Planning for the Earth-Based Instruments and Associated Sample Preparation Procedures Needed to Achieve the Scientific Objectives of MSR. David W. Beaty[1] and Yang Liu[1] [1] Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, david.w.beaty@jpl.nasa.gov.

Introduction: Mars sample return has been consistently recommended by Mars exploration advisory and analysis committees for more than three decades (for the most recent summary, see the NRC Decadal Survey 2013-2022).

There have been several recent analyses of the instruments needed in the field to most effectively select the samples that would be returned by the potential MSR, and to document their critically important field context. Primary recent examples include Pratt et al., 2009; McLennan et al., 2011; Beaty et al., 2012; and Mustard et al., 2013). However, now that NASA has selected the instruments for the proposed Mars 2020 sample-collecting rover, the attention of the instrument-planning/building community needs to shift in part to the instruments needed to evaluate the samples once received on Earth.

The planning for these instruments may depart significantly from those used on flight missions, since the optimization criteria would be very different. In the former case, factors of high importance would be detection limits, accuracy, precision, and efficient use of sample material. Some of the criteria traditionally used in the latter case (e.g. mass, volume, power, data rate) would be close to irrelevant for returned sample analysis.

An additional important consideration is that when the samples are received, they would be expected to undergo preliminary examination within a BSL-4 quality containment facility. Follow-up investigation of sample splits for scientific research may or may not be required also to be carried out within a containment facility. Thus, the instruments that may be used to investigate the returned samples may need to be operated within the context of biosafety containment. This is an extraordinary challenge, and we request that the instrument development technology program take this into consideration as investments are made in the medium-term future.

This Study: We have carried out a preliminary compilation of a set of measurements that would be sufficient to achieve the thus far identified scientific objectives of MSR. Our analysis is presented in Table 1. This table is organized around the structure of the scientific objectives for MSR as described by McLennan et al. (2011). There are 8 such objectives, which are listed in Table 1 in priority order (with the priority originating from McLennan et al. 2011). We recognize, of course, that since the objectives for returned sample science may change with time, and new approaches to sample interrogation may be developed, Table 1 needs to be thought of as a living document that will evolve with time. However, by proposing the first draft of such a list, we hope to catalyze some structured thinking by future MSR-related planning teams, particularly those related to instrument planning.

Table 1 additionally lists the sample preparation procedures classically associated with each of these measurements. We recognize three classic preparations for rock/soil samples. These methods have different degrees of destructiveness for sample material (a huge issue for returned sample science), with resulting different degrees of potential for re-use of sample material for alternate investigations.

1. preparation of a bulk rock powder
2. preparation of either mineral separates or grain mounts
3. preparation of a surface (polished or flat but unpolished)

Gas samples need a completely different kind of sample preparation prior to analysis than do solid samples, and are not discussed further here.

In some cases, the scientific objectives described by McLennan et al. (2011) can be further broken down into more than one purpose. For example, the first objective (“Past Life, habitability”) can be decomposed into seeking biosignatures, habitability assessment; and preservation potential. These subordinate purposes are identified in an investigation-by-investigation way in the preliminary lists of Table 1.

The scientific investigations shown in Table 1 are listed in approximate priority order within Objective-level groupings. Thus, the first investigation listed within an objective is judged to be generally higher priority than the investigations below it. These priorities were not quantified, and in a future revision of this table, that may be warranted. For example, one prioritization criterion should be the expected consumption of precious, irreplaceable sample material—the quantity of sample needed for each of these investigations could be estimated. Another should be degree of progress towards the stated objectives. There are clearly others, and these priorities would be the subject of much discussion before a sample analysis program was actually set in motion.

Translation from Investigations to Instruments: Part of the scientific power of Mars Sample Return would be that it is conceptually possible to carry out most of the investigations in Table 1 using more than one instrumental approach. For example, there are multiple ways to determine a sample's mineralogy, and these different methods have different detection limits, accuracy, precision, and consumption of sample material. Ultimately, we presume that the specifics of the instruments chosen to carry out these investigations would be determined by competition. However, if needed for planning purposes, it should be possible to construct models of the list of instruments implied by these investigations. This may be of value in technology planning, budgeting, operations planning, long-lead planning for the SRF, and/or community outreach.

Table 1. Preliminary list of returned sample science measurements that would be necessary to achieve the scientific objectives of MSR.

Science Objective	Working List of Mars Returned Sample Science Measurements: Feature/analysis:Sample Prep (method): (Purpose)		Sample Preparation			
	Science Investigations in Approximate Priority Order Within Groups	E2E-iSAG Ref. # from Table 6	bulk-rock powder	mineral separate /(grain mount)	polished/unpolished rock	gas
1 Past Life, habitability	Morphology (e.g., cells, subcellular structures, cell clusters):polished rock (microscopy):(Biosiganure)	[1,A1]			x	
	Rock Fabrics (e.g., stromatolites): polished rock (imaging at sub-mm to m scales):(Biosignature)	[1,A1]			x	
	Mineral (e.g., carbonates, sulfates, phyllosilicates, oxides [e.g., biogenic magnetite]):mineral separates/polished rock (spectroscopy, XRD, etc.):(Biosignature)	[1,A1]		x	x	
	Organic compounds (e.g., lipid biomarkers):bulk rock powder/rock (spectroscopy, MS, chromatography, etc.):(Biosignature)	[1,A1]	x		x	
	Stable isotopic patterns (e.g., indicators of biological redox reactions):bulk rock powder/rock (MS, laser spectroscopy):(Biosignature)	[1,A1]	x		x	
	Identification of minerals and elemental abundances:bulk rock powder/polished rock: (Habitability: Water activity & **Objective 3**)	[1,A1] & [3,B1]	x		x	
	Identification of minerals and elemental abundances: bulk rock powder/rock: (Habitability:Chemical building blocks, C, H, P, O, N, S)	[1,A1]	x		x	
	Minerals and elemental abundances(redox state):polished rock: (Habitability:energy source)	[1,A1]	x		x	
	Identification of minerals and elemental abundances(solvent, T, etc):bulk rock powder/polished rock: (Habitability: **environmenta**l conditions/**Objective 3?**)	[1,A1] & [3,B1]	x		x	
2 Evolution of Mars interior	Mieraology, mineral chemistry, texture: Polished rock:(differentiation and igneous/metamorphic history)	[2, C1]			x	
	Bulk major, minor and trace-element compositions: bulk rock powder:(igneous/metamorphic history)	[2, C1]	x			
	Radiogenic lithophile element (K-Ar, Ar-Ar, Rb-Sr, Sm-Nd, Lu-Hf) isotopes: bulk rock powder/mineral separates:(geochronology, mantle reservoirs, cooling history, impact age as **Objective 6)**	[2,C1] & [6,B2]	x	x		
	Radiogenic lithophile element (U-Pb, Pb-Pb) isotopes: bulk rock powder/mineral separate:(geochronology, mantle reservoirs)	[2, C1]	x	x		
	Radiogenic lithophile element (U-Pb, Pb-Pb) isotopes: polished rock (SHRIMP):(geochronology, mantle reservoirs, cooling history)	[2, C1]			x	
	Highly siderophile elements (W, Re, Os, PGE) and isotopes:bulk rock powder/rock?:(Accretion/core formation & **Objective 6**)	[2, C1] & [6, B2]	x		?	
	N and noble gas abundances/Isotopes: bulk rock, mineral separates?:(Planet Evolution & **Objective 4; 7**)	[2, C1]	x	?		x
	Stable isotopes of H, O, C, S etc: bulk rock, mineral separates :(formaiton/differentiation)	[2, C1]	x	x		
	Stable isotopes of H, O, C, S etc(SIMS): polished sections: (formaiton/differentiation)	[2, C1]			x	
	Paleo-magnetism: Bulk Rock/Polished Section:(core formation)	[2, C1]	x		x	
3 surface or near-surface processes with water (Sample type: A=Lacustrine;B=Hydrothermal;C=low-T alteration;D=unconsolidated	Stratigraphy&structure: rock (unprocessed&polished, A-C sample types):(context&origin& 2ndary processes)	[3, B1]			x	
	Petrography (texture, grain size,shape, etc):rock (A-D types):(context&origin&2ndary processes)	[3, B1]			x	
	Bulk rock chemistry:bulk-rock powder/rock (A,B, D types):(open vs closed system alteration & **Objective 1**)	[3, B1] & [1, A1]	x		x	
	Bulk rock mineralogy:Bulk rock powder(XRD)/rock (Spectroscopy)(A,B, D types):(primary vs secondary; **& Objective 1**)	[3, B1] & [1, A1]	x		x	
	Chemistry of soluble components (Eh, pH, soluble ions, volatiles):Bulk-rock powder(A,B, D types): (Characterize fluids & **Objective 1**)	[3, B1] & [1, A1]	x			
	Mineral chemisry/isotopes:Mineral separates/rocks(A-D types):(primary vs 2ndary, fluid history; & Objective 1)	[3, B1] & [1, A1]		x	x	
	Stable (non-traditional) isotopes: Bulk-rock powder/separates (A-D types):(fluid flow/exchange)	[3, B1]	x	x		x
	Radiogenic isotope tracers (Sr, Nd, Pb, etc):Bulk-rock powder/mineral separates(A,B, +/-D types):(fluid sources&history)	[3, B1]	x	x		
	Radiogenic isotope age(e.g., 3He, 21Ne, 36Ar, K-Ar) :bulk-rock powder/mineral separates(A,B types):(Cosmic exposure? Age of primary vs 2ndary)	[3, B1]	x	x		x

Table 1 (continued). Preliminary list of returned sample science measurements that would be necessary to achieve the scientific objectives of MSR.

Science Objective	Working List of Mars Returned Sample Science Measurements: Feature/analysis:Sample Prep (method): (Purpose)		Sample Preparation			
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4 climate change	Noble gas and their isotopes, photochemicals in gas: Gas (atmosphere/headspace gas?): (present day atmosphere)	[4, B3]				x
	trapped H, O and noble gases and their isotopes: minerals/bulk rocks:(ancient atmosphere & **objective 2 & objective 7**)	[4, B3] & [2, C1] & [7, C2]		x		
	Stratigraphy:unprocessed sample/polished section:Evidence from climate-sensitive geological processes	[4, B3]			x	
	Secondary minerals: rock sample: Evidence from climate-sensitive geological processes:	[4, B3]			x	
	Grain size/Shape: Bulk sample: Evidence from climate-sensitive geological processes	[4, B3] & [6, B2]			x	
5 hazard to human	Grain size distribution:airfall dust/surface soils:Toxicity	[5, D1]	x			
	Dust physical, chemical and structure (Surface reactivity, electrostatic & chemistry):Dust/Regolith:(Toxicity, effects on hardware)	[5, D1]	x			
	Regolith physical properties & structure:regolith as is:(effects on landing & surface systems)	[5, D1]	x			
6 surface modifying processes	Impact age (Ar-Ar), bulk-rock power:(Surface age;**Objective 2**)	[6, B2]		x		
	Exotic mineralogy in sediments/soils: bulk sample/mineral:(exo-Mars input)	[6, B2]		x		
	Photochemistry/bulk chemistry: bulk sediments:(Surface alteration processes)	[6, B2]	x			
	Grain Size, surface chemistry, lithological diversity: Bulk Regolith/dust: (Surface processes: Aeolian)	[6, B2]		x		
	Cosmic ray exposure age: bulk-rock powder:(Surface ages)	[6, B2]	x			
	Mineralogy and Petrology:Bulk regolith: (Fluvial, ice erosion)	[6, B2]	x			
7 atmosphere evolution	Isotope-H, C, N, O:Gas: Isotopic composition of present-day	[7, C2]				x
	Abundances of trace species:Gas:(Photochemistry of present-day gas)	[7, C2] & [Add, A2]				
	Suspended dust:Dust in Gas:(Dust property, interference to other gas measurements)	[7, C2]				x
8 Critical resources	Hydrated mineral compositions:bulk sample/mineral separates(e.g., H abundances, XRD):(critical resources)	[Add, A2]	x	x		
	Methane in atmosphere?:gas: rocket fuel?	[Add, A2]				x
	C-bearig component:bulk regolith/sediments:(Rocket fuel?)	[Add, A2]	x		x	
extant life	extant life on surface and in near-surface: overlap above, see above					
Planetary Protection	TBD					