WET SURFACE AND DENSE ATMOSPHERE ON EARLY MARS SUGGESTED BY THE BOMB SAG AT HOME PLATE. M. Manga[1] A. Patel[1], J. Dufek[2] and E.S. Kite[1,3], [1]Department of Earth and Planetary Science and Center for Integrative Planetary Science, UC Berkeley (manga@seismo.berkeley.edu), [2]Earth and Atmospheric Sciences, Georgia Tech, [3]Division of Geological and Planetary Sciences, Caltech

Introduction: The observations by the Mars Exploration Rover Spirit of the Home Plate deposits offer compelling evidence that they have an explosive volcanic origin [1]. The structure, stratigraphy and bedforms resemble those of maars, though a source vent has not been identified [2]. Maars are circular volcanic structures, typically a few hundred meters to a few kilometers in diameter, formed by phreatic and phreatomagmatic eruptions. Ballistically deposited rock fragments that create bomb sags are characteristic of maar deposits [3] and, indeed, a bomb sag was identified at Home Plate (Figure 1a; ref 1).

We use attributes of the bomb sag in Figure 1a to estimate atmospheric density at the time of eruption and the saturation state of the substrate onto which the rock fragment fell. We use laboratory experiments to identify controls on the main features of bomb sags. As impact sags are generally taken as evidence that "deposits were moist to wet" [4] we first document the effect of water on the morphology of impact sags. Next we obtain a relationship between the depth of particle penetration, particle size, and impact velocity, from which we can infer atmospheric density using the observed bomb sag.

Experiments: To create laboratory bomb sags, we propelled cm-sized particles with compressed air towards a bed of sand-sized particles. The impacting particles were either 1.3 cm diameter glass spheres (density 2.4 g/cm^3), natural scoria particles (mean long, intermediate and short lengths of 13.0, 9.3, and 7.3 mm, respectively, and density 1.0 g/cm^3), or 1.3 cm diameter stainless steel balls (density 7.7 g/cm^3). The stainless steel balls are used to test scaling relationships. The experimental bed was made by pouring 30 mesh sand (0.60 ± 0.17 mm major axis, 0.43 ± 0.12 mm minor axis) into a 30 x 30 x 30 cm box.

We considered dry sand, water saturated sand, and damp sand in which the sand was saturated and then allowed to drain under the influence of gravity. The Home Plate observations agree best with morphologies produced in water-saturated sand and we thus performed most of our experiments with water-saturated substrates.

Qualitative observations: Figure 1 shows substrate deformation produced for different saturation conditions. The impacting particles are the same, 13 mm diameter glass spheres with velocities of ~44 m/s. In dry sand, layers are deflected upward in the vicinity of the particle, and sand particles are ejected from the crater created by the impact. In damp sand, clots of damp sand are ejected from the crater and the layered structure is undisturbed. Ejected clumps of sand are visible in Figure 1c. In water-saturated sand, the layers are deflected downward by the impacting particle and comparatively less sand is ejected from the crater. Penetration depth is greatest in dry sand, and smallest in water-saturated sand.

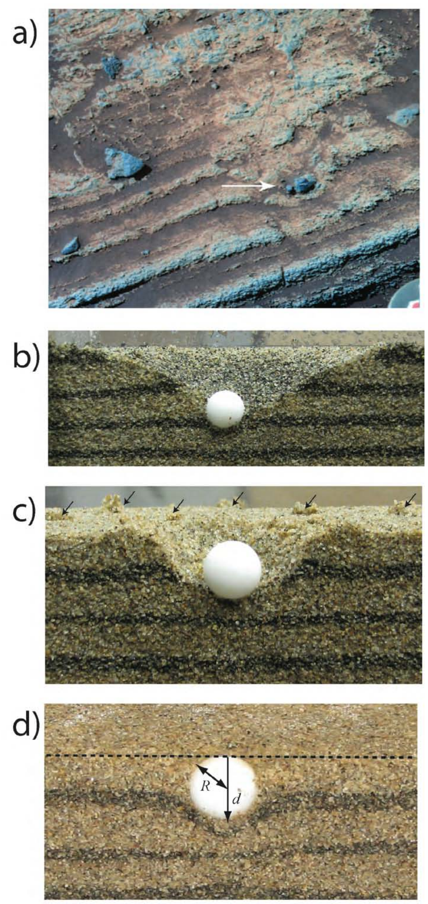

Figure 1: a) Bomb sag identified by Spirit, at Home Plate [1]. Vertical slice through the bomb sag experiments with glass spheres for b) dry sand, c) damp sand (arrows indicate clots of ejected damp sand), and d) water saturated sand. In d), the horizontal dashed line indicates the sand surface, *d* is the penetration depth, and 2*R* in the particle diameter.The layering was horizontal prior to each experiment, and layering is defined by different color sand grains. Vertical slices were made after saturating the sand and then allowing gravity to drain excess water – this provides cohesion to the sand. Velocities are 47.4, 45.7, and 43.7 m/s, for b-d, respectively. See [10] for setup details.

Quantitative observations: Figure 2a shows penetration depth *d* normalized by particle diameter 2*R* as a function of impact velocity. In Figure 2b we plot the same data with a normalization of velocity based on previous work on low velocity impacts into dry sand [5-6].

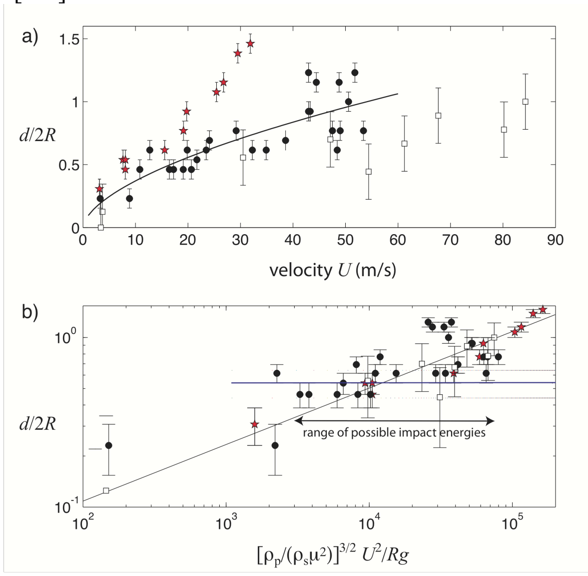

Figure 2: a) Dimensionless penetration depth (depth *d* divided by particle diameter 2*R*) as a function of impact velocity (stars: stainless steel; open squares: scoria; filled circles: glass). b) Same data as in a) but impact velocity is normalized as proposed in [7] The Home Plate bomb sag has $d/2R = 0.54 \pm 0.1$, indicated by the horizontal black and dotted lines. Values on the abscissa between $3x10^3$ and $6x10^4$ are consistent with the observed penetration depth. See [10] for details.

Caveats to keep in mind: Foremost, Spirit imaged only one bomb sag, so we have a limited ability to assess uncertainty. We thus focus on the ability to reject the hypothesis that atmospheric density was similar to that at present. Additional caveats: we have not considered the effect of grain shape, size distribution and sorting in the substrate; our laboratory bombs are smaller than the one at Home Plate; we are unable to measure the three-dimensional shape of the bomb and impact crater; the experiments were not performed in a reduced gravity environment.

Discussion and conclusions: The Home Plate bomb sag (Figure 1a) most closely resembles the water-saturated morphology in Figure 1d. We thus infer that the lower unit at Home Plate was also wet at the time of eruption. Water-saturated conditions may imply a warmer temperature due to a warmer climate, melting of snow or ground ice by hot pyroclastic material, or a warmer subsurface produced by hydrothermal activity maintained by the volcanic system that created the eruption [8].

Based on the measurements reported in [2], we estimate $d/2R$ is thus 0.54 ± 0.1. To obtain an impact velocity we assume a clast density of 2.4 g/cm^3, because the bomb size suggests that it is a lithic fragment and not a juvenile clast [9]. Low density clasts also bounce out of the craters that they form [10]. From Figure 2b, the implied impact velocity is thus between 10 m/s and 40 m/s. This is similar to the range of 10 to 50 m/s we would infer from Figure 2a, assuming that the lab experiments apply directly, and unscaled, to Mars.

Impact velocities are lower than ejection velocities at maars on Earth, typically 50-130 m/s [11-16]. Ejection velocities should not vary strongly with atmospheric pressure. Bombs and other granular material ejected during the eruption are initially accelerated by the pressure difference between steam and the weight of overlying material. Atmospheric pressure, on Earth or Mars, is a small contribution compared to lithostatic and critical point pressures, and the initial acceleration is likely insensitive to atmospheric conditions. Only later does atmospheric drag and gravity substantially influence the trajectory and velocity of the clasts. Assuming impact at terminal velocity < 40m/s requires minimum atmospheric densities of 0.4 kg/m^3; for comparison, the present atmosphere density on Mars is 0.02 kg/m^3 and the density of Earth's atmosphere at STP is 1.3 kg/m^3. Our work and calculations are described in more detail in a recently accepted paper [10].

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