THE CLAY-RICH REGION OF NILI FOSSAE AS OBSERVED WITH MARS EXPRESS DATA. N. Mangold[1], F. Poulet[2], J. F. Mustard[3], J.-P. Bibring[2], Y. Langevin[2], B. Gondet[2], V. Ansan[1], P. Masson[1], H. Hoffmann[4], G. Neukum[5], the OMEGA Team and the HRSC team. [1]IDES, CNRS and Université Paris 11, Orsay, France, mangold@geol.u-psud.fr [2] IAS, Université Paris 11, 91405 Orsay Cedex, France, [3]Brown University, Providence RI, 02912, USA,[4]DLR, Berlin, Germany[5]Freie Universität Berlin, Germany.

Introduction: OMEGA-MeX data has provided a new spatial distribution of localized concentrations of phyllosilicates on Mars [1,2,3]. The largest and the highest concentration of olivine is in Nili Fossae [1,4]. The presence of phyllosilicates indicates a weathering by different processes such as an early warm and wet climate, subsurface alteration due to hydrothermal systems in presence of strong geothermal gradients (for more details see Poulet et al., this conference. Of specific interest is the presence of hydrated minerals in this very rich olivine-bearing region [2,3]. The identification of these hydrated minerals and their spatial distribution are examined using HRSC images and other visible datasets such as MOC.

Hydrous minerals identification: We combined OMEGA data from multiple orbits which covered Nili Fossae, North-East of Syrtis Major. Strong evidence of alteration in Nili Fossae comes from the identification of phyllosilicates, especially Fe-rich or Mg-rich smectites [3]. There is a large diversity in the position of the Fe-OH band in smectite minerals which goes from 2.29 to 2.32 µm. Pyroxene is also observed, mainly as HCP on Syrtis lava flows and LCP in some Noachian outcrops. Three HRSC orbits are used together with their DTM products and correlated with the OMEGA data in a GIS software in order to improve our understanding of the local geology.

A detailed analysis of spectra lead to the conclusion that smectites with both 1.9 and 2.3 micron bands are predominant. Many spectra that do not have a well identified ~2.3 µm band nevertheless display a plateau-like right wing starting at ~2.3 µm band. Such a spectral feature is commonly observed for minerals containing all the cations Fe, Mg and/or Al typical of various phyllosilicates such as corrensite, vermiculite and chlorite. Some spectra of talc and saponite also exhibit this spectra characteristic. In a few locations the ~1.9 µm band is identified without any metal-OH band or plateau shape at ~2.3 µm; the detection can correspond to any hydrous minerals.

Of particular interest are the regions where the hydrous signatures are observed in association with the olivine signature in the 1.0-1.5 µm range. The comparison of these spectra with a suite of laboratory spectra. Although this comparison is limited by the available laboratory spectra, no minerals, including typical alteration minerals such serpentine and smectites fit the OMEGA spectra. Serpentine library spectra are usually Mg-rich serpentine with features at 2.34 µm rather than around 2.30 µm not excluding Fe-rich serpentine to have features at 2.31 µm. Stronger alteration of olivine-bearing rocks can lead to the formation of various phyllosilicates such as smectites (saponite, nontronite) or vermiculites (e.g. Righi and Meunier, 1995), but the signatures of these minerals do not fit the strong Fe^{2+} band in the 1.0-1.5 µm range. Additionally, the iron carbonate mineral siderite provides a reasonable fit in the 1.0-2.5 µm range, but this mineral is ruled out because the Mars spectra do not show the typical and very strong feature at 3.4 µm due to vibrational modes in CO_3^{-2}. Thus, we do not focus on the identification of specific olivine alteration minerals but instead concentrate on the association of signatures typical of olivine and phyllosilicates, not excluding the possibility of a single mineral such as iron rich serpentine. If the spectra correspond to a detection of two minerals, they are mixed together either by subpixel mixing of olivine and hydrous minerals in different geologic units or by microscopic mixing of both minerals in the same unit.

Finally, in some locations, the single 2.3 micron band is observed without 1.9 micron band, close to the olivine rich region (Fig. 2). This spectra might correspond to dehydrated hydrous minerals or eventually carbonates as it behaves sometimes a 2.5 micron feature usually indicating carbonates, but here too, the lack of other features, especially in the 3 to 4 micron zone is not consistent with library spectra of carbonates such as siderite.

Phyllosilicates in highlands bedrock: The region of Nili Fossae is a Noachian cratered terrain which experienced strong erosional processes as seen from dissected terrains with rough chaotic texture, isolated mesas and partially eroded craters. This rough eroded texture may explain the good spectral signatures obtained in this region. These superb exposures in this region allow us a detailed examination of bedrock compositional relationships. OMEGA has identified clays in different areas of the studied region, especially on outcrops of the Noachian crust. In some locations, deep bands at 1.93 and 2.29 microns as well as the general spectral shape imply unambiguously the presence of Fe-rich clays such as nontronite. This area follows very well the contours of a peninsula of Noachian basement surrounded by the Syrtis lava flows. Along the basement, some hydrated pixels are also observed on the scarp bordering lava flows. Hydration band is never observed directly on the lava flows. Thus, in these examples, hydrated minerals such as clay minerals are always associated with Noachian basement, without any signatures on the Syrtis Major lava flows. Because the volcanic flows on Syrtis have been dated as Hesperian [5], this likely indicates that these minerals formed earlier.

Phyllosilicates in impact ejecta: Other evidence of the enrichment of this region in hydrous minerals comes from the ejecta of large impact craters. The 60 km diameter crater C1 is surrounded by ejecta stretching over tens of kilometers away from the crater (Fig. 2). While the ejecta is poorly visible at low resolution, examination at the full resolution of HRSC shows that clays are detected at the edge of the ejecta where erosion has likely dissected its surface. Analysis of MOC data within the ejecta blanket confirms the typical elongated patterns usually visible in ejecta at high resolution. Analysis of full resolution HRSC data of the ejecta blanket in the northern and eastern quadrants shows the same pattern. Southeast and east of the C1 crater, strong hydration bands may be also related to the ejecta of this crater. Here, the ejecta deposits are strongly eroded and their outer edge is difficult to identify. The presence of clays in ejecta can be due either (1) to the excavation of clays from the crust or (2) the formation of clays in ejecta by weathering due to hydrothermal processes caused by the presence of water in the impacted material [6]. We cannot discriminate between these two possibilities which are not excluding themselves, because water in the crust can be stored in clay minerals.

Correlation with fluvial landforms: Three main types of landforms are observed in the studied region. First, ancient valleys cross the Noachian highlands. These display sinuous shapes typical of meanders of fluvial origin, having a depth that reaches locally 300 m and extends up to ~180 km in length. The valley floor exhibits a large channel with braided patterns typical of high energy flows. Their width and the presence of large channels suggest better flash floods, subsurface discharge or glacial surges, but no evidence of theater-shaped heads suggests that the valleys formed by subsurface sapping and no glacial signatures such as moraines or grooves are observed close to the valley sources. Second, deep but poorly organized valleys emerge on the rim of the Nili Fossae trough system and some other landforms Their short length, theater-shaped head and constant width are typical of sapping canyons, i.e. valleys formed by headward erosion due to subsurface flows. Several debris fans are associated with their termination in the Nili Fossae trough. In contrast to the delta fans in the crater (sediment deposited subaqueously), these deposits are likely not deltas but alluvial fans (deposited subaerially). Finally, a very distinct type of fluvial flow is observed on the lavas of Syrtis Major, at the south of the studied region. A deep and narrow valley is observed close to the lava-highlands contact. Upstream grooves are also observed as well as teardrop-shaped erosion typical of outflows channels. These observations suggest the occurrence of shallow but wide floods over the lavas of Syrtis similar to outflow channels in Xanthe Terra. OMEGA spectral data show no obvious correlation between hydrous minerals and sinuous valleys, sapping valleys or the outflow channel. However, local signatures can be found on highlands valleys (sinuous and sapping), and one fan exhibits a small signature in the canyon crossed by orbit 988 (Fig. 3). Here, the top of layered deposits display a few 1.9 µm bands at the location where the sapping valley emerges forming a terminal fan. This observation should be taken with caution because the signatures are small (2% of band depth) and need to be confirmed. Notice that the surrounding basement rocks display stronger signatures. The presence of clays in the eroded bedrock of some valleys should lead to the erosion and accumulation of clays. This observation thus suggests either (1) the occurrence of water activity was long enough to form hydrous minerals, or (2) hydrous minerals comes from the erosion, transport and deposition of material originally contained in the crust. The second hypothesis is favored because the fan is surrounded by strong signatures of hydrous minerals suggesting that alteration during fluvial processes is not necessary to explain the observation. In general, our study suggests that these landforms formed over specific conditions (a limited period of time, arid climate or low temperatures), since in general they lack any clear association with extensive phyllosilicates.

Relationships with the olivine-rich layers: Whereas most olivine signatures seem to be spatially unrelated with hydrated minerals [7], the region located close to the Syrtis Major lava flows exhibit mixtures of different materials. Indeed, this small region displays spectra that are consistent with olivine mixed with Fe-rich smectites. Many pixels on the RGB composite display turquoise (hydration band and olivine) and even yellow color (hydration, Fe-OH band and olivine) which suggest a mixture of olivine with Fe-rich smectites (Fig. 4). The question is to know if this mixture is the result of a spatial mixture due to the resolution (~600 m/pixel) or a consequence of the presence of partially weathered mafic materials. The association of olivine and hydrous signatures may represent a spatial mixing (1) if the mixing consists of an olivine-rich unit partially covered by a thin dust mantle enriched in phyllosilicates, or (2), if the mixing consists of two geologic units associated at OMEGA subpixel scale, or, alternatively, (3) it can reveal a microscopic mixing of phyllosilicates and olivine-rich material due to a partial alteration of mafic rocks. The surface observed at MOC scale is different from a spatial mixing of dust and rocks because the extraction of thermal inertia from THEMIS night data shows values of 300 to 500 J m^{-2} K^{-1} $s^{-1/2}$ [4] typical of terrains with mixtures of bedrock and gravel, not dusty terrains. In the second case, a spatial mixing between two type of rocks could reveal the presence of hydrous material present beneath the thin olivine rich unit and locally outcropping, as suggested by the presence of hydrous minerals in part of the surrounding basement. However, detailed observations of spot 1 show that the hydrated olivine outcrops have unique surface characteristics favoring a microscopic mixing (Fig. 5). Indeed, if hydrous and olivine signatures were two distinct geological units, we would likely observe two distinct textures at MOC scale, because olivine and clay minerals have different behaviors to erosion. The fact that the olivine band depth is very strong in the hydrated part is also an argument against a spatial mixing because a spatial mixing of different species should decrease their respective signature inside the mixing zone. Thus, we favor the hydrous signatures as being an alteration product of the olivine-rich unit.

Conclusion: Nili Fossae is a region of unique spectral diversity combining observations of phyllosilicates, olivine together with both types of pyroxene. Phyllosilicates are present in the ancient crust as outcrops exhumed by erosion and as ejecta of large impacts. This shows the occurrence of a strong alteration at the Noachian epoch. Fluvial and depositional landforms are poorly correlated with phyllosilicates. Their formation, subsequent to Noachian rocks rich in olivine, suggests that these landforms formed at periods during which aqueous alteration was not able to form extensive phyllosilicates. Their formation might therefore have occurred either during short periods of time, or in an arid climate, and/or under temperatures close to freezing that impeded the formation of widespread alteration minerals. Olivine is sometimes correlated with phyllosilicates and may indicate an alteration state more than a spatial combination of phyllosilicates with olivine.

References: [1] Bibring J.-P. et al. (2005) *Science*. [2] Poulet et al., 2005, *Nature*, 2005.[3] Mangold et al., J. Geophys. Res., in press [4] Hamilton et al. 2005, *Geology*, 2005 [5] Hiesinger and Head, *JGR*, 2004. [6] Newsom, H. E., Hagerty, J. J. & Thorsos, I. E. *Astrobiology* 1, 71–88 (2001). [7] Mustard et al., JGR, in press.

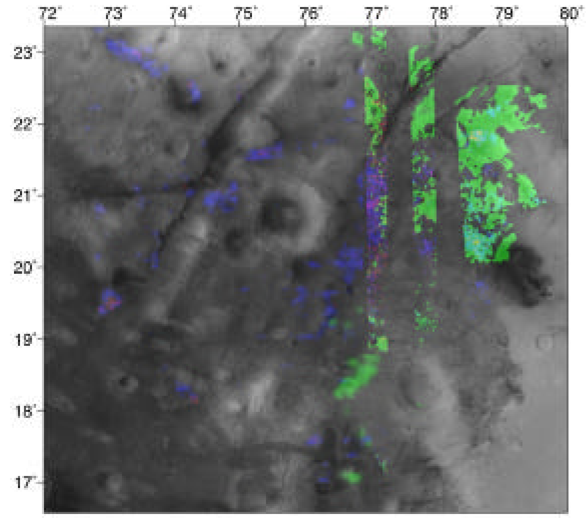

Fig. 1: RGB map of Nili Fossae region with red=Fe-OH bond at 2.3 micron, blue=hydration at 1.9 micron and green=olivine. Red and blue found together indicate Fe-rich smectites, yellow indicate clays+olivine region.

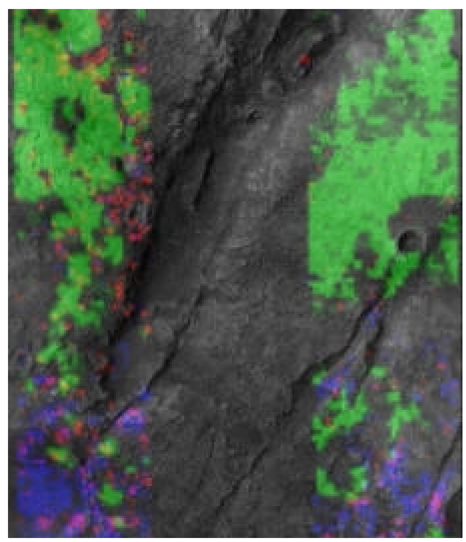

Fig. 2: Close-up of the RGB map of figure 1 at 77°E and 22°N. Note red pixels without blue pixels in the middle left indicate single 2.3 micron feature in some locations.

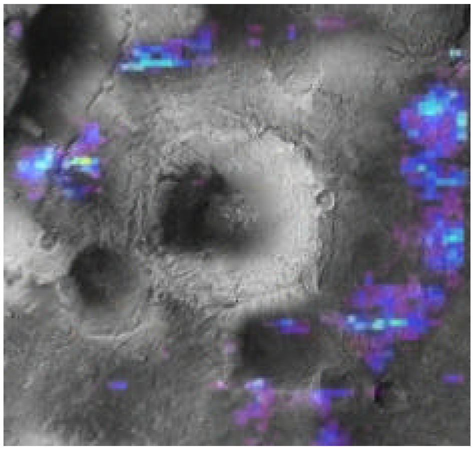

Fig. 2: OMEGA 1.93 micron band plot over HRSC image 1347. Phyllosilicates surround a 50 km large impact crater. These locations correspond to ejecta.

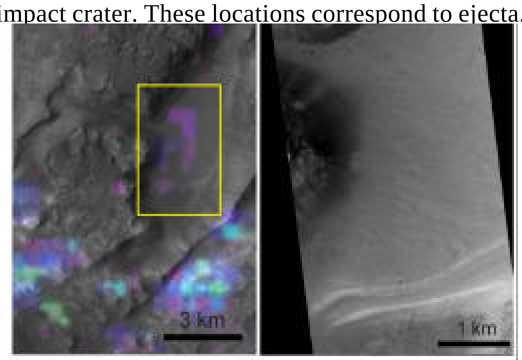

Fig.3: A slight hydration at 1.9 micron corresponding to hydrous minerals over a terminal fan visible with the layered deposits at the end of a sapping canyon.

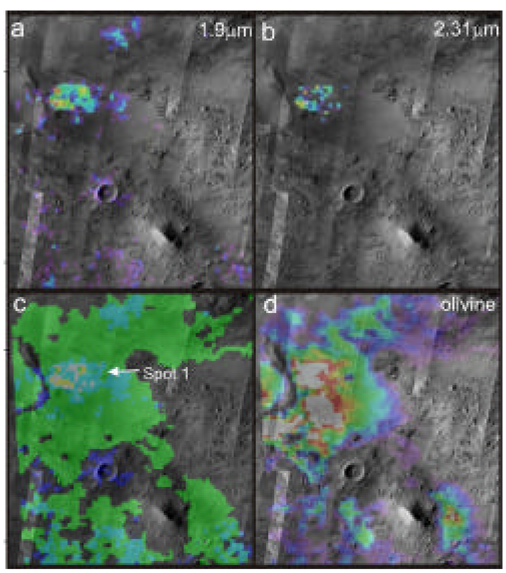

Fig. 4: Presence of strong bands of hydration (both 1.9 and 2.3 µm) together strong olivine bands.

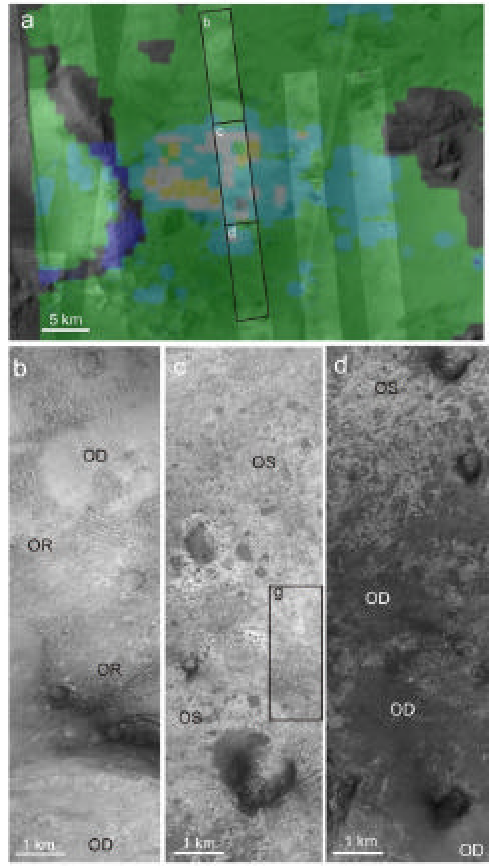

Fig. 5: Close-up on the hydrated olivine spot. OD=Olivine rich dunes devoid of hydration OR=Olivine rich rough rocks devoid of hydration OS=Olivine smooth terrain that contains phyllosilicates. Only this smooth texture display hydration together olivine.