STRATIGRAPHY OF NOACHIAN-AGED CRUST IN THE NILI FOSSAE-SYRTIS-ISIDIS REGION. J. F. Mustard[1], S. L. Murchie[2], B. L. Ehlmann[1], R. E. Milliken[3], J-P. Bibring[4], F. Poulet[4] and J. W. Head[1]. [1]Dept. of Geological Sciences, Box 1846, Brown University, Providence, RI 02912 John_Mustard@brown.edu, [2]JHU/Applied Physics Laboratory, Laurel, MD 20723, [3]JPL-CalTech, [4]IAS, University of Paris, Orsay, France

Introduction: Defining the nature of the early crust on Mars remains a challenging problem due to the breadth of time and processes that have acted upon it. Concepts of planetary evolution and geophysical modeling suggest that primary crust may have originally formed during cooling of a magma ocean or by serial magmatism [1]. Most consider this early crust to have been broadly basaltic in composition. Subsequent processes have significantly modified the original crust, through impact processes including basin formation, additional magmatism, and aqueous processes. The finding that much of the Noachian terrain on Mars exhibits evidence of phyllosilicate minerals and thus alteration [2, 3, 4] raises significant questions as to when, where, and how the alteration occurred. A significant section of well-exposed Noachian crust exists surrounding the Isidis Basin. Here we present observations that provide some constraints on the nature of the earliest crust.

Regional Geology: The Isidis Basin is a 1900 km [5] diameter impact basin dated to the Late Noachian (3.96 Ga [6]). It has been significantly modified, including loss of the northeast rim through gradational processes [7], formation of radial and concentric graben due to loading and flexure [8], and emplacement of the plains volcanics that make up Syrtis Major Planum on its western rim [9]. The loading and flexure occurred, in part, in response to filling of the basin but prior to the emplacement of Syrtis Major. Syrtis Major lavas cover $\approx 10^6$ km^2 from the central caldera, reach the western floor of the Isidis Basin, and also cover the floor of the Nili Fossae trough. Early phases of the volcanism may have filled some of the Isidis Basin floor [10]. The opening of the fractures constituting the Nili Fossae as well as significant gradation due to fluvial processes [11, 12] provide some excellent exposures of crust along scarp walls and in erosional windows. In these exposures outcrops are observed showing spectral signatures diagnostic of mafic and phyllosilicate minerals.

Mafic Composition: In exposed scarps and walls as well as materials excavated by impacts are outcrops showing mineral signatures of pyroxene and olivine. High-resolution images from the HiRISE camera show that many of these outcrops are large blocks embedded in a matrix of material that is either spectrally unremarkable or shows spectral signatures of phyllosilicate (discussed later). In HiRISE color data (IR-R, R-G, GB-B) these blocks appear green and show very sharp color contacts with the surrounding matrix. This is well illustrated in CRISM image FRT000064D9 and HiRISE image PSP_003587_2015 (not shown). CRISM spectra show the blocks to be a mixture of low- (LCP) and high- (HCP) Ca pyroxene with LCP dominant. Another exposure along the Nili Fossae scarp shows the LCP-rich rocks to be in meters-thick tabular units embedded in a phyllosilicate matrix (FRT00009D44, PSP_007200_2005) (Figure 1). Strong signatures of pyroxene in the ejecta of a 10 km diameter impact crater (23°N, 77°E; FRT0000BFD1) constitute a much larger exposure of unaltered Noachian crust. While the full dimensions and character of the crustal block are unresolved, the excavation shows that a relatively large region of unaltered Noachian crust existed at the target point of the impact. These spectra are distinct from those of the Syrtis Major Hesperian lavas that show strong enrichment in HCP and a significant olivine component.

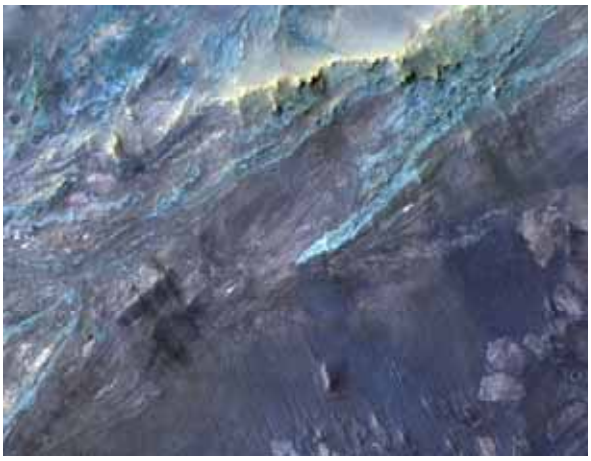

Figure 1. HiRISE color image PSP_007200_2005 of the southern scarp of Nili Fossae. Unaltered mafic rock showing strong LCP infrared spectra is shown in blue/green, and strongly altered phyllosilicate-bearing rocks are brown. The lower right hand corner shows breccia blocks 10s of m is size that are banded as if layered. Image is 1 km across

There is a remarkable olivine-rich unit observed east of Nili Fossae and along the southern edge of the Isidis Basin [10, 13, 14, 15]. The unit is clearly cut by the concentric graben of Nili Fossae and hypothesized to be pre-Isidis lava [14], Isidis impact melt [15], or associated with early phases of Syrtis volcanism [10]. HiRISE and CRISM data show that the olivine is concentrated in a banded unit, 10s of m thick that rests on phyllosilicate basement. A spectrally bland, mafic cap >100 m thick overlies the banded olivine unit. The mafic cap shows a pitted and rough textured surface. The banded olivine unit beneath a mafic cap is observed

from 24° N, 76°E (north of the Nili Fossae) to regions along the south edge of the Isidis Basin (3°N, 85°E) traversing over 2.5 km of relief. The unique olivine mineralogy, banded character, and pairing with the mafic cap are evidence that this is a coherent unit that we propose was emplaced by single event. HiRISE stereo imaging shows that the basal banded unit drapes the topography and the banding parallels the contact with the phyllosilicate basement locally covering 10s to 100s of meters of topography over 10s of km.

The presence of olivine over such a large region is evidence that large-scale aqueous alteration processes had largely ceased since emplacement of this unit [14, 15, 4]. The olivine unit rests directly on phyllosilicate-bearing Noachian basement. In places the banded unit shows spectral signatures indicative of carbonate and serpentine [16, 17]. This is evidence that small amounts of alteration did occur and may have been in response to the thermal input from the emplacement of the banded unit or brief aqueous episodes [16].

Phyllosilicate Alteration: The basement rocks over this entire region from the southern Isidis basin to west of Nili Fossae are spectrally dominated by Fe/Mg smectite clays [18]. In regions of excellent exposure distinct blocks of phyllosilicate-bearing rocks are observed, similar in size to the mafic blocks described earlier. These blocks frequently show a banded appearance suggesting layering (Figure 1). The layering may be due to sedimentation in a standing body of water or eolian processes, and thus preserve evidence of sedimentary processes from earlier periods. Elsewhere sharp contacts between altered and unaltered materials are preserved across the contact and may be indicative of alteration fronts. Collectively these show that large-scale impact processes have disrupted the crust and transported relatively coherent blocks forming a megabreccia as recently detailed by [19]. The matrix mostly appears massive and compositionally homogeneous at the scale of CRISM observations. Linear ridges 5-10 m high and several km long are observed. These do not appear spectrally distinct from the phyllosilicate basement and do not penetrate or otherwise affect the banded unit and mafic cap.

Conclusions: The Noachian crust in this region of Mars is a complex, brecciated unit of diverse compositions. Breccia blocks consisting of unaltered mafic rocks and banded phyllosilicate-bearing putative sedimentary rocks are observed throughout. In places the phyllosilicate-bearing material appears as a matrix surrounding mafic blocks, and the mafic rocks show evidence of complex folded relationships (Fig. 1) possibly formed in the turbulent flow during emplacement of basin-scale ejecta. The observations described rest either within the transient cavity of Isidis or near or outside the rim. These materials are likely the brecciated products of the Isidis basin-forming event and are a mélange of units and rock types from the earliest era of Mars history.

The low ridges may be breccia dikes [20] within the basement or post-basin mineralized fracture zones. The banded olivine unit that covers a large topographic range and drapes topography overlies the basement rocks and low ridges. This we interpret to be impact melt from the Isidis Basin forming event. It is difficult to envision extrusive lava flowing across several km of relief and yet not ponding in obvious topographic lows. While some alteration is evident (carbonate and serpentine), the persistence of olivine suggests that large-scale aqueous alteration processes had ceased by the time this unit was emplaced.

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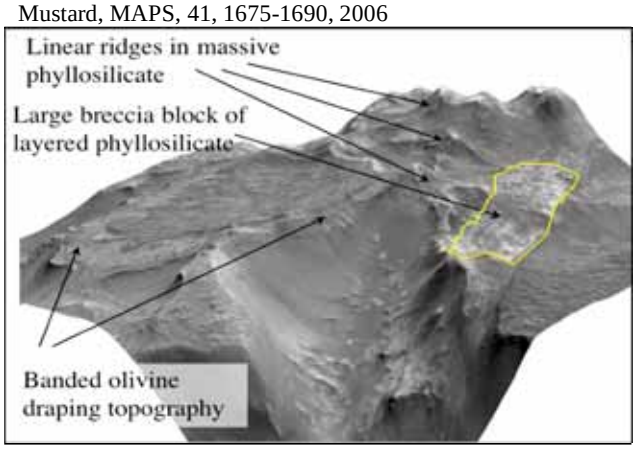

Figure 2. Perspective view of HiRISE image PSP_2176. Vertical exaggeration is 5x, image width is ≈2 km and the depth midway through the valley in the near field is ≈ 100 m. Key features of banded olivine, layered phyllosilicate blocks and linear ridges are labelled.