PROBABLE MUD VOLCANOES IN CHYSE PLANITIA, MARS: UPDATES ON MORPHOLOGICAL, SEDIMENTROGICAL AND SPECTRAL STUDIES. G. Komatsu[1], C. H. Okubo[2], J. J. Wray[3], L. Ojha[3], M. Cardinale[1, 4], A. Murana[1], R. Orosei[5], M. A. Chan[6], J. Ormö[7], and R. Gallagher[8], [1]International Research School of Planetary Sciences, Università d'Annunzio, Viale Pindaro 42, 65127 Pescara, Italy (goro@irsps.unich.it), [2]U.S. Geological Survey, Flagstaff, AZ 86001, USA, [3]School of Earth and Atmospheric Sciences, Georgia Institute of Technology, Atlanta, GA 30332-0340, USA, [4]Dipartimento di Scienze Psicologiche Umanistiche e del Territorio, Università d'Annunzio, Via dei Vestini 31, 66013 Chieti, Italy, [5]Istituto di Radioastronomia, Istituto Nazionale di Astrofisica, Via Piero Gobetti, 101, I-40129, Bologna, Italy, [6]Department of Geology and Geophysics, University of Utah, 115 S. 1460 E. Rm. 383 FASB, Salt Lake City, UT 84112-0102, USA, [7]Centro de Astrobiología (CSIC-INTA), Ctra de Torrejón a Ajalvir, km 4, 28850 Torrejón de Ardoz, Spain, [8]c/o 170 Gardner Drive Aberdeen, AB12 5SA, UK.

Introduction: Features interpreted to be mud volcanoes occur at various locations in and along the northern plains of Mars, including Isidis Planitia [1, 2], Utopia Planitia [3, 4], the Utopia/Isidis overlap [5], Acidalia Planitia [6, 7], Chryse Planitia [8, 9, 10, 11], and Arabia Terra [12]. However, there is no place on Mars where the presence of mud volcanoes is fully confirmed to date. Here, we update on our progress of the continuous investigation [13, 14] of small edifice features less than a few kilometers in diameter and up to a few hundred meters in height in Chryse Planitia (**Fig. 1**), which have been originally proposed to be mud volcanoes [11]. Our study represents the first study of the small edifices in Chryse Planitia with the HiRISE (including its stereo-derived DTMs) and CRISM datasets. Importantly, we analyzed CRISM Infrared (IR) data in search of clear evidence for hydrated minerals.

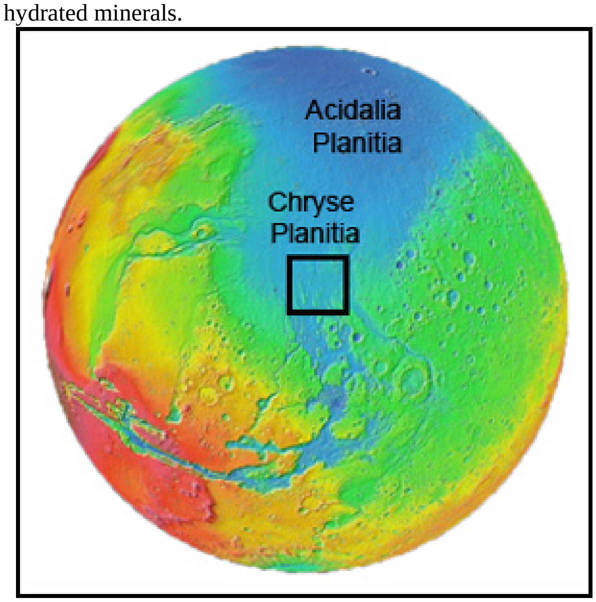

Fig. 1. Study area in Chryse Planitia on Mars.

Geological setting: The study area is located in relatively flat plains emplaced and modified by outflow events from Tiu and Ares Valles. The study area is a part of a larger region where widespread, semi-circular surface features (i.e., small edifices) occur as light toned patches in THEMIS daytime infrared images. These small edifices occur within the Late Hesperian unit HCc_4 [15]. The HCc_4 unit represents deposits in Chryse Planitia where circum-Chryse outflow channels enter the northern plains, and the deposits are interpreted to have formed by debris flows and/or by rapidly emplaced fluvial sediments from the outflow channels [15]. [16] presented multiple geological conditions on Mars that might favor plausible mud volcanism. One of these is rapid deposition of sediments and loading, which may fit well with the situation in Chryse Planitia. It is hypothesized that large quantities of water-rich sediments were delivered into the plains by cataclysmic flooding or debris flows related to the development of the gigantic circum-Chryse outflow channel system (e.g., [17]). The study area may also occur above a relatively rapidly deposited clastic wedge laid, possibly under a primordial northern plains ocean, within a paleo-basin located in the southern circum-Chryse region during the Late Noachian [18]. A terrestrial example of a geological setting similar to Chryse Planitia may be found offshore of Trinidad [19]. Here, deep-water mass transport deposits (MTDs) with sediments derived from the Orinoco Delta exhibit many mud volcanoes. The subaqueous terrestrial setting of MTDs is not applicable to the current environment in Chryse, but the hypothesized ancient oceans (e.g., [20]) may have provided a similar subaqueous setting on Mars. The rapid sedimentation in MTDs is analogous to the environment expected when the circum-Chryse outflow channels were active or sediment was transported in from the southern highlands.

Morphological characteristics: We made morphological comparisons between the mud volcanoes in established localities on Earth and the small edifices at our study site in order to assess the validity of the mud volcano hypothesis for the Chryse features. We classify the Chryse features (**Fig. 2**) as Type 1 (steep-sided cones typically with a summit crater), Type 2 (nearly flat features with single or multiple central/summit craters or cones), or Type 3 (nearly circular features in plan view, characterized by steep sides and a broadly flat summit area). The height-to-diameter ratios of terrestrial mud volcanoes in Azerbaijan and Pakistan find good correlations with those of morphologically similar small edifice features (Type 1, 2, 3 respectively) in the Chryse study area. Some additional details of the features in the Chryse study area may also find analogs in terrestrial mud volcanoes. For example, mud flows associated with terrestrial mud volcanoes occasionally exhibit well-defined levees and a central channel, similar to the morphology of the large flow feature occurring in the middle of the Chryse study area. The flat-looking infill materials observed in some craters on the Chryse features are very similar visually to mud infilling of craters associated with terrestrial mud volcanoes. The rugged hummocky texture noted in flow and edifice surfaces is consistent with surface properties of terrestrial mud flows obsered at the field scale. The boulders or aggregates observed in flow and edifce surfaces could be bedrock fragments brought up by ascending mud and/or fluid, which are common occurrences with terrestrial mud volcanoes, or alternatively they could be small gryphons.

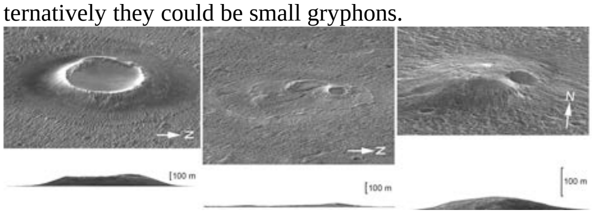

Fig. 2. 3 general types of small edifices features studied in Chryse Planitia. From left to right (Type 1, Type 2, Type 3).

Spectral characteristics: Following the terrestrial analogs, spectral confirmation of the mud volcano hypothesis would require detection of common mud volcanism constituents such as phyllosilicates (e.g., [21]) at the small edifices or their immediate proximity.

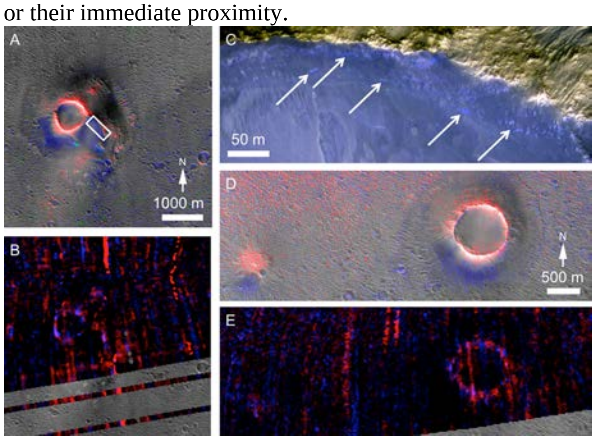

Fig. 3. CRISM analysis of small edifices in Chyrse Planitia. (A) Mineralogy of a Type 1 feature. HiRISE image colorized with CRISM VNIR data. Red is ferric oxides, blue is mafic minerals, blue+green is a distinct type of mafics. (B) Same area shown in (A), with HiRISE image overlain by CRISM IR data. Blue indicates hydrated minerals and red indicates mineralogic or adsorbed water. Nearly vertical stripes of color are noise artifacts. (C) HiRISE IRB color enlarged view of distinct mafic materials (e.g., arrows) near the cone summit crater (area outlined by box in (A)). (D) Mineralogy of a Type 1 and a Type 3 features. HiRISE image colorized with CRISM VNIR data. Color scheme is the same as in (A). (E) Same area shown in (D), with HiRISE image overlain by CRISM IR data. Color scheme is the same as in (B).

We observe in our CRISM analysis (**Fig. 3**) absorption bands at ~1.9 μm and 3.0 μm (due to fundamental stretching) on the rim of these edifices, which are indicative of unknown hydrated minerals. The 1.4 μm feature is much weaker than 1.9 μm and 3.0 μm and can disappear due to dehydration under Martian atmospheric conditions, or spectral masking by Fe-rich phases. Although the detection of the hydrated phase reported here is not definite evidence for mud volcanism, it does suggest that water was involved in the edifice depositional history. The nanophase ferric minerals detected on the Chryse small edifices by CRISM indicate alteration that might also have involved water.

Conclusions: Small edifice features that are less than a few kilometers in diameter and up to a few hundred meters in height are widely distributed in Chryse Planitia on Mars. They exhibit a broad range of morphological properties. Their origins have not been determined with certainty, but our study utilizing HiRISE images supports the interpretation of mud volcanism, based on the observed morphological characteristics of these small edifices and comparisons with terrestrial analogs. Additionally, hydrated minerals detected on these edifice features in data from CRISM, further support the mud volcano hypothesis. Alternative mechanisms such as magmatic volcanism are not excluded, but they have less support from our remote sensing observations.

References: [1] Davis P. A. and Tanaka K. L. (1995) *LPS XXVI*, 321–322. [2] Ori G. G. et al. (2000) *LPS XXXI*, Abstract #1550. [3] Skinner J. A., Jr., and Tanaka K. L. (2007) *Icarus*, *186*, 41–59. [4] Ivanov M. A. et al. (2014) *Icarus*, *228*, 1012–1023. [5] McGowan E. M. (2011) *Icarus*, *212*, 622–628. [6] Farrand W. H. et al. (2005) *JGR*, *110*, E05005. [7] Oehler D. Z. and Allen C. A. (2010) *Icarus*, *208*, 636–657. [8] Tanaka K. L. (1997) *JGR*, *102*, 4131–4150. [9] Rodriguez J. A. P. et al. (2007) *Icarus*, *191*, 545–567. [10] Oehler D. Z. and Allen C. C. (2009) *LPS XL*, Abstract #1034. [11] Komatsu G. et al. (2011) *PSS*, *59*, 169–181. [12] Pondrelli M. et al. (2011) *EPSL*, *304*, 511–519. [13] Komatsu G. et al. (2012) *LPS XLIII*, Abstract #1103. [14] Komatsu G. et al. (2016) *Icarus*, in press. [15] Tanaka K. L. et al. (2005) *USGS*, *SIM-2888*, scale 1:15,000,000. [16] Skinner J. A., Jr., and Mazzini A. (2009) *Marine and Petroleum Geology*, *26*, 1866–1878. [17] Baker V. R. (1982) *The Channels of Mars*, Univ. of Texas Press, 198 pp. [18] Rodriguez J. A. P. et al. (2015) *Sci. Rep.*, *5*, 13404. [19] Moscardelli, L., Wood, L. J. (2008) *Basin Research*, *20*, 73–98. [20] Baker V. R. et al. (1991) *Nature*, *352*, 589–594. [21] Scholte K. H. et al. (2003) *3rd EARSel Workshop on Imaging Spectroscopy*, Herrsching, 13–16.