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SHIFTING SANDS

Dunes hold heaps of material-and climate clues, too

Scientists sometimes travel to the ends of Earth in search of clues about our planet's past climate. Hidden in the accumulated layers of arctic icepacks and seafloor sediments are subtle variations that track global temperature trends. Lately, researchers have been braving a different type of extreme environment-the desert-to garner evidence of ancient weather patterns. The shifting sands of dunes, the archetype of transience, might seem an unlikely place to search for long-lasting records of environmental conditions. However, climate changes that stabilize dunes into more permanent geological formations essentially freeze them in time, transforming them into chronicles of the weather patterns that sculpted their shape.

For example, dune fields now trapped beneath grasses or other stabilizing vegetation speak of a drier past, a time when surface greenery was either sparse or nonexistent. Remnants of ancient soils buried within dunes can betray long-gone periods of wetter climate. The subtle signs of slumping sand, which indicate the direction of prevailing winds as surely as a modern wind vane, became frozen in place when heat and pressure converted ancient dunes into sandstone.

Sand dunes appear on all continents. They occur even in Antarctica, a continent that gets so little precipitation that almost the entire region is considered a desert. Overall, dunes cover 20 percent of the world's deserts, which in turn occupy about one-third of Earth's land surface. That figure doesn't include the myriad hidden dune fields now inactive beneath prairies, plains, and forests. From the high plains of North America to the Arabian peninsula, scientists are reading the dunes.

MASSIVE PILE-UP Only three things are needed to generate active sand dunes: a source of sand, winds strong enough to move that material, and a lack of stabilizing vegetation.

A dearth of vegetation seems to be more important for dune formation than high winds, says Daniel R. Muhs, a geologist at the U.S. Geological Survey in Denver. That's because even breezes as slow as 16 kilometers per hour can move unanchored material, he notes.

Mineral particles smaller than 0.2 millimeters across, such as dust, can be lofted by the wind and blown long distances-even across oceans (SN: 9/29/01). Grains of mineral that are larger and heavier-that is, sand-are sometimes suspended in strong winds. In calmer breezes, they move only short distances as wind repeatedly lifts them a few centimeters off the ground and drops them again. This process, in which sand grains bounce downwind, is called saltation. Upon impact, saltating particles can kick other grains of sand into the air. Particles too heavy to hop can nonetheless be pushed or rolled by the winds or bumped along by saltating sand.

Once sand piles up, dunes begin to form. Sand grains are blown up the windward side of the heap and over the crest until the leeward side of the dune is so steep that it slumps under its own weight. Repeated cycles of sand migrating to the top of a dune and then slipping down the backside-also called the slip face-push the bulk of the dune in the direction of the prevailing wind. The spacing of small ripples that form on the windward face of a dune is related to the average distance that sand grains travel with each bounce.

Different combinations of wind speed, sand availability, and vegetation yield different types of dune, says Muhs. When strong winds blow a relatively small amount of sand in the absence of vegetation, the long, straight crests of the resulting, so-called longitudinal dunes line up with the direction of the wind. When there's abundant sand and little or no plant cover, the crests of the so-called transverse dunes are perpendicular to the wind. Winds that blow in different directions at different times of the year, such as monsoon winds, can produce compound dunes that have a complicated shape.

CHIC OF ARABY One place where dunes are helping researchers answer questions about climates long gone is in the Sultanate of Oman.

Sediments from the bottom of the Arabian Sea include vast amounts of dust, a testament to the dry conditions on the continents nearby. However, the dust is so widespread in that part of the world that it's tough to infer the direction of the ancient winds that blew the material into the ocean. That's why scientists are studying samples of sandstone and two long cores of sediment drilled from the Wahiba Sands, a 16,000-square-kilometer sea of sand and dunes at the eastern tip of the Arabian peninsula.

Some dunes in the Wahiba Sands stand 70 m tall, and others stretch as far as 100 km in a north-south direction-from the southern Omani coastline to the base of the Oman Mountains. Today, the Wahiba Sands region receives only 10 centimeters of rain each year, says Dirk Radies, a geologist at the University of Bern in Switzerland. Winter winds in the region are generally slow because a persistent area of high atmospheric pressure straddles the area. In the summer, monsoon winds already emptied of their moisture flow along the Intertropical Convergence Zone (ITCZ) before they swerve north over the Wahiba Sands. The ITCZ is the meteorological boundary between tropical and temperate weather systems.

Until recently, says Radies, most scientists believed that the Wahiba Sands dunes formed since the last ice age, which ended about 12,000 years ago. Furthermore, current climate models suggest that the ITCZ is pushed farther south during ice ages and that prevailing winds over the Wahiba Sands during those periods flow from the northwest.

But the core samples-as long as a football field-drilled in the region suggest those climate models may be wrong. The angle of the layers of compacted sand observed in the core reveal that the winds blew toward the north during the last ice age, just as they do today. Radies and his colleagues reported their analyses in the June 14 Science.

The chemical composition of dunes can often add valuable information (see box, this page), says Radies. Although much of the material in the Wahiba Sands dune field can be traced to the interior of the Arabian peninsula, which lies to the west and northwest, half of the dunes' material is composed of carbonate minerals that derived from organisms that lived in shallow water. The closest source of such carbonates would have been the continental shelf to the south of the dunes. This material would have dried up and blown north during the last ice age, when sea levels dropped to about 100 m below what they are today.

MAINLY ON THE PLAINS The central portions of North America are also hot spots for dune researchers. This region is home to some of the continent's largest dune fields. The dune materials came from rocks pulverized beneath the ice sheets that smothered most of Canada and sagged south past the Great Lakes during a series of ice ages, says Muhs.

Each time the ice retreated northward, it left behind huge quantities of finely ground rock, much of it subsequently carried south by meltwater-fed streams. In the plains, the fine debris choked lakes and formed broad, thick river deltas. When this material dried out, the winds piled it into massive dunes. Many of these dune fields are now stabilized by vegetation, but their age and structure record snippets of information about how climate has changed during recent millennia.

Boreal forests of spruce now cover sand dunes that once stretched across the northern regions of Alberta and Saskatchewan, says Stephen Wolfe of the Geological Survey of Canada in Ottawa. The rolling floor of today's forests reflects the shape of the dunes. That terrain indicates that when these dune fields were active, between 11,000 and 8,000 years ago, cold, fierce winds that roared off the dwindling ice sheet drove sand toward the northwest.

Farther from the ancient ice sheet and to the west, an older set of sand dunes lies preserved beneath the region's plains. Core samples from those dune fields, just north of Edmonton, Alberta, show no deep layers of soil. Therefore, the scientists conclude that the dunes were continuously active from 15,000 to 10,000 years ago. At that time, the prairie grasses moved in, and conditions since then have been moist enough to support vegetation, says Wolfe.

In a region icefree for a longer period, the dunes just north of the U.S.-Canada border should be even older than those around Edmonton. However, cores of those sands suggest that the oldest layers were deposited only about 5,600 years ago. This apparent paradox arises because most evidence of earlier dune activity has been erased by a total reworking of the sand, says Wolfe. Numerous layers of soil within the prairie sands hint that this region's climate during the past 5 millennia has shifted back and forth between lengthy wet and dry periods.

Yet farther south, ancient dune fields lie hidden beneath many parts of the Great Plains. The largest such area in North America, the Nebraska Sandhills, covers a full one-quarter of that state. Although the relict dunes are now stabilized by vegetation, they're in a precarious balance, says Muhs. Surface soils there aren't thick or well developed, and they're poor in the organic matter that promotes the growth of vegetation. The dunes in some of these areas, which weren't scoured away by ice sheets or glaciers during the series of ice ages, contain a climate record for the past 200,000 years.

Sediment cores obtained throughout the region show that dune fields have been active over broad areas for several periods in the past 3,000 years. Muhs and his colleagues can't yet determine whether dunes in different parts of the region were active at the same times, but the cores plainly show that contrary to previous beliefs, the dunes haven't been frozen in place since the last ice age.

Anything that would diminish vegetation in the region could remobilize the sands and scramble any messages about ancient climate that might have been present, says Muhs. These factors include a drop in rainfall, a warmer climate, overgrazing, and some cultivation practices. For example, plowing fields after the fall harvest rather than just before the spring planting exposes the poor soil to a full season of winter's windy wrath.

Extended droughts can remobilize sands and scour away natural weather records, too. Core samples have shown that some North American dune fields that scientists thought had been frozen since the last ice age actually have been on the move during the past few centuries.

For example, a lengthy dry spell in the 1790s revived dunes on the Great Plains that stayed active long enough to frustrate westbound pioneers 5 decades later, says Muhs. The same drought reinvigorated dune fields in the Great Sand Hills region between Medicine Hat, Alberta, and Swift Current, Saskatchewan, notes Wolfe.

The climate clues that those once-inactive dunes held, like the sand itself, are gone with the wind.

PHOTO (COLOR): SPACED OUT - The distance between ripples on the windward side of a dune is closely related to how far a sand grain travels in each windblown bounce.

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By Sid Perkins
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