THE INFLUENCE OF SUBSURFACE PROCESSES ON MARTIAN BASALTS: AN EXAMPLE OF HYDROTHERMAL AND ACIDIC BASALT ALTERATION AT THE *SKOURIOTISSA* MINE, CYPRUS.

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Introduction: Alteration of basaltic materials in subaqueous to subaerial conditions seawater, hydrothermal and/or meteoric fluids in the upper 100 meters results in changes in the physical and chemical proprieties of the rocks and rock-forming minerals. The weathering is strongly linked to the nature of the rocks, for example, their composition, granumoletry, hardness, as well as to the climatic effects, such as temperature changes, that will affect their degree of friability and fracturing. Common alteration products of rock weathering by atmospheric, hydrosphere, and hydrothermal processes are clay minerals and salts.

Basalts on Mars: The early martian surface is mainly basaltic [1]. Basalts consist primarily of olivine and pyroxenes in a siliceous glass, they are essentially anhydrous. However, analyses from orbit document large areas of phyllosilicates at the surface [2,3]. The formation on these minerals is hypothesized to be due to aqueous weathering of the basaltic flows [4]. Further information about the nature and origin of the alteration facies is important for understanding the early geological processes on Mars and their influence on habitable conditions and the emergence and evolution of life [3,5].

Many of the alteration processes occur at a local scale and result in subtle changes in texture and mineralogy with distance from the main source of alteration. During an *in situ* mission, time and payload limitations may restrict the kinds of decimeter-scale analyses that are required to characterise the alteration phenomena. However, detailed knowledge of the kinds of changes that can occur based on analysis of terrestrial analogues can provide information that will aid interpretation.

Altered terrestrial basalts as an analogue for Mars: Study of the alteration of terrestrial basalts under subaqueous (seawater and/or hydrothermal) acidic and surficial conditions may reveal similarities with surface and subsurface processes occurring on Mars and thus help us to understand and interpret martian features. A suitable terrestrial analogue site should therefore consist of non-metamorphosed basalt, *i.e.* a relatively young environment [6,7] that has undergone acidic alteration similar to weathering processes on the martian surface. On Earth, typical acidic environments are found in sulphide-rich quarries and mine tailings in very massive sulphide (VMS) deposits (ore deposits). VMS deposits are widespread in the oceanic basaltic crust [8] and are related to high to medium temperature hydrothermalism at ridge crests. Primary alteration of the VMS and associated basalts by seawater and/or hydrothermal fluids occurs at the seafloor whereas secondary alteration occurs when these formations are subaerially exposed.

Example: The *Skouriotissa* mine in Cyprus is an open pit copper mine in a VMS deposit hosted by exposed pillow lavas in the Troodos ophiolite (Fig. 1). This ophiolite is young (20 Ma, [10]) and unmetamorphosed.

Fig.1: Outcrop of the weathered basaltic rocks in the Skouriotissa mine, Cyprus. On the left, the buff-coloured pillow basalts (outlined by white dotted lines) have undergone seawater/hydrothermal alteration on the sea floor (Quartz + Chlorite, red star 1). More altered basalt occurs in the middle of the figure (Quartz + Smectite, red star 2). On the right, acidic water leaching from the VMS body results in a surficial iron oxide deposit (Quartz + Smectites, then Smectites + Zeolites + Sulphates, red star 3).

We have analysed the mineralogical evolution of the basalt on a 20 meter to micrometer scale through the different alteration facies (phyllosilicates, including smectite, vermiculite, nontronite, zeolites, and sulphates), depending on the type of alteration. The basalt was initially altered by seawater and hydrothermal processes on the seafloor and then subaerially by acidic waters (pH increasing from 5 to 3 with increasing distance from the source) associated with mining activities (Fig. 1). The seawater/hydrothermal alteration formed a quartz-chlorite (chamosite type) alteration facies, whereas the acidic alteration favours the formation of specific clays, such as smectites at pH 5 and zeolites and sulphates (gypsum and natrojarosite) at pH 3-4 (Fig. 1).

Thus, in a natural laboratory, we have documented mineral associations similar to those found on the surface of early Mars in Noachian/early Hesperian (e.g. [2,3]), at the same time as being able to link them to specific subaqueous/subaerial and pH conditions of alteration. This demonstrates the utility of investigating terrestrial analogue sites for understanding of subsurface geological phenomena on Mars.

The International Space Analogue Rockstore (ISAR) collection: This suite of rocks forms part of the collection of Mars analogue rocks that is being prepared at the CNRS/Observatoire des Sciences de l'Univers en région Centre (OSUC) in Orléans to help calibrate present and future flight instruments (e.g. MSL, the ExoMars-2018 *in situ* mission). This collection, the International Space Analogue Rockstore (ISAR) and associated database are described in the following website : http://www.isar.cnars-orleans.fr [11].

Conclusion: Mineralogical changes associated with seawater/hydrothermal and meteoric alteration of basalts on Mars can be better understood by performing refined multidisciplinary mineralogical and petrological studies of terrestrial analogues. Meter- to micrometer-scale (mineral grain) analysis of the mineralogical processes across the path of an acidic flow in basalts associated with a sulphide ore deposit properly reproduces the interactions between rocks and fluids in the near-subsurface environment on early Mars.

References: [1] McSween *et al.*, 2009; Science; [2] Poulet *et al.*, 2005, Science; [3] Bibring *et al.*, 2006, Science; [4] Haskin *et al.*, 2005, Nature; [5] Ehlmann *et al.*, 2011, Nature; [6] Tosca *et al.*, 2004, JGR; [7] Hurrowitz *et al.*, 2006, JGR; [8] Jebrak and Marcoux, 2009; [9] Meunier *et al.*, in prep.; [10] Cyprus Geological Survey Department, 2007, Geological Map; [11] Bost *et al.*, in review (Icarus).