Erasmus Plus GeoPlaNet Strategic Partnership

IO7: Geological Mapping

FINAL REPORT

1. Summary

This document has been prepared by the University d'Annunzio in collaboration with the University of Padova and the whole consortium of the Erasmus+ Strategic Partnership GeoPlaNet-SP (ref. 2020-1-FR01-KA203-079773). The context is the summer school on Planetary Geological Mapping and Field Analogues organized in the framework of the same partnership.

The aim is to provide the basic conceptual information in order to conceptualize and realize planetary geological maps. Understanding the similarities and differences between geological maps on Earth and on the planets represent the baseline to manage a geological mapping effort; then the different possible mapping approaches provide the means to focus on the specific needed rationale and scale of work. Ultimately, a comment on the importance of understanding stratigraphic relations and hierarchies is introduced.

2. Planetary Geology and Geological Mapping

There are no conceptual differences between geological mapping on Earth and on other planets/satellites but the amount of available data and previous analyses are different. On Earth, we have more than 300 years of geology, including fieldwork in most of the planet, mineralogical and petrographical data, detailed different geophysical analyses at all scales, extensive borehole-derived information, etc… while planetary geology is only a few decades old with no fieldwork with the exception of few sites on the Moon and rover/lander data.

Still, the basic principles are the same: geoscience maps, regardless of the target body, are spatial and temporal representations of materials and processes recorded on planetary surfaces (Varnes, 1974; Spencer, 2000). The information provided in such maps represents the base for further science and/or applied-related investigation. Since 1961, planetary geoscience maps (maps that summarize the geology of all solid surface bodies in the Solar System beyond Earth) have been used in planetary exploration, from the identification of surface processes and deposits to the landing site characterization for human and robotic missions.

Basic stratigraphic principles and techniques provide a basis to organize different landforms in the spatial–temporal framework (vertical/lateral stratigraphic relations). Only geological mapping can summarize and display all the characters of a unit in a single document (the geological map): therefore, geological mapping should be a pre-requisite for the geological analysis of any planetary surface.

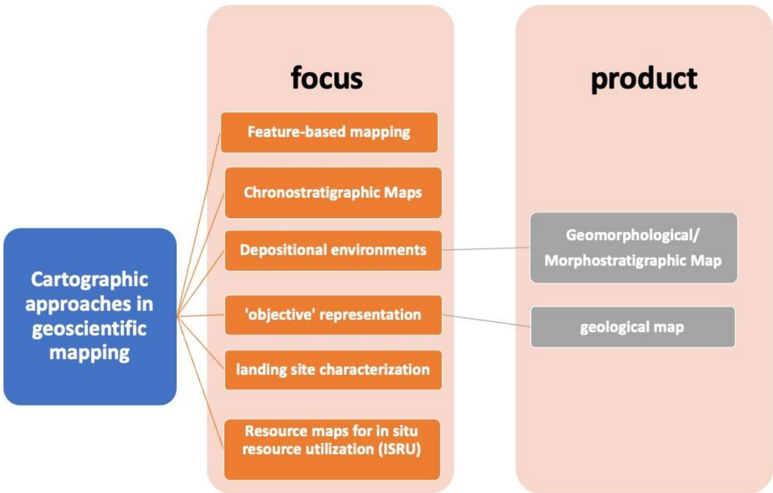
In this framework, geoscientific mapping of planetary bodies has some specific problems and peculiarities. First of all, the scale of the map is instrument-dependent. Different scales of course exist also on Earth but the choice is made by the mapper according to science and/or technical needs. In planetary geology, data provide a constraint to the possible observations, because planetary mapping is based on remote sensing with no or very limited possibility of groundtruth.
Moreover, information on rock composition is generally limited while on the other hand in most cases there is a relatively limited amount of weathering that allows good preservation of the morphologies.
For these combined reasons, planetary geological mapping has historically mostly been chronostratigraphic or geomorphological, but several others approaches are possible.

3. Cartographic approaches in geoscientific mapping

Different aims, scientific, technical, or exploration-related, lead to different approaches in geoscientific mapping (Rossi et al., 2021):

- Feature-based mapping
- Chronostratigraphic Maps
- Focus on depositional environments: Geomorphological/Morphostratigraphic Map
- Focus on 'objective' representation: Geological Map
- Landing site characterization
- Resource maps for in situ resource utilization (ISRU)

These different approaches address different science goals and are characterized by different scales and different attribute table organization.



3.1 Feature-based mapping

This mapping approach can be defined as the cartography of just one(few) specific landform(s), structure(s), and/or mineral(s) with the aim to address the distribution of such elements over the whole planetary body (or a large portion of it).

The Mars global digital dune database (Gullikson et al., 2018) is a nice example of this kind of mapping (Fig. 1). The goal is to describe the distribution of the dunes on the planet. Accordingly, the attribute table will be very simple, focusing on the geographical characters (name, coordinates) and the geological and/or morphological and/or mineralogical aspects of interest.

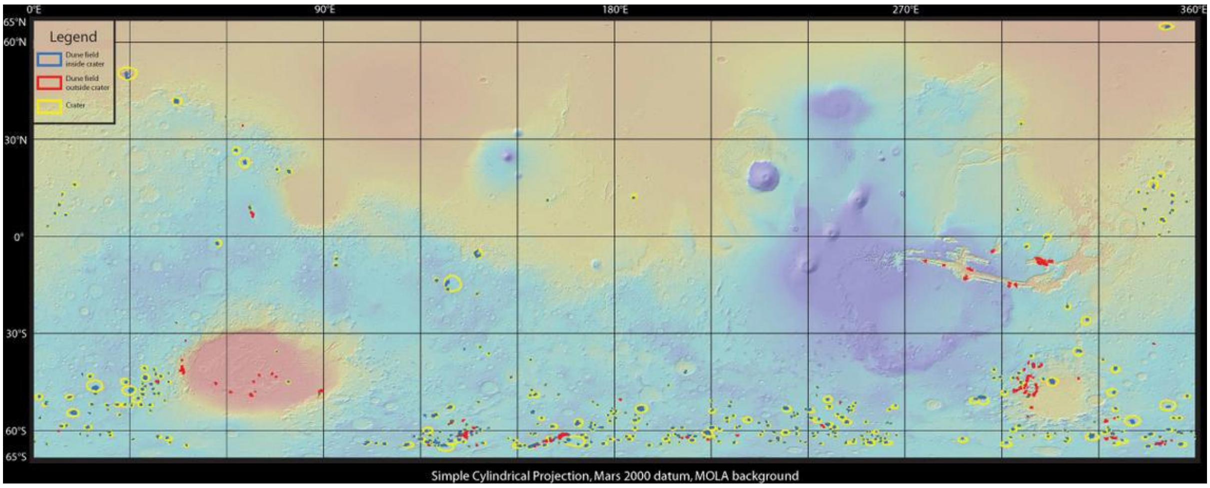


Fig. 1 - The Mars Global Digital Dune Database (MGD3) is an online repository that has cataloged dune fields larger than 1 km2 located between latitudes 90° N. and 90° S (Gullikson et al., 2018).

3.2 Chronostratigraphic Maps

This mapping approach is based on the fact that geological units are linked to stratigraphic ages, where the relative relations among the units can sometimes be tightened by absolute ages (Fig. 2).

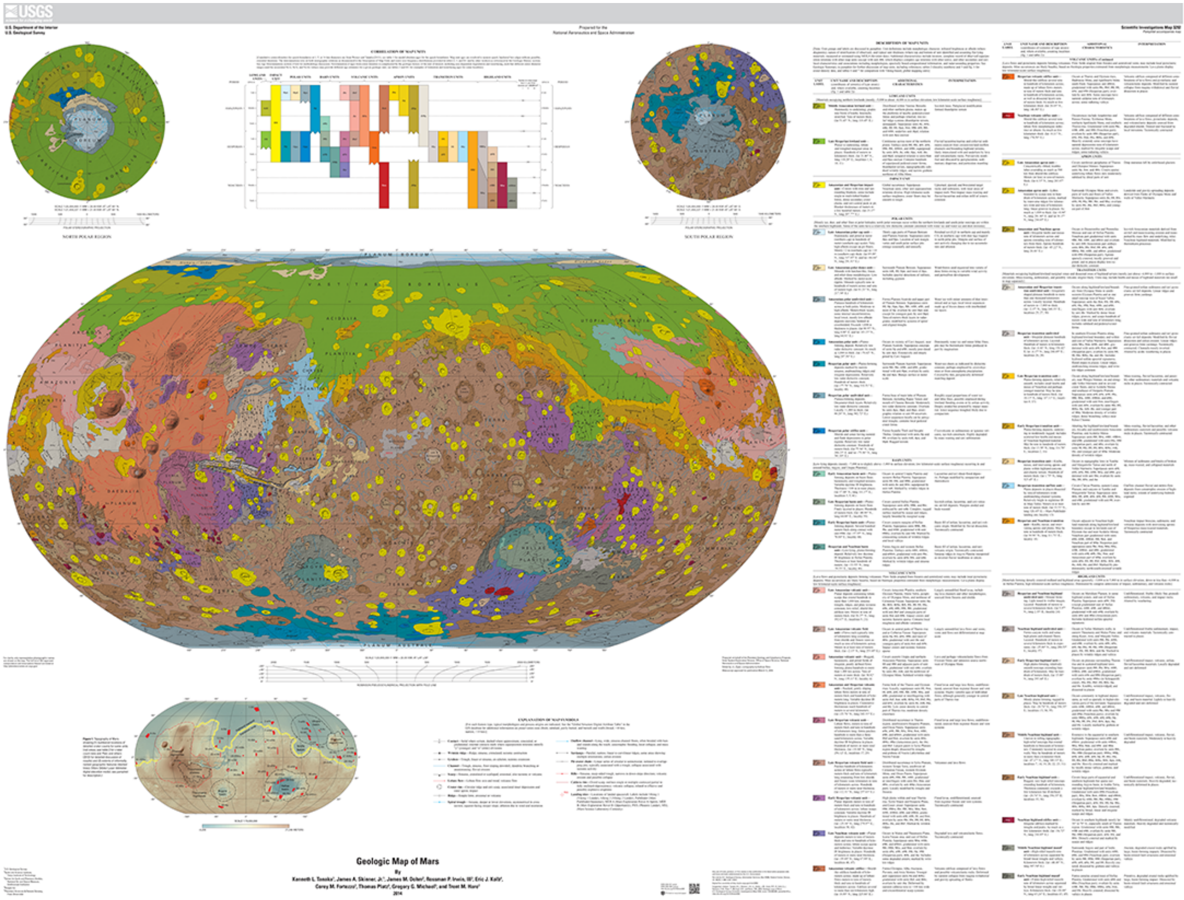


Fig. 2 - An example of a chronostratigraphic map: the Geological Map of Mars (Tanaka et al., 2014)

This approach focus on the timing of rock formation or a modification event for the specific surface and it represents the first step in the geoscientific representation and a necessary context map for further scientific enquires. The stratigraphies on planetary bodies generally are based on crater chronology (e.g., Neukum et al., 2001).

3.3 Focus on depositional environments: Geomorphological/Morphostratigraphic Map

When the focus of the scientific representation is the genetic evolution of a specific planetary surface, geomorphological (or morphostratigraphic) maps are used. These maps are intrinsically interpretative because they are based on the representation of the inferred genetic processes in which the unit was deposited. Accordingly, the name of the units will correspond to their genetic origin and this will be reflected in the attribute table. Different degrees of detail will be possible depending on the available dataset/resolution and on the mapping goals. As an example, in a volcanic setting, several lava flows cover the flanks of the volcanic edifices and of the plains around. Global and regional maps include these flows in a single unit, while at higher resolution these should be mapped individually, indicating their mutual stratigraphic relation and their typology when possible.

Relative stratigraphy among the different units is fundamental at all scales because a proper stratigraphic reconstruction is the pre-requisite to perform an interpretation not focused only on the single landforms, but on a suite of genetically associated landforms, i.e., a landscape.

A good practice consists in distinguishing the eventual different degrees of preservation within the single features. For example, craters might be distinguished as simple, complex, and peak ring basins, but also as pristine, eroded, partly covered, ghost, pedestal, and rampart craters.

An example of a geomorphological map representing the outflow system of Ares Vallis on Mars is reported in figure 3 (Pacifici, 2008).

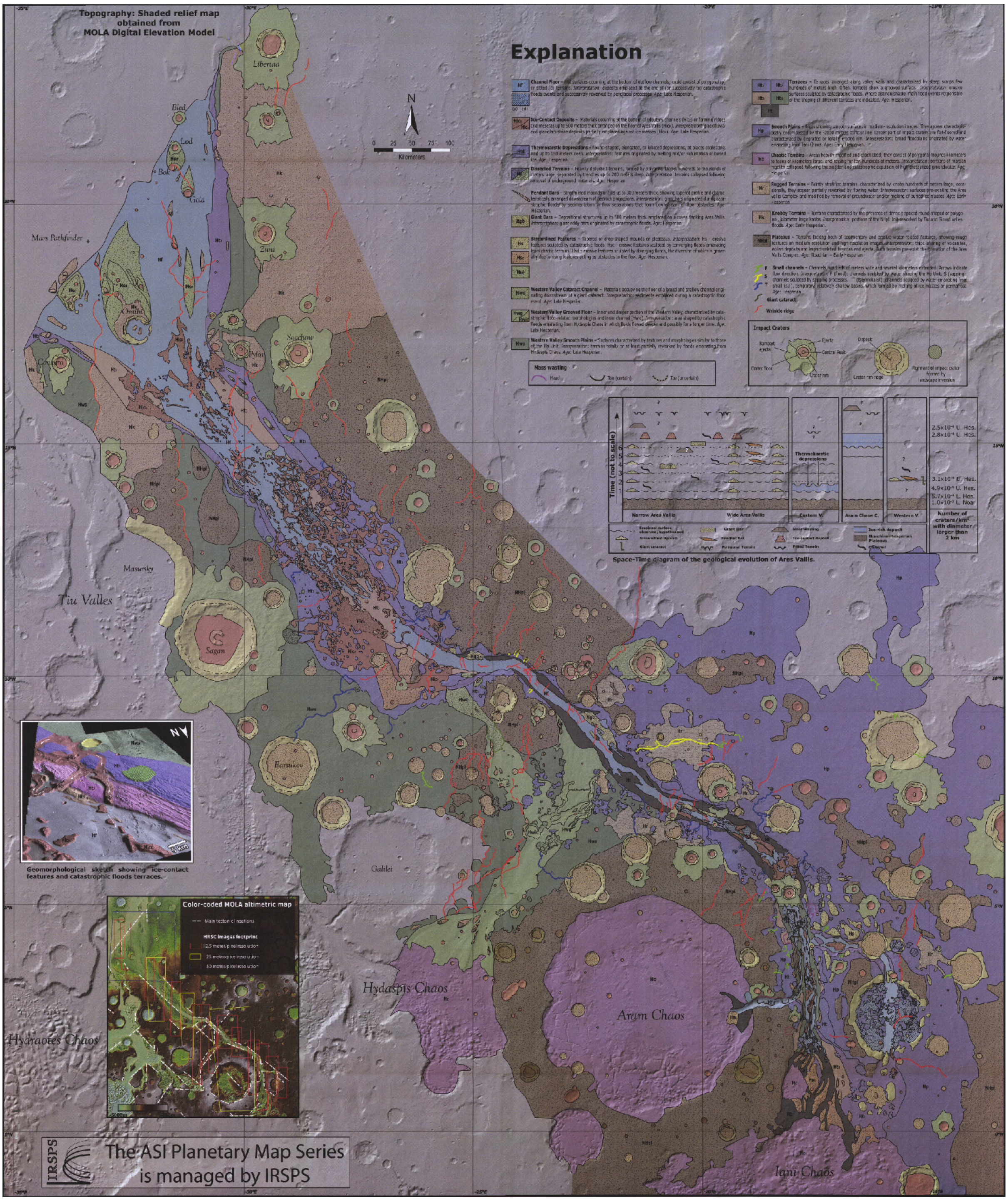


Fig. 3 - Geomorphological Map of Ares Vallis (Mars) (Pacifici, 2008)

3.4 Focus on 'objective' representation: Geological Map

Geological maps on Earth represent the first and basic geological representation of the lithologies present in a given surface, thus providing the most possible ‘objective’ representation of this area, exactly because lithologies represent an objective observable parameter. Needless to say, there are many levels of subjectivity in the realization of a geological map (whose ‘planetary’ equivalent will be discussed in section 4), but still, this representation is the most objective as possible. Accordingly, strictly speaking, geological maps cannot even exist in planetary settings where the lithological characterization can be very limited (with the few exceptions of human missions on the moon and in-situ rover-lander data). Still, a relatively ‘objective’ cartography product might be needed, for example when genetic interpretations are ambiguous.

Geological maps aim at distinguishing observations from interpretations. Evaluating the hierarchy of the different kinds of unconformities is part of the very process of mapping. Units are defined on the basis of relatively objective characteristics, such as texture, color, possible structures, association with specific morphologies (without genetic implications), and, where available, spectral information. The genetic interpretation might be added including linear symbology (e.g., limits of lava flows, fluvial channels, etc…): information present, but separate, in order to distinguish description from interpretation.

An example of a geological map representing Greg crater, Promethei Terra, Mars, is reported in figure 4 (Tsibulskaya et al., 2020).

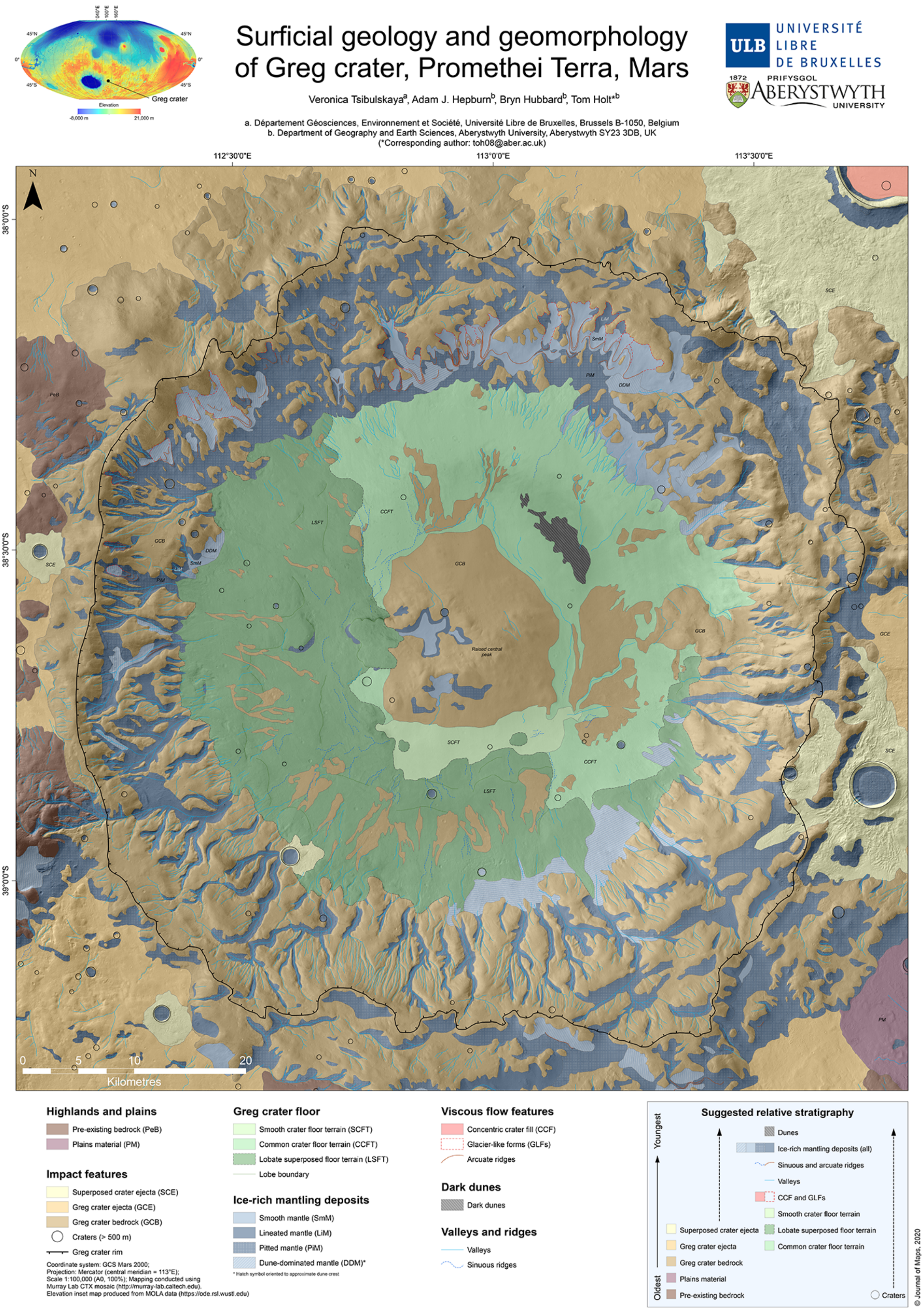


Fig. 4 - Geological Map of Greg crater, Promethei Terra, Mars (Tsibulskaya et al., 2020)

3.5 Landing site characterization

The characterization of landing sites for missions includes information to support the scientific rationale of the mission but also the technical operation at the basis for the safety of the mission itself: risk assessment and mitigation and planning of mission operations. In order to achieve these different goals, a regional chronostratigraphic map is associated with a small-scale geomorphological map of the actual landing site which is not a geological map intended for scientific analysis, but a tool used to identify different surface textures and where potential hazards may lie (Figure 5). The larger scale chronostratigraphic map provides a regional to global context for interpreting the geological history of the landing site.

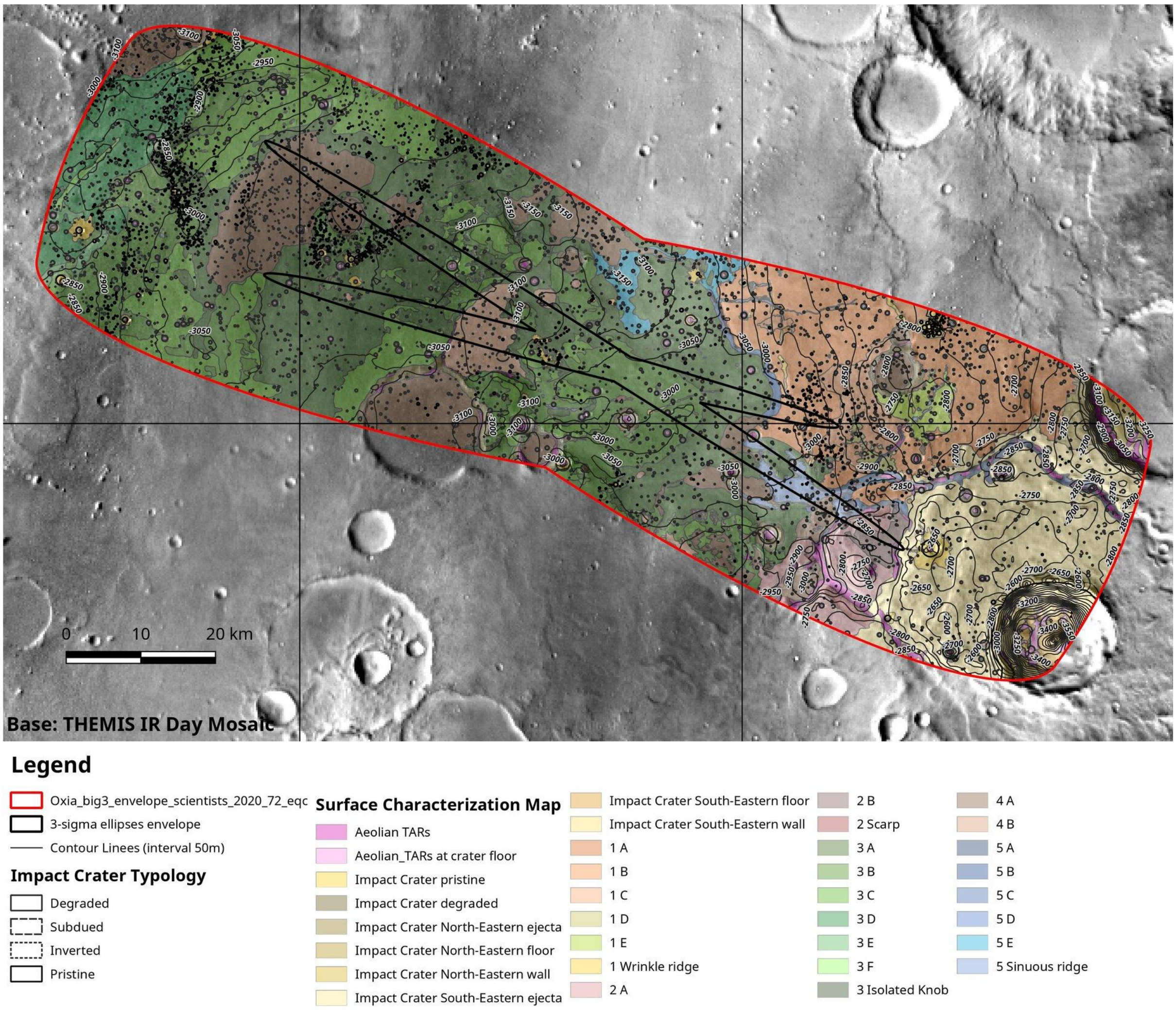


Fig. 5 - Oxia Planum landing site candidate for the ExoMars 2020 mission. The range of the possible landing ellipses is indicated, including in black the most likely landing zones. The background image is from the Thermal Emission Imaging System instrument on NASA's Mars Odyssey orbiter. Ⓒ IRSPS/TAS; NASA/JPL-Caltech/Arizona State University

3.6 Resource maps for in situ resource utilization (ISRU)

Because of the impossibility to bring all the materials from Earth in a framework of a sustained presence on an extraterrestrial body, resources that can be extracted in situ would provide a sustainable path for both exploration and science activities. Moreover, this might potentially support a future commercial planetary resources industry. Accordingly, the development and testing of in situ resource utilization (ISRU) capabilities, including the extraction of oxygen and the construction of infrastructure from regolith, is investigated by space agencies (e.g., ESA, 2019; ISEGC, 2021).

The first step in realizing planetary resource maps is to define the surficial extent of potential resource deposits using the available compositional remote sensing data. For example, in-situ oxygen exploitation is vital for any long-lasting planetary in-situ mission. On the Moon, high Ti and high Fe concentrations in mafic lunar pyroclastic deposits can be used to select locations where high ilmenite content is expected (van der Bogert et al., 2021). Oxygen can be extracted from both ilmenite and iron-rich volcanic glasses using different techniques. The characterization of materials must be then tied by groundtruth analyses to test and improve the information derived from the remote sensing datasets.

4. Reference area

Geological mapping on Earth is based on an accurate description of the units that will be mapped using a standard procedure in a physical place (stratotype) that can serve as a reference. The aim is to allow the reproducibility of these observations and address the need for an objective (or as objective as possible) definition of the units that will be later mapped. Such a concept should, with the conceptual differences inherent to a planetary study, be used also in planetary geoscientific mapping, regardless of the chosen mapping approach, by describing the unit in a 'reference area'.

The 'reference area' is a place, or even more places, if a single one cannot picture all of the unit characteristics and stratigraphic boundaries, where the unit is best exposed, visible, and data covered. Here the unit should be represented with all the pertinent datasets, including imaging and spectral data, and described at the different scales.

5. School products

The projects realized by the students of the school on Planetary Geological Mapping and Field Analogues are stored here:

https://universitachieti-my.sharepoint.com/:f:/g/personal/monica_pondrelli_unich_it/EiA9qrumgwRGoZkSeymFzvYBfpLEqq7A9QEliPQeTFq99g?e=KFJQpR

The maps include examples from Mars, Europa, and Titan.

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