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Short Communication

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Hex Code-based Geological Cross-sections Describing Landscape Dynamics in the Jeju Geomunoreum Lava Tube System

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Abstract

BACKGROUND: The Geomunoreum Lava Tube System (GLTS) is both vast and culturally valuable. The Jeju Volcanic Island and Lava Tubes, which are partly composed of the GLTS, have been declared as a United Nations Educational, Scientific, and Cultural Organization (UNESCO) World Heritage Site. Exploration of the caves is strictly regulated to conserve these vulnerable environments. Photographs provide limited information and do not describe the entire environment comprehensively. Therefore, we created several illustrations of the lava tubes to display their environmental features.

METHODS AND RESULTS: We explored six lava caves (upstream and downstream) in the GLTS and photographed their geological features and yellow walls, the colors of which are influenced by microbial mats. We compared the hex codes of the wall colors using the Clip Studio v1.10.5 software and created illustrations that accurately represent the scale and features of the caves.

CONCLUSION(S): Upstream and downstream caves of the GLTS differ in scale and volcanic features. We illustrated various characteristics of the caves including lava cave features, vegetation, and microbial mats. We also described the internal and external cave environments.

Key words: Geological Sketch, GLTS, Lava Cave, Microbial Mats, Vegetation

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Introduction

The Geomunoreum Lava Tube System (GLTS) is a cluster of large, diversely shaped tubes that formed through pahoehoe lava flows during the eruption of Geomunoreum, a satellite volcano. The lava caves are on the eastern side of Jeju Island, South Korea; despite easily accessible cave entrances, the GLTS remained preserved for thousands of years before their discovery by humans. In 2007, the GLTS was designated a United Nations Educational, Scientific and Cultural Organization (UNESCO) World Natural Heritage for its unique geological features and scenery [7, 19, 20].

The goal of world natural heritage research is to record the status of unique sites and to build conservation policies [4, 12]. Lava tube restoration is rarely feasible because lava tubes tend to eventually collapse after their formation. Although photographs are useful records of such sites, they provide limited information. The lava caves of the GLTS are too large for comprehensive photography, and light can impact their wall colors. By contrast, geological sketches are used to record geological history because they can represent conditions accurately regardless of scale or hidden features; these attributes have made fine drawing a mainstay of anatomical illustration in biology [9].

Therefore, in this study, we illustrated the fundamental characteristics of six caves in the GLTS including volcanic cave features, vegetation, and microbial mat coloration, as well as the internal and external environments of the caves.

Methods and Materials

Study Sites

We explored six upstream and downstream caves in June, August, and October 2019. We took photographs using a camera (SM-M960N, Samsung, Suwon, South Korea) and a smartphone (Vega 9, LG, Seoul, South Korea), focusing on cave vegetation, yellow microbial mats on cave walls, and geological features. The six study sites were selected as representative GLTS sites: Utsanjeon cave (UJ, 33°28′51.8″N, 126°44′08.3″E), Bukoreum cave (BO, 33°29′13.21″N, 126°44′35.969″E), Bengdwi cave (BD, 33°28′30.1″N, 126°43′09.6″E), Gimnyeong cave (GN, 33°31′42″N, 126°46′17″E), Manjang cave (MJ, 33°31′43.4″N, 126°46′17.6″E), and Yongcheon cave (YC, 33°32′55.6″N, 126°46′42.4″E).

Chemical Characterization of Yellow Microbial Mats

As reported previously, phosphate concentrations in lava tube walls are higher than those of lava water or sea water [10]. In the GN, MJ, and YC caves, we also found that calcium concentrations were higher in walls than in lava water or sea water, reaching 10,273 mg/L in the YC cave. Lava tube analysis also detected trace elements including cadmium, lead, cobalt, gallium, manganese, and nickel. Yellow wall mats indicted the formation of biofilms in the lava tubes; these were previously identified as microbial mats through staining and microscopy [10].

GLTS Vegetation

Vegetation surrounding the GLTS resembles that of Gotjawal Forest on eastern Jeju Island because they share pahoehoe lava-based bedrock, high humidity, and subsidence areas [11, 18].

GLTS Geological Sketch and Color Model

To obtain detailed wall color descriptions, we took photographs of cave microbial mats under a fluorescent lamp, and then determined the wall color hex codes, including red–green–blue (RGB), cyan–magenta–yellow–black (CMYK), and hue–saturation–value (HSV), using the Windows Paint program [2, 10, 13–16]. Illustrations were drawn using the Clip Studio Pro v1.10.5 software and a pen tablet (680TF, Huion, Shenzhen, China).

Results

The overall features of the cave entrances of the GLTS are shown in Fig. 1. The Geomunoreum volcano, which produced the lava that formed the GLTS, now features a horseshoe-shaped crater that opens northeastward [1]. The physical features of the lava caves include the cave length, passage geometry, and number of entrances.

Native vegetation surrounds the entrances to the six caves. The continuous high humidity around the caves has promoted the growth of vegetation that differs from the surrounding area, notably including diverse fern species. Some caves are characterized by the root penetration through crevices along lava cave surfaces; under certain conditions, these surface plants can grow stems and leaves within the cave. Dominant plants in the GLTS include *Pueraria lobata* (Willd.) Ohwi, *Melia azedarach* L., *Equisetum ramosissimum*

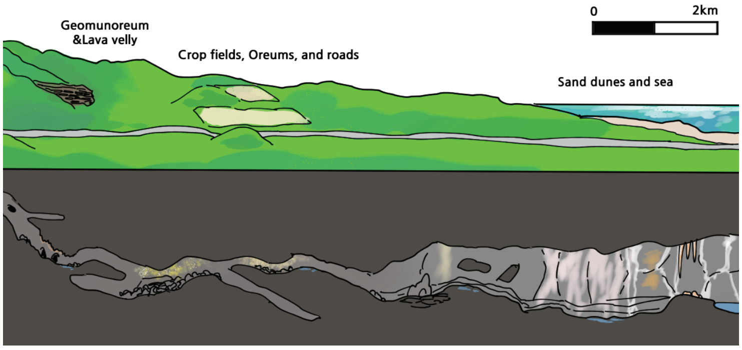

Fig. 1. Cross-sectional overview of the Geomunoreum Lava Tube System (GLTS) on Jeju Island, South Korea.

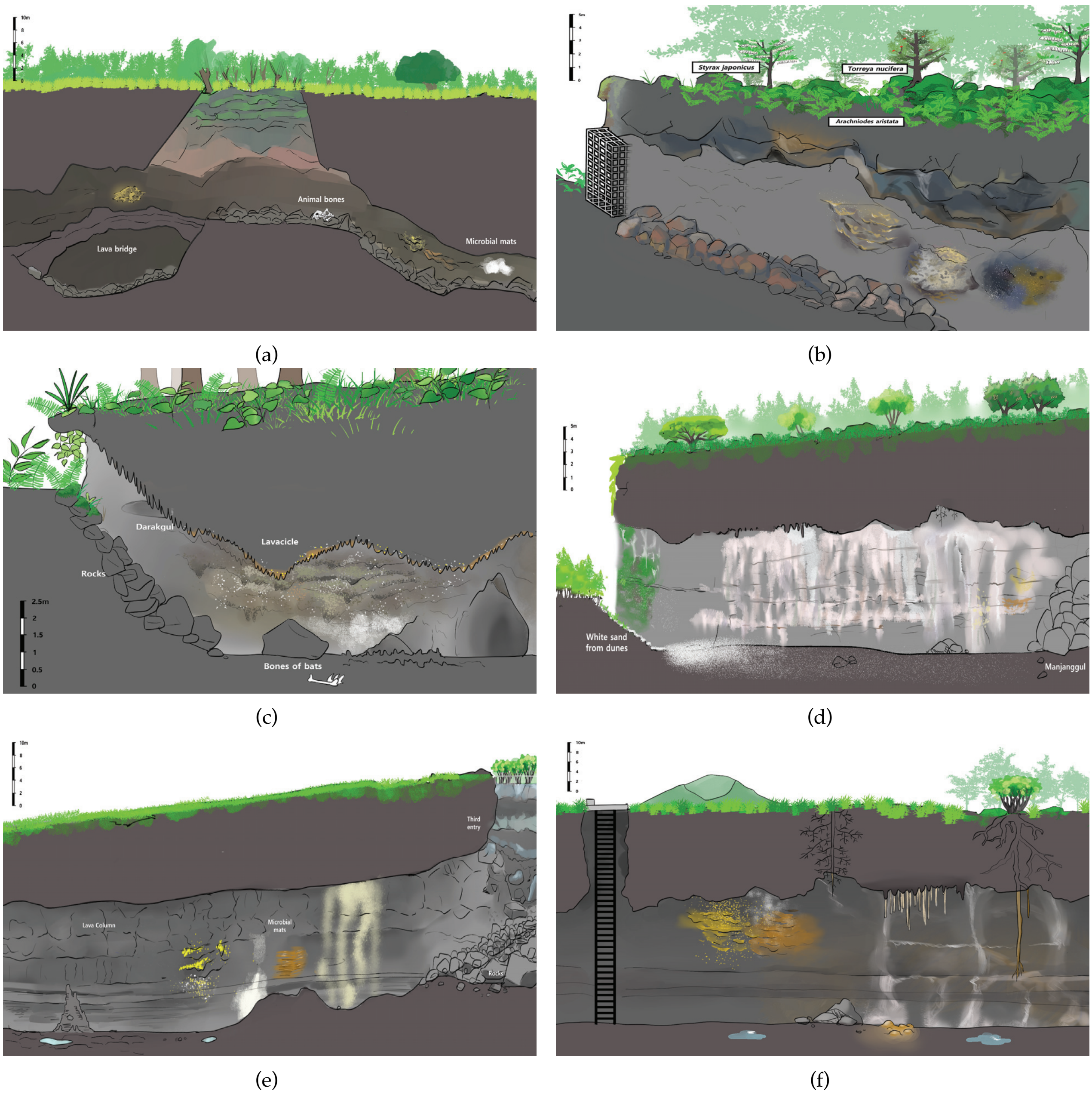

Fig. 2. Geological cross-sections of GLTS caves: (a) Utsanjeon (UJ), (b) Bukoreum (BO), (c) Bengdwi (BD), (d) Gimnyeong (GN), (e) Manjang (MJ), (f) Yongcheon (YC).

Desf., *Albizia julibrissin* Durazz., *Elaeagnusum bellata* Thunb., and *Ficus erecta* Thunb.

A previous study reported extremely high calcium levels in the YC cave, reaching 10,273 mg/L [10], indicating a pseudo-limestone lava cave that formed under the influence of shell accumulation on the nearby seashore. The GN and YC caves are situated near carbonate sand dunes, resulting in carbonate deposits in downstream caves [5, 19, 20]. These caves are characterized by fallen rocks from the cave ceilings and puddles of accumulated groundwater. The BD, UJ, UJ, GN, MJ, and YC caves were originally connected as the master tube line.

The UJ cave also contains large numbers of rocks on its floor. This cave is 2.5 km long, with two entrances and a multi-layered structure (Fig. 2a). Animal bones are found within the cave entrance. Brown, white, and yellow microbial mats cover the walls. The BO cave is an upstream cave; it is 221 m in length and has one entrance, a low ceiling, and accumulated fallen rocks from the ceiling. Thick yellow microbial mats cover its wall surfaces (Fig. 2b). Unlike the other caves, the BD cave with 12 entrances is an anastomosing system comprising several small caves linked by maze-like passages [1]. Lavacicles occur on the ceilings, which are covered with white, yellow, and brown microbial mats (Fig. 2c). The GN cave is also a downstream cave; it is 705 m long, with one entrance. White sand carried from nearby dunes forms mounds around the entrance [5]. The walls are curved into an S-shape, and most of the walls are ivory-colored, covered with white and yellow microbial mats. The end of GN cave is connected to the MJ cave; however, this link is presently blocked by rocks due to a ceiling collapse (Fig. 2d). The MJ cave is 7.4 km long, with three entrances; it is the second-largest lava tube on Jeju Island, and the 11th largest lava tube worldwide [8]. The section between a lava column and the third entry contains lava shelves and rafts, with white, yellow, and brown microbial mats on the walls (Fig. 2e). The YC cave has a particularly small entrance, and extends under roads and crop fields (Fig. 2f). Carbonates from sand dunes contribute to the formation of pale orange stalactites and stalagmites, and plant roots penetrate the ceiling [3, 17, 19, 20]. The HSV model showed diverse wall colors in this cave (Fig. 3), and the CMYK model showed 71.5% yellow [10]. Among all six caves, BO cave had the highest yellow percentage, at 92% [10].

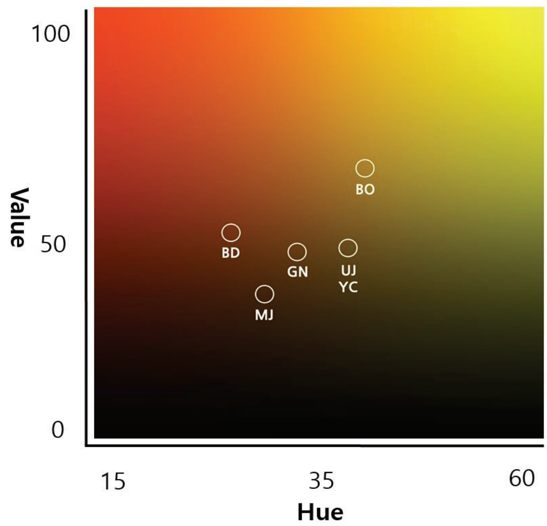

Fig. 3. Hex codes for yellow microbial mats found on GLTS cave walls obtained using hue–saturation–value (HSV).

Discussion

In most cave studies, photographs are used to illustrate sample collection sites. Although this information is important, such photographs provide little information on the cave environment. In this study, we created illustrations to describe the features of the GLTS in fine detail, including its internal and external environments. Our illustrations were drawn based on the literature, as well as exploration and measurements. Illustrations cannot capture every feature of a real cave; for example, multi-level lava tube structures are difficult to recreate. Therefore, supplementary records such as photographs, three-dimensional scans, and measurements are required to accurately represent the cave environment.

As shown in Fig. 2, the GLTS comprises many different types of lava tube morphology, which complicates cave structure description. As more analog or digital information about a cave is collected, cave illustrations become more accurate. The development of technology to analyze lava tube morphology both within and outside the caves will further improve our understanding of their environments and can be used to promote their conservation. For this purpose, we must consider cave structure, surrounding vegetation, and the effects of climate change. In particular, cave wall microbial mats may provide many clues to their long-term history, which is a strong motivation for their conservation, as novel technologies allow us to detect microbial community signatures. The microbial communities sampled in this study differ greatly from those in other caves worldwide, such as those in Pacific (Hawaii) and Atlantic (Canary Islands and Azores) islands [2, 15, 16], which are dominated by the true cave-dwelling genera *Euzebya* and *Pseudonocardia* in the Actinobacteria. By contrast, the distribution of these genera in the GLTS was very low. The former was only detected in BO cave (0.7%) and YC cave (0.30%) and the latter was in BD cave (0.22%) (unpublished data). The use of color models is a simple method for determining and describing cave wall colors in fine detail. Pigments produced from microorganisms, plant organic components, or minerals can influence the colors of microbial mats [2]. Therefore, color provides clues to understanding cave ecosystems. In addition, these pigments may represent an underutilized source for new industrial ingredients. Cave microorganisms are scarce and poorly accessible, creating potential for their production by biotechnical industries [6, 10]. Despite the suitability of color models for color description, hex codes are not related to the occurrence or abundance of microbial mat components; therefore, further research is required to examine the causes of mat color.

The present study was the first to study six caves of the GLTS, which differ in volcanic features, vegetation, and microbial mat color, and to apply hex codes to evaluate mat colors. The illustrations created in this study will contribute to the development of new tools for obtaining and displaying digital data for the description and conservation of these natural world heritage sites.

Note

The authors declare no conflict of interest.

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