

TRACKING DINOSAUR ORIGINS

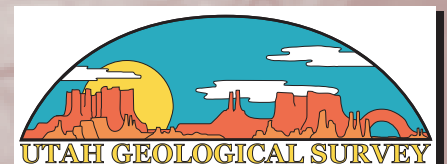


The Triassic/Jurassic Terrestrial Transition

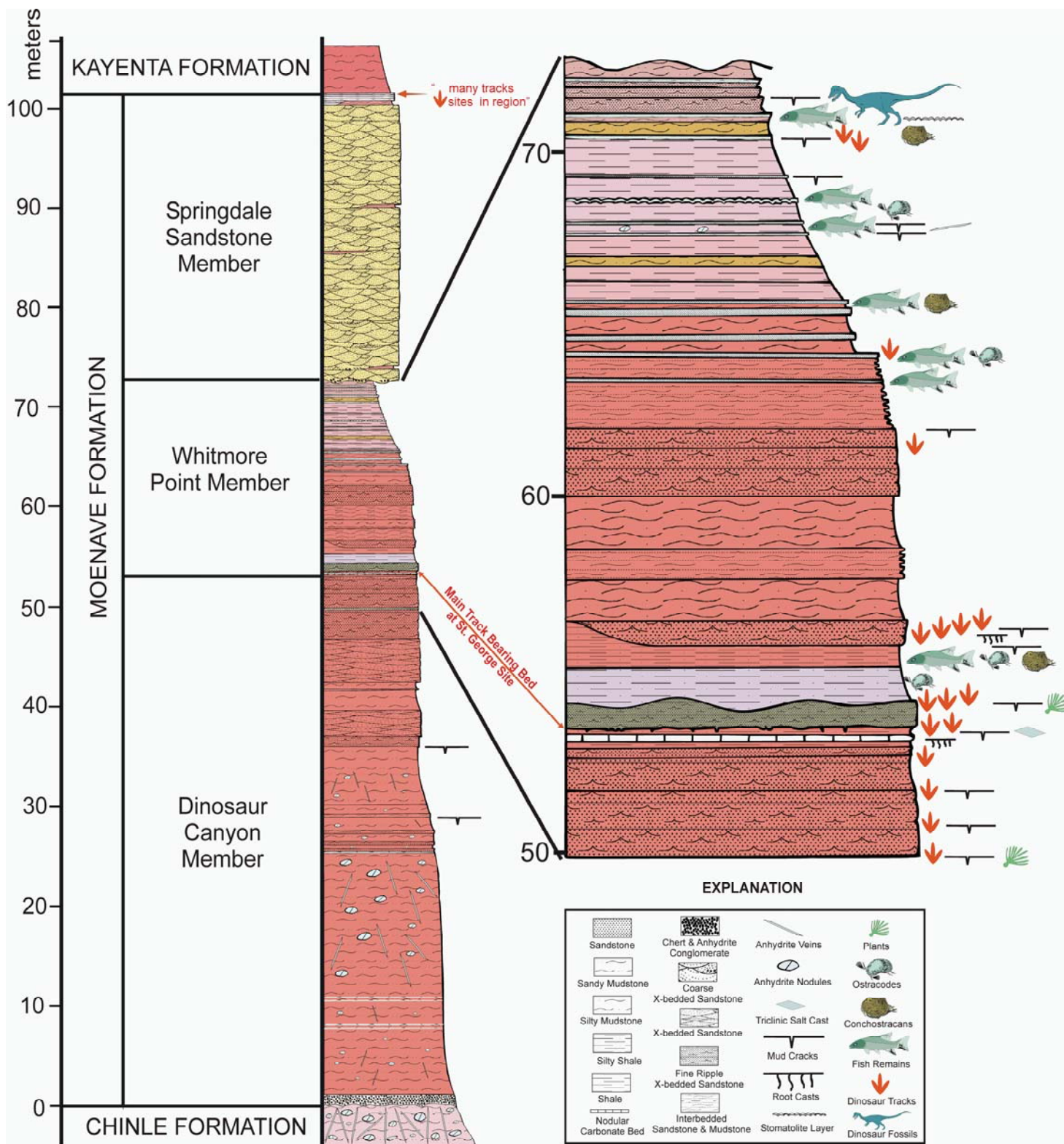
Abstracts Volume



**A conference held at
Dixie State College
in St. George, Utah
March 14-16, 2005**



Stratigraphy of the St. George Dinosaur Discovery Site at Johnson Farm and immediate vicinity



MONDAY, MARCH 14		TUESDAY, MARCH 15				WEDNESDAY, MARCH 16			
8:00-6:00	FIELD TRIP: Triassic-Jurassic stratigraphy and paleontology of the St. George, UT vicinity (J. Kirkland, B. Biek, and A.R.C. Milner leading) Departs from Crystal Inn	PLENARY SESSION	9:00-9:30	<u>Lucas & Tanner</u> : “Stratigraphic resolution and the supposed mass extinction at the end of the Triassic”		REGULAR SESSION	9:00-9:20	<u>Staker</u> : “Earliest known dinosaur trackers”	
			9:30-10:00	<u>Shibata et al.</u> : “Terrestrial ecosystems in the early Age of Dinosaurs based on energy flow models applied to data from western North America”			9:20-9:40	<u>Reynolds & Mickelson</u> : “Way out west: pterosaur ichnites in the Mescal Range, Mojave Desert, California”	
			10:00-10:30	<u>Kirkland & Milner</u> : “The Moenave Formation at the St. George Dinosaur Discovery Site at Johnson Farm”			9:40-10:00	<u>Milner, Lockley et al.</u> : “First reports of a large collection of well-preserved dinosaur swim tracks from the Lower Jurassic Moenave Formation, St. George, Utah: a preliminary evaluation”	
		10:30-11:00	— BREAK —		10:00-10:20		<u>Wright et al.</u> : “Morphometric analysis of dinosaur footprints – some preliminary results”		
		11:00-11:20	<u>Gierlinski & Sabath</u> : “Dinosaur tracks in the Upper Triassic and Lower Jurassic of central Europe”		10:20-10:40		— BREAK —		
		11:20-11:40	<u>Lucas et al.</u> : “Tetrapod biostratigraphy across the Triassic-Jurassic boundary on the southern Colorado Plateau, USA”		10:40-11:00		<u>Milner, Kirkland et al.</u> : “Late Triassic-Early Jurassic freshwater fish faunas of the southwestern United States with emphasis on the Lake Dixie portion of the Moenave Formation, southwest Utah”		
		11:40-12:00	<u>Rainforth</u> : “Ichnological diversity in the Early Jurassic of the Connecticut Valley, eastern North America”		11:00-11:20		<u>Parker et al.</u> : “New material of <i>Revueltosaurus callenderi</i> and its implications for the identification of early ornithischian dinosaurs”		
		12:00-1:00	— LUNCH —		11:20-11:40		<u>Kirkland et al.</u> : “The case for theropod dinosaurs exploiting fish as a major food resource during the Early Jurassic”		
		1:00-1:20	<u>Reynolds</u> : “Way out west: Jurassic tracks on the continental margin”		11:40-12:00		<u>Loewen et al.</u> : “Collapse preservation of a prosauropod from the Jurassic Kayenta Formation of Utah”		
		1:20-1:40	<u>Gallagher</u> : “The West Paterson Quarry: an Early Jurassic footprint site in the Newark Basin of New Jersey”		12:00-1:00		— LUNCH —		
		1:40-2:00	<u>Breithaupt & Matthews</u> : “ <i>Agialopous</i> : evidence for Wyoming’s oldest Triassic dinosaurs”		1:00-1:20		<u>Smith & Merrill</u> : “A morphometric analysis of sample variation in the skull of the Ghost Ranch theropod”		
		2:00-2:20	<u>Lockley, Milner et al.</u> : “Archosaur tracks from the Chinle Group (Late Triassic), St. George area, southwestern Utah”		1:20-1:40		<u>Lockley & Kukiwara</u> : “A morphometric analysis of the Triassic theropod dinosaur <i>Coelophysis</i> : dimorphism provides clues to intrinsic biological organization in saurischian dinosaurs”		
		2:20-2:40	<u>DeBlieux et al.</u> : “An overview of the vertebrate paleontology of Late Triassic and Early Jurassic rocks in Zion National Park, Utah”		2:30-5:30		— POSTER SESSION — Held at the St. George Dinosaur Discovery Site at Johnson Farm (SGDS) – includes viewing of museum and nearby localities		
		2:40-3:00	— BREAK —						
		3:00-3:20	<u>Hamblin</u> : “Bird-like tracks in the Kayenta Formation (Lower Jurassic), Washington County, Utah”						
		3:20-3:40	<u>Lockley, Kukiwara et al.</u> : “Drought leaves dinosaur tracks high and dry: new sites from the Lower Jurassic Glen Canyon Group, Lake Powell area, Utah and Arizona”						
		3:40-4:00	<u>Gierlinski et al.</u> : “Traces of Early Jurassic crouching dinosaurs”						
		4:00-4:20	<u>Sabath & Gierlinski</u> : “The Hitchcock enigma: first feathers or artifacts?”						
		4:20-4:40	<u>Matthews et al.</u> : “Microtopographic documentation of a sitting dinosaurs from the Early Jurassic of Utah”						
7:00-10:00	Welcome Reception & Mixer – Crystal Inn		7:00-9:00	Triassic-Jurassic Paleontological Art Show viewing and mixer – St. George Art Museum			6:30-9:00	Banquet – Gardner Center, Dixie State College	

AGIALOPOUS: EVIDENCE FOR WYOMING'S OLDEST TRIASSIC DINOSAURS

BREITHAUP, BRENT H., Geological Museum, University of Wyoming, Laramie, WY 82071 (uwgeoms@uwyo.edu); and **MATTHEWS, NEFFRA A.**, National Science and Technology Center, USDOI-Bureau of Land Management, Denver, CO 80225

Roughly 75 years ago, field parties from the University of Missouri documented the oldest dinosaur fossils in Wyoming. Numerous tridactyl tracks approximately 8 to 9 cm in length and 6 to 7 cm in width were found in a fine-grained, calcareous sandstone of the latest Triassic (Rhaetian) Bell Springs Formation (originally described as Popo Agie Formation) of Fremont County in western Wyoming. Track morphology, along with stride lengths (e.g., 43 cm) and trackway widths (e.g., 40 cm) indicate that the tracks were made by a number of small theropod dinosaurs, possibly walking in a parallel direction. Although many tracks were deep, irregular depressions, those with distinct phalangeal pad impressions were used to characterize the new ichnotaxon *Agialopous wyomingensis*. However, only two slabs, one containing a natural pes cast and the other a pes impression (originally described as a manus impression), were collected.

In the 1960s and 1980s, other Late Triassic tracks assigned to *Agialopous* were found from correlative units in northwestern Colorado. These tracks are numerous, well documented, and in some cases preserve metatarsal impressions and other characteristic sitting (resting) traces (i.e., manus impressions, ischial impressions, and tail marks). Preservation of this behavior is not unexpected in small- to medium-sized bipedal dinosaurs, as modern ratites (similar in size to small dinosaurs) commonly exhibit this activity and leave similar impressions in soft-sediment.

Additional work on these Late Triassic footprints suggests that *Agialopous* may represent the common Triassic ichnogenus *Grallator*. The fact the type ichnites for *Agialopous* are apparently lost and the locality information is sketchy, emphasizes the need for more extensive documentation in vertebrate ichnology, especially utilizing state-of-the-art photographic and photogrammetric documentation techniques.

Wyoming's abundant Mesozoic units contain a plethora of dinosaur fossils, however Triassic research is generally ignored as these formations are perceived to be too difficult to work and generally unproductive. Thus, little work has been done on the significant ichnofauna of Wyoming Triassic since the 1930s. However, the paucity of research in this period of Wyoming's past provides exciting challenges in ichnological sleuthing. Future studies will generate valuable information about Triassic dinosaur faunas in the northern part of the Western Interior.



WHERE DID THE TRIASSIC AND LOWER JURASSIC AMERICAN DINOSAURS GO? A TALE FROM THE MIDDLE JURASSIC OF SCOTLAND, UK (not presented)

CLARK, NEIL D.L., Hunterian Museum, University of Glasgow, University Avenue, Glasgow G12 8QQ, Scotland, UK (n.clark@museum.gla.ac.uk)

Dinosaurs are rare from Scotland. The bulk of the dinosaur remains come from the Middle Jurassic, although one partial tibia of a ceratosaurian dinosaur was found in the Broadford Beds Formation (Hettangian) in the Strathaird Peninsula, southern Isle of Skye (Benton et al., 1995). The Middle Jurassic remains consist mainly of small footprints identified as belonging to the *Eubrontes*, *Grallator*, or *Anchisauripus* ichnogenetic group (Clark and Barco Rodriguez, 1998; Clark, 2001a), known famously from the Lower Jurassic sediments of Connecticut (Olsen et al, 1998). There are also larger footprints, up to 55cm in length, known from the Middle Jurassic of the Isle of Skye that appear to belong to both ornithomimid and theropod dinosaurs (Clark et al, 2004). In addition to the footprints, several bones have also been found from these Bajocian to Bathonian (Middle Jurassic) sediments. A limb bone, rib, and caudal vertebra of a robust sauropod, akin to *Cetiosaurus* (Clark et al, 1995), the ulna and radius of a primitive thyreophoran dinosaur (Clark 2001b), as well as many indeterminate bone fragments. Probably the most interesting of the discoveries has been a caudal vertebra, of a small theropod dinosaur, that appears indistinguishable from *Coelophysis*.

The occurrence of small *Grallator*-like footprints and the coelophysid-like caudal vertebra, suggests that Scotland may have been a refugium for some Lower Jurassic dinosaurs of North America. The mountain chains that split the western part of North America from Europe and Africa during the Jurassic would have also acted as a

barrier for many European and African dinosaurs travelling to the Isle of Skye. Similar footprints have also been found in Middle Jurassic sediments from Yorkshire, England, UK, south of the dividing ranges (Whyte and Romano, 2001; Romano and Whyte, 2003). As more Middle Jurassic discoveries are made in the United States (Lockley et al, 1998), we may find that similar ichnogenera coexisted both in North America and Britain at this time. Perhaps the bones of a similar coelophysid-like dinosaur will also be found in the United States.

- Benton, M. J., Martill, D. M., and Taylor, M. A. 1995. The first dinosaur from the Lower Jurassic of Scotland: a limb bone of a ceratosaur theropod. *Scottish Journal of Geology* 31:171-182.
- Clark, N. D. L. 2001a. Dinosaur tracks, helicopters, and broken bones. *The Geological Curator* 7:163-166.
- Clark, N. D. L. 2001b. A thyreophoran dinosaur from the Bearreraig Sandstone Formation (Bajocian, Middle Jurassic) of the Isle of Skye. *Scottish Journal of Geology* 37:19-26.
- Clark, N. D. L. and Barco Rodriguez, J. L. 1998. The first dinosaur trackway from the Valtos Sandstone Formation (Bathonian, Jurassic) of the Isle of Skye, Scotland, UK. *Geogaceta* 24:79-82.
- Clark, N. D. L., Boyd, J. D., Dixon, R. J., and Ross, D. A. 1995. The first Middle Jurassic dinosaur from Scotland: a cetiosaurid? (Sauropoda) from the Bathonian of the Isle of Skye. *Scottish Journal of Geology* 31:171-176.
- Clark, N. D. L., Ross, D. A., and Booth, P. 2004. Dinosaur Footprints from the Duntulm Formation (Bathonian, Jurassic) of the Isle of Skye, Scotland, UK. *Scottish Journal of Geology* 40:13-21.
- Lockley, M., Hunt, A., Paquette, M. Bilbey, S.-A. and Hamblin, A. 1998. Dinosaur tracks from the Carmel Formation, northeastern Utah: implications for Middle Jurassic paleoecology. *Ichnos* 5:255-267.
- Olsen, P. E., Smith J. B., and 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, USA). *Journal of Vertebrate Paleontology* 18:586-601.
- Romano, M. and 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.
- Whyte, M. A. and Romano, M. 2001. Probable stegosaurian tracks from the Saltwick Formation (Middle Jurassic) of Yorkshire, England. *Proceedings of the Geologist's Association* 112: 45-54.



AN OVERVIEW OF THE VERTEBRATE PALEONTOLOGY OF LATE TRIASSIC AND EARLY JURASSIC ROCKS IN ZION NATIONAL PARK, UTAH

DEBLIEUX, DONALD D., KIRKLAND, JAMES I., Utah Geological Survey, PO Box 146100, Salt Lake City, UT 84114-6100; **SMITH, JOSHUA A.**, University of Utah, 1390 E. Presidents Circle, Salt Lake City, UT 84112; **MCGUIRE, JENNIFER**, University of California, Department of Integrative Biology, 3060 Valley Life Science Building #3140, Berkeley, CA 94720-3140; and **SANTUCCI, VINCENT L.**, National Park Service, George Washington Memorial Parkway, Turkey Run State Park, McLean, VA 22101

The spectacular rocks exposed in Zion National Park in southwestern Utah include fossiliferous units of Late Triassic and Early Jurassic age. In cooperation with the Utah Geological Survey (UGS), several National Park Service (NPS) interns have recently completed a comprehensive inventory of paleontological resources within the park. We have identified over 100 new sites as a result of this project. Terrestrial vertebrate body fossils have been found in the Shinarump and Petrified Forest Members of the Chinle Formation, including the remains of phytosaurs, aetosaurs, and metoposaurs. Dozens of new dinosaur track sites have been discovered in the Whitmore Point Member of the Moenave Formation, the Kayenta Formation, and the Navajo Sandstone.

The vast area of exposure of these formations in the cliffs and canyons of Zion provides an important resource for ongoing investigations of the paleontology of the St. George region. A number of different modes of track preservation are present, including true tracks, under tracks, natural tracks, and track infills. Most of the dinosaur tracks documented are attributable to theropod dinosaurs of the ichnogenera *Eubrontes* and *Grallator*, although others, including bird-like tracks and four-toed tracks, are also present. Also pertinent to the investigations at St. George are lacustrine sediments preserving the scales of semionotid fish, and dinosaur swim tracks found in both the Whitmore Point Member of the Moenave Formation and the lower Kayenta Formation.



THE WEST PATERSON QUARRY: AN EARLY JURASSIC FOOTPRINT SITE IN THE NEWARK BASIN OF NEW JERSEY

GALLAGHER, WILLIAM B., New Jersey State Museum, Trenton, NJ 08625, and Department of Geological Sciences, Rutgers University, Piscataway, NJ 08854 (william.gallagher@sos.state.nj.us); and **HANCZARYK, PAUL**, Department of Transportation, Trenton, NJ 08625.

Protracted excavations at a traprock quarry in Passaic County, NJ have yielded an abundant and stratigraphically well-constrained footprint faunule of earliest Jurassic age (Hettangian). The quarry has been variously known as the Little Ferry, UBC, R. H. Hamilton, Dell Materials or Tilcon Quarry, as it changed hands from owner to owner. The excavation mined the Orange Mountain Basalt, some 70 feet thick here, but quarrying extended down into the uppermost Passaic Formation, a reddish mudstone, siltstone, and sandstone unit of the Newark Supergroup. Within a half meter below the formational contact between the lowermost basalt and the uppermost sedimentary layer, there are two horizons that yield trackways of several ichnogenera of dinosaurs as well as footprints of the early crocodylomorph *Batrachopus*.

These two layers contain the majority of the footprints; the upper layer is about 15-16 cm below the basalt contact, while the second or main footprint layer is 30 to 46 cm below the wavy, irregular contact with the overlying vesicular basalt. The Triassic-Jurassic (T/J) boundary here is placed at three meters below the Passaic Formation-Orange Mountain Basalt contact on the basis of palynological evidence. Radiometric dates from the Palisades Sill, a possible feeder to the Orange Mountain Basalt, indicate that the palynological T/J boundary is at least 201 to 202 million years old (Olsen et al., 1996). The footprint layer is thus less than 201 m.a. old. Biostratigraphically, this footprint assemblage is correlative to the St. George track site in Utah. The footprint layers at West Paterson were formed along the margins of a rift valley lake.

On one bedding plane surface of the main or lower footprint layer, an area measuring 8 m by 8 m exposed between 150 to 175 individual footprints. Most of these footprints are of the ichnogenus *Anchisauripus*, with some smaller *Grallator* tracks present as well. This surface marks the first appearance of the larger footprint *Eubrontes* in the Newark Supergroup of New Jersey. In this layer, footprint molds are impressed into a friable mudstone that cracks irregularly and shallowly; consequently it is often easier to recover the natural casts that are developed in a more competent coarser layer of siltstone overlying and infilling the footprint negatives. Some footprints from this layer may show claw marks, hallux impressions, and skin impressions.

The upper footprint layer yields mostly *Batrachopus* footprints, often in manus-pes sets. The bedding plane at this horizon is an algally matted convolute surface.

Below the T/J boundary in the Newark Basin, dinosaur footprints are rarer and smaller. The West Paterson footprint horizons represent a record of the early Jurassic diversification and proliferation of dinosaurs, after the T/J boundary mass extinction event created new ecological opportunities. It is a curious feature of the fossil record that one mass extinction event (T/J) appears to have set the stage for dinosaurian diversification, while another mass extinction event (K/T) terminated the reign of the non-avian dinosaurs. This is probably due to differences between T/J and K/T dinosaur faunas in associated ecological parameters such as body masses, range areas, population sizes, reproductive rates, and trophic requirements.



EARLY HETTANGIAN VERTEBRATE ICHNOASSEMBLAGE FROM POLAND (poster)

GIERLIŃSKI, GERARD, Polish Geological Institute, Rakowiecka 4, PL-00-975 Warszawa, Poland; **NIEDZWIEDZKI, GRZEGORZ**, Department of Zoology, Warsaw University, Banacha 2, PL-02-097 Warszawa, Poland; and **PIENKOWSKI, GRZEGORZ**, Polish Geological Institute, Rakowiecka 4, PL-00-975 Warszawa, Poland

A large vertebrate footprint assemblage has been recovered from the Lower Hettangian Zagaje Formation excavated at Soltykow in the Holy Cross Mountains area in Poland. The Soltykow exposure is an old, long abandoned clay pit, which yielded a large number of fossils (macroflora remains, palynomorphs, ostracodes, partially preserved insects, scales of palaeoniscid fish, and dinosaur bones). The Soltykow outcrop represents a siliciclastic coal-bearing lithofacies association of a fairly well-watered alluvial plain. Three terrestrial ichnofacies

(*Coprinsphaera*, *Scoyenia*, and *Mermia*) with numerous and diversified invertebrate trace fossils were also identified in this site.

Concerning the age of deposits exposed in Soltykow, floral remains point to the earliest Jurassic (Hettangian, Liassic alpha 1-2), sequence stratigraphic correlation allows to limit its age range to the Early Hettangian (*Planorbis* biochronozone).

Large theropod (*Kayentapus soltykovensis*, *Kayentapus* sp., and *Eubrontes* sp. A, B) and sauropod footprints (*Parabrontopodus* sp.) are the most common dinosaur prints in Soltykow. Medium and small dinosaur footprints (theropod: *Grallator*, *Anchisauripus*, *Kayentapus* sp., and cf. *Stenonyx* sp.; ornithischian and supposedly ornithischian: *Anomoepus* sp. *Moyenisauropus* sp., and *Delatorrichnus* sp.) are less abundant in this track site, and their discovered prints are rather poorly preserved. Recently, Soltykow exposure yielded small vertebrate footprints. Among them, were mammal-like (*Ameghinichnus* sp.) and reptile footprints (cf. *Batrachopus* sp. and *Rhynchosauroides* sp.).



TRACES OF EARLY JURASSIC CROUCHING DINOSAURS

GIERLIŃSKI, GERARD, Polish Geological Institute, Rakowiecka 4, PL00-975 Warszawa, Poland (gierlinski@yahoo.com); **LOCKLEY, MARTIN**, Geology Department, University of Colorado at Denver, CO 80217-3364; and **MILNER, ANDREW R.C.**, St. George Dinosaur Discovery Site at Johnson Farm, City of St. George, 2180 East Riverside Dr., St. George, UT 84790 (andrew@hanmansfossils.com)

Many digitigrade tetrapods occasionally produced elongate (plantigrade or semiplantigrade) tracks with metapodial impressions. Numerous cases are recorded among Early Jurassic dinosaur tracks, and these behaviors may represent resting, crossing soft ground, hiding in ambush, crouching while eating, during mating display, or when ill/injured.

The oldest known examples come from the famous Lower Jurassic ‘Hitchcock collection’ from New England. There are a few well-preserved theropod (*Grallator*) squatting impressions, such as specimen AC 1/1 with probable left manus trace and the intriguing AC 1/7 specimen with a proposed imprint of a “scaled” or “feathered” belly imprint. Both have ischial callosity traces. The Hitchcock material also includes ornithischian sitting traces of *Anomoepus*: AC 48/1 and AC 16/5, left by an animal almost lying on the ground. *Eubrontes*-like traces from the Lower-Mid-Jurassic of China also represent a large crouching theropod. This is similar in size to large *Eubrontes* traces from the Lower Jurassic Moenave Formation of St. George Utah, which also show metatarsal, manus, ischial callosity and tail traces.

The New England crouching impressions lack tail marks, while the Chinese and St. George traces do not. Thus, the animals may have kept their tails off the ground in some cases. Four ornithischian sitting impressions from the Lower Jurassic from Lesotho do show tail marks (Ellenberger 1972, 1974). Tail drag marks may also occur in association with non-crouching traces as in the well-known, semi-digitigrade Hitchcock collection track traditionally labeled *Gigandipus*, which differs from digitigrade *Eubrontes* in the presence of a hallux trace. Hallux prints are partly a function of depth and appear in many plantigrade and semiplantigrade footprints of crouching theropods, however they are lacking in their “regular” digitigrade expressions. This pattern is clear among the Early Jurassic tracks of semiplantigrade *Kayentapus* from Hungary. Likewise, recent finds from the Lower Jurassic of Poland pertaining to *Anomoepus pienkovskii* suggest these supposedly early thyreophoran track makers used both digitigrade and plantigrade gaits. However plantigrade tracks, showing metatarsal impressions, do not always show hallux traces, suggesting that the hallux may have been directed anteriorly or dorsally, or that it was lacking.

The presence or absence of hallux, metatarsal, manus, or tail traces in association with “regular” or typical footprints has potentially important taxonomic implications for Liassic and post-Liassic tracks of crouching theropods (including *Eutynichnium*, *Theroplantigrada*, and *Bueckeburgichnus*). Among Liassic crouching/plantigrade dinosaur tracks from North American are various taxonomically problematic forms like the diminutive *Sillimanius* and *Xiphopez* that may represent juvenile theropods, *Anomoepus* track makers, or other ichnotaxa like *Stenonyx*.



DINOSAUR TRACKS IN THE UPPER TRIASSIC AND LOWER JURASSIC OF CENTRAL EUROPE

GIERLIŃSKI, GERARD and **SABATH, KAROL**, Polish Geological Institute, Rakowiecka 4, PL00-975 Warszawa, Poland (gierlinski@yahoo.com; karol.sabath@pgi.gov.pl)

First dinosaur footprints in Central Europe have been reported by Bölau from the Rhaetian of Sweden in 1953. Later, Karaszewski (1969) reported dinosaur tracks in the Hettangian of Poland, and Michalik et al. (1976) described footprints from the Rhaetian of Slovakian Tatra Mountains; in 1983, Kordos reported dinosaur tracks in the Sinemurian of Hungary. Taxa erected by those authors, such as *Neochirotherium jurassicum*, *Coelurosaurchnus tatricus*, and *Komlosaurus carbonis*, were not widely accepted. However, ichnological exploration of the area in the past two decades revealed new material and allowed to reinterpret the Central European dinosaur track record according to current paleoichnological standards.

In the Rhaetian of the Swedish Höganäs Formation, large theropod footprints of *Eubrontes* cf. *giganteus* are recognized, while from the Hettangian section of the Höganäs Formation, *Kayentapus soltykovensis* is reported. Abundant material came from the Lower Jurassic strata of the Holy Cross Mountains of Poland, including theropod ichnogenera of *Stenonyx*, *Plesiornis*, *Grallator*, *Anchisauripus*, *Eubrontes*, *Kayentapus*, and a huge theropod track; ornithischian ichnogenera *Anomoepus*, *Moyenisauropus*, cf. *Delatorichnus*, sauropodomorph ichnites of *Otozoum* and *Parabrontopodus*, as well as dinosaur swimming traces (*Characichnos tridactylus*) and some problematic forms labeled as cf. *Wintonopus* and cf. *Carmelopodus*. In the Rhaetian of the Tomanová Formation at Czerwone Żlebki (Polish Tatra Mts.), *Eubrontes* (*Kayentapus*, according to the discoverer, G. Niedźwiedzki), *Tetrasauropus* (sauropod footprint according to Niedźwiedzki) and *Pseudotetrasauropus* (*Anomoepus* in his interpretation) have been recently found. In G. Niedźwiedzki's interpretation, the dinosaur track assemblage from the Tomanová Formation suggests its Early Jurassic age, contrary to its traditional stratigraphic interpretation. The Tomanová Formation continues onto the Slovak side of the border in Tatra Mountains, and yielded there large theropod tracks of *Eubrontes* formerly reported as "*Coelurosaurchnus tatricus*").

The restudy of the Hungarian Sinemurian material revealed theropod ichnogenera: *Kayentapus* and *Anchisauripus*.

The Central European dinosaur track assemblages indicate presence of large theropods already in the Late Triassic and appearance of huge theropods (supposedly earliest allosauroids) in the earliest Jurassic, along with relatively advanced sauropod fauna. Many Hettangian track makers from Poland seem to be surprisingly advanced for their age. These derived forms include: the amazingly bird-like variant of *Plesiornis*, the giant theropod footprint from the early Hettangian of Sołtyków, morphologically closer to the Early Cretaceous *Eubrontes glenrosensis* (or *Megalosauripus sensu* Lockley) than to Liassic *Eubrontes giganteus*; and the mysterious *Moyenisauropus karaszewskii*, allegedly proto-stegosaurian footprint, markedly differing from proto-ankylosaurian tracks of *Anomoepus pienkovskii* – *Moyenisauropus natator* plexus, well represented in the Polish Hettangian track sites.

Thus, the ichnological record from central Europe illustrates a rapid faunal turnover at the Triassic-Jurassic boundary, with quickly appearing derived phylogenetic lineages.



LUNGFISH BURROWS FROM THE UPPER TRIASSIC REDONDA FORMATION, CHINLE GROUP, EASTERN NEW MEXICO (poster)

GOBETZ, KATRINA E., LUCAS, SPENCER G., and LERNER, ALLAN J., New Mexico Museum of Natural History, 1801 Mountain Road NW Albuquerque, NM 87104

The upper Norian Redonda Formation (Chinle Group) at Mesa Redonda, Tucumcari Basin, New Mexico, contains a localized occurrence of tubular casts that appear to be lungfish burrows. Homogeneity among burrows in cylindrical shape and relatively large diameter (4.8-7.2 cm) indicates excavation by a single type of organism, most likely a vertebrate. Lack of secondary branches rules out the identification of these structures as root casts. The burrows are densely concentrated over an area of about 5m², in siltstones representing a lacustrine margin facies. Comparison with architecture and surface morphology of other fossil and modern trace fossils indicates a close similarity to burrows of lungfish. The burrows are primarily vertical but weakly helical, resembling the two most common types of lungfish burrow known from other exposures of the Chinle Group and from the Permian of Texas and Kansas (test tube-shaped or flask shaped with expanded terminus). Additional similarities to lungfish burrows

include diameter (3 cm smaller than burrows containing lungfish skeletons) and diagnostic weathering into poker chip-like pieces. The burrow walls are smooth, possibly reflecting the original mucus cocoon secreted by the fish, and are devoid of digging traces except for spiraling, infilled mudcracks, also observed on fossil lungfish burrows. One burrow has a wide, faintly bilobate chamber at the base (height 11.1 cm, width 10.6 cm) with a slight depression in the center, resembling the turn-around structure formed when lungfishes coil at the base of their burrows. This chamber is flatter on one side than the other, with the flat side possibly retaining the profile of the tail. In cross-section, the burrows show concentric, differently weathered fill layers, with an innermost core of reddish (iron-rich) fill measuring ~0.55 cm across and containing calcite spar. The outer fill, or “zone of compaction,” may have been formed by the fish and typifies fossil lungfish burrows. Periodic (seasonal) water-logging and drying of the soil with fluctuation of lake level is indicated by reduction/oxidation (redox) features occurring as irregular patches of green and red on burrow walls and in the fill. Previously described fossil lungfish burrows represent estivation, reflecting the fishes’ well-known behavior of burrowing straight down and then turning to ‘stand’ inside vertical burrows. However, the living African species *Protopterus* excavates various tunnel forms, such as angled and horizontal shafts, for spawning and nesting. The variable morphology of the Upper Triassic burrows from Mesa Redonda, which nevertheless show many distinctive lungfish burrow features, may be the oldest record of diverse behavior in extinct lungfish.



BIRD-LIKE TRACKS IN THE KAYENTA FORMATION (LOWER JURASSIC), WASHINGTON COUNTY, UTAH

HAMBLIN, ALDEN H., A.H. Hamblin Paleontological Consulting, 3793 N. Minersville Hwy, Cedar City, UT 84720 (ahhamblinpaleo@accesswest.com)

A half dozen small bird-like tracks have been discovered in the Kayenta Formation (Lower Jurassic) in Washington county, southwestern Utah. The tracks occur in a fractured, mottled red-brown mudstone. Most of the tracks appear to be tridactyl and range in size from 6.0 to 8.5 cm wide and 7 to 9 cm long. Digits are slender, 0.5 to 1.0 cm wide. The angle of divarication between outer digits is approximately 85 degrees with a range of 70 to 90 degrees. One track possibly shows a caudally directed hallux. The tracks look similar to *Argoides* and, though bird-like, were likely made by a small nonavian dinosaur.



SIZE TRENDS IN THE SEMI-AQUATIC PREDATOR GUILD ACROSS THE TRIASSIC-JURASSIC BOUNDARY AND DURING THE LATER MESOZOIC (poster)

HUNT, ADRIAN P. and **LUCAS, SPENCER G.**, New Mexico Museum of Natural History, 1801 Mountain Road NW, Albuquerque, NM 87104-1375

There is a direct relationship between predator body size and prey body size. However, semi-aquatic nonmarine predator guilds (excluding turtles) during the Late Triassic-Late Cretaceous reveal unexpected patterns of body size relative to the sizes of the largest terrestrial animals, which were potential prey.

During the Late Triassic, phytosaurs dominated semi-aquatic predator guilds in nonmarine environments in Laurasia, India, North Africa and Madagascar, and proterochampsids dominated them in South America. The body lengths of phytosaurs were up to 4.5 m and thus exceeded those of all contemporaneous terrestrial tetrapods (aetosaurs, “rauisuchians,” dicynodonts).

During the Early Jurassic, there were very few crocodilians (e. g., *Peipehsuchus*) or other semi-aquatic predators (labyrinthodonts), and all were of small size relative to the largest terrestrial tetrapods (prosauropods). The rarity of semi-aquatic predators may be indicative of the generally arid climatic conditions of this time period. Middle Jurassic tetrapod faunas in China include brachyopid amphibians as the largest semi-aquatic predators, which are extremely small compared to the associated sauropods. Late Jurassic tetrapod faunas include small crocodilians such as *Goniopholis*, which are very small compared to the largest terrestrial sauropods.

The size disparity between crocodilians and terrestrial animals continues into the Early Cretaceous. In this time interval, the first spinosaurid theropods appear to have partly filled the semi-aquatic predator niche in Gondwana and Europe. During the mid to Late Cretaceous, extremely large crocodilians (*Deinosuchus*, *Sarcosuchus*) reached lengths of 12 m, which is comparable in size to the largest contemporaneous terrestrial tetrapods.

In summary, during the Late Triassic there were very large semi-aquatic predators (relative to the largest terrestrial tetrapods), from the Early Jurassic to Early Cretaceous there were only small crocodilians, in the Early Cretaceous (in some areas) spinosaurid theropods partially filled the niche, and in the mid to Late Cretaceous large crocodilians reached a relative size (to terrestrial tetrapods) comparable to phytosaurs. What filled the large semi-aquatic predator niche from the Early Jurassic to mid Cretaceous? It is possible that, as originally suggested by Molnar, the long retroarticular process of *Allosaurus* indicates that supposedly terrestrial theropods may have had a partially semi-aquatic lifestyle. Given the apparently open niche it seems likely that some theropods may have fed in shallow water during the Jurassic to mid Cretaceous.



THE TETRAPOD FAUNA OF THE LATE TRIASSIC REDONDA FORMATION OF EAST-CENTRAL NEW MEXICO: NORTH AMERICA'S BEST NEAR-TERMINAL TRIASSIC FAUNA (poster)

HUNT, ADRIAN P. and **LUCAS, SPENCER G.**, New Mexico Museum of Natural History, 1801 Mountain Road NW, Albuquerque, NM 87104-1375

Latest Triassic tetrapod faunas are rare in North America. The best faunas are both known from New Mexico and are the restricted fauna of the Rock Point Formation at the Whitaker quarry in Rio Arriba County and the more diverse fauna of the Redonda Formation in east-central New Mexico.

The Redonda fauna is still being developed but it provides diverse elements from a variety of taphofacies. The Redonda fauna occurs in a series of facies in a lacustrine-palustrine basin and includes aquatic through terrestrial components. Tetrapods occur in beach through fluvial settings. A large ichnofauna from the lake margin facies includes *Brachychirotherium*, "*Pseudotetrasauropus*," "*Tetrasauropus*," *Grallator* and two ichnospecies of *Rhynchosaurooides*.

The bone record is dominated by phytosaurs, which include several morphotypes that represent *Redondasaurus gregorii* and at least one other species. Aetosaurs include *Redondasuchus reseri* and a *Typothorax*-like form. The metoposaur *Apachesaurus gregorii* is locally common. Other larger tetrapods include the spheenosuchian *Redondavenator*, the enigmatic *Vancleavea*, a small theropod and a large archosaur. Smaller tetrapods include a possible cynodont, a sphenodontid and a procolophonid.

The fauna is notable for a number of reasons: (1) several taxa (phytosaur, aetosaur, spheenosuchian) are of very large body size; (2) the fauna has the overall aspect of Carnian-Norian faunas in being dominated by phytosaurs, metoposaurs and aetosaurs in contrast to broadly contemporaneous faunas in South America, South Africa and Europe that are dinosaur dominated; (3) this is the only Late Triassic tetrapod body-fossil fauna associated with a large ichnofauna; (4) the body fossil fauna is not accurately reflected in the associated ichnofauna; and (5) the Redonda is unusual in preserving Late Triassic vertebrate fossils in a range of taphofacies from shallow water lacustrine to paleosol.



THE MOENAVE FORMATION AT THE ST. GEORGE DINOSAUR DISCOVERY SITE AT JOHNSON FARM (SGDS)

KIRKLAND, JAMES I., Utah Geological Survey, PO Box 146100, Salt Lake City, UT, 84114-6100; and **MILNER, ANDREW R.C.**, St. George Dinosaur Discovery Site at Johnson Farm, City of St. George, 2180 East Riverside Drive, St. George, UT 84790

Extensive development in the St. George area resulted in the temporary exposure of fresh rock at the SGDS, permitting the authors to examine and describe the section of rocks at the track site in some detail. Since this study, construction has covered much of what we observed, making this the only detailed record of the Moenave Formation in this area. Additionally, all past studies specifically on the Moenave Formation in the St. George area have actually been on the lower Kayenta Formation.

We measured a total thickness of the Moenave Formation of 101.8 m. The formation is divided into three members: 1) Dinosaur Canyon Member (54.83 m thick), 2) Whitmore Point Member (19.14 m thick), and 3) Springdale Sandstone (27.85 m thick).

A poorly cemented chert and anhydrite pebble conglomerate approximately one meter thick overlies an unconformity (J-0 unconformity of previous authors) with the older Chinle Formation. Overlying the conglomerate is 34.8 m of slope-forming mudstone-dominated rocks with anhydrite nodules and secondary gypsum veins. Thin ripple-bedded sandstone layers with sharp, commonly mudcracked bases become increasingly abundant up section. Fine- to medium-grained sandstone beds, each 10 to 100 cm thick, make up a cliff-forming unit 18.9 m thick at the top of the Dinosaur Canyon Member. Medium-scale trough cross-bedding characterizes the thicker beds in the lower half, and ripple-drift cross-bedding dominates the beds near the top. A poorly sorted yellowish-tan to green sandstone bed 5 m from the top preserves abundant, identifiable plant debris. Three dinosaur track horizons are recognized above this plant-bearing bed in the upper Dinosaur Canyon Member.

The Whitmore Point Member has a more varied lithology. The lower, conformable contact is placed at the base of the first major mudstone unit overlying the cliff-forming sandstones at the top of the Dinosaur Canyon Member. The member can be divided into three intervals at SGDS: 1) a basal, complex interval that includes the main track-bearing surface; 2) a middle sandstone-dominated interval similar to the upper few meters of the Dinosaur Canyon Member; and 3) an upper thin-bedded interval. The main track site horizon is impressed into a basal 1.8 m mudstone interval with increasing thin ripple cross-bedded sandstone layers near its top. A partially chert-replaced stromatolitic bed is present 0 to 20 cm below the main track-bearing surface.

At the initial discovery site on the southeast side of Riverside Drive, the base of the main track surface is covered by deeply impressed dinosaur tracks and mudcracks. This surface was subsequently scoured by large southeast-directed flute casts 30 to more than 100 cm across. This scoured surface preserves additional dinosaur tracks and locally abundant diamond-shaped (triclinc) salt casts that may represent borate salts, such as trona. Thus, two episodes of dinosaur track formation and preservation are recognized at the base of the main track-bearing sandstone. Across Riverside Drive to the northwest, the base of the main sandstone preserves more evidence of scouring (northward-directed currents), tool marks, and fewer mudcracks, suggesting deeper water. Invertebrate burrowing and crawling traces are present along with dinosaur swim tracks and fish swim traces. Internally, the main track-bearing sandstone preserves climbing-ripple cross-bedding indicating deposition in flowing-water. Splits along internal bedding surfaces variably preserve either undulatory ripples and/or algal laminae with tracks and raindrop impression. Although the main track-bearing sandstone is laterally continuous across the entire area examined, at the initial discovery site, the top of this bed is eroded into a series of large (meter-scale) megaripples trending N. 70° W such that in small areas the sandstone is entirely eroded away. Between the megaripple crests, thin sandstone beds are dominated by undulatory ripple surfaces with either a southeast current direction or an opposing northwest current direction. Additionally, a few surfaces preserve symmetrical wave ripples and interference ripples. Rill marks indicating draining to the southwest are also present. All these beds preserve tracks.

Lacustrine mudstones 1.7 m thick overlie the main track-bearing sandstone and preserve ostracods, conchostracans, and isolated fish bones. To the north, a 65 cm thick sandstone interval rests on and fills mudcracks up to 50 cm deep. This bed pinches out to the south. Four discrete ripple cross bedded sandstones in this interval preserve dinosaur tracks, fish swim traces, and additional mudcracks with some large root traces. These lacustrine mudstones and sandstones are overlain by 1.25 m of mudstone.

The middle sandstone-dominated interval is 7.64 m thick and is characterized by interbedded reddish brown sandstone and mudstone. These sandstones are similar to those in the upper part of the Dinosaur Canyon Member in preserving mudcracks and tracks, and having ripple cross-beds. As with most of the underlying ripple-bedded sandstones preserving tracks, these sandstones are interpreted to represent lake-margin sand deposits

emplaced by longshore currents. The sand itself likely entered the lake system via fluvial channels like those preserved in the base of the cliff-forming portion of the Dinosaur Canyon Member.

Thin-bedded lacustrine sediments make up the upper 6.55 m of the Whitmore Point Member. This sequence consists mostly of coarsening-upward cycles about 20 to 50 cm thick, characterized by shale at the base containing fossil fish and ostracods. Sandstone at the top preserves algal laminae, stromatolites, mudcracks, many isolated bones, and rarely dinosaur tracks. This stratigraphic sequence may represent climatic cycles. Other less common features such as sandstone dikes and soft-sediment deformation features also occur.

The overlying Springdale Sandstone lies on an erosional surface having up to a meter or more of relief representing the J-0' or J-sub K unconformity of previous investigators. Locally, large clasts of Whitmore Point lacustrine sediments are present at this unconformity. The Springdale Sandstone is a coarse to very coarse, 0.5 to 1 m scale, trough cross-bedded fluvial sandstone correlative to the base of the Kayenta Formation east of the Moenave outcrop belt. The Kayenta Formation conformably overlies the Springdale Sandstone. The base of the Kayenta likely represents a lacustrine unit, with the Springdale fluvial sediments reworked into lake-margin deposits. Dinosaur tracks are abundant along this contact in the St. George and Zion National Park area.

The detailed descriptions of these Moenave strata provide a basis for understanding the local depositional history just prior to, during, and following the preservation of the fossil-bearing rock layers at the SGDS.



THE CASE FOR THEROPOD DINOSAURS EXPLOITING FISH AS A MAJOR FOOD RESOURCE DURING THE EARLY JURASSIC

KIRKLAND, JAMES I., Utah Geological Survey, PO Box 146100, Salt Lake City, UT 84114-6100;
MILNER, ANDREW R.C., St. George Dinosaur Discovery Site at Johnson Farm, City of St. George, 2180 East Riverside Dr., St. George, UT 84790 (andrew@hanmansfossils.com), and **NESBITT, STERLING, J.**, Lamont-Doherty Earth Observatory, Biology and Paleo Environment, 61 Route 9W - PO Box 1000, Palisades, NY, 10964-8000

Following the extinction of phytosaurs and metoposaurs (semi-aquatic predators) at the end of the Triassic, there is a gap in the record of large semi-aquatic fish-eating tetrapods. The earliest Jurassic record of a large semi-aquatic predator is the crocodilian *Calsoyasuchus* from the Kayenta Formation. With few taxa taking advantage of fish as a food source, we suggest that large theropods may have fed on fish in the Early Jurassic in the western United States.

The Whitmore Point Member of the Moenave Formation and the basal Kayenta Formation preserve evidence of extensive lake systems across southwestern Utah and northern Arizona. Although herbivore tracks are relatively common in more upland eolian facies, theropod tracks dominate almost to the exclusion of other ichnotaxa in the marginal environments of these lakes. The most common large theropod ichnotaxon is *Eubrontes*, which is usually referred to as the track of a large coelophysoid theropod such as *Dilophosaurus*. The near-complete absence of herbivorous dinosaurian ichnotaxa from this facies begs the question, what did these large theropods eat in this habitat? The fish from the Whitmore Point Member include abundant, heavy, ganoid-scale-covered semionotids of relatively large size (30-60 cm) as well as large coelacanth (~2 m), hybodont sharks (~1 m), and lungfish (~1 m). These fish could have served as a food source for large predators, as comparably sized salmon do for bears today.

Bones and teeth of theropods large enough to produce *Eubrontes* tracks have been found within the same beds as these Whitmore Point fish. The theropod remains cannot be attributed to a specific theropod taxon at present. Most of the long, slender, awl-shaped teeth display a distinctive wear pattern, having the serrations along the anterior and posterior carina that are worn off from the tip of the tooth to the base of the crown. The only teeth the authors have observed with similar wear are those of *Spinosaurus*, a theropod dinosaur that many paleontologists agree was probably a piscivore to some degree. We hypothesize that this kind of wear was produced by the teeth penetrating the “chain mail” of heavy ganoid scales covering the semionotid fish. In the case of the St. George theropods, the fish would be *Semionotus*; for the mid-Cretaceous *Spinosaurus*, the fish would be *Lepidotes*. The hard enamel covering on the scales would rapidly wear the enamel on the teeth.

Additionally, *Dilophosaurus* and *Spinosaurus* share the following characters that may be adaptive for piscivory: moderately long arms with raptorial claws, posterior nasal openings, slim jaws, and anteriorly expanded jaws with long, slender teeth (a rosette). Similar jaws are present in a number of extinct and extant aquatic and semi-aquatic fish-eating predators (e.g., crocodilians, phytosaurs, champsosaurs, and pliosaurs). A slender jaw displaces a

minimum volume of water when shut rapidly, and the rosette of teeth at the front maximizes the area for catching fish. Posteriorly placed nasal openings might permit the end of jaws to rest in water with head in a vertical “striking” position. Furthermore, the recently documented myriad of theropod swim tracks in both the Whitmore Point Member and lower Kayenta Formation indicates that theropods were regularly entering the lakes to water depths that would at least partially buoy up their bodies.



NEW DISCOVERIES OF EXTENSIVE TETRAPOD TRACK SURFACES IN THE UPPER TRIASSIC REDONDA FORMATION OF EAST-CENTRAL NEW MEXICO: INSIGHTS INTO AN EARLY MESOZOIC VERTEBRATE ASSEMBLAGE AND IMPLICATIONS FOR ICHNOTAXONOMIC RELATIONSHIPS (poster)

KLEIN, HENDRIK, Weinleite 4, D-92348 Berg, Germany (klein.dinotracks@web.de); **LUCAS, SPENCER G.**, New Mexico Museum of Natural History, 1801 Mountain Road NW, Albuquerque, NM 87104 (slucas@nmmnh.state.nm.us); and **HAUBOLD, HARTMUT**, Institute for Geological Sciences, Martin-Luther-University Halle-Wittenberg, Von-Seckendorff-Platz 3, D-06120 Halle, Germany (haubold@geologie.uni-halle.de)

Tetrapod tracks and trackways from lake-margin facies of the Upper Triassic Redonda Formation have been reported for many years from Mesa Redonda and from nearby Apache Canyon in east-central New Mexico. At Mesa Redonda, they were discovered mostly on large fallen blocks, covering the slopes below widespread, indurated, laminated and ripple-laminated, calcareous siltstone and sandstone beds, that form a distinctive bench or cliffs referred to by some previous workers as the “Redonda ledge.” Now, for the first time, two in situ track-bearing layers can be documented at several measured sections of the ledge and followed for hundreds of meters along the flanks of Spikes Canyon, Apodaca Creek and the northern peninsula of the mesa. At some places the track-bearing horizons display trampled surfaces with thousand of pes- and manus-imprints, mostly preserved as convex hyporeliefs on the undersides of overhangs.

The imprint forms can be tentatively identified as *Grallator*, cf. *Brachychirotherium* and cf. *Pseudotetrasauropus*. Small pes- and manus imprints of *Rhynchosauroides* (1-2 cm pes length) are also common at some locations. In addition, some undetermined forms, possibly representing mammal or mammal-like producers, remain to be examined.

Grallator is common and preserved as tridactyl footprints with lengths of 8-17 cm. An uncollected block displays more than 100 small specimens, and several other track ways are present. *Brachychirotherium*- and *Pseudotetrasauropus*-like forms are very abundant at Mesa Redonda and display a tri- to pentadactyl pes (10-25 cm length) with an occasionally associated, smaller tetradactyl manus. Well preserved track ways are present. *Rhynchosauroides* is small, with an ectaxonic pentadactyl pes (1-2 cm average length) and a similar shaped, partly overstepped manus.

In the chirotherian-like forms there are indications that preservational factors control track morphs previously treated as separate ichnotaxa in the literature. Thus, apparent differences in track morphology recognized in isolated pes-/manus-imprints must first be considered within the context of more extensive material, which means that representative surfaces with these forms must be found and examined before evaluating eventual taxonomic relationships. Thus, upon first examination, forms determined by isolated imprints as cf. *Brachychirotherium* and cf. *Pseudotetrasauropus* seem to be part of a preservational series- there is evidence of successive transitional morphs by which both can be connected. Whether only substrate- or other gait-related factors are responsible cannot be decided at present. In the tri- to pentadactyl pes impressions mostly the latter display an associated manus, suggesting a possible change between bipedal and quadrupedal locomotion. Other explanations, for example, the presence of undertracks in the tridactyl versions and the filtering of manus-/pes-digits by the substrate, are possible as well.

The identity of the track makers at Mesa Redonda is mostly uncertain. Interpretations favor members of the crocodylian stem group or a dinosaurian, perhaps prosauropod, origin for the chirotherian-like forms. *Grallator* should represent a dinosaur, probably a theropod. *Rhynchosauroides* shows lepidosauromorph affinities. The new discoveries and determinations indicate that at least three or four different tetrapods frequented the lake margin environment represented by part of the uppermost Triassic Redonda Formation.



INVERTEBRATE ICHNOFAUNA FROM THE UPPER TRIASSIC REDONDA FORMATION OF QUAY COUNTY, EAST-CENTRAL NEW MEXICO (poster)

LERNER, ALLAN J. and **LUCAS, SPENCER G.**, New Mexico Museum of Natural History, 1801 Mountain Road NW Albuquerque, NM 87104

Studies of Upper Triassic nonmarine invertebrate trace fossils in the American Southwest are few. Here, we document here an example of Triassic invertebrate trace fossils assigned to the *Scoyenia* ichnofacies from the upper Norian Redonda Formation of the Chinle Group. Two distinct invertebrate ichnofaunal associations of low diversity occur in Redonda strata at Mesa Redonda, which is located in the Tukumcari basin of east-central New Mexico. Numerous well-preserved *Lockeia siliquaria* are found within laterally continuous calcarenite beds ~ 14 meters below the top of the Redonda (disconformable contact with overlying Middle Jurassic Entrada Sandstone). Preservation is in convex hyporelief. Larger specimens measure between 9 mm long and 4 mm wide, which is small in comparison to most published reports of *Lockeia*. These beds also contain numerous specimens of large estherian conchostracan valves that are of similar dimensions to the *Lockeia*. Bivalves, which are generally considered to be the makers of *Lockeia*, were not found at Mesa Redonda. We conclude that conchostracans are the probable local producers of the *Lockeia*. *Arenicolites* sp. also occurs in low abundance within these beds. Abundant vertebrate tracks assigned to the ichnogenera *Brachychirotherium*, *Pseudotetrasauropus*, and *Grallator* are found in this association. The paleoenvironment was a lacustrine shoreline. A second ichnofaunal association is found ~ 7 meters below the top of the Redonda. Numerous *Scoyenia gracilis* burrows occur in sandstones and mudstones. The preservation is mostly in semi-convex relief, although many full relief specimens have weathered out. Meniscate structures within the burrows can be seen on some weathered surfaces. *Skolithos* sp. is found in low abundance. Large diameter cylindrical burrows that are probable lungfish aestivation chambers occur within this association. The paleoenvironment was likely shallow water with periodic emergent conditions. Both low diversity trace fossil associations at Mesa Redonda are similar to other reports of the *Scoyenia* ichnofacies from Triassic lake margin environments.



A MORPHODYNAMIC ANALYSIS OF THE TRIASSIC THEROPOD DINOSAUR *COELOPHYSIS*: DIMORPHISM PROVIDES CLUES TO INTRINSIC BIOLOGICAL ORGANIZATION IN SAURISCHIAN DINOSAURS

LOCKLEY, MARTIN G., (Martin.Lockley@CUdenver.edu) and **KUKIHARA, REIJI**, Dinosaur Tracks Museum, CB 172, University of Colorado at Denver, PO Box 173364, Denver, CO 80217-3364.

Coelophysis is one of the best-preserved of all theropod dinosaurs. Paleontologists recognize two morphotypes exemplified by the robust American Museum form (AMNH 7223) and the gracile form (AMNH 7224). These two morphotypes, which represent dimorphs of the same species (*C. bauri*) provide important clues to intrinsic or 'formal' biological organization (*sensu* Gould 2002), that has potentially widespread application in the study of theropods, saurischians and dinosaurs in general.

We show that the robust form (7223) has a long skull and neck, short trunk and sacrum, short forelimbs and long hind limbs. By contrast the gracile form (7224) has a short skull and neck, long body and sacrum, long front limbs and short hind limbs. Everything is 'systematically' reversed in the two dimorphs. This demonstrates an excellent example of the compensation principle (Goethe, 1795) reincarnated as the concept of heterochronic trade offs (McNamara, 1997). In summary, **any emphasis** (over- or under-development) **in any major organ** (head, neck, trunk, limb etc.) **is compensated for by an opposite or reciprocal emphasis in the adjacent organ**. Thus, the robust form has large head and neck, with a short body and long hind limbs while the gracile form has small head and neck, with a long body and short limbs. Note the coupling of adjacent organs: i.e., large head/neck and small front limbs, with short wide trunk and long hind limbs in 7223. All proportions are reversed in 7224.

Such polarity patterns are seen in all saurischian clades and are especially obvious when comparing primitive and derived clades (i.e., polar grades of organization). Thus, primitive theropods generally have posterior emphasis: i.e., they are small overall with generally long bodies, small heads, long tails and short hind legs. By contrast derived theropods, have anterior emphasis being generally larger, with larger heads and necks, shorter bodies, and longer hind limbs. The compensation between large heads (and or necks) and short front limbs is striking, not only in *C. bauri* dimorphs, but in comparing primitive ceratosaurs and derived coelurosaurs. The morphodynamic variability in coelurosaur (and bird) front limbs is particularly striking, and pertains to the coupling compensations between adjacent organs systems in the anterior part of the body.

Saurischians in general show these same trends. Thus, sauropodomorphs are larger, and have greater anterior emphasis (longer necks), shorter, wider bodies and longer limbs than theropods. Within the Sauropoda the polarity is obvious between smaller more gracile forms (e.g., diplodocids) with posterior emphasis (smaller heads, necks and front limbs, with longer hind limbs and tails) and larger, more-robust forms (e.g., brachiosaurids) with anterior emphasis (larger heads necks and front limbs, with shorter tails and hind limbs). There is also a compensatory relationship between short limbs and long feet (primitive theropod condition) and long limbs and short feet (derived sauropod condition). Such relationships hold for a wide variety of vertebrate groups.

These whole body polarities show up in trackways (Lockley 1999, 2001). Sauropods for example are divided into small-manus and narrow-gauge (probably diplodocids) and large-manus and wide-gauge (probably brachiosaurs and titanosaurs). Even in theropods there is a preponderance of small narrow-footed forms in the Late Triassic and Early Jurassic, (probably short-limbed ceratosaurs like *Coelophysis* making *Grallator*-like tracks), in comparison with larger, longer-limbed, later Mesozoic forms making wider tracks (probably coelurosaurs such as ornithomimids making *Magnoavipes*-like tracks). Even in comparisons between small *Grallator* and large *Eubrontes* it is well-known that the polarity is between small, narrow- and large, wide-footed forms.

The ultimate message has far reaching consequences for biology and evolutionary studies. The anatomical or morphological organization of natural biological groups (clades) such as theropods, saurischians, dinosaurs and vertebrates in general is not random, nor is it explainable solely in terms of **functional** adaptation. Rather, biological organization has a strong internal dynamic (**formal** component) that repeats in recognizable patterns at all levels of evolutionary organization. This repetition allows pattern recognition, and helps explain convergence. It is referred to as **iteration** and **recursion** in the study of fractals and complex systems. This paradigm has yet to be widely appreciated in morphological studies, but can be fruitfully developed through dynamic thinking and the study of heterochrony.

Goethe, J.W. 1795. Erster Entwurf einer allgemeinen Einleitung in die vergleichende Anatomie, ausgehend von Osteologie In:

Goethes Naturwissenschaftliche Schriften. Dornach: Hrsg. R. Steiner, 5 vol. (Publ. 1975).

Gould, S.J. 2002. *The Structure of Evolutionary Theory*. Cambridge: Harvard University Press, 1433 pp..

Lockley, M.G. 1999. *The Eternal Trail: a Tracker Looks at Evolution*. Philadelphia: Perseus Books, 334 pp.

Lockley, M.G. 2001. Trackways- dinosaur locomotion, pp. 412-416 in Briggs, D. E. G. and Crowther, P. (eds.) *Paleobiology II*. Malden: Blackwell Science.

McNamara, K. 1997. *Shapes of Time: the Evolution of Growth and Development*. Baltimore: John Hopkins University Press, 342 pp..



DROUGHT LEAVES DINOSAUR TRACKS HIGH AND DRY: NEW SITES FROM THE LOWER JURASSIC GLEN CANYON GROUP, LAKE POWELL AREA, UTAH AND ARIZONA

LOCKLEY, MARTIN G., (Martin.Lockley@CUdenver.edu) **KUKIHARA, REIJI, MITCHELL, LAURA J.**, Dinosaur Tracks Museum, CB 172, University of Colorado at Denver, PO Box 173364, Denver, CO 80217-3364; and **NEWCOMB, LEX**, Glen Canyon National Recreation Area, Page, AZ 86040

Dinosaur tracks and other vertebrate footprints are known from dozens of sites in the Glen Canyon National Recreation Area (GKNRA) also known to many as Lake Powell. A preliminary Survey published in 1998 reported 36 sites ranging in age from Permian (ca., 280 Ma) to Upper Jurassic (ca. 150 Ma). Most sites however are Lower Jurassic in age, originating from the Glen Canyon Group (including the Wingate, Kayenta and Navajo Formations).

Some of these sites had been reported by tourists and amateur enthusiasts but never previously documented. Many had been found before the advent of GPS systems, and so had not been accurately located.

Recent lowering of water levels by more than 100 feet (ca 30 m) due to drought has revealed new sites that have been submerged for many years. Beginning in 2004 the National Park Service (NPS) funded a survey of known track sites with the aim of compiling an updated GPS database, and recording new sites reported since 1998, including those recently revealed as a result of low water levels.

Most of the new sites have been found in the Lower Jurassic Glen Canyon Group, increasing the total of known sites by more than 40% (36 to 51). Notable discoveries and relocated sites include the Choal Canyon Sites in the Kayenta-Navajo transition zone where we find parallel trackways of theropods with metatarsal impressions, and a *Eubrontes* trackway that indicates an animal moving at an estimated speed of about 22.4 km/hour. In the Slick Rock Canyon area, there is a high density of track sites in the Kayenta-Navajo transition zone including four sites that have been mapped. These include three theropod (*Grallator* and *Eubrontes*) dominated track sites with a total of 150 tracks and an *Anomoepus* site with more than 30 tracks. Large *in situ* sites are uncommon at GCNRA as steep lakeside terrain limits exposure of large bedding surfaces.

Other important discoveries include an *Otozoum* trackway progressing up a dune foreset in the Navajo Formation, and theropod tracks, now assigned to the Entrada Formation, that were previously incorrectly assigned to the Navajo Formation.

GCNRA is a vast area that adjoins BLM and Navajo Nation lands, where other sites are known that are often most accessible from Lake Powell. However, while falling lake levels have revealed many new sites, others that were previously accessible by boat have become much harder to get to. Nonetheless, many more sites remain to be discovered in this huge area, including several that have been reported, but not yet relocated or studied.



ARCHOSAUR TRACKS FROM THE CHINLE GROUP (LATE TRIASSIC), ST. GEORGE AREA, SOUTHWESTERN UTAH

LOCKLEY, MARTIN, Geology Department, University of Colorado at Denver, CO 80217-3364; **MILNER, ANDREW R.C.**, St. George Dinosaur Discovery Site at Johnson Farm, City of St. George, 2180 East Riverside Dr., St. George, UT 84790 (andrew@hanmansfossils.com); and **LUCAS, SPENCER**, New Mexico Museum of Natural History, 1801 Mountain Road NW Albuquerque, NM 87104

Although famous for several important Lower Jurassic dinosaur track sites, the St. George region has also produced several older, Late Triassic sites. Two such sites are described here.

The first site, located west of Santa Clara, is associated with the upper surface of the coarse-grained (conglomeratic) Shinarump Formation, and reveals a single trackway of a tridactyl biped, in association with a few indistinct traces. The trackway comprises a four- step sequence oriented towards the south. Each track is about 15 cm wide and long, with a step of 50- 60 cm. The trackway is narrow (pace angulation almost 180°) and may be attributable to a theropod. The site is important because tracks from the Shinarump Formation have not previously been reported, presumably owing to the coarse grained lithology.

The second site near Harrisburg is also associated with the upper part of the Shinarump Formation. However, in contrast to the site west of Santa Clara, at this locality the lithofacies is sandstone. We identified two regular sequences of “swim tracks” that occur as natural casts on loose slabs. The tracks are large (up to 40 cm long) and represent two, three or four sub-parallel scrape marks made by digits that presumably dug into a soft substrate below the infilling sandy layer. Both sets of swim tracks comprise four large casts, with relatively regular spacing of about 60- 90 cm. However the two sequences are different. One set reveals small tridactyl tracks regularly spaced in between the large tracks, whereas the other sequence contains only large tracks. The small and large tracks may represent manus and pes traces respectively. It is possible that the two sequences belonged together when originally *in situ*.

These are the first well-preserved swim tracks reported from the Chinle Group. Although smaller swim tracks are common in the Lower to Middle Triassic Moenkopi Formation, no specimens this large have ever been described. Moreover, even in the Moenkopi Formation, documentation of swim tracks is sparse. Interpretation of swim tracks is also inherently difficult because the full foot morphology is rarely represented without the distortional effects of dynamic motion or preservational degradation associated with a subaqueous substrate at the

time the tracks were registered. Nonetheless, the Harrisburg tracks are clear, well preserved and visually spectacular and the trackway segments show a regular pattern. The traces may represent a phytosaur or large metoposaur.



COLLAPSE PRESERVATION OF A PROSAUROPOD FROM THE JURASSIC KAYENTA FORMATION OF UTAH

LOEWEN, MARK A., GETTY, MICHAEL A., SAMPSON, SCOTT D., and SERTICH, JOSEPH J.W., Utah Museum of Natural History, 1390 East Presidents Circle, University of Utah, Salt Lake City, UT 84112

Recent field work by the Utah Museum of Natural History in the Comb Ridge area of southeastern Utah between Bluff and Blanding has resulted in the recovery of the remains of a prosauropod dinosaur. The specimen, which was recovered from the top of the Kayenta Formation, immediately underlying the Navajo Formation, represents the first prosauropod skeleton collected in Utah. In the area of Comb Ridge, the Kayenta Formation consists of fluvial sands, fine-grained overbank deposits and occasional lenses of eolian sands. The specimen was recovered from chaotic fine-grained sandstone at the top of the Kayenta Formation. Thirty centimeters above the specimen the uninterrupted eolian sequence represented by the Navajo Formation continues for over 200 meters.

The specimen consists of nine dorsal vertebrae, both ischia and pubes preserved in place; both scapulae and coracoids; both humeri, radii and ulnae; the left manus; and the left tibia and pes. The caudal series, sacrum, ilia, right hindlimb, cervical series and head are missing due to erosion of the canyon prior to discovery. Additionally, both scapulae and coracoids are preserved in place, with clavicles, paired sternal plates and a complete gastral basket. Preliminary morphological and systematic analyses indicate an affinity to the Plateosauria.

The articulated preservation of the specimen, including articulated dorsal vertebrae, the complete forelimb girdles, gastral basket, manus and pes, are indicative of soft tissue present at the time of burial. Furthermore, they argue for minimal transport. The specimen is preserved three dimensionally and does not lie normal with respect to the original horizontal bedding planes directly above and below it. The orientation and preservation of the specimen are indicative of a dune collapse hypothesis, which is further supported by sedimentological and petrographic data.



EARLY JURASSIC INVERTEBRATE ICHNOFAUNA OF THE ST. GEORGE DINOSAUR DISCOVERY SITE, MOENAVE FORMATION (poster)

LUCAS, SPENCER G., LERNER, ALLAN J., New Mexico Museum of Natural History, 1801 Mountain Road NW Albuquerque, NM 87104; and **MILNER, ANDREW R.C.**, St. George Dinosaur Discovery Site at Johnson Farm, City of St. George, 2180 East Riverside Dr., St. George, UT 84790 (andrew@hanmansfossils.com)

The dinosaur track site at St. George Dinosaur Discovery Site at Johnson Farm (St. George, Utah) in the Lower Jurassic Moenave Formation yields a low diversity invertebrate ichnofauna in addition to the tetrapod tracks. Rare horizontal burrows (*Scoyenia*) are found on three bedding planes in the upper 3 m of the Dinosaur Canyon Member, and these are the only invertebrate traces in that unit. Within the “transition zone” and above it in the Whitmore Point Member, *Scoyenia* burrows are extremely common locally. Four horizons have been recognized so far. At the level of the “main tracklayer” (9.68 m above Moenave base) and the “top surface” (10.29-10.38 m above Moenave base), large areas between the museum site and the swim track locality on Washington County School District are covered with *Scoyenia* burrows. Dinosaur tracks on these surfaces are very rare. *Fuersichnus communis* occur 9.78 m above the Moenave base within the “transition zone” below and in contact with the “Johnson Farm split track layer.” Invertebrate tracks (*Kouphichnium*) are common on this bed and often very well preserved. The “top surface” has the greatest diversity of invertebrate traces. Horizontal burrows (rare *Scoyenia*) and invertebrate trails (cf. *Protovirgularia* and ?arthropod tracks: *Kouphichnium*) are present. On the “sauropod track site surface,” 12.08-12.6 m above the Moenave base, rare burrows and even rarer arthropod tracks occur. Abundant *Skolithos*

burrows cover large areas, and this layer is traceable for 30 m on strike. This bed, called the “Slauf burrow bed,” is 18.94 m above the Moenave base. Another bed of burrows, called “Sally’s burrow bed,” is 20.44 m above the Moenave base. These burrows are not as abundant or as well preserved as those in the layers below. *Palaeophycus* burrows occur at the base of a green bed where abundant fish bones, coprolites, and conchostracans are found. The base of this bed is heavily bioturbated, and it is ~ 21.81 m above the Moenave base. Seven invertebrate ichnotaxa occur at the St. George site: *Fuersichnus communis*, *Palaeophycus tubularis*, *Scoyenia* isp., *Skolithos* isp., *Scolicia* isp., *Protovirgularia dichotoma* and *Kouphichnium* isp. Overall ichnodiversity is relatively low, and there is a high abundance of horizontal and vertical burrows compared to invertebrate locomotion traces. Inferred trace makers include annelids, snails, insects and chelicerates. The traces are characteristic of the continental *Scoyenia* ichnoguild and reflect marginal lacustrine to shallow lacustrine environments.



STRATIGRAPHIC RESOLUTION AND THE SUPPOSED MASS EXTINCTION AT THE END OF THE TRIASSIC

LUCAS, SPENCER G., New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM 87104 (slucas@nmmnh.state.nm.us); and **TANNER, LAWRENCE H.**, Department of Geography and Geoscience, Bloomsburg University, Bloomsburg, PA 17815

Attempts to determine the causes of widespread extinction during the Late Triassic have long been based on the assumption that extinction at the system boundary was sudden and synchronous in both terrestrial and marine environments. Indeed, many paleontologists have long described end-Triassic extinction as one of the five largest extinctions in Earth history, and attributed it to a catastrophic cause, such as bolide impact, widespread volcanism, or methane hydrate release. However, the apparent suddenness of this extinction is largely an artifact of poor stratigraphic resolution and thus an excellent example of the compiled correlation effect. Instead, the latest Triassic was an interval of elevated extinction rates punctuated by at least four discrete extinction events--middle Norian, late Norian, end Norian and end Rhaetian.

Most taxa that supposedly became extinct at the end of the Triassic actually disappeared by the beginning of the Rhaetian, and further extinctions occurred stepwise during the Rhaetian. The supposed sudden extinctions of ammonoids, bivalves, brachiopods and conodonts appear prolonged upon examination of detailed stratigraphic data, and there is no record of a profound extinction of marine gastropods at the end Triassic. Marine reptiles underwent a substantial extinction at the end Ladinian, not at the end Triassic. Indeed, radiolarians appear to be the only marine group to exhibit a sudden, extensive turnover at the end Triassic, and even this extinction cannot be shown conclusively to be of global extent. Extinction of megafossil plant species at the end Triassic appears to be mainly regional. The apparent dramatic palynological extinction in the Newark Supergroup is less sudden in Tethyan sections, and may in fact be a local event that does not correspond to the Triassic-Jurassic boundary. Tetrapod extinctions on land are difficult to document because of a poor tetrapod fossil record from the Rhaetian-Hettangian. Tetrapod footprints do not document an end Triassic mass extinction, only modest turnover. Thus, a careful reading of the stratigraphic distribution of fossils across the Triassic-Jurassic boundary indicates a prolonged and complex evolutionary turnover, including a pronounced decline in diversity, with detectable duration, not a single mass extinction. The perception of a single end-Triassic extinction is mostly due to poor stratigraphic (temporal) resolution exacerbated by a reliance on literature-based compilations of diversity, not on a close examination of the actual fossil record.



TETRAPOD BIOSTRATIGRAPHY ACROSS THE TRIASSIC-JURASSIC BOUNDARY ON THE SOUTHERN COLORADO PLATEAU, USA

LUCAS, SPENCER G., New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM 87104 (slucas@nmmnh.state.nm.us); **TANNER, LAWRENCE H.**, Department of Geography and Geoscience, Bloomsburg University, Bloomsburg, PA 17815; and **HECKERT, ANDREW B.** and **HUNT, ADRIAN P.**, New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM 87104

Nonmarine fluvial, lacustrine and eolian strata on the southern Colorado Plateau preserve one of the world's most extensive records of tetrapod body fossils and footprints across the Triassic-Jurassic boundary (TJB). A new and more detailed lithostratigraphic framework developed for these strata enables recognition of five, temporally successive tetrapod fossil assemblages:

1. The Owl Rock Formation of the Chinle Group yields a tetrapod body fossil assemblage that includes the phytosaur *Pseudopalatus* and the aetosaur *Typothorax coccinarum*, index taxa of the Revueltian land-vertebrate faunachron (lvf), which is of Norian age.
2. The Rock Point Formation of the Chinle Group, especially at Ghost Ranch, New Mexico, yields a tetrapod body fossil assemblage that includes the phytosaur *Redondasaurus*, index taxon of the Apachean lvf. Rock Point footprint assemblages include numerous *Brachychirotherium*, a crurotarsan track that appears to be restricted to Triassic strata. The presence of *Aetosaur* in the Rock Point Formation in the Eagle basin of Colorado suggests a Norian age, so we reject previous ideas that the Apachean is wholly Rhaetian in age.
3. Most of the Dinosaur Canyon Member of the Moenave Formation and the laterally equivalent Wingate Sandstone also appear to be Triassic in age. These strata also yield the phytosaur *Redondasaurus* and the footprint ichnotaxon *Brachychirotherium*, and they lack any Jurassic index taxa. They can thus be assigned an Apachean age, and may be equivalent to all or part of the Rhaetian.
4. The uppermost Dinosaur Canyon Member, the entire Whitmore Point Member of the Moenave Formation and the uppermost Wingate Sandstone appear to be of Jurassic age. These strata yield body fossils of the crocodylomorph *Protosuchus*, the dinosaur *Megapnosaurus* ("Syntarsus") and the footprint ichnotaxa *Eubrontes* and *Otozoum*, taxa traditionally considered to be Jurassic indicators. *Eubrontes*, however, now is known to have demonstrable Triassic records, but the lack of any Triassic index taxa in the upper Moenave-Wingate interval supports the idea that it is earliest Jurassic (Hettangian) in age.
5. The Kayenta Formation yields a tetrapod body fossil assemblage that is clearly of Jurassic age. A key taxon is the dinosaur *Scelidosaurus*, known from marine lower Sinemurian strata in the United Kingdom.

Tetrapod biostratigraphy thus supports available palynostratigraphy and magnetostratigraphy to place the TJB within the Moenave Formation and equivalent strata on the Colorado Plateau.



MICROTOPOGRAPHIC DOCUMENTATION OF A SITTING DINOSAUR FROM THE EARLY JURASSIC OF UTAH

MATTHEWS, NEFFRA A. and **NOBLE, TOMMY A.**, National Science and Technology Center, USDOI-Bureau of Land Management, Denver, CO 80225; and **BREITHAUPT, BRENT H.**, Geological Museum, University of Wyoming, Laramie, WY 82071

Early in 2004 during the construction of an interpretative center at the St. George Dinosaur Discovery Site at Johnson Farm, the trace left by a sitting dinosaur was uncovered. This unique Early Jurassic ichnofossil is preserved in the transition zone between the Dinosaur Canyon Member and the overlying Whitmore Point Member of the Moenave Formation. The sitting trace includes well-preserved *Eubrontes* footprints associated with metatarsal, ischial boot, and manus claw impressions. These traces are preserved as part of a longer trackway with associated tail drag marks. In the spring of 2004, before the fate of this amazing ichnofossil was completely known, detailed photodocumentation was conducted. Close-range photogrammetric methods are an established procedure for capturing detailed information about paleontological sites. Work conducted at dinosaur track sites in Wyoming, Colorado, and Utah has resulted in a refined methodology that greatly increases accuracy and reduces the amount of time needed for establishing ground control. This process consists of taking both oblique and stereoscopic images. These images are analyzed using three-dimensional measuring and modeling software and softcopy stereoscopic

instruments, which have analytical capabilities to a sub-millimeter level. Microtopographic analysis conducted on these photographs will provide detailed digital terrain data, which will be used to generate 3-D surfaces and detailed topographic contour maps. This state-of-the-art documentation methodology digitally preserves important information about dinosaur activity at this unique Early Jurassic dinosaur track site.



LATE TRIASSIC-EARLY JURASSIC FRESHWATER FISH FAUNAS OF THE SOUTHWESTERN UNITED STATES WITH EMPHASIS ON THE LAKE DIXIE PORTION OF THE MOENAVE FORMATION, SOUTHWEST UTAH

MILNER, ANDREW R.C., St. George Dinosaur Discovery Site at Johnson Farm, City of St. George, 2180 East Riverside Dr., St. George, UT 84790 (andrew@hanmansfossils.com); **KIRKLAND, JAMES I.**, Utah Geological Survey, 1594 West North Temple, Suite 3110 P.O. Box 146100, Salt Lake City, UT 84114-6100; **CHIN, KAREN**, University of Colorado at Boulder, UCB 265, Boulder, CO 80309; and **MICKELSON, DEBRA L.**, University of Colorado at Boulder, Department of Geological Sciences, UCB 399, Boulder, CO 80399

New information pertaining to a previously poorly known fish fauna from the Early Jurassic (Hettangian) lacustrine Whitmore Point Member of the Moenave Formation provides new information obtained from large and exceptional collections of fish body- and ichnofossils from the area of the St. George Dinosaur Discovery Site at Johnson Farm in St. George, Utah and other nearby localities. This new information provides a much clearer view of Late Triassic-Early Jurassic fish assemblages overall. Fish mass-mortalities in “Lake Dixie” have resulted in the fossilization of large quantities of fish skeletal materials in distinctive concretions. Semionotids are by far the dominant fish in these mass mortalities and probably dominated “Lake Dixie” ecosystems. While *Lepidotes walcotti* is not valid, it is unclear whether all species should be assigned to *Semionotus kanabensis* or even whether some of the larger specimens may represent *Lepidotes*.

Two new species of fish are described from the Whitmore Point Member resulting from these collections thus far. The first is a hybodont shark, *Lissodus* n. sp., based on two diagnostic teeth and several dorsal fin spines. This new species is the largest recorded North American *Lissodus* known and the first record of the group from the Moenave Formation. The second new species is based on an isolated tooth plate from the lungfish we name *Ceratodus* n. sp. This specimen is the first record of dipnoans from the Moenave Formation. Thousands of additional specimens are in the preliminary stages of preparation, and include many bones of a large *Chinlea*-like coelacanth, potentially a new species. This is the first record of a coelacanth from the Early Jurassic in western North America and the largest freshwater coelacanth on record worldwide.

The Hettangian-age Moenave fish fauna, or “Lake Dixie Assemblage”, includes a similar array of fish types at both the genus and family taxonomic levels as seen in the Late Triassic. However there is a noticeable decline in diversity across the Triassic Jurassic boundary and the “Lake Dixie” fishes are distinct species. Other differences include the absence of the lungfish *Arganodus*, and the appearance of *Ceratodus* in the southwestern US. There is also a big size increase in semionotids and a reduction in paleoniscoid diversity.

The “Kayenta Assemblage” is the youngest fish fauna in this study and includes Sinemurian and possibly Pliensbachian age fishes found in both lacustrine and fluvial deposits. The Kayenta Assemblage is similar to the Lake Dixie Assemblage, although the Kayenta Formation shows even lower diversity. This low diversity is most likely due to collecting bias. Future discoveries will probably reveal more diversity in the Moenave and Kayenta fish faunas.



FIRST REPORTS OF A LARGE COLLECTION OF WELL-PRESERVED DINOSAUR SWIM TRACKS FROM THE LOWER JURASSIC MOENAVE FORMATION, ST. GEORGE, UTAH: A PRELIMINARY EVALUATION

MILNER, ANDREW R.C., St. George Dinosaur Discovery Site at Johnson Farm, City of St. George, 2180 East Riverside Drive, St. George, UT 84790 (andrew@hanmansfossils.com); **LOCKLEY, MARTIN G.**, University of Colorado at Denver, P.O. Box 173364, Denver, CO, 80217; **KIRKLAND, JAMES I.**, Utah Geological Survey, 1594 West North Temple, Suite 3110, P.O. Box 146100, Salt Lake City, UT 84114-6100; **MICKELSON, DEBRA L.**, University of Colorado at Boulder, Department of Geological Sciences, 399 UCB, Boulder, CO 80399; and **VICE, GARRETT S.**, Physical Sciences, Southern Utah University, Cedar City, UT 84720

A large and exceptionally well-preserved collection of Early Jurassic dinosaur swim tracks attributed to the ichnogenus *Characichnos* are preserved as natural casts, at the St. George Dinosaur Discovery Site at Johnson Farm (SGDS) within St. George city limits. Approximately 3000 individual claw marks, mostly in sets of three, represent many small swimming theropod dinosaurs. Size ranges and morphology are consistent with the Early Jurassic theropod *Megapnosaurus* (formerly *Syntarsus*) or a *Megapnosaurus*-like dinosaur. High track density and parallel walking and swim tracks from SGDS provide evidence of gregarious behavior among small theropods in a lake margin setting (Lake Dixie). Similar evidence from gregarious behavior is known from several other Late Triassic-Early Jurassic track and bone sites located worldwide.

Eubrontes-type tracks are also abundant at SGDS. The track makers were probably responsible for several larger swim tracks, some found *in situ*, among the smaller *Characichnos* swim tracks. A *Dilophosaurus*-like theropod dinosaur is considered the most likely producer of *Eubrontes* tracks and the larger swim tracks. Tridactyl *Eubrontes*, *Grallator*, and a single *Batrachopus* footprint, occur amongst the swim tracks, in the “Johnson Farm Main Tracklayer”. Abundant invertebrate feeding traces and burrows indicate organic-rich, well-oxygenated sediments within the upper few centimeters of mudstone directly below the infilling sandstone unit of this “Main Tracklayer”. These invertebrates were probably all detritus feeders, represented tentatively by the ichnogenus *Scoyenia*.

Well preserved sedimentary structures such as mud cracks, microbial mats, rip-up clasts, cross-bedding, flute, groove and load casts, tool marks, rotational features, current ripples, and extensive scouring, in association with dinosaur swim tracks, assist in reconstructing the paleodepositional and paleoecological events. Simultaneous formation of tracks along with rapid burial of the traces and other surface features by wave-induced long shore currents has resulted in exceptional preservation of skin impressions, scale scratch lines, and other fine details.

Swim track patterns suggest that hundreds of theropod dinosaurs were swimming and/or floundering against a mild long-shore current directed from the south to the north. The majority of animals were buoyed up and swimming against this current in a southerly direction parallel to the paleo-shoreline.

Different modes of track preservation, other sedimentary structures and invertebrate traces indicate that mosaics of paleoenvironmental conditions are represented on the same bedding surface.



GIGANTIC THEROPOD FOOTPRINTS FROM THE HETTANGIAN OF POLAND (poster)

NIEDZWIEDZKI, GRZEGORZ, Department of Zoology, Warsaw University, Banacha 2, PL-02-097 Warszawa, Poland; **GIERLIŃSKI, GERARD**, Polish Geological Institute, Rakowiecka 4, PL-00-975 Warszawa, Poland; and **PIENKOWSKI, GRZEGORZ**, Polish Geological Institute, Rakowiecka 4, PL-00-975 Warszawa, Poland

Gigantic theropod footprints were discovered in the Hettangian deposits of the Holy Cross Mountains (Poland). This discovery provides ichnological evidence for the global occurrence of gigantic predatory dinosaurs in the earliest Jurassic time.

The large theropod tracks identified in Poland came from the well-known Early Hettangian track site at Soltykow. The Soltykow outcrop represents a siliciclastic coal-bearing lithofacies association of a fairly well-watered alluvial plain. Concerning the age of deposits exposed in Soltykow, floral remains point to the earliest

Jurassic (Liassic alpha 1-2), while sequence stratigraphic correlation allows its age range to be narrowed to the Early Hettangian (*Planorbis* biochronozone).

Hitherto, seven specimens of gigantic theropod *Eubrontes*-like footprints (50-65 cm long) were found in this track site. Another large theropod footprints (30-45 cm) identified at Soltykow, resemble *Kayentapus*-like ichnoforms and classic ichnotaxa of the Newark Supergroup (i.e., *Eubrontes giganteus sensu* Olsen et al. 1998). These intriguing gigantic ichnites are more similar to large prints left by Late Jurassic theropods than to those from the Early Jurassic. These footprints seem even larger because of their large metatarsophalangeal area. Relatively large metatarsophalangeal area is observed in the large theropod footprints from the post-Liassic strata, such as *Eubrontes glenrosensis* and/or *Megalosaurus sensu* Lockley et al. 1996, 1998.



NEW MATERIAL OF *REVUELTOSAURUS CALLENDERI* AND ITS IMPLICATIONS FOR THE IDENTIFICATION OF EARLY ORNITHISCHIAN DINOSAURS

PARKER, WILLIAM G., Division of Resource Management, Petrified Forest National Park, Box 2217, Petrified Forest, AZ 86028 (William_Parker@nps.gov), **IRMIS, RANDALL B.**, Petrified Forest National Park and University of California Museum of Paleontology, 1101 Valley Life Sciences Building, Berkeley, CA 94720 (irmis@berkeley.edu), **NESBITT, STERLING J.**, American Museum of Natural History, Central Park West at 79th Street, New York, NY 10024 (sjn2104@columbia.edu), **MARTZ, JEFFREY W.**, Department of Geosciences, Texas Tech University, Lubbock, TX 79401 (lnjeff@yahoo.com); and **BROWNE, LORI S.**, Museum of Geology, South Dakota School of Mines and Technology, 501 East Saint Joseph Street, Rapid City, SD 57701 (lsb77@hotmail.com)

Discovery of new cranial and postcranial material of *Revueltosaurus callenderi* from the Upper Triassic Chinle Formation of Petrified Forest National Park, Arizona clearly demonstrates that *Revueltosaurus* is not an ornithischian dinosaur as previously supposed. Features such as the presence of a postfrontal, crocodile-normal ankle, and paramedian osteoderms with anterior bars place *R. callenderi* within the Pseudosuchia, closer to crocodylomorphs than to dinosaurs. Consequently, the dental characters previously used to place *Revueltosaurus* within the Ornithischia evolved convergently among other archosaur taxa, and cannot be used to diagnose ornithischian dinosaur teeth. As a result, all other putative North American Late Triassic ornithischians, which are all based exclusively on teeth, cannot be unquestionably assigned to that taxon. The only reasonably well-confirmed Late Triassic ornithischians worldwide are *Pisanosaurus mertii* and an unnamed heterodontosaurid from Argentina. This suggests that at least in North America, theropods were well-established much earlier than ornithischians with the earliest confirmed ornithischian being *Scutellostaurus* from the Jurassic Kayenta Formation. Presently, material from *Revueltosaurus* and other closely related taxa has also been recognized from several localities outside of Petrified Forest National Park, including the Bull Canyon Formation in New Mexico and the Pekin Formation in North Carolina. Thus, this previously unrecognized clade of presumably herbivorous pseudosuchians has a widespread distribution during the Late Triassic.



ICHTHOLOGICAL DIVERSITY IN THE EARLY JURASSIC OF THE CONNECTICUT VALLEY, EASTERN NORTH AMERICA.

RAINFORTH, EMMA C., Ramapo College of New Jersey, 505 Ramapo Valley Rd., Mahwah NJ 07430 and Lamont-Doherty Earth Observatory of Columbia University, 61 Rt. 9W, Palisades NY 10964; (201) 684-7209 (erainfor@ramapo.edu)

The Connecticut Valley of Massachusetts and Connecticut yielded the earliest-discovered fossil footprints from the United States, published on extensively by Edward Hitchcock between 1836 and 1865. This founding father of ichnology amassed a stunning collection, still housed at Amherst College, forming the basis of taxonomic works in which he named and renamed over 90 genera and 200 species, in a total of 281 combinations. Navigating the nomenclatural maze, only about 20 genera and 10 species are actually invalid. However, detailed taxonomic studies allow subjective synonymization of many of these taxa. In addition, the ichnotaxa can be broadly grouped

into two categories – Hitchcock’s Pachydactyli and Leptodactyli (broad and thin-toed prints respectively). The Pachydactyli are footprint taxa with distinct phalangeal pad impressions; associated features of the footprints (e.g. scale impressions) and substrate (e.g. raindrops) indicate that many of these taxa represent “true tracks” or, at worst, very shallow underprints. As such, they allow a detailed picture of the track maker’s pedal anatomy to be obtained. In contrast, the Leptodactyli are taxa with narrow digits, usually lacking phalangeal pads impressions, and in many cases include footprints penetrating multiple layers. Where a three-dimensional view is obtained, it can be seen that the morphology varies vertically (typically digit divarication decreases downwards). The morphology of the Leptodactyli is thus heavily influenced by the substrate conditions (apparently, surfaces that were not microbially bound) and kinematics of foot emplacement and withdrawal. Pedal anatomical details (beyond “number of toes”) are not ascertainable, and thus track maker affinity not determinable at high taxonomic resolution.

In order to gain insight into the tetrapod components of these Early Jurassic ecosystems, in which identifiable skeletal remains are rare, the pachydactylous taxa are clearly of greater use. With subjective synonymization of the Pachydactyli, we find the following morphotypes to be commonly represented: *Anomoepus* (ornithischian), brontozoids (*Grallator*, *Eubrontes*, etc.; theropods), *Otozoum* (prosauropod), and *Batrachopus* (crocodylomorph); prints attributable to lacertilians and amphibians are rare or absent. Of these four groups, the brontozoids are the most diverse ichnotaxonically at both genera and species levels; a case can be made for reducing the number of currently-valid genera from eight to one, although species-level analysis remains to be undertaken. Ongoing refinements in lithostratigraphic correlation and high-resolution stratigraphy are providing a framework on which detailed biogeographic and biostratigraphic analyses can be conducted.



WAY OUT WEST: JURASSIC TRACKS ON THE CONTINENTAL MARGIN

REYNOLDS, ROBERT E., LSA Associates, Inc., 1650 Spruce Street, Ste. 500, Riverside, CA 92507
(Bob.Reynolds@lsa-assoc.com)

Recent research in the Aztec Sandstone of the Mescal Range of California’s eastern Mojave Desert has resulted in the recognition of tracks left by three different quadruped groups. The quadruped tracks studied can be grouped by equidimensional (five ichnotaxa), elongate (two ichnotaxa), and gracile (one ichnotaxa), and secondarily by length/width ratios. The equidimensional suite plots as five groups when considering size and $L < W$, $L = W$, and $L > W$: *Navahopus* (two groups) versus *Brasilichnium* (three groups), the Mescal Range *Navahopus* differing morphometrically from *Brasilichnium*. Trackway panels demonstrate fluctuation of *Brasilichnium* morphometrics suggesting changes in consistency of substrate. The elongate group is morphometrically divisible into two unnamed categories of different length and morphology. A fifth type of track with gracile morphology may represent *Rhynchosauroides*.

Seventy percent of the tracks in the Mescal Range occurrence were left by quadrupeds; bipeds account for thirty percent. Size and symmetry of two bipeds compare with *Anchisauripus* and *Grallator*. A third, unnamed, bipedal track is symmetrical, with wide digit divarication and phalanges joined at a common webbed pad. Conservatively, the Mescal Range Aztec Sandstone contains tracks representing three bipedal theropods and eight quadrupeds. Additional ichnites attributed to invertebrates include *Octopodichnus*. Impressions of horsetails (*Equisetum*?) have been found in the graywacke.

Compression rings around tracks show paleo-slope orientation. Cross-bedding, ripple marks and raindrops are present, and cubic pseudomorphs suggest primary halite, while limonite concretions represent weathering profiles. Folded strata, secondary druzy quartz, irregular goethite stains, and liesegang weathering rings attest to a long sequence of deformation and weathering.

The Mojave Desert of southern California contains sediments and ichnites that can be compared to mid-continent occurrences. The Aztec Sandstone type section at Goodsprings, Nevada is 2100 feet (636 m) thick. The Aztec in the Mescal Range contains an abbreviated sequence of 1000 feet (303 m), and differs from the Nevada section by becoming siltier upsection, with arenaceous beds being replaced by red silty sandstones followed by graywacke, and overlying Mountain Pass Rhyolite. The Aztec also crops out west of the Mescal Range, in the Cowhole, Soda, and Ord Mountains between Baker and Victorville, Ca. The Cowhole volcanics that intrude and overlie the Aztec in the Cowhole Mountains date between 170 and 173 Ma, suggesting that the Aztec is younger than the Navajo Sandstone.

Resource management in the Mescal Range by volunteers, BLM, and NPS personnel has resulted in the location by UTM coordinates of 116 outcrops, panels, and slabs. BLM rangers patrol weekly and researchers conduct inventory four times a year.



WAY OUT WEST: PTEROSAUR ICHNITES IN THE MESCAL RANGE, MOJAVE DESERT, CALIFORNIA

REYNOLDS, ROBERT E., LSA Associates, Inc., 1650 Spruce Street, Ste. 500, Riverside, CA 92507 (Bob.Reynolds@lsa-assoc.com); and **MICKELSON, DEBRA L.**, Department of Geological Sciences, University of Colorado at Boulder, UCB 399, Boulder, CO 80399 (Debra.Mickelson@Colorado.edu)

A pterosaur trackway is described from exposures of the Aztec Sandstone Formation (late-Early Jurassic) of the Mescal Range, eastern Mojave Desert, California. The trackway preserves seven consecutive steps, repeated over a distance of 80 cm. The distinctive tracks have manus and pes morphologies similar to known early-Upper Jurassic *Pteraichnus* track localities from the modern Western Interior. The formation commonly produces vertebrate ichnites of *Brasilichnium* (a typical quadruped ichnite), and associated invertebrates trace fossils of burrowing annelid worms (*Skolithos*) and arachnids (*Octopodichnus*). The tracks are preserved as negative relief impressions in reworked, frosted, quartz arenites. The Aztec Sandstone in the Mescal Range is younger than 173 Ma, and the *Pteraichnus* tracks described here represent the westernmost known North American occurrence of this ichnogenus.

The described trackway contains side-by-side configurations of complete “sets” of manus and pes. The dimensions of the manus (4.2 x 2.5 cm) and pes (4.2 x 2.8 cm) compare well with *Pteraichnus* ichnites from other late-Lower to early-Upper Jurassic outcrops. The manus impressions are approximately twice as long as wide, with a sinusoidally convex medial margin and one or two lateral projections and a posterior projection on the exterior margin. The pes is subtriangular, the apex consisting of the tarsals. Although poorly defined, the four digits have a divarication of 25°.

In general, the Mescal Range tracks compare favorably to all other pterosaur track localities identified from the Western Interior of the North American continent, ranging from northern Arizona, throughout Utah, central and western Colorado, central and northern Wyoming and northeastern Oklahoma. These localities range from late-Early Jurassic to early-Upper Jurassic in age. The formations were deposited during the final southern transgressive/regressive interval of the encroaching/subsiding Sundance Sea. The “*Pteraichnus* facies” provides regional temporal and spatial orientation in the Western Interior. Summarized in ascending stratigraphic order, these known localities are:

- Navajo Formation (late-Early Jurassic) Utah (oldest record of the genus)
- Summerville Formation (late-Middle to early-Upper Jurassic) of Utah;
- Stump/Windy Hill Formations (early-Upper Jurassic) of Utah, Wyoming, and Colorado;
- Tidwell/Recapture/Lower Morrison Undifferentiated Members of the Lower Morrison Formation (early-Upper Jurassic) of Arizona, Colorado, Utah, and Oklahoma.



THE HITCHCOCK ENIGMA: FIRST FEATHERS OR ARTIFACTS?

SABATH, KAROL and **GIERLIŃSKI, GERARD**, Polish Geological Institute, Rakowiecka 4, PL00-975 Warszawa, Poland (karol.sabath@pgi.gov.pl; gierlinski@yahoo.com)

The Hettangian Portland Fm. of Massachusetts yielded numerous footprints studied by Rev. E. Hitchcock in the mid-19th century. A specimen originally interpreted by him as a sitting marsupial trace, and then as a track left by a squatting bird, was described as *Anomoepus major*. The holotype, AC 1/7, stored in the Amherst College, was studied almost a decade ago by one of us (GG) and reinterpreted as a trace left by a crouching theropod. Regular imprints within the abdominal impression resemble adjacent tufts of hair or feathers, each 1 cm long and 3 mm wide.

A feature expected for a marsupial or bird was surprising in a medium-sized Early Jurassic ceratosaurian theropod. The first announcement of the discovery of Early Jurassic feathers at the Continental Jurassic Symposium in Flagstaff (1996) preceded the publication of famous finds of feathered theropods from the Lower Cretaceous Yixian Formation of Liaoning, China. The Chinese material added plausibility to the idea of non-avian theropods having insulating cover of short brush-like semiplumes. Feather-like integumentary structures have been since found in various theropod taxa, including compsognathids and therizinosaurs, a group possibly very early separated from other saurischian lineages. Soft keratinous rods, resembling long unbranching feather shafts were even discovered in a ceratopsian ornithischian *Psittacosaurus*. Thus, the phylogenetic distribution of various feather-like integumentary structures among dinosaurs seems to indicate a fairly early origin of protofeathers, probably by the Late Triassic. Moreover, theropod sitting impressions with belly imprint similar to AC 1/7 were recently found in China and in Johnson Farm site near St. George, Utah.

Still, doubts about the nature of AC 1/7 linger on. Alternative explanations proposed for the regular wrinkles fringing the body impression claimed that an algal mat covered the mud, and the sitting animal caused a deformation of this organic film, producing folds mimicking feather imprints. Reexamination of the specimen in 2004 revealed no biogenic structures of the purported algal mat. The feather-like impressions surround only the abdominal imprint, and are absent from the edges of footprints. This selective presence of supposed feathers on the abdomen is difficult to explain, if they were to be an artifact due to the substrate surface properties.

Another interpretation suggests that the imprints are in fact drag marks left by scales. This interpretation, however, ignores the fact, that the “drag marks” are situated within the abdominal imprint and do not look like parallel scratches and are not separated from each other. They are also shorter than typical drag marks and have no terminal rims in close-up view.

Detailed photographs show instead the fine structure of the imprints along the belly, revealing its filamentous, brush-like structure. The repeating tufts resemble semiplumes of recent birds. Taphonomic experiments with various feathers, artificially impressed into a hardening substrate (fine sediment mixed with plaster of Paris) produced traces closely resembling those of the AC 1/7. The best results were obtained with semiplumes. Another experiment, with a duckling covered with juvenile plumage, produced a similar belly imprint in the muddy substrate.

Thus, the interpretation of AC 1/7 as a sitting dinosaur imprint with traces of protofeathers along its belly seems to best fit the morphology of the impressions and is consistent with known pattern of dinosaur phylogeny and timing of protofeather origins. Some 40 million years later, there were already fully developed *Archaeopteryx* feathers, with asymmetrical flight vanes and sophisticated barbs/barbules system.



TERRESTRIAL ECOSYSTEMS IN THE EARLY AGE OF DINOSAURS BASED ON ENERGY FLOW MODELS APPLIED TO DATA FROM WESTERN NORTH AMERICA

SHIBATA, KENICHIRO, Chiba University Graduate School of Science and Technology, Chiba 263-8522, Japan (kshibata@graduate.chiba-u.jp); **MATSUKAWA, MASAKI**, Department of Environmental Sciences, Tokyo Gakugei University, Tokyo 184-8501, Japan; **LOCKLEY, MARTIN G.**, Department of Geology, University of Colorado at Denver, Campus Box 172, PO Box 173364, Denver, CO 80127-3364, U.S.A.; and **MILNER, ANDREW R.C.**, St. George Dinosaur Discovery Site at Johnson Farm, City of St. George, 2180 East Riverside Dr., St. George, UT 84790 (andrew@hanmansfossils.com)

Ecosystem and environment existing on the earth's surface today have changed any number of times and have evolved past to present as a result of various factors. Therefore, to reconstruct the paleoenvironment and paleoecosystem, and to understand the formative process and the primary dynamic factors are a prerequisite for understanding the earth at present and in the future.

Paleoecosystems in the early “age of dinosaurs” in the Colorado Plateau region were reconstructed based on food-web and energy flow-modelings. Dinosaurs appeared in the Late Triassic and began to dominate in the Early Jurassic. Therefore, reconstructing Late Triassic to Early Jurassic paleoecosystems is important for considering the evolution of animal assemblages, including dinosaurs, and the evolution of ecosystems through time.

Footprints of dinosaurs, aetosaurs, small lizards, therapsids and other fossils occur from the Upper Triassic Chinle Group at the Peacock Canyon track site, New Mexico. This site is suitable for considering the ecosystem where dinosaurs had not yet dominated. Abundant footprints of theropod dinosaurs, primitive crocodilians, and other

terrestrial vertebrates from the Lower Jurassic Moenave Formation at the St. George Dinosaur Discovery Site at Johnson Farm, St. George, Utah are shedding light on an ecosystem where dinosaurs began to dominate. We tried to infer the energy-flow patterns of paleoecosystems based on three categories of transfer efficiency and food web-modeling. As a result, energy flow in paleoecosystems can be represented, and possible energy dynamics and population size for animals in each trophic level can be estimated and quantified in the study area.

The results are evaluated by comparison with those of other reconstructed paleoecosystems and modern ecosystems. It is inferred that differences in energy flow and population size between ecosystems are caused by differences in the types of ecosystem, the structures of the food web, and the metabolic rates of animals.

The energy flow and estimated population size suggest that a highly diverse reptile fauna in the Late Triassic changed to a low diversity fauna dominated by dinosaurs. Ecological pyramids based on productivities at each trophic level show that the ecological niche for herbivorous vertebrates was essentially empty in the Early Jurassic ecosystem. Thus, low diversity indices and the lack of herbivorous vertebrates indicate that there was a physically (and chemically) stressed ecosystem in the Early Jurassic.



A MORPHOMETRIC ANALYSIS OF SAMPLE VARIATION IN THE SKULL OF THE GHOST RANCH THEROPOD

SMITH, DAVID, University of Utah, Salt Lake City, UT; and **MERRILL, ALEXIS**, Brigham Young University, Provo, UT

It has been noted that most intraspecific theropod variation is concentrated within the facial bones of the skull. With this observation in mind, a morphometric analysis based on landmark data was undertaken to search for patterns of variation within the sample of upper Triassic theropods from the Ghost Ranch Quarry of northern New Mexico referred to *Coelophysis bauri*.

Landmark measurement data were collected from all of the skull specimens of *Coelophysis* known at the time plus a cast of the skull of *Megapnosaurus* (*Syntarsus*) *kayentakatae*. The raw data were then subjected to univariate, bivariate, and multivariate statistical analyses. Log-transforming the data did not improve the results. The univariate analysis consisted of size-distribution plots. The bivariate analyses were linear regressions of selected variables. Since the data were very highly correlated, a simple least squares regression was used. The multivariate analysis was a principal components analysis extracted from a correlation matrix. The use of a covariance matrix did not improve the results.

Although there was a considerable amount of taphonomic distortion, the analyses gave in many cases results that can be regarded as standard for theropods. The earliest region of the allometric trajectory was not captured, so the growth curve could be estimated using linear relations. The principal components analysis resulted in the first component being primarily a size vector and the second a contrast between the height and length of the snout. *Megapnosaurus* (*Syntarsus*) tended in general to have a higher, shorter snout than *Coelophysis*. One specimen, however, had similar facial proportions to *Megapnosaurus* (*Syntarsus*). This specimen was still referred to *Coelophysis* on the basis of morphological information.

The results of this analysis support the position that all of the skulls from Ghost Ranch can be referred to the single species *Coelophysis bauri*. This genus is distinct from *Megapnosaurus* (*Syntarsus*). The relationships of the factors obtained here are fairly typical for theropods despite the presence of considerable taphonomic distortion.



EARLIEST KNOWN DINOSAUR TRACKERS

STAKER, ALLAN R., 693 Front Range Road, Littleton, CO 80120 (allanoil@msn.com)

The earliest known “dinosaur trackers” scoured the hills of southern Utah many hundreds of years before dinosaurs were “discovered” and identified in the Mesozoic rocks of the West. A small, unremarkable panel of petroglyphs, located near the entry station to Zion National Park, may be one of man’s first attempts to communicate to others the fact that large, unidentified animals made tracks in the rocks of the surrounding area. At first glance the

petroglyphs appear to be similar to many hundreds of others left by the Native American People who occupied Southern Utah over the past several millennia. These petroglyphs include a primitive drawing of an animal, perhaps a mountain sheep, a spiral, and several figures which look very much like saguaro cacti or chicken tracks. But, with the recent discovery of a slab of rock, not far from the petroglyphs, along with several other outcroppings in the surrounding hills, which contain the unmistakable tracks of dinosaurs, another look at the meaning of the petroglyphs is in order. Upon close examination, the figures seem to tell a story of large animal tracks found in the near-by rocks. This discovery may confirm the theory that these early inhabitants of the area were indeed among the very first “dinosaur trackers.”



CORRELATION OF TRIASSIC/JURASSIC BOUNDARY STRATA OF NORTH AMERICA THROUGH PALEOMAGNETIC CHARACTERISTICS (poster)

STEINER, MAUREEN B., Dept. Geology & Geophysics, University of Wyoming, Laramie, WY 82071
(magnetic@uwyo.edu)

Two features of the paleomagnetic signature of the Early Jurassic have stratigraphic correlation and dating value. The first is a global feature, a relatively lengthy normal polarity interval of geomagnetic field; normal polarity characterizes the latest Late Triassic (probable late Rhaetian) through early Hettangian time. Various considerations suggest that the time duration of this normal polarity is approximately 2 m.y.

The second paleomagnetic feature is peculiar to North America: a very abrupt change in the direction of apparent polar wander (APW) occurs in close proximity to the Tr/J boundary. Detailed magnetostratigraphic sampling in Early Jurassic strata at Kanab show progressive small eastward increments of apparent pole position through the Dinosaur Canyon and Whitmore Point Members of the Moenave Formation, a continuation of the same APW path observed during the Late Triassic. Above the Whitmore Point, an abrupt reversal in paleopole motion in the overlying Springdale Sandstone terminates that eastward progression of paleopoles.

The abrupt change in paleopole position and apparent polar wander direction implies a hiatus between the Whitmore Point and Springdale Sandstone Members of the Moenave Formation. Moreover, a channeled surface with appreciable relief is present between the highest Whitmore Point and lowest Springdale Sandstone strata. The end of the eastwardly progression of the paleopoles occurs at the end of the Whitmore Point record, thus at the end of the Early Hettangian.

The lowest Springdale strata not only display a change in APW direction and paleopole that is west of those of the two Moenave members below, but also present a gap in the APW path between the highest Whitmore Point and lowest Springdale poles. An unconformity and hiatus are inferred from these data. The normal polarity bias also terminates at the beginning of Springdale deposition. Lack of detailed time markers allows only approximate estimation of the duration of the hiatus; comparison with global and local magnetostratigraphic records suggests that it could be as much as 10 m.y.

Based on the different paleopole positions and abrupt change in direction of APW, the Springdale Sandstone is clearly of a different age than the Dinosaur Canyon and Whitmore Point Members of the Moenave Formation. Consequently, the Springdale Sandstone should be removed from member status within the Moenave Formation.



LITHOSTRATIGRAPHY OF THE DINOSAUR CANYON MEMBER, MOENAVE FORMATION, IN NORTHERN ARIZONA AND SOUTHERN UTAH (poster)

TANNER, LAWRENCE H., Department of Geography and Geoscience, Bloomsburg University, Bloomsburg, PA 17815 (lhtann@bloomu.edu); and **LUCAS, SPENCER G.**, New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM 87104

Stratigraphic nomenclature in use currently assigns the Moenave to the Glen Canyon Group and subdivides the formation into the Dinosaur Canyon, Whitmore Point, and Springdale Sandstone members, in ascending order. Over most of its outcrop belt, the Moenave Formation overlies the Owl Rock Formation of the Chinle Group with pronounced unconformity and is overlain disconformably, in turn, by the Kayenta Formation (Glen Canyon Group). The Wingate Formation, which is exposed to the east of the Moenave Formation outcrop belt, is considered a partial lateral correlative of the Dinosaur Canyon Member as the two units intertongue to some degree. The Wingate Formation conformably overlies the Rock Point Formation of the Chinle Group, and the physical stratigraphy of the units measured in this study indicates that the Rock Point Formation also underlies the Dinosaur Canyon Member in part of the study area.

We measured stratigraphic sections at numerous localities along the Moenave outcrop belt in northern Arizona and southern Utah of the entire thickness of the Dinosaur Canyon and Whitmore Point members, from the basal unconformity on the Owl Rock Formation to the overlying Springdale Sandstone (or the erosional contact with the Kayenta Formation where the Springdale was not present). In general, the Dinosaur Canyon strata in these sections comprise sandstones with traction ripple lamination, small-scale trough wedge sets, and planar-tabular bed sets, rippled to laminar to massive siltstones, and minor mudstones. Sandstones interpreted as water-deposited have bases with little or no erosional relief, small-scale trough cross-beds, are locally pebbly, and display climbing ripples, and ripples with mud drapes, in tabular beds. Siltstone occurs mostly in blocky weathering beds in which bedding is crudely laminar to obscure, although thin, ripple-laminated sandstones are interbedded locally. These facies are interpreted as the deposits of both channelized and unconfined (sheet) flow processes. Thick bedded sandstones with trough to planar-tabular sets, and large-scale, steeply dipping and sigmoidal cross-beds beds are interpreted as eolian dune deposits. Burrows occur in both water-laid and eolian sandstones and siltstones at several levels in the section, including bioturbated tetrapod track surfaces at several stratigraphic levels. Rhizoliths and root traces are confined to the tops of eolian dune bed sets. The proportion of eolian lithofacies increases greatly at the expense of water-deposited facies in a southerly direction along the outcrop belt, undoubtedly reflecting an increasing influence of the Wingate erg during deposition.



LOWER JURASSIC THEROPOD TRACKS FROM THE UPPER KAYENTA FORMATION, RED CLIFFS RECREATION AREA, WASHINGTON COUNTY, UTAH (poster)

VICE, GARRETT S., Physical Sciences/Geology, Southern Utah University, Cedar City, UT 84720 (Vice5425@suuemail.net); **MILNER, ANDREW R.C.**, St. George Dinosaur Discovery Site at Johnson Farm, City of St. George, 2180 East Riverside Dr., St. George, UT 84790 (Andrew@hanmansfossils.com); and **LOCKLEY, MARTIN G.**, University of Colorado at Denver, P.O. Box 173364, Denver, CO 80217 (Mlockley@carbon.cudenver.edu)

An assemblage of ten theropod tracks has been discovered in the upper Kayenta Formation in the Red Cliffs Recreation Area, Washington County, Utah. The locality has two track horizons containing two varieties of tracks, *Kayentapus* and *Grallator*. Within the top horizon there are eight *Kayentapus* tracks and a single *Grallator* track; all occur as molds in a reddish-orange very fine- to fine-grained sandstone unit. The lower horizon has one mold of a *Kayentapus* track in a reddish-orange fine to medium grained sandstone. The *Kayentapus* tracks range in size from 22 cm to 30 cm long, 18 cm to 25 cm wide, and 0.5 cm to 2.5 cm deep and occur as isolated foot prints. The sole *Grallator* track measures 10 cm long by 9.5 cm wide by 0.8 cm deep. The tracks have no discernable direction of travel and no well-preserved trackways are evident at either track horizon.

Regionally, upper Kayenta beds were deposited in eolian, fluvial, distal fluvial/playa, and minor lacustrine environments. The beds consist of alternating siltstone, mudstone, and fine- to medium grained sandstones. The upper track horizon is comprised of a 30 cm thick bed of very fine- to fine-grained sandstone representative of a

distal fluvial/playa environment. The lower horizon is made up of a 50 cm thick bed of fine- to medium grained sandstone representative of an eolian depositional environment. Directly underneath the upper track horizon is a 30 cm ledge composed of medium grained cross-bedded sandstone. Above it is a 1 m thick, slope forming reddish-brown mudstone and siltstone. The lower track horizon overlies a thin bed of siltstone and mudstone and is covered by a 35 cm thick, fine grained sandstone.

Theropod dinosaur tracks (*Grallator*, *Eubrontes* and *Kayentapus*) are very abundant in the upper Kayenta and the Kayenta-Navajo transition zone in most of south-eastern and south central Utah, where they also occur with *Otozoum* and *Anomoepus* (representing the tracks of herbivorous dinosaurs). The discovery of tracks at Red Cliffs indicates that this zone is also track rich in south-western Utah.



WILL THE REAL *POSTOSUCHUS* PLEASE STAND UP? *POSTOSUCHUS KIRKPATRICKI* AND THE END OF AN ERA (not presented)

WEINBAUM, JONATHAN C., Dept. of Biological Sciences, Texas Tech University, Lubbock, TX 79409-3131

The Triassic-Jurassic boundary was marked by distinct faunal and environmental change. The dominant terrestrial, archosaurian predators such as *Postosuchus kirkpatricki* represented the last of its kind and along with many contemporaries, faced an abrupt extinction at the end of the Triassic. Many workers have suggested that rauisuchids such as *Postosuchus* lost their niche to large theropod dinosaurs due to inadequate locomotory or metabolic adaptations. Current research indicates that this is unfounded and that theropods replaced rauisuchids only as a consequence of the mass extinction that took place at the close of the Triassic.

The preparation of the type and paratype *Postosuchus* material along with the study of *Postosuchus* and other fossil archosaur material in several museum collections has revealed formerly unknown and unexpected details of the anatomy of this animal. This includes verification of a bipedal gait, and specific characters of the skull, braincase, and postcranial skeleton that link rauisuchids and crocodylomorphs. Also of interest is the amazing convergence between rauisuchids and theropod dinosaurs. This convergence has caused prior workers to confuse the understanding of phylogenetic relationships among the pseudosuchian archosaurs. The current research indicates a sister-group relationship between rauisuchids and crocodylomorphs, and that *Postosuchus* was an extremely successful and well-adapted predator that existed for millions of years.



MORPHOMETRIC ANALYSIS OF DINOSAUR FOOTPRINTS – SOME PRELIMINARY RESULTS

WRIGHT, J.L., MORAVEC, B.G., Department of Geography, Geology and Environmental Science, University of Colorado at Denver, Denver, CO 80217; and **SPENCER, M.A.**, Department of Anthropology, Arizona State University, Tempe, AZ 85287

The problem of consistent differentiation between such Late Triassic/Early Jurassic ichnogenera as *Grallator*, *Anchisauripus*, *Anomoepus* and *Atreipus* has long been recognized. Previous attempts to define morphometric fields for such ichnotaxa have either been inconclusive, or initially promising methods or parameters have subsequently proved inconclusive with the application of a larger sample. This preliminary study explores the utility of two dimensional morphometric techniques in addressing this problem. Landmark analysis does not allow ichnotaxa to be differentiated but a combination of angular and linear data consistently distinguishes between *Grallator*, *Anchisauripus* and *Anomoepus*.



REFINEMENT OF CHINLE GROUP (LATE TRIASSIC) BIOSTRATIGRAPHY AND MAGNETOSTRATIGRAPHY, CHAMA BASIN, NEW MEXICO (poster)

ZEIGLER, KATE E., GEISSMAN, JOHN W., Dept. of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131; and **LUCAS, SPENCER G.**, New Mexico Museum of Natural History and Science, 1801 Mountain Rd. NE, Albuquerque, NM 87104

The Chama basin, north-central New Mexico, contains excellent exposures of Upper Triassic Chinle Group strata that can be used to refine Late Triassic vertebrate biostratigraphy and to develop an improved magnetic reversal chronology for the Late Triassic. Recent fossil discoveries have expanded the known fauna for both the lower Chinle Salitral Formation and the upper Chinle Mesa Montosa Member (Petrified Forest Formation). The addition of the metoposaurid *Buettneria* and the aetosaur *Desmatosuchus* to the Salitral fauna confirms an Adamanian age for these strata. The discovery of material pertaining to *Buettneria*, the aetosaurs *Typothorax coccinarum* and *Paratypothorax*, the archosaur *Vancleavea* and other fauna confirms a Revueltian age for the Mesa Montosa Member. Paleomagnetic sampling has been concentrated on mudrocks, using a block sampling approach. Block samples typically carry a well-defined, well grouped magnetization dominated by pigment hematite that is unblocked below about 660°C (e.g., for a single horizon, with six independent samples, Decl. = 185.5°, Incl. = 0.3°, α_{95} = 6.6°, and k = 102.6). Sandstones and siltstones contain pigment hematite and, based on preliminary experiments, contain both detrital hematite and some magnetite. An initial reversal chronology has been developed for Poleo and Petrified Forest strata (middle and upper Chinle Group) in the Chama basin. The Petrified Forest Formation is characterized by fairly regular reversals, and the Poleo Formation is dominated by reverse polarity.

NOTES

NOTES

NOTES

