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LOOSE SOIL PRESENCE AND CHARACTERIZATION AT THE 2020 EXOMARS CANDIDATE LANDING SITES

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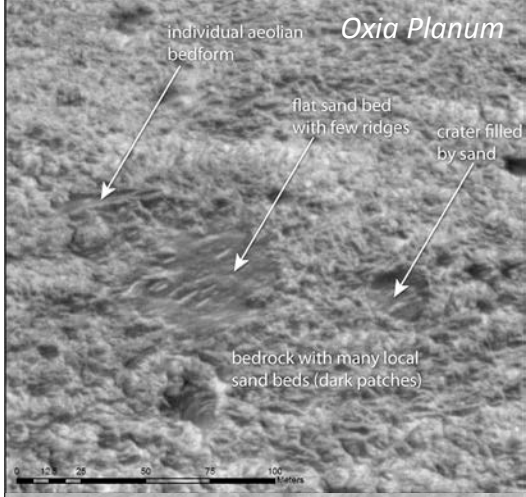
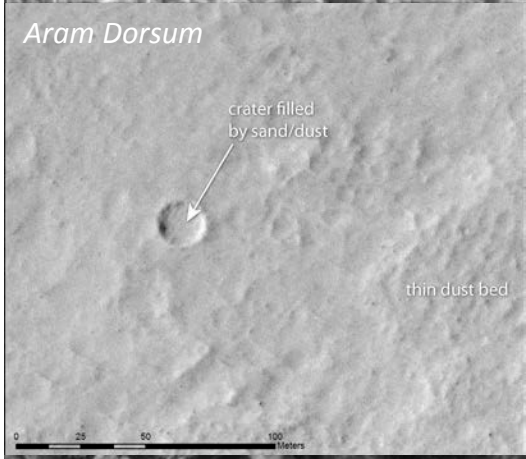
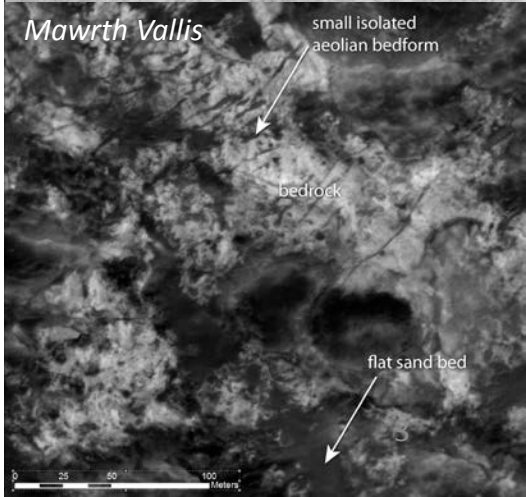
Introduction

Fig 3.2: Examples of dust, sand and aeolian bedforms at the 3 candidate sites







Loose soil (dust to sand) can form aeolian bedforms (dunes, ripples), but can also accumulate without any specific morphology, resulting in flat and uniform surfaces. Like aeolian bedforms, the surface of flat bedforms can consolidate over time, but the thickness and stiffness of this consolidated surface cannot be predicted.

Unconsolidated terrains can be an issue for a rover on the surface of Mars, and the loss of MER Spirit demonstrated the hazard represented by a sand sheet (Figure 3.1). Dust and sand are present at all candidate landing sites (Figure 3.2), in various thicknesses, surface distribution, and grain sizes.

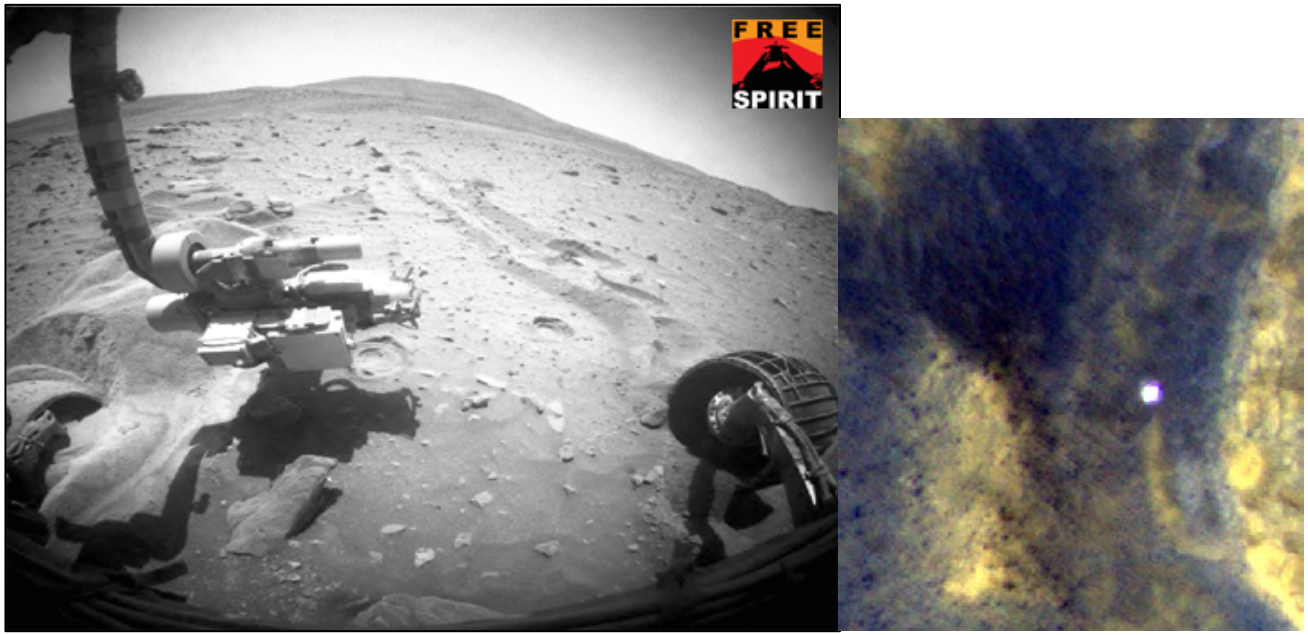
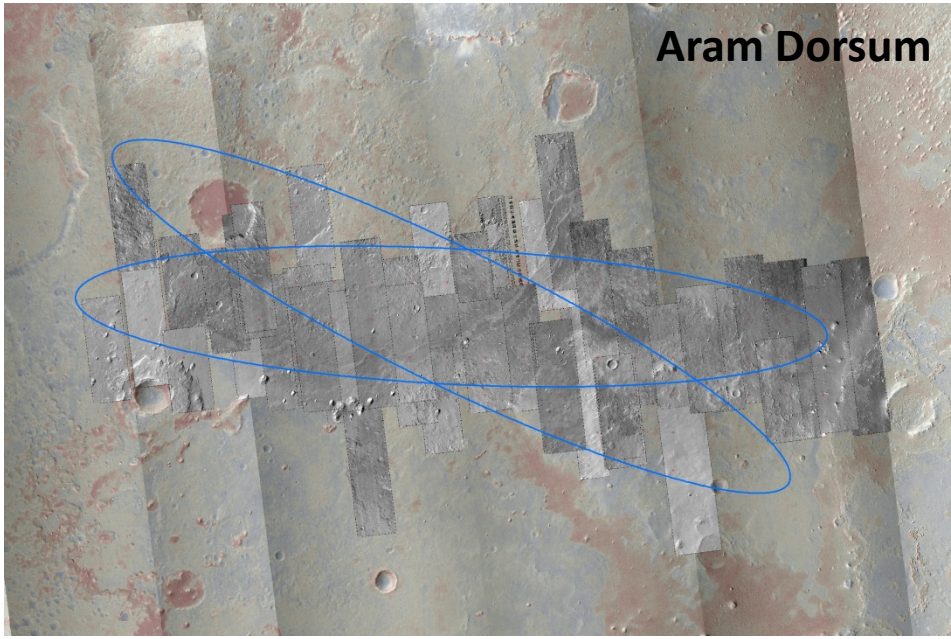


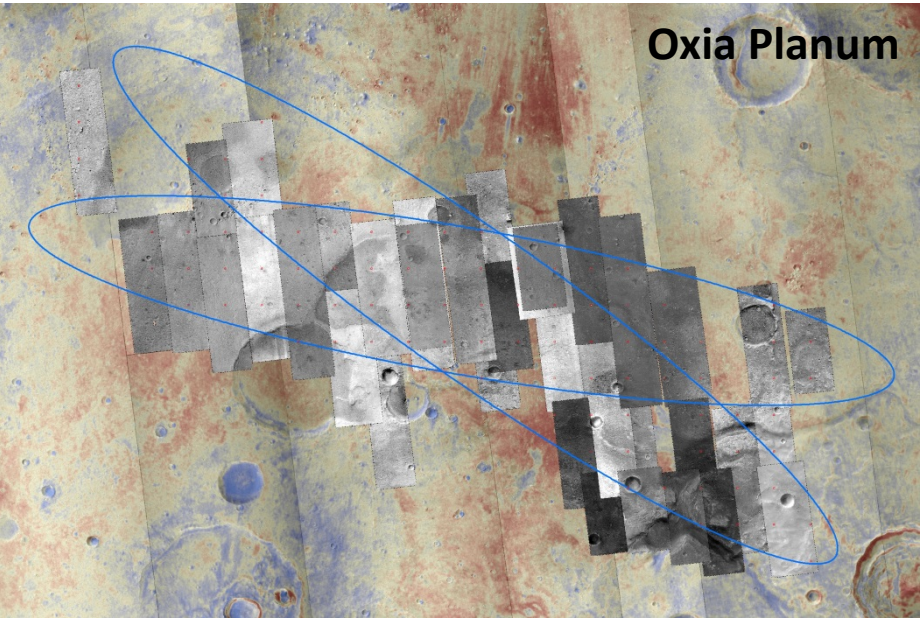
Fig 3.1: MER Spirit Rover got stuck in sand

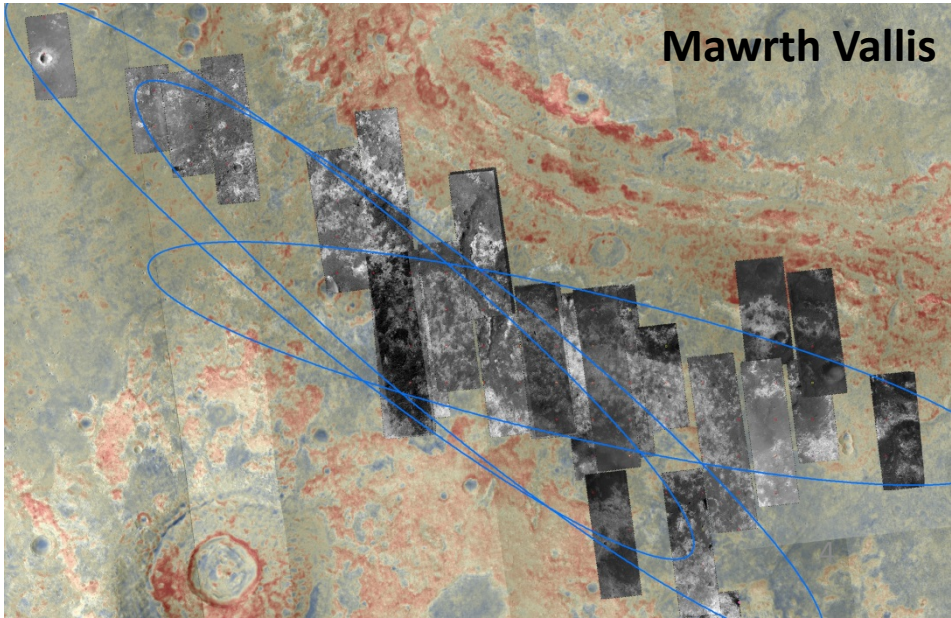
Mapping strategy (1/3)

Fig 4.1: ExoMars 2020 candidate ellipses and available HiRISE images

- Flat loose soil can occur over meter wide patches: mapping is needed at the HiRISE resolution (25 cm/pixel)
- On a large screen, one can display a HiRISE image at full resolution (one pixel of the screen for one HiRISE pixel) over ~400 m x 250 m
- Problem: The candidate ellipse dimensions (fig 4.1) are 120 km by 20 km for Oxia Planum and Mawrth Vallis (1885 km²), and 100 km by 20 km for Aram Dorsum. → To fully map one ellipse, would require at least 18,850 frames at full HiRISE resolution! And close to twice as many for the full site.





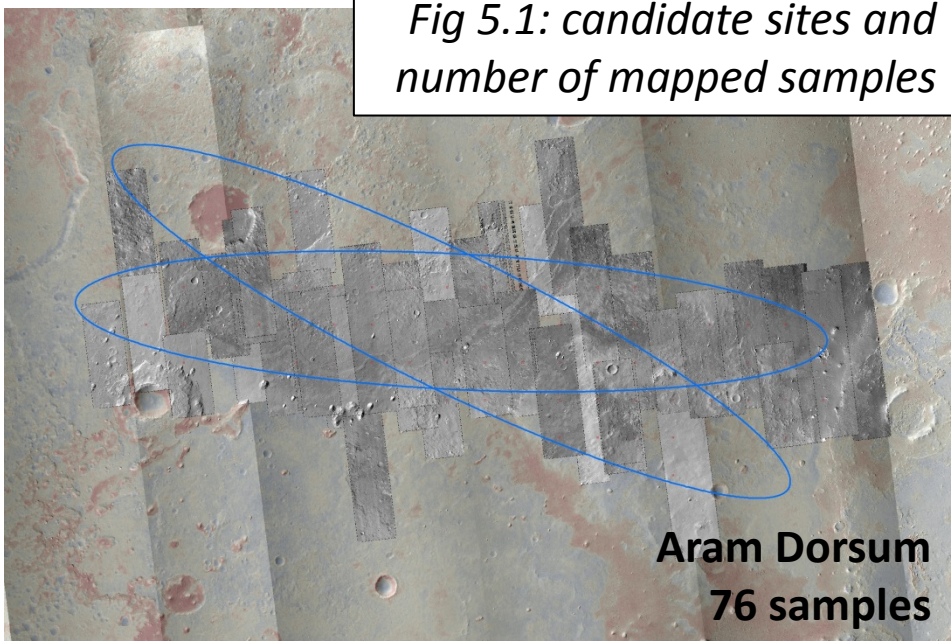


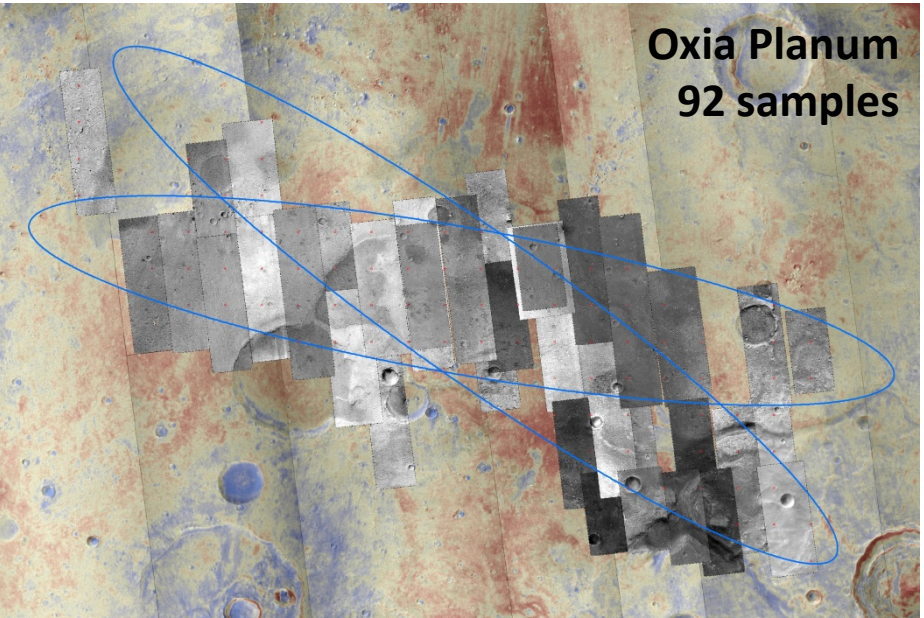
Mapping strategy (2/3)

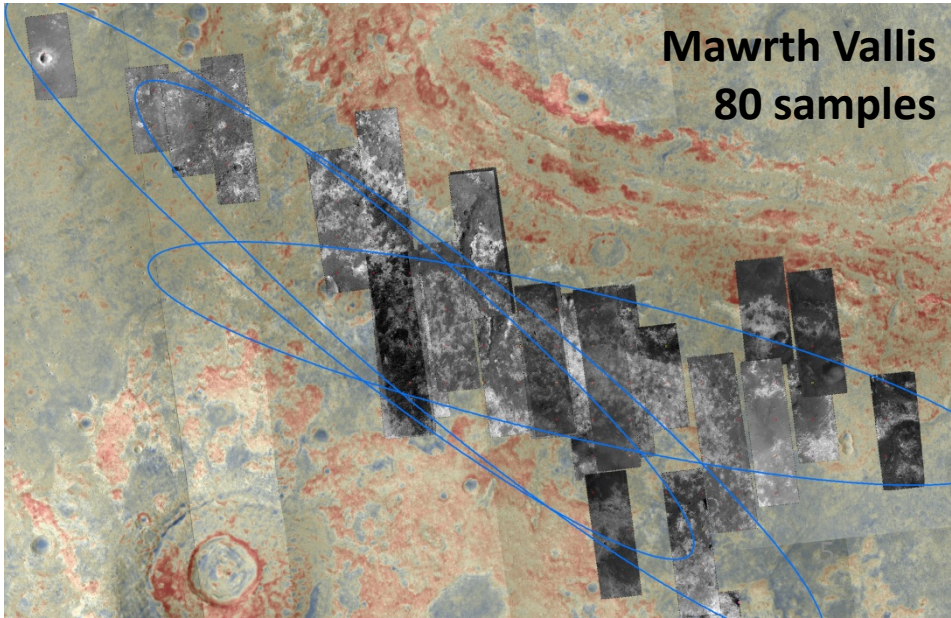
To avoid endless work, we chose to map samples regularly spaced over the three sites:

- **Samples:**
  - 200 m x 200 m squares (enable to see full square at HiRISE full resolution on a large screen)
  - Grid 5 km x 5 km (enable to have a few tens of samples per site for good representativity)
- **HiRISE images:**
  - Not available over the entire ellipse, but excellent coverage nevertheless (see Figure 5.1)
  - Only images at 25 cm/pixel were considered (images at 50 cm/pixel were discarded)
  - Images with bad signal were not discarded but were assigned a quality rating

Fig 5.1: candidate sites and number of mapped samples







Mapping strategy (3/3)

We define 5 types of surface terrain:

- **Bedrock:** this is generally a bright surface, with high frequency texture
- **Individual aeolian bedform:** an isolated dune or megaripple that is not adjacent to any other one, and can generally be avoided easily by the rover
- **Aeolian bedform field:** a field of adjacent ripples or dunes that can represent a large obstacle for the rover
- **Thick dust/sand:** a dust or sand cover that hides any underlying morphology/texture at a few tens of meters horizontal scale
- **Thin dust/sand cover:** a dust or sand cover that renders the surface smooth, hiding rocks but partly revealing underlying morphology/texture

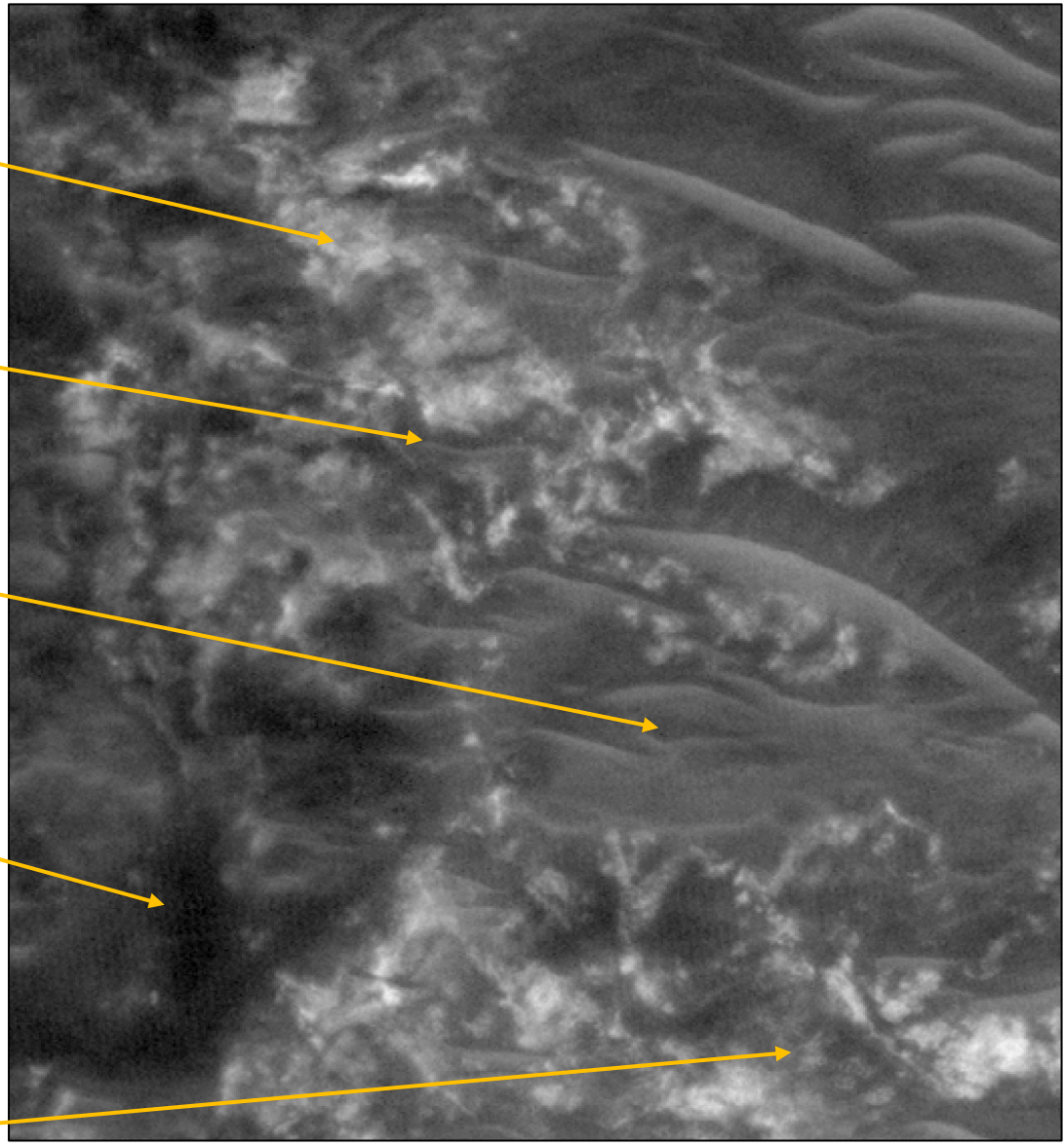
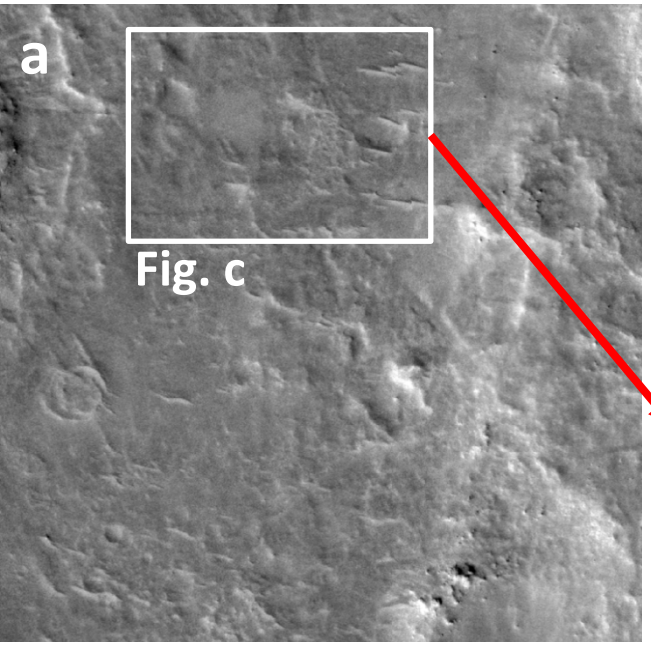
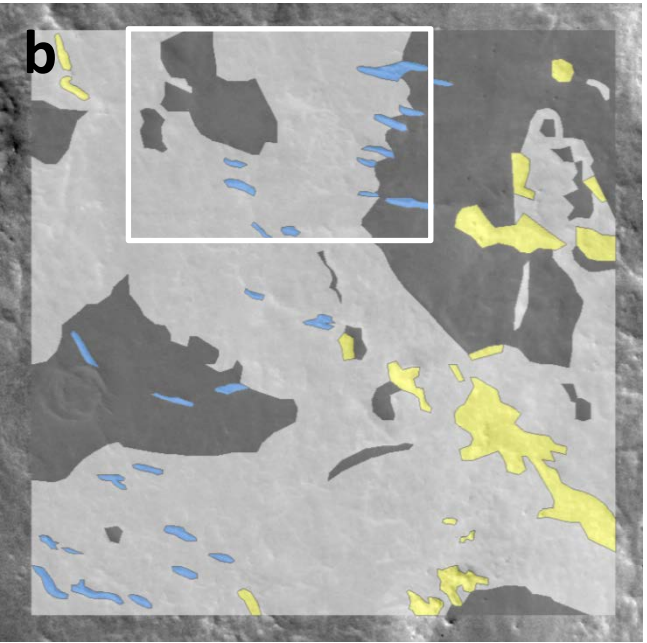
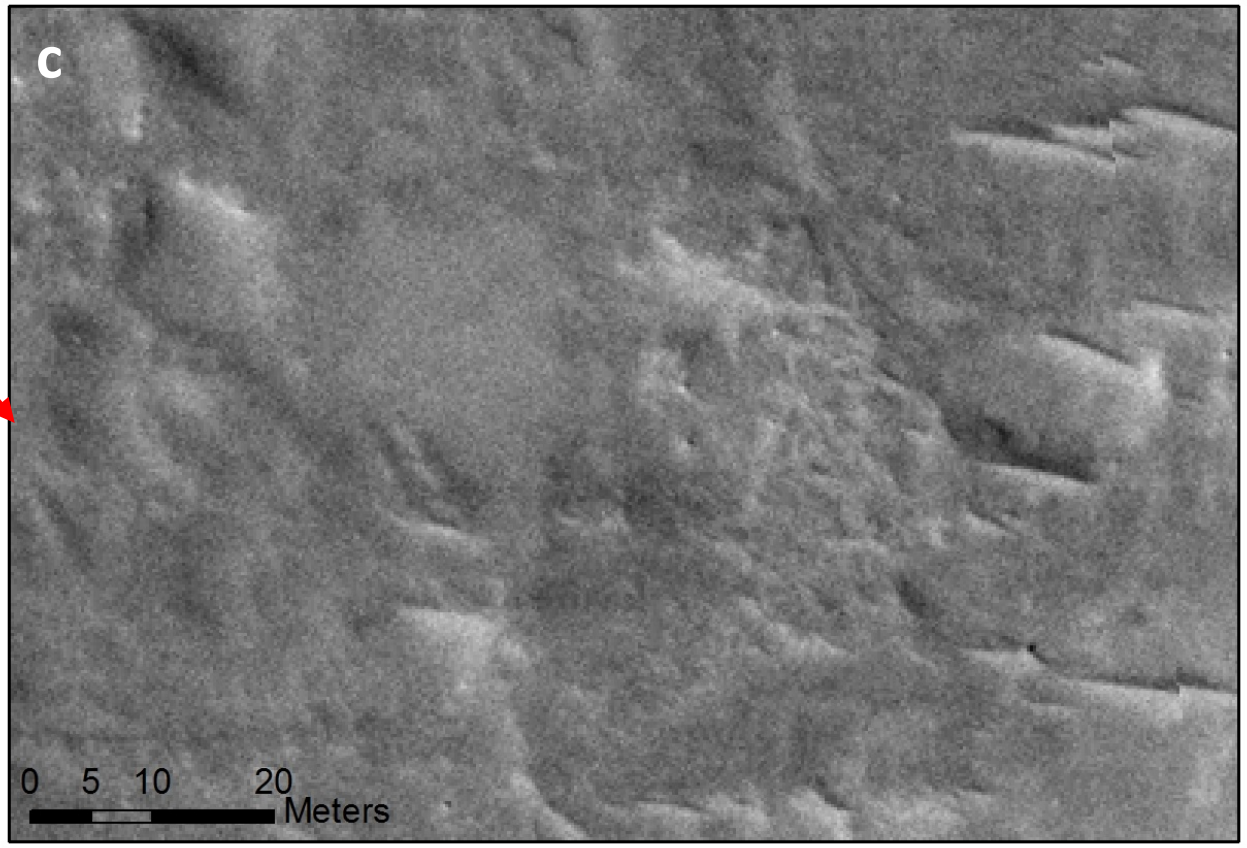


Fig 6.1: HiRISE image showing the 5 types of terrains distinguished and mapped in this project.

Thickness considerations (1/4)







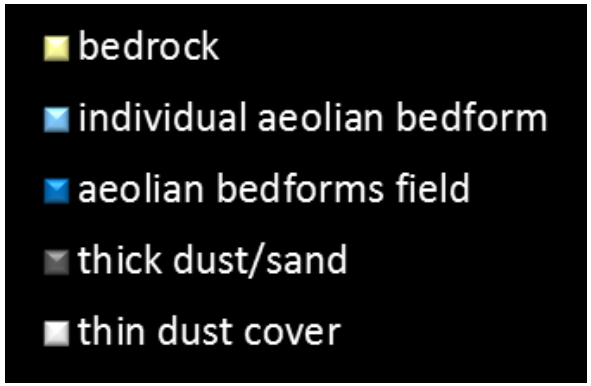
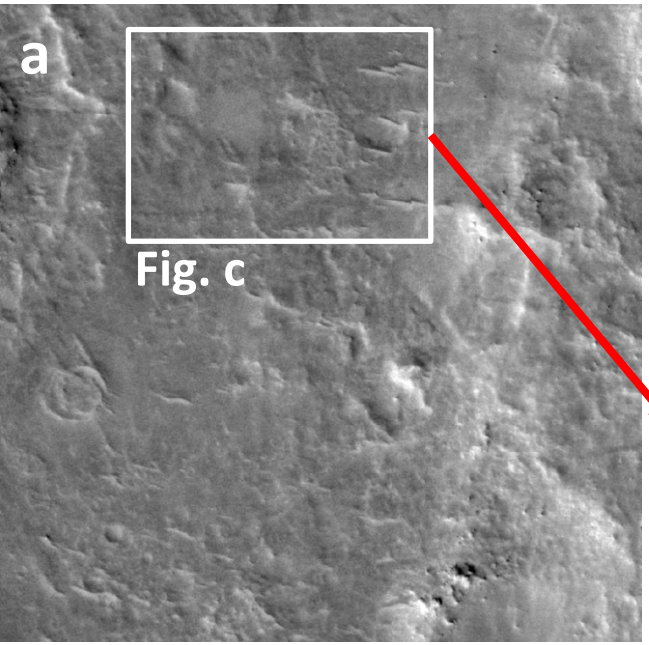
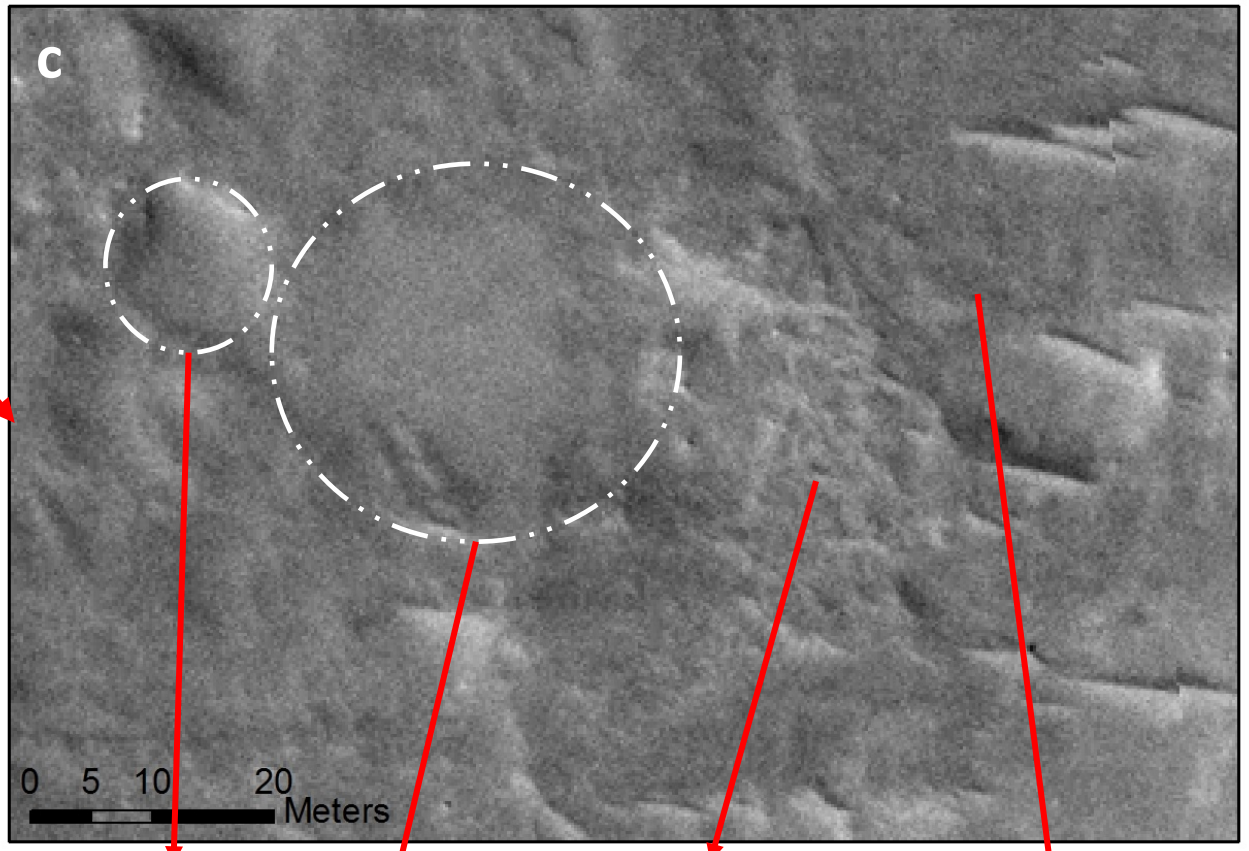


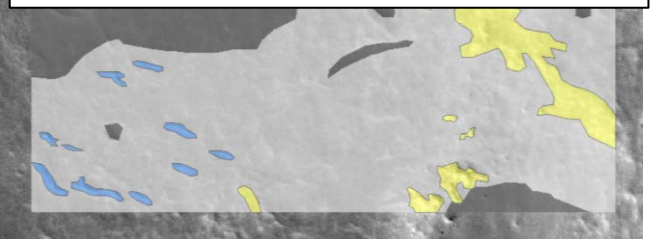
Fig 7.1: a)HiRISE observation showing dust in Aram Dorsum, b) interpretative map, c) close-up of a.

Thickness considerations (2/4)





Dust thickness can be roughly estimated from filled or partially filled structures (e.g., craters)



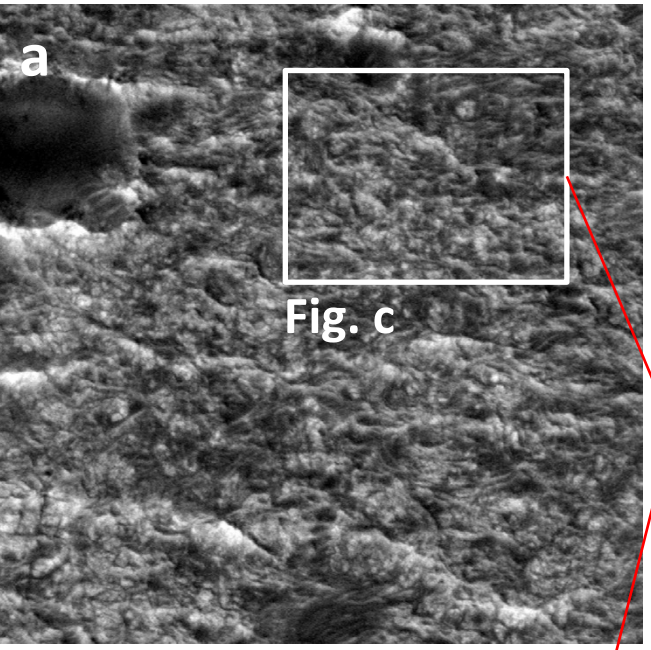
crater (12 m diam) partly filled, ~1m of dust/sand expected

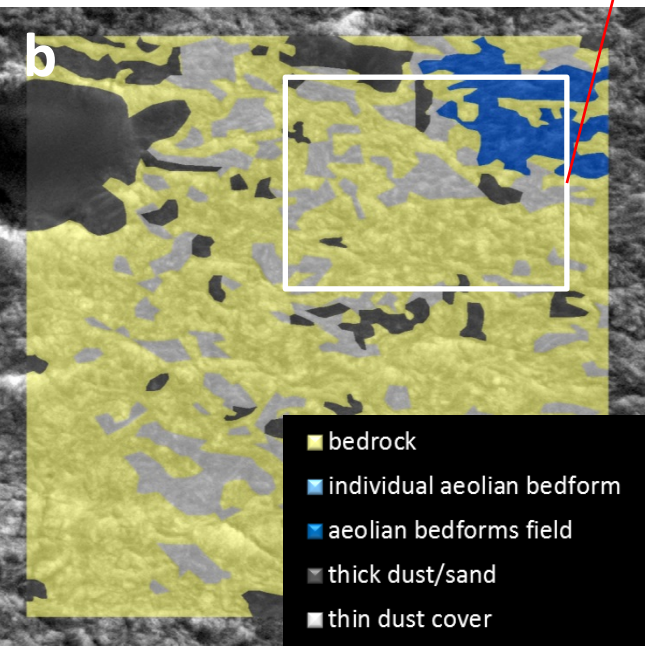
crater (30 m diam) almost completely filled, several m of dust/sand expected

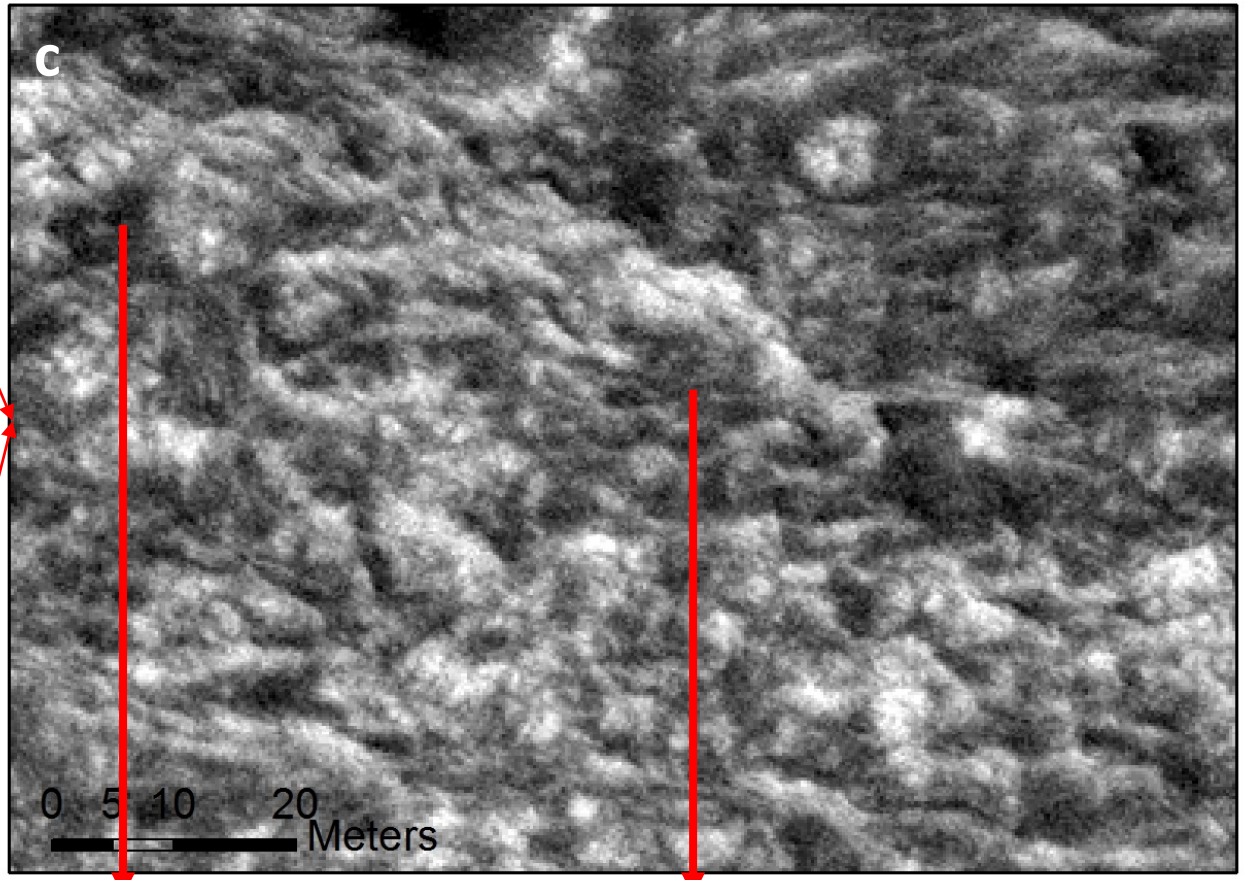
higher surface thin cover, m-scale structures visible, cm to few 10s cm of dust/sand expected

lower surface thin cover, some texture and 5m-scale structures visible, several cm to 10s cm of dust/sand expected

Thickness considerations (3/4)





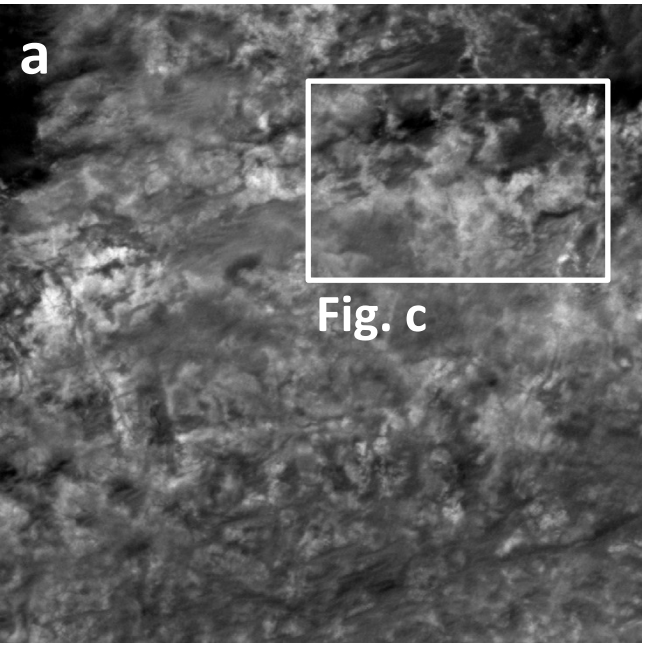


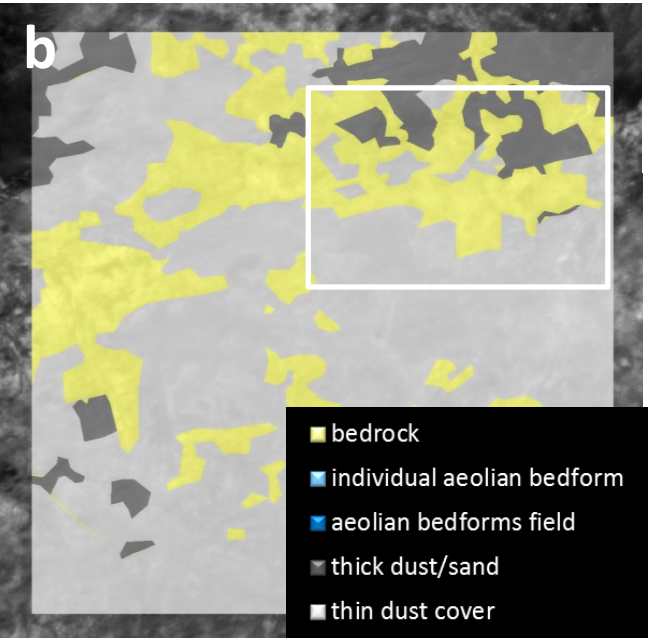
hole (9 m large), filled by sand, few 10s cm of sand expected

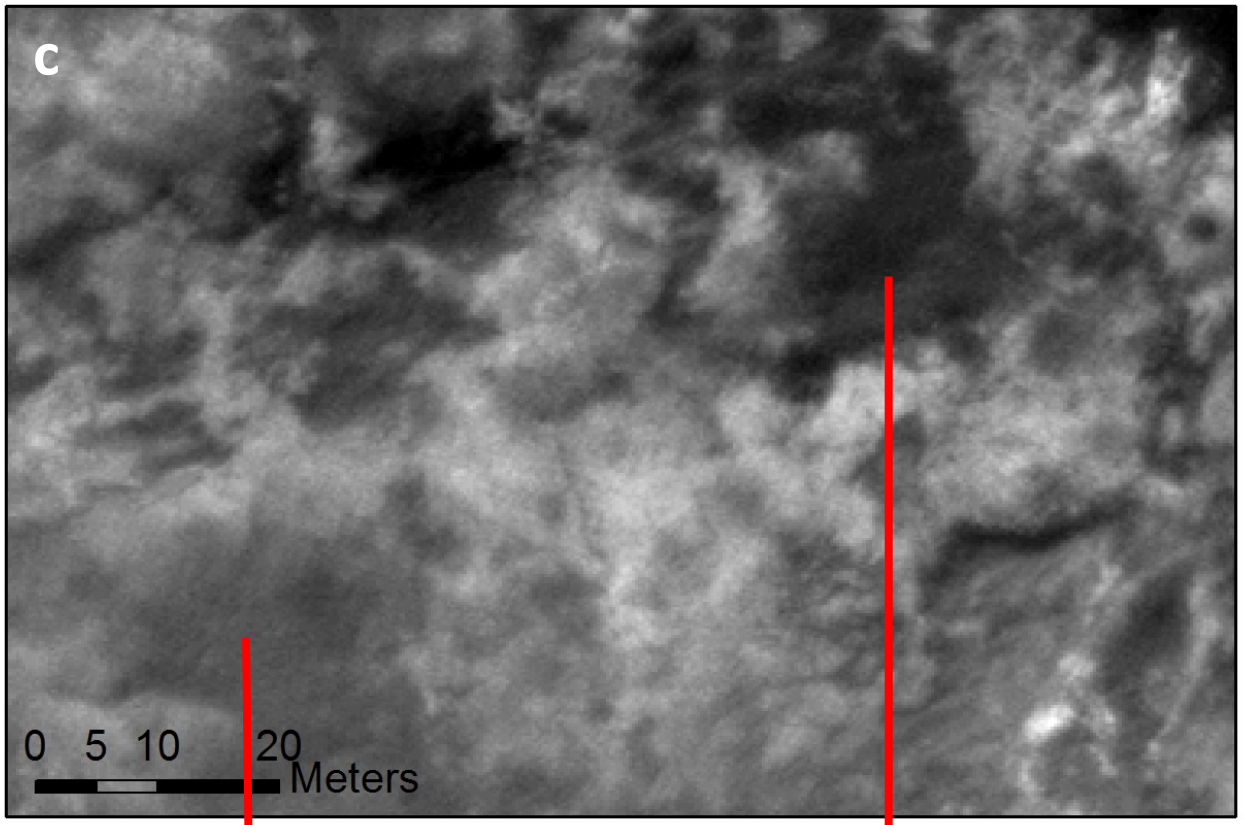
low surface, partly filled by sand, few cm to few 10s cm of sand expected

Fig 9.1: a)HiRISE observation in Oxia Planum b) interpretative map, c) close-up of a.

Thickness considerations (4/4)







sand or dust accumulation, few cm to few 10s cm of sand expected

15 m large sand accumulation, few 10s cm of sand expected

Fig 9.1: a)HiRISE observation in Mawrth Vallis b) interpretative map, c) close-up of a.

Assessing driving hazards

Safe

- **Bedrock:** the surface is hard and hence, when flat, is not a hazard. However, cracks and float rocks can be present. Cracks/fractures as large as few tens of cm can be filled by sand and not be mapped in this study.

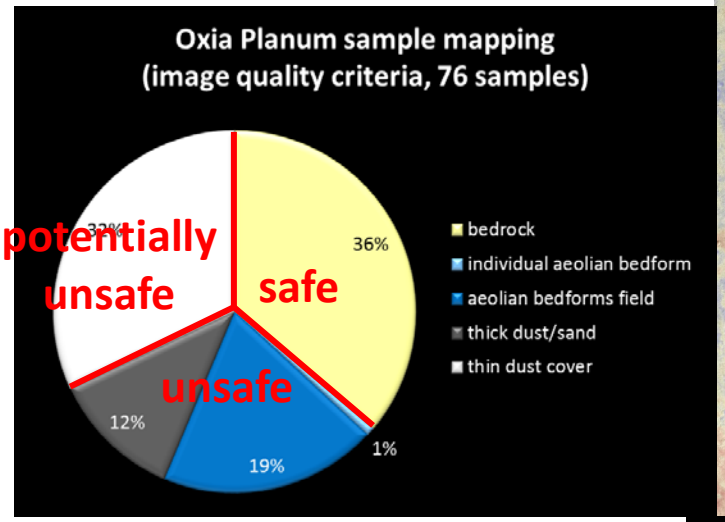
Unsafe

- **Individual aeolian bedform:** better avoided, depending on its height (see joint TAR study by Bridges et al.). Thickness range from a few cm to a few meters.
- **Aeolian bedform field:** better avoided if driving around is not much longer than driving through. Thickness can be a few cm to a few meters.
- **Thick dust/sand:** better avoided, although the surface can be indurated in some cases and could then be a nice flat surface for driving. Thickness can be a few tens of cm on flat surfaces to a few tens of meters within craters.

Potentially unsafe

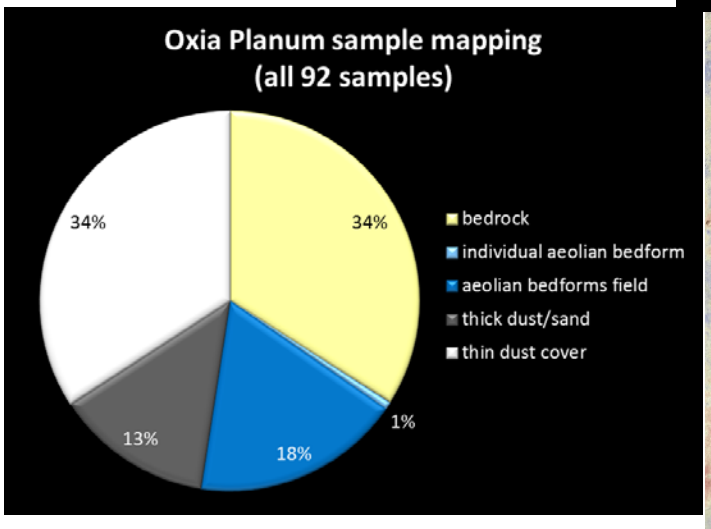
- **Thin dust/sand cover:** High uncertainty on the possibility to drive on it. Thickness highly variable, can be a few cm to a few tens of cm.

Mapping results

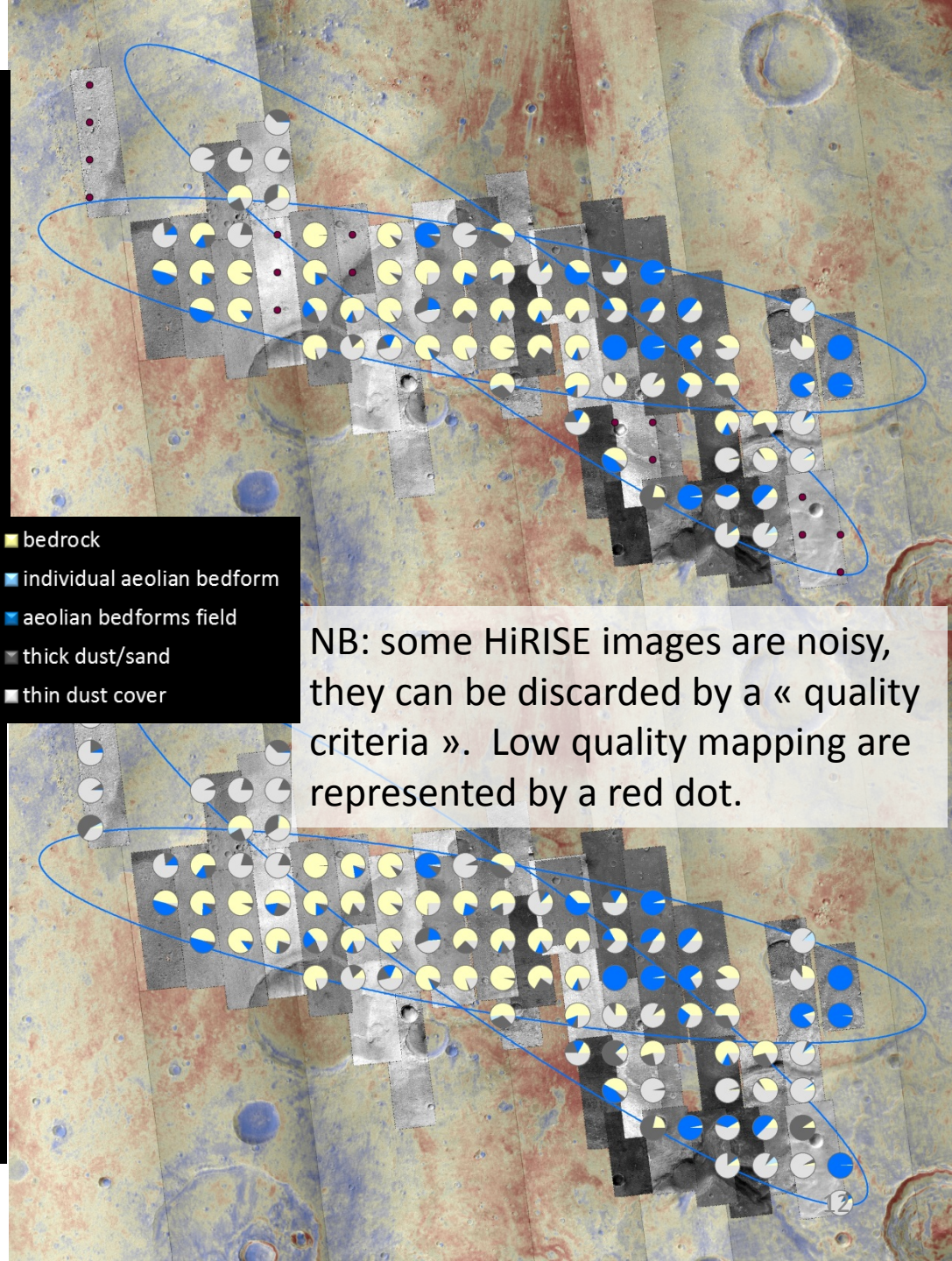


Noisy data removed

Oxia Planum

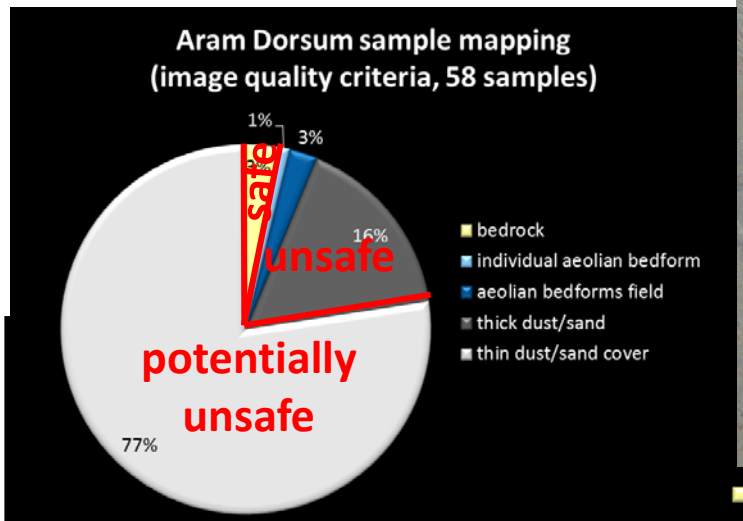


With all HiRISE images

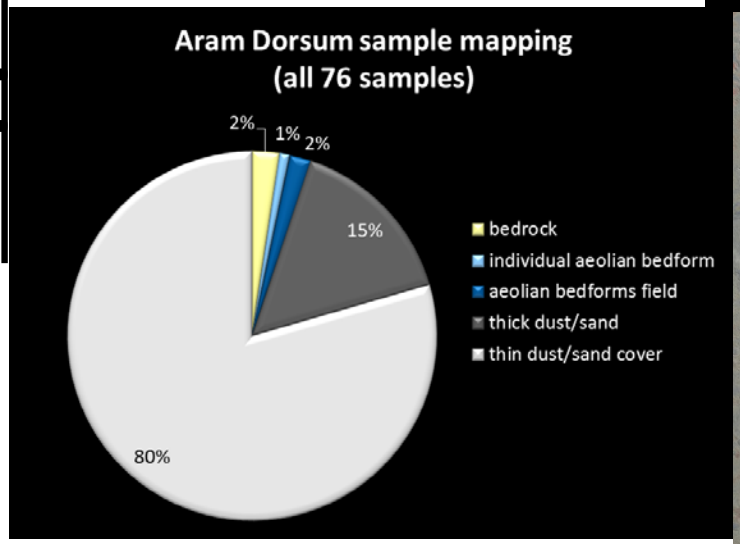


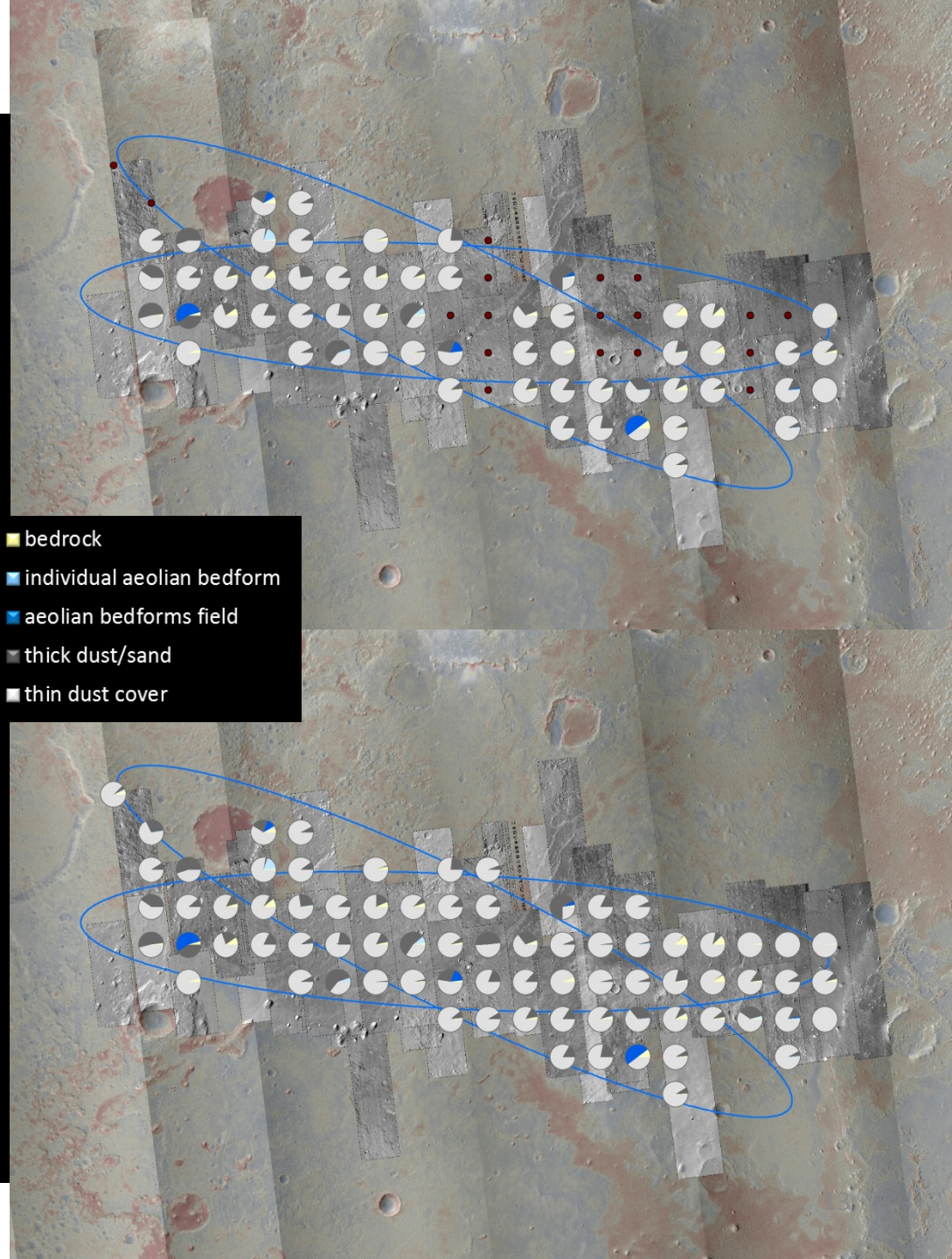
NB: some HiRISE images are noisy, they can be discarded by a « quality criteria ». Low quality mapping are represented by a red dot.

mapping results



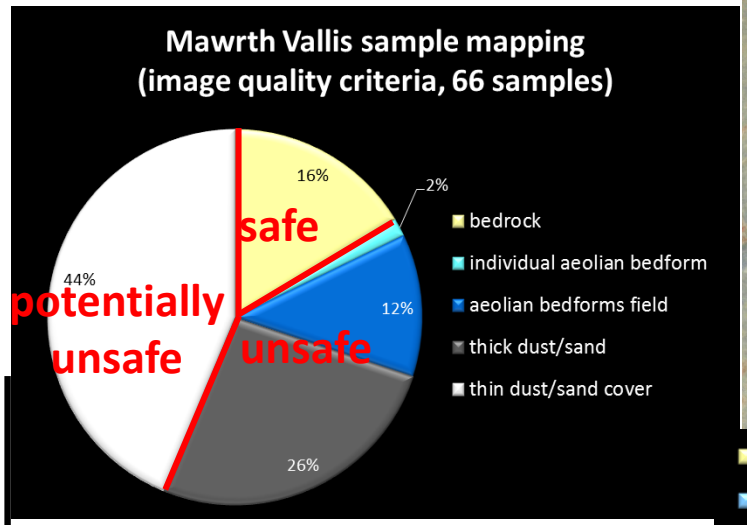
Aram Dorsum

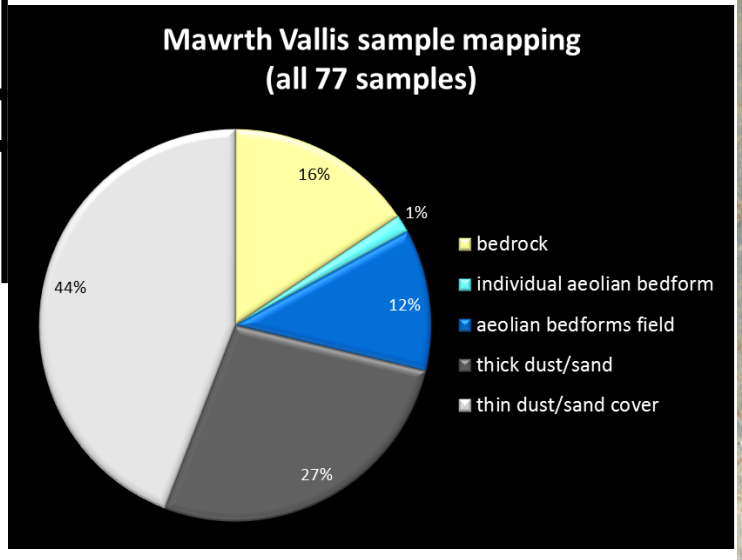


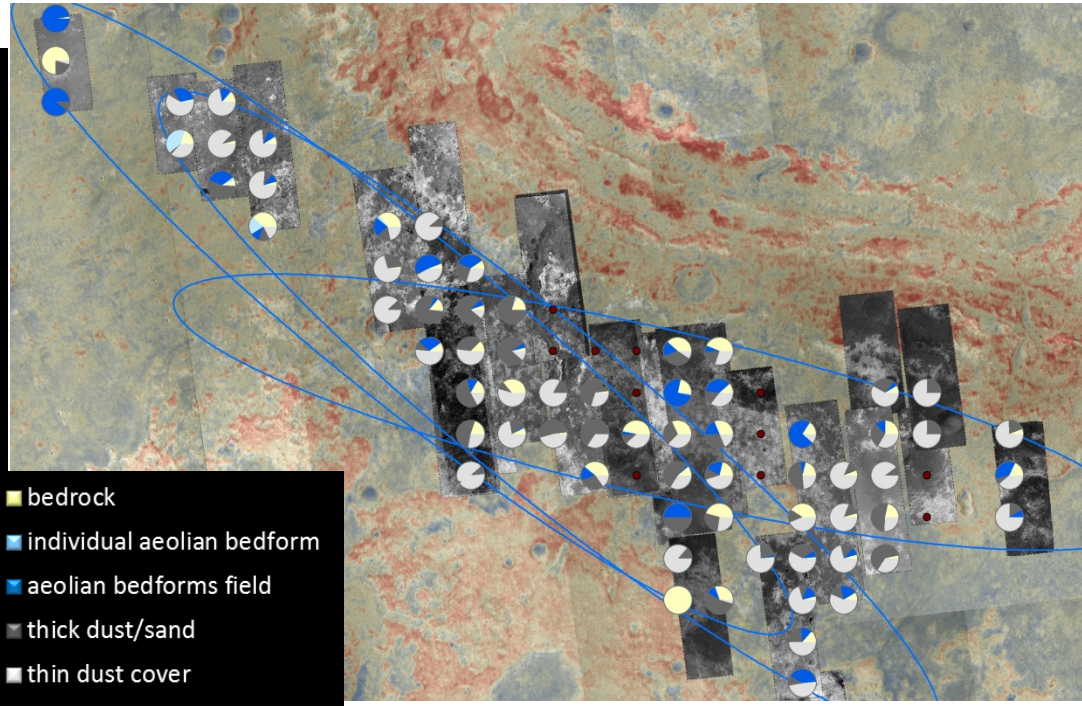


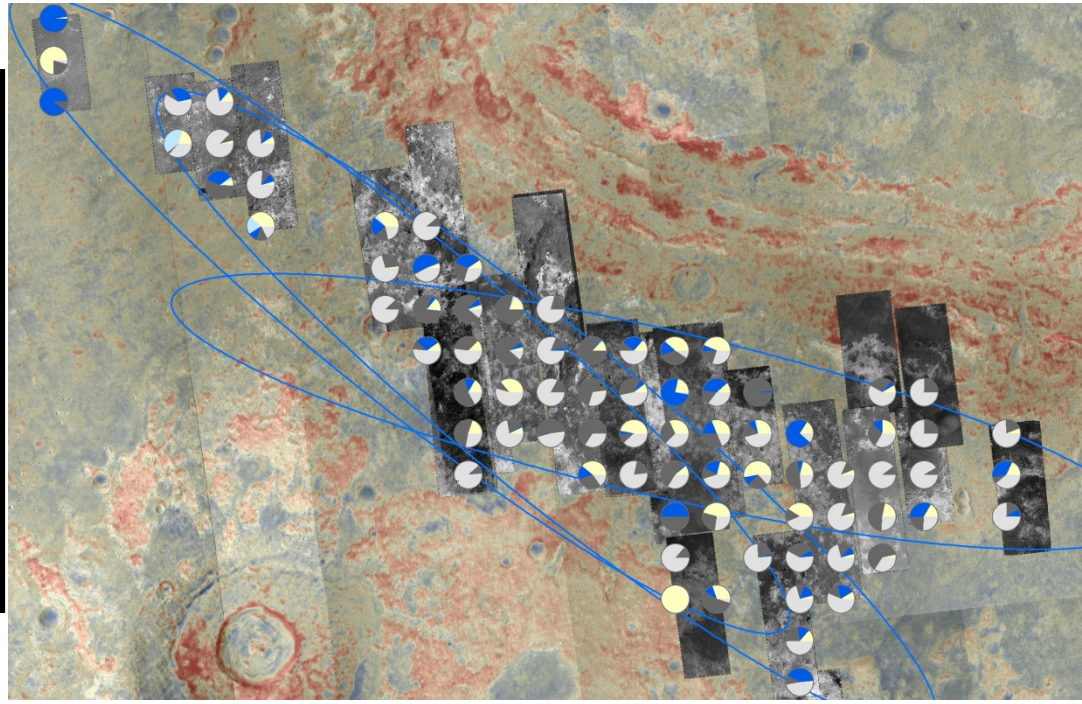
mapping results

Mawrth Vallis







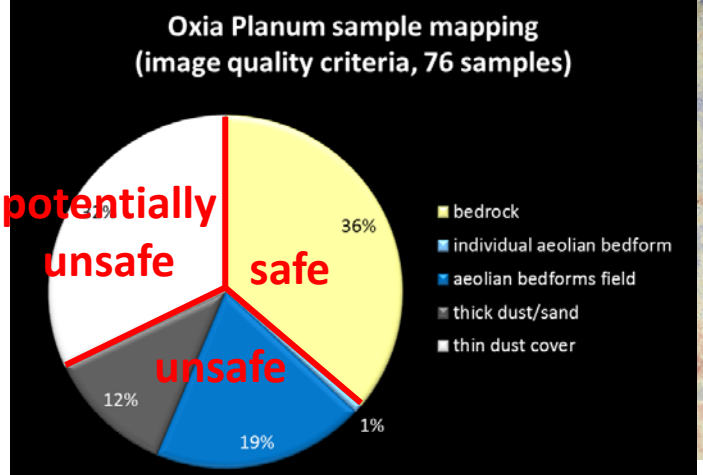


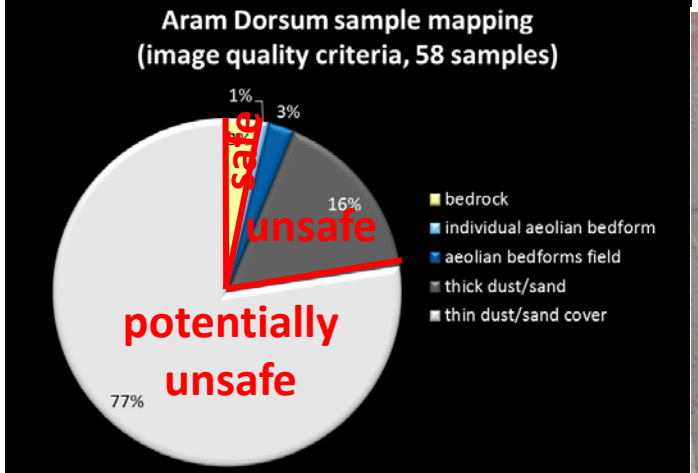
Mapping results: summary

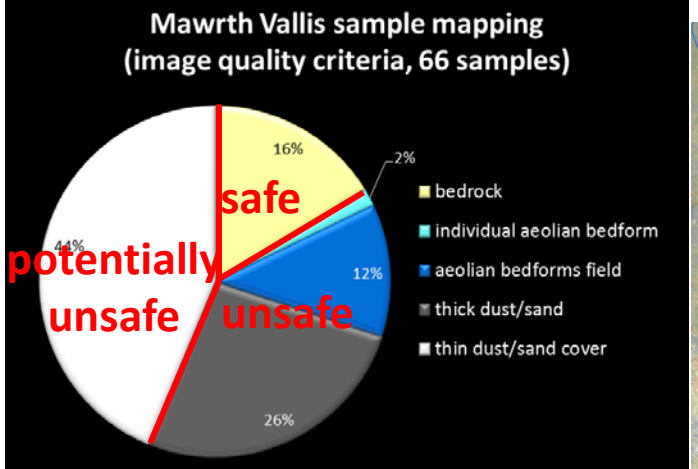
Oxia Planum has the largest percentage of bedrock exposure, with roughly 1/3 of bedrock, 1/3 of thin sand, 1/3 of thick sand deposits.

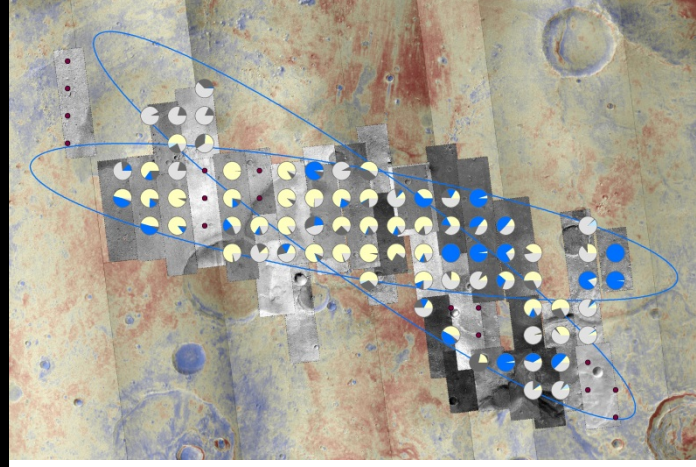
Aram Dorsum has very little bedrock exposed, less thick dust/sand cover and dunes or ripples than the other sites (20%), but more than ¾ of the surface is covered by a dust cover from few cm to few 10s cm where the surface conditions and trafficability are uncertain.

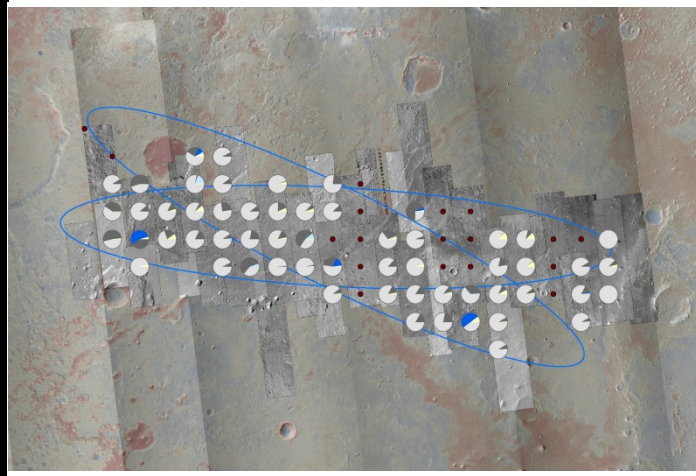
Mawrth Vallis has a significant bedrock surface, a large surface covered by a thin sand cover, and a large surface covered by sand deposits (41%).

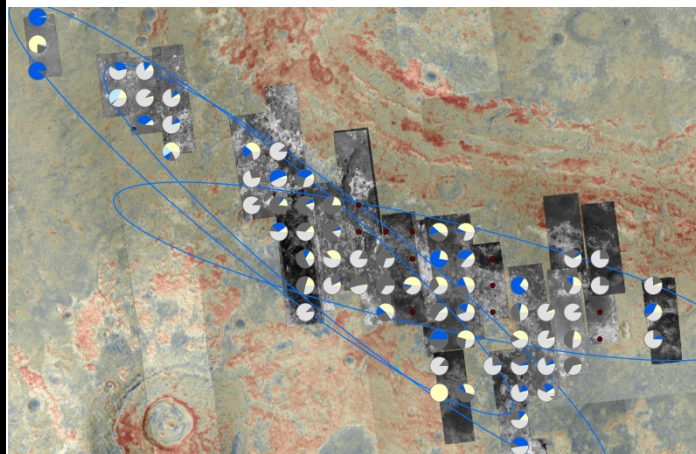






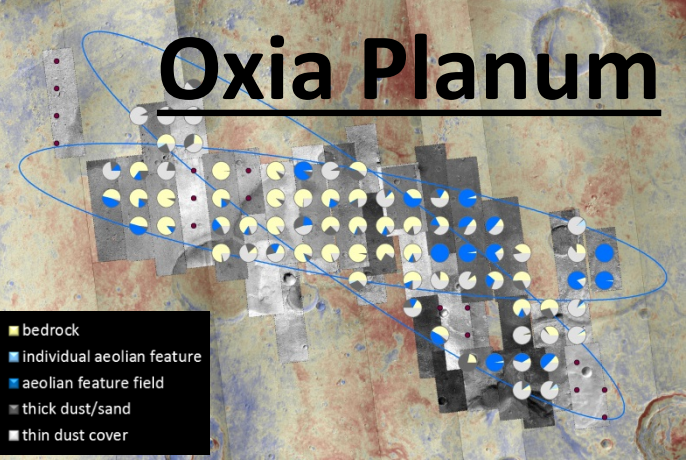


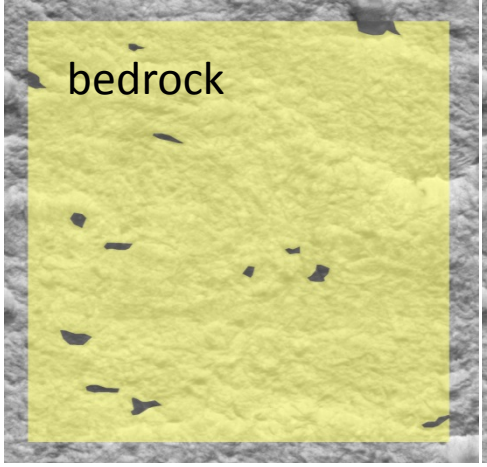


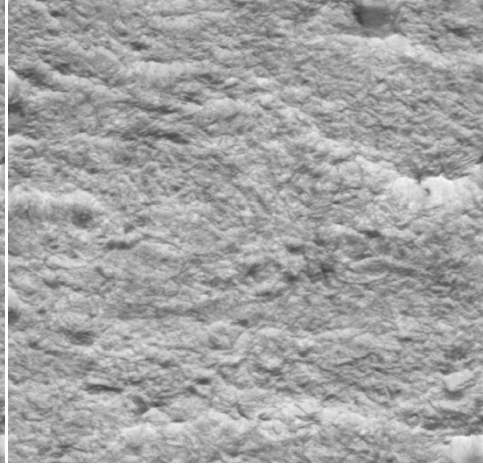


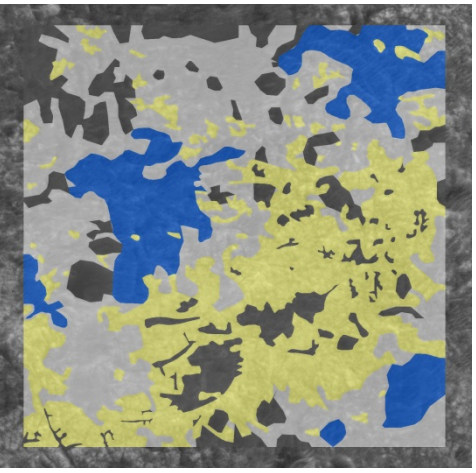
Oxia Planum

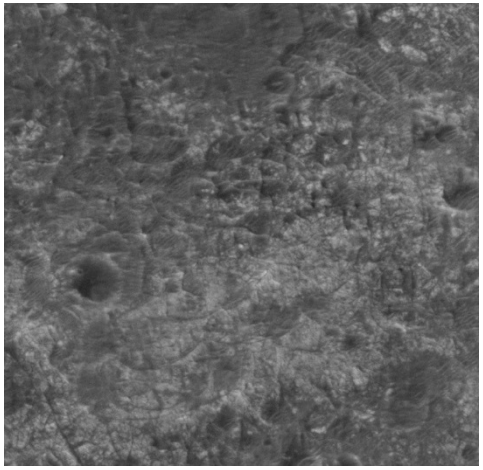
sample diversity

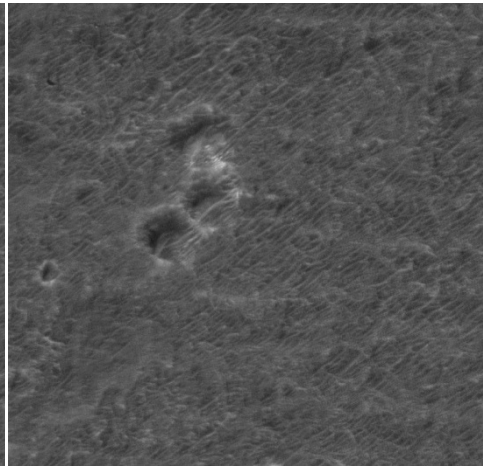


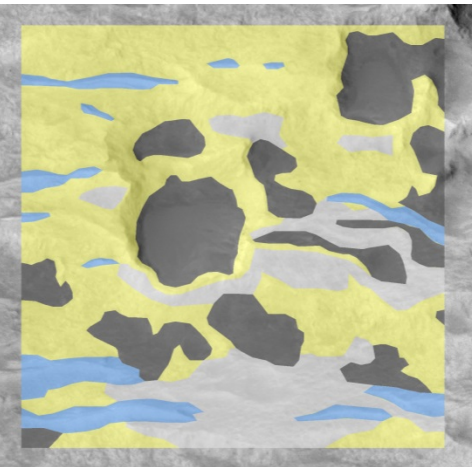


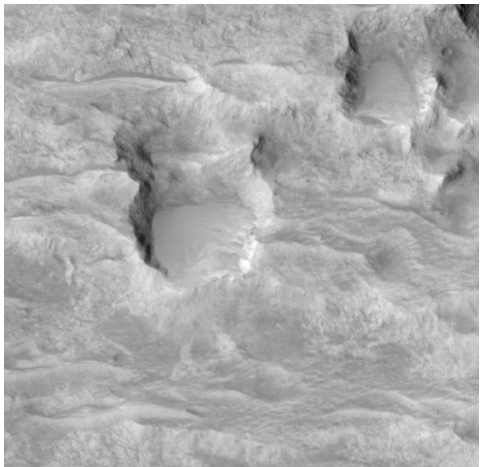


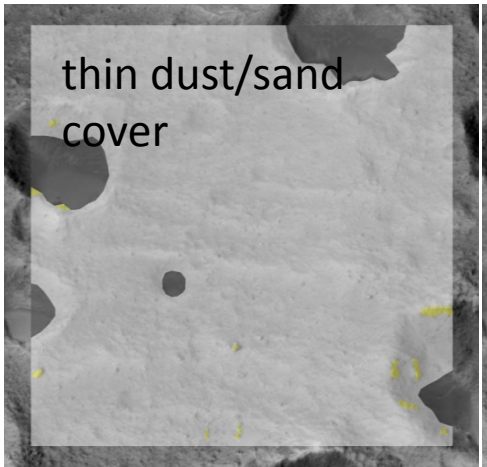


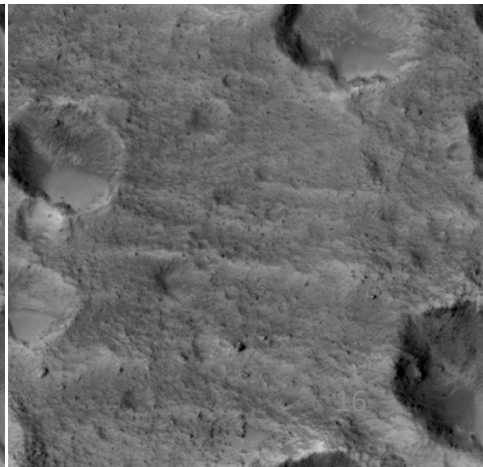






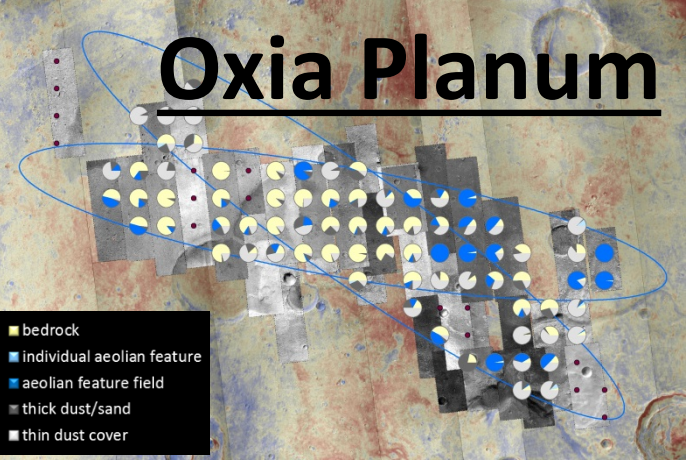


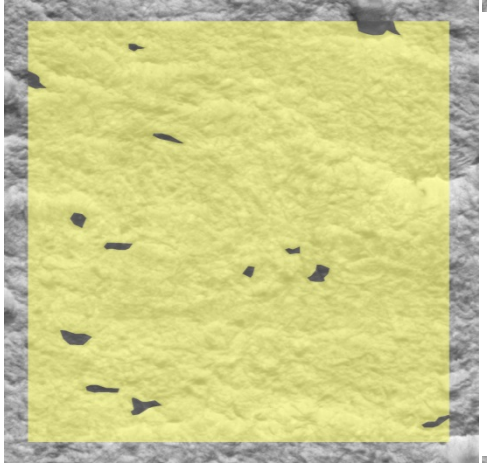


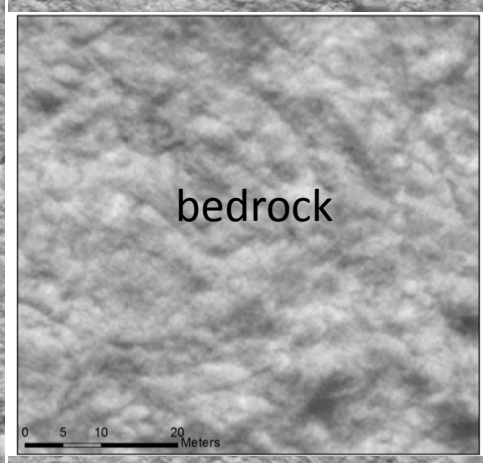


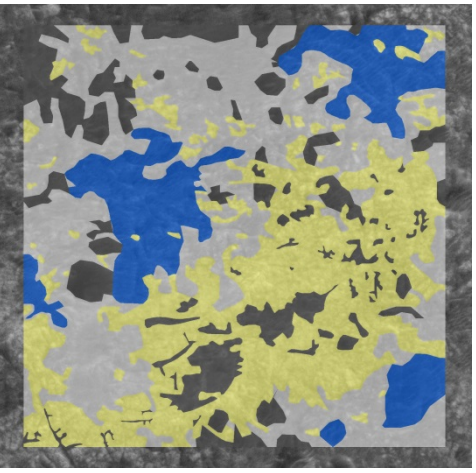
Oxia Planum

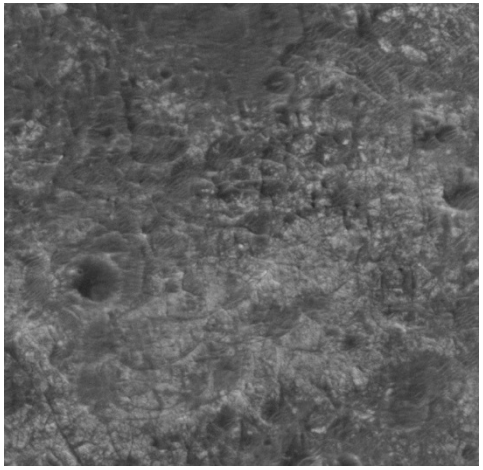
sample diversity

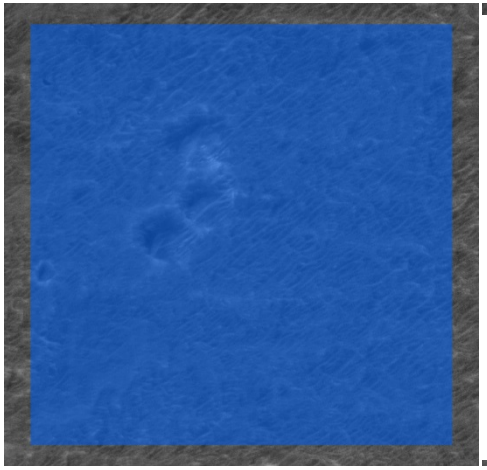


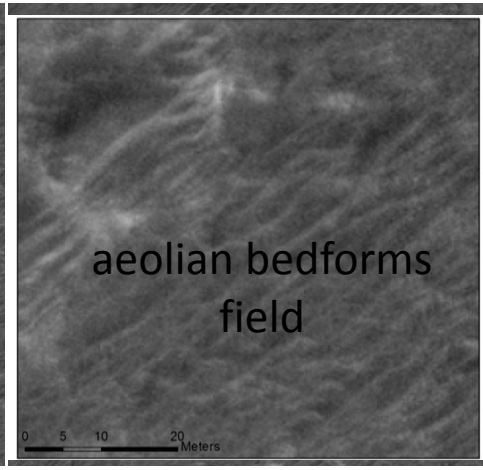


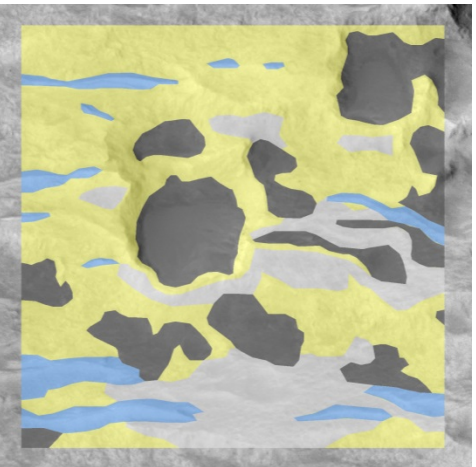


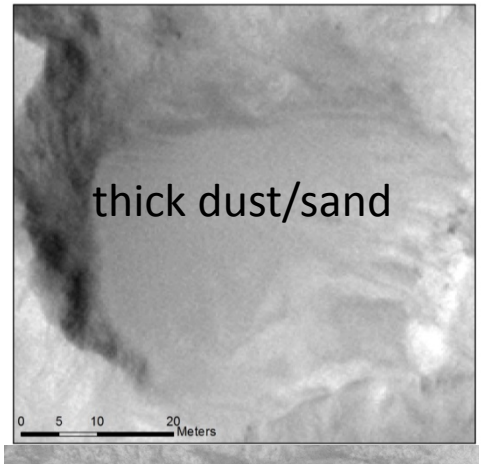


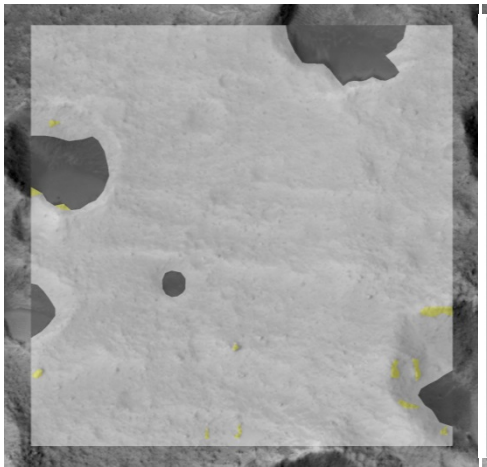


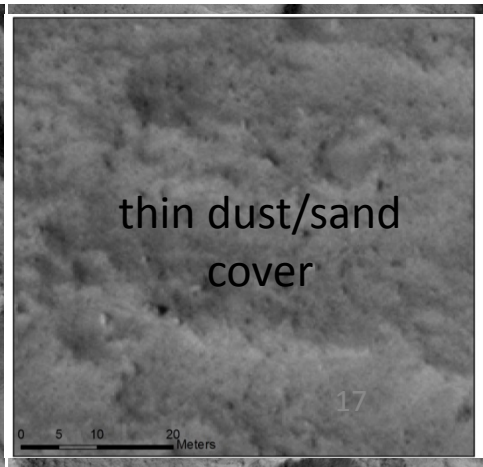












Oxia Planum

figure 18.1

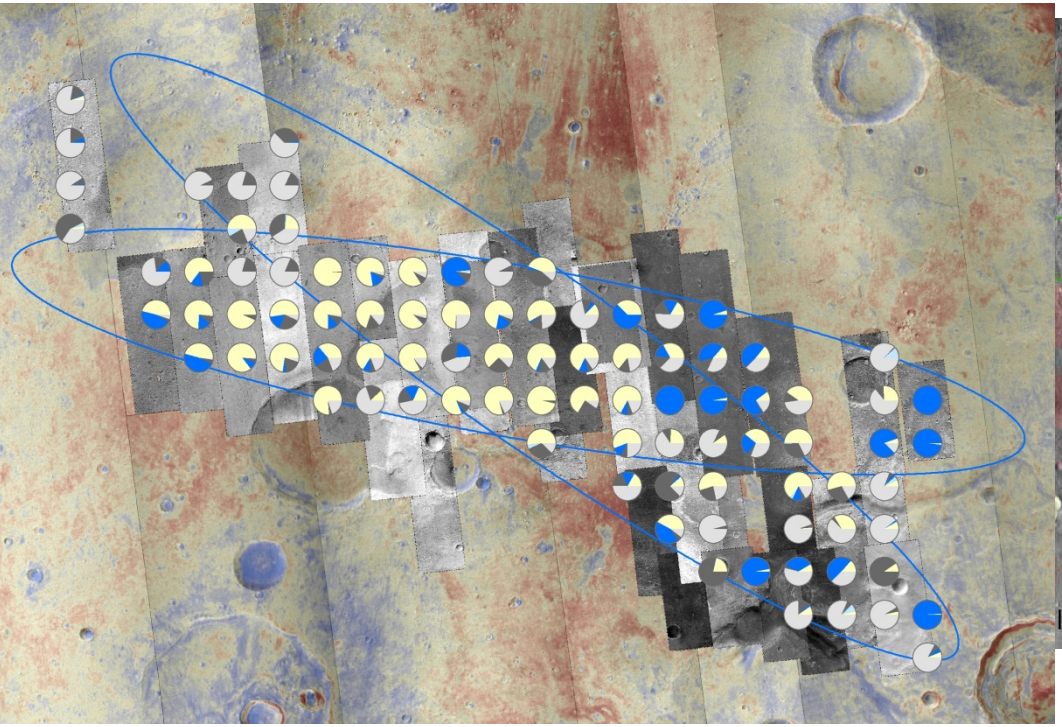
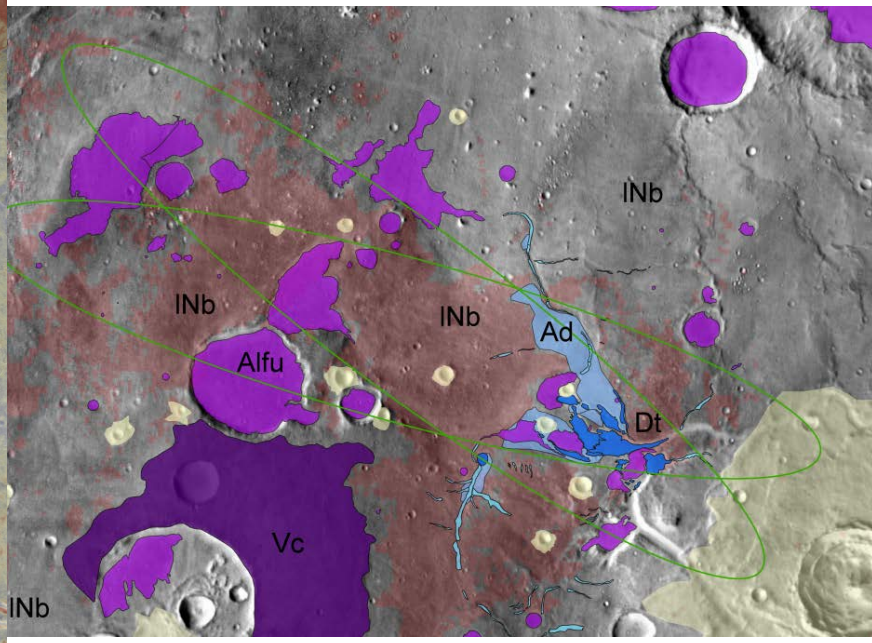


figure 18.2

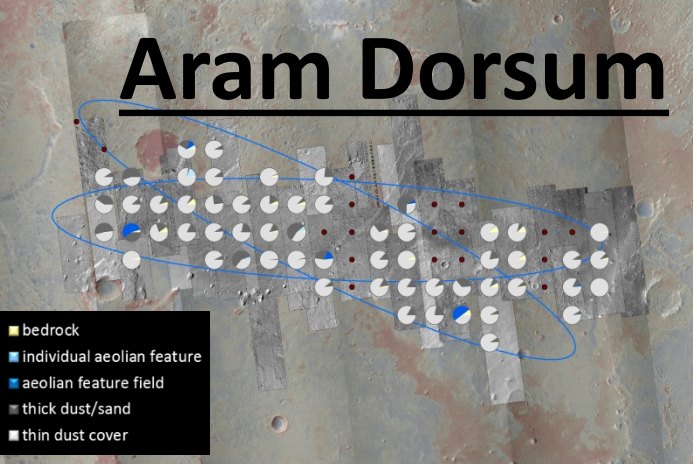


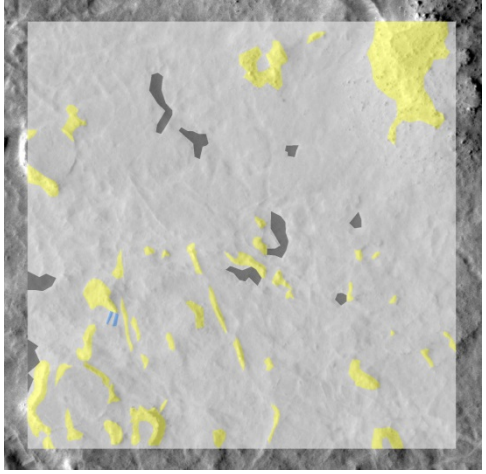
A quick look at figure 18.1 shows a higher sand dunes/ripples cover in the eastern part of the site, at the geologic unit labelled “Ad” (Figure 18.2, geologic map from Quentin et al. presentation, 3rd LSS workshop) which should be related to the delta/fan and surrounding valley deposits.

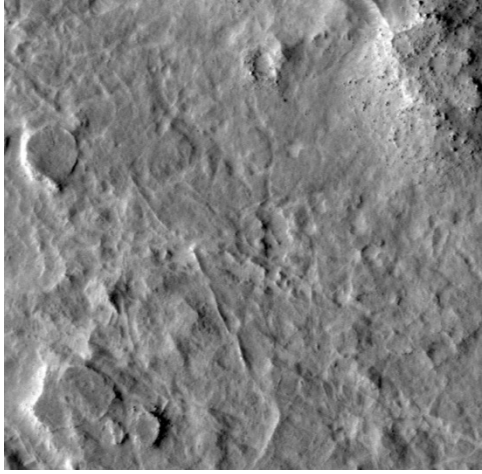
Bedrock is exposed both at the location of the clay-rich outcrops (unit lNb) and on the dark cap/lava flows (unit Alfu). Where the surface is mapped as more dusty on fig. 18.1, there is no detection of clays: this is in correlation with a larger clay-rich unit that is covered in part with dust that hides the clay signal.

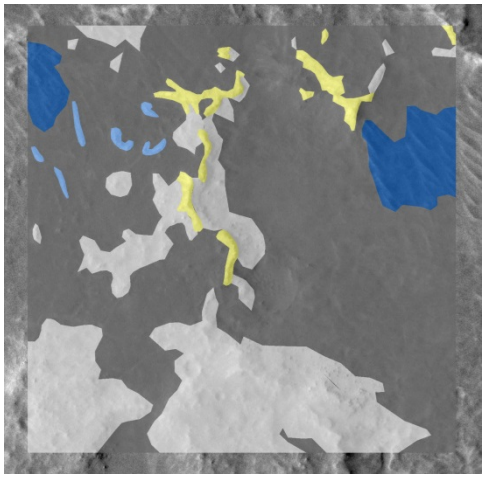
Aram Dorsum

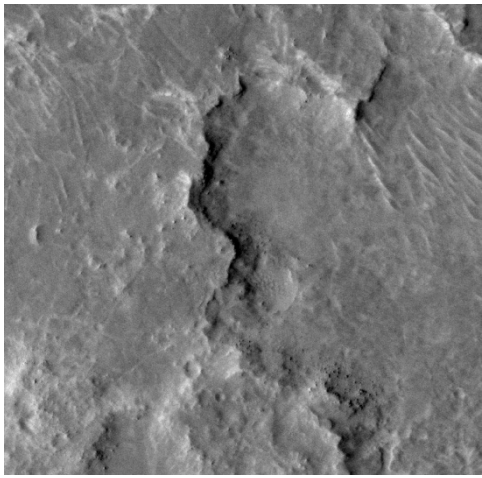
sample diversity

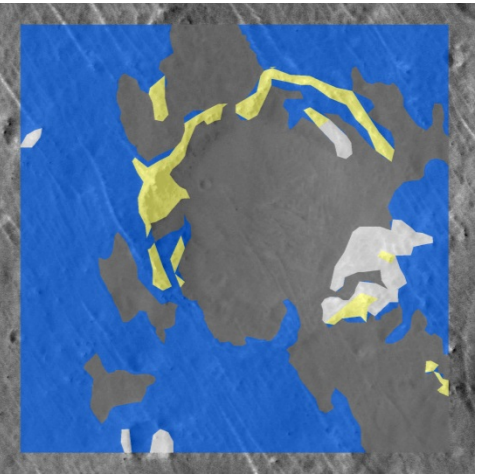


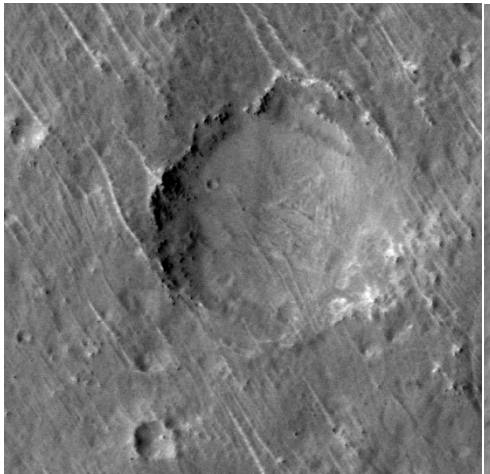


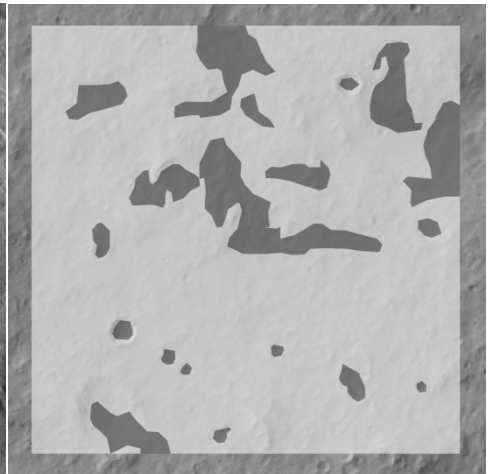


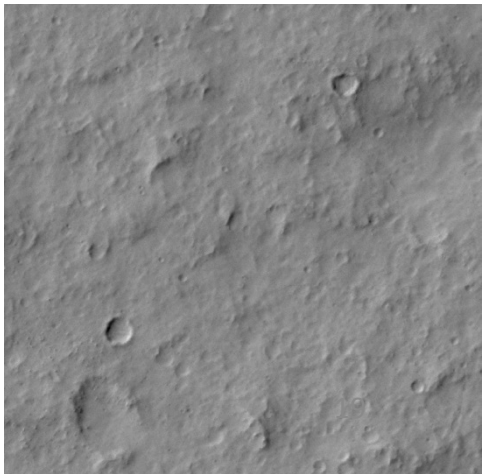






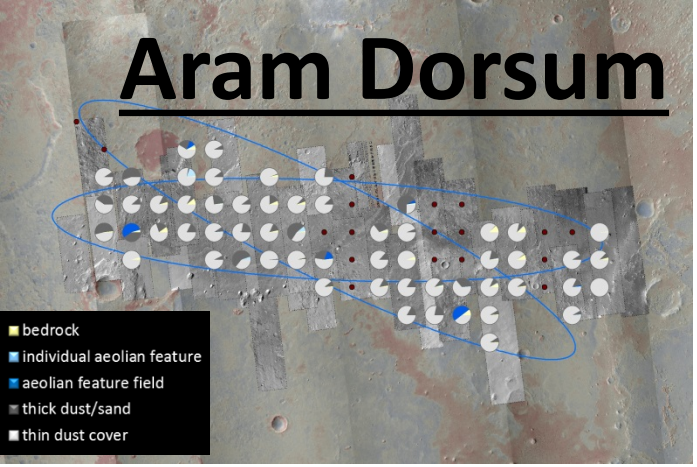


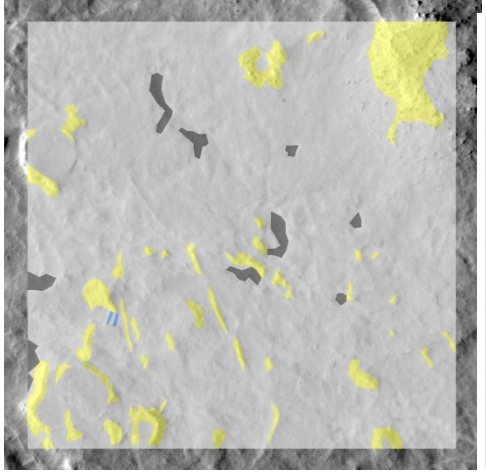


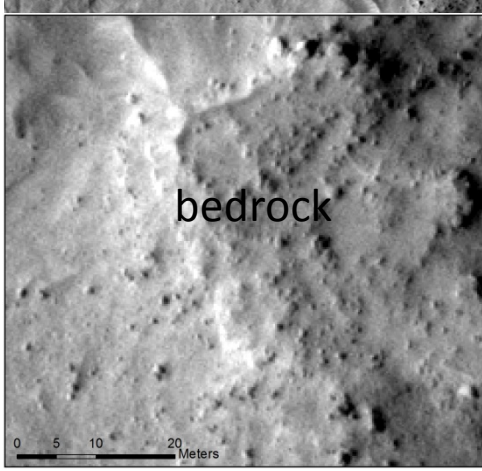


Aram Dorsum

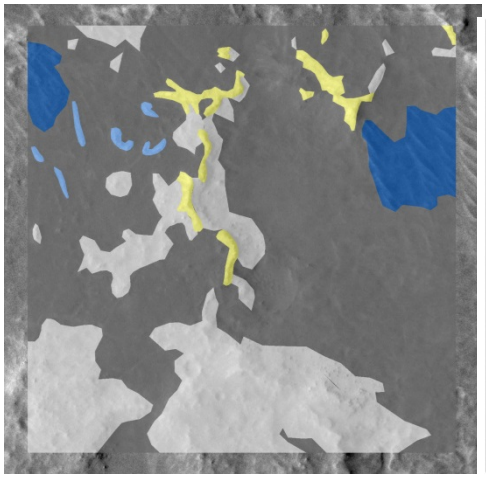
sample diversity

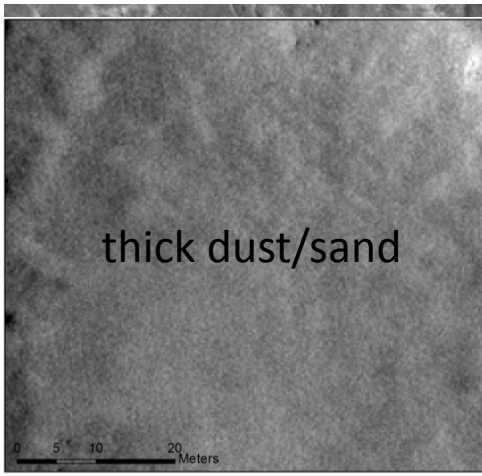


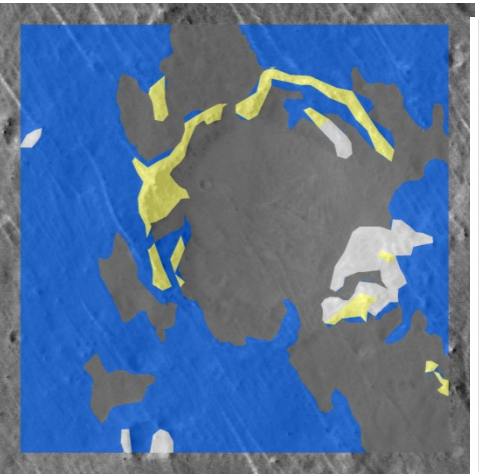


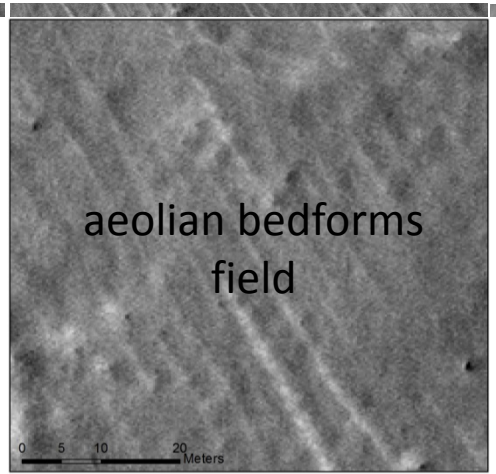


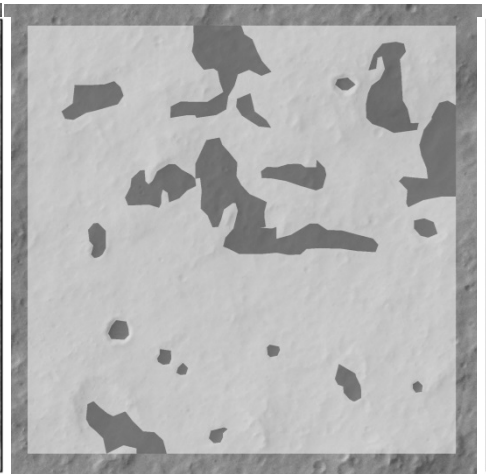
In Aram, we have mapped as “bedrock” places where rocks are under a very thin veneer of dust (probably in the order of mm to cm) or where many rocks are present, or where cliffs are present, but there is no large bedrock outcrops in Aram as seen in Mawrth Vallis or Oxia Planum.

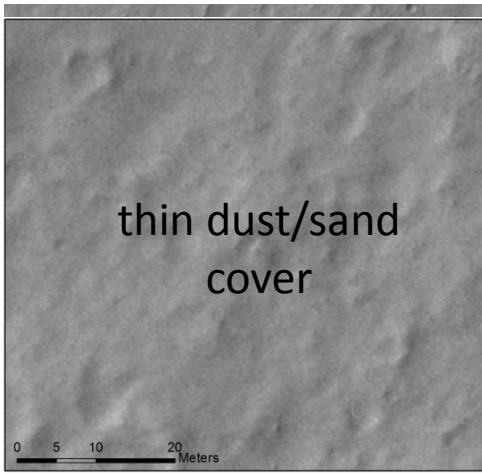












Aram Dorsum

figure 21.1

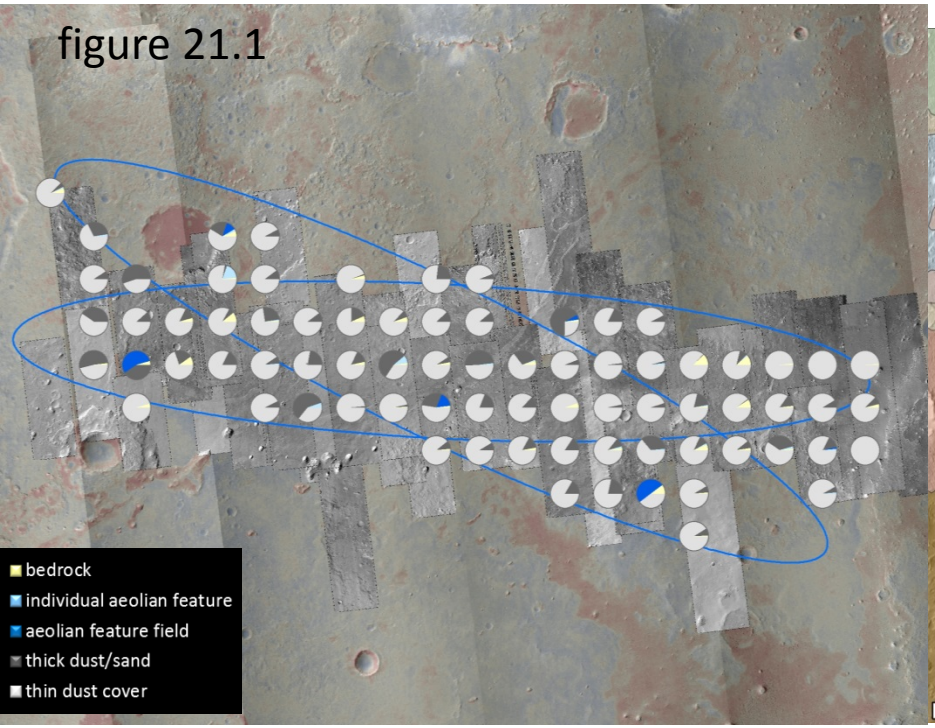
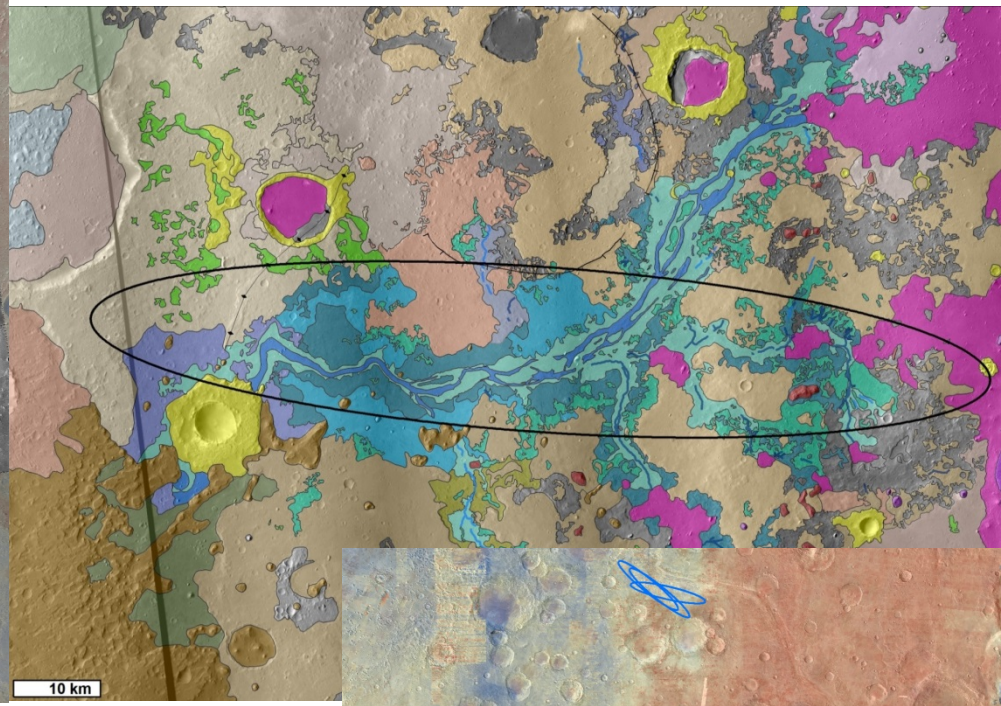


figure 21.2



A quicklook at figure 21.1 shows a higher « thick dust/sand » cover in the central part of the site, around the inverted channel (fig. 21.2, from Balme et al. presentation at the 3rd LSS workshop). The presence of aeolian bedform fields seems to be very local with only few large ones. Dust is largely present everywhere, as previously estimated from TES and OMEGA dust indexes (example fig. 21.2). Actually, when aeolian bedforms are mapped, they are also covered with dust, and when “thick dust/sand” is mapped, there is always dust at the surface, even if it may be sand underneath.

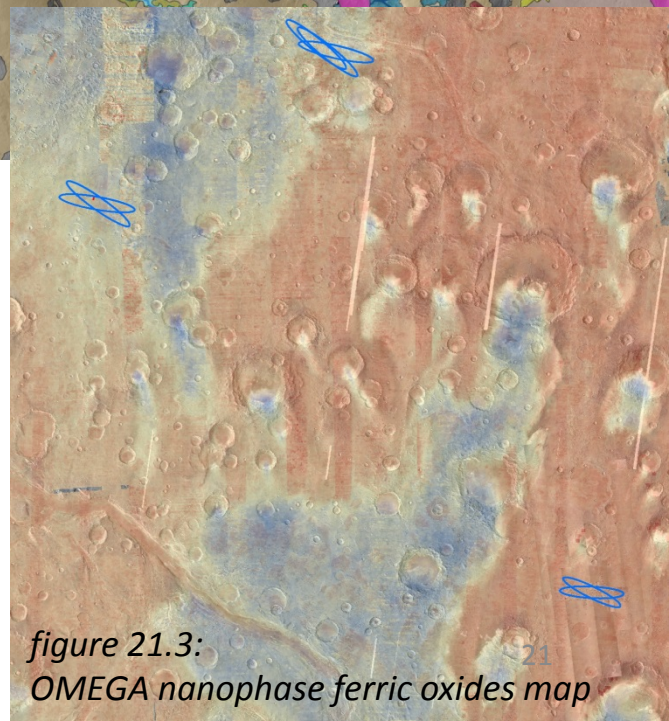
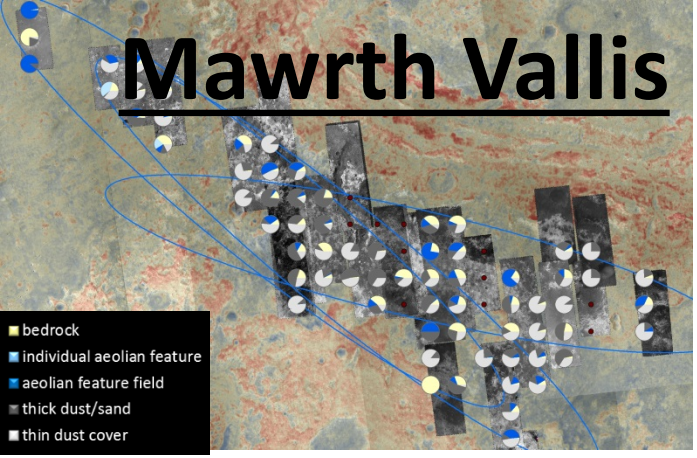
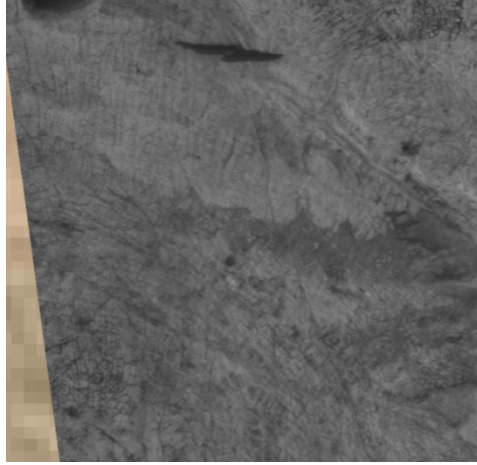


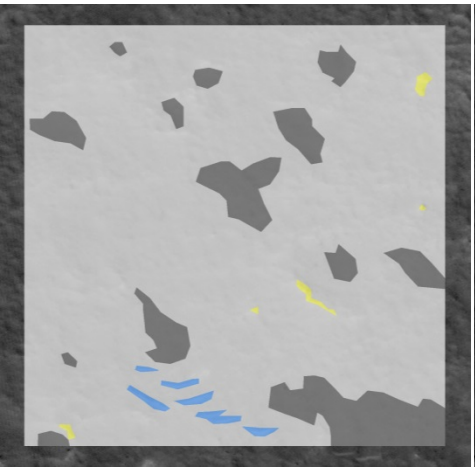
figure 21.3:
OMEGA nanophase ferric oxides map

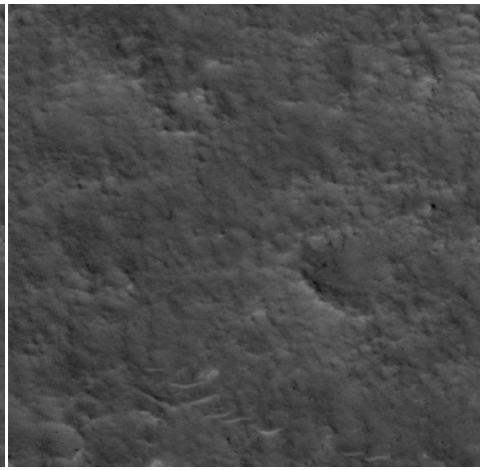
Mawrth Vallis

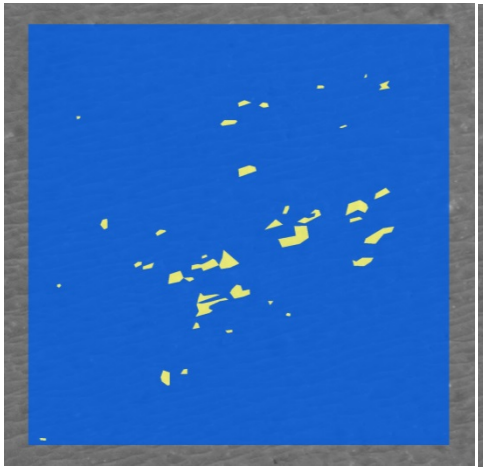
sample diversity

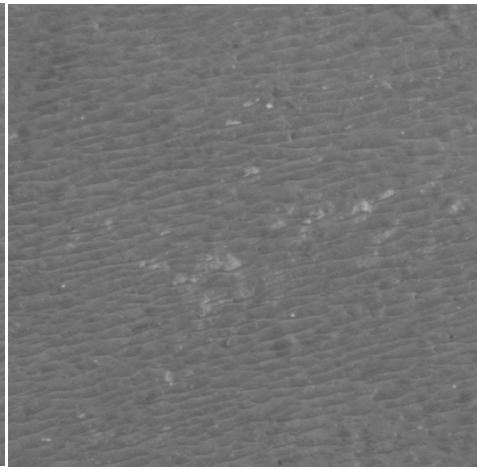


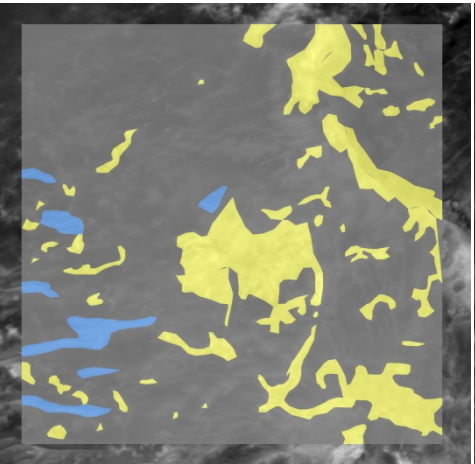


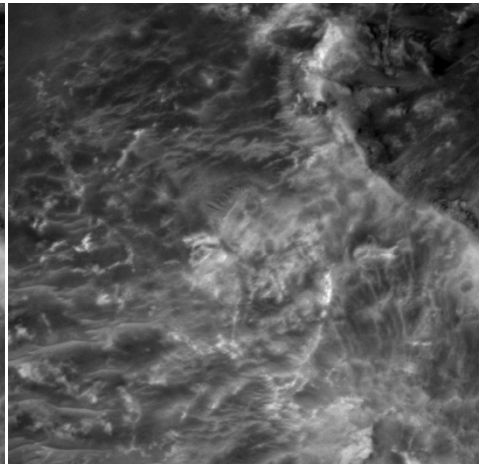


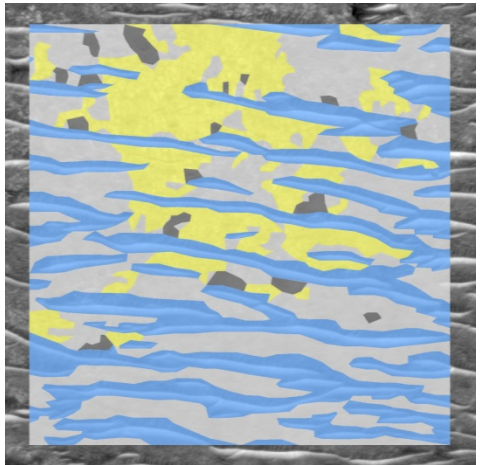


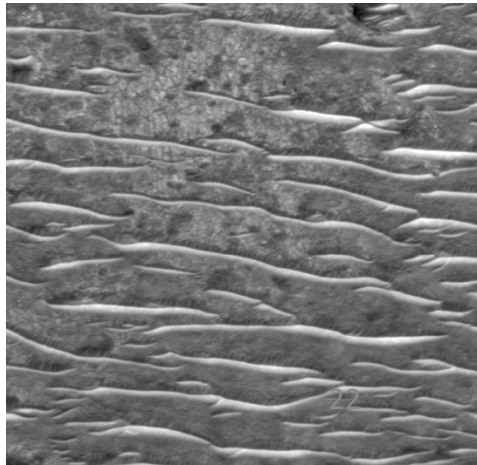






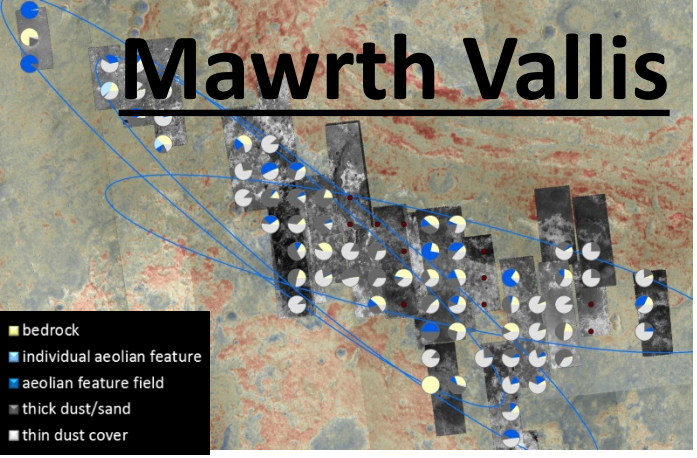


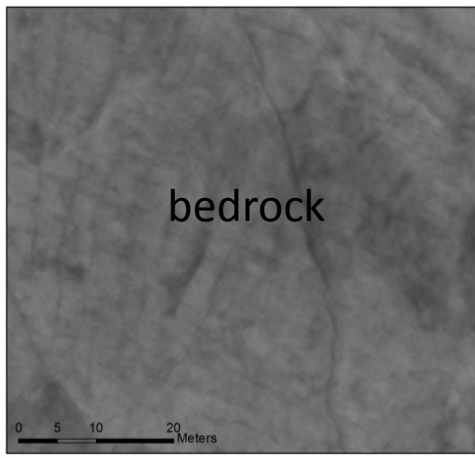


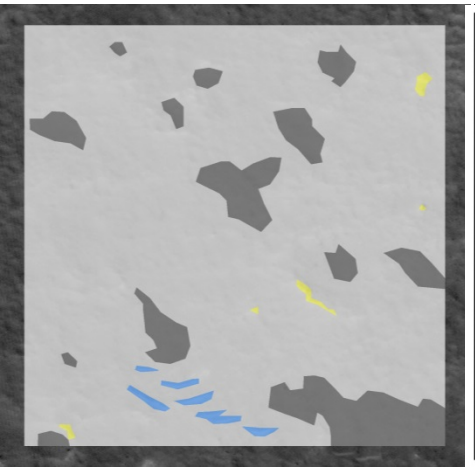


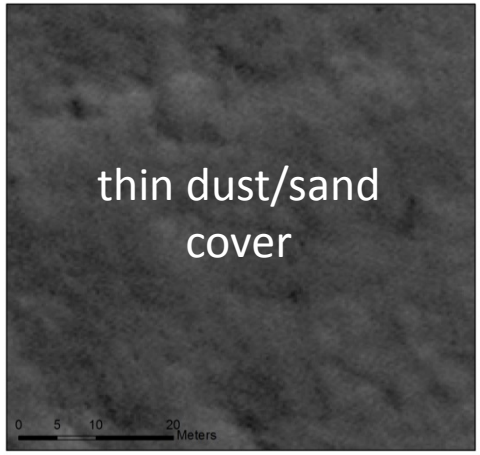
Mawrth Vallis

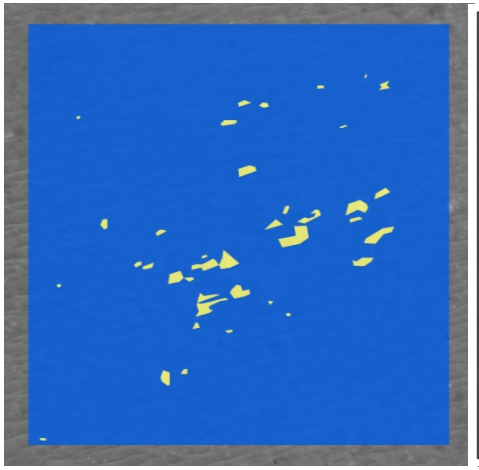
sample diversity

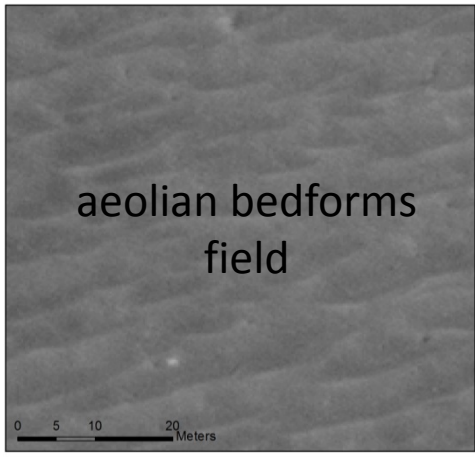


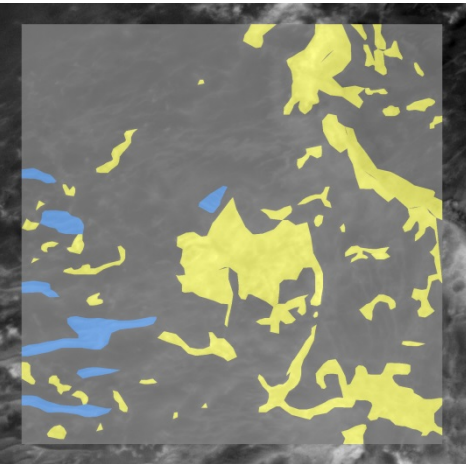


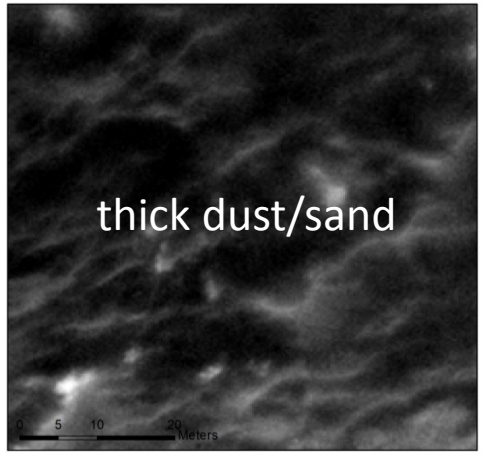


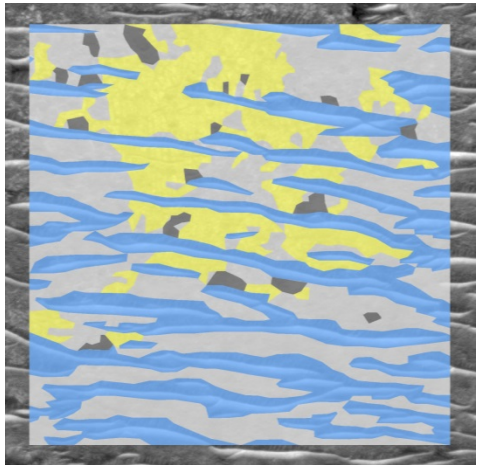


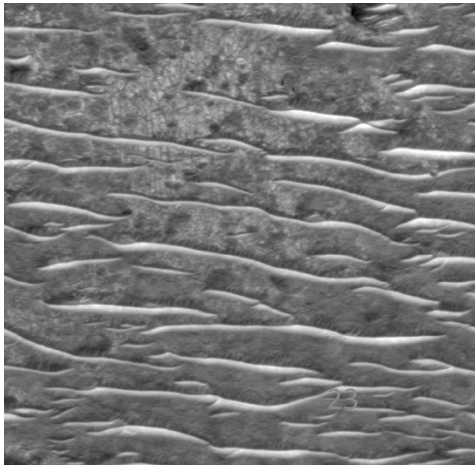












Mawrth Vallis

figure 24.1

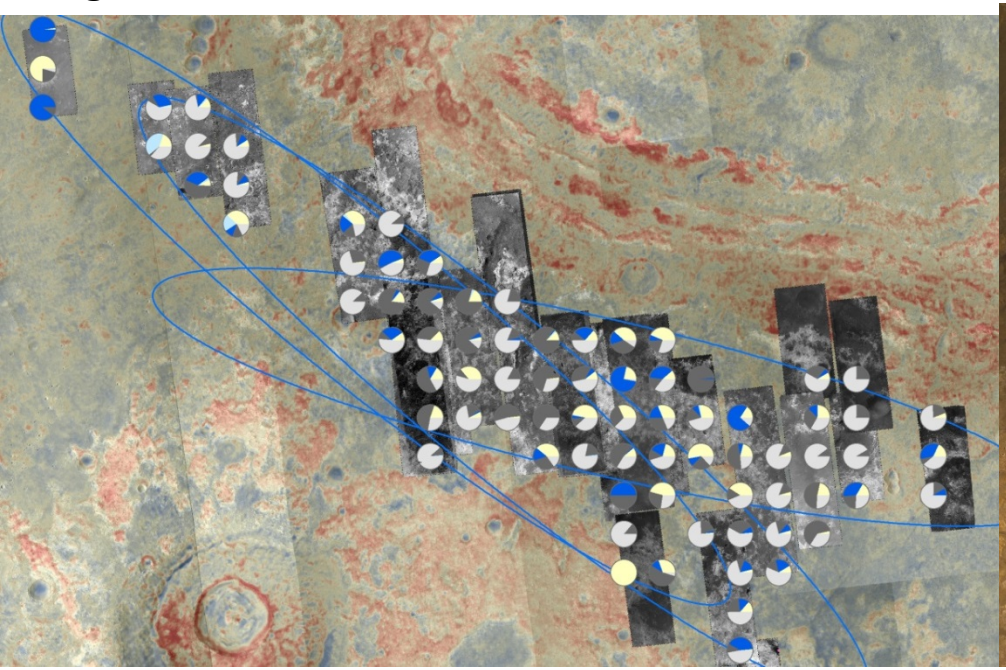
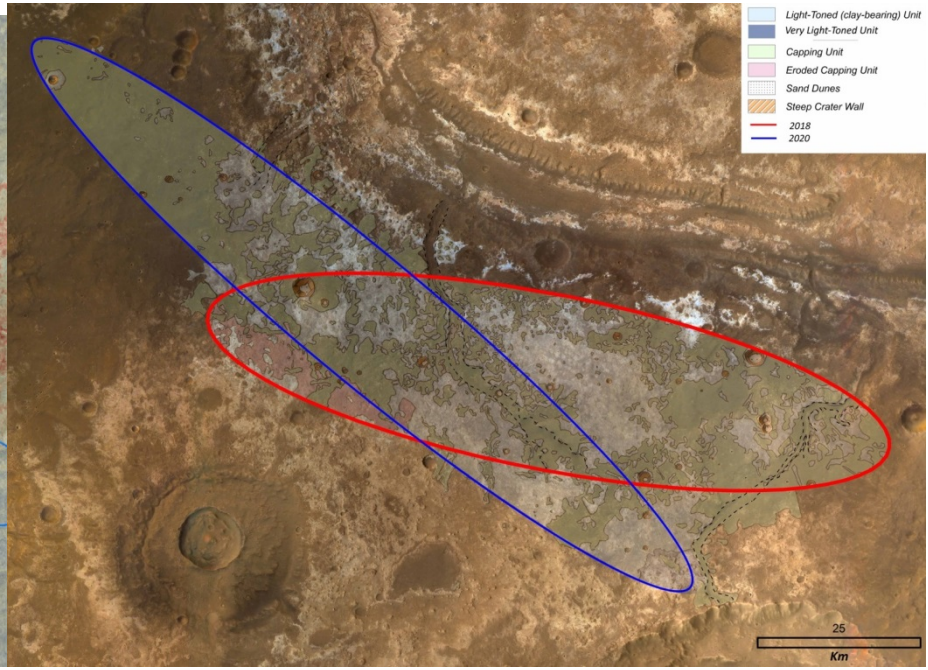


figure 24.2



A quicklook at fig. 24.1 shows that sandbeds and sand aeolian bedforms are present on and around the capping unit remnants (dark unit on fig. 24.2; from Poulet at al., 3rd LSS workshop). Bedrock is present in-between capping unit remnants, but the mapping method which uses samples (subsets) does not allow to easily evaluate the high frequency of bedrock/capping occurrences. Bedrock is well exposed to the south of the ellipses.

Comparing the sites

Bedrock: Both Oxia and Mawrth have large ~flat bedrock outcrops, which are completely absent at Aram, as all flat areas are covered with dust. The only bedrock expressions that are directly exposed at the surface in Aram are float rocks and cliffs.
However the flat bedrock outcrops in Oxia and Mawrth are not totally hazardless. A few float-rocks are present, the bedrock is fractured and sand is accumulated in lows.
Bedrock estimations are in general overestimated by the mapping method as it does not take into account the smallest dust/sand deposits.

Aeolian features: Dunes and megaripples are present at each site but in smaller amount in Aram (Aram 3%, Oxia 19% and Mawrth 14%). Two hypotheses exist for this: either dunes/ripples are less present in Aram because there is less sand, or small dunes/ripples are hidden below the thick dust cover.

Thick dust/sand cover: While the "thick dust/sand cover" maps **sand for Mawrth and Oxia**, it is possible that it maps **thick dust deposits for Aram**. This category covers similar surface percentages for Oxia and Aram, but a significantly larger area for Mawrth (respectively 12%, 16% and 26%). Thick dust/sand cover estimations are in general underestimated by the mapping method as sand/dust also accumulates in fractures and craters that were too small to be mapped.

Thin dust/sand cover: The entire ellipse of Aram Dorsum is covered with various thicknesses of dust; when looking at HiRISE images, there is little contrast on the surface except due to topography, all geologic units are similarly covered by dust. This is even more visible on HiRISE colour images, there is no colour contrast. (see next slide)
For the two other sites, dust is less ubiquitous. Locations with mixed bedrock/sand may have been mapped as "thin dust/sand cover".

Sand production:
At Mawrth, sand accumulates around and on the dark capping unit, while at Oxia, the dark patches are quite rocky and produce little sand. This is in correlation with the hypothesis that the dark cap at Oxia is made of lava flows, and at Mawrth is made of pyroclastic/aeolian deposits. Hence the dark cap at Oxia is more resistant to erosion than at Mawrth and produces less sand.
Sand in Oxia is likely related to fluvial deposits mostly located in the eastern part of the ellipse.
For Aram, it is difficult to evaluate if the thick soft deposits are made of sand or dust, as the thick deposits are covered with dust anyway.
Alluvial deposits are a likely source of sand.

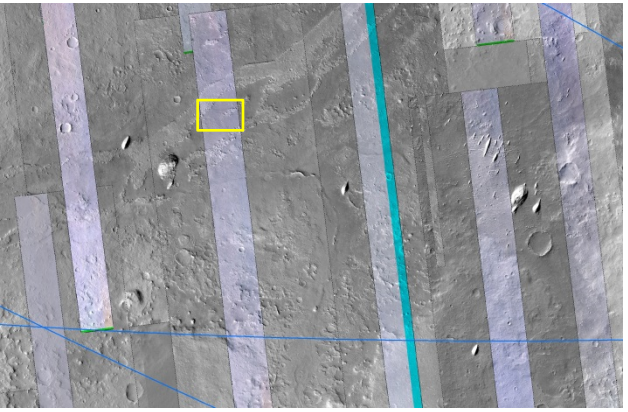
Comparing the sites: dust cover

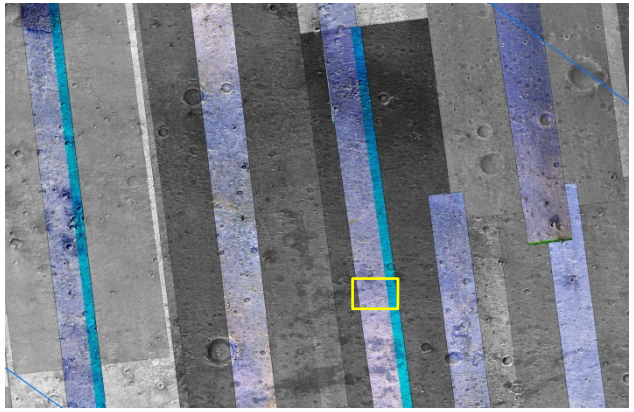
HiRISE colour images help revealing the surface diversity. We applied similar colour-strech techniques for each HiRISE colour image to maximize local contrast.

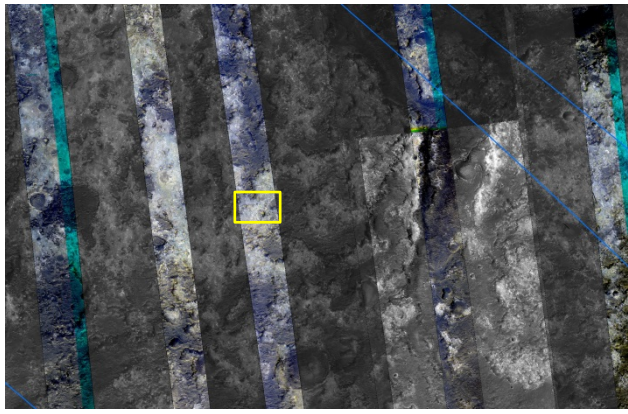
The **Aram** site is very homogeneous in term of colour, due to the global dust cover.

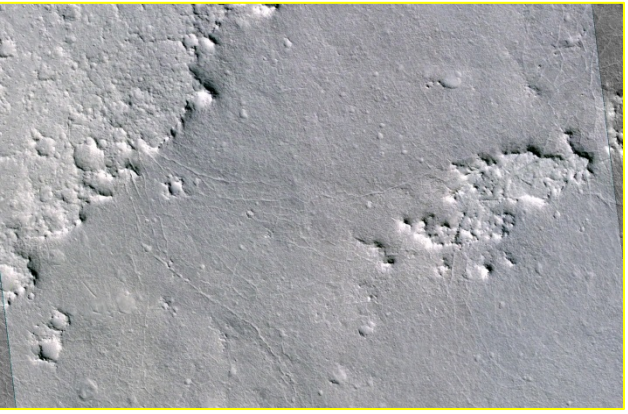
Oxia shows some contrast, especially between the clay-rich bedrock that appear light-toned, and the sand and dark cap, that appears darker and bluer.

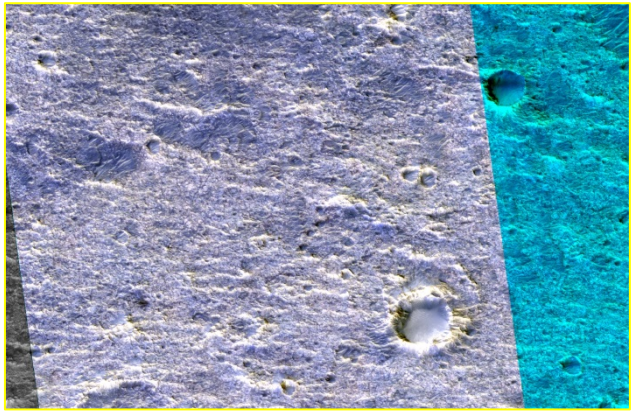
Mawrth offers the highest contrast (of the sites, and of most Mars locations as well), with colour and albedo variations observed both on the dark cap (from dark blue to bright yellow) and within the clay-rich unit (tan, white, bright blue, pink).

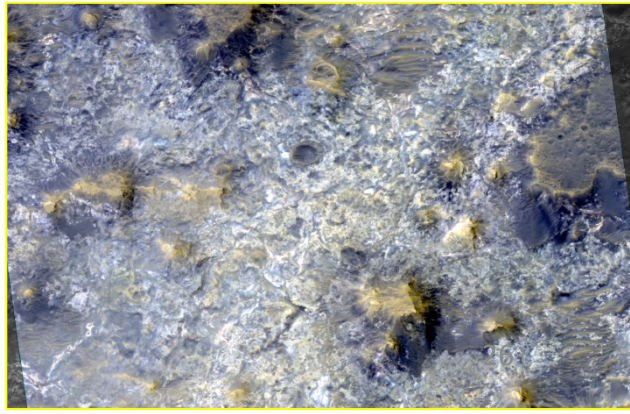












Summary and Conclusions

We think (hope?) that the sample mapping is fairly representative of the average surface area covered by the different types of surface terrains for all three sites. Only 0.1% of the sites were mapped! So given percentages are very rough estimates.
The mapping also shows —very roughly— the geographical repartition of the different types of terrain, especially when the terrain units are large.
In term of thicknesses, the limit that is given between thin and thick deposits around few 10s of cm is very hard to predict and is a big uncertainty in this study.

Oxia Planum has roughly a third of its mapped surface with exposed bedrock, a third with a thin cover of sand or dust, and a third with a thicker sand cover (either forming aeolian bedforms or flatbeds). The terrain units are relatively large, with a well identified area covered with sand in the north-eastern part of the site, and dusty areas at the edges of the site.

For Mawrth Vallis, many terrain units are small (high frequency of small dark cap remnants), which makes the mapping more difficult with the method used here.
Mawrth Vallis has the highest percentage of thick sand beds and aeolian bedforms with 41% of the mapped surface covered with these terrains that would be hard to traverse.

The case of Aram is particular, with a large majority of the mapped surface (77%) covered by a thin layer of dust, of up to a few tens of cm. It is likely that attempting to traverse this type of terrain with the ExoMars rover would result in relatively high wheel slip rates. This would at best slow the rover down, and at worse cause it to stop often by triggering the on-board safety protection.
Another issue linked to the presence of dust is the potential for dust to settle on the solar panels and to reduce the energy available each day for the rover.