# PHYSIOGRAPHIC CONDITIONS FOR THE RUBBLE SLOPE FORMATION ON MT. SHIROUMA-DAKE, THE JAPAN ALPS

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*Abstract* Well-developed rubble slopes were investigated in the alpine region of Mt. Shirouma-dake, Central Japan. On these rubble slopes, local climatic conditions, slope form, surface materials, surface micro-relief, vegetation, types of surface processes, and soil-movement rates were observed and/or measured and then the interactions between the surface processes and the others were analyzed. It was recognized that close relations exist between the surface processes and the local climatic conditions, slope form, and surface materials. Strong winter winds and abundant snowfall are very important for the rubble slope formation. In addition to them, properties of the surface materials represents one of the most important factors which controls the types and intensity of surface processes, surface micro-relief, types and coverage rates of vegetation. It is concluded that not only the local climatic conditions but also local terrestrial conditions are important for the rubble slope formation.

## 1. Introduction

Vegetation-free debris mantled slopes develop in high altitude areas above around 2,500 m in the Japan Alps. Most of these slopes occur on both the east and west flanks as the Japan Alps run roughly in a north-south direction. Schwind (1936) noticed a sharp contrast in topography and slope processes between the west and east facing slopes. Frost-induced mass-movement is predominant on the gentle west-facing slopes, while snowpatch-induced processes prevail on the steep east-facing slopes. Later, Kobayashi (1956) explained logically the cause effect relationships among the climatic conditions, past and present geomorphic processes, slope forms, vegetation, and existence of patterned ground on both slopes. Figure 1 illustrates his concept schematically. Detailed and comprehensive studies, however, have not yet been made on his concept for the relationships.

It has been suggested that the reason why these differences in processes, topographies, vegetation, etc. occur on the two slopes is related to the peculiar climate of the Japan Alps, which are exposed to strong winter westerlies and suffer abundant snow (Koizumi, 1974; Koaze, 1974; Koaze et al., 1974; Iwata, 1974). Surface processes occuring on slopes depend not only on climate but also on the vegetation cover, soil and/or soil materials, initial topography, bedrock lithology and structures, and tectonic movements. Conversely, the surface processes control the vegetation cover and soil materials and evlove the slope forms; that is, there are biological, physical, and morphological responses to the slope processes. Very com-

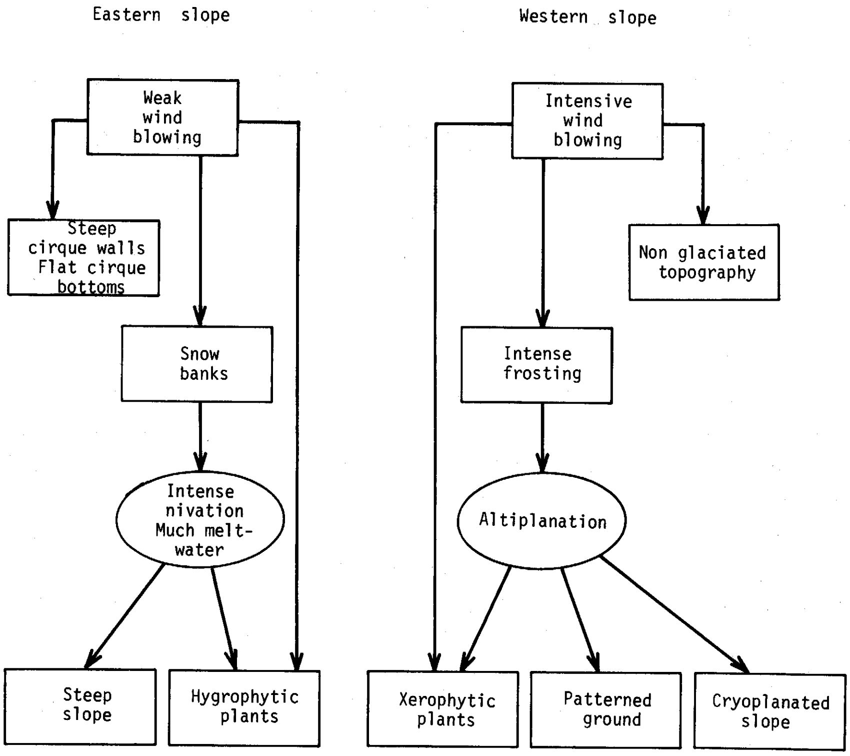


**Fig. 1.** Schematic diagram to show the Kobayashi's concept which explains the cause and effect relationships among the climatic conditions, slope forms, vegetation, etc. (adapted from Kobayashi, 1956).

plicated interactions therefore exist among the factors in the environment of the slope.

The attributes of the slope consist of the slope form, surface processes, surface materials, and environmental factors such as the surface micro-relief, vegetation, and micro-climatic conditions near the ground. These individual items are termed the slope characteristics in this article. Occasionally, the slope form is not confined to the surface, but includes the thickness and composition of the surface material both which are closely related with the slope form. On the other hand, the surface material is sometimes regarded as one of the environmental factors. Hence, the author ascribes to the surface materials an intermediate position between the slope form and the environmental factors. In this article, the author defines the surface processes as a mechanism or group of mechanisms for the dislocation and movement of debris according to Carson and Kirkby (1972, p. 99). The surface micro-relief refers to irregularities in the ground surface with dimensions of an order smaller than that of the slope sequence.

Each slope exists under peculiar regional conditions of climate, topography, and geology (lithology and structures). These regional physiographic conditions may control the slope characteristics. The regional climate, the regional topography (initial topography), and the regional lithology and structures are reflected in the micro-climatic conditions of the slopes, the slope form, and the surface materials, respectively. In order to clarify the total feature of the slope, it is necessary to investigate all the slope characteristics and their regional physiographic conditions.

Vegetation-free debris mantled slopes are very well-developed in the high mountain region around Mt. Shirouma-dake (2,933 m a.s.l., 36°45′N, 137°45′E), in the Northern Japan Alps. The region appeared to be the most favorable location in the Japan Alps for the present study. The author has carried out a series of intensive climato-geomorphologic investigations since 1970 on Mt. Shirouma-dake (Iwata, 1974, 1977, 1978, 1980; Iwata et al., 1974; Koaze et al., 1974; Research Group for Alpine Geomorphology, 1978; Sohma et al., 1979). He investigated the climatic and vegetational conditions as well as the topography, materials, and surface processes. Instrumentational measurements were carried out at certain experimental sites.

In this article, the author first describes the regional physiographic conditions, and second the slope form, surface materials, environmental factors, and surface processes. A discussion is then given of how the above-mentioned slope characteristics interact with each other. Finally, the author explains the following:

i) a concept for the interactive relationships among the slope characteristics, and
ii) the conditions under which rubble slopes are formed extensively in the high mountain region of the Japan Alps.

## 2. Study Area and General Features of Rubble Slopes

### Study area (regional physiographic conditions)

*Regional climate*

The study area is situated in the northern part of the Japan Alps, ranging in altitude from 2,300 m to 2,900 m (Fig. 2). The forest line lies at an altitude of 2,300–2,400 m. From the viewpoint of altitudinal zonation, a greater part of the study area is located in the alpine or subalpine scrub zone and the alpine meadow zone.

Meteorological data throughout the year are not yet available for Mt. Shirouma-dake and the surrounding mountains, although during the short summer season, July and August, meteorological observations have been carried out at Hakuba Sanso Hut (2,830 m). The Research Group for Alpine Geomorphology (1978, p. 149) estimated the monthly mean air temperatures at 2,600 m in Mt. Shirouma-dake from upper air data; the annual mean, mean August, and mean January air temperatures were 0°C, 12.6°C, and −11.3°C, respectively. It is considered that the annual precipitation amounts to more than 4,000 mm and the monthly precipitations for December, January, and July exceed 400 mm each judging from the Climatic Atlas of Japan (Japan Meteorological Agency, 1971). Nearly 50 percent of the annual precipitation falls as snow between November and early April, and goes into snow-patch storage until August. The inter-annual changes of July and August precipitation as obtained from observations made during the period 1968–1978 are remarkable as shown in Table 1. Extremely heavy rainfalls were recorded in August of 1969 and 1976. The directions of the prevailing winds range between west and west-southwest all the year round, and the winds blow with an average velocity of 16 m/sec during the cold months and 9 m/sec during the warm months (The Research Group for Alpine Geomorphology, 1978,

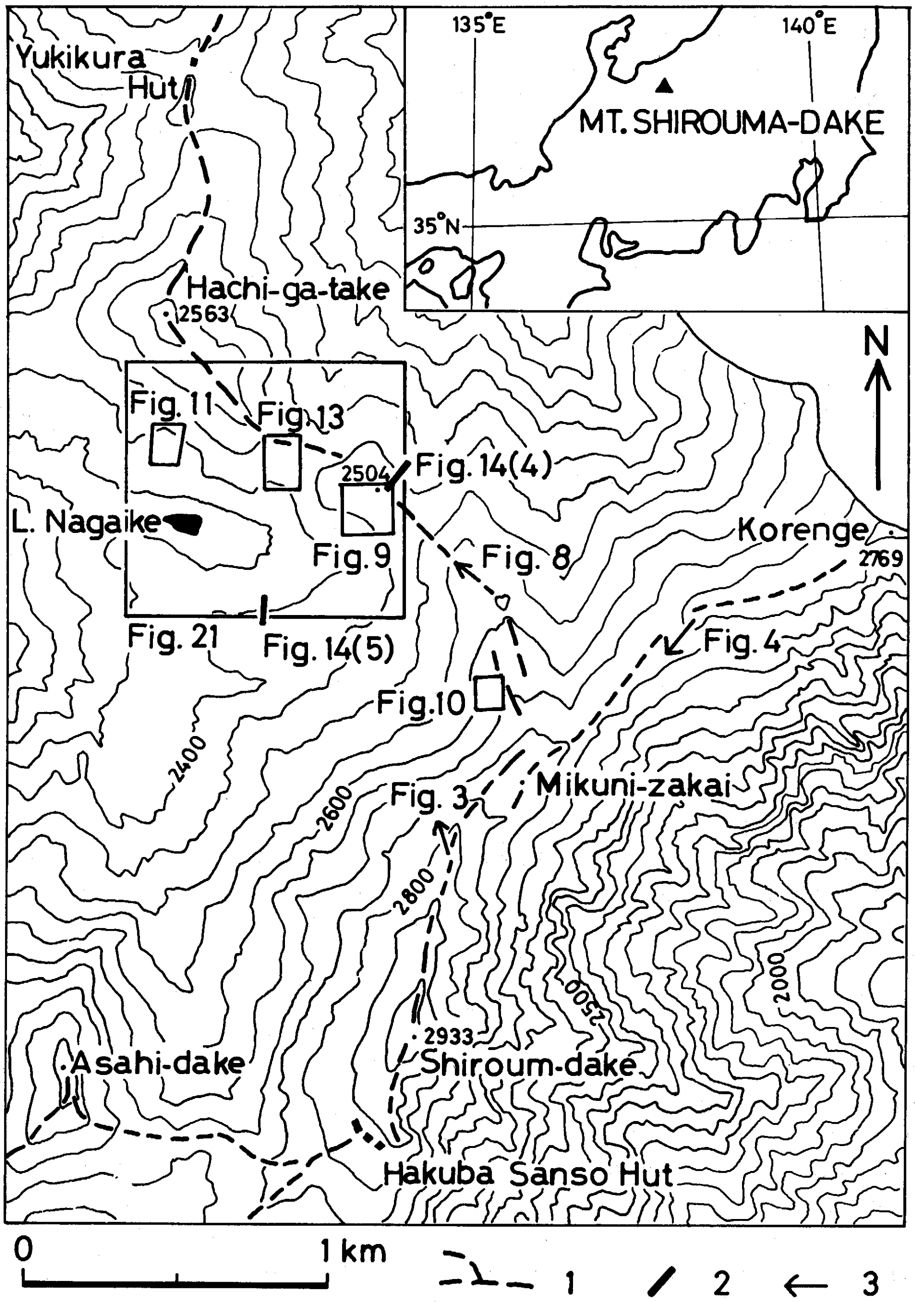


**Fig. 2.** Index map of the study area. The area is approximately 10 $km^2$. 1: Main ridges; 2: Section line shown in Fig. 14; 3: Direction in which the photograph was taken.

**Table 1.** Precipitation (in mm) at Hakuba Sanso Hut (2,830 m a.s.l.) in summer.

| | Year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 |
| July | | 511 | 379 | 681 | 559 | 92 | 609 | | 353 | 296 |
| August | 285 | 1103 | 313 | 659 | 389 | 81 | 84 | 569 | 975 | 210 |
| Maximum 24 hrs. rainfall | 98 | 336 | 81 | 421 | 112 | 32 | 151 | 295 | 350 | 106 |
| Date of occurrence | Aug. 28 | Aug. 11 | July 17 | Aug. 30 | July 1 | July 12 | July 10 | Aug. 23 | Aug. 14 | Aug. 8 |

From Nihon Kisho Kyokai (The Japan Weather Association) (1968–1977): Natsu-yama no Kisho Kansoku Hyo (Meteorological Data of the mountains in summer season).

p. 9). The regional climatic conditions in the study area are thus characterized by a low air temperature, heavy precipitation, and strong winds.

*Topography (initial topography)*

The main ridge of the Mt. Shirouma-dake range runs in a north-south direction, showing a typical asymmetrical crest form with steep east-facing and gentle west-facing slopes (Fig. 2). Smooth gentle slopes and low-relief surface with rounded knolls and shallow depressions occupy the western and northern parts of the study area (Fig. 3). The east-facing slopes of the summit of Mt. Shirouma-dake are very steep and display rugged rocky features (Fig. 4).

During the Last Glaciation, the study area was widely covered with glaciers and perennial

**Fig. 3** A view of central and northern part of the study area from the south (cf. Fig. 2), showing west-facing gentle slopes and low-relief surfaces. The photograph was taken on Oct. 7, 1978, and shows the ground surface in the foreground beeing covered with fresh snow.

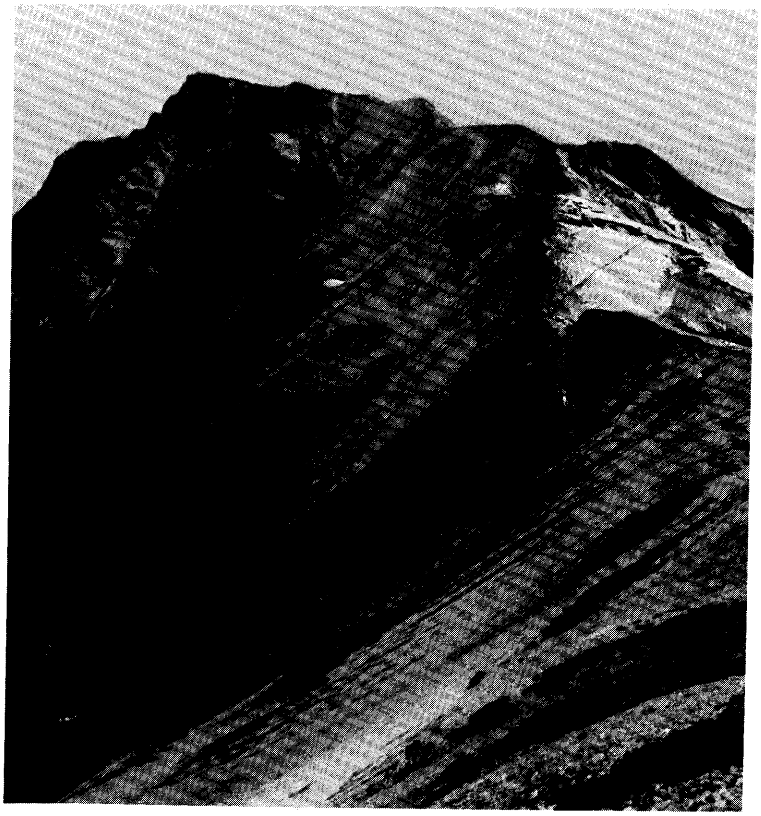

**Fig. 4.** East facing slopes of the summit of Mt. Shirouma-dake show rugged rocky features. In the middle to the right and in the foreground, the nivational rubble slopes occur in areas below an angle of 35° (Oct. 7, 1978).

ice (Iozawa, 1973; Koaze and Okazawa, 1976). The glaciers cut out cirques and cirque-like depressions, and built moraines. As the climatic amelioration ensued, rugged bedrock slopes were released from the snow and ice, and the gentle parts of them subsequently became covered with detritus produced by mechanical weathering. Thus, debris mantled slopes (French, 1976, p. 152) have developed in the greater part of the study area except for the steep rocky areas. The ridges became free from snow and ice at the early stage of deglaciation, but the cirque bottoms, depressions, and leeward slopes were occupied by snow and ice masses for much longer. Such snow and ice may have shaped out small shallow hollows in which many snowpatches at present occupy.

The chronological sequence of the slopes since 6,000 years B.P. is known from investigations of the soil and weathered materials in the study area (The Research Group for Alpine Geomorphology, 1978, p. 82–87). Figure 5 gives schematic columnar sections of the surface materials at vegetation-free slopes and their surrounding grass-covered parts. The existence of humic soil layers (partly muck soil) indicates vegetational invasions onto the slopes.

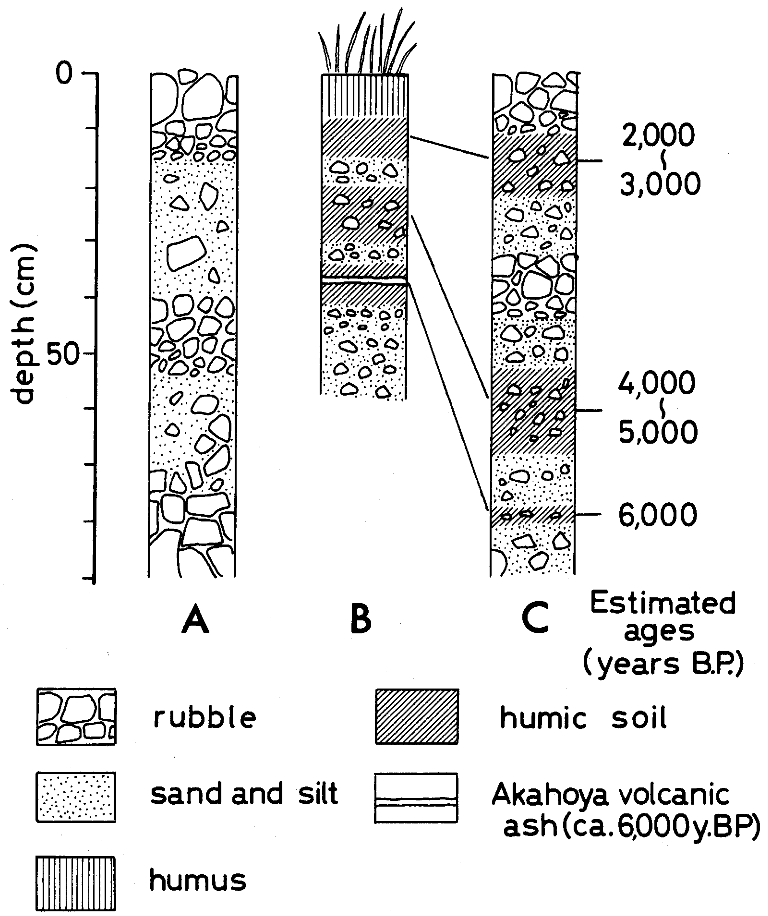


**Fig. 5.** Schematic columnar sections on and around the rubble slopes in the area near Lake Nagaike and Hachi-ga-take. Estimated ages are shown based on $^{14}C$ dates of buried soils and Akahoya volcanic ash.

Such invasions may have occurred occasionally during the period from 6,000 years B.P. to 2,000 years B.P. The debris mantled slopes developed on topography which had been deformed by certain slope processes and/or by perennial snow and ice activities following the glacial erosion.

*Lithology and structures*

A geological map of the study area (Fig. 6) was prepared from a survey by the present author based on previous studies (Ishii, 1937; Kaneko, 1956; Kano, 1975). In the southern part of the study area, there are Paleozoic sedimentary rocks, consisting mainly of alternations of slate and shale. In the central part, rhyolite rocks are dominant and most of them are of lithoiditic type without phenocrysts. Patches of granite porphyry, serpentinite, and siliceous green phyllite rocks occur in the northern part of the study area.

These bedrocks disintegrate into cubical boulders, cobbles, or pebbles with sharp edges and corners. The sizes of the rock fragments in the study area depend strongly on the rock

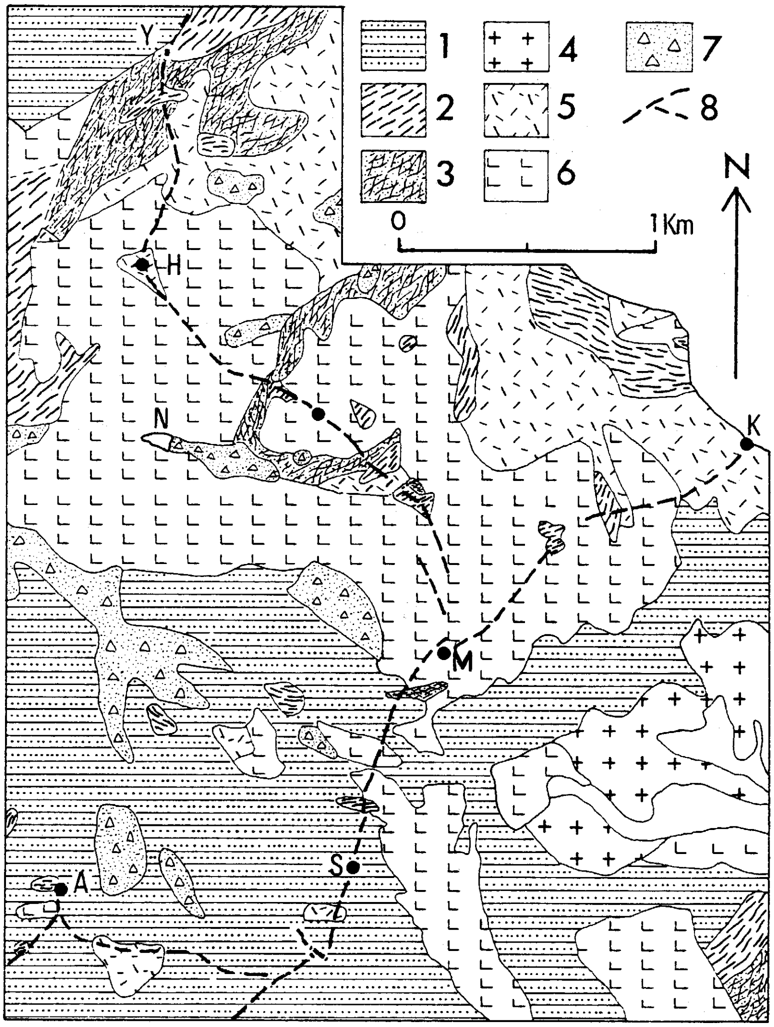


**Fig. 6.** Geological map of the study area, prepared by the author based on Ishii (1937), Kaneko (1956), and Kano (1975). 1: Shale and slate (Paleozoic); 2: Siliceous green phyllite; 3: Serpentinite; 4: Granodiorite; 5: Granite porphyry; 6: Rhyolite; 7: Quarternary unconsolidated deposits; 8: Main ridges; Y: Yukikura Hut; H: Hachi-ga-take; N: Lake Nagaike; K: Mt. Korenge; M: Mikuni-zakai; S: Mt. Shirouma-dake; A: Mt. Asahi-dake.

types. The Research Group for Alpine Geomorphology (1978, p. 23) reported the following sequence from small to large in size: serpentinite – rhyolite – granite porphyry – Paleozoic sedimentary rocks.

Two distinct joint systems run in roughly NE-SW and WNW-ESE directions, and twin ridges and linear depressions are developed on the crests and the low-relief surfaces. This situation has probably facilitated the snowpatch erosion and so controlled the forms of the depressions.

The Northern Japan Alps including Mt. Shirouma-dake have undergone uplift since the

Late Tertiary. However, the influence of such movement on the slope form can be disregarded over the short time span considered in this article.

## General features of the rubble slopes

### *An individual rubble slope*

In this article, the author has adopted the term "rubble slopes" for slopes in which rock fragments are exposed on the ground without vegetation cover. Such rubble slopes are bounded by vegetation-covered slopes and/or bare bedrock slopes within the study area. The latter refers to slopes in which the bedrock is exposed on the surface without any surface cover. Many patches or parallel bands of vegetation occur in the peripheral parts of the rubble slopes (see Figs. 3, 8, 21-C), so that the boundary line between a rubble slope and an adjacent vegetation-covered slope is drawn at about 50 percent coverage of vegetation. A continuous rubble slope of considerable extent is subdivided into individual rubble slopes. The individual rubble slope is a portion of the rubble slopes which shows a uniform morphological unit both in plan and profile forms. The morphological classification was made from the interpretation of air photographs at a scale of 1:15,000. Thus, the individual rubble slopes are defined according to differences of surface cover and/or both differences of surface cover and morphological discontinuities.

### *Distribution of the rubble slopes*

Figure 7 shows the distribution of rubble slopes in the study area. The rubble slopes are found in areas below an angle of 35°. These rubble slopes occupy about 27 percent of the study area, and the vegetation-covered slopes, bare rock slopes, and others such as river floors occupy 65 percent, 6 percent, and 2 percent, respectively.

Series of continuous rubble slopes are found mainly on the west side and on the top part of the crest where strong winds prevail. The height from the top to the lower limits of the rubble slopes commonly ranges from 50 to 100 m. Large rubble slopes occur on the east flanks of the main ridge where snow accumulates. Patches of rubble slopes also occur in the lee of knolls and in hollows on low-relief surfaces. Small patches of rubble slopes are found in windbeaten sites on east-facing slopes around shallow saddles and on the low-relief surface around Lake Nagaike.

### *Causes of rubble slope development*

The reason why plant growth is prevented on the rubble slopes has been discussed by Ohsumi and Kumada (1971), Iwata (1974), and Koizumi (1974, 1979–80). They insisted that the vegetation-free state of the rubble slopes is maintained due to climatic causes.

The prevailing winds sweep away the snow from the wind-ward slopes on the crests and knolls, so that the ground is exposed to severe coldness throughout the winter. Strong winds and severe ground frost provoke desiccation injury in plants (Sakai and Otsuka, 1970), so that the vegetation coverage is reduced to a very low state. Moreover, accelerating debris movement and debris supply caused by frost action may disturb the invasion of plants onto rubble slopes (Koizumi, 1979–80; Koizumi and Yanagimachi, 1982).

Many snowpatches remain until summer on the lee slopes where abundant snow accumulates. The growing period is too short for the plants to occupy the core areas beneath such snowpatches. Thus, extensive vegetation-free ground occurs on the lee slopes and in the hollows.

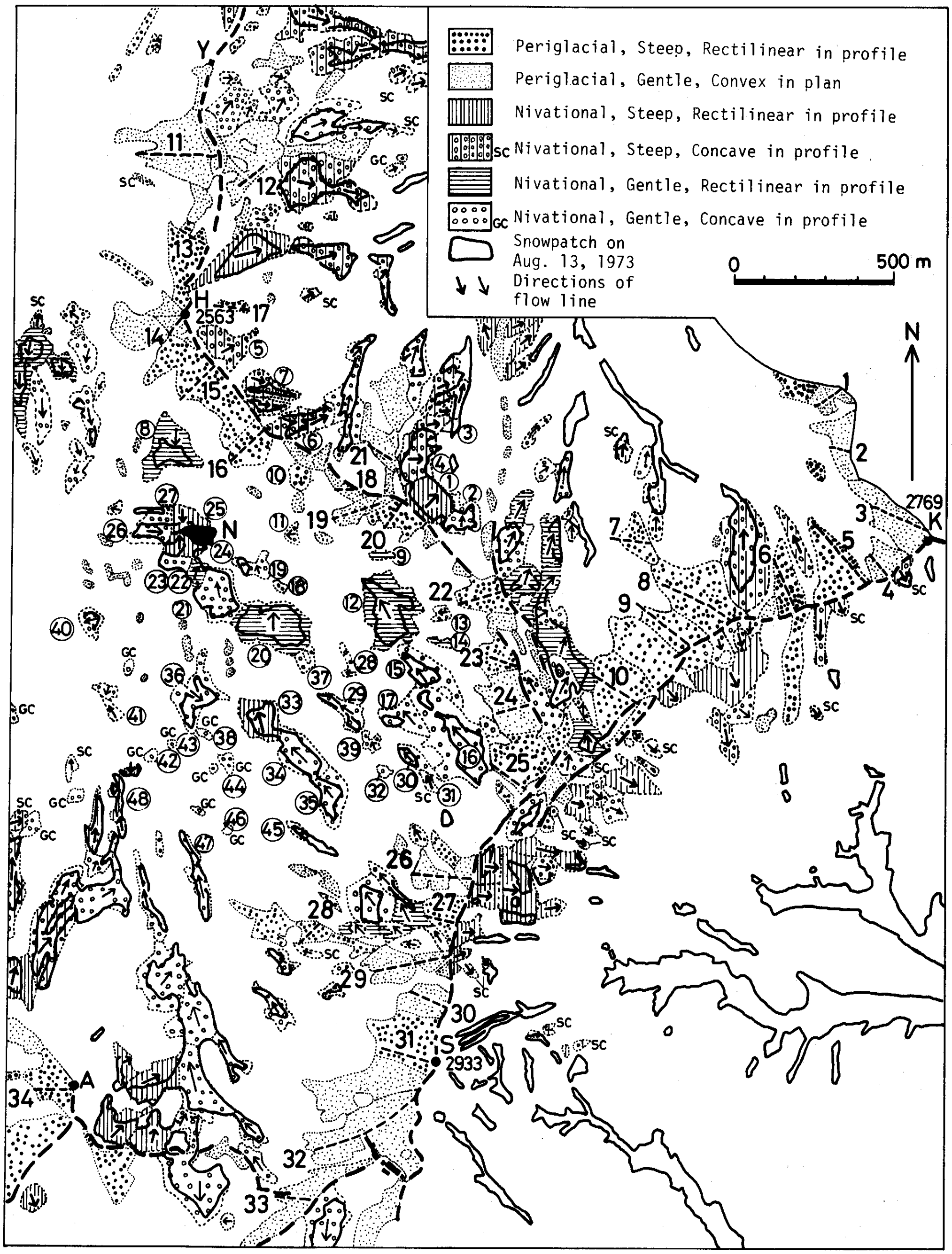


Fig. 7. Distribution and form of the rubble slopes. Climatic conditions, gradient, and dominant curvature are shown. Numbers indicate the location in Tables 2 and 3 (in circle). H: Hachiga-take; Y: Yukikura Hut; N: Lake Nagaike; K: Mt. Korenge; S: Mt. Shirouma-dake; A: Asahi-dake; Thick broken lines indicate main ridges.

Another important cause of the vegetation-free state of rubble slopes is the existence of the rubble layer which consists of large boulders and blocks, often more than 1 m in diameter (e.g. Koizumi, 1979–80). Under such circumstances it is very difficult for plants to spread, because there are large and deep interstices between the stones which contact point-to-point.

As described in detail later (see p. 23–30), the rubble slopes formed by these different causes, exist under two distinct climatic conditions. Schwind (1936), Kobayashi (1956), and Iwata (1974, 1980) previously recognized two distinct sets of surface processes acting on these rubble slopes: periglacial mass-movements and nivation. Accordingly, the author would here like to assign the term "periglacial rubble slopes" to the wind-swept and snow-free rubble slopes to the windward, and the term "nivational rubble slopes" to the snow-accumulated rubble slopes to the leeward (Fig. 8). Such periglacial rubble slopes have been termed "Glatthäng" in the mountainous regions of Central Europe, North Africa, and West Asia (e.g., Spreitzer, 1960; Höllermann, 1964). On the other hand, the nivational rubble slopes have been given names such as snowpatch depressions (Kobayashi, 1966) and nivation hollows (Lewis, 1939).

## 3. Characteristics of the Rubble Slopes

The individual rubble slopes investigated are indicated in Fig. 7 and their characteristics are summarized in Tables 2 and 3. The periglacial rubble slopes were selected from the whole of the study area, but the nivational rubble slopes were chosen only from the small area around Lake Nagaike since so many nivational rubble slopes exist over the whole study area. The features of the rubble slopes are illustrated in Figs. 9–14.

### Slope form

The rubble slopes are characterized by a smoothly-curved form. The form of a slope can be recognized as the profile form and plan form. The profile form refers to the shape along a vertical plane which follows the direction of the maximum angle. The plan form refers to the shape of the ground surface along a horizontal plane as shown by the curvature of the contours. Both curvatures in the plan and profile forms of individual rubble slopes were obtained by air photograph interpretation. Convex and concave curvatures and an almost rectilinear form were distinguished. The profiles of the periglacial rubble slopes commonly present convex curvatures or a rectilinear form, whereas those of the nivational rubble slopes have concave curvatures or a rectilinear form. Short convex segment occur above rectilinear segments of the profiles of many periglacial rubble slopes. On the nivational rubble slopes, slight concavities can sometimes be recognized on the rectilinear profiles (Fig. 14(5)), and flat or concave segments exist below the rectilinear slope segment (Fig. 14(3)). The plan form is also different between the periglacial rubble slopes with convex curvatures and the nivational rubble slopes with concave curvatures. Some nivational rubble slopes present complete hollow forms without any outlets.

The gradients of the slopes of the rubble slopes range in angle from 3° to 35°. The dominant values of the gradients for the periglacial and nivational slopes are different:

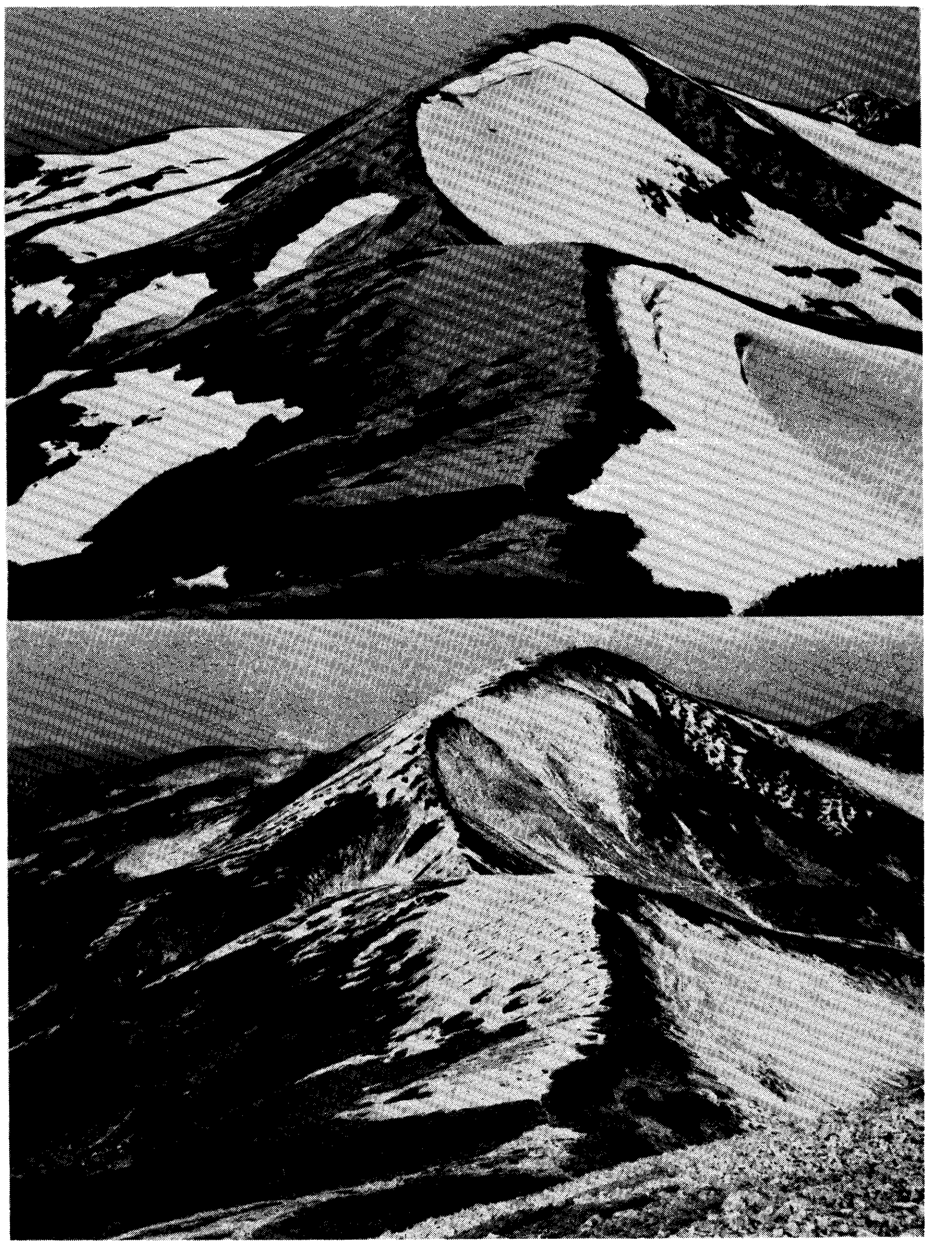

**Fig. 8.** Periglacial rubble slopes (on the left side of the ridges) and nivational rubble slopes (on the right side of the ridges) of the 2,504 m knoll and Mt. Hachi-ga-take (2,564 m, in the background). Photograph was taken on: June 4, 1980 (upper); Oct. 7, 1978 (lower).

**Table 2.** Characteristics of periglacial rubble slopes in the study area.

| Location number[a] | Aspect | Curvature[b] | | Height of slope | Slope length | Mean slope gradient (degree) | Lithology[c] | Type of surface rubble layer | Surface micro-relief[d] | | | | Type of plant community[e] | Vegetation coverage (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Plan | Profile | | | | | | Sorted net & stripes | Lobes | Turf-banked terrace | Rill | | |
| 1 | SW | CV | R | 35m | 108m | 19° | Rhyolite | Cobble-pebble | - | + | - | - | A D | 5% |
| 2 | W | R | R | 27 | 69 | 23 | Green phyllite | Ill-sorted veneer | + | - | ++ | + | B C D | 45 |
| 3 | W | R | R | 90 | 230 | 23 | Gp | Boulder | - | * | - | - | B C D | 3 |
| 4 | NW | CV | R | 25 | 91 | 16 | Gp | Cobble-pebble | - | - | * | - | B C D | 5 |
| 5 | NW | R | R | 130 | 286 | 27 | Gp | Boulder | - | + | - | - | B C D | 7 |
| 6 | NW | R | R | 100 | 213 | 28 | Gp | Boulder/Cobble-Pebble | * | ++ | - | - | A B C D | 15 |
| 7 | W | CV | R | 78 | 185 | 25 | Rhyolite/Gp | Ill-sorted veneer | - | ++ | + | - | B C D | 40 |
| 8 | NW | CV | CC | 115 | 262 | 26 | Rhyolite | Boulder | - | ++ | - | - | B C | 5 |
| 9 | NW | CV | R | 150 | 300 | 30 | Rhyolite/Gp | Boulder | - | + | + | - | B C D | 5–10 |
| 10 | NW | R | R | 110 | 227 | 29 | Rhyolite | Cobble | - | ++ | - | - | B C | 5 |
| 11 | W | R | CV/R | 60 | 184 | 19 | Serpentinite | Veneer pebble | - | - | - | + | A | 1–2 |
| 12 | NE | CV | CV | 25 | 120 | 12 | Gp | Cobble-pebble | + | - | ++ | - | A B C D | 25 |
| 13 | W | CV | R | 65 | 143 | 27 | Gp | Boulder | - | ++ | - | - | B C D | 25 |
| 14 | SW | CC | CV | 23 | 291 | 18 | Gp | Boulder | * | ++ | - | - | B C | 10 |
| 15 | SW | R | CV/R | 90 | 205 | 26 | Rhyolite | Cobble-pebble | + | - | - | - | A D | 5 |
| 16 | SW | CV | CC | 90 | 180 | 30 | Rhyolite | Cobble-pebble | - | - | - | - | A D | 20 |
| 17 | E | R | R | 90 | 186 | 29 | Rhyolite | Cobble-pebble | - | - | - | - | A D | 30 |
| 18 | W | R | R | 25 | 73 | 20 | Rhyolite | Veneer pebble | + | - | ++ | - | B C | 40 |
| 19 | W | CV | CV | 55 | 141 | 23 | Rhyolite | Pebble | - | - | - | * | A D | 15 |
| 20 | SW | R | R | 44 | 100 | 26 | Rhyolite | Cobble-pebble | * | + | - | - | A | 5 |
| 21 | NW | R | CV | 25 | 91 | 16 | Rhyolite | Pebble | * | * | - | - | D | 35 |
| 22 | W | CV | R | 70 | 154 | 27 | Gp | Boulder | - | + | - | - | B C D | 30 |
| 23 | W | CV | R | 60 | 113 | 32 | Rhyolite | Cobble | - | + | - | - | A D | 5–6 |
| 24 | W | R | CV | 40 | 98 | 24 | Rhyolite | Cobble-pebble | ++ | - | - | - | A | 1–2 |
| 25 | NW | R | CV/R | 100 | 213 | 28 | Rhyolite | Cobble-pebble | - | - | - | - | A | 1–2 |
| 26 | W | CV | R | 70 | 205 | 20 | Slate, Shale | Ill-sorted veneer | * | - | + | - | B C | 30 |
| 27 | W | R | R | 60 | 115 | 31 | Rhyolite | Cobble | - | - | - | - | | 0 |
| 28 | SW | R | R | 60 | 105 | 35 | Rhyolite | Cobble-pebble | + | - | - | - | A D | 5–7 |
| 29 | W | CV/R | CV/R | 100 | 267 | 22 | Slate, Shale | Ill-sorted veneer | - | - | + | - | B C | 30 |
| 30 | W | CC | R | 51 | 131 | 23 | Slate, Shale | Ill-sorted veneer | - | - | + | + | B C | 30 |
| 31 | W | R | R | 103 | 227 | 27 | Slate, Shale | Ill-sorted veneer | - | + | + | - | B C | 25 |
| 32 | SW | CV | R | 135 | 395 | 20 | Gp/Slate, Shale | Ill-sorted veneer | * | - | + | - | B C | 30 |
| 33 | W | CV | R | 25 | 120 | 12 | Slate, Shale | Ill-sorted veneer | * | - | + | - | B C | 30 |
| 34 | W | R | R | 75 | 142 | 32 | Green phyllite | Ill-sorted veneer | - | + | + | + | B C D | 30 |

[a] Localities are shown in Fig. 7. [b] CV: Convex; R: Rectilinear; CC: Concave. [c] Gp: Granite porphyry.
[d] ++: extremely developed; +: developed; *: scarecely; -: not existing. [e] A: alpine desert plant community; B: wind-blown meadow; C: wind-blown heath; D: *Pinus pumila* scrub.

**Table 3.** Characteristics of nivational rubble slopes in the study area.

| Location number[a] | Aspect | Curvature[b] | | Height of slope | Slope length | Mean slope gradient (degree) | Lithology[c] | Type[d] of surface rubble layer | Surface micro-relief[f] | | | | | Vegetation coverage (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Plan | Profile | | | | | | Sp | L | T | Dt | R[e] | |
| | | | | | | | | | | | | | | % |
| 1 | NE | R | R | 60m | 137m | 26° | Rhyolite | Vp/Cp | - | + | - | + | ++ | 2–3 |
| 2 | NW | CC | CC | 45 | 132 | 20 | Rhyolite/Gp | B | * | ++ | - | - | - | 10 |
| 3 | E | CC | CC | 100 | 194 | 31 | Rhyolite | Cp | - | + | - | + | + | 5 |
| 4 | NE | CC | CC | 75 | 177 | 25 | Rhyolite | Cp | - | + | - | - | + | 7 |
| 5 | NE | CC | CC | 105 | 224 | 28 | Rhyolite | Vp | - | - | + | + | ++ | 10 |
| 6 | NE | CC | CC | 160 | 379 | 25 | Rhyolite | Vi | - | - | ++ | + | ++ | 20 |
| 7 | NE | CC | CC | 120 | 240 | 30 | Rhyolite | Vi | - | - | + | + | ++ | 10 |
| 8 | S | R | R | 40 | 107 | 22 | Rhyolite | Cp/Vp | ++ | - | - | ++ | ++ | 5 |
| 9 | SW | CC | CC | 17 | 47 | 21 | Rhyolite/Serpentinite | Vi | - | + | + | - | ++ | 20 |
| 10 | SE | CC | CC | 15 | 72 | 12 | Rhyolite | Cobble/Vi | - | - | - | - | - | 10 |
| 11 | S | CC | R | 15 | 58 | 15 | Serpentinite | Vi | - | - | * | - | ++ | 25 |
| 12 | NW | CC | R | 75 | 272 | 16 | Rhyolite | Cobble | * | ++ | - | - | - | 2–3 |
| 13 | W | CC | CC | 25 | 91 | 16 | Rhyolite | Vi | - | - | ++ | - | ++ | 25 |
| 14 | W | R | R | 30 | 124 | 14 | Rhyolite | Vp | - | - | - | - | - | 5 |
| 15 | NW | CC | CC | 75 | 333 | 13 | Rhyolite/Slate, Shale | Cobble/B | - | ++ | + | - | * | 7.5 |
| 16 | NW | R | CC | 160 | 446 | 21 | Slate, Shale | B/Vi | - | - | - | + | - | 2–3 |
| 17 | NW | R | CC | 50 | 193 | 15 | Slate, Shale | B/Vi | - | - | - | - | - | 5–7 |
| 18 | NW | CC | CC | 15 | 78 | 11 | Rhyolite | Vi | - | - | ++ | - | ++ | 40 |
| 19 | N | CC | CC | 15 | 67 | 13 | Rhyolite | Vi | - | - | ++ | - | ++ | 30 |
| 20 | N | R | R | 45 | 146 | 18 | Rhyolite | Cobble | * | ++ | * | + | * | 5–7 |
| 21 | N | R | CC | 45 | 115 | 23 | Rhyolite | Cobble/Vi | * | ++ | + | + | ++ | 10 |
| 22 | NW | R | CV | 20 | 128 | 9 | Rhyolite | Vi | + | + | ++ | - | ++ | 12 |
| 23 | N | R | CC | 8 | 57 | 8 | Rhyolite | Vp | + | - | + | - | - | 10 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | N | R | CV | 40 | 70 | 35 | Rhyolite | B | – | ++ | – | – | – | 5 |
| 25 | S | R | R | 40 | 80 | 30 | Rhyolite | Vp | – | + | * | + | + | 5 |
| 26 | E | CC | CC | 10 | 52 | 11 | Rhyolite | Vi | – | + | ++ | – | + | 40 |
| 27 | W | CC | R | 5 | 57 | 5 | Rhyolite | Pebble | – | – | + | – | + | 10 |
| 28 | SW | CC | CC | 10 | 44 | 13 | Rhyolite/Slate, Shale | Cp/Vi | – | – | ++ | – | + | 40 |
| 29 | NW | CC | CC | 60 | 34 | 11 | Slate, Shale | B/Vi | – | ++ | + | – | ++ | 15 |
| 30 | N | CC | CC | 45 | 154 | 17 | Slate, Shale | B | – | – | – | – | – | 10 |
| 31 | NW | R | R | 60 | 120 | 30 | Slate, Shale | Vi/B | – | – | – | + | + | 5 |
| 32 | N | CC | CC | 30 | 62 | 18 | Slate, Shale | B | – | – | – | – | – | 5 |
| 33 | N | R | R | 75 | 150 | 30 | Slate, Shale | B | – | + | – | ++ | ++ | 5 |
| 34 | N | CC | CC | 65 | 154 | 25 | Slate, Shale | B | – | + | * | – | – | 7 |
| 35 | N | CC | CC | 65 | 374 | 10 | Slate, Shale | B | – | + | * | – | – | 10 |
| 36 | SE | CC | CC/CV | 15 | 62 | 14 | Rhyolite/Slate, Shale | Cobble/B | + | ++ | + | – | + | 10 |
| 37 | S | CC | CC | 5 | 96 | 3 | Rhyolite | Vp | ++ | – | ++ | – | – | 30 |
| 38 | W | CC | CC | 15 | 49 | 18 | Slate, Shale | Vi | – | – | ++ | – | ++ | 35 |
| 39 | N | CC | CC | 25 | 97 | 15 | Slate, Shale | Vi | – | – | + | – | – | 20 |
| 40 | W | CC | CC | 15 | 67 | 13 | Rhyolite | Cp | * | + | ++ | – | + | 25 |
| 41 | N | R | R | 50 | 87 | 35 | Unconsolidated deposits | Vi | – | – | * | – | ++ | 5 |
| 42 | S | CC | CC | 10 | 82 | 7 | Slate, Shale | Vp | * | – | ++ | – | + | 35 |
| 43 | S | CC | CC | 3 | 34 | 5 | Slate, Shale | Vi | * | – | ++ | – | + | 35 |
| 44 | NW | CC | CC | 25 | 111 | 13 | Slate, Shale | Vi | – | – | ++ | – | ++ | 25 |
| 45 | W | CC | CC | 30 | 77 | 23 | Slate, Shale/Gp | Vi/B | – | – | + | + | ++ | 20 |
| 46 | W | CC | CC | 20 | 65 | 18 | Slate, Shale/Gp | Vi/B | – | – | + | + | ++ | 25 |
| 47 | N | CC | R | 115 | 321 | 21 | Slate, Shale | Vi | – | – | ++ | + | ++ | 25 |
| 48 | E | R | R | 10 | 18 | 33 | Slate, Shale | Vi | – | – | + | + | ++ | 5 |

[a] Localities are shown in Fig. 7. [b] CV: Convex; R: Rectilinear; CC: Concave. [c] Gp: Granite porphyry. [d] B: Boulder; Cp: Cobble-pebble; Vi: Ill-sorted veneer; Vp: Veneer pebble. [e] Sp: Sorted net and stripes; L: Lobes; T: Turf-banked terraces; Dt: Debris flow tongues; R: Rills. [f] ++: extremely developed; +: developed; *: scarecely; –: not existing.

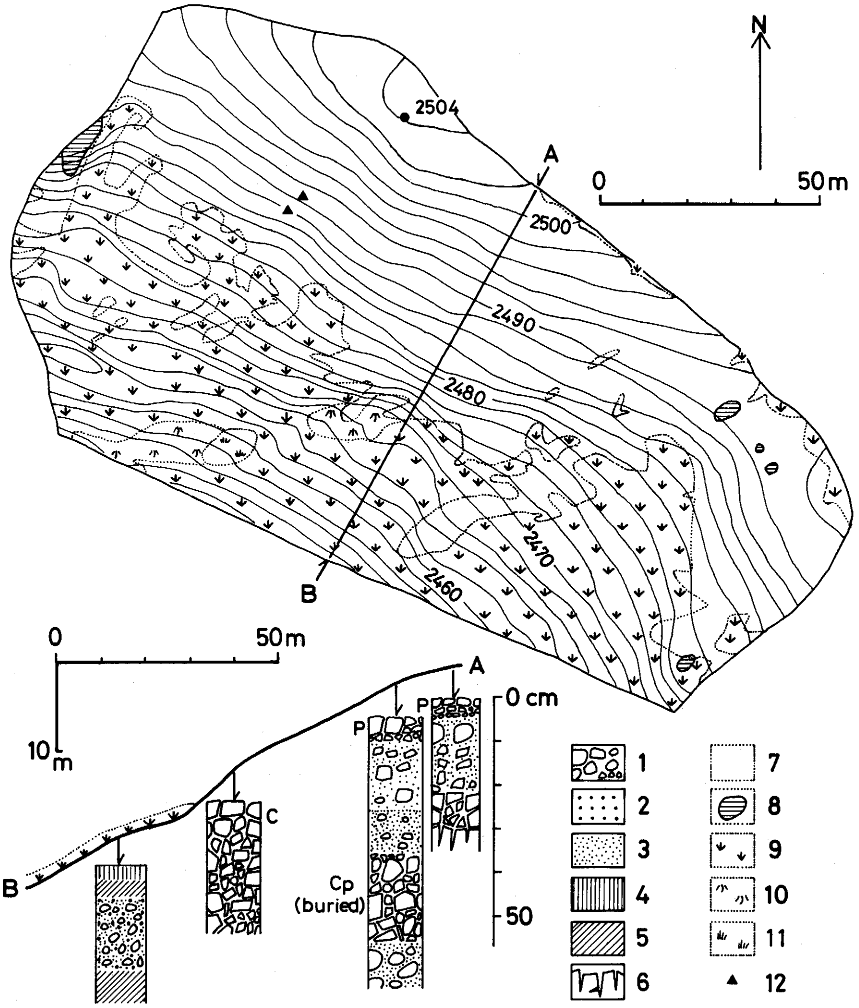


**Fig. 9.** Topography and profile of periglacial rubble slope 20. 1: Rock fragments; 2: Granules; 3: Sandy loam; 4: Humus; 5: Humic soil; 6: Bedrock; 7: Rubble slope; 8: Tor; 9: *Pinus pumila* scrub; 10: *Sasa* scrub; 11: Alpine meadow; 12: Wash trap.

62 percent of the periglacial rubble slopes are between 20° and 30°, while 42 percent of the nivational rubble slopes are between 10° and 20°.

Although the rubble slopes are characterized by relatively smooth profiles, tors are often present in the upper sections on the periglacial rubble slopes, and linear depressions (named by Suzuki, 1974) sometimes give rise to abrupt breaks in the slopes. Small patches of rugged bedrock are frequently exposed on the steep rubble slopes which are located on the east side of the main crest (Fig. 4).

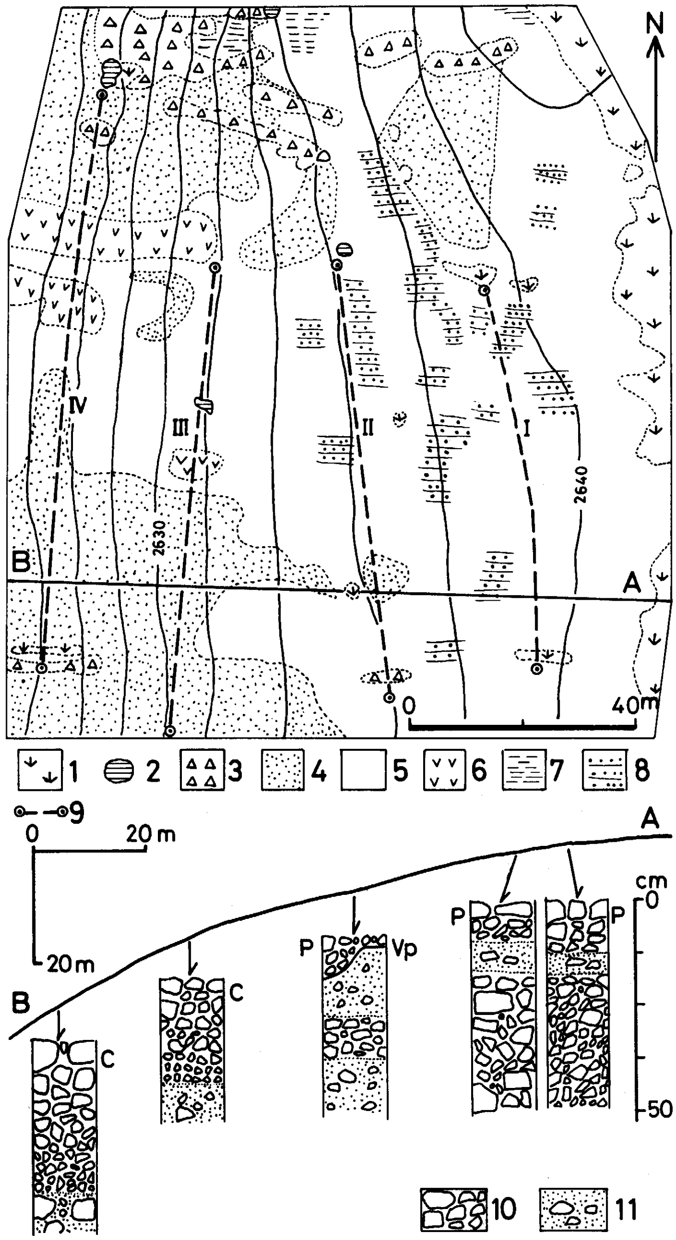


**Fig. 10.** Features of periglacial rubble slope 24. 1: *Pinus pumila* scrub; 2: Outcrop of bedrock; 3: Boulder type rubble surface; 4: Pebble type rubble surface; 5: Cobble type rubble surface; 6: Thick surface rubble of pebble type; 7: Veneer pebble type rubble surface; 8: Sorted stripes; 9: Measuring line for debris movement; 10: Surface rubble layer and buried rubble layer; 11: Gravel-rich sandy loam layer.

## Surface materials

Most of the rubble slopes are composed of debris mantles which are derived from the underlying bedrock by weathering. The debris mantle is usually less than several metres in thickness. Some other rubble slope which are located on the depositional landforms such as glacial moraines and talus are composed of unconsolidated sediments.

The rubble slopes possess a continuous or near continuous cover of rubble layers at the surface. These surface layers are openwork rubbles comprised of piles of rock fragments without interstitial fines. The thickness of the rubble layers range from a few centimetres to more than 50 cm. These rubble layer at the surface are termed "surface rubble layers" in this article. Below the surface rubble layers, gravel-rich sandy loam layers exist. As shown in the columnar sections in Figs. 11, 12, and 14, openwork rubble layers can be found lying between the gravel-rich sandy loam layers. Such rubble layers are termed "buried rubble

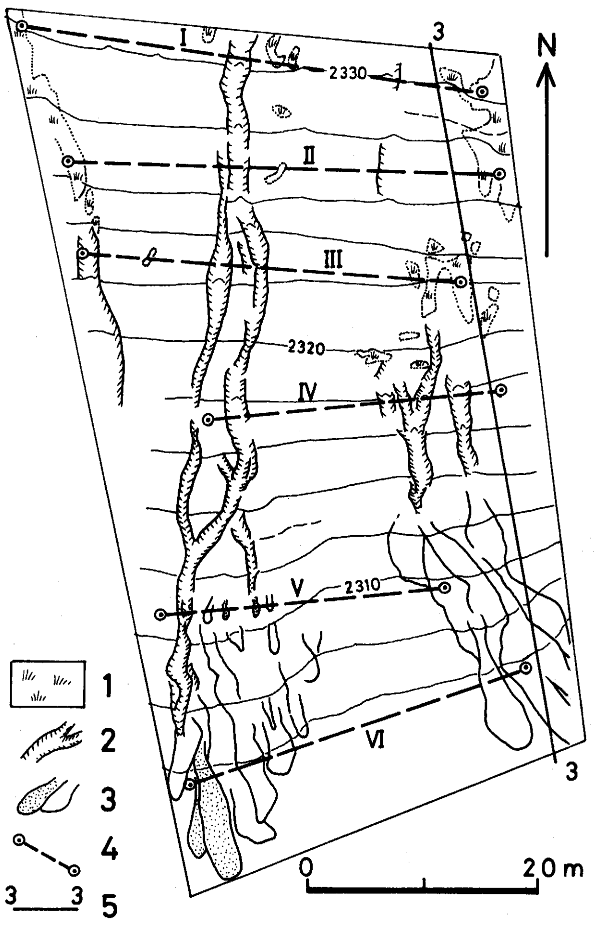


**Fig. 11.** Features of nivational rubble slope 08. 1: Snowpatch plant community; 2: Rills; 3: Debris flow tongures, shaded ones were formed in August, 1976; 4: Measuring line for debris movement; 5: Section line shown in Fig. 14.

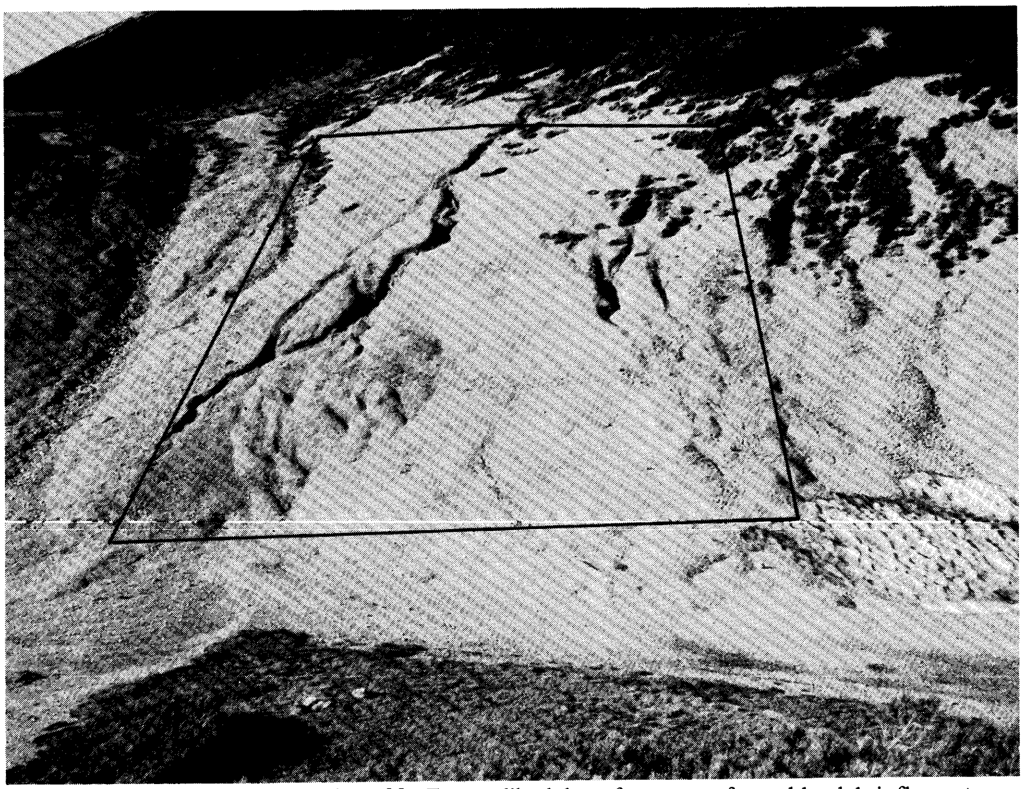

**Fig. 12.** Nivational rubble slope 08. Tongue-like lobate forms were formed by debris flows at the lower ends of rills. The photograph was taken on Sept. 30, 1975. The area in Fig. 11 is shown.

layers". One noteworthy feature of the surface rubble layer is that in most cases the size of the rock fragments decreases with depth in the layer. Such vertical sorting occurs through the vertical movement of fragments during the freeze-thaw cycles (see p. 31).

The properties of the surface rubble layers, such as the size and sorting of the material, and the thickness of the layer, vary with locality. Although the surface rubble layers present different properties in each individual slope (Figs. 9, 10, 13, and 14), the core area of the rubble slope shows definite values of size, sorting, and thickness as indicated in Fig. 15. The size of the rubble and thickness of the layers were measured in the core areas of 34 individual rubble slopes and plotted as a graph of thickness against size. As shown in Fig. 16, the values on the graph can be divided into four groups.

The Research Group for Alpine Geomorphology (1978, p. 28–40, 56–67) and Koizumi (1979–80) suggested that the features of the surface rubble layer have close relations with the mass-movement processes, vegetation, and surface micro-relief. Sohma et al. (1979) made a classification of the surface rubble layers according to the characteristics of slow mass-movement on rhyolite slopes in the study area. The boundaries of size and thickness indicated in Fig. 16 show mostly the same values to those of Sohma et al. (1979). In order to understand the local variety of surface rubble layers in the study area, the surface rubble layers can also be classified into the following four main types according to differences in size, sorting, and thickness:

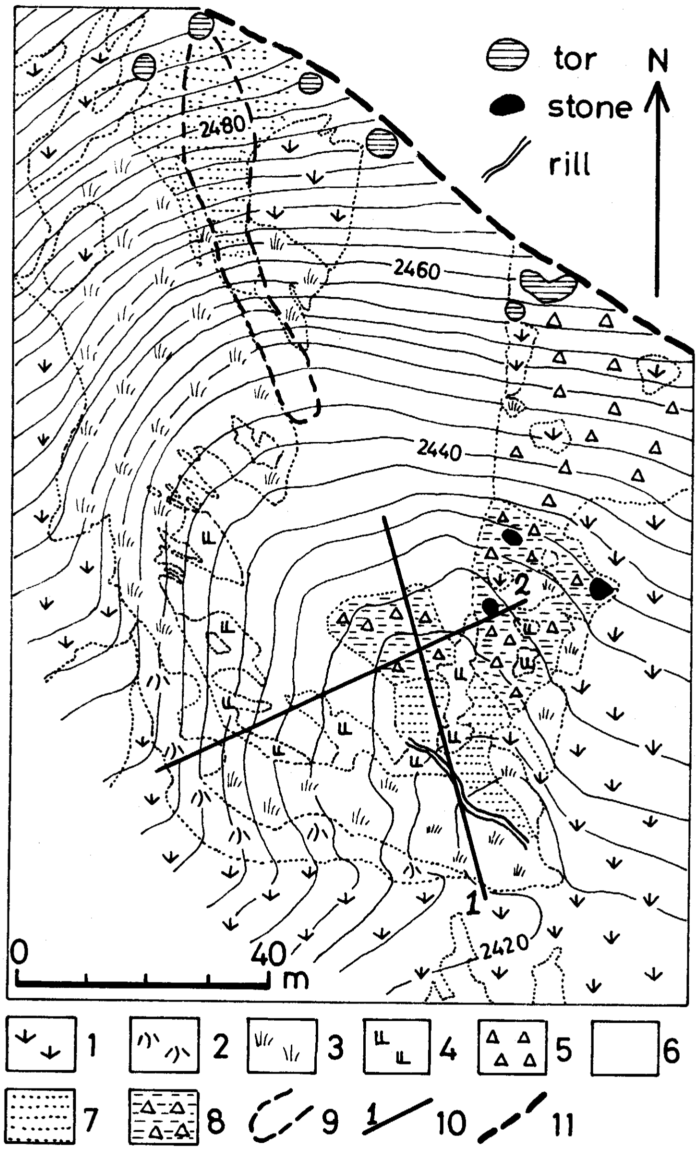


**Fig. 13.** Feature of nivational rubble slope 10. 1: *Pinus pumila* scrub; 2: *Sasa* scrub; 3: Alpine meadow; 4: Grass and dwarf scrub vegetation in patches; 5: Boulder type rubble surface; 6: Cobble-pebble type rubble surface; 7: Veneer pebble type rubble surface; 8: Ill-sorted veneer type rubble surface; 9: Distribution of rock fragments scattered by the failure of the tor; 10: Section line shown in Fig. 14; 11: Ridge.

i) Boulder type (B in abbreviations): the rock fragments on the surface are mainly larger than 20 cm in size along the long axis. As regards sorting, the fragments are mainly well-sorted but some display an ill-sorted character. The thickness of the layer exceeds 30 cm (Fig. 17-B).

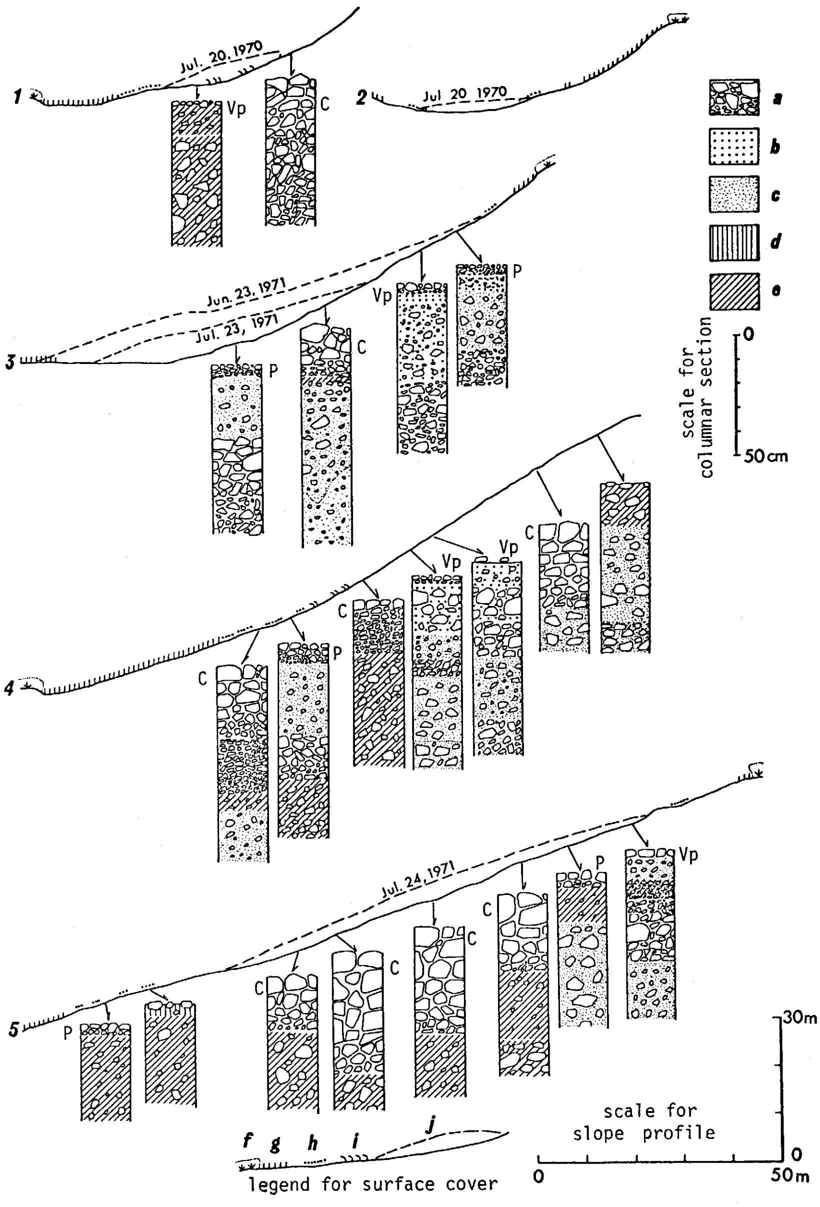


**Fig. 14.** Slope profiles on the nivational rubble slopes and their surface materials. Localities are shown in Figs. 2, 11, and 13. a: Rubble; b: Granule; c: Sandy loam; d: Humus; e: Humic soil; f: *Pinus pumila* scrub; g: Alpine meadow; h: Dwarf heath; i: Sparse Gramineae plants; j: Snowpatch.

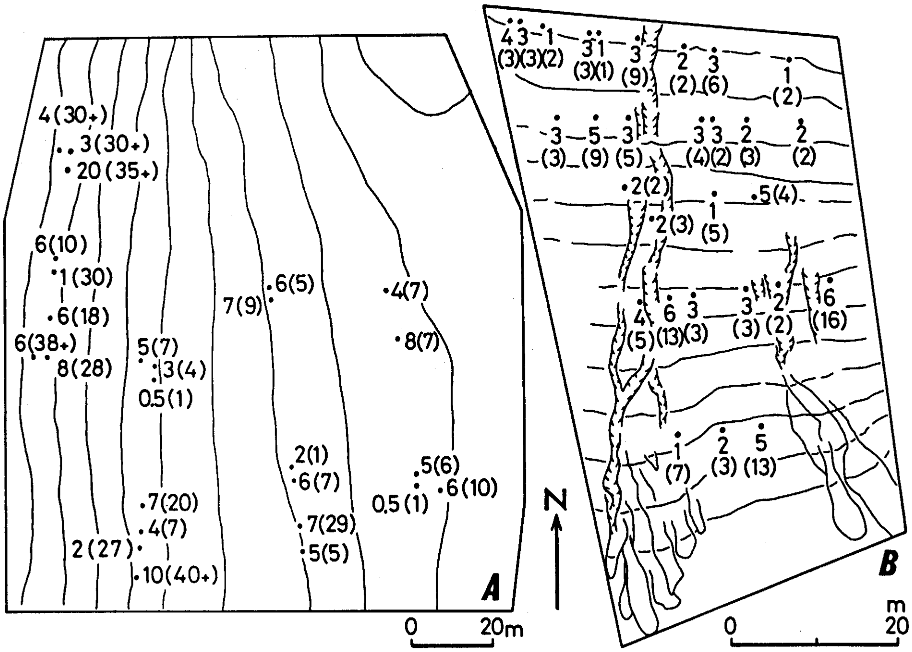

Fig. 15. Mean size of the rubble (in cm) and thickness of the layers (in parentheses in cm) in the core area of the rubble slopes. *A*: Periglacial rubble slope 24 (cf. Fig. 10); *B*: Nivational rubble slope 08 (cf. Fig. 11).

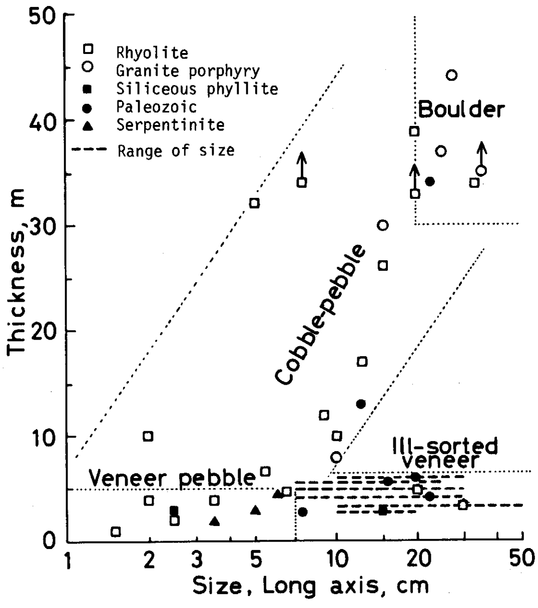


Fig. 16. Relation between mean size of the rubble at the surface and thickness of the surface rubble layer in the core area of 34 individual rubble slopes.

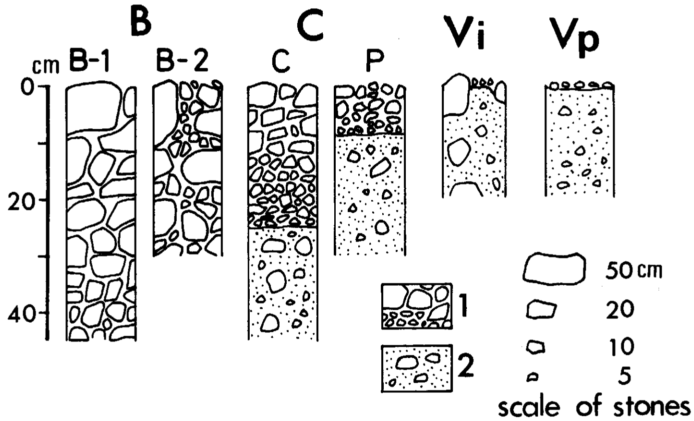


Fig. 17. Columnar sections of the types of the surface rubble layer. B: Boulder type (B-1: Well-sorted boulder type; B-2: Ill-sorted boulder type); Cp: Cobble-pebble type (C: Cobble type; P: Pebble type); Vi: Ill-sorted veneer type; Vp: Veneer pebble type. 1: Surface rubble layer; 2: Gravel-rich sandy loam layer.

ii) Cobble-pebble type (Cp): the surface rubble layer is composed mainly of well-sorted rock fragments which are smaller than 20 cm in size along the long axis. The thickness of the layer ranges from 30 cm to 5 cm (Fig. 17-Cp). This type can be subdivided into a cobble type (C) and pebble type (P) according to the size of the fragments. The fragments of the cobble type range from 20 cm to 7 cm in size of the long axis and those of the pebble type are smaller than 7 cm in size.

iii) Ill-sorted veneer type (Vi): the rock fragments exhibit various sizes ranging from pebbles to boulders, and the thickness of the layer is less than about 5 cm. The gravel-rich sandy loam layer exists just below the uppermost layer of surface rubble (Fig. 17-Vi).

iv) Veneer pebble type (Vp): this layer consists of a thin veneer of rubble. Its thickness is less than about 5 cm. The rock fragments are well-sorted and smaller than 5 cm in size of the long axis (Fig. 17-Vp).

Figure 18 shows the features of the four types of surface rubble layers, and Fig. 19 illustrates 12 examples of the size distribution of the surface materials classified into the four types of surface rubble layers. The distributions of the four types of surface rubble layers are shown in Fig. 20. A comparison between Fig. 6 and Fig. 20 reveals that the distribution of the four types of surface rubble layers corresponds broadly to that of the lithology in the study area as indicated in Table 4. This means that the formation of the surface rubble layers is strongly governed by the lithology.

## Environmental factors of the rubble slopes

### *Climatic conditions of the rubble slopes*

Snow cover plays a very important role on the slopes in the study area. The topography, seasonal changes of snow cover, and vegetation in the area around Lake Nagaike are shown in Fig. 21. It is clear that a close relationship exists among them.

The periglacial rubble slopes are situated in an environment which is almost snow-free

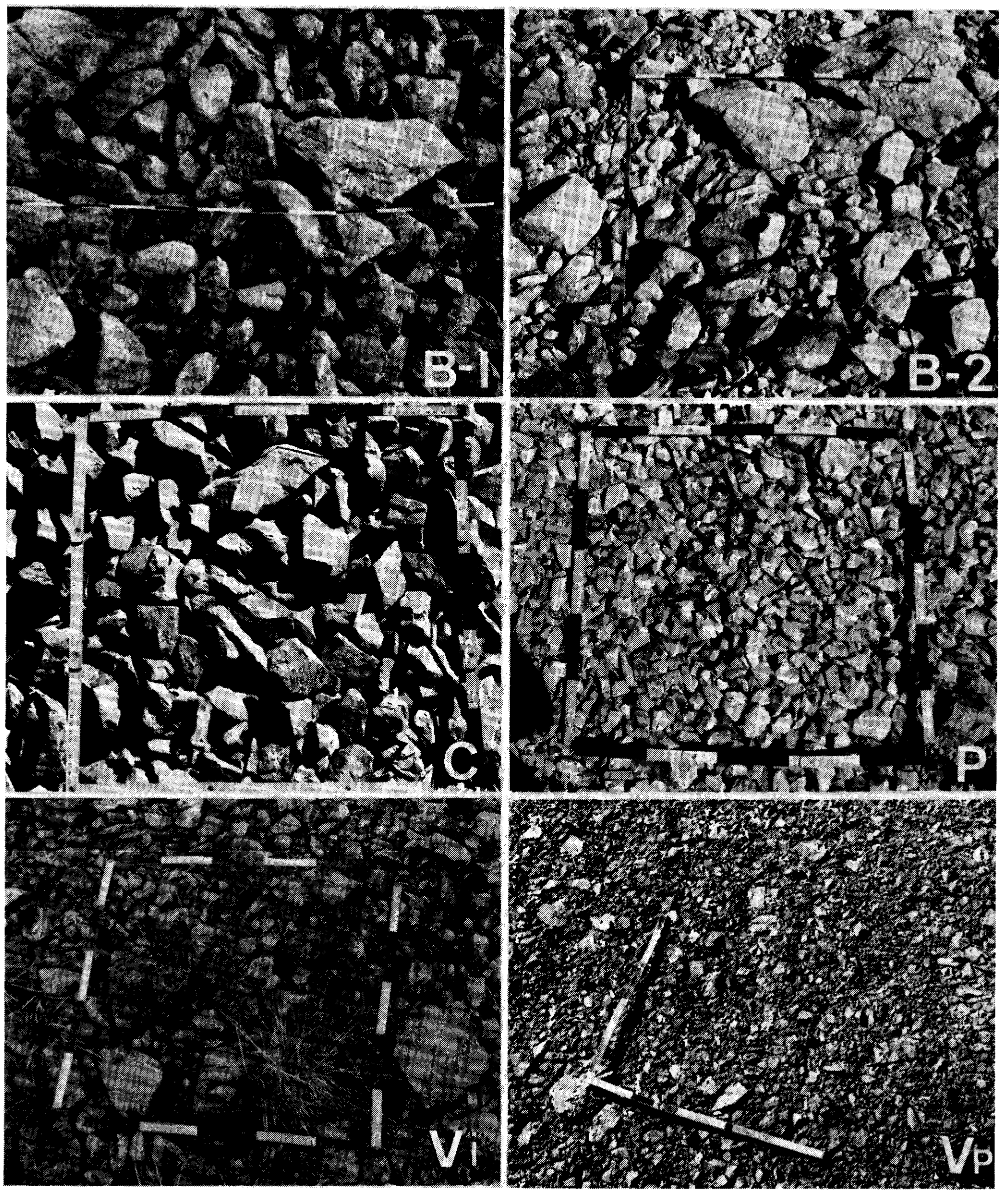


**Fig. 18.** Features of the types of surface rubble layers. Scales in the photographs are painted each 10 cm. B-1: Well-sorted boulder type; B-2: Ill-sorted boulder type; C: Cobble type; P: Pebble type; Vi: Ill-sorted veneer type; Vp: Veneer pebble type.

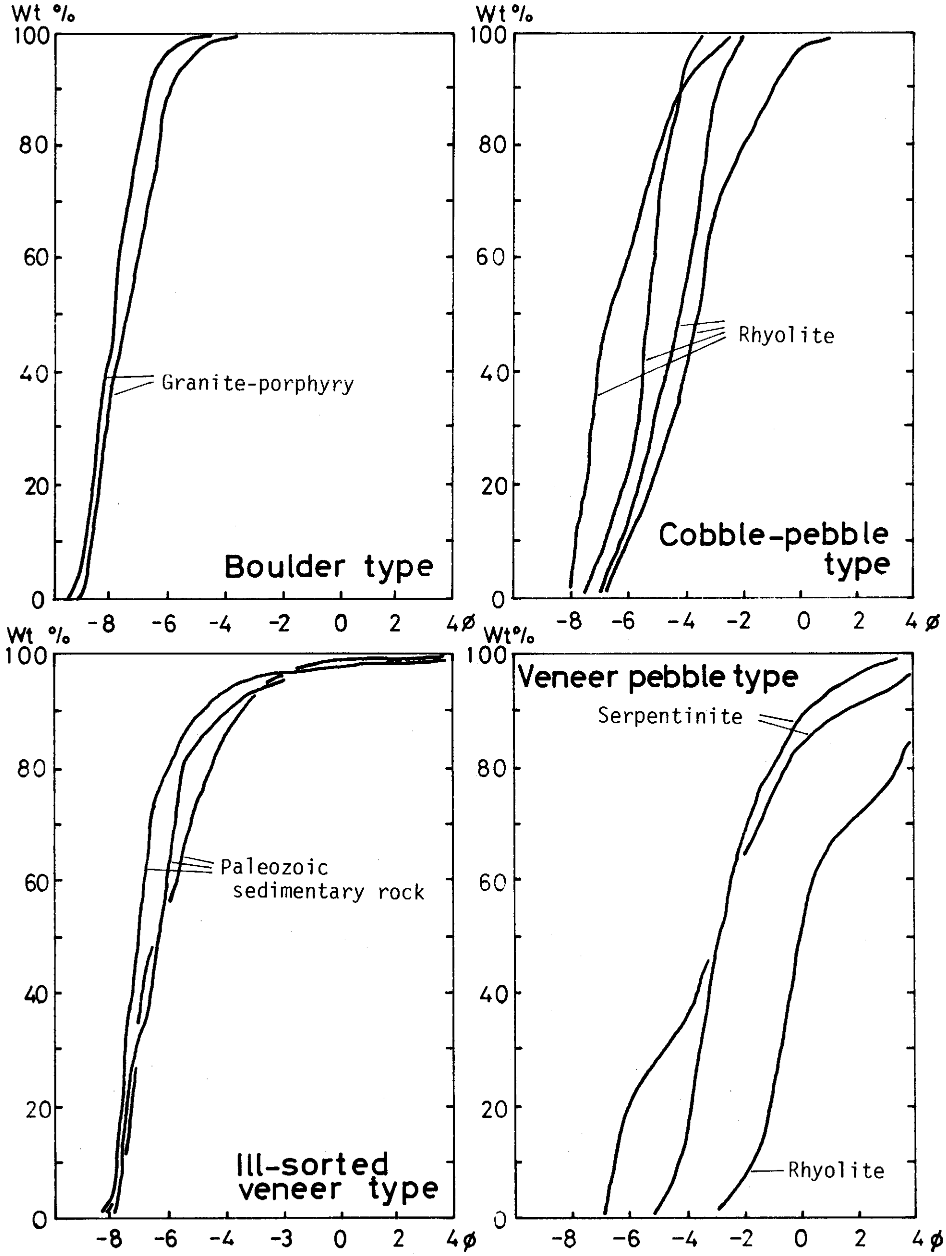


**Fig. 19.** Examples of the size distribution of the surface materials classified into the four types of surface rubble layers. Samples were taken from 1 x 1 m quadrate with thickness of about 20 cm.

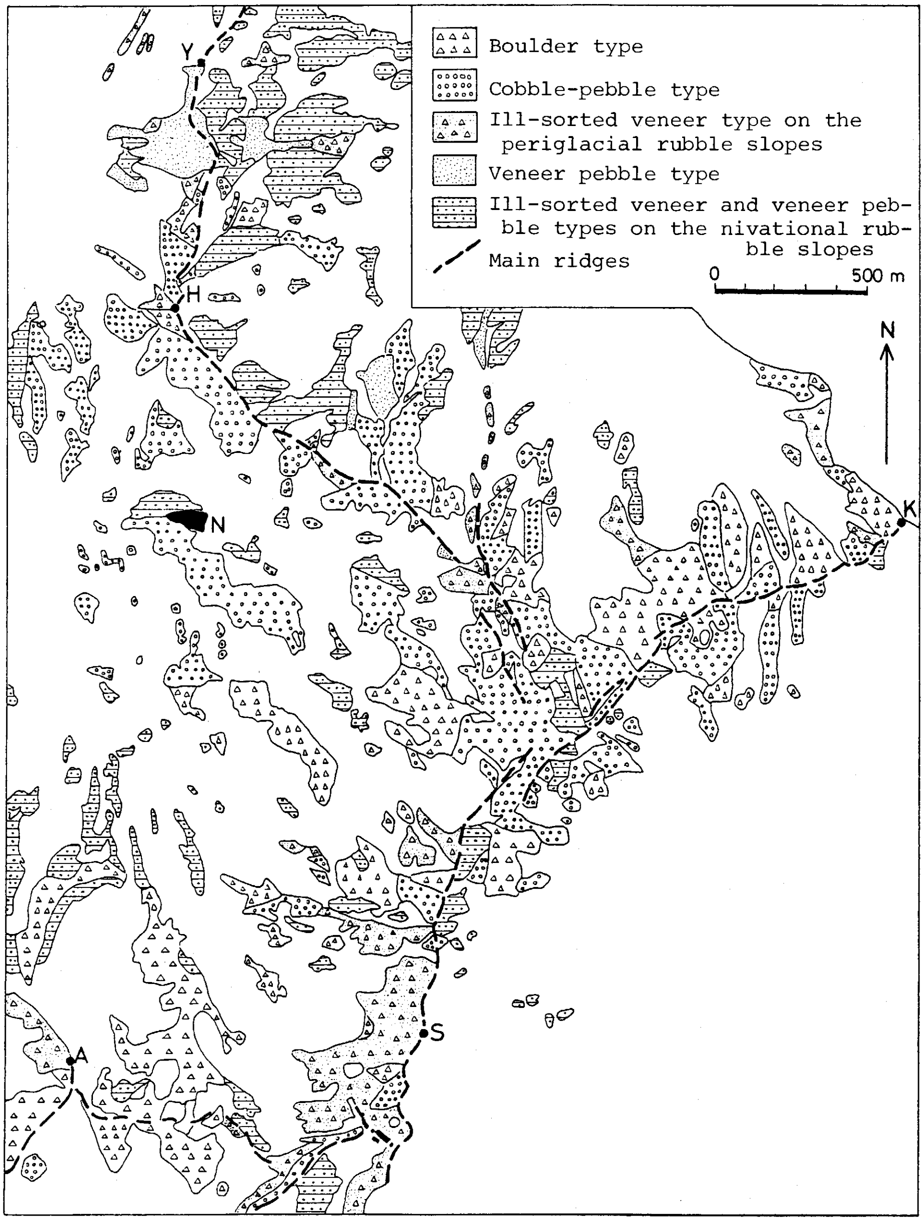


**Fig. 20.** Distribution of the four types of surface rubble layers in the study area. H: Mt. Hachi-ga-take; Y: Yukikura Hut; N: Lake Nagaike; K: Mt. Korenge; S: Mt. Shirouma-dake; A: Mt. Asahi-dake.

**Table 4.** Correspondence between types of the surface rubble layer and the lithology.

| Types of surface rubble layer | Lithology |
|---|---|
| Boulder (B) | Slate |
| | Shale |
| | Granite-porphyry |
| Cobble-pebble (Cp) | Rhyolite |
| Ill-sorted veneer (Vi) | Slate |
| | Shale |
| | Siliceous green phylite |
| | Unconsolidated deposits |
| Veneer pebble (Vp) | Serpentinite |

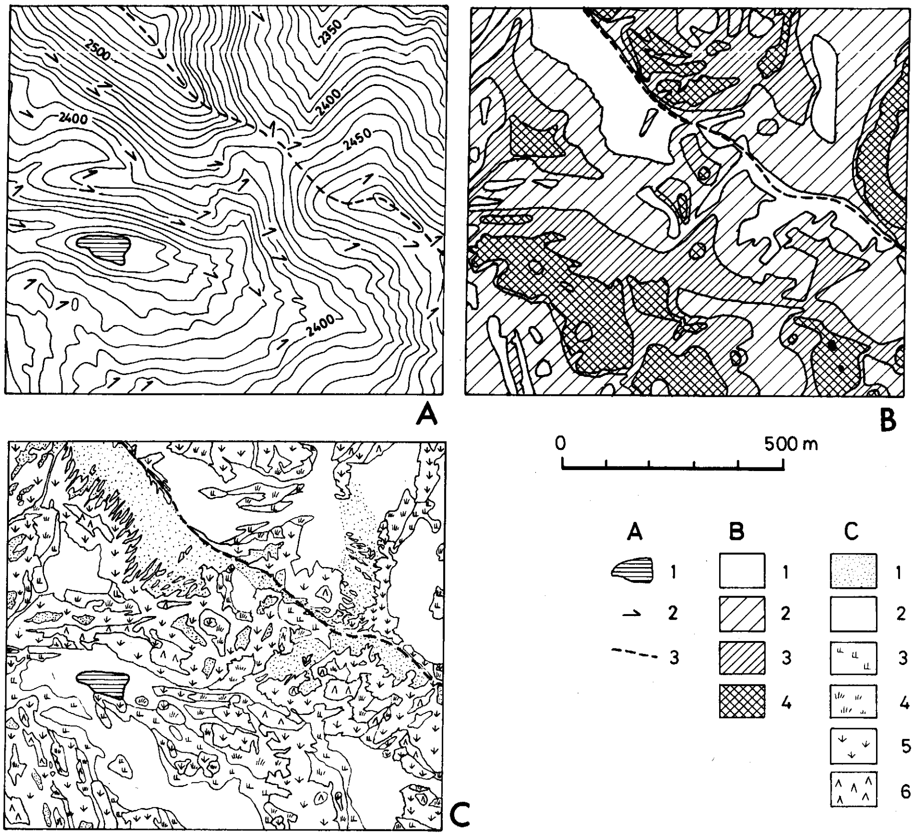


**Fig. 21.** Topography, seasonal change of snow cover, and vegetation in the area around Lake Nagaike. A: Topography. Contour interval, 10 m; A-1: Lake Nagaike; A-2: Wind direction estimated from wind-shaped conifers (*Abies mariesii*); A-3: Main ridge; B: Snow cover; B-1: Snow free area in early May, 1971; B-2: The area where snow disappeared up to middle June, 1971; B-3: The area where snow disappeared up to late July, 1971; B-4: Snowpatches remained after late July; C: Vegetation; C-1: Wind-swept bare ground; C-2: Snowbed bare ground; C-3: Area occupied by patches of herbaceous plants; C-4: Alpine meadow; C-5: *Pinus pumila* scrub; C-6: Trees (Mainly *Abies mariesii*).

during the year. The depth of snow on the periglacial rubble slopes attains only 5–10 cm during a period of maximum accumulation between mid-February and the beginning of March. Even in winter, snow-free patches may appear on the periglacial rubble slopes as a result of snow melting during periods of occasional rainy days or warm sunny days. The periglacial rubble slopes are completely released from snow cover in the period up to the beginning of May (Fig. 21-B).

On the other hand, the occurrence of nivational rubble slopes are strongly influenced by snow cover. The extent of the nivational rubble slopes coincides with the areas where snow cover exists near the end of July. The areas where the snow disappears during the period from mid-May to mid-July are covered with different kinds of vegetation. The vegetation reflects a distinct micro-zonation of plant communities due to the differences in snow protection and length of the growing periods.

The climatic conditions on the slopes in the study area can be grouped into three types: the snow-free condition on the periglacial rubble slopes, the snowy condition on the nivational rubble slopes, and intermediate conditions on the vegetation-covered slopes. The distribution of the periglacial rubble slopes and nivational rubble slopes is shown in Fig. 7.

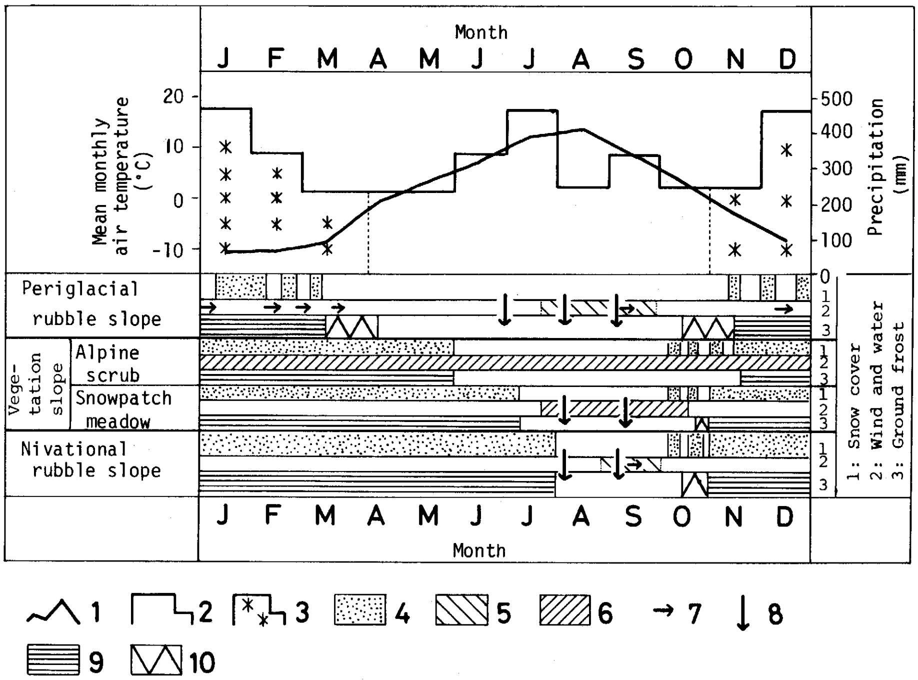


**Fig. 22.** Schematic diagram showing the seasonal changes in the climatic environments on the rubble slopes and the vegetation-covered slope. Mean monthly air temperature were estimated from upper air data as values at an altitude of 2,600 m (The Research Group for Alpine Geomorphology, 1978, p. 149). Values of mean monthly precipitation were obtained from the Climatic Atlas of Japan (Japan Meteorological Agency, 1971). 1: Air temperature; 2: Precipitation as rain; 3: Precipitation as snow; 4: Snow cover; 5: Sparse plant cover; 6: Dence plant cover; 7: Strong wind; 8: Running water; 9: Ground frost; 10: Freeze-thaw in ground.

Seasonal changes in the climatic environments on these three slopes are illustrated schematically in Fig. 22. Wind, precipitation, and ground temperature are important factors in the climatic conditions of the rubble slopes.

Wind: the periglacial rubble slopes are exposed to strong winds throughout the winter due to their windward location and lack of protective snow or vegetation cover. On the other hand, the nivational rubble slopes are influenced by strong winds only when the occasional typhoons and cyclones invade during the snow-free period.

Precipitation: even in December and March, rainfall sometimes occurs at an altitude of around 2,500 m in the study area. In such cases, the thin snow cover on the periglacial rubble slopes disappears immediately and rain water reaches the ground. Accordingly, rain water washes the ground surface of the periglacial rubble slopes at all seasons. On the other hand, the vegetation-covered slopes and nivational rubble slopes where the snow lasts for a long period are hardly influenced by rain water until the snow has disappeared. Rain water permeates down into the snow, but it cannot reach the ground since ice layers in the snow effectively prevent any further water percolation. Snowpatches, however, do supply melt water continuously up to their disappearance.

Ground temperature and ground frost: the results for ground temperature measurements in the study area are shown in Fig. 23. In the surface layer of the periglacial rubble slope, the ground temperature crosses freezing point many times in autumn and spring, and remains below 0°C through out winter. On the other hand, the ground temperature on the nivational rubble slopes begins to fluctuate between plus and minus at the beginning of October, and subsequently falls below 0°C. The insulating effect of the snow cover keeps the temperature at around 0°C until the next summer. Just after the snow melts, the temperature rises suddenly. Under the *Pinus pumila* scrub and in the alpine meadow, the diurnal amplitude of the ground temperature is smaller than that on the rubble slopes; it does not fluctuate frequently in spring and autumn but falls below 0°C in winter (Iwata et al., 1974).

These changes in ground temperatures govern the features and frequency of the ground frost. Table 5 shows the numbers of freeze-thaw and frozen days on the rubble slopes, as estimated from ground temperature measurements. Diurnal freeze-thaw cycles occur

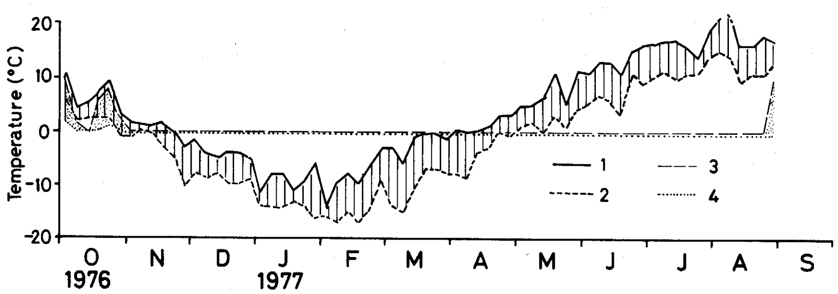


**Fig. 23.** Ground temperature record from October, 1976 to August, 1977 in the study area (The Research Group for Alpine Geomorphology, 1978). 1: Five-day mean of the daily maximum temperature, 15 cm depth on periglacial rubble slope 20; 2: Five-day mean of the daily minimum temperature, 15 cm depth on periglacial rubble slope 20; 3: Five-day mean of the daily maximum temperature, 10 cm depth on nivational rubble slope 20; 4: Five-day mean of the daily minimum temperature, 10 cm depth on nivational rubble slope 20.

**Table 5.** Numbers of freeze-thaw and frozen days in the 1975–1976 winter, as estimated from ground temperature measurements.

| Locations | Freeze-thaw days | | Frozen days |
|---|---|---|---|
| Periglacial rubble slope 20, 15 cm depth, 2,490 m | 12 (Oct.–Nov.) | 12 (Mar.–Apr.) | 138 |
| Nivational rubble slope 08, 10 cm depth, 2,380 m | 4 (Oct.–Nov.) | 0 | 309 |

From The Research Group for Alpine Geomorphology (1978).

frequently in spring and autumn on the periglacial rubble slopes, but they occur only within a brief period in autumn on the nivational rubble slopes. During the diurnal freeze-thaw cycles, needle ice can often be observed just beneath the ground surface. Diurnal freeze-thaw cycles appear to be very infrequent in the vegetation-covered slopes. During winter, the ground is maintained in a frozen state on all slopes. On the nivational rubble slopes, the frozen ground is preserved until the snow melts away. Concrete-type frozen ground with ice lenses is found beneath the snowpatches even in summer.

*Surface micro-relief*

Surface micro-relief features such as patterned ground and rills exist on the rubble slopes (Tables 2 and 3). Sorted patterned ground such as stripes and nets represents small scale unevenness due to differences in the size of the rubbles. Sorted stripes and sorted nets often occur on the gentle parts of the rubble slopes inclined at less than 20°. Indistinct sorted stripes, composed of cobbles and pebbles, are found on some nivational rubble slopes at gradients over 20°.

Lobate forms, which are well known as solifluction lobes, are common on most rubble slopes. The lobes in the present study area have various forms and dimensions, ranging from large stone-banked lobes to small turf-banked lobes. Typical stone-banked and turf-banked terraces are found on the flat top-portion of the periglacial slopes, but turf-banked terraces being oblique to the contour lines occur widely on the periglacial rubble slopes.

On nivational rubble slopes, rills are commonly found (Figs. 11 and 12). They are well developed on the surface rubble layer of the ill-sorted veneer and veneer pebble types, in places with a steep gradient, or on slopes with concave profiles. On the slopes with concave profiles, the rills form a dendritic pattern. The dimensions of the rills are 10–100 cm wide and 5–30 cm deep. Generally speaking, rills and gullies are not found on smooth surfaces of the periglacial rubble slopes. Tongue-like forms, having a length of 0.5–10 m, are frequently formed at the lower ends of the rills (Figs. 11 and 12). They arise as a result of small-scale debris flow at periods of high rainfall.

*Vegetation cover*

The vegetation on the rubble slopes occurs sparsely or in patches, except in the core area of the nivational rubble slopes where there is a completely vegetation-free surface. The vegetation consists of dwarf scrub, grasses, sedges, and low perennial herbs.

On the periglacial rubble slopes, four plant communities can be distinguished: alpine stony desert plant communities, alpine wind-blown meadow, alpine wind-blown heath (Koizumi, 1979–80), and *Pinus pumila* scrub. The types of plant communities occurring on individual rubble slopes and the vegetation coverage are indicated in Table 2. The alpine stony desert plant communities consist of only a few species, e.g. *Viola crassa, Dicentra peregrina,* or *Pleuropteropyrum nakaii,* and the vegetation coverage is extremely poor – less than about 10 percent. The alpine stony desert plant communities in the serpentinite areas are distinguished as "Serpentin-Pflanzengesellschaften" (Ohba, 1968) and the vegetation coverage is below several percent. The patches of alpine wind-blown meadow and alpine wind-blown heath occupy the lee of large blocks and banks of lobes and terraces. The vegetation coverage varies widely, from several percent on the surface rubble layers of especially coarse boulders to more than 30 percent on slopes where lobes and terraces develop. Small patches and slender bands of *Pinus pumila* scrub are also scattered on the rubble slopes, and the lower boundaries of many periglacial rubble slopes appear as irregular zigzag or inter-fingered patterns between the rubble surface and *Pinus pumila* vegetation.

On the nivational rubble slopes, so-called snowpatch plant communities develop. Differences in the plant species and coverage are controlled basically by the length of the plant-growing period after the snowpatches disappear. Many nivational rubble slopes are completely vegetation-free; even lichen can not grow on them, but sometimes gramineous grasses are sparsely scattered. In the area surrounding the bare ground, there are small patches of dwarf scrub and herbs such as *Phyllodoce aleutica,* and *Sieversia pentapetala.* Such patches commonly occupy the banks of lobes and terraces.

**Surface processes operating on rubble slopes**

*Types of surface processes*

Climate provides the driving force or triggering impacts for the surface processes. Under the climatic conditions illustrated in Fig. 22, surface processes of various types operate on the rubble slopes. Repetition of heaving and setting of the surface material during freeze-thaw cycles provokes slow mass-movements such as frost creep and needle ice creep in autumn and spring. On the other hand, slow mass-movements associated with flow phenomena, such as gelifluction and rapid solifluction, occur in wet fine materials mainly when the frozen ground melts in spring and early summer. Freezing and/or thawing, rainfall, strong winds, and organisms can induce the initial movements of rapid mass-movements such as rockfalls and rolling down as well as slow mass-movements. Creeping snow on the steep slopes sometimes drags downslope the rock fragments on the rubble surfaces. Rain and snow-melt water wash the materials and shape the channels on the rubble slopes. Extreme rainfall can cause rapid mass-movements such as debris flows in summer.

The important surface processes operating on the rubble slopes can be summarized as follows (Iwata, 1980):

Slow mass-movement: talus creep; frost creep; needle ice creep; gelifluction; rapid solifluction; movements derived from snow-pack creep.

Rapid mass-movement: rockfalls; debris flows; rolling down.

Movements by fluid flow: wash; channel erosion.

All of the processes listed above represent transport processes on, in, and through the surface materials on the slopes. Such transport processes are more important than weathering, since the development of the rubble slopes is controlled by transport processes. The surface materials have more thickness than few metres on most parts of the rubble slopes so that the rubble slopes are "transport-limited slopes". On transport-limited slopes, the weathering rates are more rapid than the transport processes, so that a debris cover developes and the slope development depends on the transporting capacity (Carson and Kirkby, 1972, p. 104–105).

*Dominant processes on two rubble slopes under different climatic conditions*

In order to clarify the dominant processes on the periglacial and nivational rubble slopes which exist under distinct climatic conditions, the intensity of the processes were measured and evaluated on a periglacial rubble slope (No. 20 in Table 2) and a nivational rubble slope (No. 08 in Table 3) (Itawa, 1980). Both slopes have almost the same height and gradient and are covered with surface rubble layers of similar character. It is not easy to compare and evaluate the various surface processes measured in disparate units and dimensions. To make a quantitative comparison of the processes among themselves, i.e. to compare the different processes within a given area, the geomorphic work of each process is usually estimated. An index for the geomorphic work with a vertical component can be defined (Rapp, 1960, p. 184) as:

$$Wv = m \times h,$$

where $Wv$ is the vertical mass transfer (ton-metres/year), $m$ is the mass of sediment involved in the movement, and $h$ is the vertical component of the movement.

The values and proportion of the vertical mass transfer of different surface processes operating on periglacial rubble slope 20 and nivational rubble slope 08 are given in Table 6. The percentages of slow mass-movement are very large on both slopes. In particular, on periglacial rubble slope 20, it amounted to 93 percent of the total, while the values for other processes were less than a few percent. On nivational rubble slope 08, however, the mass transfer in slow mass-movement was limited to 70 percent of the total, and channel erosion (22%) and debris flow (7%) assumed considerable proportions.

Slow mass-movement is thus the dominant process on both periglacial rubble slope 20 and nivational rubble slope 08, and channel erosion is a secondary process on the nivational rubble slope. Both rain wash and snow-melt wash are not so important even on nivational rubble slope 08.

Differences in the intensity of the surface processes between periglacial rubble slope 20 and nivational rubble slope 08 must be examined. In order to compare the intensity of processes in distinct areas of different size, the relative vertical mass transfer, i.e. the quantity of material moved within or removed from a unit area of 1 $km^2$ ($tons/km^2/year$) (Rapp, 1960, p. 184) is estimated. The values for the relative vertical mass transfer on the two slopes are given in Table 6. The total value of the relative mass transfer on nivational rubble slope 08 was almost three times as large as that on periglacial rubble slope 20, because the intensity of frost creep and gelifluction, channel erosion, and debris flow is higher.

*Local variations in the intensity of processes*

Slow mass-movement:

The intensity of the surface processes on the two types of slopes indicates that slow mass-movement is the most important process on the rubble slopes in the study area. The rates and types of slow mass-movement, however, vary widely from locality to locality as shown in Fig. 24. Talus creep is dominant on the surface rubble layer of the boulder type and on the cobble type on the gentle nivational rubble slopes, where the rates of movement are as

Table 6. Annual vertical mass transfer on two rubble slopes in 1975.

| Process | Periglacial rubble slope 20 (total area: 9,956 m², average gradient: 25°) | | | Nivational rubble slope 08 (total area: 5,701 m², average gradient: 23°) | | |
|---|---|---|---|---|---|---|
| | t·m/y. | % | t·m/km²/y. | t·m/y. | % | t·m/km²/y. |
| Frost creep and gelifluction | 27.4 | 67 | 2.8 | 40.0 | 58 | 7.0 |
| Needle ice creep and rapid solifluction | 10.7 | 26 | 1.0 | 8.3 | 12 | 1.5 |
| Rockfall | 0.5 | 1 | 0.1 | 0.0 | 0 | 0 |
| Tor-failure | 1.0 | 3 | 0.1 | 0.0 | 0 | 0 |
| Rolling down | 0.0 | 0 | 0 | 0.1 | 0 | 0 |
| Debris flow | 0.5 | 1 | 0.1 | 4.7 | 7 | 0.8 |
| Rain wash | 0.7 | 2 | 0.1 | 0.6 | 1 | 0.2 |
| Snowmelt wash | 0.0 | 0 | 0 | 0.4 | | |
| Channel erosion | 0.0 | 0 | 0 | 15.1 | 22 | 2.7 |
| Total | 40.8 | 100 | 4.2 | 65.3 | 100 | 12.2 |

Modified from Iwata (1980).

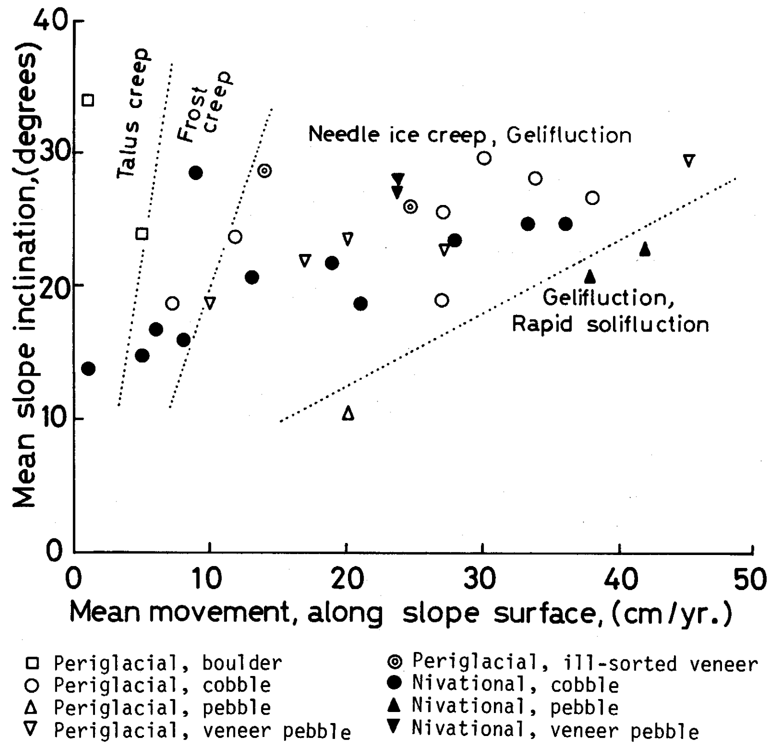


**Fig. 24.** Relation between rates and dominant types of slow mass-movement measured in 32 localities. From The Research Group for Alpine Geomorphology (1978): Table III-4, III-6; Iwata (1980): Table 3.

low as several centimetres per year. Frost creep is dominant on the rubble slopes of the cobble type and the rates range from 5–10 cm per year. Needle ice creep and gelifluction are dominant on the rubble slopes of the cobble and veneer pebble type surfaces, where the movement rates increase, ranging from 10 cm per year to as much as 40–50 cm per year, depending on the gradient. The rates are higher on the nivational rubble slopes than the periglacial rubble slopes, if the gradient is the same. This is due to the difference of processes on both slopes: frost creep and needle ice creep are dominant on the periglacial rubble slopes, while gelifluction and frost creep are dominant on the nivational rubble slopes. The movement rates on the surface rubble layer of the pebble type are higher than those on the cobble-pebble and veneer pebble types, if the gradient is the same. Rapid solifluction appears to be restricted to nivational rubble slopes composed of fine materials, but occurs both on gentle and steep slopes. On the other hand, the movement rates on the ill-sorted veneer surface may be lower than those on the cobble type and veneer pebble type. The results of the measurements indicate that the smaller in size and steeper in gradient the slope characteristics become, the greater the number of types of processes is and the more the rates of movement increase.

Quantitative comparison of the rates of the surface processes other than of slow mass-movement is not yet possible, since measurements were carried out only on the two slopes, periglacial rubble slope 20 and nivational rubble slope 08, as mentioned above. Local variations in intensity of these processes, however, have been recorded by the present author during research on the surface processes operating on rubble slopes in the study area since 1970 by means of intensive field observations.

Rapid mass-movement:

*Rockfall:* the intensity of rockfall depends on the extent of steep bare-rock surface including tors and the rates of bedrock disintegration. Bare rock surfaces are frequently exposed on the steep nivational rubble slopes which are located mostly in the Paleozoic rock areas. The rates of bedrock disintegration were assessed from the quantity of detached detritus, which is large in rhyolite and serpentinite areas but small in the slate, shale, and grantite porphyry areas (The Research Group for Alpine Geomorphology, 1978, p. 21–22, 150).

*Debris flow:* the distribution of debris-flow tongues reflects the intensity of debris flow on different slopes. Debris flow tongues are often found on rubble slopes with veneer-type surface-rubble, but they do occur rarely on slopes with a surface rubble layer of the boulder type. Debris flow occurs on gentle slopes as well as on steep slopes.

*Rolling down:* this is remarkable on steep periglacial rubble slopes where a thick layer of pebble-size rubble exists, and on steep nivational rubble slopes covered with veneer and pebble type rubbles.

Movement by fluid flow:

*Wash:* generally speaking, the erosion rate by wash increases with the slope gradient and distance from divides (e.g. Carson and Kirkby, 1972, p. 209–210; Young, 1972, p. 64). In addition, the thickness of the surface rubble layer may also affect the rate of erosion on rubble slopes. An overland flow often occurs on the surface rubble layer of the veneer type, but does not occur on boulder and cobble-pebble type rubble-surfaces. Accordingly, it seems likely that the erosion rate on the veneer-type surface exceeds those on the boulder and cobble-pebble type surfaces.

*Channel erosion:* the intensity of channel erosion can be inferred from the distribution of rills on the rubble slopes, as mentioned above (p. 30). If is high on nivational rubble slopes, particularly on rubble slopes where ill-sorted veneer and veneer pebble type rubbles occur and/or on rubble slopes with a steep gradient or concave profiles.

## 4. Discussion

The present study has clarified the basic characteristics of the rubble slopes; namely, the slope form, surface materials, surface processes, and environmental factors including the climatic conditions, surface micro-relief, and vegetation cover. In this section, the interrelationships among the various characteristics of the rubble slopes will be discussed under the following headings: 1) relationships among the slope characteristics other than the surface processes; 2) the influence of the slope form, materials, and environmental factors on the surface processes; and, conversely, 3) the influence of the surface processes on the other slope characteristics.

**Relationships among the slope characteristics other than the surface processes**

The slope characteristics apart from the surface processes have been determined for 82 rubble slopes in the study area (Table 2 and 3). The results indicate that some properties of the slope have close relationships; for example, many rubble slopes in a periglacial condition and those in a nivational condition present convex profiles and concave profiles, respectively.

In order to examine the interrelationships among the slope characteristics quantitatively, the individual slope characteristics were classified into a few categories (Table 7), and their coefficients of association were then calculated as shown in Table 8. The values obtained provide a descriptive measure of the association between categories, and a high value suggests a relatively close relation. For example, close relations were found to exist between the climatic condition and the plan curvature, the climatic conditions and the profile curvature, and the plan curvature and the profile curvature. The closely-related characteristics can be grouped into the following three: i) the climatic conditions and the plan curvature, profile curvature, surface micro-relief, and vegetation cover ii) the plan curvature and the profile curvature, gradient, surface micro-relief, and vegetation cover; and iii) the surface materials and the surface micro-relief, and vegetation cover.

It is suggested that the climatic conditions play important roles to form the different slope characteristics. In other words; the different surface processes under different climatic conditions may be related to the slope characteristics. The relationships between the surface processes and the characteristics such as the climatic conditions and forms are discussed below two sections.

The relationships among the surface materials, surface micro-relief and vegetation are shown in Table 9. The types of surface micro-relief and plant communities are closely related to those of the climatic conditions and the surface rubble layers, and the values of the vegetation coverage vary with the types of surface rubble layer.

Many studies have suggested that the surface micro-relief arises as a direct result of the

**Table 7.** Slope characteristics and their categories.

| Slope characteristic | Categories | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Climatic conditions | Periglacial | Nivational | | |
| Plan curvature | Convex | Rectilinear | Concave | |
| Profile curvature | Convex | Rectilinear | Concave | |
| Gradient (°) | 0–9 | 10–19 | 20–29 | 30–40 |
| Surface materials | Boulder (B) | Cobble-pebble (Cp) | Ill-sorted veneer (Vi) | Veneer pebble (Vp) |
| Surface micro-relief | Lobes, terraces, debris flow tongures and rills | Lobes and terraces | Rills and debris flow tongures | Not existing |
| Vegetation coverage (%) | 0–6.25 | 6.25–12.5 | 12.5–25.0 | 25.0–50.0 |

**Table 8.** Correlation matrix of rubble slope characteristics.

| | Climatic condition | Plan curvature | Profile curvature | Gradient | Surface materials | Surface micro-relief | Vegetation coverage |
|---|---|---|---|---|---|---|---|
| Climatic condition | | | | | | | |
| Plan curvature | 0.7105 | | | | | | |
| Profile curvature | 0.6396 | 0.4777 | | | | | |
| Gradient | 0.4452 | 0.3380 | 0.2803 | | | | |
| Surface materials | 0.2381 | 0.2149 | 0.1783 | 0.2176 | | | |
| Surface micro-relief | 0.5823 | 0.4910 | 0.2882 | 0.1749 | 0.3416 | | |
| Vegetation coverage | 0.3078 | 0.3772 | 0.3480 | 0.2831 | 0.3482 | 0.2819 | |

Values indicate the results of the Cramer's measure of association V ($0 \leqq V \leqq 1$) (Ikeda, 1976).

**Table 9.** Correspondence between types of surface rubble layer and occurrence of surface micro-relief and plant community.

| Climatic conditions and the types of the surface rubble layer | Number of slopes | Percentage of occurrence ($\frac{\text{Number of occurrence}}{\text{Number of slope}} \times 100$) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Types of surface micro-relief | | | | | Types of plant community | | | | | Average values of vegetation coverage |
| | | Patterned ground | Lobes | Terraces | Debris flow tongues | Rills | Nil or alpine desert | Alpine desert and/or *Pinus pumila* | Wind-blown heath and scrub | Wind-blown heath and scrub, and *Pinus pumila* or Alpine desert | Snow-patch plant community | |
| Periglacial condition | | % | % | % | % | % | % | % | % | % | % | % |
| Boulder (B) | 8 | 0 | 88 | 25 | * | 0 | 0 | 0 | 25 | 75 | 0 | 13 |
| Cobble-pebble (Cp) | 15 | 27 | 27 | 7 | * | 0 | 27 | 53 | 7 | 13 | 0 | 11 |
| Ill-sorted veneer (Vi) | 9 | 11 | 44 | 89 | * | 33 | 0 | 0 | 67 | 33 | 0 | 31 |
| Veneer pebble (Vp) | 2 | ** | ** | ** | * | ** | ** | ** | ** | ** | 0 | ** |
| Nivational condition | | | | | | | | | | | | |
| Boulder (B) | 10 | 0 | 50 | 10 | 20 | 20 | 0 | 0 | 0 | 0 | 100 | 8 |
| Cobble-pebble (Cp) | 12 | 17 | 67 | 42 | 33 | 67 | 0 | 0 | 0 | 0 | 100 | 12 |
| Ill-sorted veneer (Vi) | 19 | 5 | 16 | 89 | 32 | 68 | 0 | 0 | 0 | 0 | 100 | 22 |
| Veneer pebble (Vp) | 7 | 29 | 29 | 57 | 43 | 57 | 0 | 0 | 0 | 0 | 100 | 13 |

* Scarsely, but no exact data; ** No significant percentage.

surface processes, which are governed by both the climate and surface materials. In addition, the morphologies are directly controlled by the size of the materials. Thus, the distribution of the surface micro-relief coincides with the distribution of the surface processes and the surface rubble layers.

On surface rubble layers of the boulder type, large stone-banked lobes occur predominantly. On the cobble-pebble type rubble surface, small scale lobes are predominant both under periglacial and nivational conditions, but sorted patterned ground is also predominant on the slopes under periglacial conditions and terraces develop on those under nivational conditions. On the ill-sorted veneer type surface-rubble, turf-banked terraces are predominant. All types of surface micro-relief develop on the veneer pebble surface-rubble under nivational conditions. Debris flow tongues and rills occur widely on the rubble slopes under nivational conditions except for those with a boulder type rubble surface.

As mentioned above, the vegetation is controlled primarily by the climatic conditions such as the degree of exposure to winds and duration of snow cover, and is influenced secondarily by the local terrestrial conditions such as the surface materials and surface micro-relief. The distribution of plant communities is closely related to the lithology as emphasized by Koizumi (1979–80), although detailed examinations suggest that it coincides with the types of the surface rubble layers rather than with the lithology. Providing a suitable habitat, the surface materials directly controll the plant growth; for example, a surface rubble layer of the boulder type, in which large interstices are present, impedes the spreading of herbs and grasses. On such surfaces, patches of wind-blown heath and scrub can occur primarily, and *Pinus pumila* scrub subsequently invades very slowly. Fine surface materials, however, are also unsuitable for effective plant growth, because the root growth is disturbed by the active frost action and the relatively rapid slow mass-movement. Only stony desert plant communities can survive on such unstable ground (Koizumi, 1979–80). A correspondence between the types of surface materials and the dominant plant communities is apparent on the slopes under periglacial conditions as shown in Table 9. The value of the vegetation coverage is relatively high on rubble slopes of the ill-sorted veneer type, both under periglacial and nivational conditions. This high coverage rate is closely related with the well-developed terrace-like micro-relief; wind-blown heath and scrub inhabit the banks of terraces-like forms.

Thus, the surface rubble layers play an important role in the development of the surface micro-relief and vegetation cover. It can be safely said that the types of surface micro-relief and vegetation cover can be predicted, if the type of surface rubble layer is known.

**Influence on the surface processes**

The influence of the other slope characteristics on the surface processes can be divided into two categories: one is the influence as a driving force or triggering factor, and the other is that as a controlling factor. The former category comprises the climatic conditions, and the latter represents the influence of the slope characteristics, such as the slope form, surface materials, surface cover, and surface micro-relief.

*Influence of climatic conditions*

The driving forces and triggering factors of the surface processes were mentioned briefly above (p. 31). Frost action, extreme rainfall, and snow-melt water give rise to important surface processes. In other words, the climate exerts its influence on the surface processes through its control of temperature and available water.

The frequency of freezing and thawing and the numbers of frozen days may vary with the topographic conditions such as the altitude and slope exposure, but the local variations are slight in the study area. For example, 13 times of temperature changes crossing freezing point were recorded during the autumn of 1976 based on ground temperature measurements at a depth of 15 cm on periglacial slopes at altitudes of 2,850 m and of 2,490 m. Although the amounts and intensity of rainfall may also vary with the micro-topographic conditions, the most important difference is the duration of snow cover which protects the ground from rainfall. Moreover, the amounts and duration of supply of snow-melt water are governed by the extent of the snowpatches.

Thus, the present findings emphasize different climatic influences on the surface processes between the periglacial rubble slopes and the nivational rubble slopes. Severe ground frost tends to cause active slow mass-movement such as frost creep, needle ice creep, and also gelifluction on the periglacial rubble slopes. On the other hand, repetition of freezing and thawing in the spring season is prevented by the protection afforded by the snow cover on the nivational rubble slopes, but wash, channel erosion, debris flow, and some slow mass-movement such as gelifluction and rapid solifluction tend to be accelerated by the abundant snow-melt water continuously provided from the long-lasting snowpatches. In consequence, the rate of total movement on the nivational rubble slopes must exceed that on the periglacial rubble slopes (Table 6).

*Influence of slope form*

The slope form affects the surface processes through gravitational stress and the flow directions of the running water. The gravitational stress varies with the slope gradient: the rate of movement increases with the sine of the slope gradient (e.g. Young, 1972, p. 44). It seems, however, that the occurrence of rapid solifluction and debris flow is mostly independent of the slope gradient. The plan curvatures of the slopes control the downslope direction of the overland and sub-surface flows on the rubble slopes. Running water converges downslope on plan-concave slopes and diverges downslope on plan-convex slopes, so that the intensity of erosion may be increased on plan-concave slopes. The length of the slopes does not appear to be related to the intensity of erosion by running water on the rubble slopes.

*Influence of surface materials*

The surface processes vary in type and intensity depending on the properties of the surface materials, especially those of the surface rubble layers, as mentioned above (p. 32–35). According to an analysis of the mechanisms of slow mass-movement, Sohma *et al.* (1979) emphasized that the particle size and the thickness of the surface rubble layers control the occurrence and rates of movement. Heaving in freezing, and flow phenomena in thawing tend to occur within the sandy loam layer underlying the surface rubble layer, but a heavy load of surface coarse rubble impedes the movement. Hence, surface rubble layers of the boulder type restrict the debris movement to extremely low rates. On the other hand, freezing and thawing frequently occur within the sandy loam layers below thin surface rubble layers. Thin surface rubble layers composed of fine materials are sensitive to all kinds of impact. Accordingly, the surface materials show active movement on slopes which are covered with thin surface rubble layers composed of fine materials. If other conditions are the same, the rate of slow mass-movement may increase in the following order: the boulder type; ill-sorted veneer type; cobble-pebble type; veneer-pebble type. In spite of the veneer type surface rubble, the rate of movement is low on the rubble surfaces of the ill-sorted veneer type since the large boulders scattered on the surface inhibit the movement of the fine rubble.

Large rubbles of the boulder type restrict the occurrence of rolling down and probably that of debris flow. The ground surface without a surface rubble layer is extreme sensitive to wash and channel erosion. The veneer type surface also appears to be sensitive to these two processes. The rate of debris transport by the sub-surface wash is not known for the boulder type surface where overland flow never occurs, but it is unlikely that the transport rate by the sub-surface wash exceeds that by overland flow on veneer type surface. Thus, the surface rubble layers control the rate of wash and channel erosion.

*Influence of vegetation cover*

The main influence of vegetation on the surface processes is the provision of protection from climatic impacts and the prevention of debris movement. The *Pinus pumila* scrub and the dwarf heath and meadow vegetation composed of alpine wind-blown and snowpatch plant communities, have close leaf canopies and dense mats of organic matter and roots. They diminish the temperature changes within the ground as well as the impacts of rainfall and running water, and ultimately reduce the vertical and horizontal movement of debris. In fact, no movement was recorded in areas covered with dense vegetation.

The total protective and reductive effects may be indicated by the percentage of vegetation coverage shown in Tables 2 and 3. The alpine stony desert plant communities, however, cannot impede debris movement, since they do not form a sod mat. The scattered grasses and sedges of the snowpatch plant communities often present a step-like embanking form, and may therefore affect the debris movement.

*Influence of surface micro-relief*

Lobate forms and terraces occurring on the rubble slopes affect the surface processes. The processes tend to have decreased rates of movement on the lobe and terrace surfaces, because the gradients of the lobe and terrace surfaces are gentler than the average gradient of the surrounding areas. On the other hand, the rate of movement on steep banks and risers becomes very low due to the vegetation cover or coarse boulders.

Based on the above influences of the slope form, surface materials, and environmental factors on the surface processes, the author tentatively estimated the surface-process intensity on some rubble slopes where no measurements were actually carried out. For this purpose, the dominant characteristics of the rubble slopes in the study area were selected: the five dominant forms were obtained from Tables 2 and 3, and the four types of surface rubble layer were applied to each form. It was assumed that the relative height was 30 m (i.e., the same as the height of the two measured slopes above mentioned). The rates of slow mass-movement were derived from the values measured on the different slopes (Fig. 24). For the other surface processes, values for the relative vertical mass transfer were calculated in the case of each process-type of slope designated as above, using the values for the two measured slopes indicated in Table 6. The measured values were increased or decreased by multiplying by multipliers determined according to the variations in slope characteristics (Table 10). Even these rough estimations were able to give a broad idea of the intensity of the surface processes on the unmeasured slopes.

The total value on each slope varied widely from 0.7 × $10^3$ (minimum) to 13.9 × $10^3$ t·m/$km^2$/yr. (maximum). The values, from the smallest up to the fifth smallest, were on boulder type rubble-surface regardless of the slope forms and climatic conditions; and those, from the largest up to the fifth largest, were on steep rubble slopes under nivational conditions except for boulder type rubble surfaces.

**Table 10.** Relative vertical mass transfer estimated on various rubble slopes[a].

| Slope characteristics[b] | | | | | Relative vertical mass transfer[c] ($\times 10^3$ t·m/$km^2$/yr.) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Climatic condition | Plan form | Profile form | Gradient | Types of the surface rubble layer | Slow mass-movement | Rapid mass-movement | Wash | Channel erosion | Total | Percentage of wash & channel erosion |
| P | R | R | Steep | B | 0.7 | 0.1 | 0.1 | 0 | 0.9 | 11% |
| | | | | Cp | 4.4 | 0.2 | 0.1 | 0 | 4.7 | 2 |
| | | | | Vi | 2.8 | 0.1 | 0.1 | 0 | 3.0 | 3 |
| | | | | Vp | 4.4 | 0.3 | 0.1 | 0.7 | 5.5 | 15 |
| | CV | R | Gentle | B | 0.5 | 0.1 | 0.1 | 0 | 0.7 | 14 |
| | | | | Cp | 4.1 | 0.2 | 0.1 | 0 | 4.4 | 2 |
| | | | | Vi | 2.5 | 0.1 | 0.1 | 0 | 2.7 | 4 |
| | | | | Vp | 4.1 | 0.2 | 0.1 | 0.7 | 5.1 | 16 |
| N | CC | CC | Steep | B | 0.7 | 0.1 | 0.1 | 1.2 | 2.1 | 62 |
| | | | | Cp | 8.0 | 1.2 | 0.2 | 3.5 | 13.0 | 29 |
| | | | | Vi | 5.6 | 1.5 | 0.2 | 3.5 | 11.0 | 34 |
| | | | | Vp | 8.5 | 1.6 | 0.2 | 3.5 | 13.9 | 27 |
| | CC | CC | Gentle | B | 0.5 | 0 | 0.1 | 0.9 | 1.5 | 67 |
| | | | | Cp | 2.8 | 0.5 | 0.1 | 2.7 | 6.2 | 45 |
| | | | | Vi | 1.7 | 0.7 | 0.1 | 2.7 | 5.2 | 54 |
| | | | | Vp | 5.2 | 0.7 | 0.1 | 2.7 | 8.7 | 32 |
| | R | R | Steep | B | 0.7 | 0.1 | 0.1 | 1.2 | 2.1 | 62 |
| | | | | Cp | 8.0 | 1.2 | 0.2 | 3.5 | 13.0 | 28 |
| | | | | Vi | 5.6 | 1.5 | 0.2 | 3.5 | 11.0 | 34 |
| | | | | Vp | 8.5 | 1.6 | 0.2 | 3.5 | 13.9 | 27 |

a Taken from Iwata (1980): Table 8.

b Slopes are supposed to have same height. P: Periglacial; N: Nivational; R: Rectilinear; CV: Convex; CC: Concave; Steep: 27–31°; Gentle: Roughly 14°.

c The data of slow mass-movement were based on the values in Fig. 24. Other data were calculated based on the values in Table 6. The values were increased or decreased by mutiplying by multipliers determined according to the variations in slope characteristics. Multipliers used are as follows: [gradient] debris flow, wash, and channel erosion on steep slopes, ×1.33; debris flow, wash, channel erosion, and talus creep on gentle slope, ×0.67; tor-failure on gentle periglacial slopes, ×0.50; slow mass-movement on gentle nivational slope with Vi and Vp types, ×0.67; [surface material] channel erosion on B type slope, ×0.33; Wash on B type slope, ×0.50; debris flow on periglacial slope with Vp type and on nivational slope with Vi and Vp types, ×1.33; rockfall and tor-failure on B and Vi types, ×0.50; [vegetation coverage] all values on periglacial Vi slope, ×0.67; [other] channel erosion on periglacial Vp slope, value of nivational slope ×0.25.

**Influence of the surface processes**

The influence of the surface processes on the slope properties implies morphological, physical, and biological responses to the surface processes. Various problems require consideration in this context, from the relatively well-studied question of the surface micro-relief to that of the slope evolution, which represents one of the most difficult problems in slope studies.

*Influence on surface micro-relief*

The surface micro-relief is likely to be a direct reflection of the surface processes. Abundant rills and debris-flow tongues are formed by intensive channel erosion and frequent rapid mass-movement, respectively. Lobes and terraces are formed mainly by the action of slow mass-movement. The presently acting slow mass-movement, however, is not related to the formation of the large scale lobes occurring on the slopes with boulder type surface-rubbles. It is considered that these lobes do not reflect the extremely low rate of movement occurring at present, but were formed by past active movements.

*Influence on vegetation cover*

Slow mass-movement with a relatively high rate decreased the coverage rate of vegetation on the rubble slopes in the study area. There is no reason to doubt that debris movement prevents the expansion of patches of meadow and heath, and reduces the number of stony desert plants. Other kinds of vegetation such as dense meadows and scrub appear to be able to retain continuous covers.

*Influence on surface materials*

The surface materials on the rubble slopes consist mainly of weathering products from the bedrock lying underneath. Their size is thus controlled basically by the weathering processes.

Judging from the vertical sorting in the layers, in which the size decreases with depth, the thickness of the layers, and the presently acting processes, the surface rubble layer is formed mainly by a heaving and settling process which concentrates the rock fragments to the ground surface. Moreover, rain and meltwater wash the fine materials to form openwork rubbles. On flat surfaces where downslope movement does not occur, the surface-rubbles may subsequently thicken by continuous supply from underneath, and they may become redistributed to form patterned ground by freeze-thaw-induced lateral movement. Thick accumulated rubbles in patches are found on rubble-surfaces of the ill-sorted veneer and veneer pebble types, and in many cases, they are covered with vegetation.

The surface processes, acting on the rubble slope, cause local variations of the surface rubble layer on individual slopes. The surface materials gradually become disintegrated during their downslope movement as confirmed by the Research Group for Alpine Geomorphology (1978, p. 24–27). Rock fragments are also provided by rockfalls from the bedrock exposed on the rubble slopes and/or tors. Since the rockfalls give rise to various size of rock fragments, particularly large boulders, the ill-sorted rubble-surfaces frequently occur on slopes which situated below exposed bedrock and tors.

The materials moved by debris flow and rapid solifluction contain abundant silt and sand. They overlie the surface rubble layer, and as a result, buried rubble layers are formed. On the steep rubble slopes under nivational conditions, surface rubbles are lacking in patches, due to rapid removal by rolling down, snowpack creep, wash, and other processes, and the sandy loam layer is exposed. The general features of the surface rubble layers are thus a reflection of the weathering, but the local variations in features are also controlled by the surface processes. The surface processes affect the surface rubbles so much on the nivational rubble slopes that the correspondence between the types of surface rubble layers and the lithology is not clear on nivational rubble slopes.

*Influence on slope forms*

The slope form and its evolution are controlled by the intensity and modes of action of the surface processes. The rate of slope evolution can be inferred from the total value of the relative vertical mass transfer of th individual slope (Table 10). The rates of slope evolution are high on the nivational rubble slopes with steep gradients except those covered with a rubble layer of the boulder type. On the other hand, slopes with boulder type surface rubbles evolve slowly.

The relationships between the processes and slope form, derived from the mathematical model, indicate that the profile forms tend to be convex for soil creep, slightly concave for ungullied wash, and concave for wash with gullying (Kirkby, 1971). Table 10 shows the percentage of wash and channel erosion in relation to the total mass transfer of the rubble slopes in the study area. The data suggest that a predominance of wash and channel erosion tends to produce concavity on the nivational rubble slopes. On the other hand, convexity on the periglacial rubble slopes is probably related to a predominance of slow mass-movement. It is quite natural, therefore, for the slope forms to be different between periglacial and nivational rubble slopes.

Under periglacial conditions, the total value of the mass transfer is so high on the surface rubbles of the cobble-pebble and veneer-pebble types that the rate of slope evolution is considered to be rapid on such slopes. Under nivational conditions, the rubble slopes of the boulder-type surface rubbles exhibit a remarkable concave form and the rubble slopes of the cobble-pebble, ill-sorted and veneer-pebble surface-rubble evolve their form rapidly.

A correlation, however, between the surface materials and the slope form is not apparent (Table 10). The present slope form appears to be strongly influenced by the initial topography, and the present surface processes may have operated during only about 6–7 thousand years. In order to induce substantial changes of the slope form, surface processes need to act over periods of the order of 10,000–100,000 years (Young, 1972, p. 30). On a small scale, however, Nagatsu and Koizumi (1981) reported that the curvature rates of the crest tops of the rhyolite rock are larger than those on the granite porphyry rock.

## Important interactions and the slope characteristics

*Important interactions among the slope characteristics*

As mentioned above, it has been demonstrated that the characteristics of the rubble slopes interact in many ways. The details are illustrated schematically in Fig. 25, which represents a complex linkage. The surface processes, which include the material movement and also the resultant micro-relief formation, occupy a central position in the flow diagram, and play an important role in binding the various characteristics.

Among the five characteristics concerned in the surface processes, three basic characteristics, i.e., the climatic conditions, slope form, and surface materials, control the surface processes mainly. The two other characteristics, i.e., the vegetation cover and surface micro-

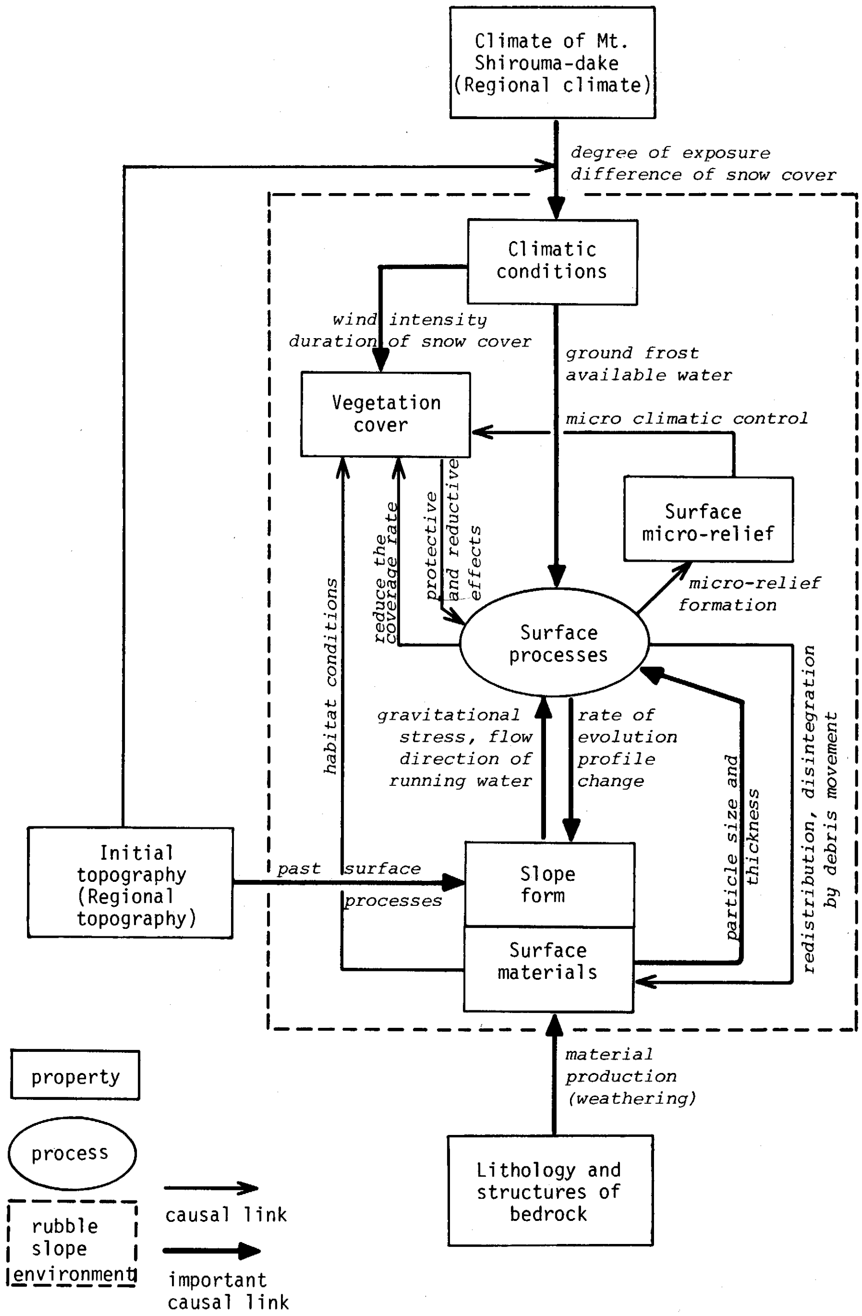


**Fig. 25.** A model of the important interactions among the characteristics of the rubble slope in the study area.

relief, are less important. The vegetation affects the surface processes, but the vegetation cover on the rubble slopes is limited to a small area. Moreover, the vegetation depends on the climatic conditions and surface materials, both of which govern mainly the surface processes. In other words, if the climatic conditions and the type of surface materials are given, the characteristics of the vegetation cover are fixed. Similarly, the surface micro-relief does not act so much as a controlling factor as a result of the surface processes. The three basic characteristics depend mainly on the regional physiographic conditions which include three independent parameters; that is, the climate of Mt. Shirouma-dake (regional climate), the initial topography, and the lithology and structures. The initial topography controls the slope form through the past surface processes, and the lithology and structures control the surface materials through the material production.

The surface processes exert a direct effect on the slope characteristics except the climatic conditions, and the slope characteristics in turn control the other slope properties. Thus, chains of influence form feedback relationships in which the influence of the surface processes affects the slope characteristics, which control directly the surface processes. Among the direct and feedback influences, three important categories of influence can be recognized: i) from the climate of Mt. Shirouma-dake to the slope form through the climatic conditions and surface processes; ii) from the lithology and structures to the slope form through the surface materials and surface processes; and iii) from the initial topography to the surface processes through the past processes and slope form.

*Importance of the surface rubble layer*

Many slope studies have emphasized the importance of the climatic conditions and slope form among the slope characteristics which control the surface processes. Also, considerable numbers of studies have discussed the direct relationships between the size of the materials and slope forms (e.g. Melton, 1965; Nagatsu and Koizumi, 1981). Only a few studies (Sohma et al., 1979; Koizumi, 1979–80), however, have so far pointed out the importance of the surface materials, particularly the surface rubble layer, as a controlling factor in the surface processes, it has been reported that the surface materials of sorted patterned ground are composed of openwork rubbles which are identical to the surface rubble layer of this study (e.g. Suzuki and Fukuda, 1971). Some surface rubble layers have been described as stone-pavements on nivational rubble slopes (Ellenberg, 1976) or as block fields, composed of boulder type rubbles (e.g. Koizumi, 1974). Nevertheless, most researchers have not been particularly interested in the surface rubble layer. The author supposes that the reason for this may be that no cobble-pebble and veneer-pebble types of surface rubbles were observed on mountains other than Mt. Shirouma-dake.

According to the author's observations, surface rubble layers of the boulder and ill-sorted veneer types occupy most of the slopes in the Tateyama Range, Yari-Hodaka Range, and southern part of the Akaishi Range. The ill-sorted veneer type is predominant and the veneer-pebble type is secondary in granitic mountains such as the Kiso, Hoh-oh, and Iide-Asahi Ranges. Also, in the Taisetsu volcanic group, where patterned ground is extensively developed, ill-sorted surface rubbles occur on the greatest proportion of the rubble slopes. According to detailed studies on the nivation hollows, the snowpatch cores in the Gassan volcano (Kobayashi, 1969) and in the Iide Range (Yamanaka, 1979, 1980) are occupied mostly by surface rubble layers of the ill-sorted veneer type. Not only on

Mt. Shirouma-dake but also on other high mountains, investigation of the surface rubble layer is important for understanding the surface processes and the resultant evolution of the rubble slopes, as well as the surface micro-relief and vegetation occurring on the slopes.

If fine materials, such as the sandy loam layer with gravel, are exposed on the surface, the ground becomes so sensitive to the climatic impacts and driving forces that the materials undergo intensive movement. The surface rubble layer thus plays an important role in protecting the sensitive fine materials underneath, and its protective effect differ depending on its types. The surface rubble layer on the rubble slopes has a similar function to the vegetation cover which protects the ground surface from various impacts. Thus, the rubble slopes in the high mountain region are clearly different from vegetation-free bare slopes such as landslide scars and artificial bare ground on which fine materials are exposed.

## 5. Conclusion

The rubble slopes on Mt. Shirouma-dake show very complex interactions among the slope characteristics as illustrated in Fig. 25. Close relations are recognized between the surface processes and the three basic characteristics of climatic conditions, slope form, and surface materials. These three parameters strongly govern the surface processes in terms of their type and intensity. The surface processes ultimately control the surface micro-relief directly, and also exert some influence on the vegetation. Over considerably longer periods, it is thought that the surface processes affect the slope form. Figure 26 illustrates the above-mentioned three basic characteristics and the resultant surface processes, vegetation cover, and the surface micro-relief. Two distinct sets of climatic conditions affect the vegetation and surface processes through the intensity of wind blowing, the duration of snow cover, the frequency of temperature changes crossing 0°C, and the availability of water. The slope form, comprising its curvatures and gradient, controls the surface processes through gravity stress and the concentration of running water. The properties of the surface materials, which refers mainly to the size and thickness of the surface rubble layers control the surface processes through the capacity of the interstitials, water permeability, sensitivity to frost action, and the resistance to geomorphic forces. Not only one factor but also multiple factors act together to control the vegetation and the surface micro-relief as well as the surface processes.

The climatic conditions, the slope form, and the surface materials are influence mainly by the slope orientation, the initial topography, and the lithology, respectively. Thus, if these three basic factors are combined, it is possible to specify the attributes of the rubble slopes in the present environment of Mt. Shirouma-dake (Fig. 27).

From investigations of the rubble slopes on Mt. Shirouma-dake, the author has been able to recognize the favorable conditions for rubble slope formation in the high mountain regions of the Japan Alps. The indispensable conditions are as follows.

i) The existence of gentle slopes which are able to retain weathered detritus on their surfaces. If the slope is steep, a bare rock slope develops.

ii) The existence of conditions which impede the development of vegetation. In the Japan Alps, the strong winds in winter and the long lasting snowpatches impede plant

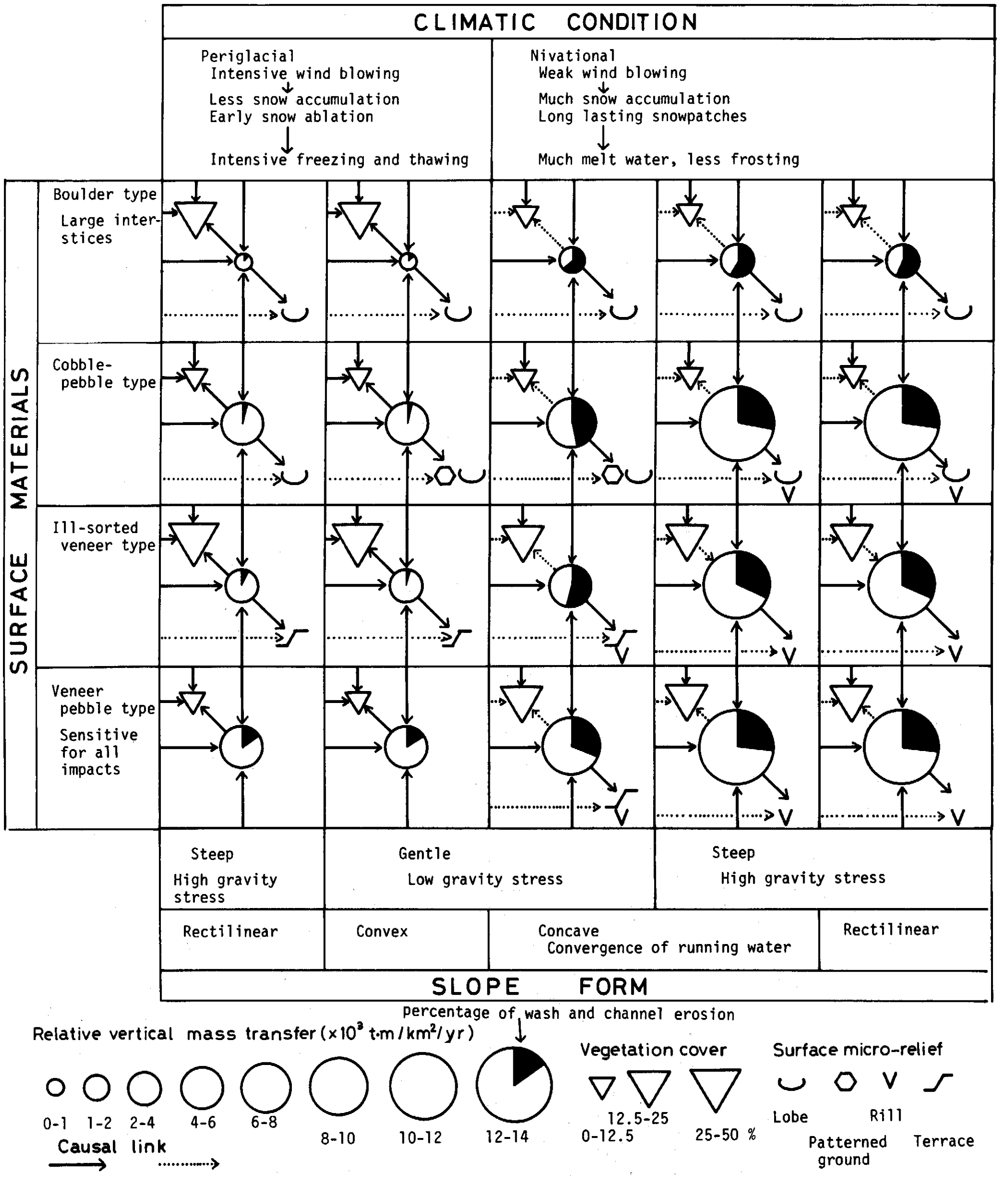


Fig. 26. Simplified diagram to show the three basic characteristics (climatic conditions, slope form, and surface materials) and the resultant material movement (relative vertical mass transfer, from Table 10), vegetation cover (from Table 9), and the surface micro-relief (from Table 9) in the rubble slope environment.

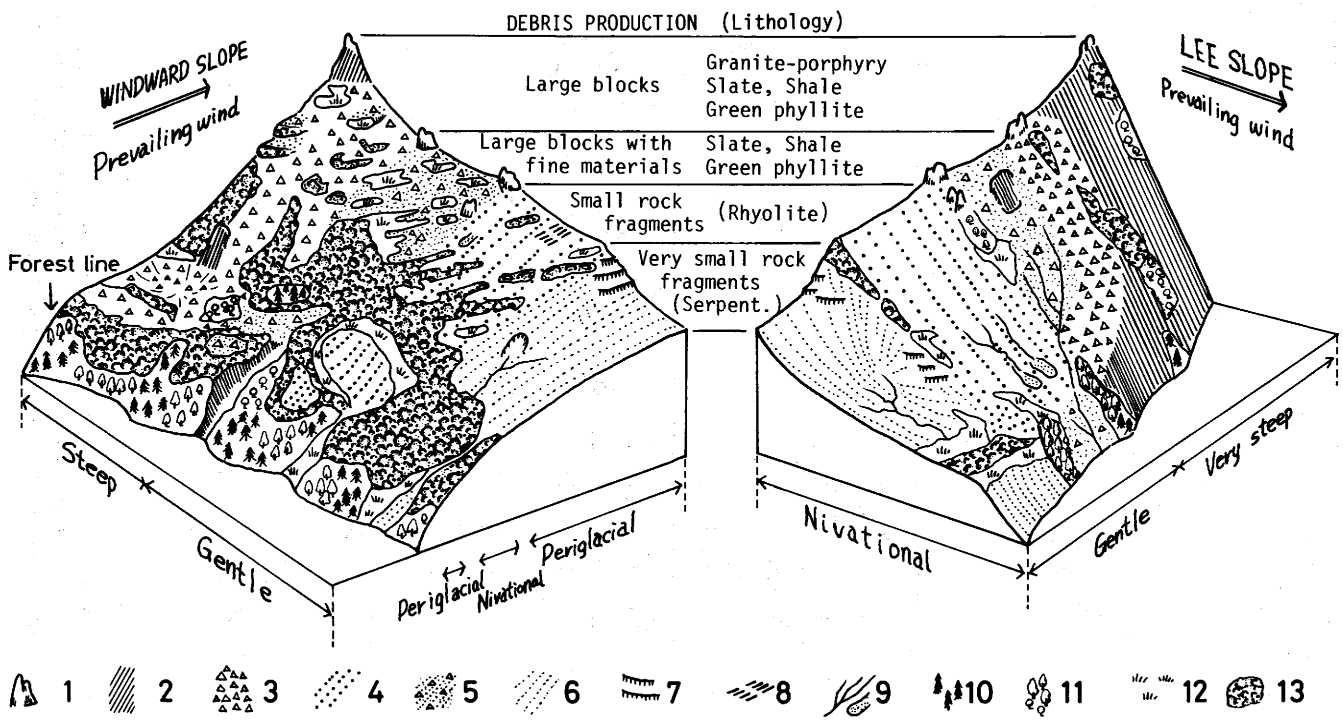


**Fig. 27.** Schematic diagram to show the combination of the three basic factors (slope orientation, initial topography, and lithology) and resultant features of the rubble slopes in the present environment of Mt. Shirouma-dake. 1: Tor; 2: Bare rock slope; 3: Boulder type surface rubble; 4: Cobble-pebble type surface rubble; 5: Ill-sorted type surface rubble; 6: Veneer pebble type surface rubble; 7: Terraces; 8: Sorted stripes; 9: Rills and debris flow tongue; 10: Conifers; 11: Broad leaved scrub and birch trees; 12: Alpine meadows; 13: *Pinus pumila* scrub.

growth, so that abundant snowfall as well as the strong prevailling westerlies are particularly important.

In addition to the climatic conditions, the development of windswept slopes and snowpatches depends on the topography.

iii) The existence of north-south ridges and low-relief surfaces. The north-south ridges develop windswept slopes to the windward and snowpatches on the lee slopes. Depressions on the low-relief surface trap the snow and extensive snowpatch-bare ground occurs.

The characteristics of the surface materials control the rubble slope development directly or indirectly through the plant growth and surface processes.

iv) The existence of bedrock which disintegrates into rock fragments of cobble or pebble size with a uniform size-distribution. They form surface rubble layers of the cobble-pebble type or the veneer pebble type on which the materials are transported at a high rate. Accordingly, the plant growth is controlled by the active debris movement and the slope evolution is expected to be relatively rapid.

v) The existence of bedrock which disintegrates into large boulders. Large boulders form surface rubble layers of the boulder type on which surface processes occur inactively. Plants exploit these rubble slopes very slowly because of the lack of fine materials.

Thus, both local climatic conditions and local terrestrial conditions are important for rubble slope formation.

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