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A Type of Slope-Failures in Volcanic Areas of Southern Kyushu, Japan

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Introduction

Four big calderas of Aso, Kakuto. Aira and Ata are located in the central and southern parts of Kyushu, Japan. Volcanic products from those volcanoes cover deeply and widely over the regions.

"Shirasu", the volcanic products from Aira volcano are distributed widely over the southern Kyushu, as shown in Fig. 1[11]. "Shirasu" is a local term for pyroclastic flow (or pumice flow) deposits mainly composed of volcanic ash and pumice. Its topography is like a plateau, around which a lot of erosional valleys are developed. The Shirasu is characterized by angular soil particles, small specific gravity of grains and erosive property lying against the action of running water, from the view point of the soil engineering[1]. Younger pumice and volcanic ash beds cover the Shirasu with unconformity.

Recently, not a few slope-failure disasters due to heavy rainfalls have occurred frequently with the development of the land-use in the Shirasu regions. In June, 1976, many slope-failures took place owing to the heavy rain accompanied by the Baiu-front in the central part of Kagoshima prefecture, in which 32 lives were lost and 37 persons were wounded.

For the prevention of these disasters, it is necessary to clarify the causes and mechanism of the slope-failures. Up to now, it has been emphasized that the slope-failures in the Shirasu regions are mainly caused by the Shirasu itself because of its erosive property. But, according to the investigation of the disaster in 1976[7], through all the types of the slope-failures, the Shirasu itself

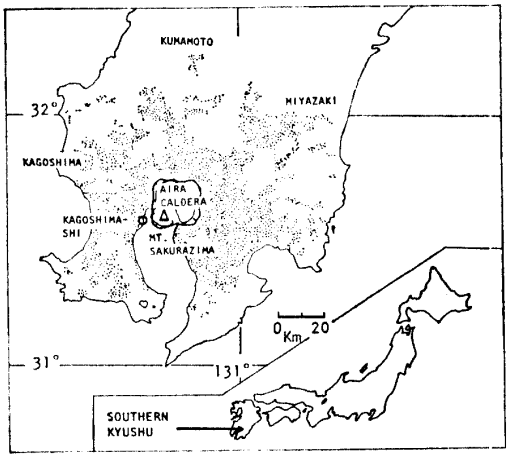

Fig. 1. Distribution of "Shirasu" (After Yokoyama 1971[11]).

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has never been the principal element of collapse. In other words, it has been ignored that the slope-failures, particularly the topsoil slides depend on the properties of the pumice and volcanic ash beds, from Mt. Sakurajima volcano, laid over the Shirasu.

Methods

Methods of this study consist of data analyses, field investigations and soil tests of the volcanic products. The data analyses were carried out, making use of the research data of disasters and aerial photographs. The factors analyzed are in the following; the occurrence-number of slope-failures owing to a rain[5], the amount of rainfall[5], the area of land reclamation during a year[8], the accumulated area of residential lands[9], and the form and scale of the Shirasu erosional valleys. The field investigations were performed in the Murasakibaru plateau of Kagoshima-shi, southern Kyushu. The matters for the field investigation are as in the following; the form and scale of the Shirasu erosional valleys, and the distribution, stratification and soil properties (apparent state, tone of color, extent of weathering, thickness, hardness of soil, etc.) of the volcanic products. The hardness was measured by using Yamanaka's soil hardness tester with the spring constant of 7.6 kg. Moreover, the soil tests were performed to ascertain the geotechnical properties of the volcanic products.

Results and Discussion

1. Transitions of the occurrence-number and the form of the slope-failures

Fig. 2 shows transitions of the occurrence-number of the slope-failures owing to a rain, the area of land reclamation during one year and the accumulated area of residential lands. The

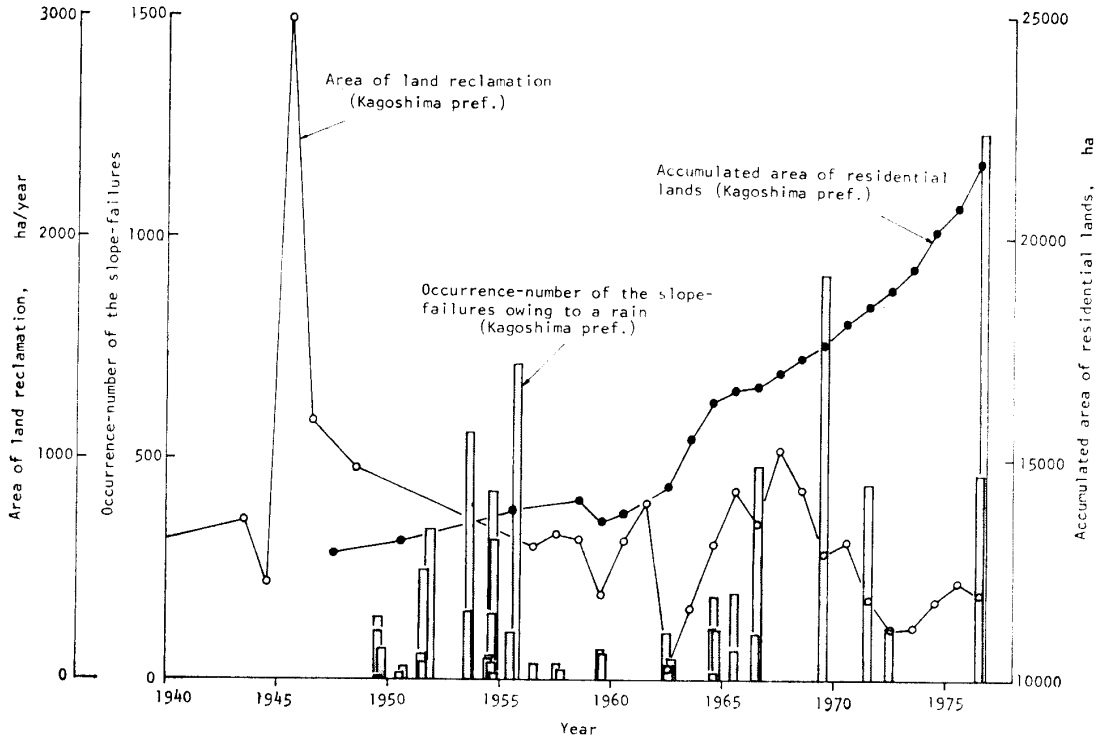

Fig. 2. Transitions of occurrence-number of the slope-failures owing to a rain, area of land reclamation during a year and accumulated area of residential lands.

occurrence-number of slope-failures is relatively large from 1951 to 1955, after that small from 1956 to 1965, and large again from 1966 to the present time. Basing on a presumption that the occurrence-number of slope-failures is to be dependent on the amount of rainfall, the relationship between the occurrence of slope-failures and the amount of rainfall was analyzed. But, no firm relationship could be found. That is to say, the amount of rainfall was not small from 1956 to 1965. Therefore, there must be any other causes for this transition.

It was the slope-failure disasters due to Della-typhoon and Dudith-typhoon in 1949 that made the disasters in the Shirasu region to be discussed publicly. According to the study of damage features by Nishi and Kimura[6], it was concluded that these slope-failures were caused by the properties of Shirasu itself affected by the land reclamation and the heavy rainfalls. Then, Tamachi[10] grouped the slope-failures in the farm lands into the following five types; failure due to saturation of the talus, lateral erosion, waterfall erosion, sinking erosion and rotational slides, on the basis of their forms and causes. As shown in Fig. 2, the farm lands were reclaimed on a large scale on and just after the World War II.

The small occurrence-number of the slope-failures from 1956 to 1965 may be caused by the decrease of the area of land reclamation during one year and the countermeasures against the disasters.

The slope-failures have been increasing in number again from 1966 to this day. During that period, Japanese economy accomplished high growth and the population came to be concentrated in the cities. The area of residential lands has increased rapidly as shown in Fig. 2. This increase is remarkable in Kagoshima-shi, Kagoshima prefecture and its neighborhood areas. The residential areas has been changed in location from flat lands to slope lands, and topographically from plain districts to mountainous districts with the increase of the residential area. The development of the land in the slopes and mountainous areas is to be attended with the earthwork on a large scale as well as with the constructions of structures such as retaining wall. As the result of that, the residential areas have shifted close to the dangerous slopes. The slope-failures which have occurred from 1966 to this day are closely related with the development of the residential lands. This can

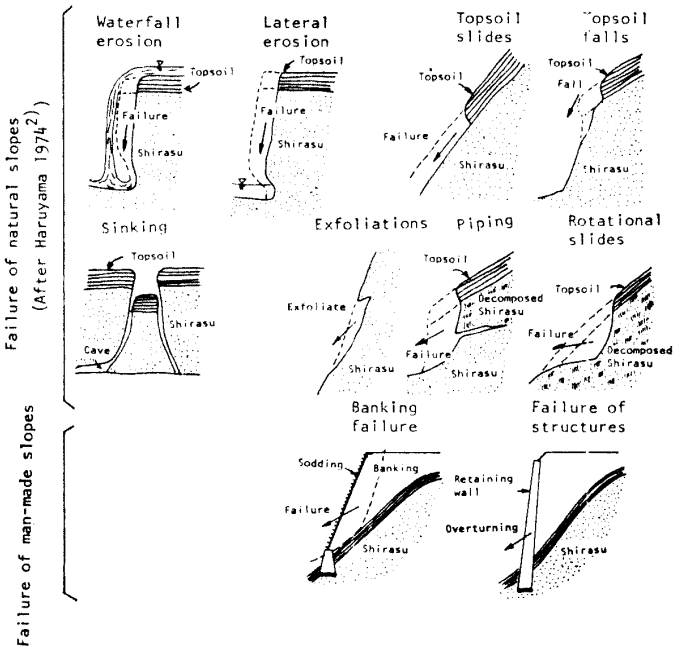

Fig. 3. Basic types of slope-failures in the Shirasu region.

be supported by some previous studies. Kimura[4] classified the slope-failures which took place in 1969 into the following types, waterfall erosion, lateral erosion, topsoil falls, topsoil slides, slope-failure due to piping, exfoliation, failures of structures such as banking slope and retaining wall and loss of soils during the development of the residential lands. The failures of structures and the loss of soils are new typed slope-failures, which are directly concerned with the development of residential lands. In general, the types of topsoil falls, topsoil slides and slope-failure due to piping took place mainly in the natural slopes, at the foot of which the residential lands were located. Moreover, according to the research of the slope-failure disasters in 1976[7], the types are composed mainly of the topsoil slides, topsoil falls, failure of banking slope and their composite type. No types of waterfall erosion, lateral erosion, and sinking erosion could be observed. As mentioned above, the occurrence-number and forms of the slope-failures have changed with the extent and forms of the land-use and the countermeasures against the disasters even for the short period of 35 years after the World War II. Fig. 3 shows the basic types of slope-failures in the Shirasu regions.

2. A typical example of the topsoil slides which occurred in 1976[7]

Table 1 shows the number of the slope-failures classified by the forms in which the failures occurred owing to a rainfall in 1976. The slope-failures shown in this table are only those which

Table 1. Number of the slope-failures due to a heavy rain in 1976

Types of slope-failures	Kagoshima-shi	Ushine	Tarumizu-shi	Kimotsuki-gun and So-gun	Total
Topsoil slides	9	3	3	7	22
Topsoil falls	3	0	0	6	9
Banking-failure and failure of structure	2	1	0	0	3

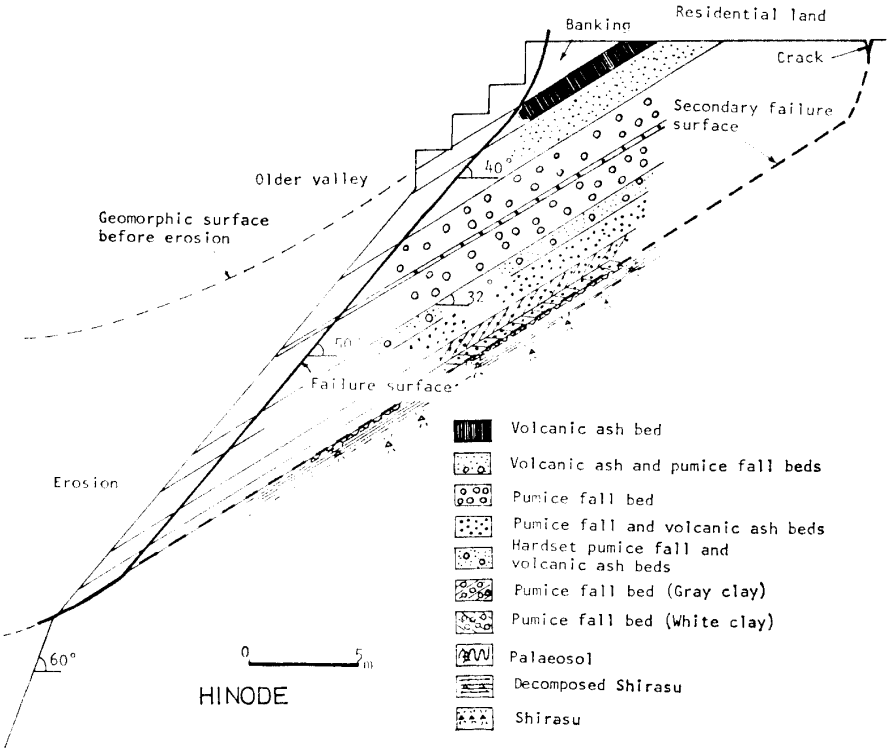

Fig. 4. A typical example of topsoil slides at Hinode, Kagoshima-shi.

brought about serious damages with the deaths of persons, the destructions of houses and the others. The greater part of the slope-failures belonged to the topsoil slides.

Fig. 4 shows a typical example of the topsoil slides with survey section. This slope-failure occurred at Hinode-cho, south part of the Murasakibaru plateau, Kagoshima-shi[7]. The slope is standing on the shallow older valley, in which the deep younger valley is formed. The topography is 40–50 degrees in dip and flat in plane shape. The geology is composed of the Shirasu, decomposed Shirasu, palaeosol, and pumice and volcanic ash beds. A banking slope was constructed with wickerwork at the upper part of the slope.

Firstly, the slope-failure took place at the banking slope. After that, the first failure was immediately followed by the secondary failure, along the slide surface between the palaeosol and pumice bed, destroying 6 houses. The type of the secondary failure is the topsoil slides. The first failure was assumed to be caused by the infiltration of rainwater into the banking slope. The secondary failure was considered to be mainly due to the intense weathering of the pumice beds on the palaeosol caused by the seepage water for a long time, and the rise of water content of the pumice beds. The geotechnical properties of the pumice beds on the slide surface are different from those of the palaeosol, as shown in Fig. 5. The pumice beds are by nature loose and easy to be infiltrated by water. Most of the topsoil slides were due to collapses of the pumice and volcanic ash beds on the Shirasu in the same manner as the above typical example.

Therefore, in order to predict the location of occurrence of this typed slope-failure, it is necessary to have some understandings about the topography of the Shirasu regions, and the distribution, stratification and geotechnical properties of the pumice and volcanic ash beds.

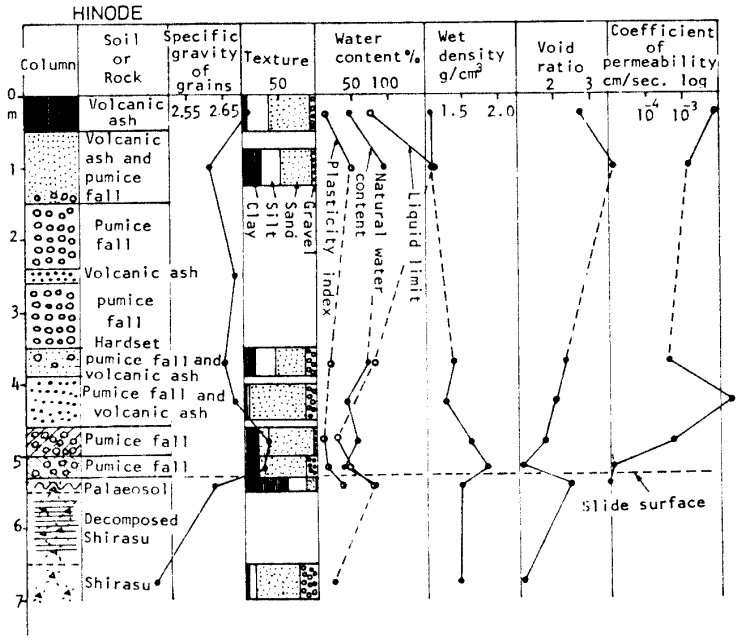

Fig. 5. Geotechnical properties of the Shirasu ground at Hinode, Kagoshima-shi.

3. Topography of the Shirasu plateau

There are two types in the valleys of the Shirasu region. The two types of valleys were formed by the following process[3]. The Shirasu plateau measuring about 100 m in relative height had been formed about 22,000 years ago and been exposed to the erosion action due to rainwater since

then to about 11,000 years ago. This period was parallel with the high prosperity of Haupt-Wurm glacial stage in which the sea level lowered at a maximum and it rained very little. Therefore, the erosion action of rainfall was so weak that the shallow older valleys were formed as shown in Fig. 6. The palaeosol was formed during the same period. Then, the Shirasu plateau was covered with the volcanic fall products (pumice and volcanic ash beds) caused by violent volcanic activities of the old Sakurajima on and after about 11,000 years ago. The erosion became intense because of the humid and warm climate on and after 5,000 years ago. As the result, the Shirasu plateau was eroded and the deep younger valleys were formed in the shallow older valleys and the other places.

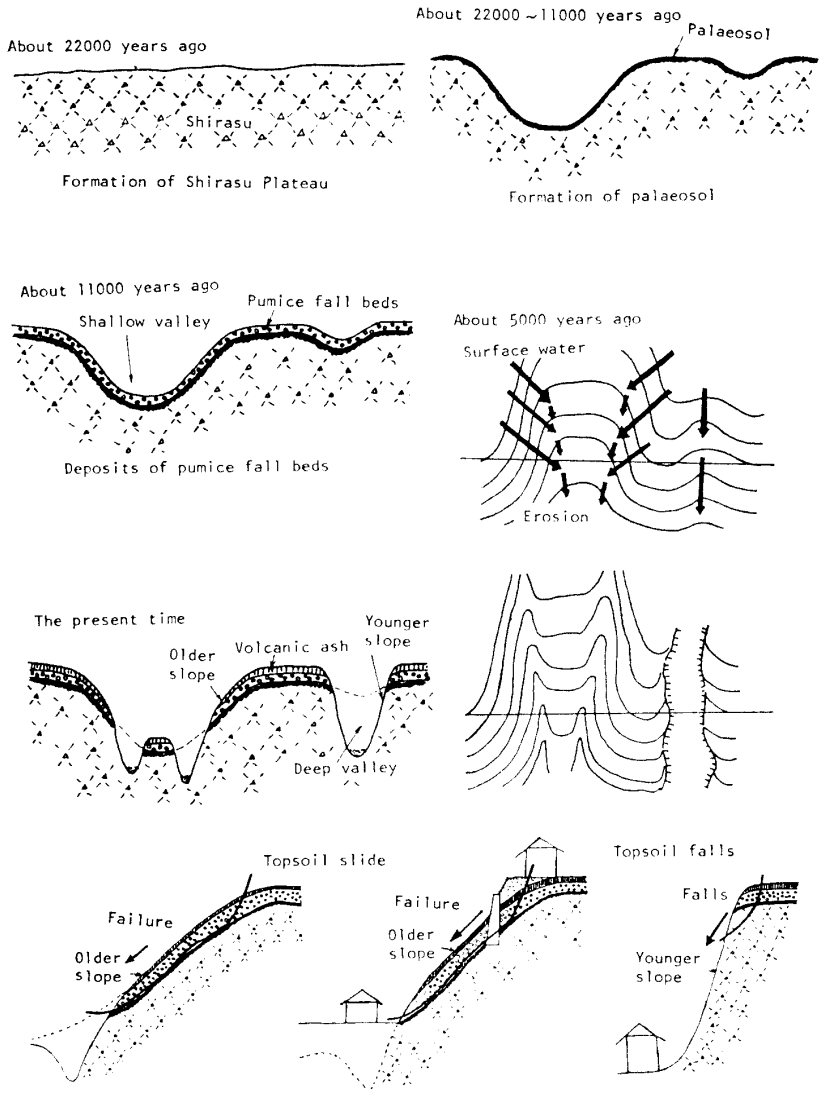

Fig. 6. Schematic topographic evolution process of the Shirasu plateau and forms of the slope-failures (This figure was made based on Iwamatsu 1976[3]).

Fig. 6 shows schematically topographic evolution process of the Shirasu plateau and the forms of the slope-failures. According to the field investigations, in the large scale older valleys, two or more deep younger valleys were formed at the bottom of the valley and at the toes of its both side slopes, and in the small scale older valleys, one younger valley was formed. The forms of the slope-failures are closely related to the types of the valleys. In the older slopes, the form of slope-failure is mainly the topsoil slides due to collapses of the surface soil layers composed of

the pumice and volcanic ash deposits. While, in the younger slopes, the form is the topsoil falls, exfoliation and so on.

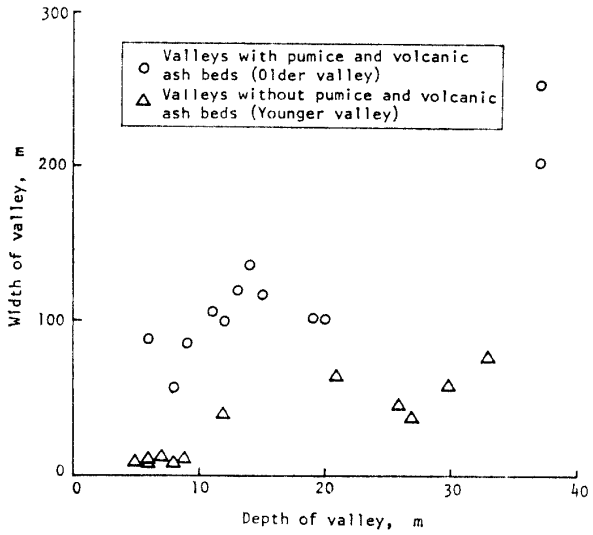

Fig. 7. Relationship between the mean width and the mean depth of the valleys.

Fig. 7 shows the relationship between the mean width and the mean depth of the valley. In this figure, the mean width and depth express the means of some measured values in the valley. The topography of the older valleys differs from that of the younger valleys. That is to say, if the depth of the valley is same, the width of the older valley is larger than that of the younger valley. The two types of valleys are divided with the application of this property.

4. Distribution, stratification and geoteehnical properties of the pumice and volcanic ash beds on the Shirasu slopes

The pumice and volcanic ash beds covered the Shirasu have been eroded under the humid and warm climate on and after 5,000 years ago[3]. But, they are still distributed widely over from middle part to ridge of the gentle slopes under 35 degrees in dip in the Shirasu regions, as shown in Fig. 8. The present topography is very complicated, but it is considered that the older topography which was present before the pumice and volcanic ash beds were deposited, had been simple, judging from their distribution form. The Shirasu slopes with the pumice and volcanic ash beds were used as farm lands after the World War II, and have been used as residential lands in recent years.

The ground of the Shirasu slope is composed of the Shirasu, and many layers of the pumice and volcanic ash. A typical example of the geologic columnar section is shown in Fig. 9. The topography of the investigated field is concave in plane shape, being about 25 degrees in dip. The palaeosol of several tens cm in thickness is formed in the surface part of the Shirasu layer. The volcanic fall products which covered the Shirasu are composed of the alternated layer of the pumice and volcanic ash. The palaeosol is not found in their beds because of their successive depositions. The pumice bed just on the palaeosol is heavily weathered and the particles have no trace of the original form, because of the topography of concave in plane shape and the stagnation of seepage water. In the other investigated fields, the pumice and volcanic ash beds had similar stratification and degree of weathering as mentioned above.

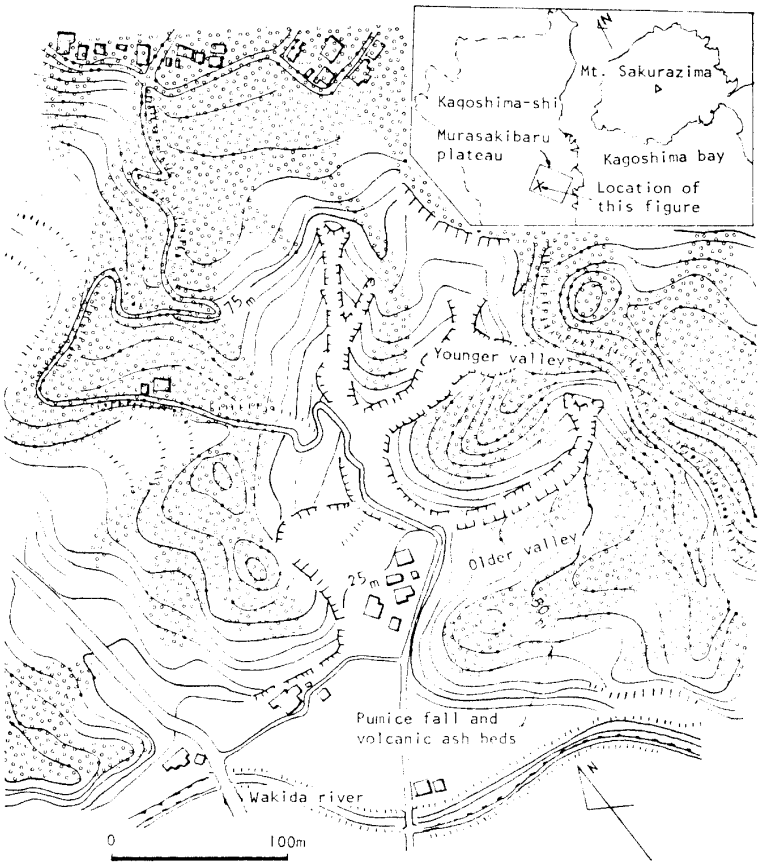

Fig. 8. Distribution form of the pumice and volcanic ash beds on the Shirasu slopes.

Fig. 10 shows the geotechnical properties of the Shirasu, and the pumice and volcanic ash beds at all the investigated fields. The pumice bed just on the palaeosol is roughly divided into the lower layer and the upper layer by the degree of weathering. There are remarkable differences in the coefficient of permeability, index hardness and unconfined compressive strength between the palaeosol and the pumice bed just on the palaeosol. And the lower layer of the pumice bed is the smallest in the unconfined compressive strength among the volcanic deposits which covered the Shirasu. Therefore, the greater part of the topsoil slides occurs along the boundary surface between the palaeosol and the pumice bed just on the palaeosol.

Conclusions

The results described above are concluded in the following:

1. The occurrence-number and the forms of the slope-failures have changed with the extent and the forms of the land-use, and with the countermeasures against the prevention of disasters even during the short period of 35 years after the World War II.

2. The greater part of the slope-failures which have occurred in recent years belongs to the types of toposil slides brought forth due to the collapses of the pumice and volcanic ash beds which covered the Shirasu.

3. There are two types of valleys, namely the older valley covered with pumice and volcanic ash beds, and younger valley without those beds, in the Shirasu regions. If the depth of the valley is same, the width of the older valley is larger than that of the younger valley. The two types of the

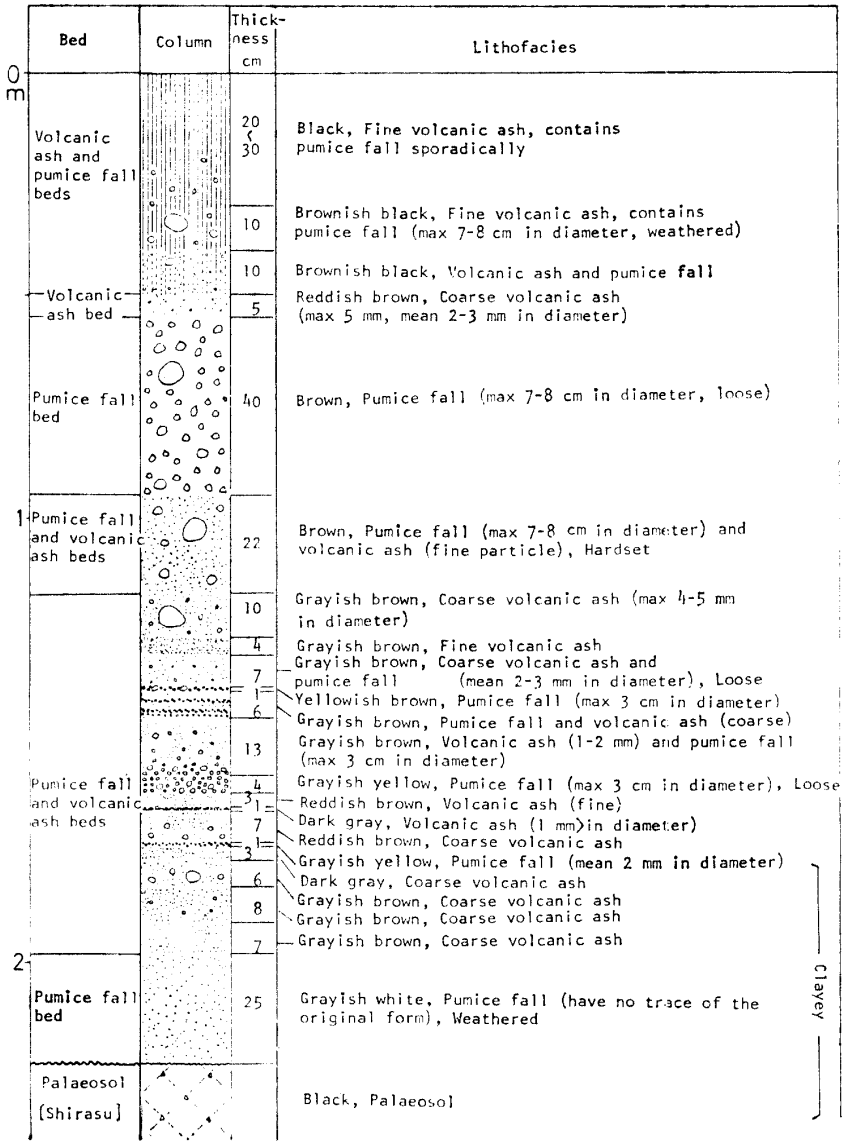

Fig. 9. A typical example of the geologic columnar section.

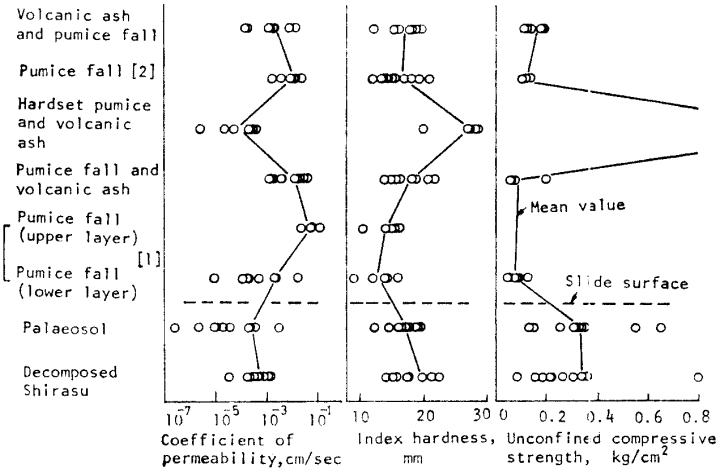

Fig. 10. Geotechnical properties of the Shirasu, and the pumice and volcanic ash beds.

valleys are divided with the application of the relationship between the width and depth of the valley. The forms of slope-failures are closely related to the type of the valley. The topsoil slides occur often at the older slopes with the pumice and volcanic ash beds.

4. The pumice and volcanic ash beds are still distributed from middle part to ridge of the Shirasu slopes. The pumice beds just on the palaeosol derived from the Shirasu are heavily weathered and the particles have no trace of the original form. There are remarkable differences in the geotechnical properties between the palaeosol and the pumice and volcanic ash beds. Most of the topsoil slides occur along the boundary surface between them.

Summary

In southern part of Kyushu, Japan, the land is broadly covered with pyroclastic flow deposits called "Shirasu". Its topography is like a plateau. In Baiu and Typhoon seasons, many slope-failures caused by heavy rainfalls have often occurred, and brought about disasters around the plateau. Of various types of the slope-failures, the topsoil slides have been frequently combined with serious disasters accompanied with the loss of lives and the damages of houses. The main purpose of this study is to clarify the causes and mechanism of the topsoil slides and to predict the location of the occurrence. The authors carried out data analyses, field investigations and soil tests. The topsoil slides were casued by the progression of weathering in pumice and volcanic ash beds, and the difference of the geotechnical properties between the Shirasu layer, and the pumice and volcanic ash deposits on the Shirasu. But, we must not forget the social factors, as well as these natural factors, as the agents causing the occurrence of the slope-failures. By considering the topographic evolution process of the Shirasu plateau, it is possible to predict the location of the topsoil slides.

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