

**PS Climate, Water Table, and Sedimentary Controls on the Evolution of a Wet Vertebrate Ecosystem,
Lower Jurassic Aztec Sandstone, Valley of Fire State Park, Southern Nevada***

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Abstract

Trackways made by arthropods, therapsids, and theropod dinosaurs have been discovered in relation to an anomalous, reddish lenticular bed in the Lower Jurassic Aztec Sandstone of eolian origin at Valley of Fire State Park, southern Nevada. At its maximum, the bed is 3.0 meters thick and is composed mostly of broken, folded, wavy, and flat laminae of mudstone, very fine-grained sandstone, and dolomitic limestone. Sandstone beds are locally cross-laminated in sets 0.1 meter thick and fill erosional scours a few centimeters deep. Bedding cycles, 0.8 to 1.0 meter thick, show vertical trends in platy calcareous fragments that increase upward in size and abundance. Vertebrate tracks found within a few meters above this interval are absent below it.

For this bed, we interpret traction, suspension, and biogenic sedimentation in a localized interdune swale now preserved among distinct eolian strata in the Aztec Sandstone. Because of subsidence of the sediment pile or a shift to a wetter climate, the water table rose and intersected a nearly lifeless interdune floor to create an ecosystem, vibrant with a diverse biota of plants and arthropods, therapsids, and carnivorous theropod dinosaurs. Limited areal extent of this interdune deposit suggests a short-lived, wet ecosystem that with time succumbed to drying conditions, lowered water table, more sediment available for wind transport, and burial by eolian dunes. Fine wind-blown sand was trapped by adhesion at the capillary fringe. Sporadic wadi floods moved small subaqueous dunes and scoured the interdune surface. Mudstone laminae settled from suspension in standing water and waning wadi flooding, and were later deformed by loading. Platy calcareous fragments may be remnants of organic mats that record vertical fluctuations in the water table in upward-wetting cycles.

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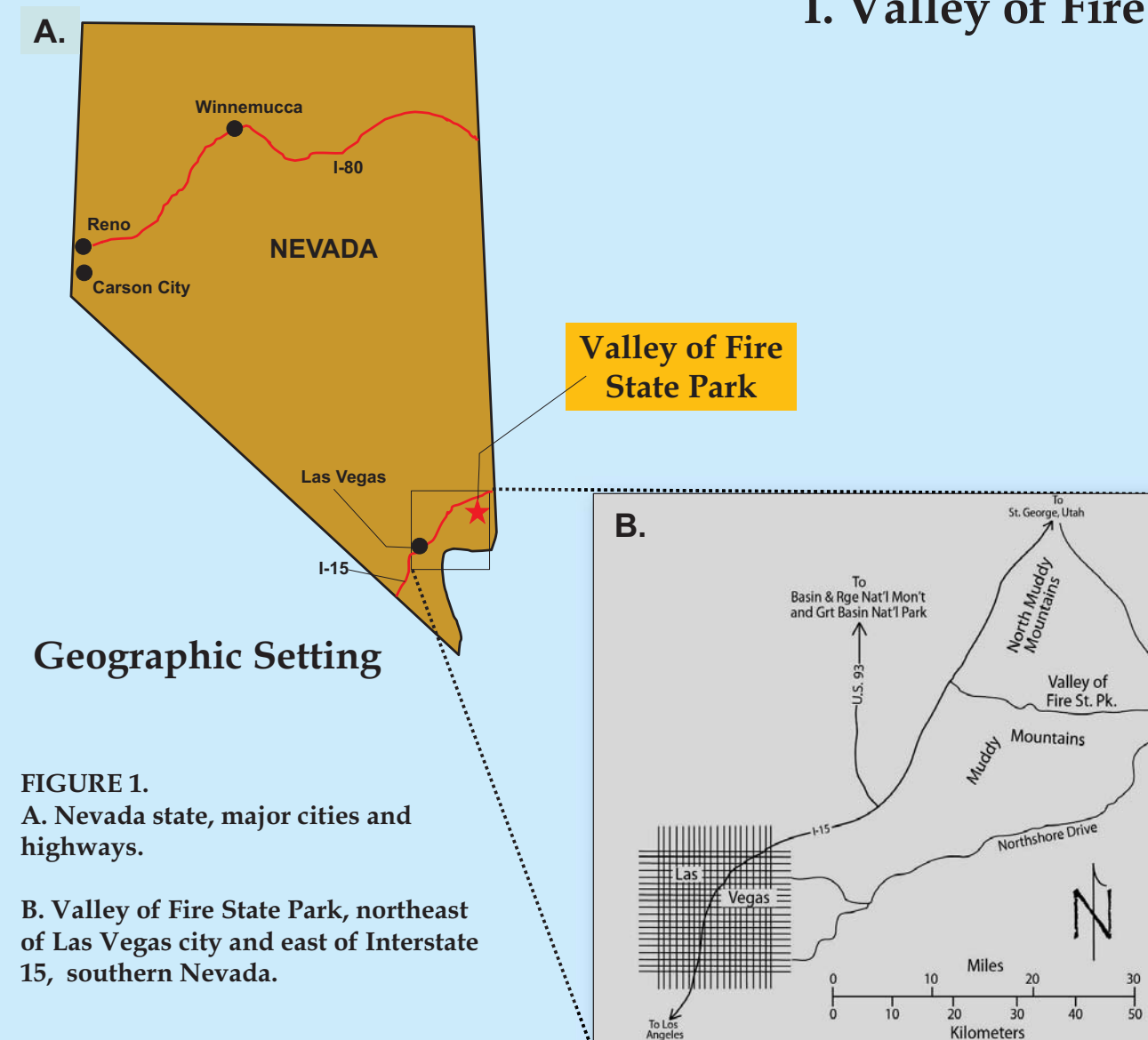


Abstract

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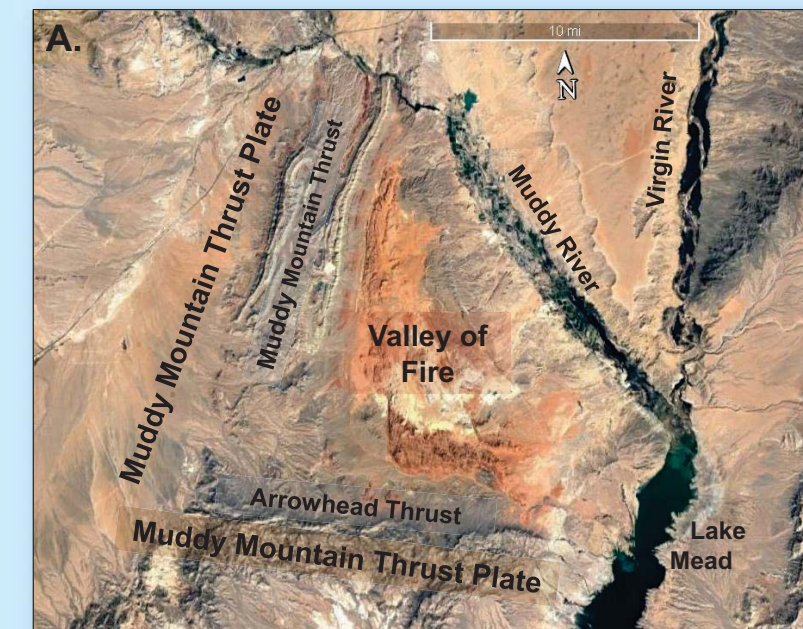
For this bed, we interpret traction, suspension, and biogenic sedimentation in a localized interdune swale now preserved among distinct eolian strata in the Aztec Sandstone. Because of subsidence of the sediment pile or a shift to a wetter climate, the water table rose and intersected a nearly lifeless interdune floor to create an ecosystem, vibrant with a diverse biota of plants and arthropods, therapsids, and carnivorous theropod dinosaurs. Limited areal extent of this interdune deposit suggests a short-lived, wet ecosystem that with time succumbed to drying conditions, lowered water table, more sediment available for wind transport, and burial by eolian dunes. Fine wind-blown sand was trapped by adhesion at the capillary fringe. Sporadic wadi floods moved small subaqueous dunes and scoured the interdune surface. Mudstone laminae settled from suspension in standing water and waning wadi flooding, and were later deformed by loading. Platy calcareous fragments may be remnants of organic mats that record vertical fluctuations in the water table in upward-wetting cycles.

I. Valley of Fire State Park, Southern Nevada



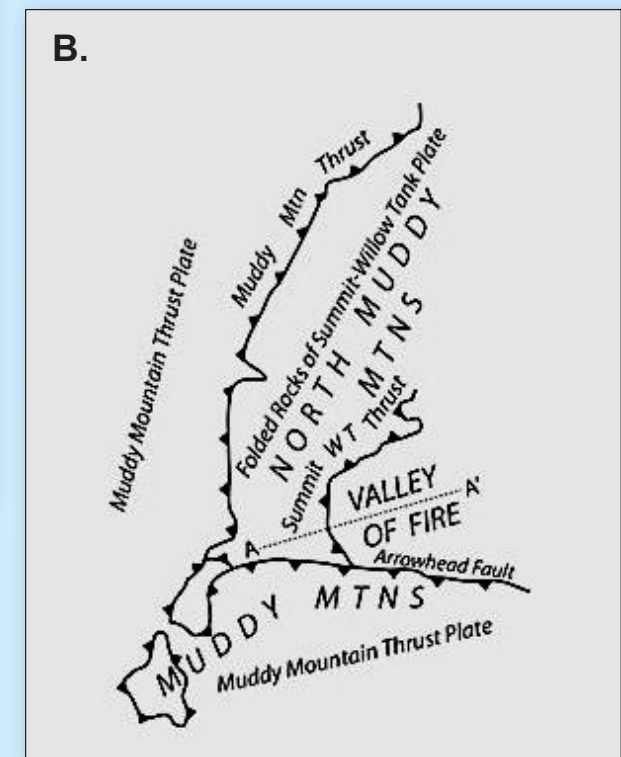
Geographic Setting

FIGURE 1.
A. Nevada state, major cities and highways.
B. Valley of Fire State Park, northeast of Las Vegas city and east of Interstate 15, southern Nevada.



Present-day Geologic Setting

FIGURE 2.
A. Satellite image of Valley of Fire State Park and vicinity with geologic and geographic features highlighted. See corresponding map on right. Ten miles on the horizontal scale (at top right) = 16 km (modified from Google Earth).
B. Generalized map of thrust faults & resulting mountains associated with deformation of the crust during the Sevier orogenic event in the Valley of Fire area (modified from Bohannon, 1983). A-A' is line of structural cross section of Figure 4A. Summit Willow Tank (W T) Thrust.



Study Location

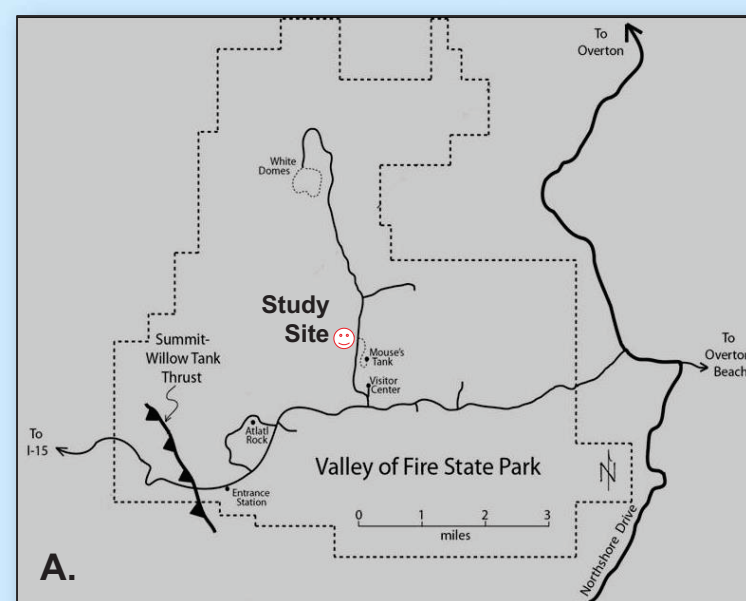


FIGURE 3.
A. Map of Valley of Fire State Park and location of Study Site in Fire Canyon northwest of Mouse's Tank.
B. Aerial image of Fire Canyon where anomalous red bed crops out within uniformly cross-bedded Aztec Sandstone (see Figure 5). Short yellow lines mark limit of visible outcrop of anomalous red bed in this part of Fire Canyon (modified from Google Earth). Six hundred feet on the horizontal scale = 182 meters.

II. Anomalous Red Bed in the Lower Jurassic Aztec Sandstone in Fire Canyon at Valley of Fire State Park

Lithostratigraphic Relations and Internal Structure of the Aztec Sandstone

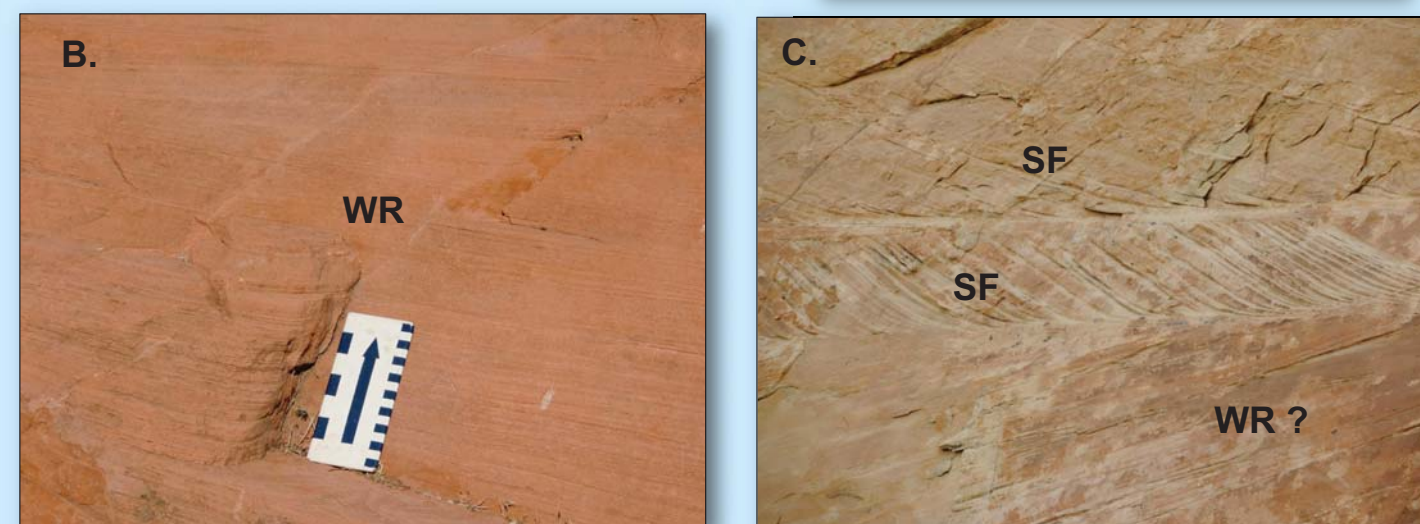


FIGURE 4.
A. Structural cross section to illustrate the lithostratigraphic character of Valley of Fire State Park. Permian Hermit, Toroweap (not labeled), and Kaibab Fms and part of Triassic Moenkopi Fm exposed in Summit Willow Tank (W T) overthrust plate. Triassic Moenkopi and Chinle Fms including Shinarump Conglomerate (Cgl) Member of the Chinle, and Jurassic Moenave/Kayenta crop out locally in the Park. Aztec Sandstone is the principal sedimentary rock in the Park; is overlain locally by Cretaceous Willow Tank and Baseline Fms. Disconformities developed at the tops of the Kaibab, Moenkopi, Chinle, and Aztec Fms (modified from Bohannon, 1983). Profile trend for structural cross section is shown as line A-A' in Figure 2B.
B. Wind-ripple toeset laminae (WR), < 2 mm thick, are dominant internal structures of the Aztec Sandstone and comprise the entire field of view in photo. Arch Rock campground, southern Valley of Fire State Park near West Entrance. Scale is in centimeters (right edge) and in inches (left edge).
C. Localized sandflow foreset cross-strata (slipface cross-beds, SF). In cliffs on east side of White Domes Road near Rainbow Vista; image captured with zoom lens.

Stratigraphic Occurrence of the Anomalous Red Bed in the Aztec Sandstone

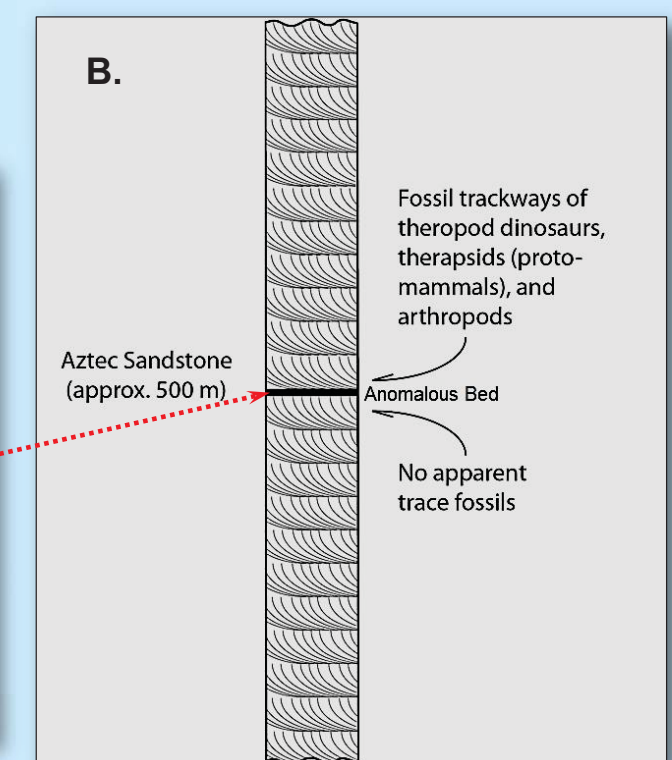


FIGURE 5.
A. Mouth of Fire Canyon viewed northward from parking and picnic pavilion area (see Figure 3B). Persistently uniform cross-bed sets of the Aztec Sandstone are interrupted by an anomalous, discontinuous red bed exposed in the northeast wall along Fire Canyon (see Figure 3B). Characteristics of this bed are given in the next section III.
B. Schematic column through portion of the Aztec Sandstone exposed in the northeast wall of Fire Canyon to show simply the stratigraphic relation between the anomalous red bed and the occurrence and non-occurrence of trackways of terrestrial organisms. Column is not to scale and stratigraphic top and base of the Aztec Sandstone are not represented in the column.

III. Outcrop Characteristics Associated with the Anomalous Red Bed–Sedimentation in a Wet Interdune Swale

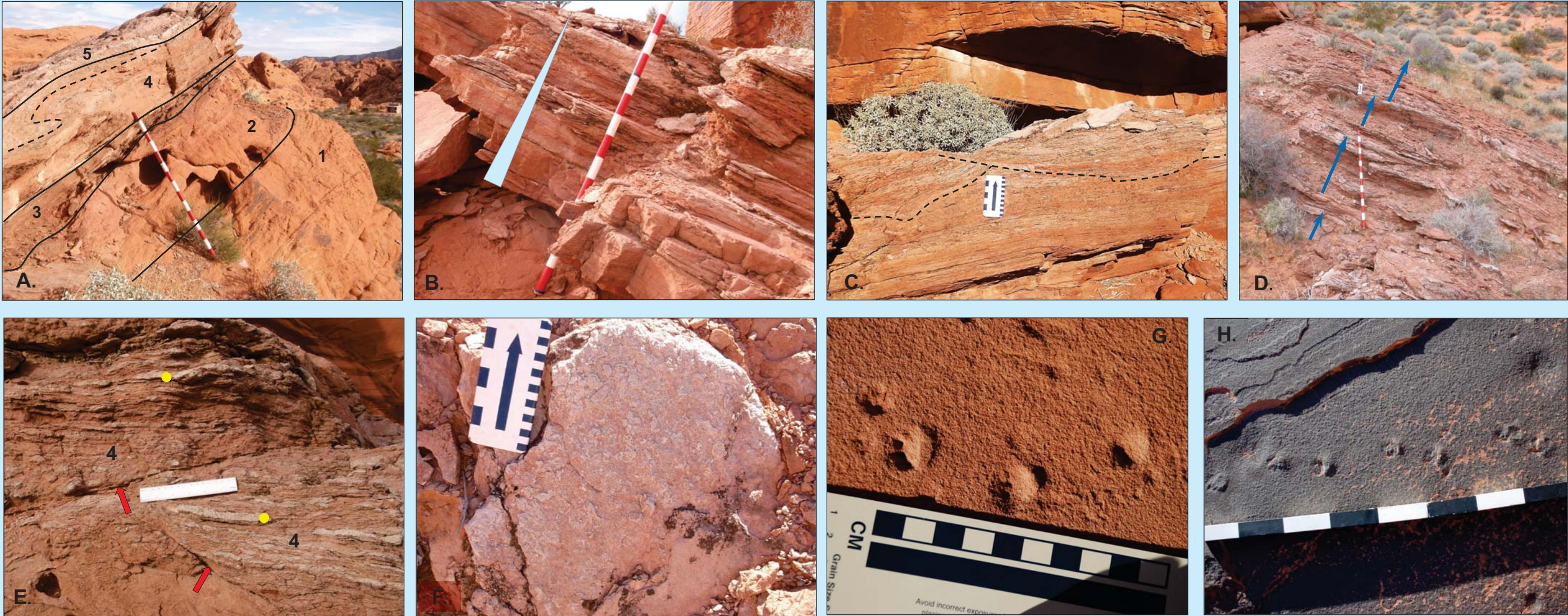


Figure 6. Sedimentary features associated with the anomalous red bed at Fire Canyon: A. Representative bedding units 1-5; contacts highlighted by black curved lines: *Bed 1*: light reddish-brown, fine-grained, well- sorted sandstone of unquestionable Aztec Sandstone in cross-bed sets 0.1-0.3 m thick and thickening down-section; *Bed 2*: light reddish-brown, very-fine grained sandstone with even to wavy, parallel laminations < 2 mm thick, similar to those in Figure 4B; *Bed 3*: darker reddish-brown, massive to laminated very fine grained sandstone; *Bed 4*: intercalated reddish-brown, mottled light gray, very fine grained sandstone, mudstone, and light gray calcareous lenses, very thin beds, and laminae; folded (curved dashed line), loaded, and truncated by erosional scours 0.2-0.3 m deep; *Bed 5*: mainly light gray calcareous, wavy and distorted lenses, very thin beds, and laminae and minor intercalated mudstone laminae. Not seen in the photo are overlying 0.1-0.2 meter-thick beds of very fine grained sandstone laminae similar to those in Figure 4B, and fine-grained sandstone in cross-bed sets that thicken upward in the Aztec Sandstone. Staff is marked in decimeters. B. Representative *Bed 4* that fines-upward from reddish-brown very fine grained sandstone to intercalated light gray calcareous lenses, very thin beds, and laminae and minor reddish-brown mudstone. Staff is marked in decimeters. C. Erosional scours (outlined with black, dashed, concave-upward curves) filled with intercalated light gray calcareous lenses, very thin beds and reddish-brown mudstone laminae of *Bed 4*. Scale is in inches (left edge) and centimeters (right edge). D. Repetitive sedimentary beds (blue arrows) grading upward from reddish-brown very fine grained sandstone and to mudstone capped by gray calcareous lenses, very thin beds and laminations. Staff is marked in centimeters. E. Erosional scours (red arrows) filled with cross-strata of intercalated reddish-brown mudstone and calcareous lenses (two are highlighted by yellow dots), very thin beds, and laminae of *Bed 4*. Scale is 6 in (15 cm) long. F. Irregular fragments of gray calcareous strata exposed on bed surface; preserved in *Bed 5* and at top of repetitive beds (see Figure 6D). Scale is marked in inches (left edge) and centimeters (right edge). G. Trackway preserved in fine-grained sandstone and assigned a tentative name, *Ichnogenus A*. H. Trackway of the ichnogenus, *Brasilichnium*, preserved in fine-grained sandstone. Staff is marked in decimeters.

IV. Provisional Paleoenvironmental Interpretations

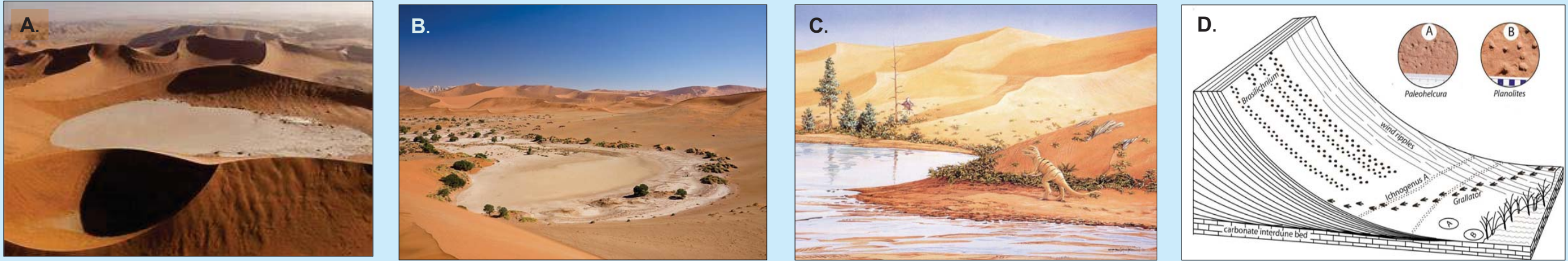


Figure 7. Based on sedimentary and trace fossil evidence collected thus far from the Aztec Sandstone, particularly from the anomalous red bed at Fire Canyon in Valley of Fire State Park, the following interpretations and conclusions are offered tentatively:

- Thin vertical and limited lateral extent, and absence of evaporites and desiccated mudstone suggest sedimentation and rapid burial in a localized, short-lived, wet interdune swale, similar to that shown in Scene A above for the Namib Desert, Namibia, Africa (from allposters.co.uk).
- Humid climate and subsiding sediment pile of the Aztec sand sea allowed the water table to emerge and intersect the interdune floor. An oasis evolved that attracted and sustained a diverse ecologic community of mammal-like reptiles, carnivorous dinosaurs, organic mats(?), and possibly other organisms for a time until the water table lowered deeply, climate parched, and wind mobilized sand in dunes.
- *Bed 1*: small dunes of the Aztec eolian sand sea; *Bed 2*: wind-ripple strata; *Bed 3*: transition between eolian traction sedimentation and capillary, suspension, and biogenic(?) sedimentation above a rising water table as climate grew moister and the sediment pile of the Aztec sand sea subsided; *Bed 4*: combined capillary trapping of wind-blown sand, mud settling after wadi flooding, and growth of organic/microbial(?) mats, deformed later by loading and shearing during eolian sedimentation or wadi flooding. *Bed 5*: growth of organic/microbial mats(?) on wet mud.
- Sporadic wadi floods scoured the interdune surface similar to that shown in Scene B above for the Namib Desert, Namibia, Africa (from everipedia.org). Suspended mud settled in short-lived, shallow pools of water. Mat-like beds, lenses, and laminations of uncertain organic/microbial origin grew on wet interdune mud, and locally draped over inactive, low-amplitude dunes to be preserved as foreset strata. Microscope study of samples is needed to verify the organic/microbial origin of these mat-like strata.
- Repetitive upward-fining beds represent interdune drying as the water table fell and interdune wetting as the water table rose to form upward-wetting cycles. During prevailing moist climate and water-table rise, fine eolian sand was trapped by capillarity near the top of the water table; climaxing with the colonizing of an organic/microbial(?) mat at maximum water-table rise. When water table was depressed, organic mats desiccated, fragmented, curled, and were buried by the next upward-wetting cycle.
- *Ichnogenus A*. tracks are thought to be made by a small *synapsid* (i.e. a vertebrate animal transitional between true reptile and true mammal; DeCourten, 1998) or a small *therapsid* (i.e. an advanced transitional animal more mammal-like than reptile-like; DeCourten, 1998). This ichnogenus is commonly preserved in wind-ripple or grainfall sand deposited at the toe or apron of an eolian dune (Rowland, 2016).
- *Brasilichnium* tracks are thought to be made by a mammal-like animal as it was walking up an eolian dune slope. The crescent-shaped rises behind each footprint suggest that the animal walked from right to left. It is most commonly found in Mesozoic eolian sandstones in the Western Interior, USA (Lockley, 2011). Other tracks including the ichnogenus, *Grallator*, made by carnivorous dinosaurs (Hilton, 2003), and trace fossils made by vegetation and epifaunal and infaunal insects have been recognized elsewhere in the Aztec Sandstone but have not been discovered yet in the Aztec Sandstone at Fire Canyon.
- Although fossils of pterosaurs and *Dilophosaurus* shown in Scene C (from DeCourten, 1998) have not been discovered in the Aztec Sandstone associated with the anomalous red bed, the scenario reasonably approximates the depositional setting of a wet interdune and associated eolian dunes interpreted in this study.
- Model D (from Rowland, 2016) is a 3-dimensional representation of a simple eolian dune. It shows an interpretation of where trackways of *Ichnogenus A* and *Brasilichnium* occur in relation to an eolian dune, dune strata, and nearby wet interdune, as envisioned for the ichnofossils found within a few meters above but absent below the anomalous red bed in this study. It was the presence of the life-sustaining wet interdune that attracted the vertebrate organisms to congregate there during Early Jurassic time.

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