ASSESSMENT OF CLAST MORPHOLOGY AT THE HUYGENS PROBE LANDING SITE.

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Introduction: Much of the history of a loose particle's modification through transport, deposition, sorting and subsequent wear are recorded in the characteristics of those particles [1-3]. Morphology, which includes the overall dimensions, three-dimensional shape, and roundness or angularity, is a crucial property to measure, as it retains the best record of sorting and abrasive effects [1,2]. Assessing morphology is a standard analysis technique for terrestrial sites, especially at sites for which the particle transport mechanism is not clear. For extraterrestrial sites such as Titan, where this is commonly the case, clast assessment can provide clues to deciphering unknown transport history, either through laboratory testing to experimentally recreate transport processes [e.g. 4 after 5,6 and others] or through measuring clast characteristics [e.g., 7 and references therein]. Here we report an initial quantitative and qualitative assessment of morphologic characteristics (size, shape, roundness) of surface particles imaged by the Huygens probe at its landing site on Titan. Our goal is to use these data to test the hypothesis that rocks at the site show evidence of fluvial alteration [e.g., 8], and generally to help constrain the boundaries of potential transport/alteration mechanisms that may have contributed to clast emplacement and modification.

Data and method: We analyzed a processed image created from 84 side-looking images that Huygens acquired after landing (see https://photojournal.jpl.nasa.gov/jpeg/PIA08115.jpg). Fifteen clasts whose entire perimeter was unobscured, and whose long axis aspect was greater than pebble-sized [9] were chosen for analysis. We utilized the methodology of [10] to estimate particle shape (in this case estimated by sphericity, or how closely a clast profile resembles a sphere), and angularity/roundness (a measure of corner sharpness). We note that, similar to data available at the Mars Pathfinder landing site [7], the Huygens data represent a single site from a stationary lander. Resolution thus coarsens with distance from the probe, so direct comparison clast to clast is problematic. Additionally, the scene includes only a small (unobscured) clast population that represents fewer clasts than populations assessed for other planets (e.g., Venus and Mars [11], Mars [7,10, 12-15]). Thus, quantitative values should be used with caution.

The long and short axes of the two-dimensional aspect shown to the camera were measured. Such measurements are best suited to clasts within the pebble- to cobble-sized range, because two-dimensional clast analysis typically overestimates clast characteristics at smaller sizes at low resolution (35–150 μm/pixel) and results in inconsistent size and shape characteristics [16].

Sphericity is primarily influenced by lithology, as noted by [17] and demonstrated by [18], while roundness is most affected by environmental transport. Sphericity has been measured using many equations; we used [19] as a high-fidelity way to estimate the three-dimensional sphericity of a clast in a two-dimensional image. Overall roundness is harder to estimate due to the coarse resolution of the available scene. It was determined primarily by using visual comparison charts [1,20]. However, these two common charts have crucial differences: [1] use perimeters, while [20] presents examples that show surface texture. [1] has the benefit of utilizing an outline, which is more directly comparable to the perimeters that 2-D methods can measure. On the other hand, because [20] also includes surface texture, this provides a more nuanced sense of how assigned classes should be interpreted. Both methods were used, except for those clasts where it was not possible to resolve surface texture, where only the perimeter method was used (e.g., clast 8).

Results: Mean sphericity was calculated to be 0.37; particles are more flat and "unspherical" than otherwise. Mean roundness was calculated as 0.53 using the method of [1] and qualitatively assessed as mostly sub-rounded [20]. This translates to a value of 2.5 based on the numerical system of [18].

Comparison to Mars clasts: The range of clast sphericities is somewhat narrow at 0.25-0.55 (average 0.37), somewhat elongate with a few cobbles more rounded. This might indicate a similar lithology but this value is difficult to interpret without similar lithologic populations against which it could be compared.

Rounded clasts occur in this location as a higher percentage of the assessed population than nearly every site on Mars studied so far; however these rounded clasts exist mixed with a larger percentage of angular clasts. This indicates that whatever process has altered these clasts is not as efficient as processes such as persistent (rather than intermittent) terrestrial fluvial action. Alternately, the rounded and "not-rounded" clasts may represent two separate populations of clasts, transported or altered at different times and/or by different means.

We note that using a combination of the two roundness comparison charts allowed for more accurate assessment, as textures sometimes provided unique information. For example, clast 4 has a protuberance that is not encompassed in its perimeter, but suggests the clast is sub-rounded rather than rounded.

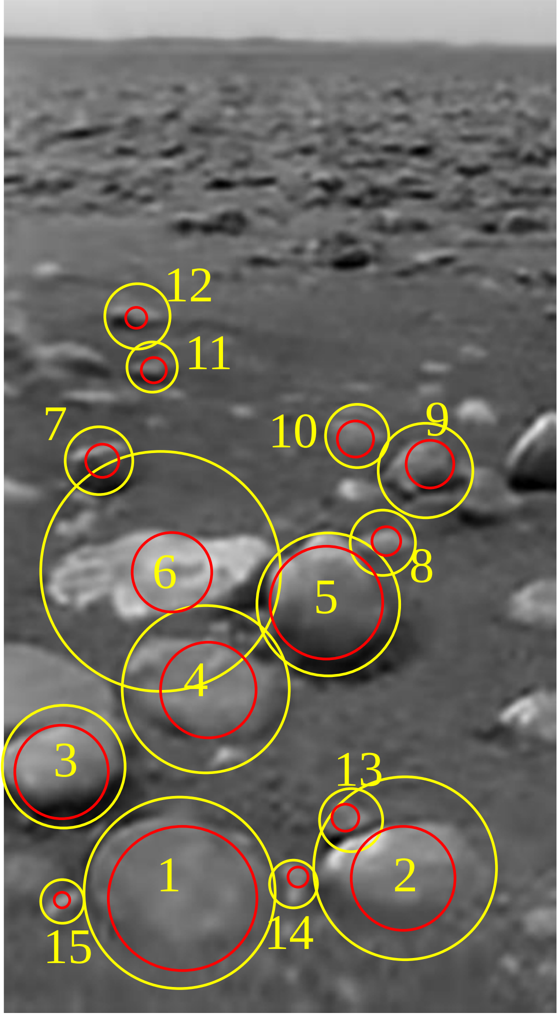

Figure 1. Huygens probe image of Titan's surface processed by Erich Karkoschka; numbered clasts are those studied for this work. Clast 1 is ~0.7 m away, while clast 12 is ~2.5 m away.

Comparison to terrestrial clasts: A better understanding of how morphology relates to modification mechanism requires comparison to a relatively well-understood baseline. Craddock and Golombek [18] examine a single lithology (Hawai'ian volcanic basalt) over a range of emplacement and transport processes, in a somewhat similar size as the clasts on Titan (>64 mm short axis diameter, i.e. cobbles or larger). While the clasts on Titan are not basalt, there are no studies that analyze lithologies likely analogous to Titan, and because [18] examine only one lithology but a broad range of processes, with a focus on comparing to planetary (i.e. 2-D) data, the data from this work are used as a standard for comparison.

Compared to the average roundness of 2.5 for Titan clasts, basalts in an alluvial fan environment were 1.43; those from an explosive eruption (Craddock and Golombek [18] assumed this process would have a similar effect on morphometry as impact cratering) were 1.40-1.84; those from a catastrophic flood were 3.52-3.83; those from chemical weathering were 2.63-3.07; those from frost shattering were 0.57-0.71; and those from a debris flow were 3.50, as were those from salt weathering. The closest values to those on Titan are from chemical weathering (2.63-3.07). In short, roundness values are greater than an analog "impact" population, less than those for populations altered by intermittent fluvial activity (alluvial fan, catastrophic flood), and similar to those for chemical weathering.

In summary, and given the caveats and limitations noted above, clast morphologies at the Huygens landing site are consistent with an inefficient (potentially non-fluvial) process of alteration, but whether through transport, as suggested by [8], or through in situ weathering of some kind cannot be determined.

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