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Article

Distribution of slope failures following the 1983 San'in Heavy Rainfall Disaster in Misumi−Kitsuka area, western Shimane, Southwest Japan

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Abstract

Small and shallow slope failures frequently occur in mountainous areas worldwide, due to intense rainfall. Regional hazard assessment on the occurrences of failures is thus an important subject, especially for developing countries. One method of assessing such hazard is based on statistical analysis of spatial distribution of past failures. As a case study for hazard assessment, we constructed detailed maps expressing the distribution of slope failures which occurred during the 1983 San'in heavy rainfall disaster in western Shimane, southwest Japan. Although similar maps have been already presented, they did not identify the source areas of failures alone, as they also included the deposit areas of slope failures and debris flows. For this study, we identified only the source areas of slope failures, using 1:8,000-scale aerial photographs that were taken just after the disaster. More than 2,300 failures were mapped in the study area. Based on the distribution of slope failures, we confirmed that they tend to appear in the steeper slopes. The average area of surface of rupture was about 1,400 m^2, and individual extent was greater in granitic rocks than in volcanic and schistose lithologies, as suggested by previous reports.

Key words: slope failure, Shimane, San'in heavy rainfall disaster

Introduction

Slope failures frequently occur in mountainous areas worldwide due to triggers such as earthquake vibrations or rainfall. Such failures tend to occur suddenly, and cause great damage and economic loss. Therefore, the regional occurrence of slope failures is serious, especially for developing countries. In the case of slope failures triggered by rainfall, their occurrence generally depends on topographic and geologic conditions as well as the intensity and duration of rainfall. Although many efforts have been made to predict the occurrences of such failures, hazard assessment is still an important issue in geoscience.

One effective method for assessing slope hazard is based on statistical analysis of past failures. Distribution of slope failures and their relation to topographic and geologic conditions permit statistical estimation of future occurrences. To obtain such information, we selected the Misumi−Kitsuka area of western Shimane, Southwest Japan (Fig. 1), where intense rainfall in 1983 caused numerous slope failures, with debris flows and flooding. This report examines the distribution of slope failures based on statistical analysis.

The study area is situated between 34°45' to 34°50' latitude north and 131°52'30" to 132°7'30" longitude east. The area corresponds to two 1:25,000 topographic map sheets, Misumi quadrangle in the west and Kitsuka quadrangle in the east, covering a total area of 155 km^2.

The 1983 San'in heavy rainfall disaster

The intense rainstorm that triggered the failures in western Shimane occurred between July 20th and 23rd, 1983. The highest rainfall was recorded in the Misumi area, where total rainfall was 742 mm and maximum hourly intensity was 90 mm/h. The total area flooded was 15,000 ha. Slope failures, debris flows, and flooding led to 91 deaths, and the overall economic loss was 360,000 million yen (Research Group of San'in heavy rainfall disaster of Shimane Univ., 1984). The maximum hourly precipitation (90 mm/h) corresponds to a 150−year recurrence, and the maximum daily precipitation (372 mm/day) corresponds to over a 200−year recurrence. Failures occurred from 100 mm of total rainfall and from 40 mm/h rainfall intensity (Wada et al., 1984). Damage was enormous, and the event is thus known as the 1983 San'in heavy rainfall disaster.

There are several reports on geological aspects of the disaster. According to Research Group of San'in heavy rainfall disaster of Shimane Univ. (1984), most failures were shallow, involving colluvium and residual soil, and were related to topographic and geologic conditions in addition to rainfall intensity. The highest frequency of failures occurred on 30° to 40° slopes, and the largest slope failures occurred in granitic rock regions. Many failures developed into debris flows. According to Okuda and Okimura (1984), the highest frequency of failures occurred on slopes with gradients of 15° to 25°, and debris flows on

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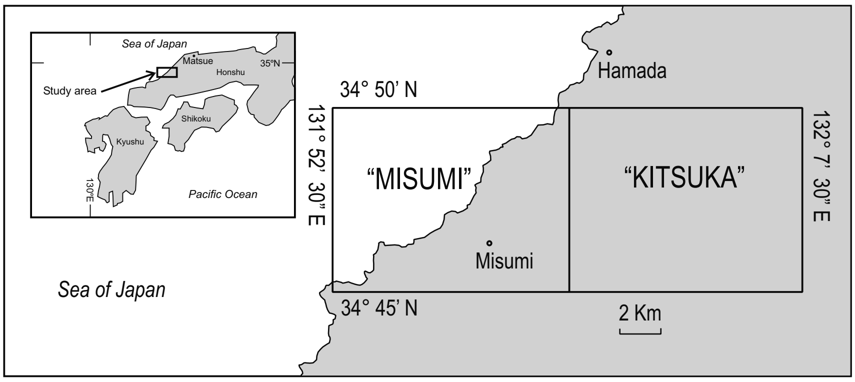

Fig. 1. Location of the study area (Misumi and Kitsuka quadrangles)

slopes with gradients between 10° and 20°. Wada et al. (1984) pointed out that slope failures were also related to geomorphology and weathering zones of topographic levels.

Research Group of San’in heavy rainfall disaster of Shimane Univ. (1984) presents distribution maps of slope failures in some major areas. However, the maps do not differentiate the source from the deposit areas of the failures and debris flows. Consequently, we attempted to make distribution maps only of the source areas of individual slope failures in an area where the highest density of slope failures and debris flows occurred.

Topographic and geologic outline

The western part of the study area is a coastal area of hills and plains with elevations generally lower than 150 m; but some isolated hills (monadnocks) have elevations between 260 m and 400 m. The eastern part is more mountainous, with peaks with elevations of up to 700 m. In general, elevation increases gradually from west to east, from sea level to about 700 m in the central to eastern part of the study area.

Some low-relief topographic surfaces occur in the region. These are the Takatsu-men (70−100 m), Iwamikogen-men (200−300 m) and Takauchi-men (350−420 m) surfaces respectively; they may control weathering conditions just below such levels (Wada et al., 1984).

According to the regional geologic map (Editorial Board of Geological Map of Shimane Prefecture, 1997), lithologies in the study area mainly consist of (a) Paleozoic to Mesozoic pelitic and psammitic schists, (b) Paleogene diorites and granitic rocks, and (c) Paleogene rhyolitic to dacitic pyroclastic and volcanic rocks. In addition to these rocks, Quaternary deposits form terraces and alluvial plains within valleys, as shown in Fig. 2.

Schists form a low hilly terrain with a relatively higher drainage density than the igneous rock terrain. The regional structural trend of the schistose rocks is NE−SW. Dioritic plutons form isolated high peaks. Volcanic and pyroclastic rocks form a higher mountainous terrain with steep slopes in the northeastern part of the study area.

Aerial photograph interpretation of slope failures

Individual slope failures were identified from stereoscopic interpretation of 1:8,000 scale black-and-white aerial photographs (Kokusai Kogyo Co., 1983) that were taken just after the rainstorm. The aerial photographs were clear and almost without clouds; their scale and high resolution permitted the mapping of the actual shape and size of even small failures. Failures were identified because the vegetation cover had been removed, and the surface of rupture had a brighter tone than adjacent areas. As shown in Fig. 3, many slope failures became debris flows along streams. However, only their source areas were selected and mapped, as shown in Fig. 3. The extents of individual slope failures ranged from large to small. Among these, only slope failures wider than 1 mm (corresponding to 25 m on a 1:25,000 scale map) were selected from the aerial photographs, and their positions plotted on 1:25,000-scale topographic sheets.

Distribution of slope failures

We constructed two distribution maps of slope failures using these procedures. The maps (Fig. 4 (a), (b)) correspond to the quadrangle sheets of the Misumi and Kitsuka areas as indicated in Fig. 1.

As shown in Fig. 4 (a), (b), most surfaces of rupture were semicircular, and their widths were generally smaller than 50 m. The failures were shallow, and involved soil and surficial deposits. Some developed into debris flows. Failures tended to occur on concave slopes in the upper parts of drainage basins, but also on slope facets. Most failures occurred on steep slopes.

The predominant vegetation cover of mountains and hills was forest. Exploited forest areas apparently had a higher failure density than areas still covered with forest. Quaternary deposits and flat topography areas were landslide free.

Failure distribution data were transferred to tracing films

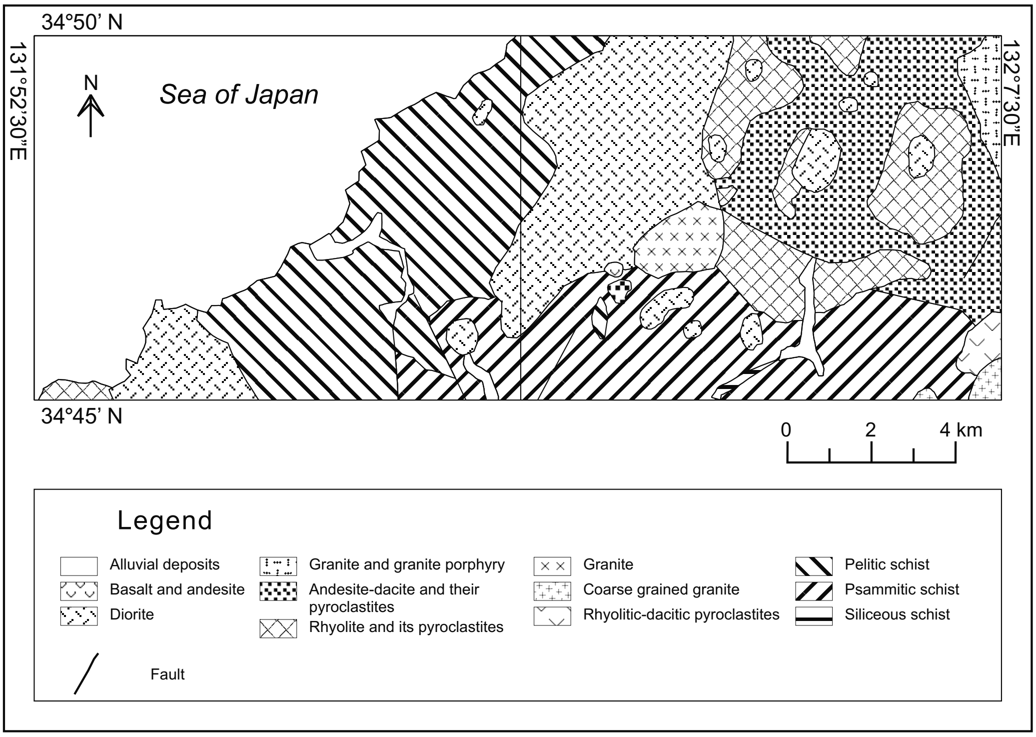

Fig. 2. Outline of lithological distribution in the study area. After the 1:200,000-scale geologic map of Shimane Prefecture (Editorial Board of Geological map of Shimane Prefecture, 1997).

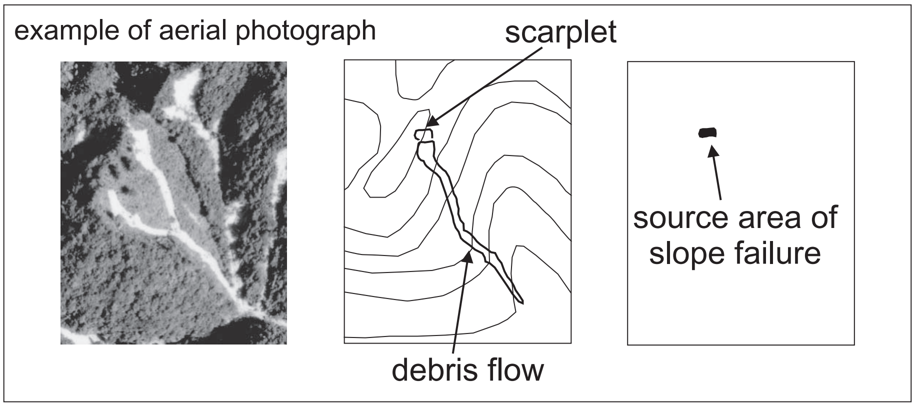

Fig. 3. Slope failures obtained from aerial photography. Each slope failure was interpreted from aerial photographs (Kokusai Kogyo Co., 1983) taken just after the San'in heavy rainfall disaster. Sources areas only were selected and mapped.

and digitized using high−resolution scanning, to produce two raster maps with a grid of 10 m × 10 m; one cell of the grid represents an area of 100 m^2 of the terrain. Maps were projected in Universal Transverse Mercator (UTM) coordinates. However, the two adjacent topographic quadrangles had different UTM zones, and different coordinate systems. Cells where failures occurred were coded as failures cells, and each failure was coded with a number. The total number of failures observed was 2,375, with 937 in Misumi quadrangle and 1,438 in Kistuka quadrangle.

Slope failure size and lithology

Geographic information systems (GIS) and raster maps of slope failures allowed estimation of the size of each failure (based on the number of failure cells) and also comparison of the distribution of failures with other spatial data. In the study area, the total area of failures was 3.4 km^2, and the average size of rupture surface was 1,400 m^2 (14 cells). Surface of rupture size values were grouped into classes; the frequency distribution is shown in Fig. 5. Some 40% of all failures fell in the 500−1,000 m^2 class.

To investigate the relationship between failure size and lithology, we then compared the failure distribution with the

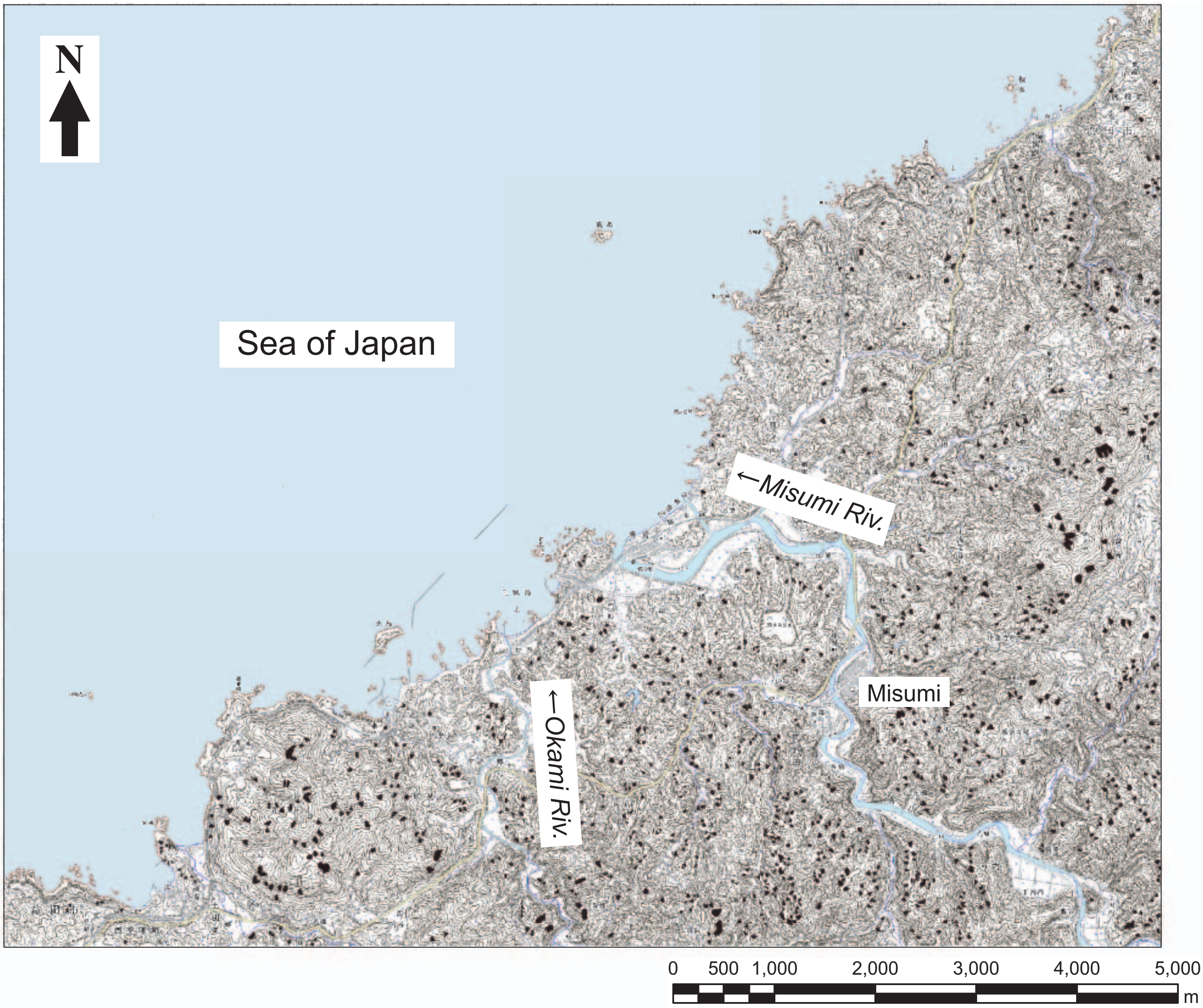

Fig. 4 (a). Distribution of slope failures in Misumi quadrangle. Only source areas were plotted, based on the interpretation of aerial photographs (Kokusai Kogyo Co., 1983).

lithologic distribution in the study area. For this analysis, lithology distribution was generalized into four classes; alluvial deposits, volcanic rocks, granitic rocks and schists, based on the map of Fig. 2. Lithology distribution was also converted to raster format to compare it with the distribution of slope failures. The areas of each lithology class were alluvial deposits 11.8 km^2, volcanic rocks 48.1 km^2, granitic rocks 40.7 km^2, and schists 54.5 km^2.

GIS functions permitted the overlaying of the failure map on the lithology map, to determine the lithology class where each failure occurred. When a failure fell into more than one lithology class, the class was manually assigned depending where most of the cells were located.

From the spatial analysis we built a table containing the following information about each slope failure: identification, number of failure cells, failure area in square meters, and lithology class in which it occurred. Numerical fields (such as failure area) can also be analyzed within the GIS to calculate statistics. For each lithology class (volcanic rocks, granitic rocks and schists) we estimated the average size and distribution of size classes of failures.

Fig. 6 shows the frequency distribution of failure size in relation to lithology. Failure size varied with lithology. Of the 1,434 failures within the schists, 44% fell within the 500−1,000 m^2 class, and average size was 1,200 m^2. Of the 550 failures within the granitic rocks, 25% fell in the 1,000−1,500 m^2 class and average size was 1,900 m^2. Of the 391 failures within the volcanic rocks, 45% fell in the 500−1,000 m^2 class and the average size was 1,300 m^2.

The results above indicate that average and predominant failure size (surface of rupture) in the study area varied for different generalized lithology classes. Average size of slope failures in the granitic rock area was greater than the average size of failures in the schist and volcanic rock areas. This agrees with the tendency noted in the report of Research Group of Shimane Univ. (1984), in that granitic

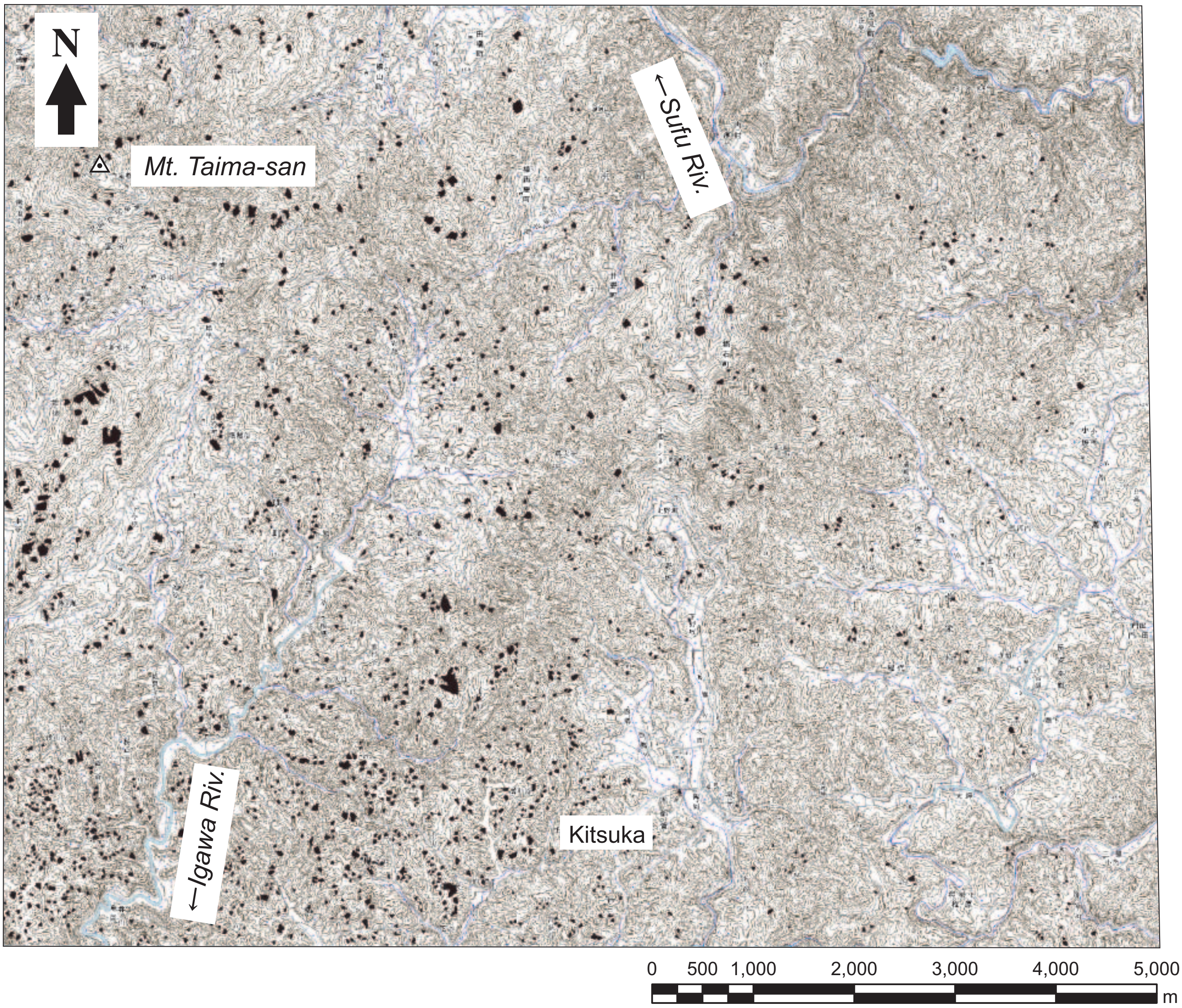

Fig. 4 (b). Distribution of slope failures in Kitsuka quadrangle. Only source areas were plotted, based on the interpretation of aerial photographs (Kokusai Kogyo Co., 1983).

rock areas presented the biggest failures.

Discussion

Since slope failures from the San'in heavy rainfall disaster involved surficial deposits and residual soil, their occurrence was greatly influenced by soil characteristics. The generalized lithology classes express soil conditions related to the occurrence of failures, because soil characteristics partially depend on the lithology of the bedrock. The lithology class may also express topographic characteristics that control the occurrence of slope failures in colluvium and residuum; therefore it is an important parameter in statistical analysis of past failures for future hazard assessment.

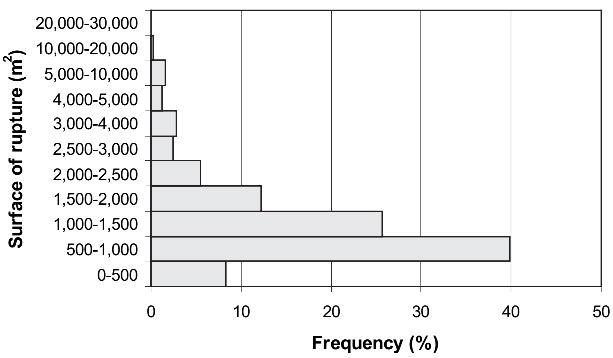

Fig. 5. Frequency distribution of size of slope failures based on number of cells of 10−m grid raster data. Highest frequency corresponds to the 500−1,000 m^2 size class.

Conclusions

(1) The distribution of source areas of slope failures in the Misumi−Kitsuka area was obtained by air photo

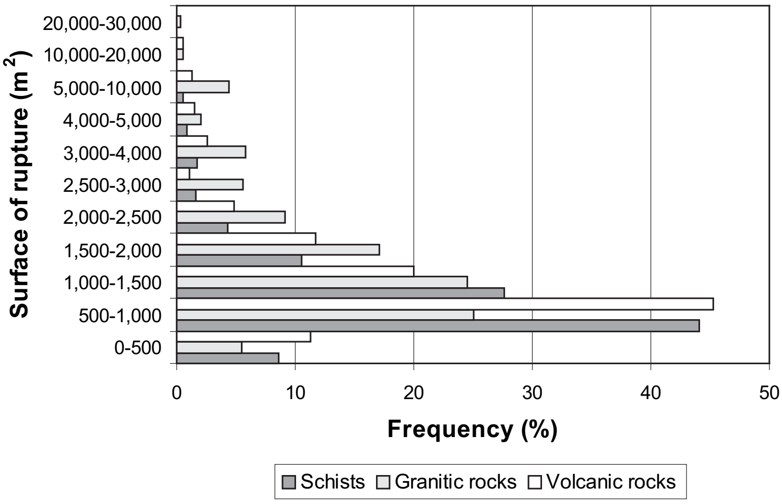

Fig. 6. Frequency distribution of size of slope failures in each lithologic region based on number of cells of 10-m grid raster data. Predominant size of surface of rupture varied with lithology. Failures in granitic rock area were larger than those in schist and volcanic rock areas.

interpretation, and was digitized. Subsequently, more than 2,300 failures were mapped in the area.

(2) Slope failures tended to appear in steep slopes. This reflects shallow landsliding.

(3) Based on digitized data of the occurrences of slope failures and their comparison with lithology, the average area of surface of rupture was about 1,400 m^2; and individual extent was greater in the granitic rock area than in volcanic and schistose rocks, consistent with previous reports.

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（要　旨）

Edgar Pimiento・横田修一郎，2006，島根県三隅・木都賀地域における 1983 年山陰豪雨災害時の斜面崩壊の分布，島根大学地球資源環境学研究報告，25，25-30

比較的規模が小さく浅い斜面崩壊は山地地域であれば，世界中の広い範囲で豪雨によって発生しうる．それゆえ，そのような斜面崩壊発生に関する広域的なハザード評価はとりわけ発展途上国では重要な課題である．広域的な斜面ハザードを予測する 1 つの方法は過去の崩壊の統計的解析に基づくものである．ケーススタディとしてこれを実施するため，筆者らは 1983 年に島根県西部で豪雨によって引き起こされ山陰豪雨災害時の斜面崩壊の分布を表現する詳細なマップを作成した．

すでに同様のマップは公表されているが，それらは斜面崩壊の発生域だけでなく，崩壊と土石流の堆積域も含んでいる．そこで，筆者らは災害発生直後に撮影された 1/8,000 モノクロ空中写真をもとに崩壊発生域のみを抽出し，図化した．結果として，2,300 箇所以上の斜面崩壊が得られた．本地域における平均は約 1,400 m^2 であり，広域的な岩相分布と対比させると，花崗岩地域のものは相対的に規模が大きいことが明らかになり，これは既存報告の傾向とも一致する．