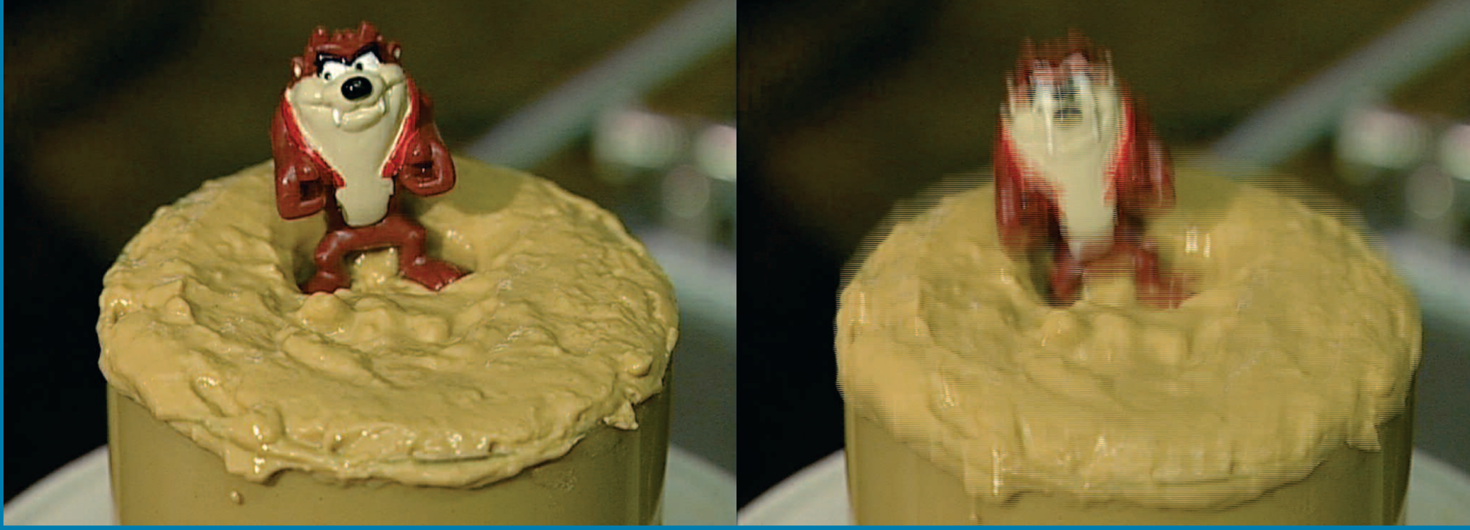

Quicksand!

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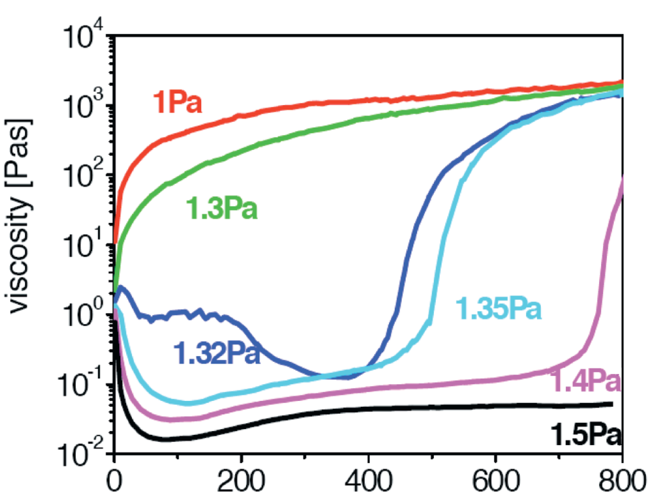
It is a classical scene from western movies. The bad guy ends up in a pool of quicksand, and sinks away in it until only his hat remains, floating on the quicksand. Or, at the very last moment, his head barely sticking out of the quicksand, he is saved by the lead character, who pulls him out of the quicksand with his horse. Hollywood produced dozens of movies in which people drown in quicksand; the most classic one is probably *The Hound of the Baskervilles*. In the movie a young lady (and later on almost Sherlock Holmes himself, also) disappears into 'wet' quicksand.

Our recent experiments at the University of Amsterdam show that when investigated by physicists, the Hollywoodian quicksand myths are mostly pure figments of imagination. The first important question is what quicksand really is. Geophysicists do not have a clear answer to this question. In most geophysics textbooks, "quicksand" is the generic name for sand that has been fluidized by upwelling water, i.e., with an underground water source. If the underground water flows sufficiently rapidly to the surface, the flow destroys the packing of the sand grains, and what remains is liquid: water with the sand particles suspended in it. This can have dramatic consequences in areas that are earthquake prone such as in Japan: after earthquakes often water wells up, and if the sand is fluidized by this, whole buildings can topple over. This however has nothing to do with the quicksand in which the poor lady of "Hound of the Baskervilles" drowned, or with quicksand that we know from muddy areas, for instance in the bay of the Mont St Michel in France.

When on holidays in Iran, one of us (DB) encountered a huge quicksand area near a salt lake between Tehran and Qom. This quicksand area is very ill-reputed in Iran (local shepherds insist that whole camels were swallowed up by the quicksand) and has the big advantage that nobody has interfered with it, as is the case for instance in certain areas of the Mont St Michel bay. The analysis of the soil samples brought back from Iran showed that besides sand and water, the quicksand contained considerable amounts of clay (5-10%) and salt. The detailed analysis of the flow properties of the quicksand then allowed us to explain the myths that have surrounded quicksand for centuries.

The first myth says that when one ends up in quicksand, one shouldn't move, because it makes you sink in deeper. The second myth says that once you are trapped in quicksand, that it is impossible to get out. The third myth is that you can drown in it. The conclusion of our research is that the first two myths are true. The third, on the other hand, is not: it is impossible to drown in quicksand.

The quantitative analysis of the mixture of salt water, sand and clay shows that there is remarkably little sand in the quicksand, only about 40% in volume. This makes the sand structure very fragile: for comparison, for a pile of oranges on the market, the fruits take up approximately two-thirds of the space. If there were a way to remove almost half of the oranges without making the pile collapse, the packing would look like that of the sand in quicksand. This fragile packing is stabilized by the presence of the clay; the clay we found in the quicksand forms a colloidal gel with the consistency of thick yogurt, preventing the sand grains from falling. The clay itself is, on the other hand, not solid enough to support your weight: if you are standing on quicksand, more than 90% of your weight is carried by the sand. All this could be verified by



▲ **Fig. 1:** Liquefaction of quicksand under stress: viscosity measurements show that there can be almost a factor of 1 million difference between quicksand in its normal 'solid' state, and quicksand that has been liquefied because it was disturbed too much (a too large stress was applied to the system).

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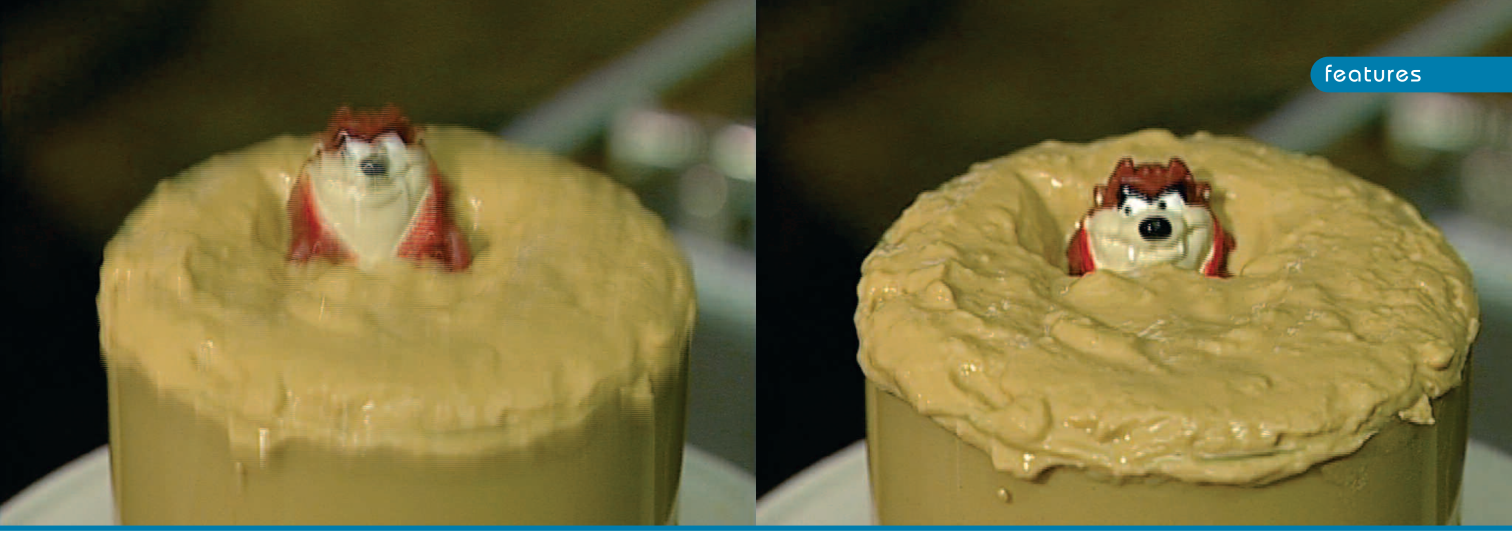

▲ **Fig. 2:** Sinking experiment: the figurine has been carefully tailored to have exactly the density of a human being. He sinks away, but doesn't drown in the quicksand.

preparing a "laboratory quicksand": a mixture of bentonite (a swelling clay) sand and salt water that perfectly reproduces the flow properties of our natural quicksand.

Once you stand on quicksand, it is not a very good idea to move. Your movement will liquefy the clay (much like yogurt, when stirred), and that allows the sand structure to collapse. In the experiments, this corresponds to a sudden viscosity decrease of a factor 1 million: the difference between sinking away with a few millimetres every hour, and sinking with a meter per second. Thus, as soon as you move, you will sink away rapidly. This has dramatic consequences: after the clay has liquefied and you have sunk away, the sand will settle to the bottom and water will float on top of it. This turns out to be where the salt is important: for a sufficient amount of salt, the clay will not only liquefy, but destabilizes completely. This is a generic feature of swelling clays: for too high salt, clay particles that were electrostatically stabilized in suspension stick together (flocculate) because of their mutual attraction due to van der Waals forces. The aggregated particles then sink to the bottom, too. The results of this is the formation of a very densely packed sand layer around your feet. The density is 80 volume%: there are smaller oranges or tangerines between the oranges, since this is a higher volume fraction than a random close packing of spheres of the same size. The only way you can unstick your foot is then to introduce water into this densely packed sand. However, the sand is so fine, with a typical grain size of 60 µm, that this turns out to be very, very difficult. For the typical poresize of the Iranian quicksand, pulling up a model 'foot' of 10 cm x 10 cm requires a force of some 10^4 N. This force is comparable to that necessary for lifting up a car! So we are forced to conclude that the second myth: once you get stuck, it is impossible to get out, is also true. The classical Hollywood-scene of the hero being pulled out of the quicksand by his horse, on the other hand, is very wrong: the horse is likely to pull our hero into two pieces.

The third myth is that one can drown in quicksand. There is however hope for people that get stuck. A simple experiment in fact shows that it is close to impossible for people or animals (including camels) to drown. The bottom line is that the density of quicksand is roughly twice that of water, and that the buoyancy force will simply make you float. The figure shows a 'cartoon' version of the experiment. Taz, the little figurine standing on the quicksand, has been carefully engineered to have exactly a density of 1 g/cm^3, the density of men and mammals. To mimic someone moving in quicksand, we vibrate the whole container with Taz on it with a mechanical shaker. We observe that indeed, he sinks away, and more quickly so if we shake harder. Still, however hard we try, we never succeed in drowning Taz completely: Archimedes was right, and Hollywood wrong. Formulating, for the quicksand, the equivalent of Archimedes' buoyancy force calculation is however a very difficult problem: a part of the weight of the sand grains is carried by other grains, and this weight does not contribute to the buoyancy force. The conclusion must therefore be that one will sink away somewhere between halfway (because the quicksand has twice the density of water) and completely (if only the water counts). The experimental reality is somewhere in between, as Taz clearly shows: it is impossible to drown.

This of course poses the question where this third myth finds its origin. We suspect that this has everything to do with the places where quicksand is usually found, namely at the estuaries of rivers. This is a direct consequence of its composition: the rivers transport clay, and where the clay meets the salty seawater, all the ingredients are present to make quicksand. The problem one may encounter then is the high tide coming in when one is stuck in quicksand: in this situation drowning is unfortunately very well possible. ■

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Asmae Khaldoun got a PhD in science at the Universite Abdelmalek Essaadi in Tetouan (Marocco) on the physico-chemical properties of clay soils. Currently she is working at the Van der Waals-Zeeman Institute of the University of Amsterdam on quicksand and quickclay.

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