ALTERATION PHASES ASSOCIATED WITH HIGH CONCENTRATIONS OF ORTHOPYROXENE AND OLIVINE ON MARS.
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Introduction: Data collected by the Mars Global Surveyor Thermal Emission Spectrometer (TES) have revealed numerous regions on Mars with high abundances of olivine relative to typical Martian basalts [1, 2] and a single location with high abundances (up to 40 vol. %) of orthopyroxene [2]. These high concentrations of mafic materials were identified initially using band matching approaches [1] or deconvolutions that used lithologic, rather than mineral, end members [2]. Based on new deconvolution analyses using mineral end members, we now are able to place quantitative constraints on the abundances of alteration phases associated with high concentrations of orthopyroxene and olivine on Mars.

Weathering on Mars: Mechanical processes almost certainly are the dominant weathering mechanism acting on the Martian surface today. But chemical weathering also has played a role, most obviously in oxidation processes producing red hematite. It seems likely that interactions between rock and water have produced secondary phases, but these have proven difficult to identify unambiguously at Mars until recently [3-5]. Overarching problems remain: how much water was present during various periods in Martian history, what were the pH, water chemistry, water/rock ratio, and temperature (to name a few) of the environment as a function of time? These factors play a critical role in determining if alteration will occur and what phases will result from a given starting material [6]. Also, there are no guarantees that the alteration products will remain in the area in which the alteration occurred [7]. However, it may be possible to use observed alteration mineralogies and their correspondence with specific geologic materials to place some constraints on alteration processes in some areas of Mars.

Defining Alteration: As applied to the mineralogy of geologic materials at Mars, the definition of "altered" rarely is quantitative, commonly is subjective, and typically varies from investigator to investigator, based on what the investigator is looking for. Unfortunately for the mineralogical remote sensing community, virtually all terrestrial schemes for classifying degree of weathering rely on qualitative visual or quantitative chemical assessments, rather than phase detection (i.e., a binary result) or relative/absolute mineralogy. Different remote sensing (spectroscopy) techniques are sensitive to different phases, abundances, and sampling depths. It is therefore important that we define what we mean by "altered," "unaltered," and degrees in between. This information is especially important for helping us (and especially the broader community) understand how to integrate remote sensing results from instruments with different sensitivities. In this study, *relatively unaltered* materials have deconvolved modal mineralogies lacking secondary phases above a generalized TES detection limit of ~15 vol.%; this does not mean that lower abundances of such phases are not present. *Slightly altered* is used to describe materials with ~15 – 25 vol.% secondary phases, and *moderately to highly altered* describes materials with secondary phase abundances of >25 vol.%.

Analytical Approach: We use TES 10 cm^{-1} sampling data meeting stringent quality constraints [2] and having Lambert albedo <0.24. This equates to ~9500 spectra around Nili Fossae and ~6300 spectra in and around Eos Chasma. The linear deconvolution approach [8] utilizes an end member library of mineral and atmospheric spectra to model the TES spectra. The output consists of the abundance of each phase used in the best-fit model, the modeled spectrum, and the root-mean-square (rms) error of the fit. Atmospheric components are subtracted and remaining components are normalized to 100%, yielding fractional abundances of phases on the surface.

End member selection. The ~50 end member spectral library utilized in this study was optimized for basaltic igneous lithologies (feldspars, pyroxenes, and olivines) and secondary phases that are predicted by-products of the aqueous alteration of basaltic lithologies, such as: silica, quartz, amphibole, albite, serpentine, oxides/oxyhydroxides, carbonates, sulfate, and "clay mineral" phyllosilicates. Most of these spectra are derived from the ASU spectral library [9]. We examine the distribution and abundances of each individual end member as well as classes of minerals (e.g., feldspar, orthopyroxene, olivine, oxide, etc.). We also compare the endmembers and groups to rms error, albedo and/or short wavelength band depth [10].

Study Regions: Because mafic minerals alter more readily then more felsic minerals under virtually all conditions, we are examining areas known to have high concentrations of mafic minerals.

Eos Chasma: [2] identified up to ~ 40% orthopyroxene (OPX) on the floor of Eos Chasma, based on spectral similarity to the Martian meteorite ALH 84001. [11] suggested that this material was not crystallized in situ, but instead represents intrusive material that was subsequently spread out onto the valley floor by failure of the adjacent wall rock. This area also contains a deposit of olivine-rich materials at least as extensive as the OPX-rich materials [2].

Nili Fossae region: Using TES data [1, 2] first identified the high concentrations of olivine in this region northeast of Syrtis Major. Using THEMIS data in conjunction with TES thermal inertia and olivine abundance maps, [12] determined that most olivine-rich materials in this region are associated with what likely are layered, bedrock units. [12] found thermophysical evidence that the olivine-rich materials are more extensive (~4x) than previously mapped, and interpreted the olivine-rich materials as olivine-rich basalts being exhumed from underneath a lower-olivine basaltic unit that thickens to the west.

Preliminary Deconvolution Results & Discussion: We have mapped the TES-derived mineralogy of a 4° x 4° area around the orthopyroxene-rich materials identified by [2] in Eos Chasma, and a 5° x 6° area around the high concentration of olivine near Nili Fossae [1, 2].

Eos Chasma: In the previously confirmed area of OPX-rich material, the solid solution composition of orthopyroxene is modeled as relatively Fe-rich ($\sim Mg_{70}$). Twenty-two pixels are modeled with >15% OPX, up to a maximum of ~60%. Virtually every individual alteration phase is identified below 15% in these pixels. When we group end members by class, phyllosilicates are the only class identified above 15%, in 5 of the 22 pixels. Oxides are modeled above 15% in two OPX-rich pixels, but these may be less reliable detections due to the grey body nature of their spectral signatures in the $1400 - 800$ cm^{-1} silicate fundamental range [13]. Carbonate phases are modeled above 15% throughout the region and in a few pixels with high OPX abundance. However, carbonates also are known to suffer from the same grey body issue as oxides, and they are detected in association with OPX only in spectra from a TES orbit acquired under higher albedo conditions than during other orbits. Serpentines and amphiboles are not modeled anywhere in the region. The olivine-rich material in this region is modeled primarily as Fo_{60-68}. Approximately 1/3 of the area of the olivine-rich material is modeled with >15% phyllosilicates. Neither the OPX- nor olivine-rich materials are modeled with silica phases, despite their identification above 15% elsewhere in the mapped area.

Nili Fossae region: There are three main "units" in this region. The first is olivine-rich ($\sim Fo_{60-68}$). The second (on the western side of the study area) is characterized by higher abundances of pyroxene and feldspar relative to olivine. The third is characterized by albedos of $0.20 - 0.24$. Amphiboles, serpentines, and chlorite were rarely identified and generally not above 15%. Phases identified above 15% in a few dozen pixels (of ~9500) include nontronite (mostly in high albedo areas), ilmenite, and quartz. Phases identified in greater numbers of pixels and >15% abundance including kaolinite, montmorillonite, Fe-smectite, gypsum, and $Mg_{54}Fe_{39}CO_3$, which tended to have higher abundances in the highest ($\sim 0.20 - 0.24$) albedo regions. In the areas characterized by low (<0.20) albedo, magnetite and silica phases commonly were identified (silica also is identified in regions with albedo >0.20). The abundance of phyllosilicates as a class is >15% throughout much of the region, with the highest abundances occurring in the high albedo regions, and with a slightly higher density of such pixels in the western basaltic region. Scatter plots show no correlation between alteration phase or class abundance and olivine abundance. The summed abundances of smectite, chlorite, goethite, and hematite constitute a proxy for iddingsite (a common alteration product of olivine), but this sum is not >15% in any spatially coherent area within this region. The lack of serpentine renders the likelihood of significant metamorphic alteration low to unlikely.

Summary: We assume no chemical or physical process(es) have acted to remove alteration phases. Removal of material is possible, but cannot be proven with available data. Phyllosilicates, dominated by the illite and halloysite end members, typically are the most abundant alteration class >15% in both regions, regardless of the dominant primary igneous composition or albedo. Phyllosilicate abundances are highest in relatively high albedo areas. Silica also is common, although not in association with orthopyroxene in Eos Chasma. Serpentines, amphiboles, and chlorite are only rarely identified and not above 15% in either region, rendering the likelihood of metamorphic alteration low to unlikely. Our results suggest that orthopyroxene-rich deposits are relatively unaltered, olivine-rich deposits appear slightly altered, and low-olivine materials around Nili Fossae may be moderately altered. No materials are pervasively altered. Results from OMEGA and CRISM may permit refinement of phases identified below TES detection limits. We are looking in detail at bedrock- and particulate-dominated materials for more clues to the origins of alteration distributions.

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