Hydrous Environments on Mars from Visible-Infrared Orbital Data

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Introduction: Data acquired over the past 5 years from the Mars Express OMEGA (Observatoire pour la Mineralogie, L'Eau, les Glaces et l'Activitié) [1] and Mars Reconnaissance Orbiter CRISM (Compact Reconnaissance Imaging Spectrometer for Mars) [2] show a wide diversity hydrated mineral phases distributed across Mars [1, 3, 4, 5, 6, 7]. The increased spatial resolution of CRISM (18 m/p) has lead to the identification of additional mineral phases as well as to refinements in the understanding of the geologic setting in which they exist.

Numerous analyses of the specific geologic settings in which the aqueous minerals are identified have recently been summarized [8] where a systematic assessment identifies at least ten distinct hydrous environments: Deep phyllosilicates, layered phyllosilicates, phyllosilicates in intra-crater fans, plains sediment, intra-crater clay-sulfate deposits, carbonate-bearing deposits, Meridiani-type layered deposits, Valles-type layered deposits, hydrated silica-bearing deposits, and surrounding the North Polar Cap gypsum plains. The listing of deposits follows the approximate age of the units that host the deposits, from oldest to youngest. We will discuss a few of these deposits classes here.

The apparent distinction between Noachian-aged terrains enriched in phyllosilicate minerals and Hesperian-aged terrains enriched in sulfate minerals was a fundamental result from the OMEGA experiment [1]. Bibring et al [1] proposed a model where the transition between these distinct mineralogic eras was a consequence of a fundamental re-organization of the martian global system. While the detailed obseravations of CRISM have supported the apparent distinction between older phyllosilicate terrains and younger sulfate terrains [5], it has also provided additional data on the specific geologic environments and identified several distinct envionrments not previously identified [8].

The largest class of aqueous deposit is the deep phyllosilicates. This is found thoroughout the southern highlands, deep exposures in Valles Marineris as well as large impact craters in the northern plains that penetrate beneath the cover of Hesperian-aged ridge plains and Vastitas Borealis formation. In the southern highlands the phyllosilicates are commonly observed associated with rims, ejecta, walls and central peaks of impact craters. The broad distribtion among all elements of impact craters implies that the target rocks were altered prior to crater formation. A survey of mineral classes associated with impact craters shows that there is no relationship between mineral type and craters size, and that Fe/Mg smectite and chlorite phyllosilicates dominate [9]. Furthermore high resolution imaging of well exposed ancient basement rocks show that it is estensively brecciated [10, 11]. Whatever process or processes resulted in the formation of deep phyllosilicates, they needed to be extensive to creat a global signature and of moderate temperature and pressure to leave a predominance of Fe/Mg smectite clays.

Clear evidence for hydrothermal assemblages are rare. Some indicator minerals are associated with impact craters where the mineral prehnite is observed, as well as chlorite, zeolite, opal/hydrated silica and muscovite/illite [7]. Serpentine has recently been identified on Mars in a few isolated regions [12], one in association with olivine-rich terrains in Nili Fossae. While hydrothermal systems in association with impact craters is widely expected on Mars [e.g. 13] the evidence for a common occurrence is equivocal.

Layered phyllosilicates are best observed in the region surrounding Mawrth Valles [14, 15]. They are regional, compositionally layered, and form discrete, polygonally fractured layers having a distinctive stratified composition. At Mawrth Vallis the layers are >150 m and form a sequence of (a) a lower layer Fe/Mg-rich clay, typically nontronite, (b) a middle layer of Al-rich smectite, possibly montmorillonite, and sometimes (c) a thin upper layer containing an Al-phyllosilicate of the kaolinite group and probably hydrated silica. The lower beds contain a strong signature of alteration to ferric phases, but ferrous phases are present both above and below the contact of the Fe/Mg- and Al-rich clays suggesting at least transient reducing conditions. In the Nili Fossae region a distinct thin unit rich in kaolinite is observed a the top of Noachian-aged sediment filling craters, possilbly the remnants of a pedogenic horizon [16]. Proposed origins of layered phyllosilicates include marine sedimentation of sorted, transported clays, alteration of volcanic ash, hydrothermal alteration by cap rock deposited as an overlying impact melt sheet, or pedogenesis of basaltic regolith.

A thin, regionally placed carbonate-bearing bedrock deposited is mostly observed in olivine-rich regions surrounding the Isidis basin, especially in the Nili Fossae region [17]. The carbonate-bearing layer is about 20 m thick, and stratigraphically it lies above local occurrences of layered phyllosilicates in association with a regional-scale olivine-rich layer [18, 19]. These deposits are thought to be hydrothermal alteration of the olivine by an overlying cap rock deposited as impact melt, or chemical sedimentation in surface waters.

Many of the intracrater fans identified by MOC imagery have been observed by CRISM and shown to contain hydrated mineral phases, dominantely phyllosilicates [e.g. 5, 6, 20, 8]. Typically the lower portions of the fans exhibit horizontal bedding and an enhanced content of phyllosilicate and the phyllosilicate signatures are consistent with that elsewhere in the drainage basins. The phyllosilicate-bearing stratified beds were apparently deposited in persistent standing water. It is not clear if the phyllosilicate was transported to the deposit or formed authigenically.

Plains sediments are an assemblage of chlorides and phyllosilicates that occurs in relatively flat areas of crater floors and intercrater plains, yet is not part of obvious depositional fans. These are largely recognized in THEMIS data as "glowing terrain" [21]. The geologically most reasonable phase with this property is chloride though no definitive spectral features are observed.

Sulfates are found in the Meridiani-type and Valles-type deposits. They are typically mono- or poly-hydrated and have a variety of possible depositional mechanisms. Like plains sediments, these represent evaporite salts formed in near surface or surface environments.

Hydrated silica deposits are thin, light-toned layered deposits superposed on Hesperian plains within about 200 km of Valles Marineris, southwest of Melas Chasma, south of Ius Chasma, south of western Candor Chasma, west of Ganges Chasma, and west of Juventae Chasma [22, 23]. These interesting and young deposits are characterized by beds about 10 m thick, polygonal fractures several meters in diameter, and are differentially eroded, presenting a morphology distinct from layered deposits within the chasmata. Stratigraphically, they appear to be above the Terra Meridiani layered deposits and comparable in age to the Valles Marineris layered deposits. Hydrated silica-rich deposits occur in some layers of the deposits where the spectral data indicate a variety of forms including altered glass, opal, and chalcedony. Other layers exhibit a suite of absorptions consistent with jarosite, indicating alteration under acidic conditions [22]. The relationship of the hydrated silica to high-Si deposits found by MER/Spirit [24] is unknown.

Proposed models for the origin of the hydrated silica overlap include acid weathering of volcanic ash or lava flows, precipitation from hydrothermal discharge, a mixture of chemical precipitation and detrital sedimentation in a fluvial or lacustrine environment [22, 23].

The diversity of deposits suggest a range of past aqueous environments. High resolution spectral and spatial imaging reveals many details of the stratigraphy that should constrain models for their formation. However, many of the details are still being investigated. Regardless the range of deposits that lend themselves to modeling hydrous environments provides a rich record.

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