Mission Concepts of Unprecedented Zipangu Underworld of the Moon Exploration (UZUME) Project


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We are planning to explore the caverns through the skylight holes on the Moon and Mars. The holes and their associated subsurface caverns are among the most important future exploration targets. The importance of the lunar and Martian holes and their associated caverns is categorized from two aspects: (1) fresh materials are easily observed and sampled there, and (2) the subsurface caverns provide a safe, quiet environment. The expectation of lunar and Martian hole and cavern exploration is increasing in Japan. We name the project as UZUME (Unprecedented Zipangu (Japan) Underworld of the Moon Exploration) whose name is after a Japanese mythology. The ultimate purpose of the UZUME project is to investigate how to expand human activity and survival in space and on extraterrestrial bodies.

Key Words: Moon, Exploration, UZUME, SELENE, Hole

1. Introduction

In 2009, three huge vertical holes were discovered in the lunar Marius Hills, Mare Tranquilitatis, and Mare Ingenii in the 10 m-resolution images taken by the Terrain Camera (TC) aboard SELenological and ENgineering Explore (SELENE, nicknamed KAGUYA) of Japan.1,2) The holes have aperture diameters and depths of several tens of meters to one hundred meters. Haruyama et al. (2009)1) hypothesized that they are possible “skylights” opened on subsurface caverns such as lava tubes. Lava tubes often form in basaltic lava areas on the Earth. Many lava tubes exist at the foot of Mt. Fuji in Japan, for instance. Similar hole structures are also found on Mars.3,4) The United States Lunar Reconnaissance Orbiter (LRO) Narrow Angle Camera (NAC) later identified more pits on the Moon,5,7) including three holes that SELENE had discovered (hereafter, “SELENE holes”). The resolution of LRO-NAC is 0.5 to 2 m/pixel, which is ten times better than that of SELENE TC. The images of LRO-NAC provided conclusive evidence that large spaces are opening around the floor of the SELENE holes.5) The vertical walls of the holes were also imaged by LRO oblique observations and they exhibit layered structures.5) The diameters and depths of the SELENE holes were re-measured/ re-estimated based on LRO-NAC data.5) The measured values of the Mare Tranquilitatis and Mare Ingenii holes were almost the same as the measurement and estimation results based on TC image data. However, the depth of the Marius Hills Hole (MHH) was shallower than that estimated from SELENE observation results. Haruyama et al. (2009) estimated the depth of the hole using SELENE Multiband Imager (MI) data because no appropriate TC data were available to estimate it. The spatial resolution of MI is 20 m/pixel; thus, the boundary of the illuminated and shadowed areas from which the depth was estimated was unclear, resulting in overestimation of the shadowed region and...
The pits in the LRO-NAC images were classified into three categories based on their locations: floors of large craters such as the King crater (80 km diameter), mare, and highlands. The pits on the crater floors were apparently formed by depression and/or degassing of cooling impact-melt lavas. Most are smaller than a few tens of meters in diameter and are not skylights of subsurface caverns. Including the SELENE holes, eight pits have been identified in mare regions. Most mare pits are smaller and shallower than the SELENE holes; an exception is the pit on Lacus Mortis (Lake of Death), which is as large as the SELENE holes, with a 140 m x 110 m axis-length oval opening and 80 m depth. The Lacus Mortis pit is located at 45 deg north latitude. For the pit, no entrance to caverns has been confirmed. In other words, the existence of subsurface caverns connecting to the pit has not been confirmed.

"Pit" is a general term for depression structures. However, vertical holes such as the SELENE holes are apparently unique, different from other smaller and shallower depressions. Thus, we use the term "hole" to refer to gigantic pit structures, such as the MIH, Mare Tranquilitatis Hole (MTH), and Mare Ingenii Hole (MIH).

Lunar and Martian holes/pits and associated subsurface caverns have much importance from the viewpoints of science and future utilization. Expectation of the exploration of lunar and Martian holes/pits and caverns is increasing, especially in Japan. Many studies of lunar and Martian holes and associated caverns have been presented in academic meetings. Some research groups are planning to explore these holes and caverns. One such plan is the project Unprecedented Zipangu Underworld of the Moon/Mars Exploration (UZUME). This presentation outlines UZUME.

2. Significance of Lunar Holes

There is much scientific significance in exploring lunar holes and caverns, which may be categorized from two aspects: (1) fresh materials are easily observed and sampled in the holes and caverns, and (2) the holes are entrances to caverns that provide a safe, quiet environment. On the Moon, numerous meteorites have impacted, radiation has constantly showered, and wide temperature oscillation has caused deformation of rocks. The surface of the Moon has been suffered from brecciation, space weathering, and fragmentation. “Fresh” rocks and materials keeping original information are rare on the surface of the Moon. On the other hand, “fresh” rocks and materials are found on the walls and floors of vertical holes and subsurface caverns. They provide information about past volcanic activity; dynamo magnetic field generation; implanted materials from the Sun, comets, and asteroids; and stratification that occurred in the deep interior. The best places to set various observation instruments are inside the safe, quiet holes and caverns.

The lunar holes are precious entrances to safe, quiet environment of caverns that is also useful for both observation instruments and human beings. Temperature oscillations are very large on the lunar surface. At the equatorial region, temperatures range from -150 to +120 deg C. Haruyama et al. (2012) estimated that the temperature oscillation at a permanently shadowed location on the floor of the MHH is -20 to +30 deg C, based on a cylindrical model for the vertical hole. The radiation environment on the lunar surface is also severe. Occasionally, fatal radiation bursts strike the lunar surface. It should be noted that covering by lunar regolith of a few meters thickness on shelters does not protect the people inside the shelters from radiation damage; rather, it yields the opposite effect. The radiation entering the regolith covering would generate weaker but more secondary radiation that reaches inside the shelters and harms the residents. Radiation risk exists even in the lunar polar region. Only lunar subsurface areas are safe from radiation. Lunar caverns do not collapse easily. Actually, terrestrial lava tubes are tough. Most lava tubes at the foot of Mt. Fuji have not been collapsed by the repeated large earthquakes in Japan. It was also reported that a magnitude 7.5 earthquake did not effect a lava tube in Hawaii. Moonquakes have such a low energy level that their hazardous risk for subsurface caverns is almost zero. The possibility of meteorite impacts that hit and destroy lunar base caverns is also quite low.

3. Increasing Expectations of Hole and Cavern Explorations

Because of the significances of lunar holes and caverns, expectations to explore them are increasing. Since 2010, many Japanese researchers have met to discuss science, exploration technology, and outreach activity associated with lunar and Martian holes and subsurface caverns. For example, more than 100 researchers totally participated in a meeting entitled...
“Conference: Exploration of vertical hole and subsurface caverns on the Moon and Mars”, held in 2015 at Fuji-Kawaguchiko Town, where there are many lava tubes, at the foot of Mt. Fuji in Japan. SELENE-2 was a mission with an intention to send a landing module to the Moon, and a lunar hole was a candidate for the landing site. However, the SELENE-2 mission was officially terminated in March 2015.

In January 2015, the Institute of Space and Astronautical Science (ISAS) of the Japan Aerospace Exploration Agency (JAXA) announced that it would start making road maps of future space mission programs, and required that space science communities provide information about space science missions that were in preparation and those that were expected. In response, the chair of the Japanese Society for Planetary Sciences and a group named by the chair surveyed missions and presented a report. This report indicated that one of expected target of future space exploration is “underground” on the Moon and planets. Thus, holes and subsurface caverns could be considered appropriate targets for future space science programs. A surface area right next to MHH is a candidate for a landing site for the Smart Lander for Investigating the Moon (SLIM), a mission that will demonstrate pinpoint landing technology on the Moon and that has been proposed as the third small science mission to be launched by an Epsilon rocket. However, SLIM will not explore inside the hole because of limited launch mass. The Hakuto team that is competing in the Google Lunar X race to send a lander to the Moon and make a rover move on the lunar surface is planning to land on an area near the Lacus Mortis pit.

4. UZUME Project

As a result of increased expectations to explore lunar holes and caverns, Japanese scientists and engineers formed a research group under the space engineering committee to consider a project to explore lunar and planetary caverns. They named the project UZUME, after a goddess appearing in the two oldest Japanese historical records, Kojiki and Nihon Shoki. These works tell us that “Once upon a time, the Sun Goddess hid into Amano-Iwato cave in a reason, and the light was lost from the world. Other gods were in trouble. Then Goddess hid into Amano-Iwato cave in a reason, and the light was returned to the world.” The project name of UZUME is the abbreviation of Unprecedented Zipangu Underworld of the Moon/Mars Exploration.

The UZUME research group is proposing a three-stage program over the next two decades. The mission concept of the first stage is technology demonstrations approaching from the landing location to a hole, descending into the hole, performing observation at the floor of the hole, and entering the cavern opening at the bottom of the hole. Details of the topography and geology of the surface around the hole, the layers exposed at the inner wall of the hole, the floor of the hole, and the inside of the caverns will be observed. Temperature, radiation, and micrometeorites hitting the bottom of the hole and the inside of the caverns will be measured. How to detect volatiles at the wall and bottom of the hole and inside the caverns is being considered. The UZUME group aims to complete this first stage in the early 2020s. The mission of the second stage, to be completed in the mid-2020s, will be a sample return from the exposed layers of the inner wall of the hole, the floor of the hole, and the inside of the caverns. The third stage will involve traveling to Mars with the technologies developed in the first two stages. The main mission of this stage is a search for life on Martian. The interiors of the Martian caverns where ultraviolet rays, a destroyer of highly compound molecules approaching to become a form of life, do not reach, is one of the most probable locations of life existence. Martian caverns may thus be appropriate residences where human beings can live on Mars for long periods.

The key technology of the UZUME project is robotics. Wheel rovers are perhaps not appropriate for investigation on the floor with scattered rocks of a few meters across. Multi-leg and humanoid robots may be needed. Robots that use the same instruments as human astronauts will be good co-workers for astronauts. A goal of the UZUME project is the development of “tele-scientists,” robots that work on the Moon and Mars using telecommunications, as alternatives for scientists staying on the Earth. We expect that the robot technology developed in the UZUME project will be used also in extreme conditions such as erupting volcanoes, deep seas, or inside of nuclear plants.

The UZUME project has a third pillar besides science and engineering. It is the public engagement of ordinary people. The knowledge and technologies acquired in lunar and planetary missions should be returned to the public. Public engagement does not need to wait for the realization of missions. Even during the planning phase, outreach activities could be tried. Publicity using a set of Karuta (Japanese cards) associated the UZUME project is one such trial.12)

5. Conclusions

In 2009, the Japanese lunar explorer SELENE (Kaguya) discovered on the Moon huge holes whose aperture diameter and depth exceeded several tens of meters. Later, evidence that the lunar holes are “skylights” of subsurface caverns was obtained using the LRO-NAC. These holes have much significance for science and future utilization of the Moon. Similar holes have been found on Mars. The Martian holes may provide safe shelters allowing terrestrial beings to survive on the planet. In the future, human beings will have a base inside the Martian caverns.

The expectations of exploration of lunar holes are increasing. A landing site candidate for the Smart Lander for Investigating Moon (SLIM) is right next to the Marius Hills Hole (MHH) that SELENE found. However it seems to be difficult for SLIM to explore inside the hole.

A group of Japanese scientists and engineers are considering missions to enter and explore lunar holes and
caverns of the Moon and Mars. The mission program is named UZUME, after a Japanese goddess in historical literatures. Researchers are planning three stages for UZUME in the next two decades. The mission of the first stage will involve the utilizing technology to approach and enter the holes and subsurface caverns. In the second stage, samples from walls and floors of a lunar hole and its connecting cavern will be returned. The targets of the third stage of UZUME will be Martian holes and caverns where extraterrestrial beings may have existed or may exist even today.

The ultimate purpose of the UZUME project is to investigate how to expand human activity and survival in space and on extraterrestrial bodies. To accumulate knowledge of the origin and evolution of the Moon, Mars, and our solar system, and the possibility of emergence and existence of extraterrestrial life is part of this purpose. The Earth may be destroyed in the far distant future, but worldwide natural disaster and/or environmental deterioration in the near future should not be excluded. The Earth may not always be kind to human beings. Nobody knows if the Moon and Mars are the best places for evacuation of human beings. Therefore, the possibility of human activity there should be investigated. UZUME seeks to investigate the possibilities.

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References