MARS GLOBAL HISTORY DERIVED FROM OMEGA/MARS EXPRESS OBSERVATIONS.

J.-P. Bibring[1], Y. Langevin[1], F. Poulet[1], B. Gondet[1], and the OMEGA Science Team, IAS, Université Paris-Sud, 91405 Orsay, France, bibring@ias.u-psud.fr

Introduction:
The coupling between the geomorphological context (imagery) and the mineralogical determination (hyperspectral NIR spectroscopy) has demonstrated its huge potential to derive a consistent history of Mars [1], described by the evolution of its global properties: minerals give access to the "enabling" environments over long durations, which in turn record planetary geological and climatic properties at large timescales.
The OMEGA/Mars Express data set covers almost the entire planet at a kilometer scale in the spectral range 0.35 to 5.1 µm, in which diagnostic mineralogical signatures can be identified: it enables to identify units formed at distinct periods, through distinct processes, tracing distinct eras.
More specifically, the discovery of a variety of hydrated phyllosilicates [2] in sites spread over the oldest (highly cratered) terrains open a window for Mars to have hosted habitable conditions with stable liquid water at or close to the surface. In this paper, we present a consistent model which accounts for the sequence of events along the early evolution of Mars, which complies with the available observational data sets.

Inputs:
1. The three families of alteration products identified and mapped have been formed sequentially: hydrated phyllosilicates first, then hydrated sulfates, then anhydrous ferric oxides. Their formation process requires distinct global environmental conditions (which indicates that they strongly evolved over time).
2. Although sulfur has been identified as an abundant surface element in all sites in situ explored up to now (Viking 1, Viking 2, PathFinder, Spirit and Opportunity), large bodies of sulfates, as identified from orbit, are located in localized sites in a restricted number of units, by contrast to the phyllosilicates, spread over the entire crust.
3. The likely major source of sulfur, observed at a planetary scale, comes from the outgassing coupled to the building of Tharsis. This event happened after the early bombardment ended (Tharsis is not highly cratered), and after the dynamo stopped (Tharsis is not remnant magnetized). By contrast, the phyllosilicates are observed in the highly cratered and magnetized crust.
4. Although the phyllosiliocate-rich sites are spread over the entire crust, the entire crust is not covered with phyllosilicates, but merely by almost unaltered mafic minerals. Phyllosilicates sites are either eroded, exhumed or unburried ancient terrains.
5. No carbonates are found, within the OMEGA sensitivity limit of a few vol.%.

Interpretations:
Phyllosilicates formed while the dynamo operated, in an environment enabling water to remain stable as a liquid, although the early Sun had a luminosity significantly lower than at present: large concentrations of greenhouses gases must have been present during this era ("phyllosian"). By contrast, sulfates (formed during the "theiikian") do not require water to be stable over long durations, but rather deposit while water evaporates. It is suggested that a global change operated after the phyllosian, triggered by the drop of the dynamo: while it operated, a dense atmosphere could be maintained, sustaining the stability of liquid water. Its drop, with that of the magnetic shield against the lethal effects of the early sun (strong EUV and solar wind emitter), led to an efficient atmospheric escape. Surface water both percolated and froze, and evaporated and escaped. Phyllosilicate formation ended. This occured at a time the early bombardment had not ceased (the bombardment and the dynamo drop are strictly independent processes, and thus are not time correlated). The further cratering (whether it constituted a monotonous decrease or a rapid one followed by a few late events, does not modify the result) buried most of the phyllosilicate-rich surface by unprocessed mafic crustal material.
The drop of the dynamo could follow the decrease of the mantle convection (given the low mass of Mars, thus the global content of radioactive elements, as compared to that of the Earth), which in turn could not sustain the convection of the core.
The further evolution of the mantle, dominated by downwelling cold plumes, triggered thermal instabilities at the core/mantle interface, resulting in the building of Tharsis, and its associated tectonic processes, long after the dynamo had stopped: massive outgassing of S-rich compounds, rapidly oxidized; opening of Valles Marineris and tilt of Terra Meridiani. The localized raise of the thermal front, in Tharsis coupled and other geophysical active areas, brought huge supplies of surface liquid water,

out of the previously percolated and frozen reservoir: large outcrops of sulfates were cemented in a variety of sites.

Some open questions:

1. Which greenhouse gases operated? For CO_2 to have constituted the dominant gases requires concentrations (either as gas or clouds) that might have never been present. Other gases might have played a role, that must be further investigated: CH_4 and SO_2 primarily. If the Tharsis formation, and its associated outgassing, started early, while the dynamo still operated, the later might have constituted the major contributor to enabling water to remain stable as a liquid.
2. Role of the impacts: the occurrence of phyllosilicates within cratered terrains demonstrates that the impacts did not destroy these hydrated phases. On the contrary, the cratering might have played a role in either or both providing energy over sustained durations ("impact-driven" hydrothermalism) and ingredients (water). Laboratory experiments/simulations are key to quantify and constrain these processes.
3. Was water stable at or below the surface? OMEGA observations can not unambiguously discriminate between these two possibilities: as an example, if the crust crystallized out of a poorly degassed magma, still highly hydrated, phyllosilicates might have been formed and trapped in its bulk, without requiring a further aqueous alteration. Similarly, impact formation with the water brought by the impacting bodies themselves would not require additional water to be present and stable to further alter the planetary surface.

Thermodynamical calculations [3] show that if the partial pressure of CO_2 was significantly higher than that of the H_2O triple point, favoring liquid surface water over sustained durations, some carbonates should have formed and be trapped within the phyllosilicates. The future in situ exploration, by NASA/MSL and ESA/ExoMars, with a capability of a microscopic mineralogical identification (MicrOmega/ExoMars), should enable to identify this potential coupling of major criticality: the lack of identification of large carbonate outcrops do not exclude the possibility that, at a microscopic scale, carbonate grains exist (as within some Martian meteorites), in relation with phyllosilicates: these associations would constitute the sites of utmost importance in the search for potential biorelics.

Conclusions:

The mineralogical and climatic history derived from the OMEGA/Mars Express data, merged with ground truth measurements from the MERs, and confirmed by the spectacular high resolution CRISM/MRO observations, comes to a consistent scenario, opening an exciting window of potential Mars habitability, to be explored in a few specific sites by future in situ missions preparing for MSR, while enlightening the critical processes that led Mars and the Earth to follow diverging evolutionary pathways.

References: [1] Bibring et al. (2006), *Science* 312, 400; [2] Poulet et al. (2005), *nature* 438, 623; [3] Chevrier et al. (2007), *Nature* 448, 60.