

**DISTINCT PROVINCES OF AQUEOUS ALTERATION IN THE WESTERN ISIDIS REGION IDENTIFIED WITH MRO-CRISM.** B.L. Ehlmann<sup>1</sup>, J.F. Mustard<sup>1</sup>, J.L. Bishop<sup>2</sup>, G.A. Swayze<sup>3</sup>, L.H. Roach<sup>1</sup>, R.N. Clark<sup>3</sup>, R.E. Milliken<sup>4</sup>, F. Poulet<sup>5</sup>, S.L. Murchie<sup>6</sup>, and the MRO CRISM Team. <sup>1</sup>Dept. of Geological Sciences, Brown University, <sup>2</sup>SETI Institute <sup>3</sup>U.S. Geological Survey, Denver <sup>4</sup>JPL-Caltech <sup>5</sup>IAS, Université Paris-Sud, <sup>6</sup>JHU-Applied Physics Laboratory (bethany\_ehlmann@brown.edu)

**Introduction:** The region west of the Isidis basin hosts the greatest mineral diversity yet mapped from orbit. Terrains bearing olivine [1, 2], low- and high-calcium pyroxene [3], and iron-magnesium smectites [4] can be mapped over thousands of kilometers in a well-defined regional stratigraphy. Both west and south of the Isidis basin in Nili Fossae and Libya Montes, phyllosilicates in the lowermost stratigraphic unit are overlain by unaltered mafic materials [5-8]. High resolution targeted observations (~18-36 m/pixel) from the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) [9] allow mapping small exposures of phyllosilicates and show great regional diversity in hydrated, alteration minerals. To date, these include nontronite, saponite, kaolinite, chlorite, illite or muscovite, zeolites, and hydrated Si-OH bearing phases whose spectra are consistent with altered, vitrified volcanic products or opaline silica [6, 10-13] (Fig. 1)

While the regional Fe/Mg smectite-bearing deposit was likely formed by the time of the Isidis impact [14, 15], outstanding questions remain as to the nature of the alteration process(es) responsible for the hydrated minerals and whether a single episode of aqueous alteration can explain all observed diversity. Potential processes include phyllosilicate deposition in sedimentary basins, weathering in near surface pedogenic conditions, near surface hydrothermal activity, or deep crustal metamorphism. Below we detail the locations, mineral associations, and geomorphology of hydrated minerals west of the Isidis basin (focusing particularly on the zeolite and Si-OH bearing phases not previously detailed in [10, 11]). Combined with geochemical data on mineral formation conditions, we begin to distinguish the nature of aqueous alteration, in some cases

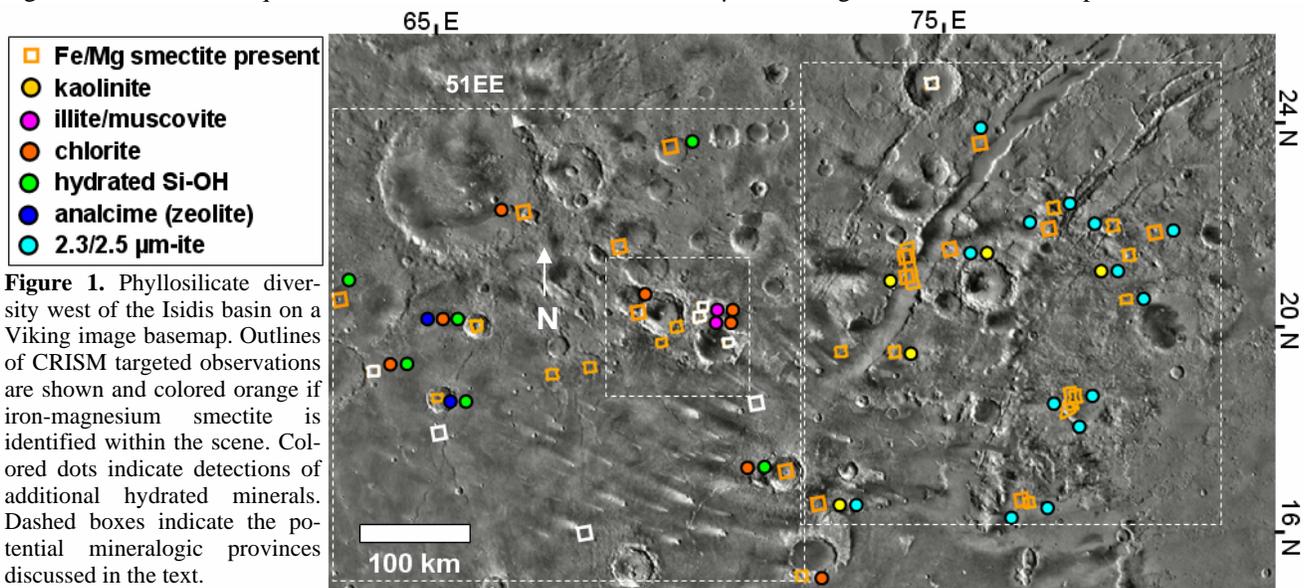
possibly due to impact-induced hydrothermal activity.

**“Provinces” of alteration:** Based on the spatial distribution of alteration mineral assemblages (Fig. 1), three distinct provinces are tentatively identified:

(1) *Western:* In heavily cratered terrain in exposures usually associated with crater central peaks and walls, Fe/Mg smectite, chlorite and hydrated Si-OH bearing phases are found. In central peaks of two craters, the zeolite analcime is also detected (one is shown in Fig. 2). These craters are those identified by Bandfield et al. [16] based on TES/THEMIS data as containing quartzofeldspathic (QF) material. Chlorite, zeolite, and smectite occur in small knobs within the crater central peak, while the Si-OH phase is associated with aeolian deposits at the base of the peak which also contain the QF material.

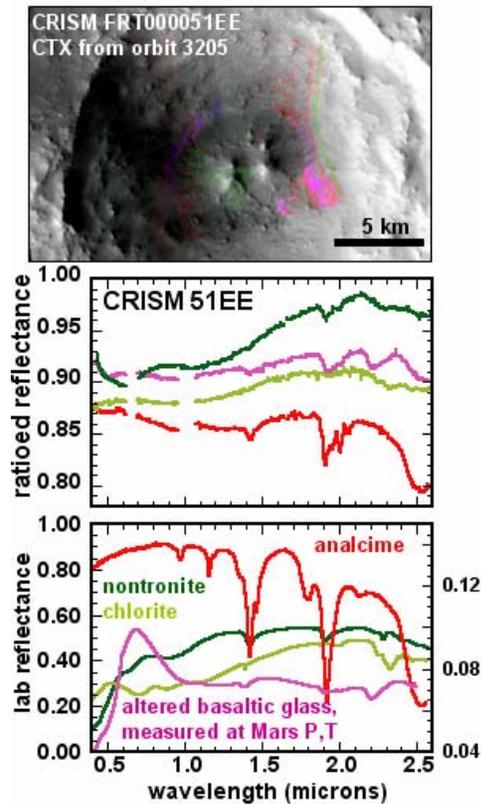
(2) *Central:* Phyllosilicates are associated with small eroded knobs and ridges in the ejecta field of a 40 km crater [10]. Chlorite dominates over smectites and a mica, illite or muscovite, is present.

(3) *Eastern:* Where in rock units, phyllosilicates underlie a cap of spectrally neutral mesa-forming material in erosional terrain around the concentric Nili Fossae grabens [6, 8]. Fe/Mg-smectite, the dominant alteration mineral, usually occurs as a ridged or polygonally fractured bright unit. Small exposures of kaolinite occasionally overlie the Fe/Mg smectite. Some phyllosilicates have been fluviably transported within a regional watershed [14] as in the delta of Jezero crater [17, 18]. For both in-situ and transported phyllosilicates, an additional 2.5  $\mu\text{m}$  absorption feature often is associated with the smectite deposits, which are identified based on characteristic absorptions at 1.4, 1.9, and 2.3  $\mu\text{m}$ . A single mineral cannot explain all the ob-



**Figure 1.** Phyllosilicate diversity west of the Isidis basin on a Viking image basemap. Outlines of CRISM targeted observations are shown and colored orange if iron-magnesium smectite is identified within the scene. Colored dots indicate detections of additional hydrated minerals. Dashed boxes indicate the potential mineralogic provinces discussed in the text.

served spectral features (see [10] for further discussion). Examination of spectral libraries and acquisition of spectra of mixtures containing smectite, zeolite, and carbonate are being used to constrain the composition of this material.



**Figure 2.** CRISM parameter map from FRT000051EE overlain on a CTX image, processing as in [6]. CRISM spectra colors correspond to mapped colors. Best match library mineral spectra colored to match CRISM spectra are from [12, 23].

**Implications:** Distinct regional assemblages of minerals suggest that the nature of aqueous activity varied in space and time across the region west of the Isidis basin. Smectites within the Eastern province are exposed as the lowermost stratigraphic unit in images sampling over 100,000 km<sup>2</sup> of terrain. The great spatial extent of this unit seems to exclude lacustrine or volcanic hydrothermal processes as the primary mechanism for regional smectite formation and instead favors pervasive near surface alteration or deep crustal hydrothermal/metamorphic alteration [19]. However, the existence of small-scale exposures of kaolinite within the Eastern province indicates that, locally, more intense weathering may have occurred due to enhanced throughflow of water or hydrothermal alteration. The late Noachian-early Hesperian fluvial activity around Nili Fossae [14] may play some role in the formation of minerals additional to smectite in the Eastern province.

Greater mineral diversity in the Central and Western provinces may have been generated in local hydro-

thermal systems related to impact events. The mineralogy associated with impact craters in the Central and Western provinces is remarkably similar to the Fe/Mg-rich smectites or chlorites with accessory zeolite, silica, quartz, and K-feldspar which result from hydrothermal alteration in terrestrial craters [20]. Indeed, such a formation process provides a solution to the enigma of granitoid intrusions on Mars [16], namely that the origin of the QF material is not igneous but hydrothermal. The low TES-modeled abundances of quartz and K-spar and association with hydrated Si-OH bearing phases (e.g. altered impact glass [22]) are consistent with such a formation process. Experimental data show smectite-zeolite assemblages result from glasses and or basalt powders and are stable at temperatures <150°C [21] while illite-chlorite assemblages are stable at T>200°C [20]. Hence, variation in the temperature of the hydrothermal system may result in the distinctive Central and Western assemblages.

An alternative hypothesis is that these alteration materials associated with craters reflect changes in underlying crustal materials westward of the Isidis basin and that aqueous alteration pre-dated formation of the 10s of km-diameter impact structures in which these minerals are mapped. Further CRISM high resolution imaging of the region—especially crater ejecta and walls—and consideration of crater superposition and age relationships will constrain the timing of mineral emplacement relative to the impacts.

Unanswered questions include what mechanism formed the Eastern regional smectite deposit and to what extent alteration minerals further west are related to this deposit. Nevertheless, multiple episodes of aqueous activity, perhaps resulting from multiple processes, suggest that the region west of the Isidis basin was, over early Mars history, persistently and unusually water-rich.

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