

# Unprecedented Zipangu Underworld of the Moon Exploration (UZUME)

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## Abstract

On the Moon, three huge vertical holes (several tens to a hundred meters in diameter and depth) were discovered in SELENE (nicknamed Kaguya) Terrain Camera data of 10 m pixel resolution. These holes are probably skylights of underground large caverns such as lava tubes, or magma chambers. The huge holes and their associated subsurface caverns are among the most important future exploration targets from the viewpoint of constructing lunar bases and many scientific aspects. We are now planning to explore the caverns through the skylight holes. We name the project as UZUME (Unprecedented Zipangu (Japan) Underworld of the Moon Exploration).

## 1. Introduction

Since Apollo 17 in 1972, the last mission, only two Moon missions were launched in the remaining 25 years of the century: Clementine, Lunar Prospector. However, in the first decade of this century, nine lunar missions were launched: Smart-1 of ESA, SELENE (nicknamed Kaguya) of Japan, Chang'E-1-3 of China, Chandrayaan of India, and LRO, GRAIL, and LADEE of USA. Accumulated data from these missions will be used for future in-situ exploration, sample return missions, and manned activity on the lunar surface. A new era of the lunar exploration is opening. However, the surface of the Moon presents a hazardous

environment. There are numerous micro-meteorite bombardments and showers of cosmic and ultraviolet rays. The temperature on the surface at the lower latitudes of the Moon varies widely, from  $-150^{\circ}\text{C}$  to  $+120^{\circ}\text{C}$ . Short-term missions may be possible, but long-duration missions on the surface may be difficult.

## 2. Lunar Holes

In 2009, three huge vertical holes (several tens to a hundred meters in diameter and depth) were discovered on the Moon in SELENE (nicknamed Kaguya) Terrain Camera data of 10 m pixel resolution [1-3]. These holes were later confirmed to connect to gigantic caverns at their bottoms by LRO Narrow Angle Camera (NAC) of 1 m resolution [4,5]. These subsurface caverns may be a way for human beings to expand their activity on the Moon and beyond. The caverns are appropriate lunar base candidates where astronauts and mission instruments are safe, unlike the harsh lunar surface environment [e.g., 6,7].

Wagner and Robinson [8] subsequently identified various steep-walled negative relief features that differ from normal meteorite craters using the LRO NAC data. They called these features "pits" and classified them into three categories by their locations: mare pits, impact melt pits, and highland pits. The holes at Marius Hills, Mare Tranquillitatis,

and Mare Ingenii found by SELENE are the largest of the mare pits.

The huge holes and their associated subsurface caverns are among the most important future exploration targets from the viewpoint of constructing lunar bases and many scientific aspects. Lava strata are observed on the vertical walls [1-5,9] where we will obtain information on the evolution of mare volcanism. The magnetic information of the strata will provide information on past lunar dynamo activity [2,3]. The floors of the holes and inside caverns are colder than the outer surface of the Moon [3,9]. Therefore, water molecules from solar wind implantation and comets/meteorites may exist there. Exploring the lunar subsurface caverns will provide much scientific knowledge.

Mars also has pits, some of which are apparently similar to lunar skylight holes, possibly connecting subsurface caverns like lava tubes [10,11]. Like the lunar caverns, the Martian caverns attract much interest as future base candidates and for geological scientific themes. The possibility of life inside the caverns is an especially high scientific interest. The caverns might have liquid water and underground magma heat that could promote chemical evolution of life precursors or even life itself. Exploring the lunar caverns will provide lessons for exploring the Martian caverns.

### 3. UZUME project

We are now planning to explore the lunar caverns through their skylight holes. From our exploration, we will accumulate geologic knowledge to understand the evolution of the Moon and to establish future lunar bases. We will also acquire the knowledge and technology to prepare for exploring the life system in the Martian underground.

We name the exploration UZUME (Unprecedented Zipangu Underworld of the Moon Exploration; a goddess that appears in the “Kojiki”, Japan’s oldest extant chronicle). The UZUME project needs to solve many technological issues such as how to approach the funnel-like outer rim of the holes, descend slowly to facilitate scientific investigation of the vertical walls of the holes, and to automatically determine the investigation routes at floors of the

holes where lots of blocks are spotted and at dark insides of the caverns. Developing these technologies will be difficult and challenging. However, the exploration will be realized through close collaboration among scientists and engineers.

## Acknowledgement

This work was supported by KAKENHI (26400459: J. Haruyama.).

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