OXIA PLANUM

Prepared thanks to this large team :

C. Quantin[1], J. Carter[2], P.Thollot[1], J. Broyer[1], L.Lozach[1], P. Fawdon[3], Joel Davis[3], Peter Grindrod[3],M. Balme[3], J. Fernando[1], Maurozio Pajola[4], E. Baratti[5], Rossato Sandro[4], P. Allemand[1], B. Bultel[1], Cédric Leyrat[6], A. Ody[1]

(1) Laboratoire de Géologie de Lyon, France; (2) IAS, France; (3) University college london (UK); (4) University of Padova, Italia ; (5) University of Bologna, Italia ; (6) OPM

1. INTERESTING SCIENCE TARGETS

We propose that the ellipses be centered at: **-24.08°E, 18.03°N**. This center was optimized to maximize science while keeping the probability of landing on an unsafe zone to a minimum. The ellipse center is the same for all azimuths. It should be noted that the exact center can be nudged by several kms. The previous ellipse center was at -24.33°E, 18.16°N. It may be argued that reverting back to this first ellipse position would minimize the risk of landing on high TAR density units to the East, but instead would increase probability of landing on the poorly traversable capping unit to the West.

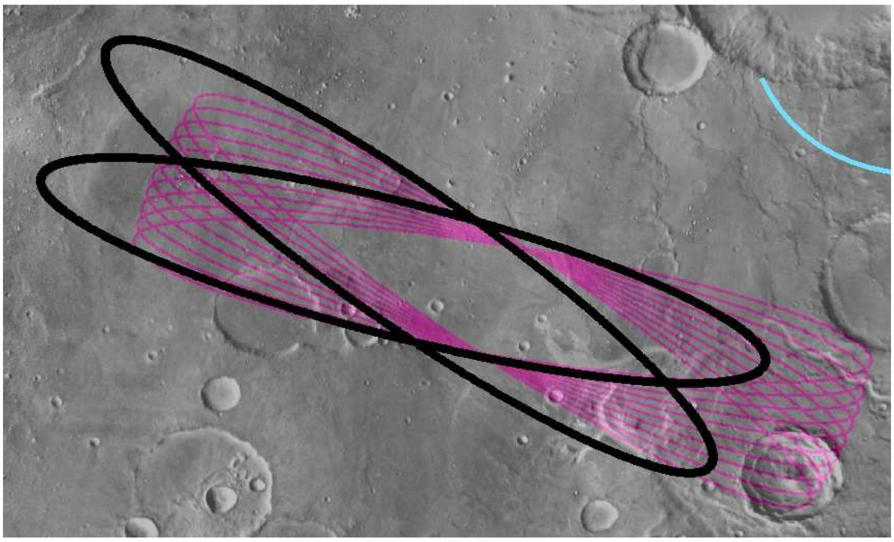

Fig. 1 : In pink, new set of ellipses based on science maximisation. In Black, the previously proposed 2020 ellipse center. Note that all slope analyses have been done on the dark ellipses.

An ArcMap-compatible file as a geotiff will be provided.

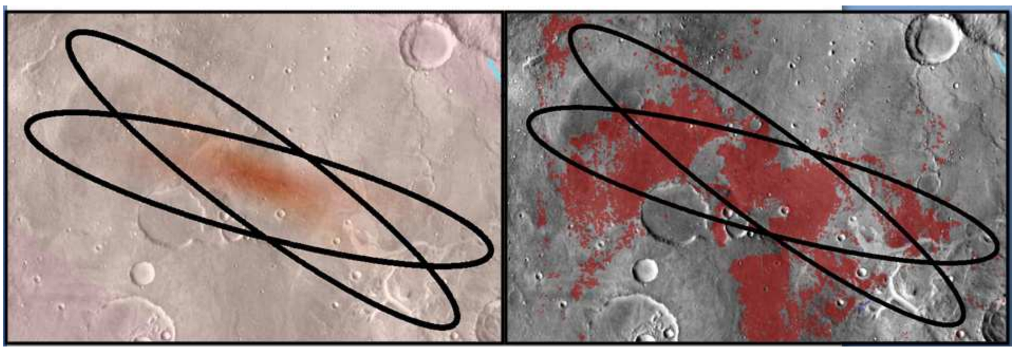

Fig. 2 : Landing probability. Left, supplied figures of probability (red denotes de highest probabilities). Right is the Clay mapping (in red)

The ellipse position optimization and statistics described in the table below are based on the assumption of a 2D Gaussian probability distribution, with a 3-sigma size [120 km ; 19 km].

Optimization uses the following empirical rule:

$$ELlipse\ position\ = MAX\left[\frac{P_{Land\ on\ FeMg\ Clays} * P_{Land\ on\ Delta}{}^{0.1} * P_{Land\ on\ Opal}}{P_{Land\ on\ Unsafe\ slope}{}^{0.1}}\right]$$

The probability of landing on FeMg clays is mainly derived from mineral maps built with CRISM multispectral data ('HSP' and 'MSP' nadir modes) in the 200m/pix sampling range with spot contributions from several targeted CRISM observations with a <40m/pix sampling. Gaps in CRISM coverage are filled with lower resolution (>1km/pix) OMEGA mapping. The probability of landing on "Opal" is based on a CRISM hydrated silica mineral map, yielding signatures within and in the vicinity of the delta deposit (see below). Aluminous phyllosilicates have been detected in minute abundances towards the eastern part of the ellipse, but with a near zero probability of reaching them based on the proposed ellipse centers. Tentative detections potentially accessible within a 5 km traverse are under investigation.

P_FeMgClay_OnSite	0.59
P_FeMgClay_1km	0.90
P_FeMgClay_3km	0.98
P_FeMgClay_5km	0.99
P_Opal_OnSite	0.00
P_Opal_1km	0.06
P_Opal_3km	0.26
P_Opal_5km	0.50
P_Delta_OnSite	0.01
P_Delta_1km	0.06
P_Delta_3km	0.16
P_Delta_5km	0.27
P_Slope_OnSite	0.01

Table 1. Normalized 2D Gaussian probabilities of ExoMars encountering relevant science targets "on-site" (~< 200 m), then within a 1 km, 3 km and 5 km traverse. Probabilities related to Fe/Mg clays and opalized (hydrated silica) minerals are based on CRISM and OMEGA detections. These values should be considered a firm lower limit because of inherent sensibility limitations of orbital data and noise filtering processes that were implemented in the making of the different mineralogical maps. We also compute the probability of landing on a high-slope area based on the mapping done by Peter Fawdon and distributed in the 09/03/2017 report.

Identification of high priority targets, regions, and formations

1. Geology and mineralogy of Oxia Planum

1.1 Global geology

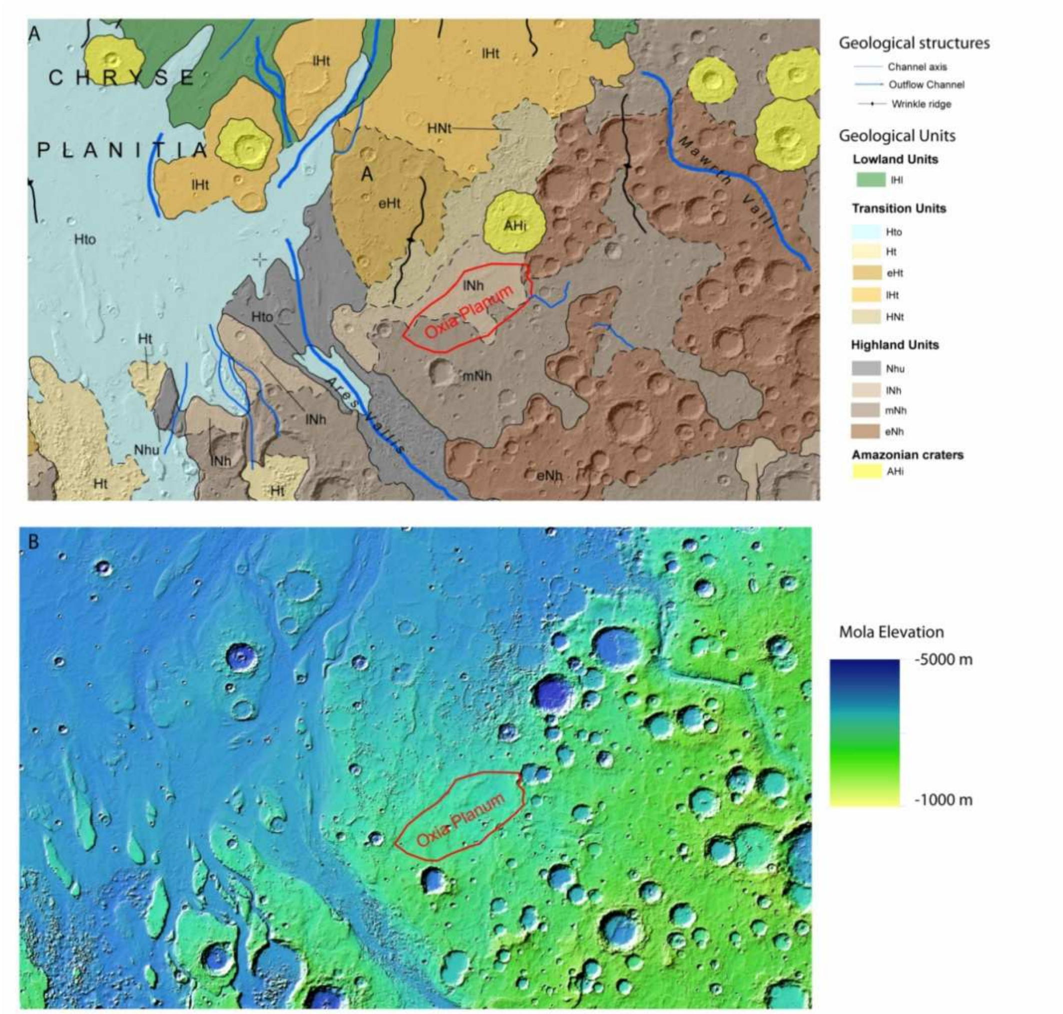

Fig. 3 : A] Oxia Planum region clay rich unit (red contour) over the global geological map. B] Oxia Planum region clay rich unit (red contour) over MOLA topography

Oxia Planum is located on the south west margin of Arabia Terra and exhibits Noachian terrains that become increasingly eroded towards the crustal dichotomy (Figure 3). The region has known a rich geological history showing diverse aqueous episodes all dated from Noachian times followed by a late volcanic activity (Figure 4). Here we summarise the keys geological units of Oxia Planum present inside the ellipse relevant for Exomars objectives: 1) the clays rich units, 2) the fluivio-deltaic system, the late volcanic activity, and the long lived erosional history of the region.

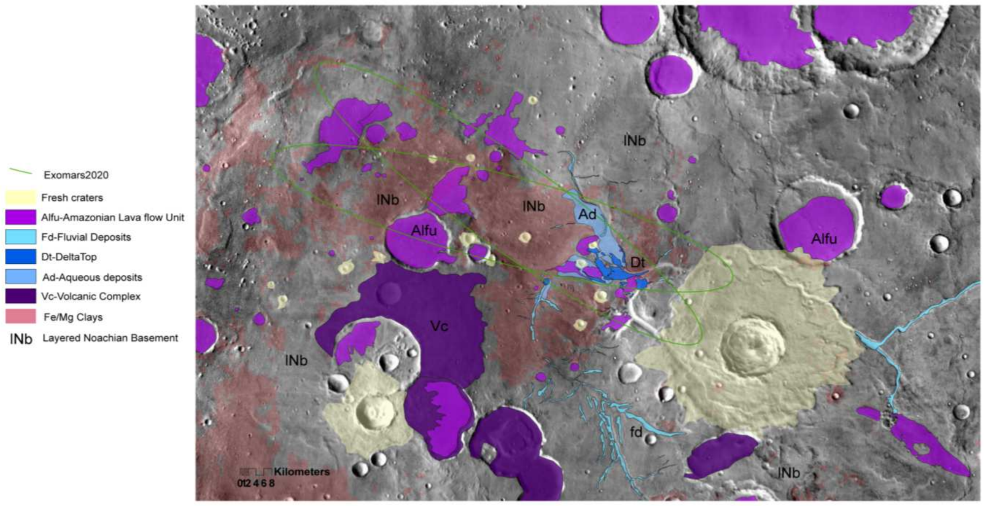

Fig. 4 : Geological map of the area. Purple color denotes the late volcanic activity of the area. Red color maps the clay rich unit and blue color are mapping the deposits related to the fluvio-deltaic system.

<u>1.1.1 The Clay rich unit:</u>

The clay rich unit overlaps terrain mapped as mid and late noachian by Tanaka et al. (2014). But detailed geological investigation of the area (that will be presented 27th March 2017) argues for a **mid-noachian or older layered clay rich formation**. The clay rich unit is layered (cf Figure 5 and 6) with layers from 0.7m to 2-3m as measured on HiRISE DTM. The thickness of this layered sequence is more than 50m but probably less than 100m. The entire clays rich unit is overlapping the pre-existing topography. The age returned from crater counts on this clay rich formation is older than 4 Gy (Figure 7). The composition detailed in the mineralogical section is dominated by Mg/Fe Clays with some sporadic detection of Al Clays.

Regional analysis of the circum Chryse Planitia deposits provides evidence that the clay-bearing deposits reported in Oxia planum are representative of a more widespread aqueously altered unit, of which exposures are found scattered over distances as large as 1900 km and which include the Mawrth Vallis clay-rich region. This is evidenced by similarities in the surface morphology (layered formation) and clay assemblage composition. An important consequence is that the in-situ investigation of the proposed site would have implications on a regional to global scale for Mars alteration. **Deciphering the formation environment for such an extensive deposit would in particular provide constraints on the paleo-climate and habitability of Mars during the Noachian.**

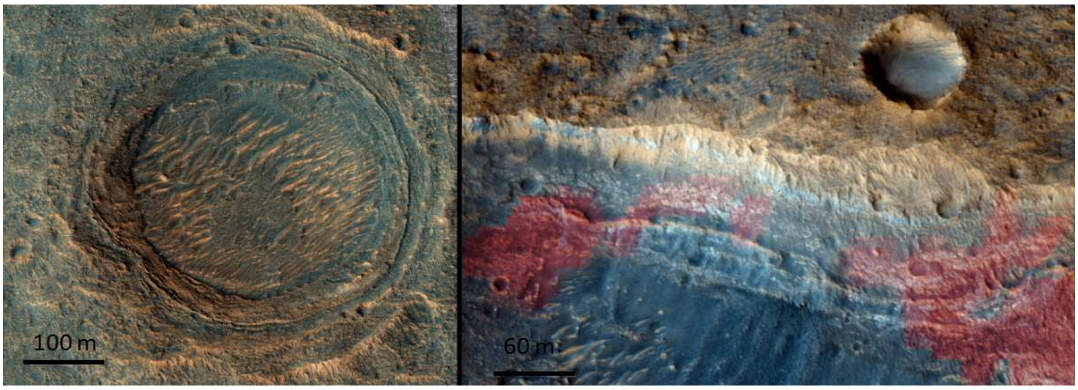

Fig. 5 : Examples from HiRISE color pictures of layers exposed in impact crater walls. Right, red maps clay signatures from CRISM targeted data

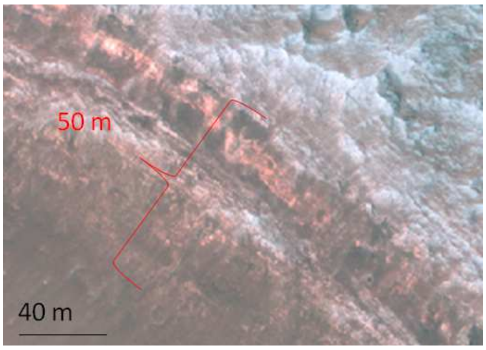

Fig. 6 : HiRISE color close up on exposed clay rich unit stratigraphy. The exposed section is about 50 m thick from CTX DTM measurement.

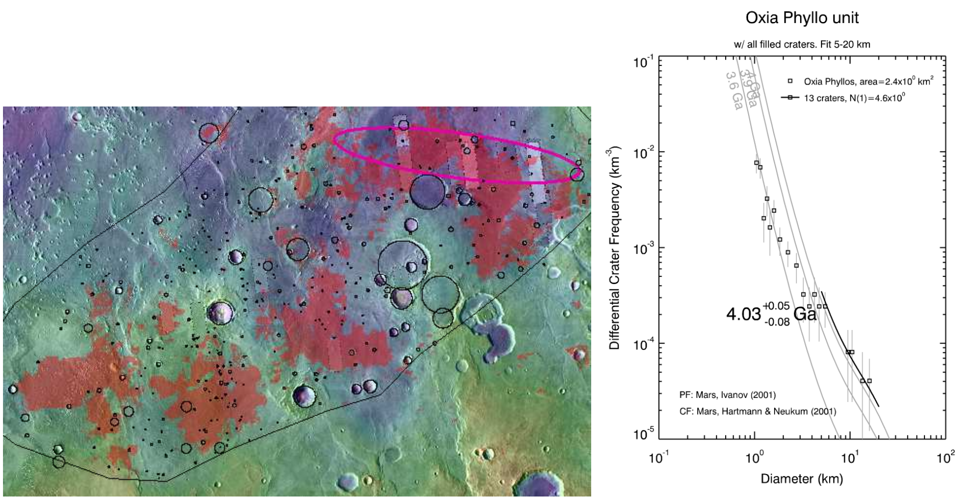

Fig.7 : Age of the layered clay rich unit. Right, crater size frequency distribution returning an age of more than 4 Gy. Left, Corresponding mapped craters. Red color maps the clays.

1.1.2 The fluvio-deltaic system:

The landing ellipse is at the outlet of a large catchment area of more than 28 000 Km^2 (Figure 8). The drainage system is not well developed but detailed analysis (that will be presented 27th March 2017) reveals that the valley system is highly eroded and overlapped by large late Noachian and early Hesperian impact craters hiding the initial state of this valley network. Furthermore many valleys like Cogoon valley have been further filled by volcanic material. At the outlet of this drainage basin a 10 km long fan-shaped feature is observed. The fan is clearly on top of the clay rich unit. The fan is layered and about 80 thick. The flat surface, the overlapping divergent Finger-like terminations argue for a deltaic system rather than an aerial alluvial fan (Figure 9). The thermal inertia signature of this delta fan highlights a fine grain formation (Figure 9). These observations argue for a body of standing water that would have covered almost the entire landing ellipse. Another possible delta-fan is also observed at the same elevation as the main delta fan and at the outlet of valleys. Down to the deltaic deposit, younger valleys eroding the delta-fan are observed arguing for a late stage fluvial activity probably correlated with a lower level of the standing body of water. The age of the fluvial activity of the main catchment area has been retrieved by relative stratigraphy and by crater count buffering technique (Figure 10). The fluvial activity would be not older than mid-noachian and would be older than 3.9 Gy. **The Oxia Planum landing ellipse is therefore located in a basin of a Noachian fluvio-deltaic system**. As detailed in the mineralogical section, the delta-fan layers are enriched in opaline silica attesting to the ponding activity. Down at the delta-fan and distal to it, the clay signatures are less intense. The clays there are covered by remnants of a widespread deposit that may be related to the ponding activity. The main concern is that this formation concentrates the TARs inside the ellipse. Indeed, the erosion of this formation seems to be favourable to TARs formation.

According to a plausible distribution of the standing body of water, the entire ellipse could display remnants of this fluvio-deltaic stage but the entire west part of the ellipse seems to be more eroded and at the first order these fluvio-deltaic deposits are observed only in the eastern part of the ellipse where they also correspond to the less trafficable areas.

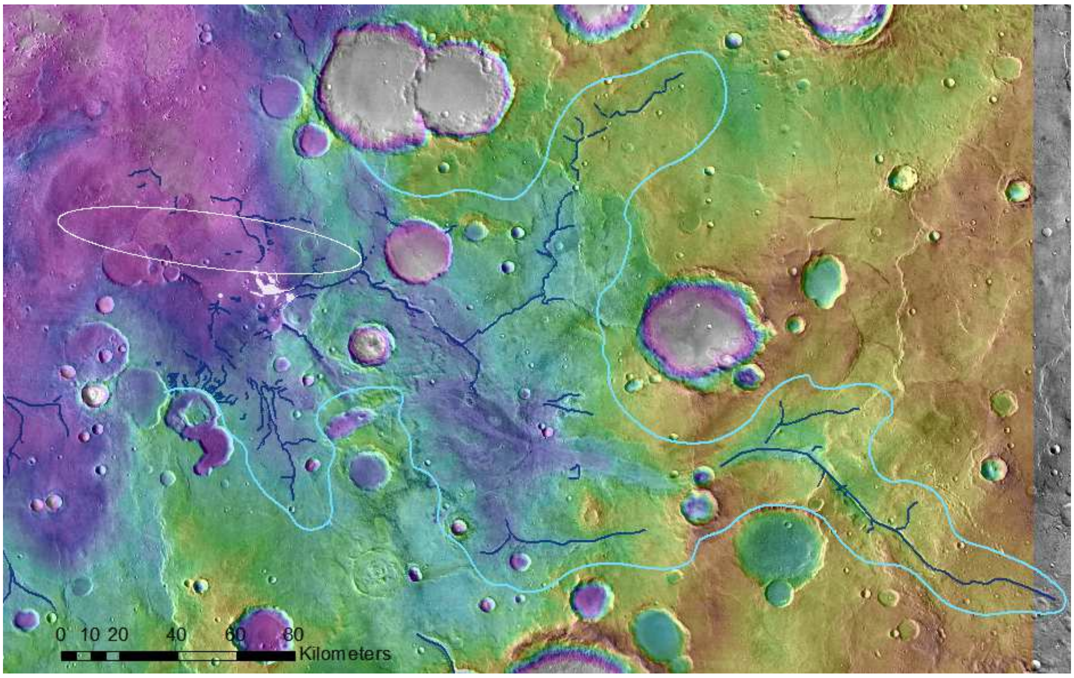

Fig.8: Global view of the fluvial morphologies and the large catchment area upstream the 2018 landing ellipse. Light blue underlines the catchment area. Blue denotes the valleys and in white is mapped the delta-fan

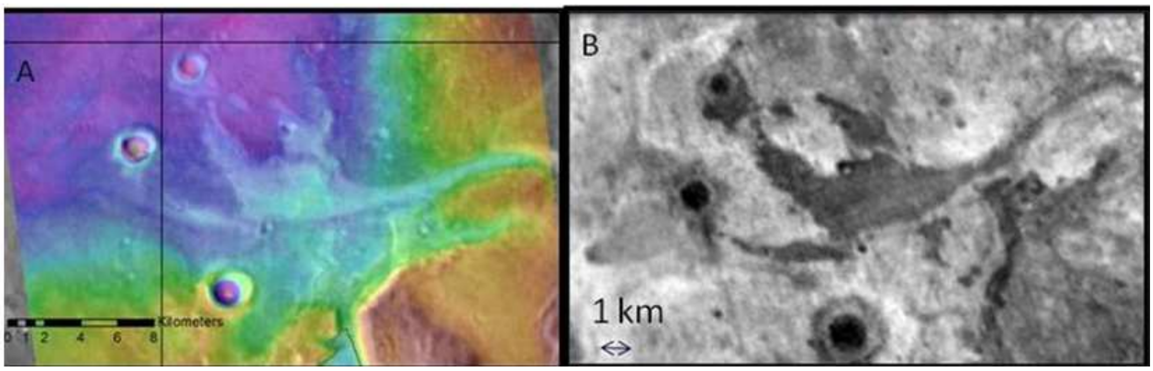

Fig.9: Left, MOLA view of the delta-fan about 80 m thick. Right, THEMIS night time image of the delta fan highlighting the low thermal inertia of the delta-fan material

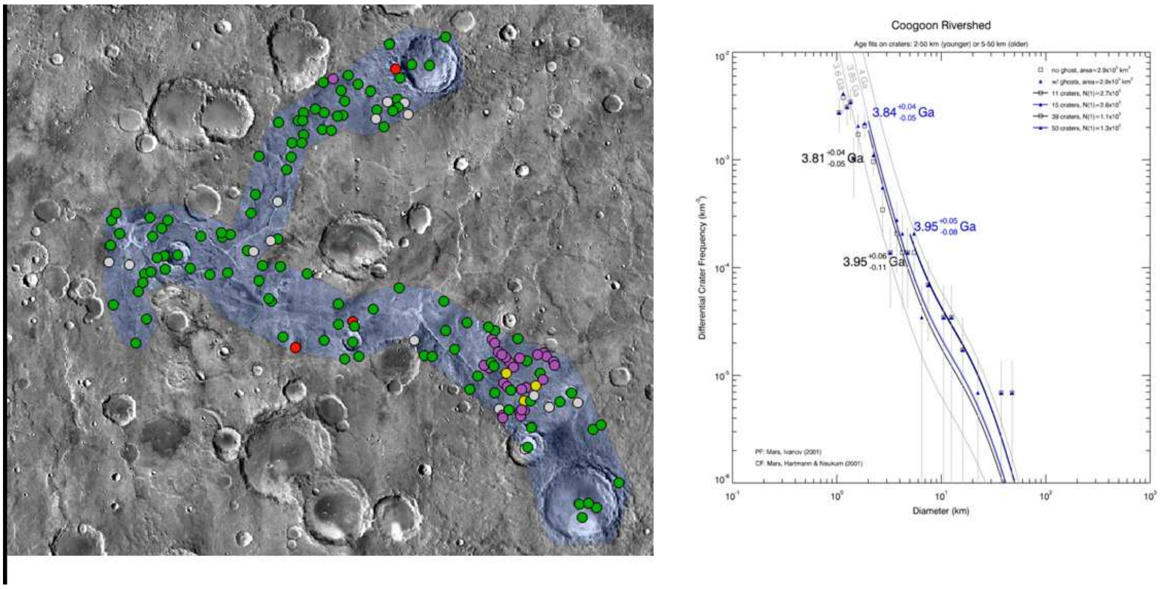

Fig. 10: Age of the fluvial activity upstream of Oxia Planum basin. Left is the counted craters superimposed to the drainage network and right if the corresponding crater size distribution.

1.1.3 The Amazonian volcanic activity:

As mapped in figure 4, a volcanic complex is observed just south to the landing ellipse post-dating the clay rich formation. Also many local topographic lows (as impact craters, ancient valleys, small scale basins) are filled by an easily identifiable unit that is more massive, with an high thermal inertia, that is at small scale more impacted and about 20 meters thick and mafic rich. As shown on figure 12, the lobated termination of a remnant unit of this deposit argues also for a lava flow. Fissural lava flow emplacement is the best scenario to explain this unit. As the entire region, this unit is eroded but more resistant to erosion than the other geological unit (figure 11) and may have played a role to preserve the older deposits such as the clays rich layered or the fluvio-deltaic deposits. The age returned by crater counts from different location is 2.6 Gy (Figure 12).

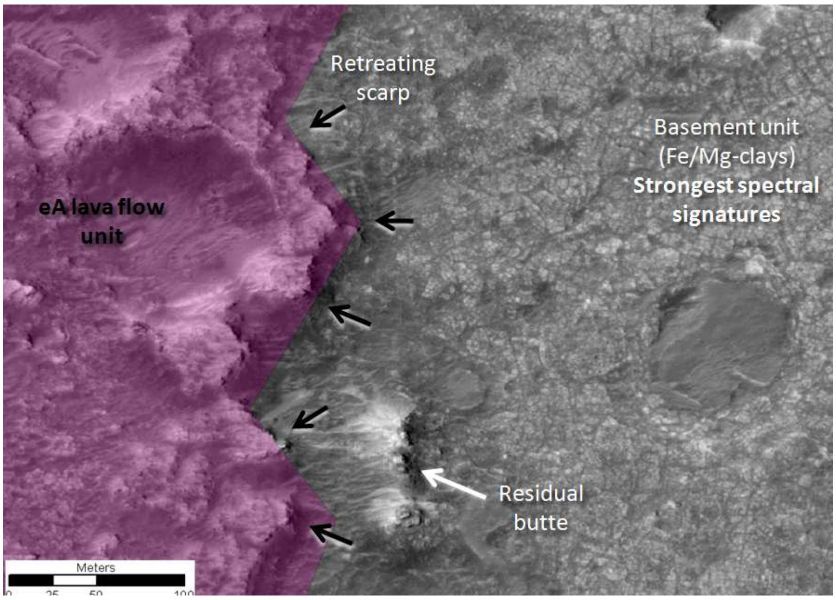

Fig.11: Zoom on the contact between the clay rich unit and the lava flow unit (HiRISE)

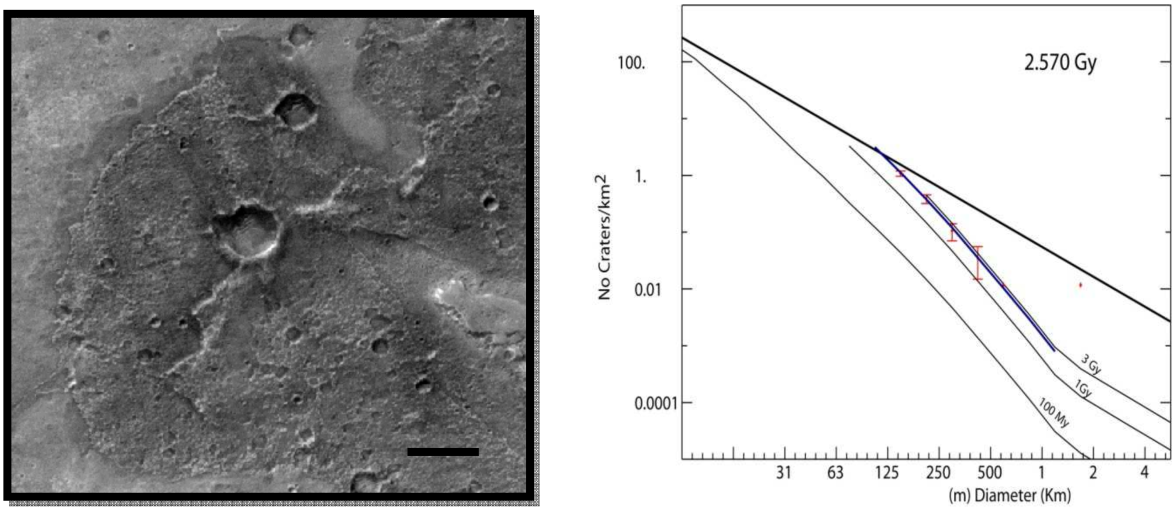

Fig.12: Left, Lobated termination of the la lava flow unit. Right, Crater counts on the lava flow unit returning an age of 2.6 Gy

<u>1.1.4 Long-lived and ongoing erosion:</u>

The entire landing ellipse shows evidence for long lived erosion. First, from crater count at small scale: whatever the geological unit, the small craters haven't the crater size distribution of the expected production function indicating continuous erosional processes. But also many inverted morphologies such as inverted impact craters, as displayed in Figure 15, or inverted channels are observed. Ongoing work suggests that the volcanic unit has been eroded but is the most resistant unit to erosion. Then, we have the clays rich layers and lastly we have the deltaic deposits that seem to be the most easily erodible material.

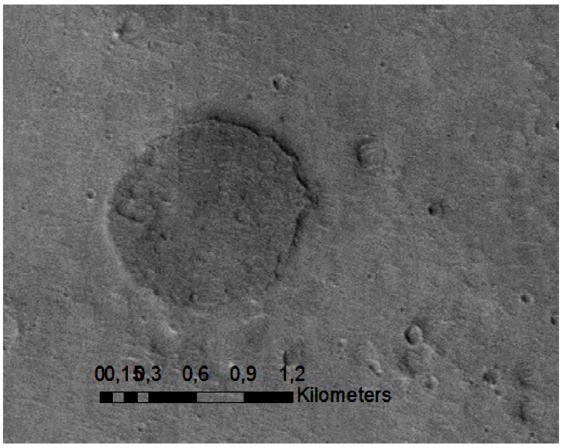

Fig.15: CTX Zoom on an inverted crater filled by the lava flow unit

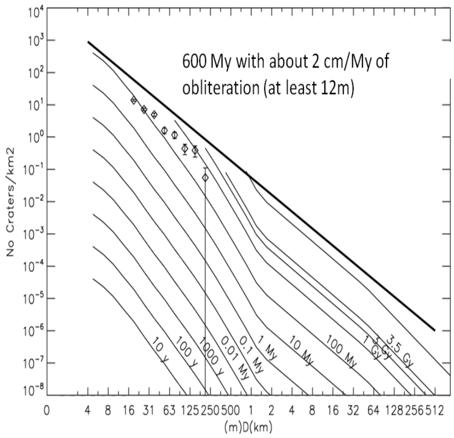

Fig.16: Crater counts at HiRISE scale on the clay rich unit revealing the ongoing erosion quantify thanks to inverse methods to 2cm/My over the last 600 My.

1.1.5 Geological history summary:

In summary, the geological history of the region can be drawn as follow : during the mid-Noachian or even before, the layered altered clay rich formation has been formed then, during the late Noachian the large catchment and the related delta-fan would have formed. A later stage of fluvio-lacustrine activity would have then occurred linked with a lower level of stand body of water. The entire Hesperian period would have eroded the previous deposits and then the volcanic unit would have emplaced. Since 2.6 Gy, according the current erosion rate estimated on the clays rich unit, at least 50m of material would have been removed.

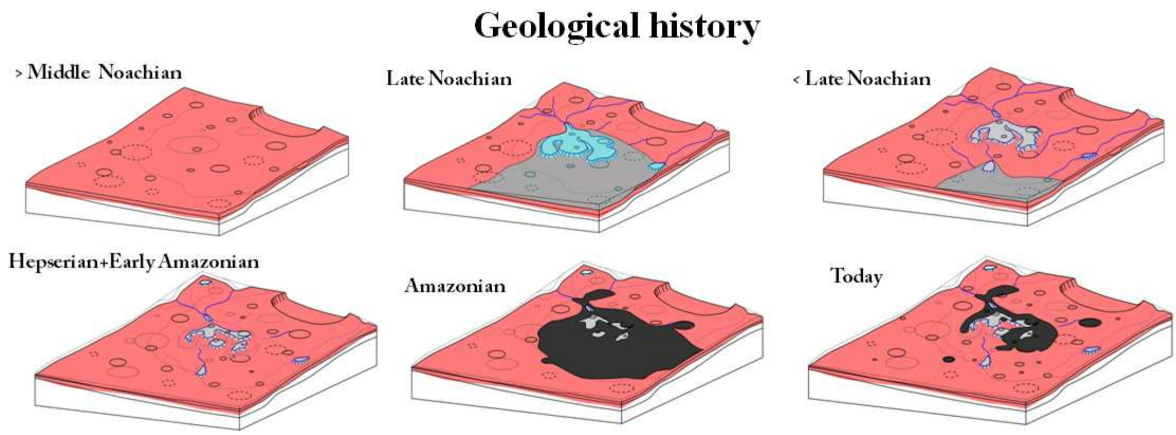

Fig. 17 : Geological evolution of Oxia Planum basin.

1.2 Mineralogy assumptions:

1.2.1 Fe/Mg clay

The clays within the Oxia ellipse are exclusively one type of Fe/Mg-rich phyllosilicate. Most likely candidates are: ferroan saponite, a smectite with mica sheets, vermiculite, berthierite. Most of these clay candidates are 2:1 clays, except berthierite (1:1-derived). Their cation composition is dominated by Fe^{2+} and Fe^{3+}, there is then some amount of Mg and some minor Al. There is ongoing work on a more quantitative assessment based on NIR spectroscopic calibrations and based on the recent paper by Michalski et al. in 2015.

The only spectral variation that is seen is the Fe-mediated slope in the 1-1.7 µm range. The absorption bands (H-O-H,O-H and MMM-OH) retain the same shape and position. The Fe^{2+}/Fe^{3+} ratio that could explain slope variations has yet to be derived, but this is challenging due to contamination by Fe^{2+} bearing olivine, probably derived from the partial volcanic capping at Oxia. There is also the possibility that the Fe^{2+} slope lessens as a function of exhumation age, which would be interpreted as ongoing slow oxidation of Fe^{2+} smectite into Fe^{3+} smectite. Such mechanisms have been proposed several times for Mars, most recently by Chemtob et al. (LPSC 2017). This has yet to be confirmed.

These Oxia type clays are found throughout the Chryse margin which straddles the dichotomy (see figure below). The mineralogy is similar, and the context seems similar is some areas, although there may be some variations. Further work is needed to address this.

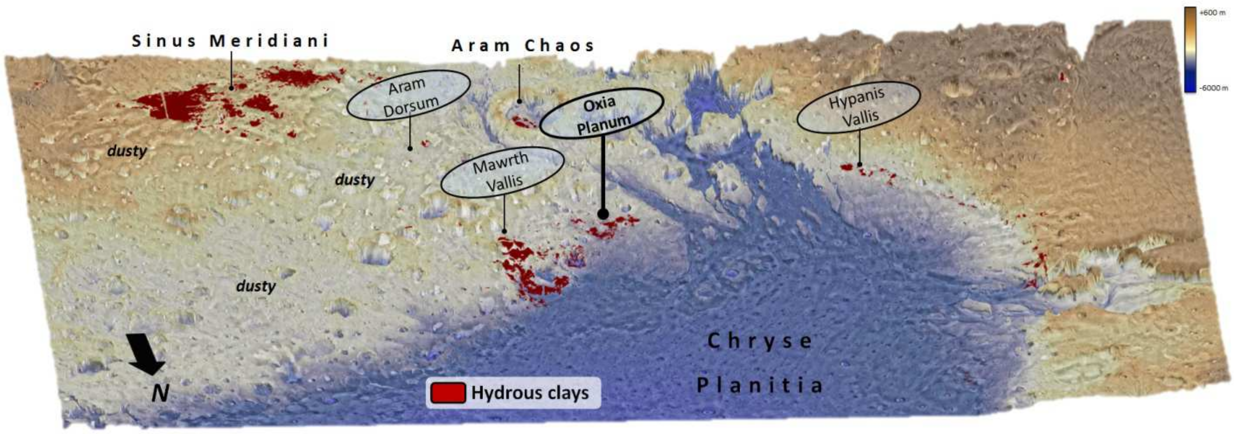

Figure 18. The Circum-Chryse clay unit, straddling the dichotomy. Here, we do not distinguish the different clay mineralogies between Oxia Planum and Mawrth Vallis.

The homogenous composition at Oxia and around much of Chryse as seen from orbit is remarkable. Few to no other sites at Mars exhibit this on such a scale. This says something about the formation process of these clays. Whatever formed them took place on a massive scale and the fluids had a homogenous geochemical state. Because having a constant geochemical state at Mars through time and on such a geographic scale is no doubt unlikely, it suggests the alteration took place or at least ended in a synchronous fashion around Chryse. This may excludes Mawrth Vallis which exhibits additional hydrous minerals and differences in its stratigraphy.

Alternatively, diagenesis transformed and homogenised variable clays into what is now seen at Oxia and most of the Chryse margin. Such shallow diagenesis is not supported by observations.

The crystallinity of these clays is unknown. However, recent work on the VISNIR properties of saponite calibrated from various crystallinity states (Fu et al., LPSC 2017) would argue that the Oxia clays are not amorphous. This is based on the qualitative assessment of the relative strength of the 1.4, 1.9 and 2.3 µm bands as well as their sharpness. More work needed here.

The clays at Oxia Planum are not the same as the bulk of those at Mawrth Vallis. Within the Mawrth stack, one to two distinct layered units have a composition similar to the one of Oxia, and one of these layers pertains to the "paleosurface" described in Loizeau et al. (2015). There, the mineralogy has been attributed to "Fe^{2+} mica" that is here ascertained to be rather an Fe^{2+} rich smectite with some mica sheets interstratified. It should be noted that the bulk of the Mawrth clays are not the same as the one seen at Oxia Planum. The former consist of 100s of meters of Fe^{3+} nontronites, capped by additional higher W:R minerals (kaolins, Al-smectite, allophanic). The Oxia clays are a species that typically form in lower water environments (less leaching, neutral pH), and lower temperature. These correspond to colder (and possibly dryer) climates when found in a supergene context on Earth (cold region soils), or to the lower soil horizons of more temperatre to tropical soils (a few meters to 10s meters deep). Redox conditions for this particular layer is not as oxidizing as Fe^{3+} nontronite species. To note that Mawrth has evidence for both oxidizing and not oxidizing/reducing conditions.

The lateral extent of the Oxia type clays around Chryse, and the lateral extent of the Mawrth type pedogenic clays within Arabia suggest that both their alteration processes took place at a large scale, if indeed these were not one same process. Some layers of Mawrth Vallis are consistent with the layers found at Oxia Planum. The search for Mawrth type pedogenic clays at Oxia is ongoing.

1.2.2 Opal in the fan

CRISM high resolution observations acquired since the last workshop have confirmed the proposed existence of hydrated "opalized" silica in association with the fan (see figures 19-20 below). The opal is genetically linked to the fan-forming event, and a likely explanation are silecrete coatings or other types of very low grade (low W:R) surficial chemical alteration and cementing during ponding of a waning lake. Every alluvial fan and delta that has been found on Mars for which we have good spectroscopic data has shown similar authigenic opal signatures (e.g. Carter et al., 2010). This is largely independent of age, as these opalized/cementing structures have ages ranging from the Noachian (e.g. Terby crater paleo-delta, Ansan et al., 2011) to the Hesperian. Several opal signatures have been found west of the fan, and may be related to now-eroded structures that were part of the fan or more distal lacustrine deposits. The context is not sufficiently preserved to distinguish clearly these distal opal deposits (black circles, figure below).

As discussed in the geology section, **the opalized delta is highly suggestive of ponding in a standing body of water within a basin that likely encompassed the landing ellipse**. **While this paleobasin may be clay and even clay-sediment covered, we do not see a basin clay sedimentation scenario. Instead, the clays predate that stage of the ponding, and drape the topography including outside of the basin, at higher elevation. The basin may be clay-filled, but there is no evidence for a basin clay-sedimentated unit - at least not during that part of the geological history.**

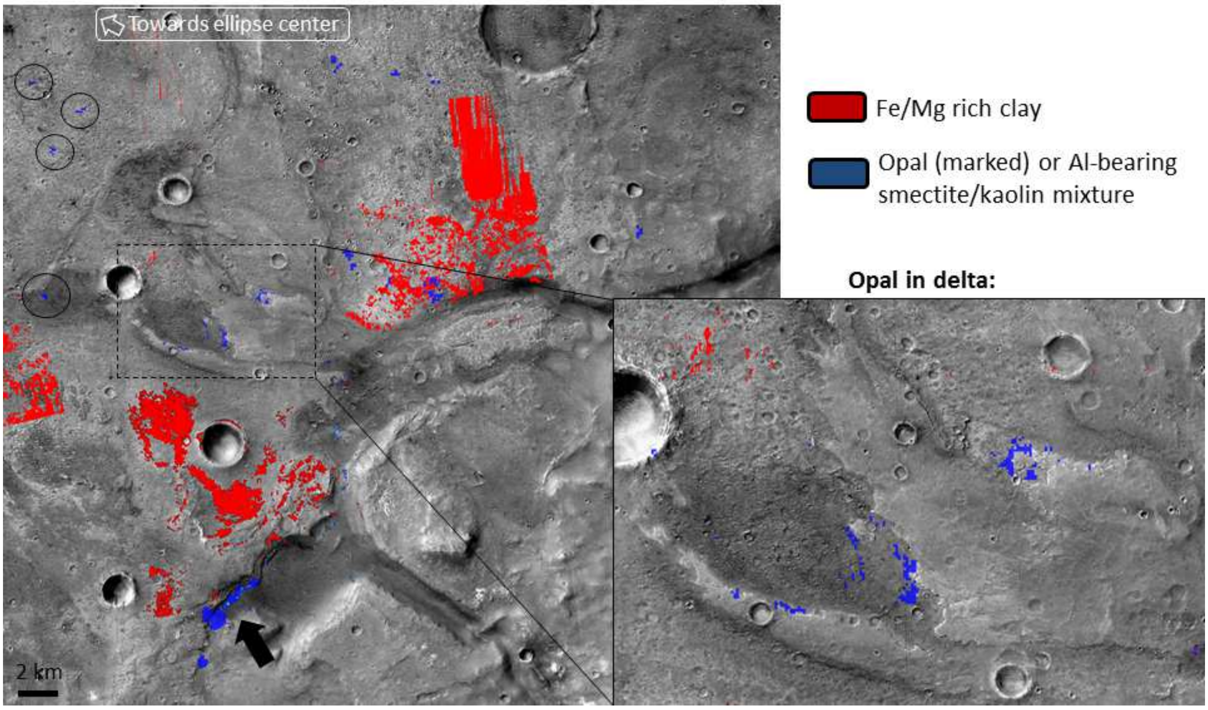

Fig. 19. High resolution CRISM mapping of the Eastern part of the ellipse, featuring the delta-fan. Fe/Mg clays are mapped in red. Opalized minerals are mapped in blue where indicated by black arrows and circles. Coverage at high resolution in the scene is partial.

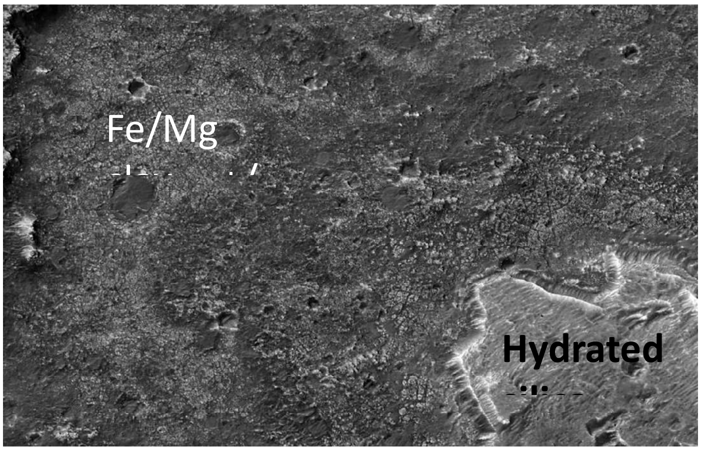

Fig.20 HiRISE close-up on a delta scarp showing the hydrated silica rich unit on top of the Fe/Mg clay unit that has an Fe^{2+} spectral slope indicative of ferrous smectite or the presence of olivine mixed. Scene is roughly 1 km wide.

1.2.3. Additional Al-phyllosilicate detections

Towards the eastern part of the ellipse were found kaolinites and mixtures of aluminous smectites with the Oxia-type, Fe/Mg-rich clay (the latter still dominates). These deposits are small and inaccessible to the rover. Ongoing work is underway to verify if none exist closer to the ellipse center.

1.3. Discussion on the aqueous environments

The following tables provide a summary of the aqueous environments that have been considered to explain the mineralogy and stratigraphy of the Fe/Mg clays at Oxia Planum. It is based on the assumptions and observations of the previous section.

PROPOSED FORMATION/EMPLACEMENT MODEL
Mudflats
Model description
Lacustrine or palustrine alteration and emplacement, through a combination of (shallow) ponding and groundwater upwelling
Terrestrial analogue
Intertidal coastal mudflats
Relevance to exobiology
Good (see detailed discussion below)
Arguments in Favour
Smectite-vermiculite mineralogy common in mudflats Basin/margin topography Laterally extensive Orbital morphology consistent with sediments. Some layering at Oxia

Climate-mediated surface weathering
Model description
Top-down surface alteration as pedogenesis in immature soils
Terrestrial analogue
Weathering sequences
Relevance to exobiology
Good (see detailed discussion below)
Arguments in Favour
Smectite-vermiculite mineralogy Laterally extensive deposit Drapping topography Wide (>500 m) elevation range

VOLCANICALLY DRIVEN SHALLOW/SURFACE HYDROTHERMAL ALTERATION
Model description
Top-down water or subglacial interaction with volcanically heated ash/sediments
Terrestrial analogue
Icelandic subglacial hydrothermal systems
Relevance to exobiology
Low (see detailed discussion below)

Arguments in Favour
Nearby volcanic caldera providing heat Pervasive volcanic infilling of Chryse after the basin formed

MAGMATICALLY DRIVEN HYDROTHERMAL ALTERATION IN A HEATED AQUIFER
Model description
Bottom-up magmatically heated aquifer forming clays in closed-water system, hypogene
Terrestrial analogue
TBC
Relevance to exobiology
Good (see detailed discussion below)
Arguments in Favour
Possibility of latent heat from basin forming event or Hesperian late radiogenic heating raising geothermal gradient enough for hydrothermal alteration, heating aquifer or melting permafrost. Topography straddling crustal dichotomy favouring water table intersection. Hypogene waters could forme homogenous, low W:R, closed-system clays such as the ones observed at Oxia. Low W:R hydrothermal circulation could alter the pre-existing layers into clays without disrupting the stratigraphy.

GLACIAL BASAL MELTING
Model description
Low grade closed-system alteration through basal melting
Terrestrial analogue
TBC
Relevance to exobiology
Poor
Arguments in Favour
Large geographic extent of Oxia type clays straddling dichotomy around the Chryse margin. Likelihood of accumulation of large amounts of ice there, as predicted by Late Noachian Icy Model and others. Low grade alteration could possibly result in the Oxia type clays detected

DEEP CRUSTAL FORMATION
Model description
Diagenesis and low grade metamorphism in the crust via hypogene waters

Terrestrial analogue
Basins
Relevance to exobiology
Poor
Arguments in Favour
Vermiculitic clays may hint to a mica rich basalt that was diagenetically transformed
Arguments against
No high T/P alteration phases have been found associated with Oxia. Layering and geomorphology in general is sedimentary or near-surface related. Craters that puncture the crust around Oxia and Mawrth do excavated higher T/P crustal minerals, including chlorites, serpentines, zeolites (and possibly carbonates). None found at Oxia

THE MARS GLOBAL MUDBALL
Model description
A planetary scale mechanism led to the alteration of 10-100s of meters of a volatile rich crust into the Fe/Mg clays observed at Oxia.
Terrestrial analogue
Hadean Earth, pre oceanic
Relevance to exobiology
Unknown
Arguments in Favour
Oxia type clays are ubiquitous everywhere in Noachian terrains. The basin margin topography likely led to a region-specific preservation/erosional history, exhuming clays all round Chryse planitia, including Oxia and Mawrth Up to 10s meters thick low W:R clays at Oxia and around Mawrth

We propose the following notional ranking of the likelihood of the various scenarios described here:

Likely	Less likely	Unlikely
Mudflats	Volcanically driven shallow/surface hydrothermal alteration	Deep crustal formation
A Mars global mudball	Magmatically driven hydrothermal alteration in a heated aquifer	Glacial basal melting
Cold climate-mediated surface weathering (polar soils)		

In summary, whatever the scenario, what can be said about the water-bearing environments at Oxia are the following:

- Oxia was altered into one type of Fe/Mg clay that is a low W:R (little leached) and low T (<100°C for sure, < 50°C likely) specie.
- Oxia likely did not undergo burial diagenesis on a scale that would matter for bio-preservation.

- Whatever formed/deposited the Oxia clays, did the same on an extended lateral scale, all around most of the Chryse Planitia Margin, and possibly at a more global scale.
- Conversely, the alteration process that formed these extensive clays was likely synchronous. While not necessarily short in time, the process should be considered to be likely "one-shot", with little posterior remobilization or diagenesis.
- A specific preservation/erosional history around Chryse Planitia probably explains the extensive clay units found there.
- The basin in which water ponded when the fan was active and during the waning phases when opal/hydrated silica formed, is not responsible for Fe/Mg clay sedimentation as subaqueous deposits. Instead, the clays existed before that stage, and drape the longer wavelength topography include at elevations higher than this basin.
- While Oxia is representative of a regional to global scale clay forming process, it exhibits in addition some later stage ponding forming the delta and precipitating opals.
- Oxia has similarities but also a number of differences from Mawrth Vallis, both in stratigraphy and mineralogy. Both sites are Noachian aged clays.

1.4 Discussion on exobiology

The upcoming discussion on the relevance of Oxia Planum and clay minerals for habitability and past life will be split into 3 categories:

- Was the aqueous environment(s) habitable and conducive to the apparition of life?
- Was the geological setting able to harbor then concentrate extinct life in the form of biological matter?
- Was the geological setting and its subsequent evolution susceptible to preserve such evidence over eons?

We will discuss these aspects based on the most likely alteration processes forming the Fe/Mg clays at Oxia as described above, and then the subsequent ponding and silicic alteration at the Oxia delta.

The first point is an open question in Earth studies of the emergence of life. Sea floor hydrothermal fumaroles are usefully put forward as the best candidates based on banded iron formation detections of life traces. No evidence of this has been found at Oxia, but none is expected to be sufficiently large and preserved to be visible at the scale of orbital remote sensing. It may be argued that a semi-closed system would be most favorable because it limits dilution while allowing intake of nutrients in the aqueous environment, much like what is thought to have been conducive to life at the cell scale. On the other hand, if life appeared at Mars and propagated, an open-system aqueous environment may have the best chance to preserving life, even if its abundance was low, because the chance of life emerging in a random closed-system elsewhere might be null. Both the Oxia and Mawrth clay units occur on large geographic scales, and it is likely that an open-system existed at the time, and that meteoritic waters were involved.

The following figure describes the notional cycle of organic matter in a fluvial-lacustrine setting. We consider that at some point in the history of Oxia, (perhaps short-lived) ponding occurred over Fe/Mg rich clay sediments, much like in the fashion described here. Although biotic processes may have to be excluded here if life existed only in minute abundances, abiotic processes are described that can lead to the accumulation of poorly ordered organic matter (kerogen) in the sediments. Drying up of the lake would result in silicification of the upper layer as observed around the Oxia delta. **Trapping of organic matter in clay rich sediments and silicified w/in hydrated silica are considered primary fossilization mediums on Earth, and both have been found at Oxia Planum and Mawrth Vallis**. Potential meter-scale desiccation cracks are not observed at Oxia contrarily to Mawrth. However, detections here are possibly hindered by dust and sand, especially as clay-rich deposits often exhibit fracturing consistent with this process (e.g. El Maary et al., 2014). Desiccation cracks in clays have been considered a prime exobiological target because the wet and dry cycles may foster proliferation of emerging life.

Larger scale fractures exist at Oxia and their nature is elusive. Whether these Fe/Mg clays have evolved since their inception can only be determined in-situ, however the wide range of altitude on which the clays are found, their draping of the long wavelength topography, and the lack of spectral variability leaning towards corrensite or chlorite collectively suggest no burial diagenesis took place here.

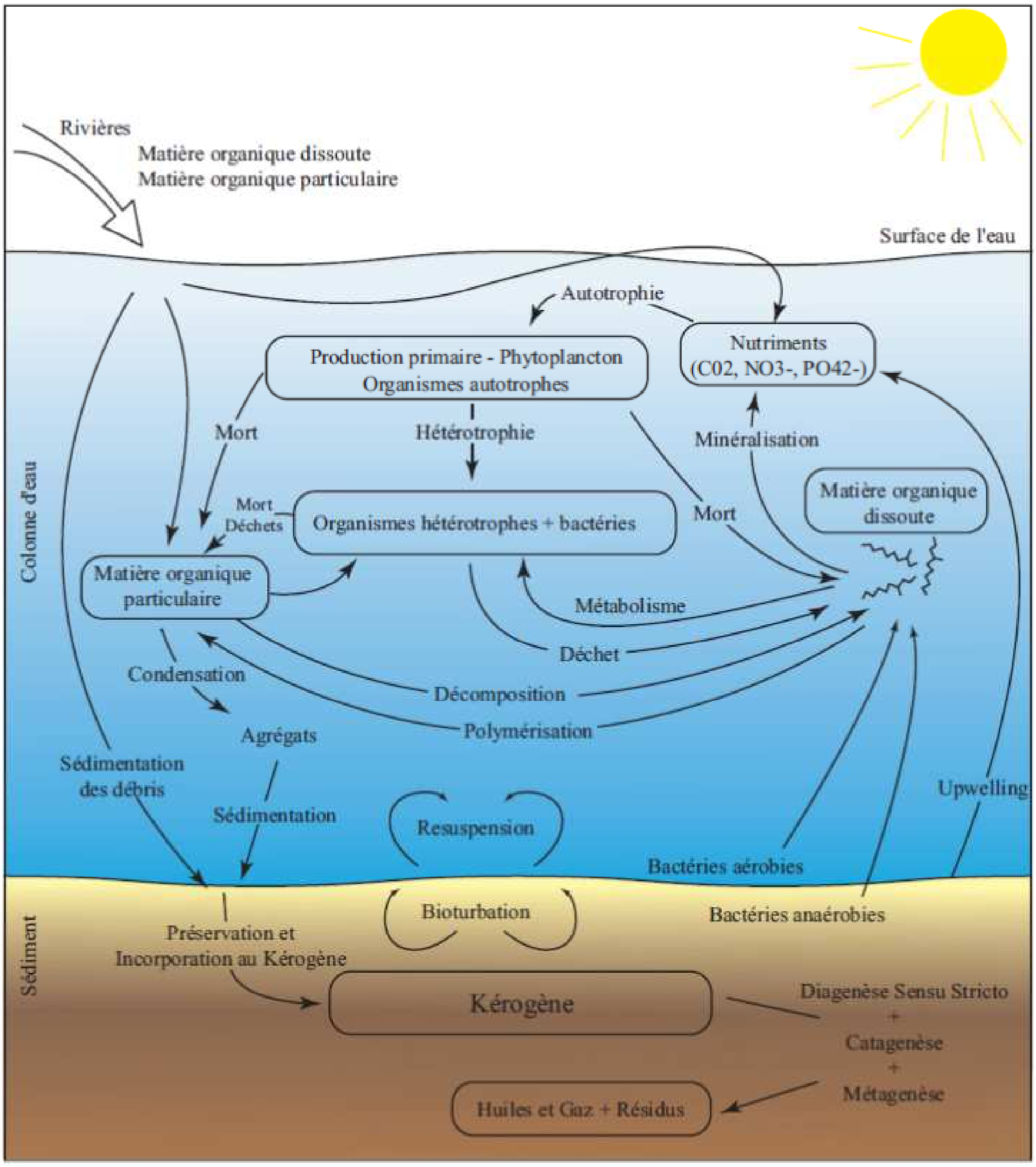

Fig.21 The cycle of organic matter in a sedimentary fluvial-lacustrine setting, from S. Bernard PhD Thesis (2008).

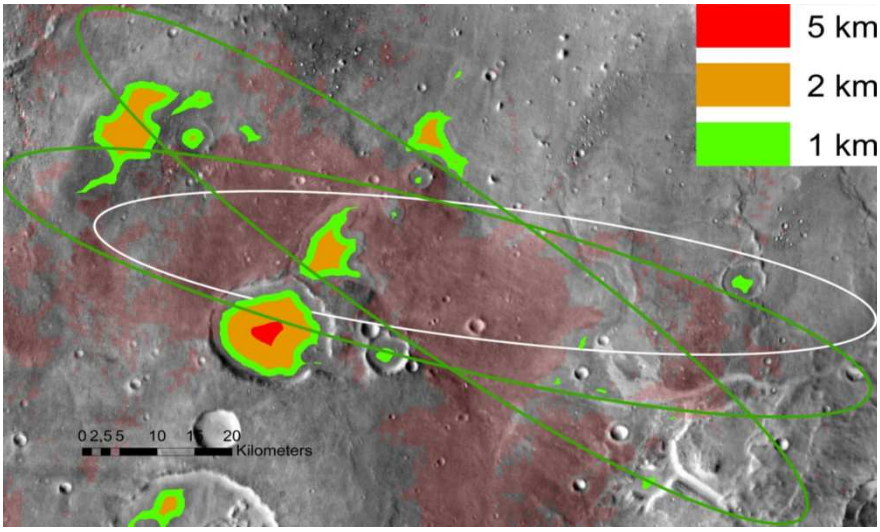

Figure 22 : Mapping of the area not defined as primary science target.

The clay rich unit and the fluivio-deltaic deposits are the primary scientific targets. The Amazonian volcanic unit is less relevant for the objectives of Exomars. But as shown in figure 22 there is no place inside the landing ellipse at more than 5km to the clays or the fluvio-deltaic deposits.

2. TERRAIN AND HAZARDS

Elevation

All elevations inside the possible 2020 landing ellipses are below -2700 m

Slopes

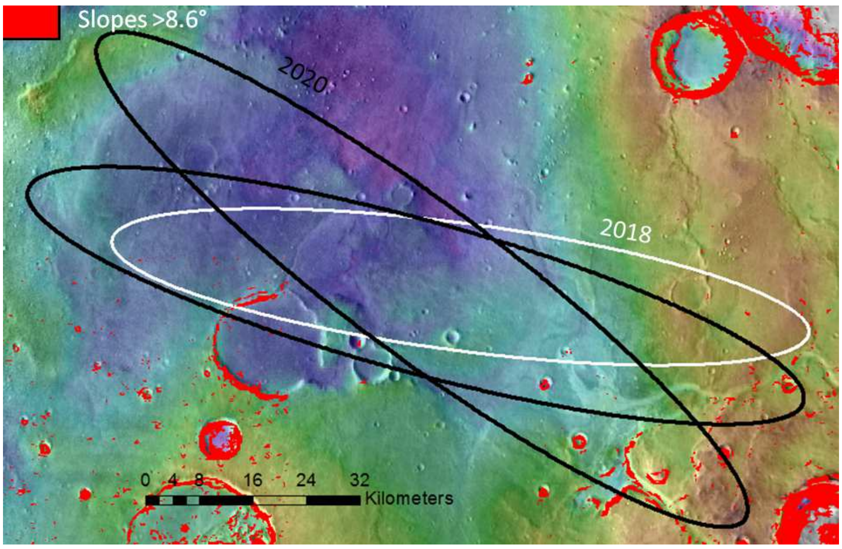

Figure 23 : Mapping of the slope larger than 8.6° on Mola

Detailed slope analysis is in Peter Fawdon's report distributed in the 09/03/2017. We agree with the results of this report.

Crater density and distribution

Globally, the crater density of craters smaller than 500m is not high due to ongoing erosion. You can find in figure 24 the crater density of the clay units, and in figure 25, the crater density on the volcanic unit and on delta-fan. If we focus for instance on the crater density of the 100m diameter crater class, we can highlight at CTX and HiRISE scale that the highest crater density is observed on the volcanic unit, then the clay rich unit and then the delta-fan (see table below). At HiRISE scale inside the clay rich formation, the crater density is variable from almost no impact crater suggesting very recent exhumation to more dense craters possibly related to recent secondary cratering (Figure 26).

The region has several large recent secondary chains possibly related to 8 My Mojave crater further south. One of this chain is inside the 2020 ellipse (see figure 27) but in the border of the ellipse where the probability to land is negligible. At HiRISE scale, we can observe that the trafficability could be affected in case of a landing inside such secondary crater(figure 28). But the probability is very low and a landing outside such secondary crater would not affect the trafficability as the crater can be bypassed.

	Amazonian volcanic unit	Clays rich unit	Delta-fans
Crater density of 100 m diameter craters	Saturated > 3 craters /km^2	< 1 crater /km^2	~0.1 crater /km^2

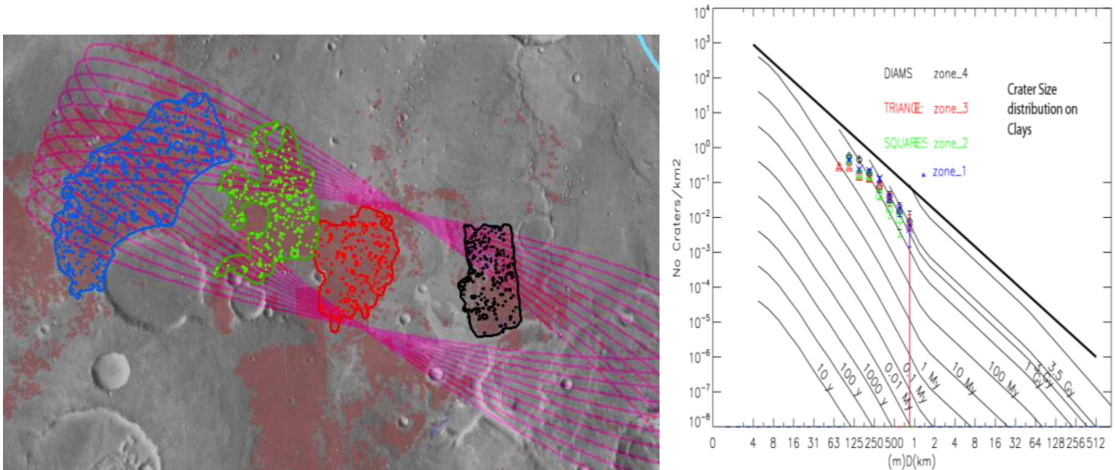

Figure 24 : Left : location of crater counts done at CTX scale over the clay rich unit. Right, Crater size distribution that shows an erosional pattern.

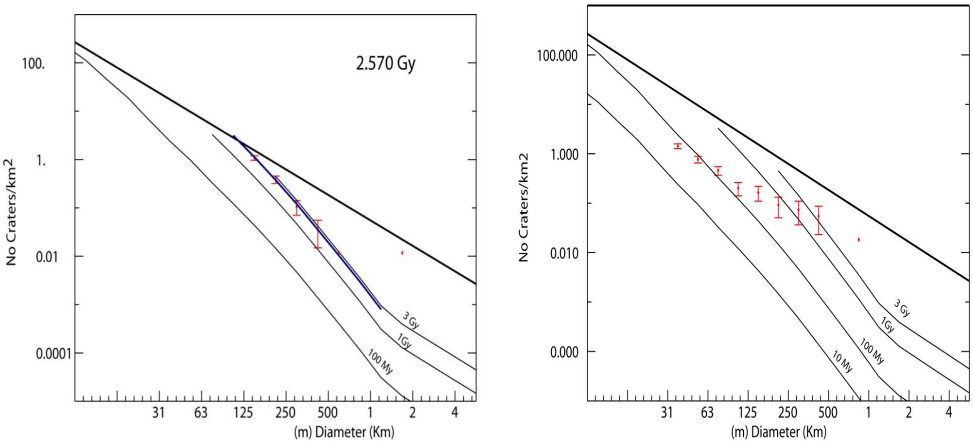

Figure 25: Left, crater size distribution in the volcanic unit. Right, crater size distribution on the delta-fan. The delta fan shows a strong erosional pattern.

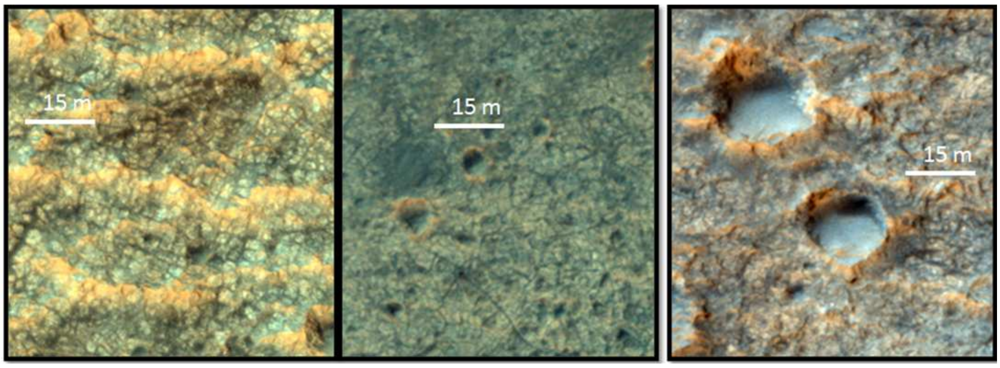

Figure 26 : Variability of the small scale crater density in the clay rich unit

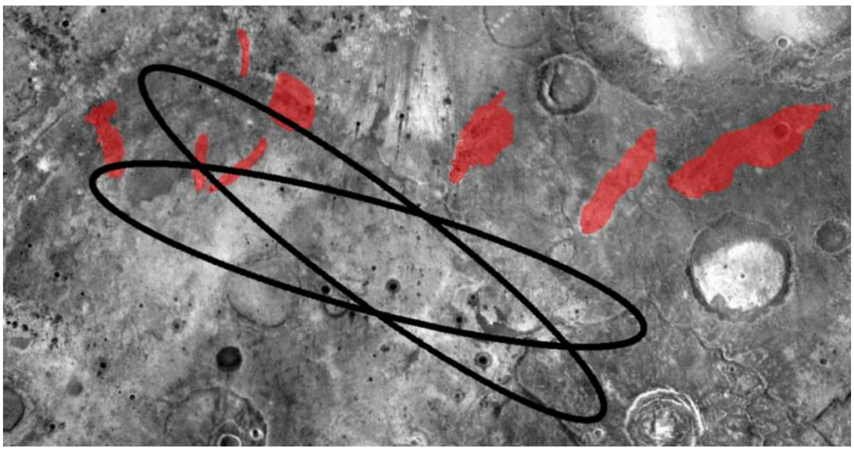

Figure 27: Large scale secondary Chain in Oxia planum region (mapped in red)

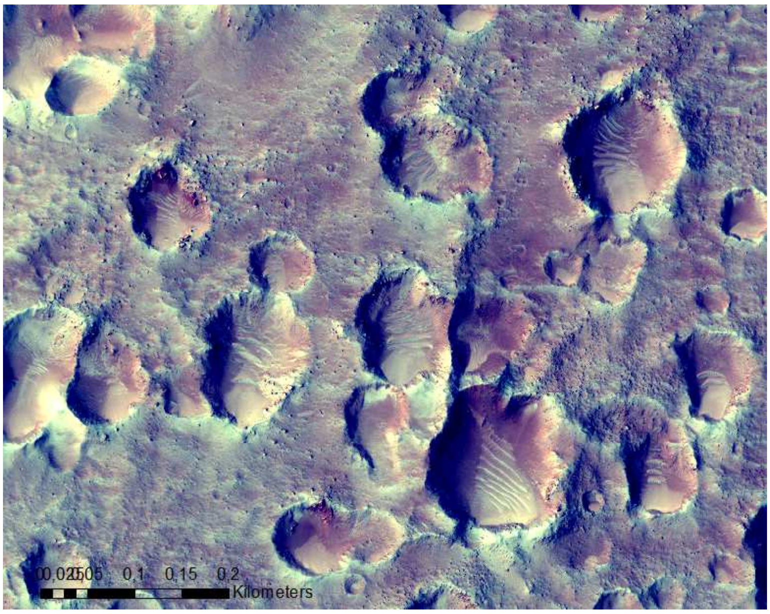

Figure 28 : Isolated secondary chain zone inside the ellipse

Albedo, Thermal inertia, Dust

TES Thermal inertia inside the 2020 ellipse : 257 to 483 $J.m^{-2}.s^{-0.5}.K^{-1}$

TES Albedo inside the 2020 ellipse: 0.18 to 0.22

Rock Abundance

See below manual boulder abundance mapping on a small area inside the ellipse.
The clay rich unit has one order in magnitude less boulders than the volcanic unit.

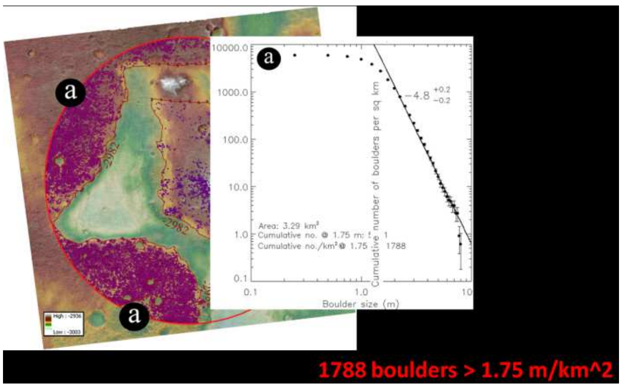

Figure 29: Boulder manual mapping on a sample of the volcanic unit

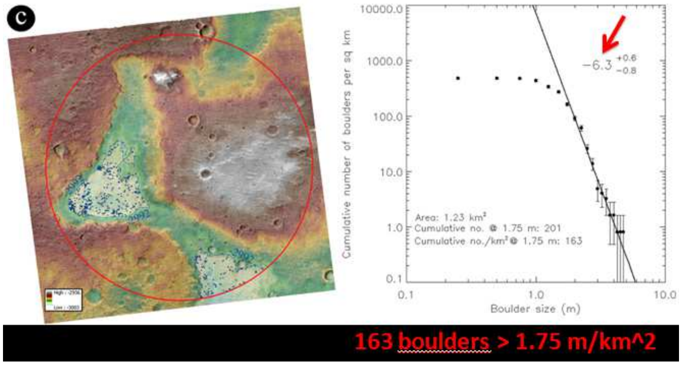

Figure 30: Boulder manual mapping on a sample of clay rich unit

Loose material :

We agree on D. Loizeau et al. work on loose material over Oxia Planum landing site.