Concept for a Semi-Permanent Moon-Analogue Habitat Inside a Lava Tube. M. V. Heemskerk[1], M. I. Daeter[1], B.H. Foing[1,2], M. Gasser[3], C. M. Feucht[3], [1] VU Amsterdam, De Boelelaan 1083, 1081HV, Amsterdam (marczijnmailadres@gmail.com, marjoleindaeter@gmail.com), [2] ESTEC, Keplerlaan 1, 2201AZ, Noordwijk (bernard.foing@esa.int) [3] 4th Planet Logistics, Mundelein. Illinois 60060 USA (christa@4thplanetlogistics.ch)

Introduction: Finding the best terrestrial moon-analogue mission sites is of utmost importance in the preparation for future, manned, lunar missions. During these moon-analogue field tests, many problems – technical and physical, but also psychological – that the astronauts will encounter during the actual mission will be discovered. The current moon-analogue bases, such as the LunAres base in Poland and HiSeas in Hawaii, are well-known and thought through, but can only represent a part of the conditions to be found around the most likely first semi-permanent living quarters on the moon. Bringing large structures to the moon will take up a prohibitively large amount of energy and time, and with that, money. Using existing structures on the lunar surface, might thus be the most logical and durable solution.

Looking into utilizing already existing features on the moon, one can think of three main ways to construct a livable habitat. ISRU-housing (In-Situ Resource Utilization), ice habitats and lava tube habitats. ISRU-housing, by making concrete, sintering regolith, or covering inflatable housing, can be a great way to insulate and design large spaces on the moon [1]. This often requires (heavy) machinery and the use of regolith for housing may negatively affect the health of the astronauts living in the habitat [2]. Utilizing the ice caps on the lunar South and North pole, with the close proximity of water and 'peaks of eternal light', alleviates the problem of having to use heavy machinery and avoids potentially dangerous regolith. One could dig a hole in the ground, while shielding themselves with the large amounts of water above their heads. The lunar ice caps however, are preserved in polar craters with temperatures of -220 ºC; this will bring large isolation problems, as also shown by the IgLuna project [3]. A third option will be to build living quarters inside the lava tubes, as recently discovered on the borders of the mares and the highland regions.

Lava tubes: Discovered by Kaguya in 2008 [4], the lunar surface shows many features that are very much alike to the lava tubes on Earth (fig. 1&2). Like on Earth, they are long, basaltic cave systems, with sporadic skylights, through which one can ascend to the surface. The estimated length and diameter of these systems vary from several meters in diameter and depth to multiple kilometers in length. Just like other cave systems, the temperature inside the lava tubes is the approximate average of the surface temperature, and relatively stable. On the moon, this leads to a temperature of about -20 ºC, which suggests that relatively little heating is needed to make a comfortable living space inside a lava tube. As some of the lava tubes discovered thus far are many meters deep, they will protect the inhabitants of a lunar lava tube base from radiation, temperature changes, and micrometeorites.

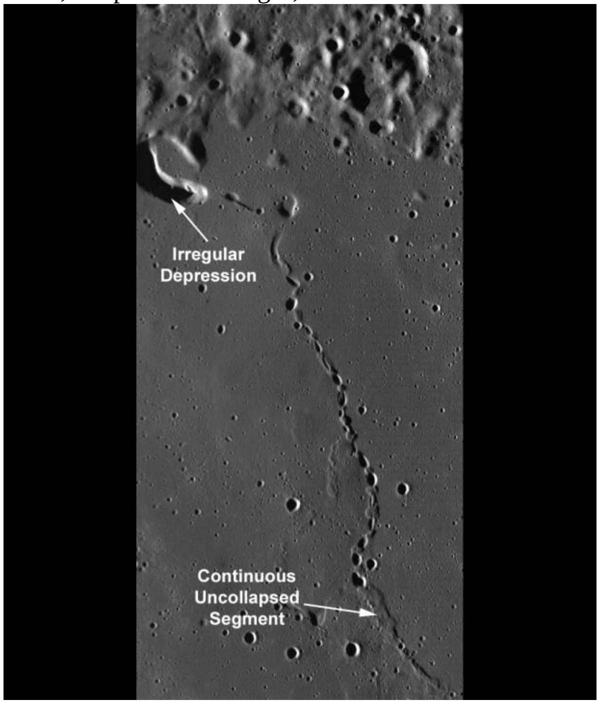

Figure 1. Partially collapsed lava tubes on the moon, as pictured by LRO (M117773324). The total length of the chain is +/- 50 km. Source: NASA/GSFC/ASU.

Figure 2. Partially collapsed lava tube of Stefanshellir, Iceland (*photo by Daniel Leeb*).

Iceland. Geochemically speaking, basalts originating from deep in the Earth, such as the ones found on volcanic islands, show great similarity with the lunar lava tubes in the basaltic mare planes [5]. In this respect, most larger lava tube systems on Earth would make interesting candidates for moon-analogue sites. However, the low temperatures and low biophysical weathering rates on Iceland makes the geomorphology of lava tubes on Iceland more comparable to what is expected of that of the lunar lava tubes.

Setting up a base in an Icelandic lava tube also creates psychological boundary conditions that are more comparable to a possible future base on the moon. Temperatures on Iceland in winter times are well below zero, meaning that going outside without special suiting can be lethal. Furthermore, the relatively smooth lava tubes on Iceland are more compatible with the option to make air-tight living quarters, including an airlock and the long winter nights in Iceland are ideal for simulating a 28 days long day-and-night cycle. Another driver of the psychological simulation is the physical remoteness. In winter months, many lava tubes that are located in the heart of Iceland, are at least several hours away from a ground station in Reykjavik, and more than a day’s travel from the control center at ESTEC, Noordwijk, the Netherlands.

The base. In September 2018, a team of researchers and interns from ESA, has visited three different lava tube systems on Iceland; Raufarholshellir (Sudhurnes), Surtshellir, and Stefanshellir (Hallmundarhraun). Raufarholshellir is the most touristic lava cave of Iceland. This makes it more suitable for public outreach, but less suited for researching the psychological aspects of the isolation. Stefanshellir has a maze-like structure (fig. 3), with longer lava tubes and a more remote location. Surtshellir is almost connected to Stefanshellir and has two large galleries, but these do not go as deep into the lava field as Stefanshellir. This makes Stefanshellir the most attractive choice for a lunar analogue base.

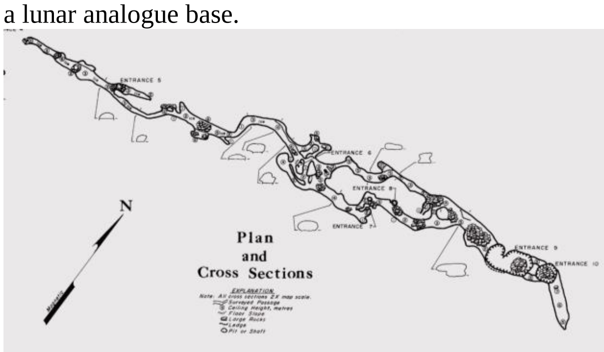

Figure 2. Map of Stefanshellir, Hallmundarhraun, Iceland. (*J.R. Reich, jr., July 1975*).

Research objectives. One of the main concerns for any extraterrestrial habitat will be the energy sources and usage. Unlike on one of the peaks of eternal light near a base on the lunar poles, the lava tubes on the moon see 14 days of blinding sunlight, followed by 14 days of total darkness. This leads to a critical amount of energy storage, needed for warmth, food, water, and waste deposition or transformation. One of the main objectives of a longer duration Iceland moon-analogue habitat will be exactly this; Is it possible to harvest enough energy, safely store it and use it to make a local, pressurized environment that is suited for living? Other objectives that can be reached within an Iceland moon-analogue base are ISRU-based, such as extracting water from dehydrating rocks [6], 3D printing building material, or soil fertility studies. Lastly, traces of past aqueous activity can often be found in recrystallization borders of lava tubes on Earth, it is expected that this can also contain a record of paleoclimates on the moon [7].

Iceland as a moon-analogue. Building a moon-analogue habitat in Iceland can be a viable addition to the already existing analogue sites - such as HiSeas, , LunAres, or MDRS – or sites currently still under development, such as IgLuna or the habitat-terrain at EAC. This base, with the possibilities of having a pressurized base, similar climatic, psychological and physical distance conditions, can later on also be transformed for mission-analogues for Mars, as lava tubes have also been photographed on the Martian surface.

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