Science Break

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Singing Sand Dunes

"Marvelous indeed and almost passing belief are the stories related of these spirits of the desert, which are said at times to fill the air with the sounds of all kinds…" (The Travels of Marco Polo, Book I, Chapter 36)

Singing sand dunes have been known of presumably since time immemorial, since they do actually exist, and the phenomenon is fairly obvious when encountered. Although they have many of the characteristics of a myth, such as the magical sounding name, some 35 dune locations across the world exhibit the "singing" behaviour, so it is very easy to validate. It has apparently been more difficult, even in our scientific age with all its equipment and knowledge (and busy little graduate students armed with government funding), to exactly determine the mechanisms at play. So while the eerie moans and throbs of sand dunes have fascinated humans for thousands of years, they have proven to be equally fascinating to scientists. A survey of the many websites devoted to the topic shows a wide divergence of thought on this topic. I will attempt to summarize this, and present the most plausible and coherent theories currently available.

The sound in question occurs only at certain dunes, and only during certain seasons, typically summer. It is heard as a loud (up to 105 dB, audible up to 10km away in certain locations) monotonous vibration (i.e. narrow frequency band), usually falling between 70 and 105 Hz. It has been described as being similar to the low frequency throbbing sound of a slow propeller engine airplane. The frequency range heard at each location is different, and tends to vary little. There are also reports of higher frequency sounds in the range of 450 Hz, presumably harmonics, but these are less common.

The dunes in which the singing occurs have some characteristics in common. They tend to be larger dunes, and crescent shaped. The angle of repose, that is the slope on the leeward side of the dune, needs to be in the range of 30 to 35 degrees. There needs to be a certain level of moisture present in the dune. If it is too dry, or too wet (as in winter in most locations), then the singing won't occur. The dunes in question are located in many places around the world – Peru, Mongolia, China, North Africa, California, etc. Figure 1 shows some beautiful singing dunes found in Altyn-Emel National Park, Almaty Province, Kazakhstan.

"Whilst staying in the town I heard an account from several of the inhabitants, of a hill in the neighbourhood which they called "El Bramador" -- the roarer or bellower. I did not at the time pay sufficient attention to the account; but, as far as I understood, the hill was covered by sand, and the noise was produced only when people, by ascending it, put the sand in motion. The same circumstances are described in detail on the authority of Seetzen and Ehrenberg, as the cause of the sounds which have been heard by many travellers on Mount Sinai near the Red Sea. One person with whom I conversed, had himself heard the noise; he described it as very surprising; and he distinctly stated that, although he could not understand how it was caused, yet it was necessary to set the sand rolling down the acclivity. A horse walking over dry and coarse sand, causes a peculiar chirping noise from the friction of the particles; a circumstance which I several times noticed on the coast of Brazil." (The Voyage of the Beagle, Charles Darwin)

Figure 1. Singing sand dunes, Altyn-Emel National Park, Almaty Province, Kazakhstan.

The singing is directly related to sand avalanches down the leeward dune side, typically caused by wind creating a buildup of sand at the crest, which then slides down the slope. Researchers have found that they can induce the avalanches and hence the singing simply by walking along the crest, and this greatly facilitates research since they don't have to wait for perfect wind conditions.

Many explanations for the singing have been put forth over the years, and most have centered on shear mechanisms related to part of the sand body moving relative to the rest. Early theories speculated that the entire dune resonated like a drum. This however does not make sense, since two side by side dunes of completely different size and dimensions will emit the same frequency sound. It would be like expecting the bass and snare drums in the same kit to sound the same. Relationships between dominant sand grain size and singing frequency have also been discounted.

Bagnold (1966) and Patitsas (2003) among others proposed theories invoking concepts involving fluidized layers, slip channels, slip planes, shear and dilation, grain size – frequency relationships, etc. I can't claim to have read a single one of these papers, but can say that many elements from this variety of work seem to have converged into a broadly accepted theory.

The theory that Andreotti (2004), Douady et al (2006) and Bonneau et al (2007) generally ascribe to involves a near surface wave, something we're very familiar with in the seismic world. The surface wave involved is trapped in the approximately 2m of dry sand that lies outside of the main

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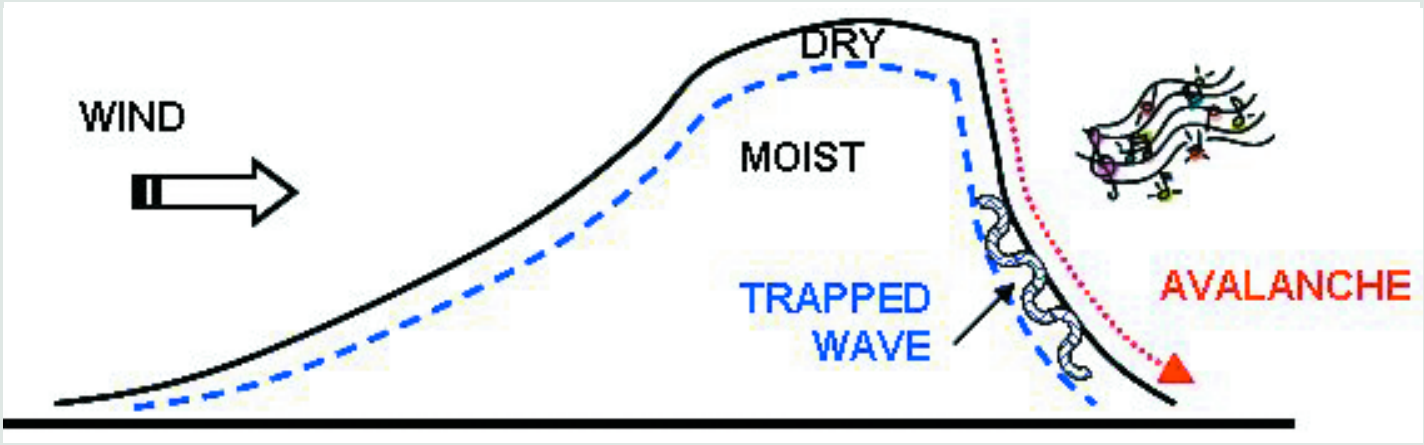

Figure 2. Singing sand dune model.

body of the dune, which is moist, and hence denser, and has experienced some minor chemical alteration that I picture as being the first stage of some kind of cementation (Figure 2).

In a simple sense, this theory suggests that the following sequence of events occurs within singing sand dunes:

- A sand avalanche occurs.
- The shear forces related to the body of sand sliding down relative to the main dune generate (i) millions of mini-collisions between grains of sand in the shear layer, resulting in small noises, and (ii) a trapped surface wave between the shear boundary and the dry/moist interface.
- The surface wave is guided within the dry layer, and possibly reverberates. It couples with the shear layer which begins to vibrate at a certain frequency, like a giant drum.
- The grain collisions become increasingly controlled by the vibrations caused by the surface wave, and these collisions become synchronized. In her website article, Caltech's Ir. Nathalie Maria Vriend refers to this phenomenon as 'wave-particle mode locking'.

The full state of "singing" is reached as the majority of collisions and their associated noises are all in harmony, at a frequency dictated by the thickness of the dry near surface layer. This general theory appears to fit or explain all the field observations.

The science is interesting enough, but what makes it even more interesting is that there is an academic bun fight involved. Andreotti and Douady, former colleagues at Ecole Normale Supérieure (ENS) in Paris, began their research as friends investigating the bachans of Morocco. After several years of cooperative work they began thinking along divergent lines, and are now no longer speaking (supposedly). Their disagreement is rooted in the synchronization mechanisms at play, with Douady believing they are all internal to the shear layer, and Andreotti believing they are the result of interplay between the shear layer and the near-surface dune layer containing the guided wave. Douady's further independent

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research suggested that a synchronization phase was not involved or not necessary, and that the singing comes purely from the grains rubbing against each other, with grain size again being related to frequency. Andreotti focused more and more on the elastic wave propagation characteristics of surface elastic waves.

More recently the Caltech group has done further research, and now it appears that perhaps Douady and Andreotti are both a bit off the mark. The research summary found on the Vriend's website (Caltech) suggests that they are trying to be more rigorous and objective in their research, rather than some of the previous work which can perhaps be better described as the intelligent pursuit of personal hunch or intuition. Among other things, they have concluded that frequency is independent of grain size, and dependent on macro dune characteristics, and they have clearly identified layers with dunes (via GPR and high res seismic) which preferentially guide waves at certain frequencies.

The final scientific chapter on the phenomenon of singing sand dunes remains to be written. And the world of scientific research lurches on, involving brilliant minds, emotion, conflict and cooperation, methodical research, trial and error, dead ends, and lucky post-doc students tramping around some of the most beautiful and mysterious corners of the world. ***R***

November issue: Skin colour.