KISS Workshop: Revolutionizing Access to the Martian Surface

Driving Science Questions for Mars

Don Banfield (Cornell University)

What are the current high priority Mars science goals?

Which can only be answered through in situ science?

What measurements are needed to address these goals?

MEPAG: Mars Exploration Program Analysis Group

MEPAG’s Goals Document

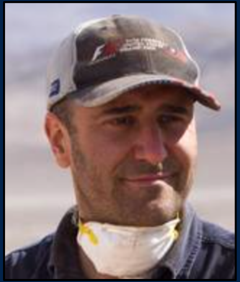
- Living document, updated every 2-3 yrs to reflect new discoveries
- Prioritizes **flight** measurements for high priority Mars science questions

“Mars Science Goals, Objectives, Investigations and Priorities: 2020 Version”, Banfield et al.

Goals Committee

Jen Stern
NASA
GSFC,
Goal 1

Alfonso
Davila
NASA
Ames,
Goal 1



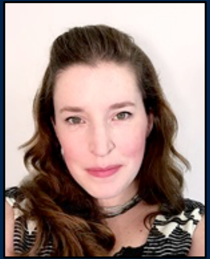
Sarah Stewart Johnson
Georgetown, Goal 1

David Brain
UC Boulder,
Goal 2

Robin Wordsworth
Harvard University, Goal 2

Don Banfield Cornell,
Goals Committee
Chair

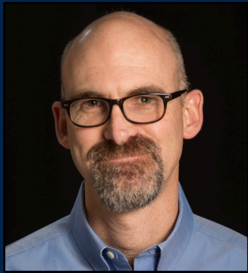
Briony Horgan
Purdue, Goal 3



Becky Williams
PSI, Goal 3

Michelle Rucker
NASA JSC, Goal 4

Paul Niles
NASA
JSC,
Goal 4



Jacob
Bleacher
NASA
GSFC/HQ,
Goal 4

Kevin D. Watts
NASA JSC, Goal 4

Broad community input

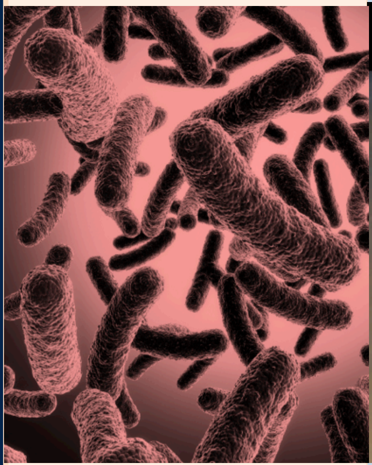
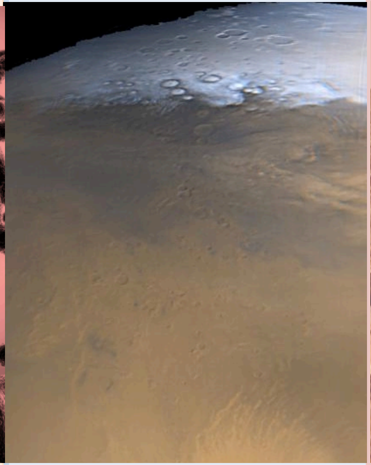
Latest revision input initiated at 9th Mars conference (July 2019)

Community feedback solicited and digested (February 2020)

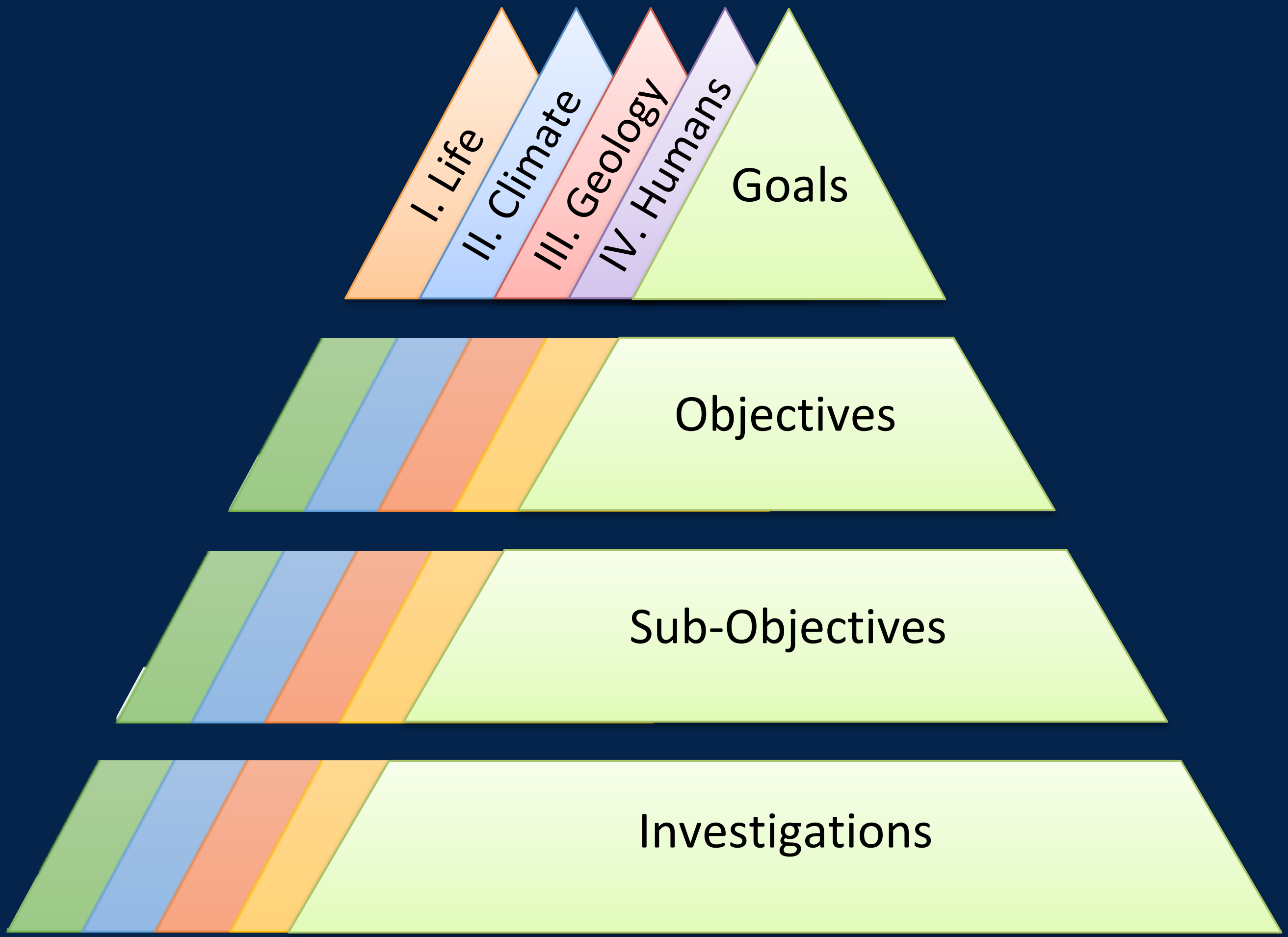
Final version March 31, 2020

Serves as a reference for Decadal Survey White Papers

KISS Workshop: Revolutionizing Access to the Martian Surface

Life	Climate	Geology	Human Exploration
			
I. Determine if Mars ever supported, or still supports life	II. Understand the processes and history of climate on Mars	III. Understand the origin and evolution of Mars as a geological system	IV. Prepare for human exploration

KISS Workshop: Revolutionizing Access to the Martian Surface



KISS Workshop: Revolutionizing Access to the Martian Surface

Life	**I. Determine if Mars ever supported, or still supports, life.**	A. Search for evidence of life in environments that have a high potential for habitability and preservation of biosignatures. B. Assess the extent of abiotic organic chemical evolution.
Climate	**II. Understand the processes and history of climate on Mars.**	A. Characterize the state and controlling processes of the present-day climate of Mars under the current orbital configuration. B. Characterize the history and controlling processes of Mars' climate in the recent past, under different orbital configurations. C. Characterize Mars' ancient climate and underlying processes.
Geology	**III. Understand the origin and evolution of Mars as a geological system.**	A. Document the geologic record preserved in the crust and investigate the processes that have created and modified that record. B. Determine the structure, composition, and dynamics of the interior and how it has evolved. C. Determine the origin and geologic history of Mars' moons and implications for the evolution of Mars.
Human Exploration Source: MEPAG 2020	**IV. Prepare for Human Exploration.**	A. Human landing with acceptable cost, risk and performance. B. Human surface exploration and EVA with acceptable cost, risk and performance. C. In Situ Resource Utilization (ISRU) of atmosphere and/or water with acceptable cost, risk and performance. D. Biological contamination and planetary protection protocols with acceptable cost, risk and performance. E. Human missions to Phobos or Deimos with acceptable cost, risk and performance.

KISS Workshop: Revolutionizing Access to the Martian Surface

I. Determine if Mars ever supported, or still supports, life

A. Search for evidence of life in environments that have a high potential for habitability and preservation of biosignatures.
A1. Determine if signatures of life are present in environments affected by liquid water
A2. Investigate the nature and duration of habitability near the surface and in the deep subsurface.
A3. Assess the preservation potential of biosignatures near the surface and with depth

B. Assess the extent of abiotic organic chemical evolution.
B1. Constrain atmospheric and crustal inventories of carbon (particularly organic molecules) and other biologically important elements over time
B2. Constrain the surface, atmosphere, and subsurface processes through which organic molecules could have formed and evolved over martian history

II. Understand the processes and history of climate on Mars

A. Characterize the state and controlling processes of the present-day climate of Mars under the current orbital configuration.
A1. Lower atmosphere dust, water, CO2 cycles
A2. Volatiles/dust exchange with surface
A3. Chemistry of atmosphere and surface
A4. Upper atmosphere/magnetosphere state & controlling processes

B. Characterize the history and controlling processes of Mars' climate in the recent past, under different orbital configurations.
B1. Determine recent climate record in polar region
B2. Determine recent climate record in low- and mid-latitudes
B3. Recent past atmospheric composition

C. Characterize Mars' ancient climate and underlying processes.
C1. Determine changes in atmospheric composition and mass through time
C2. find and interpret surface records of past climates

III. Understand the origin and evolution of Mars as a geological system

A. Document the geologic record preserved in the crust and investigate the processes that have created and modified that record.
A1. Characterize past and present water and other volatile reservoirs
A2. Document the geologic record in sediments
A3. Constrain ancient environmental transitions
A4. Determine the construction and modification of the crust

B. Determine the structure, composition, and dynamics of the interior and how it has evolved.
B1. Crust-mantle interactions
B2. accretion, differentiation and thermal evolution

C. Determine the origin and geologic history of Mars' moons and implications for the evolution of Mars.
C1. Origin of moons
C2. Impactor flux

IV. Prepare for human exploration

A. Human landing with acceptable cost, risk and performance.
A1. Atmospheric state affecting orbital capture and EDL for human missions
A2. Orbital debris environment
A3. Landing-site & environmental characteristics for safe landing

B. Human surface exploration and EVA with acceptable cost, risk, and performance.
B1. Surface radiation and dust hazards
B2. Impact of dust on hardware
B3. Dust storm risks
B4. Identify landing-site hazards

C. ISRU of atmosphere and/or water with acceptable cost, risk, and performance.
C1. ISRU resilience to varying environmental conditions
C2. Characterize water resources for ISRU for long-term human needs

D. Biological contamination and planetary protection protocols with acceptable cost, risk, and performance.
D1. Definition of "special regions" in the exploration zone
D2. Crew risk of martian biohazards
D3. Earth risk of martian biohazards
D4. Astrobiological baseline of landing site prior to human arrival
D5. Survivability of terrestrial organisms at Mars

E. Human missions to Phobos or Deimos with acceptable cost, risk, and performance.
E1. Geology to define science objectives, operations planning and resources
E2. Surface and orbital conditions for proximity operations

Source: MEPAG 2020

Goal I: Determine if Mars ever supported, or still supports, life

Objectives	Sub-Objectives
A. Search for evidence of life in environments that have a high potential for habitability and preservation of biosignatures.	A1. Determine if signatures of life are present in environments affected by liquid water.
	A2. Investigate the nature and duration of habitability near the surface and in the deep subsurface.
	A3. Assess the preservation potential of biosignatures near the surface and with depth

IA1.1 Chemical signatures of life (H): e.g., structure and composition of organic molecules
IA1.2 Physical structures of life (H): e.g., bio-minerals, cell-like structures
IA1.3 Physiological activity (M): e.g., isotopic indication of metabolites

IA2.1 Availability of liquid water (H): e.g., electrochemical measurements of regolith
IA2.2 Constrain energy sources vs depth (M): e.g., light spectrum, redox potential
IA2.3 Characterize environment re: stability of organic bonds (M): e.g., T, pH, water activity
IA2.4 Abundance of bioessential elements (M): e.g., Mass Spec for CHNOPS, Fe, Ca, Mg
IA2.5 Overall Geologic Context (M): e.g., imaging, mineralogy, radar, E&M mapping

IA3.1 Preservation of organic compounds vs depth (H): e.g., redox rate depth profile
IA3.2 Preservation of physical structures (H): e.g., sedimentation/erosion rates, diagenesis
IA3.3 Preservation of metabolic imprints (M): e.g., fine-scale chemical/mineralogical gradients

Goal I: Determine if Mars ever supported, or still supports, life

B. Assess the extent of abiotic organic chemical evolution.	B1. Constrain atmospheric and crustal inventories of carbon (particularly organic molecules) and other biologically important elements over time.
	B2. Constrain the surface, atmosphere, and subsurface processes through which organic molecules could have formed and evolved over martian history.

IB1.1 Organics on surface/subsurface vs exposure time (H): e.g., organics, isotopes, geochronology
IB1.2 Atmospheric reservoirs of Carbon over time (H): e.g., methane isotopes, organic aerosols?
IB1.3 Abiotic cycling of bioessential elements (M): e.g., N & S species in surface/subsurface, isotopes
IB1.4 Bulk Carbon in crust and mantle from Martian meteorites (M): from Martian meteorites

IB2.1 Atmospheric processes that create/transform organics (H): e.g., light spectrum/intensity, radiation
IB2.2 Ionizing radiation on organics vs depth (H): e.g., radiation vs depth, geochronology
IB2.3 Mineral catalysis role in organic evolution (M): e.g., mineralogy, geochemistry
IB2.4 Hydrothermal/serpentinization driving organic evolution (M): e.g., mineral assemblages, organic abundance

Goal II: Understand the Processes and History of Climate on Mars

A. Characterize the state and controlling processes of the present-day climate of Mars under the current orbital configuration.	A1. Characterize the dynamics, thermal structure, and distributions of dust, water, and carbon dioxide in the lower atmosphere.
	A2. Constrain the processes by which volatiles and dust exchange between surface and atmospheric reservoirs.
	A3. Characterize the chemistry of the atmosphere and surface
	A4. Characterize the state and controlling processes of the upper atmosphere and magnetosphere.

IIA1.1 Dynamics of lower atmosphere, local-global (H): e.g., turbulent fluxes, radiative forcing, networks
IIA1.2 Water, CO_2 & dust and fluxes between atmospheric reservoirs (H): mostly from orbit

IIA2.1 Surface-Atmosphere dust and volatile fluxes (H): e.g. turbulent fluxes, dust lifting processes
IIA2.2 Dust and volatile flux impacts on (sub)surface reservoirs (H): e.g., polar processes, surface-atm exchange

IIA3.1 Vertical profiles of key gas species (H): mostly from orbit
IIA3.2 Space/time variations of chemically important species/tracers (M): mostly from orbit
IIA3.3 Determine importance of heterogeneous- and electro-chemistry (M): mostly from orbit

IIA4.1 Mechanisms of transport from lower to upper atmosphere (H): mostly from orbit
IIA4.2 neutrals, ions, aerosols in upper atmosphere & magnetosphere (L): mostly from orbit
IIA4.1 Upper atmosphere state under varying driving conditions (L): mostly from orbit

Goal II: Understand the Processes and History of Climate on Mars

B. Characterize the history and controlling processes of Mars' climate in the recent past, under different orbital configurations.	B1: Determine the climate record of the recent past that is expressed in geomorphic, geological, glaciological, and mineralogical features of the polar regions.
	B2: Determine the record of the climate of the recent past that is expressed in geomorphic, geological, glaciological, and mineralogical features of low- and mid-latitudes.
	B3: Determine how the chemical composition and mass of the atmosphere changed in the recent past.

IIB1.1 How are polar layers formed (H): e.g., study annual cycle of deposition/erosion and controlling factors
IIB1.2 3D properties of Polar Layered Deposits (H): e.g., traversing/coring (composition, gases, dust, isotopes)
IIB1.3 Absolute ages of Polar Layered Deposits (M): e.g., drilling for isotopes, stratigraphy

IIB2.1 Location, structure, composition of ice and volatiles (M): e.g., orbital and ground truth sampling/coring
IIB2.2 Volatile reservoir ages/accumulation conditions (M): e.g., orbital and ground truth sampling/coring, isotopes?

IIB3.1 When & how were buried CO_2 S.Pole reservoirs formed? (M): e.g. coring?
IIB3.2 PLD trapped gas composition (M): e.g., analysis of ice cores

Goal II: Understand the Processes and History of Climate on Mars

C. Characterize Mars' ancient climate and underlying processes.	C1. Determine how the chemical composition and mass of the atmosphere have evolved from the ancient past to the present.
	C2. Find and interpret surface records of past climates and factors that affect climate.

IIC1.1 How has atmosphere changed (mass & composition) changed? (H): e.g., sample trapped gases in rocks
IIC1.2 Crustal sinks of atmospheric species (M): mostly from orbit
IIC1.3 Gas sources over time (volcanism, alternation, bolides) (M): e.g., serpentinization, meteor fluxes
IIC1.4 Atmospheric escape rates over geologic time (M): mostly from orbit

IIC2.1 Ancient water cycle from geologic record (H): e.g. rover w/ geomorphology, aqueous mineralogy, dating
IIC2.2 Ancient climate via modeling (H): e.g., validation of GCM-modeled processes.

KISS Workshop: Revolutionizing Access to the Martian Surface

Goal III: Understand the Origin and Evolution of Mars as a Geological System

A. Document the geologic record preserved in the crust and investigate the processes that have created and modified that record.	A1. Identify and characterize past and present water and other volatile reservoirs.
	A2. Document the geologic record preserved in sediments and sedimentary deposits.
	A3. Constrain the magnitude, nature, timing, and origin of environmental transitions.
	A4. Determine the nature and timing of construction and modification of the crust.

IIIA1.1 Modern extent of water & hydrous minerals (H): e.g., depth sampling, surf-atm exchange, EM sounding,…
IIIA1.2 Location, timing & extent of ancient water reservoirs (H): e.g., morphology/mineralogy/isotopes? *Needs samples?*
IIIA1.3 Structure & age of PLD, links to climate (H): e.g., traverse or core sampling, ice/gas/sediment properties, sounding
IIIA1.4 3D ice (H_2O & CO_2) distribution with time (M): mostly from orbit
IIIA1.5 Role of volatiles in modern surface processes (M): e.g., geomorphic change, env. monitoring @ active sites

IIIA2.1 Past hydrological cycles in sed. & geomorphic record (H): e.g., morphology/mineralogy/isotopes? *Needs samples?*
IIIA2.2 Diagenesis/alteration of sediments (H): e.g., microscopic relationships, textures, chemistries *may need samples*
IIIA2.3 Habitability & biosignature preservation (H): e.g., microscopic relationships, textures, chemistries, organics
IIIA2.4 Sources & fluxes of aeolian sediments (L): e.g., frequent change detection
IIIA2.5 Dust lifting mechanisms (L): e.g., dust composition, wind stress, saltation, dust lofting, dust devils, E&M forcing

KISS Workshop: Revolutionizing Access to the Martian Surface

Goal III: Understand the Origin and Evolution of Mars as a Geological System

A. Document the geologic record preserved in the crust and investigate the processes that have created and modified that record.	A1. Identify and characterize past and present water and other volatile reservoirs.
	A2. Document the geologic record preserved in sediments and sedimentary deposits.
	A3. Constrain the magnitude, nature, timing, and origin of environmental transitions.
	A4. Determine the nature and timing of construction and modification of the crust.

Continued

IIIA3.1 Link local env transitions to global evolution (H): e.g., orbital spectra/imaging & landed "geology" at selected sites
IIIA3.2 Age, duration, intermittency of ancient env transitions (H): e.g., landed "geology" at selected sites, age dating
IIIA3.3 Nature & diversity of ancient environments & implications (M): e.g., paleoclimate indicators (composition, context)
IIIA3.4 History of Sulfur & Carbon through Mars system (M): e.g., high precision isotopic analyses in context

IIIA4.1 Absolute & relative ages of geologic units (H): e.g., age dating (isotopic analysis) of several cratered units
IIIA4.2 Link petrogenesis of martian meteorites and samples to planet evolution (M): e.g., likely needs samples
IIIA4.3 Modern surface processes (L): e.g., geomorphic change, env. monitoring @ active sites
IIIA4.4 Impact effects on crust, and cratering rate (L): e.g., mostly orbital, but seismic to quantify impact rate
IIIA4.5 Surface manifestations of volcanic processes (L): e.g., composition, morphology of volcanic sites, may need samples
IIIA4.6 Petrogenesis of igneous rocks over time (L): e.g., geochemistry & mineralogy, isotopes
IIIA4.7 Planet-wide Mars evolution via global/regional mapping (L): e.g., orbital augmented with selected in situ "geology"

KISS Workshop: Revolutionizing Access to the Martian Surface

Goal III: Understand the Origin and Evolution of Mars as a Geological System

B. Determine the structure, composition, and dynamics of the interior and how it has evolved.	B1. Identify and evaluate manifestations of crust-mantle interactions.
	B2. Quantitatively constrain the age and processes of accretion, differentiation, and thermal evolution of Mars.
C. Determine origin and geologic history of Mars' moons and implications for the evolution of Mars.	C1. Constrain the origin of Mars' moons based on their surface and interior characteristics.
	C2. Determine the material and impactor flux within the Mars neighborhood, throughout martian history, as recorded on Mars' moons.

IIIB1.1 Volatiles in the mantle & crust (H): e.g., mineralogy at selected sites, may need samples
IIIB1.2 Modern tectonics, evidence of past tectonics (M): e.g., seismic network

IIIB2.1 Structure & dynamics of the interior (M): e.g., seismic network, precision tracking
IIIB2.2 Thermal state and internal heat flow (M): e.g., seismic network, precision tracking, improved heat flux probe
IIIB2.2 Origin & history of magnetic field (M): e.g., orbital and in situ (drones, balloons?) magnetometry, geochronology

IIIC1.1 Properties of the Martian moons (M): e.g., in situ on moons
IIIC1.2 Geologic history of the Martian moons (M): e.g., orbital or in situ on moons
IIIC1.1 Interior structure of the Martian moons (M): e.g., in situ on moons

IIIC2.1 Impactor flux at Mars (L): e.g., orbital
IIIC2.2 Rate of material exchange between Mars & its moons (L): e.g., orbital

Goal IV: Prepare for Human Exploration

A. Obtain knowledge of Mars sufficient to design and implement human landing at the designated human landing site with acceptable cost, risk and performance.	A1. Determine the aspects of the atmospheric state that affect orbital capture and EDL for human scale missions to Mars.
	A2. Characterize the orbital debris environment around Mars with regard to future human exploration infrastructure.
	A3. Assess landing-site characteristics and environment related to safe landing of human-scale landers.

IVA1.1 Global air temperature (H): from orbit
IVA1.2 Global aerosol distributions (H): from orbit
IVA1.3 Global winds (H): from orbit

IVA2.1 Orbital debris environment (L): from orbit

IVA3.1 Characterize selected landing sites for hazards (H): from orbit
IVA3.2 Geotechnical aspects, chemistry, mineralogy, ice content (H): e.g., in situ regolith geotechnical studies
IVA3.2 Near-surface winds (H): e.g., in situ anemometers &/or doppler lidars

Goal IV: Prepare for Human Exploration

B. Obtain knowledge of Mars sufficient to design and implement human surface exploration and EVA on Mars with acceptable cost, risk and performance.	B1. Assess risks to crew health & performance by: (1) characterizing in detail the ionizing radiation environment at the martian surface & (2) determining the possible toxic effects of martian dust on humans.
	B2. Characterize the surface particulates that could affect engineering performance and lifetime of hardware and infrastructure.
	B3. Assess the climatological risk of dust storm activity in the human exploration zone at least one year in advance of landing & operations.
	B4. Assess landing-site characteristics and environment related to safe operations and trafficability within the possible area to be accessed by elements of a human mission.

IVB1.1 Assess health risks from Neutrons (M): e.g., in situ radiation sensors
IVB1.2 Charged and neutral particle spectra and dose at surface through solar cycle (M): e.g., in situ radiation sensors
IVB1.3 Assay for toxic chemicals in dust (M): e.g., may require returned samples
IVB1.4 Dust shape/size potential for eye/lung damage (M): e.g., may require returned samples

IVB2.1 Regolith & dust corrosivity, charging, conductivity (L): e.g., in situ analysis of soil/dust properties

IVB3.1 Dust climatology (H): e.g., in situ opacity, meteorology at multiple sites
IVB3.2 Surface pressure and near-surface meteorology (H): e.g., meteorology at multiple sites
IVB3.3 Temperature and aerosol profiles even in dust storms (M): e.g., in situ lidar sounder, sub-mm sounder

IVB4.1 Trafficability hazards of potential landing sites (M): from orbit
IVB4.2 Geotechnical characterization of regolith (M): e.g., Regolith engineering properties
IVB4.3 Atmospheric electricity, meteorology and dust (M): e.g., E-fields, meteorology, aerosols, saltation

Goal IV: Prepare for Human Exploration

C. Obtain knowledge of Mars sufficient to design and implement In Situ Resource Utilization of atmosphere and/or water on Mars with acceptable cost, risk and performance.	C1. Understand the resilience of atmospheric In Situ Resource Utilization processing systems to variations in martian near surface environmental conditions.
	C2. Characterize potentially extractable water resources to support ISRU for long-term human needs.

IVC1.1 ISRU Oxygen production robustness against dust (H): e.g. MOXIE

IVC2.1 Identify usable water resource deposits (M): mostly orbital

IVC2.2 Map an equatorial site with bound water, high-latitude with ice near surface (M): from orbit

IVC2.3 Energy required to extract water from near sub-surface (M): e.g. ISRU demonstration of water extraction

Goal IV: Prepare for Human Exploration

D. Obtain knowledge of Mars sufficient to design and implement biological contamination and planetary protection protocols to enable human exploration of Mars with acceptable cost, risk and performance.	D1. Determine the martian environmental niches that meet the definition of "Special Region" at the human landing site and inside of the exploration zone.
	D2. Determine if the martian environments to be contacted by humans are free, to within acceptable risk standards, of biohazards that could adversely affect crew members who become directly exposed.
	D3. Determine if martian materials or humans exposed to the martian environment can be certified free, within acceptable risk standards, of biohazards that might have adverse effects on the terrestrial environment and species if returned to Earth.
	D4. Determine the astrobiological baseline of the human landing site prior to human arrival.
	D5. Determine the survivability of terrestrial organisms exposed to martian surface conditions to better characterize the risks of forward contamination to the martian environment.

IVD1.1 Identify Special Regions (H): from orbit

IVD2.1 Is there extant life? Is it dangerous? Can dust move it? (H): e.g. May require samples?

IVD3.1 Can terrestrial organisms survive exposure to martian material on Earth? (L): e.g. requires samples

IVD4.1 Determine astrobiological baseline prior to sending humans (H): e.g. in situ bio-assays, returned samples

IVD5.1 Can human bio-material be carried by wind/dust? (M): e.g. in situ bio-assays
IVD5.2 Can terrestrial organisms survive at Mars? (M): e.g. in situ bio-assays

Goal IV: Prepare for Human Exploration

E. Obtain knowledge of Mars sufficient to design and implement a human mission to the surface of either Phobos or Deimos with acceptable cost, risk, and performance.	E1. Understand the geological, compositional, and geophysical properties of Phobos or Deimos sufficient to establish specific scientfic objectives, operations planning, and any potentially available resources.
	E2. Understand the conditions at the surface and in the low orbital environment for the martian satellites sufficiently well so as to be able to design an operations plan, including close proximity and surface interactions.

IVE1.1 Composition of satellites (M): on satellites
IVE1.2 ISRU on satellites (M): on satellites
IVE1.3 Gravity field of satellites (M): orbiting near satellites

IVE2.1 Regolith properties on satellites (M): on satellites
IVE2.2 Determine gravity field for ProxOps & Rendezvous (M): orbiting near satellites
IVE2.3 Electrostatic charge and plasma fields near satellites (M): orbiting near satellites
IVE2.4 Thermal environments of satellites (M): on satellites