and thus their environmental impact, for example on the radiative properties of clouds. However, diatoms may well prove to be important in clouds in that part of the atmosphere directly influenced by the ocean at high latitudes, where diatom sources are close and the influence of dust is limited.

Knopf and co-workers[3] introduce the possibility that siliceous marine diatoms are lifted to cloud level, where they initiate nucleation. However, a solid conclusion about the importance of diatoms for clouds, weather and climate awaits further observational and modelling efforts. In particular, diatom species in atmospheric aerosols need to be identified, and their ice-forming potential assessed. The ability of ancient diatom fragments to initiate ice formation should also be considered, as fragments of fossilized diatoms from the Bodélé depression in Chad, situated at the edge of the Sahara Desert, constitute one of the largest dust sources in the world[11]. Only then will we be in a position to determine the atmospheric impact of one of the most abundant groups of ocean algae. ❐

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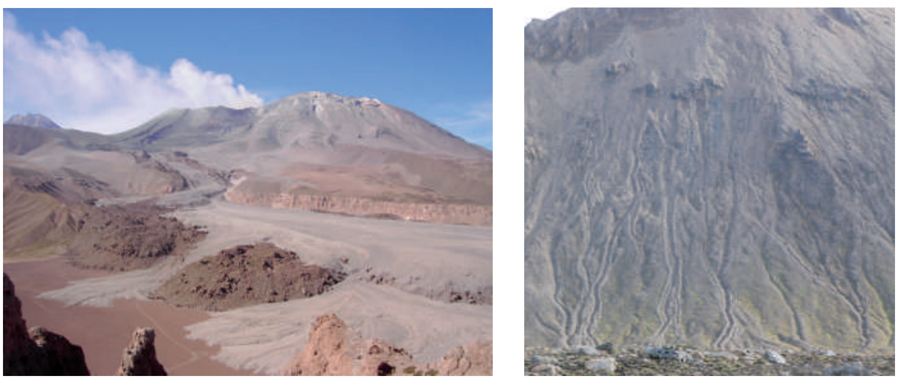
GEOMORPHOLOGY

Landslide boost from entrainment

The mechanisms that govern the growth of debris flows are largely unclear, hampering efforts to assess natural hazards in landslide-prone areas. Experiments suggest that high bed-water content increases flow velocity and mass entrainment in landslides.

Anne Mangeney

Landslides, debris flows and avalanches are natural hazards that threaten life and property in mountainous, volcanic, coastal and seismically active areas. Collectively known as gravitational flows, they begin when debris on a slope is destabilized. The mass of debris tends to accelerate as gravity pulls it down the slope, and will slow on more gentle slopes, when dissipation overcomes the driving forces. The entrainment of material along the slope has long been suspected to play a key role in flow dynamics, possibly driving landslides over unusually long distances. Writing in *Nature Geoscience*, Iverson and co-authors[1] suggest, based on large-scale flume experiments, that relatively high amounts of water in the pores of the slope bed help to drive both the acceleration of landslides and the entrainment of additional slope material.



ANNE MANGENEY

Figure 1 | The remains of debris flows. Pyroclastic flows from the 1993 eruption of the Lascar Volcano, Chile (left) and debris flows in Iceland[9] (right) both cover previous deposits from gravitational flows in these areas, hindering our understanding of the mechanisms that govern such events. Iverson and co-authors[1] use large-scale experiments to assess the role of wet bed sediments in landslide growth, and find that high pore pressures facilitate the scouring of the bed and the growth of mass and momentum in the flows.

The entrainment of sediments or debris into gravity flows is suspected to be critical to the dynamics of the flows, but measurement of material entrainment in natural flows is very difficult. Erosion tracks are often hidden by subsequent flows (Fig. 1), and it is generally hard to distinguish the flow deposit from the underlying erodible layer because they are both usually composed of the same material. Nevertheless, qualitative and quantitative field observations[2–6] suggest that material entrainment can either increase or decrease flow velocity and deposit extent, depending on the geological setting and the type of gravitational flow. In landslides involving significant amounts of water, the pore water pressure is generally considered crucial to the efficiency of the erosion of material from the bed[2,8].

Using a 95-m-long flume lined with a mixture of sand, gravel and mud, Iverson and co-authors[1] assessed the mechanics of granular flows over wet, erodible beds. They measured both the pore water pressure and the total normal stress at the base of the sediment layer during flow. Based on these measurements and on mechanical reasoning, they suggest that the loading of the overflowing material produces high pore pressures in the wet bed sediment. The high pore pressure in turn reduces friction at the base of the flow and promotes the scouring of the bed surface. Iverson and co-authors also found that the entrainment of wet material resulted in the acceleration of the flow, whereas the entrainment of material with relatively low amounts of water reduced flow velocity.

However, a similar experiment with entirely dry granular material yielded a different result[7]. In this laboratory-scale experiment, flow velocity and mass entrainment both grew despite the lack of water. Biases related to the relatively small scale of the experiment are expected to be small for dry granular materials, and as such the reasons for these apparently contradictory observations are unclear. They could be related to differences between the two sets of experiments[1,7] in terms of the slope and thickness of the erodible bed, the frictional properties of the material or the interstitial fluid content.

Alternatively, the difference could reflect the cohesive effect of the low water contents in granular materials. This principle, well known to children who add small amounts of water to dry sand when building a sand castle, is related to capillary forces and could make bed material resistant to entrainment in the flows. Completely dry granular material such as that used in the laboratory experiment, however, has no cohesion and can therefore be entrained much more easily[7]. Of course, as the water content of the bed material increases, the pore-pressure effects overcome the cohesive forces and once again lead to higher flow velocities.

The results from dry experiments raise questions as to whether the presence of fluids is necessary for the entrainment of slope material, and for debris flow growth. For purely dry granular material, growth and entrainment can be explained by considerations of exchanges of potential and kinetic energy between the erodible bed and flowing grains: with high slopes, the erodible layer is metastable, and even small instabilities can set an initially static material in motion. Yet setting off a flow becomes much harder when there are the cohesive effects of small amounts of water to overcome. As such, material entrainment in natural debris flows is probably dependent on a combination of both the physics of granular material and pore water pressure, among other processes.

The experimental results and interpretation of Iverson and co-authors[1] illuminate the pore water processes at work in wet landslides, and provide insights into the multidisciplinary problem of the transition between the static and flowing behaviour of granular matter. ❐

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