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Astrobiology vs Geology investigations: good practices in the framework of planetary missions

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Abstract. The deep link between biosignature identification and geological setting is at the foundation of astrobiological investigations on Earth and should be the same for planetary exploration. In order to constrain the analogy between the potential Earth analogue and the planetary setting, an increasingly detailed sets of analyses in an increasingly detailed scale should be performed in parallel between the Earth and the interested planetary surface. Ultimately, geological investigations are critical to correctly plan remote and *in situ* planetary missions aimed at assessing the habitability potential of a specific planet/setting. This is even more essential if a sample return mission is expected, in order to collect THE right samples and not just stones.

Key words. Astrobiology – Mars surface – Mars habitability – Sample return– Sedimentary environments

1. Baseline

Astrobiology represents an extremely interdisciplinary science, requiring inputs from many different sources. The geological settings should be the primary objectives to assess the present and past environments and their potential to host life. In particular, when dealing with planetary settings that can be studied only remotely, the comparative geological analysis with Earth potential analogue is essential. However, the importance of geology is often understated. Here we want to stress the importance of the contribute of geology for astrobiological investigations in the processes of selection, understanding, and analyses of the study areas and in bridging the gap between the different observation scales on Earth and planets in the framework of mission planning. These comparative studies are now possible because new data acquired in the last decades on many planetary surfaces allow Earth-like field geological investigations: this is especially true on Mars but increasingly important in all of the other planetary bodies, including the icy satellites. We address the importance of combining geological and astrobiological investigations on Earth and their potential planetary counterparts in order to plan remote and especially *in situ* planetary missions

2. Earth Analogues and Planetary Counterparts: concepts and issues

Common practice requires that collected sample(s) must be representative of a larger body and reflects some specific feature of variation of it: in other words, the sample representativity is largely dependent on the accuracy of geological observations that precede sampling. In particular, planning a sampling mission aimed at testing the astrobiological potential of a given target on a planetary surface, is based on the understanding of where to focus (depositional environment), which tools are needed (instruments) and finally to set the precise place where to sample within the selected environment (i.e., facies, structure, minerals...). The goal is to collect a significant sample and not just a stone.

The roots and heart of astrobiology rests in the experience acquired on the Earth analogues, because the exploration of planetary settings must be based on what can be studied and tested directly. The knowledge acquired on Earth analogues represents the prerequisite to plan the exploration of planetary settings, both to select the right science target to look for fossil or present life traces and also to test the proper techniques, that should be effective and at the same time low invasive/destructive in order to be suitable for planetary exploration. Astrobiological investigations in the field and in the laboratory require a series of protocols both for the sampling procedures (i.e., collection, preservation, and treatment) and for the data analyses (i.e., facies analysis, instruments, combination of instruments) in order to identify the presence of biosignatures. Biosignatures in the rock record include many different organic or organically mediated structures and biochemical signals (Westall & Cavalazzi 2011), which occurrence and evolution is controlled by the specific geological conditions. This means that different geological conditions lead to different types of biosignatures and consequently necessitate different analytical approaches (e.g. Cavalazzi et al. 2011, 2012, 2014, 2019). As a consequence, different protocols depend on different geological conditions, emphasizing the entangled link between geological conditions and astrobiological investigations.

Several problems may hamper the possibility to constrain the analogy between Earth and planetary settings, the main issues being the problems of scale and of equifinality (Baker 2014) (Figure 1). The scale of the available data and possible analyses is variable among planets and *in situ* data acquired by rover missions are extremely limited. The latter strongly limits the ground truth verification. In particular, while the regional analyses performed to constrain the geological context occur at similar scales (roughly 10s to 100s kms), the scales of the observations and measurements in the most favorable condition on Mars can reach a maximum detail at the meter scale (pixel around 25 cm), while on Earth even singe grains or crystals can be recognized and described already in the field. Moreover, geological analyses must always deal with the problem of equifinality, which means that similar effects may be generated by different combinations of causative processes (Figure 1). This implies that single morphologies (landforms) can be rarely unequivocally interpreted from remote sensing analysis in terms of genetic origin (depositional processes and environments). To cope with these problems, the reconstruction of a broader geological context (landscape), is necessary to understand environments and processes of deposition (e.g. Pondrelli et al. 2008, 2011, 2015, 2019). Such a scenario is built by correlating different coeval deposits, landforms, and structures, which combined analyses, using the typical multiple working hypothesis approach (Baker 2014), allows much more solid interpretations, also to support the analogy with the potential Earth analogues. In this framework, unravelling the vertical and lateral stratigraphic relations is crucial not only to reconstruct the depositional environments but also to correctly place data within the stratigraphic succession. As an example, in correspondence of the Eberswalde delta on Mars, the identification of olivine with CRISM spectral data (McKeown & Rice

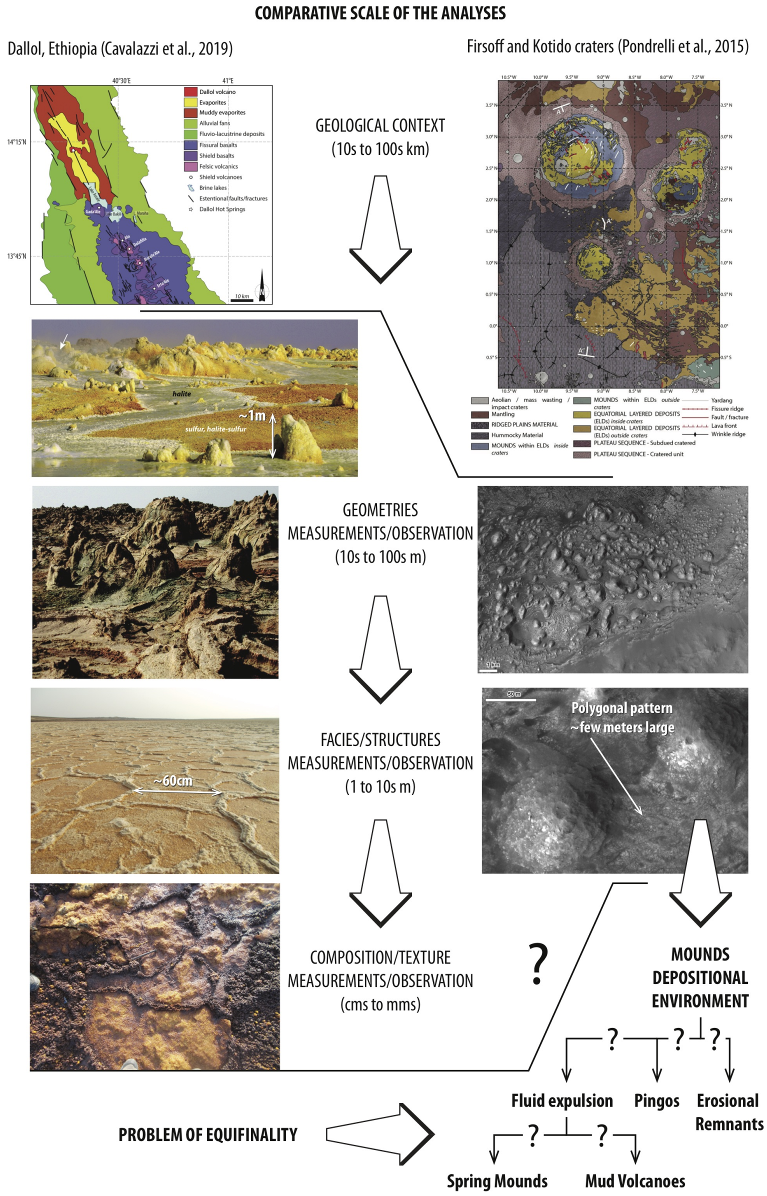

Fig. 1. Main problems affecting the comparative analyses between planetary sedimentary landforms and potential Earth counterparts and consequently the interpretation of the planetary sedimentary depositional environments.

2011), lead to doubt the deltaic origin of this feature. However, detailed stratigraphic analysis showed that olivine-bearing deposits rest in unconformity on top of the deltaic materials, meaning that they represent a different phase of the geological history of the area.

3. Planetary Scenario Mission Prediction

A solid reconstruction of a geological context is necessary on the potential planetary target, but also on the potential Earth analogues. On Earth, the depositional environments and processes can be characterized, defining the facies, facies association, lateral transitions, and structure distribution at the outcrop scale, specifically the ones that are suitable for sampling and laboratory analyses, and ultimately understanding the controls on deposition (e.g. Cavalazzi et al. 2011, 2012, 2014, 2019). This set of information provides fundamental elements to reconstruct the vertical and lateral facies/structures distribution in an analogue planetary setting (e.g. Pondrelli et al. 2008, 2011, 2015, 2019) and drives the sampling site selection but also the choice of more appropriate instrumentation. This holistic approach can provide not only a basic knowledge of the landing site/mission object area but is mandatory for a sample return mission and the selection of the right samples. The rationale for planning a sample return mission is that, one can take a rock home, but not an outcrop. Thus, context geology is the first requirement to understand where the most significative sampling should be taken. Geology represents a key science to bridge the gap between Earth and Planetary investigations and to guide future planetary exploration and mission.

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