A Preliminary Report on Dinosaur Tracksites in the Lower Cretaceous (Albian) Gates Formation Near Grande Cache, Alberta

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ABSTRACT: In recent years, surface coal mining operations near the town of Grande Cache, Alberta have exposed extensive dinosaur trackways. The tracks are located beneath the Number 4 Coal Seam in the Grande Cache Member of the Gates Formation (middle Albian). They are preserved in nonmarine sandstones originally deposited in a coastal plain or deltaic environment (Langenberg et al., 1987). Some tracks occur in a fine-grained, ripple-marked sandstone containing numerous invertebrate burrows, suggesting that the dinosaurs were walking in a shallow, subaqueous environment. Most of the tracksites are dominated by quadrupedal trackways of the ichnogenus *Tetrapodosaurus*, although bipedal dinosaur tracks (theropods and ornithopods) are present as well.

The ichnogenus *Tetrapodosaurus* was originally described from a solitary trackway consisting of 14 footprints (seven manual, seven pedal) from the Gething Formation (late Aptian–early Albian) in the Peace River Canyon, British Columbia (Sternberg, 1932). One of the *Tetrapodosaurus* trackways from Grande Cache has nearly 120 consecutive manus–pes impressions, making it the longest trackway of its type in the world. The occurrence of multiple trackways of *Tetrapodosaurus* may suggest some degree of gregarious behavior. *Tetrapodosaurus* tracks were initially attributed to ceratopsians, but recent work (Carpenter, 1984) suggests that nodosaurid ankylosaurs may have been responsible for producing these ichnites. A few occurrences of isolated tracks resembling *Tetrapodosaurus* were reported from other sites in western Canada (Currie, 1989), but no other trackways of this type were discovered prior to the Grande Cache discoveries.

INTRODUCTION

In the last decade, dinosaur trackways have been exposed by surface mining in seven locations within the Smoky River Coal Mine in the foothills and mountains north of the town of Grande Cache, Alberta (Fig. 1). An additional site outside the mine has yielded the first fossil bird tracks known from Alberta. Dinosaur tracks are often exposed on footwalls after the removal of the overlying Number Four Coal Seam within the Lower Cretaceous (Albian) Grande Cache Member of the Gates Formation (Langenberg et al., 1987). Employees of Smoky River Coal Ltd. were the first to notice footprints exposed on footwalls of open pit coal mine sites in the late 1980's. These discoveries were reported to the Royal Tyrrell Museum of Palaeontology, which sent an expedition to investigate in the spring of 1989; this expedition confirmed the dinosaurian origin of the tracks. From 1989 to the present, additional trackways have been discovered by Smoky River Coal Ltd. employees, or by staff of the Royal Tyrrell Musueum of Palaeontology.

The Smoky River dinosaur ichnofauna is quite diverse, containing the footprints of theropods (small to large), ornithopods and ankylosaurs. However, this ichnofauna is dominated by tracks belonging to the ichnogenus *Tetrapodosaurus*, which are thought to have been produced by nodosaurid ankylosaurs (Carpenter, 1984).

The Smoky River Coal Mine is the most spectacular dinosaur track locality in Canada and, next to the Peace River Canyon, it is also the richest. This area also contains the most abundant and extensive ankylosaur trackways in the world. However, these are perhaps the most difficult and dangerous tracksites for paleontologists to document, as a majority of the tracksites are on steeply dipping slopes that are in constant danger of failing. The purpose of this paper is to summarize the number and nature of known tracksites from the Smoky River Coal Mine and to compare briefly the Smoky River ichnofauna to the contemporaneous Peace River ichnofauna, located less than 400 km away. We will also use stratigraphic information to predict where new dinosaur tracksites may be found within the region where the Gates Formation is mined for coal.

DESCRIPTION OF TRACKSITES

South Pit Lake

In 1989, Greg Kanya of Smoky River Coal Ltd. discovered a solitary block containing obvious footprint impressions. These were the first fossil footprints from the Smoky River Coal Mine to be reported to the Royal Tyrrell Museum of Palaeontology. The main object of interest was a large sandstone block covered with footprint impressions of medium-sized, bipedal, theropods. This specimen contains unusual "five-toed" footprints of a theropod dinosaur that walked across a thin layer of soft mud. Theropod tracks generally show the impressions of Digits II, III and IV (Thulborn, 1990). The two extra "toes" found in this specimen represent an impression of the lower part of the metatarsus (the backward pointing "toe") and Digit I (the "dew claw"). In the spring of 1990, the main block was stabilized and removed from the Smoky River Coal Mine to the Royal Tyrrell Museum of Palaeontology (TMP 90.27.1). In addition to the "five-toed" theropod track-slab, several dozen three-toed theropod footprints were found on a slope in the same area. Most of the ichnites were on other blocks that had tumbled down from above, but some were found *in situ*. Some three-toed theropod ichnites at this site are found as natural casts (Fig. 2). It has been many years since

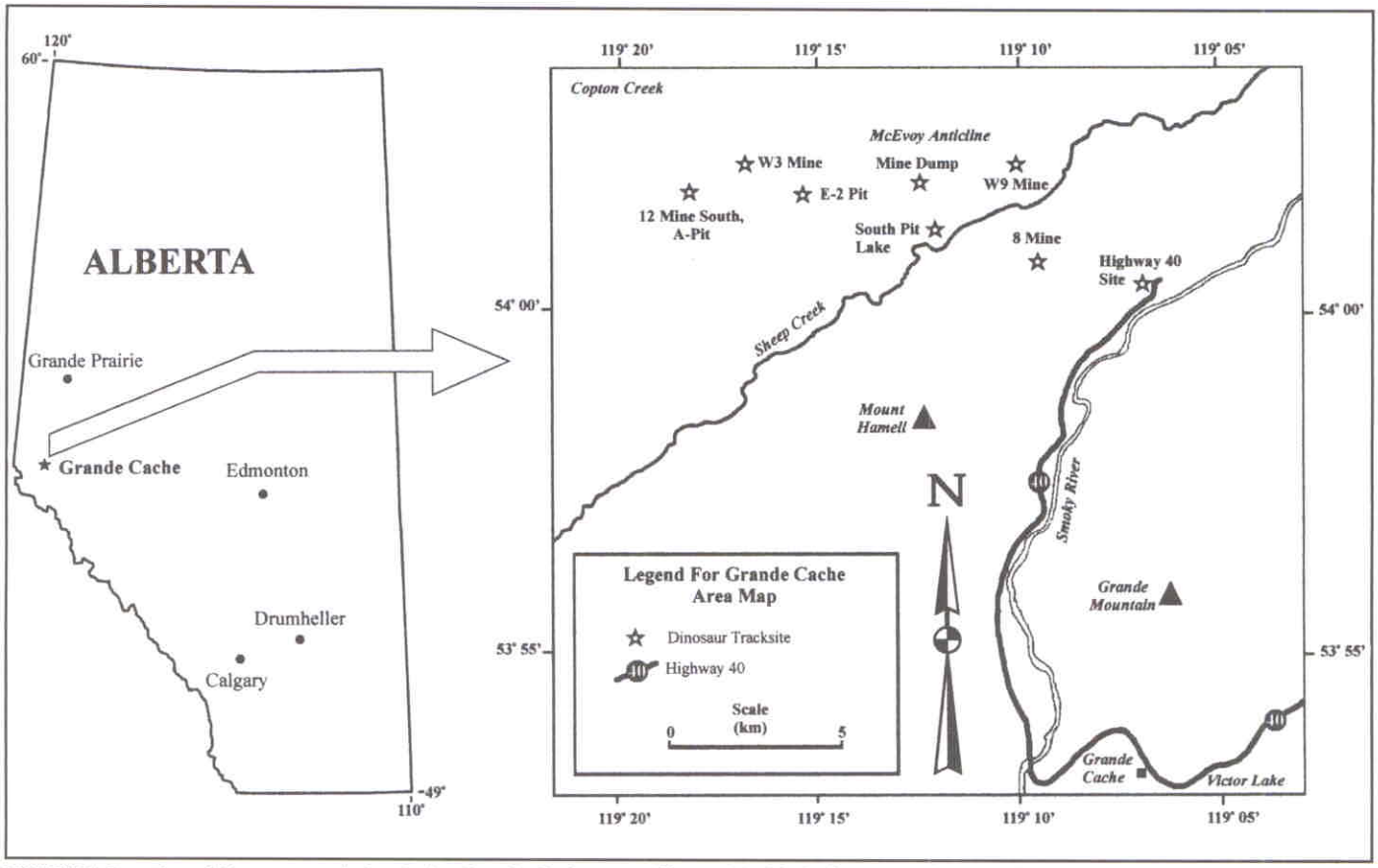

FIGURE 1. Location of dinosaur tracksites in the Grande Cache area, Alberta. Modified after Langenberg et al. (1987).

this site has been checked for new tracks weathering out of the footwall.

Highway 40 Site

In the spring of 1990, during work on the South Pit Lake, two bird footprints were discovered by Darren Tanke in a roadcut exposure near the highway entrance to the Smoky River Coal Mine. The footprints were found on a bedding plane of ripple-marked, fine-to-medium-grained sandstone belonging to the Cadomin Formation (Aptian–Albian). No further bird footprints were found at this site, and no more have since been reported. These bird footprints (illustrated in Lockley et al., 1992) are identical to *Aquatilavipes swiboldae*, which were originally described from the Lower Cretaceous Gething Formation of the Peace River Canyon in British Columbia (Currie, 1981). This discovery is one of only a handful of sites in the world that have produced bird tracks of this age, and is the first undeniable record of fossil bird footprints from Alberta. This specimen has been collected and is now catalogued (TMP 90.30.1) and stored at the Royal Tyrrell Museum of Palaeontology.

In the summer of 1997, road construction crews began to widen the section of highway between the town of Grande Cache and the Smoky River Coal Mine. The road construction may soon reach this site, and could possibly expose more fossil bird footprints.

W9 Mine (Lower East Limb Pit)

Dinosaur footprints were observed at this site by employees of Smoky River Coal Ltd. many years before they were reported to the Royal Tyrrell Museum of Palaeontology. The tracksite

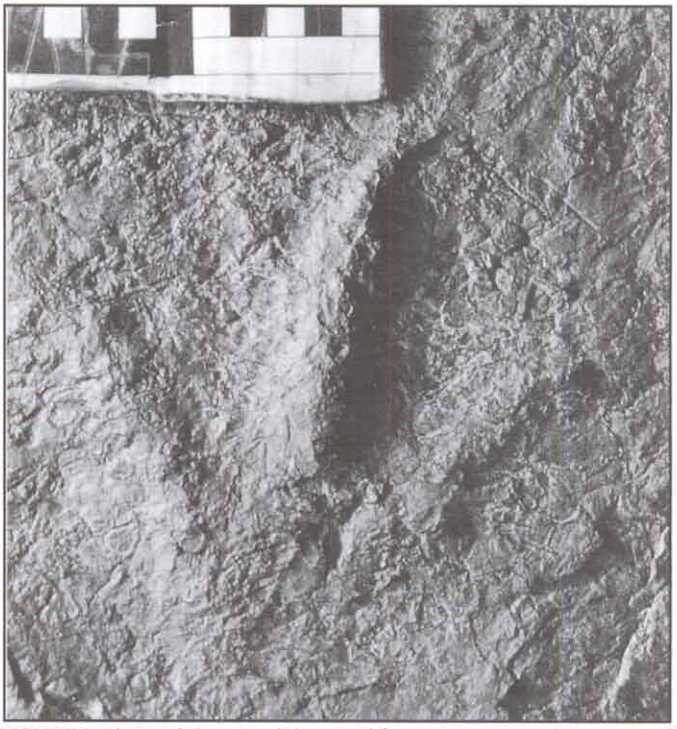

FIGURE 2. Photo of three-toed theropod footprint preserved as a natural cast from the South Pit Lake Site.

occurs on a steeply inclined bedding plane and contains many footprint impressions of small bipedal theropods, but it is particularly noteworthy because of a lengthy trackway produced by a quadrupedal dinosaur. These footprints have been identified as belonging to the ichnogenus *Tetrapodosaurus*, characterized from the Lower Cretaceous Gething Formation of the Peace River Canyon in British Columbia (Sternberg, 1932). Because this site was scheduled to be destroyed, the Tyrrell staff quickly documented as much of this tracksite as they could. Photographic reproductions of this site and its documentation have been featured recently in popular literature (Grady, 1993; Psihoyos and Knoebber, 1994). After the *Tetrapodosaurus* trackway was mapped, one block containing a manus and pes impression was cut out with a rocksaw and removed to the Royal Tyrrell Museum collection (TMP 92.107.1). Other tracks and portions of trackways were cast in latex. These had to cure under hastily erected tents equipped with heaters (courtesy of Smoky River Coal Ltd.) because of the below-freezing conditions at that time (Darren Tanke, pers. comm.). After such a valiant recovery of trackway data, Smoky River Coal Ltd. scrapped the plans that threatened to destroy this site. In the near future, Smoky River Coal Ltd. plans to resume mining operations in this area, which will likely uncover more dinosaur tracks.

E-2 Pit

In the Fall of 1991, Ron Kostiuk, a geologist employed by Smoky River Coal Ltd., reported the presence of dinosaur tracks on a recently exposed footwall of the E-2 Pit. The steep footwall containing the tracks was considered too unstable for researchers to reach to take measurements or cast the tracks. There were several, lengthy *Tetrapodosaurus* trackways; because these

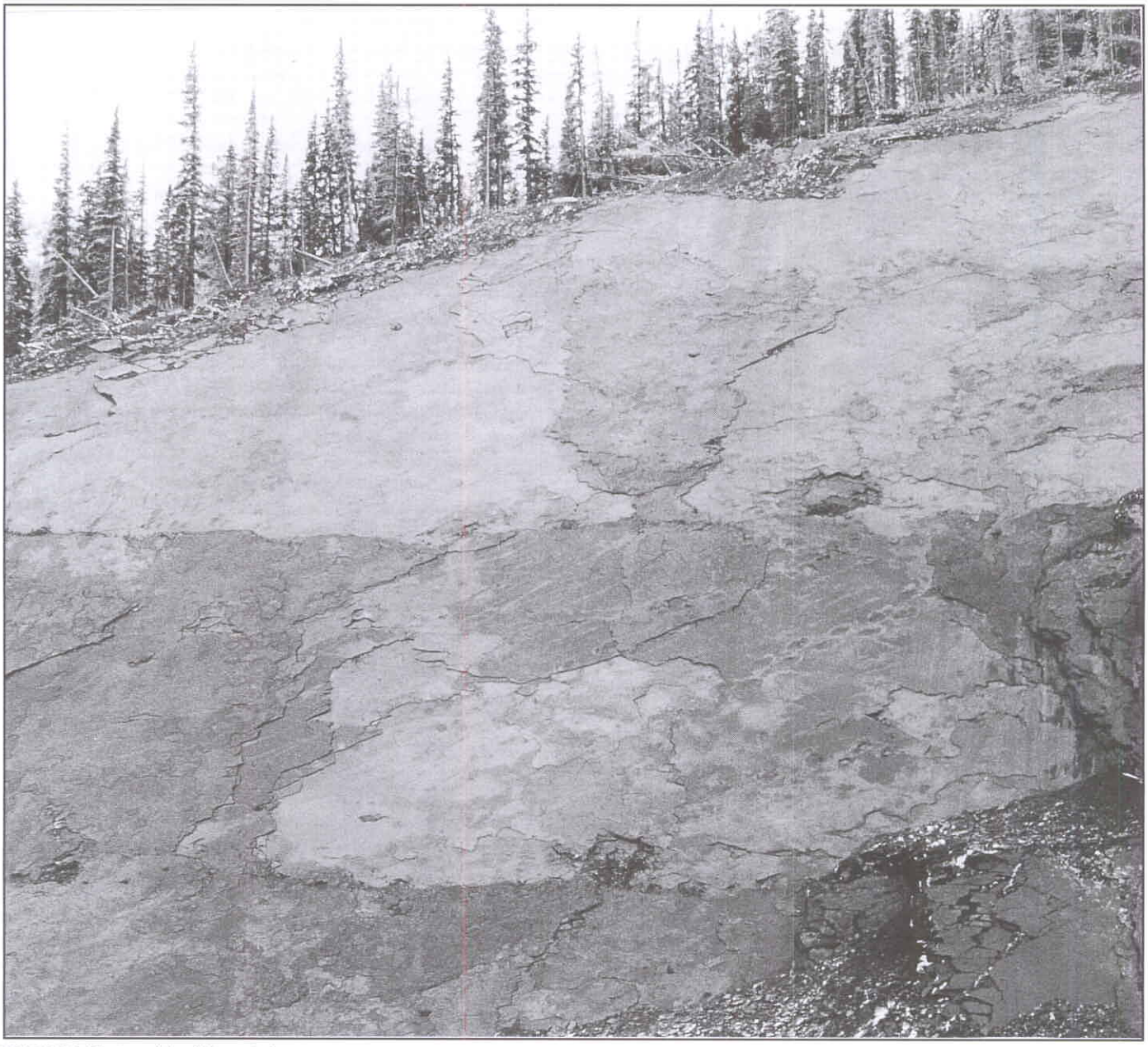

FIGURE 3. Photos of the W3 tracksite.

wandered around and between the remains of fossil tree stumps, the trackmakers appear to have been winding their way through a coal swamp environment.

The section of the E-2 footwall containing the trackways failed unexpectedly on July 4, 1991, during a National Geographic photo shoot of the site. The failure occurred only a few hours before the second author and crew were to rappel down its face (Psihoyos and Knoebber, 1994, p. 189). It is unfortunate that such a splendid tracksite was lost in this way, but it is very fortunate that no one was on the tracksite when the footwall failed. This was the second tracksite lost on this particular photo shoot and was a spectacular end to a remarkable tracksite.

W3 Mine

One of the largest tracksites in the Smoky River Coal Mine occurs on a footwall with a 60° angle, making access hazardous due to a more or less constant rain of rock debris from above. Several trackways of *Tetrapodosaurus* are evident (Fig. 3), but there is also a large bipedal theropod trackway, possibly referable to *Irenesauripus* (Sternberg, 1932). Small bipedal theropod footprints similar to *Irenichnites* (Sternberg, 1932) are present, but are only visible when observed at close proximity to the track surface. There is at least one bipedal ornithopod trackway as well. This site has weathered badly over the years, and some of the trackways are beginning to fade or erode away. There are several track-bearing layers, and different layers are exposed across the entire surface of the footwall, making it difficult to get a clear understanding of this site. It is impossible to see all of the exposed track impressions at one time, since the angle of light is a big factor in track visibility. Different tracks become visible at different times of the day or in different climatic conditions.

Mine Dump

This is the only site at the Smoky River coal mine where dinosaur footprints are found preserved solely as natural casts. Casts are weathering out of an approximately 40° slope, strewn with large blocks of rock eroding out of the exposed strata from above. The offices of Smoky River Coal Ltd. have a dinosaur footprint cast from this site on display in a glass case, indicating that this site has been known for some time. During a dinosaur tracksite survey in October of 1996, the first author retrieved a natural cast of a pes print with 4 digits (TMP 97.5.20), but left behind several other manus and pes prints to be collected in future expeditions. The casts are very dense and heavy, and are not of very high quality. The original track substrate is fine grained and friable, which does not allow natural molds to remain intact once they have been exposed. Only natural casts referable to *Tetrapodosaurus* have been identified from this site.

8 Mine

The 1996 survey discovered a new dinosaur tracksite within a steep-walled pit in an inactive part of the mine. The footprints are large and appear to be tridactyl. Unfortunately, the track surface was obscured by newly fallen snow and was too treacherous to approach to distinguish whether or not they were theropod or ornithopod tracks. The tracks are found on ripple-marked sandstone on the walls of a pit which is partially filled with water. This site will be investigated further in future expeditions to Grande Cache.

12 Mine South, A-Pit

In October, 1996, surveyors reported the existence of a new dinosaur tracksite to R. Owen Terry (Senior Environmentalist, Smoky River Coal Ltd.), in the presence of the first author, who was conducting a survey of dinosaur tracks at the time. The footprints were exposed when a 144 x 45 m section of the 12 Mine South, A-Pit, footwall failed. Initially, the tracks could only be observed with binoculars from atop the highwall facing the track-bearing footwall. Many footprints stood out orange against the gray footwall due to an enrichment of limonite in their infillings (Langenberg et al., 1987). Even from a distance it was evident that several tracks of quadrupedal dinosaurs were present.

Positive identification of the tracks was made during an expedition in the summer and fall of 1997, when the first author was able to observe the tracks in close proximity. The tracks are exposed at a level over 30 m above the base of the footwall, with a slope of over 40°, requiring ropes and other climbing gear to reach them. The individual footprints are shallow, but otherwise well-preserved, showing five digits on a manus that is cresent-shaped at the posterior margin, and four digits on the larger pes. This is consistent with a *Tetrapodosaurus* identification. Some of the footprints are very shallow and noticeable only in the early morning under oblique light conditions. Altogether, there is a minimum of eight tracks of *Tetrapodosaurus* of varying extent. The longest track contains nearly 120 consecutive manus-pes impressions, making it the longest track of its type yet discovered anywhere. The occurrence of so many tracks in this exposure may indicate some degree of gregarious behavior. The tracks are found in a richly organic, fine-to-medium-grained, ripple-marked sandstone, riddled with a great number of invertebrate burrows, indicating that the substrate was formed in a shallow, low-energy environment. A previous study of the bivalve layers and microfossil assemblages above the Number Four coal seam suggests that these sediments were formed in a brackish, coastal plain or deltaic depositional environment (Langenberg et al., 1987). The remains of tree stumps are occasionally found on the exposed track surface near some of the tracks.

Preliminary data from one of most accessible trackways have been collected. However, these measurements were taken from molds that were still infilled with sediment from the overlying strata, making manus and pes dimensions difficult to measure accurately. Some of the limonite-stained infillings were removed, revealing an accumulation of pyrite crystals between the mold and the infilling. The gray sandstone substrate in which the footprints are preserved is highly organic and was evidently in an area of poor drainage, leading to anaerobic decay and sulphate reduction, which facilitated the formation of the pyrite crystals (Collinson, 1996).

The two longest tracks at this site are in parallel orientation, but proceeding in opposite directions (Figs. 4–5). The inverse orientation of these trackways could be evidence of progression along a shoreline (Lockley, 1986). The presence of a very shallow *Tetrapodosaurus* track, cutting perpendicularily across the two figured tracks may indicate that the inverse orientation may have been influenced by some paleoenvironmental control other than a shoreline; perhaps this was merely a preferred route. It is worth noting that a portion of those tracks (not shown) appears to be smeared perpendicular to the direction of progression, suggesting the presence of an ancient channel. It appears that the *Tetrapodosaurus* track-producing animals had no reservations

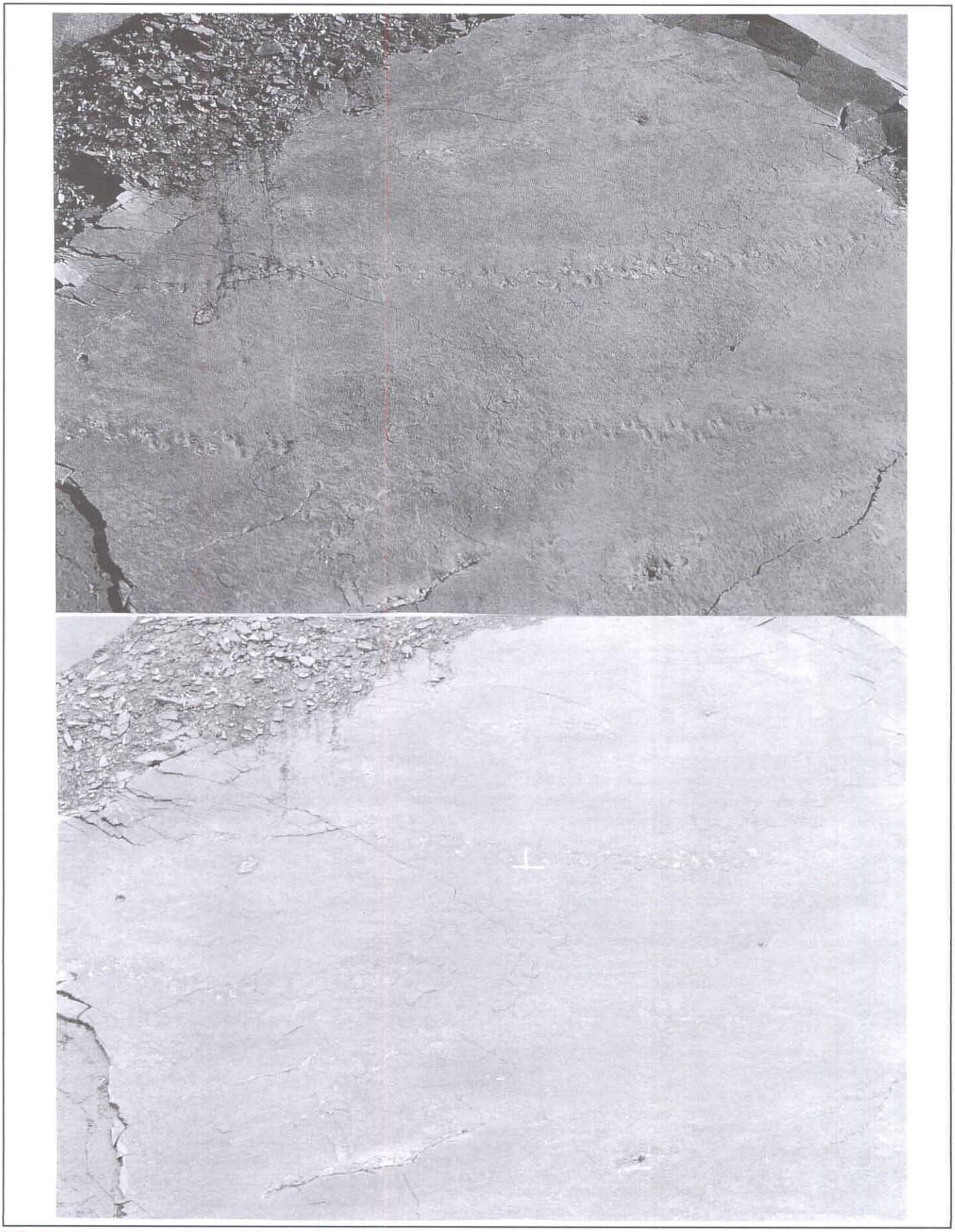

FIGURE 4. Photo (with two different lightings) of a portion of the 12 Mine South tracks.

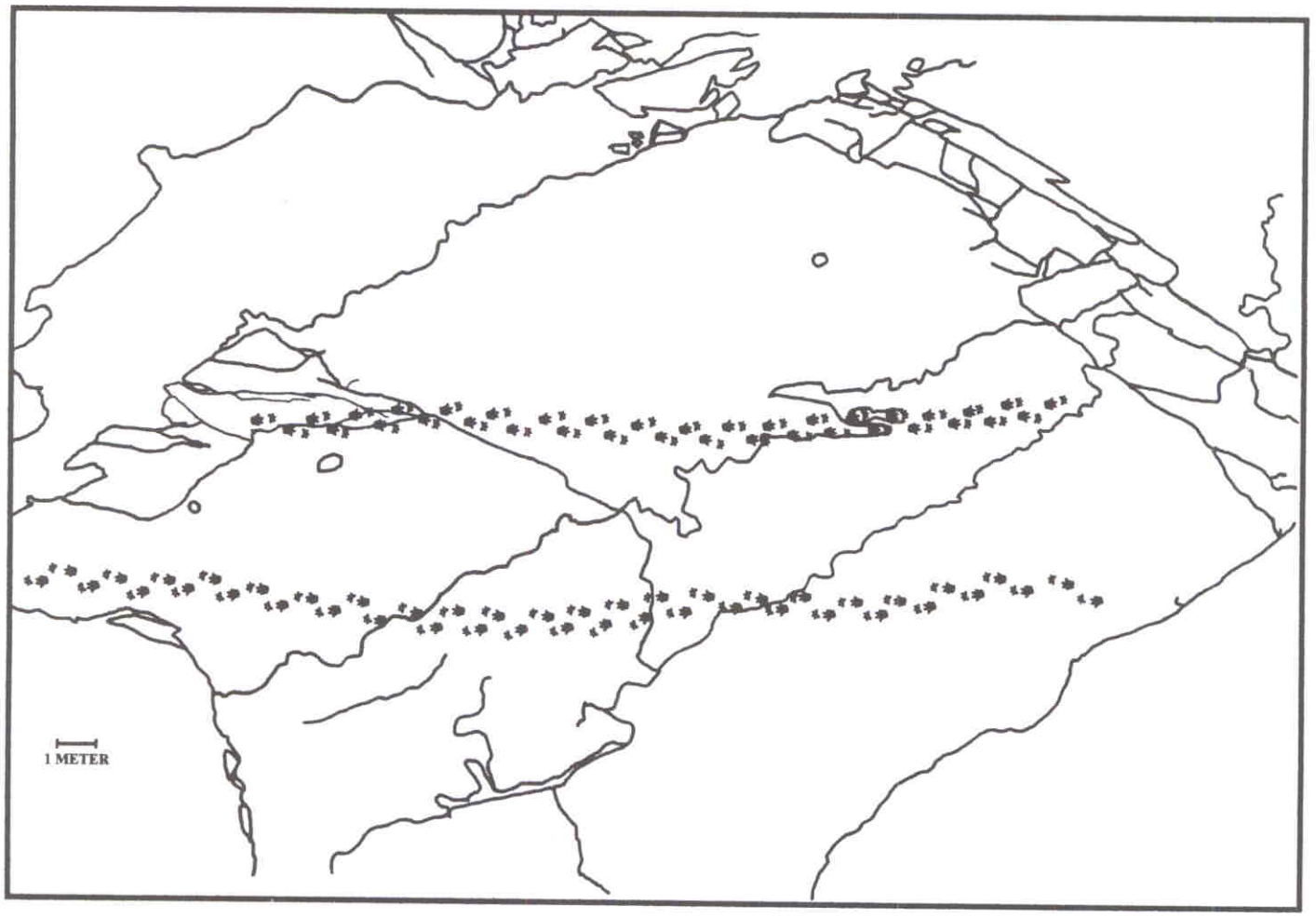

FIGURE 5. Preliminary map of 12 South tracks (with stylized footprints).

about wading in shallow water environments. If ankylosaurs are the producers of this track type, they may have preferred a wetland habitat. If this is the case, it is puzzling why their tracks are so much rarer than hadrosaur tracks at other tracksites.

Though A-Pit is no longer a site of active mining, the trackways will soon be covered by excavation debris from other parts of the mine. The process of backfilling was begun in the summer of 1997, but was postponed until the fall of 1997, and then again to the fall of 1998. Field work, planned for the summer of 1998, should be able to document this site thoroughly before it is covered up. It would be a significant blow to science if this unique tracksite is lost before it can be properly documented.

DISCUSSION

The Smoky River Coal Mine represents the only large-scale exposures of dinosaur tracks in Canada, because the Peace River Canyon (Gething Formation) tracks were flooded upon the completion of the Peace Canyon Dam in 1979 (Currie, 1989). The Gates Formation is contemporaneous with the Gething Formation, which is less than 400 km away. It is appropriate to briefly compare the two ichnofaunas. Dinosaur tracks are common in both formations, but dinosaur tracks from the Gething Formation are found at several stratigraphic levels along the Peace River Canyon (Currie, 1983), and are found preserved in almost every imaginable depositional environment (Currie, 1995). In contrast, the Gates Formation tracks are exposed only after the removal of the Number Four Coal Seam and, though there appears to be some variation in the composition of the substrate from site to site, the strata are those of a coastal plain or deltaic depositional environment (Langenberg et al., 1987). However, the close association of the Grande Cache trackways with the Number Four Coal Seam permits precise stratigraphic correlation over a large area. The Number Four Coal Seam also provides a good stratigraphic marker from which to predict future exposures of dinosaur trackways in this area.

The Peace River ichnofauna is dominated by *Amblydactylus* tracks produced by large bipedal ornithopods (Currie, 1983; Currie and Sarjeant, 1979; Currie, 1995). A wide variety of other ichnogenera contributed to this very diverse ichnofauna, which includes birds (Currie, 1981) and marsupial mammals (Sarjeant and Thulborn, 1986) as well as dinosaurs (Sternberg, 1932; Sarjeant, 1981). Even though the tracks of *Tetrapodosaurus* were first discovered and characterized from a total of 14 footprints (7 manual, 7 pedal) contained in a solitary track from the Peace River Canyon (Sternberg, 1932), they form an insignificant part of that ichnofauna. In contrast, the tracks of *Tetrapodosaurus* dominate the Smoky River ichnofauna; indeed, this is the only site in the world where trackways of this ichnogenus are common. The Smoky River ichnofauna also includes the tracks of birds, theropods, and ornithopods, though the ornithopod tracks are only found at one site.

The large number of *Tetrapodosaurus* tracks found at the

Smoky River coal mine presents the opportunity to study the only significant record of ankylosaur locomotion in the world. There is no evidence of tail drag marks associated with *Tetrapodosaurus* footprints. There also appears to be a size difference between some of the footprints in different trackways from Grande Cache, which could provide information on pedal growth. The new 12 Mine South tracksite is of particular interest, because it shows evidence of extensive, multiple trackways of this ichnogenus. Because the Peace River Canyon has been permanently flooded between two dams, no further discoveries of *Tetrapodosaurus* trackways are likely to occur in the Gething Formation in this region. Since 1932, there have been few tracks or trackways attributable to ankylosaurs worldwide (McCrea et al., in preparation). Isolated natural casts, and even short segments of tracks identified as *Tetrapodosaurus*, have been discovered over the years (Currie, 1989; Lockley et al., in preparation; McCrea et al., in preparation), but none are close to the scale seen from the Gates Formation at Grande Cache.

There is some question as to whether the *Tetrapodosaurus* tracks were produced by ankylosaurs or ceratopsians; tracks attributed to both of these groups are very rare worldwide. C. M. Sternberg (1932) originally attributed these footprints to ceratopsians when he characterized this ichnogenus, but the foot morphology of nodosaurid ankylosaurs seems to fit the track pattern better (Carpenter, 1984; Lockley and Hunt, 1995; Thulborn, 1990). Ankylosaurs large enough to produce *Tetrapodosaurus* tracks existed in the Lower Cretaceous (Carpenter, 1984), but no similar sized ceratopsians from that same time have been reported. Continuing research at the Smoky River coal mine may help resolve the question of the affinity of the *Tetrapodosaurus* tracks.

The Number Four Coal Seam is an important stratigraphic indicator of the Gates Formation in Alberta (Langenberg et al., 1987) and is actively mined in several areas, using the same mining techniques employed at the Smoky River coal mine. It is not unreasonable to predict that there could be several dinosaur track exposures in other coal mines that are either unreported or unrecognized (the presence of numerous dinsosaur tracks in heavily worked areas may seem to be impossible to escape notice, but it does happen). Sauropod tracks on a horizontal surface, exposed by surface gypsum mining in Arkansas, were regarded as irritating "potholes" before their true nature was discovered (Pittman and Gillette, 1989). There is evidence of unreported tracks from the sloping footwalls of coal mines in Alberta. The first author recognized the bipedal tracks of ornithopods in a display poster photograph describing coal mine footwall stability. The photographer and primary designer of the poster, who was a colleague in the department, seemed quite surprised by the presence of dinosaur tracks when they were pointed out. It is hoped that there will be enough resources to conduct a proper survey of all coal mines in the Gates Formation to expand the number of known dinosaur tracksites in Canada.

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