WHAT IS MARS' HIGHLANDS CRUST?

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Mars' ancient highlands crust formed very early in martian history, and is the backdrop for questions of water abundance and biologic activity on early Mars. The chemical and mineralogic nature of the highlands crust is not known. All available data are consistent with either a basaltic or 'andesitic' highlands. An anorthositic highlands seems inconsistent with the geochemistry of martian meteorites, and an undifferentiated crust seems inconsistent with optical reflection spectra.

CHOICES: From knowledge of other planetary bodies, the highlands crust of Mars might be: undifferentiated chondritic, basaltic / pyroxenitic (Vesta), gabbroic anorthositic (lunar highlands), or 'andesitic' (continents on Earth). Other types of planetary crusts in the solar system (ices, sulfur) seem unreasonable for Mars.

TIMING: Mars' highlands crust formed very early. Qualitatively, its age is apparent in its abundance of impact craters, which is comparable to that of the lunar highlands [1]. Radio-isotope data on the martian meteorites show that Mars experienced its major differentiation event, presumably including formation of the crust, by 4539 Ga [2, 3], only tens of million years after solar system formation [4, 5].

REMOTE SENSING: Most of the highlands is bright and orangish in color, independent of the morphology of the underlying surface. Much of the orange material is dust from global storms. Some orange material is indigenous, with variable proportions of ferric and hydrous minerals presumably reflecting alteration [6]. These orange materials retain no IR signature of their pre-alteration mineralogies.

Dark areas in the highlands show IR absorption bands of pyroxenes like those in the martian shergottite meteorites (basalts) [7, 8]. A few areas have pyroxene absorptions comparable to those of the martian nakhlite meteorites (augite-olivine basalts) [9], but olivine absorptions are unknown or minor.

These data suggest that the highlands are basaltic, but this inference is not unique. Dark areas in the highlands might represent transported basaltic sands, and not indigenous bedrock. Anorthositic and 'andesitic' rocks can also contain abundant pyroxenes. The absence of olivine in the highlands could argue against a chondritic crust and against a crust of alkaline basalt. But olivine alters readily to hydrous silicates and might not survive a 'warm, wet' epoch.

SAMPLES: At this time, we have only one rock from the martian highlands, the pyroxenite meteorite ALH 84001 [10, 11]. ALH 84001 is inferred to have formed by accumulation of pyroxene crystals in a body of basalt magma, and so is not likely to be representative of Mars' highlands crust. As a cumulate, it would represent only a portion of its parent magma body, which might consist mostly of gabbroic (basaltic) rocks.

GEOCHEMISTRY: Dust is ubiquitous on Mars. As analyzed by the Viking landers, the dust is basaltic in composition and quite similar to the Shergotty martian meteorite [12]. If the dust represents a global average of fine-grained weathered rock, then the highlands are almost certainly basaltic. However, the origin of the dust is not known. It might reflect singular igneous events or singular regions of altered igneous rock, and so be irrelevant to the highlands.

The martian meteorites grudgingly yield some constraints on the composition of the highlands crust. The martian meteorites are basalts, so their compositions constrain those of their source mantles and thereby the overall composition of Mars [13, 14]. Differences between the mantle and planet compositions reflect material that has gone to the core, the crust, or unsampled layers of the mantle [4, 13, 14, 15].

From the martian meteorites, it seems clear that the highlands crust is not primarily anorthositic. None of the martian meteorites has an Eu anomaly, and all have Sr/Nd near chondritic, suggesting that their parent mantles never fractionated plagioclase [2, 13]. The source mantle for the martian meteorites is, however, significantly depleted in Al [4,13, 16]. The Al could have been lost to the crust as 'andesitic' magmas, or to an unsampled lower mantle as spinel or garnet. Fractionations involving garnet have been invoked to explain the strong LREE enrichments and depletions of the martian meteorite magmas [14].

There may, in fact, be more than one non-mantle composition. Both [4] and [15] were able to interpret radiogenic isotope systematics of the martian meteorites in terms of three distinct components: mantle, lithosphere, and crust. The crust was interpreted as basalt rich in incompatible elements [15], but ‘andesitic’ rock would also fit the isotopic constraints.

CONCLUSIONS: The composition of Mars’ highland crust remains a mystery, but one that will be solved (at least in part) when the Mars Pathfinder spacecraft successfully obtains chemical analyses of rocks on the Ares Vallis outflow plains. From the data available now, it seems unlikely that the highland crust is either anorthositic or undifferentiated. It is most likely that the highlands are made principally of basaltic rock comparable to the known martian meteorites or of andesitic-composition rock comparable to the Earth’s continents.

The difference between basaltic and ‘andesitic’ crusts, though seemingly minor, is important. When melted, a dry ‘chondritic’ mantle would yield basaltic magma [17], but a wet ‘chondritic’ mantle would yield andesitic or granitic magma [18]. If Mars were initially dry, it might have a basaltic crust; water in that crust would have come from outside, e.g. meteoritic infall. If Mars were initially wet, it might have an ‘andesitic’ crust, and retain some of its initial inventory of water. Thus, the bulk composition of the highlands crust will help understand when water came to Mars, and ultimately, where it is now.

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