three largest fossil footprint collections in the western United States.

INTRODUCTION

A new, Early Jurassic dinosaur tracksite was discovered by one of us (SBJ) during the excavation of a thick sandstone bed at the base of the Whitmore Point Member of the Moenave Formation. This site is now designated the St. George Dinosaur Discovery Site at Johnson Farm (SGDS hereafter). The locality, on private land, was discovered in February, 2000 within the city limits of St. George, Washington County, Utah (Fig. 1). Within two months of this discovery, the site had received much public and media attention, and by late June had already been visited by more than 55,000 visitors. Because of this high level of interest, the offices of the Utah Geological Survey acted to obtain preliminary scientific documentation of the site through collaboration with land owners, the University of Colorado Dinosaur Tracks Museum, and other paleontologists. This interest was only heightened by further discoveries in nearby, stratigraphically-contiguous outcrops (provisionally referred to as the Darcy Stewart [DS] site).

From 2000 through 2006, efforts were made to map *in situ* tracks and document those that had already been excavated through tracings, measurements, photography and casting. This preliminary work revealed that the tracks, mainly assigned to *Eubrontes* and *Grallator* (*sensu* Hitchcock, 1858), are among the best-preserved examples of these ichnogenera ever recorded. Thus, the tracks can be compared with classic ichnofaunas from elsewhere in the Lower Jurassic, especially those found in New England referred to as the "Hitchcock Collection" housed at Amherst College, Massachusetts.

The "Hitchcock Collection" represents the greater part of the life's work of Edward Hitchcock on Early Jurassic tracks from Massachusetts and Connecticut, and is regarded as the "Rosetta Stone" of vertebrate ichnology, just as Hitchcock himself is regarded as the father of vertebrate ichnology (Hitchcock, 1858). Until recently, the Hitchcock collection was regarded as the world's largest, and best-known, fossil footprint collection. In the last two decades, however, other large collections have been developed in western North America, notably at the Dinosaur Tracks Museum at the University of Colorado at Denver and the New Mexico Museum of Natural History and Science in Albuquerque. The former collection contains a significant assemblage of tracks of all ages, while the New Mexico collections have a strong emphasis on

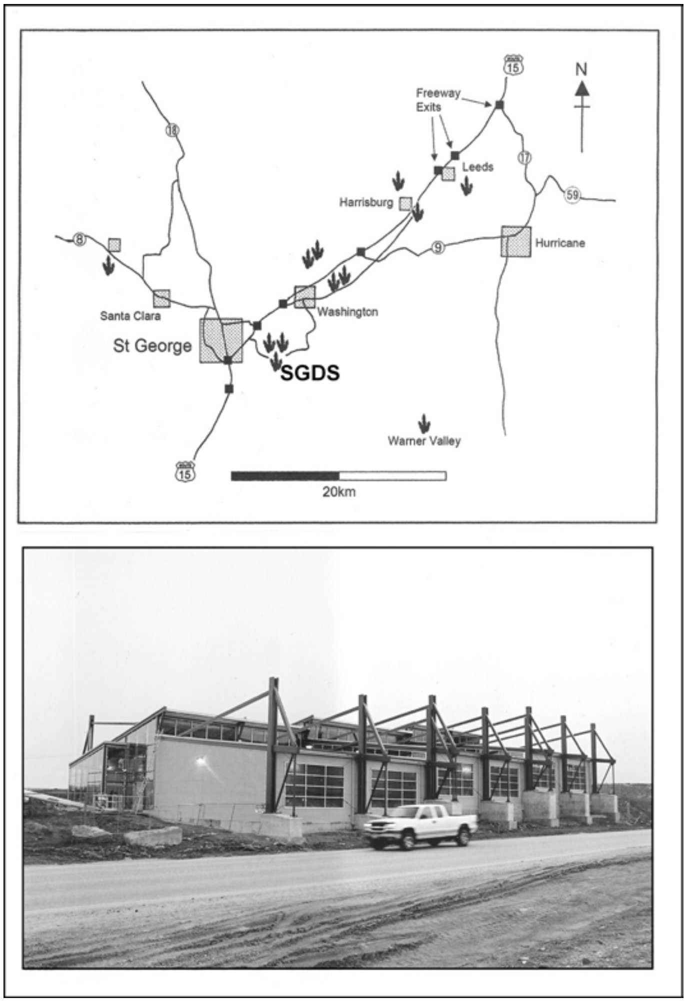

FIGURE 1. **Top**, Locality map showing tracksites in the St. George area. **Bottom**, Photo of St. George Dinosaur Discovery Site at Johnson Farm museum (SGDS on map above).

Permo-Triassic footprints. Thus, the SGDS collection, which essentially consists nearly exclusively of Lower Jurassic tracks, is, in effect, the western equivalent of the Hitchcock collection. Unlike the Colorado and New Mexico collections, it is built on and around an *in situ* exposure at a museum-style interpretive center (Fig. 1).

At the time of this writing, the collections at the SGDS consist of more than 1000 specimens with the prefix SGDS. Some of these specimens have been replicated for the CU Denver Dinosaur Tracks Museum collections where they are reposited in the series CU 177.1-CU 177.77.

The prime objective of this paper is to provide preliminary description of representative tracks, and to place them in their local, regional and global context. Track assemblages of this age in the eastern United States (Hitchcock, 1858; Lull, 1953) provide a global standard for Lower Jurassic track classification (ichnotaxonomy) despite many specialized and complex historical problems with terminology. The SGDS tracksites collectively provide a window into an Early Jurassic ecosystem associated with the shores of a lake system now dubbed "Lake Dixie."

GENERAL GEOGRAPHICAL AND GEOLOGICAL CONTEXT

Dinosaur tracks and other fossil footprints are well known in the southwestern United States (Lockley and Hunt, 1995). However, until the discovery of the SGDS in 2000, only a relatively small number of sites had been documented in this part of southwestern Utah (e.g., Miller et al., 1989). Thus, the St. George discovery fills a gap in the track record of this area. As a result, the site has generated local interest resulting in the discovery and reporting of a large number of additional sites in the vicinity, mostly in Upper Triassic and Lower Jurassic rocks (Fig. 1). Many of these other sites, described elsewhere in this volume, come from the Chinle Formation (considered a group by others) that underlies the Moenave Formation, or the overlying Kayenta Formation. Here, however, we concentrate on tracks from the main discovery site (SGDS in Fig. 1) and the immediate vicinity (Fig. 2). At least 17 fossiliferous sites have been named, including some that reveal body fossils (vertebrate skeletal remains, invertebrates and plants) rather than tracks. At many of the track sites, multiple track-bearing horizons have been identified. It is outside the scope of this paper to describe all of these all in detail, so we concentrate on the main site (no. 1, Fig. 2) with additional descriptions of representative material from other sites.

At the SGDS, the Moenave Formation is about 74 m thick; consisting of the underlying Dinosaur Canyon Member (about 56.5 m thick) and the overlying Whitmore Point Member (about 17.5 m thick) (Fig. 3; q.v., Kirkland and Milner, this volume). The Moenave overlies the Upper Triassic Chinle Formation and is unconformably overlain by the Lower Jurassic Springdale Sandstone Member of the Kayenta Formation. Thus, the Triassic-Jurassic boundary is located within the Dinosaur Canyon Member of the Moenave Formation. The focus of this study is on the track layers and tracksites in the uppermost part of the Dinosaur Canyon Member and the lower part of the Whitmore Point Member. Although many additional tracksites and track horizons occur nearly to the top of the Whitmore Point Member, they will not be dealt

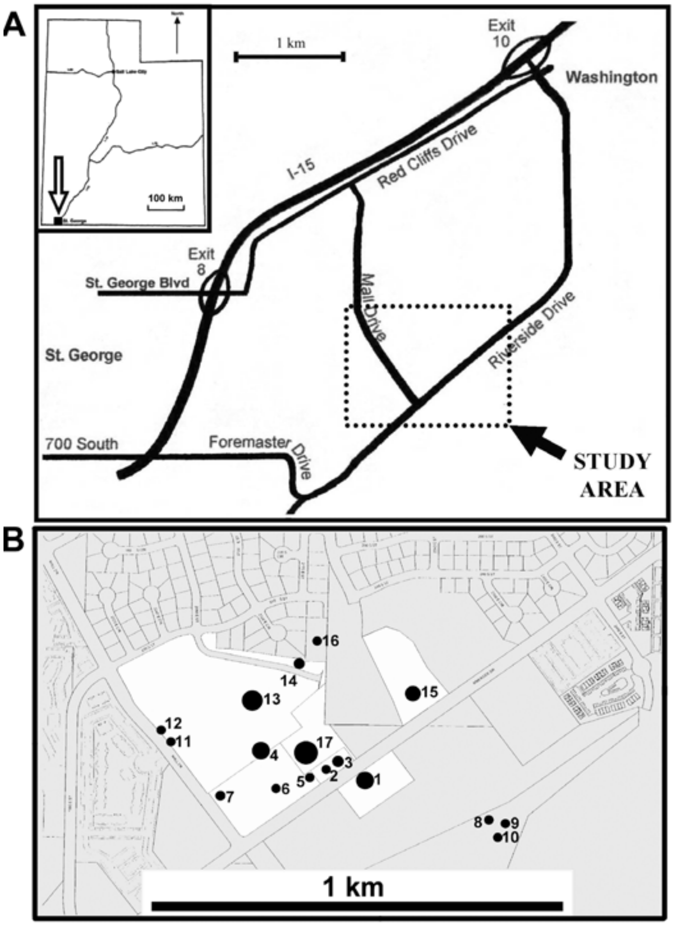

FIGURE 2. **Top**, Detail of SGDS in relation to geography of St. George in Washington County, Utah. **Bottom**, Locality map showing the 17 fossil-bearing localities (mostly tracksites) in the immediate vicinity of the SGDS, all situated within 1 km^2.

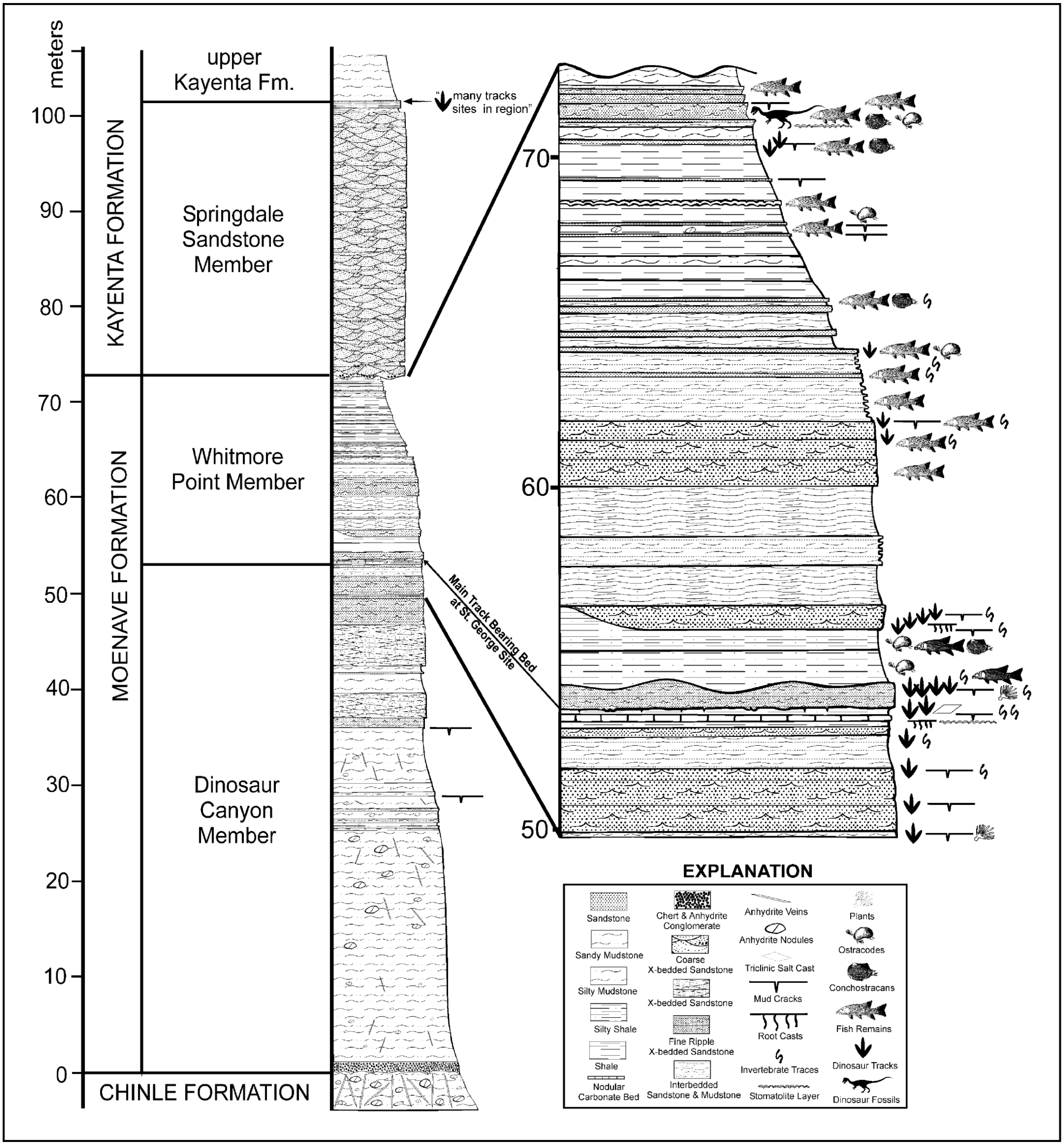

FIGURE 3. Stratigraphic section of the Moenave Formation at the SGDS showing high concentration of fossil-bearing layers in the upper Dinosaur Canyon Member and throughout the Whitmore Point Member. Note relative stratigraphic position of 19 track-bearing horizons shown in Figure 1.

with in this paper. Based on the track types and other evidence (Lucas et al., 2005), the age of the upper portion of the Moenave Formation is interpreted as Early Jurassic (Hettangian – 199.6 to 196.5 million years ago).

LOCAL GEOLOGICAL CONTEXT OF THE ST. GEORGE TRACKS

Tracks occur at as many as 25 stratigraphic levels (Fig. 3) in the immediate vicinity of the SGDS, DS, and Washington County School District property (WCSD) sites, and many of these layers have been mapped *in situ* (Figs. 4-6). The first-discovered level, called the "Johnson Farm Main Tracklayer" (MTL) at the SGDS, reveals tracks and associated mudcracks preserved as robust sandstone casts (negative relief) at the base of a thick (30-70 cm), well-sorted, fine-grained sandstone bed that lies about 53 m above the base of the Moenave Formation. The casts, which have up to 10-20 cm of relief, can only be seen after the

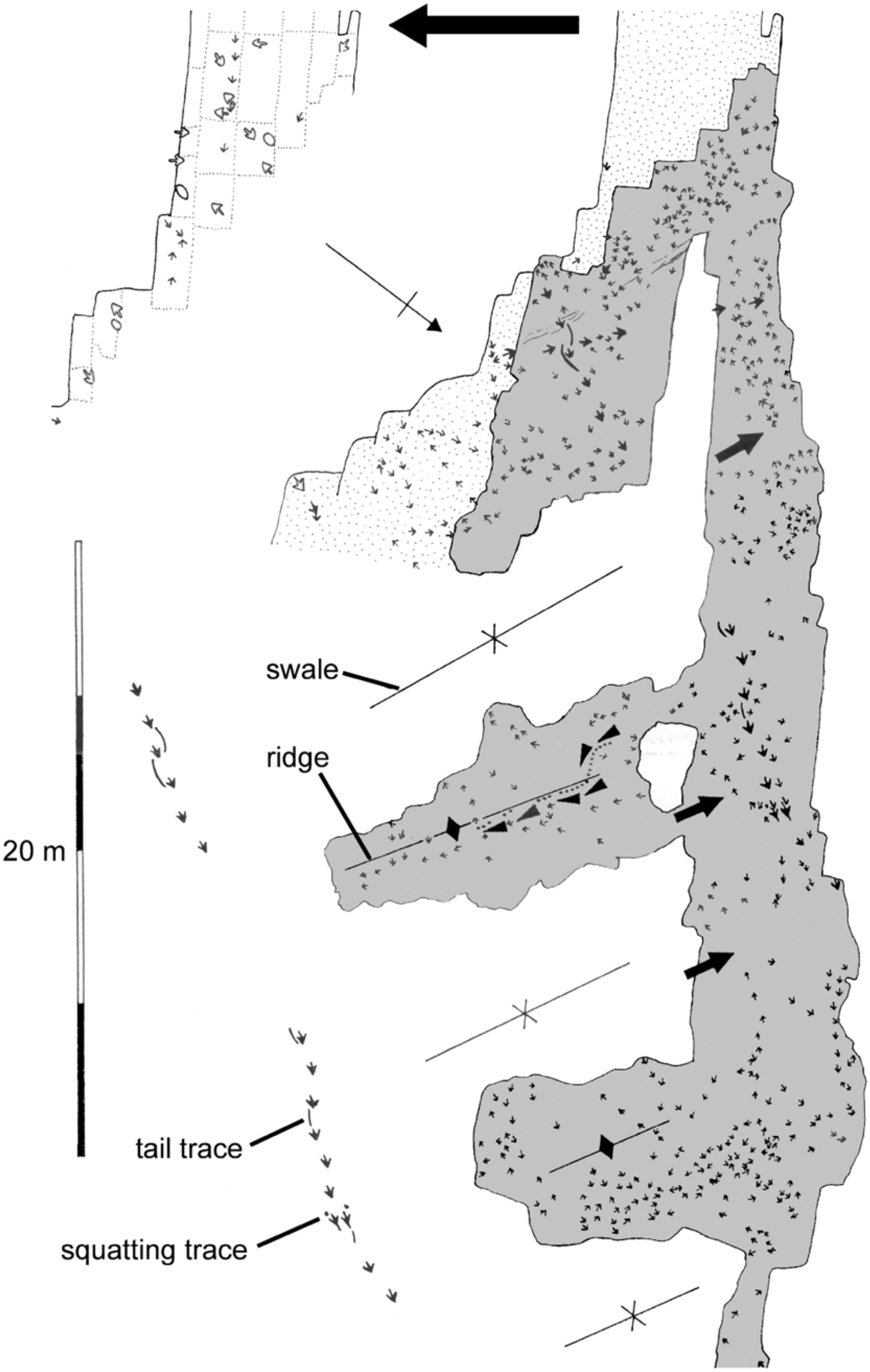

FIGURE 4. Map of *in situ* SGDS "Top Surface" tracksite and portion of the "Main Track Layer" (MTL) (no. 1 on Fig. 2). Note difference between lower MTL level, showing block outlines (left), as map of the underside of the main track-bearing sandstone bed, and upper level, or Top Surface (right; catalog no. SGDS.18), which remains *in situ*. For clarity, cf. *Gigandipus* trackway with tail and crouching traces is shown separately (lower left) in the same orientation as it occurs on the map. Note ridge and swale topography and black arrows indicating selected local flow indicators on the Top Surface.

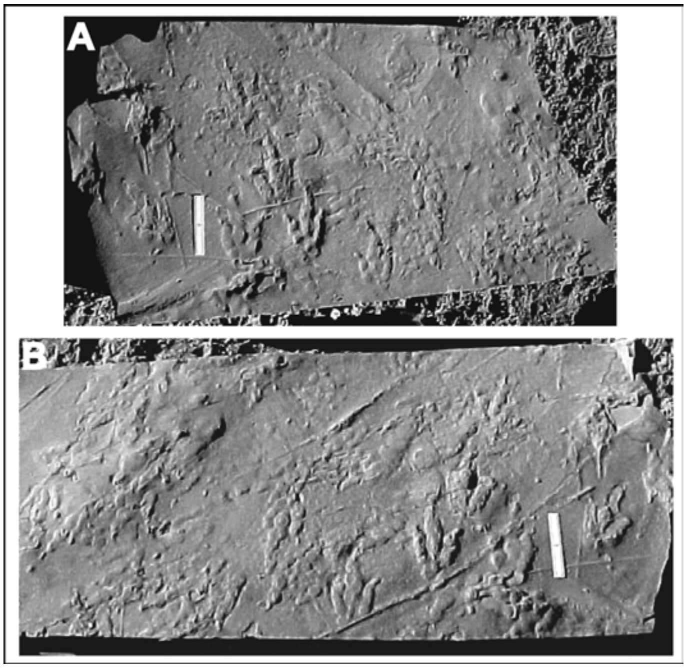

FIGURE 5. Part and counterpart specimen (SGDS.16) from the Johnson Farm "Split Layer" showing high density of *Grallator* tracks with less common *Eubrontes*. **A**, Actual track surface (part). **B**, Natural cast surface (counterpart).

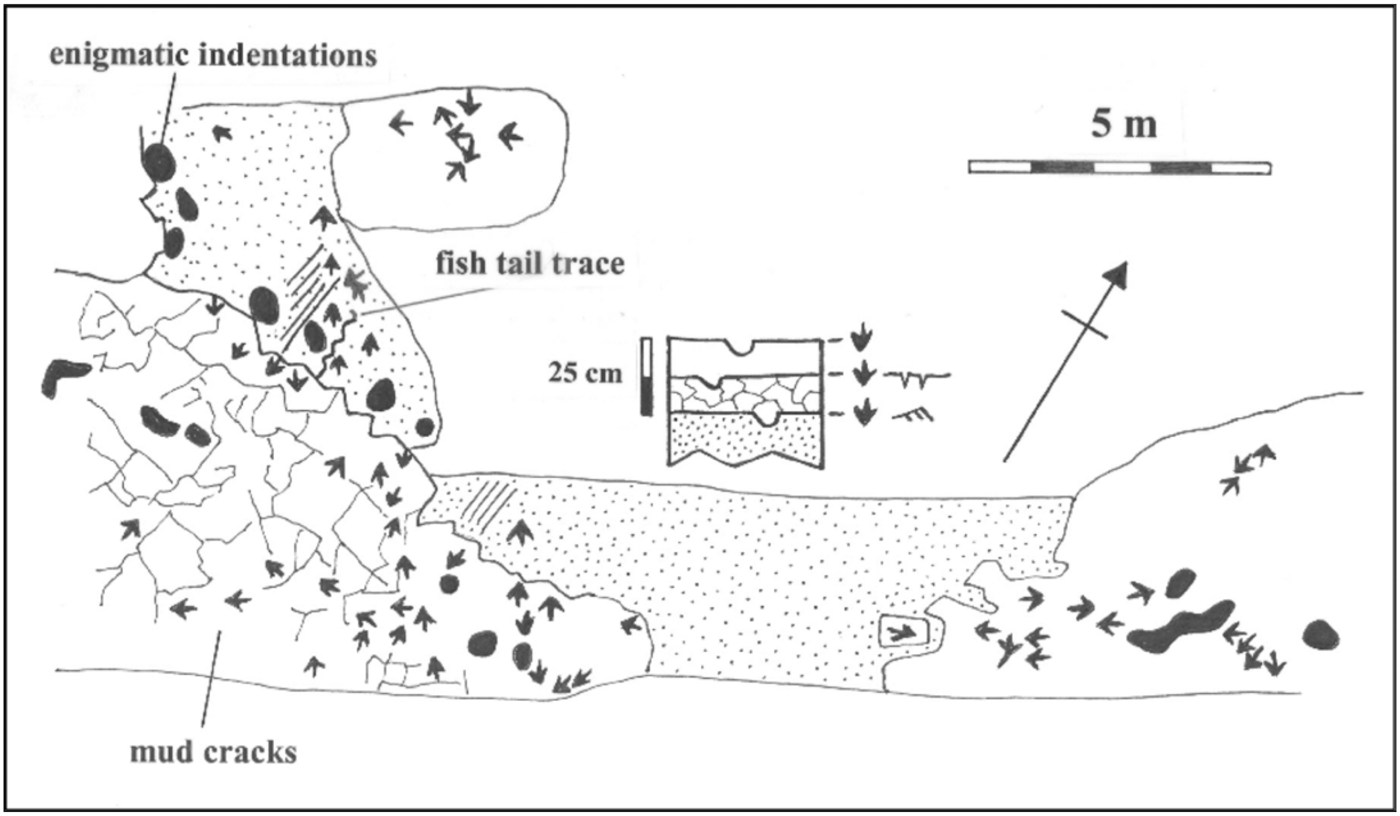

FIGURE 6. Map of track-bearing exposures called the Stewart-Walker Tracksite located north of the SGDS museum and Riverside Drive (no. 2 on Fig. 2).

sandstone bed has been turned over. This process requires heavy equipment, and necessitated removing blocks from their original *in situ* location. This process seriously disturbed tracks in the overlying layers (Fig. 4).

A layer designated the "Johnson Farm Split Tracklayer" is located approximately 4-15 cm above the base of the MTL surface. This layer contains abundant tracks assigned mostly to *Grallator* with some *Eubrontes* (Fig. 5). Other types of trace fossils include many of the best preserved arthropod, horseshoe crab, and beetle trackways (see Lucas et al., this volume), possible fish swim trails, and plant impressions. Along with the many dinosaur tracks, sedimentary structures include groove cases, locally abundant salt crystal casts, and microbial mats.

A third important track-bearing layer, called the "Top Surface," is associated with complex, undulating surfaces on the upper part of the sandstone that has the MTL at its base (Fig. 4). These surfaces lie between 54-55 m above the base of the formation. The "Top Surface" reveals several laterally variable layers in a thin stratigraphic interval, and displays a complex of irregular current ripples, regular oscillation ripples, ridges, swales, mudcracks, scour, load casts, rill marks, interference ripples, tool marks and depositional features, in addition to tracks and/or undertracks with variable preservation. Although the complex sedimentology of this surface has not been described in detail, some preliminary interpretations are outlined below and elsewhere in this volume (see Fig. 4; Kirkland and Milner, this volume; Milner et al., this volume).

More than 1200 tracks have been mapped *in situ* on the "Top Surface," though more of the surface remains to be excavated and mapped in the future. A total of 1060 of these tracks were drafted onto the first preliminary map made in early 2005 (Fig. 4). More than 650 are attributed to *Grallator*, about 375 to *Batrachopus* or a *Batrachopus*-like quadruped, and 24 to *Eubrontes* and/or *Gigandipus*. They occur in at least four track layers on top of the main track-bearing sandstone bed, the underside of which has produced most of the well-preserved casts. The relationship of the Top Surface to the MTL is illustrated in Figure 4 (see caption for details). As noted below, one trackway on this upper surface that has associated squatting and tail drag traces (Fig. 4) is similar, but not identical, to *Gigandipus* described by Hitchcock (1858) and Lull (1953). Several tracks on the Top Surface reveal slide or drag marks, attesting to soft and slippery substrate conditions on this irregular undulating surface.

One of the striking features of the SGDS is the relationship between trackways, topography, and the local paleogeography. We cannot map the paleogeography at every track level, as surfaces are only exposed sporadically, and the cost of additional excavation would be prohibitive. However, it is possible to map the main SGDS, where most of the trackways were made by walking animals on an undulating surface. Preliminary maps (Fig. 4) show tracks concentrated in topographically high areas. Tracks also occur in lower areas, but in many cases still require excavation before mapping can be completed. As noted above, this process is underway, and between 150 and 200 additional tracks not shown in Figure 4 have already been recorded. Detailed maps of the Top Surface are in preparation, but far too complex to present in this general overview.

In contrast to the "onshore" location of the SGDS museum site, extensive track-bearing surfaces discovered to the northwest (DS and WCSD properties), representing the lateral extension of the MTL, show abundant swim tracks (Milner et al., this volume), suggesting a relatively "offshore" location equivalent to the onshore surface marked by well-preserved *Eubrontes* tracks. Many fish remains have been recovered from this northern area, especially from higher levels in younger sediments (Milner and Kirkland, this volume). This gives us an indication that, at the time the Top Surface layers were deposited, the lake shoreline probably ran somewhere between the SGDS and DS sites, probably with a NNE–SSW trend.

Tracks are also exposed just to the north of the SGDS museum site at the DS localities, respectively designated numbers 1 and 2 in Figure 2. These sites are separated by a city road (Riverside Drive), and are about 2 m stratigraphically above the Top Surface. About 48 tracks at this site occur at three different stratigraphic levels separated by only about 25 cm (Fig. 6). The site contains a number of interesting features, including large indentations that some observers consider to have a superficial resemblance to sauropod tracks. However, these features do not occur in regular patterns indicative of trackways, and we regard them as enigmatic at this time. Some exhibit elongate nodular shapes that may be related to root systems. Rhizoliths commonly occur on these track-bearing surfaces. The surface also reveals fish swim trails (*Undichna*). At present, the site is being mapped in more detail, so only a preliminary map is presented here (Fig. 6). Nevertheless, it was necessary to map some of these small sites as soon as they were discovered and exposed because, in many cases, ongoing excavation and development threatened their destruction. Site no. 11 (Fig. 7) is another example of a small site that was completely excavated away soon after it was mapped. Even sites that were not in imminent danger of destruction from rapid development were in danger of deterioration through exposure to the elements and unregulated foot and off-road vehicle traffic. Further excavation at site no. 2 (Fig. 2) in August, 2005 led to the discovery of an *Anomoepus* trackway and many large cf. *Kayentapus* footprints (see Fig. 8A). Specimens were salvaged, mapped, photographed and traced from three track-bearing surfaces, but localities are now completely gone due to development.

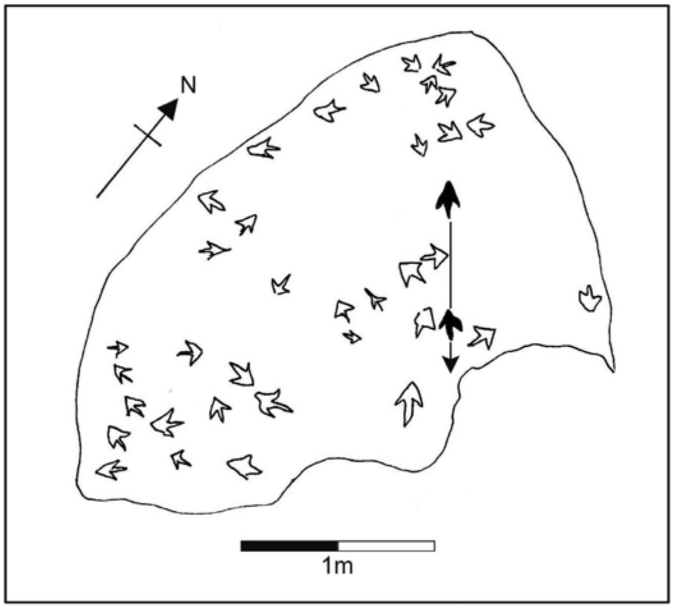

FIGURE 7. Map of site no. 11 in Figure 2, called the "Mall Drive Tracksite." Black tracks and arrow show two tracks in sequence.

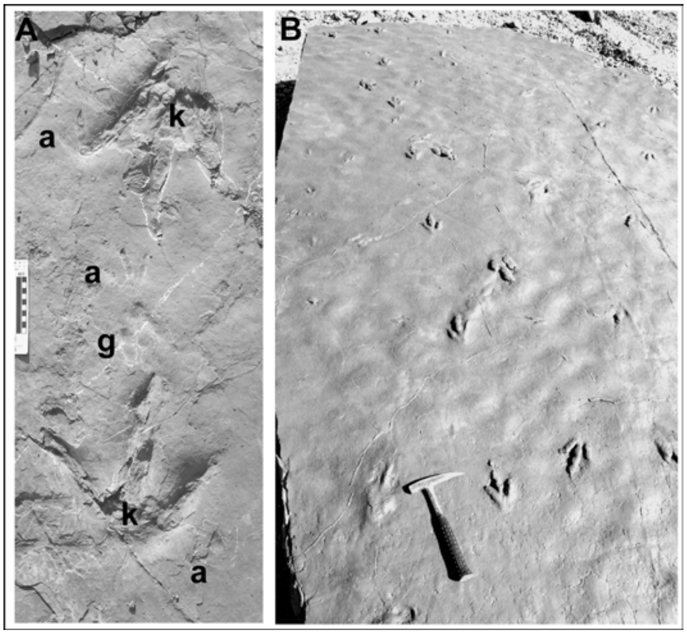

FIGURE 8. **A**, Several tracks *in situ* from the "Unit 19 Roadcut Site" (site no. 2 on Fig. 2). Abbreviations: a, *Anomoepus* footprints; g, *Grallator* track; k, cf. *Kayentapus* footprints. **B**, Photo of big, exhibit-quality block soon after excavation from "Walt's Quarry #1" (site no. 5 on Fig. 2). This block is now on display in the SGDS museum (SGDS.568). See Figures 9 and 10.

LOGISTICS AND METHODS OF DOCUMENTATION

The pace of excavation and development in St. George has been extremely rapid, and the rescue efforts of the authors and many volunteers have been complicated by many factors, including changes in ownership of small parcels of property. In general, the excavation has had many positive benefits, such as the discovery and removal of important specimens that would not otherwise have come to light. Many construction crews and landowners have been cooperative and generous in setting aside specimens for our inspection, and for providing heavy equipment to help with the transportation of multi-ton blocks. Nevertheless, there have been complex logistical challenges involved in keeping track of specimens as they were excavated and ensuring that they were preserved, not damaged, and documented in proper stratigraphic context and orientation. Essentially the process has been one of breaking up a three-dimensional jigsaw puzzle and then reassembling it. The logistical challenges were relatively straightforward at the SGDS (locality no.1), but complex at all other sites north of Riverside Drive (sites 2-7 and 11-17).

The local physical context of the SGDS, WCSD and DS tracks is best illustrated by reference to the stratigraphic section (Fig. 3) and the site maps of *in situ* track-bearing surfaces (e.g., Figs. 4-7). As noted above, Figure 4 shows the upper and lower surfaces of the main track-bearing sandstone. Prior to drafting the first clean copy of the map, more than 1060 tracks and trackways on the Top Surface were mapped *in situ* on a WNW-ESE trending outcrop delineated by conspicuous tension joints. We established a baseline parallel to this joint trend and, using compass and tape measure to construct a 1 m^2 grid system, mapped the Top Surface in detail, including ripple marks and local topography (dips from 0-30º).

All of the tracks mapped (about 30: Fig. 4) on the MTL are no longer in place. Beginning in April, 2000, in order to see more of their undersides, the main tracklayer blocks were turned over using heavy equipment (i.e., a track hoe). During this operation, each removed block was numbered and its location and upper and lower surfaces (Top Surface and MTL, respectively) mapped so as to place the disturbed tracks in their correct orientation. The resulting map of the MTL covered an area of approximately 60 m^2. To date, systematic mapping of the Top Surface has been extended to an area of about 800 m^2, and it remains *in situ* as the centerpiece of the SGDS museum exhibit (Fig. 4).

Similar inversion and removal of MTL blocks, and other units, from their *in situ* orientations took place at other sites to the north of Riverside Drive (DS site area) during excavation for construction in 2001. In 2002 and 2003, much excavation took place on WCSD property, and led to the discovery of *in situ* dinosaur swim tracks. Then, in 2004, a second large area was excavated, once again for construction, on an even larger parcel of DS property. From careful mapping and numbering of blocks during these excavations, it might be possible in the future to place some of these mapped blocks back into their precise or approximate positions in relocated displays. This was accomplished to some degree in 2004-2005 with the construction of a 13.11 x 4.57 m high wall in the first phase of SGDS museum construction. This wall is made up of eight blocks, ranging in weight from 1.36-12.25 mton, that consist of an upper Dinosaur Canyon Member tracklayer from "Walt's Quarry #2" (site 6 on Fig. 2). Approximately 200 dinosaur tracks, as well as fish swim trails and crocodylomorph tracks, have been documented in this new exhibit. However, the original orientations of many MTL blocks are unknown. It is essentially a physical impossibility to strip off 25 track-bearing layers, map both upper and lower surfaces, and find space to reassemble and preserve them. In future phases of the museum, it may be feasible, however, to reconstruct a group of blocks from MTL, WCSD and DS sites, and a large portion of mapped swim track blocks.

In addition to mapping the various sites, we documented the best-preserved tracks through tracings, photographs, latex molds, plaster and fiberglass replicas, measurements, and cataloging. Most or all of the original tracks, especially those on large blocks, will remain at the site as part of a permanent exhibit, and all have been given local catalog numbers (with the SGDS prefix).

We estimate that, in addition to about 2000 tracks mapped *in situ* (Figs. 4-7), at the SGDS, DS and WCSD sites there are hundreds of additional footprint casts exposed on overturned blocks. More than 1000 of these not *insitu* tracks have, at the present time, been designated specimen numbers, including track-bearing slabs and other non-ichnological specimens. In addition to the many *Grallator*, *Eubrontes* (and/or *Gigandipus*) and *Batrachopus* tracks, there are a number of invertebrate traces, some of which resemble arthropod traces described by Hitchcock (1858). These invertebrate traces are described elsewhere in this volume (Lucas et al., this volume).

Finally, it should be noted that a majority of the specimens so far recovered have been in need of cleaning and preparation. Many of the sandstone blocks have shaley mudstone adhering to the natural casts of tracks, and thousands of volunteer man hours have been devoted to cleaning and repairing specimens. All such activity is a prerequisite for detailed morphometric study.

In addition, preparation of the Top Surface layers within the SGDS museum is ongoing. For example, as noted above, although only 1060 tracks have been plotted on the preliminary version of the Top Surface tracksite map (Fig. 4), already more than 1200 have been recorded. Also, more than 3200 individual dinosaur swim track claw marks have been counted on about 150 blocks (Milner et al., this volume). The mapping and the documentation of the sites discussed herein are still in their preliminary phases.

DESCRIPTION OF THE TRACKS

Mapping of Selected Blocks

As indicated in the previous section, there are thousands of tracks that can be mapped and measured, and a thorough, quantitative study of the material would likely take many years. We can divide such potential study into various categories: 1) mapping of *in situ* sites, as outlined in previous sections, 2) mapping of selected blocks that may or may not have known orientations, 3) identification of characteristic morphotypes and selected specimens of special interest, and 4) other statistical and morphometric studies of tracks from known or unknown stratigraphic levels.

In this paper, we focus on the first three of these categories. The initial phases of mapping *in situ* surfaces and blocks with known orientations is important for establishing trackway orientations in relation to the local paleogeography. For example, the large block (23.59 mton) illustrated in Figures 8B and 9 is arguably the most visually spectacular, "exhibit-quality" block on display at the site. It reveals 11 *Grallator* trackways that vary in size and quality of preservation, as shown by the tracings of all specimens (Fig. 10). Ideally, it would be possible to document all slabs with illustrations and tracings, as well as tabulated measurements (Table 1). Such a treatment would only be possible in a substantial monograph. Here we provide only a representative illustration and description of this material.

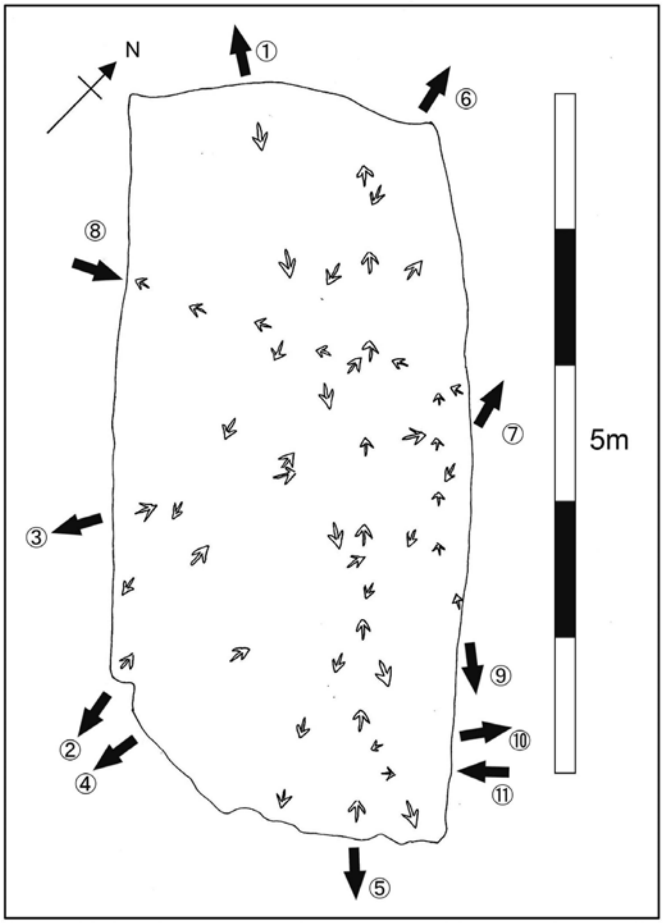

FIGURE 9. Map of big exhibit quality block (SGDS.568). Compare with Figures 8 and 10.

Identification of Ichnotaxa

The majority of tracks from the SGDS are those of tridactyl theropods and can be identified as *Grallator* and *Eubrontes* Hitchcock (1858 and 1845, respectively) with subsequent revisions by Lull (1904, 1915, 1953). These classic Liassic tracks, including the *Grallator*-like ichnogenus *Anchisauripus* and the larger track *Eubrontes*, were recently re-examined by Olsen et al. (1998). We use their evaluations and illustrations of the holotypes (Fig. 11) as a point of reference for comparison with the tracks from St. George.

Tracks from the SGDS assigned to *Grallator* and *Eubrontes*, as well as crocodylomorph tracks assigned to ichnogenus *Batrachopus* (Lockley et al., 2004), are nearly all remarkably similar to those described by Hitchcock (1858) and Lull (1953) from the Early Jurassic of New England, and from other sites in the western United States (Lockley and Hunt, 1995). Traditionally, studies of the ichnogenera *Grallator*, *Anchisauripus* and *Eubrontes* (sometimes referred to as the G-A-E plexus) have drawn attention to the large number of very similar ichnospecies. In fact, these kinds of tracks are considered so similar by some workers that it has been suggested that they may all belong to the same ichnogenus (Olsen, 1980; Rainforth, 2005a), although until now this extreme lumping has ultimately been avoided in any formal ichnotaxonomic studies (Olsen et al., 1998). As discussed below, these interpretations are fraught with difficulty and subjective interpretation of both qualitative and quantitative evidence. Thus, the ichnotaxonomy of these tracks remains an open question still under investigation (Rainforth, 2005a, b).

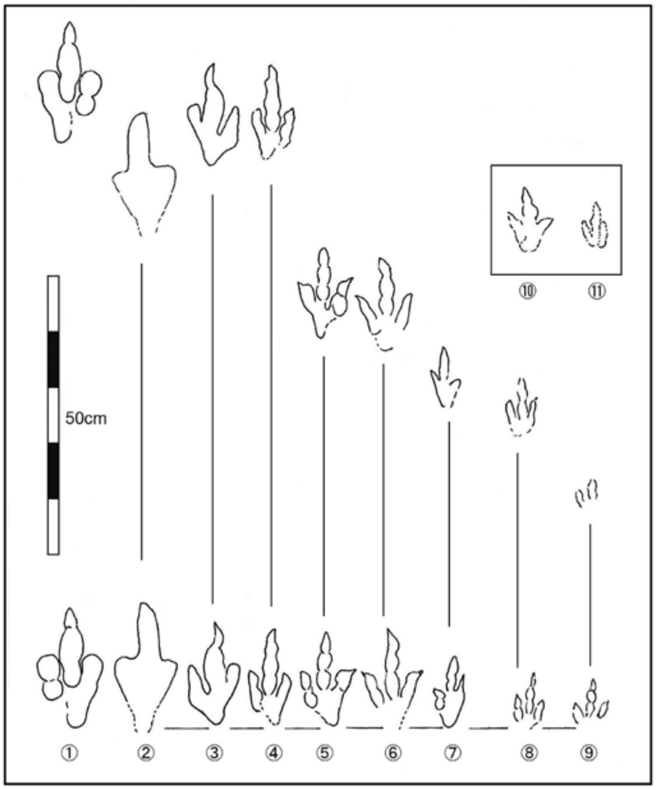

FIGURE 10. Illustrations of 11 tracks and trackways from block (SGDS.568) shown in Figures 8-9 showing variation in size and preservation.

TABLE 1. Measurements for tracks (in cm) from trackways on large slab shown in Figs. 8-10.

Trackway no.	Pes length	Pes width	Step	Stride
1	22	12	101-107	204-213
2	(20)	(11)	88	172-174
3	18	9.5	100-102	200
4	17	7.5	99	-
5	17	10	67-69	133-137
6	17	10	67-70	137
7	12	6	55	110
8	10	5.5	45-54	100-105
9	9	6	40-41	81
10	11	8	-	-
11	9	5.5	-	-

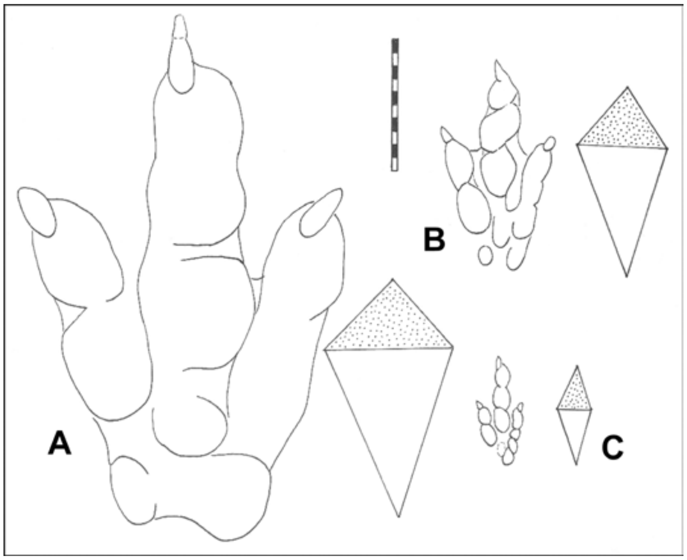

FIGURE 11. **A-C**, *Eubrontes*, *Anchisauripus* and *Grallator* drawn to the same scale, after Olsen et al. (1998). Note that the triangles defined by the three digit tips and heels differ depending on the relative projection of digit III beyond II and IV. Triangles for *Eubrontes* drawn at half scale. Scale bar 10 cm.

As discussed below, we also discuss the ichnogenus *Gigandipus*, which some authors consider a subjective synonym of *Eubrontes*. Some ichnologists (Gierliñski, 1991; Weems, 1992; Piubelli et al., 2005) also recognize *Kayentapus* as a distinct ichnogenus that is large like *Eubrontes*, but more gracile, with wider digit divarication angles. Such tracks have been recognized at other sites in SE Utah, and we have recently recognized a morphotype we refer to as cf. *Kayentapus* from the SGDS (Fig. 8A).

Diminutive *Grallator*-like Tracks

We describe the tracks from the St. George site in order of increasing size. This is not merely a convenience, but follows the conventions of ontogeny and phylogeny that recognize increase in size with growth and evolutionary development as fundamental, organic, developmental processes. Both the increase in size through time and the allometric relationships between small and large tracks have been discussed repeatedly in the literature on the *Grallator*, *Anchisauripus* and *Eubrontes* plexus (Olsen, 1980; Lockley and Hunt, 1995; Olsen et al., 2002). Some authors (e.g., Thulborn, 1990) have also drawn size distinctions between large and small theropod tracks using the somewhat arbitrary footprint length of 25 cm.

The size range within the St. George sample is remarkable. The smallest tracks are only about 2-3 cm long, but several comprise trackways with exceptionally long steps. In fact, one of the smallest trackmakers (Fig. 12A), with a footprint length of 2 cm, has a step length of 23-36 cm. Likewise, another trackmaker, with a footprint length of 5 cm (Fig. 12F), has a step of 57 cm. Some, although small, footprints (length 8 cm

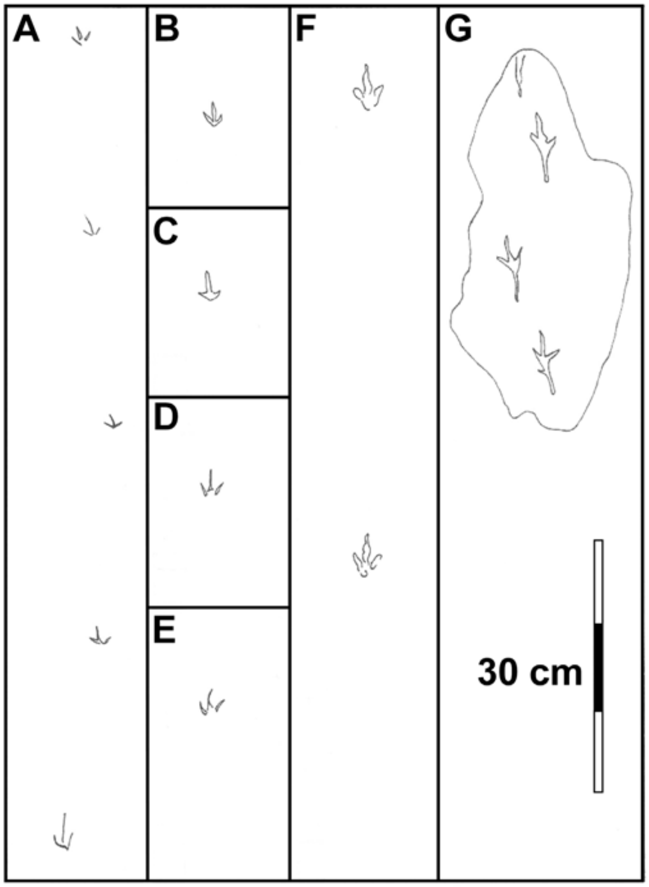

FIGURE 12. Diminutive *Grallator*-like tracks. **A**, Trackway sequence from the SGDS Top Surface (SGDS.18). **B-E**, Isolated small tracks from various localities on the SGDS Top Surface tracksite (SGDS.18). **F**, Long-step sequence from the SGDS Top Surface (SGDS.18). **G**, Short step sequence with metatarsal and hallux traces from a float block at the DS site (SGDS.286; site no. 6 on Fig. 2). All drawn to same scale.

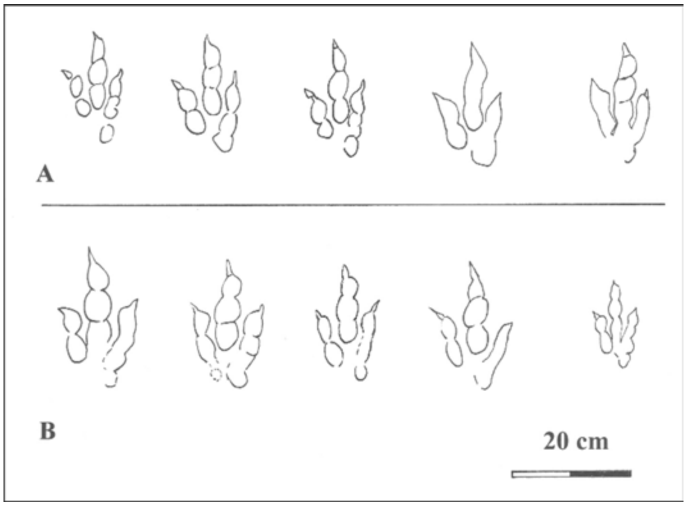

FIGURE 13. **A**, *Grallator* tracks from St. George. **B**, Similar tracks from the Lower Jurassic of the Connecticut Valley for comparison.

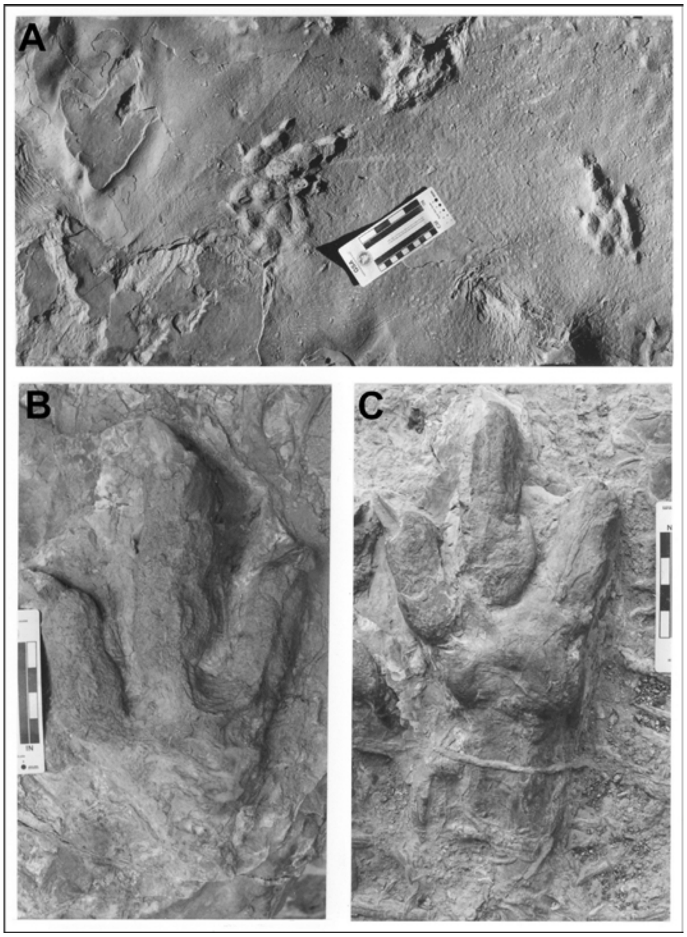

FIGURE 14. Photos of tridactyl theropod tracks. **A**, *Grallator*; note difference between sand-filled track (left) and impressions (SGDS.197A). **B**, *Eubrontes* natural cast track (SGDS.9; same in Fig. 17A on left). **C**, *Eubrontes* specimen showing a hallux and metatarsal impression (SGDS.8; same as Fig. 17B on left).

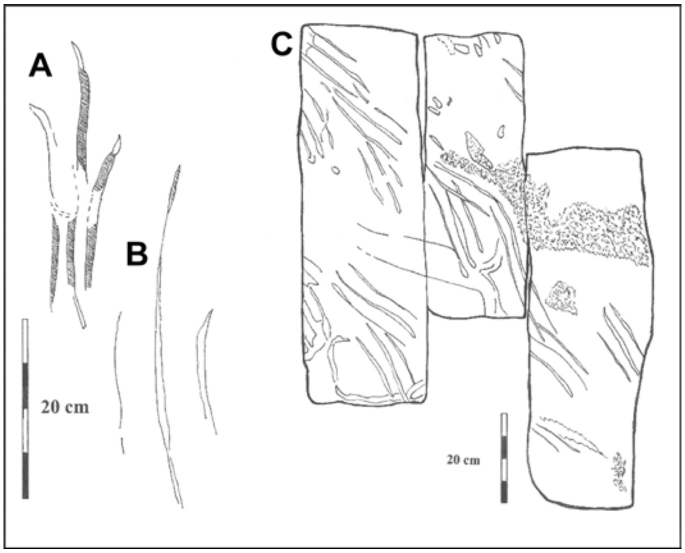

FIGURE 15. Swim and/or slide marks associated with *Grallator* tracks. Note the transition from a *Grallator* trace (SGDS.74) with three posterior slide marks (**A**) through three parallel slide marks or swim tracks (**B**, number not assigned), to multiple sets of three swim marks (**C**, SGDS.167). Reassembled blocks shown at half scale with stippled areas showing scoured portions of the surface.

including heel trace), have short steps and show traces of the metatarsal and hallux. The hallux (digit I) was small and rarely touched the ground in any other tracks from the entire sample.

Grallator sensu lato

As shown in Figure 11, when comparing the type specimens, there are various subtle differences between *Grallator*, *Anchisauripus* and *Eubrontes*. Olsen (1980) noted that the projection of digit III beyond the two lateral digits (II and IV) decreases progressively throughout the *Grallator-Anchisauripus-Eubrontes* group (or the G-A-E plexus). Although this is evident in the case of the type specimens, where the proportions of *Anchisauripus* resemble those of *Eubrontes* (Fig. 11), there is no widely agreed-upon precedent for accepting or disputing this difference as important. This boils down to a perennial debate in paleontology between "lumpers" and "splitters" that we cannot resolve here. We avoid the use of ichnogenus *Anchisauripus* that, as defined by Lull (1953) and others, is often difficult if not impossible to distinguish from *Grallator*. Many ichnologists avoid the use of this ichnogenus, while still using *Grallator* and *Eubrontes* (e.g., Lockley and Hunt, 1995; Rainforth, 2005a). Recent, and hitherto unpublished, studies of the Hitchcock collection (Rainforth, 2005b) make it premature to further evaluate the *Grallator*, *Anchisauripus* and *Eubrontes* plexus for the purposes of this paper, and we refer the reader to Olsen et al. (1998) and Rainforth (2005b) for further information.

Small tracks identified as *Grallator* have been identified on both the MTL and Top Surface (Figs. 4, 13-14). *Grallator* tracks have been identified on 23 of the 25 known track-bearing horizons in the area of the SGDS. In contrast to the *Eubrontes* tracks (foot length >32 cm), the size of the *Grallator* tracks ranges from 10-25 cm long and 8-11 cm wide (cf. Figs. 8-9). There appear to be few intermediate track sizes in the range of foot length 25-32 cm, and few *Grallator* tracks exceed 20 cm in length. Well-preserved *Grallator* or *Grallator*-like tracks from the SGDS area are hard to distinguish from similar tracks from the Hitchcock collection in New England (Fig. 13). As noted below, the reader can compare these specimens with larger tracks assigned to *Eubrontes*.

Some *Grallator* tracks, from the SGDS Top Surface, indicate that the trackmaker's pes dragged or slid through wet mud before firmly planting the foot (Fig. 15A). These give us insight into theropod dinosaur behavior and locomotion in the context of local topography in this marginal lacustrine setting. When traced northward, track-bearing layers with such slide or scratch marks (Figs. 15A-B) become more abundant and constitute a swim track facies (Fig. 15C), recently labeled the *Characichnos* ichnofacies (Hunt and Lucas, in press). It is outside the scope of this paper to discuss swim tracks (see Milner et al. [this volume] for further discussion). However, Figure 15 is presented to show the transition from an obvious tridactyl track (modified *Grallator*) to swim tracks that somewhat resemble those originally described by Coombs (1980) from the Lower Jurassic of New England (see Milner et al., this volume).

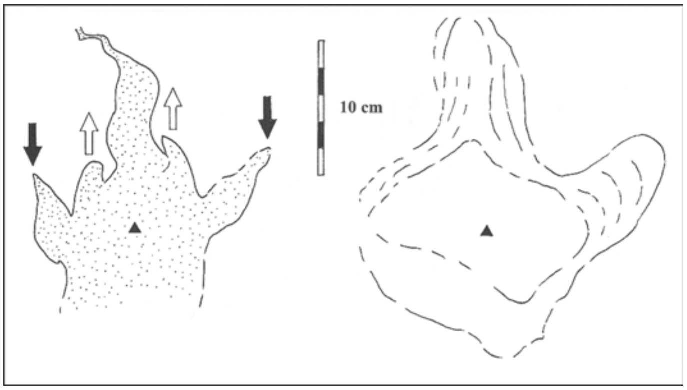

FIGURE 16. Top view of outline of sandstone fill of *Grallator* track cast (left) broken off at bedding plane level and corresponding rounded under track 10 cm below the bedding surface (specimen SGDS.815). Black triangles indicate the approximate position of a vertical line drawn through center of the track cast at its deepest point. Note that the traces of the outer toes (II and IV), upon penetration of the substrate (black arrows) and during withdrawal of the foot (white arrows), indicate that the trackmaker retracted its outer toes together when lifting its foot.

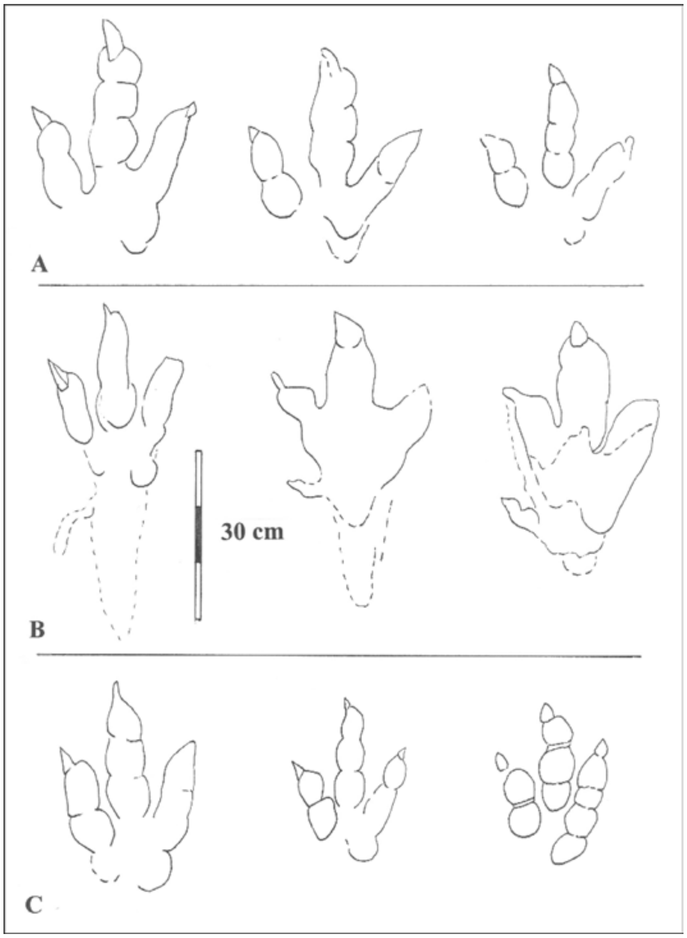

FIGURE 17. Tracings of SGDS and Connecticut Valley large theropod tracks. **A**, *Eubrontes* tracks without hallux impressions from the MTL at the SGDS (catalog numbers from left to right: SGDS.9, SGDS.131, SGDS.59). **B**, *Eubrontes* tracks from the MTL at the SGDS with hallux and partial metatarsal impressions (catalog numbers from left to right: SGDS.8, SGDS.24, SGDS.50). **C**, *Eubrontes* tracks from Connecticut Valley. Note that hallux impressions are rare in all samples and that they can be confused with other features, such as toe impressions associated with other tracks, if preservation is not optimal, or with mudcracks.

A few tracks appear to have blunt toes, and look somewhat similar to large ornithopod tracks. Most of these are shown to be underprints or under tracks; in one case, the outline of a *Grallator* track, cast in sandstone, was cut out using a concrete saw from the MTL: i.e., 10 cm above the indistinct bulge that we call an underprint, where the track above deforms layers of sediment below without actually penetrating it (Fig. 16). The two expressions of the same track are entirely different, and prove conclusively that the under track is of theropod origin despite its misleading appearance. This specimen, among others, shows the widely splayed impressions where digits II and IV entered the substrate, and the much more closely-spaced impressions where the animal brought its three toes (II, III and IV) together as it extracted its foot from the footprint.

Eubrontes and *Gigandipus*

One of the most interesting features of the large tracks, herein referred to as *Eubrontes* (*sensu lato*), is that they are deep and essentially preserve a three-dimensional replica of the trackmaker's foot (Figs. 14, 17). In some cases, the track is sufficiently deep to preserve traces of the metatarsus and hallux (collectively referred to here as "posterior traces":

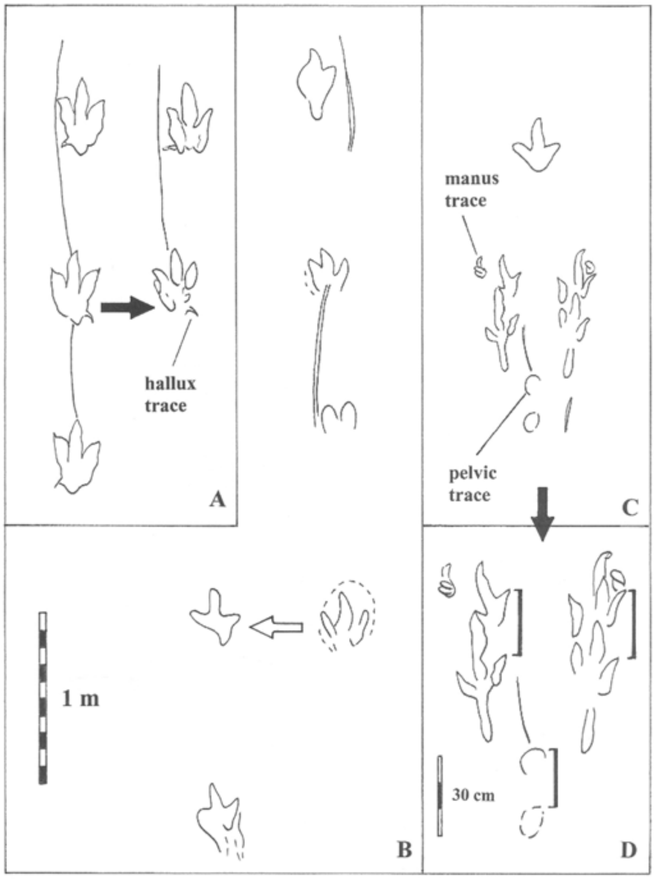

FIGURE 18. A “*Eubrontes*” trackway with tail and crouching traces. **A**, Type specimen of *Gigandipus* after Lull (1953) on the left, and partial tracing of the same specimen by the second author (MGL) on the right. **B**, Five consecutive footprints of *Eubrontes* from the SGDS museum *in situ* Top Surface showing tail traces (SGDS.18.T1). Note that the first two in the sequence (offset to left) were traced in 2002, while the remainder was traced in 2000 when first exposed. White arrow shows the change in shape after weathering for two years. **C**, Crouching trace, uncovered in 2004, from the same SGDS Top Surface trackway as in **B**. **D**, Enlargement of **C** to show double print of hind feet and pelvic (ischial) traces. This suggests that the dinosaur shuffled forward while crouched on one of the ridges along the lakeshore (compare with Fig. 4).

FIGURE 19. Photos of large theropod trackway with tail trace (SGDS.18.T1). **Left**, Three footprints at distal end of trackway clearly shows tail trace, and cast of tail trace, just after excavation in 2000. **Right**, Five footprints at distal end of trackway after further excavation. Note loss of detail of tail trace. Note that this trackway also shows evidence of squatting; compare with Figure 18.

Fig. 17B). To the best of our knowledge, there are no well confirmed reports of *Eubrontes* tracks with hallux or “heel” (i.e., metatarsal traces). To date, the only named large Lower Jurassic theropod track with distinctive hallux traces is *Gigandipus* (Hitchcock, 1858; Lull, 1953), from the Lower Jurassic of Turner’s Falls, Connecticut. Interestingly, this unique trackway is also associated with a tail trace made by the same animal that made the tracks. Lull (1953, p. 184-185) noted that “*Gigandipus caudatus* resembles *Eubrontes giganteus* very closely in general form and dimensions and is doubtless sometimes confused with that species when the hallux and tail trace are not present in the specimen.” Recently, Weems (2003) inferred that *Eubrontes* and *Gigandipus* were likely made by the same trackmaker.

The possibility that *Eubrontes* and *Gigandipus* represent different modes of preservation of the same track type creates some problems of interpretation. Lull’s descriptions of *Gigandipus caudatus* indicate that, as the name implies, it has a tail trace and hallux traces, though he implied that one or the other may not be present. If neither is present, it is presumably labeled *Eubrontes*. Among the SGDS tracks, we have examples of *Eubrontes*-like tracks with hallux impressions but no tail traces and examples of *Eubrontes*-like tracks with both tail and hallux traces (Figs. 18-19). Technically, this trackway on the Top Surface with hallux and tail traces should be named *Gigandipus*; however, the pes morphology more resembles that of true *Eubrontes* tracks. To be consistent in deciding which characteristic (tail or hallux trace), if any, is most important in deciding the appropriate name, we must look at Lull’s description of *Eubrontes*. Here, Lull (1953, p. 179) states “no indication of a hallux claw with one possible exception, or of a dragging tail.” Given that the trivial name *caudatus* indicates a “tail,” this would imply that Lull’s concept of *Gigandipus* places greater emphasis on the tail trace than on the hallux. We stress that such arguments are, for the purpose of a suitable working label, not a rigid definition. It is already clear that *the two ichnospecies could be regarded as the same, or different, depending on the weight given to different characters*.

Another observation that has arisen as the result of discoveries at St. George is that the tail trace may easily be lost to weathering and erosion after the traces are exhumed, while the footprints, being deeper, remain, and change morphology with prolonged weathering (Fig. 18B).

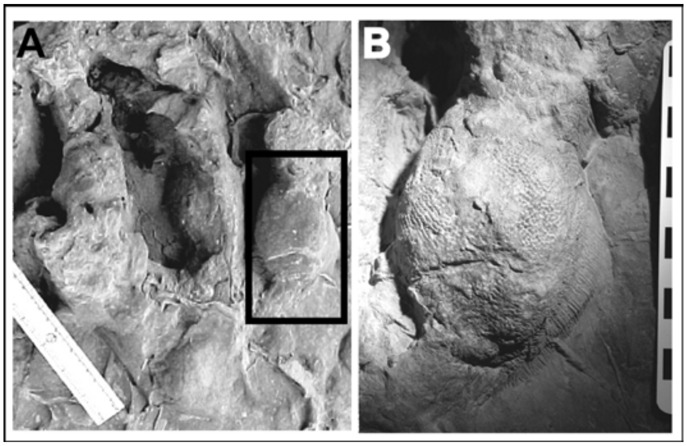

FIGURE 20. Skin impressions associated with a *Eubrontes* track (SGDS.15). **A**, Photo of the track; black box indicates location of skin impressions shown in **B**. **B**, Clear skin impressions all over and around toe pad, and scale scratch lines visible on the right side of the pad.

Thus, *Gigandipus* could become *Eubrontes* after some time! Such problems are not unusual, as the partial loss of any morphological detail can always potentially change our interpretation of a given fossil.

Let us then return to the hallux. Given that this is not characteristic of *Eubrontes*, and that the *Gigandipus* hallux is located very close to the posterior end of digit II, we argue that the hallux position in most of the SGDS tracks is in a different location, further from the posterior end of digit II, i.e., somewhat further "up" the metatarsal. Here again we must avoid being too rigid in our definitions since 1) the difference is not very well marked, and 2) it is known that hallux position may be variable owing to preservational, rather than inherent morphological, differences (Gatesy et al., 1999).

Our provisional conclusion, based on comparison with Lull's descriptions of *Gigandipus* and *Eubrontes*, and the original sources and material from which they were synthesized, is that the specimens with hallux traces must either be considered variations of the normal *Eubrontes* configuration (i.e., with more pronounced hallux), possibly owing to greater depth of the tracks, or examples of *Gigandipus* where the tail trace is not preserved. In either case, our Early Jurassic sample of large, hallux-bearing theropod tracks is enlarged, and we can make a plausible case for considering the St. George sample one of the first to show some examples of a hallux associated with the ichnogenus *Eubrontes*.

In our preliminary survey, we identified tracks that were well-preserved and worth replicating and tracing. These mostly range in size from about 32-42 cm long (excluding posterior traces) to 24-33 cm wide. The longest posterior (metatarsus trace) associated with the smallest track (32 x 24 cm) is 28 cm long (Fig. 17). However, it is unfortunately not possible to infer that this represents the full length of the metatarsus, and it could be interpreted as a heel drag trace.

The illustrated tracks (Fig. 17) clearly show the typical 2-3-4 phalangeal pad formula attributed to digits II-III-IV, respectively. Generally, the tracks have parallel-sided digits that are not strongly tapered toward the distal (anterior) end. However, many of the track casts terminate with sharp claw impressions. In some cases, traces of skin impressions have been preserved (Fig. 20).

To date, few large tracks attributable to *Eubrontes* have been identified from the upper track-bearing layer.

Crouching Theropod Traces

As noted in the previous section, the large theropod trackway with tail traces (Figs. 4, 18-19) has features characteristic of both *Eubrontes* and *Gigandipus*. However, four years after the discovery of this trackway, as more of the proximal portion was excavated, evidence that the trackmaker squatted or crouched down was discovered (Fig. 18). Such squatting traces should be given the same formal track name as the associated footprints and tail trace. So we face the same question as Lull (1953): should we name it *Eubrontes* or *Gigandipus*? Regarding nomenclature, the simplest solution could be to use the name *Eubrontes* because it has historical priority (Hitchcock, 1845) over *Gigandipus caudatus* (Hitchcock, 1856).

There were no previous reports of squatting or crouching dinosaurs associated with the type material of *Eubrontes* or *Gigandipus*, although a crouching trace, and associated tail trace, made by a *Eubrontes*-like trackmaker was recently reported from the Early-Middle Jurassic of China (Lockley et al., 2003). At the SGDS, where this crouching trace is associated with the same trackway that contains tail traces, we have evidence that the trackmaker squatted or crouched while crossing over a small topographic ridge, and, in doing so, left manus (hand) and ischium (pelvic) impressions, as well as "shuffling" forward for a distance of about 20-25 cm (Fig. 18D). This crouching trace as a whole is well enough preserved to infer important details about morphology that will be analyzed in detail elsewhere.

Anomoepus Tracks

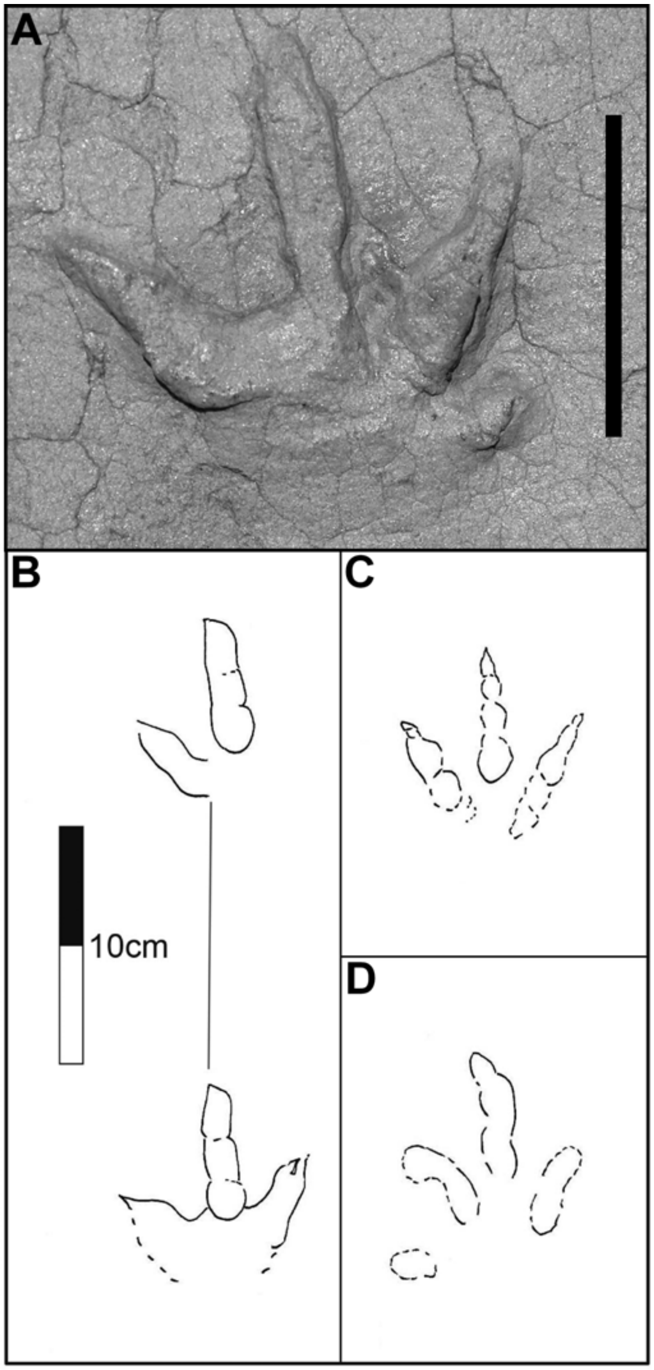

FIGURE 21. *Anomoepus* tracks from the SGDS. **A**, Well-preserved and small *Anomoepus* natural cast track (SGDS.867) collected in May, 2005 by SGDS volunteer David Slauf. **B**, Tracing of two *Anomoepus* tracks in sequence (SGDS.443). **C**, Isolated track assigned to *Anomoepus* showing clear phalangeal pads (SGDS.443). **D**, Isolated track assigned to *Anomoepus* showing a fourth digit (SGDS.166).

Anomoepus tracks are common in the Lower Jurassic Newark Supergroup of the eastern United States (Hitchcock, 1858; Lull, 1953; Olsen and Rainforth, 2003) and have been identified in many other regions, including the western United States (Lockley and Hunt, 1995). However, they are not as common in much of the Glen Canyon Group as they are in the Newark Supergroup. As a result, they prove difficult to identify in the West. Tracks originally named *Hopiichnus* (Welles, 1971) from the Kayenta Formation of northern Arizona are probably poorly preserved *Anomoepus* (Lockley and Hunt, 1995; Lockley and Gierliñski,

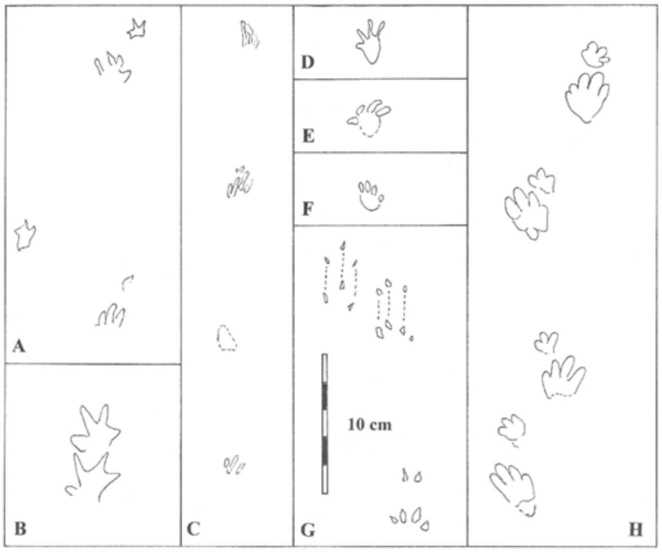

FIGURE 22. **A-G**, Examples of *Batrachopus* and other quadruped tracks and trackways from the SGDS. **A**, Partial *Batrachopus* trackway (on SGDS.18 Top Surface tracksite). **B**, Probable *Batrachopus* double print (on SGDS.18 Top Surface tracksite). **C**, Partial *Batrachopus* trackway (SGDS.470). **D-F**, Three separate *Batrachopus* pes prints. **D**, SGDS.18.T6.12. **E**, Unnumbered SGDS specimen. **F**, SGDS.18.T6.26. **G**, Assemblage of toe prints with slide marks from an indeterminate quadruped (SGDS.18.T3). **H**, Type specimen of *Batrachopus* from the Early Jurassic of Massachusetts.

this volume). Similarly, tracks named *Trisauropodichnus moabensis* from the Kayenta Formation in the Moab area of eastern Utah are probably examples of gracile *Anomoepus* (Lockley and Hunt, 1995; Lockley and Gierliñski, this volume). Tracks assigned directly to *Anomoepus* have also been found in the Kayenta Formation near Moab (Lockley and Hunt, 1995; Lockley and Gierliñski, this volume) and in the Lake Powell area (Lockley et al., 1998b; Lockley, 2005a, b; Lockley and Gierliñski, this volume).

At the SGDS, there are few well-preserved examples of tracks assigned to *Anomoepus*. In August, 2005, an *Anomoepus* trackway was found at locality no. 2 (Figs. 2, 8A) showing important characteristics that confirm the presence of the ichnogenus within the lower Whitmore Point Member at the SGDS. Again in May, 2006, SGDS volunteer David Slauf discovered a small and well-preserved *Anomoepus* track on a float block near locality no. 2 (Figs. 2, 21A). This is much smaller than the 2005 *Anomoepus* find. These tracks represent the first ornithischian evidence from the SGDS and are probably the oldest known *Anomoepus* tracks from the western United States (Lockley and Gierliñski, this volume). Prior to August, 2005, we had identified three specimens, two in a probable trackway sequence that were tentatively assigned to *Anomoepus* (Figs. 21B-D). In a recent review of *Anomoepus*, Olsen and Rainforth (2003) described the distinctive skin impression of this ichnogenus, which may help with its identification.

Batrachopus Tracks

Many small, non-dinosaurian tracks have been found on the SGDS Top Surface and on various loose blocks from multiple track horizons. Most resemble the well-known Early Jurassic ichnogenus *Batrachopus* (Olsen and Padian, 1986) that is usually attributed to small crocodylomorphs (Fig. 22). Tracks of this type typically fall in the size range of 1-5 cm in length, though maximum lengths of about 8 cm are known. The hind footprint, which is most commonly preserved, is larger than the front footprint. In fact, the hind footprint may sometimes cover the front footprint. Such overprinting is not a common phenomenon among quadrupedal animals. *Batrachopus* trackways are hard to follow in detail, though several have been recorded, including one that runs for several meters paralleling the top of a ridge on the Top Surface within the SGDS museum (Fig. 4).

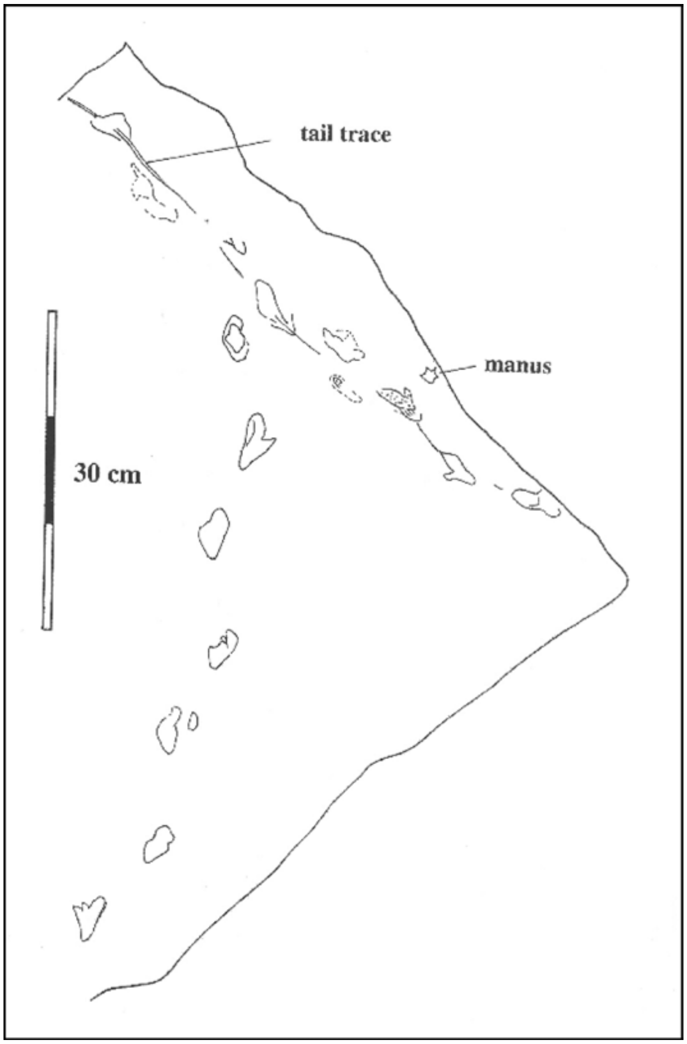

FIGURE 23. *Selenichnus* tracks from St. George site (SGDS.175) is probably a variant of *Batrachopus* caused by locomotion on a soft substrate. After Lockley et al. (2003).

Various other incomplete tracks may suggest the presence of lizard-like animals (possibly sphenodontians) and protomammals (synapsids). Such tracks are known from other Triassic-Jurassic boundary sequences in the western USA (see below), but both trackmakers, especially the synapsids, tended to prefer dry habitats and are found almost exclusively in eolian deposits (Lockley and Hunt, 1995; Lockley et al., 2004a).

Selenichnus Tracks

Selenichnus is an ichnogenus name given to distinctive trackways from the Lower Jurassic of New England that consist of elongate, crescentic traces associated with a tail trace (Lull, 1953). Examination of the type specimens reveals the passage of a small animal over or "through" a soft substrate with many raindrop impressions. Recent studies (Lockley et al., 2003) have concluded that this track type is also present at St. George (Fig. 23), and that it likely represents a variant of a *Batrachopus* trackway that was caused by a trackmaker moving over a muddy surface.

If the elongate, curved, and bifurcate *Selenichnus* tracks are interpreted as separate traces caused by the arcuate motion of the hind and front feet (and portions of the distal limb) during locomotion, then a reasonable explanation is provided for the lack of separate manus and pes tracks throughout most of the trackway's length: i.e., the trackways do not represent bipedal animals. As noted by Lockley et al. (2004b), the St. George tracks lack clear tail drag traces in one trackway, and show at least one separate manus trace. If the *Selenichnus* morphology is an extramorphological variant of *Batrachopus* morphology, then the ichnological correlation with the eastern United States is strengthened. Moreover, such conclusions support the suggestion that other small, but better-preserved, tracks from the SGDS may be assigned to *Batrachopus* (see below). Furthermore, since *Batrachopus* has been attributed to a small crocodylomorph, we may infer that the St. George trackmakers may also have been crocodylomorphs.

COMPARISON WITH TRACKS FROM OTHER AREAS

It has only been in comparatively recent times that paleontologists have recognized that Lower Jurassic tracks from the western United States are very similar to tracks of the same age from other regions. Welles (1971), for example, in describing tracks from the Moenave-Kayenta transition zone in the Tuba City region of northeastern Arizona, named *Eubrontes*-sized tracks *Dilophosauripus* and *Kayentapus*. These may be junior synonyms of *Eubrontes* (Lockley, 1986; Lockley and Hunt, 1995; Irby, 1995), though Weems (1992) argued that *Kayentapus* is distinctive (Lockley, 2000). Previously described tracks most similar to those from the SGDS in terms of geologic age, geographic location, morphological type (and taxonomic designation) are those assigned to *Eubrontes* purportedly from the Dinosaur Canyon Member of the Moenave Formation at Warner Valley (Miller et al., 1989). As noted below, we agree with the identification of the tracks as *Eubrontes*, but do not agree with the stratigraphic assignment. We also do not agree with their interpretation that the trackmaker was a prosauropod. Even though Weems (2003) supported the prosauropod interpretation, this has long been a minority opinion (Lull, 1953; Olsen, 1980; Lockley and Hunt, 1995; Farlow and Galton, 2003; Smith and Farlow, 2003).

Eubrontes-like theropod tracks are also known from the vicinity of Washington and Leeds to the northeast of St. George (Fig. 1). These tracks (Fig. 23), from the Kayenta Formation, have not been previously reported in the scientific literature, but have recently been investigated (Hamblin, 2004) and described elsewhere in this volume (Lockley et al., this volume; Hamblin et al., this volume). Herein we include tracings from the CU Denver Dinosaur Trackers Research Group library that allow for preliminary comparisons with the SGDS, and suggest that they include forms that are *Kayentapus*-like and more gracile than the larger *Eubrontes*-like forms from St. George and Warner Valley (Fig. 24) that, *contra* Miller et al. (1989), we now assign to the Kayenta Formation (see also Lucas and Tanner, this volume).

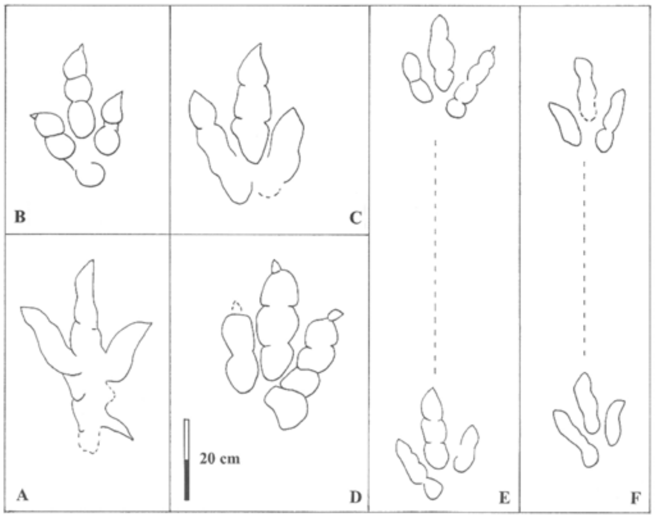

FIGURE 24. *Eubrontes* tracks from other Early Jurassic localities near St. George and elsewhere in the western USA. **A-C**, Tracks from the Kayenta and Navajo formations, Lake Powell area, southern Utah: note hallux on track **A**. **D**, *Eubrontes* from the Kayenta Formation at the Warner Valley site. **E**, Partial trackway from the Washington site. **F**, Partial trackway from the Spectrum site.

Larger theropod tracks, also of the *Eubrontes* type, have also recently been reported from another site near St. George. These tracks are found on top of the basal sandstone of the Kayenta Formation (Springdale Member), at a site designated the "Spectrum" site, (after the *Spectrum* newspaper, St. George), but designated the "Grapevine Wash" site by Hamblin (2004). These tracks are up to at least 50 cm in length, but maybe somewhat enlarged by post-exhumation weathering. They have been described elsewhere (Hamblin, 2006; Hamblin et al., this volume). Lucas et al. (2005) consider this surface to be part of the Springdale megatracksite.

Lockley et al. (1998a) and Lockley (2005a, b) described tracks referred to *Eubrontes* from the Navajo Formation in the Lake Powell region, at least two of which show clear pad impressions (Fig. 23). A third track, also from the Navajo Sandstone in this same area, shows a hallux impression. Tracks from this stratigraphic level are younger than those found in the Moenave Formation in the vicinity of St. George.

Turning to the classic footprint assemblages of Connecticut and Massachusetts collected by Edward Hitchcock in the 1830s through 1860s (Hitchcock, 1858), we can compare the western track assemblages with the type material from which the concepts of *Eubrontes* and *Grallator* originate (Figs. 13, 17). At first sight, there are few obvious differences between eastern and western tracks. Moreover, the tracks from both regions originate from beds of approximately the same age. However, as noted above, the ichnotaxonomy of *Eubrontes* and *Grallator* tracks is both complex and problematic (Olsen et al., 1998). Since Olsen (1980) first discussed this problem and introduced the aforementioned *Grallator-Anchisauripus-Eubrontes* plexus – technically the subgenera *Grallator* (*Grallator*), *Anchisauripus* (*Grallator*) *and Eubrontes* (*Grallator*) – no formal amendments to the descriptions of these tracks have been suggested based on North American material (Lockley, 2000). However, Weems (1992) proposed that *Kayentapus* (Welles, 1971) is a valid ichnogenus. A few authors have followed Olsen's 1980 scheme or mentioned it (e.g., Gierliñski, 1991; Irby, 1995), though many have not (e.g., Haubold, 1984, 1986; Lockley and Hunt, 1995; Lockley and Meyer, 2000). Given the uncertainty of applying ichnogenus names, even in the type area of New England, we avoid trying to assign the western tracks to any of the several ichnospecies to which they might be compared if a more exhaustive study were undertaken.

However, we provide illustrations (Figs. 13, 17) of the Hitchcock material drawn (traced) by the same hand (MGL) as the western footprints. It should be borne in mind that most of the eastern tracks are impressions (positive relief), whereas the St. George material consists mostly of casts (negative relief). Despite these differences, the tracks are clearly very similar in size and morphology. There also appears to be a clear size differentiation between *Eubrontes* and *Grallator* tracks, even though the shape difference may not be so obvious (Olsen, 1980). As indicated above, the presence of tracks assigned to *Batrachopus*, *Selenichnus*, and *Anomoepus* supports the conclusion that Lower Jurassic ichnofaunas from the eastern and western United States are quite similar.

According to many authors (Haubold, 1984, 1986; Lockley and Hunt, 1995; Lockley and Meyer, 2000; Lucas, in press; Hunt and Lucas, this volume), ichnofaunas characterized and/or dominated by *Eubrontes*, *Grallator*, *Anomoepus*, and *Batrachopus* had essentially worldwide distributions in the Lower Jurassic. These widespread Early Jurassic ichnofaunas have been cited as evidence that early Mesozoic tracks, like those from the late Paleozoic, have potential for biostratigraphic correlation (Haubold and Katzung, 1978), although Lucas (in press) suggests that resolution of "palichnostratigraphic" zones beyond the levels of series or stage has limitations.

The conclusion that there is a global *Eubrontes*- and *Grallator*-dominated ichnofauna (with *Batrachopus*) from the earliest Jurassic (mostly Hettangian) is borne out by reports from other areas where tracks of this age have been intensively studied. For example, in Europe, especially in France (Lapparent and Montenat, 1967; Demathieu, 1990, 1993; Demathieu and Sciau, 1995), Poland (Gierliñski, 1991), and Sweden (Gierliñski and Ahlberg, 1994), *Eubrontes* and *Grallator* have been widely reported and often given the same specific names as in North America (see Lockley and Meyer, 2000, for summary). Similar tracks are also known from southern Africa (Ellenberger, 1972, 1974) although here they have mostly been given different names, to which some authors object (see Olsen and Galton, 1984 and Lockley and Meyer, 2000, for further discussion).

Eubrontes and *Grallator* and/or *Eubrontes*- and *Grallator*-like tracks are also known from many localities in southern China (Yang and Yang, 1987; Zhen et al., 1989) where they have been given a large number of local or provincial names. Preliminary attempts at comparison of these tracks with those described from the classic North American localities of Hitchcock (1858) suggest that most Chinese names are synonyms of *Eubrontes* and *Grallator*, or, in some cases, *Anomoepus* (Matsukawa et al., 2002; Lockley et al., 2003).

AFFINITIES OF THE TRACKMAKERS

Despite uncertainty about the naming of *Grallator* and *Eubrontes* tracks, these two ichnogenus names have been widely used to describe Hettangian tracks and other Early Jurassic (Liassic) tracks of the type found at the SGDS. These names are not widely used to describe tracks from series other than the Lower Jurassic, and sometimes the Upper Triassic. As noted above, these tracks have some biostratigraphic utility as Lower Jurassic index fossils (Haubold, 1986; Lockley and Hunt, 1995; Lucas, in press). Thus, we should look for possible trackmakers in beds of the same age.

The best known Late Triassic to Early Jurassic theropods, that are most often suggested as the probable makers of *Grallator* tracks, are *Coelophysis*, from the Upper Triassic Chinle Formation, and *Megapnosaurus* (formerly *Syntarsus*), from the Lower Jurassic of southern Africa and from the Moenave and Kayenta formations of Arizona. Both of these genera, which are primitive ceratosaurian theropods, are known from well-preserved skeletal remains, and there can be no doubt that their foot skeletons provide close matches for the tracks (à la Cinderella, *sensu* Lockley, 1998). *Coelophysis* occurs in beds that predate the Moenave Formation; *Megapnosaurus* fossils have been found in the Moenave (Lucas and Heckert, 2001) geographically close to the SGDS, but the taxon is known primarily from the overlying Kayenta Formation. Thus, while it is tempting to attribute the SGDS *Grallator* tracks to *Megapnosaurus*, the possiblity cannot be ruled out that they were made by another theropod with similar pedal morphology and locomotory habits. Indeed, theropod teeth found in the immediate vicinity (site no. 14, Fig. 2) do not belong to either of these genera, attesting to the presence of as-yet unknown theropods that lived in Moenave time.

Eubrontes tracks are often attributed to the genus *Dilophosaurus*, a well-known, crested ceratosaur from the Kayenta Formation of Arizona. This correlation is almost inevitable given that *Dilophosaurus* is the only large theropod from this epoch that is well known from complete skeletal remains in North America. For example, although *Dilophosaurus* is known primarily from the western USA, it is used as a model of the purported *Eubrontes* trackmaker at Dinosaur State Park in Connecticut, where *Eubrontes* has been adopted as the Connecticut state fossil.

This correlation between *Eubrontes* and *Dilophosaurus* is further strengthened by the naming of a *Eubrontes*-like track, other than *Kayentapus*, from the Kayenta Formation of northern Arizona as *Dilophosauripus* (Welles, 1971). Many authors agree that *Dilophosauripus* could be a synonym of *Eubrontes* (Lockley, 1986, 2000; Irby, 1995; Lockley and Hunt, 1995, and referenced cited therein), though *Kayentapus* may be distinct from *Eubrontes* (Weems, 1992; see Lockley, 2000, for a review).

PALEOGEOGRAPHICAL INFERENCES

As noted above, swim tracks and other lines of evidence, including abundant fish remains, conchostracans, ostracodes, and plants, suggest a lake or lake margin setting for the SGDS tracksites. Indeed, the name "Lake Dixie" has obvious paleogeographic connotations denoting the lacustrine characteristics of the Whitmore Point Member that overlies the underlying Dinosaur Canyon Member (Fig. 3). The sheer volume of track material in the uppermost Dinosaur Canyon and lowermost Whitmore Point members briefly outlined here prevents us from discussing the sedimentary geology, paleogeography, and paleoecology in detail, which is instead done elsewhere (Kirkland and Milner, this volume; Milner et al., this volume).

Nevertheless, detailed mapping of the main SGDS tracksite (no. 1) and identification of swim tracks to the north (site no. 4) reveals details of the local paleogeography. For example, the swim tracks are in an offshore position relative to site no. 1 so the shoreline may be inferred to run approximately from NE to SW. We recognize that any notion of a fixed shoreline position is unrealistic (see Milner et al., this volume for detailed discussion). Shoreline orientation and position can be estimated from many indicators, including trackway orientations (Ostrom, 1972; Lockley, 1986), but such interpretations are often difficult to prove. Moreover, in a complex track-bearing sequence, the shoreline presumably changed dynamically in space and time.

As indicated in Figure 4, the SGDS Top Surface has an interesting topography consisting of a series of NNW-SSE trending ridges and swales that are complexly draped by thin layers that show many small-scale biogenic and inorganic sedimentary structures. Some of these indicate the complex history of reworking and sediment flow associated with local topography and drainage off the ridges and within the swales, all of which potentially affected the preservation of tracks. As shown in Figure 4, one *Batrachopus* trackway (SGDS.18.T6) mounts a ridge and follows its crest toward the SSE. The large theropod trackway (SGDS.18.T1) indicates progression toward the WSW, perpendicular to the ridge and swale topography and parallel to the shoreline.

We anticipate that the SGDS will provide material for many future generations of ichnologists to study. Now that part of the site is protected from the elements, there is considerable potential for detailed study of the relationship between the tracks and traces and the sedimentary geology. Such studies have the potential to considerably elaborate on, refine, and amend the preliminary descriptions and interpretations presented herein.

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