Authors' Response to Referee Comments ESURFD 2, 1005-1022, 2014

Response to Referee Comment 2 (R LeB Hooke)

On the significance of the present work beyond a companion paper by Norris et al. (PLoS One, 2014) let us recapitulate its graphic content:

1. four field images showing movement of a distant (~500m) rock relative to the shore
2. GPS records of movement of several rocks
3. context field images of some trails and ice/terrain/water interactions.
4. meteorological records

The present paper complements that report in several significant respects with:

1. frames from actual video showing rock movement in real time
2. Two sets of photos from only a few meters away, showing rocks BEFORE AND AFTER DISPLACEMENT, SHOWING THE TRAIL THAT RESULTED.
3. Kiteborne images, and frames from a six-week long timelapse sequence, setting the geological context and the flooding/freezing history of the playa.
4. An analysis of ice buckling stresses, since ice fracture was seen as a novel element in allowing adjacent rocks to have sometimes very different movements

The ESURF paper should be seen not only as a paper in its own right (emphasizing the trail formation in the mud, rather than the movement of the rocks), but as the formal documentation of the timelapse and video data online, which are key elements in demonstrating the movement events beyond mere anecdote or media report. The results are the conclusion of seven years of field observation, and Gigabytes of timelapse data, which it was neither feasible nor appropriate to include in a single paper. The before/after photos (figures 2 and 3 of the present paper) in particular are expected to be definitive images in future discussion of this phenomenon. Thus we consider the Norris paper insufficient documentation.

We make a further observation here, not in our original submission, of rock fragmentation apparently in association with the movement episodes. We observed one rock break, and saw more than one freshly-fragmented rock at the end of a trail (e.g. figure 1 below) suggesting the breakup occurred during or shortly after the movement event.

Figure 1. Image acquired at 13:48 LT, showing a rock at centre with fresh trail and 'bow wave' of mud. The rock has fractured, with the leftmost part falling backwards. The rock at lower right has a near-congruent trail, and similarly has broken up, with fragments falling back away from the bulldozed mud piled up in front (right).

This additional observation will be an important constraint on understanding the size distribution of rocks on the playa, and on the budget of supply and removal of rocks.

The ice buckling analysis is novel, and appreciated by the reviewer who suggests some improvements (see below re: line 151) – we have found some even more relevant experimental data supporting the model and interpretation.

On his other specific remarks

'exceptionally rare' - did not seem hyperbolic to us for a few minutes out of a million, but that is subjective: we have no objection to reducing to 'rare'

This is a fair comment : 'not reported in the scientific literature, as far as we are aware' is more defensible.

Agreed – our comment was intended only to describe the event we observed, but indeed others may allow all rocks in a sheet to be displaced.

151-155 Ice buckling. We are grateful for the referee's scrutiny of this issue, and are gratified that the formulation he has presented yields an ice thickness within a factor of two of that which we report (since the quantities depend on the modulus of the ice which is strongly temperature-dependent). We would agree that the 3mm he determines is 'pretty thin' – we ourselves were struck by how effective such a thin sheet of ice was at bulldozing rocks, despite being less than a centimeter thick.

We have in fact found some experimental force measurements under conditions very similar to that which we observed. Ice edge indentation tests peformed by Sodhi (1998, 2001), with a screw-driven 25cm wide ram pushed at 8 mm/s into a floating ice sheet 41 mm thick (test 551 of Sodhi, 1998) yielded a sawtooth force history swinging between 0 and ~30kN as the ice alternately compressed then buckled. In some conditions (Sodhi, 2001), the ice may simply crush rather than buckle. For a constant indentation or rock width, the force – which depends only weakly on the ice speed – will vary directly with the ice thickness for crushing, or with the cube of thickness for buckling failure. For a thin sheet, buckling is likely, and is what we observed, which suggests our 5-8mm thick ice could generate forces on a 25cm rock of ~100-512 times smaller than this laboratory test, i.e. 60-300 N, encompassing the estimate based on the fracture length scale in our paper, and an ample force to drive rocks against friction.

We will follow up with the referee's minor editorial corrections.

<u>Response to Referee Comment 1 (R A Yingst)</u>

1. Pithy – we will scrub the text

2. The assertion was made by Sharp and Carey (we in fact disagree) that the mud mounds sometimes ahead of rocks at the end of trails suggests the mud was thrown during rapid movement ('as a guess...0.5 to 1 m/s'). Whether this is true or not, the referee is correct that this does not require a purely wind-driven movement. We will attenuate this language.

Congruence was meant in its high-school geometry sense (qv congruent triangles), to denote (as described by Reid et al. 1995 and others) parallel line segments

3. Embedded vs bulldozed rocks. In fact we observed both effects to occur – this should be made clearer

4. The question of movement dependence on morphology is an interesting question. We did not notice any correlation, although our observations cannot claim to be exhaustive. Messina and Stoffer (Geomorphology, 1998) performed correlation analyses between trail lengths and rock parameters and found no significant relationships.

Specific Comments

This figure may be clearer with reference to the timelapse video sequence

Fig 7 – indeed

Technical corrections can be addressed

References

Messina, P. and P. Stoffler, 2000. Terrain analysis of the Racetrack Basin and the Sliding Rocks of Death Valley, Geomorphology, 35, 253-265

Sodhi, D. 1998. Nonsimultaneous crushing during edge indentation of freshwater ice sheets, Cold Regions Science and Technology, 27, 179-195

Sodhi, D., 2001. Crushing failure during ice-structure interaction, Engineering Fracture Mechanics 68, 1889-1921