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The History of Dinosaur Footprint Discoveries in Wyoming with Emphasis on the Bighorn Basin

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Dinosaur traces are well known from the western United States in the Colorado Plateau region (Utah, Colorado, New Mexico, and Arizona). Utah contains the greatest abundance of known and documented dinosaur footprints and trackways. Far less well known, however, is the occurrence and distribution of dinosaur footprint-bearing horizons in Wyoming. Scientific studies over the past 10 years have shown that three of the four Middle and Upper Jurassic formations in northern Wyoming contain dinosaur footprints. Two of the footprint-bearing horizons are located in geologic intervals that were once thought to have been deposited in offshore to nearshore marine settings and represent rare North American examples of Middle Jurassic (Bajocian and Bathonian) dinosaur remains. Some of these new Wyoming sites can be correlated to known dinosaur footprint-bearing horizons or intervals in Utah. Wyoming has a great potential for additional discoveries of new dinosaur footprint-bearing horizons, and further prospecting and study is warranted and will ultimately lead to a much better understanding of the geographic distribution and behavior of the potential footprint-makers.

Keywords Dinosaur, Jurassic, trackways, footprints, trace fossils, Wyoming

INTRODUCTION

In this paper we summarize the known distribution of Jurassic dinosaur footprints and trackways in Wyoming. The paper further focuses on the Bighorn Basin of northern Wyoming because of the recent discoveries and investigations of track-bearing intervals therein. We briefly discuss the geology of these intervals and suggest for future exploration other Jurassic intervals that appear to have the potential for trackway preservation.

In order to see *in-situ* dinosaur footprints that span most of the Mesozoic, plan a trip for the western United States—specifically those states of the Colorado Plateau region (Fig. 1). The state of Utah has the greatest number of known and documented footprint-bearing horizons in North America. Virtually every Upper Triassic and Jurassic formation in Utah contains dinosaur footprints (Fig. 2) (Lockley and Hunt, 1994, 1995). Curiously, those states that are situated north of the Colorado Plateau, such as Wyoming and Montana, while still preserving many of the age-equivalent strata found on the Colorado Plateau, pale by comparison to Utah, Colorado, Arizona, and New Mexico in regards to the number of known footprint-bearing horizons that have been documented. This situation most likely reflects the simple fact that few geologists and paleontologists have looked for them north of the Colorado Plateau.

The oldest known dinosaur footprints in Wyoming, and apparently the first Wyoming dinosaur footprints studied scientifically, occur in the Popo Agie Formation (Norian-Rhaetian), a Upper Triassic unit that is equivalent to the uppermost part of the Chugwater Formation (Fig. 2) (Branson and Mehl, 1932; Colbert, 1957; Picard, 1993). These footprints are specifically known as *Agialopous wyomingensis*, and are interpreted to have been made by a small theropod dinosaur (Lucas, 1994).

Agialopous wyomingensis was reported from the western part of the Wind River Basin (Fig. 1) by Branson and Mehl (1932). A second exposure exhibiting these footprints has yet to be reported in the state, although they are apparently the "single most common kind of footprint found" in age-equivalent strata

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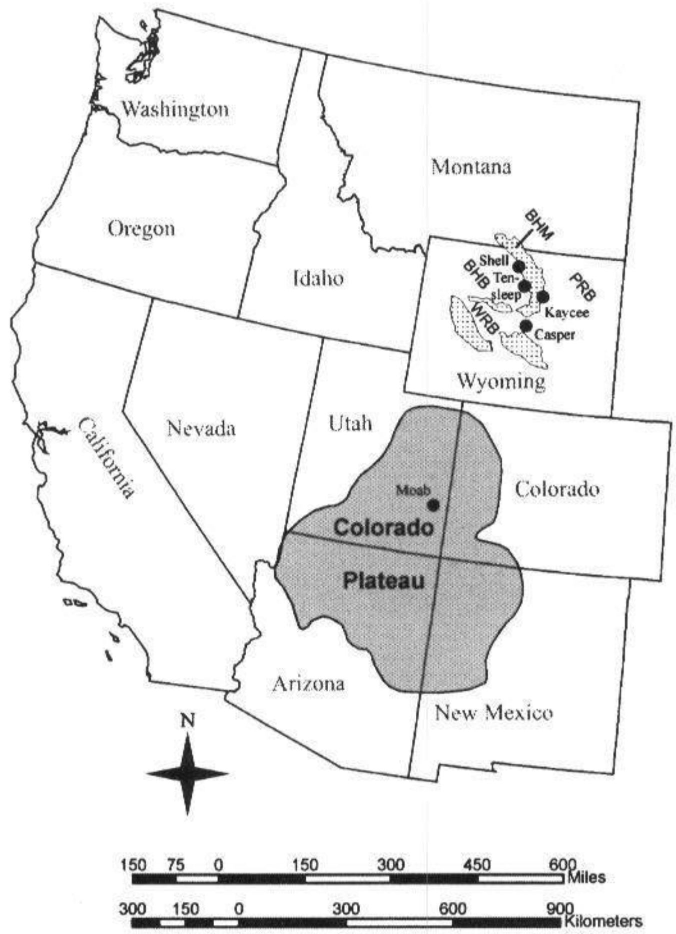


FIG. 1. Map of the western United States showing locations mentioned in the text. BHM = Big Horn Mountains; PRB = Powder River Basin; BHB = Bighorn Basin; WRB = Wind River Basin.

in northwestern Colorado and northeastern Utah (Lucas, 1994, p. 111). In fact, the single outcrop occurrence of *A. wyomingensis* remains the only known Wyoming dinosaur footprint for a succession of rocks and interspersed unconformities that spans an interval from the Late Triassic through the Early Jurassic (roughly 30 million years of time).

Few dinosaur footprints were found, or at least reported, in Wyoming for the 50 years following the discovery of *A. wyomingensis*. Footprints that were discovered include those reported by Barnum Brown, the famed American Museum of Natural History dinosaur paleontologist. He described dinosaur footprints found in roof rocks of underground coal mines in the Mesaverde Formation, an Upper Cretaceous unit, in Wyoming (Brown, 1938). He had apparently known about the footprints for some time but did not subject them to any sort of detailed scientific study. Like most 20th century researchers hunting for dinosaur remains in Wyoming, he was mostly interested in the bones. As recently as 1994, the Wyoming Geological Association dedicated a volume to "The Dinosaurs of Wyoming." This publication contains several articles on dinosaur remains, of which only one report mentions dinosaur footprints (see Lucas, 1994).

Mesozoic vertebrate footprints, in general, did not receive much attention in the state throughout most of the 20th century with the notable exception of the incredible trackways of knuckle-walking pterosaurs from the upper Sundance Formation (or lower Morrison Formation, *sensu* Peterson, 1994) in central Wyoming (Logue, 1977). Kvale and Vondra (1985) reported the occurrence of a single poorly preserved trackway made by a small bipedal dinosaur in the Upper Jurassic Morrison Formation in northern Wyoming, north of the town of Shell (Fig. 1). Weed (1988) reported on several unidentified dinosaur footprints from a basal Morrison eolinite near the town of Kaycee, also in northern Wyoming (Fig. 1).

Wyoming dinosaur footprints were not studied in detail until the 1990s. The first of these studies investigated footprints (some of which are interpreted to be theropod prints) found in association with sauropod bones excavated from two dinosaur bone quarries in the Upper Jurassic Morrison Formation: the Howe Dinosaur Quarry (northcentral Wyoming) and the Houston Quarry (northeastern Wyoming) (Foster and Lockley, 1995; Lockley et al., 1998).

The new millennium brought the documentation of Middle Jurassic tridactyl prints made by bipedal dinosaurs in Wyoming. These footprint- and trackway-bearing surfaces are primarily associated with limestones in the lower part of the Sundance Formation and in the Gypsum Spring Formation (Kvale et al., 2001a). Ironically both of these footprint-bearing horizons are in units once thought to have been offshore to nearshore marine deposits.

JURASSIC STRATA IN THE BIGHORN BASIN

The Jurassic of the Bighorn Basin is represented by one Upper and three Middle Jurassic formations (Fig. 3). These deposits, from oldest to youngest, are the Middle Jurassic Gypsum Spring, Piper, and Sundance formations and the Upper Jurassic Morrison Formation. The stratigraphy of the Middle Jurassic units is discussed in detail elsewhere (Brenner and Peterson, 1994; Kvale et al., 2001a, 2001b); however, it is important to note here that several regional unconformities can be mapped through these formations which allows for a broader correlation to the Colorado Plateau further south (Piperingos and O'Sullivan, 1978; Kilibarda and Loope, 1997; Kvale et al., 2001a) (Figs. 1 and 2). Each of the unconformities bounds a transgressive-regressive cycle that is marked at the base by a flooding surface and is capped by a shoaling upward regressive succession that in some cases terminate in facies that indicate subaerial exposure (Fig. 2). Each of these subaerial exposure surfaces has the potential to preserve dinosaur footprints in outcrop. To date, we have identified footprints on an unnamed surface in the Gypsum Spring Formation and on the "J2b" unconformity within the Sundance Formation. Footprint-bearing horizons have also been identified in the Morrison Formation within the Bighorn Basin.

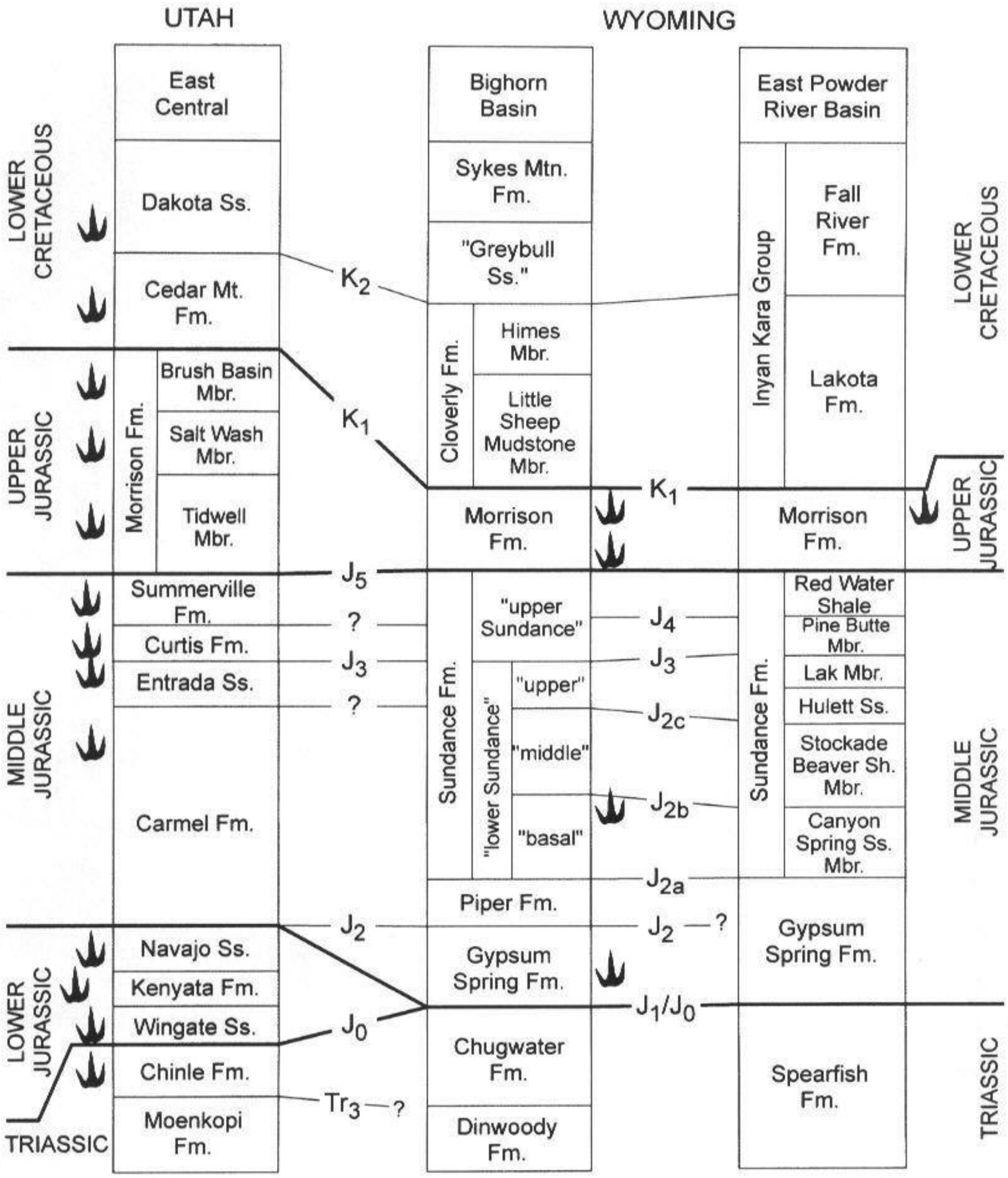


FIG. 2. Stratigraphic correlation chart for dinosaur footprint-bearing units in Utah and Wyoming. The Utah stratigraphy is from east central Utah near the town of Moab (Doelling et al., 2003). The stratigraphic occurrences of dinosaur footprints in Utah are from Lockley and Hunt (1995) and Mickelson (unpublished data). Those from the Jurassic of Wyoming are discussed in the text.

Gypsum Spring Formation

The oldest known Wyoming Jurassic dinosaur footprints and trackways that are currently documented are found in the Bighorn Basin and occur in the Middle Jurassic Gypsum Spring Formation. They have been dated as Late Bajocian in age (~170 Ma), and were first found in 1999 near the town of Shell (Kvale et al., 2001a). The footprint-bearing interval within the Gypsum Spring is the most extensive dinosaur footprint-bearing unit currently known from the state of Wyoming, and likely is one of the most extensive in North America. Its age makes this track-bearing horizon one of the rare discoveries of North American Bajocian dinosaur remains.

The trackways and footprints occur within multiple, closely spaced horizons separated by up to several centimeters (a few inches) in a 2 m-thick (6 foot-thick) interval of interbedded micritic and stromatolitic limestones and calcareous mudstones. The horizons are described in greater detail elsewhere (Kvale et al., 2001a, 2001b). These carbonates are interpreted to have been deposited in a transitional marine environment that fluctuated from a limey upper intertidal flat to a shallow subtidal setting in an arid to semiarid climate. The intertidal intervals contain well preserved tridactyl prints made by small- to medium-sized bipedal dinosaurs, some of which may have been theropods (Fig. 4a). Some of the subtidal carbonates exhibit swim marks

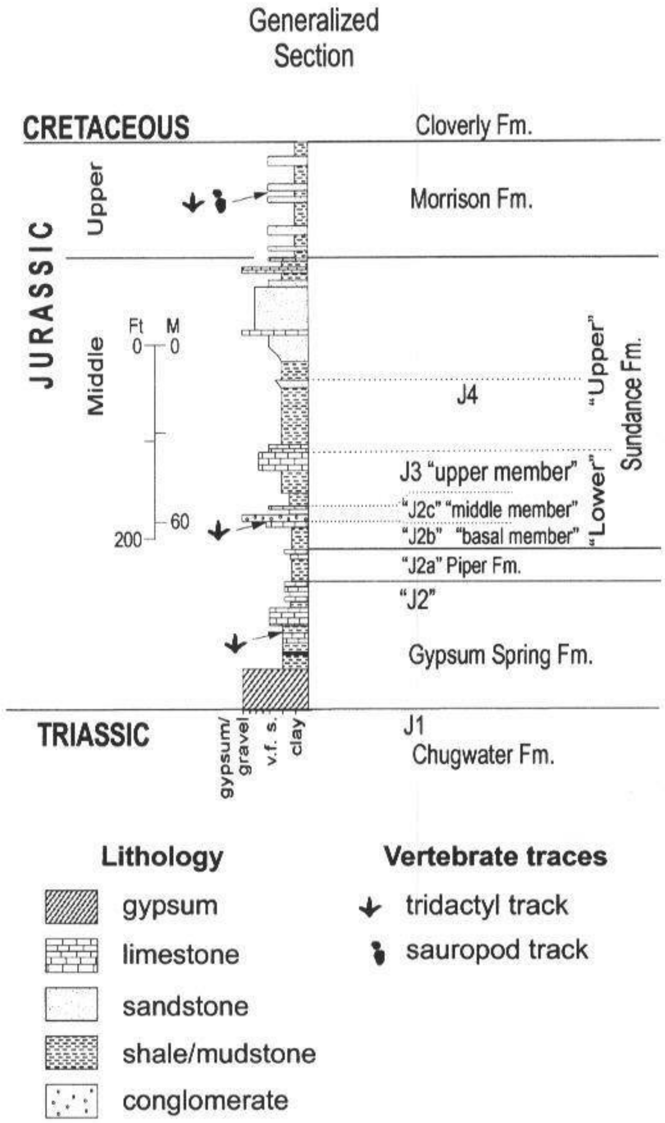


FIG. 3. Composite graphic section of the Jurassic formations present in the northeastern portion of the Bighorn Basin, Wyoming.

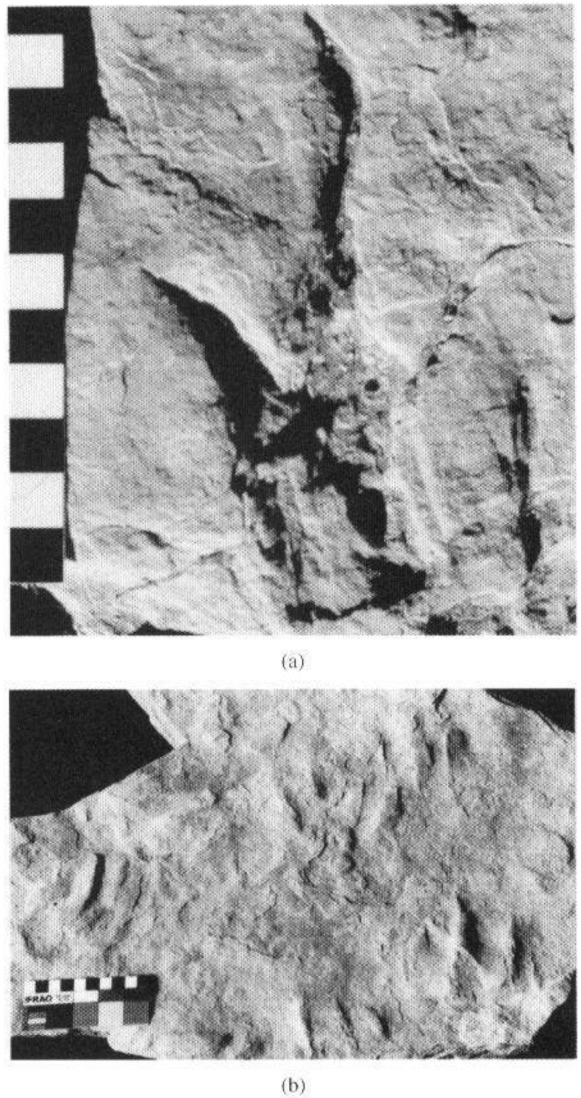


FIG. 4. Gypsum Spring Formation footprints. a: Possible theropod footprint. Note the features attributed to theropod footprint impressions including the long sinuous middle digit and the tapering toes that appear to terminate in claw-like impressions. Ten-centimeter scale on the left. (From Kvale et al., 2001a). b: Slab showing linear arcuate features attributed to swimming reptiles. Scale is in centimeters. These features were attributed by Kvale and others (2001b) to swimming crocodilomorphs or swimming bipedal dinosaurs.

interpreted to have been made by crocodiles, and perhaps bipedal dinosaurs (Fig. 4b) (see Kvale et al., 2001a, 2001b; Mickelson, unpublished data).

This footprint-bearing interval in the Gypsum Spring Formation appears to extend from the Wyoming-Montana border to at least as far south as the town of Tensleep on the eastern half of the Bighorn Basin, a distance of 130 km (approximately 80 miles). The western half of the basin has not yet been examined for comparable reptilian trace fossils. Kvale et al. (2001) showed that the footprint-bearing interval occurs near the top of a 10 m-thick (approximately 30 ft-thick) upward coarsening cycle that can be identified on oil and gas geophysical logs on the east side of the basin. It is not yet clear what the cycle represents; however, the results of limited outcrop studies and geophysical log profiles suggest that the cycle indicates a transgressive-regressive event that affected a large portion of the basin. Still younger Gypsum Spring coarsening upward (shoaling upward?) cycles are also identified on these same geophysical logs, suggesting the existence of other potential trackway-bearing intervals.

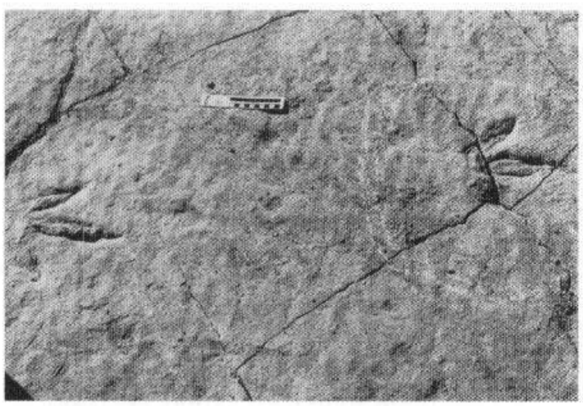
Piper Formation

No dinosaur footprints have been identified within the Piper Formation (Early Bathonian). However, geophysical logs from within the Bighorn Basin suggest that the Piper is part of a "shoaling upwards" cycle that appears to terminate at the "J2a" interval and is a candidate for preserving dinosaur ichnites.

Sundance Formation

At least five cycles interpreted to represent transgressive-regressive cycles can be identified within the Middle Jurassic Sundance Formation on geophysical logs along the eastern side of the Bighorn Basin (Kvale et al., 2001). On outcrop, the bases of three of these cycles exhibit surfaces with unmistakable evidence of subaerial exposure ("J2b," "J2c," and "J3"). Tridactyl footprints made by bipedal dinosaurs have been identified on "J2b" (Figs. 5a, b). The "J2b" unconformity is Bathonian in age (~167 Ma.) (Kvale et al., 2001a). Like the Gypsum Spring footprints, the "J2b" Sundance tracks occupy an interval of time for which there are only rare remains of dinosaurs in North America. However, many footprints found in both the Sundance and Gypsum Spring formations resemble Bathonian tridactyl footprints known from Great Britain (e.g., Sarjeant, 1974; Delair and Sarjeant, 1985). "J2b" footprints include those found at, and in the immediate vicinity of, the Red Gulch Dinosaur Trackway site approximately 5 km (3 miles) southwest of the town of Shell, 8 kilometers (5 miles) north of the town of Shell, and 5 kilometers (3 miles) northeast of the town of Greybull.

(a)



(b)

FIG. 5. Sundance Formation dinosaur footprints. a: Bipedal dinosaur trackway exposed on the surface of the Red Gulch Dinosaur Tracksite, southwest of the town of Shell. Each track is approximately 25 cm in length. Trackway was enhanced with a mixture of flour and water shortly after discovery to facilitate photography and study. b: Two footprints from a bipedal trackway showing digitigrade aspect typical of Sundance Formation footprints. Ten-centimeter scale at top of photograph.

Footprints have not been found to be associated with either the J2c or J3 unconformities. The J2c horizon in the vicinity of the Red Gulch Dinosaur Tracksite exhibits well-developed desiccation features (sand-filled mudcracks), and based on geophysical logs is easily recognized along the eastern margin of the basin along the Big Horn Mountain front. This surface remains largely unstudied and unprospected for footprints.

The J3 unconformity caps a succession marked by a locally preserved eolian sandstone that was deposited just prior to the formation of the J3 unconformity (Kilibarda and Loope, 1997). This unit likely correlates with the dinosaur footprint-bearing Entrada Sandstone of Utah (Fig. 2). Footprints have not yet been found associated with the J3 unconformity or the eolian dunes that underlie it, but investigations on this surface have been limited.

The J4 unconformity in the upper Sundance is marked by a shoaling upward cycle terminated by a shallow-water facies marked by local accumulations of *Ostrea* sp. Results of preliminary work show no direct evidence that this unconformity experienced subaerial exposure in the northeastern portion of the basin.

The uppermost part of the Sundance Formation in the Bighorn Basin appears to be equivalent to what has traditionally been referred to as the Windy Hill Member of the Sundance Formation (or lower part of the Morrison Formation, *sensu* Peterson, 1994) in central Wyoming, south of Casper (Fig. 1). This member has been proposed to exist above the J5 unconformity which traditionally has been viewed as the contact between the Morrison and Sundance formations (Peterson, 1994; Brenner and Peterson, 1994). However, Uhlir et al. (1988) described the contact between the Sundance Formation and the overlying Morrison Formation in the Bighorn Basin as transitional and didn't recognize the J5 unconformity within the basin.

Within the Windy Hill Member south of Casper, well-preserved manus and pes impressions of pterosaur trackways assigned to *Pteraichnus* have been identified (Logue, 1977). Tridactyl footprints are now known to exist within this horizon in conjunction with the pterosaur footprints (Mickelson, unpublished data). Comparable flaggy-bedded sandstone facies in the uppermost part of the Sundance Formation are also present in the Bighorn Basin. Possible pterosaur, crocodilian, and turtle tracks have been identified in these units, which offer significant potential for the preservation of other reptilian ichnites (Harris and Lacovera, this volume).

Morrison Formation

The Upper Jurassic (late Kimmeridgian to Tithonian) Morrison Formation of the Western Interior is one of the most prolific dinosaur bone-bearing horizons in North America. Ironically, only recently were dinosaur footprints and trackways reported from the Morrison Formation of the Bighorn Basin. The earliest report of a dinosaur footprint from the Wyoming Morrison was a single poorly preserved trackway published in 1985 (Kvale and Vondra, 1985; Kvale, 1986). More recent discoveries come from one of the most famous Morrison dinosaur bone quarries, the Howe Dinosaur Quarry, just north of Shell in the Bighorn Basin. In the 1990s, several impressive dinosaur footprints were reported from the Howe Quarry, including two interpreted to have been made by *Allosaurus* (Lockley et al., 1998). Photographs of these footprints are illustrated in Ayer (1999).

More recently, Kvale et al. (2001b) reported a variety of footprints made by large bipedal (possible theropod and/or ornithopod) and quadrapedal (sauropod) dinosaurs from the Coyote Basin area just east of the Howe Quarry (Fig. 6). Research on these and other recently discovered Morrison footprints and trackways is currently underway. Even with limited study it is apparent that Upper Jurassic Morrison footprints are much more diverse in their morphology than those found in either the Middle Jurassic Gypsum Spring or Sundance Formations, which are dominated by tridactyl prints of small- to medium-size bipedal dinosaurs. This observation is consistent with trends in Jurassic ichnite diversity seen on the Colorado Plateau (Lockley and Hunt, 1994, 1995).

Bighorn Basin Morrison footprints are now known to exist throughout the formation and are largely associated with floodplain deposits (Kvale et al., 2001b; Hasiotis et al., unpublished data).

FIG. 6. Sandstone cast of a tridactyl print from the Morrison Formation exposed near Shell. Slab is upside down and cast is standing out in relief. Scale is in centimeters.

CONCLUSIONS

The Bighorn Basin and Wyoming, in general, have remained largely unprospected for dinosaur footprints despite a long history of geologic and paleontologic investigation in the basin. Yet, recent Jurassic discoveries show that the potential remains high for new footprint/trackway localities. Reconnaissance studies of dinosaur footprint-bearing horizons in the marine-dominated Gypsum Spring and Sundance formations in the Bighorn Basin were aided by the use of oil and gas geophysical logs on which shoaling upward cycles were identified (Kvale et al., 2001). With the identification of these cycles, potential subaerially exposed horizons have been identified, and investigative efforts in identifying new footprint-bearing locations can now be more easily focused in northern Wyoming and elsewhere in the state.

Footprint investigations in the United States traditionally have been most intense in those areas already known to have produced dinosaur footprints. Expanding ichnological studies into areas that have received less attention from vertebrate paleontologists and ichnologists will serve to expand our knowledge of the geographic range of certain vertebrate ichnites, and consequently the range and behavior of dinosaurian and other reptilian tracemakers.

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