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A roadmap to cave dwelling on the Moon and Mars

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Abstract

Habitat in lava tubes recently discovered on the Moon and Mars, should become a unifying concept for occupancy. Basic motivations and specifications for such a habitat are briefly reviewed.

The first step is to obtain a consensus from Agencies on the validity of the concept. Afterwards, two types of research programs should be implemented:

(1) Search for lava tubes by dedicated polar orbiters.Mapping, classification and choice of site should be achieved before 2020.
(2) Development of specific technology to begin by the end of the 2020s:
   – Bulldozers, elevators, and cranes for access.
   – Inflatable cylindrical structures of large dimension for housing.

Since apprenticeship is needed for Mars habitat, Moon lava tubes would be used as a first step. Use of lava tubes provides therefore a unifying concept for exploration. A roadmap is proposed.

Keywords: Lava tube; Habitat; Mars; Moon

1. Introduction

The purpose of this paper is to suggest a plan for the study of Martian lava tubes as eventual locations of permanent settlements (Boston, 2004; Boston et al., 1992, 2001a, 2003a; Greeley, 1971, 1975; Hörz, 1995). A lava tube is a cave created when low viscosity basaltic lava flows from a non-explosive volcano. By cooling, splattering in a turbulent flow or mixing up with a more viscous lava, an empty cylindrical tube can be formed, coated with lava on the floor, walls and ceiling.

Terrestrial lava tubes, very frequent, have a diameter typically less than 15 m; on Mars and the Moon, tubes are believed to exist that are more than hundred meters in diameter, due possibly to low gravity. If smaller diameters are expected on Mars, they remain yet to be identified. A skylight is formed when a section of a cave roof has collapsed.

All linear features are not lava tubes: they can be also:

- Graben with pits, of tectonic or volcanic origin, with dimensions varying from tens of meters to kilometers.
- Craters due to secondary impacts, with dimensions varying from meters to kilometers.
- Volcanic vents created by ejection of magma through fissures, with dimensions from meters to kilometers.

On Earth, the morphology of lava tubes is characterized by:

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– Length: from a few cm to kilometers.
– Width: constant, from a few cm to meters.
– Origin: fluid lava of pahoehoe type.
– Aspect: sinuous.
– Slope: superior to 4°; larger width if slope inferior to 4°.
– Skylights: diameter inferior to the width of the tube.

On the Moon, Haruyama et al. (2009, 2012) have detected with the SELENE 10 m/pixel resolution camera a hole in the Marius Hills at 303.3°E, 14.2°N in a 48 km long sinuous rille. They estimate the hole diameter at 65 m and its depth at least 50–88 m. It would be formed in an intact lava tube with a minimum width of 370 m. An unsuccessful search for additional skylights along three other sinuous rilles nearby indicates that skylights on the Moon are rare. However, holes have also been observed in Mare Tranquillitatis and Mare Ingenii (diameters 120 and 140 m). The Marius Hills region has long been considered as an accessible exploration target, both scientifically and technically.

The NASA Lunar Reconnaissance Orbiter (LRO),[1] launched in 2008, carries a camera with 0.5–1 m/pixel resolution, which has acquired detailed images at high solar-elevation angles. From these data, the axis length of the Marius feature is estimated at 59 m by 50 m with a depth of 47 m. SELENE cameras had overestimated the depth due to their lower spatial resolution.

The LRO images of the Mare Tranquillitatis hole provide a length of the long-short axes to be 98 and 84 m and a depth up to 107 m. Both those holes are considered to be skylights of a subsurface cavern.

The Mare Ingenii hole somewhat differs from the others in that LRO images reveal an eccentric feature; the inner slope from the rim is more gradual. The long-short axes are 118 m and 68 m long respectively, the depth 47–76 m from the edge.

There are no boulders around the holes, implying there are not volcanic vents.

The survey for such holes cover more than 95% of the lunar Maria; thus such large deep holes are rare and probably limited to these three.

Cushing et al. (2007) and Léveillé and Datta (2010) have identified seven possible skylight entrances into Mars caves on the volcano Arsia Mons, dubbed the “Seven Sisters”. Using images from the Mars Odyssey Thermal Emission Imaging System (THEMIS) these features were found to exhibit diurnal temperature variations that were smaller than their surrounding surfaces.

A preliminary search around Elysium (25°N, 147°E) by Alain et al. (2012), shows evidence for the existence of 28 lava tubes, but yet without observations of skylight entrances. Some are found in the northern part of the region (30°N).

[1] Appendix A contains a table of acronyms.

The existence of lava tubes on Mars and the Moon calls for an extensive study of the value of their eventual utilization for human settlement, as has been imagined by the science fiction writer Kim Stanley Robinson in the book *Green Mars* (1994), studied by many others as Penelope Boston and advocated by the Oregon L5 Society. In 2009, the International Space University (ISU) summer program performed a design project on human habitat inside a Mars lava tube called ACCESS MARS (2009) in which quantitative estimates of the life requirements for small colonies are given.

2. When to settle on Mars and why

Human mission to Mars, when? The answer to this question was given by Werner von Braun et al. (1952) since he wrote, in the book published in 1952, that *Mankind will reach Mars in hundred years*. Well, Werner used to be right, and we will take him to his word by supposing that this event will happen in 2050 ± 5. We have forty years for planning. With the time constant of Moore’s law taken at 2 years, to be continued by nanotechnology, the performances of the electronic components will have been improved in 2050 by 8–10 orders of magnitude. Moravec (1988) in his book *Mind Children, The future of Robot and Human Intelligence* extrapolates the secular growth of computing power for a prediction of availability of human brain equivalent microcomputers around 2040. We have therefore to expect robots with near-human intelligence and high capacity communication systems. 2050 will not be 2010.

No persuasive arguments or schedule can be given for or against sending men to Mars. We take for granted that it will happen and be followed by permanent settlements.

The objective of human settlement would be:

- **National prestige** is an established driver, maybe the most powerful, but its importance cannot be assessed.
- **Exploration**: in 2050, the exploration will have progressed with a number of samples having been returned to Earth, and many robotic “visual” inspections by rovers. The need for sampling will grow in order to obtain a complete and detailed description of the past and present geology of the planet. At that time, it is to be expected that the choice of samples and the field reconnaissance will be performed as well and even better by primitive humanoids than by humans. The sample analysis will be centralized in a main laboratory situated on Mars, at the manned stations, equipped with high performance heavy instrumentation for optical, structural, chemical and isotopic studies, including search for eventual living organisms.
- **Inventory** of the soil components for various sites and depths leading to fabrication of Martian products susceptible of applications on Earth, to be obtained by local manipulation of dust, minerals, molecules and living organisms, as well as utilization of these products by the settlers on Mars.