Booming Sand

Though known for centuries, sound-producing sand remains one of nature's more puzzling phenomena

by Franco Nori, Paul Sholtz and Michael Bretz

For thousands of years, nomads traveling through deserts heard mysterious sounds they thought were made by ghosts or demons. Marco Polo reported that evil spirits "at times fill the air with the sounds of all kinds of musical instruments, and also of drums and the clash of arms." Today a nonoccult explanation is available: those diverse noises are all acoustic emissions produced by shifting sands.

At least 30 "booming" dunes have been found in deserts and on beaches in Africa, Asia, North America and elsewhere. Listeners have likened the sounds they make to bells, trumpets, pipe organs, foghorns, cannon fire, thunder, low-flying propeller aircraft, the buzzing of telegraph wires, even moaning or humming. Nevertheless, researchers do not agree on just how and why, in many parts of the world, under certain conditions, the sand sings.

Is it the size or shape of individual grains of sand? The way in which they interact? All these elements, among others, are at work. Very few systematic examinations of the phenomenon have been conducted, however, and no one scenario completely elucidates the mechanism that produces sound. We do not have the final answer but aim to raise questions that could point the way to a satisfactory explanation.

The sounds made by sand are not always dramatic. Walking on some beach sand, for example, elicits squeaking noises underfoot. This type of sand, called "squeaking" or "whistling," can be found at beaches, lakes, shores and riverbeds around the world. Its less common cousin, booming sand, transfixed not just Marco Polo but intrigued Charles Darwin and mystified countless others. Booming occurs almost exclusively in large, often isolated dunes deep in the desert or on "back beaches" far from water.

Listeners often compare the sounds of booming sand to those of musical instruments. In some cases, the peals occur in steady beats, sounding like drums or tambourines. In other dunes, the sand produces sounds more akin to trumpets, stringed instruments or bells. Such remarkably clear reverberations usually occur only when small quantities of sand move in response to some force, yielding just one frequency of vibration at a time. In 1994 we observed that small, induced avalanches at Sand Mountain in Nevada created sounds similar to those of a didgeridoo, an Australian aboriginal instrument characterized by a low, droning cadence.

Sounds of the Desert

Squeaking sand produces sounds with very high frequencies—between 500 and 2,500 hertz, lasting less than a quarter of a second. The peals are musically pure, often containing four or five harmonic overtones. Booming sand makes louder, low-frequency sounds of 50 to 300 hertz, which may last as long as 15 minutes in larger dunes (although typically they last for seconds or less). In addition, they are rather noisy, containing a multitude of nearby frequencies. Booms have never been observed to contain more than one harmonic of the fundamental tone.

These dramatic differences once led to a consensus that although both types of sand produce acoustic emissions, the ways in which they do so must be substantially different. In the late 1970s, however, Peter K. Haff, then at the California Institute of Technology, produced squeaks in booming sand, suggesting a closer connection between the two.

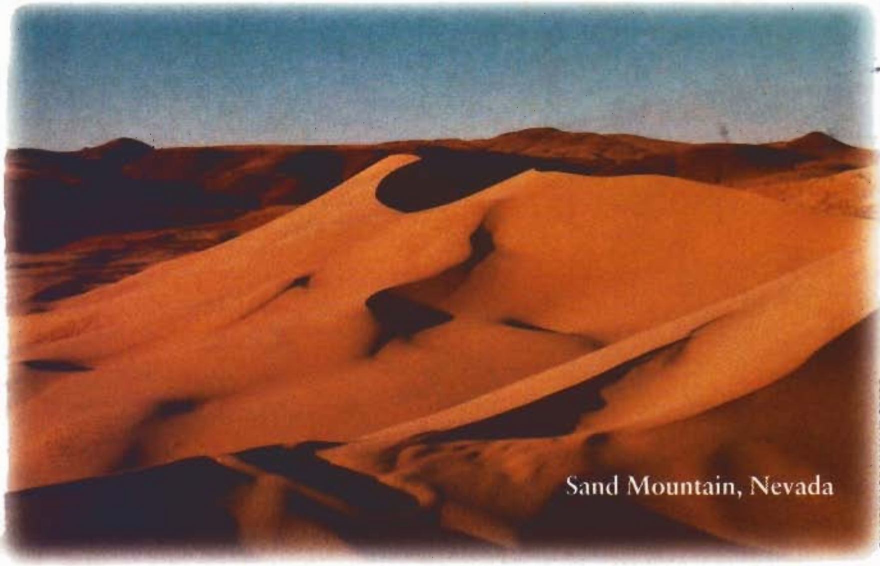
Both kinds of sand must be displaced to make sounds. Walking on some sand, for example, forces the sand underfoot to move down and out, producing squeaks. In the case of booming sand, displacement occurs during avalanches. It is within the avalanche that sound begins and where the answers must be hiding.

Before an avalanche can occur, winds must build a dune up to a certain angle, usually about 35 degrees for dry desert sand. Once the angle is achieved, the sand on the leeward side of the dune begins to slump. Intact layers of sand slip over the layers below, like a sheared deck of cards. At the same time, the individual grains in the upper layers tumble over the grains underneath, momentarily falling into the spaces between them and bouncing out again to continue their downward journey. Their concerted up-and-down motion is believed to be the secret source of sound. Fully developed avalanches, in which sliding plates of sand remain intact for most of their motion, have the greatest acoustic output. In some places, where large amounts of sand are involved, booming can be heard up to 10 kilometers away.

The mysteries of the vibrations are many. To begin with, the multiple frequencies of booming sand are not well understood. In the 1970s David R. Criswell and his collaborators at the University of Houston found that each frequency seems to exhibit its own rise-and-fall time, independent of the others. Taken together, these frequencies can cover a fairly broad range, the width of which is determined by various factors. For example, Sand Mountain booms at roughly 50 to 80 hertz; sands at Korizo, Libya, drone at between 50 and 100 hertz; and in the Kalahari Desert of South Africa, the frequencies range from 130 to 300 hertz. Such output—presumably caused by multiple modes of vibration within the shearing plates—is often unmusical and jarring.

NAMIB DUNES in southern Africa produce deep booms during avalanches. The droning can be heard for miles.

JIM BRANDENBURG *Minden Pictures*



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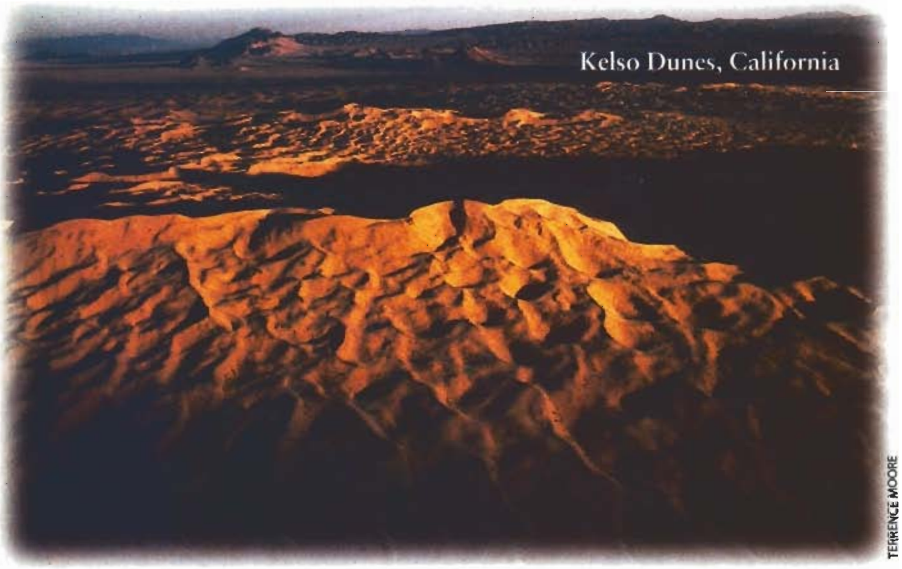

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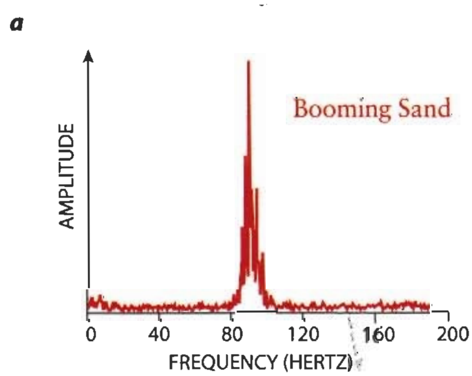
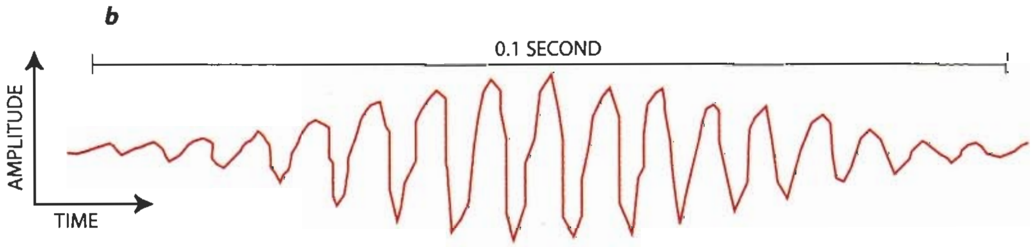
BOOMING SAND (*red dots*) **is found around the world; some sites are shown in the map and the photographs. Sound produced by booming sand has a range of nearby**





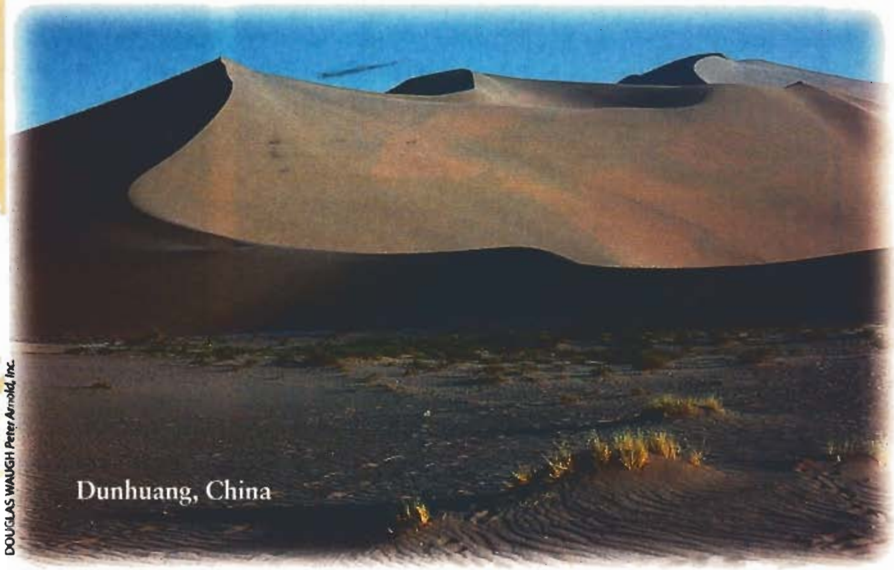
Because it is caused by large volumes of shearing sand, the roaring is also loud. In fact, sounds made by booming sand can be nearly deafening, and the vibrations causing them can be so intense that standing in their midst is nearly impossible.

A good place to start in exploring the vibrational properties of sand is with the grains themselves. The mean diameter of most sand grains, whether acoustically active or not, is about 300 microns. Usually the grains in a booming dune are very similar in size, especially near the leeward crest, where the sound most often originates; such uniformity allows for more efficient shearing. Otherwise, the smaller grains impede the smooth motion of the larger ones.

Similar sizes do not alone allow sand to boom. On the contrary, the booming sands of Korizo and Gelf Kebib, also in Libya, feature an uncharacteristically broad range of particle sizes. Moreover, silent dune sand often contains grains somewhat similar to nearby booming sand.

Grains of booming sand also tend to have uncommonly smooth surfaces, with protrusions on the scale of mere microns. Booming dunes are often found at the downwind end of large sand sources; having bounced and rolled across the desert for long distances, the sand grains in these dunes are usually highly polished. Over time a grain can also be polished by repeated shifts within a moving dune. And squeaking sand as well tends to be exceptionally smooth.

Close inspection of Sand Mountain and Kalahari booming sand, however, reveals that not all grains are highly spherical or rounded. And in 1936 A. D. Lewis in Pretoria, South Africa, even claimed to have produced booming in



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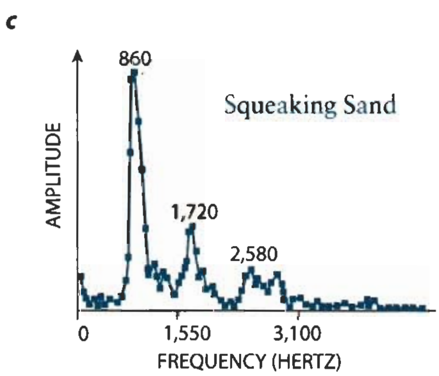
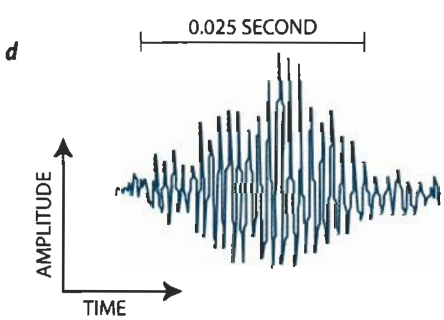
frequencies (*a*), pronounced beats and relatively long duration (*b*). Sound from squeaking sand contains harmonics of a fundamental note (*c*) but is very brief (*d*).





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the cubed grains of ordinary table salt. Conversely, spherical glass beads cannot be made to boom. These findings show that although smoothness and roundness are essential to producing sound, so is some degree of roughness.

Another important factor is humidity, because moisture can modify the friction between the grains or cause sand to clump together, thus precluding shearing. Sounds occur in those parts of the dune that dry the fastest. Precipitation may be rare in the desert, but dunes retain water with remarkable efficiency. Sand near the surface dries quickly, however, and sand around a dune's crest tends to dry the fastest.

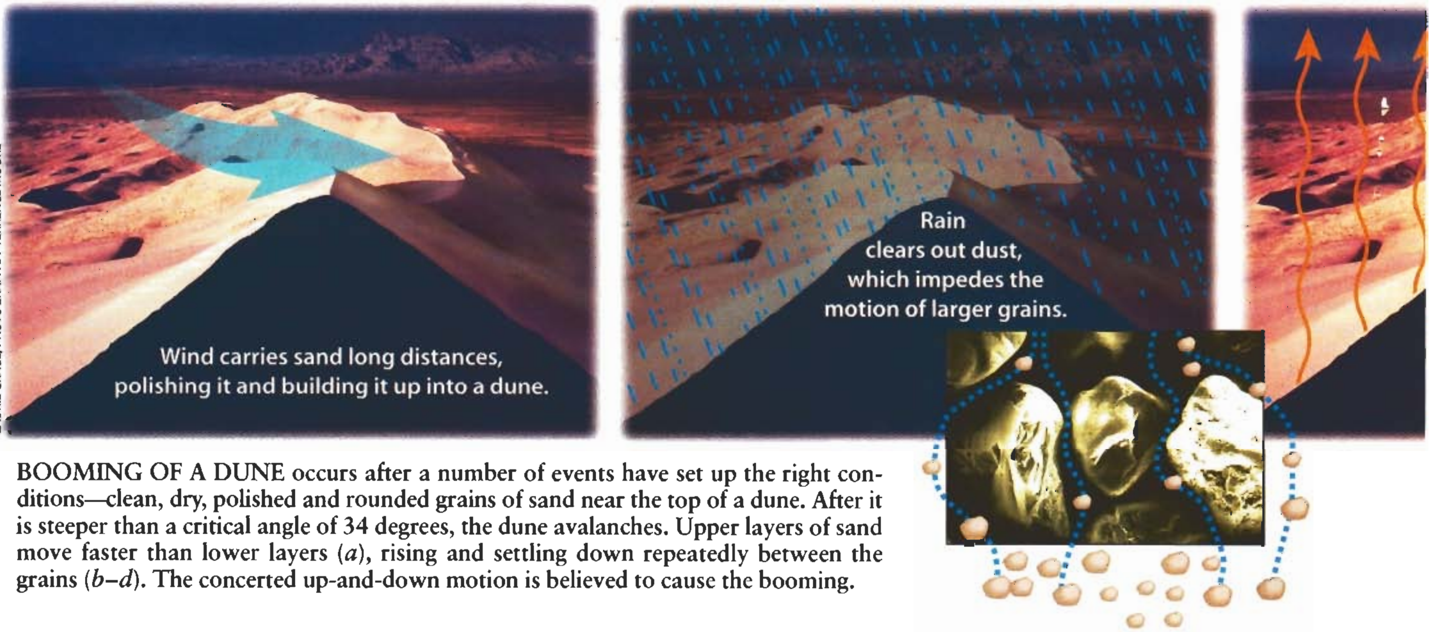
Near the leeward crest, the combination of smooth, well-sorted grains and lack of moisture leads to conditions more likely to produce sounds during shearing. And because wind usually deposits more sand closer to the top of the lee face, sand accumulates there faster than in lower regions, thereby slowly increasing the dune's incline to where avalanches occur.

Typically, large platelike slabs of sand break off near the crest. In booming sand, these plates tend not to slow into loose flows as they encounter gentler slopes. Instead their upper parts collapse or telescope violently into the lower parts. The plates' eventual breakup is unusually turbulent.

Learning more about sound-producing sand has not been easy. Research has been hindered by the rarity of the phenomenon—especially booming sand—and the difficulty in reproducing sounds in laboratories. In addition, for years researchers did not clearly differentiate between booming and squeaking sands, making the early literature on the topic less than reliable.

A Century of Study

In 1889 the American geologist H. Carrington Bolton published one of the first studies of the phenomenon. He proposed that the sounds result from thin films of soluble impurities deposited on the grains by the gradual evaporation of water. The vibration of elastic air cushions between shearing planes would create acoustic emissions, with the volume and pitch of the sounds being modified by the surface structure of



LAURIE GRACE; PHOTOGRAPH BY TERRENCE MOORE

BOOMING OF A DUNE occurs after a number of events have set up the right conditions—clean, dry, polished and rounded grains of sand near the top of a dune. After it is steeper than a critical angle of 34 degrees, the dune avalanches. Upper layers of sand move faster than lower layers (*a*), rising and settling down repeatedly between the grains (*b–d*). The concerted up-and-down motion is believed to cause the booming.

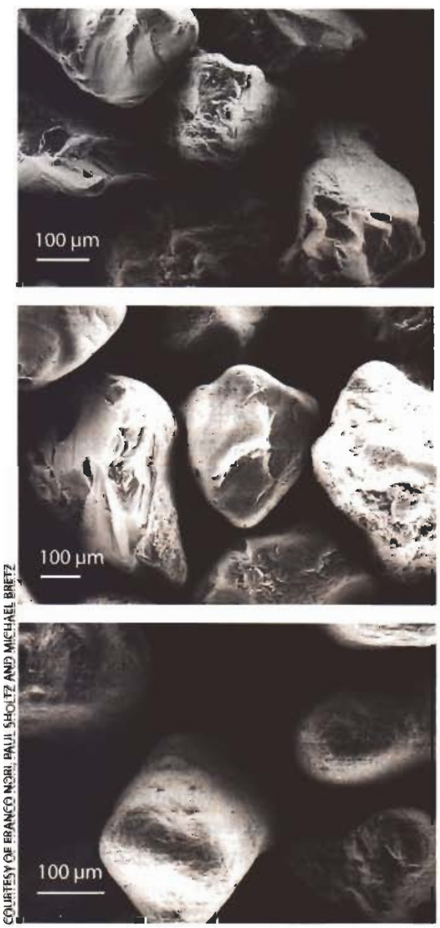
the grains themselves. Bolton concerned himself mainly with squeaking sands but used the same model to explain booming sands.

Around the same time, the British scientist Cecil Carus-Wilson suggested that squeaking sand produced its sounds as a result of the effects of friction on individual grains. He was the first to conclude correctly that grains found in sound-producing sand are usually spherical, well rounded and "well sorted," a term used to describe a high concentration of grains of similar size. Criswell and his collaborators later quantified these results.

In 1966 the British engineer and field commander R. A. Bagnold published "The Shearing and Dilatation of Dry Sand and the 'Singing Mechanism'" in the *Proceedings of the Royal Society.* In the first comprehensive attempt to discuss the phenomenon, Bagnold argued that both squeaking and booming were in fact caused by the same process. His argument is based on the concept of "dilatation," a measure of the empty space between the grains. As one plate slides over another, he argued, it tends to rise up and fall periodically as the grains settle into the spaces between the grains below. The frequency of sound produced by this collective vibration varies as the inverse square root of the mean size of the grains.

Although elegant, the mechanism does not completely describe a booming event. It does not, for example, account for how four or five separate modes of ground vibration could be created simultaneously from a single slab of grains. Nor does it explain the low-frequency beats that typically accompany prolonged flows.

Bagnold's arguments are more conducive to explaining squeaking sand. Stepping on squeaking sand, he proposes, causes it to shear along planes in a manner similar to those that form during avalanches. The only difference, he contends, is the applied force. Whereas the weight of sand itself causes avalanches and booming, the compressional stress of a footstep leads to the shearing that results in squeaking sounds. In fact, the frequencies exhibited by squeaking sand match Bagnold's model better than those caused by booming sand.



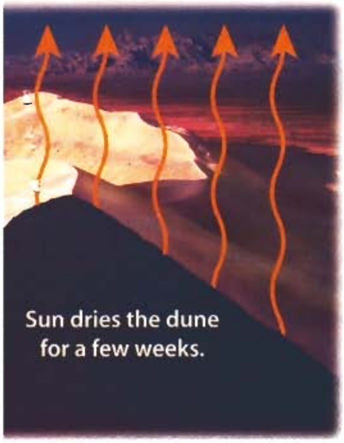
COURTESY OF FRANCO NORI, PAUL SHOLTZ AND MICHAEL BRETZ

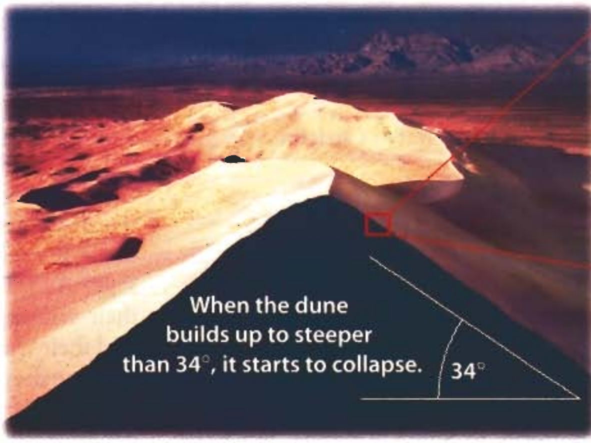
ELECTRON MICROGRAPHS show grains of normal beach sand (*top*) collected from Lake Huron at Bay City, Mich., having rough edges. Squeaking beach sand (*middle*) from Lake Michigan at Ludington, Mich., is smoother; even more polished is booming dune sand (*bottom*) from Sand Mountain, Nev.

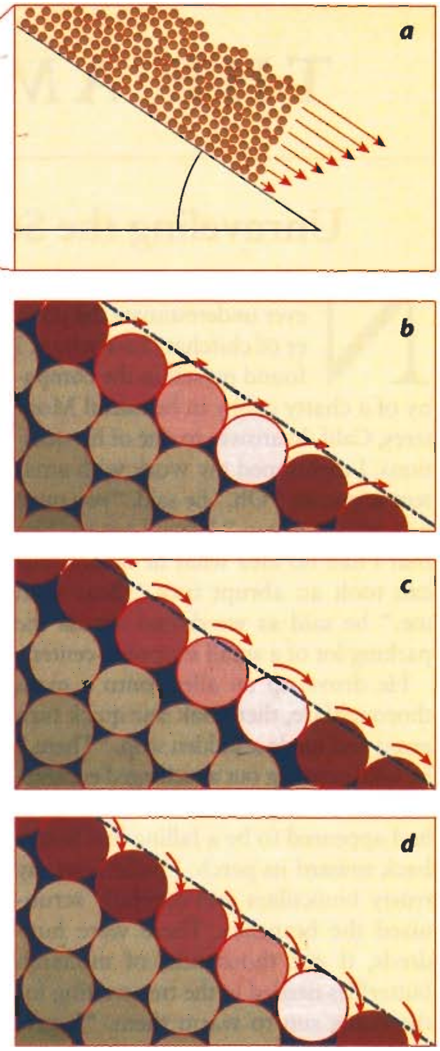
Probing the Mystery

We have been unable to produce squeaking sounds in booming sand, but as far back as 1889 there have been suggestions that the same type of sand is capable of yielding both. Bolton wrote that sand in Hawaii "possesses the acoustic properties" of both beaches and deserts, producing the same sounds during avalanches as Jebel Nagous, an Egyptian booming dune, and yielding "a peculiar hoot-like sound when struck together in a bag, like the sands of Eigg [in Scotland]; Manchester, Mass.; and other sea-beaches."

In the 1970s Haff also induced high-frequency "squeaks" using booming sand from the Kelso Dunes in southeastern California. This discovery provides some support for Bagnold's theory that the only difference between squeaking and booming sands is the mechanism by which they are produced: compression versus avalanche.







LAURIE GRACE

There are, however, differences between booming sand that can be forced to "squeak" in a laboratory and sand known to squeak in its natural setting. Haff's analysis shows that multiple frequencies are present in squeaking emissions from booming sands—unlike the purer notes that are produced by true squeaking sand.

For sand to boom, a few conditions must be met. First, the dune should be far from its original sand source so that winds can carry grains along for great distances, depositing similarly sized, well-rounded grains at or near the top of a dune. A good rain should wash dust and smaller particles out from between the grains. Next, a week or two of drying must occur. Finally, the wind should be sufficient to push sand over the top, causing an avalanche.

The most critical parameter governing the ability of sand to boom appears to be its resistance to shear. Sand that is packed too tightly cannot shear, whereas grains that are too loosely grouped take on the properties of a fluid and do not shear properly. All these factors are known to affect the sounds made by sand, but how they intermix to create them requires further study.

Hawaii may be a good place to start. Back-beach dunes on the islands of Kauai and Niihau are the only known examples of nondesert sand that boom. Their sands possess more moisture than typical desert dunes, and the grains are unusually large—about 460 microns in diameter. Moreover, the sand is unlike any other sound-producing variety: the dunes are composed primarily of calcium carbonate grains formed from seashells and are believed to be the only booming sands not made of quartz. Because the exception sheds the most light on the rule, studying these beaches might prove very profitable.

Booming and squeaking can be reproduced in buckets or bags. To figure out exactly how sound is produced, however, a glimpse deep inside the shearing process is needed. It may be possible to get that look with sophisticated radiological equipment, but such an analysis has not yet been completed.

An intriguing avenue for research is the electrical behavior of sand. When a grain of silica is compressed, it tends to develop opposite electrical charges at either end; this charge separation can cause grains to attract one another. In 1936 Lewis observed that on slowly pouring Kalahari booming sand, grains would occasionally adhere to form filaments as long as half an inch; an electroscope verified that these threads were indeed electrically charged. Nevertheless, we have found that electrically grounding the sand has no effect on its acoustic output. And although electrical effects may help explain why humidity precludes booming, so far no one has collected any strong evidence.

Other promising routes of investigation include systematically probing the mineral composition of booming sand grains to study the importance of shearing strength. Creating synthetic booming sand could also prove fruitful, allowing researchers to manipulate different parameters and thus test their role.

But perhaps the greatest attraction of singing sand is that it remains an unsolved puzzle. SA

The Authors

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Further Reading

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