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Sandstone arches form under their own stress

Downward pressure and erosion combine to create celebrated rock formations.

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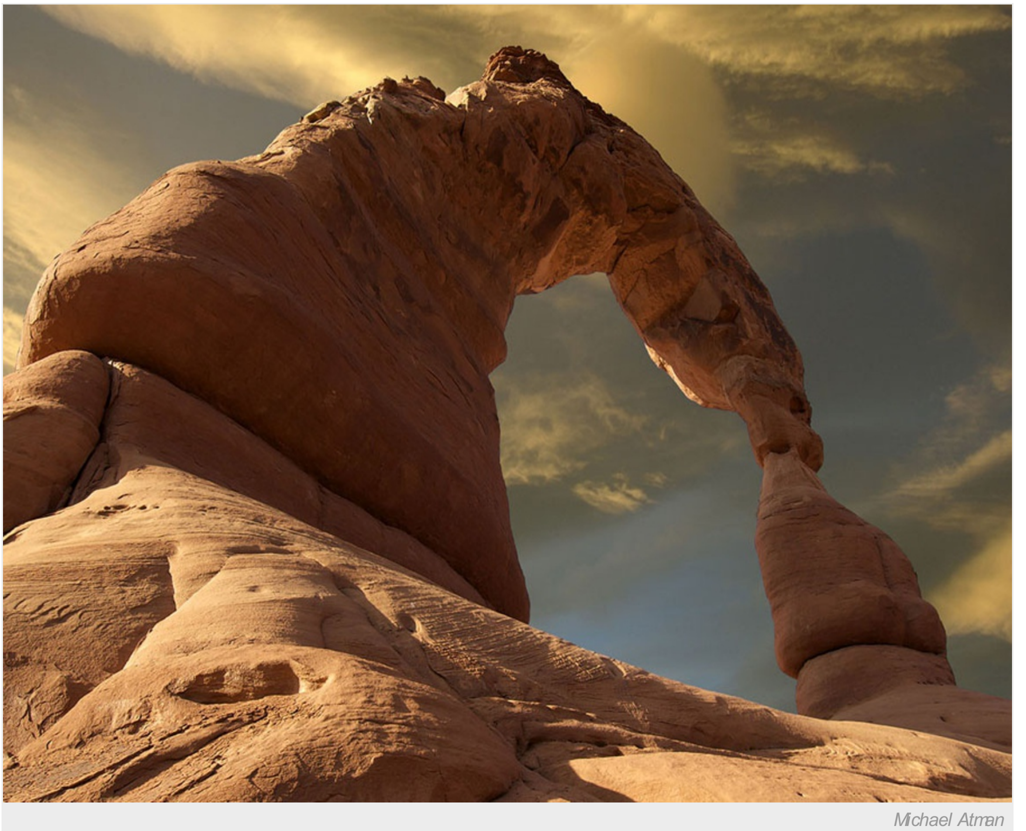

Michael Atman

Sandstone structures such as Delicate Arch at Arches National Park in Utah owe their shapes to the way gravity consolidates sand grains together, creating pillars that are more resistant to erosion.

The fantastical arch shapes of sandstone formations have long been thought to be sculpted by wind and rain. But a team of researchers has now found that the shapes are inherent to the rock itself.

“Erosion gets [excess] material out, but doesn’t make the shape,” says Jiri Bruthans, a hydrogeologist at Charles University in Prague, who led the research. Rather, erosion is merely a “tool” that works in combination with more fundamental factors embedded in the rock.

These factors are stress fields created by the weight of overlying rock. Under low stress, Bruthans says, sandstone erodes easily. But as stress mounts — as parts of a cliff or pillar are eroded away, for example — the sand grains on the surface of the remaining rock lock together and become more resistant to further erosion[1].

Bruthans’ insight came when he visited the Stralec Quarry in the Czech Republic, where a loosely packed form of sandstone known as 'rock sand' is mined.

Even though there is no natural cement binding the sand grains into rock, mining it requires blasting at the sandstone’s face to break the sand loose, says Alan Mayo, a hydrogeologist at Brigham Young University in Provo, Utah, and a co-author of the study. But once the rock is disrupted, he says, “it just disintegrates”.

Bruthans adds that after blasting, the sandstone in the quarry rapidly formed arches and other features common to the tourist attractions seen in places such as Utah’s Arches National Park.

To find out how such soft material could do this, the scientists took samples into the lab, cut them into small cubes, and used pressure plates to simulate the weight of overlying material. They then subjected the cubes to simulated rain or other erosive forces.

What they found, as report today in *Nature Geoscience*[1], is that when subjected to such pressures, even these otherwise crumbly materials quickly eroded into arches, alcoves and pillars that then became extremely resistant to further erosion. Subsequent experiments with more firmly consolidated sandstones from the North American Southwest produced the same result (see video below).

What happens, Mayo says, is that as erosion undercuts the material in ways that would normally cause it to collapse, pressure mounts along the remaining rock where the greatest amount of material has been removed. Eventually, a critical pressure is reached at which the sand grains lock together and become “incredibly stable”, he says.

Numerical modelling revealed that the resulting shapes followed the stress fields — a finding that also applied to natural landforms such as Utah’s emblematic Delicate Arch, a free-standing structure that is 20 metres tall.

Supporting the theory, Mayo adds, was a field trip to a part of Arches National Park where there have been recent rock falls. “We looked at the blocks on the ground, and they were completely disintegrated,” he says. “[They] no longer had that critical stress.”

Other scientists, (including sedimentologist Chris Paola of the University of Minnesota in Minneapolis, who wrote an accompanying News & Views), say the work provides an answer to the long-standing question of how such sandstone landscapes form. Gordon Grant, a research hydrologist at the US Forest Service's Pacific Northwest Research Station in Corvallis, Oregon, calls the explanation "simple, elegant, and plausible".

The findings do not mean that all sandstone arches, alcoves or other features should be identical. “Nature is very complex,” Bruthans says. “Initial conditions matter.”

How natural arches form

The team exposed 10-centimeter blocks of sandstone from a Czech quarry to erosion by water. The push of gravity distributed itself unevenly, which led to the formation of pillars (one in the first experiment, two in the second) that lasted longer than the surrounding material. The first sequence is a continuous recording of about 90 minutes, accelerated by 200x. The second is accelerated 100x in the first half, followed by two cuts, and the process lasted just over an hour.

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References

1. Bruthans, J. *et al*. *Nature Geosci.* http://dx.doi.org/10.1038/ngeo2209 (2014).