INVESTIGATION OF TOPSOIL HORIZONS OF MOUNTAIN SLOPES AS A BASIS OF EXPERIMENTAL GEOMORPHOLOGY

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Abstract

The results of simplified penetration test, in situ permeability test for its vertical distribution and other supplementary survey which were carried out in six test fields demonstrate that the microstructure of the soil horizons and their physical properties directly reflect the current geomorphological processes active on the slopes in question. Investigation of the structure of topsoil horizons in and around the landslide scars reveals the critical conditions for their occurrence. In situ measurement of the physical properties of finely stratified soil gives important information about the dynamic balance between weathering and denudation. The methods of investigation as described here will be useful as a preliminary procedure for more detailed geomorphological experiments on mountain slopes.

1. Introduction

In the normal cycle of the geomorphological evolution, topographic changes take place mainly as removal, deposition and deformation of loose material (topsoil) beneath the ground surface. Investigation of the occurrence, properties and behavior of topsoil horizons is, therefore, essential for the study of the geomorphological processes. This paper describes a method of in situ measurement of the vertical variation of the mechanical and hydraulic properties in topsoil horizons and in the substratum as the preliminaries for the observation of individual process. Results from some test fields are presented to demonstrate their geomorphological significance.

2. Methods

Vertical variation of the mechanical strength of soil can be measured in situ by cone-penetrometers. A variety of cone-penetrometers have been proposed and used so far, among which a portable one is suitable for the investigation of topsoil horizons on mountain slopes. Doken-type (also referred to as PWRI-type) simplified penetrometer was used by the authors. It has a cone resistor of an apex angle of 60° and of a diameter of 30 mm, which is driven into the ground by the impact of an

Table 1   Physical properties of different horizons in Aotani Experimental Basin as compiled by Okimura[1]

Soil horizons	I	II	III	IV	V	VI
Pedological identification	A	B	B—C	C	← D →	
N_{10} by Doken-type penetrometer	0~3	3~7	← 7~25 →		25~50	>50
N_{10} by Kobe Univ. type penetrometer	0~2	2~5	5~10	>10		
Permeability index P (cm^{-1}·min^{-1})	0.33	0.011	0.0004			
P-wave velocity V_p (m·sec^{-1})	← 350 →					
Electrical resistivity ρ (Ω·m)	102	46	20			
Dry bulk density γ_d (g·cm^{-3})	0.93	1.08	1.19	>1.30		
Porosity n	0.53	0.48	0.46	<0.41		
Angle of internal friction ϕ (deg.)		15~23	26~29	>30		
Cohesion C (kg·cm^{-2})		0.13~0.14	0.09~0.12	<0.05		
Thickness	10	60	25			

iron weight of 5 kg falling down from the height of 50 cm. Another type of portable cone-penetrometer (Kobe Univ. type) designed by Okimura[1] is based on the same specification except that the diameter of the cone resistor is 23 mm. Though the Swedish sounding penetrometer is often used in testing the mechanical strength of the ground, it is not very suitable for use on mountain slopes, because heavy weights are needed.

Cone-penetration resistance is expressed in this paper by N_{10} which denotes the number of impacts needed for each depth increment of 10 cm. Okimura[1] has found that each soil horizon defined in pedological terms has a particular value of penetration resistance (**Table 1**), and that the latter is well corelated to the dry bulk density γ_d of the soil (**Fig. 1**). Since the dry bulk density decreases as the weathering proceeds, the cone-penetration resistance is also a good measure of the degree of weathering.

Comparing the vertical profiles of N_{10} in landslide scars with those of the adjacent part in the Rokko mountains, Okimura[1] has revealed that N_{10} obtained by the Kobe Univ. type apparatus commonly shows the values of about 10 at the depth of the slip surface. Thus, the mechanical stability of a slope can be examined by measuring the depth of the topsoil horizons at which N_{10} attains the critical value. Hatano[2] has found that the penetration limit of a boring stick coincides with this depth. Boring sticks are useful for rapid sounding on mountain slopes.

The mechanical strength of the soil is correctly determined by the triaxial test. However, it needs undisturbed samples of a certain size, which make the continuous
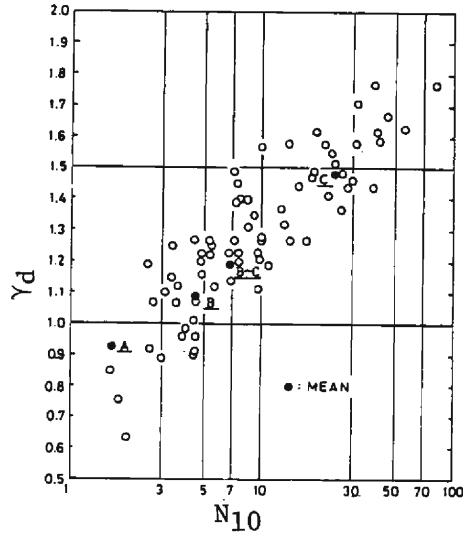
Fig. 1 Correlation between the dry bulk density γ_d and the cone-penetration resistance N_{10} measured by Kobe Univ. type apparatus. Closed circles represent the average values from each horizons. after Okimura[1]

measurement of the vertical variation difficult. Moreover, a large effort needed for the laboratory procedure of the triaxial test make a dense measurement (in the vertical and horizontal direction) difficult so that one can obtain only a rough trend of the spatial variation of the mechanical strength of the soil through the triaxial test. It would be, therefore, practical to make a dense sounding by a portable cone-penetrometer and to estimate, thereby, the three dimensional distribution of the mechanical strength. The triaxial test will serve as a standard apparatus there (see **Table 1**). Permeability represents a characteristic hydraulic property of the soil. Extreme variability of permeability of topsoil in the vertical direction, however, makes its laboratory determination difficult just for the same reason as with the case of mechanical strength. Existing methods of determining the vertical distribution of the permeability in situ[3] are not applicable to topsoil horizons, because they are oriented to the tests in great depths.

Okunishi[4] has proposed a simple method of estimating the vertical distribution of the permeability by pouring water into an auger hole and by measuring the drawdown rate of the water level due to radial seepage. Accordingly, the value of the hydraulic conductivity $K(z)$ at any depth z is given by

$$K(z) = \frac{r_0{}^2 P}{2} \ln\left(\frac{r_e}{r_0}\right) \tag{1}$$

under ideal conditions, where r_0 is the radius of the auger hole, r_e the radius of influence in analogy to the pumping test for aquifer evaluation, and P the permeability index defined as

$$P = \frac{\mathrm{d}^2 v(z)}{\mathrm{d}z^2} \qquad\qquad\qquad\qquad (2)$$

where $v(z)$ is the time rate of the drawdown of the water level at the depth of z. Okunishi[4] has shown that Eq. (1) is valid if the soil is loamy, but that if the soil is sandy, numerical treatment using a modified equation is needed because r_e varies with time. In the latter case, P as calculated from Eq. (2) is no longer constant, even if K is constant. The values of P in different soil horizons are compared with those of K, γ_d and N_{10} in **Fig. 2**. The value of P could not be evaluated for the depth of 0–10 cm because the drawdown of the water level was too fast there. It is shown that the variability of P is much greater than that of K, which indicates that P is not necessarily proportional to K. It is, however, recognized that any discontinuous change in K is accompanied by a marked discontinuity of P. Therefore, this method of measuring P for K is effective for the identification of different soil horizons from the hydraulic point of view.

Some other measurements would be needed to complete the above procedure. Seismic prospecting has been modified, for example, by Nakagawa[5] to examine a fine structure of smaller depths. Electrical prospecting by a portable apparatus is often convenient for investigating the subsurface distribution of moisture[6].
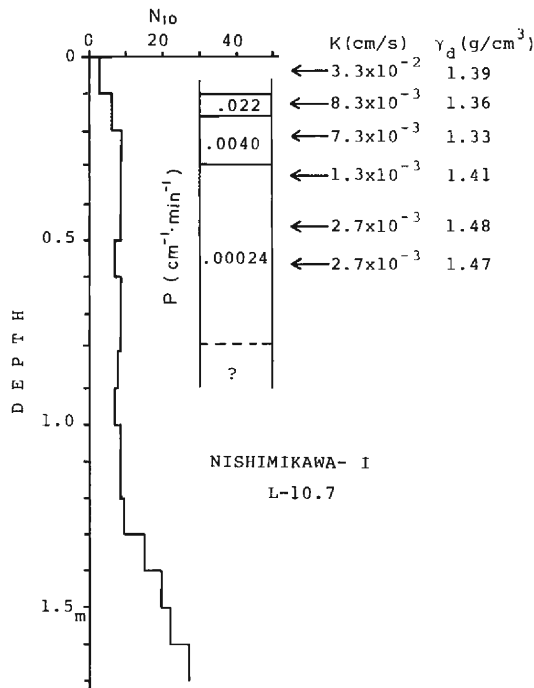

Fig. 2   Comparison of the values of N_{10} (by Doken-type penetrometer), permeability index P and the hydraulic conductivity K (by a laboratory apparatus) for different horizons in Taruki Experimental Basin (cf. Sec. 3.4).

3.   Results from some test fields

The methods described in the previous chapter were devised primarily for use in the granitic area.   Granitic rocks often yield thick sandy regolith, called Masa-soil in Japan, which makes the cone-penetration test and the auger boring easy for its homogeneity.   It is noted that the disasters due to a dense occurrence of topsoil slumps inducing debris avalanches and debris flows mostly take place in the region of weathered granite.   It suggests that the topsoil is geomorphologically much more active in the granitic areas than in the other areas.   Thus, most of this chapter deals with the result of the field survey in the granitic areas.   The location of the test fields is shown in **Fig. 3**.

3. 1   Aotani Experimental Basin in the Rokko mountains

Aotani Experimental Basin was established in 1973 at the southern foot of the Rokko Mountains for the research of landslides[7].   Geology and geomorphology of the Rokko mountains have been summarized by Huzita et al.[8]   The regolith from granodiolite in and around this basin is rich in clay minerals, which provides good conditions for vegetative growth.

An intensive field survey of the structure of the topsoil horizons was carried out
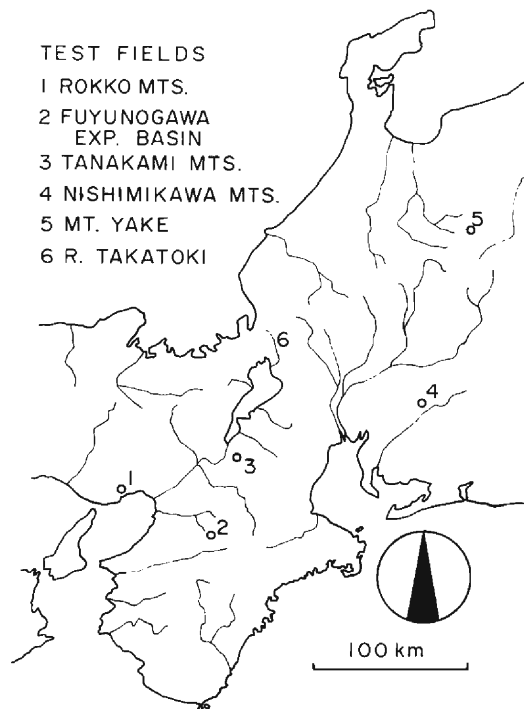
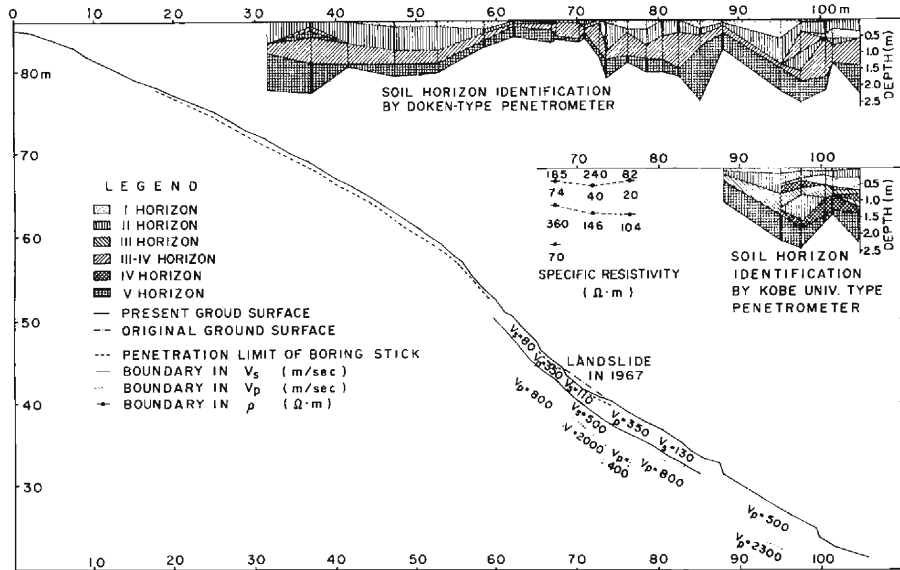

Fig. 3   A map for the location of the test fields.

Fig. 4 Identification of soil horizons in a longitudinal cross section of a hollow named R-1
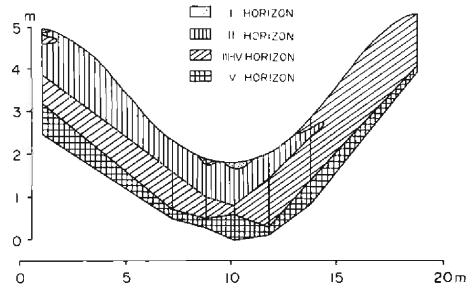according to different methods of survey after Nakanishi et al.[9]

Fig. 5 Identification of soil horizons in a transverse cross section
of R-1 according to N_{10}.

by several researchers[9,10] using their original techniques at a hollow named R-1
(in this paper concave-contoured unit slopes are referred to as hollows).   The result
is illustrated in longitudinal and transverse cross sections as **Fig. 4** and **5**, where the
identification of tospoil horizons is made according to **Table 1**.

A landslide scar at a horizontal distance of 70 m in **Fig. 4** is due to a landslide
in 1967.   It is, however, noted that the distribution of N_{10} and the elastic wave
velocity shows more pronounced concavity in the underground structure, which is
due to a fault crossing R-1 at this point[9].   Historical descriptions on the other hand,
give an evidence of repeated occurrence of landslides.   It is estimated that once a
landslide takes place on a slope, the landslide scar will begin to be gradually buried
by the loose material due to its production by weathering and its migration from the
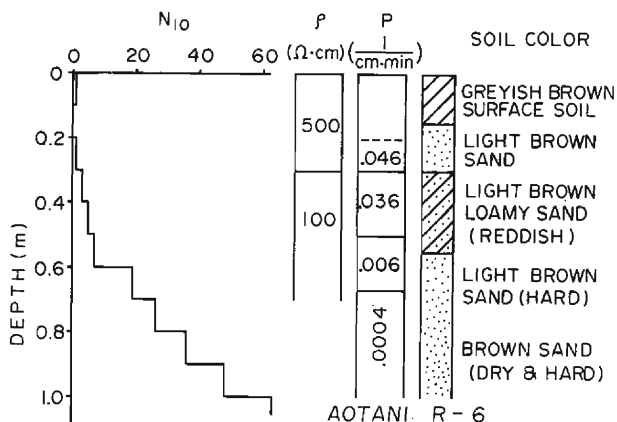
Fig. 6   Comparison of the vertical profile of the topsoil horizons according to differ-
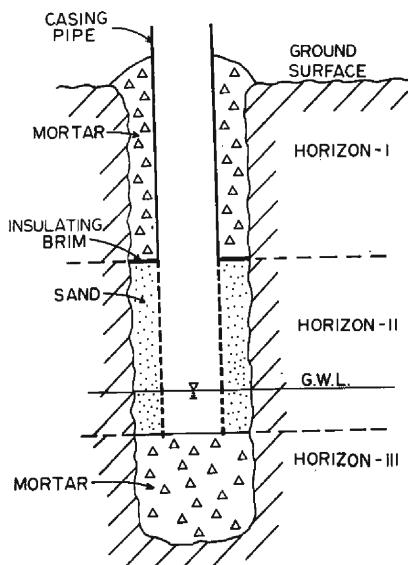ent methods at a measure point at the center of the hollow R-6.

Fig. 7   Structure of the observation well for the water level of throughflow (not to
scale).   The water in the well is connected solely with that in horizon-II.

upper part of the slope, preparing the next landslide.   This interpretation is support-
ed by **Fig. 5** which illustrates that the horizons of loose material is thickest in the
bottom of the hollow at which the transverse profile is most concave.   More detailed
discussion about the mechanism of the development of hollows due to repeated occur-
rence of landslides has been given by Iida and Okunishi[11].

Similar investigation was carried out in another hollow named R-6, the result
of which is shown in **Fig. 6**.   The auger hole for the in situ permeability test and
the sampling for soil color was drilled at the point where the cone-penetration test
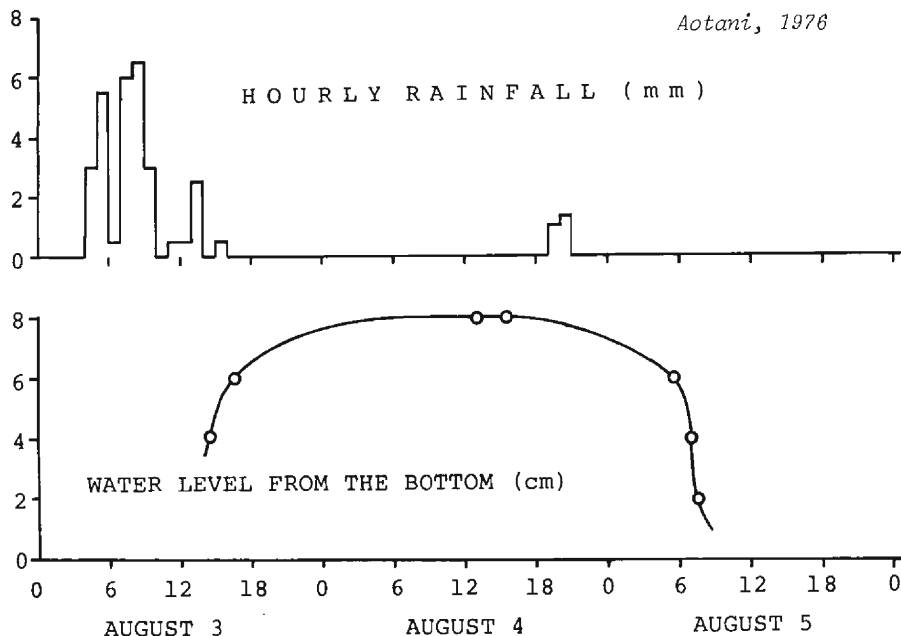
Fig. 8 A stage hydrograph of throughflow in an observation well at the same location with Fig. 6.

had been carried out.   It has again shown that the soil horizons as identified by different physical properties essentially coincide with each other.   **Fig.** 6 was used by Fukuo[12] who observed the displacement, deformation and internal stress of the soil horizons due to rainfall at the same place.

Fig. 6 suggests that subsurface storm flow (or throughflow), which may cause surface landslides, will take place at a heavy rainfall at the depth of 65 cm, because the hydraulic conductivity K evaluated from Eq. (1) is only about 3 mm/h below this depth, while that of the overlying horizons is estimated to be more than 40 mm/h, much larger than the intensity of usual rainstorms.   Thus, the observation of the water level of the throughflow was carried out in the auger hole described above. The structure of the observation well illustrated in **Fig.** 7 improves the response to the occurrence of throughflow by preventing the occurrence of dead water in the well. It also prevents shallow water to enter into the well through the interstices around the casing pipe.   A multi-electrode water level detector designed by Okuda et al.[13] was set in the well for automatic recording.   Only one occurrence of throughflow (**Fig.** 8) was recorded during the observation period of August to October in 1976. The maximum water level took place about 20 hours after the peak of rainfall.

3. 2.   Fuyunogawa Experimental Basin in the Ryumon mountains

Fuyunogawa Experimental Basin was established in 1975 for hydrogeomorphological study of mountain slopes.   Geomorphological processes in this basin have
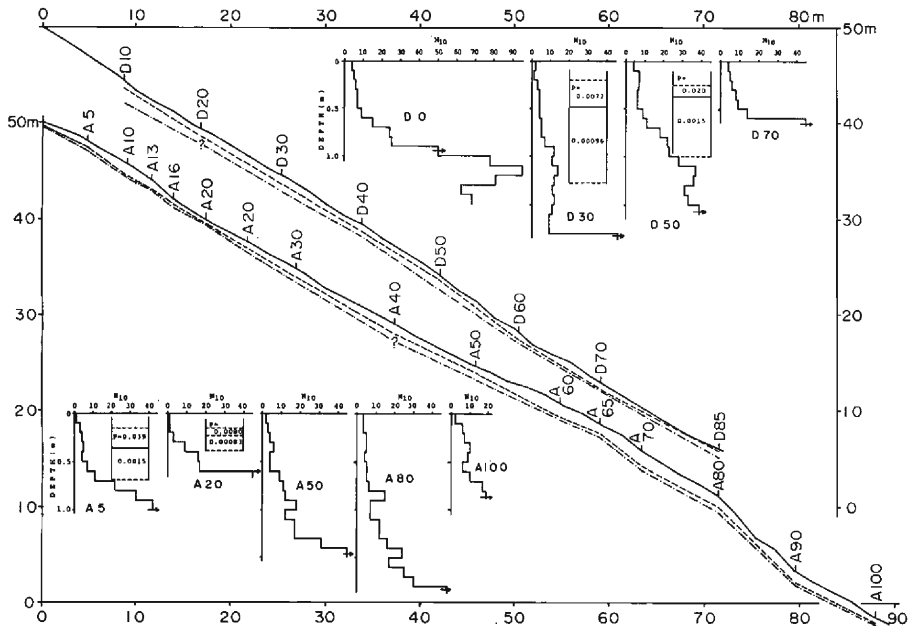
Fig. 9 Longitudinal cross sections of Fuyunogawa Experimental Basin along the ridge (line-D) and along the bottom of a first order valley (line-A). The isopleth lines of $N_{10} = 10$ and $N_{10} = 50$ are shown by broken lines and chained lines, respectively.

been discussed by Uemura[14] on the basis of topographic analysis and the observation of water and sediment discharge. The bedrock in this area consists of Ryoke granite[15]. The topsoil horizons are rich in clay minerals and organic matter. It is estimated that an active tectonic movement related to the Median Tectonic Line crushed the bedrock and thereby stimulated the chemical weathering from which resulted clay minerals[15]. The topsoil horizons are rich in organic matter and suggest a high rate of plant growth.

The authors made an investigation of topsoil horizons along some measure lines within this basin. **Fig. 9** shows the result in the longitudinal cross sections along the talweg of a first order valley (line-A) and along the ridge (line-D) bordering the latter from another valley. Remarkable concavity of the ground surface is found at the horizontal distance of about 16 m on the measure line A, whereas the isopleth lines of N_{10} are fairly straight. Since surface slumps take place predominantly in hollows and at valley heads, such concave feature are estimated to be landslide scars of the past. Convex profile found at the part of the horizontal distance between 50 m and 80 m is attributable to local rock control or to an effect of minor faults. The pattern of the vertical change in N_{10} varies site to site suggesting a heterogeneity in the weathering zone.

3. 3 Experimental slope in the Tanakami mountains

Field experiments on the topsoil horizons were carried out in 1970 on a low ridge (**Fig. 10**) in the Tanakami mountains.   Though the result has been partly reported by Nakagawa[5,6], Okunishi[16] and Esumi and Okunishi[17], an examination of the data from the geomorphological point of view has not yet been made.

The bedrock (coarse grained biotite granite named Tanakami granite) is covered by its weathering product (dry Masa-soil) which contains only a small quantity of clay minerals.   **Fig. 11** shows the cross section of the weathering zones of this ridge according to the seismic prospecting by Nakagawa[5] and to the ground survey by Matsuda and Okunishi[18].   The top zone (Zone-I) consists of Masa-soil, the P-wave velocity being about 400 m/sec.   Zone-II consists of a mixture of Masa-soil and rock pieces, the mixing ratio varying with depth.   At the bottom of this zone, the rock becomes the bedrock which contains Masa-soil in its dense fissures.   Zone-III is the bedrock with the P-wave velocity of 4.0 km/sec.   Though a ground observation gives such impression of deep weathering as revealed in the Rokko mountains[7,19], the cross sections in **Fig. 11** present the structure characteristic of surface weathering.   Because hydrological analysis of the land waters in this area
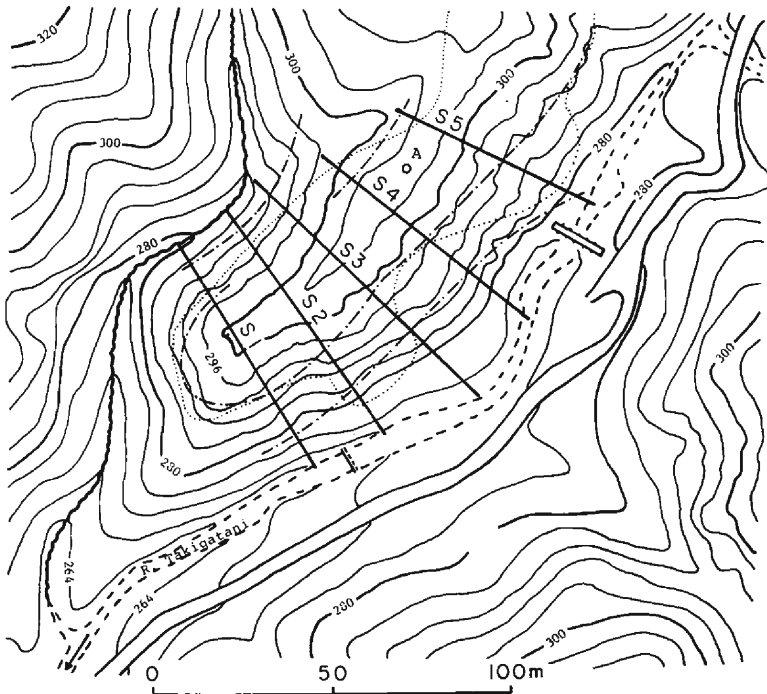

Fig. 10   A topographic map of the experimental slope in the Tanakami mountains (contour interval: 4 m).   Dotted line and chained lines on the slope show the boundary between entirely bare part and sparsely vegetated part and the break in slope angle, respectively.

by Okunishi and Natsukawa[20] suggests inactive chemical weathering, the predominant agents of weathering in this area is estimated to be physical ones such as unloading, temperature change and moisture change.

The slopes shown in **Fig. 10** present a typical landscape of waste bare-land in this region[18]. Trees are sparsely growing outside the dotted line stretching their roots into the fissures of the bedrock. There is a forest land to the north-east of the ridge in **Fig. 10**, where topsoil horizons are obviously different from those of the bare-lands. **Fig. 12** shows that the particle size distribution varies with depth from the ground surface to the depth of 80 cm in the forest land, whereas essentially no variation is found in the bare-land. Because the bare-lands in this area were caused by overlogging and accelerated erosion[21], such difference is attributable to the removal of topsoil in bare-lands. Accumulation of coarse grains at the ground surface of the bare-land in **Fig. 12** is caused by the selective removal of finer sand and silt by running water[18]. Vertical profile of N_{10} in the bare-land (**Fig. 13**) also shows the lack of A and B horizons. A small value of N_{10} at the depth 0–10 cm is due to the loosening of particles by freeze and thaw cycles[18]. Though
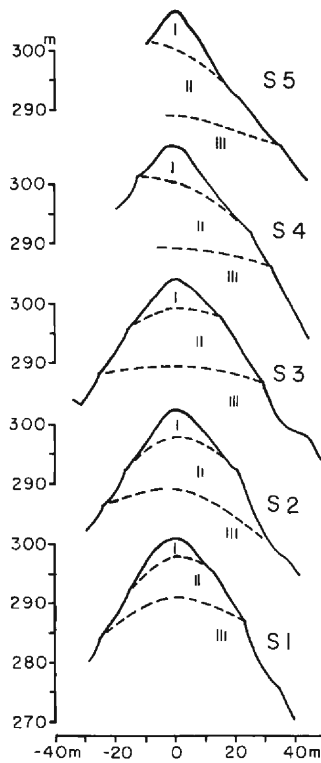

Fig. 11 Vertical cross section of the experimental slope along different lines shown in Fig. 10.

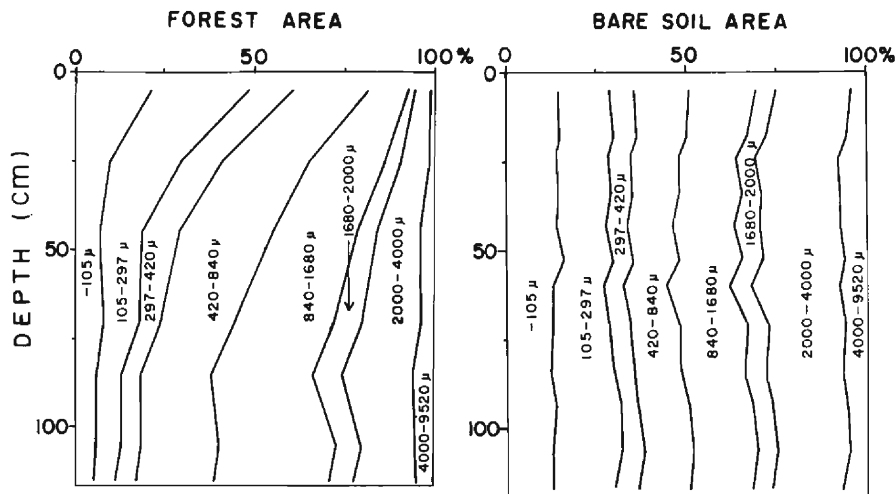**FOREST AREA**

BARE SOIL AREA

Fig. 12 Vertical variation of the particle size composition (in weight) of the soil in a bare-land and in a forest land.
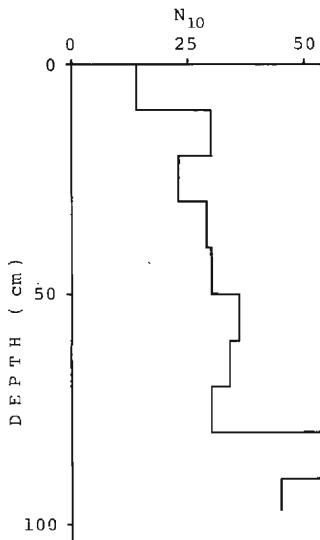
Fig. 13 Typical N_{10} profile on the ridge in Fig. 10.

not very obvious, a jump of N_{10} is found at the depth of about 80 cm, which is thought to correspond to an discontinuity in electrical resistivity at the depth of 90–100 cm reported by Nakagawa[6].

Behavior of soil moisture within the topsoil horizons in this area is discussed by Esumi and Okunishi[17] and Okunishi[22,23]. Accordingly, the retention capacity of the topsoil in the bare-lands is so small that the suction of soil moisture easily exceeds the permanent wilting point when there are several successive fine days. In the forest lands, on the other hand, the topsoil is always kept moist because A and B horizons have a large retention capacity.

3. 4 Experimental basins in the Nishimikawa mountains

A swarm of landslides took place in the Nishimikawa mountains in 1972. According to Okuda et al[25], the density of land-slides attained as much as $200 \, km^{-2}$. The bedrock of this area is coarse-grained granitic rock referred to as hornblende bearing biotite adamelite[24]. Because the weathering product (Masa-soil) contains only a little amount of clay minerals, most of the hillslopes are usually dry, so that the vegetative cover is poor, consisting mainly of red pine and shrubs. It is estimated that waste bare-lands were once predominant in this area[21]. Some ridges have a very sparse vegetative cover even today.

In the research project on landslides organized by Tanaka[7], three test fields were established for the investigation of landslides, among which the field experiments on topsoil horizons were mainly carried out in an experimental basin called Take-daira-NW Basin[25,26]. **Fig**. 14 shows the result of the in situ permeability test carried out there. It is shown that the soil color is consistent with P-value and that the topsoil is thinner in the hollow than on the ridge reflecting the erosional processes acting in the hollow (note that the longitudinal profile of this hollow is convex at this point).

Another experimental basin (Taruki Experimental Basin) was established by the authors and field experiments on the topsoil have been carried out there since 1977. Structure of tospoil horizons in the representative cross sections was examined using Doken-type cone-penetrometer, and on this basis, the occurrence of landslides and resultant topographic evolution were analyzed by Iida and Okunishi[11]. Comparison of the results of the in situ permeability test and the laboratory determination of hydraulic conductivity of topsoil horizons in this basin is shown in **Fig**. 2.

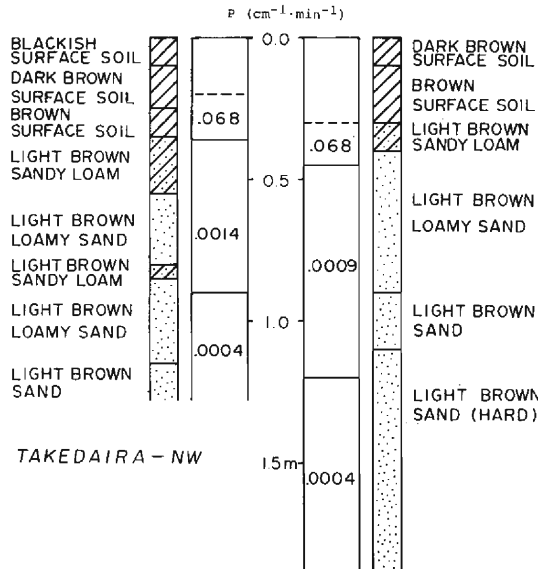The structure of the topsoil horizons shown in **Fig**. 2 is different from that

Fig. 14 Vertical profile of the permeability index P and the soil color on a ridge (right) and in a hollow (left) on the same contour line crossing the side slope of a first order valley in Takedaira-NW Basin.

observed on most slopes in Taruki Experimental Basin in that the horizons where N_{10} value is about 10 are fairly thick. Because a landslide removed the soft layer (the horizons where N_{10} is less than 10) of a thickness of about 1 m at this site in 1972[27], the original topsoil prior to the 1972 landslide had been thicker than that shown in **Fig. 2**. Though some possible causes could be estimated for such a structure, no conclusive evidence has been obtained yet. The surface 20 cm of the toposil in **Fig. 2** in which N_{10} is less than 10 and K is around 10^{-2} cm/sec is estimated to have been formed in the period of five years after the landslide of 1972.

Observation of soil moisture and throughflow using tensiometers and observation wells has been carried out by the authors[28] in this experimental basin since 1979. In order to investigate how the topography and the structure of the topsoil affect the movement of soil moisture, tensiometers were set at several depths of the top and the bottom part of a ridge and a hollow. Accordingly, soil moisture is highly variable and its flux is upwards except during and immediately after the rainfall on the ridge, whereas in the hollow, soil moisture is constantly high and its flux is always downwards feeding the baseflow. Structure of the observation wells for the throughflow was the same as shown in **Fig. 7**, but the bottom was set at the boundary between the regolith ($10 < N_{10} \leqq 50$) and the bedrock ($N_{10} > 50$). Though the permeability of bedrock is not correctly known, a high contrast in N_{10} between the regolith and the bedrock suggests a high contrast in permeability. Occurrence of throughflow was detected in this well even at the time of moderate rainfall (**Fig. 15**). Since the throughflow makes a preferable conditions for chemical
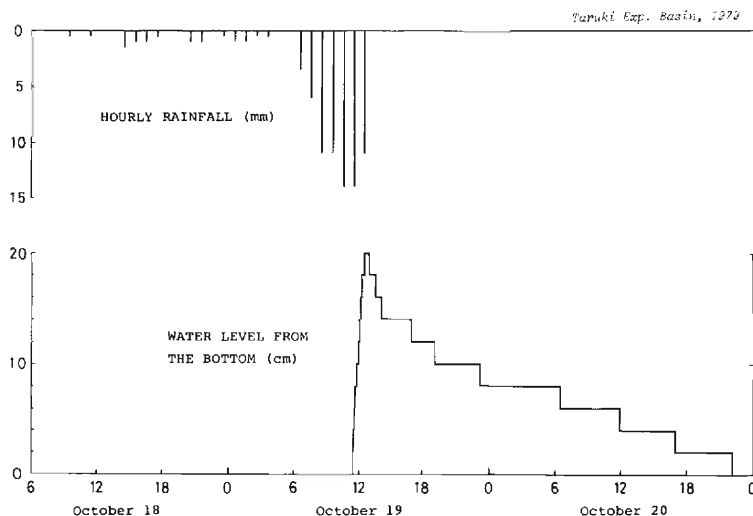
Fig. 15   An example of the stage hydrograph of throughflow in an observation well
           in the Taruki Experimental Basin.

weathering[28]), it is expected that more detailed investigation into the hydrologic properties of topsoil horizons will offer valuable information about weathering conditions.

3. 5   Catchment of the Toge-zawa valley on the eastern slope of Mt. Yake

Field experiments on debris flows has been carried out in a gully called Toge-zawa (also referred to as Kamikamihorizawa) on the eastern slope of Mt. Yake by Okuda and co-workers[29]).   At the time of the vapor eruption in 1962, volcanic ash brought about a thick deposition at the head part of this gully.   Thereafter, this part has remained waste because of heavy erosion.

A cross section of the geologic formation can be easily observed at the side walls of the gully since it has entrenched into the ground as deep as 10 m.   Andesite basement is covered by a strata of andesite boulders (pyroclastic deposition) laminating nearly parallel to the ground surface.   Above the reddish horizons of soil and boulders which overlie the pyroclastic deposits, there are found the roots of bamboo grass and trees which suggest the level of the past ground surface.   The top hozizon is a whitish deposit of volcanic ash and volcanic sand of a thickness of 60–100 cm which occurred at the time of the 1962 eruption[30]).

Field survey of topsoil horizons was carried out by Okuda et al.[30,31]) as the preliminaries for a hydrological investigation into the occurrence of debris flow. Distribution of N_{10} and P in a vertical cross section along a longitudinal measure line is shown in **Fig. 16**.   The N_{10} profile at each measure point is shown in **Fig. 17**. Though the topsoil is soft, the existence of stones in it caused larger values of N_{10} thus introducing a kind of noise in this profile.   However, the trend of N_{10} varying
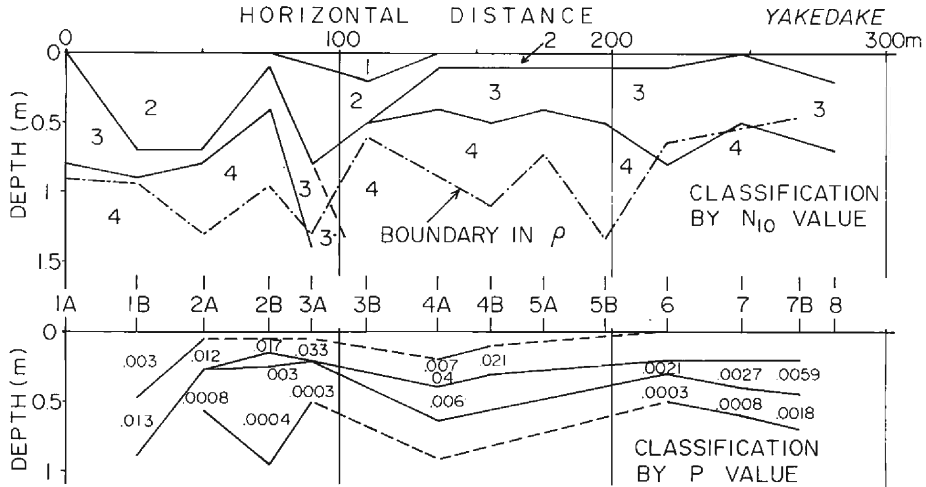
Fig. 16   Identification of topsoil horizons by N_{10} and P in the vertical cross section along a longitudinal measure line on the eastern slope of Mt. Yake.
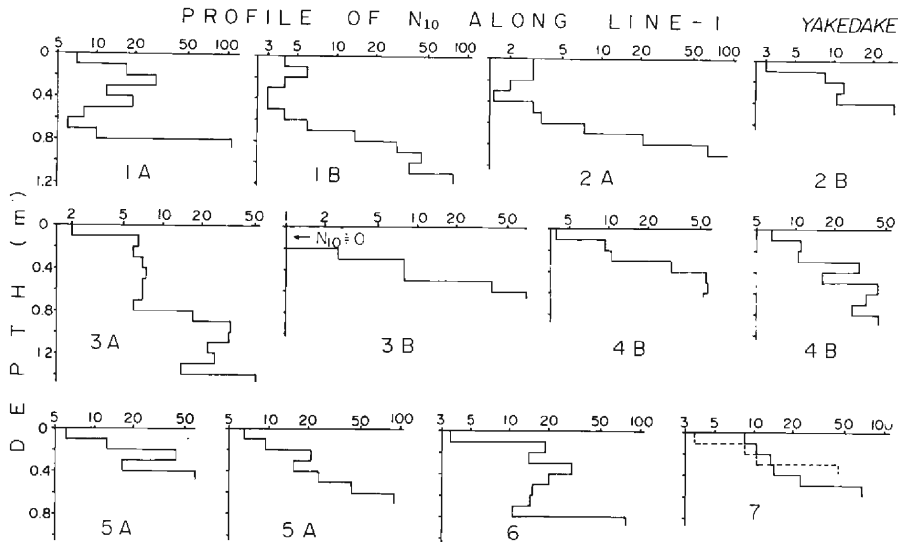
Fig. 17 N_{10} profiles at each measure points shown in Fig. 16.   Measurement was twice carried out at the point-7.

with depth can be roughly classified into several standard patterns which reflect the conditions of deposition and the processes of weathering and migration of the material.   Since the observed values of N_{10} present a log-normal distribution, topsoil horizons have been identified in **Fig. 16** according to the criterion $2^{n-1} < N_{10} < 2^n$ for the n-th horizon.

At the in situ permeability test, the side wall of the auger holes became irregular
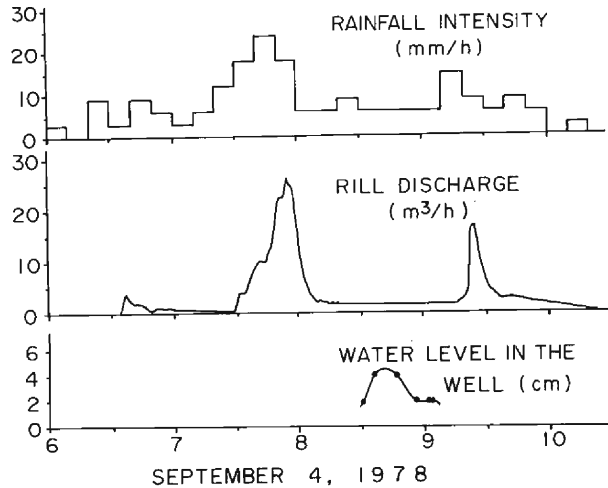
Fig. 18   An example of the stage hydrograph of throughflow (bottom) in an observation
well installed near the measure point 2B in Fig. 16.

because of the stones in the soil.   It may possibly have introduced a large error into
the values of *P*.   Classification of topsoil horizons into several subdivision was,
however, possible because of great vertical variation (with the range of variation of
about 10^3).   Four observation wells for throughflow as explained in Sec. 3. 1 were
prepared according to the vertical distribution of the *P*-value.   An example of the
observational results from a well installed near the measure point 2B (see **Fig. 16**)
at a depth of 44 cm is shown in **Fig. 18**.   The water level in the well, or the stage of
throughflow, attained its peak about one hour after the peak of the rainfall, when
the discharge of the adjacent rill had already decreased to nearly zero.   A large
rate of the recession of throughflow shown in **Fig. 18** is attributable to the perco-
lation of water into the underlying horizons.

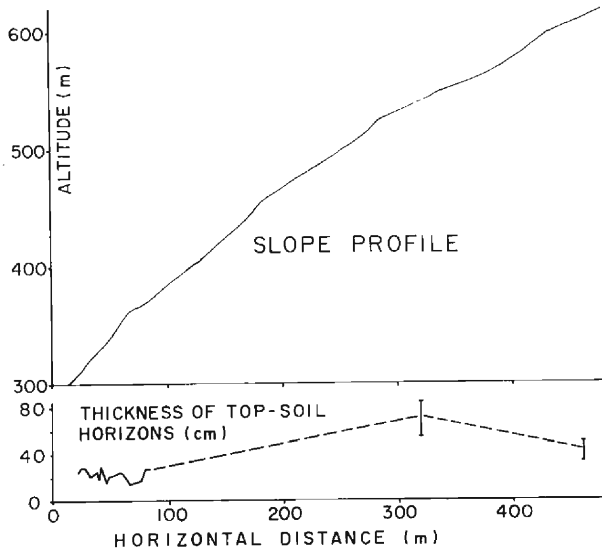### 3. 6   Catchment of the Takatoki river

The Takatoki river pours into Lake Biwa from the north.   The bedrock of the
drainage area is paleozoic rocks interbedded with chert, shale, sandstone and
schalstein.   The weathering zone is highly heterogeneous because the dip of the
strata is great and a dense fault-joint system occurs.   Many lineaments which reflect
a particularity in vegetation along linear geologic structures can be easily traced in
an aerophotographs.   It is, therefore, suggested that the heterogeneity in the
bedrock has a significant effects on the topsoil.   According to a hydrological study
by Okunishi[32,33], the coefficient of direct runoff of this river is somewhat larger
than that of other rivers pouring into Lake Biwa, though the base flow is highly
stable.

The valley-side slopes of the Takatoki river is very steep except at its head
reaches.   A longitudinal profile of one of such steep slopes along the southern divide

of Obanashi Experimental Basin established by Okunishi[33] is shown in **Fig. 19**. The slope segments bordered by some breaks become gentler as they become higher, which suggests that this area has been upheaved by geodynamic stress[34].

The result of a preliminary survey of topsoil horizons with a boring stick is also shown in **Fig. 19**. At the bottom part of the slope, the survey was carried out at an interval of several meters. Because a high content of angular pebbles in the topsoil horizons caused a large random variation in the penetration limit of the boring stick,

Fig. 19 Thickness of topsoil horizons as measured by a boring stick along the southern divide of the Obanashi Experimental Basin.
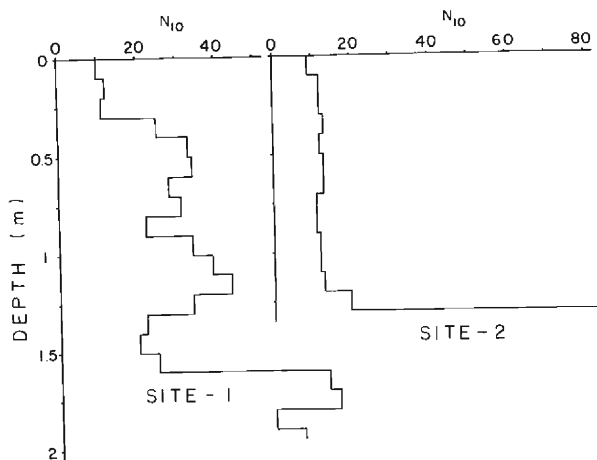
Fig 20 N_{10} profiles at two measure points on the northern divide of the Takatoki river basin.

the trend of the variation along the measure line is not obvious. Several measurements were averaged for the measure points at the horizontal distance of 320 m and 460 m, respectively. Because these measure points belong to older geomorphic cycle than the bottom part, the topsoil horizons at these points are thicker than at the latter part[18].

The result of the sounding with the Doken-type cone-penetrometer carried out on another ridge of an altitude of about 750 m which is regarded as a relic of the upheaved peneplain[34] is shown in **Fig. 20**, where site-1 represents a flat but slightly inclined strip on the ridge and site-2 the bottom of a small rill entrenching the strip to a depth of about 1 m. Because the topsoil contains plenty of pebbles, N_{10} at site-1 is subject to a random variation. However, the horizons can be roughly subdivided into three horizons at depths of 0–30 cm, 30–160 cm and more than 160 cm, according to the values of N_{10}. The difference in N_{10} among these horizons is attributable to the difference in the content of pebbles in the soil. It is also suggested that a periodic vertical change in N_{10} reflects the geologic structure of the mother rock. The horizon where $N_{10} \doteqdot 10$ at site-2 is estimated to have been formed by the deposition in the rill[32].

Though the investigation of topsoil horizons in this area was not complete as a basis for geomorphological experiments, it has been shown here that the outline of the structure of the topsoil horizons can be surveyed with such simple instruments notwithstanding the significant heterogeneity in the physical properties of the material. Further field experiments are needed to explain the difference in topsoil horizons between different geomorphic conditions.

4. Discussion and conclusions

There is some difference in the abundance of data of the field survey of topsoil horizons among the six field tests. It was, however, commonly suggested that the structure of the topsoil horizons of mountain slopes reflects the predominant geomorphic processes acting on the pertinent slope.

In the granitic areas, the microstructure of the topsoil horizons was revealed by the combination of cone-penetration test and in situ permeability test, and the result was interpreted in terms of geomorphic processes. In the paleozoic area and on the volcanic slope, fundamental structure of topsoil horizons was revealed by the same method notwithstanding the noise component in N_{10} due to the admixture of pebbles in the topsoil. It was shown that the boring stick method is useful in the survey of topsoil horizons over a wide area, though the fine structure of topsoil horizons can not be obtained.

Detailed analysis of the structure of topsoil horizons makes it possible to test the hypothesis about the geomorphic evolution by examining whether the theoretically predicted processes of weathering and mass transport can produce such topsoil horizons as actually observed. Iida and Okunishi[11] have successfully carried

out this procedure concerning the geomorphic processes which cause landslides. Measurement of the vertical distribution of the physical properties (e.g. mechanical strength and permeability) would lead to a quantitative discussion about the mass balance of topsoil due to the production by weathering and the removal by various transporting agents.

Appropriate instrumentation of the field experiments on mountain slopes would be possible on the basis of a preliminary survey of the topsoil. In this paper, it was exemplified by the instrumentation of the observation well for throughflow. It is expected that the field experiments on weathering, surface erosion and soil creep will be effectively designed on the basis of such preliminary survey as described here.

References

1) Okimura, T.: Structure of the soil horizons and landslides. in Tanaka[7], 1977, pp. 27–32 (in Japanese).
2) Hatano, S.: Slope morphology as a factor of landslides. in Tanaka[7], 1977, pp. 23–27 (in Japanese).
3) Milligan, V.: Field measurement of permeability in soil and rock. In Situ Measurement of Soil Properties, Vol. II, an ASCE Publication, 1976. pp. 3–54.
4) Okunishi, K.: In situ measurement of permeability of different horizons on the mountain slopes. Correspondence at the First Symposium of the IGU Commission on Field Experiments in Geomorphology, unpublished 1978.
5) Nakagawa, A.: A study on the ground of mountainous region (I). Ann. Disast. Prev. Res. Inst., Kyoto Univ., No. 14A, 1971, pp. 589–597 (in Japanese with English abstract).
6) Nakagawa, A.: A study on the ground of mountainous region (II). Ann. Disast. Prev. Res. Inst., Kyoto Univ., No. 15B, 1972, pp. 183–196 (in Japanese with English abstract).
7) Tanaka, S. (ed.): Study on the Relationship between Landslides and the Geological and Geomorphological Structures. Report of the Special Research of Natural Disaster Sciences, A-51-4, 1977, 135p. (in Japanese).
8) Huzita, K., T. Kasama, M. Hirano. T. Shinoda and M. Tanaka-Yamashita: Geology and geomorphology of the Rokko area, Kinki District, Japan. Jour. Geosci., Osaka City Univ., Vol. 14, Art. 4, 1971, pp. 71–124.
9) Nakanishi, S., Y. Fukuo, S. Tanaka, K. Okunishi, A. Nakagawa, T. Okimura and S. Hatano: Investigation of landslides in Aotani Experimental Basin. in Tanaka[7], 1977, pp. 53–79 (in Japanese).
10) Okunishi, K.: Field experiments in Aotani Experimental Basin. Excursion Guide-book for the Third Symposium of IGU Commission on Field Experiments in Geomorphology, 1980, pp. 37–42.
11) Iida, T. and K. Okunishi: On the slope development caused by the surface landslides. Geographical Review of Japan, Vol. 52, No. 8, 1979, pp. 426–438 (in Japanese with English Abstract).
12) Fukuo, Y.: Deformation of weathered soil as a factor of landslides. in Tanaka[7], 1977, pp. 37–41 (in Japanese).
13) Okuda, S., H. Suwa, M. Nakano and K. Yokoyama: Synthetic observation on debris flow, Part 2. Ann. Disast. Prev. Res. Inst., Kyoto Univ., No. 20B-1, 1976, pp. 237–263 (in Japanese with English abstract).
14) Uemura, M.: Water and sediment discharge from a small mountainous drainage basin. Proc. Ann. Meeting, Assoc. Jap. Geogr., No. 12, 1979, pp. 40–41 (in Japanese).
15) Huzita, K.: Tectonic development of Southwest Japan in the Quaternary Period. Jour. Geosci., Osaka City Univ., Vol. 12, Art. 5, 1969, pp. 53–70.
16) Okunishi, K.: Characteristic erosional processes in granitic drainage basins as found in

Tanakami mountain range, Shiga Prefecture, Japan. Bull. Disast. Prev. Res. Inst., Kyoto Univ., Vol. 24, Part 4, 1974, pp. 233–261.

17) Esumi, S. and K. Okunishi: Hydrological studies on small mountainous drainage basins (V). Ann. Disast. Prev. Res. Inst., Kyoto Univ., No. 18B, 1975, pp. 283–292 (in Japanese with English abstract).

18) Matsuda H. and K. Okunishi: Geomorphological characteristics of bare-lands in Tanakami mountain range. Ann. Disast. Prev. Res. Inst., Kyoto Univ., No. 13A, 1970, pp. 541–555 (in Japanese with English abstract).

19) Suzuki, T., M. Hirano, K. Takahashi and E. Yatsu: The interaction between the weathering processes of granites and the evolution of landforms in Rokko Mountains, Japan, Part 1. Bull. Fac. Sci. and Eng., Chuo Univ., Vol. 20, 1977, pp. 343–389 (in Japanese with English abstract).

20) Okunishi, K. and T. Natsukawa: Hydrological studies on small mountainous drainage basins (I). Ann. Disast. Prev. Res. Inst., Kyoto Univ., No. 11B, 1968, pp. 89–101 (in Japanese with English abstract).

21) Chiba, T.: Culture in Bare Mountain Areas. Gakuseisha, Publ. Co., 1973, 233p. (in Japanese).

22) Okunishi, K.: Hydrological studies on small mountainous drainage basins (II). Ann. Disast. Prev. Res. Inst., Kyoto Univ., No. 13A, 1970, pp. 587–599 (in Japanese with English abstract).

23) Okunishi, K.: Hydrologic change due to afforestation in waste bare-land. Publication of IAHS, No. 117, 1975, pp. 465–473.

24) Nakai, Y.: Compositional variations of the Inagawa granitic rocks in the Asuke area, Aichi Prefecture, Central Japan. Jour. Jap. Assoc. Min. Petr. Econ. Geol., Vol. 69, No. 6, 1974, pp. 215–224.

25) Okuda, S., S. Nakanishi, S. Tanaka, K. Okunishi, A. Nakagawa, S. Hatano, N. Oyagi and K. Yokoyama: Investigation of landslides in Obara Village and its neighborhood, Aichi Prefecture. in Tanaka[7], 1977, pp. 102–126 (in Japanese).

26) Tanioka, S., S. Hatano and S. Niwa: Topographic changes in landslide scars. Proc. Ann. Meeting, Assoc. Jap. Geogr., No. 16, 1979, pp. 76–77 (in Japanese).

27) Okunishi, K. and T. Iida: Study on the landslides around Obara Village, Aichi Prefecture (I). Ann. Disast. Prev. Res. Inst., Kyoto Univ., No. 21B-1, 1978, pp. 297–311 (in Japanese with English abstract).

28) Iida, T., K. Okunishi and A. Nakagawa: Study on the landslides around Obara Village, Aichi Prefecture (II). Ann. Disast. Prev. Res. Inst., Kyoto Univ., No. 23B-1, 1980, pp. 395–403 (in Japanese with English abstract).

29) Okuda, S., H. Suwa, K. Okunishi, K. Yokoyama and M. Nakano: Observation on the motion of a debris flow and its geomorphological effects. Zeitschrift für Geomorphologie, Suppl. Bd., No. 35, 1980, pp. 142–163.

30) Okuda, S., H. Suwa, K. Okunishi, K. Yokoyama, M. Nakano, K. Ogawa and S. Hamana: Synthetic observation on debris flow, Part 4. Ann. Disast. Prev. Res. Inst., Kyoto Univ., No. 21B-1, 1978, pp. 277–296 (in Japanese with English abstract).

31) Okuda, S., H. Suwa, K. Okunishi, K. Yokoyama, K. Ogawa and S. Hamana: Synthetic observation on debris flow, Part 5. Ann. Disast. Prev. Res. Inst., Kyoto Univ., No. 22B-1, 1979, pp. 157–204 (in Japanese with English abstract).

32) Okunishi, K.: Hydrology of the Takatoki river. Report of the Special Research of Environmental Science, B57–R12-4, 1980, pp. 17–20 (in Japanese).

33) Okunishi, K.: Hydrology of the Takatoki river (continued). Report of the Special Research of Environmental Science, B105–R12-12, 1981, pp. 74–81 (in Japanese).

34) Mizuyama, T.: Geomorphology and climatology of the upper reaches of the Takatoki river. Report of Academic Investigation of the Upper Reaches of the Takatoki River, 1973, pp. 1–22 (in Japanese).