

## Chapter 8

### Conclusions

“Geologists base many of their most far-reaching deductions on evidence obtained *after the fact* and without the possibility of laboratory duplication, or observation of the process in action. The moving stones present a geological problem susceptible of both.” (Bradley, 1963)

The Racetrack Playa has been the focal point of casual observations and formal scientific inquiry for nearly a century. Despite the extensive work conducted most notably by Kirk (1952), Stanley (1955), Sharp and Carey (1976) and by Reid et al. (1995) the causative conditions promoting the sliding rocks' motions remain unclear.

At the outset this project was conceived and designed in hopes of revealing predictable order in the sliding rock trails. The patterns have been successfully captured for the first time to high accuracy standards, and they do indeed show general trends. Yet the degree of chaotic motion implied by the furrows, and the insignificant correlations of rock and trail parameters, are remarkable. Perhaps the most surprising outcome of this research is the unanticipated *lack* of order in this natural system. Countless efforts to establish statistically significant relationships between rocks, trails and terrain characteristics yielded disappointing results. However, this in itself may be considered one of the project's accomplishments. Despite the unusual, sometimes apparently random patterns observed,

this research has contributed much to the understanding of the Racetrack's sliding rock phenomenon. Perhaps given more time and additional observations, the questions would be resolved.

## **8.1 Establishment of a Baseline**

Among this project's achievements is the construction of the first complete, high-accuracy database of rock positions, descriptions and trail characteristics (as of July 1996). Visual records and locational data of this research are on file at Death Valley's Resources Management Division Headquarters; selected data are also available over the Internet. Hard copies of individual trail maps and rock identities are found in Appendix I. Any future studies of Racetrack activity will rely on the existence and availability of this archive. The identifying photo library facilitates the future monitoring of sliding rock activity without the need for permanent markings on the rocks, a practice formerly exercised by previous researchers, although never condoned by the National Park Service. As a baseline for comparison, changes in rock positions and trail data may be input directly to a Geographic Information System (GIS) using this survey's map as a control.

With over 10,000 coordinates (defining the vertices of every sliding rock trail) recorded to an accuracy of approximately 30 centimeters, this data set represents the most exhaustive and complete survey ever conducted of this phenomenon. Subsequent quantitative analyses revealed any and all relationships between rock parameters, trail characteristics and terrain elements.

## **8.2 A Record of Order and Chaos**

Where it was initially hypothesized that trail character is intrinsically related to

rock size, rock shape and/or lithology, this survey has established that it is decidedly not. Among the surprising results, this research demonstrates that neither trail length nor trail straightness are appreciably related to rock size, except when spatially-bound subsets of the data are excluded (discussed below).

While there is a trend for large rocks to produce shorter trails, when the two fields are plotted their resulting correlation coefficient is insignificant. When rock volume is compared to the number of turns per trail, it is evident that there is a *tendency* for large rocks to produce straighter trails, but the two fields are only weakly related.

Neither a rock's degree of extension into the atmospheric boundary layer, nor its footprint on the playa significantly affects its traveled route. Rock motion appears to be only slightly affected by rock shape, if there exists a relationship at all.

Regularity emerges when considering only limited sections of the lake bed individually. Placement of rocks on the playa and trail patterns are clearly *not* isotropic. Since most rocks match the lithology of the cliff face at the playa's south end, the cliff face is their probable source. Yet once these fragments tumble onto the mud flats, their repositioning to new locations is controlled by aeolian processes, with clear evidence of motion preferences to the north-northeast. This is not surprising given the generalized wind patterns of the region, and considering the forced flow of air through a prominent topographic channel to the playa's southwest.

This research discovered that trails closest to the center of the boulder field tend to be the most chaotic. Trails closer to the east end of the playa are produced by a strikingly-homogeneous group of small cobbles (76%), which represent only 31% of rocks on the playa's complete extent. These trails are generally longer and show a greater degree of

straightness than the majority of those scarring the Racetrack. This natural, geographically-isolated subgroup seems to be subject to straight-line winds, where more westerly counterparts near the playa's center are jostled erratically by turbulent winds. The formation of wind vortices is likely due to the convergence of natural air channels onto the central playa region, similar to documented patterns observed through urban wind corridors and along natural mountainous obstructions and islands.

Similarly, the impressive lengths of the trails in this subgroup are spatially controlled. This area's proximity to the three springs and to the topographic low of the nearly-flat lakebed suggests that it is most often wet and slick, either from collecting precipitation or hydrologically-induced saturation, or a combination of factors. Hence while contributing somewhat, trail character is not dependent exclusively on rock character.

Terrain aspects of surrounding viewsheds show statistical significance in influencing general trail headings. A preponderance of north-northeast trail segments corresponds to the abundance of east-southeast and west-northwest terrain elements. Hence, the Racetrack's bounding landforms may be at least as influential over rock propulsion as the physical nature of the playa surface and rocks themselves.

As per National Park Service regulations, long-term direct wind measurements cannot be logged on or around the Racetrack. Therefore, wind velocity may only be inferred. GIS analyses imply that air is funneled through two topographic saddles, resulting in intense gusts on the playa and high-turbulence zones at the junction of the two air-streams.

The Racetrack Playa, encompassing an area of 680 hectares, may best be recognized as an melange of micro-environments, each with its own surface characteristics

(microtopography, sediment composition, saturation sources, algal growth potentialities, solar absorption characteristics, local aerodynamics) and resulting range of rock-traction potentials. The sliding rock phenomenon owes its existence to a complex interaction of geography, lithosphere, hydrosphere and atmosphere. The likelihood of future events are dependent on the optimum combination of lubrication and wind climate, which vary considerably between each spatial domain.

### **8.3 Wind as the Motive Force**

Most Earth particles are eroded by running water which acts as an efficient sorting medium. The agent responsible for sliding rock activity has proven to be indiscriminate of clast size or shape. While ice is noted for its ability to transport and deposit a range of unsorted particles, there is reason to believe that ice is not necessary for activity to occur on the Racetrack. Evidence supporting the existence of extensive ice rafting as proposed by Reid et al. (1995) was absent in the physical records left by the pre-July, 1996 sliding rock episode. The most convincing indication is found in congruent but converging trails, (Figure 7.8, page 210). The general lack of parallelism among trails supports independent, wind-induced motion.

Measurements taken on the Racetrack in December, 1997 revealed up to six-fold variations in simultaneous wind speeds between areas separated by less than 400 meters (Table 4.4, page 122). On the day of this wind survey, winds were fairly calm. Yet if such variation is common, then extreme gusts may be typical in highly localized areas of the playa on windier days.

Wind is a superlative sorting medium, typically capable of transporting only up to

sand-sized material. However, wind vortices have been shown (both naturally and experimentally) to have the competency to carry particles of a great variety of sizes. This enhanced ability is derived from the severe barometric pressure gradient typical of rotating winds. While straight wind speeds on the Racetrack may be compared to the 40 meter-per-second gusts common on Owens Lake (Bacon, Cahill and Tombrello, 1996), their intensity is probably enhanced by the Racetrack's increased elevation and topographic configuration. In addition, the likelihood of dust devil formation dramatically increases the capability of airflow-caused traction events, and rock activity independent of rock weight or shape.

Having experienced Death Valley wind events (most notably in July and December 1996) in which pebble-sized materials pelted the sides of the research vehicle, it is not difficult to imagine the local wind climate fostering even more dramatic effects. Given a near friction-free surface, as would be expected after a heavy rain or similar influx of water through runoff and subsurface flow, the Racetrack would most certainly be a dynamic place during strong wind events.

#### **8.4 Final Remarks**

The National Park Service policies supporting only nonintrusive studies of this and other wilderness areas are imperative and highly appreciated. It is recommended that follow-up studies be conducted, including DGPS map generation of future rock trails, wind tunnel studies and three-dimensional automated airflow modeling of the area. Long-term direct measurements of wind velocity in the area would be quite helpful, yet their impact may be too great for consideration by the National Park Service in the future. Such under-

takings were precluded in the present survey by budgetary and time constraints.

It is the conclusion of this research project that wind acting alone on a saturated, but not necessarily frozen playa surface is responsible for sliding rock activity. Saturation may be achieved after local precipitation events and/or as a result of ground water discharge through springs. The proliferation of cyanobacteria and the deposition of a fine clay film assist the process by establishing a remarkably low-friction surface. It is further concluded that rotating winds are likely contributors to the dislodging and incipient traction of rocks on the playa. Airflow is greatly influenced by the Racetrack's elevation, flatness and surrounding terrain configuration, which results in a great degree of sliding activity toward the north and the northeast. However, until researchers actually observe the rocks in action, the cause still remains controversial.