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Characteristics of crushed rocks observed in drilled cores in landslide bodies located in accretionary complexes

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ABSTRACT

The recent development of high-quality boring, which uses foam surfactants, has made it possible to examine the detailed geological constitution and structure of landslide bodies. However, geological information related to landslides has not been obtained appropriately even from undisturbed high-quality drilled cores. Moreover, it has been difficult to distinguish between rocks crushed by landslide movement and the fault breccia in accretionary complexes. We examined the detailed geology of high-quality drilled cores of landslide bodies on the Shimanto Belt and the Chichibu Belt. The fault breccia near the landslide bodies was found to exhibit planar fabrics while the crushed breccias in the landslide bodies showed a random fabric. We discovered that classifying the degree of crushing and inspecting the planar fabrics of rocks are effective in the geological determination of landslide bodies.

1. Introduction

Landslide bodies have been identified based on the topographical and geological characteristics of the site and the results of movement observations. However, only the planar configuration can be estimated from the topographical characteristics, not a profile such as the accurate depth of slip surfaces. Movement observations cannot detect the slip surfaces of landslide bodies that have stopped moving. Geological determination of landslide bodies by field works is very difficult in Japan, because exposure of outcrops is rare in landslide areas due to covering of vegetation. So, geological determination is usually performed by observing drilled cores. Geological determination of landslide bodies, which uses ordinary drilled cores, involves the detection of slip-surface clay and analysis of the degree of weathering, shape and rock mass classification of the cores. However, the slip surface is sometimes not sampled because the clay is soft, so it flows out during drilling. The slip-surface clay can also be difficult to distinguish from the fault gouge, hydrothermally altered clay and weathered clay. The degree of weathering may not always be related to a landslide body.

Crushing caused by landslide movement may be difficult to distinguish from fault breccias of the fault shear zones formed by tectonic movement. Many fault shear zones are distributed in accretionary complexes in Japan. The presence of many faults shear zones causes serious problem in determining crushed rocks of landslide origin in accretionary complexes when ordinary drilled cores are used for the determination, especially in a landslide body where crushing has not progressed. Recent developments in high-quality drilling methods those involving the use of surfactants have made it possible to sample undisturbed cores even from zones that have a mixture of soft and hard rocks (Kameo et al., 2003; Suzuki et al., 2008). The geological constituents and fine structure of landslide bodies can now be examined in detail, which was previously almost impossible.

High-quality cores drilled from a landslide (landslide A) in the Shimanto Belt, which is a Cretaceous to Miocene accretionary complex, and nearby adits and outcrops, were examined to investigate the detailed geological characteristics of the landslide body and the fault shear zones. The landslide body was found to contain characteristic crushed rocks (breccias) distinguishable from fault breccias, which constituted the fault shear zones (Wakizaka et al., 2012). This characteristic crushed rock was observed in the other landslide bodies in the accretionary complexes. This characteristic crushed rock is considered to be a ubiquitous constituent in landslide bodies in the accretionary complexes. We discovered that the degree of crushing can be used as a geological indicator of a landslide body.

2. Methods

2.1. Geological settings of studied landslides

Four landslides situated in two types of typical accretionary complexes in Japan, the Shimanto Belt and the Chichibu Belt were studied (Fig. 1). The Shimanto Belt is a Cretaceous to Miocene accretionary

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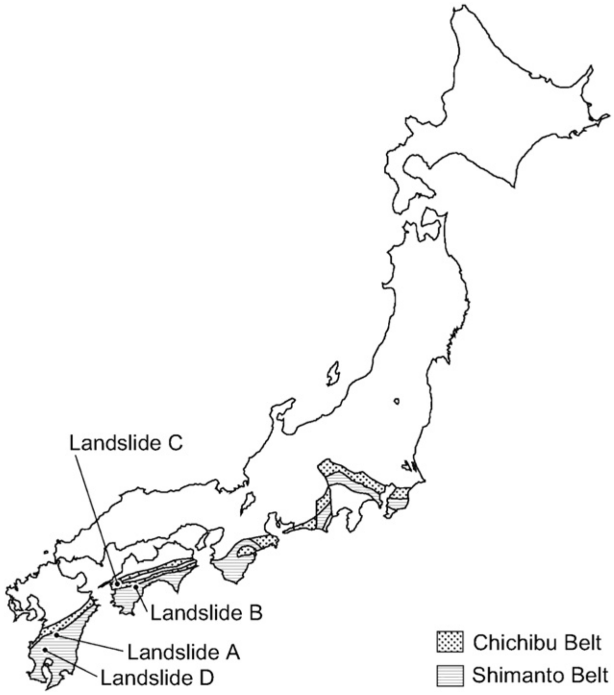

Fig. 1. Locations of the studied landslides.

complex, whereas the Chichibu Belt is a Triassic to Jurassic accretionary complex. Landslides A and D belong to the Shimanto Belt, while landslides B and C belong to the Chichibu Belt. The main focus of the investigation was on landslide A (Wakizaka et al., 2012).

The bedrock of landslide A consists mainly of a mixture of slate, which is dominant, and sandstone (Fig. 2). Irregularly shaped sandstone blocks, alternating layers of tuff and slate, alternating layers of slate and sandstone, and thin layers of tuff are distributed among the mixed rocks. Mixed rocks are derived from melange. The general strike of the strata is northeasterly or east-northeasterly to southwesterly or west-southwesterly. The strata are inclined 40 to 60° toward the north. Because the landslide is on a west-facing slope, the cross section along the main survey line apparently shows a gentle dip slope of the strata. There are low-angle faults in various directions and medium- to high-angle faults along the bedding plane and in the northwest, east–west and northeast directions near the landslide. In a mixture of slate and sandstone, and in sandstone which are distributed outside the landslide body, four systems of joints are developed; NE, NW, NS and EW systems. Dips of these joint systems are as follows: NE system, 20° to 85° SE and 30° NW to 90°; NW system, 50° to 80° NE and 10° to 85° SW; NS system, 20° to 90° W and 30° E to 90°; and EW system, 30° S to 90° and 20° N to 90°. Average interval of joints in sandstone is approximately 10 to 30 cm.

The bedrock of the landslide B is composed of semi-pelitic schist to slate, slate, massive chert, bedded chert, tuff, dolomite and altered volcanic rocks (Fig. 3). The general strike of the strata is northeasterly to southwesterly. An anticline axis is distributed near the main scarp of the landslide, so the strata are horizontal above the main scarp, whereas the strata under the landslide body are inclined 30° toward the southeast. The slip surface apparently shows a gentle dip slope of the strata.

The bedrock of landslide C is composed of a mixture of slate, which is dominant, and sandstone, sandstone, altered volcanic rocks, limestone and tuff (Fig. 4). The origin of the mixed rock is attributed to melange. The general strike of strata is northeast to north-northeast and inclined 25° to 80° northwest. The slip surface apparently shows a gentle dip slope of the strata. Joints are divided into two systems, NE with 40° NW to 90° dips, and EW with 30° to 70° N dips.

The bedrock of landslide D consists mainly of massive sandstone and partly consists of alternating sandstone and shale (Fig. 5). The general strike of these rocks is east or northeast to west or southwest. These strata are inclined 60° to 80° toward to the valley and are distributed parallel to the slip surface on the head of the landslide and obliquely to the slip surface on the middle to valley side of the landslide.

2.2. Drilling of studied landslide

As shown in Table 1, there are multiple boreholes in each landslide. Some boreholes were drilled by a high-quality method. High-quality drilling used foam surfactants as the drilling fluid, and is thus called air-bubble boring. Minute bubbles reduce the friction at the cutting edge and remove the slime, allowing a reduction in fluid pressure from that when using water or mud. Undisturbed cores were obtained by a high-quality method in each landslide. Diameter of all cores drilled by a high-quality method is 68 mm. The other boreholes were drilled by an ordinary method using water or mud as drilling fluid. Diameter of all ordinary cores is 48 mm.

2.3. Movement observation

Some of the boreholes are equipped with borehole inclinometers to detect movement of the landslide (Table 1). The observation periods of the borehole inclinometers of each landslide are more than two years. Based on the observations, cumulative shear displacement due to landslide movement was detected in the landslides A, B and C. As of September 2012, the borehole inclinometers in landslides D had not detected landslide movement.

2.4. Identification of the landslide body

For each landslide, the landslide body was identified as follows. In landslides A and B, many borehole inclinometers indicate cumulative shear displacement due to landslide movement and then a clayey part near a point where cumulative shear displacement detected was identified as a slip surface in a drilled core. In landslide C, a few borehole inclinometers show cumulative shear displacement due to landslide movement and then a clayey part near a point where cumulative shear displacement was also identified as a slip surface in a drilled core. On each section, clayey parts in the same horizon as the clayey part with shear displacement were traced as slip surfaces. In landslide D, no shear displacement was detected, so the landslide body was identified geologically and topographically. The depth of the landslide body was determined by the deepest clayey parts which were identified as the slip surface. The plane of the landslide body was identified by topographic features such as a main scarp and small valley. A part above the slip surface was identified as the landslide body in each landslide.

2.5. Observation of drilled cores and outcrops

High-quality drilled cores, walls of adits and outcrops adjacent to landslide A were visually examined. For the other landslides, only visual observation of high-quality cores for landslides B, C and D, and observations of ordinary cores (borehole No. C-2) for landslide C were performed. State of cracks, size distribution and shape of fragments, ratio of fragments and matrix, fabrics such as arrangement of fragments, foliation and shear plane were examined in crushed parts of cores. Lithology and sedimentary structures were also observed.