THE EFFECTS OF AQUEOUS PROCESSES AND IMPACTS ON MINERAL ALTERATION AND WEATHERING IN LIBYA MONTES AND TYRRHENA TERRA, MARS. D. Tirsch[1], J. L. Bishop[2], C. Viviano[3], D. Loizeau[4], L. L. Tornabene[5], M. D. Lane[6], and R. Jaumann[1,7] [1]Institute of Planetary Research, German Aerospace Center (DLR), Berlin, Germany (daniela.tirsch@dlr.de). [2]Carl Sagan Center, SETI Institute, Mountain View, CA, USA. [3]Johns Hopkins University Applied Physics Lab (JHUAPL), Laurel, Maryland, USA. [4]IAS, Université-Sud, Orsay, France. [5]Dept. of Earth Sciences, Centre for Planetary Science and Exploration, University of Western Ontario, London, Canada. [6]Fibernetics LLC, Lititz, PA, USA. [7]Institute of Geological Sciences, Freie Universität Berlin, Berlin, Germany.

Introduction: A variety of aqueous alteration materials as well as unaltered mafic rocks have been identified by investigations across the region between Isidis and Hellas Planitias [e.g., 1-6]. Exposed views of ancient crustal rocks, lava flows from Syrtis Major, alteration from the large Isidis and Hellas impacts, and multiple stream beds and deltas make this region unique on Mars [e.g., 7-10]. Previous studies of morphologic and spectroscopic features using coordinated CRISM-HRSC and CRISM-HiRISE-CTX imagery observed distinct stratigraphic units containing phyllosilicates, carbonate, olivine and pyroxene in isolated regions [e.g., 11, 12]. We extend this work across a broader area of Libya Montes and south across Tyrrhena Terra in order to 1) characterize the types and occurrences of phyllosilicates, opal, zeolites, and carbonates; 2) assess relationships between these aqueous outcrops and surface features such as craters, aqueous channels, and deltas; 3) investigate whether the surface rocks were altered by the Syrtis flows or Isidis impact; 4) determine relationships between smaller craters (e.g., Dulovo, Hashir, Bradbury, Lipany, Auki, and Lopez) and the surface rocks; 5) evaluate the surface mineralogy across the study region in relation to thermal inertia and elemental abundances; and 6) determine the effects of impact alteration in formation or transformation of the mineralogy.

Methods: We are conducting analyses on multiple data sets acquired at Mars, especially from the Mars Reconnaissance Orbiter (MRO), Mars Express (MEX), Mars Global Surveyor (MGS) and Mars Odyssey spacecraft. We are using coordinated analyses to maximize the data generated by these individual instruments. We are mapping rock compositions using Mars Odyssey THermal EMission Imaging System (THEMIS) data and modeling MGS Thermal Emission Spectrometer (TES) data across the region to document variations in mafic and silicate components on a regional scale and analyze physical properties of the surface determined from thermal inertia [e.g., 13, 4]. Furthermore, we are using Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) [14] multispectral mapping data for analyzing the overall mineralogical composition of the study area and for selecting specific regions of interest. We are investigating targeted CRISM images across the Libya Montes and Tyrrhena Terra region and projecting those with mineral signatures over Context Camera (CTX) [15] and Mars Express High Resolution Stereo Camera (HRSC) [16, 17] nadir images and mosaics in order to view occurrences of olivine, pyroxene, phyllosilicates, carbonates and other minerals in a geologic perspective. We are analyzing the outcrops with mineral signatures using HRSC Digital Terrain Models (DTMs) in order to gain an understanding of the stratigraphy and regional geology. We are creating maps of surface morphology and geology across Libya Montes and Tyrrhena Terra based on maps prepared recently in sections of Libya Montes [11, 12, 18, 19] using crater counting and morphologic mapping techniques in ArcGIS. The mineral signatures from CRISM and TES/THEMIS will be analyzed in concert with the geologic features and elemental abundances from the Gamma Ray Spectrometer (GRS) on Mars Odyssey in order to understand and illustrate the stratigraphy and geologic history of the surface. We are also analyzing High Resolution Imaging Science Experiment (HiRISE) [20] images and several DTMs of these aqueous outcrops in order to characterize the morphology and stratigraphic relationships of the mineralogically distinct spectral units and determine how the altered materials are related to the mafic rocks.

Current Status: We conducted a geological mapping on HRSC nadir image data with the aid of corresponding HRSC DTMs (Fig. 1). This map is intended to provide a geological and geomorphological overview of the wider study region. Hence, the mapping scale was selected to be 1:500,000 and the HRSC data were down-sampled to a ground pixel size of 50 m/px for image data and 100 m/px for the DTMs, respectively. Coverage gaps were filled with Viking Orbiter image data (231 m/px) and the blended MOLA-HRSC DTM mosaic available from the USGS (200 m/px).

Noachian massif (Nm) is the oldest geological unit, which comprises ancient highland rocks featuring a high relief, rugged slopes and sharp crests [cf., 7]. *Noachian/Hesperian heavily eroded materials (NHhe)* are mapping units that involve dissected and degraded surfaces, stratigraphically younger than the *Nm* unit. They are further discriminated by the degree and type of erosion: *NHhe1* are primarily fluvially dissected surfaces and *NHhe2* are somewhat less degraded and show fewer channel features. *Hesperian/Amazonian ridged*

and smooth plains (HArsp) involve relatively flat surfaces, that may comprise wrinkle ridges, and thus are often related to volcanic deposits but are not limited to that origin. Since one scope of this study is to analyze the effects of water-related processes in the study region, *fluvial channels (fc)* is one of the most important mapping units. The majority of the mapped channels are dendritic in pattern, however, linear channels occur randomly as well. In places, the fluvial channels are interbedded in wider valleys, representing interior channels in that case. The sediments covering these broader valleys were mapped as *Noachian/Hesperian/ Amazonian valley deposits (NHAvd)* that can be of various ages. The relative ages of all mapping units was estimated by means of crater-size-frequency-distributions derived from CTX image data. Most fluvial channels are incised into Noachian- and Hesperian-aged surfaces. Also the *crater ejecta (ej)* are of various ages and are typically found around impact craters of different sizes. The last mapping unit comprises deposits left or caused by mass movements and is thus called *mass movement deposits (mmd)*. To this latter unit belong landslides (often along inner crater walls) as well as (alluvial) fan-shaped deposits, both found wide spread across the study site.

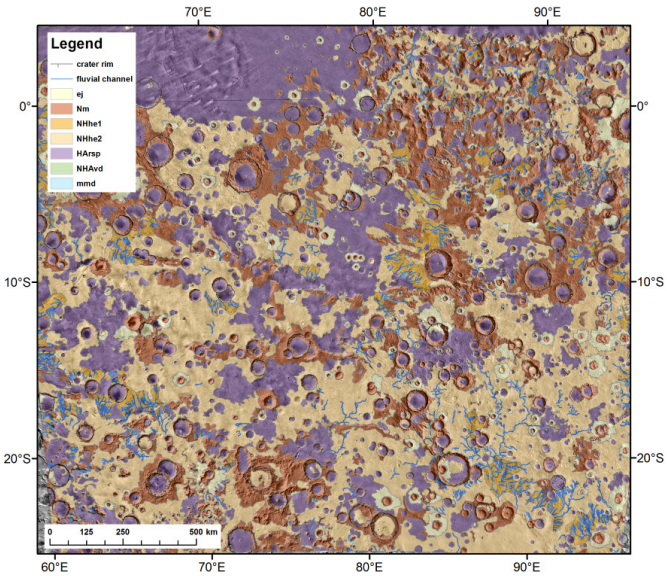

Fig. 1: Geologic mapping of the entire study region reaching from the southern Isidis Planitia region, bordered by the Libya Montes, across Tyrrhena Terra, down to the northern Hellas Planitia rim region. Compare Figure 2 for labels of regions and major crater names. Mapping base: HRSC nadir and DTM data. Image Background: Viking Orbiter data.

CRISM mineral maps are currently being evaluated in order to select individual regions of interest for detailed spectral analyses. We are concentrating on locations that exhibit altered mineral signatures and that are covered by targeted CRISM images and HiRISE data. In these mineral maps, olivine outcrops are mapped in bright green, pyroxene outcrops in dark blue, and Fe/Mg-phyllosilicates in orange/red (Fig. 2). Our study site includes several large phyllosilicate-rich regions that we will evaluate with TES/THEMIS in order to gain information about the abundance of the alteration products, olivine and pyroxene.

What's next? HiRISE DTM data processing is currently in progress. We are furthermore working on detailed geological mappings of particular regions of interest, e.g., two alluvial fans in Harris crater. We seek to coordinate the mineralogy, surface morphology, age and aqueous features to constrain the types of formation processes at these sites.

References: [1] Craddock R.A. (1994), *LPSC XXV,* Abstract #291. [2] Ivanov M.A. & Head J.W. (2003) *JGR, 108,* E6. [3] Rogers A.D. & Christensen P.R. (2007) *JGR, 112,* E01003. [4] Tornabene L.L. et al. (2008) *JGR, 113,* E10001. [5] Loizeau D. et al. (2012) *Icarus, 219,* 476-497. [6] Rogers A.D. & Hamilton V.E. (2015) *JGR, 120*, 62-91. [7] Crumpler L.S. & Tanaka K.L. (2003) *JGR, 108,* 12. [8] Jaumann R., et al. (2010) *EPSL, 294,* 272-290. [9] Erkeling G., et al. (2012) *Icarus, 219*, 393-413. [10] Ivanov, M.A., et al. (2012) *Icarus, 218,* 24-46. [11] Bishop J.L., et al. (2013) *JGR, 118,* 487–513. [12] Tirsch, D., et al. (2018) *Icarus, 314,* 12-34. [13] Mellon M.T., et al. (2000) *Icarus, 148,* 437-455. [14] Murchie S.L., et al. (2009) *JGR, 114,* E00D06. [15] Malin M.C., et al. (2007) *JGR 112,* E05S04.[16] Neukum G., et al. (2004) ESA SP-1240, 1-19. [17] Jaumann R., et al. (2007) *PSS, 55*, 928-952. [18] Tirsch D., et al. (2016) LPSC XLVII, Abstract #1444. [19] Erkeling G. et al. (2016) LPSC XLVII, Abstract #1451. [20] McEwen A. et al. (2007) *JGR, 112,* E05S02.

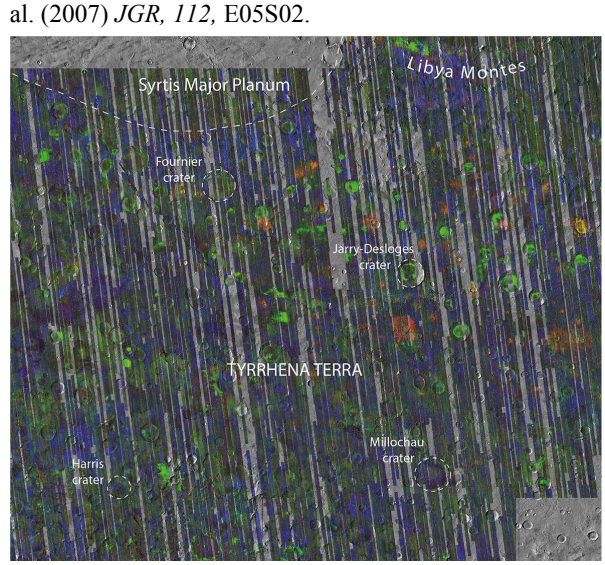

Fig. 2: RGB composite of a CRISM multispectral survey dataset related to Fe/Mg-bearing phyllosilicates, as well as olivine and pyroxene (R:D2300, G:BD1300, B:LCPINDEX). This figure covers the same region as Figure 1.