PROSPECTING IN-SITU RESOURCES FOR FUTURE MANNED MISSIONS TO MARS. C. Gross[1], M. Al-Samir[1], J.L. Bishop[2], F. Poulet[3], D. Schubert[4], and P. Zabel[4], [1]Institute of Geological Sciences, Planetary Sciences and Remote Sensing Group, Freie Universität Berlin, Germany (christoph.gross@fu-berlin.de); [2]SETI Institute & NASA-ARC, Mountain View, CA, USA; [3]Institut d'Astrophysique Spatiale, Paris- Sud University, Orsay, France; [4]German Aerospace Center (DLR), Institute of Space Systems, Bremen, Germany.

Introduction: The installation of planetary and lunar outposts is a necessary step for the future exploration of the solar system. Humans, living and working in these artificial habitats will depend on bio-regenerative life support systems to produce and recycle oxygen, water and food. Mars is rich in natural resources vital to supporting astronauts for extended periods of time. Instead of launching resources such as water, fuel, food and other materials, it could potentially be much more cost effective to send automated machinery to harvest resources from the Martian surface and atmosphere in preparation for the human arrival. Prospecting for usable resource deposits, the concentration and possible contamination of the raw materials and the feasibility of extraction and mining are open questions and deserve intense study.

In-Situ Resource Utilisation (ISRU) Experiments: The European Space Agency plans a robotic mission by 2025 to demonstrate that water and oxygen production is possible at the lunar surface [1]. Oxygen may be the first resource produced locally to support manned missions as part of the fuel supply or life support systems. NASA also made a first step towards investigating the use of local resources with the MOXIE experiment on the Mars 2020 Perseverance rover by producing oxygen out of atmospheric CO_2.

Food is also an important factor to reduce logistics from Earth. Since 2018, the EDEN research group from the German Aerospace Center operates a space-analog test facility greenhouse near the Neumayer III station in Antactica (Figure 1), maybe the closest analog we can find on Earth and therefore categorized as ISRU here. In the first year of operation, 268 kg of edible biomass was produced on the 12.5 m^2 cultivation area of the greenhouse and with an energy consumption of 240 kWh/day [2]. Growing plants for food production also has the advantage of removing CO_2 from the atmosphere and producing oxygen.

Examples of Exploitable Resources on the Martian Surface: A variety of water-bearing sulfate minerals have been discovered in various regions of Mars [e.g. 3]. Among them, magnesium- and potassium sulfates including kieserite ($MgSO_4 \bullet H_2O$), epsomite ($MgSO_4 \bullet 7H_2O$) and K-jarosite $KFe_3(SO_4)_2(OH)_6$. These minerals can for example be used in pure form, without refinement for nutrient solutions in hydroponic systems for food production.

Clay minerals are also present on Mars, partly in very large quantities [4, 5, 6, 7] and could be used to produce ceramics. The large specific surface of the phyllosilicate minerals and the ability of smectite clays to exchange cations also allows for the usage of these clays as ion exchangers for example as a filter for water treatment or for decontamination purposes. The clay mineral chlorite can be used as filler in plastic materials or in joints and gaskets. Foamed clay, a very porous, burned clay product can be used as building insulating material and for hydroponics. The utilization of Martian clays as construction material has also been studied [8].

Water will be the most important resource needed by humans if sent to Mars. Massive amounts of water are present at the poles, especially the North Pole. However, it is hardly accessible and it can be assumed, that a manned mission would not target such an inhospitable, forbidding region. The water concentration in the atmosphere is very low (<0.03%) and has a very high spatial, diurnal and seasonal variability, making an extraction difficult.

Figure 1: The EDEN ISS greenhouse in Antarctica with the Neumayer III station in the background (top). Cultivation area inside the test container (bottom).

However, water can be found and extracted from i.e. hydrated sulfate minerals and clays in a comparatively simple extraction process [9, 10].

Reconnaissance of Resources on Planetary Surfaces: In a first step we will identify surface materials using Vis-NIR spectroscopy data from OMEGA on Mars Express and CRISM on MRO followed by mapping of selected deposits that could be significant for future missions. Important factors like the mineralogy, the evaluation of the amounts present at the deposit and the stratigraphy will be assessed. Easy access to the resources is also very important, therefore an intense landing site investigation has to be carried out. Geologic difficult structural conditions can be analyzed by using VR-methods for visualization as described by [11]. Uncertain mineralogy can be narrowed down using geochemical modelling and lab experiments [12].

Example Regions of Interest: Widespread layered clay-bearing deposits are observed at the rims of Cryse Planitia and very prominent at *Mawrth Vallis* (Figure 2). Mawrth Vallis is an ancient flood channel. OMEGA and CRISM instruments have identified a great diversity of altered, water-bearing minerals in association with light-toned deposits. A thick (>200 m) stratigraphic section exhibits spectral evidence for Fe/Mg- smectites, Al-smectites, iron-oxyhydroxide (ferrihydrite), ferrous phases, amorphous silica, kaolinite, ferrous mica and sulfate minerals. The diversity, amount and proximity of resources at Mawrth Valles is unmatched making the region a promising exploration target [13, 14].

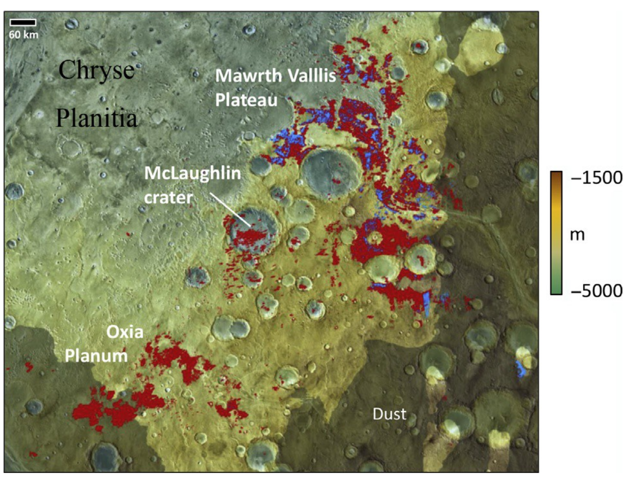

Figure 2: Clay-rich outcrops in the Cryse Planitia region [15]. Fe/Mg phyllosilicates (nontronite, saponite, chlorite and serpentine) mapped in red. Al/Si-rich clays (kaolins, smectites, opal and allophane) shown in blue. Note the important deposits in the Mawrth Vallis region.

Juventae Chasma represents another interesting exploration target. It is a >5 km deep basin located north of Valles Marineris. It contains several light-toned interior layered deposits (Figure 3). The deposits are composed of monohydrated (MHS) sulfates with one water molecule per cell and polyhydrated sulfates (PHS), which have multiple water molecules built in their structure. The deposits are very large, ranging from the smallest mound A 25.15 km³ to the largest mound C with 1028.23 km³ [16]. The majority of the MHS exhibits a kieserite signature. The PHS show different Mg and Fe-PHS phases such as for example starkeyite ($MgSO_4 \cdot 4H_2O$) [17]. The high H_2O content makes these deposits interesting for water extraction [9]. In addition, the hydrated sulfate materials could be used for nutrient solutions in hydroponic systems.

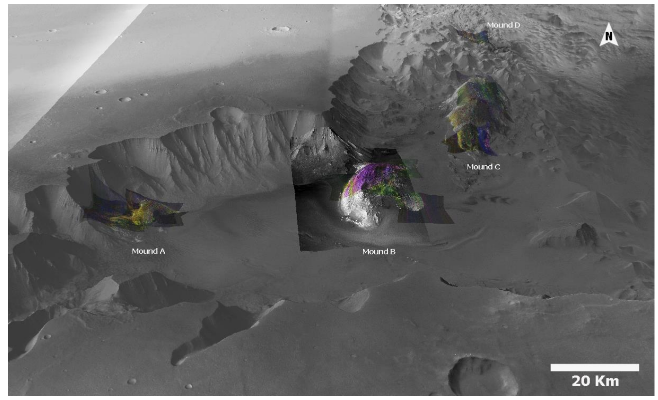

Figure 3: Oblique view of the sulfate-bearing mounds in Juventae Chasma. HRSC image mosaic and DTM. CTX image (mound B) and CRISM overlay showing polyhydrated sulfate in purple and monohydrated sulfate in yellow.

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