MUD VOLCANOES - A NEW CLASS OF SITES FOR GEOLOGICAL AND ASTROBIOLOGICAL EXPLORATION OF MARS. C.C. Allen[1], D.Z. Oehler[1], and D.M. Baker[2] [1]NASA Johnson Space Center, Houston, TX 77058 carlton.c.allen@nasa.gov, dorothy.z.oehler@nasa.gov [2]Brown University, Providence, RI 02912 david_baker@brown.edu

Introduction: Mud volcanoes provide a unique low-temperature window into the Earth's subsurface – including the deep biosphere – and may prove to be significant sources of atmospheric methane. The identification of analogous features on Mars would provide an important new class of sites for geological and astrobiological exploration. We report new work suggesting that features in Acidalia Planitia are most consistent with their being mud volcanoes.

Previous Research: Terrestrial mud volcanoes are low shields or domes, meters to over one kilometer in diameter, composed of mud and rock. They have been documented at over 40 sites onshore and over 20 subsea locations [1]. The largest concentration of mud volcanoes is in Azerbaijan and the adjacent Caspian Sea. Mud volcanoes are formed when overpressured gases and liquids from as deep as several kilometers breach the surface, carrying slurries of fluid, mud, and rocks [2]. These conditions often occur in regions of rapid sedimentation and hydrocarbon generation, and many mud volcanoes emit copious quantities of volatiles, primarily water and methane.

Mud volcanoes have been cited as possible analogs to martian features from a wide range of locations. These include the dichotomy boundary regions near Isidis [3] and Utopia [4], the Borealis "back basin" [5], and Chryse Planitia [6,7]. Farrand *et al.* [8] hypothesized that numerous domes and cones in Acidalia are either mud volcanoes or spring mounds. We have reexamined these features, using the full range of datasets now available from Mars orbit.

Acidalia: Domes and cones, hundreds of meters to kilometers in diameter, are scattered across much of Acidalia Planitia. These features overlie the Vastitas Borealis plains, mapped as Hesperian to Amazonian sedimentary units of basaltic composition [9,10].

Farrand *et al.* [8] based their analysis on images from the MOC (Mars Orbiter Camera; 1.5 to 12 m/pixel) and THEMIS (Thermal Emission Imaging System; 19 m/pixel visible; 100 m/pixel infrared) instruments. We conducted high-resolution morphologic and spectral analysis of specific Acidalia features employing HiRISE (High Resolution Imaging Science Experiment; 0.3 m/pixel) panchromatic and color images, as well as multi-spectral images and point spectra obtained by the CRISM (Compact Reconnaissance Imaging Spectrometer for Mars; 16 to 20 m/pixel; 0.362 to 3.920 μm spectral range) instrument.

Farrand *et al.* [8] reported that the domes and cones appear darker than the adjacent plains in THEMIS nighttime infrared images. This observation demonstrates that the domes and cones are composed of material with lower thermal inertia than the plains.

HiRISE images show isolated and overlapping high-albedo domes and cones, many with central depressions. The centers (inferred high points) of the features often show concentric layering, while the outer portions are finely furrowed and generally rock-free at sub-meter resolution (Fig. 1). The dome material clearly overlies the plains. Meter-scale texture characteristic of the underlying plains is locally detectable at the margins of the domes, indicating that this material can thin to a feather edge. Impact craters that pierce several domes indicate that the bright material is irregularly layered and tens of meters thick. Small dunes of bright material, possibly eroded from the domes, are observable within nearby troughs.

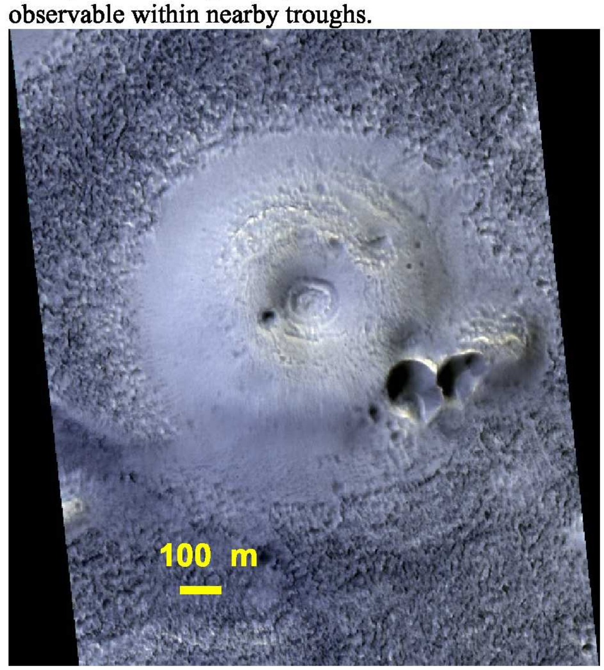

Figure 1. High-albedo dome in Acidalia Planitia (HiRISE image PSP_008522_2210 IRB).

A CRISM image (3837 vnir_fem browse product; 11] demonstrates that the Acidalia domes and plains have distinct and consistent spectral signatures. The plains in this image appear blue, indicating the presence of olivine and / or pyroxene. The domes appear green, indicating coatings on rocks or ferric oxides.

The CRISM spectra of individual domes, with corrections for the martian atmosphere and dust, were ratioed to spectra representative of the adjacent plains (Leah Roach, Brown Univ.; Fig. 2). The visible (VIS) portion of the ratio shows a steep shoulder near 0.6 μm, indicative of ferric iron. The near-infrared (NIR) portion of the ratio shows positive features in the same positions as the negative features in spectra of high-calcium pyroxene. These imply that the dome spectrum is essentially flat in the NIR, and that the ratio is showing the inverse signatures of pyroxene in the plains material. The ratio spectrum shows no features corresponding to precipitates or evaporite minerals.

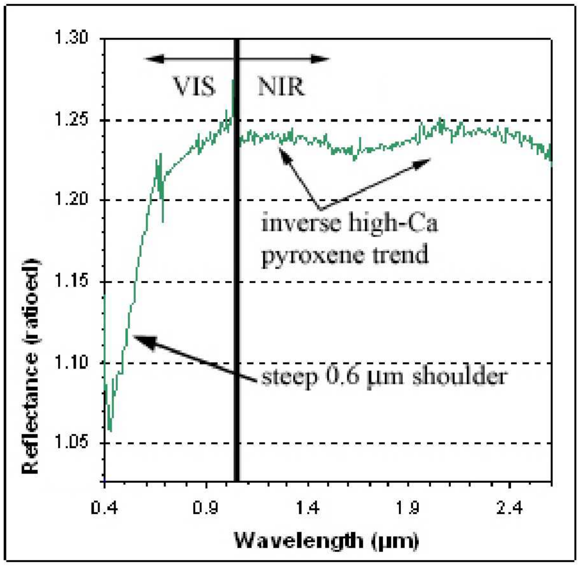

Figure 2. CRISM 3837 ratio spectrum (dome / plains material).

These observations, in combination, argue against a number of possible origins for the Acidalia domes including impact, volcanic eruption, or deposition from springs. Impact craters of similar scale exhibit deeper depressions and blockier ejecta blankets than the domes. The dome materials have lower thermal inertia than the plains, as well as featureless NIR spectra, indicating that the domes are not composed of basalt. The lack of spectral signatures for evaporites and precipitates argues against a spring mound origin.

Conversely, the observations are consistent with mud volcanoes. Dried mud has lower thermal inertia than rock, and is likely friable enough to be smoothed by wind erosion. The lack of specific mineral signatures in the VIS and NIR spectra is consistent with amorphous or poorly-crystalline materials like those found in clay-rich mud. The ferric iron signature indicates that dome material is more oxidized than plains material, suggesting an origin associated with water. This is consistent with conclusions by Wyatt [10] that aqueous alteration occurred in Acidalia Planitia. It is also consistent with regional assessment by Oehler and Allen [7] that the Chryse-Acidalia area is a prime candidate for having developed extensive mud volcanism.

Implications for Astrobiology: If the Acidalia domes or similar features elsewhere on Mars have an origin similar to that of terrestrial mud volcanoes, then these martian features are potentially important sites for martian geology and astrobiology. Mud volcanoes bring material from depth to the surface at temperatures well below those associated with impact cratering or volcanism. On Earth some mud volcanoes sample deep sedimentary strata, carrying physical and chemical biosignatures to the surface. While the depth sampled by the martian features is unknown, seismic and stratigraphic studies demonstrate that terrestrial mud volcanoes sample as deep as several kilometers.

Terrestrial mud volcanoes also erupt significant quantities of water. The Acidalia domes do not show evidence of channeling, suggesting that large amounts of water did not flow from their craters. The lack of channels may also reflect this material's susceptibility to wind erosion. The oxidized nature of the dome material, as witnessed by its abundance of ferric iron, suggests that the material interacted with water at depth. Thus, these domes may hold important clues to the subsurface hydrosphere.

Many terrestrial mud volcanoes are located in regions of abundant hydrocarbons. The Azerbaijan and Caspian features are closely associated with major oil and gas fields. Mud volcanoes are known to erupt large amounts of methane derived from subsurface hydrocarbons [1]. Methane has been detected in the martian atmosphere, where its short lifetime suggests currently active sources [12-14]. We are exploring the possibility that a portion of this methane may derive from the martian equivalents of mud volcanoes.

References: [1] Milkov A.V. (2003) *AAPG Ann. Mtg.* Abs. [2] Kvenvolden K.A. & Rogers B.W. (2005) *Marine Petrol. Geol.* 22, 579-590. [3] Tanaka K.L. *et al.* (2000) *LPS XXXI*, Abs. #2023. [4] Skinner J.A. & Tanaka K.L. (2007) *Icarus 186,* 41-59. [5] Kite E.S. *et al.* (2007) *AGU Fall Mtg.* Abs. [6] Rodriguez J.A.P. *et al.* (2007) *Icarus 191,* 545-567. [7] Oehler D.Z. & Allen, C.C. (2009) *LPS XL,* Abs. #1034. [8] Farrand W.H. *et al.* (2005) *JGR 110,* E05005:1-14. [9] Tanaka K.L. *et al.* (2005) *USGS Sci. Invest. Map 2888.* [10] Wyatt M.B. (2008) *GSA Ann. Mtg.* Abs. #268-3. [11] Pelkey S.M. *et al.* (2007) *JGR 112,* EO8S14, doi:10:1029. [12] Krasnopolsky A. *et al.* (2004) *Icarus 172*, 537-547. [13] Mumma M.J. *et al.* (2004) *36th DPS*, Abs. #26.02. [14] Formisano V. *et al.* (2004) *Science 306*, 1758-1761.