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Author(s)	SOKOBIKI, Hirotaka
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Evaluation Studies of Mountain Sediments and Supply Source in the Rokko District with Potentiality for Sediment Disaster

By

Hirotaka SOKOBIKI

with 5 Tables and 30 Text figures

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ABSTRACT

In Rokko district, many cities are developed between Osaka and Kobe, and these cities have suffered from numerous disasters caused by the sudden discharges of large amounts of sediments. To prevent and/or to forecast the disasters, geomorphological and geological characteristics as well as those of engineering technology were investigated in detail. A new conception "movement potentiality" and "occurrence potentiality" were established in order to present the "preventative geological map" and "hazard map". The results obtained can be summarized as follows.

The mountain sediments (torrent bed and slope sediment) were classified with the concept of movement potentiality. Concerning the cross section, the torrent bed sediments were divided into four kinds of depositional surfaces of S-I to S-IV according to the relative height from the present torrent bed. For the longitudinal-section, the torrent bed sediments were divided into three sediment stages (expressing the amount of sediment) and ten morphological types based on the bed inclination and the catchment area (expressing force of the stream). The slope sediments were classified into seven types based on the concept of scree.

A supply system of mountain sediments was examined mainly by evaluating the correlation between the geomorphological and/or geological condition and collapse in Rokko district. The lithologic character regulates grain size and resistivity against weathering, and the existence of fault regulates the scale and the occurrence position of the collapse. In the Rokko district, the weathering profile of granitic rocks has a piling structure of younger weathering zone upon the older weathering zone, the latter being formed more than several hundreds of thousands of years ago.

The movement of mountain sediments can be understood as the fluctuation of occurrence potentiality of sediment disaster through quantitative change of the torrent bed sediments in the longitudinal section. From this point of view, the occurrence potentiality of sediment disaster was determined by evaluating quantitatively the amount of sediment and potential energy of the mountain sediments.

The River Hirami area (catchment area 0.370km²) in Rokko district was taken as an example for establishing a preventative geological map. In this paper, hazard map of 1 : 2,500 scale was presented in which various factors such as slope inclination, geology, sediment, collapse land in the past (desolution condition) and vegetation were taken into consideration.

For the mountain sediments on the fractionaized slopes, the occurrence potentiality of sediment disaster was evaluated. Based on this evaluation, the amount of sediment from the torrent bed and bank were determined. The calculations were made based on the sediment discharge at a probability of exceedent rainfall in 200 years according to the tractive formula of Meyer Peter.

Finally, significance of the presented "preventative geological map" for the prediction and forecast of the sediment disasters was discussed.

CONTENTS

I. INTRODUCTION

Recently, various kinds of geological disasters have become more frequent due to the development of our life style. Especially, the loss of human life, land and property due to sediment disaster is not only a major social problem in Japan but also is a world wide problem. The study of forecast and prediction of sediment disaster is advancing rapidly according to the recent progress of the related science and technology.

In a sediment disaster, mountain sediment is an important factor as a movable sediment as well as a sediment from slope collapse (Kobashi, 1978). As for mountain sediments deposited relatively thickly on the mountain slope, various studies have been published up to the present in the geomorphological field dealing with moving form, accumulating form, quantitative change and other things of denuded substances according to slope retreat and decline (cf. Penck, 1924; Ollier, 1969; Scheidegger, 1970). Although, there have been few systematic studies, especially those concerning geomorphology and geology of the torrent bed sediments so far, a running process of debris flow has been disclosed through a geological procedure (Imamura, 1976 and 1977). Sokobiki et al. (1986 a and b) showed qualitative correlation between the torrent bed sediments and the gemorphological and/or geological characteristics in the catchment area in the Rokko district. The torrent bed sediments were morphologically classified in relation to geomorphological procedure of terrace (Machida, 1963) and the depositional surface of the torrent bed was classified into S-I to S-IV according to the relative height from the torrent bed (Sokobiki et al., 1978). It has also been shown that the cross sectional profile of the torrent bed can be classified by the concept of the probability of exceedent rainfall (Moss et al., 1978).

Extensive studies on slope sediments in the Tirol district in Austria have been done by Bunza (1975). He classified the slope sediments into fifteen kinds of forms and described them on a topographic map of a scale 1 to 25,000. To estimate the danger degree of slope collapse, Moser (1975, 1980) noticed the significance of size, kind and shape of the mass movement in the slope sediments, and evaluated stability of the sediments including rocks. Mosley (1979, 1980) gave a geomorphological classification of mountain sediments in New Zealand, and adopted five erosion forms as one of the criteria to evaluate sediment source. He expressed the slope sediments as "scree" and tried to chart a subsurface geological map for explanation.

The present author has already pointed out that the supply system of those sediments are strongly controlled by their vessel, the geomorphological and geological condition in the catchment area of the Rokko district (Sokobiki et al., 1986 b). For the supply system of mountain sediments, creep is possible as well as a relatively quick landslide and/or collapse (Costa et al., 1981; Takei et al., 1982). Kuroda (1973) and Kuroda et al. (1982) described collapse and landslide occurred in several geologic provinces in the Japanese Islands in relation to the characteristics of rock and stratum. Kimura (1974) showed that each type of rock produced different material derived from mass movement. Tanaka (1982) suggested a close relation between fault and collapse in the Rokko district, and Sokobiki et al. (1986 a and b) also pointed out that faults are included as one of the occurrence factors for debris flow and null order stream collapse. Yamamoto et al. (1973) showed that the occurrence of landslide collapse in Hiroshima Prefecture is strongly controlled by faults and joints.

Concerning the weathering, many studies have been published particularly in relation to "Masa" (Kashiwagi, 1963; Kakitani, 1974 and 1975; Kohno, 1984; Raj, 1985). Miura (1966, 1969, 1970 and 1975) has revealed the geological characteristics of "Masa", especially the characteristic features of clay mineral and also explained the mechanism of the collapse. Marui et al. (1978) have disclosed the shearing strength properties of "Masa" in Nunobiki granodiorite area in the Rokko district and described the mechanism of collapse and debris flow.

A hazard map is a chart which indicates the degree and zone of danger for various disasters. As for slope disasters, at an early period, Kobashi et al. (1974) made a ranking of the danger degree of slopes along the JNR Takayama Line by a statistical method. Recently, estimation of danger degree, establishment of dangerous zone and forecast of occurrence time of deblis flow have been performed by the Ministry of Construction on a nation wide scale. For landslide, a study to determine the probability of the occurrence i s also advanced by the use of the type II quantification theory (Kawakami, 1984). In the Alps district in Europe, four kinds of danger areas, i.e., flood, debris flow, snow avalanche and slope collapse are mainly investigatated paying special attention to the records of previous disasters. The dangerous zones are, then, established based on hydrologic-hydraulics and erosion control (Aulizky, 1975). The activity of those factors is classified for the synthetic judgement of danger degree (Moser, 1980). In the United States, such kind of studies started almost at the same time, and have been advanced mainly as one of evaluation items for land use (Hill et al., 1972; Mathewson, 1974). To be noted is that many of the studies are concerned with earthquake disaster (Kockelman et al., 1984) and landslide (Radbruch, 1971). Like those in other countries, the hazard maps in Japan have given almost no consideration on slope sediments and on torrent bed sediments in the catchment area, except for the cases of large scale, up to present.

Therefore, it is necessary to perform more detailed analysis on many factors in areas like Japan, which has very complicated geomorphology and geology, and dense land use. Concerning the Rokko district, charting of a hazard map related only with debris flow, drawn on a scale of 1 to 25,000, was already established. For the purpose of the Sabo plan in the north section of the Rokko district, a geologic map was made with a scale of 1 to 2,500 (Ministry of Construction, 1977, 1978, 1979, 1980 and 1981).

The main subject of this paper is the geomorphological and geological analyses of mountain sediments of Rokko district. First, the author will classify the mountain sediments, the largest supply source of the sediment disasters, with the concept of movement potentiality, then examine the geological condition of the supply source of the mountain sediments. In addition, with case studies, the author will explain the evaluation method of the movement and the supply potentiality, which are concerned with the condition of the mountain sediments and the geology, as an occurrence potentiality. Finally, by utilizing the preventative geological map which shows occurrence potentiality, process for establishing the more detailed hazard map and the significant efficiency will be described.

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II. DESCRIPTION OF THE MOUNTAIN SEDIMENT UNDERSTOOD AS MOVEMENT POTENTIALITY

The supply source of sediment discharge can be divided into mountain sediments and sediments from collapse. The mountain sediments can further be classified into the torrent bed sediment and the slope sediment, and the former is subjected to the effect of erosion, transportation and deposition due to flowing water on a torrent bed, and the latter moves and deposits due to the gravitation on a slope. Fig. 1 shows the amount of sediment discharge at the disaster in 1967, in terms of supply source with accumulated frequency. As shown in this figure, amount of the sediment discharge from the torrent bed in the second order stream is more than that from collapse (null order stream). As for collapse, the present author has already reported a method of forecast for occurrence probability in relation to null order stream (Sokobiki et al., 1986 a and b).

The Rokko district is mainly composed of weathered granitic rocks and moreover, it is in very fragile condition due to the crushing effect during the Rokko movement of the late Pleistocene age. At the foot of the mountain district between Osaka and Kobe many towns have been developed. These towns enter deeply into the mountain district, and when a heavy rain falls, these towns have been subjected to an unprecedented disaster due to the sudden discharge of large amount of sediment (Ministry of Construction, 1974). For this reason, in this paper, the mountain sediment composed of the torrent bed sediment and the slope sediment will be treated as a main subject since the sediments are the main supply source of discharges in the Rokko district.

In the catchment area in the Rokko district investigated in Fig. 1, there were large sediment disasters and a large amount of sediment was discharged in 1967 as well as in 1938.

When the torrent bed is examined in the cross-section, it is recognized that the larger is the relative height from the present torrent bed, the larger is the force of the stream at its formation period but the smaller is the probability of the formation of depositional surface. In other words, in accordance with probability of exceedent rain fall, the depositional surface is formed by the force of the stream, which depends on the inclination of the depositional point and the largeness of catchment area. When it is examined in the longitudinal section, the bed inclination and the

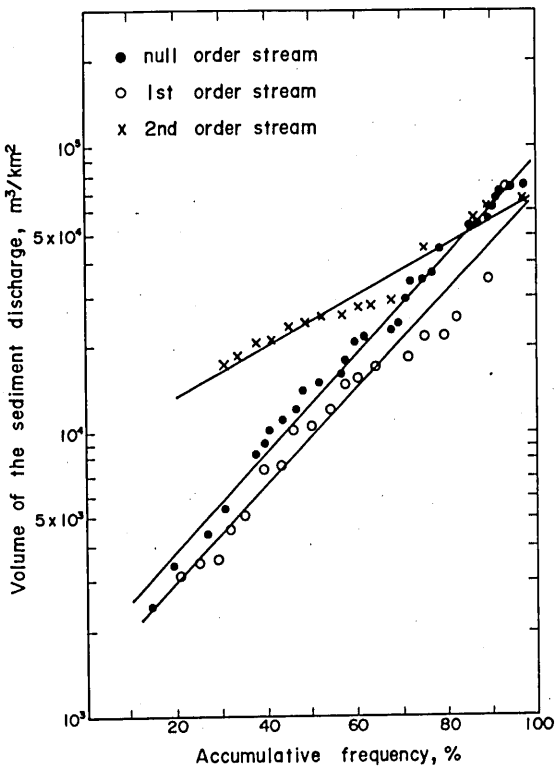


FIG. 1 Variation of the volume of the sediment discharges in the second order basin of Rokko district at the Rokko disaster 1967. Note that the discharges from the null order valley were derived from the collapse land.

catchment area change also for upstream and downstream. According to the force of the stream, each point shows different depositional stage and so different movement potentiality of sediment.

Concerning slope sediment distributed on slopes in the mountain district, the idea of the potentiality for the torrent bed sediment can also be applicable. The sediment has movement potentiality according to its amount and is subjected to shear stress which originates in the slope inclination.

This concept of movement potentiality is, then, applied to a case study of a disaster in 1967 in the Rokko district. At a place in Suishodani, which has height of 532 meters above sea level, inclination of 6° and a catchment area of 0.92km², it was recognized that there was a large amount of sediment transportation due to the outcropped torrent bed in step-like form and the torrent bed sediment left at the relative height of 5 meters. On the other hand, the torrent bed sediments did not move at the same place during the disaster in 1938 even though there was almost the same amount of rainfall. The reason for this might be that the torrent bed sediment at this place had resistance capacity against the effective force of the stream. In other words, the torrent bed sediments had low movement potentiality at that time. The other case is a place in Gosukedani, which has height of 640 meters above sea level, inclination of 19° and a catchment area of 0.19km². As shown in Fig. 2, a large amount of torrent bed sediments from a side wall of the torrent bed has deposited behind the place due to a collapse of falling rock pebbles of a diameter of 60 to 200 cm. Because this place had no debris flow during the disaster in 1967, it can be said that the torrent bed sediments had low movement potentiality at that time. However, this torrent bed sediment will discharge in the future, if it is subjected to an anomalous force of the stream larger than its movement potentiality and if a large scale debris flow occurs in the upstream area. Furthermore, at that time, the energy of the debris flow would be almost equivalent to that of the debris flow in the Suishodani because of the amount of the deposition. As one can see, low movement potentiality of torrent bed sediment means there is enough torrent bed sediment to resist the force of the stream acting on its sediment. Once the sediment begins a movement, it is expected that the lower is the movement potentiality, the larger is the energy of flow.

In the following, the mountain sediments in the Rokko district will be first described and classified based on the concept of movement potentiality, and then geomorphology and geology which are the conditions of the mountain sediment source will be explained. For some comparative studies the following catchment areas in middle and small mountain districts of western Japan were also investigated. These are catchment areas of River Yahata, River Otani, Sennan Basin, River Shinjo and River Seno (see Fig. 3).

A. Torrent Bed Sediment

1. *Analysis of Cross-Section*

In the crross section of the respective area, the torrent bed sediments extensively form an step like

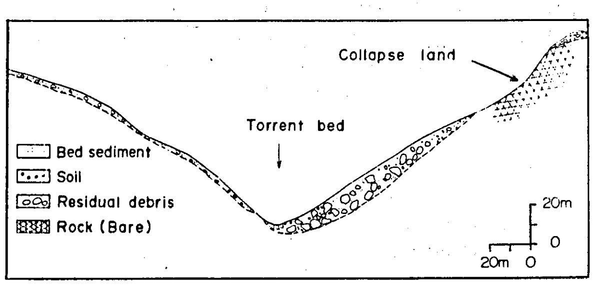


FIG. 2 Schematic cross-section of Gosukedani river basin illustrating the relationship between the residual debris and the torrent bed.

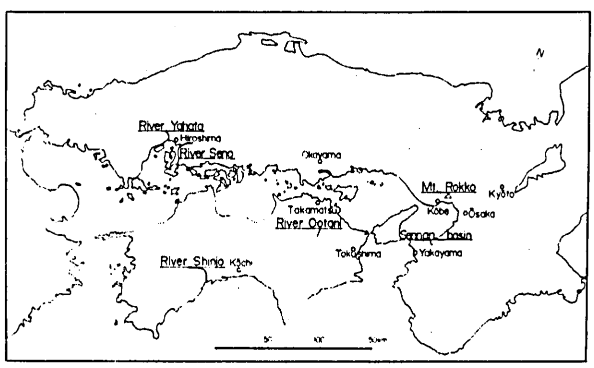
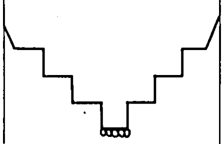
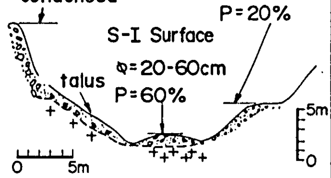
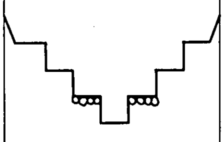
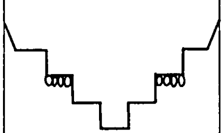
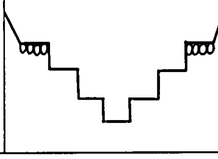


FIG. 3 Location map of Rokko district and other investigated districts.

TABLE 1 SCHEMATIC CROSS-SECTION OF THE BED SEDIMENTS SHOWING THE GEOMORPHOLOGICAL CHARACTERISTICS OF THE SEDIMENTS.

Surface	Idealized Schematic Diagram of Surface	Recurrence Interval (Years)	Degree of Compaction	Typical Example	Remarks
S-I		< 5	Loose	 bed inclination of 15° 360m in height φ: diameter of gravel P: percent of gravel On the Sanmon-no-tani, River Saigo	Sediments shift commonly. Sediments are transported by torrent run off at severe rain fall.
S-II		≦ 100	↕		Sediments are transported as debris flow, when rain fall intensity is stronger than that of the initial sedimentation time.
S-III		> 100			The soil fall commonly on the steep slope and/or cliff. Shoulder parts of the sediments collapse occasionally.
S-IV		> 10^5	Condense	Illustrated in Fig.7	Cliff of the sediments is often apart from the torrent bed. Accordingly, sediment supply to the torrent bed is small.

structure in the region from the downstream to the upstream. Based on the relative height from the torrent bed, the depositional surface was divided into four kinds of surfaces as is illustrated in table 1.

The S-I surface is the depositional surface of the present torrent bed. The sediments on this surface are composed of grains which have a diameter balanced against the tractive force from the regular stream and /or grains larger than the balanced size. The latter are not only residual grains but also are formed by other factors than the force of the stream, such as collapse. The sediments are always repeating the process of growth and of vanishing on this surface.

The S-II surface is a depositional surface which has the relative height of about 2 to 3 m from the present torrent bed. The sediments on this surface are deposited mainly at the recession stage of a medium-sized flood, and they will have the movement potentiality of discharge at the subsequent flood. But the surface of S-II shows drastic change from middle stream to upstream. Under a stronger force of the stream than that of regular stream, the sediments of S-II surface is repeating the process of growth and of vanishing and it is also subjected to other factors than the force of the stream. For dealing with sediment disasters in the future, it is extremely important to estimate the recurrence interval which is necessary to form this surface. For example, in the Suishodani, there is a trace of the debris flow in the confluence area of the main stream. The trace is thought to have been left in the disaster in 1967 which had a recurrence interval of 100 years. Fig. 4 shows the position of this trace and it is clear that the width of flow is equal to that of S-II surface. The width of debris flow can also be estimated by the regime theory. For the S-II surface in the catchment area of the Sennan basin, the width of debris flow is calculated at the recurrence interval of 100 years, and the same fact is actually measured during the site survey. Because both values correlate very well as shown in Fig. 5, the formation period of S-II surface can be said to be about probability of exceedent in 100 years.

S-III surface is a depositional surface along the present stream and the relative height from S-II surface is 1 to 2m. As shown in Fig. 6, in the mouth of a narrow valley, some of the S-III surfaces are thought to have been formed almost at the same time as that of the S-II surface because the two surfaces show almost

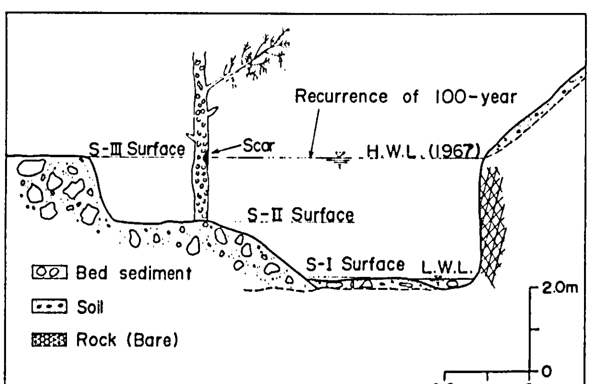


FIG. 4 Schematic interpretation of the historical relations between the 100-year flood and the S-II surface recorded on a pine tree (note the arrows).

the same relative height from the present torrent bed at the mouth of the valley. On the other hand, there is also an old S-III surface which is estimated to have been formed by 5 to 10 thousand years possibility judged from its size. This depositional surface is often composed of the sediments of debris flow.

S-IV surface is a depositional surface which is equivalent to the higher and the middle terrace deposit. This depositional surface distributes at various altitude and has received the effect of the Rokko movement. Along Suishodani, in the confluence area of the main stream, the terrace deposit is distributed at 380m above sea level. In the middle stream area, the terrace deposit is distributed at 540m above sea level and at 40m of the relative height from the present torrent bed as is shown in Fig. 7.

Because sediments on the S-III and the S-IV depositional surfaces are in large scale and have possibility of catastrophical breaking, it can be said that the sediments have a very low movement potentiality. The sediment supply to the torrent bed is always constant but the quantity is small. When the sediments on S-IV surface are compared with those on S-III surface, the former are somewhat compact. Moreover, most areas of S-IV surface are distributed far from the present torrent bed and the sediments on S-IV surface contribute less to sediment supply for the torrent bed.

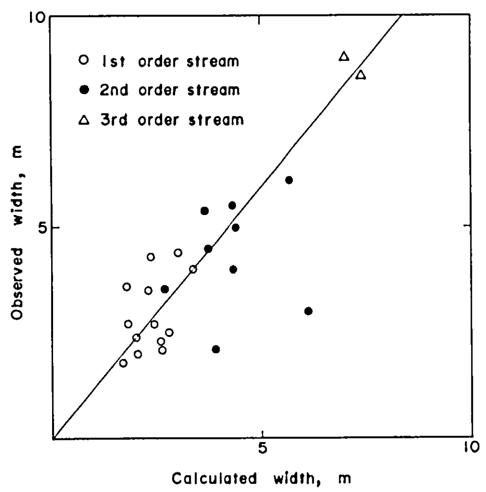


FIG. 5 Relation between the observed and calculated widths of S-II surface. The calculation was based on the Regime-theory related 100-year discharge.

2. *Analysis of Longitudinal- Section*

Fig. 8 shows the classification of the depositional form of S-I and S-II surfaces in longitudinal-section.

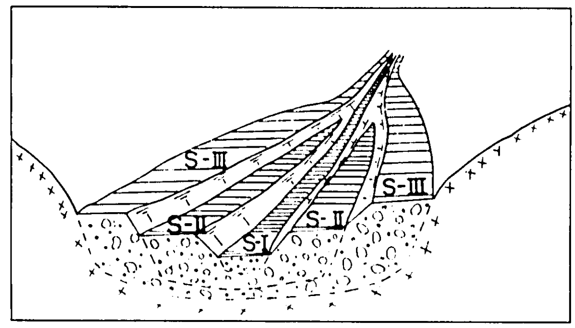


FIG. 6 Schematic illustration showing the detailed characteristics of the respective sediment surfaces. Note the relative heights of the surfaces at the mouth (see text).

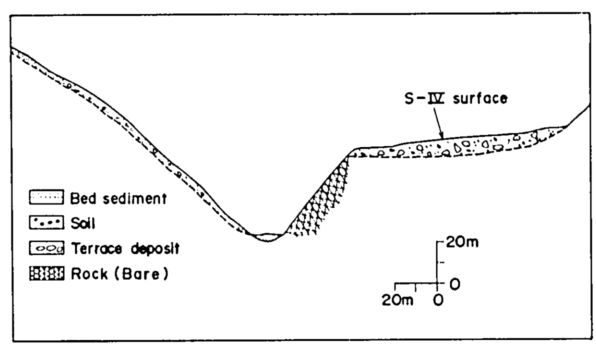


FIG. 7 S-IV surface (terrace deposits) developed at relatively higher level compared with that of the torrent bed (see text).

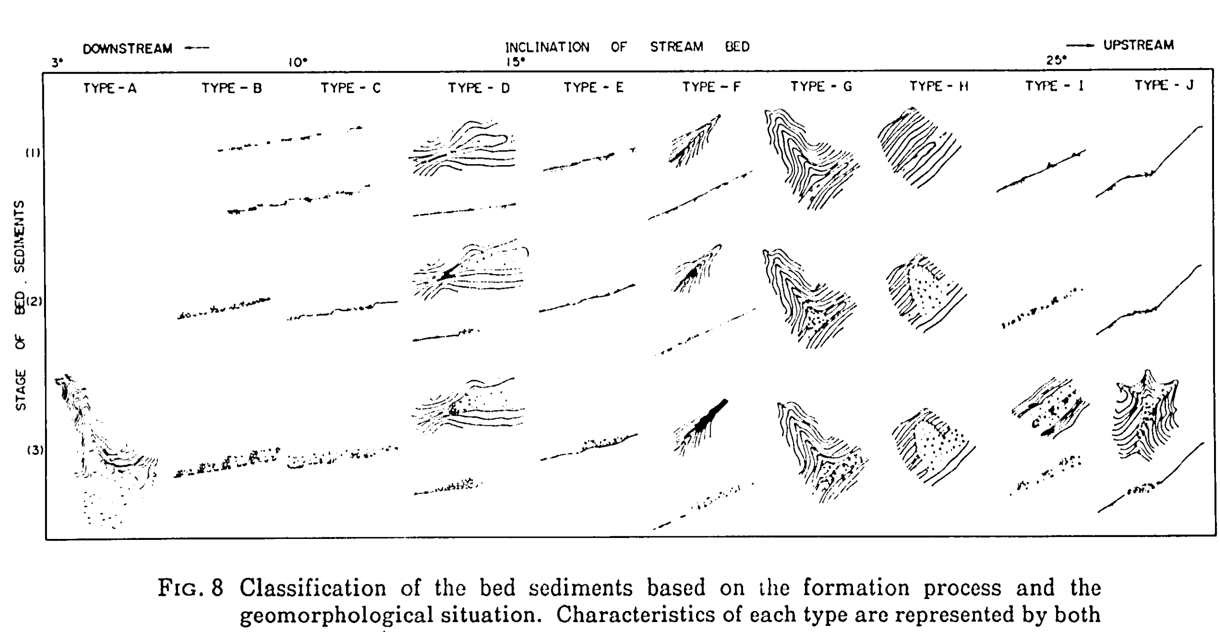


FIG. 8 Classification of the bed sediments based on the formation process and the geomorphological situation. Characteristics of each type are represented by both vertical and/or horizontal planes.

The axis of ordinate expresses the amount of sediments and the amount of sediment increase towards the lower. The abscissa expresses the bed inclination and the size of the catchment area of the sedimentary position.

TYPE-A is an alluvial fan where sediment deposits and is formed at the cross point of a stream and a broader lowland. There are two kinds of relations between a surface shape of the fanhead and a depositional surface on the upstream side. In one of the relations, the fanhead connects to a depositional surface of large relative height on the upstream side. In another relation, the fanhead connects to the present torrent bed. The former, the alluvial fan at higher position, is often subjected to a large vertical or horizontal erosion due to the present stream, and this fan has been formed at an older time (Ashida, 1985). The latter is a newer alluvial fan and is still continuing growth, i.e., the movement potentiality is decreasing even at the present. The distinction between a new alluvial fan and an old one is important to determine the dangerous zone for a debris flow disaster.

TYPE-B is a sediment of the regular step-pool structure which can be seen at the middle stream area. The formation mechanism of this step-pool structure is thought to be the combined effect between the formation of a bed wavelength-antidune and an armoring process (Whittaker et al., 1982). The growth size of this sediment effects the quantity of the energy of the debris flow (Ashida et al., 1983).

TYPE-C is located on a torrent bed having an inclination range of 10° to 20°. The characteristics of this type is a step-like structure of the base of torrent bed. The depositional area of TYPES-B and C is a place in the middle stream area which has a relatively small inclination and a large catchment area. During a long time preceding to the flood of large scale, these types could supply a large amount of sediment because of their active sedimentation.

TYPE-D indicates the condition of deposition on the upstream side of narrow points growing often inside of torrents. In many cases of this type, a very large amount of sand and/or gravel accumulates behind narrow point (Baba et al., 1983). It can be said that the movement potentiality of this sediment is relatively small.

TYPE-E and TYPE-F have left a deposit of sand and/or gravel behind obstruction, and their movement potentiality decreases. When the obstruction and the sediments are destroyed by a debris flow, most of the sediments move and increase the energy of the debris flow.

TYPE-E can be seen on a torrent bed with inclination of less than 20°. In this type, boulders of a diameter of 1 to 3 m play a role of obstruction (e.g. a weir) on the torrent bed, and sand and/or considerable amount of gravel deposit is usually developed.

TYPE-F indicates a condition where relatively loose sediments accumulate on a rock-pipe shaped torrent bed with an inclination of more than 20°. This type has a relatively high movement potentiality tending to cause a debris flow due to its large inclination.

In TYPE-G, a cone is formed by a debris flow or a rock avalanche originating in a lower order stream which flows into the torrent from the side slope. In this type, the cone plays role of a weir, and sediments derived from the upper-stream have been deposited. During a flood, the cone acts like a temporary weir and the sand, gravel and water often flow out altogether at a stroke vanishing the movement potentiality. Consequently, the cone, which can be seen at present, was formed later than the time of the peak flood in the main stream or was formed at a totally different time. The cone of this type can be formed in a wide range of area from the downstream to the upstream. From the view point of contribution concerning deposition of the sediment, the definition of this type is limited to the condition of areas in the upstream and the middle stream which are located on a relatively narrow torrent bed of inclination of more than 10°.

TYPE-H is a condition of sand and/or gravels supplied by a collapse derived from the slope in a side of the torrent bed. Those sediments close the main stream and, at the same time, the sediments play a role of weir resulting accumulation of deposits and water behind the weir. Like TYPE-G, this type is located in areas in the upstream and the middle stream, and the trace of the sediment is not preserved in many cases.

TYPE-I is what is called lobe of debris flow. The type has a shifting movement potentiality and this type performs, in general, reconstruction. It is found extensively in places like an alluvial fan in the downstream area, especially at a knickpoint in the middle stream area as well as on a torrent bed of an inclination of 20° and 30° in the upstream region. Until a large scale flow occurs, it develops and moves many times, decreasing the movement potentiality.

TYPE-J indicates a condition where sediments deposit on the bottom of a corn-shaped basin developed in the head of a torrent. In general, the sediments of this type are characterized by the uppermost stream of the depositional place in the head area and have a large bed inclination on the downstream side. The movement potentiality of these sediments effects strongly on the occurrence and scale of a debris flow.

B. Slope Sediment

In the field of applied geology in Japan so far, slope sediment has been usually treated as talus, but in this paper, the slope sediments are divided into seven types together with landslide block and residual debris. Fig. 9 shows the classification of the slope sediments

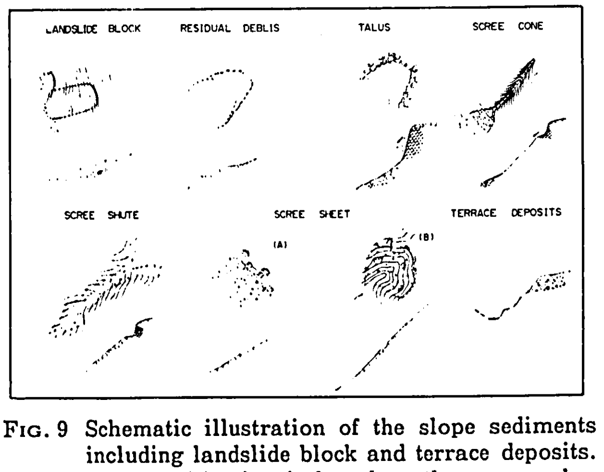


FIG. 9 Schematic illustration of the slope sediments including landslide block and terrace deposits. The classification is based on the geomorphological environments.

and the definition of each sediment is as follows.

Landslide block is a sediment accompanying certain landslide phenomenon at present and/or a sediment which has a clear trace of a previous landslide. The condition of a slide of this type is important in relation to the movement potentiality. The existence of new scarps which show the activity of a landslide and tension cracks indicates the increasing movement potentiality of the land slide block, and it would cause a large sediment flow if a sudden slide occurs.

Residual debris is a sediment which is located on or around collapse land. With respect to the movement potentiality, the geomorphological condition of this sediment gives more direct effect on a debris flow than the quantity. The dumping effect of residual debris is clearly shown in TYPE-H.

Talus is formed by fallen material clustered at the foot of a steep slope. Because most of the sediments of this type are composed generally of gravel and have a large angle of internal friction, it can be said that they have a lower movement potentiality concerning slope stability compared with other slope sediments. What differs from the residual debris is that the talus has a longer formation period and is relatively stable.

Scree cone is a cone-shaped sediment at the foot of a slope and always has a trace of flow on the upper slope. In a debris flow, the movement potentiality of this sediment type is very similar to that of the residual debris. As a typical example, there is a scree cone, which is composed of gravel of a diameter of 20 to 30 cm, in quartz porphyrite area of Kuroiwadani.

Scree shute is located between a scree cone and source of scree shute, i.e., a moving area of scree. The area shows a straight valley in mountainside having a relatively wide bottom area compared with catchment area. The potentiality of this type often depends on the stability of the upper slope.

Scree sheet is a condition where sediments are distributed on a relatively flat slope showing a sheet-like form. Scree sheet has a large inclination accompanying collapse occured frequently on its upper side as well as the inside of the scree sheet. Therefore, this sediment is repeating distinct growth and vanishing. Unlike talus, it has no clear cliff as a sediment source and shows two kinds of geomorphological conditions. One is the so-called rectilinear slope (A) and the other (B) is a rectilinear slope in a valley bottom in the head area (see Fig. 10). The slope inclination is more than 30°.

Terrace deposit has been formed two to three hundred thousand years ago. Although terrace deposit looks very stable at first glance, terrace deposit has a very low movement potentiality but is important for occurrence of catastrophical collapse. In the catchment area of the River Otani, terrace deposit contributed to increasing flow energy of a debris flow as a large scale landslide collapse, pushing sediments into the torrent bed.

III. CONDITION OF MOUNTAIN SEDIMENT SUPPLY

For establishment of the quantitative amount of fluctuation of mountain sediment, it is necessary to clarify the characteristics of geology, the vessel of the mountain sediment, as the sediment source. Supply condition of mountain sediment varies according to the geological characteristics. This means that the geology itself has a supply potentiality. Based on the

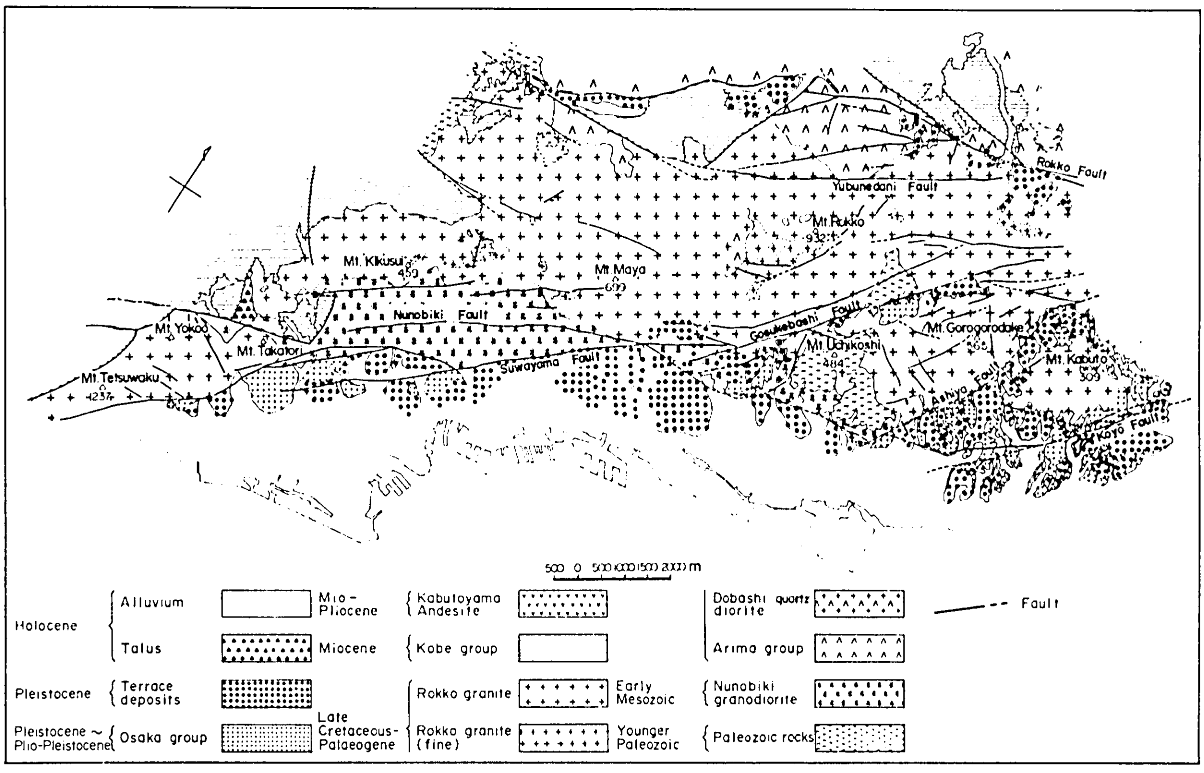


FIG. 10 The geological map of Rokko district, Kinki, Japan. (after Huzita et al., 1966 and 1971, partially modified by the present author).

understanding of the geology as supply potentiality, lithology, geological structure and weathering profile will be described in this chapter based on the field observations.

A. Lithology

As shown in Fig. 10, various kinds of rocks and strata beds both has different formation periods are distributed in the Rokko district (Fuzita et al., 1966 and 1976). Table 2 shows the results of a field survey carried out just after the disaster in 1967. The thickness of collapse was measured for each lithology and stratum bed at 202 typical collapse lands and the results are shown in terms of the scale. Selection of the 202 collapse lands was based on the examination of statistical viewpoint as well as of geomorphological and /or geological one. Therefore, results can be thought to indicate the features of slope collapse in each distribution area (Ministry of Construction, 1971). Fig. 11 shows percentage of collapse occurrence for each lithology and stratum bed. The number of slope collapse at the disaster in 1967, and the distribution of lithology and stratum bed were totalized for each 500m × 500m mesh (Sokobiki et al., 1986 b). Through collapse phenomenon in these tables and figures, the supply potentiality of lithology was estimated as follows.

The Palaeozoic formation of the Rokko district is composed of alteration of sandstone and shale overlied on the granite as roof pendant. The rock is often changed into hornfels and becomes hard and compact mass of rocks. The rock of this type is strongly resistive against weathering and accompanied with a thin layer of residual soil, and moreover, it mainly consists of clayey soil mixed with angular gravel. Therefore, it shows shallow collapse. The rock frequently supplies boulders of a diameter of about 1 to 3 m at the foot of a steep slope. The boulders are supplied with collapse due to joints of wide intervals

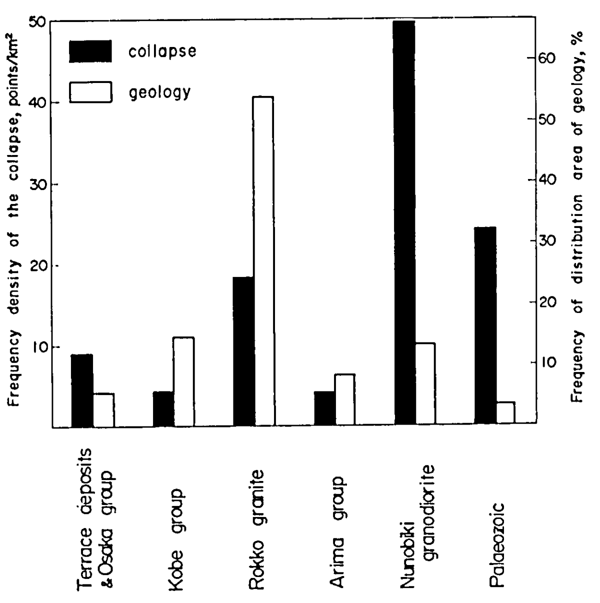


Fig. 11 Correlation of the frequency density of the collapse (solid pillar) and the distribution area of geology (open pillar).

Table 2 Relation between the collapse thickness and the geology in Rokko districts at the Rokko disaster of 1967 (data were taken from the Ministry of Construction, 1971).

	Collapse thickness of each scale (m)			
	0–200 m²	201–400 m²	>401 m	Average
Terrace deposits (Pleistocene)	1.29	0.80	0.80	1.15
Osaka group (Pleistocene)	0.83	1.00	1.00	0.97
Kobe group (Miocene)	0.76	3.50	1.78	1.57
Arima group (Cretaceous)	1.67	2.71	3.06	2.48
Rokko granite	1.09	2.41	2.46	2.23
Nunobiki granodiorite	0.49	0.83	0.96	0.89
Palaeozoic	0.51	0.70	1.00	0.91

and contribute to deposit the sediments (torrent bed sediment TYPE-D) on the upstream side of the boulders.

Seventy percent of the Rokko district is composed of granitic rocks which have intruded at the late Cretaceous age of about one hundred million to eighty million years ago. Though the Nunobiki granodiorite has shallowest collapse, it has a very high percentage of collapse occurrence. The Rokko granite, on the other hand, has a very deep collapse. However, in the mountain district of Kure in Hiroshima Prefecture, where Hiroshima granite of the same geological age is distributed, the most frequent thickness of collapse was 0.2 to 0.3m as shown in Fig. 12. The data are taken from the results of field survey performed on collapse land occurred in 1967 (Aboshi et al., 1972). From these results, it can be said that the deep collapse in the Rokko granite resulted from the effect of the Rokko movement which makes the whole rock fragile. Surface collapse shown in Fig. 12 is more general for its feature of collapse due to the lithological characteristics. It is well known that granitic rocks are easily subjected to weathering compared with other rocks and often form residual soil called "Masa" in Japanese. This makes frequent occurrence of surface collapse easily. The Nunobiki granodiorite, which contains much mafic mineral and plagioclase, has a smaller resistivity against weathering and it forms more "Masa" composed of fine grains on the slopes compared with the Rokko granite of higher acidity. Therefore, on the slopes in the Nunobiki granodiorite

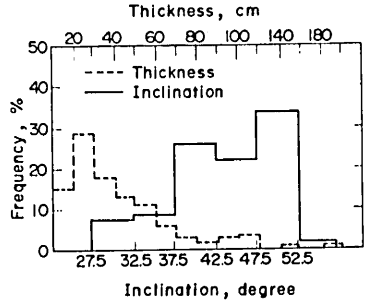


Fig. 12 Frequency distribution of inclination and thickness of the collapse at the Kure disaster of 1967 (by Aboshi et al.,1972)

area, more collapse occurs and supplies various forms of slope sediments containing much fine grains.

The Mesozoic Arima group is composed of rhyolitic tuff and rhyolitic tuff breccia. Though its lithology is generally hard and compact, joints of narrow intervals usually develop. Most of collapses occurr before the formation of residual soil and therefore, thin layer of slope sediment is formed on the slope. However, large scale collapse, the so-called structural collapse, can also be seen in places like fracture zone due to faults which have the effect of alteration and argillization. Because most of the collapses resulted from faults, the Arima group has the deepest but least frequent collapse as shown in Table 2 and Fig. 11.

For the relation between lithology and joints of the Rokko granite distributed in the upstream of the River Sumiyoshi, Ikeda (1968) showed that the joint interval became larger in the following order of grain size of rock forming mineral; fine grain (smaller than 1mm), medium grain (1 to 3mm), and coarse grain (lager than 3mm). Comparative studies of the joint interval of the Arima group of fine grain to that of the Rokko granite of fine to coarse grain in the north part of the Rokko district, reveal that the joint interval of Arima group is obviously smaller than the latter as is shown in Fig. 13. Lithology is not only the dominant factors of the joint interval but it is also necessary to consider other factors such as the effect of faults (Hirano, 1971 a). In any event, in a district which has small joint intervals like in the case of Arima group, there is a large supply of rock waste and gravelly slope sediments. As a similar case, Kuroiwadani in the River Sumiyoshi can be pointed out. Here, quartz porphyrite is distributed with a view of spectacle of desolution land.

The Kobe group belongs to the Miocene age and is distributed almost horizontally. Several layers of relatively continuous tuffaceous bed are intercalated in the sandstone and the gravel bed. The collapse thickness is relatively deep with average thickness of 1.57 m and the occurrence frequency is very small, because the foot of the vertical side wall of the torrent bed is eroded and its wall collapses in block due to the wide interval of joints. Moreover, the collapses of this group occur in fault zone. Generally, the Miocene tuff has been weakened by the repetition of a dry and wet climate during the geological ages, and those contained montmorillonite often cause large scale landslide in relation to the condition of the dip of the bed.

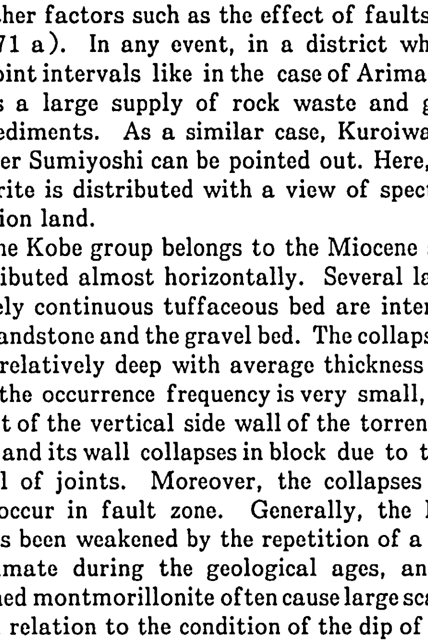


FIG. 13 Frequency distribution of joint interval observed in the granite and the rhyolitic tuff (Arima group). The data are those of in the catchment area of River Yamada, northwest of Mt. Rokko.

The Osaka group and the Terrace deposits in the Rokko district mainly consist of a somewhat compact gravel bed. They often form a cliff and would have a relatively deep collapse if there is a collapse involving a shoulder of the cliff. But in general, many of the collapses are originated from the surface, and slope sediments accumulated at the foot of the slope.

From the factors described above, district of the granitic rocks in the Rokko district has a very high percentage of collapse occurrence and high supply potentiality compared with other lithology and stratum beds. In addition, the different development of the joints due to the variation of lithology controls the character of the mountain sediment. Accordingly, lithology has marked effects in determinig the features of the supply material.

B. GEOLOGIC STRUCTURE

In the Rokko district, there develope large scale faults of NE to SW system, such as Gosukebashi fault, Suwayama fault, Ashiya fault and Koyo fault, as well as medium and small faults of WNW to ESE and EW systems. These faults are generated by a crustal movement called the Rokko movement which was activated two to three hundred thousand years ago (Fuzita et al., 1971). In an aerial photograph of the Rokko District, those faults can be recognized as clear lineaments. Fig. 14 shows these lineaments (Ministry of Construction, 1966). The relation between the fault and the collapse occurred in 1967, is reviewed in Fig. 15 for all of the Rokko district. In this figure, the width of the effected range of the faults is determined as 50m, and the collapse lands were divided into two parts, i.e., one in that range and the other out of that range. The number of collapse occurrences was compared for each unit area. From these results, it can be safely said that the collapse is not always affected by the faults. Fig. 16 shows the frequency of the angle between the direction of the main stream and that of the faults in the first order stream basin. The frequency was calculated according to the existence of debris flow. From this figure, it is evident that debris flow occurs when the direction of fault corresponds to that of the main stream, i.e., the fault valley. As it was pointed out by the present author, the debris flow in the null order basin is almost equal to the collapse, and more than 80% of the debris flow is moved down to the higher order stream (Sokobiki et al., 1986 b). Therefore, it may be concluded that there is a close relation between fault and collapse. Fig. 17 shows typical areas indicating the above relations. Case (a) is located around the Nunobiki fault and has many collapses with no relation to the fault, and case (b) has many collapses affected by Gosukebashi fault. The collapse lands in the Rokko district, which were formed during the dissaster of 1967, were also divided into the collapse lands occurred close to fault zone, deep weathering zone, outcrop zone, and to other conditions. Fig. 18 shows the proportion of each collapse land expressed by the accumulative frequency. From this figure, it can be seen that the proportion of collapse accompanied by fault is rather low (about 20% among the total case) and surface collapse represented as other conditions in Fig. 18 has the largest number of cases. However, the existence of a fault has a clear relation

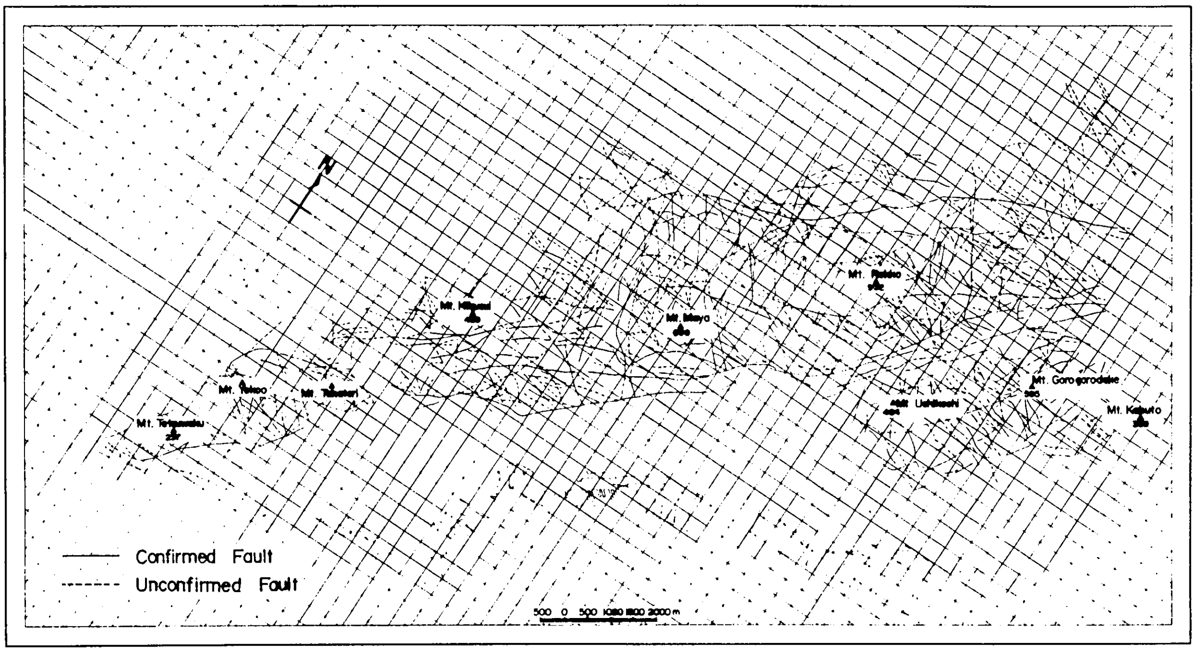


FIG. 14 Linearment map of Rokko district.

to the occurrence of collapse. Especially in cases where faults are found at the valley in the upstream area, such as the catchment area of first order stream, the collapse tends to occur in that slope. The fault also has another effect on the collapse, to make the scale of collapse larger. This type of collapse occurs when a sliding plane corresponds to a fault which is deeply located and accompanied by weakened fracture zone. The frequent occurrence of this type of collapse is expressed by the depth of collapse as is represented in Table 2. The large scale collapse supplies sediment catastrophically but a fracture zone caused by large fault often forms desolution land and supplies sediment regularly.

The existence of a fault is important because the

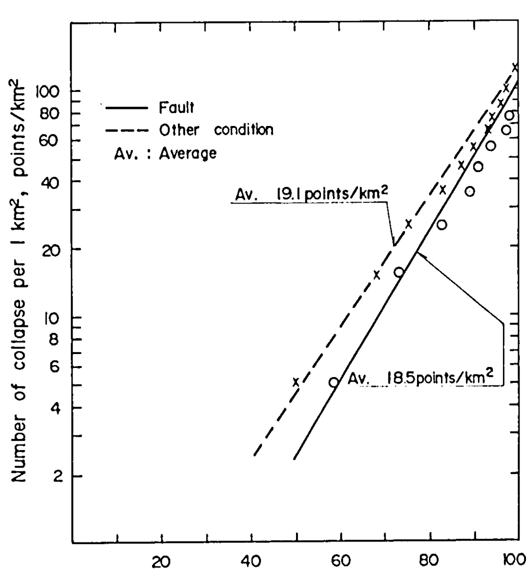


FIG. 15 Collapse frequencies showing the relation between those of the fault zone and those without fault.

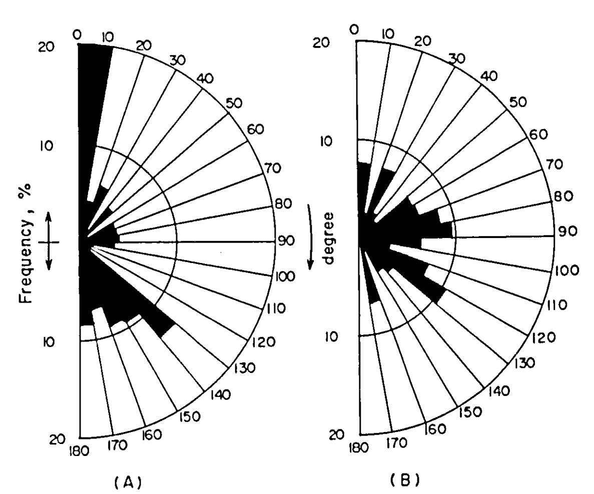


FIG. 16 Interrelationship between the directions of faults and valleys in the first order stream basin. (A) is the result of the disaster district and (B) is that of non-disaster area.

fault can be restricted to the place of high supply potentiality, that is, the places where the collapse centralizes, a large collapse occurs and sediment is supplied regularly.

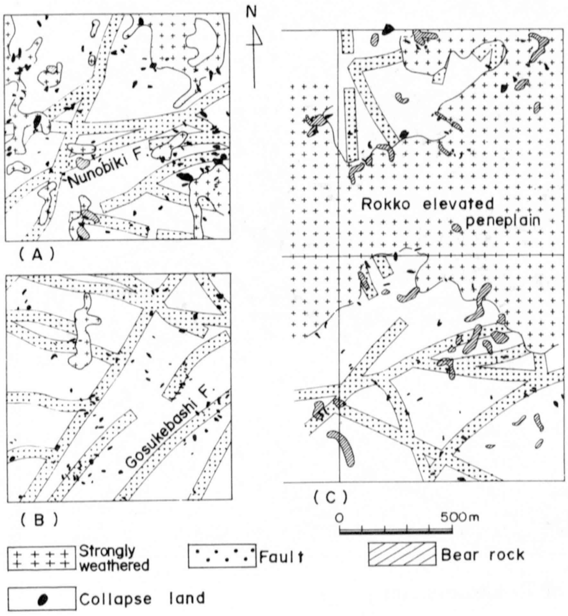


FIG. 17 Distribution patterns of collapses occurred at the Rokko disaster of 1967.
A. occurred apart from the fault.
B. occurred close to the fault.
C. occurred mainly on the shoulder slope of the thick weathered granite.

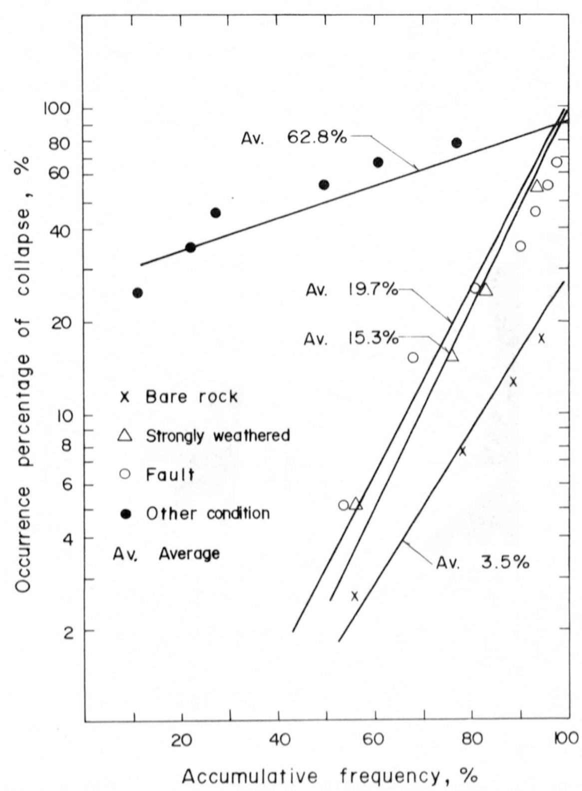


FIG. 18 Relation between collapse frequency and the geological factors.

C. WEATHERING PROFILE

The Rokko district was upheaved by a crustal movement of the Rokko movement, and achieved the present elevation. This movement has occurred during the Early Pleistocene to the Middle Pleistocene (two to three hundred thousand years ago) resulting from compression from an east to west direction (Fuzita et al., 1971). Therefore, weathering profiles are formed before the movement and are distributed at various altitudes at present. The Rokko district is recognized geomorphologically as a planation surface (e.g., Rokko elevated peneplain) accompanying common distribution of "Masa". Fig. 19 shows the grade of weathering in the torrent beds located in the areas where the most typical step fault topography is developed. Fig. 20 shows the cross section of the same district. As shown in Figs. 19 and 20, an older weathering zone is left over the planation surface because the chemical weathering zone of C3 to C1 defined by Kakitani (1974) which corresponds to CL to D zones in the classification of Tanaka (1964) appears repeatedly under each

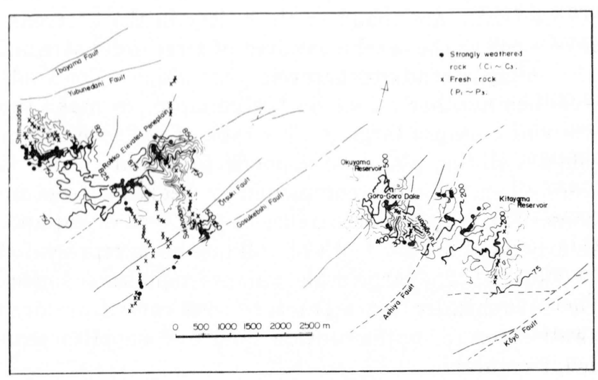


FIG. 19 Characteristic distribution of the strongly weathered rock (C1-C3 : circle) in Rokko district which is consisted of several fault blocks with steep fault scarps. Hard rocks of P1-P3 are represented by crosses. See Fig. 20.

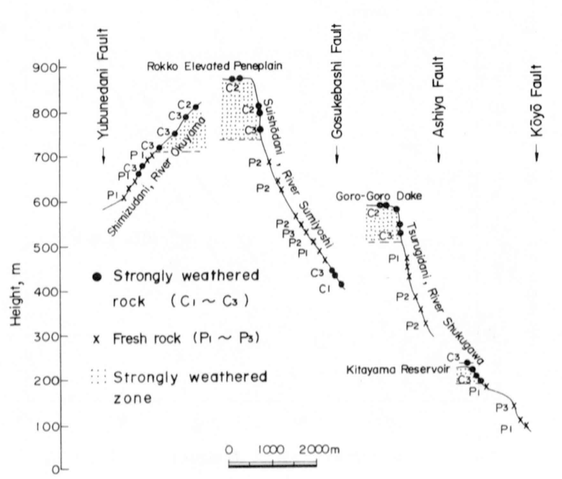


FIG. 20 Schematic cross-section profile of the districts shown in Fig. 19. See text.

planation surface. Furthermore, the large scale fault forms the boundaries of each weathering block. As regards this point in the Rokko district, the distribution area of granitic rocks has a condition where a new weathering profile is piled up on an older weathering profile represented by planation surface.

The present author has already pointed out that collapse in the null order stream could be the trigger for debris flows in the Rokko district (Sokobiki et al., 1986 a and b). The collapses in the null order stream are closely regulated by the geomorphological and geological conditions. The fact is reasonably understandable because many of the null order streams are formed in the Cl to C3 zone of an old weathering zone. Fig. 17 (c) shows the condition of the collapse lands distributed on steep slopes in the Cl to C3 zone which develop widely on the Rokko evaluated peneplain. In each zone, the sediments are supplied mainly by collapses. The type of collapse in C1 zone is a superficial collapse containing much sandy soil. In C2 zone, the collapse of "Masa" and/or core stones occur and that in C3 zone tends to be a rock collapse.

As was described above, the weathering profile restricts places of high supply potentiality and regulates its qualitative character. To determine form and character of the mountain sediments, it is necessary to clear up the weathering profile of the upstream slopes.

IV. Evaluation Method as Occurrence Potentiality of Sediment Disaster

In the scale of geomorphological and geological time, sediment disaster accompanied with the movement of mountain sediment can be understood as an ordinary portion of the denudation phenomenon of the lands. In the field of Sabo, it is treated as a phenomenon of sediment production and discharge. From the point of view of hydrologic hydraulics, it is the movement phenomenon of a fluid. In this paper, the author defines the temporal and spacious movement of sediment as a variation of occurrence potentiality of sediment disaster and, significance of the idea will be discussed in this chapter.

A. Variation of Movement Potentiality

Concerning the movement potentiality, two kinds of definitions will be used, one in the broad sense and the other in the narrow sense. In the broad sense definition, the movement potentiality is concerned with a broad geomorphological and geological scale as well as a long temporal scale. In this case, the movement potentiality means the relative height from the base level for stream erosion, which is the result of upheaval or submergence caused by crustal movement as well as the movement of sea level. In the narrow sense definition, the movement potentiality is concerned with a short temporal scale within a limited area, where the geomorphological and geological field can be fixed closely to the present state of condition. This movement potentiality in the narrow sense is the movement potentiality of the mountain sediment and the supply potentiality based on the geological conditions which were mentioned in the previous chapters.

Concerning a certain mountain district, the movement potentialities of various levels are distributed in various positions, and the sum of these potentialities is the highest movement potentiality of this mountain district, i.e., the latent movement potentiality. An occurrence of anomalous sediment discharge in a mountain district does not mean a discharge of all sediments based on this latent movement potentiality but a discharge of a part of them. The undischarged sediments will be re-equilibrated into a new movement potentiality under new conditions. A sediment discharge is a natural phenomenon and will not be called as sediment discharge until the sediment discharge will relate to our life in the form of a debris flow or a continuous large sediment discharge. The movement potentiality, which is concerned with the sediment discharge, is defined as "occurrence potentiality" of sediment disaster.

In other words, "occurrence potentiality" is a evaluation of the movement potentiality of mountain sediment which is distributed in mountain districts and has a relation to the next sediment disaster. Therefore, it can be said that the form, scale and location of the mountain sediments, the geological classification and structure as well as the distribution of the weathering profile and other factors express "occurrence potentiality".

At first, it should be noted how the torrent sediment moves in the longitudinal section. Fig. 21 shows the amount of movement of the sediment during the disaster in 1967. It was measured per unit length at each location in the main stream in the Rokko district. In the respective figure, the upper side of the broken line expresses the discharged amount and the lower side expresses the deposited amount. In (a), the state of the Suishodani in the River Sumiyoshi is shown. Every location has quite different amount of sediment and a large sediment discharges. In (b), the state of the River Arino is shown, where a small amount of ediment shifts repeating accumulation and discharge. In (c), the state of the River Ashiya is shown. There is a sediment discharge at every location although the amount is not as much as that in the Suishodani. In (d), the state of the River Uji is shown. Here, the sediment is subjected to small movement, indicating small amplitude and a large cycle. In addition, the existence of large sedimentation means deposition of sediment on a checkdam.

As is evident in Fig. 21, the movement pattern of the sediment varies depending on the geomorphological condition of the torrent bed and each torrent bed is oscillating with its own amplitude and cycle.

Because there is a fluctuation in the amount of sediments in the longitudinal section of the torrent bed and the oscillation varies according to the geomorphological condition before the movement of the torrent, another type of oscillation is expected to occur at the next flood. The fluctuation means that an amount of the sediment is varying continuously at each location of torrent bed as is seen in Fig. 22. Concerning the Rokko district, the frequency distribution of amount of sediment measured through field survey of 272 torrents is shown in Fig. 22 for the respective value obtained by multiplying the catchment area by the inclination of each location. It is seen that the depositional amount varies even between similar depositional conditions, and moreover, the frequency distribution also varies depending on the depositional condition.

This kind of movement expresses the quantitative change in the torrent bed sediment, that is, the growth and vanishing of the sediment. The movement also causes the ocsillation because it brings out the variation in potential energy due to change in depositional condition in the longitudinal-section. Naturally, this kind of movement is strongly effected by the shifting of the slope sediment toward the torrent bed.

As a typical example, the case of the Suishodani can be pointed out where very large movement caused a large amount of deposition of the torrent bed sediments before the flood, and moreover, the movement potentiality in that area was low. Probably, there was a slope sediment with catastrophic factor in a slope of that catchment area and a large scale debris flow took place.

If the sediments are concerned with a conception of growth and vanishing with the passage of time, a certain location in a torrent bed can be expressed as shown in Fig. 23. In Fig. 23 (A), the ordinate expresses an amount of the sediment, and the abscissa expresses the time. and the change of torrent bed is schematically expressed. One of the cycles of the change is enlarged in (B). The sediment started to accumulate at point (a) and with the duration of time, it underwent a flood at point (b) and shifted suddenly, then reached point (c). After that, the accumulation process stopped for a while and the torrent bed started to decline. These occurrences are included in one cycle which will continue until the ideal graded profile of the river will be achieved as was suggested by Davis (1954). Though the scale of the cycle can be determined with probability, it should also be noticed that we are looking only at one cycle of the present state. When we forecast future disasters,

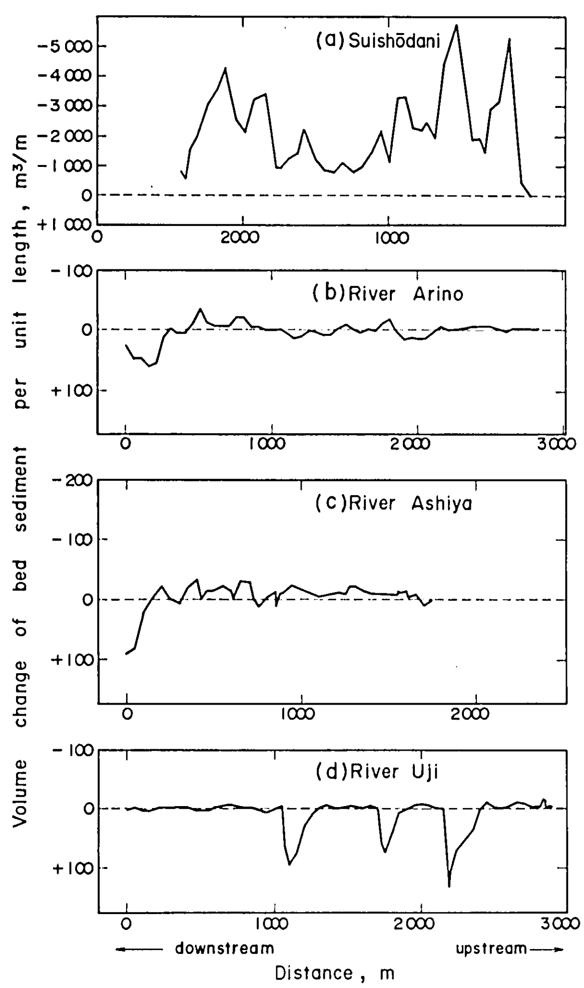


FIG. 21 The volume change of the bed sediments along several rivers at the Rokko disaster of 1967. The dotted line separates the discharge (above) and deposition (below). See text.

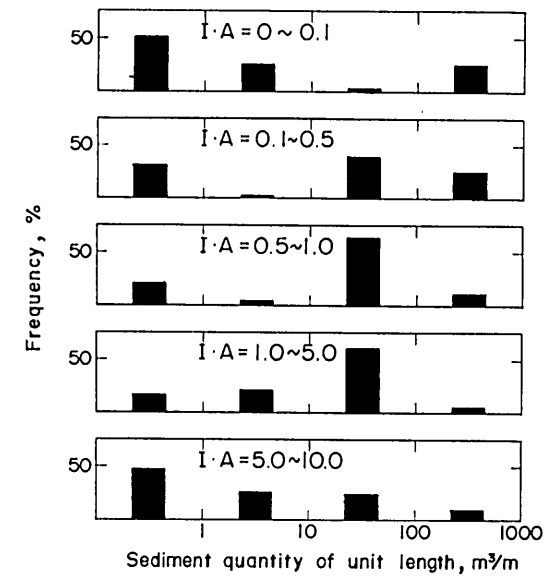


FIG. 22 Dependence of frequency distribution of movable sediments on the I×A. I: bed inclination, A: Catchment area.

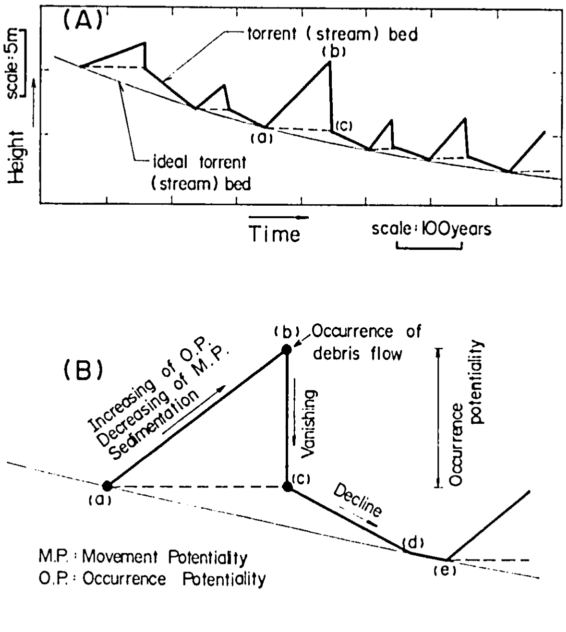


FIG. 23 Schematic illustrations of the movement and disaster potentialities.

it is necessary to estimate the grade of movement potentiality. The potentiality, which moves from point (b) to point (c) during the next sediment disaster, can be called as "occurrence potentiality". Therfore, the total of these potentialities in all the related catchment areas also can be called as the "occurrence potentiality".

With this in mind, it is possible to evaluate the occurrence potentiality concerning the amount of torrent bed sediment according to the following qualitative classification of the three grades: 1) a condition where outcrops can be seen on the torrent bed, 2) a condition where the sediment grows abnormally and 3) a condition between the previous conditions. The evaluation also includes the states whether the present condition of each grade is growing or conversely vanishing. The force of the stream can be evaluated from the catchment area and bed inclination in the depositional area; in short, the force can be estimated in the longitudinal position.

B. Evaluation Method of Occurrence Potentiality

1. *Criteria*

The present state of the occurrence potentiality is evaluated from a distribution map of the mountain sediments (Fig. 24). The numerical system was adopted for the evaluation, and a sediment with a higher number of points was evaluated to have a higher occurrence potentiality. The torrent bed sediment is evaluated by these degrees as is shown in Table 3, in which the ordinate is divided into three ranks of 1 to 3 points. TYPE-A is not treated here because a discharged sediment shows the movement potentiality in depositional area. For the axis of abscissa, a sediment of rank 1 is given 1 point, and that of ranks 2 and 3 are given 4 and 5 points respectively, when a place satisfies the geomorphological condition of the bed inclination of more than 15° or the catchment area of more than 0.1 km². Using the above procedure, the occurrence potentiality can be evaluated and further, total movement potentiality of the sediment together with force of the stream can also be established. Table 3 shows the distribution of the points obtained by this procedure. The values in this table are for the cases where the torrent bed belongs to TYPE-E～TYPE-J and has a bed inclination of more than 15° and/or a catchment area of more than 0.1 km².

With the same conception, the occurrence potentiality of the slope sediment will be defined and evaluated. Ideally, the movement potentiality of the slope sediment is the same as that of the torrent bed sediment. The stability of the slope sediment depends on the ratio between the shearing strength against the shearing stress caused by slope inclination. Because this ratio is a function of the slope inclination, the potentiality is evaluated equivalently as the force of the stream in the torrent bed sediment.

As shown in Table 4, each type shown in Fig. 8 is evaluated into four ranks from 1 to 4 points according to its slope inclination. As the datums inclination, angle of 35° was used becase the degree is the standard angle of internal friction of a gravel sediment. For the sediment accompanied with phenomena of vanishing, 2 points were added. For example, existence of scarp, gully, scar of collapse and trace of flow are those phenomena, resulting from the point raised to 3 to 4 points. The movement potentiality is relatively determined by the distribution area of the sediment and the numerical system is not used for the evaluation (Fig. 24).

Because the geology of the basement is an important supply source of mountain sediment and the geology itself has a supply potentiality as mentioned before, it will be necessary to evaluate the geology for its occurrence potentiality. A certain geological condition itself such as lithology, existence of fault and location in weathering profile has the supply potentiality. Consequently, the occurrence potentiality can be evaluated from the condition of geological distribution as was described in chapter Ⅲ.

With these evaluation methods, the statistical data of mountain sediments and a geological condition have converted into dynamic data. The occurrence potentiality of the River Hirami on the north side of the Rokko district was evaluated by the method described above and the results will be explained in the following.

TABLE 3 EVALUATION MARKS OF THE DISASTER POTENTIALITY FOR THE RESPECTIVE TYPE OF THE SEDIMENTS. TYPE A IS NOT EVALUATED IN THIS PAPER BECAUSE OF THE EXTENSIVE URBANIZATION. THE MARKS IN THE DOTTED RANGE (TYPES F-J) ARE ADDED 2 POINTS RESPECTIVELY, BECAUSE THESE SEDIMENTS ARE RELATIVELY IMPORTANT IN THE CATCHMENT AREA (MORE THAN 0.1km²) AND IN STEEP INCLINATION (ABOVE 15°).

Stage \ Type (Inclination: 3° 10° 15° 25°)	A	B	C	D	E	F	G	H	I	J
(1)	—	1	1	1	1	1	1	1	1	1
(2)	—	2	2	2	2	4	4	4	4	4
(3)	—	3	3	3	3	5	5	5	5	5

TABLE 4 EVALUATION MARKS OF DISASTER POTENTIALITY FOR THE SLOPE SEDIMENTS.

Stage \ Type	LS	RD	T	SC	SSHU	SSHE	TD
<35°(S)	1	1	1	1	1	1	1
>35°(S)	2	2	2	2	2	2	2
<35°(U)	3	3	3	3	3	3	3
>35°(U)	4	4	4	4	4	4	4

LS: Landslide block RD: Residual debris T: Talus
SC: Scree cone SSHU: Scree shute SSHE: Scree sheet
TD: Terrace deposits (S): Stable (U): Unstable

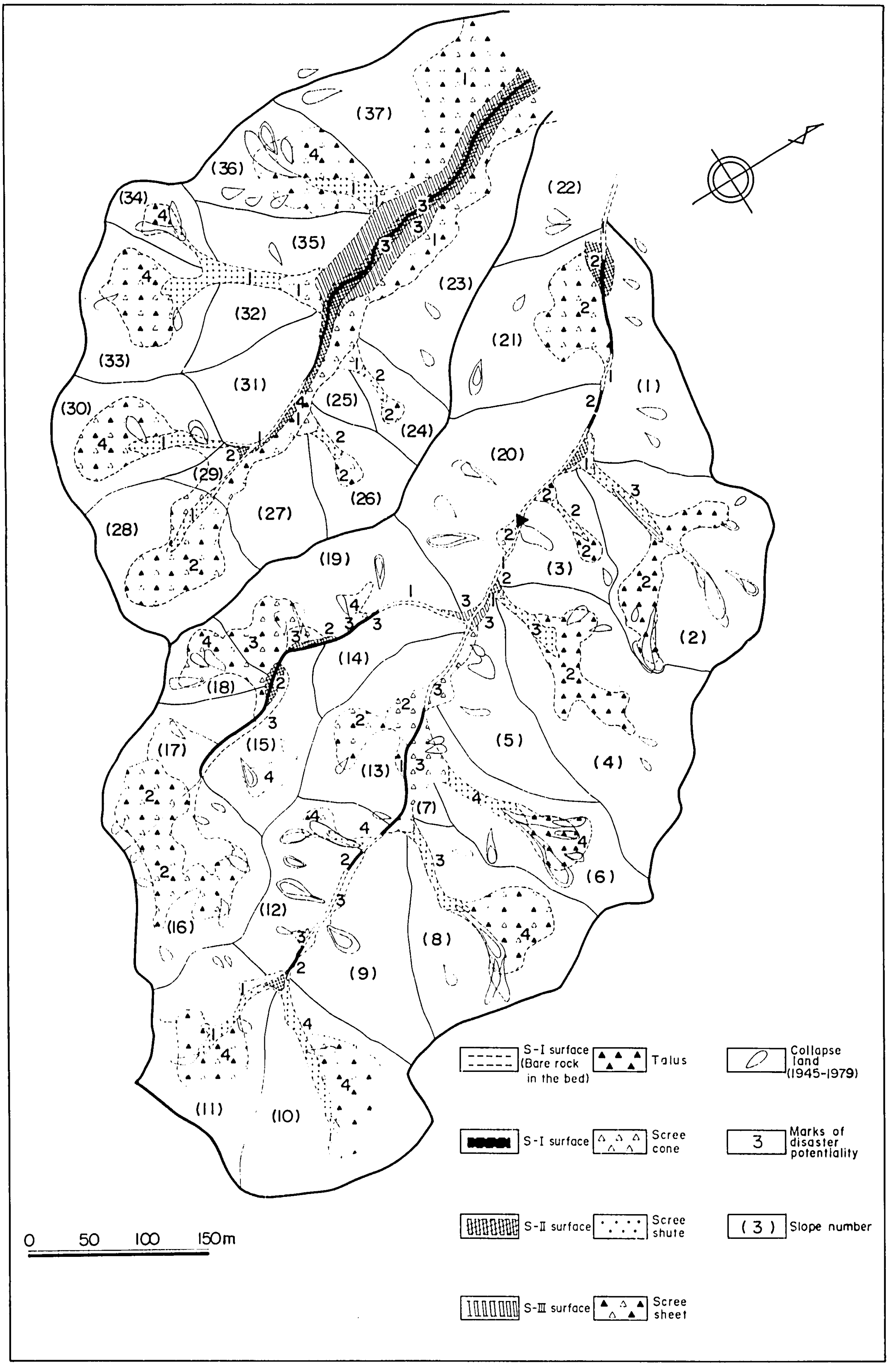


FIG. 24 Preventative geological map of the River Hirami basin , Rokko district (I).

2. *Case Study*

(1) Evaluation of Occurrence Potentiality of Sediment Disaster Concerning Geology

As is shown in Fig. 25, the geology of the district is composed of medium-grained Rokko granite whose average grain size is 1 to 3mm. In the upstream area of the right tributary, the grain size became somewhat larger and in the outside of the catchment area, the medium grained granite changes to that of coarse-grained (more than 3 mm). In the middle stream area, porphyrite dike of a width of 10 m is distributed in the NE to SW direction. Because of the distribution of granite, it is shown that this area has a very high percentage of collapse occurrence, i.e., high occurrence potentiality (cf., Sokobiki et al., 1986b). As the geological structure, the Yubunedani fault is recognizable in NE to SW trends on the north side of the catchment area. This fault is accompanied with fracture zone of about 50m with a thick fault clay. In the catchment area, secondary faults can be recognized as lineaments. Among these faults, L-4 and L-5 show good succession, and exact evidence of fault is confirmed on L-5 and L-6. L-5 fault is accompanied with fracture zone filled by fault clay of about 40cm width, and L-6 is accompanied with a zone of numerous joints. The width of the zone is about 1m.

The three joint systems are recognized in the district, i.e., vertical NE and NW systems, and almost horizontal one with slight inclination to the west. The interval between those joints is about 20 to 100 cm. When those faults exist on the upper part of a torrent, it can be said that the torrent has a high occurrence potentiality for collapse and sediment supply. Slope numbers (2), (4), (6), (28), (30), (33) and (36) are typical examples.

With respect to weathering structure, an older weathering profile is recognized, that is, "Masa" of C1 zone in the planation surface of the source area, C2 zone in areas at an altitude of more than 640m and of C3 zone in areas at an altitude of less than 640 m. A new weathering profile is piled up on the older one and a thin layer of "Masa" is formed all over the slopes. Taking these facts into consideration, potentiality concerning the area of sediment supply in each weathering zone and potantiality for grain size of accumulated substances can be evaluated. For example, a large amount of sediment will be accumulated in the C1 and C2 zone.

(2) Evaluation of Occurrence Potentiality of Sediment Disaster for Mountain Sediments

Fig. 24 shows a distribution of mountain sediments and the evaluated point of the occurrence potentiality. The evaluation point is obtained based on the method described in Table 3.

In the right tributary, the torrent bed has a step-pool structure and frequently shows outcrops. In some places, waterfalls of a height of 1 to 5m are formed (TYPE-C; 1 point). There develops often a thin layer of gravel deposits on the step like surfaces (S-I surface). The distribution of S-II surface is seldom and TYPE-G (2 points, the cone is destroyed and shifted from STAGE 3 to STAGE 2) and TYPE-I (2 points, the lobe is eroded after the deposition and converted from STAGE 3 to STAGE 2) are distributed in the left tributary. In the downstream area, S-III surface is widely distributed at the place with relative height of 5m from S-I surface (TYPE-D; 3 points). The S-II surface is distributed at a relative height of 1m with width of 10m.

In this surface, an older stream of the torrent is developed indicating the shift of the S-I surface (TYPE-G; 3 points). The S-I surface, which corresponds to TYPE-C (3 points), is composed of sediment containing about 50% gravel of a diameter of 10 to 20cm. In the middle stream area, the S-I surface forms TYPE-B which is composed of gravel with 20 to 30cm diameter (4 points, bed inclination of more than 15°). The S-II surface shows the form of TYPE-C (4 points). From these results, it can be said that the left tributary has a higher occurrence potentiality of the torrent bed than the right tributary at this point of time.

In slopes of the valley type, talus and scree sheet are commonly distributed. In (2), (4) and (6), the talus is surrounded by a rock wall. The bottom surface of the valley is relatively clear and is composed of gravel whose average diameter is in the range of 20 to 30cm and the largest diameter becomes almost 80cm. The slopes in (2) and (4) were given 2 points and that in (6) was given 4 points because of many traces of collapses. A part of the sediment supply of the talus includes rock collapse and has the character of residual debris. On the contrary, the scree sheet has no clear bottom surface of the valley, and lies flat all over the slope. The sediment of scree sheet mainly consists of "Masa" and contains a small amount of gravel with diameter of about 20cm. In many cases, a small collapse land can be seen on the upper slope of the scree sheet distribution area as the source of sediment supply. In the scree sheet distribution area, plants are relatively poor and the slow movement of sediment has been estimated because of the progress of a gully and the discharge of fine grained sediments (16). Many of these slopes have an inclination of more than 35° and they are evaluated at 2 points. Another feature is the frequent occurrence of collapse in the scree sheet. Because this condition is significant in slopes (10), (18), (36), they have been evaluated at 4 points. In the upstream area, the scree sheet along the torrent bank becomes unstable due to the torrent bank erosion. In such a case, 3 points are given as it directly supplies sediment to the torrent bed by the torrent bank collapse. Scree shute is evaluated at 4 points because it often leaves a trace of flow (6, 10), and moreover it has a large inclination. In locality (24), a new scree shute was caused by a large scale rock collapse (evaluating point is 2). A scale of scree cone not only depends on the area, grain size and depositional form of the upper slope, but also depends on whether the scree cone is easily washed out in the torrent bed or not. For instance, the size is relatively small in localities (2), (4), (10), (11) and (30) and is rather large in (6) and (32). As shown above, the relation between the scree cone and the torrent bed is also included in determining the evaluation value and the points are determined by the same method as in the case of the scree sheet along the torrent bank.

Figs. 24 and 25 are composed according to the above procedure and they show the locations of high

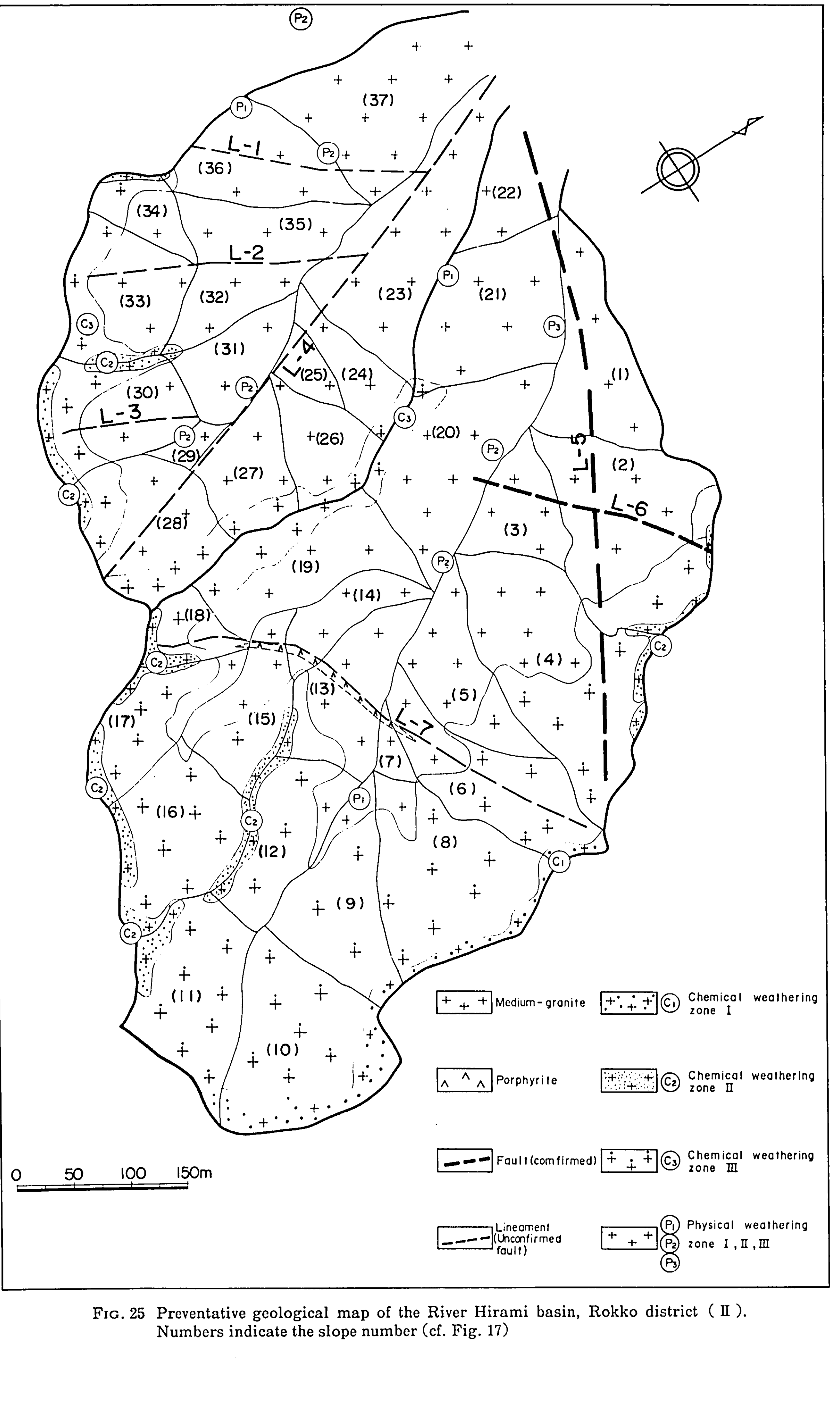


FIG. 25 Preventative geological map of the River Hirami basin, Rokko district (II). Numbers indicate the slope number (cf. Fig. 17)

occurrence potentiality as well as their distribution. Therefore, for the construction (charting) of a hazard map or a Sabo plan based on these figures, one should obtain a rational plan reflecting more precisely the geomorphological and geological condition of the catchment area than that made before.

V. Hazard Map Charting for Sediment Disaster

A. Charting Method

In general, a hazard map has been charted based on the various kinds of factors to determine the degree of danger and or dangerous zone of certain district. On this occasion, the first problem is the scale of the map. Most of the previous hazard maps are drawn on a scale of 1/200,000 to 1/25,000. However, a more precise hazard map is needed for cases like Rokko where the geomorphology and geology are complicated and the towns enter deeply into the mountain district. In this chapter, the author tries to chart a hazard map of the catchment area of River Hirami which has an accuracy of the scale of 1/2,500.

Based on the previous researches by the present author (Sokobiki et al., 1986 a and b), factors illustrated in Fig. 26 were chosen. This figure also shows the general procedure for hazard map charting accepted generally at the present. But the "occurrence potentiality", which is indicated by a broken line, is newly introduced into the factors. This introduction allows more precise reflection of the geomorphological and geological characteristics of the catchment area.

B. Featurez of Catchment Area of River Hirami

1. *Geomorphology*

The River Hirami flows on the steep slope risen from the elevated peneplain. This elevated peneplain develops on the northen slope of the Rokko district at an altitude of 700 to 800m on the hanging side of the Yubunedani fault.

The catchment area treated in this analysis corresponds to the source area of the River Hirami. The area is 0.37km² and the ratio of relief energy is calculated as 0.65. A part of the elevated peneplain can be seen near an altitude of 700m. From this point, a steep slope at an inclination of more than 35° develops continuously (Fig. 27). The covered catchment area in the right tributary is 0.245km² and has an average bed inclination of 14.3°, and in the left tributary, the area is 0.125km² and has with an average bed inclination of 13.4°.

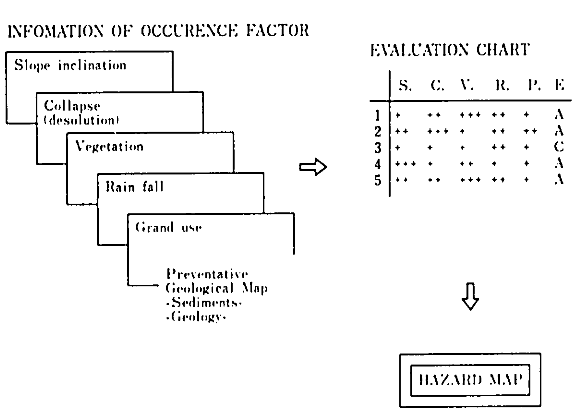


Fig. 26 Flow chart illustrating the composition process of the hazard map.

2. *Condition of Denudation*

Fig. 28 shows the collapse lands occurred during 1945 to 1979. Examination of the collapse in relation to faults reveals that collapse land centralizes upon the upper part of the slope accompanied with the faults of L-1, 5, 6 and 7. In relation to the weathering profile, there is more collapse in the upper part of the C3 zone. As for the geomorphological condition, more collapse is seen in the neighbourhood of knick point between C1 and C2 zones. Considerable numbers of collapses are also found in P1 and P2 zone. These collapses are restricted by joints and originated in "Masa" formed by weathering at the earlier period.

3. *Vegetation*

Fig. 29 shows the distribution of the vegetation in the district. In this figure, the distribution is divided into four zones, i.e., 1) density of needle-leaf trees (pine), 2) coarse of needle-leaf trees (pine), 3) deciduous trees and 4) grassland, scrub and bare land. The distribution of the deciduous trees closely corresponds to that of the scree sheet and the torrent bed sediment. The distribution of the bare land almost corresponds to that of C2 and C3.

C. Hazard Map Charting for Sediment Disaster

From the above geomorphological and geological data, it is possible to evaluate the stability for each slope and the amount of sediment discharge in the recurrence interval of 200 years in the River Hirami, and to establish the dangerous zones corresponding to the evaluation.

In Table 5, the slopes are evaluated for five items and divided into three classes. The degree of danger is estimated by its total evaluation. The results are shown in Fig. 30, the hazard map. With respect to the amount of the sediment discharge, Kobashi et al. (1978), Sokobiki et al. (1981), and Tani et al. (1982) have already explained the state of the torrent bed movement mainly in the River Sumiyoshi during the disaster in 1967 using the Mayer Peter's tractive formula. Especially, the present author (Sokobiki et al., 1981) has estimated the amount of sediment discharge from the slopes using the forecasting formula for slope collapse proposed by Kobashi et al. (1978). In that paper, the present author has established a computer program including the amount of sediment discharge. Using this established program, the amount of sediment discharge was caluculated in this paper. In this case study, the sediment is supposed to be discharged from the most dangerous slopes obtained from the data listed in Table 5, and the quantitative evaluation is performed based on the results shown in Fig. 24. As a result, a sediment discharge of 5,000m³ is forecasted

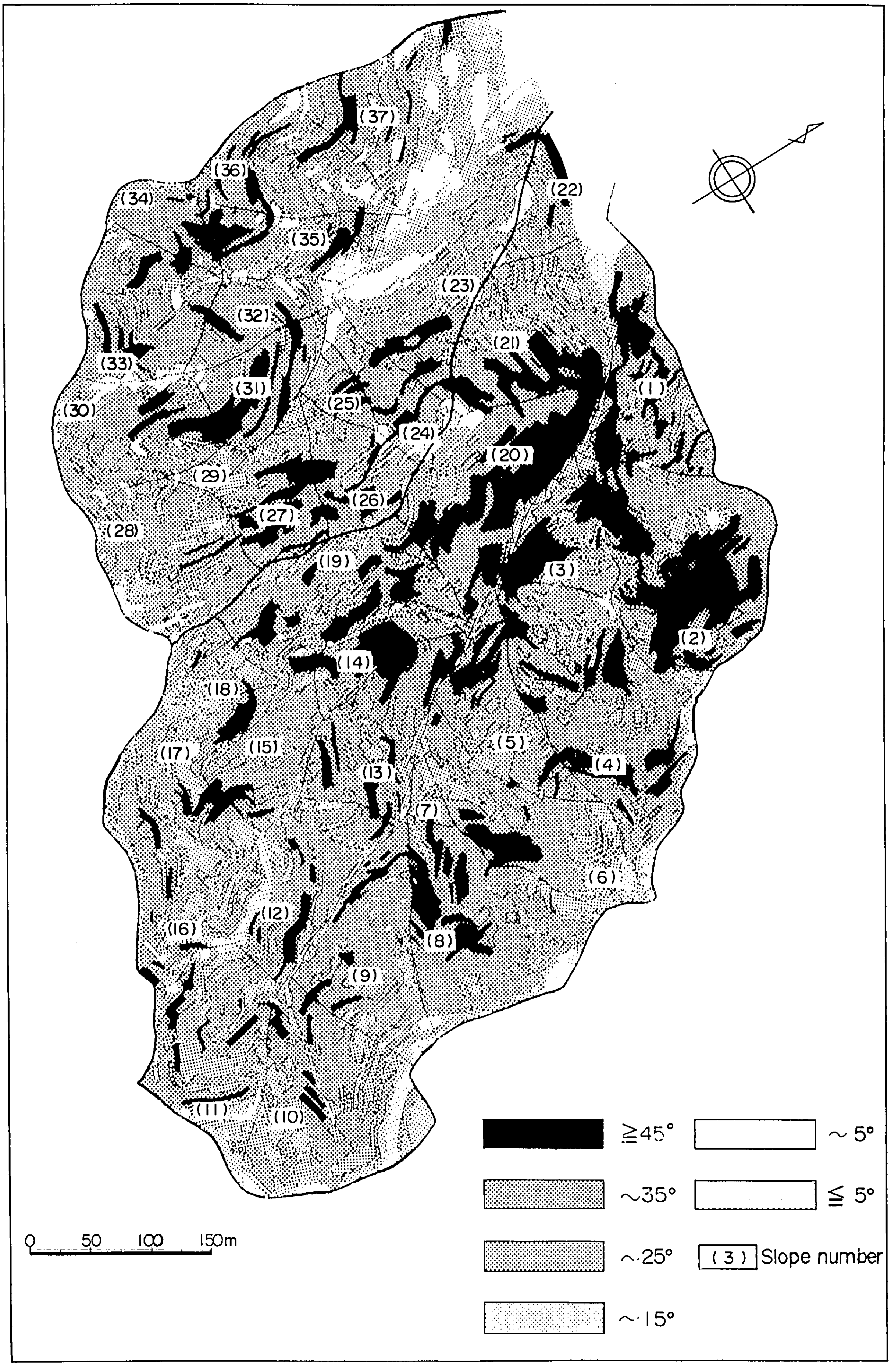


FIG. 27 Slope inclination map of the Rriver Hirami basin, Rokko district.

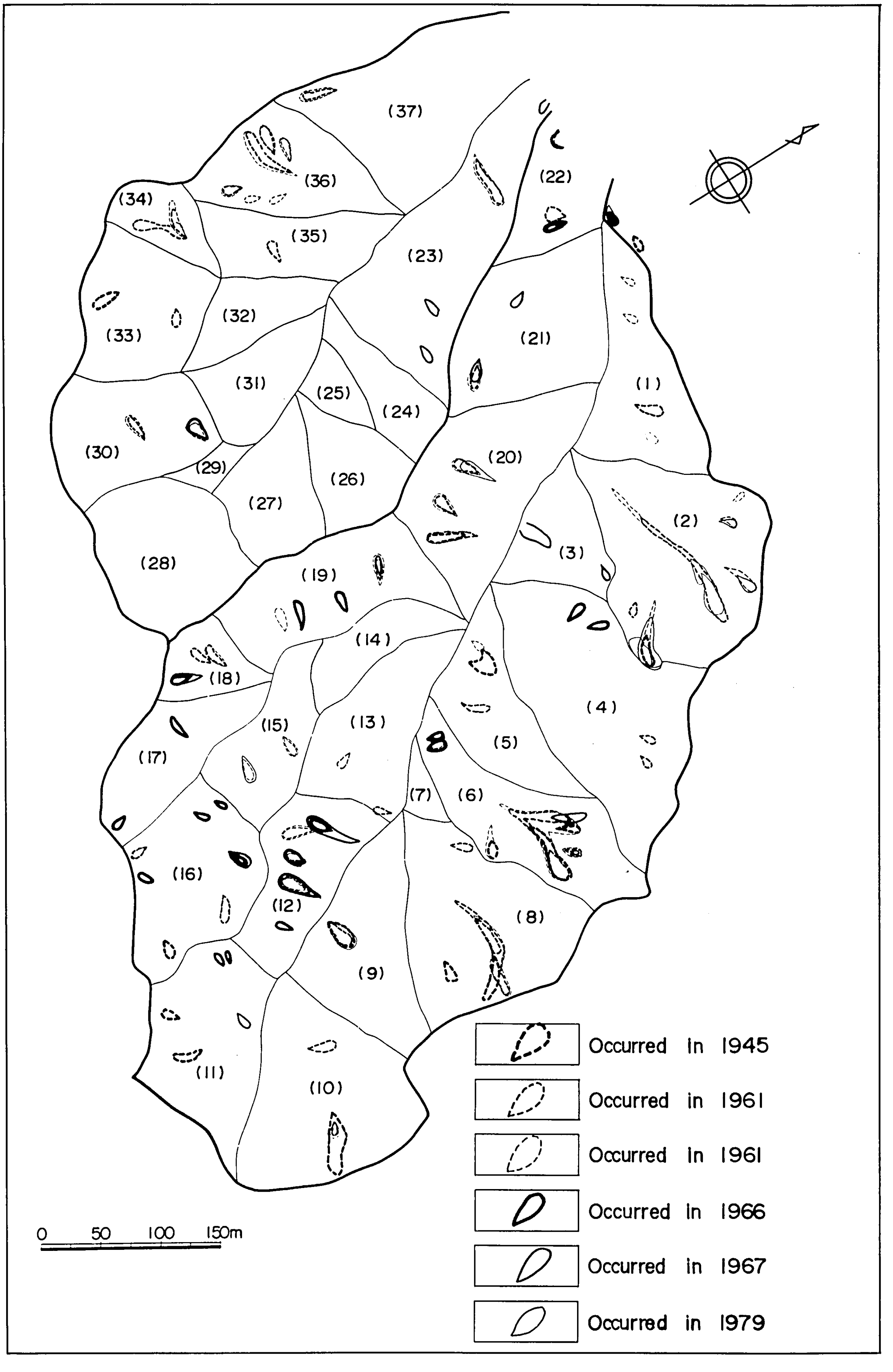


FIG. 28 Collapse land distribution map of the River Hirami basin, Rokko district.

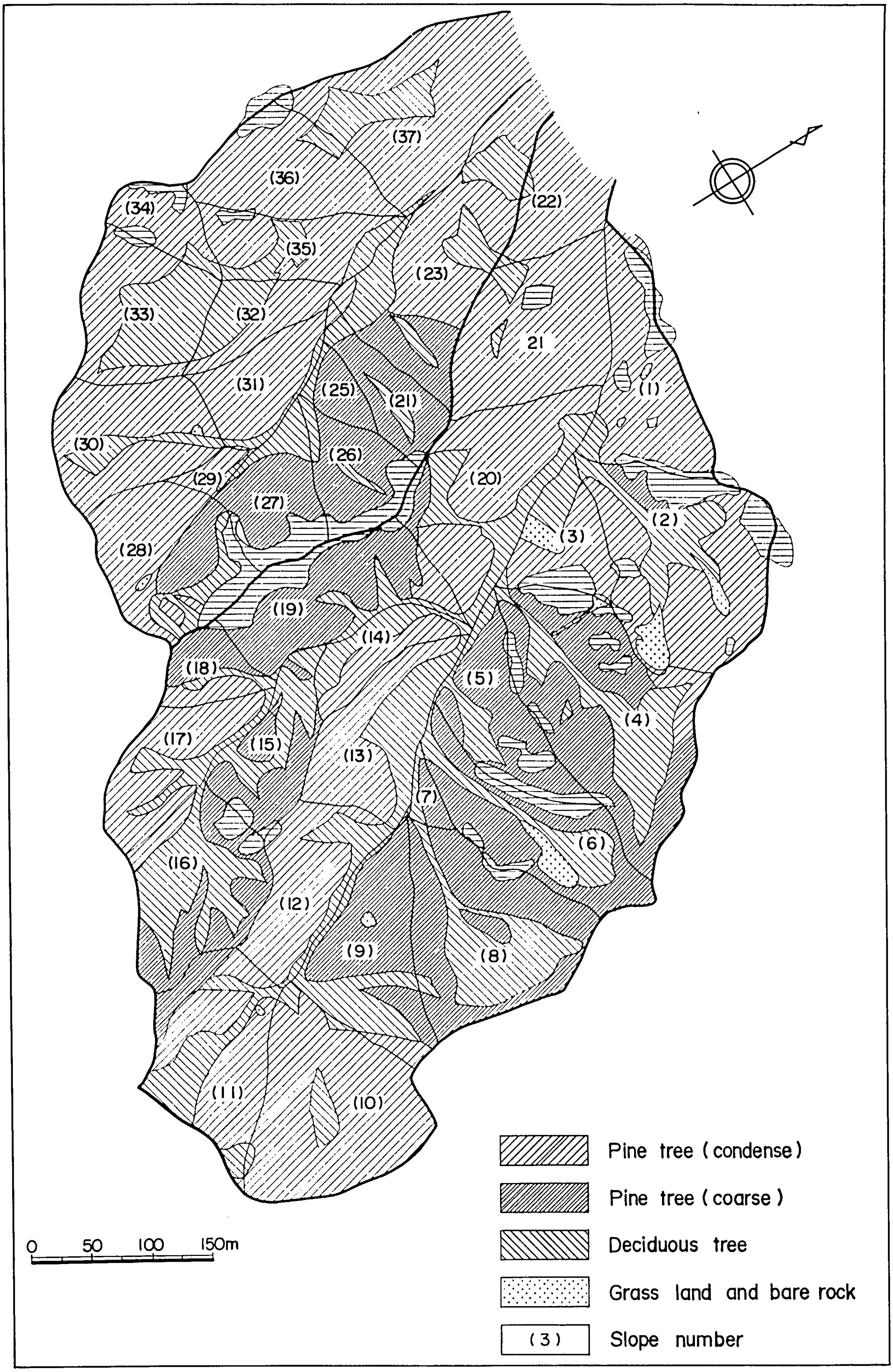


FIG. 29 Vegetation distribution map of the River Hirami, Rokko district.

TABLE 5 EVALUATION CHART OF THE HIRAMI RIVER DISTRICT. DANGEROUS RANK OF THE RESPECTIVE SLOPE WAS DETERMINED BY CONSIDERING ALL THE FACTORS LISTED IN THE TABLE. DETAILED PROCESS OF THE DETERMINATION IS ILLUSTRATED IN FIG. 26 AND THE LOCATION OF THE NUMBERED SLOPE IS SHOWN IN FIG. 30.

A: most dangerous
B: less dangerous
C: least dangerous degree of contribution
+: low importance ++: middle importance
+++: high importance

No.	CA	IC	BG	VT	CL	SO	T	SSHU	SSHE	SC	Rank
1	++	+++	++	++	++	++	–	–	–	–	B
2	+++	+++	++	+++	+++	+++	+++	+++	–	+	A
3	++	+++	++	++	+	+	+	+++	–	+	B
4	+++	+++	+++	+++	++	+++	+++	+++	–	++	A
5	++	+++	+	+++	++	++	–	–	–	++	B
6	++	+++	+++	+++	+++	++	+++	++	–	++	A
7	+	+++	+	+++	+	+	–	–	–	++	B
8	+++	+++	++	+++	+++	+++	–	+++	+++	++	A
9	++	+++	++	+++	+	++	–	–	–	+++	B
10	+++	++	++	+	+	++	–	+++	+++	–	A
11	++	++	++	++	++	++	–	+++	+++	–	A
12	++	+++	++	+	+++	++	–	+++	+++	++	A
13	++	+++	++	++	+	++	–	–	+++	++	A
14	++	+++	++	++	+	+	–	–	–	–	C
15	++	+++	++	++	+	++	–	–	+++	–	B
16	++	++	++	++	+	++	–	–	+++	–	A
17	++	++	++	+	+	++	–	–	++	–	B
18	+	+++	+++	+++	++	++	–	–	+++	–	A
19	++	+++	+	+++	++	+++	–	–	++	++	A
20	+++	+++	++	+++	++	++	–	–	–	+	B
21	++	+++	+	+	+	++	–	–	++	–	B
22	++	+++	+	+	+	++	–	–	–	–	C
23	+++	+	++	++	+	+++	–	–	++	–	B
24	++	+++	++	++	++	+	–	+++	++	++	A
25	+	++	++	++	+	+	–	–	++	–	C
26	++	+++	+	+++	+	+	–	+++	+++	++	A
27	++	++	+	+++	+	++	–	–	+++	–	B
28	++	++	++	+++	+	++	–	+++	+++	–	A
29	+	+++	+	+	+	+	–	–	–	–	C
30	+++	++	++	+	+	+	–	+++	+++	–	B
31	++	+++	+	+	+	+	–	–	–	–	C
32	++	+++	+	++	+	+	–	+++	–	++	B
33	++	+++	++	+++	+	++	–	+++	+++	–	A
34	+	+++	+	++	+	++	+++	+++	–	–	B
35	++	+++	+	++	+	+	–	+++	–	++	B
36	++	++	++	+	+++	++	–	++	+++	+	A
37	++	+	++	+	+	++	–	–	+	+	C

CA: Catchment area
IC: Inclination of slope
BG: Geology
VT: Vegetation
CL: Old collapse (desolution condition)
SO: Stream order system
T: Talus
SSHU: Scree shute
SSHE: Scree sheet
SC: Scree cone
Rank: Dangerous rank of the slope

for the right tributary and that of 5,600m^3 is forecasted for the left tributary.

Fig. 30 shows the depositional range of this discharged sediment in the downstream area. For the establishment of this depositional range, several methods have been tried, such as the method of random walk by Imamura et al. (1980) and Takei (1982), as well as the numerical simulation considering the depositional model by Takahashi et al. (1984). However, in this paper, the author uses three methods, that is, the method proposed by the Ministry of Construction (Nakamura, 1980), Rokko's method (Kobashi et al., 1982) and the method proposed by the Japan Road Corporation (Sabo Technical Center, 1980).

Thus, an example of the hazard map including the concept of the occurrence potentiality has been established. The preventative geological map has various important meanings in addition to expressing the occurrence potentiality. When a sediment discharge from the catchment area was investigated, the value of specific sediment discharge determined by the catchment area and geology was regarded as important up to the present. Actually, the geomorphological and geological characteristics in each catchment area have not been given a due consideration.

Even in similar catchment area in the Rokko district, different kind of characteristics, such as those accompanied with very large accumulation of sediment or without sediment, are usually developed complicatedly. Consequently, it is necessary to gather detailed field data through careful survey.

Finally, the author wishes to point out the usefulness of the "preventative gelogical map" in various fields if the map is based on the concept described in this paper, i.e., "occurrence potentiality". For establishing the final map, evaluation process according to the detailed description and classification of the mountain sediments is indispensable.

VI. CONCLUSION

Mountain sediment and the geology as the source of sediment discharge were investigated. Furthermore, the results were treated in terms of movement potentiality and supply potentiality in order to understand the sediment discharge more precisely. Thus, charting of the hazard map was tried on the basis of this understanding. The results obtained so far can be summarized as follows.

1) The mountain sediments in the Rokko district were investigated together with those of several catchment areas in western Japan. In addition to the detailed description of the sediments, a systematic morphological classification of the sediment which expresses both the stage of the sedimentation (growth and vanishing) and the position of the sedimention (catchment area and bed inclination) have been made.

2) The supply system of mountain sediment in the Rokko district was established through examination of the relation between the collapses and the condition of the geomorphology and geology. The lithology affects the resistivity against weathering and the size of the joint interval. Supply amount of the gravel sediments in the form of collapsed rocks and fallen rocks is predominant in the areas where fine grained and compact rocks are distributed. The collapse tends to occur in the lower order fault valley, and existence of faults specifies the position of the sediment supply. The importance of the faults can be recognized as supplies of a large amount of sediment as well as occurrence of frequent collapses. In the Rokko district, the new weathering profile is piled up on the older weathering profile which has formed before the Rokko movement. In the C1 zone (Kakitani, 1974), fine grain materials are supplied from collapse of "Masa", in the C2 zone, sand and gravel are supplied from denudation and collapse of core stone, and in the C3 zone, gravel is supplied from collapse of rocks.

3) The movement of torrent bed sediment accompanies an oscillation during the sediment discharge in the longitudinal-section, and amplitude and cycle of the oscillation differ according to the location and time. It means that the torrent bed sediments are repeating the process of growth and vanishing. This process can be realized with the concept of occurrence potentiality which is equivalent to the movement potentiality. Further, a concept of occurrence potentiality including factors of the inclination and the catchment area of the depositional area has been presented.

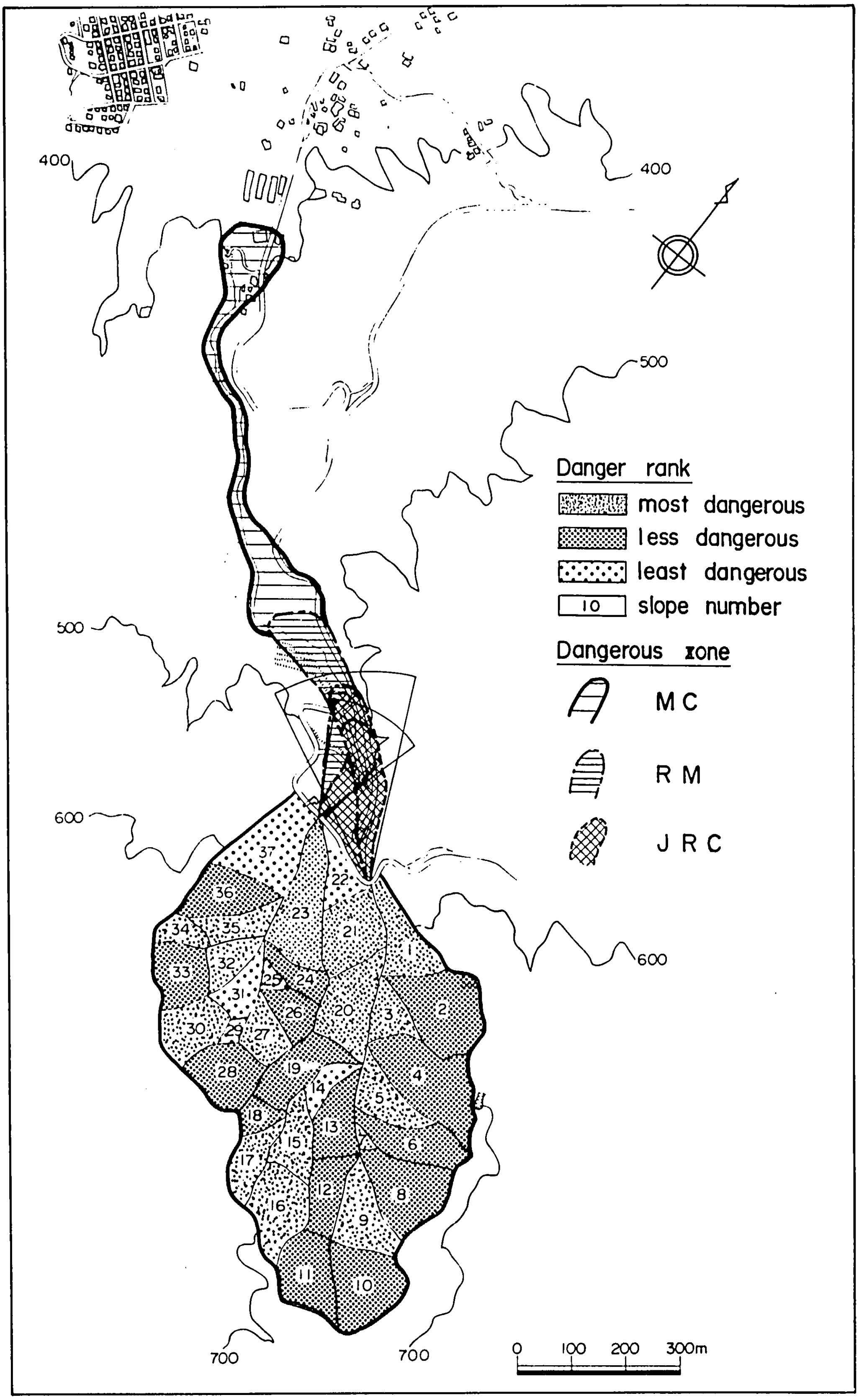


FIG. 30 Hazard map of the River Hirami basin, Rokko district. Respective dangerous zone are represented by different symbols. MS: proposed by the Ministry of Construction, RM: Rokko's Method, JRC: proposed by the Japan Road Corporation.

4) Hazard maps for sediment disaster were established using the topographical map drawn on a scale of 1 to 2,500. Several districts along the River Hirami located on the north slope of the Rokko district were selected for the case study. The occurrence potentiality of sediment disaster was evaluated as one factor together with other factors such as inclination, geology, weathering profile and state of denudation and vegetation.

5) Compared with previous hazard maps of sediment disaster, the present maps have some significant differences such as follows. The mountain sediments are considered as the main supply source of sediment and are treated in terms of occurrence potentiality. Characteristics of geology, lithology, geological structure and weathering profile were taken into consideration as a supply source of mountain sediment. With these factors, a hazard map of sediment disaster can reflect the catchment area in more detail than the previous ones.

6) For the prediction and forecast of sediment disasters in the future, necessity of the "preventative geological map" like Figs. 24 and 25 were pointed out.

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