Estimating the Occurrence Ages of Deep Catastrophic Landslides using Tephrochronological Approach

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INTRODUCTION

Deep catastrophic landslides (DCL) have more than 10 m failure depth and cause various subsequent sediment disasters such as debris flow and natural dam formation. To develop countermeasures of DCL, estimation of magnitude and frequencies of DCL are critical. However, specific frequencies of DCL occurrence have not been identified because the frequency of DCL can be low, occurring at centurial to millennial scales. For examining the long-term stabilities of hillslopes, tephrochronological approach had been applied especially for shallow landslides [*Shimizu et al.*, 1995]. This approach permits us to identify geomorphic features ages over time scales from recent centuries to millennia. The objectives of this study were (1) identifying the geomorphic characteristics of DCL that have occurred in the past using aerial photo interpretation and GIS analysis, and (2) estimating the occurrence ages of DCL using tephrochronological approach.

METHODOLOGIES

(1) Study site and GIS analysis

This study was conducted in the Chiroro River basin and adjacent area of the upper Saru River systems (1,350 km2) in the eastern Hidaka Mountains region of Hokkaido, Japan. Mean annual precipitation and mean annual temperature was 1,292 mm, 6°C, respectively. The underlain geology is complex, with marine sedimentary rock and accretionary complex (sedimentary rock, ultramafic rock, basalt blocks and chert blocks). We identified topographic features of DCL using LIDAR data taken in 2012 and aerial photo taken in 2007. We adopted *Public Works Research Institute*'s criterion of DCL, which are large-scale collapse reaching deep bedrocks and collapsed soil moved to outside of the collapse area. All of the information was archived in ArcGIS to analyze topographic parameters such as areas, volumes, height, altitude and slope gradient.

(2) Field Survey and Volcanic glass analysis

Selected DCL features were field surveyed in 2012 and 2013. We observed 1 to 2 m of soil profiles in concave collapse areas and deposition zones. Six types of index tephra supplied from Mt.Tarumae, Mt.Eniwadake, and Mt.Komagatake. Ta-a (A.D.1793), Ta-b (A.D.1667), Ta-c (2,500 yrs BP), Ta-d (9,000 yrs BP), En-a (17,000 yrs BP) and Ko-c2 (A.D.1694) were expected to be deposited in this study site [*Machida and Arai*, 1992]. Based on the soil and tephra stratification, we determined approximate formation ages of geomorphic features of DCL. We conducted volcanic glass analysis to confirm identification of index tephra.

RESULTS AND DISCUSSION

Thirty-two geomorphic features of DCL were identified. Among them, nine DCL scars located around the Chiroro River were investigated for topographic characteristics of DCL

(**Fig 1**). Seven DCL scars were located in marine sedimentary rocks and the other two scars were located in ultramafic and accretionary rocks. Mean altitude ranges of the upper ends of scars was 660 m (SD: 71 m). Mean hillslope gradient of DCL scars was 32° ranging from 20° to 40°. Areas and volumes of DCL scars ranged from 1.6 x 10^4 to 2.4 x 10^5 m^2, 9.2 x 10^4 to 4.5 x 10^6 m^3, respectively.

We confirmed weathered bedrock or gravel layers at 1-2m soil depth in scar and deposit zone of DCL. At seven DCL scars, Ta-d layers with 0.2-0.9m thick appeared above either on weathered bedrock or gravel layer. Therefore, these topography features were formed before the occurrence of Ta-d fallout, 9,000 yrs ago. Another DCL scar potentially formed before 9,000-2,500 yrs ago because of presence of Ta-c and absence of Ta-d layer in soil profile. One DCL scar with no tephra layer was likely formed after A.D.1739.

The characteristics of deposits can be confirmed using the volcanic glass. Ta-d deposits consisted by reference Ta-d (**Fig.2**). This result implied that Ta-d layer was pure and stable after the fallout even though it had been on a hillslope. In contrast, reference sample in slope, not DCL scar, have multiple peaks of refractive index which suggested the mixture of Ta-d and Ta-c. Therefore, we considered that the mixture of tephra by subsequent soil movement may have also occurred on the slope of DCL.

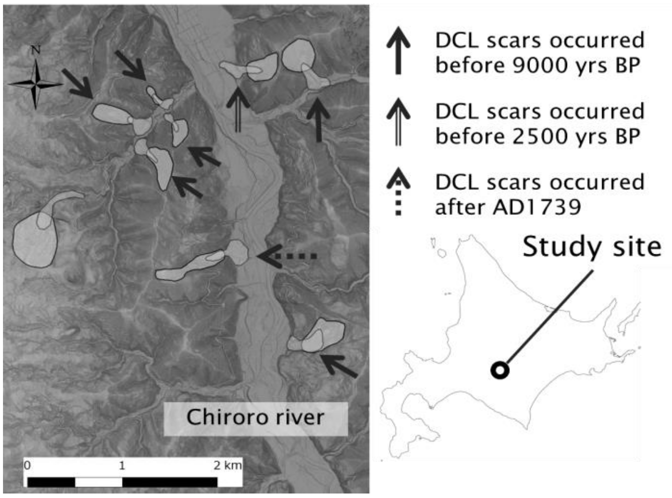

Fig.1 Study area and the result of field survey in the Chiroro River.

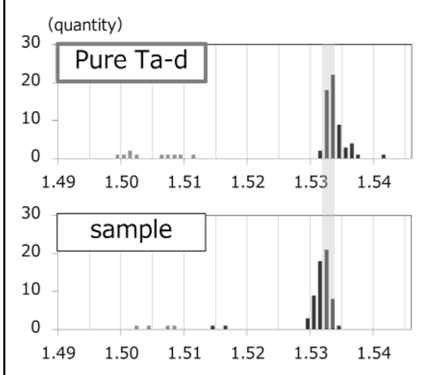

Fig.2 The frequency distribtion of refractive index of volcanic glass

CONCLUSION

The findings of this study were summarized as follows. (1) The geomorphic features of DCL were similar to that occurred in contemporary records. (2) The ages of occurrence of DCL can be identified using our tephrochronological approach. (3) The plurality of DCL scars in Hidaka had occurred before 9,000 yrs ago. (4) Analysis of soil stratification and volcanic glass can identify the subsequent soil movement within DCL scars and deposit zones.

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