Aeolian Research 19 (2015) 1–3

Contents lists available at ScienceDirect

Aeolian Research

journal homepage: www.elsevier.com/locate/aeolia

Racetrack Playa: Rocks moved by wind alone

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ARTICLE INFO

Article history:
Received 25 May 2015
Revised 27 August 2015
Accepted 27 August 2015

Keywords:
Racetrack Playa
Playa scrapers
Wind
Coefficient of friction

ABSTRACT

Recent studies have documented the movement of rocks on Racetrack Playa by wind-driven floating ice. Here we report observations of movement of the rocks on a slick playa surface *by wind alone*.

1. Introduction

Rocks weighing up to 320 kg (Sharp and Carey, 1976) have been pushed across the surface of Racetrack Playa in northern Death Valley National Park, California, leaving distinct trails (Fig. 1). These trails were first described in the geological literature in 1948 by McAllister and Agnew. They are not unique. Similar trails have been described from eight other playas in southern California (see Sharp and Carey, 1976, for details) and also from the Tunisian Sahara (Di Cesare and Pratelli, 1967, referenced in Sanz-Montero and Rodriguez-Aranda, 2013) and South Africa (Eriksson et al., 1996). It has always been assumed that the rocks were moved by wind when the playa surface was wet and thus slippery. Details of the mechanics of the process, however, have been debated for years.

Recently, Norris et al. (2014) observed rocks being moved when sheets of ice, 3–6 mm thick, began to melt in the late morning sun and broke up under 4–5 m/s winds. Ice panels, tens of meters in size, pushed multiple rocks at speeds of up to 80 mm/s "along trajectories determined by the direction and velocity of the wind as well as that of the water flowing under the ice." Fresh ice surfaces are commonly extremely smooth, and the traction exerted by wind on such a surface thus small; however, rocks projecting up through the surface and shingling of broken ice slabs, subsequently refrozen, will significantly increase the roughness. Stanley (1955) and later Reid et al. (1995) mapped tracks that paralleled each other, forming identical "signatures" as they moved. In one case, the tracks were distributed in such a way as to suggest an ice sheet measuring 100 × 300 m. Such a size seems more consistent with thick ice than with thin ice breaking up around rocks as it moved past them while also pushing them along. Lorenz et al. (2011) have discussed the physics of movement of a single rock surrounded by and buoyed up by ice collars a few centimeters in thickness. Norris et al. documented their observations with photographs; with records of precipitation, temperature, and wind speed from a weather station set up on a near-by alluvial fan; and with records from GPS units concealed in cavities in some blocks that later moved. They are indisputable.

However, these observations do not explain some commonly-reported characteristics of the tracks, such as those ending at "inconspicuous low broad pile[s] of fine-grained sediment" (McAllister and Agnew, 1948), or at such sediment piles with rocks resting on them (Kletetschka et al., 2013). To explain such features, Kletetschka et al. (2013) noted that rocks have a higher thermal conductivity than either water or ice. Thus, when an ice sheet forms, some of the underlying playa sediment may become frozen to the base of the rock while liquid water persists between the ice and the playa surface. If the ice sheet is sufficiently thick, further addition of water to the playa may then lift the rock and sediment package enough to allow wind to move the ice sheet together with the entrained rock and sediment. Later, thawing of the rock base and perhaps still further addition of water could lift a rock off a sediment pile and carry it away, leaving an impression of the rock in the top of the pile.

Rocks of considerable size may also be moved by wind alone, without assistance of ice. The purpose of this short note is to describe such an event.

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http://dx.doi.org/10.1016/j.aeolia.2015.08.001
1875-9637/

Fig. 1. Photograph of a playa scraper (sliding rock). Back pack is roughly 0.3 × 0.4 m. Note the low flat-topped mound of mud in front of and to the right of the rock, apparently thrown forward when the rock stopped moving. The length and linearity of the pile suggests a moderately high speed. A slurry pushed by a slowly-moving rock, and thus lacking momentum, would likely have spread more radially. It has been suggested that such piles might be emplaced by ice moving into the lee of a boulder, but such ice movement, if it were moving sediment, would leave converging tracks around the boulder (Photo: RLH c. 1990).

2. Observations

One of us (RJ) observed the movement. The time was 1972 or 1973 and the month was probably April or May. Rain showers had occurred over the preceding several days in this part of Death Valley National Park. The playa was dry except for a small part of the southeast corner, which is ~5 cm lower (Sharp and Carey, 1976) than the rest of this dry lake bed. The lake bed is hard-packed, consisting of ~¼ clay, ⅓ fine sand, and the rest silt (Sharp and Carey, 1976). From the west side of the playa, one could see a wet area extending some distance out from the southeastern shore. The day was clear and sunny but a slight breeze came up in the late afternoon. During the afternoon, the moist area slowly expanded westward, presumably as the recent rain, seeping through the permeable rocky slope in the SE corner, reached the playa. Wind can shift water on playa surfaces (Torgersen, 1984; Stout, 2003, p. 64) and the expansion may have been assisted by the southeasterly breeze. RJ monitored the areal expansion of this moist clay. There was a thin film of water on the playa surface, and it was slippery.

During the night, the wind came up more strongly, blowing in gusts from the SE, maybe ESE, with greater and greater intensity. Based on experience logging weather in the US Navy, RJ estimated that the wind speed was likely 25–35 m/s, or perhaps higher. The wind was generally from one direction but would occasionally shift 20 or 30°. At about midnight curiosity drove RJ to venture out onto the playa with a flashlight. He could scarcely stand in the strongest gusts. The moist area in the southeast corner had progressed quite a bit further west.

Before he reached the area of the playa in which rocks were concentrated, RJ observed small pieces of dry brush sliding with the wind across the surface, leaving small "scratch" marks in the wet clay. The sticks ranged from 2 to 4 mm in diameter and larger, and were maybe 0.5 m long. They lay with three points of contact on the mud. They would move smoothly ½ to perhaps 1½ m, depending on the length of time the wind blew, and then either slow down or stop as the wind abated, or change direction by 10–20–30° in accord with a change in direction of the gusts. These twigs adhered to the surface; none tumbled in the wind or were blown away. Next, scraps of burro poop (burro pies) were observed to be moving in the same manner, leaving very shallow marks.

Finally, after reaching the area of the playa with scattered rocks, RJ watched several move, leaving tracks commensurate with their weight. RJ was on a slightly damp part of the playa watching moving rocks that were in a wetter area, only a few meters away, where the water was barely a few millimeters deep. The range of his flashlight was only ~10 m. The moving rocks left fresh, wet, soft tracks. The rocks ranged up to ~0.25 m (or perhaps more) in mean dimension, and moved downwind in directions governed by the azimuth of the wind gusts. The total period of observation was about an hour.

By the next morning the wind had died and it was perfectly calm and sunny. The water had continued to advance in some places, coming to within ~250 m of the southwestern shore of the playa, but in other places it was receding. This was probably due to the very low slope of the playa surface, the distributed nature of water input, and the reduction in wind stress. The tracks of rocks that had moved were fresh but drying out. Some had moved for quite a distance, maybe 30–40 m. The tracks looked just as they do in photos of the "moving rocks" but fresh and slick, without the mudcracks seen in older tracks in dry mud. The tracks ranged from 6 to 25 mm in depth. Many of the rocks were tagged with paint and marked; some were identified as from UCLA and may have been marked by Sharp and Carey whose study spanned this time period. Not all the rocks had moved simultaneously and some had not moved at all. The weather that night was warm, without a trace of ice anywhere – on the surface or around the rocks.

Sharp and Carey (1976, p. 1704) presciently remarked, "Some immutable law of nature probably prescribes that movements occur in the darkness of stormy moonless nights, so that even a resident observer would see newly made tracks only in the dawn of a new day."

3. Analysis

Based on these observations, it is possible to make a rough estimate of the coefficient of friction, μ, between the rocks and the playa surface. The relevant equation is:

$$\mu = \frac{1}{2N} C_D \rho v^2 A$$

where N is the normal force, the mass of the rock multiplied by the gravitational acceleration; C_D is the drag coefficient; ρ is the density of air; v is the wind speed; and A is the cross sectional area of the rock exposed to the wind. At the altitude of Racetrack Playa, 1130 m, the air density on a warm spring night will be $\sim$1.1 kg/m^3. The local bedrock lithology is dolomite (e.g. Sharp and Carey, 1976). A cube of dolomite $0.25^{+0.02}_{-0.05}$ m on a side, weighs $\sim 45^{+11}_{-22}$ kg, presents a cross sectional area of $0.063^{+0.009}_{-0.023}$ m^2, and has a drag coefficient of $\sim$1.05 ± 0.05. We used a wind speed of 35^{+5}_{-15} m/s. Speeds at ground level may have been slightly less, but Bacon et al. (1996) point out that the boundary layer is very thin over a smooth flat surface such as a playa. The coefficient of friction is then $\sim 0.10^{+0.10}_{-0.03}$. The uncertainty is based on the uncertainties in rock size and wind speed shown and on standard rules of error propagation.

This coefficient of friction is rather lower than estimated by previous studies of Racetrack's sliding stones (Sharp, 1960; Reid et al., 1995) but it is consistent with the calculations of Bacon et al. (1996).

4. Conclusions

RJ's observations were made many years ago. He had neither the equipment nor the motivation to make quantitative measurements of key parameters, and his recollection of many details is incomplete. None of this detracts from his memory of his key observation, which is sharp and clear: *wind alone moved sizable rocks on a water-slickened playa surface*!

It has always been assumed that intense wind and a water-slickened playa surface were required to move the rocks on Racetrack Playa, and now observations have been made in the field of movement by wind alone and by wind operating on thin sheets of ice. These modes of movement do not, however, explain all observations. Thicker sheets of ice seem to be required to explain the observations of Kletetschka et al. (2013), and there is no reason to suspect that they don't form occasionally.

Acknowledgement

The School of Earth and Climate Sciences at the University of Maine supported preparation of this paper. D. Belknap produced the electronic version of Fig. 1.

References

Bacon, D., Cahill, T., Tombrello, T.A., 1996. Sailing stones on Racetrack Playa. J. Geol. 104 (1), 121–125.

Di Cesare, Pratelli, 1967. Moving stones of the Tunisian Sahara (Bir Pistor). In: Martin, L., (Ed.), Petroleum Exploration Society of Libya, 9th annual field conference, Guidebook to the Geology and History of Tunisia 66, p. 273.

Eriksson, P.G., Foertsch, E.B., Snyman, C.P., Lingenfelder, J.H., Beukes, B.E., Cloete, W., 1996. Wind-blown rocks and trails on a dry lake bed; an alternative hypothesis. J. Sediment. Res. 66, 36–38.

Kletetschka, G., Hooke, R.LeB., Ryan, A., Fercana, G., McKinney, E., 2013. Sliding stones of Racetrack Playa, Death Valley, USA: the roles of rock thermal conductivity and fluctuating water levels. Geomorphology 195, 110–117.

Lorenz, R.D., Jackson, B.K., Barnes, J.W., Spitale, J., Keller, J.M., 2011. Ice rafts not sails: floating the rocks at Racetrack playa. Am. J. Phys. 79 (1), 37–42.

McAllister, J.F., Agnew, A.F., 1948. (Abs). Playa scrapers and furrows on the Racetrack playa, Inyo County, California. Geol. Soc. Am. Bull. 59 (12), 1377.

Norris, R.D., Norris, J.M., Lorenz, R.D., Ray, J., Jackson, B., 2014. Sliding rocks on Racetrack Playa, Death Valley National Park: first observation of rocks in motion. Plos One 9 (8), <www.plosone.org>.

Reid, B.J., Bucklin, E.P., Copenagle, L., Kidder, J., Pack, S.M., Polissar, P.J., Williams, M.L., 1995. Sliding rocks at the Racetrack, Death Valley: what makes them move? Geology 23 (9), 819–822.

Sanz-Montero, M.E., Rodriguez-Aranda, J.P., 2013. The role of microbial mats in the movement of stones on playa lake surfaces. Sed. Geol. 289, 53–64.

Sharp, W.E., 1960. The movement of playa scrapers by the wind. J. Geol. 68 (5), 567–572.

Sharp, R.P., Carey, D.L., 1976. Sliding stones, Racetrack-playa, California. Geol. Soc. Am. Bull. 87 (12), 1704–1717.

Stanley, G.M., 1955. Origin of playa stone tracks, Racetrack Playa, Inyo County, California. Geol. Soc. Am. Bull. 66, 1329–1360.

Stout, J.E., 2003. Seasonal variation of saltation activity on a high plains saline playa: Yellow Lake. Texas Phys. Geogr. 24 (1), 61–76.

Torgersen, T., 1984. Wind effects on water and salt loss in playa lakes. J. Hydrol. 74, 137–149.