DIVERSITY OF HYDRATED MINERALS AND DEPOSITS AT NOCTIS LABYRINTHUS: IMPLICATIONS FOR LATE HESPERIAN TO AMAZONIAN AQUEOUS ACTIVITY ON MARS. C. M. Weitz[1] and J. L. Bishop[2], [1]Planetary Science Institute, 1700 E Fort Lowell, Suite 106, Tucson, AZ 85719 (weitz@psi.edu); [2]SETI/NASA AMES, 515 N. Whisman Rd., Mountain View, CA 94043.

Introduction: Noctis Labyrinthus consists of a network of intersecting linear troughs that merge with rounded pits and pit chains (Figure 1). Eastward, these linear troughs connect to the continuous Tithonium and Ius chasmata of Valles Marineris. The troughs and pits of Noctis disrupt Late Hesperian to Early Amazonian age lava plains [1], which means any sedimentary deposits within the troughs and pits must have formed after this time. Consequently, they record environmental conditions during the post-Noachian when the climate is thought to be colder and drier [2].

We have targeted and analyzed sedimentary deposits within Noctis Labyrinthus using both HiRISE and CRISM data. Spectral information extracted from CRISM was combined with high-resolution imaging and Digital Terrain Models (DTMs) derived from HiRISE to map out geologic units associated with the deposits and infer aqueous processes. Although we analyzed all CRISM images for the Noctis Labyrinthus region, we only discuss those images that show evidence for hydrated minerals. Similarly, we examined all HiRISE image for light-toned materials that could be possible deposits or alteration materials, but only discuss those images where these types of rocks were identified. Medium-toned layered deposits were also commonly seen in HiRISE and CTX images throughout Noctis, but these deposits lacked hydration features and are assumed to be materials formed by some other processes unrelated to aqueous activity (i.e., eolian, lava flows, etc.).

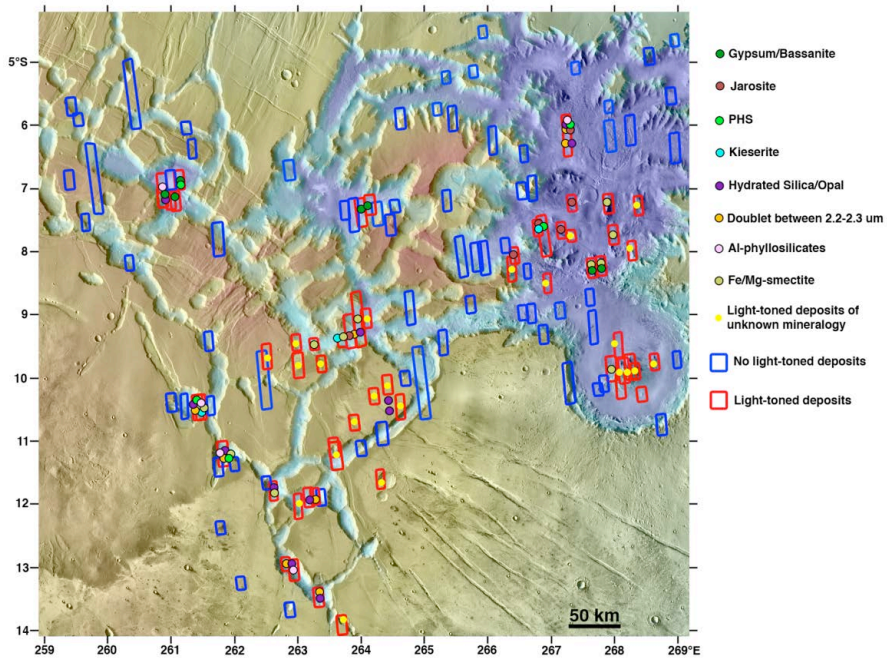

Figure 1. THEMIS daytime infrared mosaic with MOLA topography overlain in color for the Noctis Labyrinthus region. HiRISE images are outlined by red and blue rectangles while minerals interpreted from CRISM spectra are noted by colored circles.

Results: Numerous minerals have been identified within this region (Fig. 1), including several kinds of sulfates (monohydrated (kieserite) and polyhydrated sulfates, jarosite, and Ca-sulfates (gypsum, bassanite)), clays (Fe/Mg-smectites and Al-phyllosilicates), and hydrated silica/opal. We also identified a doublet feature between 2.2-2.3 µm in several of the troughs. This same doublet has been noted previously in two of the Noctis troughs [3,4], Ius Chasma [5], and Melas Chasma [6]. The doublet feature could indicate mixtures of jarosite and clays, including leached clays [5,6]. Most hydrated deposits superimpose disrupted floor materials and landslides along trough and pit floors. However, gypsum and clays are located along hilltops where erosion has removed an overlying layered darker mantle (Fig. 2). The deposits appear heavily fractured and faulted, some of which resemble brecciated textures. The faulting and uplift of these hydrated deposits indicates continued extension and disruption within the larger trough where they occur.

Light-toned layered deposits are also observed along the central plateau. They display weak hydration absorptions at ~1.93 µm, but no other diagnostic features that would allow us to infer a mineralogy. A few

medium-toned deposits associated with the light-toned layered deposits along the plateau have weak spectra consistent with hydrated silica/opal. Similar appearing deposits that contain jarosite and opal have been identified along the Valles Marineris plateau to the east [7-10]. Unlike the plateau deposits to the east, however, these Noctis plateau deposits are not associated with valleys and inverted channels. CRISM images of Oudemans crater in SE Noctis were also analyzed but we found only a few very weak signatures of Fe/Mg-smectites associated with the uplifted light-toned layers exposed within the central peak.

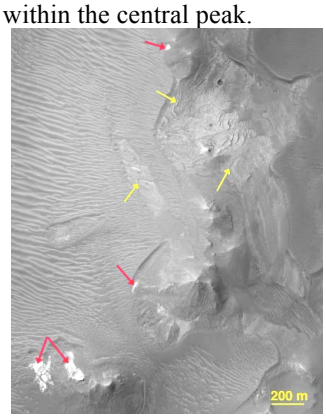

Figure 2. HiRISE image showing light-toned layered clay-bearing deposits that are disrupted and faulted (yellow arrows) within hills in eastern Noctis. Red arrows identify bright fractured Ca-sulfate deposits.

Discussion and Summary: Our observations and analyses indicate a diverse range of deposits and minerals within the depressions of Noctis Labyrinthus and along portions of the plateau. While some troughs appear to have experienced the same aqueous conditions that produced similar minerals, most contain a distinct suite of minerals, suggesting that each trough underwent a unique depositional and alteration history particular to that trough. For example, while hydrated silica is commonly observed in Noctis, it occurs in different settings. Along the plateau and in some troughs it is found by itself, while in one trough it is found along wallrock slopes beneath gypsum, and in other troughs it is associated with the doublet material, jarosite, and/or Fe/Mg-smectites. In addition, the morphologic appearance of this hydrated silica-bearing material in HiRISE images varies. In some cases it appears as a thin, patchy, medium-toned surficial alteration of pre-existing rocks, while in other troughs it is associated with light-toned layered beds. Hence, the deposits and their associated mineralogies must have formed under localized geologic settings and environmental conditions to explain the diversity of observed lithologies. The most complex assemblages as reflected by the largest number of minerals identified within CRISM data occurs in two troughs to the far west [3,4] that display several hundred meters of interlayered sulfates and smectites (Fig. 3), suggesting either a long period of deposition or alteration of the layers under variable water geochemistries. The presence of clays in many of the troughs indicates that water conditions were at times long-lived and habitable.

Figure 3. Enhanced HiRISE color image showing Fe-smectite deposits beneath layered sulfates (ferricopiapite) inside a trough in western Noctis.

Hydrothermal activity and the presence of volcanic ash are plausible conditions to explain many of the deposits observed in this region given their proximity to the Tharsis volcanoes. Young volcanic flows have been identified in one of the troughs [11], indicating that heat was available in the Amazonian to melt ice and/or snow that may have accumulated in the troughs, and subsequently, alter rocks. Thus far, only one trough with hydrated minerals has associated valleys and channels [12] that are interpreted as evidence for melting ice/snow, supporting that water may have been available within the troughs. The Late Hesperian to Amazonian ages of these deposits indicate that aqueous activity occurred within this region relatively late in martian history, and may be contemporaneous to other young Valles Marineris hydrated deposits and fluvial features identified to the east [5-10, 13-14].

References: [1] Tanaka K.L. and Davis P.A. (1988) *JGR, 93,* 14893-14917. [2] Bibring J-P. et al. (2006) *Science,* doi: 10.1126/science.1122659. [3] Weitz C.M. et al. (*2011) Geology 39*, 899-902. [4] Thollot P. et al. (2012) JGR 117, doi:10.1029/2011JE004028. [5] Roach L.H. et al. (2010) *Icarus 206*, 253-268. [6] Weitz C.M. et al. (2014) *Icarus*, in press. [7] Weitz C.M. et al. (2008) *Geophys. Res. Letts. 35*, doi:10.1029/2008GL035317. [8] Weitz C.M. et al. (2010) *Icarus 205*, 73-102. [9] Bishop J.L. et al. (2009) *JGR 114*, doi:10.1029/2009JE003352. [10] Le Deit L. et al. (2010) *Icarus 208*, 684-703. [11] Mangold N. et al. (2010) *EPSL 294*, 440-450. [12] Weitz C.M. et al. (2013) *PSS 87*, 130-145. [13] Mangold N. et al. (2004) *Science 305*, 78–81. [14] Qunatin C. et al. (2005) *JGR 110*, doi:10.1029/2005JE002440.