LARGE-SCALE EOLIAN BEDFORMS AND STRATIGRAPHIC ARCHITECTURE AT VICTORIA CRATER, MERIDIANI PLANUM, MARS

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Abstract:

The Mars Exploration Rover *Opportunity* has recently completed its observations of Victoria crater, the largest crater yet explored by the rover at Meridiani Planum. At ~750 m in diameter, Victoria crater exposes cliffs up to ~15 m high, revealing thick bedsets (3-7 m) of large scale cross-bedding, interpreted as fossil eolian dunes. *Opportunity* was able to drive into the crater at Duck Bay, located on the western margin of Victoria crater. Data from the Microscopic Imager and Panoramic Camera reveal details about the structures, textures, and depositional and diagenetic events that influenced the Victoria bedrock. Detailed stratigraphic analyses at Duck Bay, and nearby promontory Cape Verde suggest that these outcrops may be part of a larger-scale draa architecture. This insight is possible only due to the larger-scale exposures at Victoria crater, which significantly exceed the more limited exposures at previously explored Erebus, Endurance, and Eagle craters.

Introduction:

Opportunity has investigated several impact craters in Meridiani Planum, Mars, studying the exposed sedimentary rocks in an effort to better understand the role of aqueous activity in its geologic history. As the mission progressed the rover explored increasingly larger outcrops over a greater spatial scope, and it became clear that both depositional and diagenetic processes acted regionally in extent [1]. One important observation is that most primary sedimentary bedforms are not only regional in extent, they are also of very large magnitude. This is important because it facilitates a greater understanding of the processes controlling deposition as well as the scale of the depositional environment.

Victoria crater lies 6 km southeast from the original *Opportunity* landing site in Eagle crater. Topographic measurements made by the Mars Orbiter Laser Altimeter (MOLA) indicate that the plains surrounding Victoria crater are ~10 m higher in elevation than those surrounding previously explored Endurance crater, suggesting that Victoria crater exposes a stratigraphically higher section (assuming flat dip of strata). The outcrop exposed at Victoria crater may lie at the same elevation as the uppermost unit in Erebus crater, allowing for possible stratigraphic correlation between these two locations. Outcrops at Victoria crater provide exposures of on the order of 15 meters of true stratigraphic thickness, which permits analysis of larger scales of cross-stratification, and thus larger-scale primary bedforms can now be reconstructed. Detailed measurements of the stratigraphy were taken as Opportunity descended into the crater at Duck Bay.

Stratigraphy at Duck Bay and Cape Verde:

A lithostratigraphic subdivision of bedrock units was enabled by the presence of a light-toned band that lines much of the upper rim of the crater. *Opportunity's* ingress path in Duck Bay intersects three stratigraphic units, named Lyell, Smith and Steno, in ascending stratigraphic order; Smith is the light-toned band. All three units consist of sulfate-rich cross-bedded sandstone, interpreted as fossil eolian dunes. Smith is interpreted as a diagenetic band, exhibiting a lighter tone and poor expression of lamination consistent with recrystallization. Evidence of the diagenetic unit reworked in the impact breccia indicates that Smith formed prior to the crater impact. Strike and dip measurements, calculated from Pancam stereo imagery, show that all three units dip 2° to the west (away from the center of the crater) likely as a result of the crater impact. The contact between Smith and Lyell is gradational, and the darker tone and well-defined stratification of Lyell gradually fade upward. A clear erosional contact distinguishes Smith from the overlying Steno unit. Inclined stratification in Smith is truncated by the lower bounding surface of Steno (figure?). Strike and dip measurements suggest that this truncation surface between Steno and Smith has a dip of ~10° to the southeast. These units, as observed by the Panoramic Camera (Pancam) and Microscopic Imager (MI), define the "Reference Section" for Victoria crater. They can be traced visibly around much of Duck Bay, but cannot be directly correlated with the nearest promontory, Cape Verde, which is separated by a large area of breccia.

After completing its observations of the Duck Bay strata, *Opportunity* made a close approach to the outcrop at Cape Verde. The strata exposed at Cape Verde contain a light-toned band similar in thickness to that of Smith, overprinting well-laminated sandstone with low-angle cross-bedding. In some places, strata indicative of small climbing dunes is super-imposed on the larger dune cross-stratification.

The base of the Cape Verde cliff face contains a truncation surface dipping ~10° to the southeast. Given that the erosional contact at the base of Steno also has a ~10° dip, we infer that the erosional contact at the base of Steno correlates with the erosional surface at the base of Cape Verde. Although these surfaces lie at different elevations, they have a similar dip into the crater and projection of this dip shows the potential continuity of the surface between elevations. Therefore, this surface indicates deposition at the same time between locations, but on pre-existing topography. The surface represents an architectural element larger than the scale of the cross-bedding.

Reconstruction of Eolian Bedforms

The erosional surface likely represents a larger scale architectural element within a sand sea, and may be interpreted as second-order eolian bounding surface, representing the migration of dunes on a larger bedform [2]. The larger bedform, underlying the erosional surface may be termed a draa.

Further consideration of the geometry of the cross-bedding produces additional insight. Strata below the erosional surface, both at Duck Bay and at Cape Verde, dip to the west/southwest, which implies a wind direction primarily from east to west. In contrast, the erosional surface and the strata above it dip to the southeast, suggesting a wind direction from northwest to southeast. These opposing wind directions suggest that the erosional surface may represent a draa-scale reactivation surface, responding to shifting wind directions. This interpretation is consistent with observations of terrestrial draas, which may contain reactivation surfaces representing the migration of dunes across a draa in opposite directions [3]. Work by Hayes et al. (in progress) indicate that this pattern of reversing transport direction is observed at other locations around Victoria crater, and also with juxtaposition of cross-bed sets across larger-scale surfaces. The picture that emerges is one of possibly seasonally changing wind directions driving dunes back and forth across the ancient draa.

Conclusions

The strata exposed at Duck Bay and Cape Verde indicate deposition in an eolian dune environment, with further modifications though diagenesis. In the Reference Section, Smith is interpreted as a secondary, diagenetic unit, which also is bounded by a primary, erosional contact, but elsewhere in the crater the diagenetic band cross-cuts the primary stratigraphic surfaces. Correlation with nearby promontory Cape Verde suggests that there is an erosional surface at the base of the cliff face that likely corresponds to the erosional contact below Steno. This surface is interpreted to represent the migration of dunes across a draa, and its orientation suggests that the draa was migrating from northwest to southeast at the time that the surface was formed. The stratal geometry above and below the erosional surface reveals dune migration in opposing directions, suggesting that the erosional surface may be interpreted as a draa-scale reactivation surface. Additionally, the presence of three orders of bedforms and a complex wind regime suggest that the strata may have been part of a very large sand sea, with no evidence for aqueous deposition as observed at Eagle and Endurance craters. Victoria crater not only reveals the regional extent of processes seen elsewhere in Meridiani Planum, but the greater size of its outcrop exposures reveals the building of ever larger eolian bedforms.

References

[1] Squyres et al., *Science* 2009; [2] Fryberger *Geological Society Special Publications* 1993; [3] McKee, *Sedimentology* 1966