Interaction bedrock groundwater – Runoff in a catchment affected by creep deformation. Implications in the generation of deep seated landslides.

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1. Introduction

The analysis of the interaction between the bedrock groundwater and surface-subsurface discharge has been gain importance in the Japanese territory in the last years. Progressively more studies show the relevance of bedrock groundwater in the hydrological behavior and response of mountainous and forested hillslopes and catchments. However, the analysis of this interaction with highly fractured bedrock has been poorly studied. The characteristics of the bedrock groundwater are important in the analysis of the generation of landslides, especially deep seated landslides, a disaster that repeatedly happens in Japan after heavy rainfall events. This study presents the analysis of the interaction bedrock groundwater – runoff in catchments of Mt Wanitsuka (1,118 m asl), Miyazaki prefecture. In this area, the pass of the typhoon No 14 in 2005 induced the generation of several deep seated landslides (DSLs). The objective of this study is to characterise the interaction bedrock groundwater – runoff in catchments of Mt Wanitsuka defining water pathflows in the hillslopes affected by creep deformation. This characterization can allow to understand the mechanism of the generation of deep-seated landslides in this area.

2. Study area and instruments

The study area is located in Mt. Wanitsuka (Fig 1). The bedrock geology corresponds to shale interbeded with sandstone. In some slopes it was identified creep deformation which affect also to the bedrock increasing the fracture conditions on it. In the area selected for this analysis it was identified creep deformation. It were installed 2 boreholes (Bh10: 10m depth, deposit cover groundwater; Bh40: 40 m depth, bedrock groundwater) to measure the groundwater levels (Gw) and two parshall flumes to measure the discharge of two catchment (D: 1.44 ha; U: 5.42 ha). The instruments are situated in the vicinities of a DSLs scar that took place in 2005. Form the measured point in were collected water samples to analyse the electrical conductivity, EC, concentration of stable isotopes (^{18}O and ^{2}H, deuterium) and major elements (Ca^{2+} and Si). The collection of data and samples was carried out from 2008 to 2012.

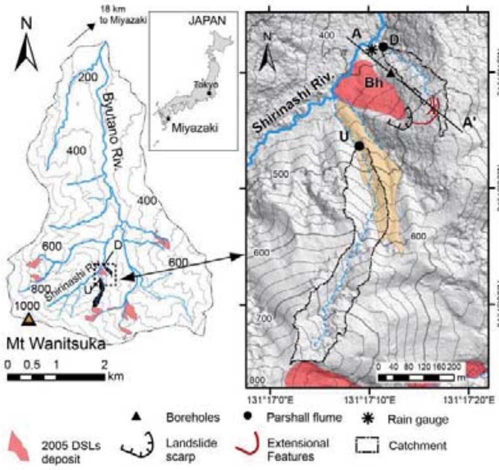

Fig 1. Study area and instruments location.

3. Results and discussion

3.1 <u>Groundwater responses</u>: The analysis of groundwater response shows a very quick response of Bh40 which represent the response of the bedrock groundwater after rainfall events (Fig 2). These quick changes in the bedrock groundwater levels are also expressed in a quick decrease in the EC properties. In the other hand, the Bh10 borehole presents small variations of groundwater levels and EC. The quick changes in the bedrock groundwater can be interpreted as fast infiltration of rainfall water into the bedrock aquifer. The detailed analysis of the response of groundwater shows also differences depending on the precipitation level (Fig 3). Two types of responses were identified in Bh40. For precipitations lower than 100mm of API6 (Antecedent precipitation index with 6 hour half life) the response in bedrock groundwater shows a double peak as it shown in Fig 3a, Lp. Rainfall over 50 mm of API6 can generate another type of response, Hp, where the double peak is replaced by a single peak with a very

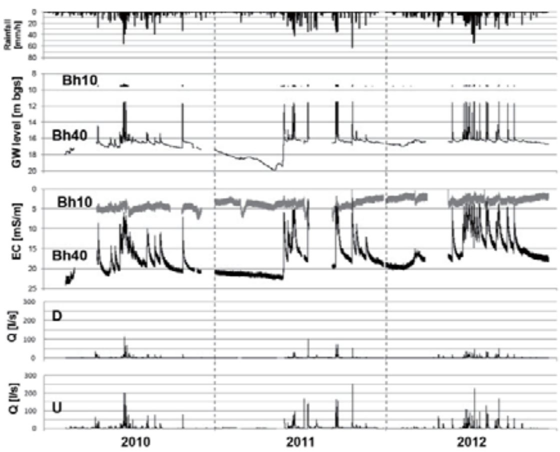

Fig 2. Rainfall - Gw level - Gw EC - Discharge catchment U and D.

steep rising limb and a stable maximum at approximately 11.5 m bgs. Between 50 and 100 mm of API6 the rainfalls could generate both types of responses, Lp and Hp. Observations in the borehole core samples reveal the existence of sets of fractures that can be involved in the different response of Gw. Those sets are associated to the creep deformation that affects the deposit cover and the bedrock. The analysis of Gw during Hp peaks indicates a high variability of concentration of 18O and 2H during the peak, but more stable values during the base level before and after a response. This can be interpreted as that most of the water that rapidly infiltrate into the bedrock can also rapidly be discharged from the bedrock aquifer.

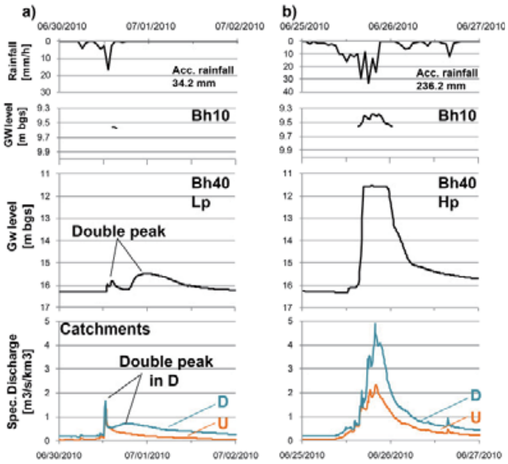

Fig 3. Detailed hydrographs of Gw and discharge in catchment U and D During Lp and Hp responses.

3.2 <u>Catchment responses and evidences of interaction with groundwater</u>: Even though the catchment U and D present different areas and therefore different discharges, the comparison of the specific discharge shows similar quickflow discharges, represented by the first peaks in the catchment response (fig 3). After the similar quickflow, it is observed an increase on the specific discharge in catchment D over catchment U. That increment in the specific discharge in D generates a delayed peak; similar situation observed in the Lp peaks in Bh40. During the base level, it is observed a continue discharge in catchment D even in dry season whereas in U there is no discharge after extended periods of no rain. Form the water balance in both catchments it is possible to observe that catchment D present a very small storage; periods of positive storage are followed by negatives storages not observed in catchment U (Fig 4). In terms of water quality, it was measured relatively high concentration of ion Ca^{2+} in catchment D (7 ~15 ppm) especially during the base level that can be correlated to High concentrations of Ca^{2+} measured in Bh40 (more than 20 ppm) but no in Bh10 (less than 5 ppm). The hydrograph separation based on the concentration of deuterium (rainfall water and Gw as end members) show a groundwater contribution over 50% of the specific discharge (fig 5). The slightly greater contribution of Gw in U can be reflecting the greater contribution of new water (rainfall water) in the discharge of D coming from the discharge from the bedrock aquifer. The analysis of the concentration of Ca^{2+} and Si in the catchments show the greater decrease of Ca^{2+} values in D from the base level compared with U. The lower concentration of Ca^{2+} is coincident in both catchments with the maximum discharge. However, the lowest concentrations in Si values are correlated with the peak of intensity of rainfalls, during the quickflow. This also can be related with relatively new water that is discharged from the bedrock groundwater.

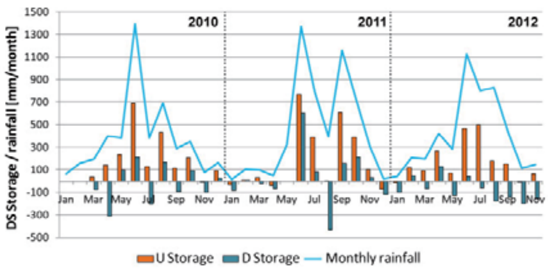

Fig 4. ΔStorage of catchment D and U .

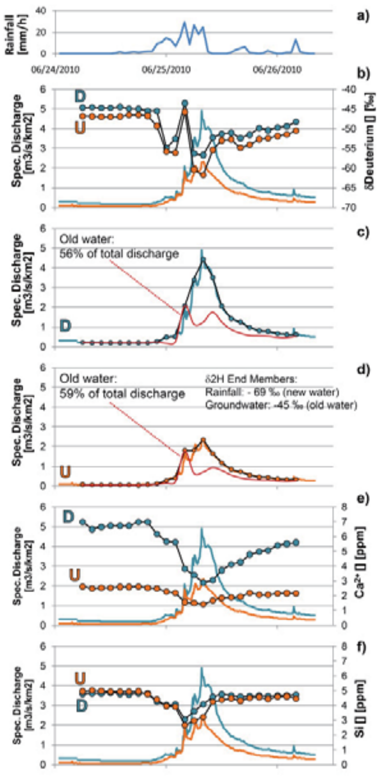

Fig 5. Chemical analysis of discharged water in D and U.

4. Conclusions

The characteristics of groundwater response reveal a strong control of its levels by structures in the bedrock. Those structures can be linked to the creep deformation observed in the hillslope. The analysis of the discharge in two catchments (catchments U and D) in the area shows how the groundwater levels affect more strongly the one who present evidences of creep deformation (Catchment D). The water balance show low storage for catchment D (short residence time).The rapid response of bedrock groundwater and its relatively rapid expression in the discharge seems to be related to the relationship between the timing of peak rainfall intensity and the occurrence of landslides in 2005 almost simultaneously. The proportion between the infiltrated water that remains in the catchment D and the groundwater discharged by the catchment is proposed as a parameter in order to define conditions of generation of DSLs in the area.