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# A Morphological and Chronological Study on the Process of Sediment Movement in Saru River

By

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# 沙流川河床堆積地の樹木年代解析による土砂移動履歴の評価手法

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## Abstract

A method of investigation, analysis and evaluation of the past movement in riverbed was examined. Based on the topographical and vegetational indicators on sediment movement of Saru River, the movement occurrence years were estimated. The estimated years were almost confirmed by the records of floods and hydrological events.

The distribution of sediment volume at each year was expressed as the equation, $Vp = aT^b$ (Vp: potential sediment movement volume ($m^3/km^2$), T: return period (year)). The a and b were defined as the basin characteristics' indices on sediment movement process. The value of a, which is corresponding to the annual sediment yield, was smaller in Saru River of Pleistocene and metamorphic areas than those in the other volcanic and Tertiary rivers. From the conformity between the value of a and the annual sediment yield, the proposed method for evaluating the basin characteristics was considered to be applicable.

Assuming the alternative movement model of riverbed sediment, the sediment movement volume of each year was estimated, by multiplying the cross sectional area by the estimated movement length, derived from the wave length of sediment distribution. While the estimated volume partly agreed with the sediment yield, the estimation of sediment movement volume, from the movement model, need further examination.

**Key words:** Sediment movement, Chronology of deposit, Topography of riverbed, Potential sediment movement volume, Basin characteristics.

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## I. Introduction

It is necessary to foresee the occurrence time and scale of debris movement for taking the necessary precautions against debris disasters by setting prevention facilities according to the forecast and clarification of the process of debris movement from hillside slopes to outlet of river in a basin.

There are, however, many factors affecting the clarification of the mass movement of debris such as rock-cliff falls, landslides, debris and sediment flows. In particular, the contingency of movement occurrence, irregularity of scale and frequency in occurrence, and individuality of basin's topographical and geological characteristics have been retarding the solution of the problems related to debris movement which are due to discontinuity of movement in time and place.

It is considered that the most difficult problems in this respect are a lack of field investigation methods and of continuous surveying data at gauging stations on the actual conditions of debris movement, especially on the chronological deformation process of deposits. There are fewer records of debris movement than those on water flow, in spite of the fact that many check dams have been constructed for a long time in Japan.

The purpose of this study is to examine the applicability of tree ring analysis, which has been developed in the small torrential rivers. Also based on the analysis of the regularity of sediment distribution along longitudinal distance and deposition time, it is to suggest a method for expressing basin characteristics' index on sediment movement and to propose a sediment movement model derived from volume and distance of movement in channel bed.

## II. Method of Surveying the Chronology of Sediment Movement in Riverbed

### 1. Information on chronological indicators

The chronology of past debris movement can be surveyed with the following method: investigating the chronology of earth surface's movement, especially of mass debris movement (i. e., landslide, collapse and avalanche of soil and rocks, debris flow, etc.) in the past, approximately, one hundred years and surveying the scale of the sediment deposit (area, range and quality). With this data, an estimation of the debris movement in each basin can be made. This method, whose accuracy is being verified by surveys of river basins, performed in the districts in and outside Hokkaido, can be of great assistance in chronologically analyzing the past debris movements which occurred in the surveyed areas.

Aerial photography and the tephro-chronological methods have been applied to analyzing the debris movement in some areas, but it is difficult to assess the scale of movement and the time of occurrence when utilizing these methods. The chronological information obtained from the study of vegetation, however, can be very useful in debris movement

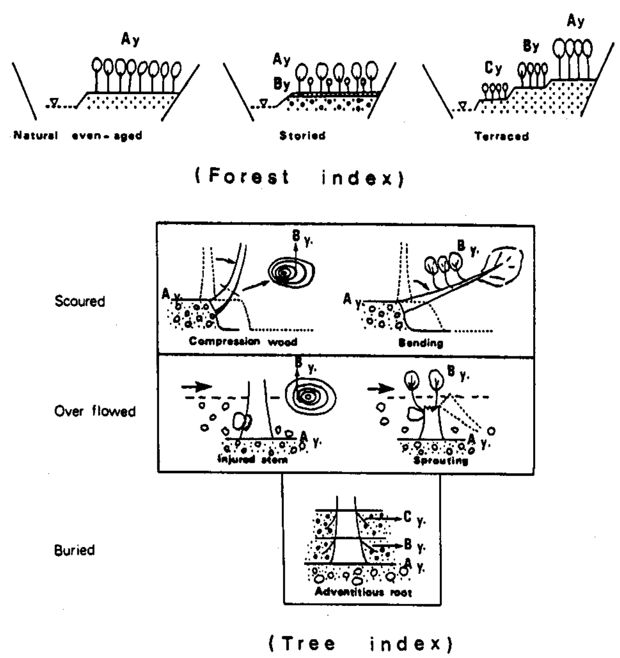


**Fig. 1.** Forest and tree index on sediment movement in riverbed.

control plannings as a time index, because it is measured on a hundred years' scale with a unit period of one year.

The plant indicator, especially trees, illustrates the changes of the earth's surface by the presence of deformed trees, abnormal roots and occurrence of natural invasion of trees (*2, 3, 4*) (Fig. 1). The deformation of trees is recognized in the slant and bending of stems, upward growth of branches, sprouting of branches, and the irregularity of tree crowns. Abnormal roots is recognized as the development of adventitious roots. A uniform forest formed by the invasion of trees can be observed as a natural even-aged forest with similar crown heights and stem diameters, consisting of pioneer trees such as *Salix, Betula, Alnus, Populus* and other species. A chronology of the earth surface movement is registered on the annual rings of the deformed trees and of even-aged forest trees. It is, therefore, possible to assert the chronology of these changes by examining the annual rings of the affected trees (as typical plant indicator and forest index) which indicate the occurrence of sediment movement in riverbed.

**2. Method of analysis**

For slopes, minor topographical changes, caused by debris movement, are recognized as traces of deposition on collapsed bare land, landslide area and talus cone. For riverbeds, they are recognized as traces of deposition due to debris and sediment flow occurrence in riverbed and alluvial fan. The survey of chronology of movement for hillside slopes provide information about minor topographical changes such as cracks and warped accumulative terrains caused by creeping and landsliding. For riverbeds, it pertains to information such as river course changes and terraced and deformed deposits formed in riverbeds.

The chronology of the past movement is obtained from the information about the past minor topographical changes in combination with informations about the time of movement occurrence (*1*). The scales of these minor topographical changes are determined by the range and area of the change, and the depth and volume of sediment in the changed areas. In this report, the width and cross sectional area of sediment movement in each movement age were estimated by examining the cross sections of the riverbed. The volumes of sediment in the surveyed plots by year were calculated from the plane and cross sectional area of each deposit.

In addition, representative values of sediment movement in the upper and lower streams of R. Saru basin were estimated from the state of sediment distribution in each movement age. These values were compared with those of other river basins.

Subsequently a movement model was formulated by assuming the extent of movement in each age from the distance between deposits and the peaks of sediment volume distribution in each age. Sedimentation data from Iwachishi Dam were utilized to estimate the range of the movement for the movement model.

**3. Surveyed basins**

In order to examine the characteristics of R. Saru basin, a comparison was made with the following basins: R. Nukkakushi-Furano basin (drainage area-8.7km$^2$, main stream length-8.1km, slope-1/8 to 1/10); R. Furano basin (22.6km$^2$, 20km, 1/10-1/40) and R. Usubetsu basin (64.8km$^2$, 14.8km, 1/12-1/25) (Fig. 2). R. Nukkakushi-Furano and R. Furano, the upper torrential streams of R. Sorachi (the left tributary of R. Ishikari), are running on the devastated hillside slopes of Mt. Tokachi, one of the most active volcanoes in Japan, whose surface ground is composed of volcanic detritus newly erupted in this century. R. Usubetsu whose geology is composed of Tertiary strata and lava, is the upper stream of R. Toyohira, the left tributary of R. Ishikari, flowing to the alluvial fan on which Sapporo city is developing.

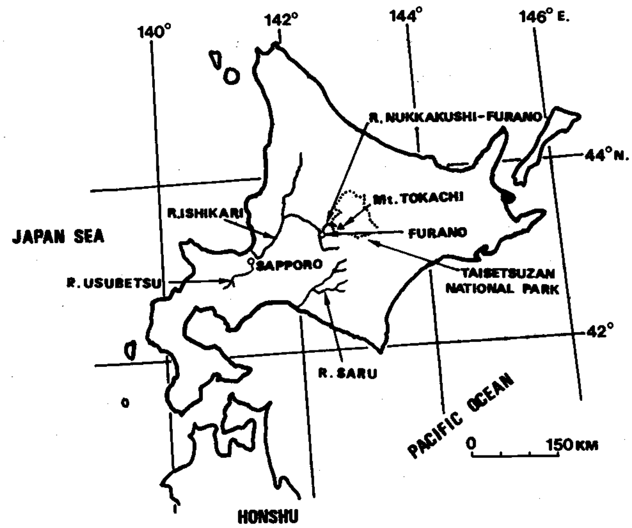


**Fig. 2.** Surveyed rivers for comparison of basin characteristics.

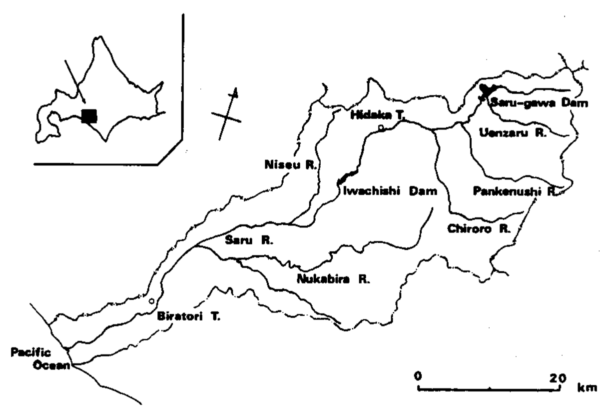


**Fig. 3.** R. Saru for major survey.

R. Saru (839km$^2$, 71km, 1/100-1/200) is composed of metamorphic and Paleozoic rocks in upper area, and Tertiary rocks in down area. In this report, the stream below the Iwachishi Dam is called the lower stream (296km$^2$, 29km, 1/100-1/200), and the stream above the Dam is called the upper stream ($597km^2$, 43km, 1/15–1/100) which has three main tributaries of R. Chiroro ($134km^2$, 24.5km, 1/18), R. Pankenushi ($118km^2$, 19.7km, 1/15) and R. Uenzaru ($70km^2$, 15.8km, 1/15). The surveyed section of R. Saru was above the Saru-Nukabira confluence. In particular, the following plots were under careful survey; 15.5km section between the Saru-Nukabira confluence and the Saru-Niseu confluence in the lower stream, and 17 plots above the Saru-Chiroro confluence in the upper stream (Fig. 3).

## III. Cross-sectional Topography of Riverbed and Chronology of Deposit in Upstream Areas of R. Saru

In the upper stream of R. Saru, the following plots were chosen for the deposit survey; six plots (No. 1–No. 6) between the Saru-Chiroro confluence and the Saru-Pankenushi confluence, one plot (No. 7) at the headwater of main stream, six plots (No. 8–No. 13) on the tributary R. Chiroro, two plots (No. 14, 15) on the tributary R. Pankenushi and two plots (No. 16, 17) on the tributary R. Uenzaru. The cross-sectional figures of the area above the Saru-Chiroro confluence are as follows and their typical examples are shown in Fig. 4.

### 1. Upper mainstream of R. Saru

No. 1: The mainstream at 100m above the Saru-Chiroro confluence exhibited the following: river width 100m, watercourse width about 14m, the cross-section of the riverbed being terraced with five steps of 0.4, 0.8, 1.2, 2.0, and 4.4 meters in height (mh). Three-years-old (referred to as 3y) trees of *Salix* spp. were growing on the 0.4 mh terrace surface, 8y and 22y trees of *Salix* on the 0.8 mh terrace surface, and 22y trees of *Salix* spp., *Populus maximowiczii* and *Acer mono* on the 1.2, 2.0 and 4.4mh terrace surfaces.

No. 2.: The upper stream of Chisaka No. 5 intake weir: river width 100m, watercourse width 33m. *Salix* trees (10y) were growing on the deposit along the watercourse and 22y trees of *Betula* and *Populus* on the distinct 2.2mh terrace surface.

No. 3: The Saru-Iokamappu confluence: river width 110m, watercourse width 10m. *Salix* and *Populus* trees (18y) were growing on the 1.5mh terrace, 22y *Salix* trees on the 3 mh terrace.

No. 4: The stream above the Saru-Iokamappu confluence: river width 70m, watercourse 10-20m. *Salix* trees (4y, 6y, 8y, 9y) were growing on the lower terrace and 22y *Salix* trees on the higher terrace. Upward growth of 3y branches was observed on the latter *Salix* trees.

No. 5: Lower stream of Chisaka No. 3 intake weir: river width 70m, watercourse width 6m. The deposit was terraced in three stages of 1.5, 2.0 and 3.5mh. *Salix* trees (8y) were growing on the 1.5 mh, 12y *Salix* trees on the 2.0mh and 22y *Populus* trees on the 3.5mh terrace. The development of 3y sprouting at broken stems was observed in the 8y *Salix* trees, and 7y injured stems and the development of 3y adventitious roots were recognized in the 12y *Populus* trees.

No. 6: The Saru-Pankenushi confluence: river width 80m, watercourse width 22m, with 5m-wide old watercourse observed on the left bank. There were deposits of two different heights, 1.2mh and 1.8mh. *Salix* trees (3y) were growing on the lower terrace, and 22y *salix* on the upper.

No. 7: The uppermost stream of R. Saru: river width 60m, watercourse width 13m. There were deposits of two different heights, 0.5 and 1.0mh. *Alnus* and *Salix* trees (22y) were growing on almost all parts of the deposits.

As described above, most of the ages of the deposits on the upper stream were 22y, and the rate of younger deposits was increasing on the lower stream of Chisaka No. 3 intake weir.

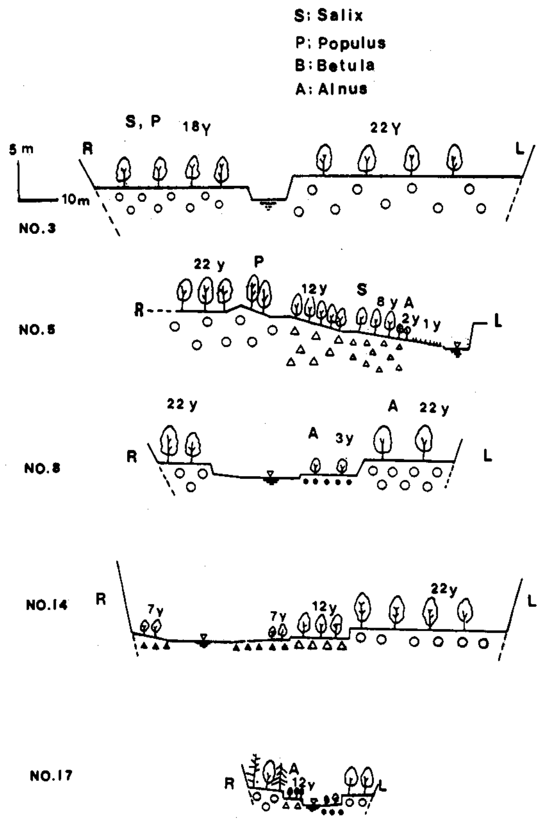


**Fig. 4.** Examples of cross sectional figures.

## 2. Tributary rivers

1) R. Chiroro

No. 8: 100m upstream of the Chiroro-Mainstream confluence: river width 70m, watercourse width 15m. There were 0.2, 1.5 and 2.2mh terrace deposits. *Alnus* trees of 22y were growing on almost all parts of the deposits with the exception of 3y *Alnus* trees on the 0.2mh terrace.

No. 9: The river width was 50m, watercourse width 10m. There were terrace deposits of three different heights, with 1y, 3y and 8y *Salix* and *Alnus* trees growing on each deposit, respectively.

No. 10: A narrow section of the river width 10m and watercourse width 3m, had only one terrace with 8y *Alnus* trees growing on it.

No. 11: This was also a narrow section with two terraces. A 3y deposit was observed indicating that the 8y deposit was scoured.

No. 12 : The river width was 30m, and watercourse width 10m. A new deposit was formed in the shape of bar. The 22y deposit was scoured and deformed, resulting in the development of 8y and 1y deposits.

No. 13 : The river width was 45m, a little wider than those of plot No. 10-12. Most parts of the 22y deposit were scoured, resulting in the development of 1y and 3y deposits.

2) R. Pankenushi

No. 14 : A deposit was formed by sedimentation in the check dam reservoir made by the forest conservation project : the river width was around 100m, with a watercourse width of 16m. Most parts of the deposit were of 2.2mh height, being occupied by 22y *Populus, Salix* and *Betula* trees. This deposit was scoured, resulting in the formation of a 12y (*Populus* trees) deposit of 1.0mh and a 7y deposit of 0.5mh.

No. 15 : 16km upstream of the Pankenushi-Mainstream confluence. The river width was 90m. The deposit was of 2.0mh height, occupied by 22y *Salix* and *Alnus* trees.

3) R. Uenzaru

No. 16 : The narrow river course was 13m wide, with a watercourse of 6m wide. There was not much deposited sediment. The deposit was of 0.5 height,occupied by 12y (*Alnus*). Damaged stems (8y, 5y and 3y) formed by the passage of sediment were observed on the trees as flood marks.

No. 17 : No. 4 valley of R. Uenzaru : the river width was assumed to be 26m, but it could not be identified clearly. On the whole, there was only a small amount of deposited sediment with a growth of 12y and 3y *Alnus* trees, along the present watercourse (5m wide). There has not been much sediment movement in total and each age.

## IV. Distribution of Age and Sediment Volume of Deposit

### 1. Age of deposit

For the 16km section on the lower stream of R. Saru, the width of the river course and the relative height of each survey section (every 300m) in each deposit period, and the range, width, depth, area, volume and chronology of each deposit were measured.

The deposit distributions by age on the upper and lower streams are shown in Fig. 5. The results were obtained by examining the ages of the naturally invaded trees and abnormal annual rings on both streams. Figure 5 illustrates the following facts : for the whole R. Saru basin, the deposit age is classified into 3, 6, 9, 12, 18, 22 and 40y ; a large number of deposits occurred in 22y in the upper stream ; in the lower stream, a large number of deposits occurred in 3, 6, 9 and 12y, but in 22y it was relatively small.

These deposit ages were compared with the history of flood damages in R. Saru basin. The following ages corresponded with the years when flood damages occurred : 3y-1981 (Aug. 5), 9y-1975 (Aug. 24), 18y-1966 (Aug. 19) and 22y-1962 (Aug. 4). The 6y and 12y did not correspond with any flood damage years, but their presence can be considered reasonable from the sediment yield at Iwachishi Dam and discharge-rainfall data obtained at the gauging station of the lower stream (Table 1).

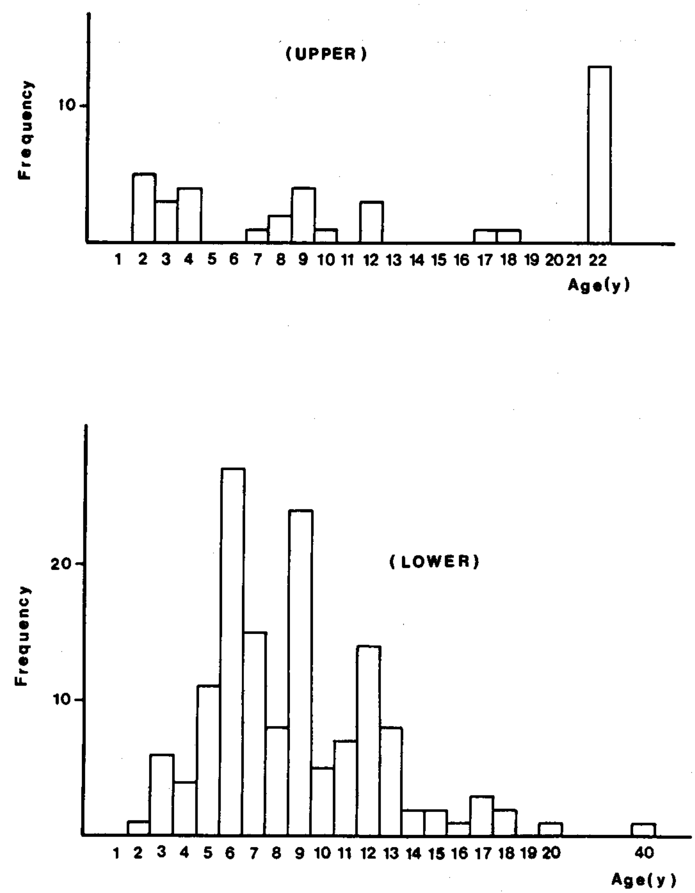


**Fig. 5.** Deposit distribution by age.

## 2. Sediment volume of deposit

The scale of sediment movement in each age cannot be described only by the numbers of deposits in each age, the volume of deposited sediment in each age should also be taken into consideration. The configuration and sediment volume of deposits are summarized in Table 2, from the data obtained by the deposit survey of the lower stream. Table 2 shows that the largest deposit volume, about 480,000m$^3$, occurred at 40y and the second largest, about 400,000m$^3$ in 1y. A 1y sediment is capable of participating in movements all the time in the average year, so it has no stable period. Though there were comparatively many 3y and 6y deposits, their volume was not large, about 160,000m$^3$ and 100,000m$^3$, respectively. The deposit volumes of 9y and 12y were large, about 240,000m$^3$ and 260,000m$^3$, and that of 22y was 170,000m$^3$.

In the distribution of deposited sediment volume at each age, there is a tendency for the deposit volume to be large in the 0-2km, 3-4km and 6-8km sections. The actual distribution differs with each age: 1y sediment is largely deposited in the 0-1km and 6-8km sections: 9y to the 6-8km section: 12y to the 6-8km, 10-12km and 13-15km sections:

**Table 1.** Hydrological data at the gauging stations

| | Biratori | | | | Iwachishi—Dam | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Date | flood-water-level (m) | annual flood ($m^3$/sec) | total daily mean flow ($m^3$/sec·day) | rain fall (mm) | total daily mean flow ($m^3$/sec·day) | annual flood (date) ($m^3$/sec) | annual-precipitation (mm) | daily-maximum-rainfall (date) (mm) | annual-sediment-yield ($x10^3m^3$) |
| 1958. 8.20 | 25.67 | 580.4 | 17,319.90 | | | | | | |
| 59. 6. 2 | 25.65 | 650.7 | 17,054.97 | | 7,730.70 | ( 6. 2) 151.5 | 1,419.0 | ( 6. 1) 70.3 | |
| 60. 6.30 | 25.18 | 345.9 | 10,699.10 | | 7,005.24 | ( 6.29) 119.3 | 1,265.9 | ( 6.27) 68.6 | |
| 61. 7.26 | 27.60 | 1,487.6 | 19,756.30 | | 9,092.15 | ( 7.26) 599.3 | 1,690.4 | ( 7.25) 133.9 | 59 |
| 62. 8. 4 | 28.57 | 3,466.0 | 24,052.50 | 135.0 | 10,595.95 | ( 8. 4) 1252.5 | 1,877.7 | ( 8. 3) 192.8 | 2000 |
| 63. 5.15 | | | | | 8,541.00 | ( 5.15) 281.5 | 1,540.7 | ( 8.15) 79.1 | |
| 64. 8. 9 | 25.11 | 564.0 | | | 7,316.34 | ( 4.26) 242.5 | 1,453.6 | ( 9.13) 100.5 | |
| 65. 9.18 | 25.55 | 722.3 | 26,138.70 | | 8,249.00 | ( 9.18) 159.5 | 1,463.7 | ( 9.16) 61.9 | |
| 66. 8.19 | 25.75 | 1,688.0 | 34,694.86 | 134.0 | 10,179.85 | ( 8.18) 488.5 | 1,731.3 | ( 7.20) 118.3 | 637 |
| 67. 4.20 | 24.32 | 593.4 | 15,002.31 | | 6,679.50 | ( 5. 1) 206.5 | 1,333.1 | ( 9.15) 46.0 | 49 |
| 68.10. 1 | 24.05 | 393.0 | 15,894.31 | | 7,612.80 | ( 5.14) 218.5 | 1,156.0 | ( 9.30) 77.0 | 51 |
| 69. 6.30 | 23.77 | 421.4 | 29,408.42 | | 8,223.45 | ( 9. 1) 139.5 | 1,415.5 | ( 6.29) 81.0 | 47 |
| 70.10.26 | 24.82 | 1,249.5 | 21,001.42 | | 9,847.70 | (10.26) 594.5 | 1,451.5 | (10.25) 97.0 | 52 |
| 71. 7.29 | 24.31 | 857.0 | 18,660.53 | | 9,563.00 | ( 7.29) 394.3 | 1,329.5 | ( 9. 4) 81.0 | 73 |
| 72. 9.18 | 23.27 | 313.0 | 21,793.81 | | 10,295.58 | ( 9.11) 193.5 | 1,440.0 | ( 7. 4) 58.0 | 46 |
| 73. 8.23 | 24.31 | 1,851.0 | 25,751.64 | 127.0 | 10,909.85 | ( 8.23) 612.6 | 1,784.4 | ( 8.17) 103.0 | 17 |
| 74. 8.27 | 24.44 | 1,697.1 | 23,651.08 | | 10,446.30 | ( 8.27) 549.4 | 1,667.2 | ( 8. 6) 90.0 | 19 |
| 75. 8.24 | 25.13 | 2,250.9 | 24,599.88 | { 145.0 129.4 | 10,628.80 | ( 8.24) 643.3 | 1,525.2 | ( 8.20) 133.0 | 51 |
| 76.10.21 | | 610.9 | 15,852.34 | | 6,972.30 | (11. 4) 270.0 | 1,415.0 | (10.20) 87.0 | 76 |
| 77. 5.16 | | 555.6 | | | 7,168.60 | ( 4.18) 134.9 | 1,240.4 | ( 9. 3) 72.5 | 69 |
| 78. 4.21 | | 726.4 | 13,977.59 | | 6,807.25 | ( 5. 1) 354.5 | 1,090.4 | ( 8.10) 61.0 | 129 |
| 79. 4. 9 | | 699.0 | 18,733.03 | | 9,103.10 | ( 8.27) 284.3 | 1,423.5 | ( 8.27) 115.0 | 47 |
| 80. 4. 7 | | 557.0 | 15,887.93 | | 7,762.86 | ( 4. 6) 250.4 | 1,171.0 | ( 5.26) 81.5 | 145 |
| 81. 8. 5 | 24.25 | 1,159.0 | 22,417.99 | | 10,052.10 | ( 8. 5) 576.1 | 1,756.0 | ( 8.22) 91.0 | 72 |
| 82.11.30 | | 493.3 | 17,333.09 | | 7,927.80 | (11.30) 198.8 | 1,014.5 | ( 9.12) 49.5 | 249 |
| 83. | | | | | 5,843.65 | ( 4.16) 154.0 | 867.5 | ( 8.22) 37.5 | |

18y to the 0-3km section: 22y to the 0-2km and 9-11km sections: 40y to the 1-2km and 3-4km sections. As can be seen, the sediment volume of each age is unevenly distributed being concentrated in particular sections.

The upper stream, on the other hand, was not examined as closely as the lower stream. Therefore, cross sectional area of the flow was estimated by the flow width and the relative height in the 4.35km section upstream of the Iwachishi Dam (from the Saru-Chiroro confluence to the Saru-Pankenushi confluence). By multiplying the cross sectional areas by the length of deposits, the deposited sediment volume was calculated. According to the result, 22y sediment occupied the 82% of the total, but 12y and 9y had similar volumes of

**Table 2.** Configuration and volume of deposits in the lower stream of R. Saru

| Age | Number of deposits | Average distance (m) | Average river width (m) | Average length (m) | Average depth (m) | Volume of deposits ($x10^3m^3$) | (%) |
|---|---|---|---|---|---|---|---|
| 1 | 77 | 200 | 84.3 | 257.6 | 1.7 | 415.4 | (22) |
| 3 | 32 | 480 | 101.2 | 210.4 | 2.1 | 164.1 | ( 9) |
| 6 | 29 | 580 | 101.4 | 152.2 | 2.3 | 104.4 | ( 5) |
| 9 | 34 | 450 | 119.5 | 165.0 | 2.8 | 239.5 | (12) |
| 12 | 20 | 770 | 135.9 | 282.3 | 3.0 | 255.1 | (13) |
| 18 | 12 | 1,280 | 150.6 | 133.7 | 3.2 | 78.4 | ( 4) |
| 22 | 15 | 1,020 | 170.2 | 214.0 | 4.2 | 166.3 | ( 9) |
| 40 | 9 | 1,710 | 178.7 | 262.2 | 5.6 | 481.8 | (25) |
| | | | | | Total | 1,905.0 | (100) |

5-6%. The volume of 18y, 6y and 3y was very small, less than 3% of the total. While this shows a similar tendency in the lower stream, upper stream has the following differing characteristics: 40y sediment was not observed, and a large amount of 22y and very little 1y sediment were observed.

## V. Indication of Basin Characteristics

### 1. Cross sectional area

The probability of movement of unstable sediment in riverbeds can be calculated by estimating the potential movement volume from the past chronology of debris movement in river basins. As illustrated in Fig. 6, this method is to assume cross sectional area of

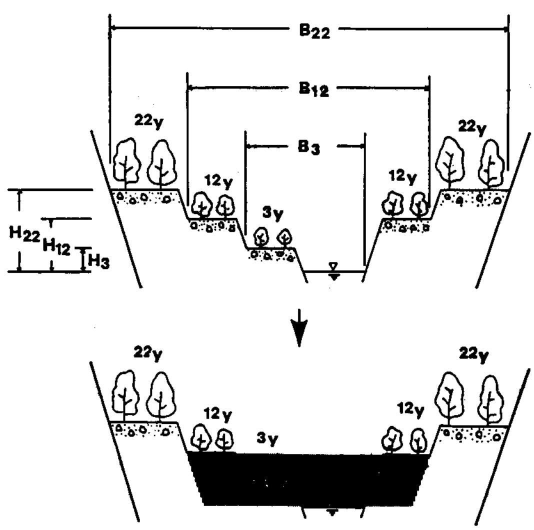


**Fig. 6.** A model of cross sectional area in sediment movement.

the flow from the flow width and the depth of scour (or flow) of the cross-section of each deposit.

In this figure, flow width $B_{12}$ equals 12y deposit width added to 3y deposit width and the width of the present river course, and flow depth $H_{12}$ was assumed to be the relative height, from the surface of the present riverbed to the 12y deposit surface.

The cross sectional areas of R. Saru and the three tributary rivers, Chiroro, Pankenushi and Uenzaru, are indicated in Fig. 7. In short, the cross sectional area is small

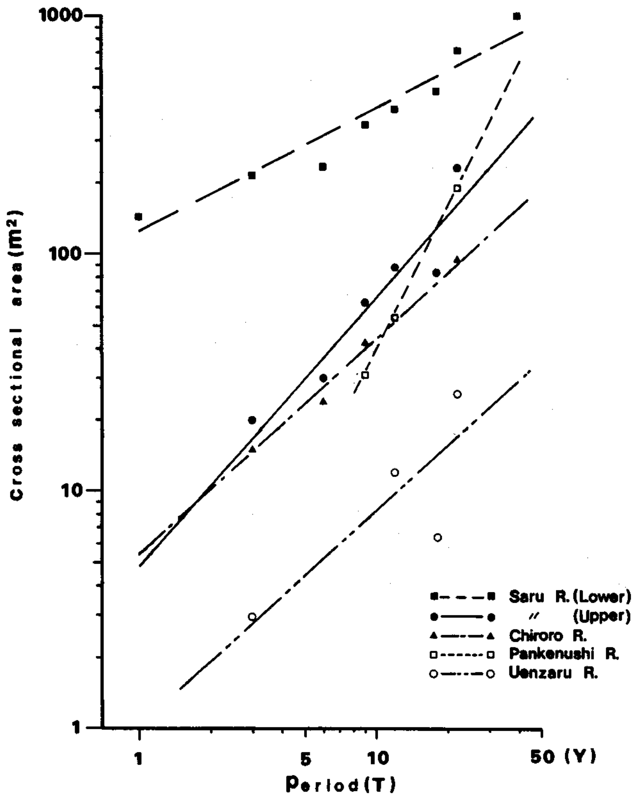


Fig. 7. Comparison of cross sectional areas in R. Saru.

in R. Uenzaru, with R. Pankenushi, R. Chiroro and the upper stream of R. Saru having about the same value, and the lower stream of R. Saru the largest. The above result confirms the chronological distribution of the potential movement volume of sediment estimated by deposited area which showed that the upper stream of R. Saru had a higher value than R. Chiroro.

By comparing the lower stream of R. Saru with these upper stream basins, it was found that the cross sectional area of the lower stream basin was relatively high. But the slopes of the regression lines for upper stream basins were steeper than the slopes of the lower stream basin, which means that the ratio of the cross sections of the less frequent large-scale movement and that of more frequent small-scale movement is large in upper stream basins.

**2. Potential sediment movement volume (Vp)**

Deposited sediment volumes of each age in lower stream basins were estimated from the results of the field survey (*3, 8*).

From the deposited sediment volume at each age (Vdi), the potential sediment movement volume at each age ($\Sigma$Vdi) was calculated. Vp is the potential sediment movement volume at each age, shown by sediment volume per unit area ($km^2$). It is expressed by the following equation (1);

$$Vp = aT^b \quad \cdots\cdots(1)$$

The potential value calculated by the regression equation obtained from chronological distribution of potential sediment movement volume, is specific to the debris movement in each river basin because the coefficients a and b are so specified as 2,100 and 0.47 for the lower stream;

$$Vp = 2{,}100T^{0.47} \quad \cdots\cdots(2)$$

As the deposited sediment volume at each age was not examined as closely for upper stream basins as for lower stream basins, the sediment volume data in the 4.35km survey section was applied to the upper mainstream by multiplying by the ratio of cross sectional area.

For each tributary river, the sediment volume was estimated by applying an average cross sectional area and ratio of flow width in the calculation. Potential sediment

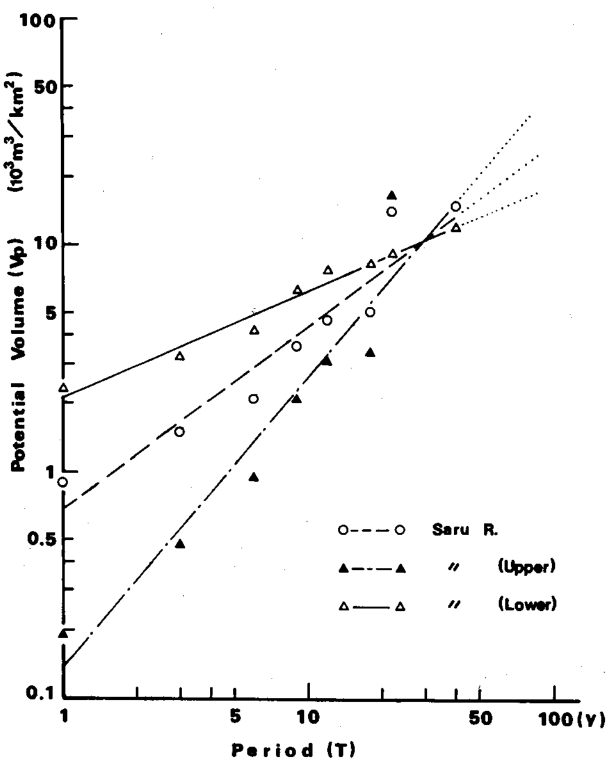


Fig. 8. Potential sediment movement volume in R. Saru.

movement volume (Vp) was found for each tributary river. Vp in upper Saru basin was estimated by the following equation;

$$Vp = 140T^{1.28} \quad \cdots\cdots (3)$$

Vp in the whole R. Saru basin was estimated as follows:

$$Vp = 680\, T^{0.81} \quad \cdots\cdots (4)$$

Potential sediment movement volume in each river basin is shown in Fig. 8. In this figure, the lower stream has a higher potential than the upper stream.

$Vp_{1y}$ (=ap) with T=1, means potential sediment volume which corresponds to annual sediment yield, from the viewpoint of sediment run-off. In the same manner, $Vp_{100y}$ with T=100, corresponds to design sediment discharge.

Therefore, the ap value is calculated to be 2,100m³ in the lower stream and 140m³ in the upper stream. The bp value (slope of the regression line) is larger (steeper) for the upper stream than for the lower stream, which means that the scale of movements with high frequency and those with low frequency do not differ so largely in the lower stream. It also means that in the upper stream, the scale of movements with high frequency is small, and the scale of movements with low frequency being as large as in the lower stream.

The potential sediment movement volume ($Vp_{100y}$) of 15,000m³/km² is also confirmed

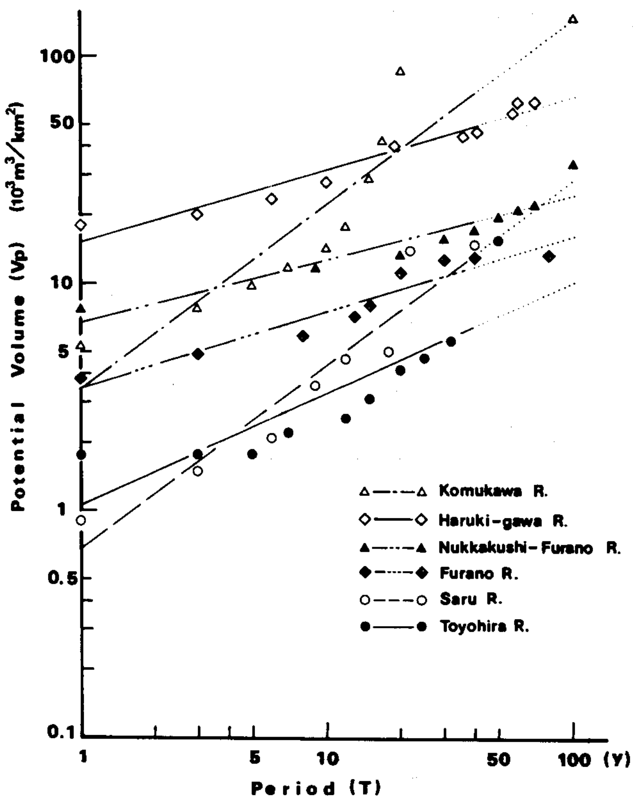


Fig. 9. Potential sediment movement volume of each river in period.

by the result that the volume of unstable sediment in hillside slopes and riverbeds was found, by Hokkaido Forestry Bureau, to be approximately 25,000m$^3$/km$^2$, and the volume of unstable sediment in riverbeds about 14,000m$^3$/km$^2$.

### 3. Comparison of basins

The whole R. Saru basin is naturally ranked between the upper stream and the lower stream as shown in Fig. 8. Geologically old rocks such as metamorphic and Paleozoic rocks occupy higher percentages in the geology of the upper stream basin than in the lower stream. This is assumed to be attributed to the difference in landslide distribution, looseness of soils and nature of rocks, which cause the sediment production volume from mountain hillside slope to riverbed in the lower stream basin to be larger than that in the upper stream basin. The difference of potential sediment movement volume among river basins is the result of the difference in the nature of the soil, as demonstrated in the difference between the upper stream basin and the lower stream basin described above.

Following is a comparison of R. Furano and R. Nukkakushi-Furano which are running on the active volcano of Tokachi and R. Usubetsu basin on the upper stream of R. Toyohira (Tertiary and lava).

The ap values of R. Furano and R. Nukkakushi-Furano (volcanic) are 3.8 and 7.7, respectively. The ap of R. Toyohira (Tertiary and lava) is 1.8 and that of R. Saru (Paleozoic-Tertiary) is 0.9, the lowest. The bp is around 0.3 in volcanic rivers, 0.5 for R. Toyohira, and 0.6 for R. Saru, the steepest.

The ap values of R. Komu and R. Haruki, representatives of desolated rivers in the mainland of Honshu, are 5.1 and 18.1, while the bp values are 0.7 and 0.3, respectively. These two rivers have larger potential sediment movement volumes than the rivers in Hokkaido, because they are greatly influenced by past large mass movements in the river basins such as fault valley (R. Haruki) and large-scale collapse (R. Komu). However, by comparing the three rivers in Hokkaido which did not undergo geologically big changes such as the above it was found that volcanic river basins have the largest sediment volume, followed by Tertiary-Paleozoic sedimentary rock basins (the lower stream of R. Saru), Tertiary and lava basins (R. Toyohira), and Paleozoic-metamorphic rock basins (upper stream of R. Saru). As a result, it can be assumed that the basin characteristic values are

**Table 3.** Characteristics of river basins

| River basin | Geology | Area (km$^2$) | $VP_{1y}$(ap) ($10^3$m$^3$/km$^2$) | $VP_{100y}$ ($10^3$m$^3$/km$^2$) | $VP_{100y}/VP_{1y}$ | bp |
|---|---|---|---|---|---|---|
| Haruki | Cretaceous-Tertiary (fractured) | 20.8 | 18.1 | 63.3 | 3.5 | 0.27 |
| Komu | Granite | 44.6 | 5.3 | 149.9 | 28.1 | 0.72 |
| Nukkakushi furano | Volcanic | 8.7 | 7.7 | 33.6 | 4.4 | 0.32 |
| Furano | Volcanic | 22.6 | 3.8 | 13.4 | 3.5 | 0.27 |
| Toyohira | Tertiary-lava | 64.8 | 1.8 | 15.7 | 8.8 | 0.47 |
| Saru | Paleozoic-Tertiary | 839 | 0.68 | 15.0 | 16.7 | 0.81 |
| Upper Saru | Paleozoic-Metamorphic | 543 | 0.19 | 16.8 | 88.4 | 1.28 |
| Lower Saru | Tertiary | 296 | 2.3 | 11.7 | 5.0 | 0.35 |

influenced primarily by the soil structure in the river basin, particularly by the weakness of the parent rock.

Each basin's characteristic value is shown in Table 3 (*3*). Chronological distribution of Vp in each river basin is illustrated in Fig. 9.

## VI. Examination of Sediment Movement Volume

### 1. Distance between deposits

The length of deposits (L) and the distance between deposits (D) at each age in the lower stream was found.

The L values of new deposits (1, 3, 6y) were larger, 250-270m, than the older deposits (9, 12, 18y), 130-170m. While the data of distance were highly scattered, the D values of new deposits (1, 3, 6, 9y) were smaller, 500-1200m, than the older (12, 18, 22, 40y), 1500-2600m.

From the above mentioned trend, it is assumed that a deposit will become smaller mainly by scouring, resulting in the enlargement of the distance between deposits.

For younger deposits, in particular 1y, 3y and 9y deposits, whose distance between deposits does not vary widely, the length of deposits was 1.4-3.1 times larger than the flow width at each age, and the distance between deposits was 6.0-8.0 times greater than the flow width at each age (Table 4).

**Table 4.** Length of deposit and distance between deposits of each age

| Age | Average length L(m) | Average river width B(m) | Average distance between deposits D(m) | L/B | D/B |
|---|---|---|---|---|---|
| 1 | 260 | 84 | 500 | 3.1 | 6.0 |
| 3 | 210 | 101 | 800 | 2.1 | 8.0 |
| 6 | 150 | 101 | 1,200 | 1.5 | 12.0 |
| 9 | 170 | 120 | 900 | 1.4 | 7.5 |
| 12 | 280 | 136 | 1,700 | 2.1 | 12.5 |
| 18 | 130 | 151 | 2,600 | 0.9 | 17.2 |
| 22 | 210 | 170 | 1,500 | 1.2 | 8.8 |
| 40 | 260 | 180 | 2,400 | 1.5 | 13.3 |

### 2. Distribution of deposited sediment volume

The deposition is the characteristic of sediment movement and the sediment movement is longitudinal repetition of scour and deposit. It has been assumed that there is a wave in the deposition of sediment due to the "mutuality of sediment movement" as alternation of deposition and scouring in the same area (*1, 7*). From the riverbed movement survey results on R. Furano at the foot of Mt. Tokachi, the sediment movement was recorded in a cyclic pattern (Fig. 10.) From the figure, the following were recognized as the sections indicating the occurrence of deposits: 300-400m and 1,800-2,000m for the movement in 1980; and 200-300m, around 400m and 1,200-1,400m for the movement in 1981. (*5*).

It was confirmed from the riverbed movement survey of R. Nukkakushi-Furano (at the

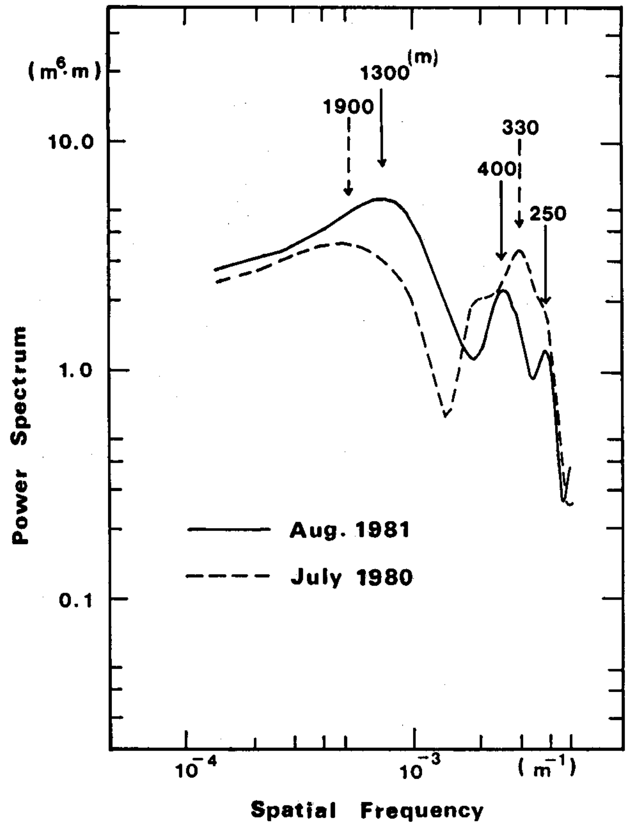


**Fig.10.** Wave length in sediment movement (R. Furano).

foot of Mt. Tokachi) that the deposited sections could change into scoured sections and vice versa. This phenomenon has been called "chronological mutuality of sediment movement" (*5, 6*).

From the distribution of deposited sediment at each age, the following distances between the peaks were estimated: 3y: 800m, 6y, 9y: 1,000m, 12y: 1,200m and 22y: 2, 000m.

Fig. 11 illustrates the result of spectrum analysis which regarded the distribution of sediment volume at each age in cyclic patterns, and some patterns, which were indicated by the following peaks, were recognized: 3y-850m, 9y-clear peak at 1,000m and indistinct peak between 300-400m, 12y-1,200m and approximately 500m, and 22y-a small indistinct peak at 2,000m. In particular, for 3, 9 and 22y, which involve a large volume of deposited sediment with comparatively distinct distances between deposits and between maximum points of sediment volume, both distances were very similar.

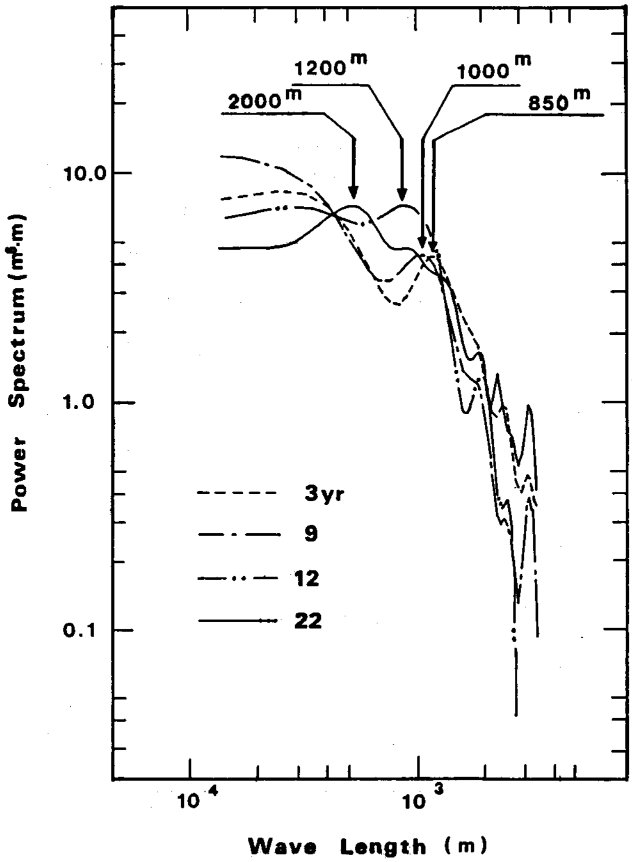


Fig.11. Wave length in distribution of sediment volume (R. Saru).

### 3. Alternative sediment movement model

Up to now, sediment movement volume has been considered as the total sediment movement volume or maximum sediment volume during the period of a flood. The volume is estimated by calculating bed load from hydraulic conditions existing during the movement. However, it is very difficult to know the exact volume because the actual sediment movement in river basins is random. It is also difficult even to estimate the probability of sediment movement volume at the present time because the required continuous survey data on sedimentation in dams or of riverbed movements have not been gathered.

This also holds true for the sedimentation data in Iwachishi Dam on the upper stream of R. Saru; no clear relation can be recognized between the sedimentation volume in the dam and hydrologic data. For example, annual sedimentation volume, annual run-off and annual maximum run-off vary considerably (Table 1). This illustrates the difficulty in examining the sediment movement volume through hydraulic and hydrological data. This is due to that the type, frequency and scale of sediment movement vary with the place and time of the occurrence of movement ; i.e., sediment movement is discontinuous in regard to space and time.

An alternative movement model was proposed and examined after finding that deposition occurred in alternative patterns in regard to longitudinal distance and time as described previously (*1, 5, 7*). In this model, the interval between the maximum points of deposited sediment volume is assumed to be approximately equal to the length of sediment movement. Multiplying this interval by the assumed flow cross sectional area, sediment movement volume (Vm) can be found. On the other hand, when sediment movement volume is known, the length of sediment movement can be found by dividing sediment movement volume (Vmi) (i.e., sedimentation in dam) by flow cross sectional area at each age (Fig. 12).

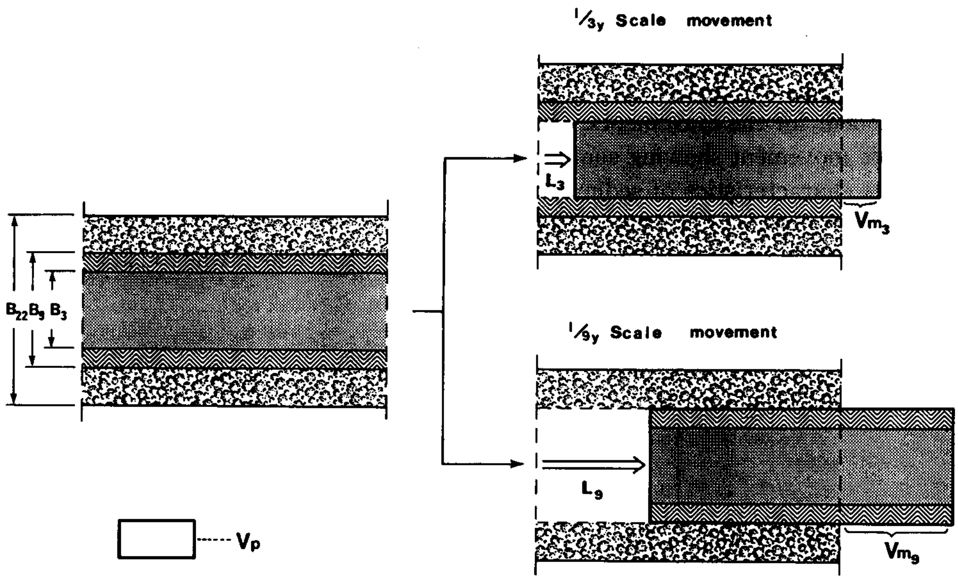


**Fig.12.** A model of sediment movement (Vp : potential sediment movement volume, L : movement length, Vm : sediment movement volume).

The sedimentation data in Iwachishi Dam consists of annual sedimentation volume. By assuming the annual sedimentation volume to be sediment movement volume at only one movement in the year and by dividing it by flow cross sectional area, the length of sediment movement in the three cases (when relatively large sedimentation occurred in the dam) was found to be as follows : 22y-2.8km, 18y-1.3km, 6y-0.6km. For 22y and 6y, the length of sediment movement was similar to the interval between the maximum points of deposited sediment volume (Table 5).

On the other hand, if the probability in each return period was found from the dam sedimentation data, then the length of movement corresponding to this value of probability can be found as follows : 22y-2.4km and 6y-1.2km, which were similar to the above values within a certain range. When the mutual distance of deposition and flow cross sectional area were found, the planned sedimentation volume at dam and planned length of sediment

**Table 5.** Sediment movement distance estimated

| Age | Year | Cross sectional-area of movement ($m^2$) | Distance between deposits (m) | Distance between sediment volume peaks (m) | Annual sediment yield in the Dam ($10^3m^3$) | Movement distance estimated from the Dam sedimentation (m) |
|---|---|---|---|---|---|---|
| 3 | 1981 | 212.0 | 800 | 800 | 72 | 300 |
| 6 | 1978 | 233.0 | 1,200 | 1,000 | 129 | 600 |
| 9 | 1975 | 335.0 | 900 | 1,000, 350 | 51 | 200 |
| 12 | 1972 | 408.0 | 1,700 | 1,200, 500 | 46 | 100 |
| 18 | 1966 | 482.0 | 2,600 | | 637 | 1,300 |
| 22 | 1962 | 715.0 | 1,500 | 2,000 | 2,000 | 2,800 |

movement could be assumed by probability.

As described above, this model is applicable to 22y, 6y and 3y, but not to 9y and 12y. It is estimated that the shorter wave length (e.g. 9y : 300-400m, 12y : around 500m) was the most excellent for the movements. In summary, the length of movement is regulated by small-scale movement showing some short wave length, so it is necessary to examine the qualitative characteristics of sedimentation in dam.

**4. Sediment movement volume and scour ratio**

Sediment movement volume at each occurrence of movement was found by estimating

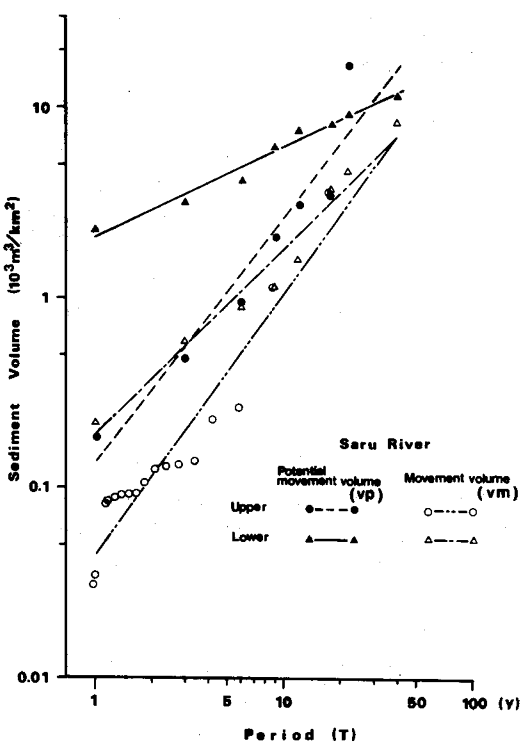


Fig.13. Relation between Vp and Vm in R. Saru.

the (unit) length of sediment movement at an occurrence of movement with the model above mentioned. Then the sediment movement volume in each return period can be found (Fig. 13).

As shown in this figure, there is a considerable difference between sediment movement volume (Vm) and potential sediment movement volume (Vp) in the lower stream basin. The difference is not as great in the upper stream basin.

$Vm_{1y}$, which corresponds to an average annual sediment yield, was estimated to be $200m^3/km^2$ in the lower stream of R. Saru and $50m^3/km^2$ in the upper stream basin. The data in other river basins, similarly estimated were as follows: upper stream of R. Toyohira-$100m^3/km^2$, torrential river of Mt. Tokachi-$800m^3/km^2$. From this data, it was shown that the upper stream of R. Saru (metamorphic and Paleozoic) had the least movement volume, R. Toyohira (lava and Tertiary) had a greater volume, followed by the lower stream of R. Saru (Tertiary-Paleozoic), and volcanic river basins which had the largest. This trend corresponds with the geologic features affecting Vp described previously.

The ratio (E) of Vm and Vp indicates the scour ratio to potential sediment movement volume at each age. Table 6 illustrates the sediment volume and the scour ratio at each age. The upper stream shows a high scour ratio and the lower stream a low rate, being less than 50% with the scale of movement less than 1/20.

**Table 6.** Potential sediment movement volume and sediment movement volume in the lower and uppem streams

| Return period (Y) | Potential movement volume (Vp) ($10^3m^3$) | | Sediment movement volume (Vm) ($10^3m^3$) | | Ratio of erosion Vm/Vp (E) | |
|---|---|---|---|---|---|---|
| | Lower | Upper | Lower | Upper | Lower | Upper |
| 1 | 415 | 43 | 67 | 24 | 0.16 | 0.56 |
| 3 | 580 | 137 | 180 | 109 | 0.31 | 0.79 |
| 6 | 684 | 304 | 278 | 284 | 0.41 | 0.93 |
| 9 | 923 | 622 | 335 | 495 | 0.36 | 0.79 |
| 12 | 1,179 | 957 | 489 | 736 | 0.41 | 0.77 |
| 18 | 1,257 | 1,047 | 1,234 | 1,287 | 0.98 | 1.23 |
| 22 | 1,423 | 5,835 | 1,430 | 1,696 | 1.00 | 0.29 |
| 40 | 1,905 | — | 2,355 | — | 1.23 | — |

The regression equations of the ratio (E) were obtained as follows: $E=0.09T^{0.5}$ in the lower stream basin and $E=0.31T^{0.1}$ in the lower stream basin. Therefore $E_{1y}=9\%$, $E_{10y}\fallingdotseq 30\%$, $E_{40-50y}=60\%$ and $E_{100y}=90\%$ in the lower stream basin of R. Saru, while $E_{1y}=30\%$, $E_{10y}=40\%$, $E_{40-50y}=45\%$, $E_{100y}=50\%$ in the upper stream basin.

This means that the rate of erosion increases to the increase of probability and that it is not until the movement with over 1/50 corresponding scale occurs that half of potential sediment volume moves in the lower stream basin. It also means that half of potential sediment volume moves at the same rate corresponding to movement of any scales in the upper stream basin.

For R. Nukkakushi-Furano, $E=0.07T^{0.8}$, $E_{1y}=7\%$, $E_{10y}=50\%$ and $E_{30y}=100\%$, which means that half of potential sediment volume runs off by a movement with 1/10 corresponding scale in volcanic river basins (Table 7).

**Table 7.** The a and b values of Vp, Vm and E.

| | R.Saru | | R. Nukkakushi |
|---|---|---|---|
| | Lower | Upper | -furano |
| Vp($m^3$) | 2100 $T^{0.47}$ | 140 $T^{1.28}$ | 7700 $T^{0.3}$ |
| Vm($m^3$) | 190 $T^{0.97}$ | 44 $T^{1.38}$ | 530 $T^{1.5}$ |
| E | 0.09 $T^{0.5}$ | 0.31 $T^{0.1}$ | 0.07 $T^{0.8}$ |

## VII. Conclusion

From the results of the study of topographical and vegetational information on the past sediment movement in R. Saru, it became clear that the tree ring analysis is an efficient method for clarifying the chronology of the sediment movement.

Basin characteristics' index, which are proposed for comparing rivers on sediment movement, are considered to be useful. The differences in river basin characteristics are thought to be due to geological and geographical differences, especially, to the differences in sediment supply, coarseness of sediment materials, basin area and slope, related to the transport capacity, and detention capacity of riverbed sediment.

It is suggested that the sediment movement model, which is proposed from the trend of sediment distribution, provides the possibility for estimating the sediment movement volume (Vm) and scour rate (E). This suggestion, however, may need further examination.

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## 要　　約

流域内の土砂移動痕跡の収集による土砂移動履歴の復元とその評価手法について検討した。

沙流川河床堆積地の微地形指標（段丘），植生指標（樹木・群落）をもとに，土砂移動年代を推定した。推定移動年代は水害・水文観測記録（流量・降雨量・ダム堆砂量）とほぼ合致したが，対応しないものも認められた。

各年代堆積土砂量分布から，移動可能土砂量 $Vp_i$（$m^3/km^2$）を推定すると，$Vp=aT^b$ (a, b：流域ごとの定数，T：時間（年））に回帰することから，この a，b を土砂移動に関する流域特性値として意義づけた。とくに平年流出土砂量に対応する a 値は，沙流川（古生層・変成岩）が他河川流域（火山・三紀層）にくらべ小さな値（$10^2$オーダー）を示し，土砂流出実態とも適合していたことから，本評価手法の妥当性がうかがわれる。

さらに，土砂移動形態を堆積・洗掘の交互モデルと想定し，堆積土砂量縦断分布の波長を本モデルの移動距離と仮定して，移動土砂量の推定を試みた。この推定移動土砂量とダム堆砂量との適合さが一部に認められたが，この方法は今後の検討課題となった。