Carbonate abundance in putative Martian paleolake basins

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The discovery of massive carbonate deposits on Mars could greatly help in the understanding of the climatic history of the planet. In fact, the presence of massive and widespread carbonate deposits on the Martian surface could strongly indicate that bodies of liquid water, today absent, existed on the Martian surface for a sufficiently long period of time in the past, implying an ancient surface environment much wetter and warmer than the current one.

Apart from the identification of small quantities of carbonates in the Martian dust (Ref. [1]), no carbonate deposits have been found so far on Mars (Ref. [2]). In addition to the assumption that massive carbonate deposits never formed on Mars, many other hypotheses have been proposed in order to explain why remote sensing instruments have not identified such deposits (see [3] and references therein).

Here we report about a recent work of our group (Ref. [4]) that studies the possibility that the concentration of any carbonates, when mixed with other sedimentary deposits, may be lower than the detection limits of current instruments. For this study we considered a sample of putative paleolacustrine basins and first used a sediment transport model (Ref. [5]) adapted to the Martian case (Ref. [6]) to estimate the volume of water necessary to remove the sediments and carve the inflow valleys. Then, with reasonable assumptions on the content of Ca^{2+} and Mg^{2+} in Martian groundwaters, we evaluated the abundance of carbonates in the sediments present on the basin floor and compared these abundances to the detection limits of the spectrometers TES, OMEGA and CRISM flown respectively on Mars Global Surveyor, Mars Express and Mars Reconnaissance Orbiter.

For our calculations, we looked at craters where geologic features (terraces, deposits, inlet and/or outlet channels and putative deltas) suggest the former presence of standing bodies of water. We started with 222 sites considered suitable for a spectroscopic search for carbonates by means of the Planetary Fourier Spectrometer (PFS) instrument onboard Mars Express (Ref. [7]). From the initial 222 sites, we first restricted the sample to 167 sites listed as "closed basins", that is impact structures associated with one or more inflow valleys but for which no spillways are observed. Using an interactive Viking data map, we then selected only the systems that appear well-developed, have regular and well defined edges, are at least 20 km across and have one or more inlet valleys longer than the crater radius. In addition we excluded all craters characterized by uneven ground and jagged boundaries, as well as those that appear to have undergone subsequent impacts. This left 20 sites for further analyses.

For each site, the total volume of clastic material was estimated from the volume of the inflow valleys, with the assumption that all the eroded material was deposited in the crater. The inflow valley volumes were calculated by multiplying the average cross-section area for a given valley segment by the segment length, and then summing the individual segments along the inflow valleys.

The total volume V_w of water required to transport sediment of volume V_s is given by (Ref. [6]):

$$V_w = \frac{\bar{u}H(\rho_s - \rho_w)g}{i} V_s \qquad (1)$$

where i is the sediment transport rate in units of immersed weight per unit stream width per second (Ref. [5]), $\bar{u}$ is the mean stream flow velocity, H is the channel hydraulic radius (open channel stream depth), ρ_s and ρ_w are the sediment and water densities, and g is the gravitational acceleration at the surface of Mars. For all basins we took $H = 1$ m and $H = 5$ m, consistent with the range typically observed in small terrestrial rivers. Following the approach described in Ref. [6], it is possible to evaluate the other two quantities i and $\bar{u}$ present in Eq. 1, if the mean grain size and the slope of the channel are known.

For the sediment size distribution, we followed two different approaches: (1) we assumed the sediments seen on basin floors today are the same as those deposited during the past periods of fluvio-lacustrine activity, using thermal inertia measurements to derive sediment grain size for each crater, by means of the empirical relation obtained by Kieffer and colleagues (Ref. [8]); (2)

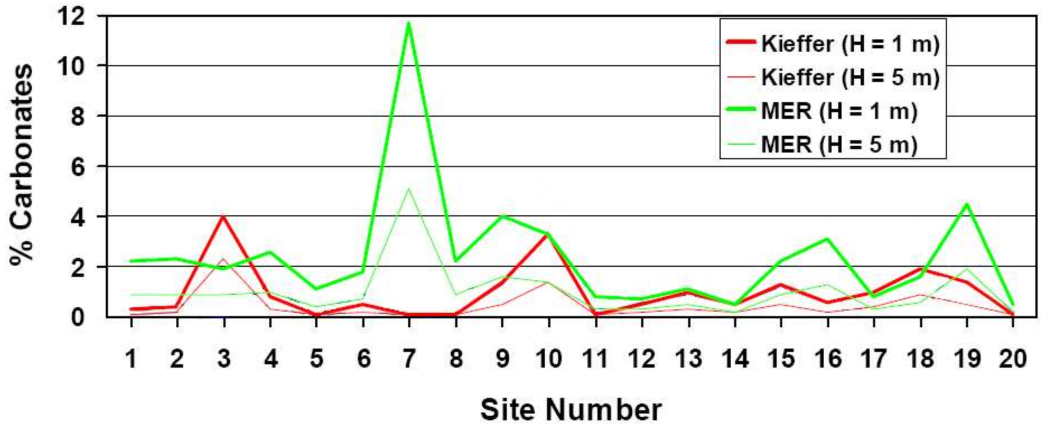

Figure 1. Estimated carbonate abundance in total fluvial sediment volumes deposited in 20 closed basins (the list of the sites is reported in Ref. [4]). Carbonate abundances are calculated using two values for the inflow channel hydraulic radius ($H = 1$ m and $H = 5$ m) and two different estimates for the mean grain size of the sediment eroded from the inflow valleys (from thermal inertia measurements using the equation in Ref. [8] and for a constant grain size of 0.7 mm based on MER observations, as reported in Ref. [9]).

we assumed the sediments of all the basins have a mean size of 0.7 mm consistent with the grain sizes observed by the Mars Exploration Rover (MER) Microscopic Imager at the landing site of NASA Opportunity (Ref. [9]).

The resulting carbonate abundances are typically about a few percent of the total sediment volume and are shown in Fig. 1.

The detection limit of carbonates derived for the TES spectrometer in the thermal IR is about 10-12% for coarse particles (Ref. [10]). The OMEGA and CRISM spectrometers have carbonate detection limits of about 4% in the near IR (Ref. [11]). This means that the quantity of carbonates estimated for each basin (Fig. 1) could easily escape detection by the spectrometers flown to Mars so far.

As an important by-product of our study, applying the sediment transport model to the well studied Eberswalde crater (not previously included in our original selection - Ref. [7]), we found that the fluvio-lacustrine activity in this basin should have lasted for a period on the order of 10^3 - 10^4 years (Ref. [4]), in good agreement with previous works (see [12] and references therein). Our results suggest that a hydrological cycle, able to move large volumes of water and to create relatively stable lakes, could have been active intermittently on Mars in the past, producing carbonate deposits that could escape detection by the instruments that have flown to date.

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NOTE ADDED IN PROOF: Ehlmann, B.L. *et al.* very recently (December 2008, Nature 322, 1828-1832) reported the orbital identification of carbonate-bearing rocks on Mars in the Nili Fossae region.