LANDSLIDE FEATURES IN THE DAMJI AND GASA DISTRICT, GASA DZONGKHAG, NORTHWESTERN BHUTAN

Yoshihiko KARIYA, Jiro KOMORI and Toshiyuki TSUZUKI

Abstract Landslides in the Damji-Gasa district were investigated. Linear depressions, several kilometres long, were discovered on the major ridge and its side slopes. Mesoscale landslides with continuum slopes from the upper shallow concave to the lower gentle convex shapes were also found on the ridge side slopes. Furthermore, many shallow landslides were present beside a forest road. Gneiss is a crucial diathesis as it creates dip-slope conditions favourable for the onset of landslides. High precipitation is also important. Landslides seem to be a potential threat to the Damji-Gasa district. Further data is required to mitigate and prevent geohazards.

Key words: landslide, mass rock creep, Bhutan Himalaya, geohazards

1. Introduction

Geoenvironments in mountain areas situated in a plate convergence zone such as the Himalayas and the Japanese archipelago, are characterized by Neogene rapid uplift, well-deformed and complex geology, and a dominance of steep terrains. In these areas, geomorphic changes through weathering and mass-movements occur extensively from the summits to the valley floors. Climatic conditions are also an important factor for triggering changes in landforms. For example, both the Himalayas and the Japanese archipelago receive high rainfall every summer due to monsoonal circulation. As a result, a wide range of geohazards (e.g. landslides, debris flow and slope failure) take place and are widespread. Bhutan, in the eastern Himalayas, is no exception in this regard.

Whereas a Japan–Bhutan joint study focusing on glacier and glacial lake outburst flood (GLOF) and its risk evaluation has progressed over recent years (e.g. Ageta *et al*. 2000; Karma *et al.* 2003), geohazards in the mountainous areas of Bhutan, particularly landslide features, have rarely been studied (Higaki *et al*. 2001; Sato *et al*. 2010). To prevent and mitigate possible geohazards, Pleistocene–Holocene development and recent changes in mountain landforms should be clarified at a different scale of space and time as fundamental data. To this end, we carried out a pilot survey of landslides from geological and geomorphological perspectives in the Damji and Gasa district of

* Department of Geography, Senshu University.
** Faculty of Modern Life, Teikyo Heisei University.
*** Komaba Toho Junior and Senior High Schools.

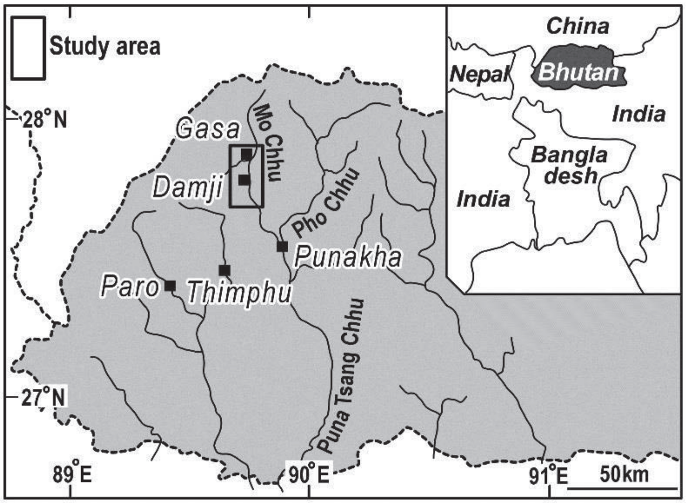

Fig. 1 Study area.

the Gasa Dzongkhag (Prefecture), northwestern Bhutan, in late January 2011. In this paper, we briefly describe the landslide features in the study area.

2. Study Area and Methods

The Damji and Gasa district is situated in northwestern Bhutan (Fig. 1). In this district, Mo Chhu (the Mo River) runs from north to south and several major mountain ridges up to 4000 m ASL are present on both sides of this river (Fig. 2). In contrast, the valley floor of Mo Chhu lies at 1700–2200 m ASL and the fluvial terraces along the river are poorly developed in this district.

The basic geological information in the study area has already been mapped by Gannser (1983). The main bedrock is gneiss belonging to the high Himalaya main crystalline. Marble, limestone and leucogranites are occasionally intercalated in the gneiss. According to Gannser (1983), the schistosity of the gneiss and marble strikes northwest–southeast and dips north at 10–20 degrees in general. We obtained similar values of bedrock structure at several outcrop localities (Fig. 2).

Besides the field description of geology and geomorphology focusing on landslides, we collected soil samples and interpreted the topographical maps on a scale of 1:50,000 issued by the Bhutanese Government as well as bird's-eye images from Google Earth.

3. Landslide Features

Linear depressions

We could not find permanent trails to the major ridge west of Damji (Ridge W in Fig. 2), contrary to our expectations by prior investigation. As an alternative, we carefully observed a number of

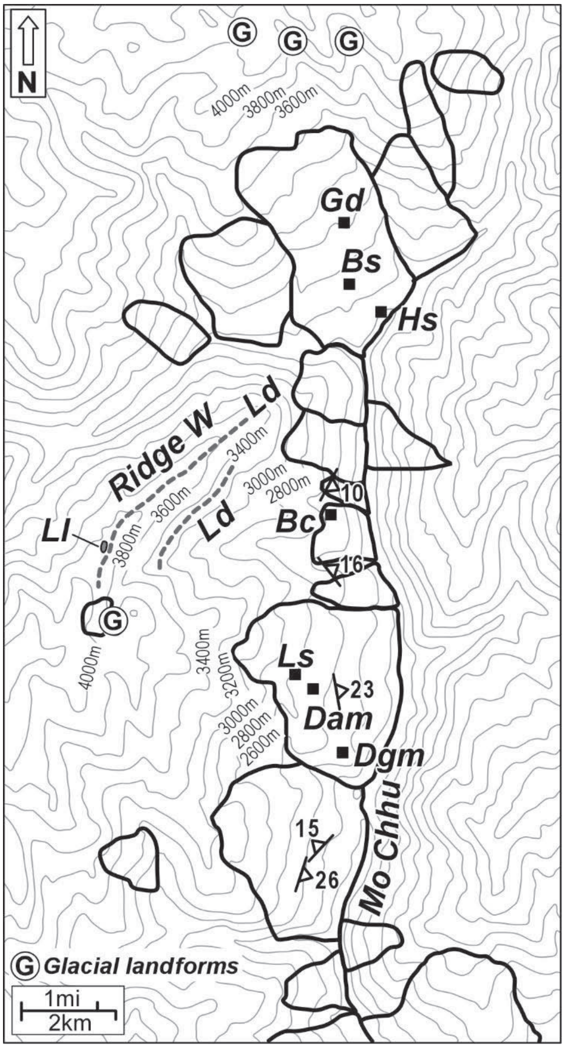

Fig. 2 Large landslide masses (thick line) and the measured strike-dip of schistosity of crystalline rocks in the study area.
Bc: Base camp site of our team, *Bs*: Outcrop locality where buried soil layers were observed (Fig. 4), *Dam*: Central Damji, *Dgm*: Storehouse of the Department of Geology and Mines, *Gd*: Gasa Dzong, *Hs*: Gasa hot spring, *Ld*: Linear depression, *Ls*: Lake on landslide body, *Ll*: Lake in linear depression. Contour interval is 200 m.

screen images of Google Earth taken from various viewing locations and conventional topographical maps.

A semi-closed linear depression up to ca. 4.5 km long was found on Ridge W west of Damji

(Fig. 2). Some parts of this depression are thought to be covered with grass or shrubs judging from their brown colour in the Google Earth images. A depression-derived lake whose perimeter is 700 m is also present. A small cirque and a glaciated trough occur in an area above 3700 m ASL along Ridge W. These cirque and trough are partially truncated by the linear depression. Another linear depression ca. 2.5 km long has also developed on the side slopes immediately east of Ridge W (Fig. 2).

Linear depressions on a mountain ridge or a ridge side slope or their assemblages are known to be a feature caused by rock deformation such as mass rock creep, deep-seated gravitational creep or sagging, although a similar form is occasionally produced by rock control and/or fluvial erosion (e.g. Radbruch-Hall 1978; Varnes 1978; Chigira 1992). High-angle extensional shear surfaces in the upper part of the deforming slopes could produce graben-like depressions, double-ridges and antiscarps. On the other hand, the lowermost parts of the ridge side slopes often show compressional features such as bulging. Although the geological structures have not yet been investigated in detail in the study area, gravitational mass rock creep could occur beneath and/or within the side slopes of Ridge W. In particular, the schistosity directions of the NE–SW strike and the dips 10 to 30 degrees to the SE are nearly parallel to the direction and gradient of the eastern side slopes of Ridge W. Furthermore, some of these structures show highly weathered and fractured layers. We found well-weathered clayey layers within the limestone near Damji, probably caused by faulting along a slip plane due to landslide activities (Fig. 3). These structures and fragile state provide dip-slope conditions that are favourable for generating landslides.

It is difficult to predict whether mass rock creep in and around Ridge W will generate large landslides and threaten the local communities. However, we should observe the characteristics of the mass rock creep, which has long attracted attention because this phenomenon is thought to be a precursor of deep-seated slope failure or rock avalanches in various locations.

Fig. 3 Outcrop locality of limestone beds along the forest road near the base camp site north of Damji.
CWZ: Clayey weathered zone in limestone, probably formed along a landslide slip plane.

Landslides on ridge side slopes

From Damji to Gasa, the upper parts of the side slopes of Ridge W at about 2600–3000 m ASL show a gentle concave shape in both horizontal and longitudinal directions. In contrast, the lower parts of the side slopes exhibit a gentle convex shape. A transition zone from the upper parts to the lower parts forms a nearly flat surface where the settlements and cultivated areas are located. Some parts of this flat surface are gently tilted toward the back (westerly direction). As described in the next section, the forest road runs mainly through the lower convex slopes. Outcrop localities along this road helped us understand the inside structures of the bedrock. Deformation of gneiss and limestone with buckling, open cracks and toppling was commonly observed.

The development of linear depressions on the major ridge and its side slopes as well as a slope continuum from the upper concave shape to the lower convex shape indicate that a deep landslide is likely to occur as a result of mass rock creep on the right bank of Mo Chhu. There is no indication of whether these landslides will occur in the near future with landslide debris running into Mo Chhu. In fact, a few local farmers 55 to 74 years old living in Damji said that in their lifetime, they have not experienced any noticeable damage due to landslides in the area. However, if a large landslide will occur, Mo Chhu would be dammed by landslide debris forming a natural lake. Subsequently, a break in this dam will cause a devastating flood along the lower Mo Chhu.

Shallow slope failure on the road side

Shallow slope failures were observed along the forest road in and around Damji and Gasa. In many cases, the depths of these failures were several metres. As described above, strong deformation with open cracks, buckling and toppling were clearly identified in rock columns. In addition, small collapses of fluvial debris and gravel were found at the mouths of small channels from the west. A mountaineering report by a Japanese author (Hori 1986) had already mentioned some serious problems caused by shallow slope failures which the team noticed during their pass to Gasa through a trail on the right bank of Mo Chhu.

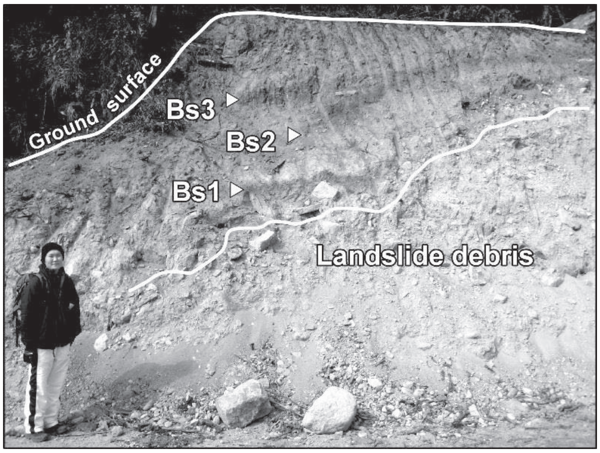

Fig. 4 Buried humic soil layers in Gasa.
Bs1, Bs2 and Bs3 are buried soil layers which include small fragments of charred wood.

These slope failures would have been affected by mass rock creep within the upper and lower slopes of the side slopes of Ridge W. These failures are of low magnitude but high frequency, requiring continuous removal of debris to maintain the road.

Buried soils on landslide debris

Buried humic soil layers of dark brown colour were found in many outcrop localities (Fig. 4). The thickness of the soil layers was 10 to 30 cm. Small fragments of charred wood were often found in the soil layers. We collected these charred wood fragments for ^{14}C dating in the future.

In Nepal, migration of local people and paleoenvironmental changes have been discussed based on the ages of the buried soil layers (Saijo 1993; Iwata *et al*. 1996). In the study area, the origin of the buried soil layers would have been affected by landslide activities and subsequent slope stabilization with or without cultivation.

4. Concluding Remarks

Landslide topographies are widely present in and around the Damji and Gasa district. However, these landforms have not been sufficiently studied. The volume of traffic through the forest road is expected to increase over the next several years with the economic and tourism development of the Gasa Dzongkhag. To protect the local community and economy from a wide range of geomorphic changes causing serious geohazards, both fundamental and applied studies of the geology and geomorphology of the area should be carried out. Precise interpretation using air photos and satellite images as well as the preparation of a geomorphological map are examples of ways to improve our understanding of the spatial distribution and historical development of landslide features. Although dense scrub and forest prevent us from easily accessing the slopes in the study area, a combined investigation through both field and laboratory analysis is feasible. Risk evaluations of slope disaster based on these data are necessary.

Acknowledgements

This study was supported by JSPS KAKENHI Grant Number 21501004. We thank Dr. Samten Wangdi, Mr. Thuja Yunten, Mr. Ringin Dorji and Ms. Akemi Yoda for their help in the field. We are grateful to all the relevant staffs at the Department of Geology and Mines, Ministry of Economic Affairs, Royal Government of Bhutan.

References

Ageta, Y., Iwata, S., Yabuki, H., Naito, N., Sakai, A., Narama, C. and Karma. 2000. Expansion of glacier lakes in recent decades in the Bhutan Himalayas. *Proceedings of an international workshop held at the University of Washington in Seattle, 2000; Debris-Covered Glaciers*. IAHS Publication **264**: 165–175.

Chigira, M. 1992. Long-term gravitational deformation of rocks by mass rock creep. *Engineering*

Geology **32**: 157–184.
Gannser, A. 1983. *Geology of the Bhutan Himalaya.* Basel: Birkhauser Verlag.
Higaki, D., Motegi, M. and Dorji, Y. 2001. Sediment disaster in August 2000 in Bhutan with special reference to the upper catchment topography formed by slope movement. *Quarterly Journal of Geography (Kikan-Chirigaku)* **54**: 29–33. **
Hori, R. 1986. *Idainaru Shishi Mosang Gang hou Tochou* (*Getting to the top of Mosang Gang, An Unclimbed Peak in the Bhutan Himalayas*). Tokyo: Kodansha Ltd.*
Iwata, S., Miyamoto, S. and Kariya, Y. 1996. Deforestation in eastern and central Nepal. *Geographical Reports of Tokyo Metropolitan University* **31**: 119–130.
Karma, Ageta, Y., Naitou, N., Iwata, S. and Yabuki, H. 2003. Glacier distribution in the Himalayas and glacier shrinkage from 1963 to1993 in the Bhutan Himalayas. *Bulletin of Glaciological Research* **20**: 29–40.
Radbruch-Hall, D.H. 1978. Gravitational creep of rock masses on slopes. In *Rockslides and Avalanches−Natural Phenomena*. ed. Voight, B. 693–705. Amsterdam: Elsevier Scientific Publishing Co.
Saijo, K. 1993. A ^{14}C date of buried charcoal fragments found in the middle mountains of Nepal. *Mountain Research and Development* **13**: 377–378.
Sato, G., Higaki, D., Koike, T., Umemura, J., Norbu, P., Penjore, T. and Komori, J. 2010. Landslide distribution as a potential GLOF risk in Mangde-chu River Basin, Bhutan. *Journal of Nepal Geological Society* **41**: 118.
Varnes, D. J. 1978. Slope movement types and processes. In *Special Report Transportation and Road Research Board, National Academy of Science **176**: Landslides: Analysis and Control.* eds. Schuster, R.L. and Kriezek, R.J. 11–33. Washington DC: Transportation and Road Research Board, National Academy of Science.

(*: in Japanese, **: in Japanese with English abstract)