HUMAN EXPLORATION FOR RESOURCES ON MARS

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I consider two main periods of resource exploration: (1) Near term, defined as the first ten years of operation of a base on Mars, and (2) Long-range resources. I argue that the search for long-range resources must begin during the first ten years.

1. Near-term resources

Searching for water/ice

Undoubtedly a lot of work will have been done to find sources of water or its frozen equivalent before selecting a base on Mars, and surely the base will be near a supply of water if they are identified remotely. Nevertheless, an active base that is expected to grow must have a well-defined supply of water. Hence, the local and regional aquifer must be characterized. This requires:

- Drilling, probable in more than one place
- Examination and study of cores or cuttings to identify lithologies
- Measurement of physical properties of the rocks (permeability etc.)
- Measurement of the ice/rock ratio
- Electromagnetic surveys
- Tracer studies, if liquid water is present
- Sample selection for detailed studies
- Detailed studies of the local and regional geology

Of these tasks, humans may be essential for:

- Core/cuttings examination (macroscopic)
- Determining the ice/rock ratio
- Measurement of the physical properties
- Sample selection for geologic studies, and doing those studies
- Geologic studies

Studies of core samples or cuttings will be valuable for many reasons, not just the exploration for water resources and aquifer characterization. Such studies will help understand local resources in general, such as identifying particularly iron-rich horizons, clay layers, etc.

Resources for Agriculture

It will be crucial for base inhabitants to grow their own food on Mars. This will require using Martian surface materials as soils. However, it is unlikely that we will be able to take any random soil and grow plants in it. We will need:

- The right mix of drainage and water retention, implying both sand and clay components
- Experiments on the value of local regolith as a useful soil for agriculture
- Search for soil additives to increase soil productivity (e.g., sand, clay)
- Search for key fertilizers, such as phosphates and nitrogen.

Nitrogen might be abundant enough in the regolith, though a source of nitrates would be useful. Exploration for rich deposits of phosphates may be difficult. On Earth, these form in

marine sedimentary environment and depend on organisms concentrating the phosphorous. This will not have happened on Mars, unless it was teeming with life. Instead, Martians will need to search in other geologic environments. Sediments might still be promising, depending on how they were deposited, the composition of the waters that deposited them, etc. Igneous rocks could be use if highly evolved so that the phosphorous content was increased greatly. The most promising near term source might be the regolith because it contains a few tenths % of P_2O_5. Soil processes, which are not understood at all, might have concentrated P to some extent. This will require detailed studies of the upper meter or so of the regolith.

Aggregates

Aggregate is extremely important when building an infrastructure. It is by far the most mined material in the United States (2.3 billion tons per year). It is used for roads, concrete, bridges, roofing materials, and glass. On earth, the main sources are sand and gravel deposits, and solid rock quarried to produce crushed stone. At first, Mars explorers might simply grade surfaces to make simple roadways, or smooth paths by repeated use. More actively, they will have to seek out naturally occurring aggregates on Mars. These will occur at the bases of gullies and cliffs, and in river beds. The Martian regolith near the site will be the first naturally occurring aggregate that they will use. Depending on the site, there ought to be a range of grain sizes and materials. All these possibilities will need to be characterized by field observations and measurements (e.g., grain size distributions).

Structural materials

The prime resource for structural materials will be the regolith. Humans will have only minor role in exploring the regolith for use as shielding, raw material for bricks, or a source of iron (the regolith has 13-18 wt% FeO). However, humans will play a major role in searching for concentrations of Ca-sulfates and carbonates for cements and clays for ceramics. This will require many soil samples and shallow drill cores. Although in principle some of this exploration could be done by autonomous rovers equipped with instruments that do not exist yet, it is likely that humans will be needed to assess the total resource potential of the regolith in the vicinity of the base.

2. Long-term resources

Essential for future Martian development

Development of all the resource potential on Mars is essential to the continued exploration of the planet. We will need to continuously enhance the Martian infrastructure, and that requires long-range planning. Most important, we will need to eventually export commodities useful elsewhere in the Solar System. For comparison, LEO has its microgravity environment to sell. The Moon has a very hard vacuum, huge solar energy export potential, and possibly ^{3}He. What will be the commercially viable products from Mars? The answer will come only from extensive exploration for resources, and that exploration must begin during the first few years of Mars base operations.

Need vigorous program of industrial research and development

We do not know what resources will be most important on Mars. One important way of determining that will be to develop manufacturing processes on Mars. Experiments will elucidate the value of the unique Martian environment; for example, could the highly oxidizing properties of the regolith be a useful property that could be exploited? Industrial R&D will help define what resources are needed, hence shape the exploration program. Finally, the development of an

industrial infrastructure on Mars will give us opportunities to experiment with unique resources found on Mars. As above, this must be done soon after the base is established.

Potential long-term resources

Some possibilities are pretty clear:

- Find rich iron ores
- Discover other metal deposits (Ni, Ti, Au, Ag, Cr, Al, Cu, Zn, Pb, Pt-group, etc.)
- Organic compounds
- Extensive clay deposits

Finding these resources requires intensive, global geological exploration

We need to explore certain logical geologic settings for potential resources:

- Sedimentary deposits (clays, evaporites, maybe even placers)
- Hydrothermal deposits (Cu, Zn, S, Au, Ag)
- Differentiated igneous provinces (Ti, Cr, Ni, Cu, Pt-group, S, possibly REE, halogens)
- Search in assorted tectonic settings.

Global search requires both humans and robots

Astronauts will not be able to travel all over the globe. But they can beam themselves into teleoperated rovers equipped with high-quality vision systems, multispectral imaging, and chemical analytical sensors. These must be operated by geologists at a base on Mars. The long time delay prohibits thorough geological field work, though some tasks can probably be handled from Earth (e.g., doing the chemical analysis and anything else that takes a long time).

Conclusions

- Resources needed during the first decade of Mars operations need to be kept simple: use the local regolith for as much as possible.
- Water will be essential, so a thorough characterization of the local aquifer must be done. This will require drilling, E-M surveys, and study of drill cores and the properties of subsurface rocks.
- A search will probably need to be done for certain key ingredients, such as fertilizer and other agricultural components. High quality aggregates might also be needed.
- Once the base is operational and local resources are relatively well defined, it will be essential to begin planning for the future. An industrial R&D program must be established. This can include experiment done of Earth before being implemented on Mars. The experiments will help define what resources will be needed.
- A global search for resources must be started early. This is important in attracting capital for Martian investment.
- Humans will need to do most of the exploration. However, they can be helped by appropriate robotic devices, including those teleoperated from Mars, autonomous, and those guided from Earth.