Supplemental Background Information

NASA has begun a process to identify and evaluate candidate locations where humans could land, live and work on the martian surface referred to as Exploration Zones (EZs). Given current mission concepts, an EZ is a collection of Regions of Interest (ROIs) that are located within approximately 100 kilometers of a centralized landing site. ROIs are areas that are relevant for scientific investigation and/or development/maturation of capabilities and resources necessary for a sustainable human presence. The EZ also contains a landing site and a habitation site that will be used by multiple human crews during missions to explore and utilize the ROIs within the EZ.

Any Landing Site (LS)/Exploration Zone (EZ) proposal should describe how the identified Regions of Interest (ROIs) meet the listed criteria. Discussion of sites that uniquely or exceptionally meet one or more threshold/required criteria, but not all, is encouraged. Proposed EZs should contain a set of ROI's that collectively meet the threshold/required criteria as well as several qualifying/enhancing criteria. Proposals should also identify particular needs for data that can be collected with currently available resources.

Science Objectives

Introduction. The Human Science Objectives Science Analysis Group (HSO-SAG 2015) was tasked with outlining the set of science objectives that might be considered for a human mission to Mars in 2035. The team was also tasked with developing a set of ROI criteria from these scientific objectives that could be used to support ongoing human LS/EZ selection work.

The team considered a forecast of the state of knowledge for the 2030's and concluded that although the coming Mars exploration missions and scientific research of the late 2010s and 2020s will make eagerly anticipated discoveries, it is unlikely that the high level science objectives and priorities for Mars will not change significantly prior to 2030.

Scientific Objectives. The scientific objectives listed below were identified considering intrinsic scientific merit, magnitude of the benefit of a proximal human, opportunity to make simultaneous observations from different vantage points, and opportunity to deliver scientific payloads of higher mass/complexity. The objectives are not prioritized across the different groups: Astrobiology (A), Atmospheres (B), Geology (C), and Cross Cutting (D). The Geology objectives (C1 and C3) are further informed by a set of questions identified below.

Astrobiology:

A1. Past Life: search for and characterize past habitability potential in environments with highest preservation potential for ancient biosignatures.
A2. Determine if evidence of past life is present in such environments.
A3. Present Life: search for and characterize modern environments with high habitability potential for extant life.
A4. Determine if evidence of extant life is present in such environments.
A5. Investigate the exchange and cycling of material between the subsurface, surface and atmosphere.
A6. Investigate the complex chemistry (e.g., degree of covalency, organic chemistry and redox gradients) in the near surface, understand the mechanisms for organosynthesis, alteration and destruction.

Atmospheric Science:

B1. Simultaneously quantify the atmospheric state and forcings near the surface at four or more locations supplemented by regular vertical atmospheric structure information.
B2. Constrain past climate states and atmospheric composition through analysis of samples from the Noachian and Hesperian, including trapped gases and inclusions.
B3. Characterize the local source and sinks in the dust, water and CO2 cycles, and the key parameters that determine these sources and sinks across a diversity of surfaces.
B4. Quantify photochemical and electrochemical cycles and potential subsurface trace gas sources through the measurement of trace gases, heterogeneous reactions and the electrical environment.
B5. Infer previous climate states and atmospheric composition under different orbital configurations through chemical and isotopic analysis of sediments and water ice emplaced during the Amazonian.
B6. Provide simultaneous context for near-surface atmospheric characterization through the global monitoring and quantification of the atmospheric state, forcings, and the distribution of airborne aerosols and trace gases.

Geosciences:

C1. Characterize the composition of surface units and evaluate the diverse geologic processes and paleoenvironments that have affected the martian crust; determine the sequence and duration of geological events, and establish their context within the geologic history of Mars to answer larger questions about planetary evolution (to be refined based on discoveries during the next decade).
C2. Determine relative and absolute ages of geologic events and units, determine their history of burial, exhumation, and exposure, and relate their ages to major events through martian history.

C3. Constrain the dynamics, structure, composition and evolution of the martian interior, to answer larger questions about planetary evolution (to be refined based on discoveries during the next decade).

Additional Questions:
Q1. How have the mineralogical and geochemical properties of martian igneous rocks changed over geological time and across global length scales, and how do these changes reflect changing conditions in the martian interior?
Q2. In what ways are the oldest martian rocks similar or different in composition or formation mechanism to the oldest terrestrial and/or lunar rocks.
Q3. How has the mineralogy and geochemistry of alteration products changed over geological time (epochs and obliquity cycles), and what does that indicate about changing climate or subsurface environmental properties?
Q4. How do impacts disrupt and redistribute crust and mantle material?
Q5. What were the processes of magmatic activity on Mars, how did they change with time, does volcanism persist to the present, and how does this contribute to crustal formation and resurfacing?
Q6. What is the nature and diversity of tectonism (faulting and flexure) over martian geological history?
Q7. What was the role of ice-related processes in modifying the martian surface?
Q8. What was the history and abundance of surface water and groundwater on Mars, and how is this reflected in the sedimentary and geochemical record?
Q9. How has the atmosphere of Mars changed over time and how has it affected sedimentary and erosional processes?
Q10. What was the history of the martian dynamo, and what was the cause and history of its cessation?
Q11 What was the compositional and dynamical evolution of Mars' mantle?
Q12. What is the structure of the martian interior?
Q13. What was the origin of Mars and its thermal evolution?
Q14. What are the modern sources of seismicity on Mars and how do they relate in magnitude or location to global tectonic or structural processes that have been active in the past?

Cross-Cutting:
D1. Assuming the mission accesses at least one significant concentration of water at part of its ISRU operations, evaluate that deposit for its implications to astrobiology, atmospheric science, and geology.
D2. Characterize the impact of humans on the martian environment.
D3. Evaluate variability in the martian radiation environment.

ROI Criteria. These science objectives were then used to construct a set of ROI criteria, which can be used to identify potential human LS/EZs on Mars with high potential for substantial scientific discovery. Two types of criteria were identified in this study: Threshold and Qualifying. The threshold criteria listed below can be viewed as the highest priority and a "must have" for any potential ROI. Qualifying criteria are other high priority criteria that address important science questions and that add breadth to the scientific potential of a ROI.

Threshold:

- Access to deposits with a high preservation potential for evidence of past habitability and fossil biosignatures AND/OR Presence of sites that are promising for present habitability, e.g. as a refugium.
    - *Both of these criteria were viewed as highest priority but finding a place on Mars that accomplished both may be difficult. Therefore these should be considered as an "and/or" requirement for inclusion in an exploration zone. Therefore at least one of these should be present, and an exploration zone that meets both is not required but highly desirable.*
- Noachian and/or Hesperian rocks in stratigraphic context that have high likelihood of containing trapped atmospheric gasses.
    - *Specifically rocks that might effectively inform objective B2 and Q9 from the science criteria. In this case trapped gases might also include rocks/minerals formed from atmospheric constituents that would also help inform the state of the atmosphere at a particular time.*
- Exposures of at least two crustal units that have regional or global extents, that are suitable for radiometric dating, and that have relative ages that sample a significant range of martian geological time.
- Access to outcrops with morphological and/or geochemical signatures (with preference given to sites that link the two) indicative of aqueous processes or groundwater/mineral interactions.
- Identifiable stratigraphic contacts and cross-cutting relationships from which relative ages can be determined.

Qualifying:

- Access to deposits with high potential for containing organic matter (indigenous or exogenous) with various lengths of surface exposure.
- Presence of meteorological diversity in space and time.
- High likelihood of surface-atmosphere exchange of dust (e.g., aeolian and dust devil activity) and water across a diverse range of surface types (e.g., dust cover, albedo, thermal inertia, surface roughness, and rock abundance).
- Access to Amazonian-aged subsurface ice, high latitude water ice (e.g., polar layer deposits), and Amazonian-aged sedimentary deposits.
    - *Although Amazonian aged subsurface ice is typically located in the polar regions, this criteria is included with the hope that future work may identify near surface Amazonian ice nearer the equator.*
- High likelihood of active surface trace gas sources.
    - *Surface trace gas sources are included here in anticipation of further results from MSL and future results from the Mars Trace Gas Orbiter. A convincing case for localized trace gas emissions on Mars would be highly pertinent to ROI discussions.*
- Access igneous rocks that can be clearly tied to one or more distinct igneous provinces and/or from a range of different martian time periods.

- Access to near-surface ice and/or glacial or permafrost-related sediments.
- Access to Noachian or pre-Noachian bedrock units.
- Access to outcrops with remnant magnetization.
- Access to diverse deposits from primary, secondary, and basin-forming impacts.
- Access to structural features that have regional or global context.
- Access to a diversity of aeolian sediments and/or landforms.

Although the scientific interpretation of individual sites on Mars may change with time, the overall science objectives should not significantly change with time. In many cases the ROI criteria are subject to scientific interpretation, so proposers should make the case for how their identified ROIs meet the criteria, drawing on any data and analysis to support their claim.

Resource Objectives (including Civil Engineering)

Introduction. The ISRU and Civil Engineering Working Group (ICE WG) was tasked with developing a set of objectives that satisfy NASA's general goal of a permanent, sustainable human presence on Mars that is Earth independent. NASA continues to make progress on the Evolvable Mars Campaign (EMC) examining alternatives that address all aspects of this goal – from Earth launch, to Mars surface operations, to Earth return. The ICE WG focused on just those portions of the EMC dealing with achieving a permanent, sustainable presence on the surface of Mars that minimizes (ideally eliminates) reliance on Earth. This means developing a local capability to provide for basic human needs of air, water, food and shelter along with other critical operational needs such as power, fuel/propellants, and the ability to manufacture selected items.

For purposes of this Exploration Zone activity two broad categories – in situ resource utilization (ISRU) and civil engineering (CE) – were used to group these concepts. But there remains several concepts – for example food production – that do not ideally fit into either of these categories but nonetheless are important and are being considered. The remainder of this discussion is built primarily around the ISRU and CE groups but other concepts are included as appropriate.

ISRU and CE objectives. Three primary objectives have been identified for ISRU and CE at an EZ site on Mars. While other objectives may emerge, these three will be used as guidance for candidate EZ identification:

1. Demonstrate the ability to prospect for and extract useful commodities from local materials in a cost effective and sustainable fashion and begin using those commodities in nominal operations as soon as possible.

The highest priority commodity for this objective is water. Important but of a secondary priority are metals, silicon, and structural building materials. Water can be used for multiple purposes that are mission enabling or enhancing (e.g., propellant/fuel cell reactant production, life support, radiation shielding, plant growth, etc.). Metals will be important for in-situ fabrication of spare parts and repairs.

2. Demonstrate the ability to manipulate the surface for infrastructure emplacement and protection of hardware.

The highest priority capability for this objective is foundation improvement and surface stabilization (including construction of landing pads, roads, berms, etc.) Of secondary priority are capabilities to build structures and enhance radiation shielding for the crew (and possibly plants assuming food production is implemented). Each candidate site will exhibit strengths and weaknesses with respect to this objective. For example, berms and roads may be used to improve mobility around surface infrastructure elements and help to minimize vehicle maintenance. Selected areas may require manipulation of the surface to create a suitable foundation for surface infrastructure such as modular habitats or crop growth chambers. While very important, radiation shielding may be enhanced using water walls before surface material is required. But determining the potential value of using surface materials for radiation protection will be one of the unknowns that will be investigated. Thus each candidate site will be assessed for factors such as these and an overall site plan will be developed noting where improvements are required.

3. Demonstrate capabilities that reduce reliance on supplies from Earth using indigenous materials, resources, and the environment.

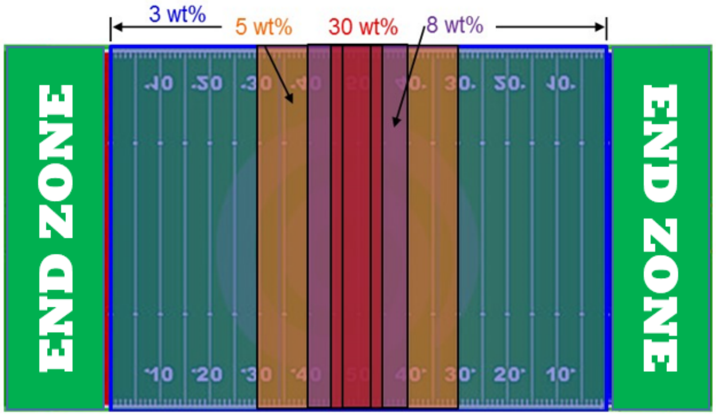
The highest priority capability for this objective is food production. Of secondary priority is in-situ manufacturing and construction with locally derived feedstock. Food is one of the largest (perhaps the largest?) consumable items that must be imported from Earth in current mission scenarios, so the ability to produce food locally will help improve sustainability by reducing logistical mass requirements as well as improving crew health with the use of fresh food. An in situ capability to manufacture and construct items has a potentially broad range of options to consider but collectively these will help to minimize long term costs, logistics, and crew risk.

EZ/ROI Selection Criteria. These objectives have been used to generate criteria to guide selection of candidate EZs for human crews. Every attempt was made to make these criteria as quantitative as possible to enhance their use in the candidate EZ identification process but it was also recognized that data may not currently exist to definitively identify locations that meet these criteria. As a result the term **potential** was introduced into some of these criteria to indicate that indirect evidence that a candidate site meets one or more of these criteria. Sites that satisfy these "potential" criteria may become targets for gathering additional data using instruments on existing and future spacecraft as well as the focus of specific analysis by qualified teams using existing and future data sets.

The following criteria are considered <u>requirements</u>:

1. The proposed EZ must have at least one location with access to raw material that exhibits the potential to (a) be used as feedstock for water-generating ISRU processes and (b) yield significant quantities (>100MT) of water. The raw material can be in the form of ice, ice/regolith mix, or hydrated minerals and the top of the raw material deposit should be as close to the surface as possible.

The resource feedstock deposit must be of a size that is sufficient to support one or all of the following needs for several human missions: enhanced radiation shielding, life support, EVA, and propulsion. To meet all of these needs a quantity of water approaching 20,000 kg must be produced for each crew. If the raw material is in the form of hydrated minerals, then it must have a **potential** for a high concentration (greater that 5% by weight). The following figure is provided to illustrate the volume of material that must be acquired to realize a certain amount of water, based on the weight percentage of water contained in that raw material and using a U.S. football field as a representative surface area to be mined. For this particular example a quantity of approximately 14, 000 kg was sought and the ISRU process was assumed to be able to extract up to 80% of the water at a production rate of 1.238 kg/hr (thus requiring 480 days to produce all of the water). A similar analysis can be used to estimate the potential yield for candidate raw material sites of different areal extent and for different estimated water yield.



H_2O 1.238 kg/hr Soil 1500 kg/m3
480 days Ice 940 kg/m3

Water wt%	Soil wt%	Water kg	Soil kg	Total kg	Extraction 80%	Ave Density kg/m3	Tot Vol m3	FB Depth cm	FB Field yds
3	97	14261.76	461130.2	475392.0	594240.0	1483.20	400.65	9.58	100.00
5	95	14261.76	270973.4	285235.2	356544.0	1472.00	242.22	5.79	60.46
8	92	14261.76	164010.2	178272.0	222840.0	1455.20	153.13	3.66	38.22
30	70	14261.76	33277.4	47539.2	59424.0	1332.00	44.61	1.07	11.14
70	30	14261.76	6112.2	20373.9	25467.4	1108.00	22.99	0.55	5.74

Mining this raw material is likely to occur when no crew are present at the site. Even if crew are present, little crew time is likely to be available to operate or supervise the mining operation. So the raw material should be in a form that can be easily mined by highly automated equipment. Due to this use of automated equipment the location where the raw material is acquired must be sufficiently flat (TBD based on rover stability and loading design, but less than approximately 10°) to permit excavation and soil storage. Major natural obstacles along the most direct traverse between resource feedstock and usage area must not be present that exceed planned mining mobility platforms such as canyons, cliffs, vertical outcrops, and wide crevices. Rock size must not allow impact to rover mobility <30 cm (TBD based on rover clearance). Rock distribution must not allow for impact to excavation operations.

The raw material must located less than 3 km from the ISRU processing plant and power infrastructure – the value of the raw material decreases with increased distance (i.e., increased transportation "costs") from processing point or utilization point. Terrain features must not prevent direct-line-of-site communications between ISRU processing system and rover/excavators if possible (adds need for communication repeaters). In addition, the raw material must be as close to the surface as possible; ideally no more than 1 meter beneath the surface. Buried raw material requires extensive removal of overburden and/or multiple segment drill decreasing the value of the raw material (i.e., added time and "cost" to remove the overburden).

The resolution for the data used to assess potential should be <1000 meters in scale, with a desired resolution <100 meters.

2. Access to at least one region where infrastructure construction can be emplaced or constructed. This region must be less than 5 km from a central landing site and contain flat, stable terrain. The region should exhibit evidence for an abundant source of cobble-sized or smaller rocks and bulk, loose regolith.

Within this construction region there should be no indication (or minimal indication?) of seasonal changes over the majority this area.

The identified raw materials (e.g., sand, cobbles, bulk regolith) are intended for use in a variety of construction techniques such as leveling roadways, enhancing roadway surfacing, constructing berms, burying habitats for radiation protection, etc. For reference, cobbles are defined as 64-256 mm (2.5-10 in) in size.

3. Access to raw material that exhibits the **potential** to be used as metal or silicon feedstock for ISRU and construction purposes. Of primary interest are iron, aluminum, and silicon; titanium and magnesium are of secondary interest. Raw material should be as near to the surface as possible and be in a form that is minable by highly automated systems

The systems used to acquire the raw materials for use in these processes are likely to be similar to those used for acquiring raw material for processing into water. Thus the distance, depth, and features favorable to automated systems described previously for water ISRU also apply here.

The following criteria are considered enhancements. What this means is, for example, food production is very likely to part of the activities taking place in the EZ but there are options for implementing this capability that are site independent (e.g., hydroponically grown plants using artificial lighting) but EZs satisfying these criteria could enhance the efficiency or reduce the Earth-supplied materials needed for the activity.

1. The proposed EZ may have additional locations with access to raw material that exhibits the potential to be used as feedstock for water-generating ISRU processes. The raw material can be in the form of ice, ice/regolith mix, or hydrated minerals and the top of the raw material deposit should be as close to the surface as possible.

The location of these additional raw material locations can be greater than 5 km from the processing location or from point of use. Concentrations should be greater than 5% by weight to justify extended range operations from processing location or from point of use. A plausible traverse route must be evident for these additional sites (detailed assessments of traversability will be conducted separately). Terrain features must not prevent direct line-of-site communications between ISRU processing system and rover/excavators if possible (to avoid need for communication repeaters). Finally, slopes, rock size/distribution, and soil properties should allow for road/path construction between resource excavation location and centralized ISRU processing systems if these additional locations are required for sustained use.

2. Natural terrain features that can be adapted for construction purposes (e.g., to enhance habitat radiation protection) are considered an enhancement of the EZ. Examples include shallow depressions, narrow (but accessible) valleys, and lava tubes. Many of these terrain features are likely to be found within any EZ but their value to the EZ will depend on their proximity to the centrally located infrastructure location and the ease with which they can be adapted to these civil engineering purposes. Northern latitude sites below 40 degrees latitude are somewhat preferential due to less extreme climate variations and higher solar flux.

3. Food production is considered highly likely but successful operations are not as dependent on the EZ location as other criteria describe. Food production could be accomplished using hydroponically grown plants and artificial lighting. But food production could be implemented more efficiently (in terms of infrastructure required) if local regolith and natural lighting is used. With this in mind, an EZ with the following characteristics would be better suited to support food production: (a) a low latitude for more consistent lighting throughout the year, (b) no local terrain feature(s) that could shadow light collection facilities, (c) access to locally produced water, and (d) access to dark, minimally altered basaltic sands for use as soil base for crop growth; augmented with other material to improve crop growing potential. The locally acquired soils should avoid heavily weathered and/or altered soils (e.g., hydrothermal or fumarolic vent/system) because they are likely to be more deficient in plant essential nutrients and thus require augmentation before they can be used.

Engineering Constraints

As noted in the Landing Site (LS)/Exploration Zone (EZ) Workshop announcement, an EZ has a central area with an LS and a habitation zone (HZ). It is expected that, across multiple cargo and crewed missions, infrastructure will be emplaced and a Mars surface "field station" will evolve, such that multiple crews across multiple missions would live and work at this central location and would regularly depart from this location on traverses to explore Regions of Interest. Within that operational framework, engineering constraints and considerations for human missions to the surface of Mars are presently being defined; although these constraints and considerations will continue to be established and refined over several years, preliminary values related to factors that will eventually determine allowable locations and surface properties have been defined and are described below.

Engineering constraints regarding human crews on the surface of Mars are driven by a number of operational considerations. For example, it will be necessary to repeatedly, reliably, and safely land large (on the order of 10+ MT) payloads and crews at the same landing site; additionally, emplaced infrastructure will need to be protected from debris associated with landing. Within the HZ, an area containing elements supporting such functionality as habitation, local work areas, In Situ Resource Utilization (ISRU) infrastructure, supporting utilities (e.g., power, communications), handling of large cargo items, "mobility zones," and protected areas will evolve over time and missions. Crewmembers and robotic systems will need to safely traverse both within the HZ and from the HZ to the surrounding terrain (up to 100 km from the central area) to perform exploration and science. Each of these operations has associated engineering considerations and constraints and they collectively will define and bound allowable locations on the surface of Mars.

The Mars crew lander community is assuming a target accuracy of landing within a circle of 100 m diameter, within which it must be safe for landing and roving. Additionally, they are assuming the landing circle can be placed anywhere on Mars that is below +2 km MOLA reference elevation and within +/- 50° latitude of the equator (50°N to 50°S). Steady state horizontal and vertical winds and wind gusts are a concern during descent and landing, so areas with potentially high winds will need to be compared with landing system tolerance during development. Over time there will be multiple crewed missions with large landers; therefore, the landing site must accommodate a "lander blast zone" that allows 1 km minimum separation distance between landers and other infrastructure. We assume an area of approximately 25 km^2 within which the terrain is generally level (slopes less than ~10 degrees) and significantly devoid of landing hazards (e.g., large and/or closely concentrated craters, mountainous terrain, broken/jumbled/chaotic terrain, extensive dune fields, etc.). Whereas the LS must accommodate multiple large cargo and crewed landers, the HZ must also accommodate multiple large elements, such as habitats, logistics modules, crew pressurized rovers, and power systems. Therefore, the LS and HZ must be relatively flat and relatively free of rocks and hazards and they must have load bearing surfaces with a low level of fine-grained dust (e.g., extremely low thermal inertia and high albedo). In addition to the LS and HZ engineering constraints, the EZ central area must allow for crews in capable pressurized rovers to traverse up to 100 km away from the central LS/HZ; therefore, traverse paths must be available from the EZ central zone.

The draft Mars LS/HZ/EZ engineering constraints are summarized in the following table:

ENGINEERING PARAMETER	TARGET VALUE
Latitude	50º N to 50º S
Elevation	≤ +2 km
Load bearing surface	Low thermal inertia, high albedo, not dominated by dust
Landing circle radius Landing "blast zone"	- Target = < 100 m radius - ~1 km diameter
Terrain Relief	TBD, use MSL: 100 – 130 m (assume 1 – 1000 m baseline)
Slopes	- LS & HZ: < 15º assume 20 m length scale - Crew Pressurized Rover: <30º, paths ~5x wider than rover width
Rock height and abundance	- Lander: TBD, Use MSL: <0.5% probability of at least one ≤0.55 m high rock in 4 m^2 area (rock abundance <8%) - Crew Pressurized Rover: <20% coverage by obstacles >radius of rover wheel
Exclusion Zones	1-5 km radius from excluded element (e.g., nuclear power system)
Surface winds	TBD, use MSL: <15 m/s (steady); <30 m/s (gusts); steady winds never exceed 40 m/s

Elevation Limit = +2 km Latitude Limits = +/- 50°