Tracks and Burrows in Jurassic Dune Deposits

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ABSTRACT

Animal tracks and burrows are abundant in portions of the Jurassic Navajo and Entrada Sandstones of southern Utah. These trace fossils are especially well preserved in wind-blown (eolian) sandstones because they disrupt the distinct layering produced by sand avalanches and by migration of wind ripples. Tracks at Coyote Buttes were both made and buried in dry sand that freely avalanched as the animals moved across the steep dune slopes. Although the surface expression of such tracks is erased, the lower parts of the tracks are preserved. Large burrows (up to 63 cm in diameter) in the Entrada Sandstone were excavated high on dune slopes into sand that had been made cohesive by infiltrating rainwater. The abundance of tracks and burrows demonstrate that the ancient dunes must have periodically received enough rainfall to support a thriving ecosystem.

Keywords: trace fossils, Navajo, Entrada, sandstone, eolian, paleoecology

Introduction

When a geologist sees a formation of sedimentary rocks exposed on a canyon wall or coastal cliff, a question immediately arises: What kind of a place was this when the sediment was delivered (before it was cemented into rock)? Sediments accumulate at the surface of the earth. Sandstones, for instance, can record sediment accumulations in ancient river channels, desert dunes, beaches, tidal inlets, or deep-sea floors. In each of these kinds of places, animals moving over or through the sediment make distinctive records – trace fossils – that are of great help in determining the environment of deposition. These trace fossils are not only more abundant than body fossils (skeletal parts), but they also directly record something that skeletal remains cannot – animal behavior. Further, unlike body fossils, they are unlikely to be transported away from where they were formed.

In southern Utah and northern Arizona, many of the canyon walls reveal sandstones deposited in vast inland deserts. In this paper, I describe signs of ancient life from two sandstones widespread on the Colorado Plateau – the Lower Jurassic Navajo Sandstone (about 190 million years old), and Middle Jurassic Entrada Sandstone (about 160 million years old; Fig. 1). The abundant trace fossils in parts of these formations indicate that there was (at least periodically) enough rainfall on the dunes to support a thriving ecosystem (Loope and Rowe, 2003).

Whether it is moved by wind or water, sand almost always moves as migrating ridge-like piles – ripples (less than 2 cm-high) or dunes (higher than 0.5 m). When the flow is strong enough to move the grains, the dunes and ripples migrate and produce cross-bedding (Fig. 2). Crossbeds slope in the downflow direction, because the steep, downflow side of the migrating dunes or ripples is repeatedly buried. By itself, the crossbedding in the Navajo and Entrada Sandstones doesn't tell us that the environment of deposition was a desert; we have to look for other clues. Probably the best evidence that these formations were deposited by sand-laden winds is the great abundance of wind-ripple deposits; wind ripples make layers that are quite different from water-laid ripples (Hunter, 1977). Bones and other skeletal fossils are very

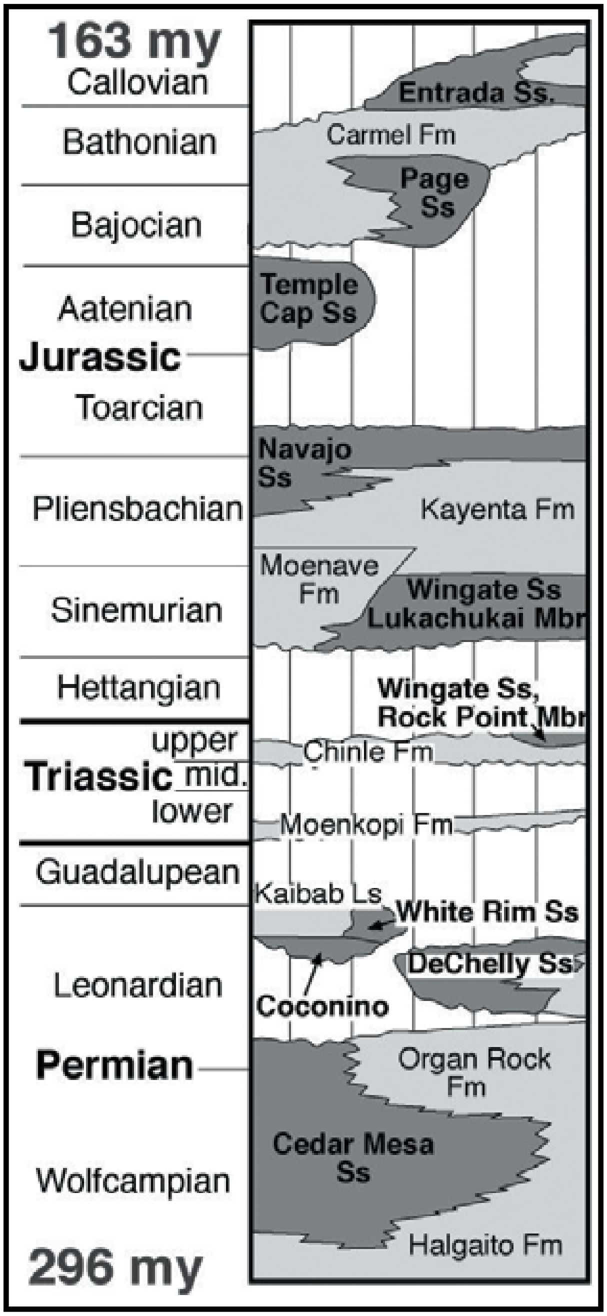

Figure 1. Stratigraphic column showing eolian (wind-blown) sandstones (dark shading) of the Colorado Plateau (from Blakey et al., 1988).

rare in both formations, but trace fossils can be very abundant, and these support the other lines of evidence for a desert environment (as opposed to the aqueous environments).

Green plants, the primary producers in ecosystems, are sparse on actively migrating dunes, so few animals can live in dunefields. Most of these animals are small, and many have adapted to the harsh habitat by becoming nocturnal. A walk over a desert dune in the early morning commonly reveals abundant animal trails, many of which start or stop at the throat of a burrow. Although most of these tracks and burrows are destroyed as erosion removes sand from the upwind side of the dune, tracks and burrows are preserved within the crossbeds that escape scour as the dunes migrate and climb over one another. Some geologists have argued that moistening of the loose sand is a requirement for the preservation of tracks and trails, claiming that all dry-sand tracks are eroded away. In this paper, I'll attempt to show that many of the tracks in the Navajo Sandstone were both made and preserved in dry sand.

Figure 2. Crossbedding in the Navajo Sandstone, produced by large dunes migrating left to right. Horizontal lines are erosion surfaces produced by migration of the troughs between dunes. Each set of crossbeds (interval between successive horizontal lines) is only a fraction of the full height of the original dune. Avalanche layers are indicated by a's, wind-ripple layers by w's.

Tunneling into subtropical dunes allows animals to avoid the intense heat of the surface and to escape predators. Some of the animals that live in dunes – the sand swimmers – can force their way into and through loose, dry sand. The sand collapses immediately behind these animals; all that is left is a disruption of the layering in the sand. Other modern animals dig burrows that stay open because they are surrounded by cohesive

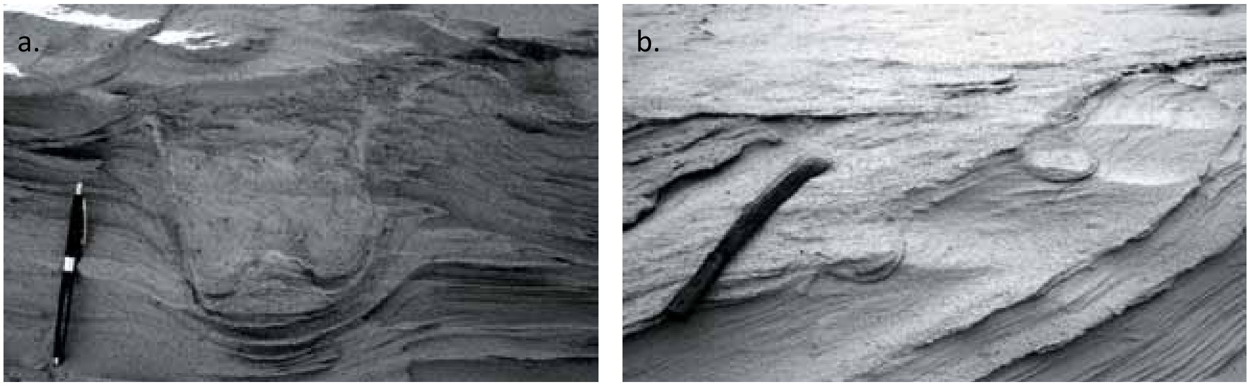

Figure 3. 1,000-year-old bison tracks buried within the Nebraska Sand Hills and seen in cross-section. (a) Note the cloven hoof, and the down-bending of the layering. Track is within nearly horizontal, wind-ripple lamination). (b) Bison tracks (arrows) in steep crossbeds. From Loope (1986).

Figure 4. Human tracks across a rain-moistened dune. Note the many "crumbs" of cohesive sand (Coral Pink Sand Dunes, Utah).

material. Dune sand lacks the material that makes most soils cohesive (silt, clay, and organic matter), and it therefore is cohesive only when it has been moistened (sand castles on the beach). Tunnels excavated in damp sand stay open only as long as the sand remains moist. Burrows dug into damp sand are relatively common in some parts of the Entrada Sandstone, and some of them are surprisingly large.

Tracks in the Navajo Sandstone at Coyote Buttes

When an animal steps on the soft, layered sand on a dune slope, it bends the layers downward in a distinctive way (Fig. 3). If the sand is moist, abundant "crumbs" or blocks of sand are formed (Fig. 4), and the animal's foot does not sink very deeply into the sand. If the sand is dry, the animal's feet sink deeply and produce long avalanches of dry sand with each step (Fig. 5).

Most of the tracks at Coyote Buttes are visible in cross-section (side-view instead of map-view). Only two of the tracks I've seen there contain broken blocks of moist sand, but thousands show smooth bending of the sand layers. The numerous tracks that show the smooth folding (Fig. 6) are preserved within sand layers that were formed by avalanching. In parts of the Navajo where tracks are absent, the layers formed by avalanching are up to 10 cm thick and are many meters wide. The avalanches that display the tracks are much thinner and narrower than typical avalanche layers in the Navajo (Fig. 1).

Some of the tracks appear in a line, suggesting a trackway seen in cross-section (Fig. 6). The upper part of each of the tracks in the line is truncated by a flat, erosional surface. A closer look shows that some of the tracks in the line are older than others – they deform slightly different layers (Fig. 6). This is the pattern to expect if a moving animal disturbs steep, loose (dry) sand: the animal

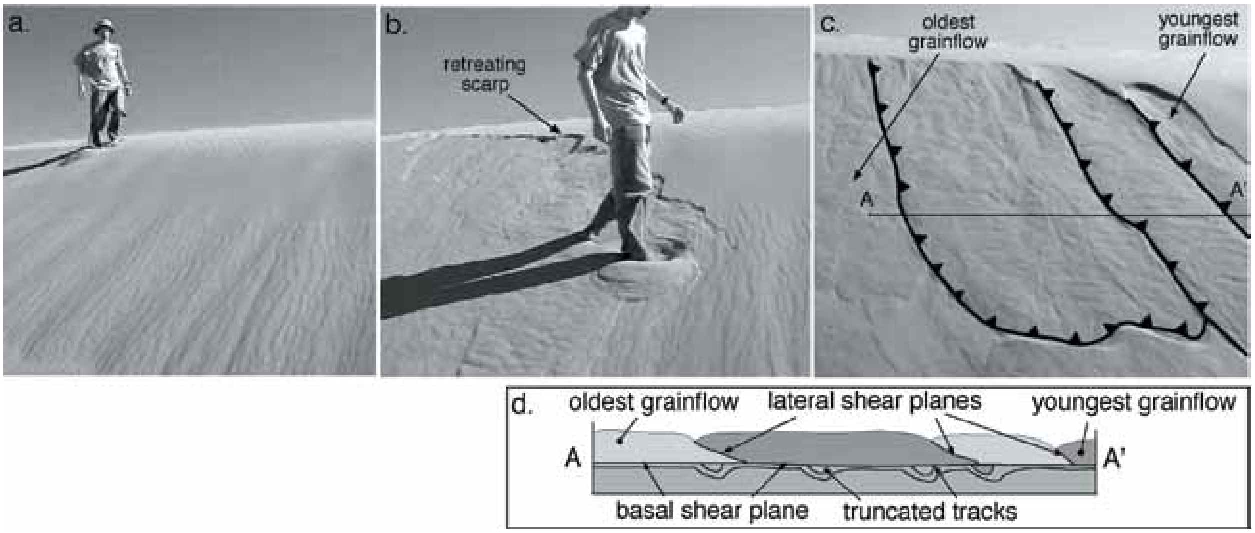

Figure 5. An animal moving across a dry dune slope (a) generates avalanches (b) and then steps on them. The surface expression of tracks is obscured (c), but the tracks deform the layers to a greater depth than the sliding sand can erase (d). Killpecker Dunes, southwestern Wyoming; from Loope (2006a).

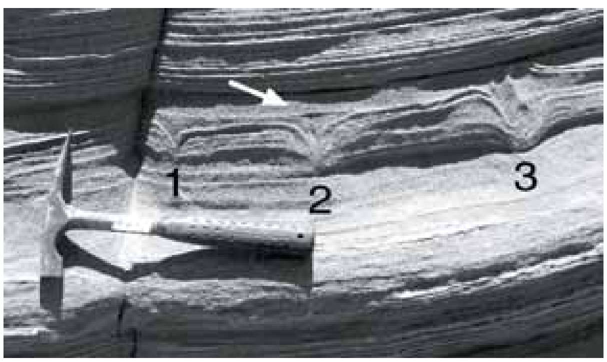

Figure 6. Thin avalanche layers with three down-folded tracks made by an animal moving across the dune slope from left to right. (Navajo Sandstone at Coyote Buttes). The view is of a near-vertical rock surface, looking in the downslope direction. The white arrow marks an avalanche layer. This layer overlies an erosion surface that cuts tracks 1 and 2, but the erosion surface and the overlying avalanche layer are folded by track 3. Conclusion: tracks 1 and 2 are a few seconds older than the track 3, and the animal started a dry-sand avalanche with each step; from Loope (2006a).

repeatedly makes an avalanche and then steps on it. So, although some tracks are older than others, they are only seconds older. When tracks like this are made, it may look (from above) as if the avalanches erase the tracks, but the tracks are deep and only the top part each track is erased.

It therefore appears that nearly all of the tracks at Coyote Buttes were made in dry sand. Each sand layer was dry when it avalanched into position, and when an animal disturbed it, it slid again to make another avalanche. When the wind blows over dunes in areas without animal life, avalanching is rare and each avalanche is thick. The avalanches that have tracks in them are thin because the repeated disturbances cause frequent avalanching.

Just because dry sand is easy to erode doesn't mean that dry sand tracks can't be preserved in the rocks. It is certain that many dry-sand tracks, dry-sand avalanches, and wind-ripple layers made with dry sand were eroded after they were deposited, and before they were buried. But it is also certain that the Navajo Sandstone reaches a thickness of 700 meters, and that nearly all of the sand now in the formation was transported and deposited while it was dry. Apparently the Jurassic wind wasn't a perfect eraser: more dry sand was deposited than was carried away.

Burrows in the Entrada Sandstone Near Escalante, Utah

The distinct, relatively thin layering that is produced by avalanching on dune slopes and by the migration of wind ripples allows geologists to see features that would be invisible in crudely bedded deposits. Anything that disrupts the layering requires an explanation. Some broken and folded layers in eolian sandstones record ancient earthquakes (Horowitz, 1982). Before the sand is cemented into sandstone, but after it has been buried below the water table, shaking can turn it into quicksand. During the brief time during which it changes from solid to liquid, and then back to a solid, the sand can flow several meters, creating large folds. Avalanche layers are more likely to do this because they are more porous than wind-ripple deposits. Cohesive sand above the water table is sometimes broken by small faults when the sand below it turns to quicksand.

Trace fossils also disrupt the layering in dune deposits, but these disruptions are usually easy to distinguish from the quicksand features. As described above, the weight of an animal can create small, distinct folds in the sand layers. Animals that dig into dunes disrupt or terminate the layers that they encounter. Near Escalante, Utah, cylindrical burrows of several different sizes cut the layering in the upper part of the Entrada Sandstone. Insects probably made the smallest burrows, which are less than 5 mm in diameter. Some of the burrows, however, reach a diameter of 63 cm and lengths greater than 3 m . Fairly large vertebrates – comparable in size to a badger– must have made these excavations.

Animals dug the burrows relatively high on the dune slopes, far above the groundwater table. The burrows slope downward at about 20º, and sometimes end in an expanded chamber. Some of the burrows are filled by structureless (non-layered) sandstone, and others contain large, angular blocks of layered sandstone that must have formed during collapse of the burrow. Several of the burrows, however, are filled by crossbedded sandstone (Fig. 7a). The crossbeds indicate that small drifts of wind-blown sand entered the open throats of the burrows and progressively filled them.

These burrows clearly could not have been dug into dry sand; the only likely explanation is that they were excavated into rain-moistened sand. When the dune's surface dried, the wind again began to transport loose sand; some of this sand drifted into the open burrows. Because body fossils are almost completely absent from the Entrada Sandstone, the identity of the burrower remains unknown (Loope, 2006b).

Medium-sized burrows, ranging from 25-35 mm in diameter are also common in the Entrada. Some of these burrows change upward from parallel-walled cylinders to cones just before they terminate below an undisturbed layer (Fig. 7b). A possible explanation for these burrows is that they were excavated after a rain-moistened dune surface had started to dry out. By this explanation, the throats of the burrows are wide because dry sand at the top of the burrow continuously collapsed as the burrowing progressed, but after the animal reached moist sand, the walls were stable. When kangaroo rats dig in modern dunes, the uppermost parts of their burrows are cone-shaped; blocks of moist, cohesive sand in the filled cones indicate that moist sand lies a short distance below the surface (Fig. 7c). Another possible explanation for a cone-topped burrow is that the uppermost part of a moist-sand, cylindrical burrow collapsed as the dune surface progressively dried.

Conclusions

Tracks and burrows are locally abundant in both the Lower Jurassic Navajo Sandstone and the Middle Jurassic Entrada Sandstone. These trace fossils are visible because they disrupt distinct layering produced by avalanching sand and migrating wind ripples. Some geologists have claimed that tracks made in dry sand are not preserved in ancient strata. The Navajo contains a huge volume of sand layers that were deposited under dry conditions, and locally abundant animal tracks that disrupted them while they were dry. Although many dry-sand layers and tracks may have been eroded by Jurassic winds (and thus not preserved), these features are nevertheless prominent in the rock that is preserved. The upper Entrada Sandstone contains many animal burrows, some of which exceed half a meter in diameter. The burrows probably provided escape from the high daytime temperatures that prevailed in the subtropical sand sea. The burrows were dug into rain–moistened sand, and drifts of wind–transported sand filled

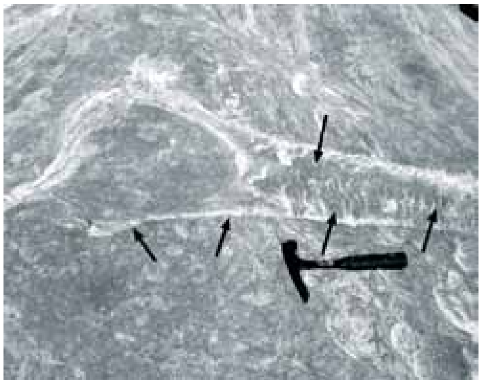

Figure 7a

Figure 7b

Figure 7c

Figure 7. Burrows in the Entrada Sandstone near Escalante, Utah, and in a modern dune. (a) Large burrow that cuts large-scale crossbeds, descends to the right at about 20°, has sharply defined margins, and is filled with small-scale crossbeds (arrows). Burrow was dug into rain-moistened dune sand and was eventually filled by drifts of loose sand (moving left to right) as the dune progressively dried. (b) Cone-shaped top of a cylindrical, medium-sized burrow that was probably dug while the surface sand was dry and subsurface sand was moist. The cylinder is seen in cross-section between the white arrows. After sediment filled the cone, the surface was eroded flat, and was then buried by migrating wind ripples. (c) Three burrows dug by a kangaroo rat into the base of a modern dune—a possible modern analog for the burrow shown in B. The surface of dune slopes toward the viewer at 32°, and is dry. The upper parts of the burrows are conical with angle-of-repose slopes. Blocks of cohesive sand that are present in the cone-fills were dug from moist sand that lies at shallow depth. [(a) from Loope, 2006 b; (b) and (c) from Loope, 2008].

several of them with small crossbeds. These trace fossils demonstrate that, for at least a small portion of their depositional timespan, the Navajo and Entrada sand seas received sufficient rainfall to support an active animal population.

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