EVIDENCE FOR REGIONAL DEEPLY BURIED CARBONATE-BEARING ROCKS ON MARS. James J. Wray[1], S. L. Murchie[2], B. L. Ehlmann[3], R. E. Milliken[4], K. D. Seelos[2], E. Z. Noe Dobrea[5], J. F. Mustard[6], and S. W. Squyres[1], [1]Department of Astronomy, Cornell University, Ithaca, NY 14853, USA (jwray@astro.cornell.edu), [2]JHU/Applied Physics Lab, Laurel, MD, USA, [3]IAS/Univ. Paris, Orsay, France, [4]Univ. Notre Dame, Notre Dame, IN, USA, [5]Planetary Science Institute, Tucson, AZ, USA, [6]Brown Univ., Providence, RI, USA.

Introduction: Modern Mars has a <10 mbar atmosphere dominated by CO_2. A thicker ancient atmosphere is suggested by isotopic and geomorphologic observations as well as estimates of outgassed volatiles [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]. Yet at scales of a few kilometers or larger, no carbonate-bearing rocks have been found on Mars [e.g., 4,5].

Mg-rich carbonate has recently been identified in Noachian outcrops adjacent to the Isidis basin [6] and in Gusev crater [7]. However, it is unclear whether these reflect widespread aqueous paleo-environments or only localized alkaline conditions. Here we describe new orbital evidence for a regional occurrence of ancient Fe- and/or Ca-rich carbonate-bearing rocks.

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 CRISM "version 2" I/F data [8]; a spatial/spectral noise filter was also used [9]. Spectra of interest were ratioed to bland areas in the same scene to account for systematic artifacts.

The ~450-km diameter (*D*) Huygens basin (~14°S, 55°E) exposes ancient materials of diverse compositions [10]. A crater superposed on the basin rim hosts a distinct spectral phase with broad absorptions centered at 2.33 and 2.53 µm, consistent with Fe- and/or Ca-carbonate but not with pure Mg-carbonate (Fig. 1). Adjacent outcrops exhibit Mg-phyllosilicates, and the spectrum in Fig. 1 likely represents a mixture of carbonate and phyllosilicate, with the latter adding water-related absorptions at 1.40 and 1.9 µm and contributing to the depth and width of the 2.3 µm band. Even minor phyllosilicates can distort this carbonate band [11]. A weak feature at 2.25 µm may reflect the presence of chlorite. The broad spectral curvature from 1 to ~1.7 µm is consistent with Fe-carbonate, chlorite, or other ferrous phases, or dehydrated Fe^{3+}-smectite [12].

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 well as Fe/Ca-carbonate. These absorptions have consistent positions and shapes in other nearby CRISM observations. Additional features at ~3.45 and 3.9 µm (not shown) provide further evidence for carbonates, as in [6]. Analysis of these >3 µm features using recalibrated "version 3" CRISM data is ongoing.

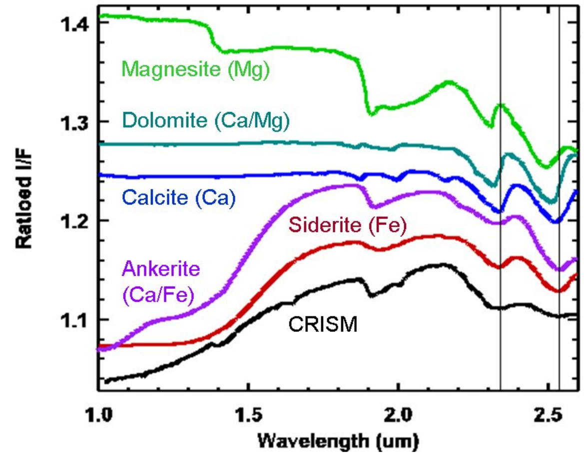

Figure 1. CRISM FRT000124B3 spectrum compared to rescaled carbonates from CRISM & USGS libraries.

Geologic Setting and Morphology: Several other CRISM observations in and around the Huygens basin exhibit similar broad absorptions at ~2.33 and 2.53 µm. These 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' northwestern rim crest (Fig. 2a). Here, carbonate and phyllosilicate can be mapped to specific outcrops on the central pit wall (Fig. 2b). The carbonate-bearing rocks are jointed and possibly layered (Fig. 3).

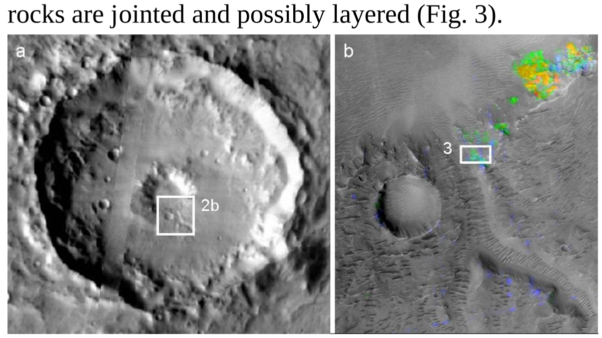

Figure 2. (a) *D*~35 km crater superposed on Huygens rim crest, exposing carbonate (THEMIS daytime IR). (b) Phyllosilicate (orange) and carbonate (blue/green), FRT000124B3 on HiRISE ESP_012897_1685. R/G/B are D2300/BDCARB/CINDEX from [13].

Crater central pits may form from vaporization of target volatiles [e.g., 14], perhaps including CO_2 and H_2O from carbonates and phyllosilicates in the target rocks. Valleys feeding the central pit (Fig. 2) might have been carved by impact-mobilized fluids. These valleys are filled with younger aeolian dunes, and the interdunes expose possible cemented cross-strata [15].

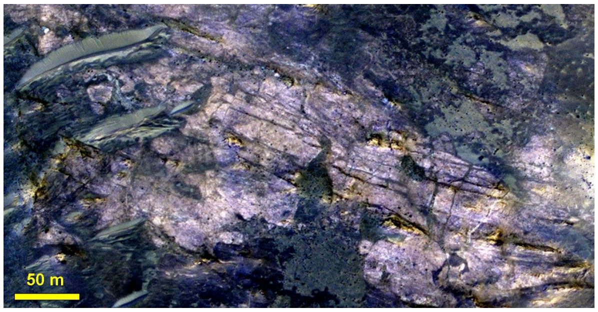

Figure 3. Fractures and possible layers in carbonate-bearing rocks (HiRISE ESP_012897_1685).

Discussion: The inferred Fe/Ca-carbonates in and around Huygens basin are compositionally distinct from the Mg-carbonates previously identified on Mars by CRISM [6] and by other orbital [16,17] and surface [18] IR spectrometers. 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 [19]. Ca-carbonate has also recently been found in high-latitude soils by the Phoenix lander [20], and the carbonate in the Columbia Hills at Gusev crater contains Fe [7]. Thus the Huygens examples likely lie within the compositional range of previously identified Martian carbonates.

The association of Fe/Ca-carbonates with complex craters 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 [e.g., 21], they are typically a relatively minor component of the impactites [e.g., 22]. 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 [23] basin, in which case they would predate the Late Noachian carbonates near Isidis [6] and many layered phyllosilicates on Mars [e.g., 24].

Prior to the impact that formed the crater in Fig. 2, 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 [e.g., Equation (3) of ref. 25]. Early burial could have protected these carbonates from possible later surface acidity [5], and could help explain why few large exposures of carbonate-rich rocks have been identified.

Independent from this work, Fe/Ca-carbonate has been identified with CRISM in the *D*~65 km Leighton crater on the western flank of Syrtis Major [26]. This carbonate is associated with phyllosilicates in layered deposits exposed in Leighton's central uplift from an estimated depth of ~6 km, interpreted as evidence for widespread, buried layered carbonates. These detections expand the geographic distribution of known carbonate-bearing rocks on Mars (Fig. 4), and suggest a regional environment in which conditions were suitable for Fe/Ca-carbonate formation. 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.

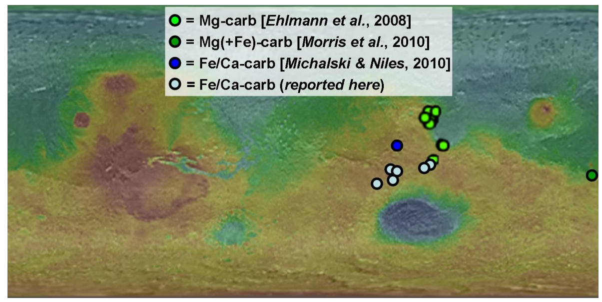

Figure 4. Carbonate-bearing rocks found on Mars to date, on MOLA topography (modified from [6]).

References: [1] Pollack J. B. et al. (1987) *Icarus, 71*, 203–224. [2] Jakosky B. M. and Phillips R. J. (2001) *Nature, 412*, 237–244. [3] Kahn R. (1985) *Icarus, 62*, 175–190. [4] Christensen P. R. et al. (2001) *JGR, 106*, 23823–23871. [5] Bibring J.-P. et al. (2006) *Science, 312*, 400–404. [6] Ehlmann B. L. et al. (2008) *Science, 322*, 1828–1832. [7] Morris R. V. et al. (2010) *Science, 329*, 421–424. [8] Murchie S. L. et al. (2009) *JGR, 114*, E00D07. [9] Parente M. (2008) *LPS XXXIX*, Abstract #2528. [10] Seelos K. D. et al. (2010) *LPS XLI*, Abstract #2400. [11] Perry K. A. et al. (2011) *this conference*. [12] Morris R. V. et al. (2010) *LPS XLI*, Abstract #2156. [13] Pelkey S. M. et al. (2007) *JGR, 112*, E08S14. [14] DeVries R. J. and Barlow N. D. (2009) *LPS XL*, Abstract #1929. [15] Bourke M. C. and Wray J. J. (2011) *this conference*. [16] Bandfield J. L. et al. (2003) *Science, 301*, 1084–1087. [17] Palomba E. et al. (2009) *Icarus, 203*, 58–65. [18] Christensen P. R. et al. (2004) *Science, 305*, 837–842. [19] Bridges J. C. et al. (2001) *Space Sci. Rev., 96*, 365–392. [20] Boynton W. V. et al. (2009) *Science, 325*, 61–64. [21] Osinski G. R. et al. (2001) *M&PS, 36*, 731–745. [22] Hagerty J. J. and Newsom H. E. (2003) *M&PS, 38*, 365–381. [23] Werner S. C. (2008) *Icarus, 195*, 45–60. [24] Murchie S. L. (2009) *JGR, 114*, E00D06. [25] Tornabene L. L. et al. (2008) *JGR, 113*, E10001. [26] Michalski J. R. and Niles P. B. (2010) *Nature Geosci., 3*, 751–755.