Study of the Hokusho landslides in northern Kyushu, Japan and similar failures in the region of neogene volcanics, Slovakia

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Abstract. Specific geologic, hydrologic, morphologic conditions together with a combination of high precipitation in northern Kyushu make this area prone to various types of slope movements. For example, the recent large-scale disaster caused by torrential downpours in July 1972 around Kumamoto and Nagasaki or in 1982 in Nagasaki and many others, included numerous debris flows and also human casualties: 543 deaths in the 1972 event and 493 deaths in the 1982 event (Japan Landslide Society, 2001). According to the Slope Conservation Division (1997), the Nagasaki prefecture has 135 designated landslide-treated areas of 2,788.16 ha under the jurisdiction of the Ministry of Land, Infrastructure and Transport.

In the present paper common slope movements that occur in northwestern Kyushu, so called the *Hokusho* landslide in Japanese literature, are studied. Moreover, a practical example of the Shiraidake landslide in Nagasaki prefecture is discussed. The main causes and factors influencing the slope stability of the landslide are summarized. It can be concluded that a combination of geology, hydrogeology with heavy rainfall are the main causes for landslides in this area.

Finally, a comparison between the *Hokusho* landslides and similar types of slope movements, developed in the region of *Neogene volcanics* in Slovakia, is also presented. Whereas the material of underlying rocks is almost the same in both areas, the cap rocks of the *Hokusho* landslides are composed of basalts, while in the region of *Neogene volcanics* these rocks are usually andesites and their pyroclastics. In the case of morphologic features, the landslides in the *Neogene volcanics* occur in higher altitudes with high relative relief.

Key words: Hokusho-type landslide, Matsuura Basalt, landslides in the region of Neogene volcanics

1. Introduction

Japan has suffered from many landslides and natural disasters since ancient time. The country is predominantly mountainous - about three-fourths of the national land are mountains. The mountain region displays a wide variety of topography with steep terrain in the stage of maturity. Furthermore, the islands are located within a monsoon zone of abundant rainfall. The combination of steep terrain and intensive rainfall often leads to landslides (Japan Landslide Society, 2001).

A number of authors, e.g. Varnes (1978), Nemčok (1982), Dikau et al. (1997) have classified landslides according to their material composition, type, velocity of movement, etc. Based on the velocity, landslides in Japan are classified into two categories: *Jisuberi* represents sliding and *Hokai* rapid failure. The occurrence of landslides in Japan is closely related to the geological conditions. Therefore, depending on the geological features, classically according to Koide (1955) landslides are classified into three categories: *Tertiary system, fracture zone* and *hydrothermal zone* landslides.

The *Tertiary system* represents the areas of the highest frequency of landslide occurrence on the Japanese islands. They are distributed mainly along the Sea of Japan and are rather dominant in the Tohoku, Hokuriku, northern Kyushu and San in, as shown in Fig. 1.

These landslides consist mostly of Neogene and some Paleogene semi-consolidated clastic materials and volcanic rocks, which overlie Mesozoic and Paleozoic sedimentary rocks, metamorphic rocks, intrusive rocks and plutonic rocks. Non-siliceous mudstones easily weather or decay into clays due to increased water content. Alteration of volcanic rocks ejected from the sea bottom changes the color to a greenish appearance, and thereafter they are called "green tuff". Tuffaceous mudstones contain abundant smectite clays, and contribute to one of the primary causative factors of landslides (Japan Landslide Society, 2001). Tertiary landslides often occur on gentle slopes and the movement velocity tends to be slow. According to Shuzui (2001), recurrent movement can be found in these types of landslides. The Ishikura landslide, Nagasaki prefecture, can be used as an example where the movement was first activated in 1952-53 and reoccurred in 1990.

The present work deals with a study of common type of landslides in the *Tertiary system* named the *Hokusho-type* in general. Furthermore, a practical example of the *Hokusho-type,* the Shiraidake landslide in Nagasaki prefecture, has been selected for a detailed study. To under-

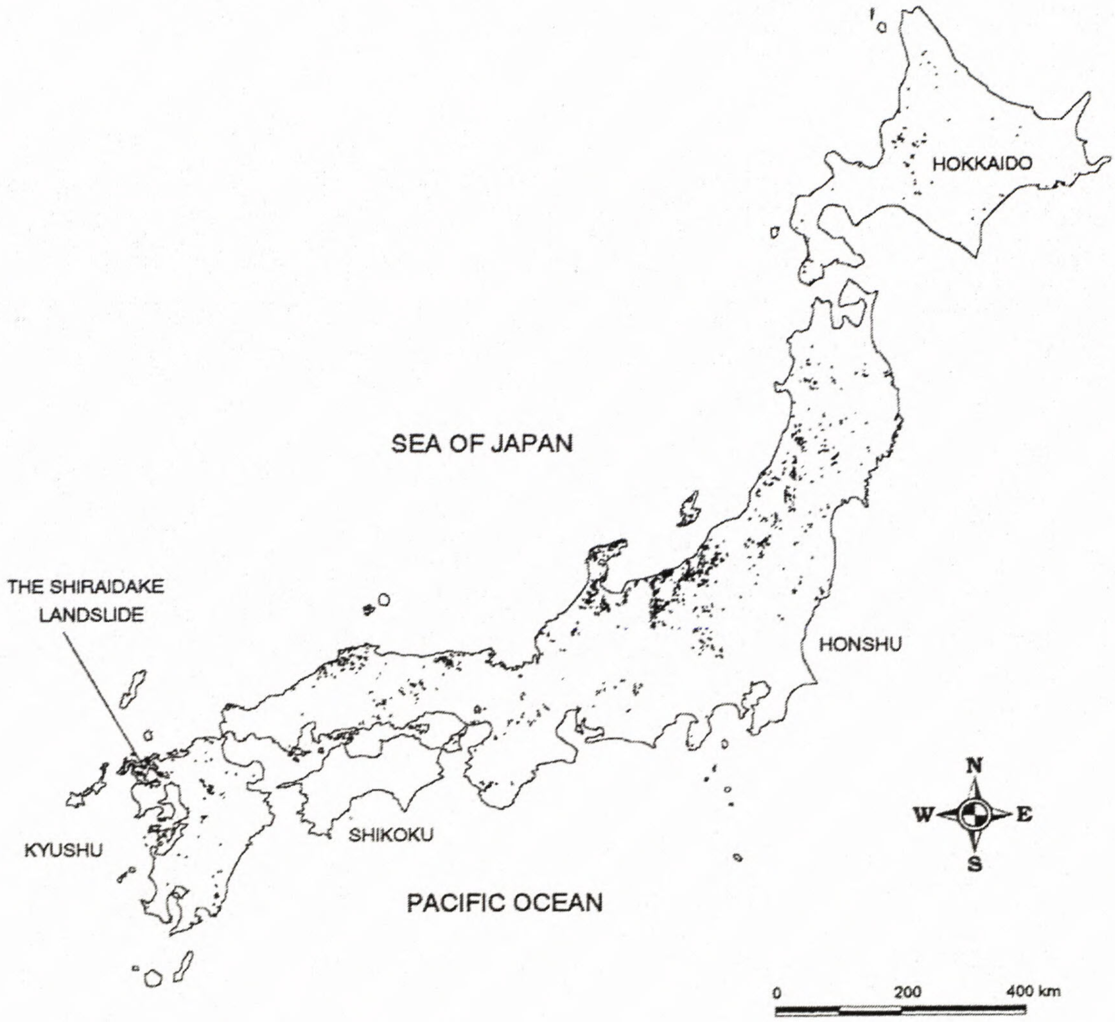

Fig. 1: Distribution of the Tertiary landslides in Japan (according to the Slope Conservation Division 1997)

stand the mutual relationship of the studied *Hokusho* landslides and the similar types of slope movements on the border of *Neogene volcanics* in Slovakia, a review and comparison of the above was carried out.

2. Geological background and history of the Hokusho landslide

The *Hokusho* landslides developed along the boundary between northern Nagasaki prefecture and Saga prefecture. They are named after Hokusho region in the northwest part of Matsuura, Kyushu. Landslides in this area are very frequent. The famous sites are for example: the Ishikura landslide, the Ningyooishiyama landslide, the Hirakoba landslide, the Koba landslide, the Washiodake landslide and many others.

Northwestern Kyushu is characterized by a remarkable volcanism that produced the alkali *Matsuura Basalt* during the Late Miocene and Pliocene with subsidiary andesite and rhyolite volcanism occurring nearby. The basaltic lava flows occurred repeatedly, in period between 10.6 and 2.7 Ma (Kimura et al. 1991). When molten basalt flow cools rapidly on the earth's surface, systematic cooling joints develop vertically. The basalt is further disintegrated by morphological processes. This disturbed material assists water infiltration into deep cracks along joints and subsequently promotes weathering. Moreover, presence of the discontinuous *Hatinokubo Gravel Formation,* inserted between igneous cap rocks and underlying sedimentary rocks serves, as an aquifer system. As generally accepted, ground water is the dominant inducting factor and the driving force of a landslide. An increasing ground water level increases pore water pressure within a slope and consequent reduction of shear strength can often lead to a landslide. Furthermore, the rigid basaltic body overloads the upper parts of slopes. The load may increase the shear stress and the pore water pressure, which induces a decrease in the strength and cause deep landslides in the underlying soft sedimentary rocks. The *Matsuura Basalt* flows overlie the early Tertiary sedimentary rocks, the *Kishima* and the *Sasebo Groups*, dominated by sandstone, mudstone, shale and

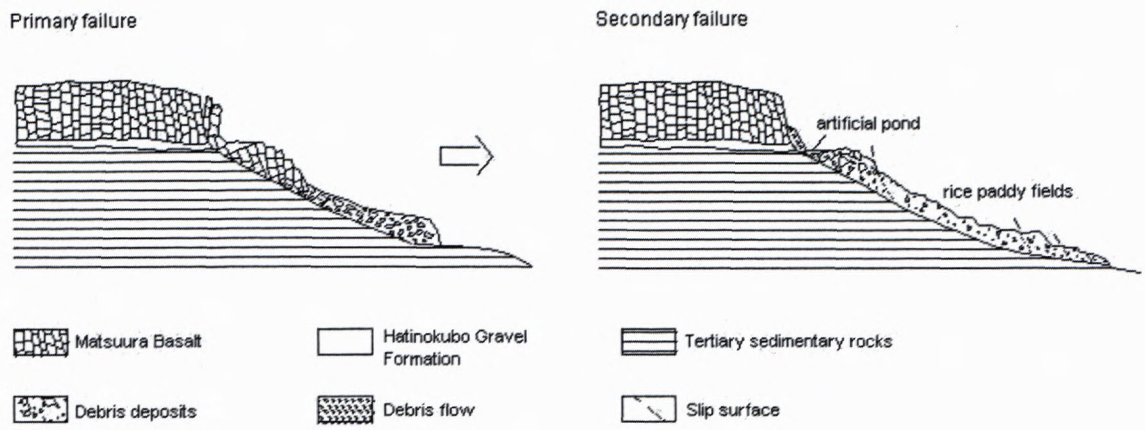

Fig. 2: Development of the Hokusho-type landslide (modified after Yamazaki 1980 in Karakida et al. 1992)

gravel. Sandstone and shale/mudstone layers consist of 2-3 thick tuffaceous layers accompanied by thin coal seams. This tuffaceous layers with clay prepare typical environment for the development of a slip surface. Therefore, landslides occur over much of the area.

The *Hokusho* landslides start to slide in front of block failures and block fields, which spread laterally on the marginal parts of the capped basalt layers as primary failures. They are combined with slides or debris flows as secondary failures, as shown in Fig. 2. The secondary failures often developed after agricultural utilization of their gentle slopes. These are usually cultivated as rice paddy fields, which require a lot of water. To supply water for the paddy fields an artificial pond is often built in the upper part of a landslide, which of course can support underground water.

3. The Shiraidake landslide

3.1 Location and general characteristics

The Shiraidake landslide is located in the Nagasaki prefecture, northwestern part of Kyushu. The landslide developed on the west-side slope of the Shiraidake Mountain, which elevation is 358.8 m, on the right bank of the Tsukinokawa River. The type of movement is a moderately deep-seated secondary slide, the *Hokusho* landslide. Some general views of the Shiraidake landslide are shown on Photos 1 and 2. The former shows the landslide area with the cross section 1-1' on the left, whilst the later shows detailed view of the landslide on the right side of the photograph. Fig. 3 illustrates the Shiraidake landslide and the cross section 1-1'.

The size of the investigated area is about 1.4 x 1.75 km. Terrain elevation ranges from 60 to 190 m asl. (above sea level), the slope is generally gentle up to 10°. Due to Japanese geographical location between North latitude 45° 33' and 20° 25', the climate varies considerably from north to south, with marked seasonal change. Japan, except of Hokkaido, is generally a rainy country with high humidity in summer. The studied area can be characterized as warm climate with mild dry winters and hot humid summers. According to the nearest meteorological station in Sasebo city, the annual precipitation varies between 2,000 and 2,500 mm (Bulletin, 1995-1999). However, it is necessary consider that the annual evaporation is about one third of the annual precipitation. Fig. 4 illustrates monthly precipitation in this area during five years starting from January 1995 till December 1999.

As can be seen, up to 70 % of the annual precipitation falls during 4 months between June and September. The monthly precipitation culminates in June and July, when the seasonal rain front moves progressively from the southernmost island toward the north. These rains often cause landslides and debris flow disasters. Typhoons usually generate strong winds and heavy rainfall, which cause flooding, sedimentation disasters and landslides. In the spring, numerous landslides are triggered by underground water, supplied from snowmelt on the slopes facing the Sea of Japan (Japan Landslide Society, 2001). The average annual temperature in the investigated area is about 16.2°C with an average minimum temperature 5.8°C in January and an average maximum temperature of 26.4°C in July (Bulletin, 1995-1999).

A comprehensive survey of the landslide area from geologic, geomorphologic and hydrologic points of view was done during the sliding activity between years 1952 and 1997. According to the activity of landslide at Shiraidake, the whole area was divided into five blocks A, B, C, D and E (Report, 1997). The investigation works were mainly conducted in the most active B and E blocks, where all the boreholes are concentrated. The data were collected from the surveys, and a simple spatial database was created. The database provided some general information about the investigated landslide and was also used as input data layers to calculate the slope stability. According to the records, the depth of the slip surface varies from 4.7 m at foot and head up to 23.0 m in the middle part of the landslide. Likewise, the ground water level through the landslide area varies from 1.0 m at foot to 9.5 m at head, corresponding to about 40 % of depth.

3.2 Geological setting and mechanism of the Shiraidake landslide

Tertiary sedimentary rocks of the *Fukui Formation* and the *Kase Formation* underlie the landslide. Both formations belong to the *Sasebo Group*, which is about

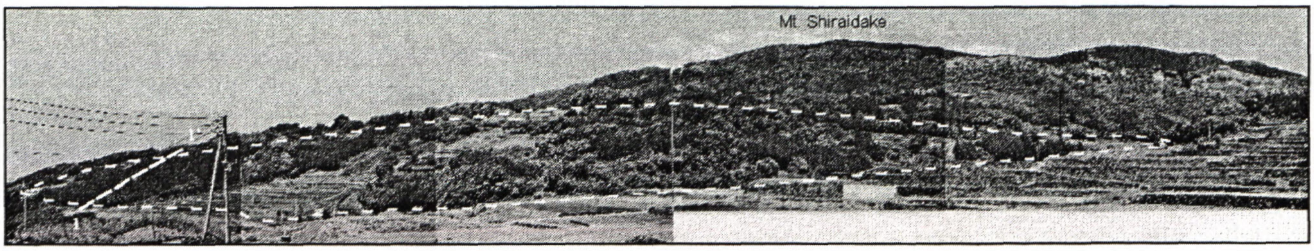

Photo 1: The Shiraidake landslide with longitudinal profile 1-1' illustrated on the left

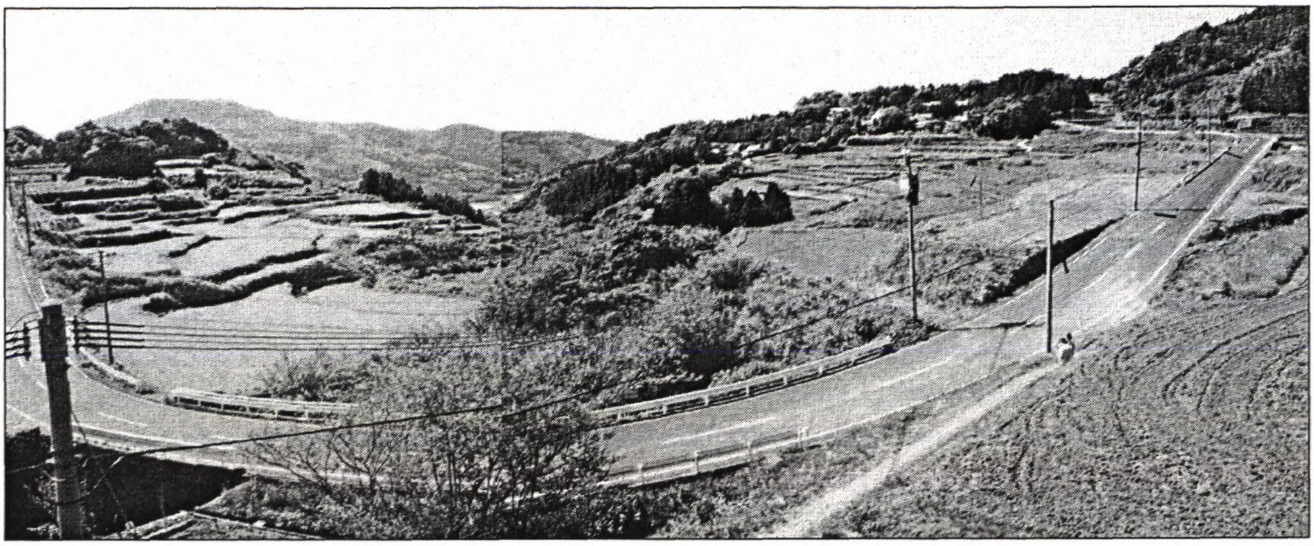

Photo 2: Detailed photo of the Shiraidake landslide (right side)

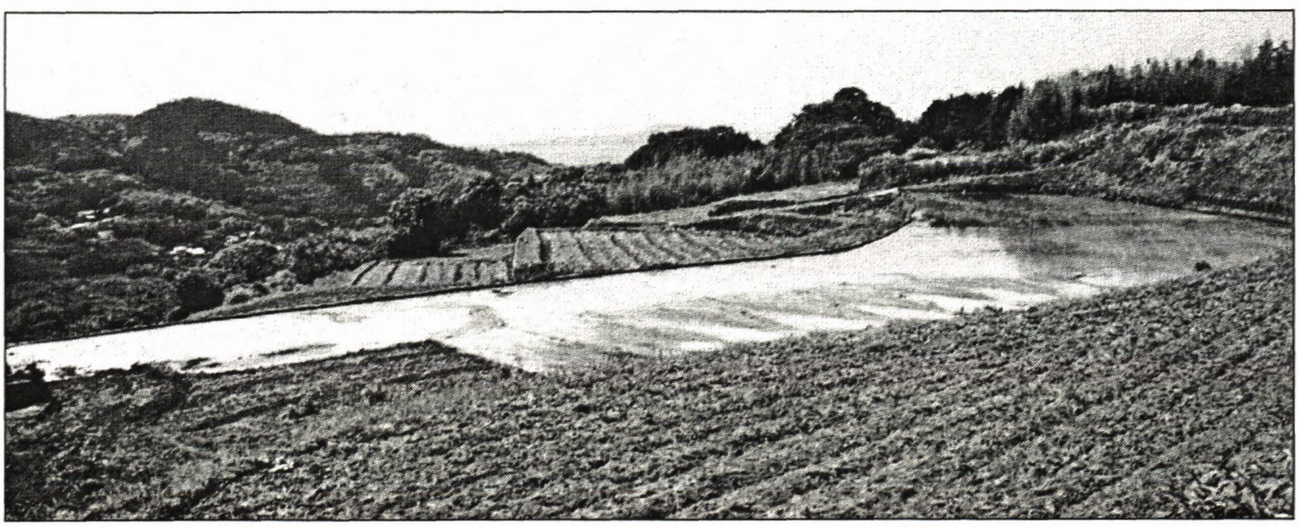

Photo 3: Gentle slopes of the Shiraidake landslide cultivated for rice paddy fields, which are sometimes full of water

1,000 to 1,600 m thick and composed of eight formations. The uppermost *Kase Formation* cosist of marine mudstone. Each of the other formations is composed of a single cyclothem that begins with a layer of marine or brackish facies and ends with a non-marine coal seam. All the strata consist of monocline structures, which are inclined gently towards the northwest. Near the summit these sedimentary rocks are overlain by the *Matsuura Basalt* as well as by the Quaternary deposits. According to the Geological map of the Saga prefecture (Kinoshita et al. 1954) the thickness of the basalt flow is between 50 and 150 m, occasionally 300 m.

The Shiraidake landslide belongs to the *Tertiary system* of landslides, representing the highest frequency of landslide occurrence in Japan. Landslides are usually caused by complex factors. In the Shiraidake landslide the following causal factors can be summarized:

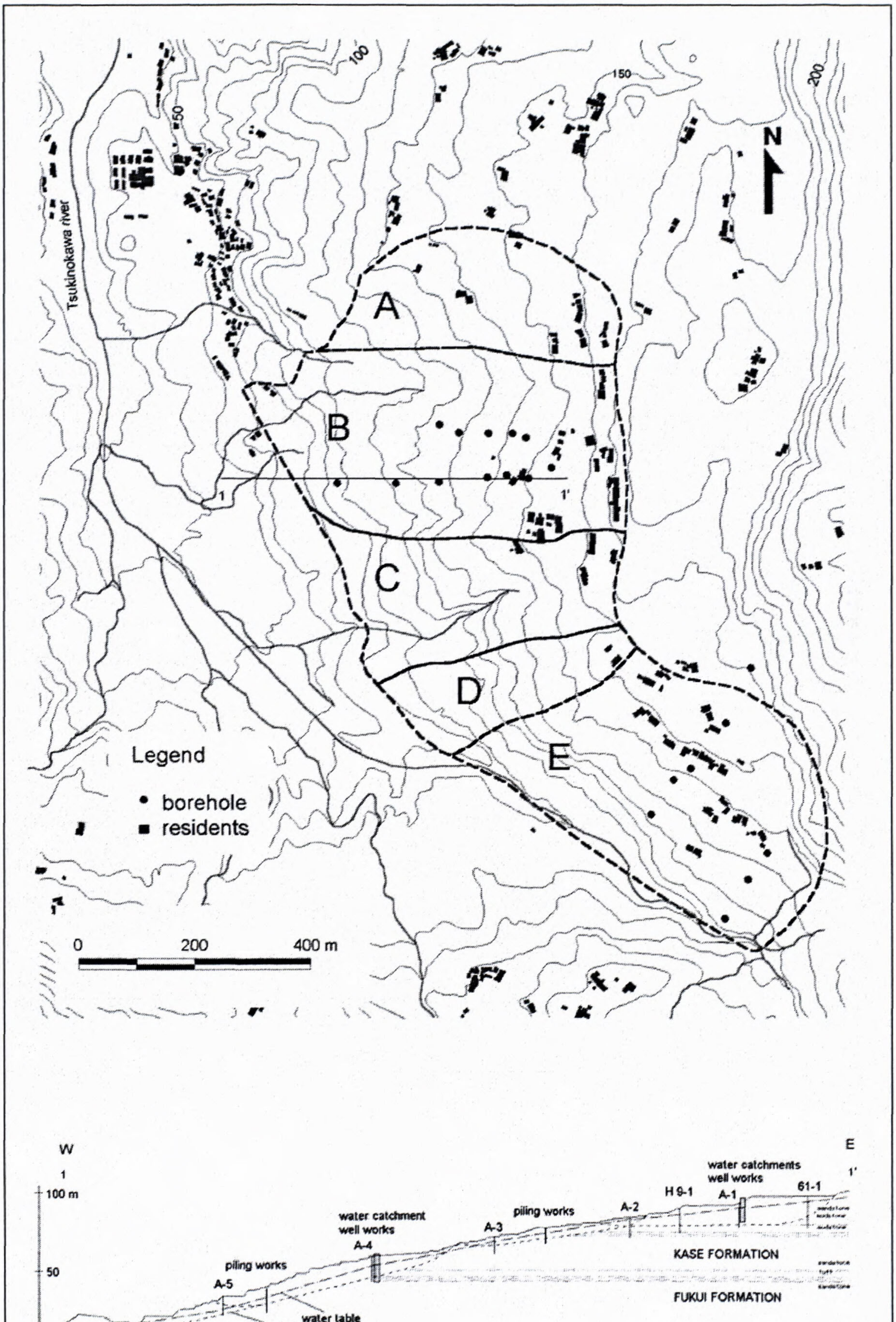

Fig. 3: The Shiraidake landslide with the cross section 1-1' through the B block

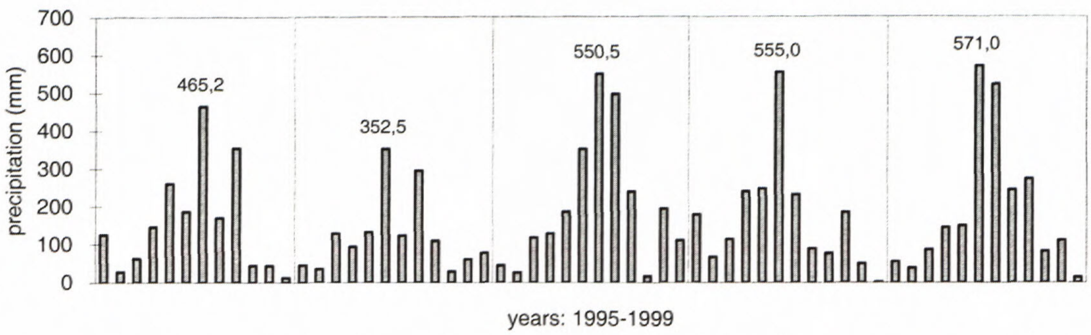

Fig. 4: Monthly precipitation chart for Sasebo city during the period 1995-1999

Table 1: Comparison of some general characteristics of the Hokusho landslides in the Tertiary covering sediment zones in Japan and the landslides in the region of Neogene volcanics in Slovakia

Parameters	Hokusho-type landslide in the Tertiary covering sediment zones in Japan	Landslides in the region of Neogene volcanics in Slovakia
Cap rock/era	Matsuura Basalt, Late Miocene, Pliocene	Andesite and their pyroclastics, rhyolite, basalt and their tuffs, Tortonian (Middle Miocene) Sarmatian (Upper Miocene)
Underlying rock/era	Semiconsolidated Tertiary sedimentary rocks: tuffaceous mudstones, shale, sandstone, coal seams, pyroclastic rocks	Pelitic and aleuric shales of Paleogene or semiconsolidated fine-grained strata, i.e. clayey-silty-sand rocks of Neogene
Climate	Warm temperate climate with four seasons, rainy season and typhoons; mild dry winters and hot humid summers	Continental climate with four distinct seasons; warm and mild, dry to moderately warm and humid
Average annual precipitation	2,000-2,500 mm	650-1,000 mm
Relief type	Hilly mountains with moderately steep slopes dissected by valleys	Intensively structured upland and highland type
Height	200-400 m asl.	900-1,490 m asl.
Relative relief	50-300 m	150-600 m
Slope angle	<10 °	6-8 °
Maximum landslide's dimensions	Width 4 km, length 5 km	Width 5.5 km, length 2 km (continuous landslide's ranges)
Maximum depth of slip surface	100 m	40 m
Failure types	Lateral spreading, block failures, block fields, landslides, debris flow, rock fall	Block failures, block fields, sliding of blocks, landslides, flow, surficial and deep seated creep, rock fall

(1) Favorable geological structure and lithology, i.e. the sliding surface forms along a bedding plane and along intercalation of coal seams between tuff layers, where the contact of strata can act as a slip plane.

(2) Intensive weathering. Geographical regions with much rainfall and warm temperatures such as Japan have led to weathering of natural materials. This usually implies that these regions also have the deepest soils, which can be a potential risk of a landslide.

(3) Formation of smectite in the slip-surface mudstone (Yagi et al. 1999). Smectite can originate as an alterion product of tuff, contacted with groundwater. In particular, smectite is one of the clay minerals with lower frictional resistance, and supply for slip surface in fine clastic sedimentary rocks, such as mudstone (Shuzui 2001).

(4) Interbedded impermeable and permeable rocks, Quaternary gravel layer with the possibility of formation of a perched aquifer system.

(5) Much and extremely intensive precipitation in the area (the annual precipitation up to 2,500 mm).

(6) The undulating relief terrain of the area. A gentle dip slope (up to 10°) is typical for the occurrence of such landslides.

The slope has been stabilized by the effective retaining structures. The area is covered by vegetation; the gentle slopes are cultivated by rice paddy fields (Photo 3). There are also some residences in upper parts of the slope. The last landslide activity was recorded in the 1990's (Report, 1997).

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Cap rock/era	Matsuura Basalt, Late Miocene, Pliocene	Andesite and their pyroclastic, rhyolite, basalt and their tuffs, Tortonian (Middle Miocene) Sarmatian (Upper Miocene)
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4. Slope movements in the region of neogene volcanics in Slovakia

Similar features and subsequently the types of the slope movements such as the *Hokusho* landslides in northwestern Kyushu, where the cap rock formations of hard component overly soft incompetent formations, are common in recent or past volcanic regions, as for example in Italy, Irkutsk and Siberian Plain in Russia, Washington, Oregon, Idaho, Colorado, Arizona and New Mexico in the USA, New Zealand (Nemčok, 1982), Konkan coast in India and Cooee in north-west Tasmania (Nagarajan et al. 2000). Likewise, these type of slope movements are developed in the region of *Neogene volcanics* in Slovakia, where rigid volcanic materials, predominantly andesites and their pyroclastics, rhyolites and basalts, overly soft, plastic and weakly cemented sedimentary rocks, i.e. pelitic and aleuritic shales of Paleogene or clayey-silty-sand rocks of Neogene (Nemčok, 1982). In order to understand the relationship between the *Hokusho* landslides in Japan and the landslides in *Neogene volcanics* in Slovakia, a literature review (Japan Landslide Society, 2001; Shuzui, 2001; Nemčok, 1982; Matula & Pašek 1996 and many other unpublished data) and subsequent comparison of some general features was carried out (Table 1).

By comparing the above sites it was found that the cap rocks of the *Hokusho* landslide are composed of basalt, while andesite and their pyroclastics are dominant rocks in the region of *Neogene volcanics*. Underlying rocks are built by quite similar units of semiconsolidated Tertiary sedimentary rocks. The climate shows considerable variation, it is warm and continental. The average precipitation is 2-3 times higher in the area of the *Hokusho* landslide than in Slovakia. From geomorphologic point of view, the landslides in the *Neogene volcanics* occur in higher altitudes with high relative relief, while the area in the *Hokusho* landslide shows a softer relief with smaller variation in relative relief. The dimensions of landslide and the slip surface depth are a little bit larger in the *Hokusho* landslides. It is likely that many failures are combinations of several different failure modes: slides or debris flows are linked to lateral spreads; a slide can also develop into a flow form at the toe, or a deep-seated creep on the margin of the highlands can transform into a rock fall.

5. Conclusions

This paper presented some of the general features and factors contributing to the slope stability in the *Hokusho-type* landslides in northern Kyushu. Based on the information obtained, it can be concluded that the main causes of the Shiraidake landslide are a combination of hydrological and geological settings of the area, deep and intensive weathering. The triggering factor was probably an increase in the ground water level after heavy rainfall during the rainy season from early June up to middle of July or during typhoon season in September. This is supported by very high monthly precipitations up to 571 mm.

Comparison between the *Hokusho* landslide and the slope movements in the region of *Neogene volcanics* showed some similarities between the studied sites. Some similar characteristics are related to the material of the underlying rock. The main differences are in the composition of cap rocks, which are basalts in the *Hokusho* landslides and andesites with their pyroclastics in the *Neogene volcanics*. From the morphological point of view, the landslides in the *Neogene volcanics* occur at higher altitudes with high relative relief, while areas in the *Hokusho* landslide show a softer relief with smaller variation in relative relief.

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