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MER-Class Rover Investigations of Mars in the Coming Decades. David Blake[1], Kris Zacny[2], Thomas Bristow[1] and Philippe Sarrazin[3]. [1]Exobiology Branch, MS 239-4, NASA Ames Research Center, Moffett Field, CA 94035 (David.blake@nasa.gov); [2]Honeybee Robotics, Pasadena, CA; [3]SETI Institute, Mountain View, CA.

Introduction: It is likely that the level-of-effort and cost of Mars Sample Return will preclude Flagship-class missions to Mars for the indefinite future, limiting a full and comprehensive characterization of the Mars surface to only two sites: Gale and Jezero Craters. However, dozens of geologically diverse and scientifically compelling landing sites were characterized during MSL and Mars 2020 site selection workshops. In order to understand the geology of Mars, its early habitability and its potential to support ISRU and eventual human habitation, full and comprehensive science investigations are needed at many diverse sites.

The MER rovers Spirit and Opportunity were among the most successful landed Mars missions of all time, exceeding expectations for mission duration and science return. This legacy of mission success and scientific accomplishment must be continued. Moreover, two further decades of spacecraft instrument development and miniaturization now allow for Flagship-class instrumentation to be packaged in payloads suitable for MER rover architectures [1-2].

With regard to geologic environment, habitability potential and biosignature identification, there are 3 principal characteristics that define rocks or soil: *Structure* (mineralogy as defined by crystal structure), *Elemental Composition*, and *Morphology*. Mineralogical analysis alone can be used to fully characterize a geologic environment. Elemental analysis is useful to determine the composition of X-ray amorphous material (if present) and to identify minor or trace elements suggestive of secondary processes. Morphology provides spatial context and timing. Are there veins, concretions, macroscopic crystals present in the sampled volume?

A MER-class payload that would provide a full and comprehensive characterization of a scientifically compelling site on Mars could be (for example): A Robotic Arm equipped with a mini-powdering drill, a Rotary Abrasion Tool (RAT) and an imaging X-ray Spectrometer. Drilled and powdered materials could be delivered to an X-ray Diffraction / X-ray Fluorescence instrument (XRD/XRF) in the body of the rover, to provide definitive and quantitative mineralogy of the drilled materials. A mast camera or arm-mounted hand lens camera could provide context for the measurements. Figure 1 shows an example MER-class rover with an XRD and powdering drill and figure 2 shows an implementation of a powder collection system.

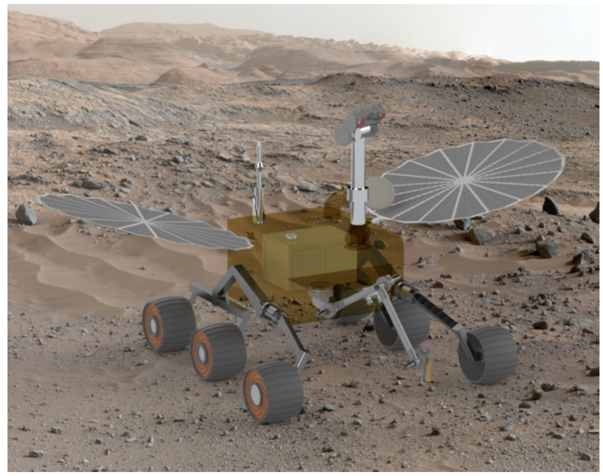


Figure 1. Implementation of a Powder Collection and Delivery (PCD) system and Instrument Sample Manipulator (ISM) on a MER sized rover (as modeled ~2.0X1.0X1.0m, 120-150 kg). The PCD is fitted to the arm of the rover and collects powdered samples from the ground. The powder is delivered to an XRD/XRF instrument visible inside the rover and hosting the ISM. The proposed technology will enable definitive mineralogical analysis in smaller rovers.

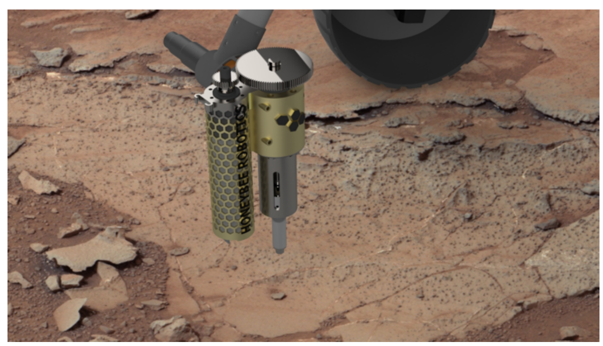


Figure 2. Implementation of a powder collection system based on a miniaturized design of Honeybee Robotics powder drill [3].

Example XRD/XRF analysis - Cumberland Mudstone, Gale crater (Mars Science Laboratory CheMin Instrument): As the first crystallography instrument ever flown in space, the XRD/XRF instrument CheMin's mineralogical analyses have been critical to a number of first-of-their-kind achievements. CheMin's third analysis, "Cumberland" is shown here in its entirety to illustrate the power and unique capability of X-ray diffraction in characterizing complex mineral assemblages. Tables 1-3 illustrate the data set obtained from this measurement.

Table 1 shows the mineral identifications and elemental compositions of major crystalline phases obtained through Rietveld refinement [4]. In addition to determining mineral compositions, refined lattice parameters are also used to measure cation deficiency in magnetite and the structural state of the potassium feldspar [5-6]. Clay minerals are identified and quantified using FULLPAT analysis [7]. The clay mineral in Cumberland is identified as a smectite from the position of its 001 peak. The position of the 02*l* diffraction band of the smectite indicates that it is a Fe-rich and trioctahedral.

Table 1. Mineral Abundances in		
Mineral	Wt.%	
Plagioclase Feldspar[1]	42.8 (2)	$Ca_{0.}$
Pigeonite[1]	17.0 (11)	Mg_{1}
Orthopyroxene[1]	14.5 (8)	Mg_{0}
Magnetite[2]	11.5 (4)	$Fe_{2.8}$
Sanidine[1,3]	4.9 (7)	$K_{0.77}$
Olivine[4]	3.3	(FeN
Bassanite	2.3	CaS(
Akaganeite	1.6	Fe^{+3}
Anhydrite	1.3	CaS(
Hematite[4]	0.8	Fe_2(
Total	100.0	
[1] Elemental composition determined fron		
[2] Cation deficiency determined from refin		
[3] Structure state determined from refined		
[4] Considered to be contamination from pi		

Table 2. Mineral, Clay Mineral and Amorphous Abundances in the Cumberland Mudstone	
Component	Wt.%
Crystalline Minerals	51
Smectite Clay	18
Amorphous Material	31
Total	100.0

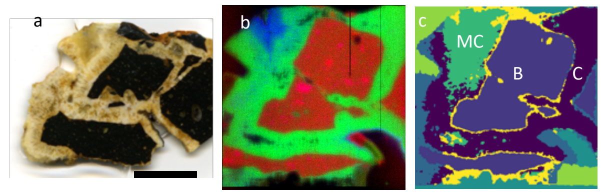
Table 3. Normalized composition (oxide wt.%) of Crystalline and Amorphous components			
	Total	Xtal.	Amorph.
SiO_2	41.13	46.93	25.56
TiO_2	0.99	0	3.66
Al_2O_3	8.63	11.84	0
Cr_2O_3	0.46	0	1.7
FeO_T	21.95	23.41	18.03
MnO	0.29	0	1.09
MgO	9.32	6.28	17.53
CaO	6.66	5.01	11.12
Na_2O	3.01	3.51	1.66
K_2O	0.62	0.65	0.53
P_2O_5	0.86	0	3.18
SO_3	4.61	2.04	11.54
Cl	1.19	0	4.40
F		-	0
H_2O	-	0.33	-
Prop.	-	0.737	0.263

The proportions of crystalline minerals, clay minerals and amorphous material are shown in Table 2. The composition of the amorphous component is found by subtracting the crystalline composition from the overall composition determined by the Alpha Particle X-ray Spectrometer (APXS) on MSL (Table 3).

MER-class XRD/XRF Analysis: *CheMinX* [1,8], a next-generation XRD/XRF instrument, provides improved capabilities relative to CheMin, at one third the volume and one half the mass with reduced power requirements, in a package suitable for inclusion on MER-class rovers.

MER-class Arm-based Elemental Imagery: On Mars landed missions to date, many features seen with arm-based optical imagery (concretions, veins, macroscopic crystals) cannot be uniquely identified or characterized because the elemental /mineral analysis instruments (APXS, Mossbauer) lack spatial resolution. The inclusion of an arm-based elemental imager along with an XRD/XRF will allow for structure, composition *and* morphology data to be collected contemporaneously, yielding a comprehensive and synergistic dataset for Earth-based interpretation.

MapX [2,9] is an imaging XRF Spectrometer suitable for moderate resolution (~100 µm) elemental imaging, suitable for inclusion on MER-based rovers. Figure 3 shows a partial MapX dataset collected from a brecciated basalt infilled with hydrothermal carbonate cements from Spitsbergen, Norway.



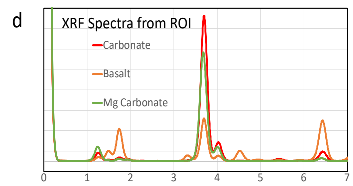


Figure 3. Basalt breccia cemented by carbonate. a). image of basalt breccia, scale bar = 1 cm (note: the image shown is the obverse of the side used for X-ray imaging); b). RGB image from MapX-III prototype, Fe=Red, Ca=Green, Mg=Blue; d). instrument selected Regions of Interest (ROI) having common compositions, B = basalt breccia, C = Carbonate, MC = magnesian carbonate; e). XRF spectra from ROI.

Conclusion: A MER-class rover equipped with a powdering drill, XRD/XRF and arm-based elemental imager, along with context instruments such as a Mast camera and hand-lens imager, will provide a comprehensive characterization of Mars surface regolith.

A cookie-cutter approach to the development of a MER-class architecture suitable for multiple mission opportunities would reduce cost and risk. Only by accessing and fully characterizing multiple sites representing the full diversity of geologic and morphologic features on Mars will we be able to fully elucidate its early history and habitability potential.

Refs: [1]. https://odr.io/view/downloadfile/60863 [2]. https://odr.io/view/downloadfile/60861 [3]. Zacny, K. (2013), IEEE Aerospace Conference (pp. 1-11). IEEE, Big Sky, Montana, March 2-9. [4]. Bish, D.L. and J. E. Post (1993), *Am. Min.,* **78**, 932-940. [5]. Morrison, S.M., et al. (2018a), *American Mineralogist.* DOI: 10.2138/am-2018-6123. [6]. Morrison, S.M., et al. (2018b), *American Mineralogist.* DOI: 10.2138/am-2018-6124. [7]. Chipera S.J. and D. L. Bish (2002), *J. Applied Crystallography* **35**, 744-749. [8]. Sarrazin, P. et al (2019), LPSC 50, abstr.# 2236. [9]. Blake et al., (2019). 9th Int'l Conf. on Mars Abstr# 6329.