REGIONAL GEOLOGY AND STRATIGRAPHY OF THE NILI FOSSAE-SYRTIS-ISIDIS REGION: NEW INSIGHTS FROM CRISM AND MRO DATA.

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Introduction: Bibring et al [1] proposed that Mars mineralogic evolution is defined by three phases that loosely correspond to the stratigraphic time periods of Noachian (phyllosilicate), Hesperian (sulfate) and Amazonian (oxide formation). The Noachian-Hesperian boundary marks an evolution from early Mars, with abundant gradational/fluvial processes [2], formation of phyllosilicate [3], a magnetic field, a denser atmosphere and different climate than today to a period markedly different with plains volcanism [2], sulfate formation [1], acidic environments [4] and a drier, colder climate. With new data sets provided by instruments on the Mars Reconnaissance Orbiter, we are testing this hypothesis with high resolution Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) [5] mineralogic data. Here we focus on the Isidis Basin-Syrtis Major region, which presents superb exposures of Noachian- and Hesperian-aged terrains in contact emphasizing geologic contacts that traverse the Noachian-Hesperian boundary.

Regional Geology: The Isidis Basin is a 1900 km [6] diameter impact basin dated to the Late Noachian (3.96 Ga [7]). As with all martian basins, it has been significantly modified, including loss of the northeast rim through gradational processes [8], formation of radial and concentric graben due to loading and flexure [9], and emplacement of the plains volcanics that make up Syrtis Major Planum on its western rim [10]. The loading and flexure occurred, in part, in response to filling of the basin but prior to the emplacement of Syrtis Major. The lavas of Syrtis Major 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 basin floor of the Isidis Basin [11].

A variety of fluvial and sedimentary landforms are found in the region. Sinuous channels leading to fans in Jezero Crater show no evidence for sapping and the source of the water (e.g. glacial, groundwater, precipitation) is unclear [12, 13, 14]. Deep, poorly organized valleys are found along scarps of the concentric graben of Nili Fossae. Their size and morphology are typical of sapping channels and several have fans deposited on the floor of Nili Fossae [13]. A distinct sinuous channel with grooves and teardrop-shaped landforms upstream is observed crossing northeast Syrtis Major emptying in the Isidis Basin, suggestive of a shallow, wide flood [13]. The dating of the fluvial activity is complicated, showing apparent activity from the Noachian into the Hesperian. However, the magnitude of the activity apparently diminishing strongly with time.

Composition: The composition of rock units in the Isidis region is highly diverse. Where bedrock is well exposed beneath a cover of dust or surface oxidation we find that distinct mineralogic signatures can be assigned to many of the geologic units. The lavas of Syrtis Major have been well studied and are characterized as typical basalt with 40-50% feldspar, low (LCP) and high (HCP) Ca pyroxene with more HCP than LCP, and variable olivine [15, 16, 17]. The igneous composition of the Noachian crust also shows abundant feldspar [15], but with comparable amounts of LCP and HCP [16, 17].

There is a remarkable unit rich in olivine largely observed east of Nili Fossae, but also found along the southern edge of the Isidis Basin [11, 18, 19, 20, 21]. The unit is clearly cut by the concentric graben of Nili Fossae and hypothesized to be pre-Isidis lava [19], Isidis impact melt [20], or associated with early phases of Syrtis volcanism [11]. This unit is a critical time-stratigraphic marker and mineralogic mapping indicates that it is mostly free of alteration minerals. This indicates that the environments that supported the abundant alteration observed in the region (discussed below) must have ceased by the time of the emplacement of the olivine-rich unit.

The Isidis region is rich in outcrops showing strong visible-infrared spectral signatures diagnostic of phyllosilicate minerals [3, 13, 22, 23]. The spectra show strong absorptions at 1.9 μm (combination tone of the H_2O bend and OH^- stretch) and near 2.3 μm (combination tone of Metal-OH bend and OH^- stretch) associated with Fe/Mg smectite clays such as saponite or nontronite. Mapping of these minerals with the OMEGA instrument suggests that the phyllosilicate minerals are restricted to rocks of Noachian age [13, 20].

New observations by CRISM as well as the imaging instruments on MRO (Context Imager (CTX) and the High Resolution Imaging Science Experiment (HiRISE)) place important constraints on the stratigraphic and geology evolution of this region. CRISM is a visible-infrared that can acquire high-resolution targeted observations at 544 wavelengths from 0.36-3.92 μm at 18-36 m/pixel and multispectral survey data with 72 wavelengths at 100-200 m/pixel. Observations are processed to account for all instrumental effects and reduced to radiance [24]. From these data, I/F is calculated and then corrected for solar incidence angle. The effects of atmospheric transmission absorptions are removed using an approach similar to that used by the OMEGA experiment [16] where the data are divided by a scaled, empirically derived atmospheric transmission spectrum obtained from an observation across Olympus Mons.

For each observation spectral parameters, indicators of mineral presence or diversity, are calculated [25]. The parameters indicate where minerals a likely to be present, but require follow-up analyses to validate the occurrence.

We have targeted many regions of the olivine-bearing unit (11 images) to determine its geologic setting and relationship to the phyllosilicate-bearing units. We see a consistent stratigraphy of phyllosilicate-bearing basement, often showing polygonal fractures and textures, overlain by a thinly layered (meters) olivine-bearing unit that is itself overlain by tens of meters thick coherent unit that erodes to large blocks and boulders. The coherent unit shows no definitive spectral features. Despite being in direct contact with phyllosilicate units, the olivine shows no definitive evidence of alteration. This sequence of three units has been observed north of Nili Fossae, a broad region around 21°N, 78°E, and along the south edge of the Isidis Basin floor. This encompasses a distance of 1300 km and over 3 km of elevation. The lack of alteration in the olivine indicates that the intense period of alteration that formed the phyllosilicate units had ceased at the time of olivine emplacement, approximately at the time of the formation of the Isidis Basin. This was previously suggested [13, 20] but the CRISM data clearly establishes the stratigraphic and mineralogic framework.

We have also targeted many regions of well exposed sections of the Noachian-Hesperian boundary in the Nili Fossae Trough, and the northeastern boundary of Syrtis Major. At these well-exposed contacts between Hesperian-aged volcanics and phyllosilicate-bearing Noachian basement, the mineralogic contact is very sharp at the scale of CRISM (20 m/pixel) with no evidence of an alteration horizon or zone. Thus despite the presence of a heat source adjacent to volatile-rich rocks, no evidence of hydrothermal alteration is observed. This suggests that the availability of water was limited at the time of Syrtis Major emplacement in these regions.

The region of the proposed landing site in the Nili Fossae Trough [26] shows detailed stratigraphy between Noachian-aged walls of Nili Fossae, a large sapping channel, and the Hesperian-aged floor materials of Nili Fossae. The floor of Nili Fossae consists of coarsely bedded units that have a weak spectral signature of Fe/Mg smectite clay. Lavas from Syrtis Major overlie the floor materials and there is no evidence of deposits associated with the sapping channel overlying these. The outcrops exposed in the walls of the sapping channel and Nili Fossae show a mixture of intensely altered rock showing strong Fe/Mg smectite clay signatures surrounding large blocks of unaltered LCP-rich Noachian basement. These new observations combined with previous work indicates that the trough of Nili Fossae is filled first by material shed from the walls of the trough and the sapping channel and second by a thin covering of lava. A thick-layered fill is also observed in the trough to the east of main Nili Fossae trough. Combined with observations of layered, phyllosilicate-bearing sediments in craters in the Nili Fossae region indicate that there was an intense gradation period with abundant sediment transport and deposition following the formation of the Isidis Basin but the alteration appeared to be pre-Isidis. Thus this gradational period quickly declined, though there is evidence for intermittent episodes of gradation through the Hesperian.

CRISM data, together with other MRO instruments clearly document (a) a three-part stratigraphy of phyllosilicate overlain by olivine overlain by a blocky unit across a large region and (b) direct contact of unaltered Hesperian lava with Noachian-aged phyllosilicate-bearing units.

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