学 位 論 文 内 容 の 要 旨/Dissertation Abstract

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Mapping periglacial landforms in Daisetsuzan National Park, Japan
（大雪山国立公園における周氷河地形のマッピング）

Periglacial regions are geomorphologically highly active, often dominated by permafrost-related processes and frost activity, covering approximately 25% of Earth's surface. The freeze-thaw processes in these areas create a wide variety of periglacial landforms, which serve as sensitive indicators of climate change. As such, studies of periglacial geomorphology provide crucial records of environmental change and enable paleoclimate reconstructions. Daisetsuzan National Park in central Hokkaido, Japan, is one of the representative mountain regions where periglacial landforms have developed extensively. However, detailed geomorphological data at high resolutions and accuracy remain scarce, limiting the comprehensive understanding and discussion of these important landforms.

This study addressed this gap by selecting two study areas within the Daisetsuzan region. An approach of uncrewed aerial vehicle (UAV) and Structure from Motion (SfM) were employed to map and analyze the spatial distribution, morphological characteristics, and their relationship with the topographical conditions of periglacial landforms in Daisetsuzan National Park. This approach generated high-resolution orthomosaic images (2.0 cm/pixel for Area A and 1.8 cm/pixel for Area B) and digital elevation models (DEMs) (3.9 cm/pixel for Area A and 3.6 cm/pixel for Area B). These high resolutions provided a solid foundation, making it feasible to identify and analyze landform features, even those at the decimeter scale.

This study began by summarizing the periglacial landforms distributed in the study areas. Visual interpretation methods and Geographic Information System (GIS) technology were used to create detailed distribution maps of all identified periglacial landforms. The largest landforms in terms of area are the earth hummocks and the nonsorted steps. Across the two study areas, 18,838 individual earth hummocks were mapped over approximately 82,599 m², while nonsorted steps were mapped over 105,552 m² from 50 sites. Compared to previous distribution maps created using traditional mapping methods, these maps provided significantly higher positional accuracy, more detailed landform classifications, and an expanded study area unconstrained by site accessibility. These maps established an important foundation for future research on periglacial geomorphology.

The morphological features of the landforms that dominated the study areas' topography were then analyzed to determine their relationship with topographical conditions using orthomosaic images and DEMs. Key morphological parameters and distribution characteristics, including slope, aspect, topographic wetness index (TWI), and Geomorphon Landforms, were summarized.

For earth hummocks, the average length (L), width (W), and height (H) were 1.22 m, 1.03 m, and 0.15 m, respectively. Statistical analysis revealed significant correlations between the morphological parameters of the earth hummocks and topographical factors such as slope, aspect, and geomorphon landforms. The average slope of the distribution areas was 8.3°, mostly below 20°, and earth

hummocks tended to develop in areas slightly elevated above the lowest gully bottoms. The study demonstrated that earth hummocks were more densely distributed in areas with gentle slopes and specific moisture conditions, highlighting the influence of local micro-climatic and topographical factors on their formation.

For nonsorted steps, the average riser height (H), tread width (Wt), riser width (Wr), and terrace length (L) were 0.20 m, 1.00 m, 0.73 m, and 5.08 m, respectively. Terrain condition analysis showed that nonsorted steps were predominantly located on gentle slopes below 10°, primarily around hiking trails in sparsely vegetated areas with low TWI values. The study found a significant positive correlation between riser height and slope, while tread and riser widths showed a slight decreasing trend with increasing slope. Aspect distribution indicated that nonsorted steps in Area A were primarily oriented toward NNW aspects, while those in Area B faced WNW. Geomorphon landform classification identified "Slope" as the dominant landform type for nonsorted step distribution.

Other periglacial landforms were also characterized to enhance the overall understanding of their morphology and topographical influences. This study documented a total length of 2991 m of thermal contraction cracks, much longer than previously recorded. The presence of sorted patterned ground was also confirmed with high-resolution UAV imagery, offering more detail compared to earlier field surveys. Insights into the interaction between thermal contraction cracks and nonsorted steps provided a clearer view of their sequential formation processes. Additionally, the study discussed the irregular patterned ground in the study areas.

This study presented detailed classification standards, methodologies, and extraction approaches for these landform parameters. The advantages of the UAV-SfM approach were summarized and compared with those of previous studies. This study used multi-directional hillshade maps to represent and classify landforms, highlighting their reliability. Object-based image analysis (OBIA), with its higher accuracy also facilitated the extraction of morphological parameters more precisely and efficiently. The detailed work-flows and methodologies presented can serve as references for similar studies in other periglacial regions worldwide.

Finally, this study discussed potential improvements for future research and proposed an ideal framework for studying the peri-glacial environment, supporting the long-term monitoring of periglacial environments. Specifically, a Python-based U-Net model was developed using manually extracted samples, demonstrating that deep learning could significantly enhance the efficiency of landform recognition within high-resolution imagery data. The proposed research framework also suggested integrating UAV data with satellite imagery and citizen science 3D scans. For instance, Sentinel-2 satellite data were used to predict the distribution of periglacial landforms across a broader area within Daisetsuzan National Park. These suggestions along with the distribution maps, the recorded morphological parameters, and distribution characteristics of the periglacial landforms in this study can serve as a foun-dation for further research on the periglacial geomorphology in the Daisetsuzan region.