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# Erosion and sediment transport measurement in a weathered granite mountain area

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ABSTRACT In the Tanakami region, a mountainous area underlain by weathered granite, erosion and sediment yield have been measured at several observational scales. First, the peg method, involving measurements of the height of pegs driven into the soil, was applied on three plots (70-115 $m^2$); measurements were made every month over 10 years. The results show that the annual rate of erosion from each plot is almost constant. Second, the sediment yield from a bare and a reforested plot (5x20 m) and from a small basin (2.66 ha) have been measured for individual storm events using settling basins. The results show that the sediment yield can be estimated using the bed load formula of Meyer-Peter & Müller. Third, the sediment transport from a large basin (1.4 $km^2$) was measured using sand sampling apparatus which permits the collection of sediment samples at any desired position in the cross section of the river. The results show that particle size is important in influencing the separation between the bed load and the suspended load.

Mesure d'érosion et transport de sédiments dans les montagnes de granite altéré

RESUME Dans la région de Tanakami, qui est couverte de montagnes très érodées de granite altéré, l'érosion et le transport de sédiment depuis le plus petite pente jusqu'au chenal le plus large ont été mesurés en quelques points d'observation. D'abord, la méthode de l'aiguille mesurant la hauteur de l'aiguille restant enfoncée dans la terre a été utilisé sur trois parcelles nues (70-115 $m^2$). Les mesures ont été exécutées une fois par mois pendant plus de 10 ans. Ces résultats montrent que la profondeur d'érosion sur chaque parcelle est presque constante. Puis, les quantités de transport de sédiment à l'issue d'une parcelle nue (5x20 m) et d'un petit bassin versant (2.66 ha) ont été mesurés dans des fosses à sédiments pour chaque crue individuelle. Les résultats montrent qu'on peut estimer la quantité de transport de sédiment raisonnablement par la formule de Meyer-Peter et Müller, formule de matériaux charriés. Troisièmement, la quantité de transport de sédiments à l'issue d'un bassin plus grand (1.4 $m^2$) a été mesurée par l'appareil d'échantillonage de sable qui permet de recueillir l'eau et les sédiments en un point quelconque du profil en travers du chenal. Ce résultat montre que le diamètre des grains de sable est important pour la separation des matériaux charriés et des matériaux en suspension.

## NOTATION

| | |
|---|---|
| $B$ | width of cross section (m) |
| $d$ | mean diameter of a cumulative distribution |
| $g$ | gravitational constant |
| $H$ | depth of water |
| $k$ | ratio of effective energy |
| $k_s$ | equivalent roughness of sand |
| $n$ | Manning's roughness value |
| $Q$ | discharge ($m^3\ s^{-1}$) |
| $q_b$ | bed load rate (volume per unit time and unit width) |
| $S$ | channel slope |
| $U_*$ | shear velocity ($=\sqrt{gHS}$) |
| $\alpha$ | parameter |
| $\delta$ and $\rho$ | specific weight of sand and water, respectively |

## INTRODUCTION

The Tanakami region is a hilly and mountainous area underlain by weathered granite and reaching 500 m in altitude. It is well known for its devastated bare land caused by continual deforestation and war fires. The region is situated in the central part of Japan (Fig. 1). The mean annual temperature is 13°C and the mean annual precipitation is 1650 mm.

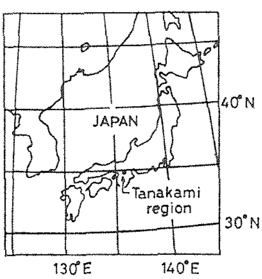


**Fig. 1** Location of the Tanakami region.

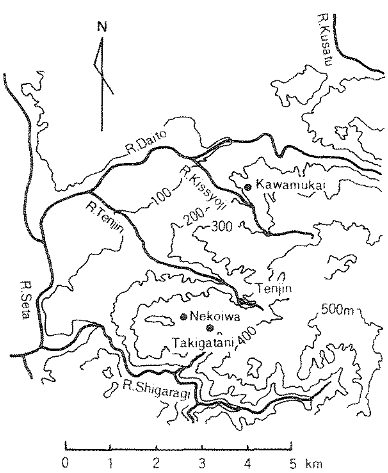


**Fig. 2** Location of each observation station.

A series of measurements and observations has been carried out to determine the processes of erosion and sediment transport from a slope to a river channel. The work was undertaken with the cooperation of the Ministry of Construction, which has carried out the erosion control works in the area for over 100 years. Different methods of study have been used depending on the phenomena and its scale of operation.

First, at the Takigatani observation station (Fig. 2), three plots were set up for the measurement of erosion on bare slopes. Second, at the Nekoiwa and the Kawamukai observation stations, the sediment yields have been measured for every rainstorm by settling basins. Third, at the Tenjin observation station, the sediment transport has been measured by a sand sampling apparatus which we designed.

**Table 1** Characteristics of each plot at the Takigatani station

| Plot | Area ($m^2$) | No. of pegs | Slope | Aspect |
|---|---|---|---|---|
| No. 1 | 110 | 42 | 35° | N80°W |
| No. 2 | 115 | 42 | 34° | S80°E |
| No. 3 | 70 | 30 | 28° | S20°E |

*(a) Erosion measurement by the peg method*

At Takigatani station, the three plots were set up to measure erosion on bare hillslopes typical of the source areas of sediment. The characteristics of each plot are shown in Table 1. The peg method based on measuring changes in the height of exposed pegs driven into the ground was used. Figure 3 shows plot no. 3 as an example. A plan of each plot is shown in Fig. 4. The pegs were located at the line intersections shown in Fig. 4 to form a grid network of pegs 2 m apart. The mean monthly erosion rate was calculated, averaging the determination for triangular sub-areas defined by three pegs within the catchment, weighted by area. The exposed heights of the pegs were measured every month for 10 years.

The cumulative monthly erosion rates for 1965-1975 are shown in Fig. 5. To investigate the cause of the fluctuations in erosion rates, the three pegs representing the head, the middle and the foot in plot no. 1 (points A, B and C in Fig. 4) were examined. It can be seen from Fig. 6 that though the cumulative monthly erosion rate at point A increases almost monotonously, the erosion rate at point C, coinciding with the position of a rill, fluctuates very widely. Especially noticeable is the lack of erosion at point C in winter from January to March every year when the rills are buried by frost action. The severe erosion at the same point in the rainy season from April to September indicates that rills appear or expand. Figure 7 shows rills at plot no. 1. Instances of negative erosion at point A, located at the head of the slope, result from the lifting of the surface soil by frost action.

Figure 8 shows the cumulative annual rates of erosion. The erosion rate in the 5 year period 1965-1970 was almost constant for each plot, but since 1970 the erosion rate has decreased slightly. Because the surrounding reforested trees grew up rapidly it is supposed that the frost action became milder. In

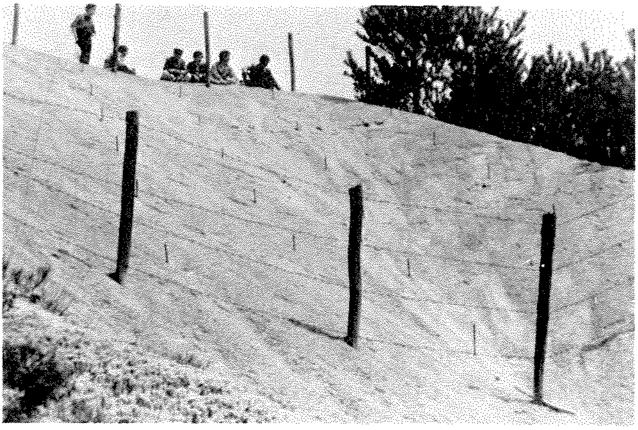

**Fig. 3** Plot no. 3 at Takigatani station.

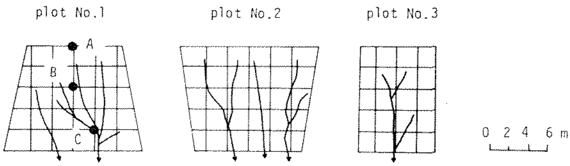


**Fig. 4** Plans of the three plots at Takigatani station. Arrows mark rills. Pegs were driven in at the intersections of the lines. Points A, B and C represent the head, the middle and the foot of the plot respectively.

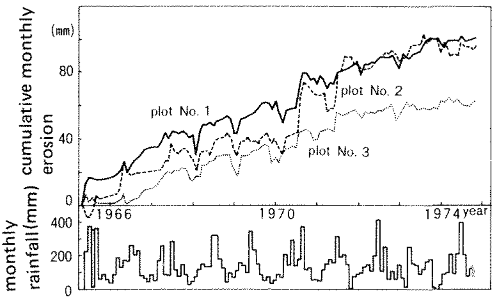


**Fig. 5** Cumulative monthly erosion rates at each plot.

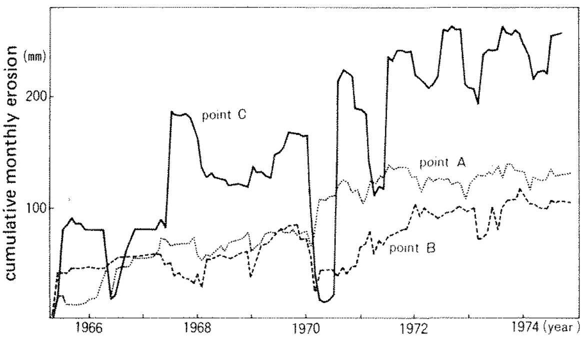


**Fig. 6** Cumulative monthly erosion rates at points A, B and C in plot no. 1 shown in Fig. 4.

the initial 5 years, the rate of erosion was about 13 mm year$^{-1}$ at plots no. 1 and no. 2 with 35° slopes, and was about 9 mm year$^{-1}$ at plot no. 3 with a 28° slope.

The peg method is effective for the measurement of the surface

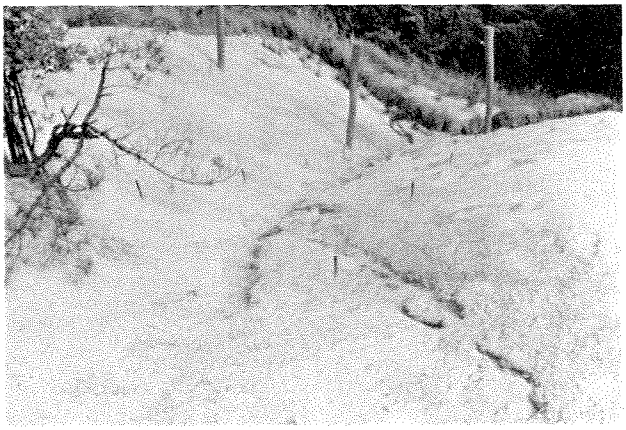

**Fig. 7** Rills at plot no. 1.

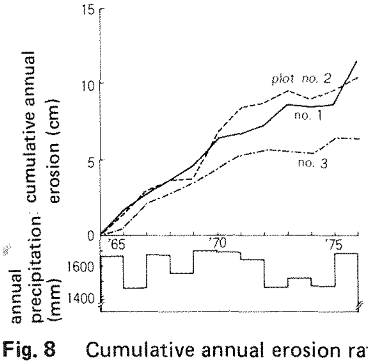


**Fig. 8** Cumulative annual erosion rates of each plot.

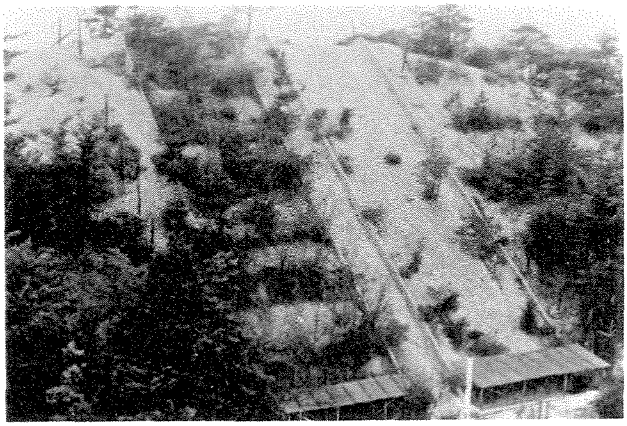

**Fig. 9** Plots at Nekoiwa.

erosion on such bare slopes.

*(b) Sediment yield measurement by the settling basin*

*(i) Small plots* At Nekoiwa, two plots were set up side by side to clarify the effect of reforestation. Figure 9 shows the two plots. The area is 5x20 m and the slope is 35° at each plot. One plot is bare and the other is reforested with pine and alder. The walls on each side of the plots were made of concrete. The surface flow enters the water tank, which has a 30° V notch weir, through the settling basin. The rainfall and the water level were recorded automatically. The sediment yield was measured by volume after every rainstorm.

The sediment yield as shown in Table 2 was 4500 $m^3$ $km^{-2}$ $year^{-1}$ on the bare plot, and 14.8 $m^3$ $km^{-2}$ $year^{-1}$ on the reforested plot, based on 14 years of data. With the effect of reforestation,

**Table 2** Sediment yield at Nekoiwa

| Year | | Sediment yield | | | |
|---|---|---|---|---|---|
| | | Bare plot | | Reforested plot | |
| | | (l) | ($m^3$ $km^{-2}$ $year^{-1}$) | (l) | ($m^3$ $km^{-2}$ $year^{-1}$) |
| 1962 | D | — | | — | |
| | R | 752 | (9 180) | 4.41 | (53.8) |
| 1963 | D | 12.9 | | 0.34 | |
| | R | 356 | 4 500 | 0.80 | 13.9 |
| 1964 | D | 24.0 | | 0.36 | |
| | R | 406 | 5 240 | 0.46 | 10.0 |
| 1965 | D | 14.3 | | 0.21 | |
| | R | — | — | — | — |
| 1966 | D | — | | — | |
| | R | 858 | (10 500) | 0.25 | (3.05) |
| 1967 | D | 16.7 | | 0.31 | |
| | R | 214 | 2 810 | 0.29 | 9.32 |
| 1968 | D | 8.9 | | 0.45 | |
| | R | 195 | 2 490 | 0.39 | 10.3 |
| 1969 | D | 7.8 | | 1.01 | |
| | R | 229 | 2 890 | 0.62 | 19.9 |
| 1970 | D | 10.3 | | 0.24 | |
| | R | 482 | 6 020 | 0.61 | 10.4 |
| 1971 | D | 11.7 | | 0.48 | |
| | R | 228 | 2 920 | 0.56 | 12.7 |
| 1972 | D | 3.25 | | 0.46 | |
| | R | 334 | 4 120 | 0.36 | 10.0 |
| 1973 | D | 13.1 | | 0.43 | |
| | R | 93.3 | 1 300 | 0.48 | 11.1 |
| 1974 | D | 3.91 | | 0.46 | |
| | R | 65.0 | 842 | 0.46 | 11.2 |
| 1975 | D | 4.76 | | 0.49 | |
| | R | 245 | 3 040 | 0.68 | 14.3 |
| 1976 | D | 34.3 | | 0.69 | |
| | R | 548 | 7 110 | 0.71 | 17.1 |
| Average | D | 12.8 | | 0.46 | |
| | R | 357 | 4 500 | 0.79 | 14.8 |

D: dry season from November to April; R: rainy season from May to October.

the sediment yield decreased to about 1/300 of that on bare ground. The sediment yield in the rainy season was only twice that in the dry season at the reforested plot, but 28 times that in the dry season at the bare plot. The sediment yield at the bare plot seemed to be determined by the hydraulic condition. So, the bed load formula of Meyer-Peter & Müller (1948), was applied to the observed data. This equation is written as follows:

$$\frac{q_b}{\left[(\delta/\rho-1)gd^3\right]^{\frac{1}{2}}} = 8\left[\frac{U_*^2}{(\delta/\rho-1)gd}k - 0.047\right]^{\frac{3}{2}} \tag{1}$$

At the bare plot, the particle diameter d = 2.4 mm, $d_{90}$ = 7.0 mm, and S at the foot of the plot is 0.314. Calculations were made in metre-second units.

Now, from the equation of the Manning-Strickler type

$$n = 0.0404\ k_s^{\frac{1}{6}} \tag{2}$$

The n value determined by equation (2) for the bare plot is 0.018 ≃ 0.02. The section shape in this plot is expressed according to regime theory by

$$B = \alpha\sqrt{Q} \tag{3}$$

When n = 0.02 was used, α was calculated to be 7.0. The value k was assumed to be 0.4. The time interval for the calculation was 10 min. Figure 10 shows the relation between sediment yields calculated using observed discharge and equations (1), (2) and (3), and measured sediment yields. The true volume of sediment is 50% of the measured apparent volume. Although this plot is steep, the observed and predicted values show a fairly good agreement.

*(ii) A small basin* There is a small basin of 2.66 ha at the Kawamukai observation station. Though reforested, the growth of vegetation was not good. At this station, the discharge has been observed continuously using a 90° V notch weir. The sediment yield is deposited in a settling basin and is measured by volume after every rainstorm. The rainfall and the water level were recorded automatically. Figure 11 shows the settling basin and the V notch weir.

The mean annual sediment yield as shown in Table 3 was 11.3 $m^3\ km^{-2}\ year^{-1}$ according to the data of 18 years. Although this value is of the same order as that of the reforested plot at Nekoiwa, the sediment transport in this station is considered to be restrained by the hydraulic condition. So, equation (1) was again applied. The values of the parameters for this station are d = 2.7 mm and S = 0.0177. The other parameters are the same as those of the bare plot at Nekoiwa. The time interval used in the calculations was 20 min. Figure 12 shows the relation between the calculated values and the measured values. They show approximately good agreement.

*(c) Sediment transport measurement by the sand sampling apparatus* To measure sediment yield in a basin larger than those of the Tanakami region, and to clarify the difference between bed load and suspended load, the Tenjin observational station was set up in 1977.

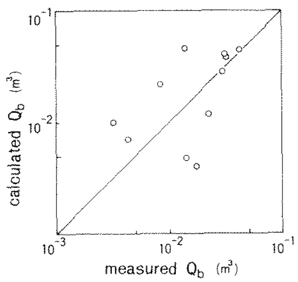


**Fig. 10** Relation between calculated and measured sediment yields for each rainstorm at the bare plot, Nekoiwa.

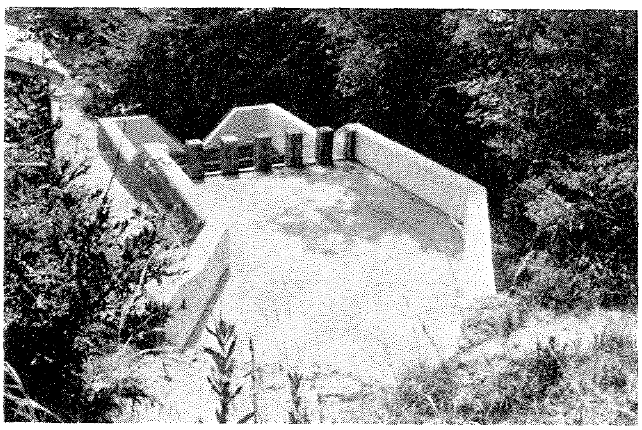

**Fig. 11** Settling basin and V-notch weir at Kawamukai.

**Table 3** Sediment yield at Kawamukai

| Year | Sediment yield ($m^3$ $km^{-2}$ $year^{-1}$) | Year | Sediment yield ($m^3$ $km^{-2}$ $year^{-1}$) |
|---|---|---|---|
| 1962 | 27.21 | 1972 | 19.20 |
| 1963 | 6.44 | 1973 | 2.94 |
| 1964 | 0.87 | 1974 | 3.15 |
| 1965 | 42.25 | 1975 | 6.25 |
| 1966 | 15.93 | 1976 | 9.69 |
| 1967 | 20.08 | 1977 | 3.11 |
| 1968 | 10.43 | 1978 | 2.49 |
| 1969 | 3.13 | 1979 | 0.43 |
| 1970 | 12.63 | | |
| 1971 | 6.05 | Average | 11.3 |

The basin area is 1.4 $km^2$. The sand sampling apparatus used at this station is shown in Fig. 13. It is installed under a sand check dam and is able to collect the water and sediment at any desired position in the cross section of the river. A raingauge, a water level gauge and a current meter with an electric wave were also installed. The sand sampling apparatus has three mouths of 6x6 cm. The mouth size is about 3 times that of the maximum diameter of the bed material.

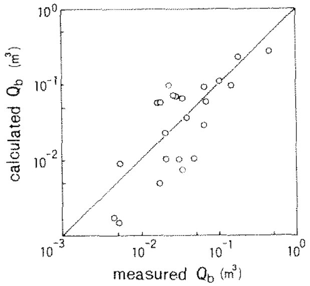


**Fig. 12** Relation between calculated and measured sediment yields for each rainstorm at Kawamukai.

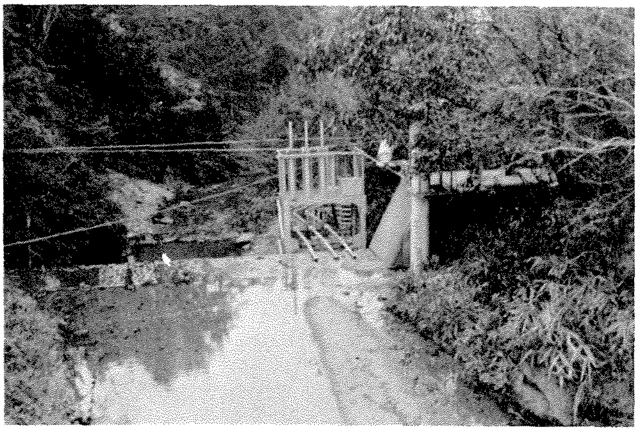

**Fig. 13** Sand sampling apparatus at Tenjin.

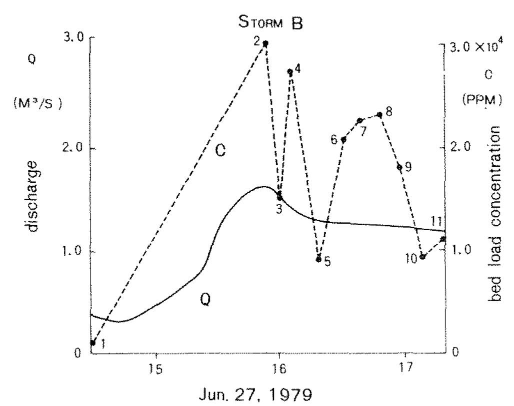


**Fig. 14** Bed load concentration for a rainfall hydrograph.

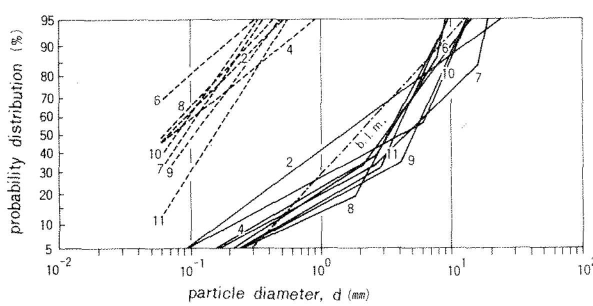


**Fig. 15** Probability distribution of particle size. ——— bed load; ----- suspended load; b.l.m. = bed load material; numbers coincide with values in Fig. 14.

Because the observations only started recently, measured data are very few. So, only an example is presented here. Figure 14 shows the bed load concentration for a rainstorm hydrograph. Though the bed load concentrations fluctuate widely, changes in the concentrations correspond with changes in discharge. During the same rainstorm, a 2 litre bottle was used to sample suspended load near the surface of the river at the same hour the bed load was sampled. The distribution of the collected particle size is shown in Fig. 15. It is clear that the distribution of the bed load differs from that of the suspended load. If the critical particle size separating bed load and suspended load is assumed to be 0.5 mm, then 95% of the suspended load is less than this critical size, and 80% of the bed load contained more than this critical size. The suspended load is presumed to be wash load, considering the particle size distribution of the bed material.

## REFERENCES

Meyer-Peter, E. & Müller, R. (1948) Formulas for bed load transport. *Proc. 2nd Congress of the International Association for Hydraulic Research* (Stockholm, Sweden).