# Dry-Sand Tracks and Thin, Animal-Triggered Avalanches in the Navajo Sandstone, Southern Utah


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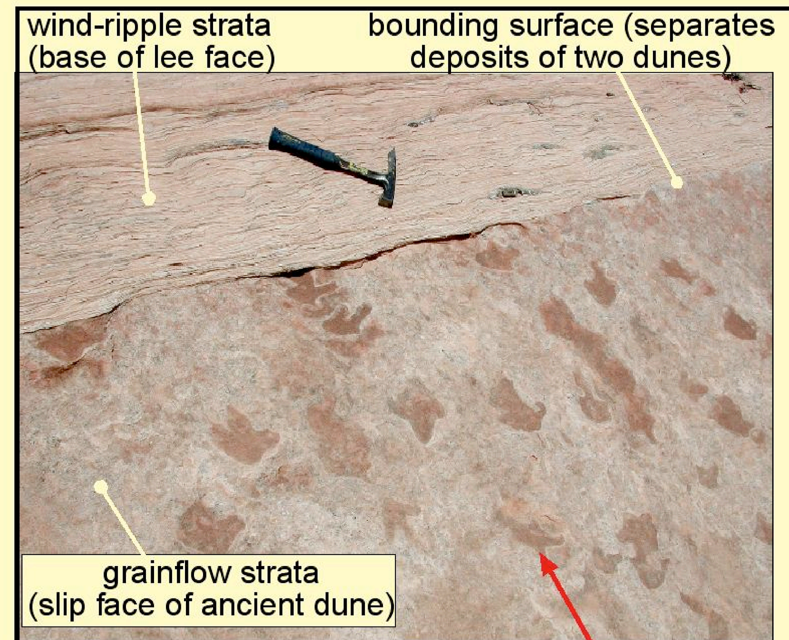
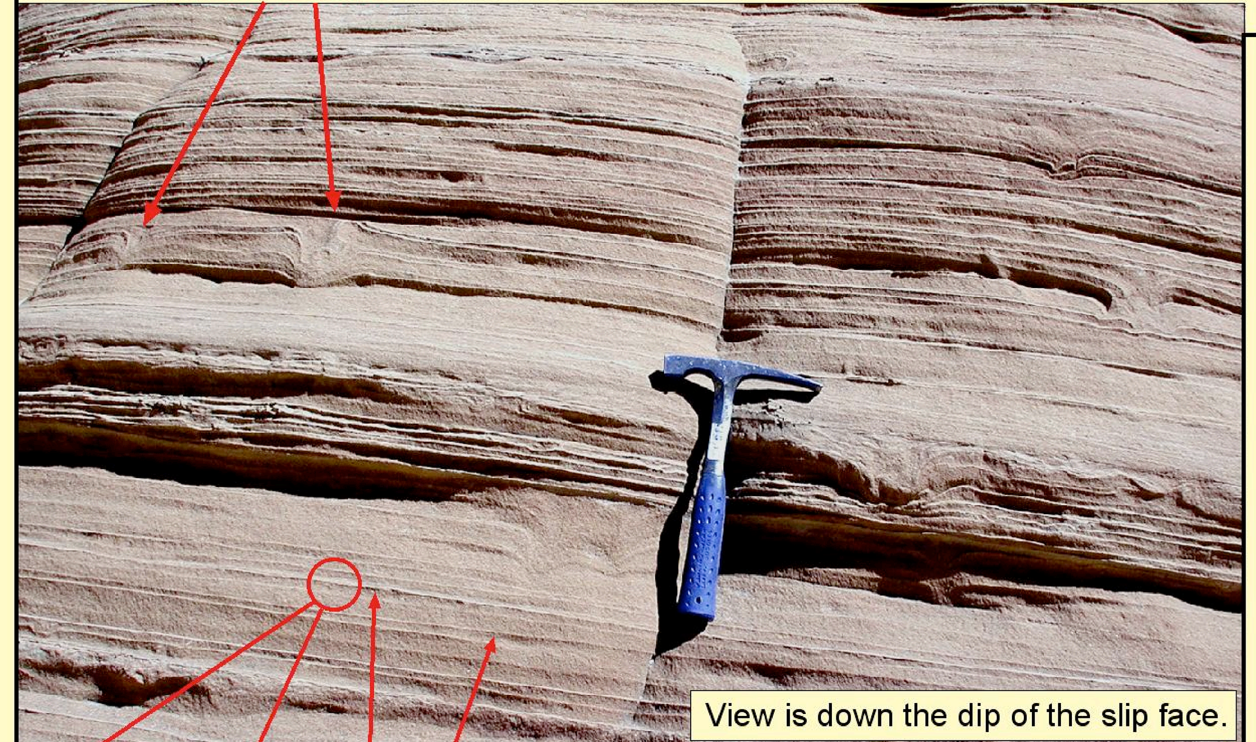
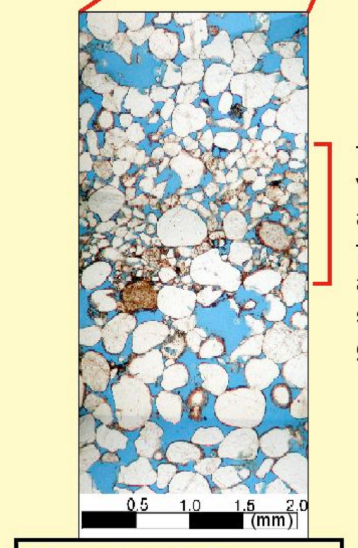



Theropod tracks (*Grallator*) in plan, and cross-section.


## ABSTRACT

Thousands of animal tracks are preserved in thick sets of eolian cross-strata of the Lower Jurassic Navajo Sandstone at Coyote Buttes on the Arizona-Utah border. Tracks are preserved in thin grainflows, and, in cross-sectional views, laminations are smoothly folded. There is no sign of a central shaft left open when the trackmaker's foot was withdrawn. Folds at the tops of tracks are commonly truncated by the shear plane at the base of the next grainflow. Within some trackways, progressively younger tracks move upsection to progressively younger grainflows, indicating that animals triggered dry avalanches as they moved along the slip face. Although dry dune sand has been previously denigrated as a medium for track preservation, this example shows that dry eolian grainflow strata, due to their position in the zone of flow separation and their loose packing, can preserve clear tracks. Although scour by younger grainflows can remove shallow tracks, the loose packing of grainflows ensures that the tracks of larger animals will penetrate well below the next shear plane.

**Pin stripes** are thin layers of very-fine sand and coarse silt that accumulate at the basal shear plane of grainflows.

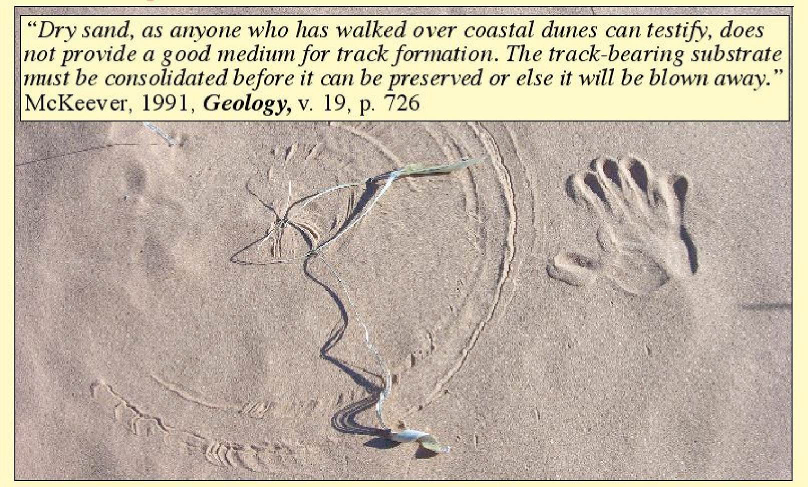
## Why are tracks in *thin* grainflows?


Mean grainflow thickness in cross-strata without tracks = 3.19 cm; n=127

Mean grainflow thickness in cross-strata with abundant tracks =1.19 cm; n=176

In southwestern and south-central Utah, the Navajo contains grainflows up to 17 cm thick (black arrows, above). Because they deliver a very large volume of sediment to the foot of the lee face, a long period of sand build-up on the upper or middle lee face is a pre-requisite for a thick flow. Thick grainflows therefore must have occurred much less frequently than thinner flows. The association of abundant animal tracks with thin grainflows (left) makes sense: animals on the slip face would have triggered frequent, low volume grainflows (see upper right, Examples #'s 1 &2) and prevented the build-up of the thick wedge of unsupported sand required for deposition of thick grainflows.

## Can Dry-Sand Traces Be Preserved?



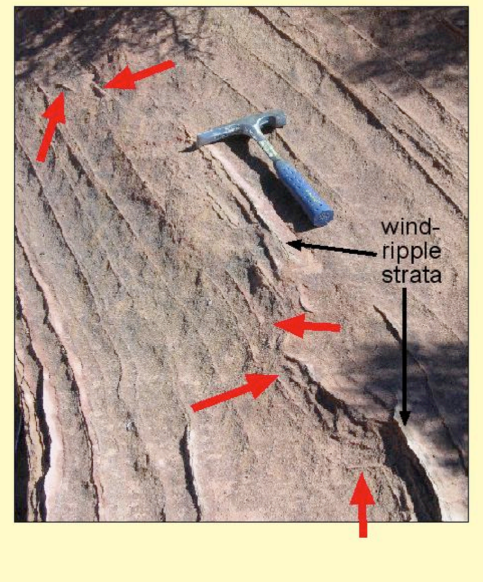

Although some have concluded otherwise (see above quote), the abundant tracks described here show that tracks in dry sand can be preserved, especially if they penetrate grainflows. These strata are deposited on the dune slip face within the zone of flow separation (where little erosion takes place) and are loosely packed. Tracks are likely to penetrate them deeply, thereby improving the chances of preservation (and discovery).

**Evidence for a dry-sand origin: 1) form of the tracks; and 2) stratigraphic relationships between tracks and grainflows.**

1) Pin stripes are smoothly folded and remain unbroken, indicating that the sand was not cohesive and was free to flow. There is no preserved hint of an open shaft (right), where the foot of the trackmaker was removed from the sediment. Instead, sand appears to have flowed immediately into the void.

2) Within a trackway, progressively younger tracks move up-section deforming progressively younger grainflows, showing that, as they walked, animals triggered dry-sand avalanches (see Examples #1 & 2 above).

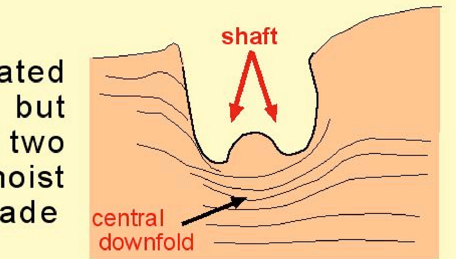
**If substrate is cohesive, laminae are broken, not smoothly folded.**



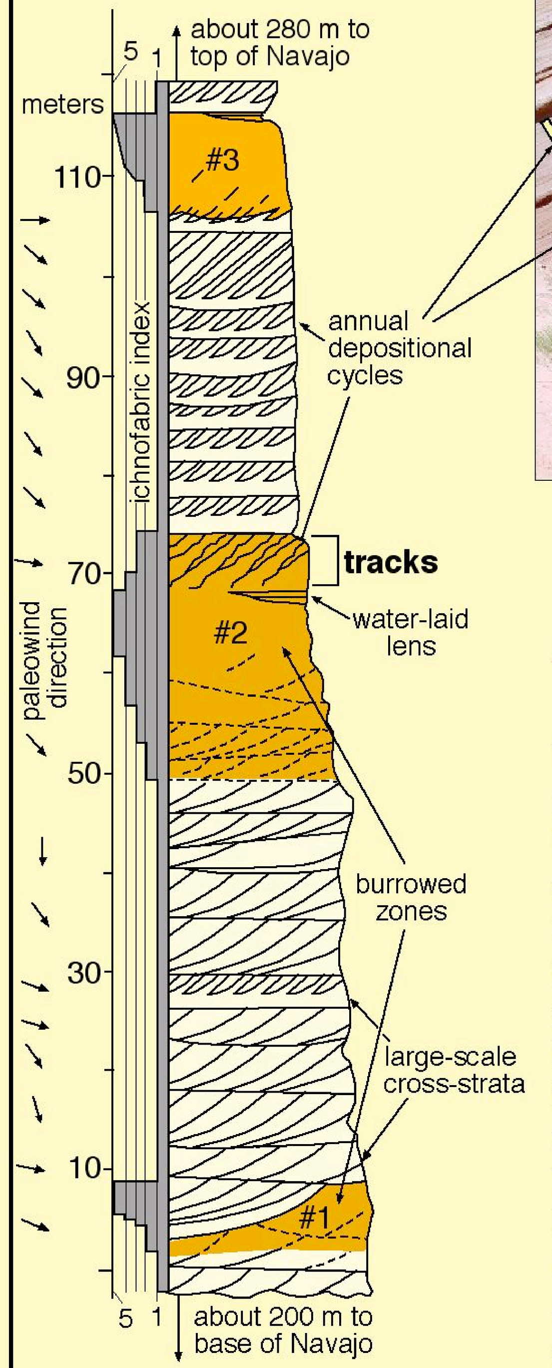

The red arrows at left point to broken pin stripes within the deformation zones associated with two large *Otozoum* tracks.

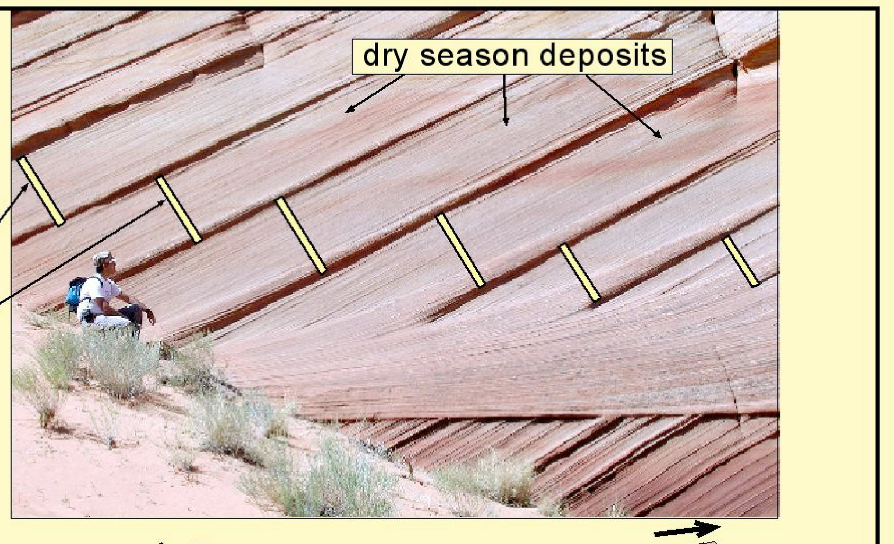
*These are the only broken pin stripes observed within the Navajo tracks* (all other tracks smoothly *fold* rather than *break* pin stripes).

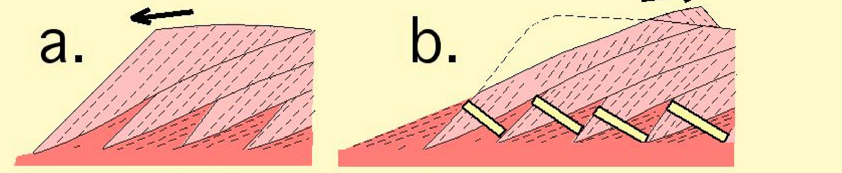
**Interpretation:** Water-saturated and dry sand lack cohesion, but *moist sand is cohesive*. The two tracks at left were made in moist sand, but all others were made in dry sand.


Tracks made in cohesive sediment retain an open shaft. Bison track, Nebraska Sand Hills; (modified from Loope, 1986)




## Paleoclimatic Setting

The tracks lie within the middle (#2) of three burrowed zones (left) that Loope and Rowe (2003) interpreted as evidence of long-lived pluvial episodes during Navajo deposition. The dry-sand interpretation for the tracks presented here is consistent with recent conclusions on the Navajo paleoclimate (Loope *et al.*, 2004). The tracks lie within grainflow cross-strata that dip to the southeast. Dominant, northwesterly winds (above, a) blew across the equator during December-January-February. These winds crossed the dry interior of northern Pangea as Trade Winds immediately before turning to cross the Navajo sand sea as Tropical Westerlies. **Grainflows thus record the dry season.** The rainy season was June-July-August (when no grainflows were deposited and opposing winds pushed wind-ripple strata against the slip face (above, b). Yellow bars (above) mark individual annual depositional cycles.

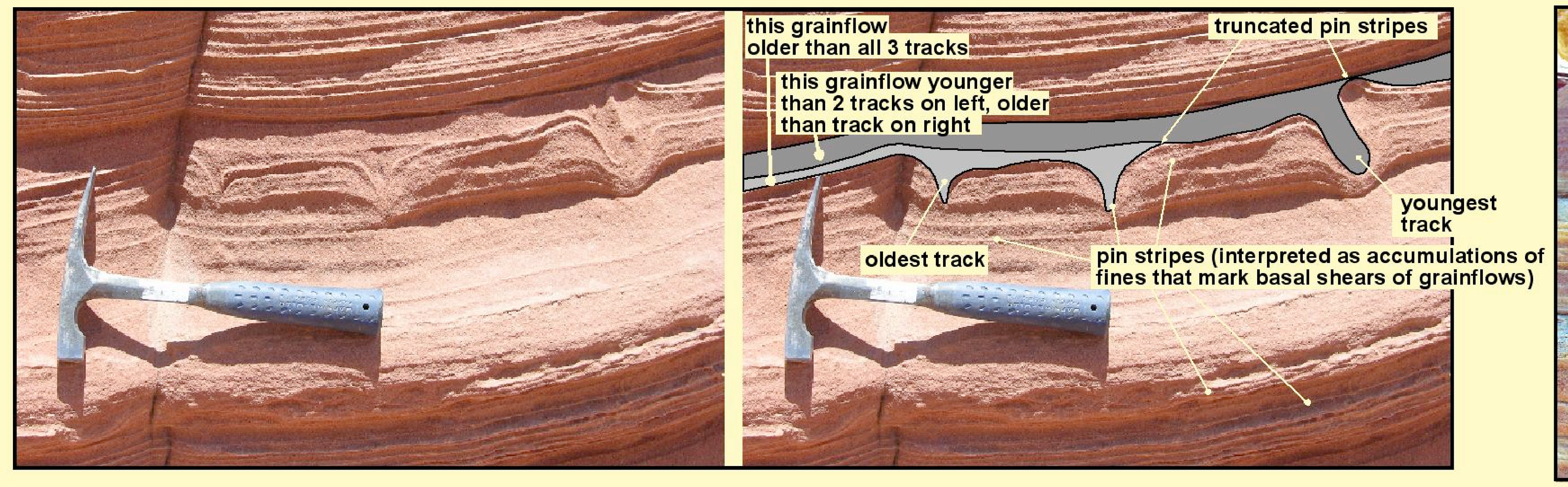
## In cross-section, some trackways are diachronous, *i.e.* tracks move up-section in the direction of travel

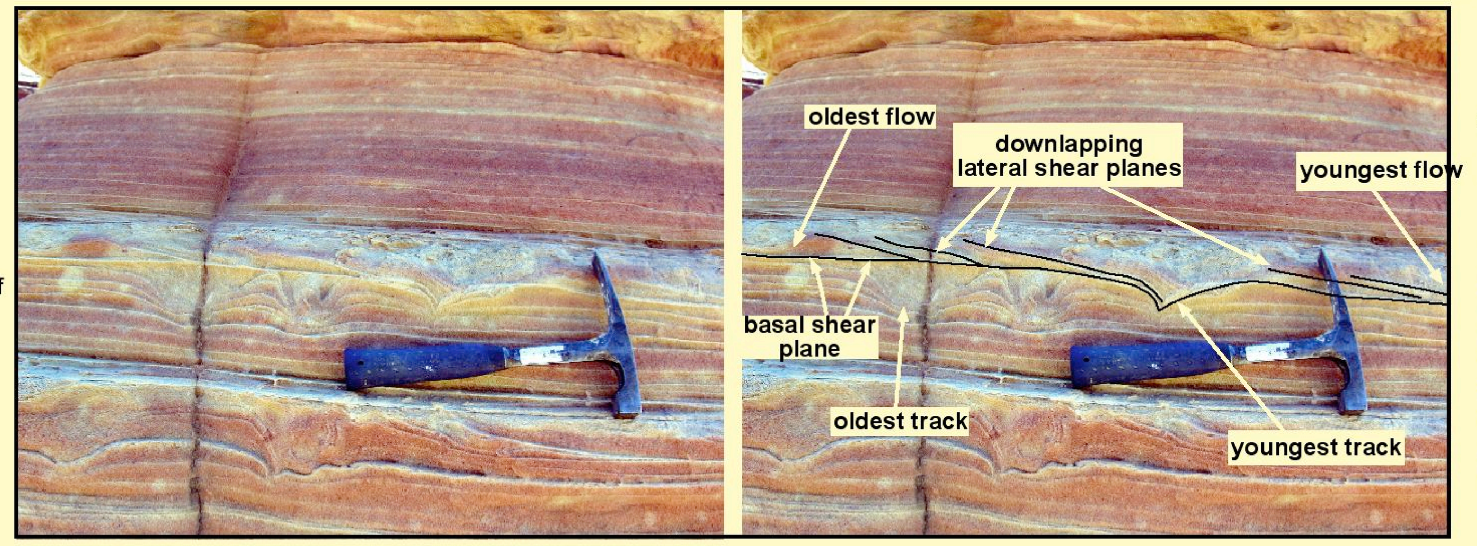
### Example #1

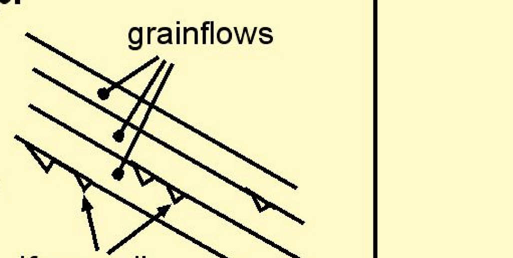
Cross-sectional view of thin grainflows with three equally spaced *Grallator* tracks; view is down dip.

### Example #2

Three more *Grallator* tracks in thin grainflows. Again, view is down depositional dip.



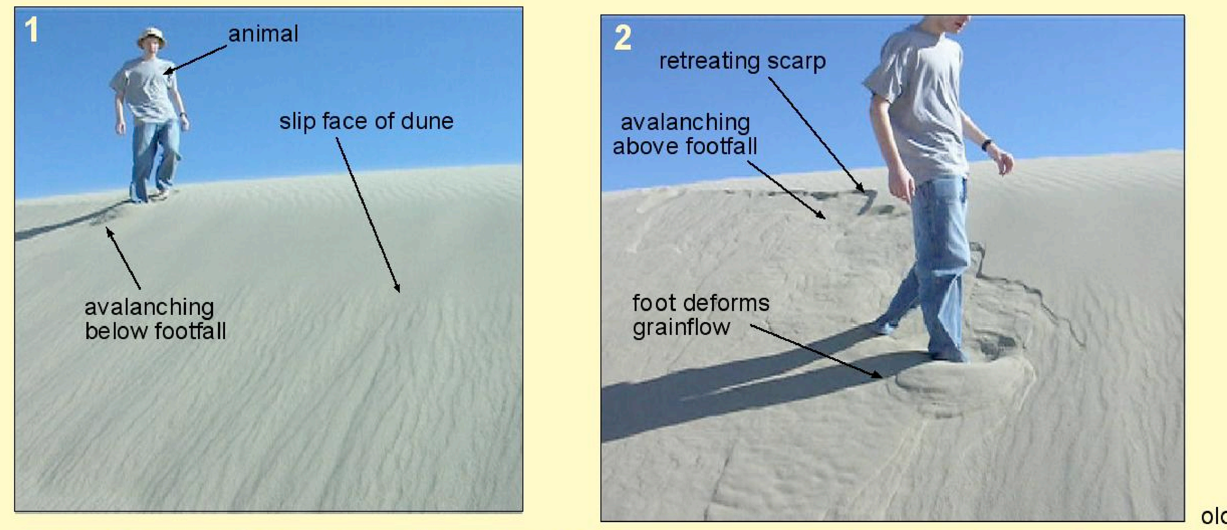



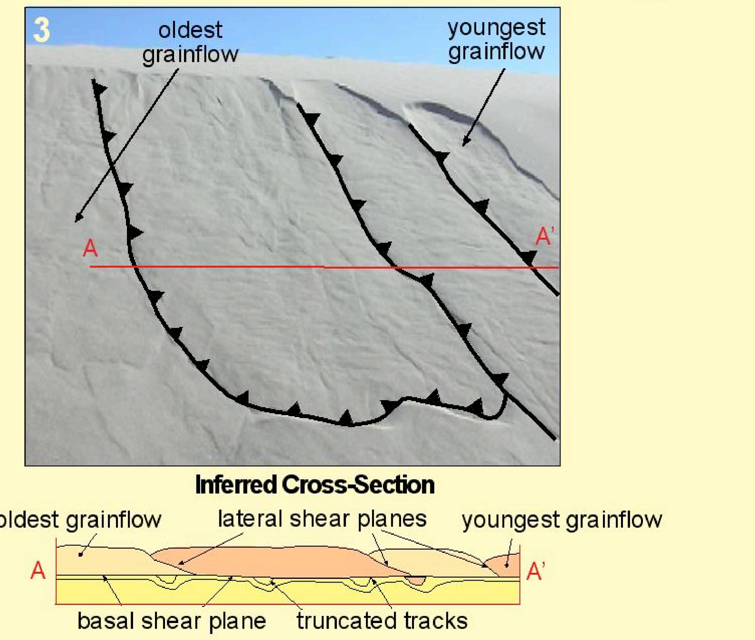




If a small animal moved obliquely downslope, triggering small avalanches, each bedding plane might show only a partial trackway

**Interpretation:** In both of the above examples, the animal moved from left to right, triggering avalanches as it moved along the slip face, thereby providing direct evidence that the substrate was dry. Brand & Tang (1991) called attention to trackways that abruptly start or stop, and interpreted this as evidence that the trackmaker floated off the substrate (supported by water). If dry grainflows are thicker than the depth of track penetration, their deposition could easily create this effect as the trackway is shifted to a progressively higher bedding plane (line drawing, above right).

## Modern Analog: Animal-triggered avalanching at Killpecker Dunes, Wyoming



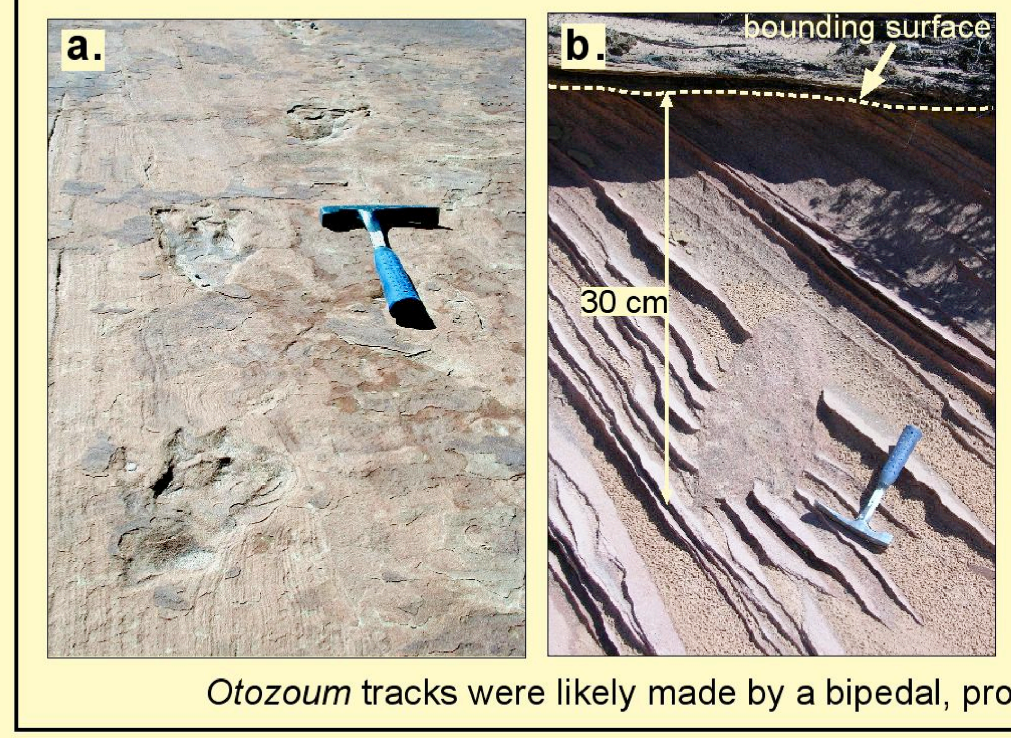




Animal generates avalanching at two locations: *below footfall*; and *above footfall* as scarp retreats upslope. A series of animal-triggered grainflows potentially can preserve evidence of younging in the direction of travel (*i. e.* left to right, in this case). Although surface expression of tracks is destroyed (3), deeper parts of tracks can be preserved below the basal shear plane of avalanches (cross-section). As it proceeds alongslope, animal deforms progressively younger grainflows.

Downlap of strata (dip of lateral shear planes) shows direction of grainflow younging. Uppermost parts of tracks are removed by erosion, but deformed layers are preserved beneath the basal shear plane. Youngest track (on right) deforms an animal-triggered grainflow.

## Underfoot, Vast Differences in Consistency

Wind-ripple Deposits (tight packing) Grainflows (loose packing)




*Otozoum* tracks were likely made by a bipedal, prosauropod dinosaur (Lockley and Hunt, 1995, p. 133-137).

Large tracks (*Otozoum*) on bounding surfaces underlain by wind-ripple strata (**a**), and by grainflow strata (**b**). In **a**, deformation is shallow (less than 2 cm), but in **b**, deformation extends at least 30 cm below the bounding surface. The animal walked without difficulty over the tightly packed substrate, but was forced to slog over and through the looser avalanche deposits. Based on his extensive experience traversing North African dunes both on foot and in wheeled vehicles, Bagnold (1954, p. 236-237) was the first to report the vastly different supporting properties of wind-ripple and avalanche deposits (see photo far right).

Brand and Tang (1991) interpreted tracks on foresets of cross-strata within the Coconino Sandstone as subaqueous. They failed to recognize the abundant wind ripple strata in the same sets of cross-strata with the tracks (Loope, 1992). Both water-saturated sand and dry sand are cohesionless, and therefore deform in similar fashion (see above). Could the Navajo tracks have been made under water? Wind ripple strata have proven to be the most useful criterion for recognizing eolian strata (Hunter, 1977; Kocurek and Dott, 1981). The differential penetration of the two substrates shown here further corroborates the wind-ripple interpretation.

Shallow footprints on tightly packed wind-ripple strata, Killpecker Dunes, Wyoming (compare to *Otozoum* tracks, in **a** and **b**, to left).

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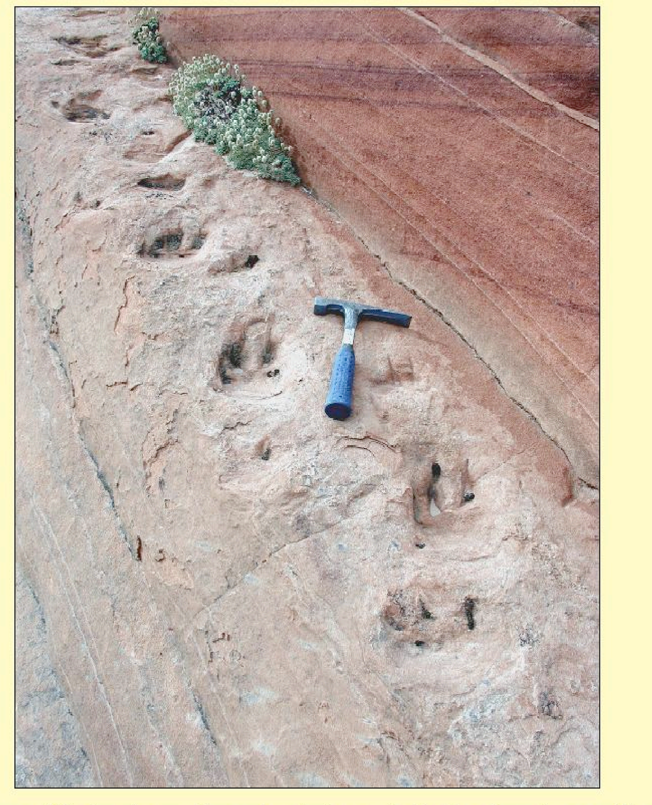

*Brasilichnium* (probably a tritylodont reptile; Lockley and Hunt, 1995, p. 137) trackway ascending an angle-of-repose slope.