Study of dune dynamics will help scientists understand the topography of Mars

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Researchers at the University of Campinas conducted more than 120 experiments with dunes of up to 10 cm that interact for a few minutes, obtaining a model valid for dunes on the surface of Mars that are many miles long and take more than a thousand years to interact. Credit: Agência FAPESP

Barchans are crescent-shaped sand dunes whose two horns face in the direction of the fluid flow. They appear in different environments, such as inside water pipes or on river beds, where they take the form of ten-centimeter ripples, and deserts, where they can exceed 100 meters, and the surface of Mars, where they can be a kilometer in length or more. If their size varies greatly, so does the time they take to form and interact. The orders of magnitude range from a minute for small barchans in water to a year for large desert formations and a millennium for the giants on Mars.

They are formed by the interaction between the flow of a fluid, such as gas or liquid, and granular matter, typically sand, under predominantly unidirectional flow conditions.

"What's interesting is the similarity of their formation and interaction dynamics, regardless of size. As a result, we can study aquatic barchans in the laboratory to make predictions about the evolution of the dunes in Lençóis Maranhenses [a coastal ecosystem in the Northeast of Brazil] or to investigate the origins of the topography in the Hellespontus region on Mars," said Erick Franklin, a researcher and professor at the University of Campinas's School of Mechanical Engineering (FEM-UNICAMP) in the state of São Paulo, Brazil.

Working with his Ph.D. student Willian Righi Assis, Franklin performed more than 120 experiments and identified five basic types of interaction between barchans.

The study, conducted entirely at UNICAMP, is reported in an article published in the journal *Geophysical Research Letters*. It was supported by FAPESP via a Phase 2 Young Investigator Grant awarded to Franklin and a direct doctorate scholarship awarded to Assis.

A striking aspect of the topic is that as well as having a robust shape that appears in many different environments, barchans typically form corridors in which their sizes are approximately the same. Analysis of individual dunes suggests they should grow indefinitely, becoming steadily larger, but this is not the case. One explanation for their characteristic size in a given environment is that binary interactions, especially collisions, redistribute the mass of sand, and instead of growing continuously they subdivide into smaller dunes.

"This has been proposed in the past, but no one had extensively tested and mapped these interactions, as dune collisions take decades to happen in terrestrial deserts," Franklin said. "Taking advantage of the fact that underwater barchans are small and move much faster, we conducted experiments in a hydrodynamic channel made of transparent material, with turbulent water flow forming and transporting pairs of barchans while a camera filmed the process. We identified for the first time the five basic types of binary interaction."

In the experiments, the researchers varied independently each of the parameters involved in the problem, such as grain diameter, density and roundness, water flow velocity, and initial conditions. The images acquired were processed by computer using a numerical code written by the researchers. Based on the results, they proposed two maps that supplied a general classification of the possible interactions.

"Our experiments showed that when a binary collision occurs, the barchan that was originally downstream, i.e. in front, expelled a dune of an approximately equal mass to that of the barchan upstream, i.e. behind," Franklin said. "The first impression was that the upstream barchan passed over the other barchan like a wave, but the use of colored grains helped us show this didn't happen. Actually, the upstream barchan entered the downstream barchan, which became too large and released a mass more or less equal to the mass received."

Interactions between the two barchans basically involved two mechanisms. One was the disturbance caused in the fluid, which bypassed the upstream barchan, accelerated and impacted the downstream barchan, which eroded. This is termed the "wake effect". The other was the collision in which the colliding barchans' grains merged.

"Our experimental data showed that these two mechanisms caused five types of barchan-barchan interaction," Franklin said. "Bearing in mind that the velocity of a dune is inversely proportional to its size, the simplest two are what we call chasing and merging."

Chasing occurs when the two barchans are roughly the same size and erosion due to the wake effect makes the downstream dune decrease in size. The two barchans then move at the same velocity and remain at a constant distance from each other. Merging happens when the upstream barchan is much smaller than the downstream barchan. Erosion caused by the wake does not substantially decrease the size of the upstream dune, so that the barchans collide and merge, forming a single dune.

The third type of interaction is exchange, which is more complicated. "Exchange happens when the upstream barchan is smaller than the downstream barchan, but not much smaller. Here, too, the upstream dune catches up with the downstream dune and they collide. As they do so, the smaller dune ascends and spreads over the larger one. During this process, however, the fluid flow, which is deflected by the new dune, strongly erodes the front of the dune, which ejects a new dune. Because it is smaller and emerges downstream, the new dune moves faster and a gap opens up between the two dunes," Franklin said.

The last two types of interaction happen when fluid flow is very strong. "What we call 'fragmentation-chasing' is when the dunes are of different sizes. The wake effect on the downstream dune is so strong that it splits into two. Both the resulting dunes are smaller than the upstream dune. The result is three dunes with gaps widening between them. The last type is 'fragmentation-exchange', which is similar. The difference is that the upstream dune reaches the downstream dune before its division into two is complete," Franklin said.

The five types are easy to understand in the accompanying video. In fact, the researchers were able to construct the typology thanks to the visual support afforded by the movies described in the article. "Our results, obtained for subaqueous barchans that were centimeters in length and developed in minutes, significantly advance the understanding of the dynamics and formation of this type of dune," Franklin said. "Through laws of scale, they enable us to transpose the findings to other environments, where sizes are larger and timespans longer. Understanding the past of Mars or projecting its distant future, both of which are currently of interest to scientists, could be greatly facilitated by these findings." Barchans are crescent-shaped sand dunes whose two horns face in the direction of the fluid flow. They appear in different environments, such as inside water pipes or on river beds, where they take the form of ten-centimeter ripples, and deserts, where they can exceed 100 meters, and the surface of Mars, where they can be a kilometer in length or more. If their size varies greatly, so does the time they take to form and interact. The orders of magnitude range from a minute for small barchans in water to a year for large desert formations and a millennium for the giants on Mars.

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More information: W. R. Assis et al, A Comprehensive Picture for Binary Interactions of Subaqueous Barchans, *Geophysical Research*

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