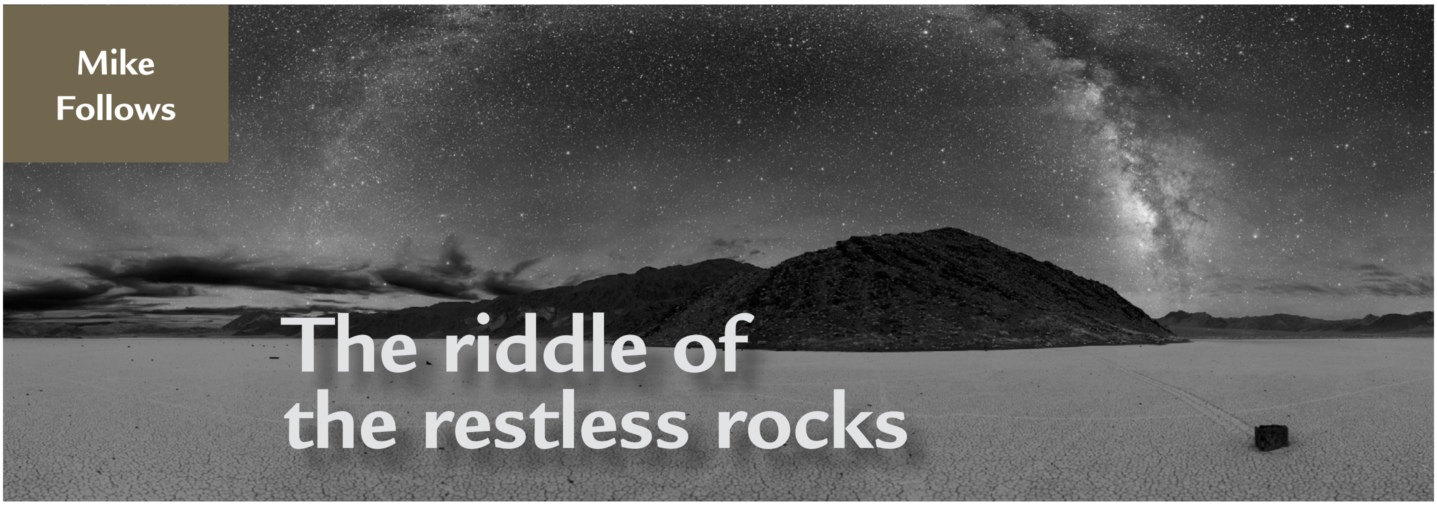
Mike Follows

The riddle of the restless rocks



Racetrack Playa seen below the night sky

Key words

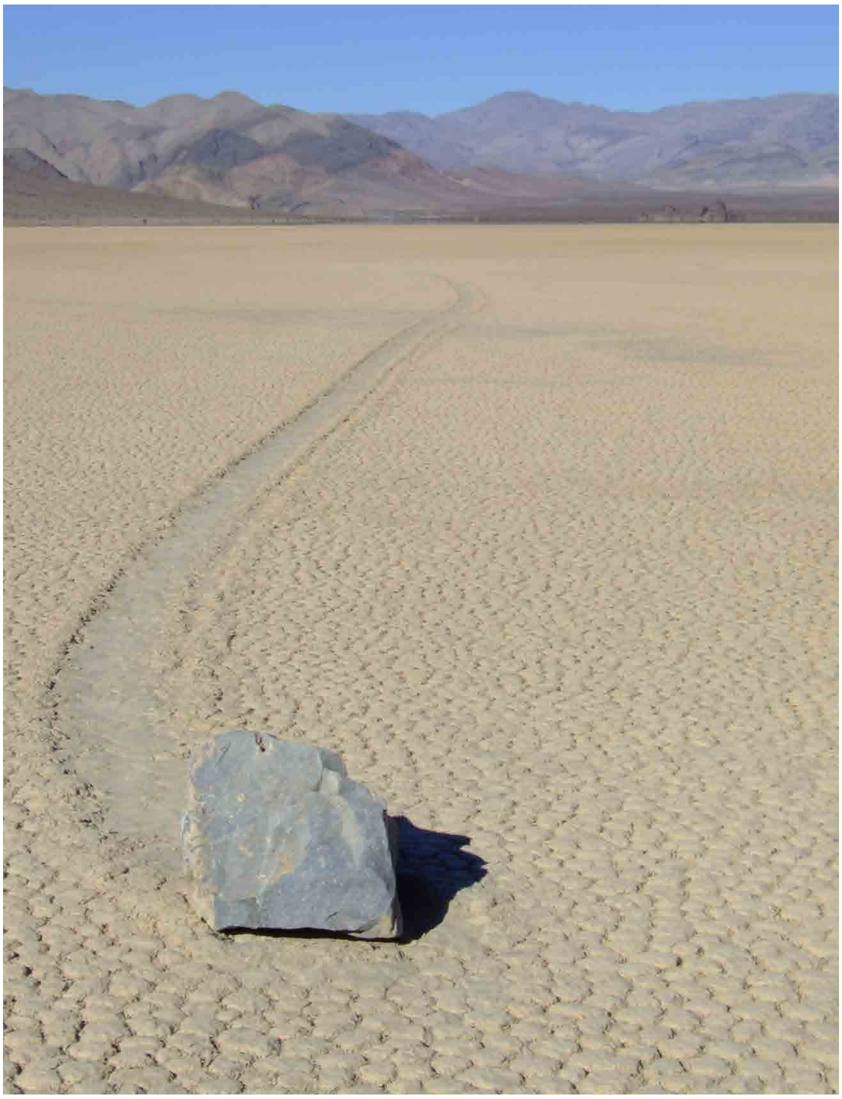
weight

upthrust

density

hypothesis

Racetrack Playa in Death Valley National Park, California, is a dry lakebed, very flat and level. It gets its name from the tracks of moving rocks which have slid across its surface. These rocks might have been overlooked except that they show up dark against the very uniform beige-coloured playa and often appear at the end of long furrows ploughed into the playa surface.



This rock has left a clear track as it has moved across the playa.

Racetrack's 'sailing stones' are usually cobbles or small boulders but some have masses of hundreds of kilograms. The dark rocks originate from the ancient dolomite cliffs at the playa's southern end, where frost shattering causes pieces to break away and crash to the ground below, where they embark on their northward journey.

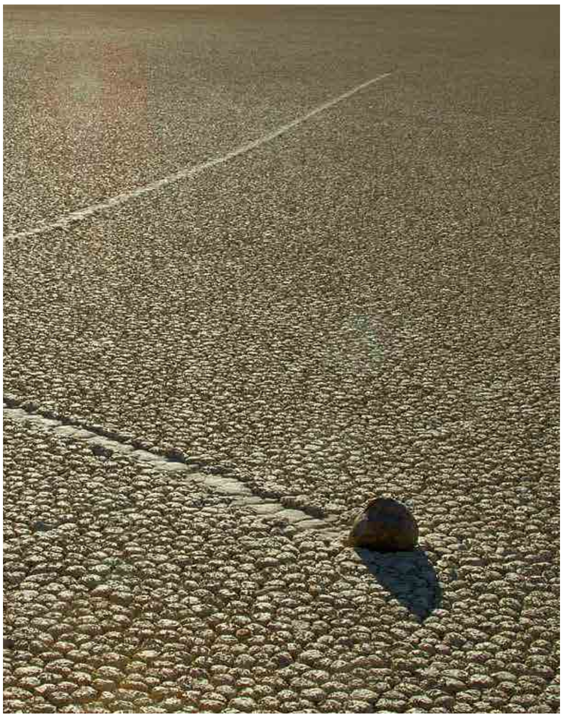
Racetrack Playa is 1130 m above sea-level, where snowstorms are common. The snow melts to produce a shallow pond. This periodic wetting of the surface clay helps explain its extreme flatness, with only a few centimetres of relief across its entire 2 km by 4.5 km area. A prospector named Joseph Crook was the first to witness the movement of the stones when he visited the site in 1915.

Racetrack Playa seen from space

Competing hypotheses

So how do these rocks move? Calculations show that winds at Racetrack are not strong enough on their own to shift them, so people have suggested that friction between the rocks and the ground could be reduced by the growth of slippery algae when the playa is wet. Others have blamed aliens or dismissed the phenomenon as a prank by university students.

In 1955 George Stanley, a geologist at California State University, suggested the rocks might get frozen into large ice rafts which act like big ‘sails’. As the air blows over the ice, friction between the air and the ice (known as skin friction) pushes the floating ice along. This is why floating on an inflatable at the beach can be dangerous – a small breeze can push you out to sea.



Did the wind change direction as this stone was sliding?

Laboratory experiments

Ralph Lorenz, a NASA scientist, investigated the ‘ice raft’ idea in more detail. He suggested that water freezes around the rocks, forming collars of ice that float the rocks off the ground. Reducing the friction between the rocks and the ground, this would allow the rocks to be blown along by light winds.

He tested his idea by pouring a bed of sand into a plastic container. He placed a rock onto the sand and added water until the rock was almost completely submerged. He then placed the container in the freezer. Once the water was frozen, he took out the container and allowed the ice to partially thaw. When he ended up with a small raft of floating ice with the rock embedded in it, he gently blew across the container so that the rock was dragged across the sand, reproducing the furrows observed at Racetrack. But is this model supported by observation?

A student studies the track of a sliding rock.

Field observations

Given that the rocks so seldom move, it wasn’t practical to have scientists observing the rocks around the clock. Instead they deployed remote sensing equipment. Ralph Lorenz joined forces with two cousins, James and Richard Norris, who received funding for their Slithering Stones Research Initiative in 2011. They drilled holes into 15 test rocks in order to insert motion-activated GPS receivers. The receivers revealed the speed and direction of the rocks, which could be compared to data recorded by their nearby weather station. As well as temperature and rainfall, wind speed and direction data was collected at one-second intervals. By the end of 2013 they added wind-triggered time-lapse photography. The cousins happened to be present at Racetrack on 20 December 2013 when they actually observed more than 60 rocks moving. Some rocks moved a staggering 224 metres between December 2013 and January 2014.

A GPS receiver being installed in a rock

Results

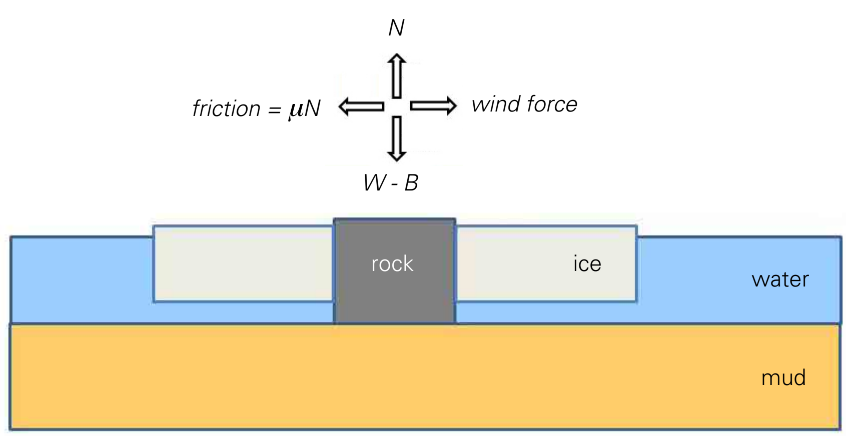
Moving the rocks requires a rare combination of events. First, snow melts to flood the playa to a depth of 7 cm. This freezes to form 'windowpane' ice less than 5 mm thick. On a sunny day this ice melts and breaks up to form large floating panels. Light winds of about 3 to 5 m/s (10 miles per hour) push the panels and these shove the rocks in front of them, much as a bulldozer would, leaving trails in the soft clay beneath. A large mass of ice, even if it is not moving very quickly, can have a large momentum (as momentum = mass × velocity).

The work done by moving ice should not be underestimated. After all, an ice shove event in 1952 uprooted enough telephone poles at a lake in Nevada to break a transcontinental telephone line. Researchers also observed rock-less trails formed by grounding ice panels – features that the Park Service had previously suspected were the result of tourists stealing the 'sailing stones'.

Observations do not yet support the model proposed by Stanley and developed by Lorenz. But it might still work for small cobbles being carried at night. For example, a cube of rock with sides of 10 cm would have a mass of 2.7 kg and weigh 27 N. Even for such a small rock, 'window pane' ice that is only 5 mm thick would need to be more than 2 m across to provide sufficient buoyancy. Moreover, once the Sun comes up, the dark rocks will absorb solar radiation and melt the ice in contact with the rock so that the rock will no longer be buoyed up by the ice.

The model

The ice raft can be represented as a free-body diagram – see the figure below. The weight W of the rock and ice acts downwards while the reaction force N of the mud pushes back upwards. As a result of Archimedes' Principle, there is also a buoyant force B acting upwards, equal to the weight of the water displaced. (When you go for a swim, you experience the buoyant force of water pushing up on you.) This displacement of water reduces the reaction so that $N = W - B$. If the weight and buoyant forces were equal, N would be zero and the ice raft would just float off the playa surface.



The forces on an ice-encrusted rock surrounded by water.

It turns out that the rock can be floated by about 20 times its volume of ice as shown in the Box: Forces on an icy rock. If the ice raft were nearly as thick as the rock then the raft need only be about five rock diameters across.

It is not necessary for the rock to be lifted completely off the bottom of the playa surface. Indeed it is important that the some weight is still exerted in order for the furrows to be created. As the weight of the raft is reduced so is the reaction force, N, which reduces the force of friction between the rock and playa surface, given by the equation $F = \mu N$, where m is the coefficient of friction. The coefficient of friction depends on the surfaces in contact. For example, it is easy to slide on ice because the coefficient of friction between the sole of your shoe and ice is close to zero. The coefficient of friction between the rock and the playa surface has been measured to be around 0.5. For the ice raft to move, the wind must have enough puff to exceed this force of friction.

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Box: Forces on an icy rock

A rock sinks in water but ice floats. So how much ice does it take to make a rock float?

Imagine a cubic metre of rock of density 2700 kg/m^3. We have
mass = density × volume and weight = mass × gravitational field strength, so

- weight = density × volume × gravitational field strength

So, for a cubic metre of rock, weight W = 2700 kg/m^3 × 1 m^3 × 10 N/kg = 27 000 N

The upthrust on the rock is equal to the weight of water displaced (i.e. of 1 m^3 of water).

- upthrust U = 1000 kg/m^3 × 1 m^3 × 10 N/kg = 10 000 N

Thus when the rock is submerged in water there is a net downward force on it of 17 000 N.

Now think about 1 m^3 of ice immersed in water. Ice is less dense than water (density = 9170 kg/m^3) so there is a net force of $W - B$ = 9170 N – 10 000 N = -830 N.

Notice the minus sign; this means that the force is upwards, a buoyant force. (This is why ice floats with part of its volume above the surface.)

So 1 m^3 of ice can provide 830 N of upthrust to help float a rock. In order to float 1 m^3 of rock, there needs to be about 20 cubic metres of ice (because 20 × -830 N is opposite and roughly equal to 17 000 N).