GLOBAL INVESTIGATION OF HYDRATED EXPOSURES ON MARS: EVIDENCE FOR A CLAY CYCLE. J. Carter[1,2], F. Poulet[1]. [1]IAS, CNRS/Université Paris-Sud, Orsay, France. [2]ESO, Santiago, Chile. John.carter@ias.u-psud.fr.

Introduction: The discovery of hydrated minerals including clays, carbonates and sulfates on Mars has spawned a new era of intense scrutiny of its ancient (> 4 Ga) aqueous environments (e.g. *Poulet et al. 2005, Murchie et al. 2009*). Their coupled investigations with the aqueous morphology (e.g. valley networks, deltas, fans, *Hynek et al., 2010*) provide key constraints on the alteration processes and thus on the ancient surface or sub-surface environments of Mars.

Over the years, many thorough investigations of selected sites have been carried out, from which local alteration scenarios have been derived, some of strong astrobiological relevance and justifying sending rovers there such as the MSL. By comparison, our approach is to investigate the chemical alteration of Mars at a global scale from a systematic overview of the hydrated signatures detected by the NIR imaging spectrometers CRISM and OMEGA. We present the main results of this global investigation in terms of composition, geological settings and age of hydrated deposits.

Global trends: We identified over 1240 individual OMEGA and CRISM cubes showing the presence of hydrated minerals (Fig. 1A). Exposures are predominantly found in Noachian terrains, in agreement with previous studies. After accounting for observational and selection biases, we find the ancient crust to have a homogenous surface density of hydrated exposures. The northern plains of Mars are not devoid of alteration signatures: dozens of craters excavate hydrated minerals from the buried Noachian crust and the few preserved ancient crustal exposures also exhibit hydrated signatures. These detections indicate Mars was altered at a planetary scale during the Noachian.

Over 80% of the sites exhibit signatures of Fe/Mg smectites or vermiculite with some evidence for inter-stratification with chlorite minerals. Great mineral diversity is reported, with in order of decreasing frequency: Al-bearing smectites and kaolins, chlorites, opaline silica, zeolites, serpentines, prehnite, micas, carbonates and epidote. This indicates various geochemical formation and transformation environments.

Diverse geological settings exist, but the dominant morphological contexts are impact craters (Fig. 1B). Although the neo-formation of hydrated minerals through an impact-driven hydrothermal system has been proposed for a few sites (e.g. Toro and Majoro craters, *Marzo et al., 2009, Mangold et al., 2012, submitted*), the large number of hydrated crater ejecta indicate that impacts likely dominantly excavated hydrated minerals. It has been recently proposed that the formation process of phyllosilicate-bearing deposits was largely dominated by subsurface alteration (*Ehlmann et al., 2011*). However, our global investigation actually suggests evidence for a clay cycle on early Mars as discussed below.

A clay cycle on Mars? On Earth, clays form, are transformed and accumulate in 6 geological contexts (Fig. 2): pedogenic (on the surface, in soils), detrital (as sedimentary deposits), authigenic (formation during the deposition), diagenetic (transformation during the burial of sediments), metamorphic (transformation at greater depth) and hydrothermal (formation with a heat source at various depths). Detailed mineral/morphological investigations of sites of interest reveal that all these geological contexts are also found on Mars and hint towards the existence of a clay cycle during the Noachian (fig. 2).

Pedogenic. Dozens of locations, which exhibit a vertical stratigraphy of Mg/Fe smectites overlain by Al-smectites or kaolins, are present throughout the planet. These observations are consistent with weathering sequences as part of pedogenesis as seen on Earth (e.g. *Gaudin et al., 2011*). Previous observations (*Loizeau et al., 2007, Noe Dobrea et al., 2010*) revealed that most of these sequences were found in the Arabia Terra / Mawrth Vallis region. Our observations show that these sequences are common on Mars, and at times buried at shallow depth suggesting they may be more widespread than inferred from orbit.

Detrital. Smectites have been found associated with layered infilling in basins, deltaic features and alluvial fans which suggest transport of detrital clays from a source region (e.g. *Milliken et al., 2009, Carter et al., 2012, submitted*). One striking new detection of these detritic clays was found in a sedimentary unit in Gusev crater.

Authigenic. Authigenic formation of clays is difficult to detangle from detrital deposition, however global investigation of deltas and alluvial fans on Mars (*Carter et al., this meeting*) reveal that the vast majority exhibit opaline silica (a clay precursor) which is seldom found in the Martian crust, and thus likely an authigenic product.

Diagenetic. Diagenetic transformation of clays has been postulated for many exposures (*Milliken et al., 2011, proc. LPSC*). We found clear evidence for such transformation in Terby crater. This crater exhibits km-thick layers deposited in a deltaic environment (*Ansan et al., 2011*). The mineralogical composition (including zeolites, opaline silica and Fe/Mg smectite) suggests deep-sea zeolitisation of detrital smectites deposited in the sub-aqueous environment.

Metamorphic. The presence of prehnite which can only form at depth on Mars (*Ehlmann et al., 2009*) is a strong indicator of burial metamorphism on Mars. We found prehnite excavated by craters both in the southern highlands (see also *Loizeau et al., 2012*) and in the northern plains (*Carter et al., 2010*).

Hydrothermal. Hydrothermal formation of carbonates and serpentine has been inferred for the exposures in Nili Fossae and Gusev (*Ehlmann et al., 2010, Morris et al., 2010*). We report the detection of a new hydrated mineral on Mars, epidote, found in volcanic units of Hesperian age, suggesting hydrothermal formation near the surface at high temperatures (>200-250°C).

Open questions: All these contexts collectively suggest the presence of a clay cycle on early Mars. However, their spatial and temporal relationship still remains to be established. In particular, the lack of plate tectonics on Mars renders less likely the possibility of multiple cycles on Mars: metamorphic minerals can only be recycled at the surface when excavated by large impact craters. However the clear association between fluvial structures and hydrated minerals for some deposits supports that alteration at the surface could have occurred. In other locations, the degraded contexts, younger resurfacing processes and inherent limitations of orbital remote sensing make it difficult to constrain the alteration and putative clay cycle during the Pre- to Early-Noachian eons, while the observations suggest a complex system of transport and deposition over large extents of the Martian surface (e.g., from the Terra Tyrrhena highlands down to the Hellas Planitia basin).

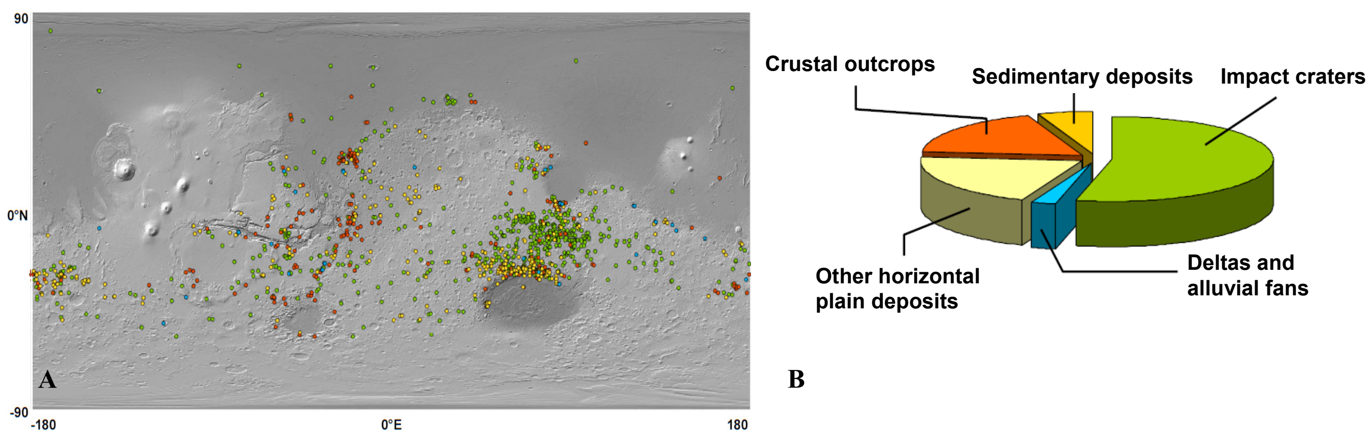

Figure 1. (A) Global map of hydrated minerals on Mars. Each detection is color-coded according to the geological contexts of figure B. (B) Geological settings of the 1240 hydrated mineral exposures on Mars.

Figure 2. The clay cycle on Earth (*Eslinger and Pevear, 1988*) and examples on Mars.