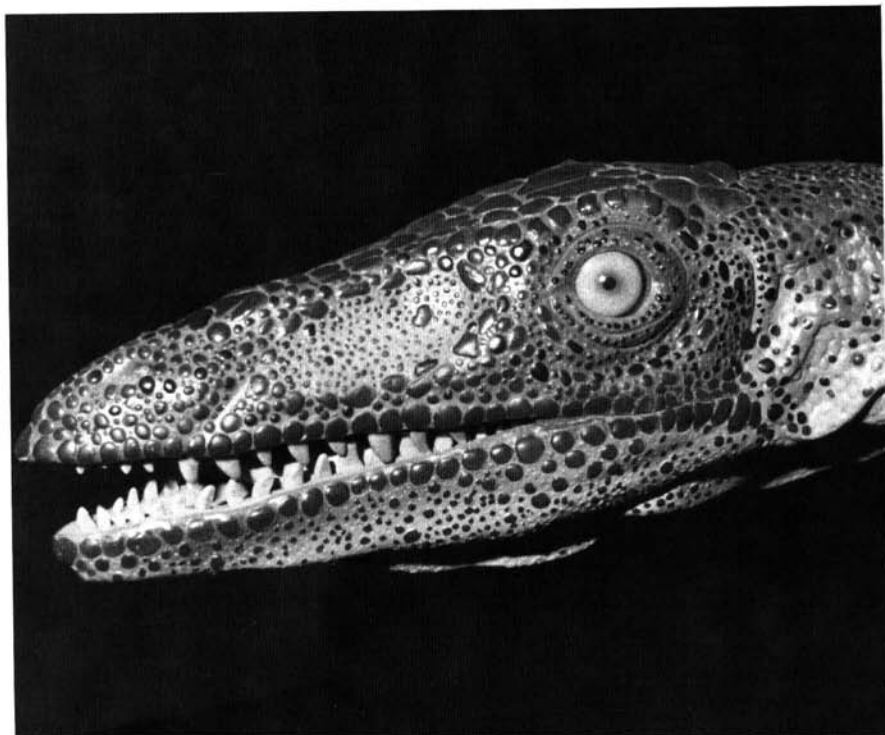


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THE GRATERFORD DINOSAURS: Tracking Triassic Travelers

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Paleontologists are often asked to identify a "dinosaur bone," "dinosaur egg," or "dinosaur track." More often than not, these turn out to be nothing more than a soup bone, concretion, or some nondescript sedimentary structure, much to the chagrin of the proud discoverer. On rare occasions, these finds are scientifically significant. Such is the case with the recent discovery of dinosaur footprints at the State Correctional Institution at Graterford, Pa.

DISCOVERY. Late in 1993, inmate Wayne Covington, an amateur archaeologist and paleontologist, accidentally discovered footprints in an outcrop of the Late Triassic Lockatong Formation, which was exposed in a ravine on prison property. Personnel at The State Museum of Pennsylvania were notified of the discovery, and together with a geologist from the Pennsylvania Geological Survey, they conducted a joint field trip to assess the site.

The Graterford site consists of several rock layers that crop out in two ravines. The surfaces of these rock layers occur within a 2-meter (7-ft) sequence and contain scattered fossil footprints of various sizes. These are trace fossils, or *ichnites* (from the Greek *ichno*, meaning trace or track). The footprints are oriented in various directions, and some trace the path of a single individual. A few of the footprints are superimposed on preserved mudcracks and ripple marks. The myriad of footprints, and the extent of the locality, make it the largest dinosaur trackway site ever discovered in Pennsylvania.

Two large trackway horizons were uncovered and removed for study and conservation. The largest measured over 6 m (20 ft) long and 3 m (10 ft) wide. Prior to removal, a grid system was outlined on the bedding surface using natural subparallel fractures as a guide. In order to preserve the integrity of the trackway, each grid unit was se-

quentially numbered so that the trackway could be easily reassembled back in the museum laboratory. The sections, measuring approximately 1 m (3 ft) square and 10 to 15 cm (4 to 6 in.) deep, were cut using a portable rock saw (Figure 1). Crowbars were then used to pry up and remove the trackway sections.

HISTORY. The occurrence of dinosaur footprints in eastern North America is not new or uncommon. The first historical account of fossil footprints is credited to a young boy named Pliny Moody, who discovered a series of footprints in 1802 while plowing a field in the Connecticut River valley (Hitchcock, 1858).

When the young Moody stumbled upon these tridactyl (three-toed) tracks, dinosaurs were completely unknown to humans. In fact, the first fossilized dinosaur remains (isolated teeth) were not discovered and described until 1822, by Gideon Mantell, and the comparative anatomist Sir Richard Owen did not coin the term “Dinosauria” (which means “terrible lizard”) until 1841. The distinctive three-toed tracks, although much larger, were similar in shape to those made by modern-day birds.



Figure 1. Using a cut-off saw, sections of the trackway were cut along a marked grid and were removed and taken to the museum to be studied.

Hence, they were considered by the common folk of the time to have been made by giant "poultry" or "Noah's Raven" (Hitchcock, 1858).

During the early and middle 1800's, thousands of Connecticut Valley footprints were discovered and became the subject of intense study by Rev. Edward Hitchcock, who published comprehensive accounts of these fossil tracks (Hitchcock, 1836, 1858, 1865). By the middle of the nineteenth century, over 21,000 footprints had been collected from various Connecticut Valley sites and were deposited in the Appleton Cabinet (now the Pratt Museum) of Amherst College in Amherst, Mass. (Hitchcock, 1865).

Hitchcock recognized that the footprints came from strata equivalent to the Liassic (Late Triassic) and Jurassic rocks of Europe and that these units occurred discontinuously in Massachusetts, Connecticut, New Jersey, Pennsylvania, Virginia, and North Carolina (Hitchcock, 1858). Hitchcock died not knowing that many of the footmarks he studied were made by prehistoric reptiles known today as dinosaurs.

For over a century, three-toed footprints were considered to have been made by dinosaurs that walked exclusively on their hind legs (obligatory bipedal dinosaurs). It was assumed that these dinosaurs walked solely on their hind legs because no manus prints (those made by the forelimbs) had been described in association with pes prints (those made by the hind limbs). Recently, Olsen and Baird (1986) reexamined a number of footprints from the Passaic and Lockatong Formations of the Jurassic-Triassic Newark Supergroup basins of New Jersey and Pennsylvania. They noted tridactyl manus impressions associated with some of the footprints and concluded that these tracks were made by a facultative quadrupedal dinosaur (one that occasionally got down on all fours), rather than a bipedal dinosaur. These prints, which were previously named *Gigandipus?* (*Anchisauripus*) *milfordensis* (Bock, 1952), were reclassified and put into a new ichnogenus, *Atreipus*, and were considered to have been made by an ornithischian ("bird-hipped") dinosaur rather than a saurischian ("lizard-hipped") dinosaur (Olsen and Baird, 1986).

The morphology of the manus prints associated with some of the *Atreipus* pes prints seems to exclude *Atreipus* from the dinosaur order Saurischia, because these manus prints are characterized (in part) by having well-developed tridactyl impressions of digits II, III, and IV rather than digits I, II, and III (see the sidebar at the top of the next page on "Fingers and Toes," and Figure 2) as would be expected with

FINGERS AND TOES. Paleontologists and biologists have devised a convenient way of referring to the fingers of the forelimb and the toes of the hind limb. Fingers and toes are called digits, and each digit is composed of bones referred to as phalanges (singular, phalanx). The proximal phalanx (the one closest to the body of the animal) articulates with a metacarpal (if in the forelimb) or metatarsal (if in the hind limb). The number of phalanges of each digit varies by digit and by species of animal (Figure 2). Digits are assigned Roman numerals. In the forelimb, digit I is the pollex (thumb); in the hind limb, digit I is the hallux (large toe in humans). The next digit (next to the thumb or large toe) is II, and so on.

Paleontologists have ascertained that the phalangeal formula for primitive reptiles is 2.3.4.5.3 (Romer, 1956). That is, there are 2 phalanges in the pollex, 3 phalanges in the next digit, and so on. In saurischian dinosaurs, digit II is the longest; in theropod dinosaurs, digit I of the forelimb is either absent or reduced, digit IV of the forelimb is reduced or absent, forelimb digit III has reduced (short) first and second phalanges, and digit IV of the hind limb is reduced. The ornithischian dinosaurs are in part characterized by a reduced digit V composed solely of a small metatarsal (no phalanx) (Benton, 1990).

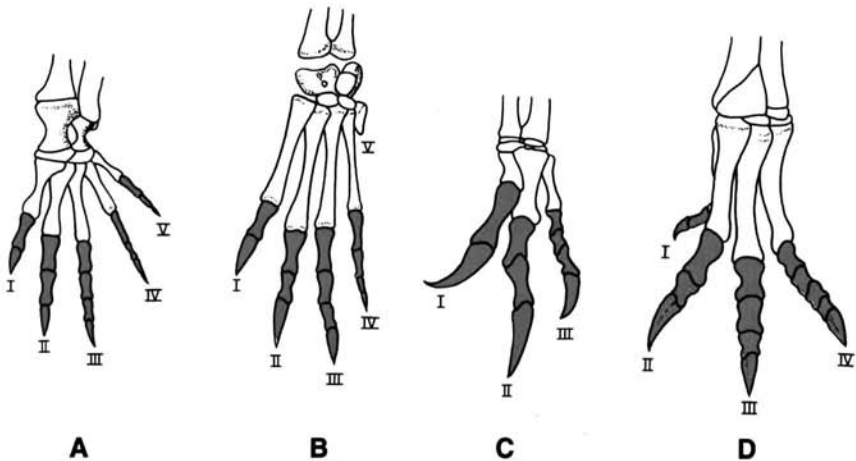


Figure 2. Manus (forelimb) and pes (hind limb) of the crocodile *Crocodylus* (A and B) and the theropod dinosaur *Allosaurus* (*Antrodemus*) (C and D) showing digits and phalangeal formulas (colored phalanges). (After A. S. Romer, *Osteology of the Reptiles*, University of Chicago Press. © 1956 by the University of Chicago. All rights reserved. Published 1956. Second impression 1968. Printed in the United States of America.)

theropod (advanced saurischian) dinosaurs (Olsen and Baird, 1986). However, there are other tridactyl pes prints that occur alone. Were these tracks made by a two-legged or a four-legged beast?

Surprisingly, the evidence is inconclusive for two reasons. First, the taxonomy of tridactyl footprints is confusing because a plethora of names has been given to the various similar prints. Second, the relationships of footprints to each other, and to the animals that made them, is far from certain.

Four ichnospecies of *Atreipus* are recognized in eastern North America (Olsen and Baird, 1986) and are similar to those named *Grallator* and *Anchisauripus*, which have been considered to be members of different ichnofamilies! *Grallator*-like footprints, and those currently called *Grallator* (*Grallator*) and *Grallator* (*Anchisauripus*), are still considered to have been made by Late Triassic obligatory bipeds like the well-known saurischian dinosaur *Rioarribasaurus* (= *Coelophysis*) (Lockley, 1991). Twelve ichnogenera have been recognized in the sedimentary rocks of the Newark basin, seven of which have been reported as occurring in the Lockatong Formation (Silvestri and Szajna, 1993).

THE GRATERFORD TRACKWAYS. At the Graterford site, three, or possibly four, distinct footprints have been uncovered, three of which can be attributed to dinosaurs. The smallest prints, which are nondinosaurian, measure no more than 2 cm (0.8 in.) in length. They are pentadactyl (five-fingered) in form and pertain to "lizard-like" footprints called *Gwyneddichnium* or *Rhynchosauroides* (not figured). The largest of the dinosaur pes prints, some of which are associated with tridactyl manus impressions, are considered *Atreipus milfordensis* and measure 15 cm (6 in.) in length (Figure 3). A few of these large prints are not associated with manus impressions and may belong to another ichnogenus called *Grallator* (*Anchisauripus*). Owing to variations in preservation, these prints may have, in



Figure 3. A pes print of the ichnotaxon *Atreipus milfordensis* from the Graterford site.

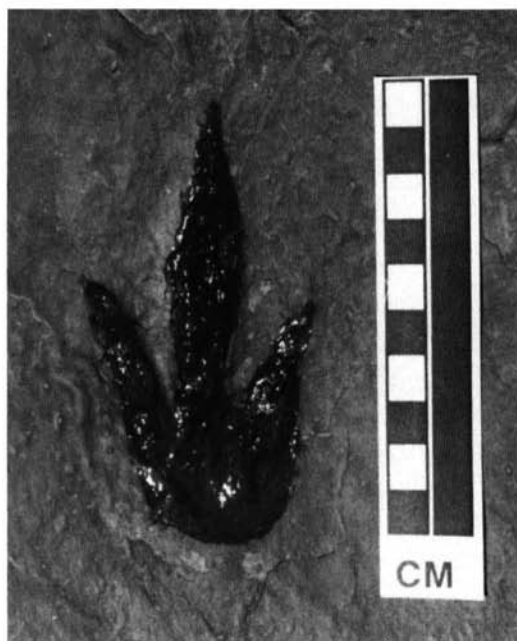


Figure 4. A pes print of the ichnotaxon *Coelosaurichnus* sp. from the Graterford site. Its occurrence in the Lockatong Formation extends the biostratigraphic range of the footprint earlier in time.

fact, been made by dinosaurs within the same taxon.

Of particular significance is the occurrence of the tridactyl dinosaur footprint referable to *Coelosaurichnus*. These pes prints measure 9 to 9.5 cm (3.5 to 3.7 in.) in length and have an elongated middle toe (digit III) with a digit divarication (angle formed between

two digits) of 28 degrees (Figure 4). If our identification of these prints is correct, this is the first occurrence of this ichnotaxon in the Lockatong Formation and is the oldest known occurrence of this footprint in the Newark Supergroup, based on data provided by Silvestri and Szajna (1993).

TRAVELING THE TRIASSIC TURNPIKE. What dinosaurs made these tridactyl footprints? We know that three-toed dinosaurs roamed between what is now the United States, Great Britain, and South Africa before the supercontinent of Pangaea began to break up some 220 million years ago. The skeletal remains of two relatively small and very closely related ceratosaur dinosaurs have been found on the continents of North America, Europe, and Africa. The saurischian dinosaur *Rioarribasaurus* is known from Late Triassic sediments of the southwestern United States. *Syntarsus* has been discovered in Late Triassic rocks of England and Rhodesia (Zimbabwe). It is also known from the Early Jurassic Kayenta Formation of Arizona and now appears to be present in the Late Triassic Rock Point Formation (Chinle Group) of New Mexico (Sullivan, in preparation). These dinosaurs



Figure 5. Pangaea during the Late Triassic. North America, Europe, and Africa were together, allowing for faunal interchange to occur between these geographic regions. (Modified from Spencer G. Lucas, *Dinosaurs: The Textbook*. Copyright © 1994 Wm. C. Brown Communications, Inc., Dubuque, Iowa. All rights reserved. Reprinted by special permission.)

are believed to be responsible for some of these tracks (see cover photograph).

The interchange of vertebrate life between these distant places was certainly not an uncommon event. During the Late Triassic, Pennsylvania, the southwestern United States, and Europe were all situated near the equator (Figure 5). As in the present, southern Africa was then geographically distant, yet land connected these vastly separated regions, allowing for faunal dispersal. Perhaps these dinosaurs wandered along the equatorial corridor, leaving their footprints in Pennsylvania. They continued to do so until the vast rift that ultimately became the Atlantic Ocean prevented their wanderings.

The discovery at Graterford provides new information concerning vertebrate life during the Late Triassic of Pennsylvania. Except for the discovery of a couple of ornithischian dinosaur teeth a hundred years ago (Hunt and Lucas, 1994), and isolated footprints occasionally observed in our state, direct evidence of dinosaur life has been conspicuously absent. The search continues for skeletal remains of the elusive Pennsylvania dinosaur.

We thank Wayne "Fang" Covington and Ahmed Sabur for preparing the trackway site and for their enthusiastic support and help in

this project. Thanks are extended to Robert Larkin, who brought the discovery to our attention; Superintendent Donald Vaughn, Deputy Superintendent Thomas Stachelek, and their staff at the State Correctional Institution, for allowing us to collect the Graterford footprints; and Dr. Hartmut Haubold (Geiseltalmuseum, Halle, Germany) for his discussions and insight on ichnite identifications.

NOTE: The Graterford locality continues to be an active research field site. Because of our ongoing research, and the fact that it is located on state prison property, only personnel authorized by the State Correctional Institution at Graterford are permitted on the grounds.

REFERENCES

- Benton, M. (1990), *Origin and interrelationships of dinosaurs*, in Weishampel, D. B., Dodson, P., and Osmólska, H., eds., *The Dinosauria*, Berkeley, University of California Press, p. 11–30.
- Bock, W. (1952), *Triassic reptilian tracks and trends of locomotive evolution*, *Journal of Paleontology*, v. 26, no. 3, p. 395–433.
- Hitchcock, E. (1836), *Ornithichology—Description of the foot marks of birds, (Ornithichnites) on new Red Sandstone in Massachusetts*, *American Journal of Science*, v. 29, no. 2, p. 307–340.
- _____ (1858), *Ichnology of New England, A report of the sandstone of the Connecticut Valley especially its fossil footmarks, made to the Government of the Commonwealth of Massachusetts*, Boston, William White, 199 p. [reprinted by Arno Press Inc., 1974].
- _____ (1865), *Supplement to the Ichology of New England, A report to the Government of Massachusetts in 1863*, Boston, White and Potter, 93 p.
- Hunt, A. P., and Lucas, S. G. (1994), *Ornithischian dinosaurs from the Upper Triassic of the United States*, in Fraser, N. C., and Sues, H.-D., eds., *In the shadow of the dinosaurs: Early Mesozoic tetrapods*, Cambridge, Cambridge University Press, p. 227–241.
- Lockley, Martin (1991), *Tracking dinosaurs—A new look at an ancient world*, Cambridge, Cambridge University Press, 238 p.
- Lucas, S. G. (1994), *Dinosaurs: the textbook*, Dubuque, Iowa, William C. Brown Publishers, 290 p.
- Olsen, P. E., and Baird, D. (1986), *The ichnogenus Atreipus and its significance for Triassic biostratigraphy*, in Padian, K., ed., *The beginning of the age of dinosaurs*, Cambridge, Cambridge University Press, p. 61–87.
- Romer, A. S. (1956), *Osteology of the reptiles*, Chicago, University of Chicago Press, 772 p.
- Silvestri, S. M., and Szajna, M. J. (1993), *Biostratigraphy of vertebrate footprints in the Late Triassic of the Newark basin, Pennsylvania: reassessment of stratigraphic ranges*, in Lucas, S. G., and Morales, M., eds., *The nonmarine Triassic*, Albuquerque, New Mexico Museum of Natural History and Science Bulletin 3, p. 439–445.