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FIRST REPORT OF DINOSAUR, SYNAPSID, AND ARTHROPOD TRACKS IN THE AZTEC SANDSTONE (LOWER-MIDDLE JURASSIC) OF RED ROCK CANYON NATIONAL CONSERVATION AREA, SOUTHERN NEVADA

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Abstract–We document the occurrence of tridactyl, grallatoroid dinosaur tracks, up to 14 cm long, at three remote sites within the Aztec Sandstone of Red Rock Canyon National Conservation Area, a short distance west of Las Vegas, Nevada. We also report the presence of *Octopodichnus* (arthropod) and synapsid tracks. One of the dinosaur tracksites preserves a single, distinct track; another contains several dozen tracks and at least three trackways, exhibiting various types of preservation; and a third tracksite preserves a distinct trackway of 17 tridactyl tracks, as well as two *Brasilichnium*-like synapsid trackways. At all three sites, the dinosaur tracks are interpreted to be undertracks. Through the use of photogrammetry, at one of the tracksites we are able to reconstruct the rheological history of the emplacement of the dinosaur's right foot into moist sand as the animal traversed diagonally downward, across the moist, sloping face of a dune. Evidence at all three sites indicates that the tracks were made on a sloping surface. Additional analysis of these and other tracks in the Aztec Sandstone is underway.

INTRODUCTION

The Aztec Sandstone is a Lower-Middle Jurassic eolian sandstone exposed in southern Nevada and southeastern California. It is correlative with–and lithologically very similar to–the Navajo Sandstone of southern Utah and northern Arizona (Marzolf and Anderson, 2005). Prior to Miocene extension, these two sandstone units were contiguous bodies of rock (Marzolf, 1993); they have different names only because the geologists who named them did not yet know that they were part of the same Jurassic sand sea (erg), separated by post-depositional tectonics.

The Navajo Sandstone is commonly considered to be entirely Lower Jurassic in age (e.g., Peterson and Pipiringos, 1979; Lockley and Hunt, 1995; Irmis, 2005), however Marzolf and Anderson (2005, p. 287) argued that "the age of the top of the Navajo Sandstone probably is as young as Bajocian (ca. 170 Ma)." The Bajocian Stage is lower Middle Jurassic; the Lower-Middle Jurassic boundary is placed at 174.1 Ma (Ogg and Hinnov, 2012). In the Cowhole Mountains of eastern California, the Aztec Sandstone interfingers with volcanic rocks that date between 173 and 170 Ma (Reynolds, 2006b), thus there is little question that the Aztec Sandstone is partly Middle Jurassic. The tracks described in this paper are probably uppermost Lower Jurassic in age, but it is possible that some of them are lower Middle Jurassic.

A small number of body fossils (Winkler et al, 1991; Parrish and Falcon-Lang, 2007; Sertich and Loewen, 2010) and a wide variety of invertebrate and vertebrate trace fossils, including at least four ichnotaxa attributed to dinosaurs, have been reported from the Navajo Sandstone (Faul and Roberts, 1951; Baird, 1980; Lockley and Hunt, 1995; Rainforth and Lockley, 1996; Hamblin and Bilbey, 1999; Smith and Santucci, 2001; Irmis, 2005; Lockley, 2005; Loope, 2006; Ekdale et al., 2007, Milàn et al., 2008; Milner et al., 2012).

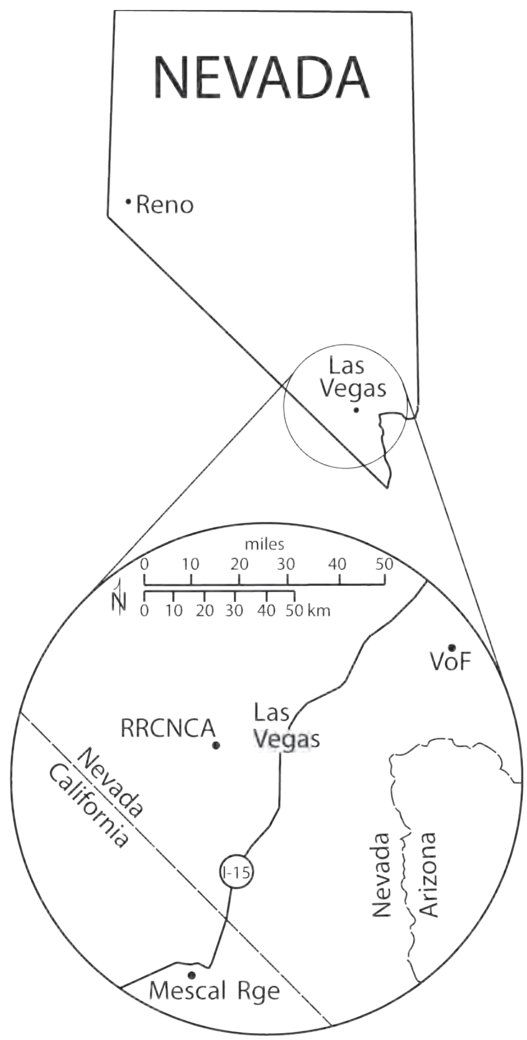

FIGURE 1. Index map showing locations where tracks have been reported in the Aztec Sandstone; Red Rock Canyon National Conservation Area (RRCNCA), Valley of Fire State Park (VoF), and Mescal Range (Mescal Rge).

Aztec Sandstone exposures in the Mescal Range of eastern California (Fig. 1) have also yielded a diverse assemblage of vertebrate and invertebrate trace fossils (Reynolds, 2006a, b). Out of concern for losing the Mescal Range tracks (including the only dinosaur tracks known from the State of California) to illegal collectors, most of them have been collected and are now reposited in the San Bernardino County Museum and the Natural History Museum of Los Angeles County (Springer et al., 2009).

Anomalously, southern Nevada exposures of the Aztec Sandstone have appeared to be conspicuously less fossiliferous than exposures of the same formation across the border in California, and less fossiliferous than the Navajo Sandstone in Utah and Arizona. Prior to 2011, the only report of tracks in

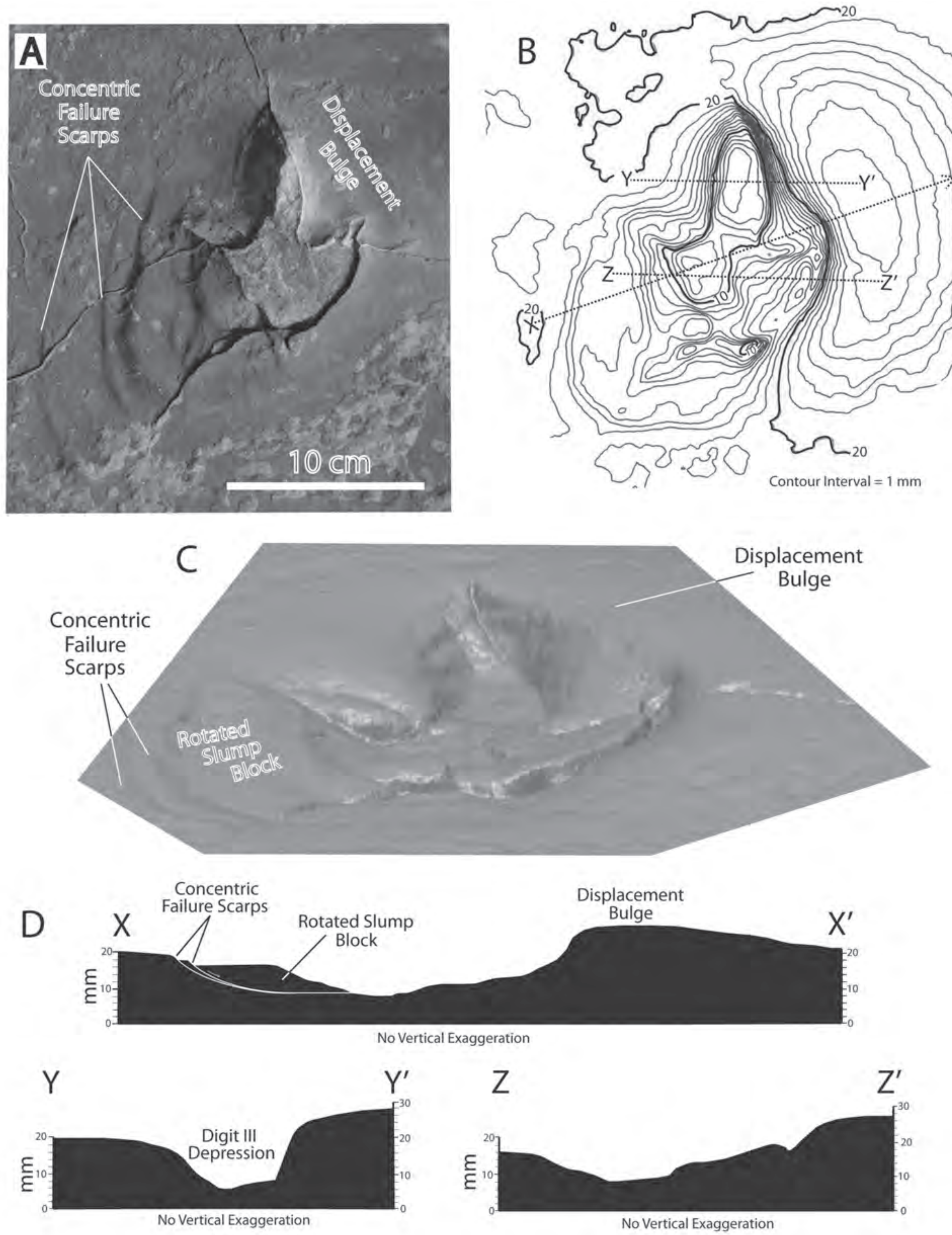

FIGURE 2. **A**, Photograph of a solitary, tridactyl dinosaur track at Tracksite UNLV-AZ-005. **B**, Topographic map of the track and the surrounding surface, generated from photogrammetric data. **C**, Low-angle, oblique view of orthophoto image of the same track, generated from photogrammetric data. **D**, Topographic profiles X-X', Y-Y', and Z-Z', as defined in B. Profile X-X' extends slightly farther to the upper right than indicated on the topographic map.

Nevada exposures of Aztec Sandstone was a brief account of the mammaloid ichnogenus *Brasilichnium* (presumably made by a tritylodontid therapsid trackmaker) in Valley of Fire State Park (Fig. 1) (Rowland and Mercadante, 2007). Stoller et al. (2013) recently documented the presence of small, tridactyl dinosaur tracks, along with the scorpionoid ichnogenus *Paleohelcura*, in the Aztec Sandstone of Valley of Fire State Park, but no tracks have previously been documented from the Aztec Sandstone of Red Rock Canyon National Conservation Area (RRCNCA) adjacent to Las Vegas (Fig. 1).

In 2011, hikers in RRCNCA alerted one of us (MS) that they had discovered possible dinosaur tracks in 2010. This turned out to be a tracksite (UNLV-AZ-004) with several dozen, variably preserved, tridactyl tracks (Brean, 2011a, b). Another tracksite (UNLV-AZ-005), with a single isolated tridactyl track, was discovered on a hike to examine the first site. The locations of these tracksites, in remote portions of RRCNCA, were not revealed to the public for preservation and safely reasons, but newspaper articles about the discoveries, with photographs of the tracks, triggered considerable local interest among hikers, RRCNCA employees, and the general public. A temporary exhibit featuring the newly discovered dinosaur tracks was placed in the RRCNCA Visitor Center in 2012. The heightened awareness of fossil tracks in the Aztec Sandstone in turn has led to the discovery of several additional vertebrate and invertebrate trace fossil sites within RRCNCA and elsewhere in southern Nevada.

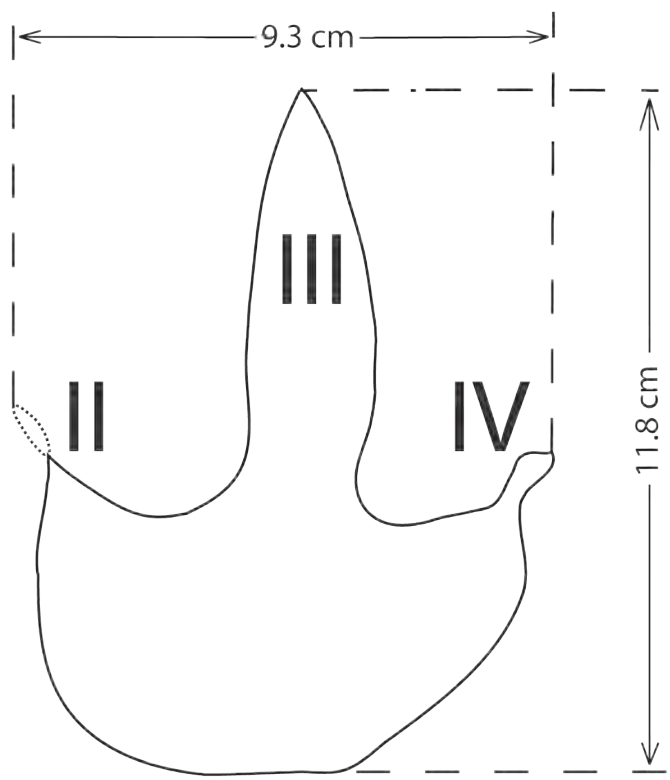

FIGURE 3. Outline and measurements of the track at Tracksite UNLV-

It now appears that the Aztec Sandstone in Nevada is not as ichnologically depauperate as previously thought, and that observation bias was the main reason for the paucity of reported tracks in southern Nevada. However, it is too soon to make detailed comparisons with California exposures to the southwest and with the Navajo Sandstone to the east. The purpose of this paper is to provide preliminary descriptions of three tracksites in the Aztec Sandstone of southern Nevada—all within RRCNCA.

Most of the dinosaur tracks described in this paper are undertracks attributable to the ichnogenus *Grallator*, with morphologies that have been distorted by the process of transmission through some thickness of sediment. However, some well-preserved footprints are present at one site that preserves excellent morphology, including digital pad impressions.

DESCRIPTIONS OF THE TRACKSITES

Tracksite UNLV-AZ-005

Figure 2A illustrates a nearly bilaterally symmetrical, tridactyl track. It is a solitary track on a narrow exposure of a bedding plane, much of which is covered, possibly concealing other tracks produced by the same animal. Rock varnish coats the bedding plane, which most likely has helped to preserve this track. The track is 11.8 cm long and 9.3 cm wide, with a length/width ratio of 1.3 (Fig. 3). It is likely that the posterior portion of the animal's footprint is not preserved, so the length dimension shown in Figure 3 is probably not an accurate measurement of the length of the animal's foot. For reasons explained below, we interpret this to be a right footprint, and the digits are numbered accordingly (Fig. 3).

We obtained photogrammetric data for this track, following techniques described by Breithaupt et al. (2004) and Matthews (2008). The photogrammetric data yielded a high-resolution topographic map with a contour interval of 1 mm (Fig. 2B), and a low-angle, oblique-view, orthophoto image of the track (Fig. 2C). The photo and map, along with topographic profiles X-X', Y-Y', and Z-Z' (Fig. 2D), show that the deepest portion of the footprint (the imprint of digit III) is 15 mm deep, compared to the adjacent surface on the left side of the track. The second deepest portion, near the proximal end of the left digit, is 14 mm deep. These two topographic depressions are separated by a saddle that is 2 mm higher than the shallower of the two depressions.

As shown on topographic profile Z-Z' and the topographic map, digit II created a distinct, deep imprint, while the imprint of digit IV is much shallower. The claws of digit III and digit II appear to have penetrated deeply into the sediment, while the claw of digit IV did not. The depths of both the proximal and distal portions of the imprint of digit IV are conspicuously shallower than those of digit II.

As shown on topographic profile X-X', as well as on the topographic map, lateral to the digit III depression there is a prominent topographic high, 7 mm higher than the surrounding surface. We refer to this feature as the displacement bulge (Fig. 2A and C). Posterior to the footprint, and wrapping around the posterior left side, are three, concentric, mm-scale escarpments, labeled concentric failure scarps. These are especially conspicuous on the photo (Fig. 2A).

The photogrammetrically-generated topographic map (Fig. 2B), oblique-view orthophoto image (Fig. 2C) and topographic profile X-X' (Fig. 2D) document a pronounced asymmetry in the geometry of the track and surrounding sediment. The wall on the right side of the digit III depression is nearly vertical, while the wall on the left side of the depression slopes

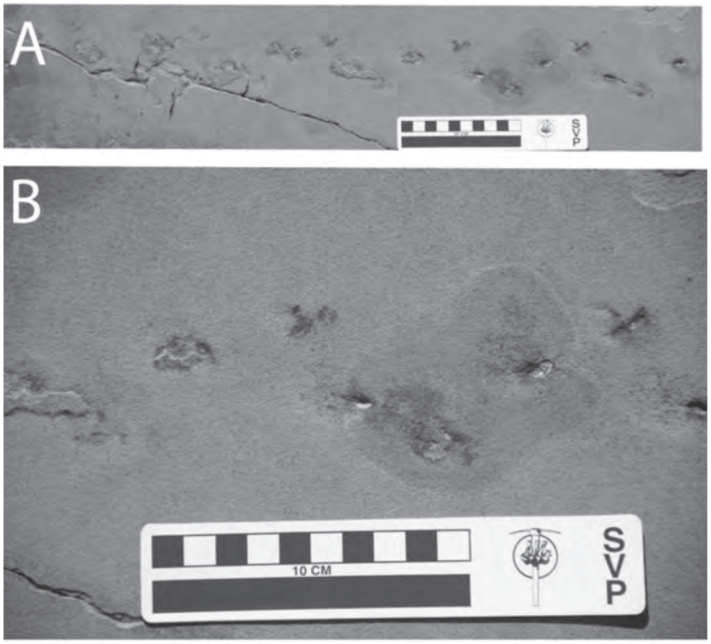

FIGURE 4. **A**, Photograph of *Octopodichnus* trackway at Tracksite UNLV-AZ-006, adjacent to UNLV-AZ-005. **B**, Detail of *Octopodichnus* tracks.

less steeply (see profile Y-Y' in Fig. 2D). We suggest that the dinosaur's foot entered the sand nearly perpendicular to the exposed surface, but it exited obliquely—forward and toward the left—causing the right side of the digit III depression to be steeper than the left side.

In addition, two features associated with this track suggest that the dinosaur was traversing a sloping surface, with the upslope direction on the animal's left side. One feature that suggests this is the fact that the left side of the foot sank deeper into the sand than did the right side, as discussed above and documented in Figure 2. This would occur if the animal were traversing a sloping surface, with the left side of its body on the uphill side of the slope.

The second feature that suggests that the dinosaur was crossing a sloping surface is the asymmetrical morphology of the sandstone surface adjacent to the track. We interpret the concentric failure scarps and rotated slump block on the left, posterior side of the track (Fig. 2) to represent brittle failure of moist cohesive sand on the uphill side of the track, in response to the penetration of the animal's foot into the sand. Simultaneously, the sediment on the downhill side of the penetrating foot (the right, anterior side of the track) experienced a pulse of increased pore pressure. The increased pore pressure permitted the sand to flow away from the impact of the dinosaur foot, creating the 7-mm-high displacement bulge on the right-anterior side of the footprint (Fig. 2). Assuming that the failure scarps and slump block were directly uphill from the point of foot penetration, and assuming that the displacement bulge developed directly downhill, it is interpreted that the dinosaur was walking diagonally downslope, at an angle of approximately 20˚ from the strike of the slope, with the upslope side on its left.

We can also say something about the moisture content of the sand. Neoichnological experiments with dry, moist, and saturated sand have shown that recognizable tracks can form only when the moisture content of the sand is in the range of 2-24% by weight (Manning, 2004). Below 2% moisture, the sand is not sufficiently cohesive for distinct tracks to form, and above 24% the sand flows under its own weight, also preventing the development of tracks. In the case of the track at Tracksite UNLV-AZ-005, the moisture content was probably toward the upper end of that range. Clearly, the sand was cohesive enough to preserve the track and also for brittle failure to occur. Moreover, it contained sufficient moisture that the increase in pore pressure, caused by the penetration of the dinosaur's foot into the sand, permitted the sand to flow, thus creating the 7-mm displacement bulge.

The topographic characteristics of the track and surrounding sediment suggest that this track is the impression of a dinosaur's right foot. This reconstructed penetration and exit scenario is biomechanically plausible for a bipedal dinosaur's right foot, entering vertically (or slightly obliquely from the right on a sloping surface) and exiting obliquely to the left, but it is biomechanically less plausible for a left foot. Thus, we interpret the track at site UNLV-AZ-005 to be a right footprint emplaced in very moist sand, made by a dinosaur moving diagonally downward across a sloping surface.

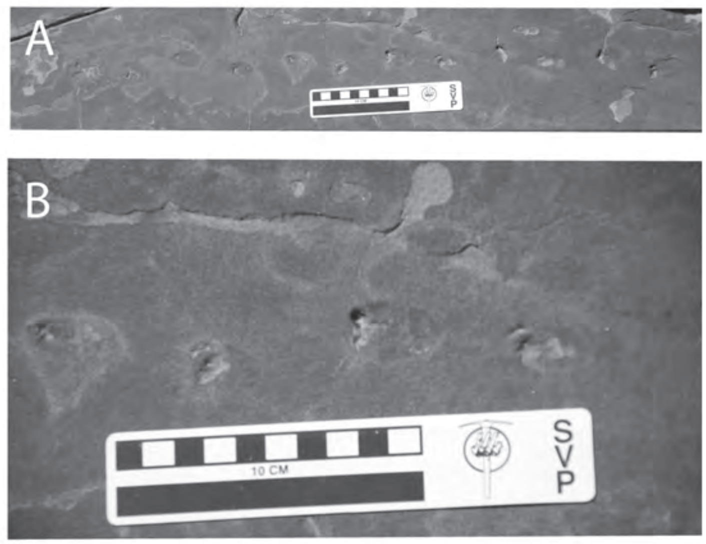

FIGURE 5. **A**, Photograph of unnamed synapsid trackway at Tracksite UNLV-AZ-006, adjacent to UNLV-AZ-005. **B**, Detail of trackway, showing 10-cm stride.

A few meters away from the solitary dinosaur track, on a bedding plane that is 4 cm stratigraphically higher, is a 1.8-m-long *Octopodichnus* (arthropod) trackway (Fig. 4). On a nearby bedding plane, stratigraphically 2.3 m below the dinosaur-track surface, is an undescribed, 2-m-long trackway made by a small synapsid with a stride of approximately 10 cm (Fig. 5).

Tracksite UNLV-AZ-004

This site was the first dinosaur tracksite to be recognized within RRCNCA (Brean, 2011a, b). The tracksite lies on top of an interval of thin, planar strata, 1.35 meters above the base of a cross-bedded set (Fig. 6). The exposed trackway surface is roughly oval in shape, approximately 6 meters long and 3 meters wide, although a large portion of the surface is obscured by an overlying layer of sandstone (Fig. 7). More than 50 poorly preserved undertracks occur on this surface, as well as some well-preserved tracks exhibiting digital pad impressions. Of the

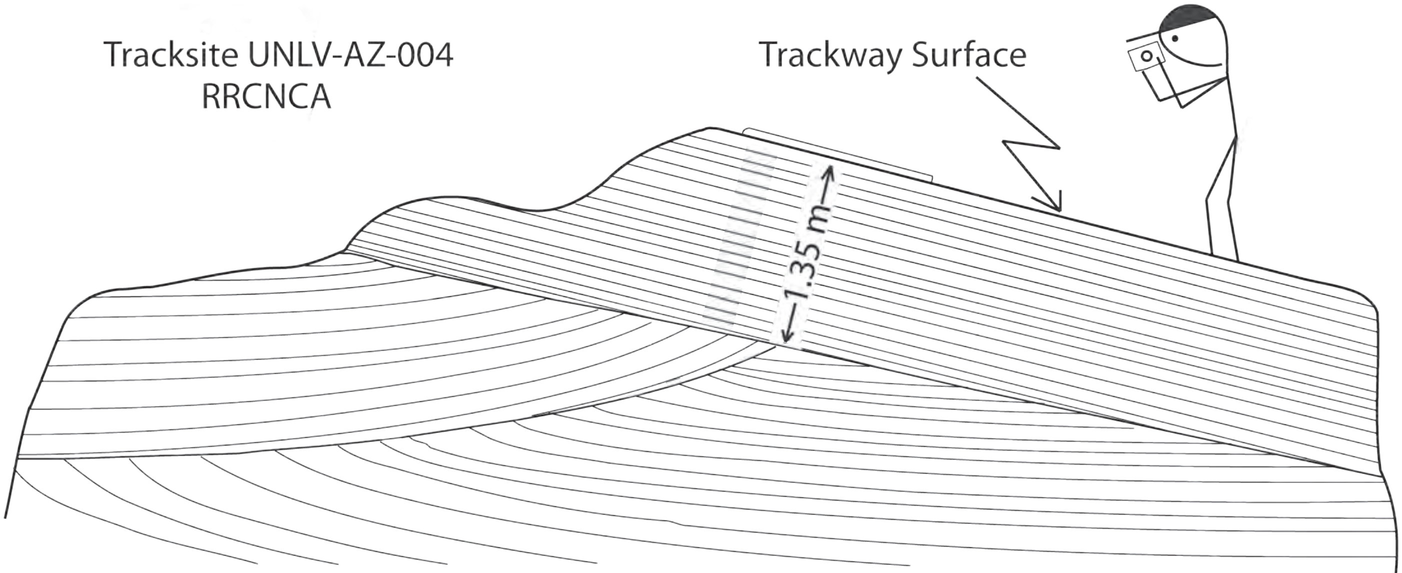

FIGURE 6. Cross-section sketch of Tracksite UNLV-AZ-004.

tracks that are distinct enough for the orientation to be determinable, some are oriented northward (Fig. 8), while others are oriented eastward (Fig. 9). Many of the tracks are too indistinct for an orientation direction to be determined. We identify three trackways at this site, all of which are oriented in a generally eastward direction, within 20° of one another. The tracks in these three east-directed trackways all exhibit a bulge or sand crescent on the right posterior margin of the track, suggesting that the animals were traversing diagonally up a slope, with the upslope direction on their left side.

Many of the tracks are approximately 13 cm long and 11 cm wide (Fig. 8), but some tracks as short as 5 cm are also present (Fig. 9A). Figure 9 shows a photogrammetrically derived orthophoto image of a portion of the trackway surface (Fig. 9C), with topographic maps of individual footprints (Fig. 9A-B), indicating the variation in size and preservation of footprints present at this site. The two types of preservation of tracks at this site may indicate different track generation episodes, with some tracks being made in wetter conditions than others. Interpretations related to track generation and behavioral implications of the footprints related to the trackmakers are underway as the analysis of this site is not yet complete.

Tracksite UNLV-AZ-008

Tracksite 008 consists of a 10-meter-long, allochthonous block of sandstone with a trackway of 17 tridactyl tracks on a rock-varnish-coated, bedding-plane surface (Fig. 10). In contrast to the tracks at Tracksite UNLV-AZ-004, the tracks at this site are deeper (Fig. 11), being up to about 1.5 cm deep. Digit III is typically well represented, however impressions of the distal portions of digits II and IV are not present (Fig. 11), indicating that these are undertracks. The track illustrated in Figure 11 is one of the most clearly defined tracks in the trackway. It is 14.0 cm long and 7.7 cm wide, with a length/width ratio of 1.8. The footprint is distinctly asymmetrical. Divarication angles are shown in Figure 11B.

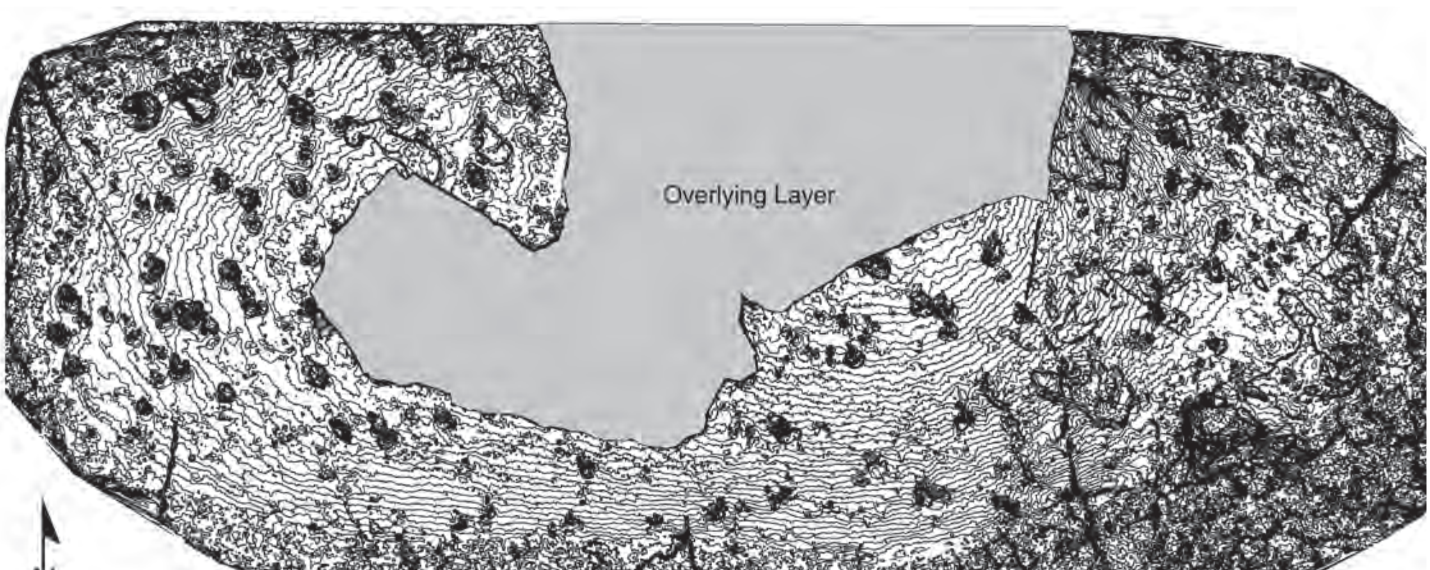

FIGURE 7. Topographic map of Tracksite UNLV-AZ-004, generated from photogrammetric data. Contour interval is 1 mm.

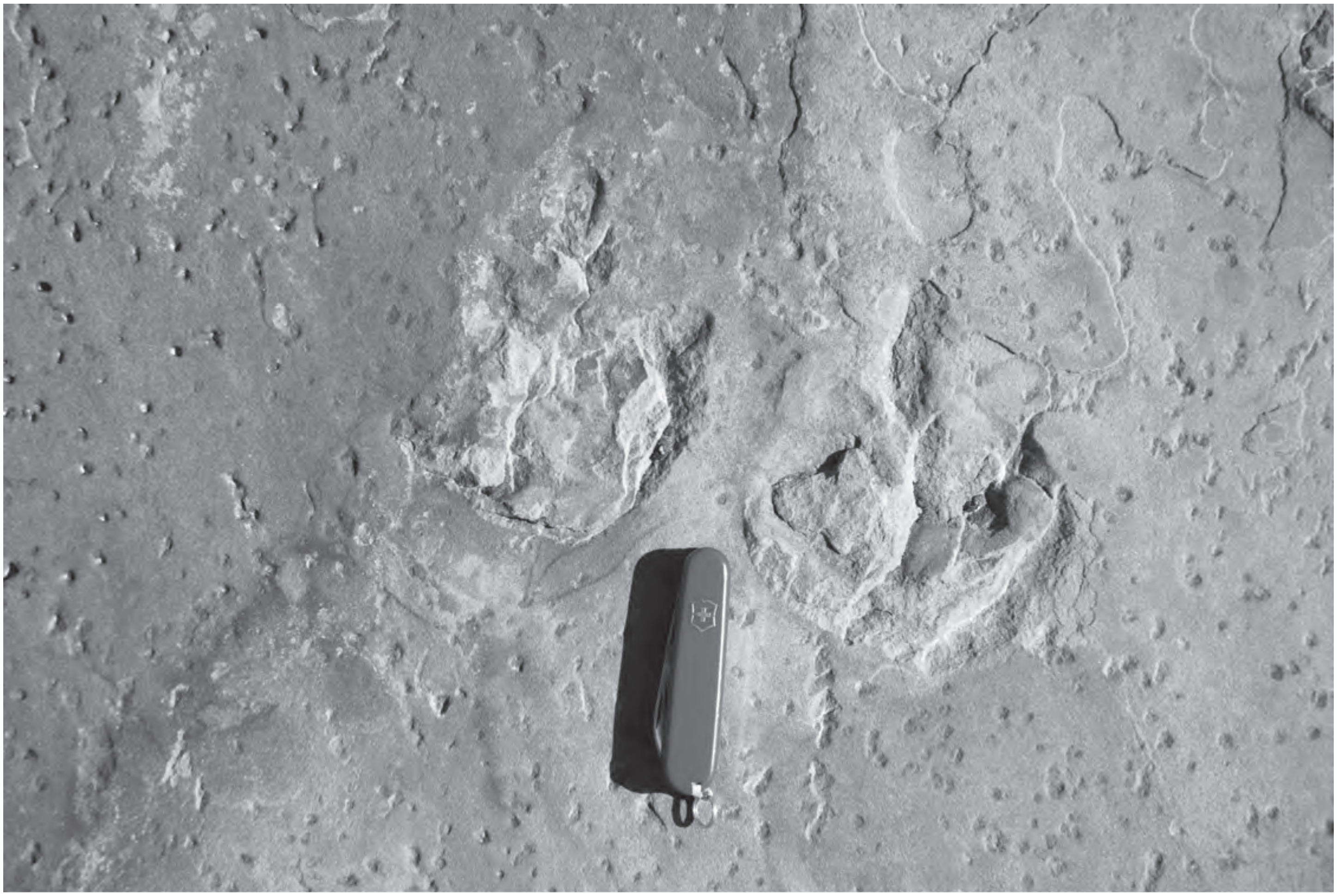

FIGURE 8. Photograph of two northward-directed tracks at Tracksite UNLV-AZ-004. Knife is 8.5 cm long. Tracks are 13 cm long and 11 cm wide.

Figure 12 shows a preliminary photogrammetric image (Fig. 12A) and a topographic map (Fig. 12B) of the trackway surface. A conspicuous feature visible on the topographic map is the presence of crescent-shaped mounds, typically 5 to 7 mm in elevation, adjacent to the posterior edge of each track (Fig. 12B). We interpret these mounds to be displacement bulges that formed on the downslope side of each foot penetration, similar to the displacement bulge at Tracksite UNLV-AZ-005, discussed above. These indicate that the animal was walking upslope, and also that the sand contained sufficient moisture for an increase in pore pressure (caused by the penetration of the foot) to cause the sand to flow.

Figure 13A is a map of the entire trackway; the 17 individual tracks are identified with letters “a” through “q” Figures 13B and 13C are a photograph and map, respectively, of the central portion of the trackway, with quantitative characteristics labeled in Figure 13C.

Visible in both the photogrammetric image and the topographic map of Figure 12 are two *Brasilichnium*-like synapsid trackways that run sub-parallel to the dinosaur trackway. These tracks are approximately 3 cm wide, 2 cm long and a few mm deep (Fig. 14). One of these trackways appears near the lower left corners of Figures 12A and B; it crosses the dinosaur trackway and continues along the right margin of each image toward the top. The other *Brasilichnium*-like trackway appears near the left-central edge of Figures 12A and B; it also goes diagonally upward, crossing the dinosaur trackway, eventually merging with the other synapsid trackway. Both *Brasilichnium*-like trackways are oriented in the same general direction as the dinosaur trackway.

Additional analysis is being done at this site to interpret the activities and behaviors represented by the dinosaur and synapsid trackways.

SUMMARY AND CONCLUSIONS

As shown in these three examples, dinosaurs and other animals did indeed inhabit the Jurassic dune-field environment now represented by the Aztec Sandstone of RRCNCA. In one case, Tracksite UNLV-AZ-005, a single theropod dinosaur track is preserved, with *Octopodichnus* and synapsid trackways occurring nearby on different bedding planes. Through the use of photogrammetry, we interpret the theropod track, together with the morphology of adjacent sediments, to record the emplacement of a dinosaur’s right foot into moist sand as the animal moved diagonally downward across a sloping surface. In the case of Tracksite UNLV-AZ-004, several dozen dinosaur tracks are present, exhibiting various types of preservation. Three subparallel trackways suggest that some of the animals were moving diagonally upward across a sloping surface. And at Tracksite UNLV-AZ-008, a distinct dinosaur trackway is preserved, along with numerous *Brasilichnium*-like synapsid

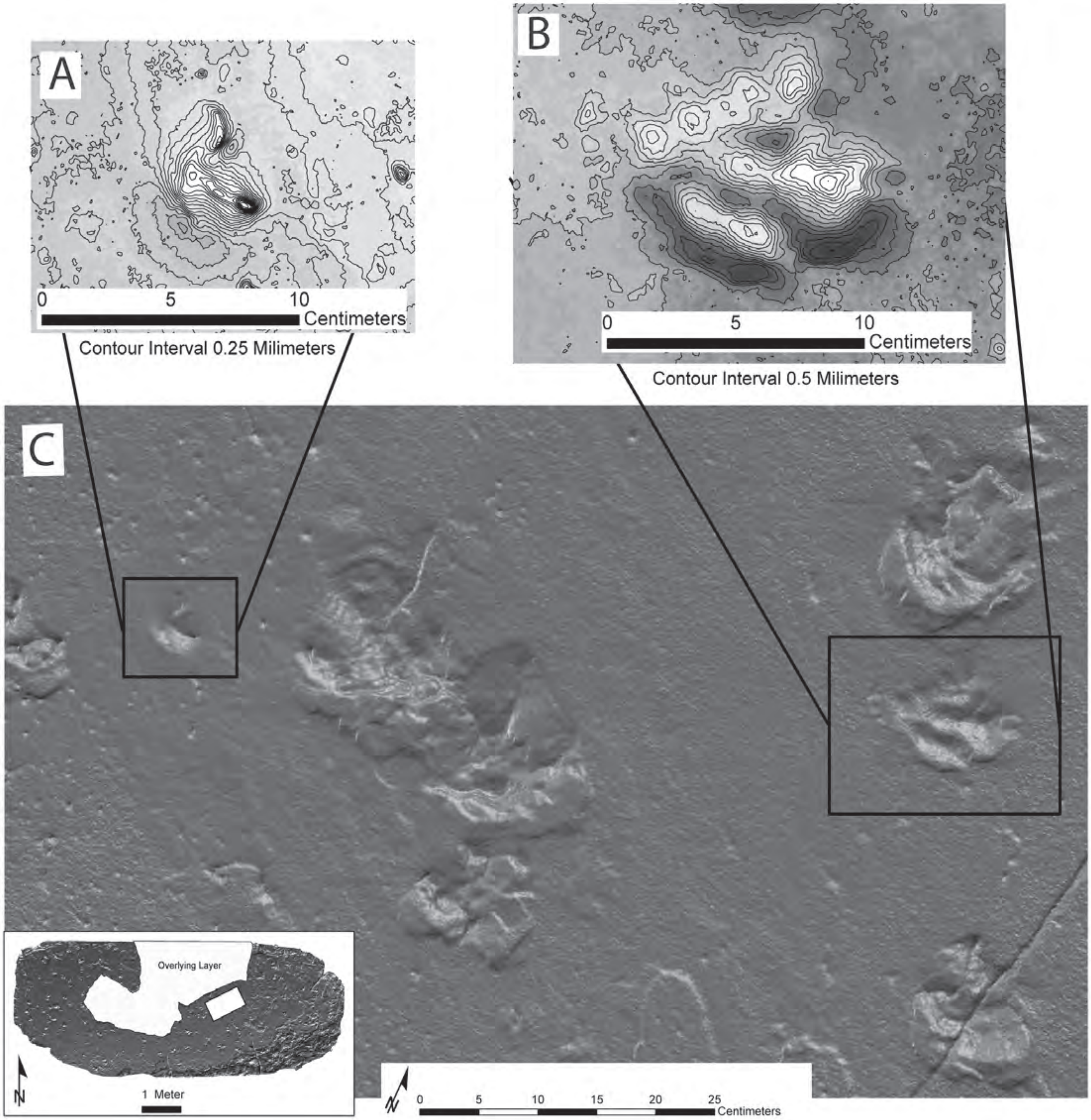

FIGURE 9. Orthophoto image (C) of a portion of Tracksite UNLV-AZ-004, and topographic maps of two tracks (A and B) within image C, created from photogrammetric data. Inset in C shows position on the tracksite surface.

tracks; we interpret these animals to have been walking directly upslope.

The morphology of most of the dinosaur tracks, with broad bases and the absence of distinct digital pad traces, indicates that they are undertracks. However, excellent tridactyl footprints occur at Tracksite UNLV-AZ-004, preserving digital pad impressions. In addition, differential preservation related to water content, paleoslope, and track generation episodes, is also indicated by the tracks under study.

While we were preparing this first report of tracks in RRCNCA, hikers have alerted us to additional, previously unreported Aztec Sandstone tracksites in RRCNCA and elsewhere. Some of these consist of dinosaur tracks, while others consist of synapsid tracks, arthropod tracks, or an intertaxonomic medley of animal traces. We anticipate that the study of additional sites, along with continued research on the sites described in this paper, will lead to a much richer picture of life in the Jurassic Aztec sand sea.

ACKNOWLEDGMENTS

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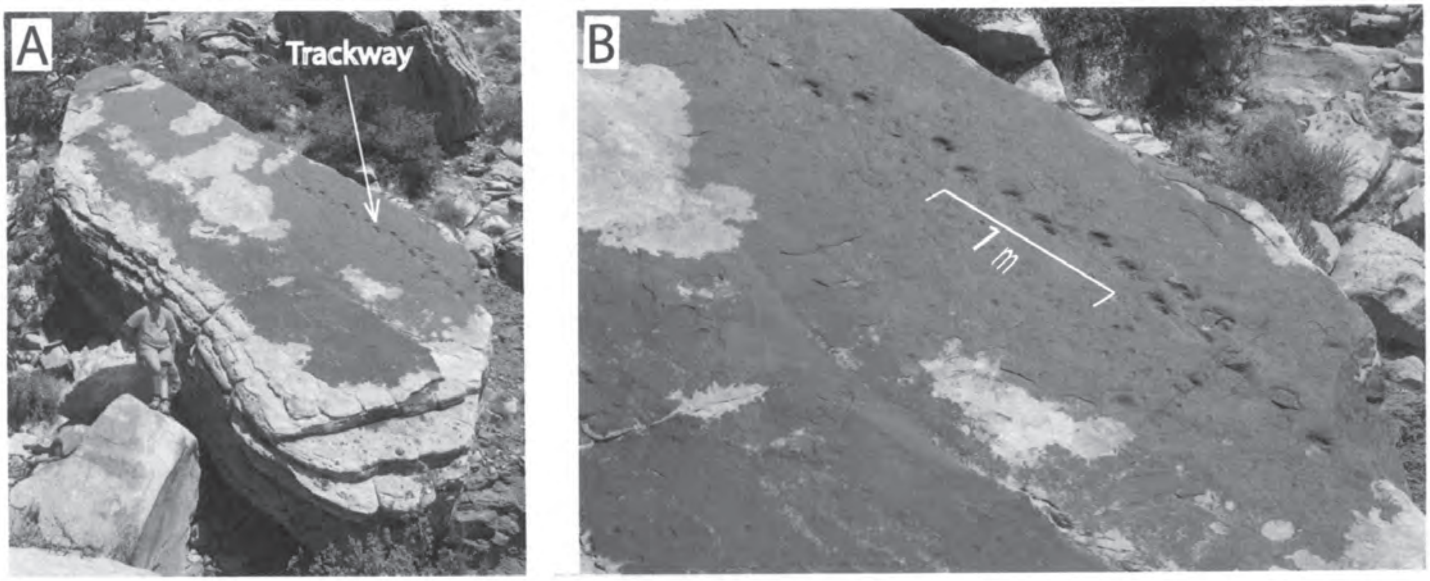

FIGURE 10. **A**, Photograph of allochthonous block at Tracksite UNLV-AZ-008, with arrow pointing to dinosaur trackway. The sandstone boulder is 10.0 m long, 3.6 m wide at the widest point, and 2.5 m thick. **B**, Close-up view showing trackway.

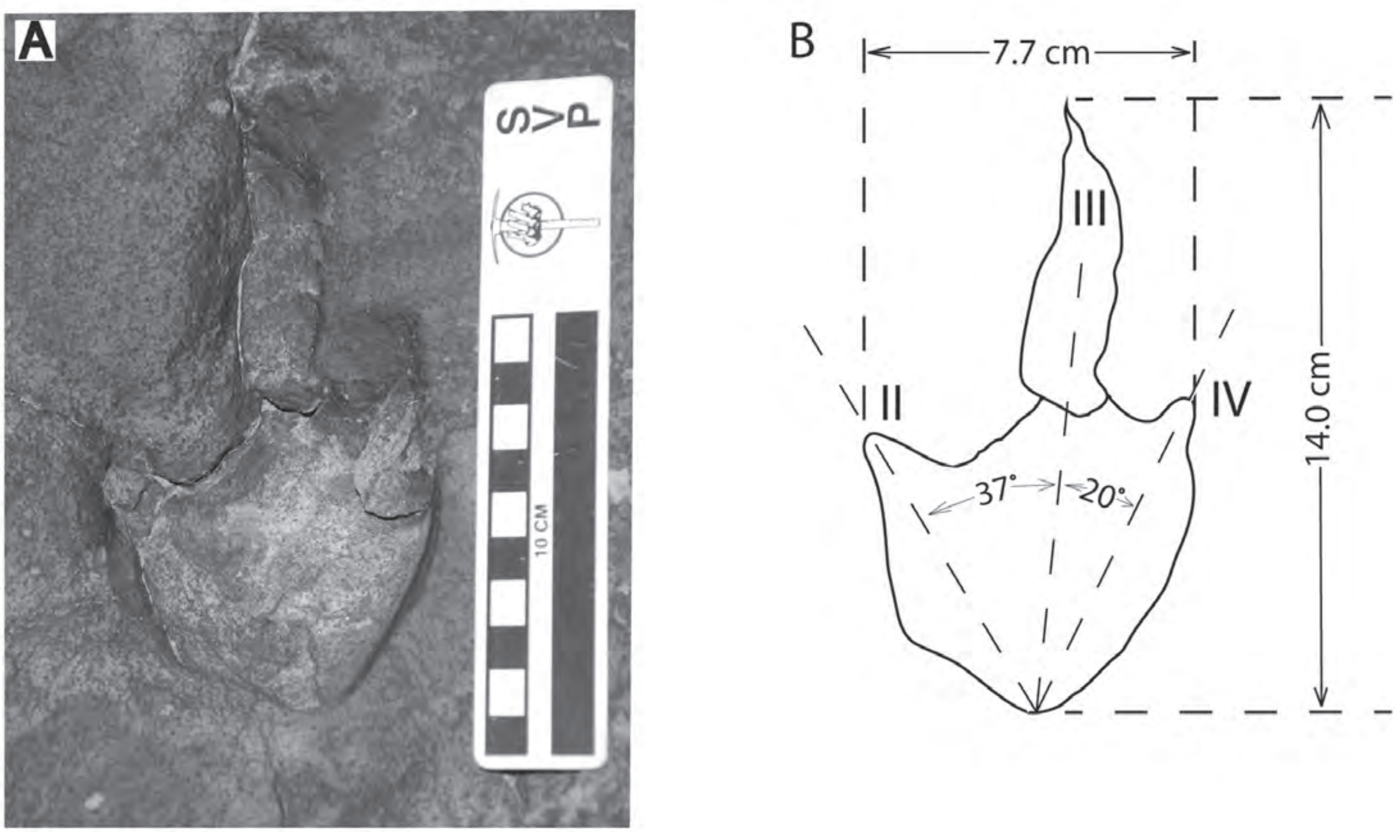

FIGURE 11. **A**, Photograph of track "b" at tracksite UNLV-AZ-008 (see Fig. 13). **B**, Dimensions and divarication angles of track "b."

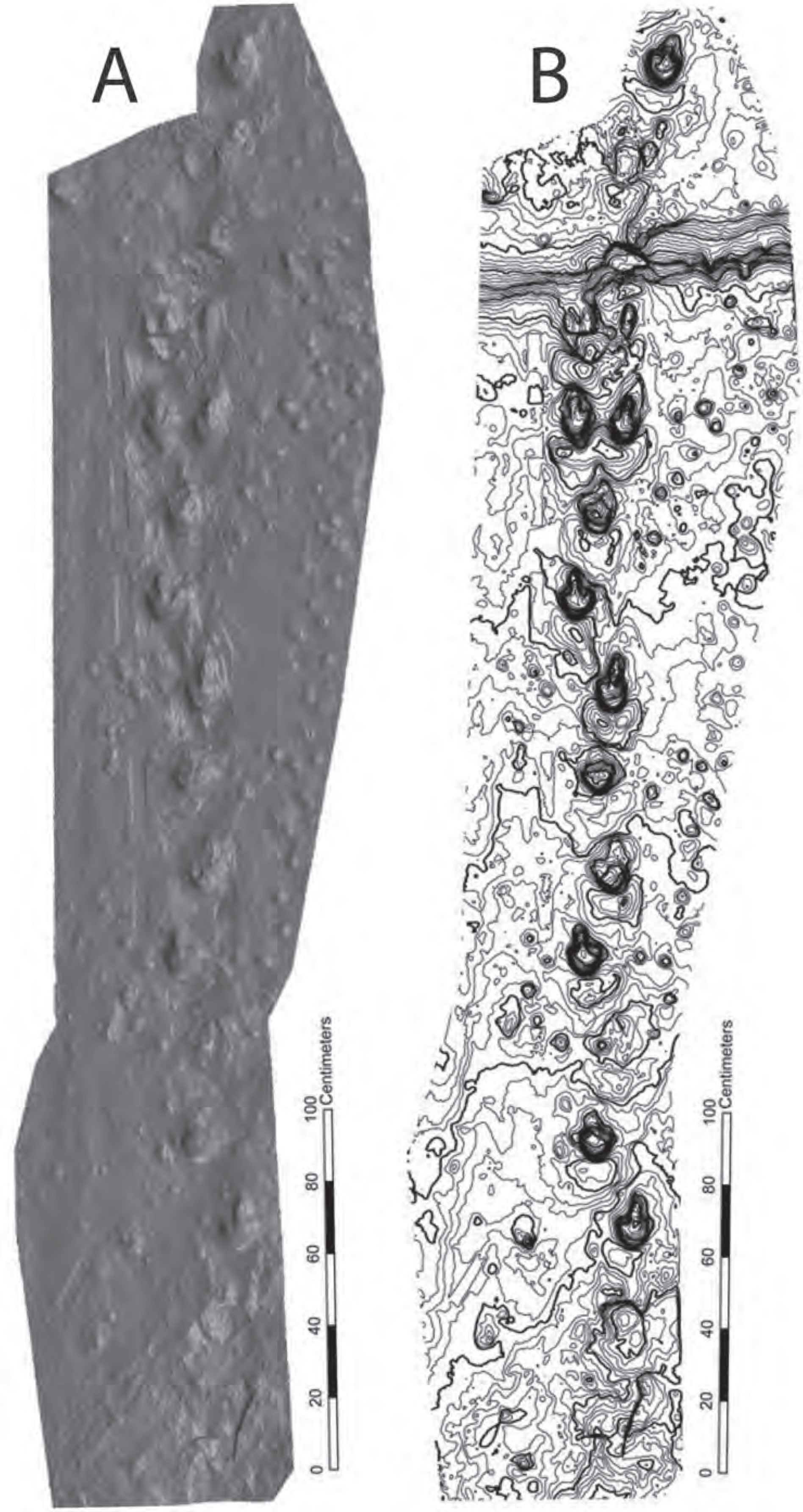

FIGURE 12. Orthophoto image (A) and topographic map (B) of a portion of Tracksite UNLV-AZ-008 created from photogrammetric data. Contour interval of topographic map is 1 mm.

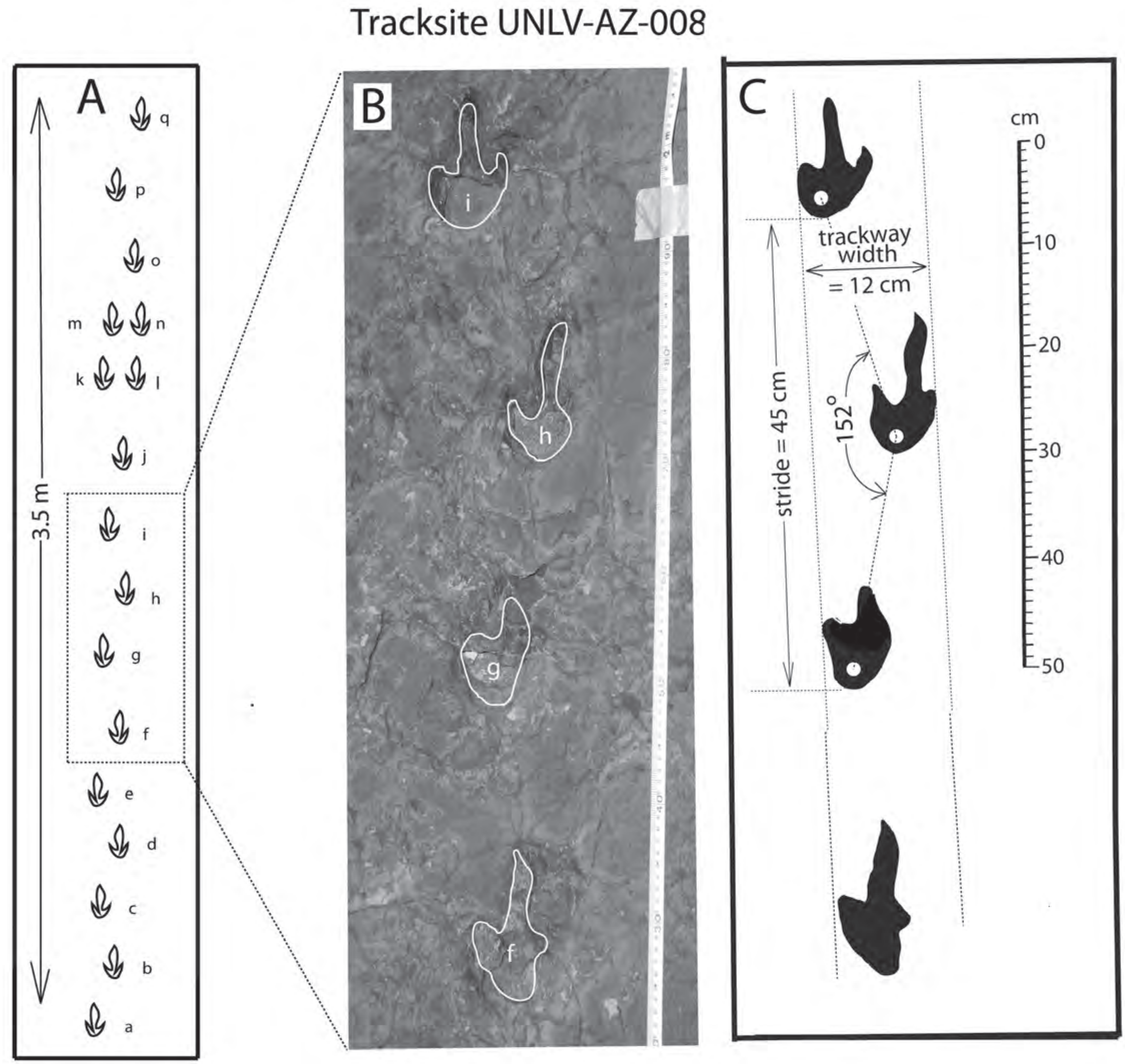

FIGURE 13. **A**, Map of the dinosaur trackway at Tracksite UNLV-AZ-008. **B**, Photograph of a portion of the trackway, with tracks 'f' through 'i' outlined in white. **C**, Map of tracks 'f' through 'i', showing measurements of stride, trackway width, and pace angulation.

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REFERENCES

Baird, D., 1980. A prosauropod dinosaur trackway from the Navajo Sandstone (Lower Jurassic) of Arizona; *in* Jacobs, L.L., ed., Aspects of Vertebrate History: Essays in Honor of Edwin Harris Colbert. Flagstaff, Museum of Northern Arizona Press, p. 219-230.

Brean, H., 2011a, Dinosaurs hiked Red Rock: Las Vegas Review-Journal, November 21, 2011, p. 1B, 3B.

Brean, H., 2011b, Hikers stumble onto dinosaur prints: Las Vegas Review-Journal, December 4, 2011, p. 1B, 8B.

Breithaupt, B.H., Matthews, N.A. and Noble, T.A., 2004, An integrated approach to three-dimensional data collection at dinosaur tracksites in the Rocky Mountain West: Ichnos, v. 11, p. 11-26.

Ekdale, A.A., Bromley, R.G. and Loope, D.B., 2007, Ichnofacies of an ancient erg: A climatically influenced trace fossil association in the Jurassic Navajo Sandstone, southern Utah, USA; *in* Miller III, W., ed., Trace Fossils: Concepts, Problems, Prospects, p. 562-574.

Faul, H. and Roberts, W.A., 1951, New fossil footprints from the Navajo(?) Sandstone of Colorado: Journal of Paleontology, v. 25, p. 266-274.

Hamblin, A.H. and Bilbey, S.A., 1999, A dinosaur track site in the Navajo-Nugget Sandstone, Red Fleet Reservoir, Uintah County, Utah; *in* Gillette, D.D., ed., Vertebrate Paleontology of Utah: Utah Geological Survey Miscellaneous Publications, p. 51-57.

Irmis, R.B., 2005, A review of the vertebrate fauna of the Lower Jurassic Navajo Sandstone in Arizona; *in* McCord, R.D., ed., Vertebrate Paleontology of Arizona: Mesa Southwest Museum Bulletin Number 11, p. 55-71.

Lockley, M.G., 2005, Enigmatic dune walkers from the abyss: Some thoughts on water and track preservation in ancient and modern deserts: Canyon Country (Museum of Moab), v. 54, p. 43-51.

Lockley, M.G. and Hunt, A.P., 1995, Dinosaur tracks and other fossil footprints of the western United States: New York, Columbia University Press, 338 p.

Loope, D.B., 2006, Dry-season tracks in dinosaur-triggered grain flows: PALAIOS, v. 21, p. 132-142.

Manning, P.L., 2004, A new approach to the analysis and interpretation of tracks: examples from the dinosaurian; *in* McIlroy, D., ed., The Application of Ichnology to Palaeoenvironmental and Stratigraphic Analysis: Geological Society, London, Special Publication 228, p. 93-123.

Marzolf, J.E., 1993, Palinspastic reconstruction of Early Mesozoic sedimentary basins near the latitude of Las Vegas: Implications for the early Mesozoic Cordilleran cratonal margin; *in* Dunn, G., and McDougall, K., eds., Mesozoic Paleogeography of the Western United States—II, Pacific Section SEPM, Book 71, p. 433-462.

Marzolf, J.E. and Anderson, T.H., 2005, Lower Mesozoic facies and crosscutting sequence boundaries: Constraints on displacement of the Caborca terrane; *in* Anderson, T.H., Nourse, J.A., McKee, J.W., and Steiner, M.B., eds., The Mojave-Sonora Megashear Hypothesis: Development, Assessment, and Alternatives: Geological Society of America Special Paper 393, p. 283-308, doi: 10.1130/2005.2393(10).

Matthews, N. A., 2008, Aerial and Close-Range Photogrammetric Technology: Providing Resource Documentation, Interpretation, and Preservation: Technical Note 428, U.S. Department of the Interior, Bureau of Land Management, National Operations Center, Denver, Colorado, 42 p.

Milàn, J., Loope, D.B. and Bromley, R.G., 2008, Crouching theropod and *Navahopus* sauropodomorph tracks from the Early Jurassic Navajo Sandstone of USA: Acta Palaeontologica Polonica, v. 53, p. 197-205.

Milner, A.R.C., Birthisel, T.A., Kirkland, J.I., Breithaupt, B.H., Matthews, N.A., Lockley, M.G., Santucci, V.L., Gibson, S.Z., DeBlieux, D.D., Hurlburt, M., Harris, J.D. and Olsen, P.E., 2012, Tracking Early Jurassic dinosaurs across southwestern Utah and the Triassic-Jurassic transition; *in* Bonde, J.W., and Milner, A.R.C., eds., Field Trip Guidebook for the 71st Annual Meeting of the Society of Vertebrate Paleontology, Nevada State Museum Paleontological Papers 1, p. 1-107.

Ogg, J.G. and Hinnov, L.A., 2012, Jurassic; *in* Gradstein, F.M., Ogg, J.G., Schmitz, M.D. and Ogg, G.M., eds., The Geologic Time Scale 2012: Elsevier, p. 731-791.

Parrish, J.T. and Falcon-Lang, H.J., 2007, Coniferous trees associated with interdune deposits in the Jurassic Navajo Sandstone Formation, Utah, USA: Palaeontology, v. 50, p. 829-843.

Peterson, F. and Pipiringos, G.N., 1979, Stratigraphic relations of the Navajo Sandstone to Middle Jurassic formations, southern Utah and northern Arizona: U. S. Geological Survey, Professional Paper 1035F, 43 p.

Rainforth, E.C. and Lockley, M.G., 1996, Tracks of diminutive dinosaurs and hopping mammals from the Jurassic of North and South America; *in* Morales, M., ed., The Continental Jurassic: Museum of Northern Arizona Bulletin 60, p. 265-269.

Reynolds, R.E., 2006a, Way out west: Jurassic tracks on the continental margin: New Mexico Museum of Natural History and Science, Bulletin 37, p. 232-237.

Reynolds, R.E., 2006b, Jurassic tracks in California; *in* Reynolds, R.E., ed., Making Tracks Across the Southwest: California State University Desert Studies Consortium, p. 19-24.

Rowland, S.M. and Mercadante, J., 2007, Gregarious behavior recorded in the tracks of a Jurassic therapsid: Journal of Vertebrate Paleontology, v. 27, Supplement to no. 3, p. 137A.

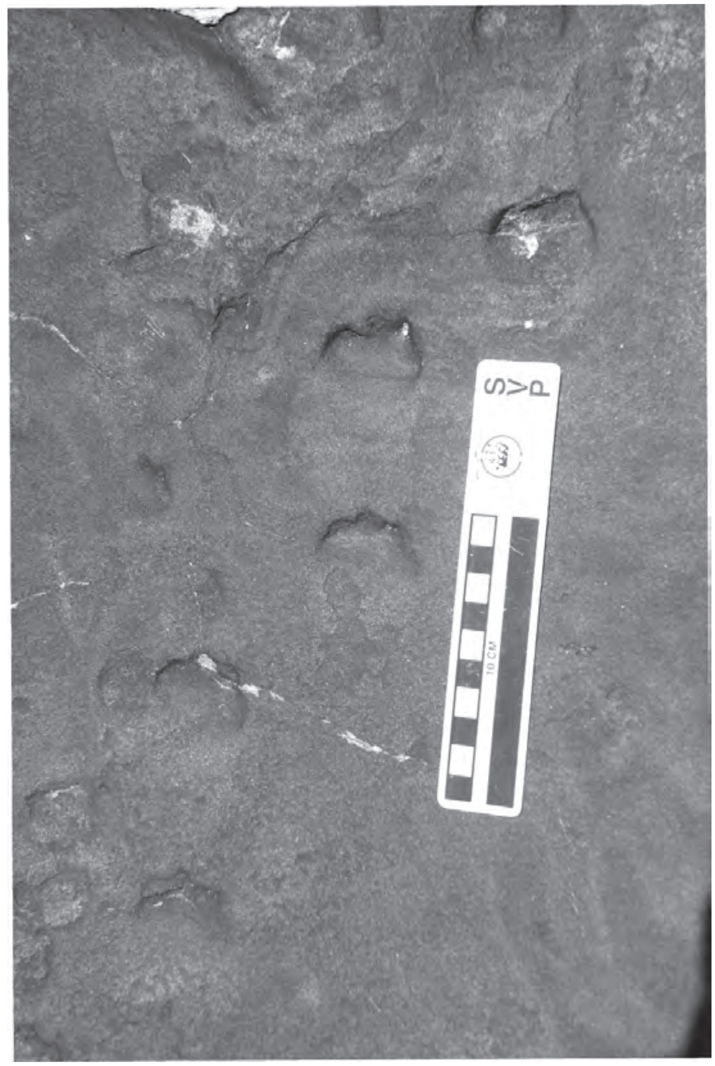


FIGURE 14. Photograph of *Brasilichnium*-like synapsid tracks at Tracksite UNLV-AZ-008.

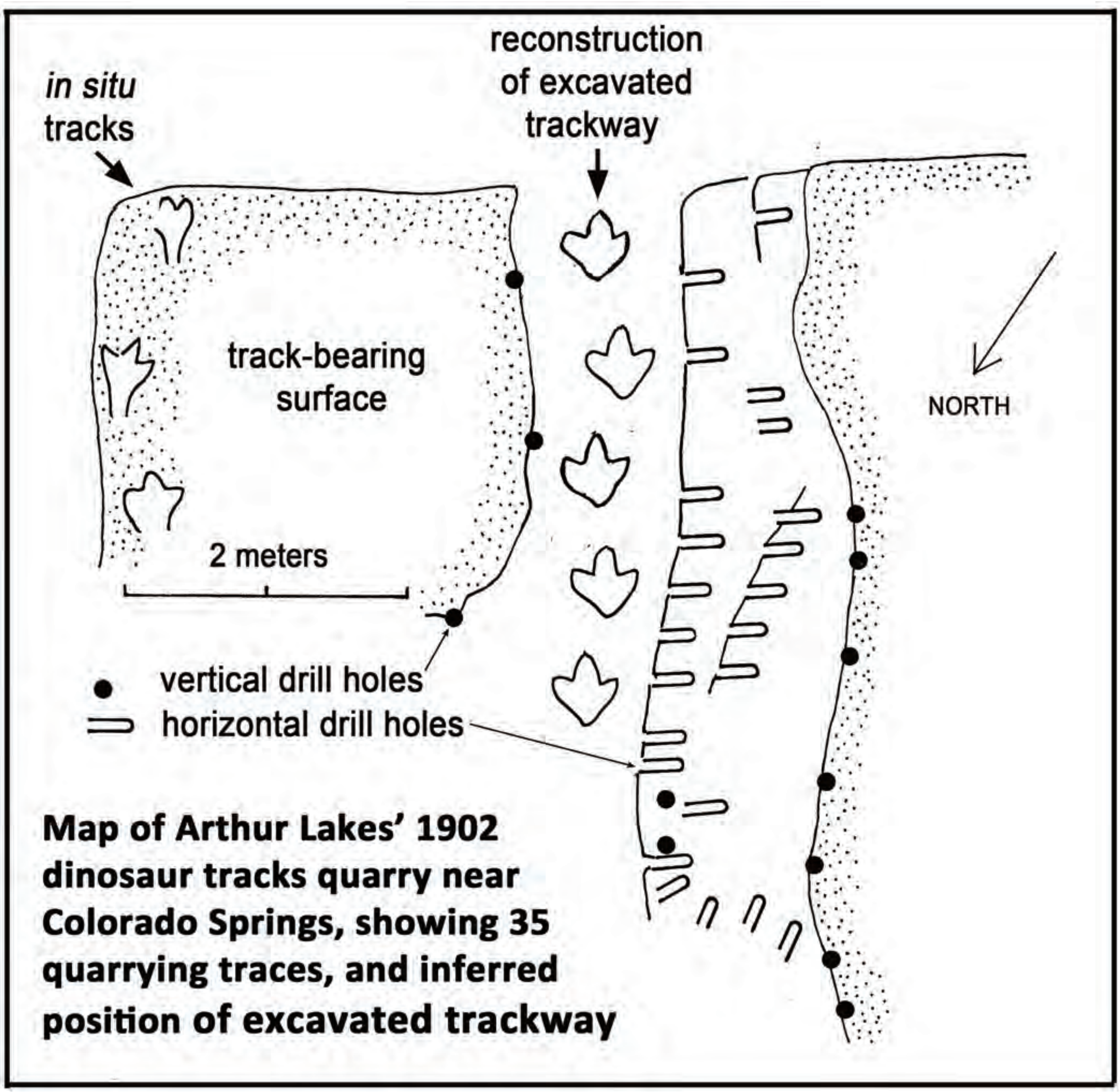
Sertich, J.J.W., and Loewen, M.A., 2010, A new basal sauropodomorph dinosaur from the Lower Jurassic Navajo Sandstone of southern Utah: PLoS ONE 5(3): e9789. doi:10.1371/journal.pone.0009789.

Smith, J.A. and Santucci, V.L., 2001, Vertebrate ichnostratigraphy of the Glen Canyon Group (Jurassic) in Zion National Park, Utah; *in* Reynolds, R.E., ed., The Changing Face of the East Mojave Desert: California State University, Desert Studies Consortium, p. 15-19.

Springer, K.B., Chiappe, L., Sagebiel, J.C. and Scott, E., 2009, Preserving California's only dinosaur trackways by collection—an unprecedented opportunity for public protection and interpretation of fossil specimens from federal land; *in* Foss, S.E., Cavin, J.L., Brown, T., Kirkland, J.I., and Santucci, V.L., eds., Proceedings of the Eighth Conference on Fossil Resources: St. George, Utah, p. 26-27.

Stoller, H.M., Rowland, S.M. and Jackson, F.D., 2013, Dinosaur and arthropod tracks in the Aztec Sandstone of Valley of Fire State Park, Nevada; *in* Reynolds, R.E., ed., Raising Questions in the Central Mojave Desert: California State University Desert Studies Consortium, p. 159-164.

Winkler, D.A., Jacobs, L.L., Congleton, J.D. and Downs, W.R., 1991, Life in a sand sea: Biota from Jurassic interdunes: Geology, v. 19, p. 889-892.



Map of Arthur Lakes' 1902 dinosaur tracks quarry near Colorado Springs, showing 35 quarrying traces, and inferred position of excavated trackway