PHOBOS AND DEIMOS SAMPLE COLLECTION & PROSPECTING MISSIONS FOR SCIENCE AND ISRU.
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Introduction: Mars missions, both Mars Sample Return (MSR) and human exploration, would benefit greatly from the use of In-Situ Resource Utilization (ISRU) to reduce launch mass, cost, and risk primarily from in-situ propellant production (ISPP). Usually ISRU has meant production of ascent propellants on the Mars surface from carbon dioxide (CO_2) collected from the atmosphere and water from the regolith [1]. However, several reports [e.g. 2-3] have examined the alternative of using propellant production, heat shields, and radiation shielding manufactured on Mars' moons Phobos and Deimos. Robotic sample collection, analysis, and resource prospector missions to these moons are highly desireable to locate and quantify their resources for later use in MSR and human missions.

Rationale for Phobos/Deimos Exploration: One significant advantage of ISRU on these moons is that delta-V to reach them from LEO (1.8 km/s) is much smaller than the surface of Mars (5.7 km/s) [4]. A remaining science question is that Phobos and Deimos are both enigmatic moons in that it is not clear whether they formed along with Mars, they were expelled from Mars during a giant impact similar to the formation of Earth's moon, or they are captured asteroids. Subsurface examination would assist in both determining their origin and confirming what resources are available for enhancing exploration of Mars and its moons. Phobos and Deimos resemble asteroids with surface spectra similar to dehydrated carbonaceous chondrites. If their near surface compositions are actually similar to this type of meteorite, they would be resource-rich, with significant concentrations of carbon, organic compounds, nickel-iron alloys, and water. The absence of water at the surface is easily explained by its exposure to sunlight and the high vacuum of space. Below the surface, the temperatures will be much lower, allowing the preservation of water. Bell et al. [1] have summarized observations that show the presence of permafrost in the martian satellites is highly likely, though at depths of >20 m at their poles and >200 m at their equators, which would be very challenging to obtain.

The probable presence of much less volatile complex organic compounds and even amino acids near the surface leads to an alternate source of hydrogen that could be used to extract oxygen from iron oxides in the regolith. The organic compounds, especially kerogen, can be pyrolyzed to make shale oil, which can be refined in a similar manner to petroleum, leading to a plethora of useful products.

Benefits of Phobos/Deimos Resources: Studies have shown that Mars ISRU propellants can reduce human surface mission mass by up to 30 MT [1] and enable larger samples for MSR with a higher likelihood of success. Martian moon ISRU could also benefit such missions by providing propellant already in Mars orbit to allow refueling of arriving or departing spacecraft with either oxygen extracted from the regolith via mineral extraction, such as hydrogen reduction, or H_2/O_2 propellant from water electrolysis, or space-storable methane or kerosene/O_2 propellant obtained by reforming the organic compounds. The oxygen could be used for life support for human missions. Recovery of nitrogen from amino acids could provide buffer gas for breathing gas as well. The petroleum from kerogen would provide a very valuable source for lubricants and hydraulic fluids. If water is readily available, it has life support uses and would provide an excellent radiation shield for Earth return flights. Hogue and coworkers [3], at the Kennedy Space Center (KSC), are developing processes that use regolith from Deimos or Phobos as heat shields. Regolith can be used as a radiation shield as well.

Recovery of Phobos/Deimos Resources: The extremely low gravity of the martian moons is an advantage in that landing and escape velocities are very small, but also a disadvantage in that operating equipment on the surface will require innovative designs that do not depend on high gravity for anchoring or processing. Anchors, tethers, etc. have been proposed for asteroid processing and will need to be developed. Digging machines will need to be anchored and to account for low gravity effects. New technicques, such as electrostatic transport [5, 6] should be considered as well. Processing of gases is relatively unaffected, but condensation of liquids will require freezing onto cold surfaces and possible centrifugation to collect liquids or use of adsorption/wicking. Methods to produce brief periods of microgravity on Earth (drop towers and parabolic flights) will be needed to verify designs along with emerging commercial microgravity rocket flights and the International Space Station for long term testing. Also, lessons learned from ISS equipment operations should be used.

Phobos/Diemos as the Initial Base for the Human Exploration of Mars: A very interesting option arises if resources prove to be readily available on the martian moons: establishing the first outpost for human exploration of Mars. Such an outpost will depend upon which resources are relatively easy to obtain, but as noted above, using carbonaceous chondrites as a model, much more than silicate regolith is likely to be available. This combination is a treasure trove of starting materials that could be readily used for many components needed for Mars exploration. In addition to propellants and breathing gas, water makes an excellent shielding material along with its usual applications for drinking, cooking, washing, and even as a heat transfer fluid. Indigeneous nickel-iron alloys (essentially meteoritic steel) could also be extremely useful as construction and repair materials using makerbots for the outpost. The design of the outpost is an open question, but it could be buried under the surface for radiation protection, but provision for artificial gravity for the long duration missions could be added by having a rotating structure either underground or securely anchored to the surface with shielding added.

Astronauts aboard the outpost could perform near-real time operation of rovers exploring the surface of Mars below them, making scientific measurements and selecting samples to be launched to the outpost using ISRU propellants from the outpost for detailed analysis without returning them to Earth, a planetary protection advantage.

Potential Benefits for Commercial NEO Mining: Currently, NASA's next human destination is a Near Earth Asteroid (NEO). The techniques for robotic and human exploration of NEOs can be tied to Phobos/Deimos exploration. While human NEO missions seem to be somewhat short in duration, a long duration Phobos/Demos mission would provide the benefits described here regarding consumables, radiation shielding, etc. but also demonstrate techniques and operations that might lead to commercial mining of NEOs. Mining operations on NEOs will face the same challenges as those on Phobos/Deimos and need long term testing. Phobos and Deimos provide sites with well-known, already-planned launch windows every 26 months with relatively small delta-Vs.

Phobos/Diemos Prospecting Missions: Work being performed to acquire and process surface/subsurface samples to characterize water/ice and other volatiles at the lunar poles is synergistic with Phobos/Deimos ISRU and lunar science objectives. Since development of a prototype lunar polar ice/volatile experiment (RESOLVE [7]) is supported by NASA's Human Exploration and Operation Mission Directorate (HEOMD), Office of Chief Technology (OCT), and the Canadian Space Agency; and sample acquisition hardware is under development by SMD, coordination of objectives and funding is possible with the SMD for Phobos/Deimos ISRU. A modified RESOLVE-like hopper (because of the low gravity) would be an excellent candidate for these missions to the martian moons.

Summary: Phobos and Deimos exploration missions have the following advantages and benefits:

- Establish ground truth for martian moon resources
- Enable planning for optimizing utilization of those resources for MSR and human missions
- Greatly advance scientific understanding of martian moons and similar asteriods
- Potentially establish Phobos or Deimos as the first landing site and base of operations for human missions to the vicinity of Mars, and
- Possibly lead to the founding of a major ISRU facility to supply propellants, oxygen, plastics, metals, shielding, reentry shields, and more for Mars and asteroid exploration.

For these reasons and others as discussed above, it is highly desirable to explore the advantages of martian moon ISRU vs. lunar, asteroid, and Mars surface resources, and if found to be significantly superior, design and carry out the initial prospecting and scientific missions required, beginning with the 2018 launch opportunity.

The Kennedy Space Center and Johnson Space Center have a robust ISRU (including electrostatic dust mitigation and filtration) and planetary surface mining program that has been underway for many years. In addition with cooperative work with the Canadian Space Agency, the program is supported by the Glenn Research Center and several outstanding contactors, forging a team that is uniquely qualified to pursue the prospecting and surface systems development that would lead to the establishment of an ISRU depot on Phobos and/or Deimos to support Mars exploration and beyond.

References:

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