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https://doi.org/10.5109/23925

出版情報：九州大学大学院農学研究院紀要. 33 (1/2), pp.153-165, 1988-10. Kyushu University

J. Fac. Agr., Kyushu Univ., 33 (1・2), 153－165 (1988)

A Geomorphological Study for the Distribution of Sediment and the Constant Shifting of Balance on Devastated Stream Beds

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(Received June 30, 1988)

The purpose of this paper is to clear the effect of geomorphological balance on devastated stream beds by the geomorphological analysis of depositional features. Qualitative zoning and observing the transformation of terraces show that terraces are not composed of the sediment with a single stroke of debris flow but of the gathering of many transformable units with sedimentation and scour on small scale. Depositional features of devastated stream beds can be characterized by the cross sectional area of the sedimentary load per unit stream width, i. e. the average depth of sediment. The average depth is considered to be an indicator of frequency of sedimentation and/or an indicator of sediment instability. A stream channel is divided into sections where the average depth increases (sedimentary sections) and sections where it decreases (scouring sections). The lengths of sedimentary sections (L_{dn}) and scouring sections (L_{cn}) are respectively measured along stream course.

The results are as follows : lt was found that, after external factor-e. g. debris flow from a branch stream-induced an episodic geomorphic change, the ratio of L_{dn}/L_{en} tends to approach a constant value in a reach of stream course. It is considered that the ratio value and the reach length reflect the level and the power of the constant shifting of balance. At devastated stream beds, the re-distribution of sediment does not lead to the uniform depth of sediment, but to the balanced sequence of sedimentary and scouring sections. The constant value for the ratio (L_{dn}/L_{en}) observed in a reach must be caused by the constant shifting of sediment balance on devastated stream beds.

INTRODUCTION

We depended on following two methods for reducing the disaster with debris transportation-e. g. debris flow from a branch stream-on devastated stream beds. One is the method to reduce the kinetic energy of debris flows, and the other is the method to adjust the depositional features changing at intervals of debris flows. The process of debris transportation is influenced temporarily and intensively by high dams and longitudinal dykes reducing kinetic energy, and it is influenced long and gradually by cross dykes and low crowded dams system adjusting depositional features.

In the study of geomorphic history, it is considered that the depositional feature in a river bed is a kind of materialization of geomorphological balance. Therefore, we can efficiently apply the concept of geomorphological balance in river beds to control the process of debris transportation on devastated stream beds. The purpose of this paper is to clear the effect of geomorphological balance on devastated stream beds by the geomorphological analysis of depositional features.

THE CONCEPT OF GEOMORPHOLOGICAL BALANCE

Geomorphological balance on river beds is considered as a kind of dynamic equilibrium in an open system of thermodynamics (Leopold et *al., 1962).* Actually, the dynamic equilibrium is expressed as the condition of the longitudinal balance between sedimentary load and scouring load at every sections in river beds. According to this concept, after the bedrock of devastated stream beds has covered with a large quantity of sediment, depositional features of sedimentary beds can be changed episodically with periods of aggradation interrupting degradation, until a new stable condition of depositional features has been achieved (Schumm, 1985). Namely in the lower course of river beds, it is found out the agency to keep changing river profiles continuously into more fresh river profiles, after the episodic interruption has been brought with geomorphic changes on large scale. In geomorphology, the agency on river beds is called as the constant shifting of balance (Mackin, 1948). And the geomorphological balance of this agency on river beds is materialized in the changes of bed gradient and meandering form.

In devastated streams, the continuous observations on the process of debris transportation are important for the practical application of the constant shifting theory in river beds, because debris transportations occur frequently on small scale with geomorphic changes. And a large quantity of sediment with the first extention in unstable condition is transported to the lower course of stream bed. Therefore, the geomorphological balance is attributed to the transformable unit with the debris transportations, which are smaller than a single stroke of the debris flow with first extention, on devastated stream beds.

THE TRANSFORMABLE UNIT IN DEVASTATED STREAM BEDS

In general, the depositional feature in devastated stream beds is considered to be caused by a single stroke of debris flow, because a large quantity of sediment must be transported to a long distance in a very short term. But it is found out many traces with sedimentation and scour in a smoothly continueing terrace, by the author's analyses for particle size and stratification on some devastated stream beds of the western part of Japan. From these analyses, author understands that the terrace is made of many transformable units with the high frequency of debris transportations.

In Fig. 1, two districts are illustrated with zoning into transformable units by particle size analyses (about particles under 2 mm diameter) and stratigraphic classifications (samples of sediment are picked up from pits digging terrace surface). Liquidity of debris depends on the matrix content of debris, which is mostly composed of particles under 2 mm diameter (Marutani et al., 1986). Zoning into transformable units is based on a fact that the same kind of sedimentary strata is transported with identical debris flow.

In Fig. 2, two districts are illustrated with zoning into transformable units by rock size analyses (about rocks above 100 mm diameter) and dispersion patterns of rocks (about rocks above 500 mm diameter) calculated with I_δ index (Morishita, 1959). Zoning into transformable units is based on a fact that the same scale of rocks approaching mutually are transported with identical debris flow.

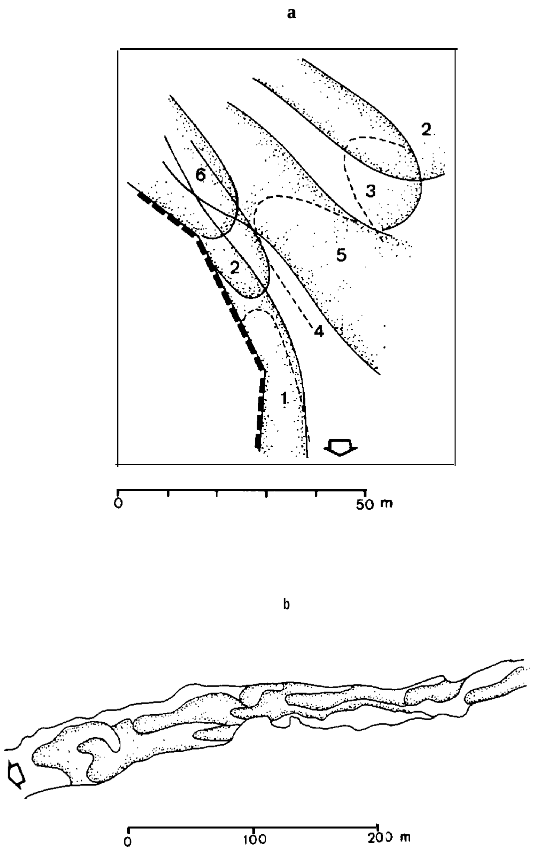

Fig. 1. Two districts of zoning into transformable units by particle size analyses (about particles under 2 mm diameter) and stratigraphic classifications (samples of sediment are picked up from pits digging terrace surface). (a) : Zoning of kurokamigawa fun in Sakurajima, (b) : Zoning of Osakigawa River in Nagasaki pref..

The process of debris transportation is demonstrated more exactly by the qualitative zoning of terraces than by morphological zoning of them. The plane shape of transformable units is slender in channels, and that is broad in fans. The plane area of transformable units is nearly constant, and it is as same scale as the sub-unit in Nikkou (Imamura et al., 1978) or the lobe in Mt. Yakedake (Suwa et al., 1982).

THE TRANSFORMATION OF DEPOSITIONAL FEATURES

Author had observed the transformation of depositional features in a volcanic torrent channel, i. e., Nojirigawa in Sakurajima, from September 1980 to October 1981, and it is found that a smoothly continueing terrace is to be formed with many transformable units by sedimentation and scour (Marutani, 1984). Figure 3 shows the transformation of depositional features with the isopleth on level fluctuations. The

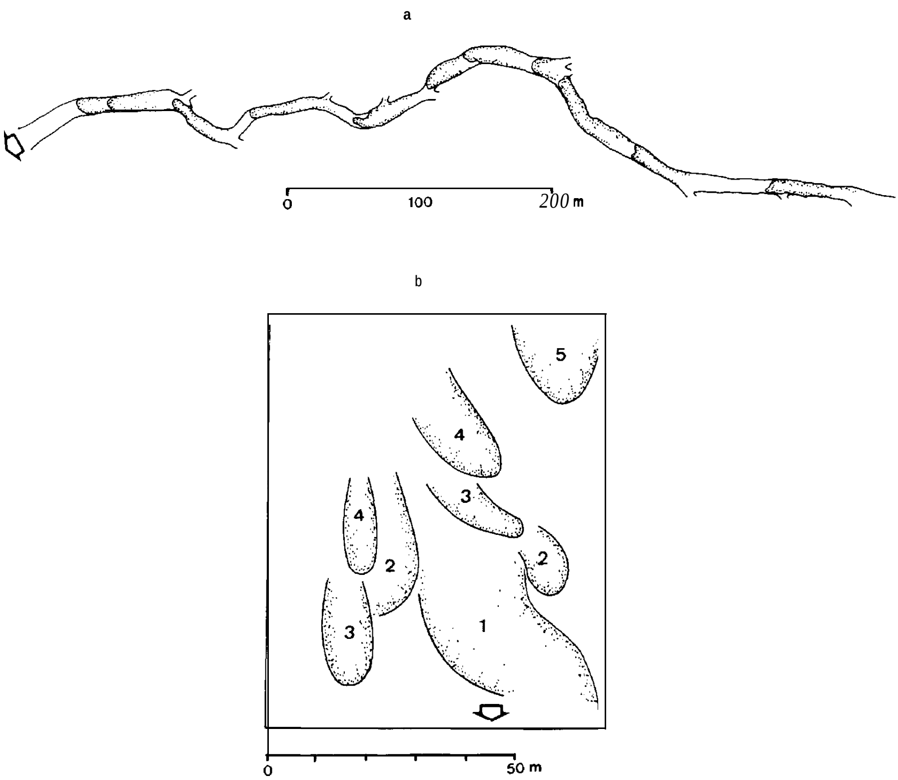

Fig. 2. Two districts of zoning into transformable units by rock size analyses (about rocks above 100 mm diameter) and dispersion patterns of rocks (about rocks above 500 mm diameter) calculated with I_δ index (Morishita, 1959). (a) : Zoning of Touzadani River by rock size analyses, (b) : Zoning of Kurokamigawa fun by dispersion patterns of rocks with I_δ index.

variations of isopleths are calculated from the levels of terrace surface before and after debris transportations. The left part of Fig. 3 is the transformation of depostional features in September 30 $\sim$ November 26, 1980, and the right part of Fig. 3 is the transformation of that in November 26, 1980 $\sim$ June 9, 1981. Increasing parts on the level of terrace surface are represented with black ground, and decreasing parts on that are represented with white ground.

According to spectrum analyses, the complex shape of material surface can be produced by a single harmonic in one direction and a single harmonic in the other. So, it is useful that the complex shape is analyzed by double Fourier series with two harmonics, which is one of spectrum analyses (Davis, 1973). Figure 3 shows the very complex shape of the isopleth on level fluctuations, so author represented typical trends of the isopleth on level fluctuations by double Fourier series. Figure 4 shows the isopleth on level fluctuations which are described with approximate value calculated using reappearance parcentage 30%. It had been observed that debris flows occur on

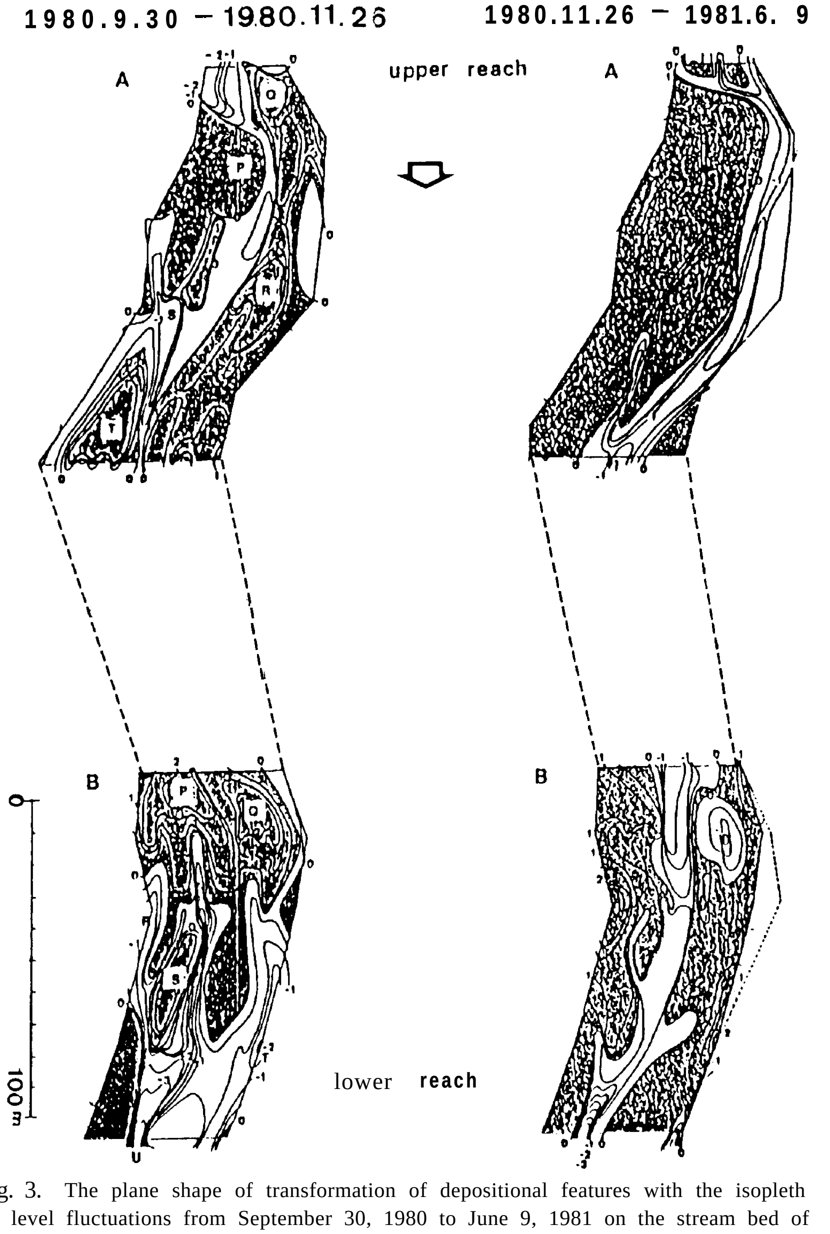

Fig. 3. The plane shape of transformation of depositional features with the isopleth on level fluctuations from September 30, 1980 to June 9, 1981 on the stream bed of Nojirigawa in Sakurajima.

small scale in September ～ November and on large scale in November ～ June. According to these analyses, the depositional features transform on small scale in short period by debris transportations, and on large scale in long period by debris flows along stream courses. From the comparison of the isopleth on level fluctuations in two

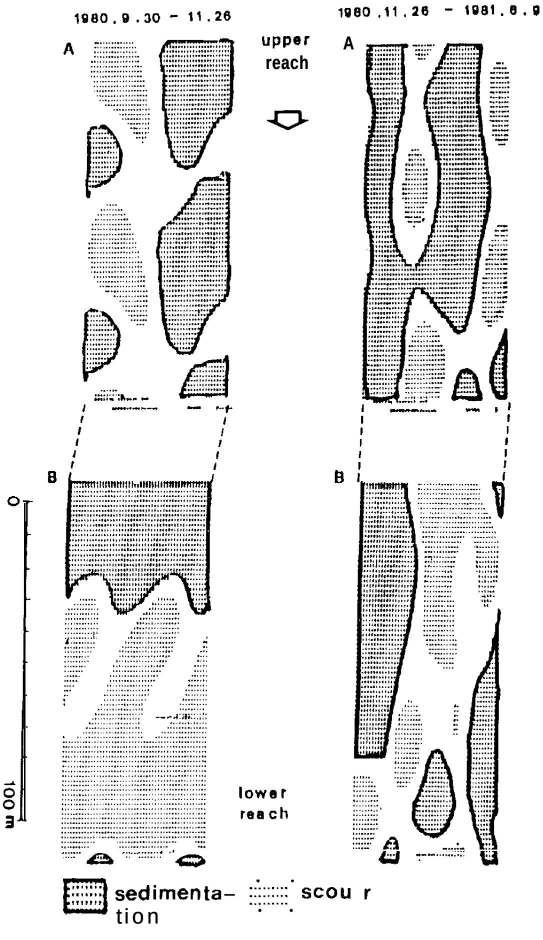

Fig. 4. The plane shape of isopleth on level fluctuations by double Fourier series with two harmonnics, which are described with approximate value calculated using re-appearance percentage 30%.

terms, i. e. September ~ November and November ~ June, we can believe that a terrace is formed with many transformable units.

On devastated stream beds except volcanic stream beds, it will take long term to bring about the transformation of depositional features by debris transportations on small scale. So, it is considered that a terrace is not composed of the sediment with a single stroke of debris flow but of the gathering of many transformable units with sedimentation and scour on small scale.

DISCUSSION

The Alternation of Sedimentary Sections and Scouring Sections

The observation on level fluctuations lead to the understanding that depositional features on devastated stream beds can be characterized by the cross sectional area of sedimentary load per unit stream width, i. e. the average depth of sediment. The average depth is considered to be an indicator of frequency of sedimentation and/or an indicator of sediment instability. Because, after the first extention of sediment with external factor-e. g. debris flow from a branch stream- , sedimentary load increase and decreases locally according to frequency of geomorphic changes with the transformable units (Fig. 5). Figure 5 (a) shows the first extention of sediment just after geomorphic change by external factor-e. g. debris flow on large scale. Figure 5 (b) shows the re-distribution of sediment in several months after the first extention by external factors. Figure 5 (c) shows the fixing of sediment several years hence after the first extention by external factors. Figure 6 shows plans of depositional features above the surface of water in investigation areas, i. e. Mitaki-gawa, Uchidadani-gawa, Tanouchi-gawa, Otani-gawa and Okumasu-gawa. The investigation for this paper is at the time of Fig. 5 (c).

Figure 7 shows fluctuations of the average depth of sediment, in which the ratio ($Q=$ S/B) of the cross sectional area of sediment (S) per unit stream width (B) in vertical axis and distance (L) from the point of the first extention of sediment with

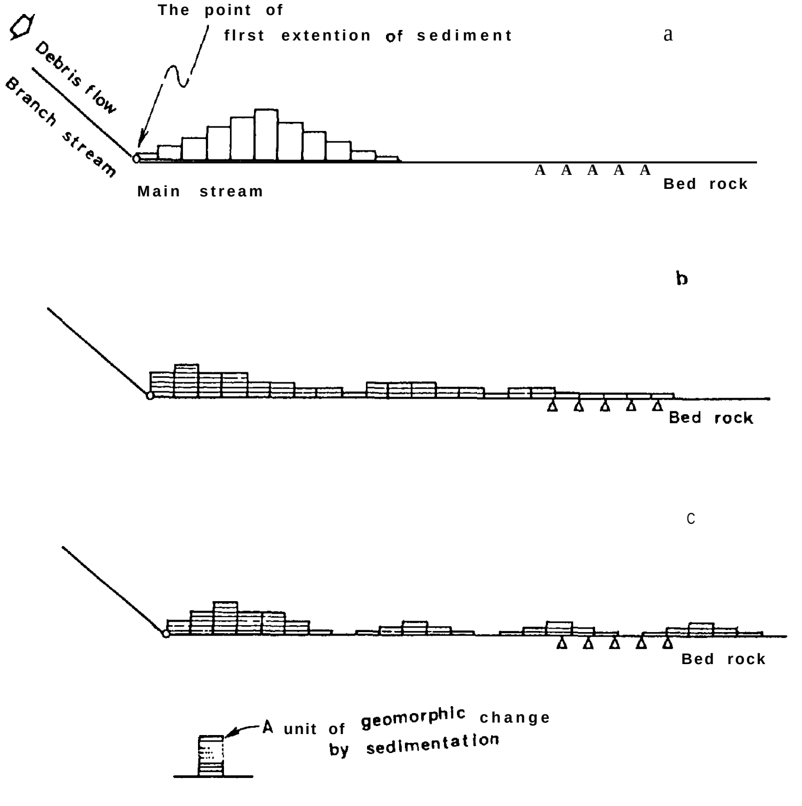

Fig. 5. The process of geomorphic change on devastated stream beds after the first extention of sediment with external factor-e. g. debris flow from a branch stream.

external factor-e. g. debris flow from a branch stream-in transverse axis. In Fig. 7, each stream is characterized particularly by changes in wave length. And a stream channel is divided into sections where the average depth increases (sedimentary sections) and sections where it decreases (scouring sections). The lengths of sedimentary sections (L_{dn}) and scouring sections (L_{en}) are respectively and alternately measured along stream courses.

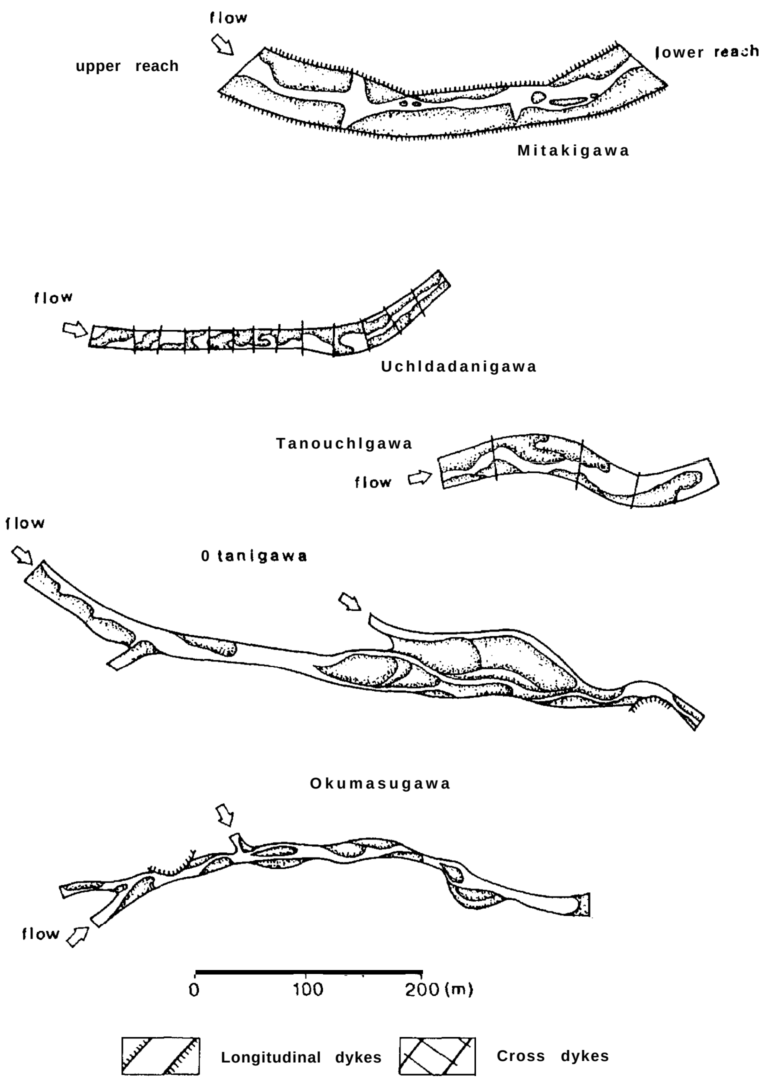

Fig. 6. Plans of depositional features above the surface of water in investigation areas.
Mitaki-gawa is with longitudinal dykes. Uchidadani-gawa and Tanouchi-gawa are with cross dykes. Otani-gawa and Okumasu-gawa are without channel works (natural stream).

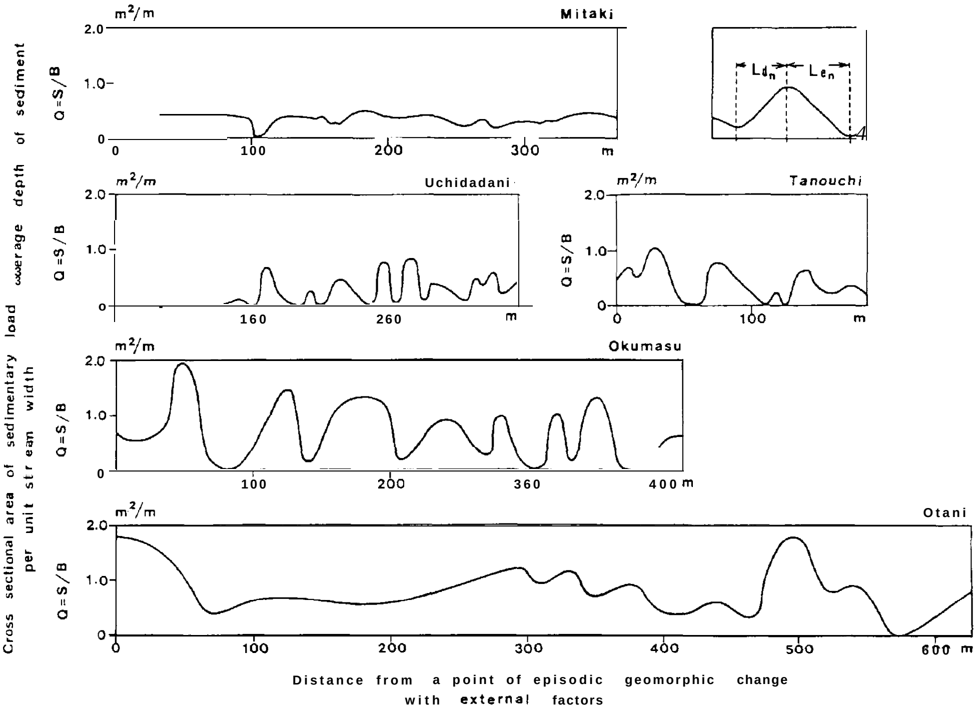

Fig. 7. Fluctuations of the cross sectional area of sedimentary load per unit stream width (the average depth of sediment).
Vertical axis (Q) : The ratio of cross sectional area of sediment against stream width.
Transverse axis (L): Distance from the point of first extention of sediment with external factor.
Top right : Measuring method of the length of sedimentary section (L_{dn}) and the length of scouring section (L_{en}).

Figure 8 shows changes in lengths of (L_{dn}) along vertical axis and lengths of (L_{en}) along transverse axis. In Fig. 8, coefficient (n) is section number from the point of external factor-e. g. debris flow from a branch stream (k = 1, 2, 3,……, n), on the basis of data measured in Fig. 7. It was found that the ratio of L_{dn}/L_{en} tends to approach a constant value in a reach of stream course after the appearance of the first extention of sediment with an episodic geomorphic change. As shown in Fig. 5, the constant value of the ratio in each channel is given with dashed line. And author define that γ is the constant value $(\gamma = L_{dn}/L_{en})$, and μ is the reach length from the point of episodic geomorphic change with external factors to the point of recovery of γ by the constant shifting of balance $(\mu = \mu_d + \mu_s)$, and τ is the year after the appearance of the first extention of episodic geomorphic change. These data are calculated from Fig. 8 (see Table 1). Figure 9 shows these data plotted as γ vs μ. Relationship between γ and μ can be expressed by exponential function as follows.

$$\mu = 10^2 \cdot \log_e\{2/(2-\gamma)\} \qquad (1)$$

From equation (1), it is considered that the constant value and the reach length

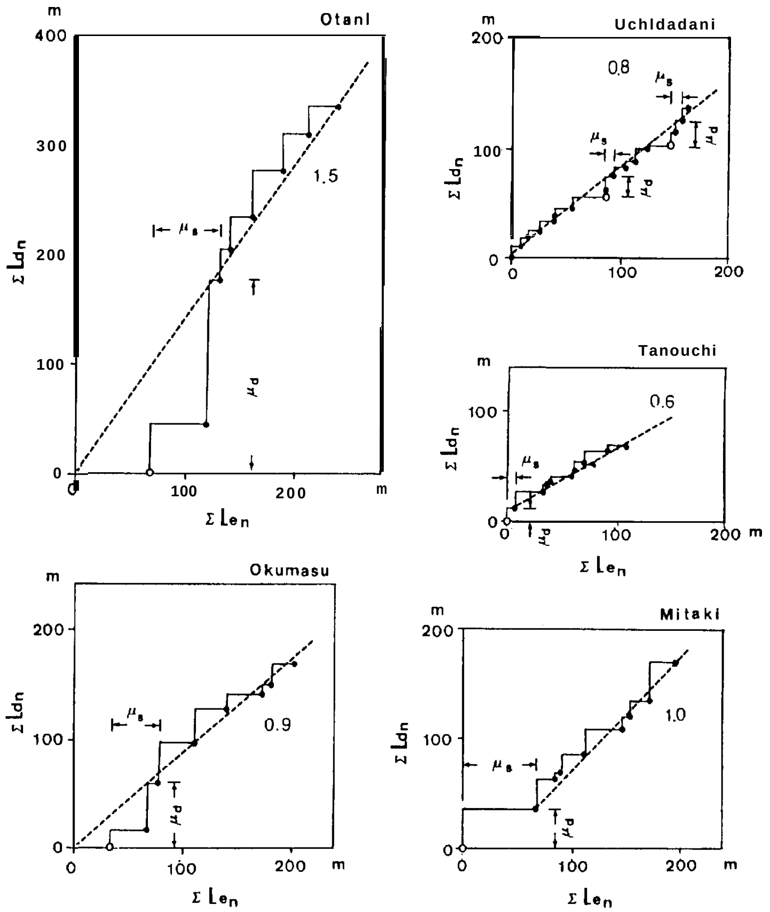

Fig. 8. Changes in the lengths of L_{dn} and L_{en}.
Vertical axis : Summation of L_{dn} (n= 1, 2, 3,······, k).
Transberse axis : Summation of L_{en} (n= 1, 2, 3,······, k).
Coefficient n : a section number from the point of external factor-e. g. debris flow from a branch stream.

reflect the level and the power of the constant shifting of balance. Equation (1) shows that the higher the constant value (γ), the longer the reach length (μ), which is need for recovering geomorphological stability. Namely, the stream bed with long sedimentary sections is more powerful for recovering its geomorphological stability than that with long scouring sections.

Equation (1) can be expressed as,

$$\mu = 70 - 100 \cdot \log_e(2-\gamma) \tag{2}$$

The incline of graded river channel is given by Aki's equation (Aki, 1944).

$$X = A - 1.4 \cdot B \cdot \log_e(\lambda \cdot d_m) \tag{3}$$

Table 1. The ratio $L_{dn}/L_{en}(\gamma)$, the distance (μ) and the time after the appearance of the first extention of sediment with episodic geomorphic change (τ).

Stream		μ (m)	γ	τ_v (year)
Mitaki-gawa	(三滝 III)	102	1.0	6
Tanouchi-gawa	(田内川)	16	0.6	7
Uchidadani-gawa	(内田谷川)	31-32	0.8	7
Okumasu-gawa	(奥溢川)	106	0.9	2
Otani-gawa	(大谷川)	239	1.5	2

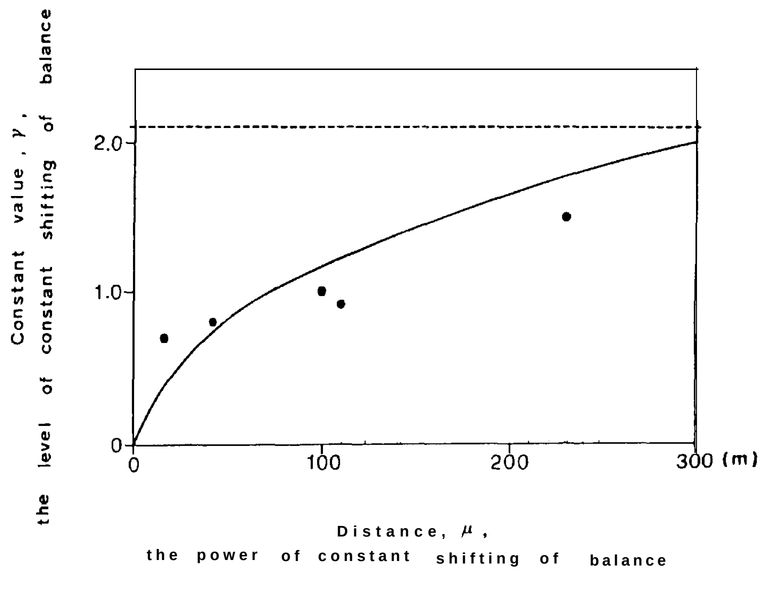

Fig. 9. Relationship between the constant value (γ) and the distance (μ) from the point of episodic geomorphic change with external factor to the point of recovery of γ with the constant shifting of balance.

Where X is the length along channel course between two points in which reach there is not geomorphic change with external factor, and d_m is the mean diameter of sediment in a point of upper reach, and λ is the rate of vacant space in a river channel bed, and coefficient A and B are inherent values in each river channel. The similarity of equations (2) and (3) is reasonable, when the following correlations can be given.

$$y = 2 - \lambda \cdot d_m, \ A = 70, \ B = 70$$

The Process of Debris Transportation and Geomorphological Balance

In Fig. 10, Author can propose the model expressing the process of debris transportation based on the concept of the constant shifting of balance in devastated stream beds. Debris transportation with massive load keeps making sedimentation at the upper part of previous depositional features, and it keeps making scour at the lower part of that. As the result of analyzing this process, depositional features show type

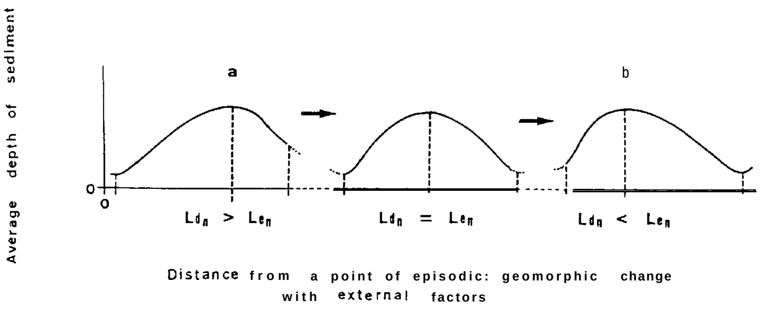

Fig. 10. Variation of the value (y) along stream courses according to the constant shifting of balance.

(a) with degradation in the upper part and with aggradation in the lower part. Debris transportation with tractive load keeps making scour at the upper part of previous depositional features, and it keeps making sedimentation at the lower part of that. As the result of this process, depositional features show type (b) with aggradation in the upper part and with degradation in the lower part. At devastated stream beds, the re-distribution of sediment does not lead to the uniform depth of sediment, but lead to the balanced sequence of sedimentary sections and souring sections. Since rock diameters in upper reach are larger than that in lower reach, debris transportation with massive load occcur more frequently in upper reach than in lower reach. Seeing the shape of depositional features in broad respective, it changes from type (a) to type (b) along stream courses.

The concept that stream bed profile shows recession in parallel with the antecedent profile can be applied to evolution in depositional features, and the concept that stream bed profile shows the alternation of sedimentary sections and scouring sectrions in receding process can be applied to the geomorphological balance in depositional features. Author considered that the constant value for the ratio (L_{dn}/L_{en}), observed in a reach, must be caused by frequency of sedimentation according to the constant shifting of balance on devastated stream beds. Exactly, geomorphological revolution and geomorphological balance with sedimentation and scour are the mutual supplementary process in fluctuation of sedimentary profile of stream beds. The unstable profile changing by debris transportations is recovered to stable profile with the constant shifting of balance in devastated stream beds. And so, stream bed profile evolve into a new stage of profile with the recovery of geomorphological balance.

ACKNOWLEDGEMENTS

I am greatly indebted to Prof. K. Takeshita, Prof. M. Takayama and Assoc. Prof. H. Nakao of Kyushu University for comments on the manuscript. Thanks are due to Prof. S. Higashi, Assoc. Prof. T. Araya of Hokkaido University, Dr. M. Kimura of Gifu University, Dr. H. Shimizu of Kokudo Bousai and Dr. S. Hayashi of Kyushu University for their fruitful discussion. I also wish to thank Prof. M. Kakihara for his suggestion.

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