Dune patterns reveal environmental change on Earth and other planets

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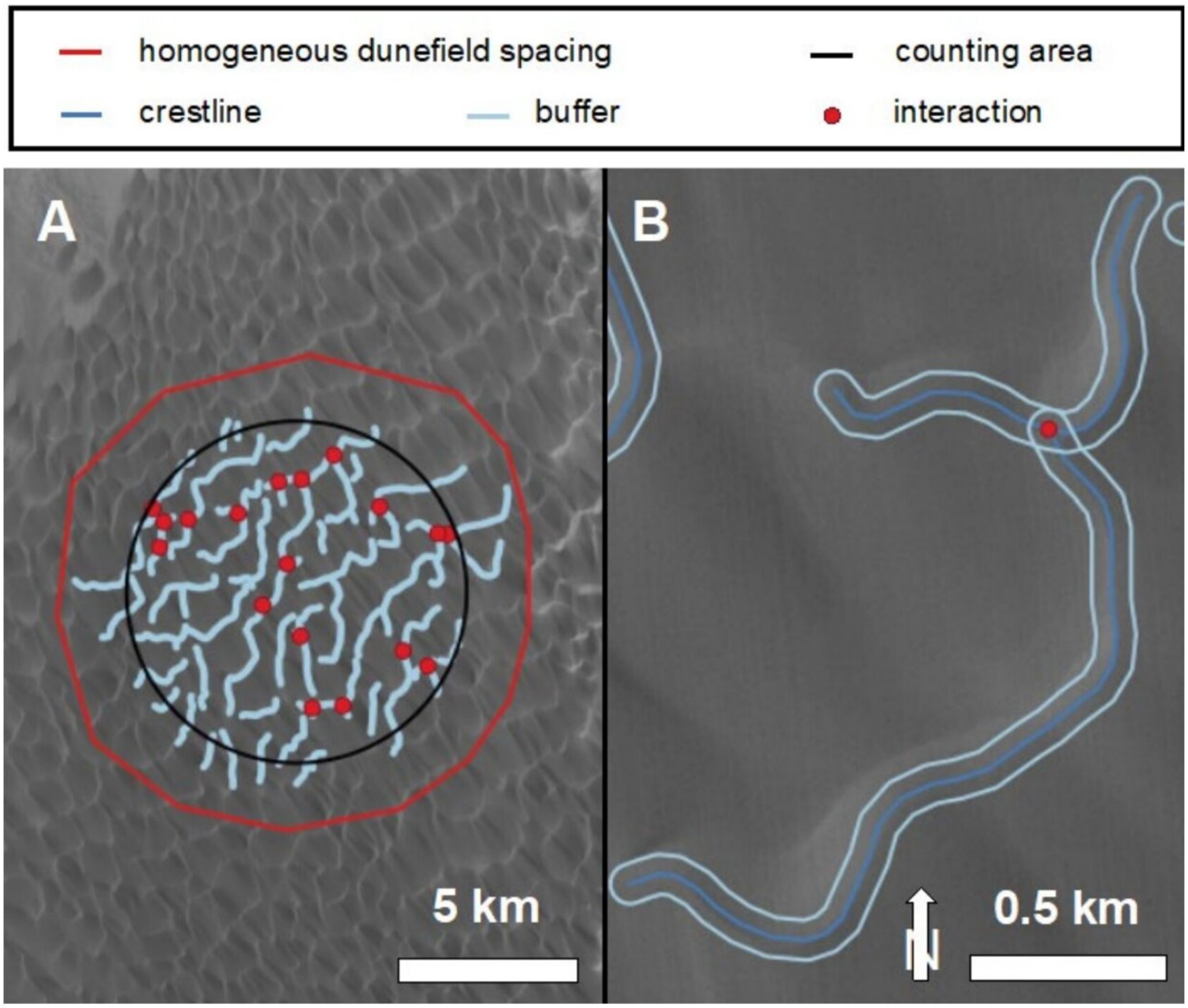

(A) Digitized counting area at Rabe Crater on Mars. (B) Zoomed in display showing buffers of 0.05?? generated around dune crestlines. Basemap from Dickson et al. (2018) mosaic. Credit: *Geology* (2023). DOI: 10.1130/G51264.1

Dunes, the mounds of sand formed by the wind that vary from ripples on the beach to towering behemoths in the desert, are incarnations of surface processes, climate change, and the surrounding atmosphere. For decades, scientists have puzzled over why they form different patterns.

Now, Stanford researchers have found a way to interpret the meaning of these patterns. Their results, published in *Geology*, can be used as a new tool for understanding environmental changes on any planetary body that harbors dunes, including Venus, Earth, Mars, Titan, Io, and Pluto.

"When you look at other planets, all you have is pictures taken from hundreds to thousands of kilometers away from the surface. You can see dunes—but that's it. You don't have access to the surface," said senior study author Mathieu Lapôtre, an assistant professor of Earth and planetary sciences in the Stanford Doerr School of Sustainability. "These findings offer a really exciting new tool to decipher the environmental history of these other planets where we have no data."

The scientists analyzed satellite images of 46 dune fields on Earth and Mars and studied how the dunes interact, or exchange sand. Physically, dune interactions manifest themselves as locations where the crestlines of two dunes get very close to each other. Through such interactions, dunes evolve toward a pattern that is free of defects, reflecting a state of equilibrium with local conditions.

Thus, the researchers hypothesized that a high number of interactions, in turn, must signal recent or local changes in those boundary conditions. To test their hypothesis, they used data from Earth and Mars to verify how known changes in environmental conditions, such as wind direction or the amount of sand available, affected dune interactions in the dune fields.

Finding a pattern

In a part of China's Tengger Desert, researchers once flattened a dune field to have a baseline for understanding its subsequent reformation. The study authors analyzed satellite images of the dune field from 2016 to 2022 to see how it grew from a flat bed to large dunes in equilibrium with their environment.

"When the dunes and their patterns were not in equilibrium with their current conditions, the interaction density was high, and through time we could see it decreased consistently, as is expected from our hypothesis," Lapôtre said.

Next, they investigated dunes migrating through a valley in the Namib Desert to see how changes in the wind conditions, triggered by topography, impacted dune patterns. They found that dunes outside the valley displayed few defects in their patterns, but as they migrated through the valley—which starts very wide, then narrows, then becomes wide again—dunes interacted more with each other.

"As both sand and winds get funneled into the valley, the dunes feel a change in their boundary conditions, and their pattern needs to adjust," said lead study author Colin Marvin, a Ph.D. student in Earth and planetary sciences. "They move into the portion outside the valley and they again readjust to their unconfined conditions, and we see a drop in the number of interactions. This trend is exactly what we expected to see."

They also found that pattern to be true on Mars, where a big dune field occurs around the north pole. There, the migrating dunes have settled into their current conditions—they're well spaced, they look the same, they're the same size—and because of that, they interact very little with one another.

But further downwind, the winds become more variable and frost locally makes it harder for grains to be blown away. There, the dunes react to that change until they have migrated far enough into these new conditions for their pattern to have once again matured, decreasing the number of dune interactions.

Testing the tool

"We have an upper bound on the time that it takes for a given dune to adjust to changes in environmental conditions, and that is the time it takes for a dune to migrate by a distance of one dune length," Marvin said. "We can use this to diagnose recent changes in environmental conditions on planetary bodies where we don't have any information other than images taken from orbit or radar for example."

Understanding the recent climate of Mars by analyzing current dune patterns could possibly help scientists better pinpoint, for example, the latitudes and depth where future astronauts might be able to find water ice in the subsurface, Lapôtre added.

The study also informs experts about the mechanics of dunes on Earth, which can help them better interpret Earth's rock record, and thus, our planet's distant past. On Saturn's moon Titan, this approach could reveal information about topography around the equator and tropics, which is near where the Dragonfly Mission is going to land in the mid 2030s.

"Topography can tell you about a lot of different things; for example, the geological history of the planet: Does Titan have tectonics? How does the interior of Titan work, and how is it coupled with the surface? Is there significant erosion?" Lapôtre said. "Interpretations of dune patterns could trigger kind of a chain reaction, where you provide a new constraint, and it's going to be useful to a bunch of people to make a bunch of discoveries down the line."

Because other planets have various sizes, gravities, temperatures, and compositions, their geological processes will differ. Compared with a rover that lands on one point of a planet to collect information, the satellite data of entire dune fields can greatly increase scientists' understanding of these extraterrestrial bodies and how they can inform our understanding of Earth.

"If we want to understand what happened in the past, or if we want to predict what will happen in the future, it's hard to do when all you have to create those models is one data point, or just one planet," Lapôtre said. "Ultimately, this kind of information allows us to make much better interpretations of Earth's past and also predictions of Earth's future."

More information: M. Colin Marvin et al, Dune interactions record changes in boundary conditions, *Geology* (2023). DOI: 10.1130/G51264.1

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