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月の縦孔を利用した基地に関する検討

Examination of Lunar Bases Using the Vertical Holes of the Moon

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1. Introduction

The lunar surface is a dangerous environment exposed to harmful radiation and meteorites. The underground cavity discovered in recent years is expected to be a promising candidate site for base construction due to no such risks and the mild temperature change. The vertical holes now being discovered in the Marius Hills are about 60 m in diameter and 50 m in depth. Underneath these vertical holes, there is an underground space that exceeds the diameter of the vertical holes, some of which are expected to have horizontal holes of about 50 km. Various studies have been conducted on the construction of a lunar base since ancient times. These large vertical holes are considered to be indispensable gateways for human beings to live underground.

In 2009, JAXA's lunar explorer SELENE discovered a huge and previously unknown vertical hole (60 m in diameter and 50 m in depth) in the Marius Hills region of the Moon, known as the Marius Hills Hole (MHH) (303.3°E, 14.2°N).[1] A global survey conducted using SELENE data also revealed two other huge vertical holes (several tens of meters to 100 meters in both diameter and depth).[2] One is the Mare Tranquillitatis Hole (MTH) (33.2° E, 8.3° N), and the other is the Mare Ingenii Hole (166.0° E, 35.6° S). Figure 1 shows the locations of the three vertical holes discovered by SELENE.

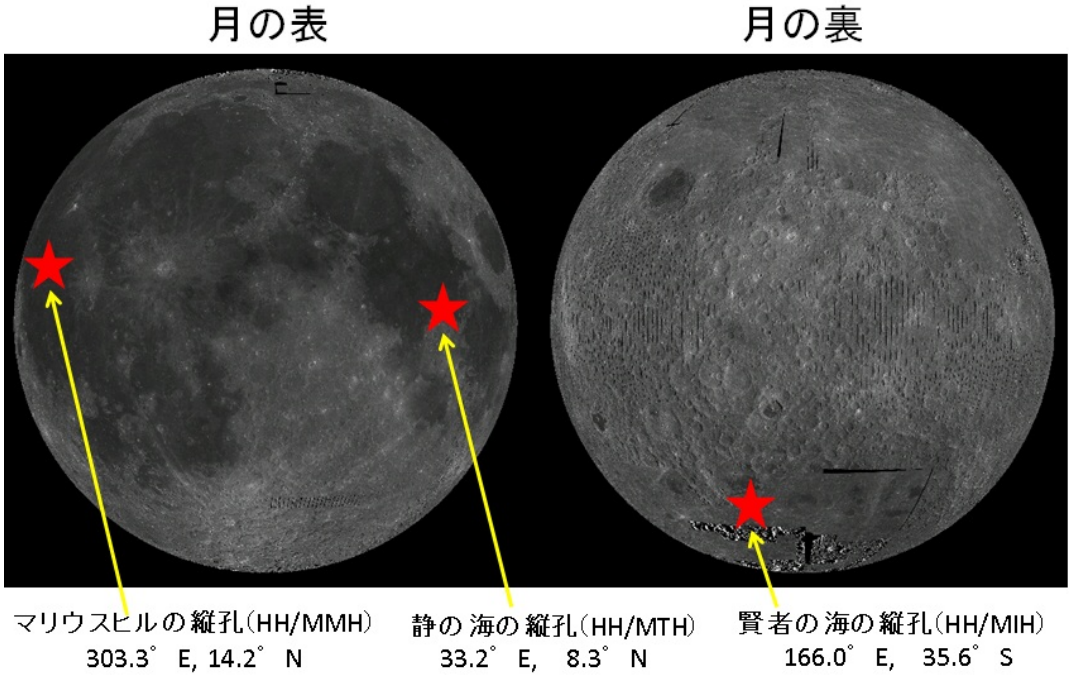

Fig. 1. Locations of the three vertical holes on the Moon discovered by SELENE

Subsequently, data have suggested that underground cavities exceeding the diameter of the vertical holes have expanded under these vertical holes.[3),4] And in 2017, data analysis by SELENE's radar sounder showed that the vertical

hole in the Marius Hills region was followed by a large horizontal hole (underground cavity) 50 km in length, which is thought to be a lava tube.[5)]

These vertical holes and underground cavities, such as lava tubes and skylights opened there, are thought to have been formed as a result of volcanic activity and crustal movements by analogy with the similar topography of Earth. The underground cavity leading to a lunar vertical hole has a ceiling that shields it from the large amount of radiation and ultraviolet rays that fall on the lunar surface, and thus eliminates the danger of meteorite impact or scattered objects. And given the extremely stable temperature of the underground cavity, fewer resources are expected to be required for overnight stays. In addition to the scientific significance, prior exploration of the lunar vertical holes and underground cavities is extremely important from the perspective of future lunar/planetary exploration technology and lunar base development.

It is clear that the radiation and temperature environments are suitable for long-term stays by humans, but how many meters deeper than the vertical hole will the radiation environment be at a sufficiently safe level for such long-term stays? And what are the upper/lower temperature limits in a month (one day on the Moon)? Such information is essential for designing a base in an underground cavity, and must be accurate unless it is directly measured (in-situ observation), including how far the horizontal hole discovered in 2017 extends in terms of kilometers. As such information cannot be currently obtained, our research community (UZUME RG) is thus considering the UZUME project, marking the first attempt to descend directly into the "Haruyama Hole" of the Moon discovered by SELENE.

Ever since UZUME RG was established, we have been conducting research on bases using the vertical holes and underground cavities of the Moon.[6)] As a base for the near future in the previous stage, we considered how to make a habitation module by expanding the inflatable structure from the lander that landed at the bottom of the vertical hole, and also applied for the Space Architecture Award.[7)] The lunar vertical hole/underground cavity utilization base is also included in the Space Long-Term Vision 2050 of the Japan Aerospace Society, which was compiled in 2019.[8)]

2. Advantage of bases in vertical holes and underground cavities of the Moon

The lunar vertical holes[1, 2)] discovered by SELENE and the underground cavities that follow them offer many favorable conditions for the construction of future lunar bases. The underground cavity leading to a lunar vertical hole has a ceiling that shields it from the intense radiation and ultraviolet rays that fall on the lunar surface, and thus eliminates the danger of meteorite impact or its scattered matter. Radiation of up to 4200 mSv (exceeding the median lethal dose of 4000 mSv) was observed on the lunar surface in 1989 when a flare occurred, but it is possible to evacuate to safe shelter in about an hour, in order to ensure the safety of astronauts.

Given that the depth of a vertical hole ranges from 50 to 100 m, the temperature at the bottom of the vertical hole is extremely stable compared with that on the lunar surface. Figure 2 shows the temperature analysis results of the lunar vertical holes and underground cavities in comparison with the lunar surface. As shown in the upper-right portion of Fig. 2, the points analyzed are the north side of the sunlit hole bottom (green ▲) and the south side of the sunless hole bottom (blue ◇). The temperature on the lunar surface is expected to fluctuate from -170 to 110°C (covering a range of approx. 300°C), while the north side of the bottom of the hole rises to a maximum of 150°C in sunshine, but only to -20°C on the low temperature side. The range of temperature fluctuation is expected to be about 170°C without lowering, and that on the north side of the hole bottom (not exposed to the sun) is expected to be -20°C to 30°C, with said range being extremely stable at about 50°C. For this reason, it is expected that the resources required for an overnight stay, which pose a problem on the lunar surface, will be reduced to a fraction.

Air, water, food, energy, etc. are required for a long-term stay by human beings, but transporting all of these resources from Earth is not realistic given the extremely expensive transportation and maintenance costs required. Therefore, in addition to energy, we are thinking about increasing the regeneration rate and self-sufficiency rate of air, water, and food in the future.[10)]

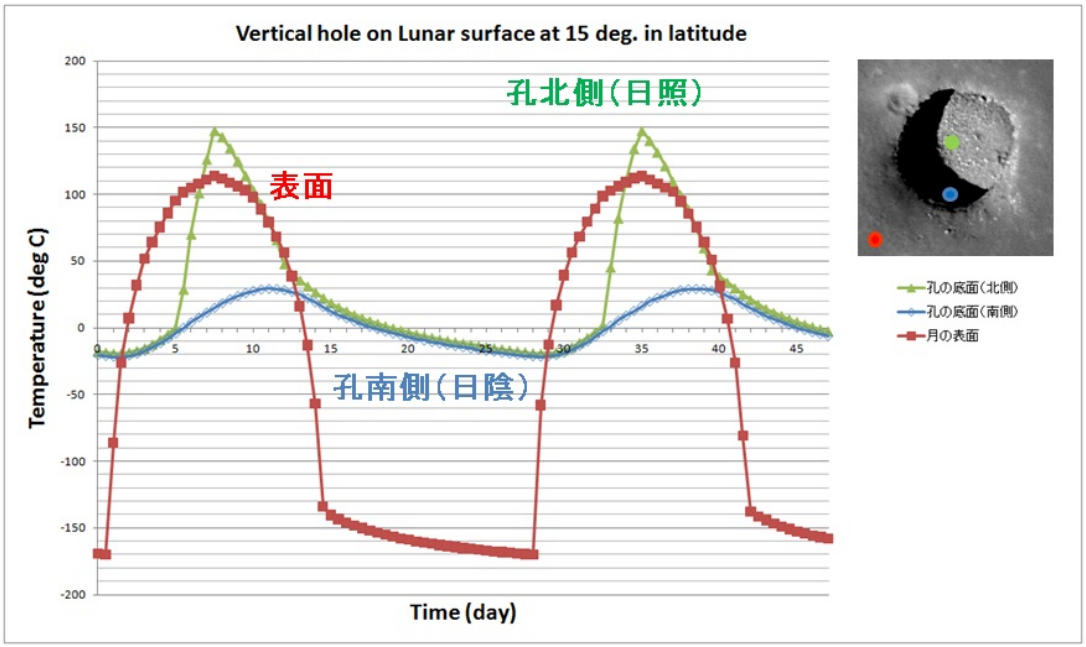

Fig. 2. Moon vertical hole vs. lunar surface temperature analysis results 4)

References

1) Junichi Haruyama et al.: Possible lunar lava tube skylight observed by SELENE cameras, Geophysical Research letter, VOL. 36, L21206, doi: 10.1029/2009 GL 040635, 2009.

2) Junichi Haruyama et al.: New discoveries of lunar holes in Mare Tranquillitatis and Mare Ingenii, 41st Lunar and Planetary Science Conference, #1285, Lunar and Planetary Science Institute, 2010.

3) Ashley, J. W. et al.: Lunar pits: Sublunarean voids and the nature of Mare emplacement, 42nd Lunar and Planetary Science Conference, #2771, Lunar and Planetary Science Institute, 2011.

4) Junichi Haruyama et al.: Lunar holes and lava tubes as resources for lunar science and exploration, in Moon: Prospective Energy and Material Resources, Ch. 6, pp. 140 – 164, ed. by Viorel Badescu, Springer-Verlag Berlin, Heidelberg, 2012.

5) T. Kaku, J. Haruyama et al.: Detection of Intact Lava Tubes at Marius Hills on the Moon by SELENE (Kaguya) Lunar Radar Sounder, Geophysical Research Letters, 10.1002/2017GL074998, 2017.

6) 河野功　春山純一　他：月惑星の縦孔・地下空洞探査システムの研究，第 58 回宇宙科学技術連合講演会講演集 2K17, 2014

7) 茂渡真理　新井真由美　他：UZUME 計画：月の縦孔・地下空洞を利用した基地の建設コンセプト，第 61 回宇宙科学技術連合講演会講演集 2B04, 2017.

8) 日本航空宇宙学会宇宙長期ビジョン 2050，https://www.jsass.or.jp/wp-content/uploads/2019/05/JSASS_SpaceVision2050_20190313_JPN.pdf

9) 山本幸生　春山純一　他：2020 年代における「月の静の海の縦孔」探査時における縦孔底からの地球視認性，第 63 回宇宙科学技術連合講演会講演集 3C08, 2019.

10) 桜井誠人：宇宙機における生命維持システムについて，生物工学　第 96 巻　第 12 号，2018.