
Introduction: The HiRISE camera provides an unprecedented combination of spatial resolution, color information, and coverage of the surface of Mars. The ground sampling distance (i.e., pixel dimension) is as small as 25 cm, allowing 1-m diameter objects to be confidently resolved. Typically, a 20,000 pixel (~6 km) wide image is collected through a broad bandpass red filter while the central 4000 pixel (~1.2 km) swath is simultaneously imaged through a blue-green and a near-infrared filter. This allows 3-band false color images to be constructed over the central ~20% of each image. The MRO spacecraft is able to roll up to 30° off-nadir, allowing most of Mars to be imaged from orbit every two weeks. This allows stereo coverage to be collected before lighting conditions change significantly with season. Further details of the HiRISE camera and the MRO mission are provided by [1].

The HiRISE science plan divides Mars science and exploration into 18 themes. Here we report on the initial results from the volcanology science theme. Within the broad theme of Mars volcanism, there are a diverse range of volcanic processes that we are beginning to examine. We have chosen to categorize this diversity into the following subthemes: (I) vent processes, (II) shield volcanoes, (III) flood lavas, and (IV) water-lava interactions. Given the emphasis that the NASA Mars Exploration Program places on aqueous processes, we have decided to put our long-term emphasis on water-lava interactions. Early results of the work on that subtheme are already being reported by [2-5] and will not be discussed here. In this abstract, we focus on primary volcanic features (sub-themes I-III).

Sampling Strategy: During the first 6 months of the Primary Science Phase (PSP) (orbits 1316-3536), the goal has been to sample a diverse set of volcanic (and possibly volcanic) terrains. In the early part of PSP, the HiRISE targeting data base contained just under 400 potential volcanic observations. 30 of these were elevated to the top priority before the start of PSP to provide a broad sampling. As of this writing, we have acquired or planned 124 volcanic images, of which 14 were on the top priority list. Figure 1 shows the location of the initial images.

Figure 1. Location map of HiRISE images with “Volcanic Processes” listed as a primary or secondary science theme. The goal was to sample a diversity of volcanic terrains and focus on lava-water interactions. The concentration of images in the equatorial region is largely driven by geology (i.e., the Tharsis and Elysium volcanic centers). Most images are of young volcanic terrains, but some sampling has been attempted of older edifices as well.
As detailed in [1] the HiRISE camera can be operated in a myriad of different modes. Perhaps the most important point for the user is that fact that the camera uses 14 separate charge-couple detectors (CCDs) that can each be commanded to behave differently. For the initial sampling, we favored a mode that binned the outer CCDs to a greater extent than the central CCDs. This means that resolution decreases in discrete steps away from the center of the final image product. This helped us select which resolution is optimal for each terrain type. However, we are now favoring images that have uniform binning across all CCDs.

As we gained some experience with imaging volcanic terrains with HiRISE, we began to aggressively collect stereo pairs over high priority targets, taking full advantage of the MRO spacecraft’s ability to roll off nadir. At the end of 6 months of PSP, we have +22 completed stereo pairs over volcanic targets. While quantitative digital elevation model production has only just started [6], anaglyph production has been largely automated utilizing a series of programs from the U.S. Geological Survey’s Integrated Software for Imagers and Spectrometers version 3 (ISIS3) [7,8].

**Vent Structures:** Mafic eruptions can be fed by either extended fissures or by more localized point sources. It is common for an eruption to start along a fissure segment and then become focused on one or a few point sources along the fissure. If the eruption is re-invigorated by a new episode, a new fissure segment can open though a single point source can also feed multiple eruptive episodes. Earlier orbital imaging of Mars had identified a number of both fissure and point vents [e.g., 9,10].

The early HiRISE observations have imaged the Late Amazonian Cerberus Fossae volcano-tectonic fissure system in three locations. In the first two (TRA_00827_1875 and PSP_001342_1910), the fissure appears to be a graben with no evidence for local effusion of lava. In the third (PSP_001408_1900), it has fed an eruption of low viscosity lavas. The plains surrounding the vent preserve evidence of multiple surges in an extended fissure eruption [2,4]. However, even at this very young feature, mass-wasting has widened the fissure, erasing any small vent structures (e.g., spatter ramps) that may have existed. Future imaging of narrower parts of the fissure system may show preserved vent structures.

Three low shields marking point sources have been imaged to date. The first, Mareotis Tholus, is located in Tempe Terra, to the east of Alba Patera. The region is extensively fractured by volcano-tectonic fissures, including the Mareotis Fossae. The shield is remarkably smooth and devoid of boulders, even in crater ejecta (Fig. 2). Lobate flows are also notably indistinct. It is possible that the mantling layer is so thick here that all volcanic features are completely obscured.

However, the lack of evidence for lava stratigraphy in the walls of a 0.73 km diameter crater, even where cleaned by mass-wasting, suggests an alternative possibility. Mareotis Tholus could be composed almost entirely of pyroclastic materials. While a ~6-km-diameter cinder cone is much larger than any terrestrial example, it is predicted that fountains on Mars would disperse material more extensively than on Earth. This is because of both the lower atmospheric pressure and the lower gravity [11]. While not conclusive, this observation supports the idea that some Martian eruptions have been largely explosive, rather than effusive.

**Figure 2.** Mareotis Tholus. Anaglyph produced from HiRISE images PSP_001364_2160 and PSP_001364_2160. The elongated central pit is the volcanic vent. The circular depression on the southwest is a superimposed impact crater. Evidence for lava flows, in the form of resistant layers, boulders, and lobate scarps, are notably absent. Note that the elongation of the summit is roughly parallel to the dune-filled graben south of Mareotis Tholus.
In contrast, the other two shields (in Tharsis and Elysium) show evidence for extensive lava flows and lava ponds. The summit is marked by a series of nested depressions rimmed by a raised lip. We interpret this lip as levees built up by small overflows. The gradual accretion of these levees allows the lava pond depth to build up over time. The failure of the pond wall allowed lava to flow through the breach, forming a channel and depositional fan of lobate flows (Fig. 3). The low shields also have a distinctly lower flank slope than Mareotis Tholus.

However, all of these small vents show strong evidence of structural control on their orientations. For example, the member of the Cerberus Tholi that was imaged by the HiRISE stereo pair PSP_002806_1870 and PSP_003096_1870 consists of a series of irregular ponds along a fissure that is oriented parallel to the nearby Cerberus Fossae. Overall, at least for the more recent volcanic features, it seems that regional tectonics has very strongly influenced where magma is able to ascend. While a number of recent studies have suggested that tectonic fissures on Mars formed in response to dike injections [e.g., 12, 13], it is possible that the dikes may have played a more passive role.

Shield Volcanoes: One somewhat disappointing, but not surprising, result is that HiRISE has not (yet) added substantially to our understanding of the large shield volcanoes. This is because the tall volcanoes are covered by a thick layer of dust. The deposits are, at least locally, several tens of meters thick. While this dust shows interesting features of its own, it obscures all volcanic features at the meter scale (Fig. 4).

**Figure 3.** Low shield near the Ceraunius Fossae (Tharsis). Anaglyph produced from HiRISE observations PSP_002328_2080 and PSP_002605_2080. The central depression is the volcanic vent. The vent was covered by a lava lake impounded by levees. Lava flows formed after the levees were breached on the southwest.

**Figure 4.** Ascreaus Mons flank lava flows. Portion of PSP_002209_1865. At low spatial resolution, we infer inflated pahoehoe in the north and rubbly pahoehoe in the southeast. The inset provides a full resolution (26.6 cm/pixel) sample showing nothing but intricately carved dust at the meter scale.
Images of steep scarps, such as caldera walls and the basal scarp on Olympus Mons provide some windows through the dust. These do show layers of hard rock, undoubtedly lava flows exposed in cross-section. However, we have not (yet) found exposures that allow observation of the flow tops and bottoms at the meter scale. We remain optimistic that we will be able to find a few such outcrops on the large shiel volcanic. Such observations, will provide a new view into the lava flow emplacement process, possibly providing some insight into the vertical distribution of vesicular and dense lava.

We will also examine the dust in some detail. It is possible that some significant fraction of this fine-grained material is volcanic ash. It has been variably indurated by unknown processes, but acidic volcanic gases may have played a role. Finally, there are many suggestions of ice-rich surficial materials on and around the shield volcanoes e.g., [14, 15], potentially leading to interesting lava-groundic interactions in the geologically recent past.

**Flood Lavas:** Most of the young volcanic plains on Mars are covered by vast “floods” of lava. Earlier MOC-based studies have shown that Martian flood lavas predominantly have a platy-ridged surface texture [16, 17]. By comparison with terrestrial analogs in Iceland and the Columbia River Plateau, we infer that these are rubbly pahoehoe lava flows. These lava flows are distinguished by a brecciated flow top consisting of broken pieces of pahoehoe, rather than the classic aa clinker [18].

HiRISE has followed-up the MOC observations of platy-ridged lava in (a) Elysium Planitia, (b) Amazonis Planitia, and (c) Kasei Valles. In each of these areas, the lavas show clear evidence of large rafted plates of brecciated material atop the fluid flow. Similar, but more dust-covered examples can be found on the Tharsis rise. We note that the idea that this surface texture is formed by pack-ice on a frozen sea [19] would require that (a) near-surface ice be stable at the equator of Mars for more than a billion years and (b) the sea have selectively covered unconfined “basins” at many different elevations.

HiRISE is also finding evidence that these rubbly pahoehoe flows behave in a more classically pahoehoe-like manner when their size is restricted. For example, along the margins of some of the flows, there are small uplifts that are identical in size and morphology to tumuli. Furthermore, we have discovered a partially collapsed lava tube in a location where the flow was channeled between topographic obstacles (Fig. 5). This provides the most direct evidence that (at least some of) these flows were emplaced under an insulating crust.

Interaction between flood lavas and ground water or ice has been seen [2-4], but is not discussed here.

![Figure 5. Partially collapsed lava tube in flood lava flows weaving between the Tartarus Colles. Portion of PSP_001420_2045. Note the uncollapsed bridge. Lavas appear to have debouched from Marte Valles and embayed knobs of ancient terrains as they moved north toward Amazonis Planitia.](3314.pdf)