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Orbital evidence for iron or calcium carbonates on Mars

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Abstract

Carbonates are key minerals for understanding ancient Martian environments. Previous remote sensing has identified Mg-rich carbonates in Martian dust and in a Late Noachian rock unit bordering the Isidis basin. Here we report evidence for potentially older Fe- and/or Ca-rich carbonates exposed from the subsurface by impact craters and troughs.

1. Introduction

Modern Mars has a <10 mbar atmosphere dominated by CO_2. A thicker ancient atmosphere is suggested by estimates of outgassed volatiles and by isotopic and geomorphologic observations [e.g., 1,2]. Ancient atmospheric CO_2 could have been sequestered via precipitation of carbonate minerals from surface waters, a mechanism consistent with the modern atmospheric pressure [3]. Mg-rich carbonate has recently been identified in outcrops adjacent to the Isidis basin [4] and in Gusev crater [5]. Fe/Ca-carbonates, which precipitate at higher water activity, have been reported in rocks uplifted by Leighton crater on the western flank of Syrtis Major [6]. However, it is unclear whether these carbonates reflect widespread aqueous paleo-environments or only localized alkaline conditions. Here we describe new orbital evidence for additional outcrops of Fe- and/or Ca-rich carbonate-bearing rocks.

2. Spectral analysis

We identify carbonates using the Mars Reconnaissance Orbiter's Compact Reconnaissance Imaging Spectrometer for Mars (CRISM). Standard atmospheric and photometric corrections were applied to filtered CRISM I/F data [7]. Spectra of interest were ratioed to bland areas in the same scene to account for systematic artifacts.

In and around the ~450-km diameter (D) Huygens basin (~14°S, 55°E), several craters reveal a distinct spectral phase (Fig. 1) with broad absorptions centered at 2.33 and 2.53 µm, consistent with Fe- and/or Ca-carbonate. Other hydrous minerals also absorb near 2.3 and/or 2.5 µm, but no linear mixture of non-carbonate phases in our spectral libraries matches the CRISM absorptions as closely in position and shape. Features at 3.5 and 3.9 µm are also consistent with Fe/Ca-carbonates. By contrast, in Mg-rich carbonates (even dolomite) all these spectral features occur at shorter wavelengths (Fig. 1). Mg-phyllosilicates co-occur with the putative Huygens carbonates, and a weak feature at 2.25 µm may reflect the presence of chlorite.

Elsewhere on Mars, some spectra exhibit all the above features, but with a narrower 2.3 µm band at a shorter wavelength (Fig. 1, bottom spectrum). This is consistent with minor Fe/Mg-smectite mixed with carbonate, as demonstrated by [8].

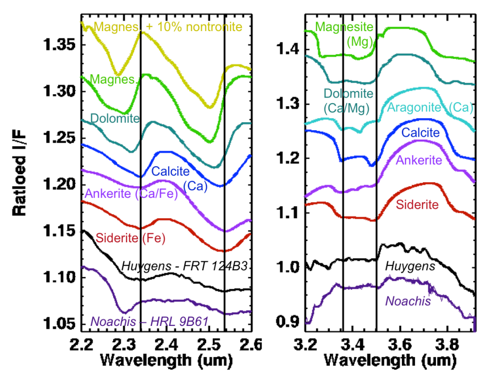

Figure 1: CRISM spectra compared to rescaled carbonates from CRISM and USGS spectral libraries. Magnesite and mixture spectra from [8].

3. Geologic setting and morphology

Huygens basin outcrops with broad absorptions at ~2.33 and 2.53 µm occur primarily in the ejecta and interiors of D~10–40 km impact craters. Some are on the rim or floor of Huygens, whereas others probably lie beyond its original continuous ejecta. The spectrum in Fig. 1 is from a central (floor) pit crater superposed on Huygens' rim crest. Prior to the impact that formed this crater, its carbonates may have been buried ~5 km beneath the Martian surface, based on the 1.8 km elevation difference between central pit and pre-impact Huygens rim crest plus the predicted ~3.3 km of structural uplift (from the equation used by [6]). These carbonate-bearing rocks are jointed and possibly layered, with cross-cutting ridges that may be dikes or large veins. Huygens has an uplifted central peak ring, and carbonates on the basin floor all occur outside this ring, mostly adjacent to the dissected basin walls; these carbonates could have been eroded and transported from the basin rim.

The possible carbonate in western Noachis Terra (Fig. 1) occurs within an extensive regional subsurface layer of Fe/Mg-phyllosilicates mapped by [9]. Features consistent with carbonate are not ubiquitous in this layer; the particular outcrop where we have found them is along the walls of Her Desher Vallis (~26°S, 47°W). The phyllosilicate layer may stretch hundreds or even >1000 km from Argyre basin to Valles Marineris [9], and searches for other possible carbonate occurrences within it are ongoing.

4. Discussion

The Fe/Ca-carbonates described here are compositionally distinct from the Mg-carbonates previously identified on Mars by CRISM [4] and other orbital spectrometers [e.g., 10]. However, Martian meteorites exhibit a broad compositional range including Fe-rich carbonates in the Nakhlites and Ca-rich cores in the carbonate grains of ALH84001 [11]. Ca-carbonate has also recently been found in high-latitude soils by the Phoenix lander [12], and the carbonate in the Columbia Hills at Gusev crater contains Fe [5]. Thus our new examples likely fall within the compositional range of previously identified Martian carbonates.

The association of Fe/Ca-carbonates with complex craters—including Leighton [6] and those around the Huygens basin—suggests impact-related formation and/or exposure of previously buried carbonate. Carbonates occur in impact hydrothermal assemblages on Earth, but unless the target rocks contained abundant carbonates, they are typically a relatively minor component of the impactites. Although we have not quantified their abundance, we infer that carbonates likely existed in the subsurface around Huygens prior to the impacts that exposed (and possibly modified) them. Indeed, the presence of these carbonates in Huygens rim rocks suggests they may predate this Early Noachian basin, in which case they would predate the Late Noachian Mg-carbonates near Isidis [4] and many layered phyllosilicates on Mars. Early burial could have protected these carbonates from possible later surface acidity, and could help explain why few large exposures of carbonate-rich rocks have been identified. On the other hand, the possible carbonate in Noachis Terra co-occurs with layered phyllosilicates in the shallow subsurface, and could be younger.

These detections expand the geographic distribution of known carbonate-bearing rocks on Mars, and suggest that conditions suitable for Fe/Ca-carbonate formation were at least regionally widespread. It remains unclear whether such conditions were global or only regional. We continue to search for additional exposures, focusing on central uplifts of mid-sized craters across Mars and especially on the oldest rocks, such as megabreccias.

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