GEOLOGIC AND GEOMORPHOLOGIC FEATURES ON GROUNDWATER SITUATION OF LARGE SCALE LANDSLIDES INDUCED BY TYPHOON 1112 (TALAS) IN NARA PREFECTURE, JAPAN

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ABSTRACT

Typhoon 1112 (Talas) which passed through the west Japan from 30th August to 4th September 2011, led to the record heavy rain. The total precipitation in the southeastern part of the Kii Peninsula due to this typhoon was more than 1000 mm for 5 days. Many landslide disasters in the mountainous watershed area of the Kumano River occurred due to this heavy rain. Large scale landslides more than 1000 m^2 in area have been confirmed 54 locations by Nara Prefectural Office. These landslides mostly occurred in the mountain slopes consisting of the Cretaceous accretionary prism of the Shimanto Group. We conducted geological and geomorphological investigations at several landslide sites in Nara Prefecture. This paper reports on the characteristics involved in the groundwater situation of these mountain slopes.

1. INTORODUCTION

Typhoon 1112 (Talas) passed through the west Japan from 30^{th} August to 4^{th} September 2011. This typhoon led to the heavy rain record that the total precipitation for 5 days in the southeastern part of the Kii Peninsula more than 1000 mm. The maximum record was 1652 mm for 72 hours and total precipitation of 1814 mm at Kami-kitayama Village, Nara. This total precipitation for 5 days is roughly equivalent to the annual rainfall average of Japan and 60% of the annual rainfall in this village. These were significantly higher than the observed record（AMeDAS: Automated Meteorological Data Acquisition System）of statistics since 1976 (Japan Meteorological Agency, 2013).

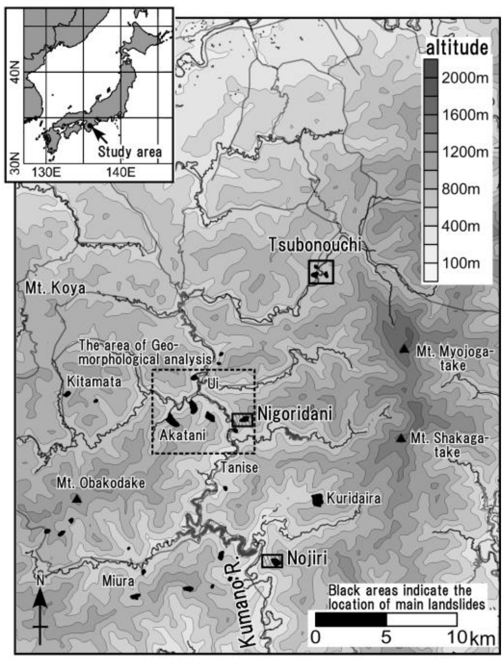

Figure 1. Location map of study area.

Total site of landslides induced by this typhoon in the mountainous southern part of the

Kii Peninsula were more than 3,000 sites. Almost landslides correspond to the surface failure and debris flow occurred in the surface soil and strong weathered rock zone. On the other hand, large scale landslides (deep sheeted landslides) more than 1000m^2 in area have been confirmed 54 locations by Nara Prefecture. 13 sites of these large scale landslides induced natural damming of river channels with debris deposits (Kinki Regional Development Bureau, Ministry of Land, Infrastructure and Transport, 2013).

These large scale landslides mostly occurred in the mountain slopes consisting of the Cretaceous accretionary complex of the Shimanto Group. We conducted geological and geomorphological investigations at several landslide sites in Nara Prefecture (Figure 1). This paper reports on the geological and geomorphological characteristics involved in the groundwater situation of these mountain slopes.

2. TECTONOSTRATIGRAPHIC UNIT OF ACCRETIONARY COMPLEX

The accretionary complex of Shimanto Group consists of basalts, cherts, limestones as oceanic sediments, and alternation of slates and sands as terrigeneous sediments. The ocean plate stratigraphy on the oceanic crust essentially composes of the sequence from oceanic sediments to terrigeneous sediments in ascending order. These sediments, scrapped off subducting oceanic crust and accreted to continental margin at a subduction zone, had been deformed by the tectonic underplating. The oceanic sediments as the lower part of the ocean plate sequence are formed the chaotically deformed zone (broken formation /mélange). The younger sedimentary unit in an accretionary wedge is generally on the bottom of the older sedimentary unit with a thrust. Tectonostratigraphic units of accretionary complexes are divided by the evaluation of geologic structure of units and paleontological dating with radiolarian fossils in sediments.

Large scale landslide mainly occurred in the Cretaceous accretionary complex of Shimanto Group (Kishu Shimanto Research Group, 2012). Oceanic and terrigeneous facies are alternated in each tectonostratigraphic unit consisting of several thrust sheets. The Oceanic facies intercalated in the lower part of thrust sheet is well sheared, and formed the tectonic mélange. The shear deformation is stronger in the older complex units located in northern part of the Shimanto Group terrain. The basal shear plane of large scale landslides are mainly formed in the lower part of the thrust sheet consisting of muddy tectonic mélange zone.

2.1 Tsubonouchi Area

At Tsubonouchi area in Ten-kawa Village, three large scale landslides occurred in the shale, basaltic tuff, and basalt layers of the Cretaceous Hnazono Formation (Hanazono Accretionary Complex; Kishu Shimanto Research Group, 2012; Figure 2). The Hanazono Formation in this area is composed of two units of ocean plate sequence. These layers are strongly sheared

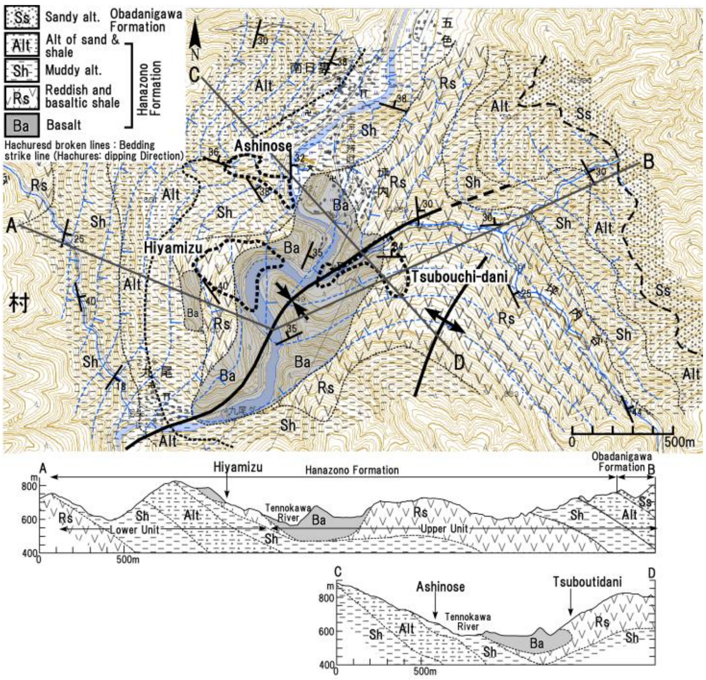

Figure 2. Geologic map of Tsubonouchi Area.

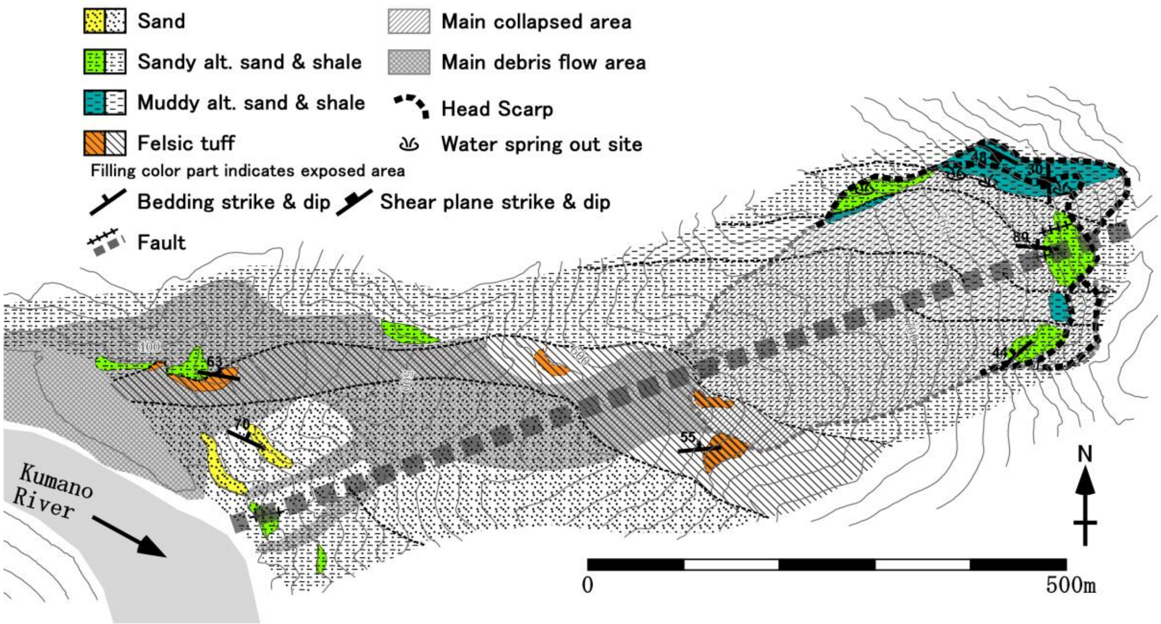

Figure 3. Geologic map of Nigori-dani area.

near the ocean plate sequence boundary with a thrust. There is the syncline structure with axis trending to NE-SW direction in this area. The direction of the axis of syncline is along the main river valley. The dipping of main structure of the layer in each landslide site is almost same to the mountain slope dipping direction (dip slope condition). The basaltic hard block distributes along the syncline axis. The former topography of each landslide site are recognized the feature of slope movements, such as horseshoe-shaped surface stepping, gentle concave slope, and linear depressions.

2.2 Nigoridani Area

The main collapse area of this landslide is located in the upper part of the Nigoridani valley, Totsukawa Village. The collapsed debris flowed along the lower part of the valley below 650 meters of altitude. The main collapse part consists of the well fractured muddy alternation of sand and shale of the Cretaceous Miyama Formation (Miyama Accretionary Complex; Kishu Shimanto Research Group, 2012; Figure 3). Several vertical faults trending to EWE-WSW direction are exposed at the head scarp. These faults control this valley direction. On the other hand, a dense felsic tuff layer is intercalated beneath the main collapse part. This felsic tuff layer has the potential of the accumulation of groundwater in the upper part of the valley and controlling the lower limits of the collapse part.

2.2 Nojiri Area

The main collapse area ranging from 540 to 760 meters of altitude mainly consists of the well sheared muddy tectonic mélange containing blocks of basalts of the Cretaceous Miyama Formation (Ryujin Accretionary Complex; Kishu Shimanto Research Group, 2012; Figure 4). The shear planes of the layer mainly dipping to northeastward are accorded with slope inclinations. The head scarp of the failure located along a ridge mainly consists of the alternation of sand and shale. A unit boundary thrust of the accretionary prism is assumed between the mélange unit and the alternation unit. On the other hand, a large basalt block exposed more than 200 meters of width is located beneath the main collapse part. This basalt

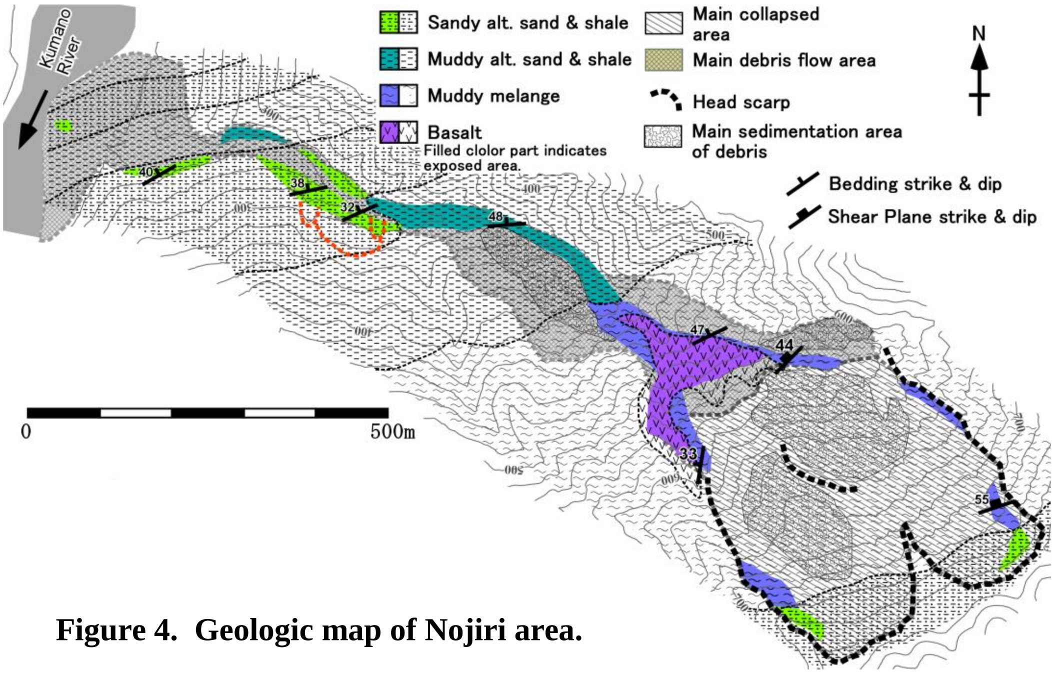

Figure 4. Geologic map of Nojiri area.

block also has the potential of the accumulation of groundwater in the upper part of the valley and controlling the lower limits of the collapse part.

3. WELL SHEARED ROCK MASS AND SLIDING

The well sheared rock mass of the muddy tectonic mélange includes lenticular shaped blocks of basalt, chert, and sand ranging from centimeter order to kilometer order. There are many shear planes among these blocks and muddy matrixes. These shear zones are comprised of the complex shear planes trending different directions. The rock mass slides down along these complex shear planes forms gently undulating slide plane (Figure 5). Before the large landslide, slight creeps previously have been intermittently occurred in the rock mass. Open clacks are often formed in the sliding block near the convex part of the gently undulating slide plane. Groundwater often springs out at these parts of the sliding block. Because the opening of the clacks gradually becomes wider with slight creeps of the rock mass, the permeability of rock masses in the shallow part of the slope increase, and the infiltration of the precipitation also becomes easier.

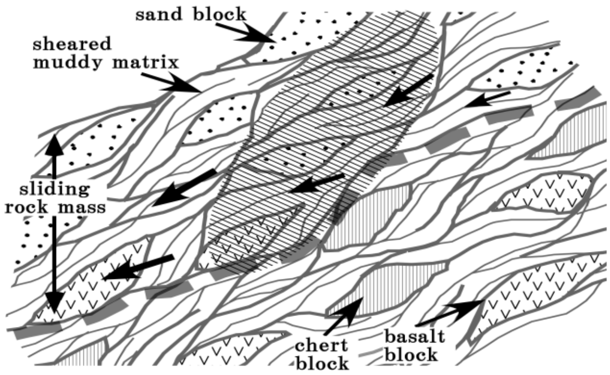

Figure 5. Pattern diagrams on developing of loosened area in creeping rock mass of mélange

Sheared muddy rock mass including various blocks slides on a gently undulating slide plane (thick broken line). Open clacks are often formed in the sliding block (hatched area with thick oblique lines) near the convex part of the slide plane.

4. GEOMORPHOLOGICAL FEATURE

An example of slope angle distribution map before the landslide made with 5 meters mesh DEM of the Geospatial Information Authority of Japan (GSI) by the method of Moore

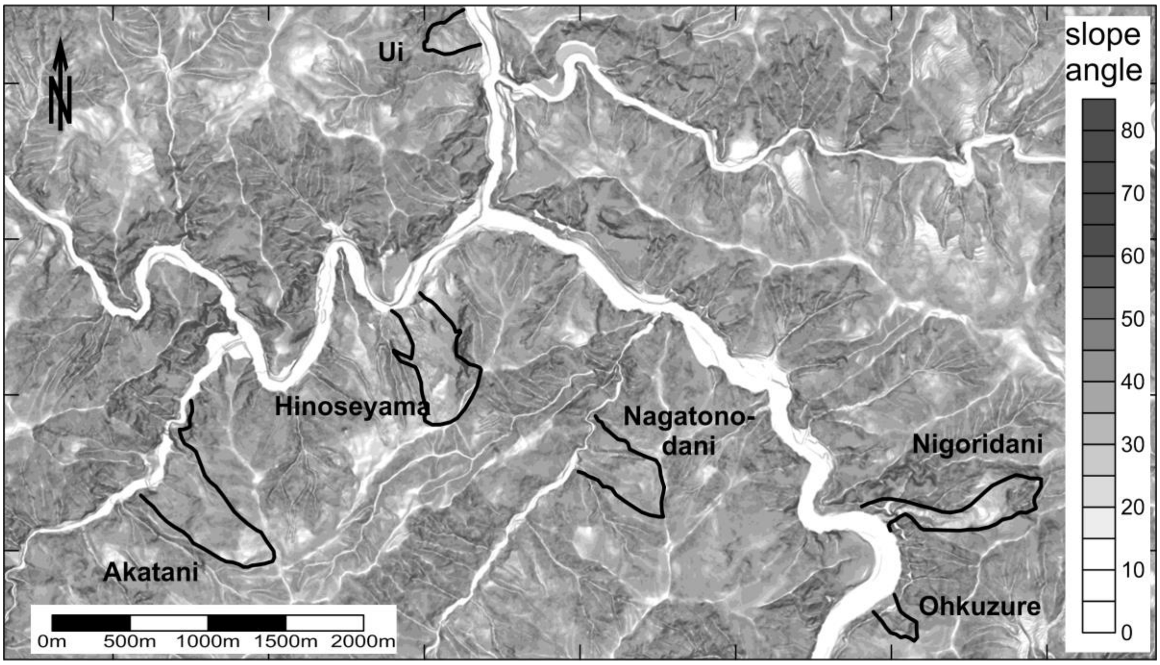

Figure 6. Slope angle distribution map before the landslide with 5 meters mesh DEM of GSI.

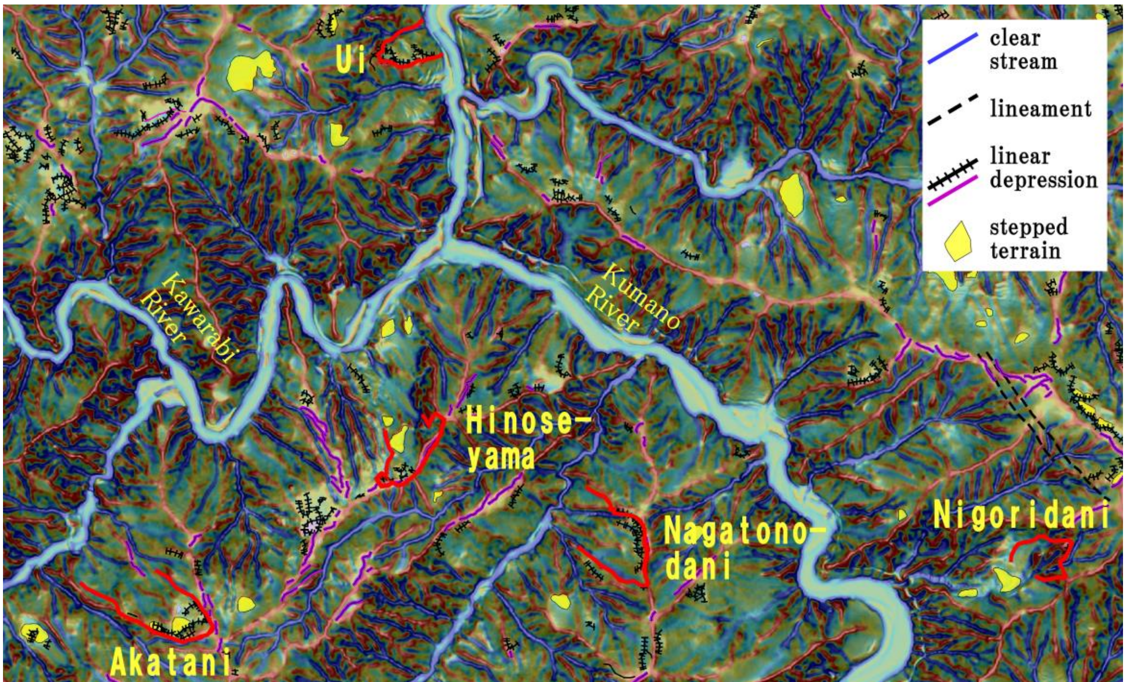

Figure 7. Result of wavelet analysis and clear geomorphological features with 5meters mesh DEM of GSI.

et al. (1993) is showed in Figure 6. The result of the two-dimensional wavelet analysis in the same area by the method of Fujisawa and Kasai (2009) is showed in Figure 7.

Slope angle in the upper part of the each main landslide area is gentle less than 20 degrees. On the contrary, the lower part dips more than 40 degrees. Several slopes before the landslide, such as Akatani, Nagatono-dani, and Hinose-yama, formed stepped terrains. Linear depressions are commonly found in the ridges just above landslides. These geomorphological features suggest the creep mass movement of slopes before the large scale landslides.

As the result of two-dimensional wavelet analysis, clear mountain streams were not distributed in the slopes before the landslides. These low drainage density of slopes suggests the large rainfall infiltration to the rock mass with precursory creeps.

5. CONCLUSIONS

As the results of the geological survey and DEM analysis around the large scale landslide area induced by Typhoon 1112 (Talas) in the southern Nara Prefecture, geologic and geomorphologic features on groundwater situation of the landslide areas are clarified as follows;

1) The main sliding rocks are well sheared rock mass, and slope surface inclines to the same direction as the main dip of these underlying sheared rock mass (dip slope condition).
2) There are often faults in the landslide area. These faults control these valley directions and sliding area. The fracture zones along these faults facilitate the rainfall infiltration into the rock mass.
3) In cases where the large dense block such as basalt, felsic tuff and chert is located at the lower part of the slope, groundwater is easily backed up in the rock mass at the upper part of the slope.
4) The slide plane frequently seen in well sheared rock mass gently undulates. Open clacks trend to develop in the sliding block near the convex part of these slide plane.
5) The Geomorphological features in/around the landslide area, such as stepped terrains and linear depression along the ridges, suggest that landslides are repeated intermittently creep before the main slide out.
6) The low drainage density of slope indicates the large rainfall infiltration to the rock mass with precursory creeps.

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