Paluxy River Field Trip Guidebook, 2009 American Scientific Affiliation Meeting

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Welcome to the geology field trip for the 2009 ASA meeting! This trip will go to Dinosaur Valley State Park (www.tpwd.state.tx.us/park/dinosaur/dinosaur.htm). Although there are a variety of interesting modern organisms, including the endangered golden-cheeked warbler that only nests in central Texas, the main reason for Dinosaur Valley State Park is the well-preserved dinosaur trackways in and along the Paluxy River. However, there are other aspects of the regional geology that we can observe as we travel.

What should you bring?

Looking at tracks in a river in the summer in Texas means that you need to be prepared for heat and water/mud. Sunscreen, water bottle, old shoes, maybe a swimsuit, sun hat, *etc*. are advisable. Since this is a park, there is fairly easy access to some of the main track sites, unlike some paleontology trips. On the other hand, this means that collecting should be done only with cameras. Glen Kuban's web site, http://www.paleo.cc/paluxy/paluxy.htm , is a very handy source of information and would be good to browse before the trip.

What geology can we observe on the way?

Last time I was on a geology field trip in the summer in Texas, the windows on the bus were so fogged up from the air conditioning that nothing could be seen. However, assuming we can see out the windows, the first impression is generally that we're looking at miles and miles of miles and miles (Sheldon, 1979). While we won't see anything dramatic, relatively subtle differences in topography and vegetation reflect differences in the underlying rock (as well as other factors). Although Texas has deposits ranging from the Precambrian to Recent, our entire trip will be over Cretaceous deposits. We start out in the upper Cretaceous at Waco (apart from the more recently deposited river sediments) and will be looking at lower Cretaceous beds at the park. The prairies on relatively soft upper Cretaceous rocks give way to hills as we head west. Hard limestone (especially the Edwards Limestone, Fredericksburg Group) forms the top of flat-topped hills, while softer marls and shales make up the lower slopes of the hills and the bottoms of the valleys.

How do we go from younger to older rocks by going uphill?

It's not my fault; it's the Balcones and Mexia-Talco fault zones. As sediment accumulated many miles deep to the east (from the Mississippi River system, among other sources), the rock layers bent and broke. To the east, the layers moved lower. Thus, what we see at the surface in Waco includes the upper Cretaceous Austin Chalk and Taylor Shale. Rock similar to what we see at the surface at the park is deeply buried further east. This affects not only the rock layers but also the water travelling through them. Limestone is made of calcium carbonate. If you ever made a baking soda-vinegar volcano, you know what carbonate does with acid. Rainwater is much less acidic than vinegar, but over time it can dissolve limestone, forming holes ranging in size from tiny spaces to vast caverns. Additionally, the limestone may have started out with holes in it from fossils or other features. As a result, limestone beds can typically hold a lot of water and let it move through relatively rapidly. At the faults, the limestone layers can be juxtaposed with other rock types that don't let the water through, making the water find an alternate route which may lead to the surface. This produces a number of springs along the fault line (Brune, 1981). However, the high human demand for water in the relatively dry local climate has led to depletion of some aquifers, and several historical springs have dried up. This is particularly bad for organisms that depend on springs, and several spring-living fish, crustaceans, and snails are known to be extinct; even many river-dwelling animals are severely imperiled or exterminated as a result of human impacts.

Further east, deep in the subsurface, some of these same rock layers have petroleum rather than water in the spaces. High demand has depleted that, too.

What do we see at the park?

The upper beds exposed in and around the park are part of the Paluxy Formation, the lowermost unit of the Fredericksburg Group. Underneath it is the Glen Rose Limestone, of the Trinity Group. The Glen Rose formation has a wide range of fossils in various areas, but is most famous for dinosaur footprints, especially those exposed by the Paluxy River at several places in the park. (Figure 1)

Although local residents had noticed them before (guessing that the large round prints might have come from mammoths), this tracksite was first studied in detail by Roland Bird in 1938 (Lockley, 1991). It is in the top of the lower Glen Rose Formation, about 110 million years old. Several additional sites in this layer or at the top of the upper Glen Rose Formation also have dinosaur tracks in central Texas, as do rare sites in the Paluxy and Edwards formations (Pittman, 1989; Hawthorne, 1990). Roland Bird initially began excavating large theropod (meat-eating) dinosaur footprints (up to about 60 cm long). Then he realized that the up to nearly 1 m long holes in the limestone where he had been dumping the dirt and mud were footprints of a large sauropod dinosaur (long-necked, long-tailed, giant plant eaters). Although Bird had looked at a site in Colorado with sauropod prints on his way to Paluxy, these were the first well-documented examples of sauropod prints. Further excavation (assisted by a Works Progress Administration team) revealed about 12 sauropod trackways and three theropod trackways, all headed in the same direction. Along with the nearby Davenport Ranch site, this was one of the first instances where it was suggested that dinosaurs often traveled in herds. Several hundred additional trackways are exposed along the river upstream and downstream from Bird's site, both in and outside the park. One local trail and a few elsewhere in Texas, as well as many from other parts of the world, are tracks of (at least sometimes) bipedal plant-eating ornithischian dinosaurs, but most reports from this area in fact are less well-preserved tracks of theropods. (Some ornithischian tracks are fairly similar to clawless versions of theropod tracks.)

Most of the best tracks are exposed in the river bed. Bird's WPA team built a temporary dam and excavated the area, but the park rules forbid excavating today. When the water level is low, as is typical for late summer, the tracks are generally well-exposed, but when the water is high, the best views may be in the visitor center. Additionally, old tracks are worn away and new ones exposed as the river continues to erode through the layers, so tracks mentioned in historical reports are not always easy to study today.

What made the tracks?

Unfortunately for studies of fossil footprints, it's rare for an animal to drop dead in its tracks and get preserved as a fossil. Although the general type of animal making a track is often obvious, the exact kind is often much harder to determine. Because of this, trace fossils get their own names. The name for the theropod track has been listed as *Eubrontes glenrosensis* or *Irenesauripus glenrosensis*, but Lockley (1998) argued that no current genus name applied well to *glenrosensis*. The sauropod tracks were officially named *Brontopodus birdi* (Kuban website). Nevertheless, we can speculate on likely trackmakers. Only one large meat-eating dinosaur is known from deposits of similar age in the general region (Oklahoma and Texas): *Acrocanthosaurus*. A skeleton was found very close to the park. Although nothing is known that would distinguish its footprints from those of similar dinosaurs, its feet are compatible with the tracks. It is the state dinosaur of Oklahoma, but the best specimen yet found is now on display at the North Carolina Museum of Natural Sciences (Fig. 2-3). It is an allosaurid or carcharodontisaurid and thus fairly closely related to some of the largest known meat-eaters, but relatively distantly related to *Tyrannosaurus*. Like a handful of other dinosaurs, it has rather tall spines on its vertebrae which presumably supported some sort of crest or hump. Similar teeth are known from as far east as Maryland, suggesting that *Acrocanthosaurus* was the dominant land predator in much of eastern North America in the early Cretaceous.

For the sauropod, the most likely culprit also comes from nearby deposits: *Paluxysaurus* (Rose, 2007) (Fig. 2, 4), although *Sauroposeidon*, a brachiosaur known from a neck from Oklahoma, is another possibility. Although *Paluxysaurus* was enormous by most standards, it was not exceptional for a sauropod. Other relatives, including *Sauroposeidon*, were much bigger.

Many sources cite *Pleurocoelus* as the sauropod, and it was designated the state dinosaur of Texas. However, this name was historically used as a wastebasket for any early Cretaceous (or even Jurassic) sauropod from North America. The original *Pleurocoelus*, from Maryland, is probably a synonoym of *Astrodon* (the state dinosaur of Maryland) (Carpenter and Tidwell, 2005). This is perhaps only fair, as Maryland's state fossil, a snail, was originally cited as *Ecphora quadricostata*, which is not found north of Virginia; the Maryland form is a different, older species. Regrettably, the name *Astrodon* was based solely on teeth. However, *Pleurocoelus*, based on assorted bones, has matching teeth and comes from the same beds. Other sauropods have similar teeth, making certainty difficult. A particular problem is that sauropod skulls have a bad habit of not being preserved with the rest of the body. This is probably because the skull is relatively small and lightweight in comparison to the massive limb bones and vertebrae. Nevertheless, existing pictures of *Pleurocoelus* are probably not far off the mark for *Paluxysaurus*. According to Rose (2007), it "differs from *Pleurocoelus* in the shape of the caudoventral margin of the maxilla, the shape of the distal scapular blade, and the shape of the proximal condyle of the tibia". This probably does not drastically alter the general appearance.

As a result of the description of *Paluxysaurus*, a bill was introduced to change the Texas state dinosaur. It was overwhelmingly passed in the House, aided by two politicians donning dino suits, despite the objection of one member who claimed that "the author cannot even spell or pronounce all the words in his resolution." (Funk, 2009) Action on this important issue in the Senate is still pending.

What didn't make the tracks?

A number of misconceptions have been associated with these tracksites. Relatively few good dinosaur bone sites are known from the lower Cretaceous of North America, and most of the major discoveries are very recent. As a result, the famous trackways from here are often associated with dinosaurs of other ages in displays. The two fiberglass models at the park were leftovers from Sinclair Oil's dinosaur exhibit at the New York World's Fair in 1964, *Apatosaurus* (aka *Brontosaurus*) and *Tyrannosaurus rex*. Timothy (age four), when asked if these belong in the lower Cretaceous, says "Nooooo!". (*Apatosaurus* is late Jurassic; *Tyrannosaurus* is latest Cretaceous.) Even the American Museum of Natural History originally used upper Jurassic species for their display with Cretaceous tracks collected from here by Bird. The new exhibit at the North Carolina Museum of Natural Sciences is closer to the mark with *Acrocanthosaurus* and "*Pleurocoelus*".

Beginning with Bird, the trackways have often been cited as showing evidence of predation. The three theropods did walk past not too long after the sauropod group, as shown by the superimposing of prints, but we can't tell how long after. The trackways in Texas are generally roughly parallel to the Cretaceous shoreline (Lockley, 1991) and probably represent a natural direction for travel, so the two groups may be coincidental. However, Bird thought that an apparently missing footprint from one of the theropod trackways represented a point when the predator had a foot off the ground as it attacked its intended prey. This scenario has been popular with illustrators and is reflected in the original AMNH exhibit and the current one in North Carolina; a painting at the park also depicts this. Lockey (1991), however, pointed out that the large tail of the sauropods would have interfered with the envisioned movement of the theropod. Also, the "missing" print would fall directly on top of a sauropod print, where the mud was already compacted. Another problem is that the sauropod track continues unchanged. Despite the relatively small brains of sauropods, it seems likely that they would respond to being attacked. If the theropods were tracking the sauropods, they probably stayed at a distance, at least while making these tracks.

Another unjustified claim about tracks in this area is that they show herding by sauropods with the smaller individuals kept protectively in the center. Although there are groups of footprints in central Texas in which animals of different sizes clearly made up a herd, if any pattern is present in these sites, it is that the large ones tended to be towards the front of the herd rather than surrounding the smaller ones (Lockley, 1991). It's certainly possible that herbivorous dinosaurs did use protective herding when attacked by predators, but there's not good evidence of that here.

Early thinking about giant sauropods tended to put them in the water, where their great bulk would be supported and the long necks might serve as snorkels. The discovery of these tracks suggested a more terrestrial environment than had been generally thought. Bird initially thought that the lack of tail drag marks suggested tails floating in shallow water, but modern thinking on sauropod biology has the tails kept off the ground as fairly stiff counterbalances to the long necks. Additionally, some of the trackways in this area have mud clumps that fell from the feet of the dinosaurs as they walked, which would not be formed under water. A nearby site, along with tracks from other parts of the world, features poorly preserved front footprints and poor to absent hind prints. These have been interpreted as prints from swimming dinosaurs; however, they more likely represent undertracks, impressions made in a layer below the actual surface stepped on (Lockley, 1991). Because the top layers of sediment would bear most of the dinosaur's weight, lower layers would have less of an impact. Sauropods had smaller front feet than hind feet (reflecting bipedal ancestors), so the front feet generally held more weight per unit area and often made deeper prints. The old idea of using the neck as a snorkel doesn't work because the water pressure that would be on the submerged body is much greater than atmospheric pressure and would prevent the lungs from expanding.

The footprints likewise help counter the old idea of dinosaurs as sprawling lizard-like walkers. In fact, many sauropods would require a conveniently-placed ditch for their bellies in order to hold their legs to the side in lizard fashion. What's more, their enormous weight requires pillar-like legs underneath the body, similar to those of large mammals such as elephants. Happily, the tracks and the engineering calculations match up-the hind feet in particular are fairly close together, under the body. As the models at the park date from the mid-1960's, they're rather more dumpy than modern reconstructions, and the tails would probably have been about parallel to the ground in life posture for most dinosaurs.

The tracks do tell us a lot about the behavior of the dinosaurs, however. For example, more widely spaced tracks indicate a faster gait; one track in the park shows fast running, about 30 mph (discovered by Glen Kuban, using formulas developed by R. M. Alexander). Dinosaurs sometimes slipped in the mud. Plant-eating dinosaurs often travelled in groups.

The trackways also have notoriety for their misuse by some advocates of a young earth (or old humanity, in the case of Hare Krishnas) for the supposed juxtaposition of human and dinosaur prints. Such claims were quite popular and widely invoked for a while, but now major young earth organizations have rejected them. A few people on the fringes still invoke them, however (see, *e.g.*, Carl Baugh's "Creation Evidence Museum" just south of the Park). Glen Kuban (an ASA Fellow), who began investigating the tracks as a young-earth advocate, has thoroughly documented the error of identifying any of the tracks here as human. Much detail about the tracks in general is available at his web site. In general, the "human" prints are too big to be human. Some are unusual dinosaur prints. In particular, dinosaurs, like birds and most running mammals, usually walked on their toes, with the foot bones functioning as part of the leg. (This is why it looks as though bird knees bend backwards-it's actually their ankles.) However, at least some theropod dinosaurs could put more of the foot –the whole metatarsal region, sole and heel, on the ground, making a much longer print (Figure 5) ("Toe bone connected to the foot bone, foot bone connected to the ankle bone"=phalanges connected to the metatarsals, metatarsals connected to the tarsals). Well-preserved prints of this sort conspicuously have three toes, but less distinct ones may be confused with a human-like print (wearing giant-sized moccasins). Erosion, mud squishing back in at the time of print formation, not quite as squishy mud making a shallower print, and other factors can make a print less like the idealized form. The Taylor site near the park has many metatarsal trackways that were later filled in with contrasting sediment, affecting their appearance. Other "human" prints are not true prints at all but merely erosional features that do not display the true contours of a footprint (*e.g.*, ball of the foot and heel lower and arch higher), or indistinct marks of unclear origin. Such features also do not form proper trackways. Selective moistening of such features, plus careful choice of camera angle, can produce a photo that looks much more like a footprint than the original. If that is not enough, there's always the option of carving something yourself. However, any attempt to carve a footprint ought to begin with some basic knowledge of the actual shape of a human foot such as the contour of its base and the position of toes. Additionally, carved footprints cut across the features of the rock. Carving footprints of various sorts to sell to tourists was practiced locally long before young earthers got interested in the site. The handful of examples of carved prints are in loose blocks, which further detract from their authenticity. On the other hand, seeing carved tracks for sale in New Mexico pointed Bird towards investigating this locality.

Today, you can put your footprint with replica tracks for comparison (Fig. 6).

What was the environment where the tracks were made?

The Glen Rose Formation near the park has some fossils of shallow-water marine animals. The habitat at the time of the tracksite formation seems to have been a carbonate-mud-rich coastal plain area, similar to modern southern Florida. Like many of the Cretaceous limestone layers in this part of the world, there is a gradation in habitat from offshore marine deposits, including coral/rudist reefs, through shallow water to intertidal deposits with ripple marks, footprints, plant fossils (notably cycads), and evaporitic minerals (mainly gypsum) and then a transition to non-marine sediment. Marine fossils from the Glen Rose include, besides the corals and rudists (bizzare, often giant bivalves, forming reefs in the Cretaceous), ammonites, oysters and other bivalves, gastropods, serpulid worms, crustacean burrows, fish teeth (one of which was publicized as a human tooth), echinoids, foraminifera, algae, brachiopods, and ostracods. Dinosaurs seem to have used the tidal flats as a convenient highway for traveling, presumably avoiding the trouble of walking through thicker vegetation inland. (Of course, there would be little chance for footprints to be preserved in such a habitat.) Similar behavior can be seen today; for example, in more remote parts of eastern North Carolina, bears often walk on roads instead of pushing through thickets.

In the Jurassic, the Gulf of Mexico opened up. When the Glen Rose Limestone was deposited, the coastline would have been roughly similar to today but much farther inland, with a bay covering the Big Bend area of southwest Texas. Later in the Cretaceous, the ocean extended through the present Great Plains region to the Arctic. The latitude in Texas was a little further south than at present due to plate tectonic motion, but the global temperatures were much warmer, so the climate would probably have been tropical to subtropical.

Other large reptiles from the Glen Rose Limestone and related deposits include a giant azhdarichioid pterosaur (the group including the largest flying animals ever), a large-clawed, medium sized theropod like *Deinonychus*, crocodiles, and the herbivorous ornithischian dinosaur *Tenontosaurus*. These are illustrated along with some younger forms from the same general area at http://www.texas-geology.com/Texas%20Cretaceous%20Hill%20Country%20and%20P%20Lakes.html .
However, the illustrations are not always based on the actual Texas forms; in particular, the "*Paluxysaurus*" appears to have longer front legs than hind legs, like a brachiosaur but unlike *Paluxysaurus* and most other sauropods.

References:
Web sites:
Dinosaur Valley State Park www.tpwd.state.tx.us/park/dinosaur/dinosaur.htm
Glen Kuban's Paluxy River dinosaur track web site http://paleo.cc/paluxy.htm
Cretaceous Texas reptile fossils: http://www.texas-geology.com/Texas%20Cretaceous%20Hill%20Country%20and%20P%20Lakes.html

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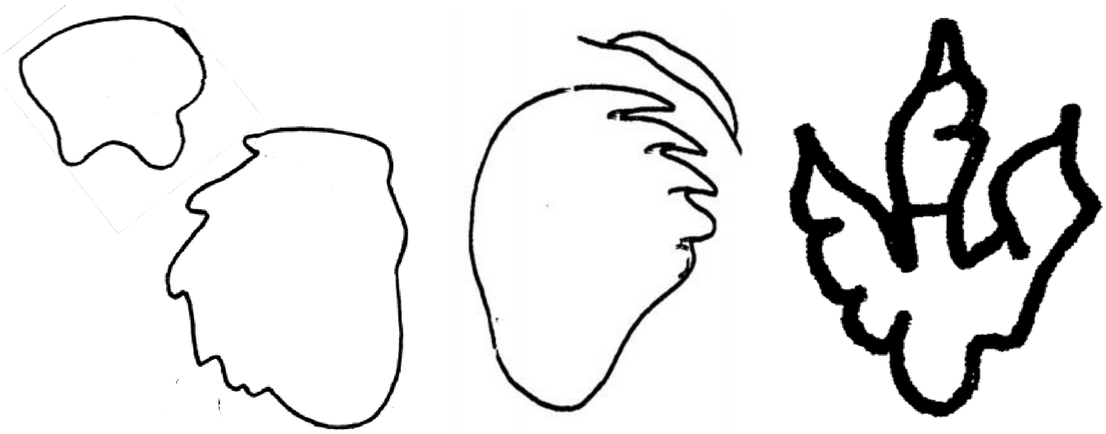

Figure 1. Sauropod (left, middle) and theropod (right) footprints. The left shows idealized complete prints, but often the hind foot stepped onto the front print, leaving just a crescent (middle) or entirely obliterating it. Redrawn after Lockley (1991); middle from Glen Kuban.

Figure 2. *Acrocanthosaurus* skeleton and *Pleurocoelus/Paluxysaurus* reconstruction, North Carolina Museum of Natural History (Susan Campbell, Elizabeth Monk). The reconstruction features some deconstruction by *Acrocanthosaurus*.

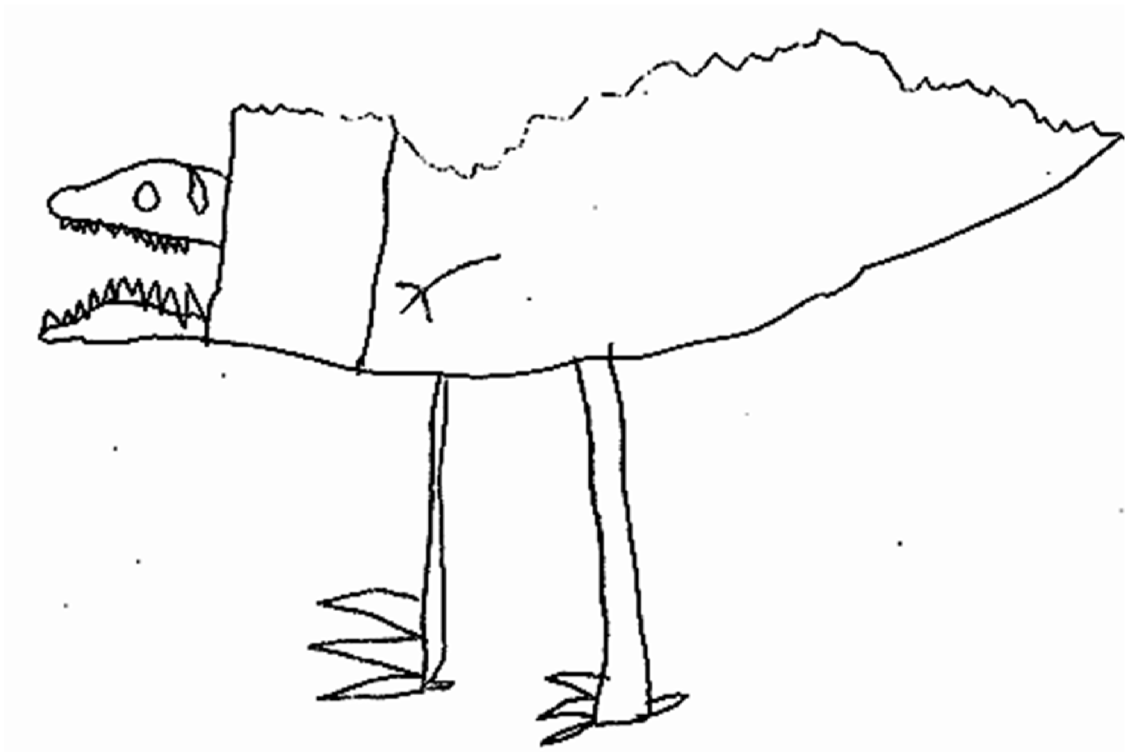

Figure 3. Reconstruction of *Acrocanthasaurus*. (Timothy Campbell)

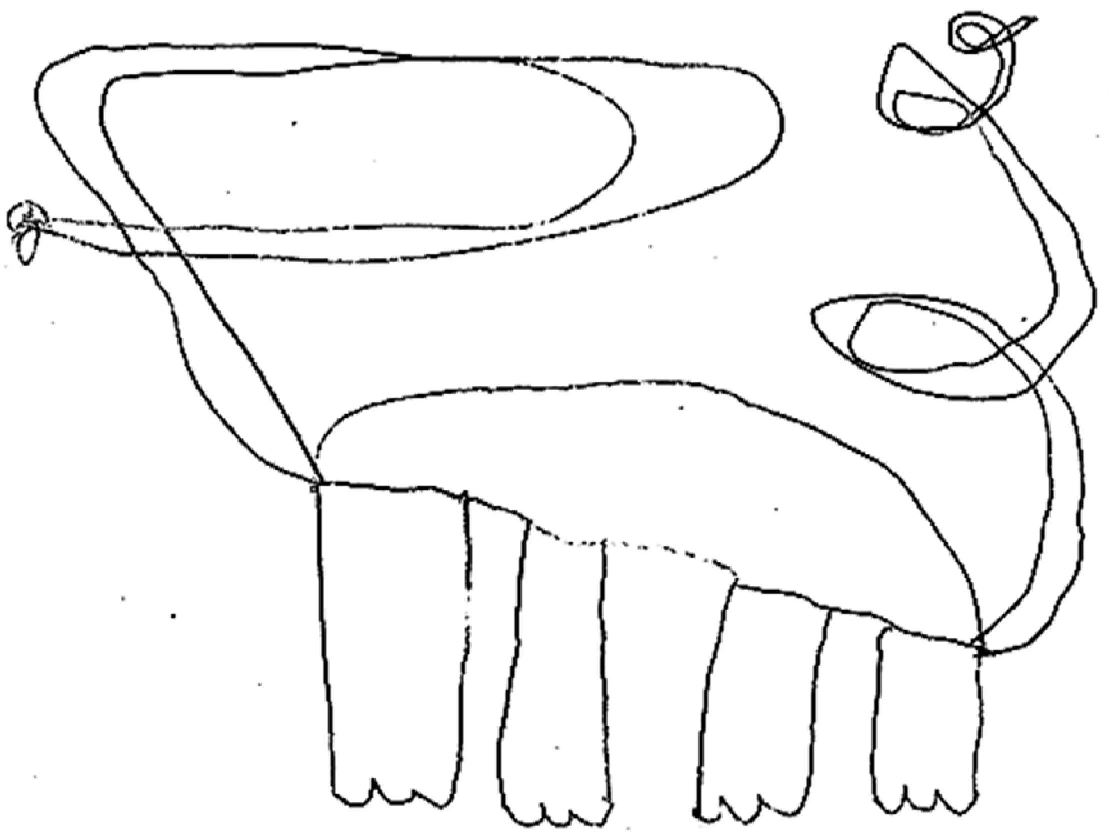

Figure 4. *Paluxysaurus* reconstruction (Timothy Campbell). The neck and tail are somewhat longer and more flexible in this illustration than probably was the case in real life, and the hind legs were longer than the front legs.

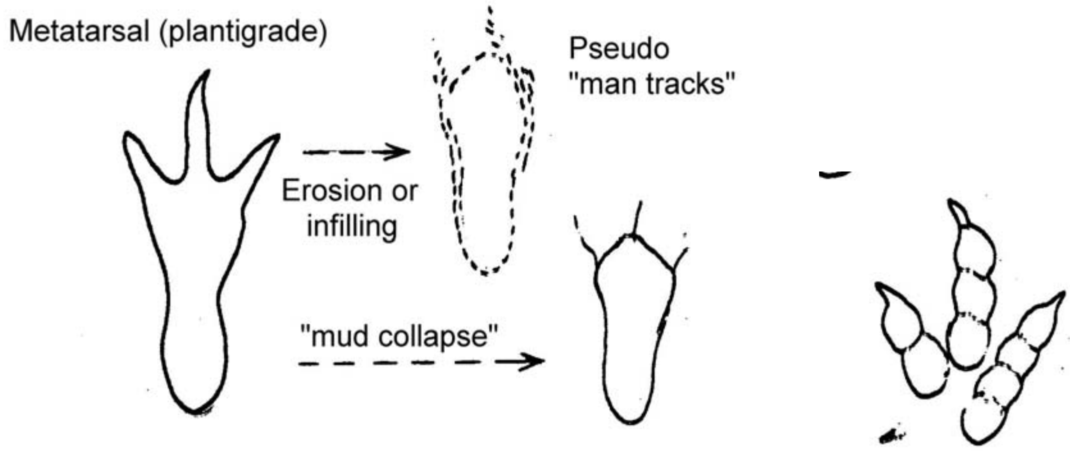

Figure 5. Long theropod dinosaur footprint, including the metatarsals as well as the toes. Many "human" prints from this area are poorly preserved examples of this type of print. To the right is a well-preserved normal toes-only theropod print. From Kuban.

Figure 6. Human prints not coeval with dinosaur prints. Replica of sauropod track from Glen Rose, North Carolina Museum of Natural Sciences. Timothy was 45 inches tall. (Susan Campbell)