LANDFORMS GENERATED BY WIND EROSION OF NAVAJO SANDSTONE OUTCROPS AT THE WAVE (COLORADO PLATEAU, UTAH / ARIZONA BORDER)

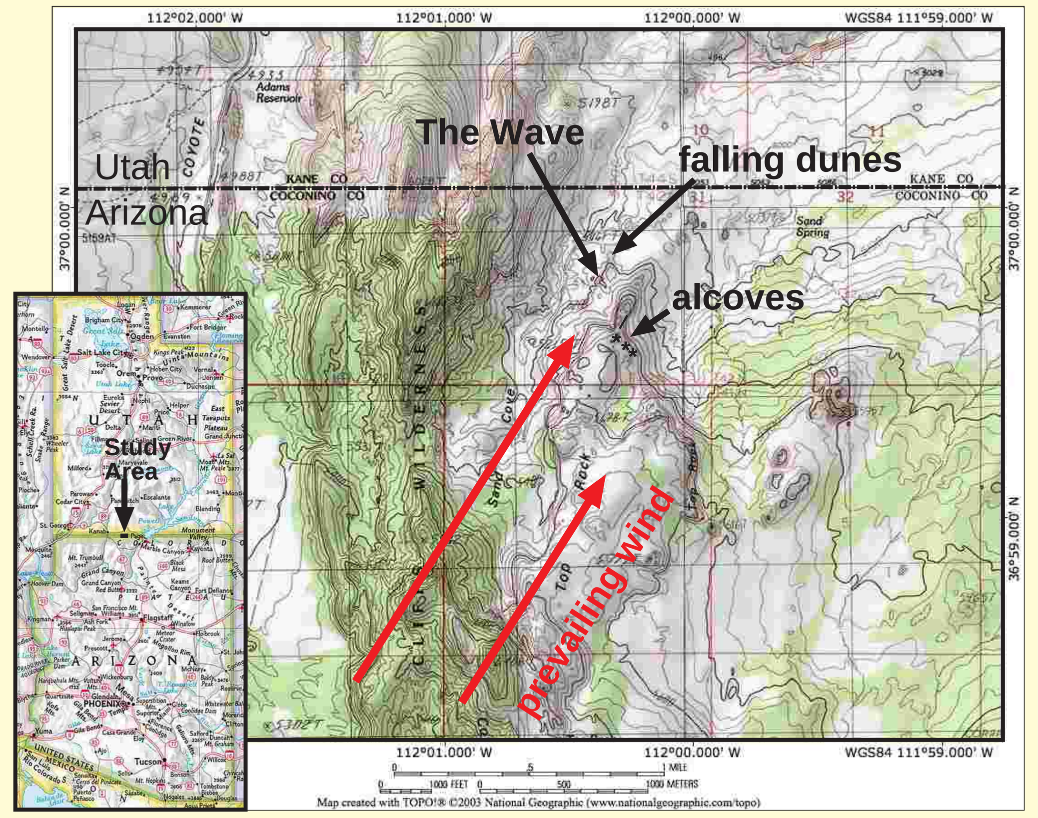
David Loope *Department of Geosciences, University of Nebraska-Lincoln;* dloope1@unl.edu
Joseph Mason *Department of Geography, University of Wisconsin-Madison;* mason@geography.wisc.edu

ABSTRACT

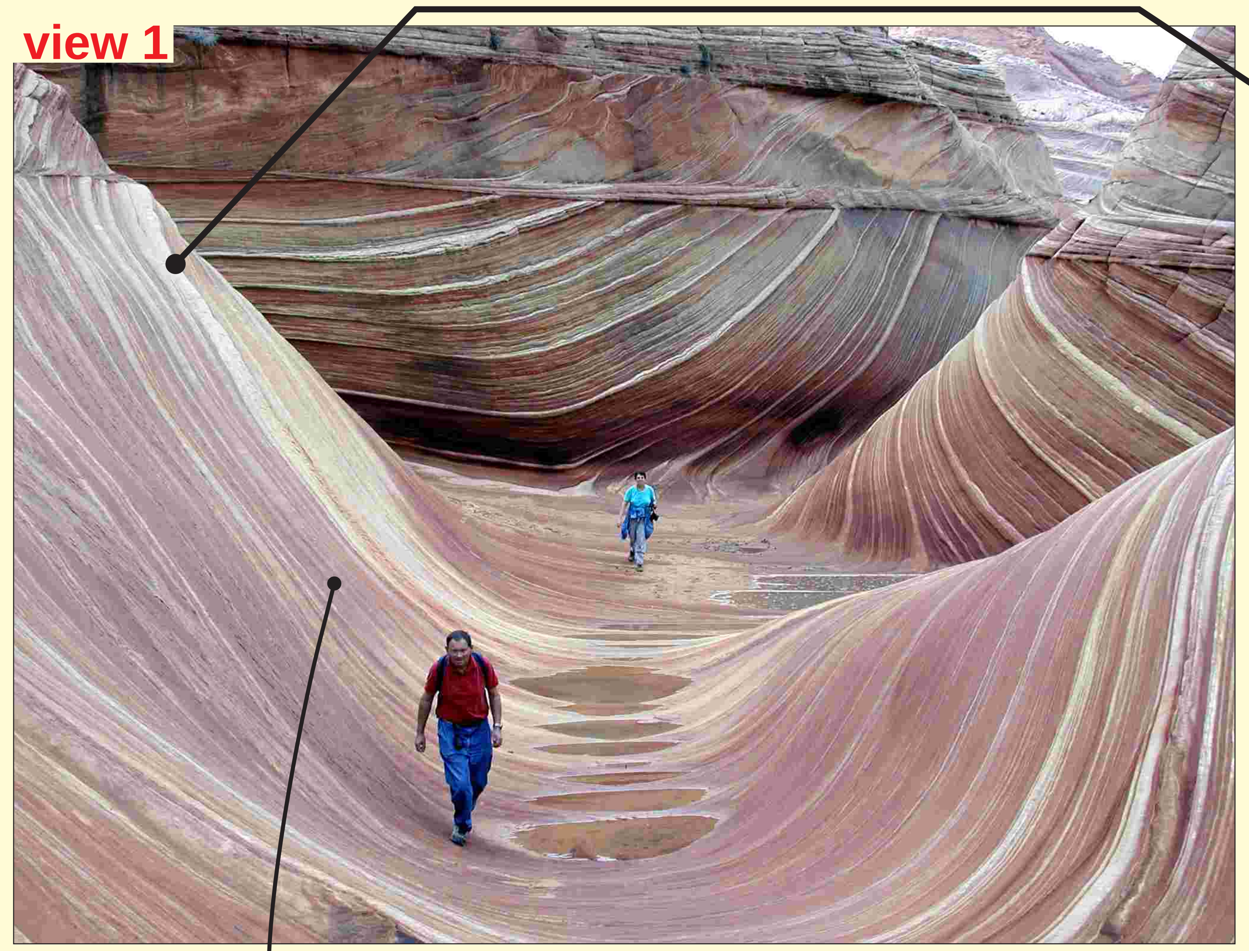
Along the eroded crest of the East Kaibab Monocline, sand driven by strong southwesterly winds has abraded Navajo Sandstone outcrops, generating distinctive features on both a small and a large scale. The exceptional exposure of Jurassic sedimentary structures in this area has resulted from sand-blasting of friable outcrops. Sloping rock surfaces commonly display a "stepped" morphology: steep, laterally continuous, 3-4 mm-high risers face the dominant wind direction and are spaced 10-15 cm apart; they cut Navajo Sandstone sedimentary structures at a high angle. The steps may be the erosional equivalent of wind ripples: high-energy impacts cut the steps, and each step shields a downwind flat from the low-angle approach of impacting grains.

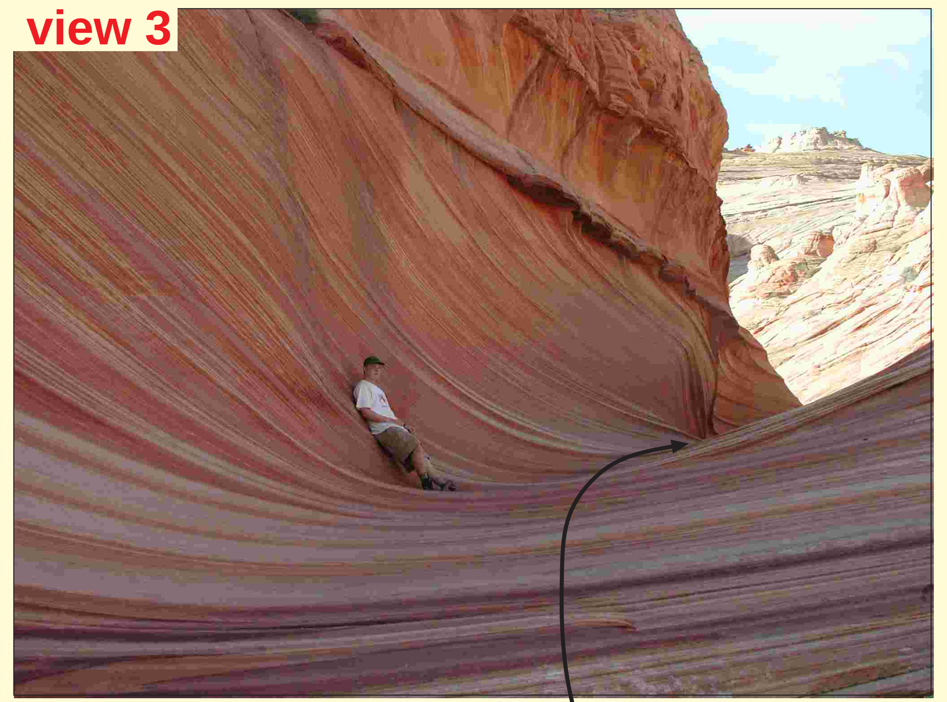
Where echo dunes approach steep, southwest-facing sandstone escarpments, eddying airflow has cut deep recesses and alcoves that are tens of meters wide and up to 10 m high. Fluted scours line the inner walls of alcoves and a dune or an abraded, conical sandstone mass occupies the central floor. In one alcove, rockfalls have generated large arches in abrasion-thinned walls. The Wave, a site within Vermillion Cliffs National Monument that is well-known to hikers and photographers, lies within a kilometer (below and downwind) of three adjacent alcoves. At The Wave, abrasion by saltating and suspended sand has removed a sandstone wall that once stood between two adjacent, wind-abraded "channels". Removal of the wall generated an undrained depression with four points of entry. Iron-oxide-cemented sandstone clasts form a lag on the floor of the depression. Sand that exits The Wave accumulates in a falling dune that lies directly northeast of the site.

Although sand-blasting may be an ineffective agent of erosion over broad areas of the Colorado Plateau, it is important to landscape development at our sites because Navajo Sandstone outcrops there are dominated by thick, very weakly cemented eolian grainflows. These outcrops are much more friable than those dominated by finer-grained, less-well-sorted, and better-cemented wind-ripple strata. Removal of grains from the friable sandstone provides a positive feedback for the erosion process because it supplies additional tools for abrasion.



Falling dunes have accumulated northeast (downwind) of The Wave and the alcoves described here.



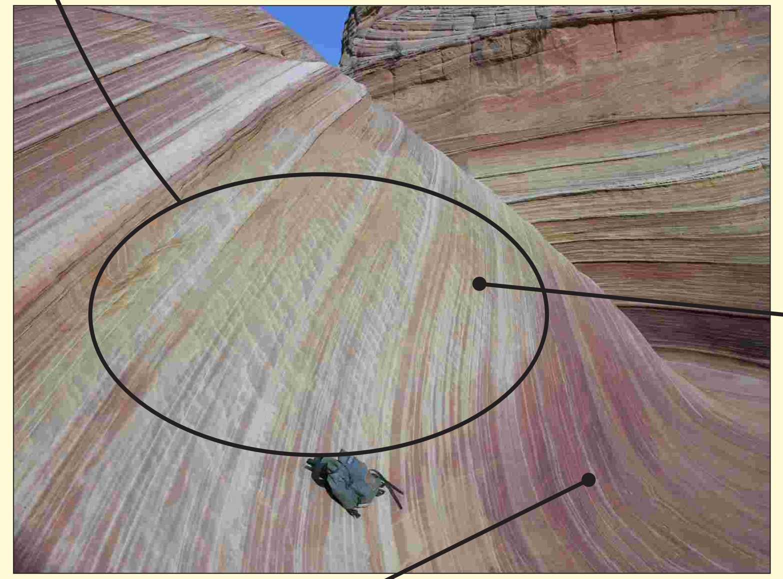


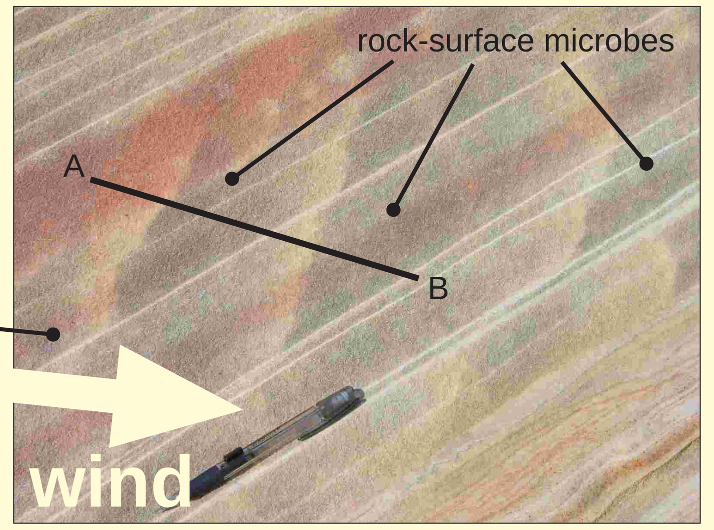
Start Here!

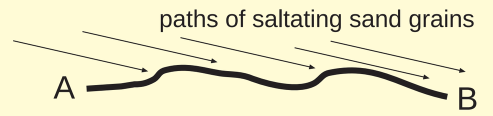
"The Wave" is a small site (~200 m^2) within Vermillion Cliffs National Monument that has become very popular among photographers and hikers. The Navajo Sandstone has been eroded into four converging, erosional troughs. The troughs have smooth, curving walls that display every detail of the Jurassic sedimentary structures. One wall (photo above right) is reminiscent of a breaking wave-- hence the name. Although water collects in shallow pools after precipitation events, the catchment area is tiny (<0.25 km^2) and flowing water does not play an obvious role in formation of the troughs. Resistant beds form "thresholds" on the floors of troughs (see middle photo above); these would be highly vulnerable to erosion by flowing water. The presence of small-scale erosional bedforms (see below, left) on the walls of the large troughs, and nearby large, wind-scoured alcoves (below right) provide evidence that it was wind, not water, that carved The Wave.


Iron-oxide-cemented sandstone clasts form lags on the floors of troughs. The clasts are derived from rockfalls.

Erosional Bedforms: Direct Evidence for Eolian Abrasion

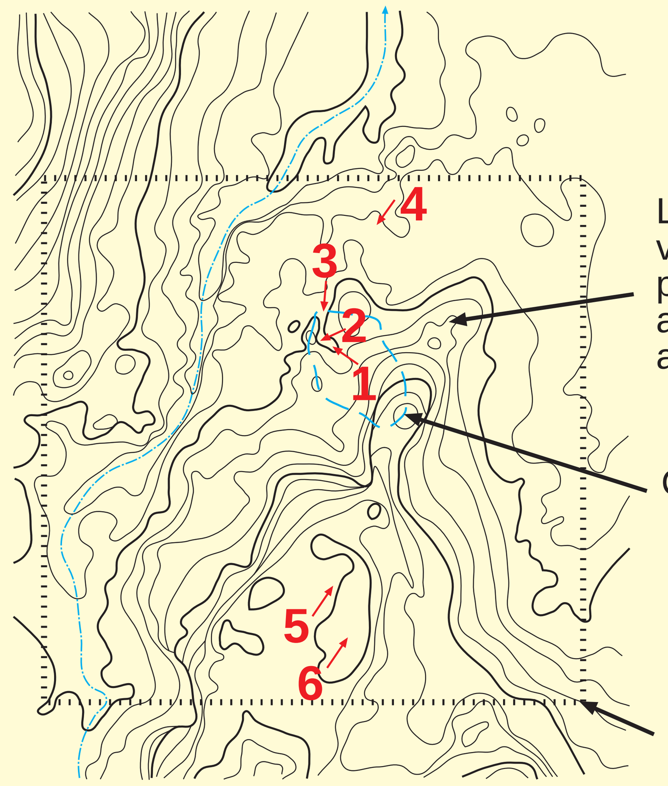






Small-scale erosional bedforms caused by impacts from saltating sand grains are widespread on this wall. These features are similar in origin to the structures cut into Navajo Sandstone described by Kurtz and Netoff (2001). They demonstrated that rock-surface microbes form hardened crusts that are undercut by wind abrasion.

In the photos above and to the left, note the microbially darkened rock surface on the right (downwind) side and the lighter, freshly exposed rock surface on the left (upwind) side of each ridge. Saltating grains impact the steep upwind side of the bedforms at a low angle; the darker rock (inhabited by microbes) lies in the "shadows" of the ridges and suffers few impacts.

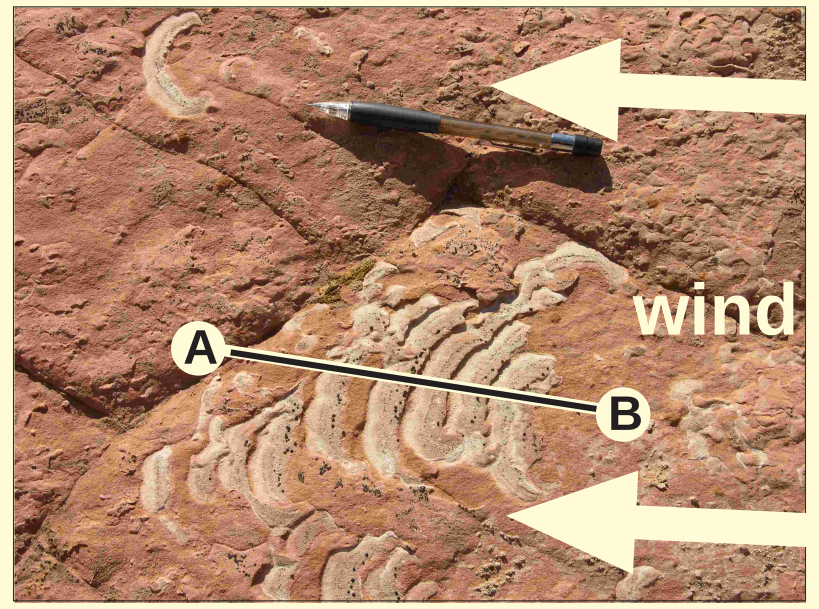


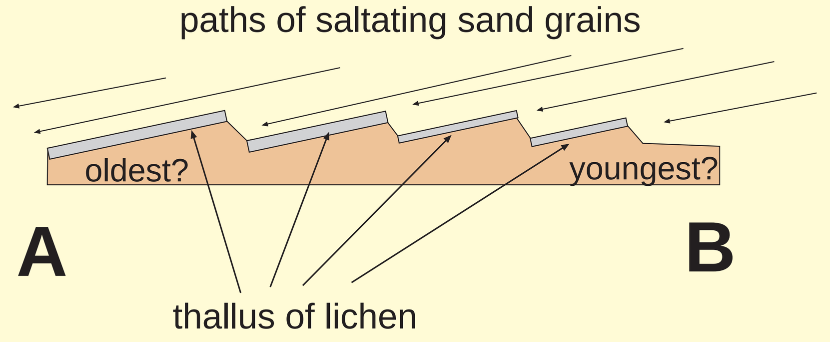
References:

Anderson, R.S., 1990, Eolian ripples as examples of self-organization in geomorphological systems: *Earth Science Reviews* **29**, 77-96.
Kurtz, H.D. & Netoff, D.I., 2001, Stabilization of friable sandstone surfaces in a desiccating, wind-abraded environment of south-central Utah by rock surface microorganisms: *Journal of Arid Environments* **48**, 89-100.
Netoff, D.I. & Shroba, R.R.,1993, Morphology and possible origin of giant weathering pits in the Entrada Sandstone, southeast Utah:*U.S.G.S. Open File Report* **93-390**, 45 p.
Sharp, R.S., 1963, Wind ripples: *Journal of Geology* **71**, 617-636

Spinoff-Observation: Lichens Can Be Indictors of Eolian Abrasion and Wind Direction

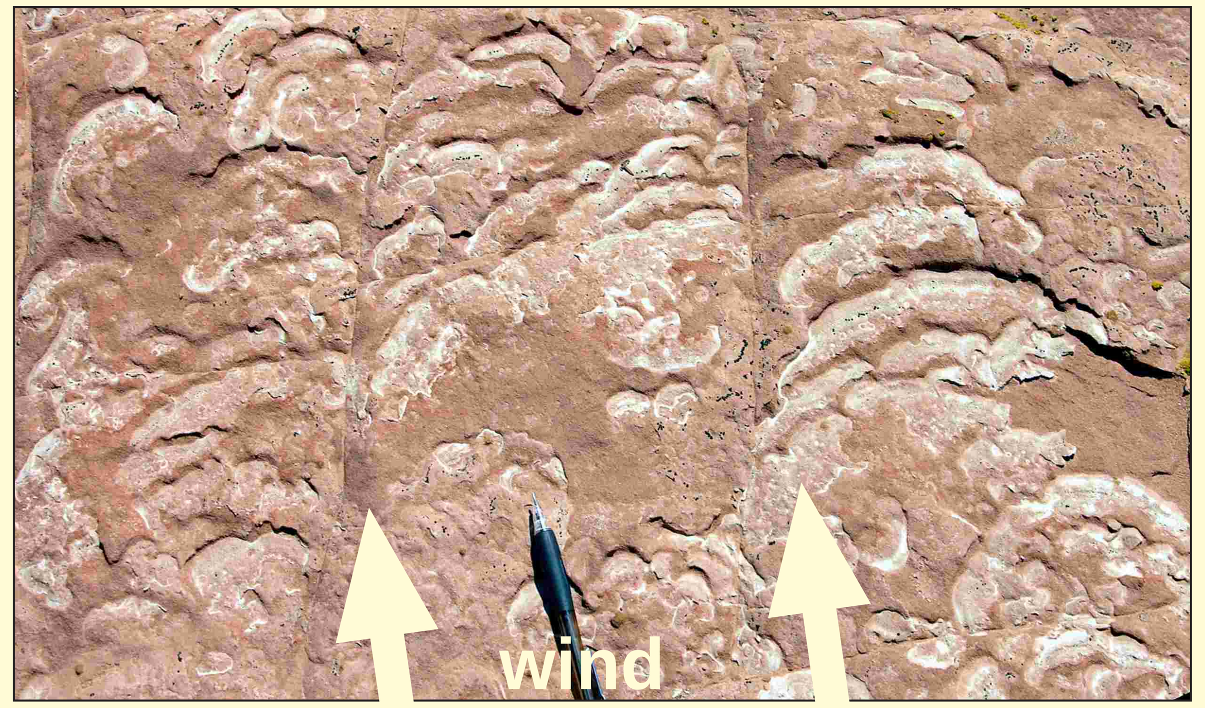
On Navajo Sandstone outcrops in open terrain near the Wave, encrusting lichens and the microtopography of the sandstone surface provide evidence of abrasion by saltating sand. The photos at right show that lichens occupy a "stepped" substrate: a series of parallel escarpments about 5 mm high face the dominant wind direction. Lichens occupy the "flats" between successive escarpments. This phenomenon is similar to the one involving microbial crusts described by Kurtz and Netoff (2001) and shown in the bottom, right corner of this poster. In both cases, development of the erosional bedforms causes abrasion by saltating grains to be concentrated on a small percentage of the substrate, leaving the remainder available and suitable for biological activity.





Do older portions of the lichen lie in the downwind direction? Undercutting of the the erosional escarpment on the left may have formed new surfaces that were each colonized by the lichen and subsequently undercut. Or are all portions of the lichen the same age--parts of an integrated, migrating system?

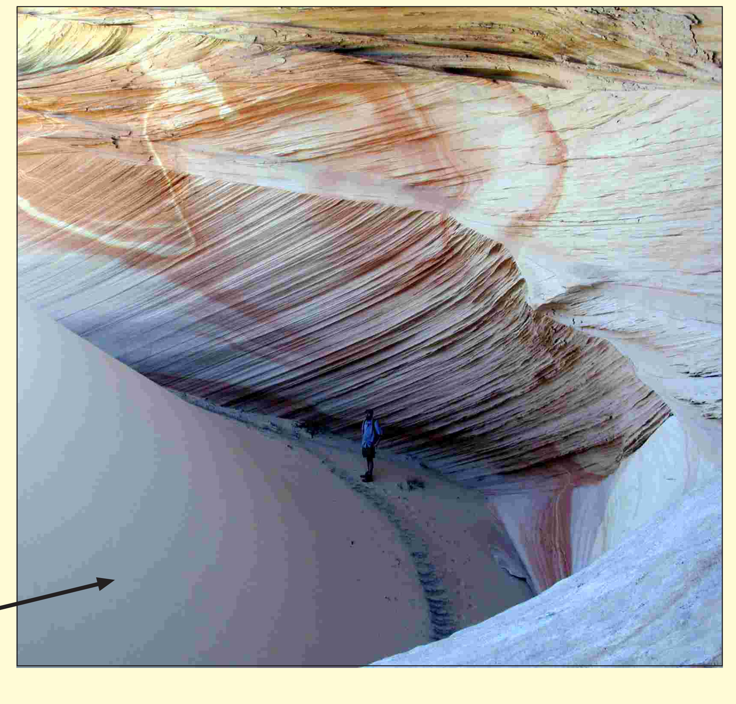
Larry St. Clair (B.Y.U.) identified the lichen as *Lecidea tessellata*, which is common on Utah sandstones.



Wind-Scoured Alcoves

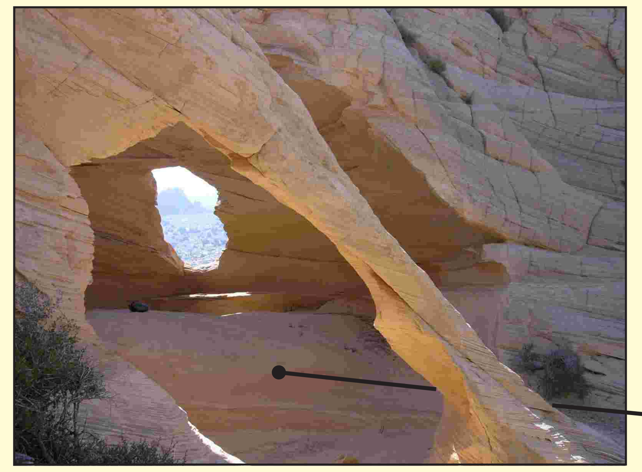
At the top of the plateau that lies 70 m in elevation above and 500-600 m southwest of The Wave, wind abrasion has formed **three alcoves** (black arrows, below. See topographic map at left for locations of alcove views). These landforms are directly exposed to strong southwesterly winds. All three alcoves have prominent scours on their inner walls. The northernmost alcove has a **large dune** in its center. These alcoves share many characteristics with the large weathering pits in south-central Utah described by Netoff and Shroba (1993) and Kurtz and Netoff (2001).

Inside the northern alcove, a sand dune has accumulated, and the walls have been deeply undercut by strong, swirling winds.

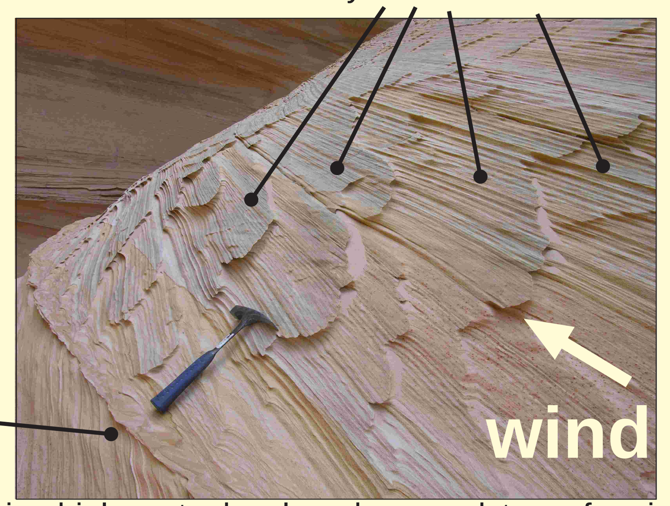



Sinuous scours abraded by saltating and suspended sand are well-developed on alcove walls. Flowing water played no role in formation of these scours.

Wind erosion inside the southernmost alcove (above)has thinned its walls, causing rockfalls that formed two arches.



crusts made by rock-surface microbes



Saltating sand has undercut microbial crusts developed on sandstone, forming a series of transverse, erosional bedforms. Crusts are eroded at their upwind margins and grow downwind, colonizing newly exposed sandstone. As in wind ripples (Sharp, 1963; Anderson, 1990), the low angle of saltating grains allows the high point of each crust to cast a long "shadow".