Chronological Study on the Torrential Channel Bed by the Age Distribution of Deposits*

By

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山地急流河川における河床堆積地の形態に関する 年代学的研究

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Abstract

The differences of sediment movements between placid and torrential stream channels are reflected in shapes and age distributions of sediment. The bars formed as islands in placid streams show the gently convex shapes cross sectionally and the ages of the vegetation on the bar change sequentially from down to upstream tip. On the contrary, the deposits formed in torrential streams show the stepped shapes and even-aged forests. Based on the field researches three kinds of wavy movements, which show alternate scouring and deposition, were found in torrential streams. These wavy movements cause the stepped shapes and each wave has different wave length.

The shapes of channel bed in torrents are classified into three types which are named fixed, divergent and stable channels. The actual field measurements show that fixed channels are formed in topographically narrow places and divergent channels develop in wide places where active movements of debris have occurred. The stable channels develop where the debris movements occur at chronologically long intervals. Consequently these configurations of torrential channel beds were found to be complex shapes which are formed by topographical and chronological characteristics.

Keywords: Sediment, torrent, age distribution, wavy movement

Contents

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Introduction

The debris movement in torrential stream is so dramatic that the shape of channel bed is suddenly changed. This characteristic reflects to the shape of channel bed and the configuration different from placid stream is formed. The purposes of this study, however, are:

1) To clarify the morphorogical characteristics of torrential channel bed
2) To analyze the wavy movements of debris in relation to the configuration of channel bed
3) To explain the process of the debris movement in each storage (retardation area of debris) characterized by the shape of channel bed.

Because the age distribution of vegetation which are established on the deposits shows the history of sediment movement, tree rings are used for dating.

I. Investigated watersheds and study methods

Investigated watersheds of Mt. Tokachi are shown in Fig. 1. Furano River and Nukkakushi-furano River rise in Mt. Tokachi (2077 m) and Mt. Furano (1912 m). In this district, the hourly and daily maximum precipitation registered so far are 39 mm and 211 mm, respectively and annual average ranges from 900 to 1,200 mm. The main stream length of Furano River is 40 km, watershed area is 292 km^2 and the mean slope is 1/200. Nukkakushi-furano River is 32 km, 74 km^2 and 1/180 respectively[2]. These two rivers are typical volcanic torrential rivers and the debris movements have occurred frequently.

Geomorphological and dendrochronological survey were carried out in this study. Details are as follows.

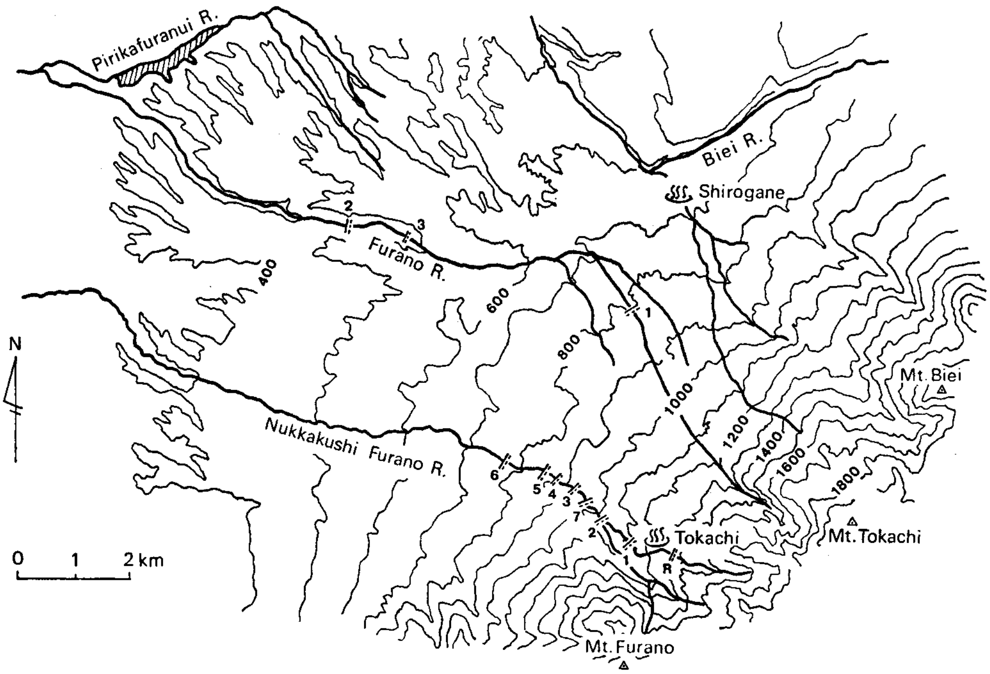

Fig. 1. Investigated watersheds.
図—1 調査流域

1) Geomorphological survey

After the close observation of channel bed, the longitudinal and cross sectional features were measured by field surveying at each river. As regards the deposits on the channel bed, the site, length, width, depth and volume were measured. These measurements were related to chronological data to know the morphological change of channel bed in time.

2) Dendrochronological survey

The tree rings, the scars remained mostly lower part of the stems, compression wood, adventitious roots etc. gave us the chronological information on the debris movements[6,7]. The age of vegetation on the deposits shows when deposition had occurred and the age distribution shows how deposits had been changed. Therefore the dendrochronological survey was carried out on each deposit.

II. The shape of deposit in torrent in comparison to placid river

1. The differences of shapes on profile and cross section

The deposits formed in placid and torrential streams have substantially different shapes. Furano River, where the researches were carried out, is the volcanic torrential river where debris movements have occurred frequently. Accordingly, deposits observed in this river are actually different from other placid rivers. The generalized shapes of sediment in both streams are described in Fig. 2. This figure

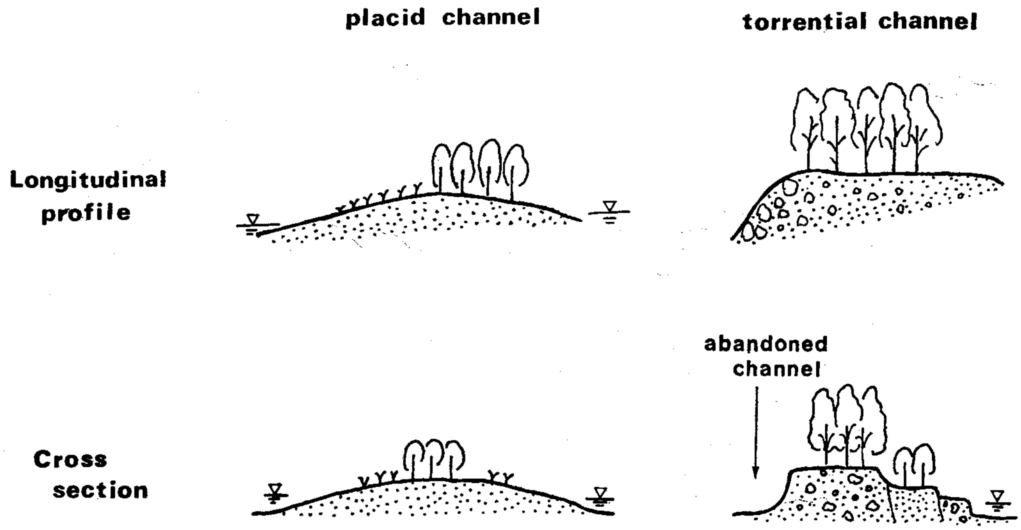

Fig. 2. Longitudinal profile and cross sectional shapes of channel bed at placid and torrential stream.

図—2 緩流河川，急流河川における堆積地の形態的特徴

shows the longitudinal profile and cross sectional shapes of deposits formed as island in the channel. The clear differences between placid and torrential streams appear in the cross sectional shapes. The cross sectional shapes of deposits in the placid rivers are gently convex as bars but the deposits observed in the torrents are carved as steps. Some deposits in the torrents have several steps which were formed by corresponding number of past debris movements.

The central bars in placid streams are sometimes sink in high water surface, that is at the time of flood or snow melting season, and emerge at low flow. On the other hand, the steps in the torential streams are covered with flood from low to high steps, and those deposits below the water surface are sometimes removed and sometimes covered with further deposition. Sudden change of channel bed caused by large deposition or scouring that force the channel to another direction are frequently observed in active torrents. The main differences of channel beds in both placid and torrential streams, such as convex shape or stepped shape and formation on the changes of stream direction, suggest the differences of water and sediment movement occurred in each river.

2. The age distribution of vegetation growing on the deposits

After a debris movement occours in the stream, a lot of bare lands are formed by deposition and scouring. Vegetation invades these bare lands in first year or next year and the vegetation grows up if the deposits are stable. Such vegetation growing on the deposits are observed both in placid and torrential river but the age distributions of vegetation are different. The age of vegetation indicate not only the absolute time when the bare lands were formed but the relative stability of the deposits.

The bars formed in placid stream tend to be covered with high flow several times a year as it was mentioned before. Sometimes due to the impact of ordinary water flow the bars are gradually moved or extended to downstream, and by strong flow such as flood they tend to disappear. Because the higher parts of bars are relatively stable, grasses and trees such as Salix, Alnus, Populus and Betula spp., which are dominantly observed along the channel sides, are growing on that part but lower parts submerged frequently are bare. In natural placid stream the vegetation is established at the upstream tip of bars because the bars grow by successive addition at its downstream end, which are relatively unstable, except the channels where some control works are carried out. The sequence of age of vegetation on the bars, which is sometimes observed in the field, shows that the bars are extended downstream with time and this means the sediment movement is more successive in placid river than torrent[13].

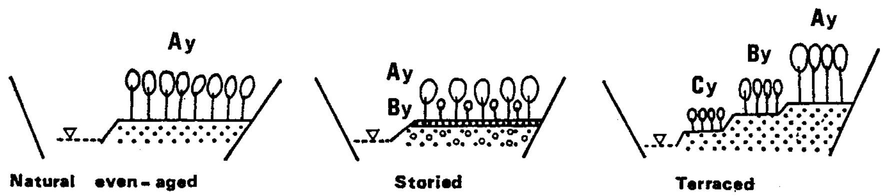

Fig. 3. Typical forests on the stepped deposits (ARAYA, 1982).
図—3 地形指標と植物 (樹木群) 指標 (原図 新谷, 1982)

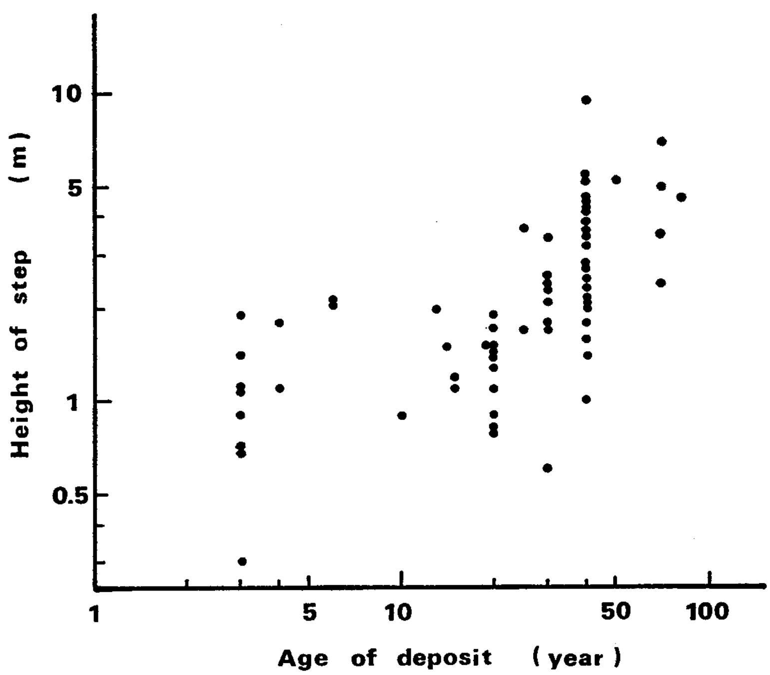

Fig. 4. The relationship between age and height of deposit.
図—4 階段状堆積地の年代と比高

As it is refered before, the cross sectional shapes of deposits in torrential stream are stepped and even-aged forests tend to be established on each step. Even in placid stream the bars attached to river banks, which were formed by past big floods, are sometimes stepped and even-aged forests are formed. ARAYA (1971) studied this kind of forest in torrential channels and confirmed that the forests on deposits are even-aged and furthermore used their ages to determine the date when these steps were formed[1,2] He classified them into three types shown in Fig. 3. The left figure shows the type of natural even-aged forest formed after one deposition. The middle figure is the storied forest formed with new deposition on the old one. The right figure is the forest formed on three steps of recent, new and old deposition[2]. Generally the older the forest age is, the higher the height of step from the lowest base tend to become. This relation was investigated in Furano River (Fig. 4). The evenness of forest age on each step shows that many bare lands are created suddenly by the strong impact of water flow on the deposits and the seeds of vegetation invade these lands subsequently.

3. Differences of sediment movement

The differences of channel bed shape and the age distribution of vegetation show the characteristics of sediment movement in placid and torrential stream. In placid river bars isolated as islands have convex shape cross sectionally and sequential change of vegetation age. On the other hand in torrent deposits are stepped and even-aged forests are established on these steps. This contrast reflects the differences of sediment movement occurred in both streams.

That is, in torrent, debris movement caused by high water is discrete and cause sudden change of channel bed. Usually there is very less water or no water in these channels, but at the period of flood the high water surface suddenly rises up and moves the debris to downstream all at once. The channel direction is mostly changed by large deposition and many of former courses are remained as abandoned channels which are commonly found in wide places.

It is estimated that these discrete movements of water and debris in size and frequency make carved steps and even-aged forests at torrent, and the gently continuous movements of sediment in placid river, however, create the convex shape and the sequential change of vegetation age on the bars.

III. Three different shapes of channel bed observed in Furano River

Shape of channel bed and the age distribution of vegetation on the deposits have changed relating to the surrounding topography. Three typical shapes of bed configuration were found in Furano River. They were named "fixed", "divergent", and "stable" stream channel.

1. Fixed stream channel

This shape was observed where the course of stream channel is confined topographically. The plane and cross sectional shape of fixed stream channel are shown in Fig. 5, and Fig. 6 is three dimensional view (3DV) of surrounding topography. The vertical height of all 3DV in this paper is exaggerated three times of horizontal length and the dip angle is 40°. As Fig. 5 and 6 shows the surrouning topography of this channel shape has been steepened and hard rock was appeared at some places of channel bed. The deep V-shape gully has been formed

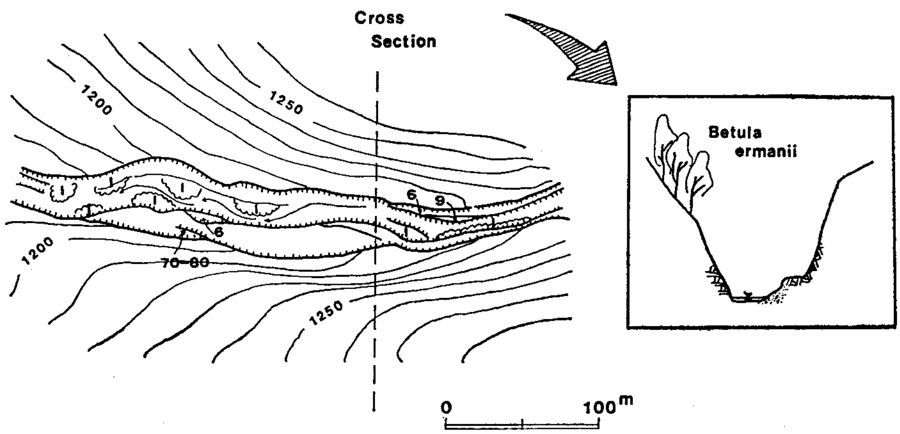

Fig. 5. Plain and cross sectional shape of "fixed" stream channel (The number marked on the deposit shows the age of vegetation).

図—5 定形流路の平面形および横断形（堆積地上の年代は成立している同齢林の樹齢を示す。）

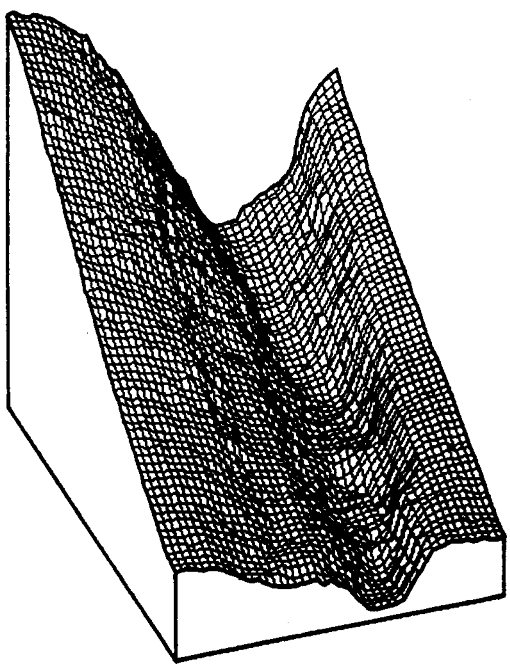

Fig. 6. Three dimensional view of topography where fixed channel is formed.

図—6 定形流路形成区間の地形的特徴

as a result of accelerated erosion with relatively narrow bed where few deposits were formed.

The numbers marked on deposits in Fig. 5 show the passage years after the deposits were formed. The passage years were estimated by dendrochronological survey, but the mark of "1" year is exceptional. In this paper, 1 year means within one year and the deposits without vegetation cover were also included in this group. Because the debris movements are confined into the deep V-shape gully and the deposits are removed easily, generally the ages of deposits are young. Considering the ages and small amount of deposits, this section is thought to be the transporting zone of debris without large deposition and scouring.

2. Divergent stream channel

In relatively wide places of channel, a lot of deposits were observed and form complex shape of channel bed[9]. This complex shape shown in Fig. 7 was named "divergent" stream channel, because many stram courses were found in the river. This kind of the configuration of channel bed has been known as "braided" stream in river morphology. River braiding is characterized by channel division around alluvial islands during low flow and form single stream during high flow when islands are submerged into water[13,18]. But divergent stream channel is different from above definition of braided river because usually there are no water flow in most of channel courses. Those abandoned channels were cleary recognized in the field and reason why those channels were formed was found to be the large deposition at the entrance of the channel courses.

Field observation clarified the fact that the divergent channel appears at the wide place, as Fig. 8 shows, and this characteristic is similar to braided river. It is considered that, at wide place of river width, the deposition has occourred by the sudden decreasing of flow depth following increase of width. This deposition

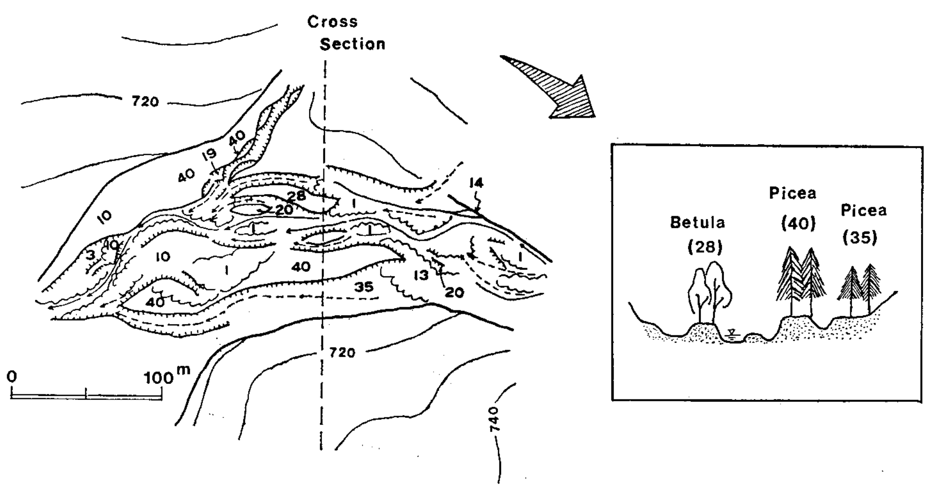

Fig. 7. Plain and cross sectional shape of "divergent" stream channel.

図—7 変動流路の平面形および横断形

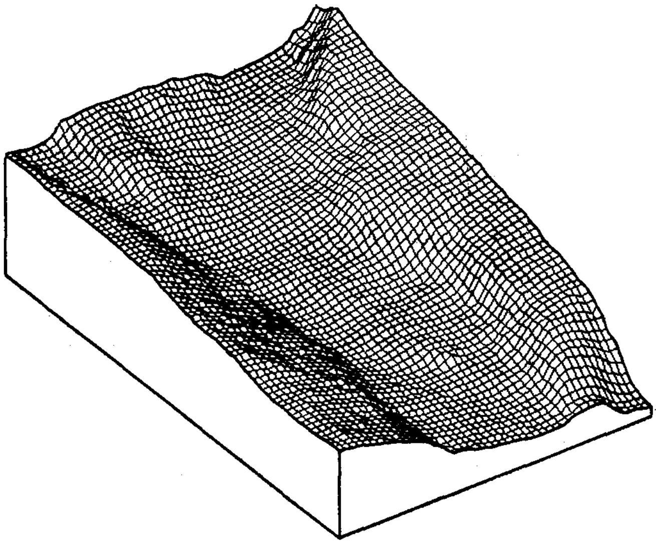

Fig. 8. Three dimensional view of topography where divergent channels develop.

図—8 変動流路形成区間の地形的特徴

interrupt the stream course and the water flow losing the way is forced to change its course and make new course at the sides of deposition. Due to this movement the new course sometimes locate at upper level than former course. As a result of these lateral movements, former courses are remained as abandoned channels and complex divergent channel of which cross section is alternating U-shape is formed. In this area many kinds of even-aged forests which were formed in different years were established on deposits separated by channel courses. The variety of vegetation ages shows the frequency of debris movements, therefore, it is estimated that the lateral changes of channel courses have constantly occurred in this area. The frequent changes of channel courses sometimes cause the erosion of channel banks and widen the channel bed.

3. Stable stream channel

At the section of stable channel, the banks were stabilized with relatively old-aged forests and a single stream course was formed and no abandoned channels were observed (Fig. 9, 10). The cross sectional shape of this channel bed is stepped and some of higher steps are used for afforestation at Furano River. The plane shape of this stream is sinuous as it is shown in Fig. 9.

The stepped deposits which were formed by past debris movements have remained in this area and most of deposits were occuppied by old-aged forest. From the age distribution it is found that the large debris movements, which flow into or out of this area, have not occurred during past 15 years and recent movements were small enough to be confined into stream course. The sinuous channel bank has been stabilized with growth of vegetation and deeping process of channel

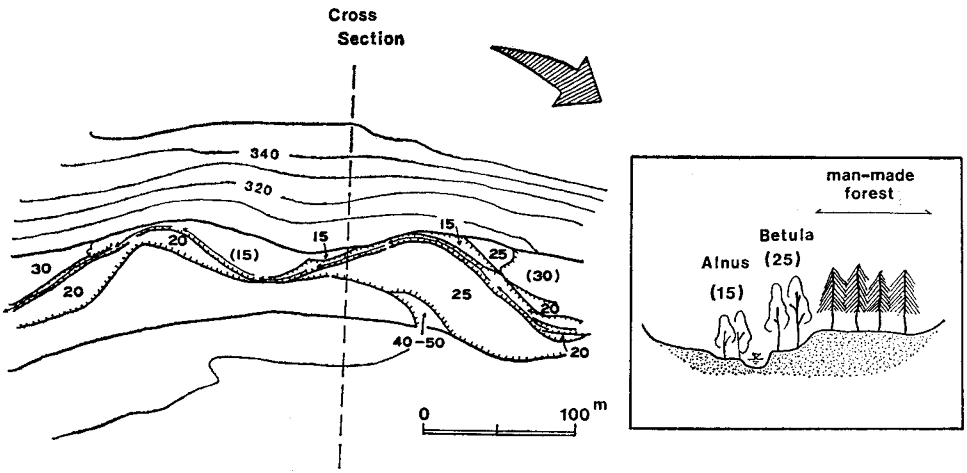

Fig. 9. Plain and cross sectional shape of "stable" stream channel.

図―9 安定流路の平面形および横断形

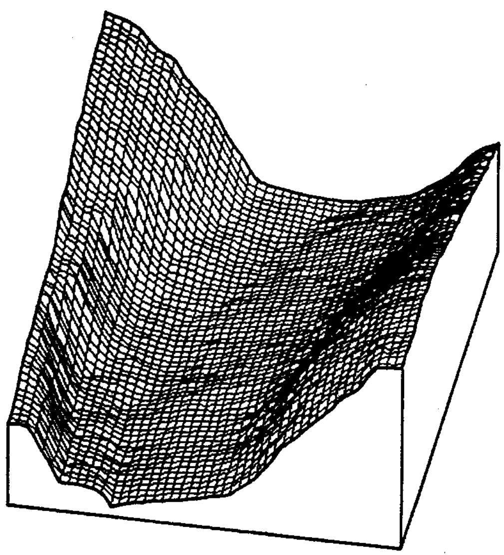

Fig. 10. Three dimensional view of topography where stable channel is formed.

図―10 安定流路形成区間の地形的特徴

bed. In comparison to divergent channel, it is found that the deepening process is more dominant in this area than widening process.

IV. Characteristics of wavy movements

Three representative characteristics of wavy movements were found at Furano River. One of those is alternate deposits that are regularly formed on channel bed and considered to be the smallest unit of bed configuration. Other two characteristics are difficult to recognize by field observation because those are not formed as a shape, but recognized as the differences of in- and outflow volume of debris movement.

1. Alternate deposits

KINOSHITA (1957, 1958) has discovered the formation of alternate bars and developed his idea to apply for mechanism of meandering[11,12]. The similar shape as he discovered was also found in Furano River. Fig. 11 shows the plane shape of this pattern. From the vagetation age (three-year-old trees) on the deposits it is estimated that the alternate deposits were formed at same time and remained until now. These deposits had been formed on one side and then on the other side of channel alternately and they force the water to take a sinuous path at low flow. The alternate deposits were seen at the relatively narrow section where divergent channel would not develop. The smallest unit of bed configuration is thought to be alternate deposits and the distribution of this pattern makes larger unit of debris movement that are refered in next section.

2. Alternate scouring and deposition in time and space

The alternate bars didn't always develop in all of channel courses but undeveloped bars, which are difficult to be recognized as bars for their unclear shape, were formed in some areas. KINOSHITA (1955) reported about this phenomenon and concluded that developed bars are formed where the channel bed rises up by cumulative deposition and undeveloped bars are formed where scouring is dominant. Moreover, he found the wavy movement of scouring and deposition and from his explanation 4∼7 bars were included within a wave length[10]. This phenomenon refered above could not be clearly found in Furano River because very complex configuration of channel bed developed in torrential stream. But the unit larger than alternate deposits was found by field measurements.

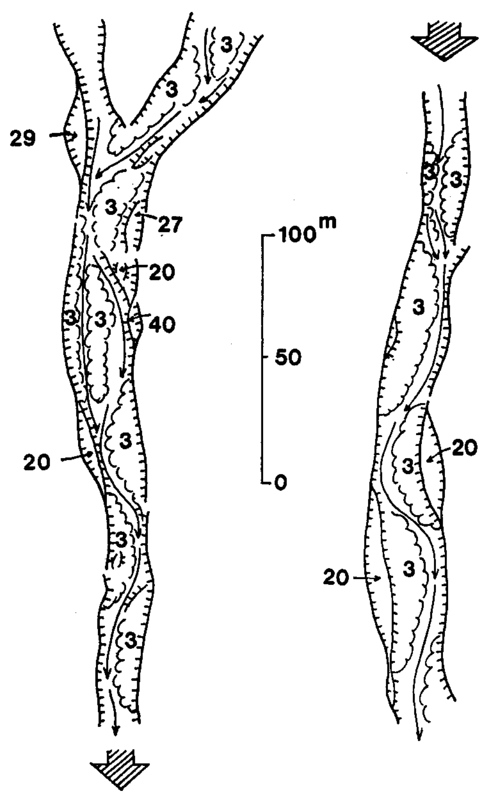

Fig. 11. Plain view of alternate deposits formed in Furano River.

図—11 荒廃河川富良野川において形成された交互砂レキ堆

The measurements were carried out at upper reaches of Furano River from 1980 to 1981 and the debris movement had occurred two times, on July 1980 and August 1981. The distribution of deposited and scoured areas and the stream course at low flow are shown in Fig. 12. Alternate scouring and deposition in space were recognized in 1980 and 1981 movement respectively. In 1980 the deposition had occurred at the section 16.75~17.0 km and 17.1~17.2 km, while scouring occurred from 16.95 to 17.1 km. In 1981 the deposition occurred from

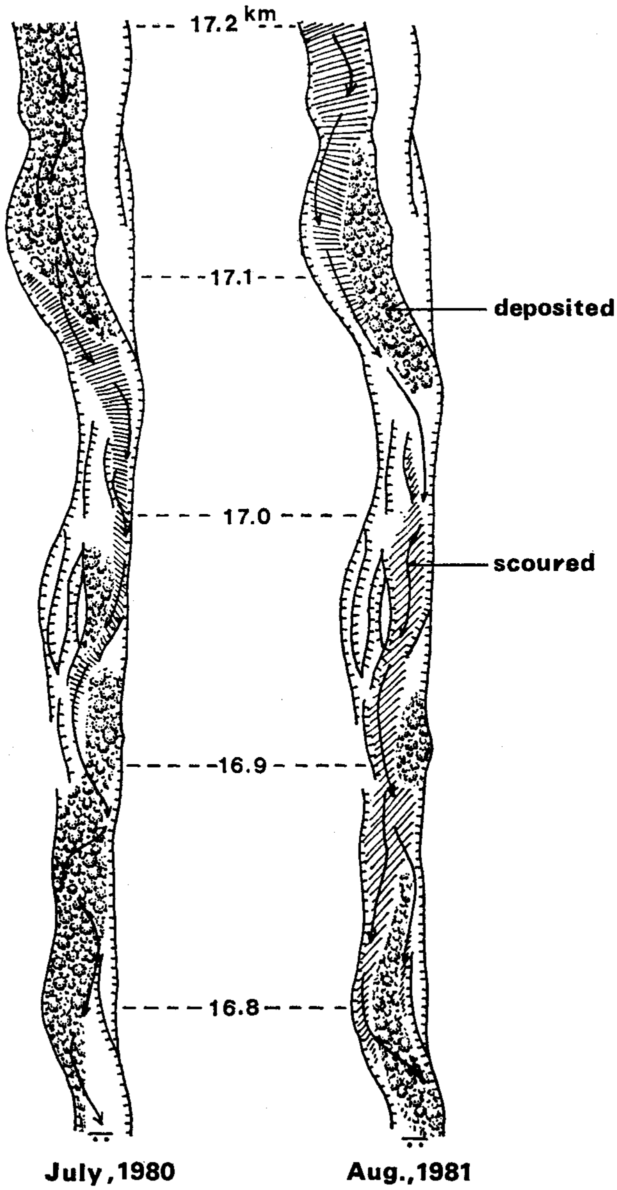

Fig. 12. Alternate scouring and deposition in time and space observed in Furano River.

図—12 富良野川 1980 年, 1981 年の移動で観察された堆積, 洗掘の位置的・時間的交互性

16.75 to 16.85 km and 17.05～17.15 km, while scouring occurred from 16.8 to 17.0 km and 17.1～17.2 km. This figure also shows the stream course at low flow by sequential arrows. The stream course from 16.75 to 17.0 km in 1980 showed the sinuous pattern from one bank to the other but no alternate deposits were formed except very obscure alternate deposits observed from 16.9 to 17.0 km. Cross sectional deformation of channel bed are shown in Fig. 13 where the alternate scouring and deposition in space can be seen clearly.

The deformation in time are shown by comparing 1980 and 1981 movement which are marked by solid and dashed wave lines in Fig. 13. These two waves had just opposite phase which means deposited and scoured area were replaced between two movements. Alternate characteristics of debris movement which are different from alternate bars were analized by ARAYA (1971) and he explained them relating to topographic factors like channel width. But in this measurement section there were not so much change of channel width and slope that alternate characteristics are thought to be difficult to connect with topographic conditions. Therefore these phenomenon were found to be one of the characteristics of debris movement itself rather than influence of topographic factors. Although the explanation of this mechanism is not the aim of this study, it is however clear that the wavy movement, which is difficult to explain based on the theory of tractive force, is recognized in the debris movements[5,14,17].

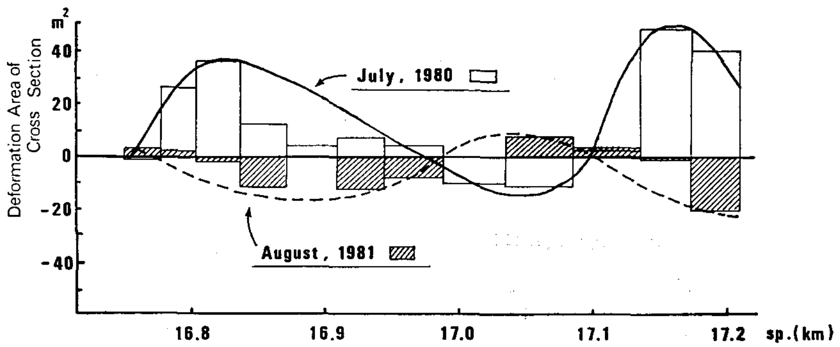

Fig. 13. Cross sectional deformation of channel bed on July 1980 and August 1981

図—13 1980年, 1981年の移動による河床断面変化量

3. Retardation of debris movement in wide places of stream channel

It is natural that debris movements are affected by topographic conditions. Fig. 14 shows the distribution of volumes per 100 m unit of deposition and scouring (A), slope of channel bed (B) and width of debris flow (C), on July 1980. To compare (A), (B) and (C) in Fig. 14, it was found that the large deposition or scouring occurred at the relatively wide places of channel and small change at narrow places. But the relation between the bed slope and debris movement was not recognized. The same trend was shown in Fig. 15 which shows the debris flow on August 1981. Assuming the debris movements have paticular several waves of deposition and scouring as it were refered previous section, larger wave unit of debris movement is thought to be the distance from one wide place to another, which are topographically fixed[9]. The units determined by visual division of width were 13.8～15.0 km, 15.0～16.4 km and 16.4～17.8 km section at Furano

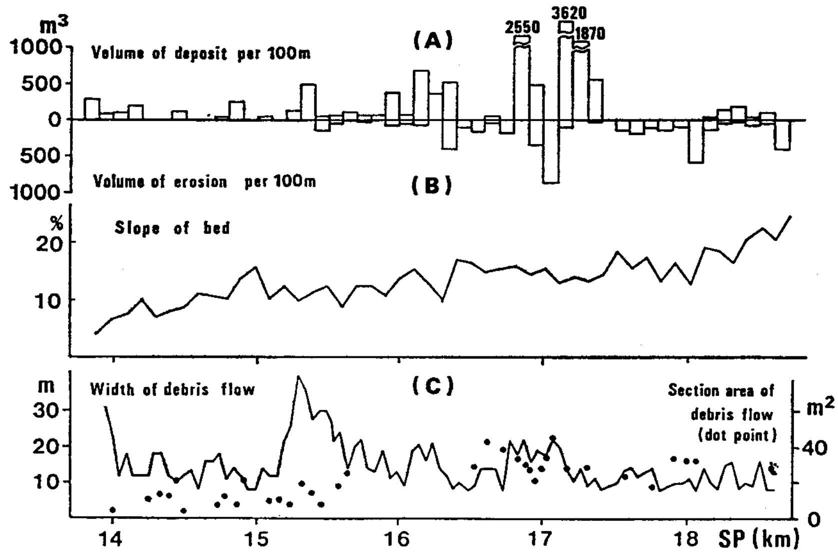

Fig. 14. The distribution of volumes per 100 m unit of deposition and scouring (A), slope of channel bed (B) and width of debris flow (C) on July 1980.

図—14 1980年7月移動時の河床変動量(A), 河床勾配(B), 流下幅(C)

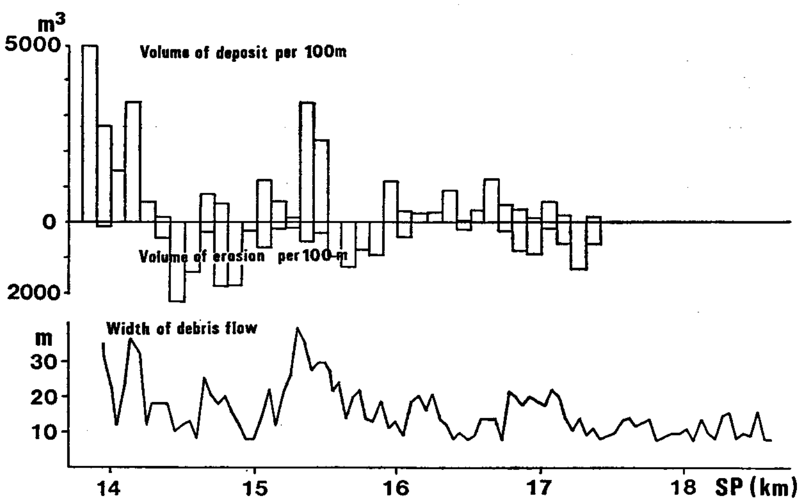

Fig. 15. The distribution of volumes per 100 m unit of deposition and scouring and width of debris flow on August 1981.

図—15 1981年8月移動時の河床変動量(上)と流下幅(下)

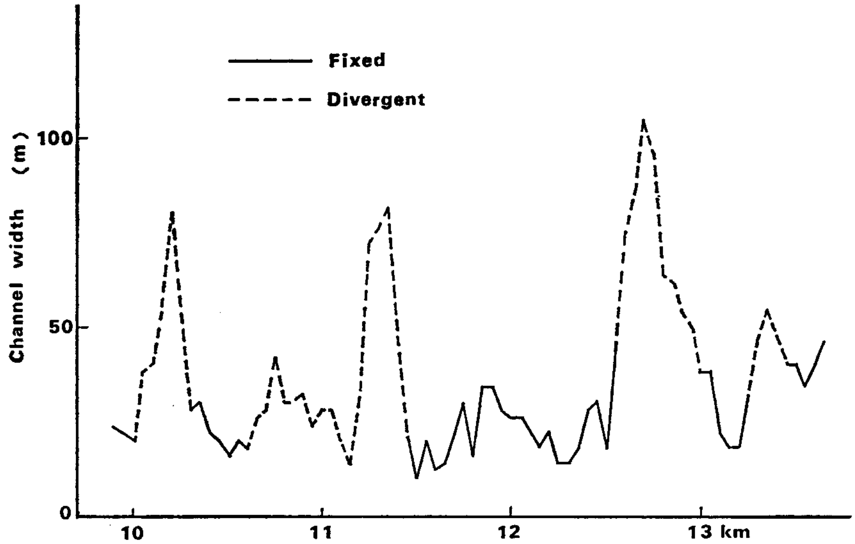

Fig. 16. The relation between channel width and the shape of channel bed at upper reaches of Furano River.

図—16 富良野川上流域における河床幅の変化と河床形

River. Such wavy movements, which are divided by change of channel width, are thought to be similar to alternate movement which was reported by ARAYA (1971)[1].

Fig. 16 shows the relation between channel width and the shape of channel bed at upper reaches of Furano River. As it is clear seen in this figure, the divergent stream channels develop at relatively wide places and those places become large deposition areas. Consequently the wide places of channel are thought to be the storages of debris and retard the outflow of debris to downstream. The influences of such wide areas on the debris movements are thought to be reflected in the configuration of channel bed as "divergent" and the age distribution of vegetation on deposits, which are discussed in following chapter.

V. The age distribution of deposits

The storages of debris in torrent are formed at the relatively wide places ; the area where tributaries join the main river and artificial storages such as check dams and retardation works. Especially, under natural conditions, stream junctions are thought to be important as storages in the river where channel width does not change so much. The check dams in the gully not only hold the debris in their pockets but also create the wide area at their upper reaches.

Fifteen storages were selected in surveying areas of Furano River as Table 1 shows. Among the selected storages, the storages of stream junction are No. 11, 12 and 14 and the artificial storages formed by check dams are No. 8 and 12. The volume of sediment in the storages shows the differences between in- and outflow volume and the age of vegetation on the deposits indicates the stability of deposits as well as the dates when movements had occurred. As a result, the

Table 1. The age distribution of sediment in selected 15 storages which are formed in wide places of channel

表—1 河床拡幅部に存在する堆積地の年代別土石量

No.	Section (m)	Area (m^2)	Slope (%)	Volume (m^3)							
				1-5y	6-10y	11-15y	16-20y	21-25y	26-30y	31-35y	Total
1	sp. 700- sp. 1400	16800	2.1	2340	1790	930	4410	0	120	0	9590
2	1400- 2100	10600	1.7	320	1060	2170	670	0	0	0	4220
3	2100- 2800	11800	2.4	320	120	880	2890	820	0	0	5030
4	2800- 3500	15600	2.6	220	260	240	7300	0	630	0	8650
5	4200- 5200	22500	2.7	5550	0	150	890	1220	600	0	8410
6	5800- 6200	4700	2.8	110	30	0	1770	0	0	0	1910
7	6200- 6700	7000	2.5	170	30	60	1120	0	1180	0	2560
8 (dam)	7000- 7900	54300	2.7	11920	0	500	37060	0	6140	0	55620
9	9600-10400	19800	4.2	4140	640	8090	4010	510	2000	310	19700
10	10500-11500	37000	5.6	15770	2030	210	1530	0	760	580	20880
11	12300-13000	31100	7.1	6460	360	9490	350	880	1280	100	18920
12 (dam)	13000-14300	55900	6.9	10210	4610	9470	910	670	8960	1680	36510
13	14700-16000	40300	11.5	24130	9960	0	430	160	0	0	34680
14	16000-16500	9300	13.3	4160	1110	0	240	250	1090	0	6850
15	16500-17500	19600	14.8	8360	1630	1080	0	0	0	0	11070

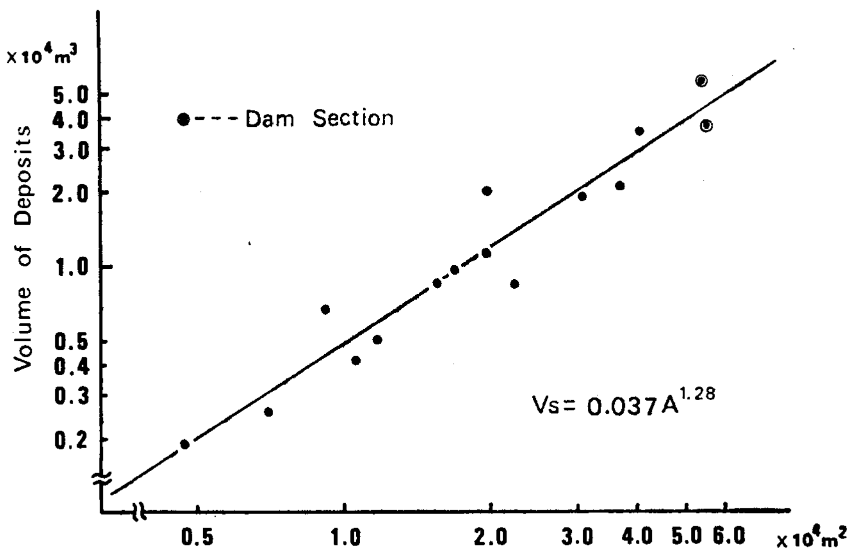

Fig. 17. The relation between the area of channel bed and the volume of sediment.

図—17 拡幅部面積と総堆積土石量の関係

distribution of volume of each age shows quantity and quality aspects of storage. The total volume of sediment in each storage was thought to be related to the area of storage because the large deposits were clearly observed in wide places.

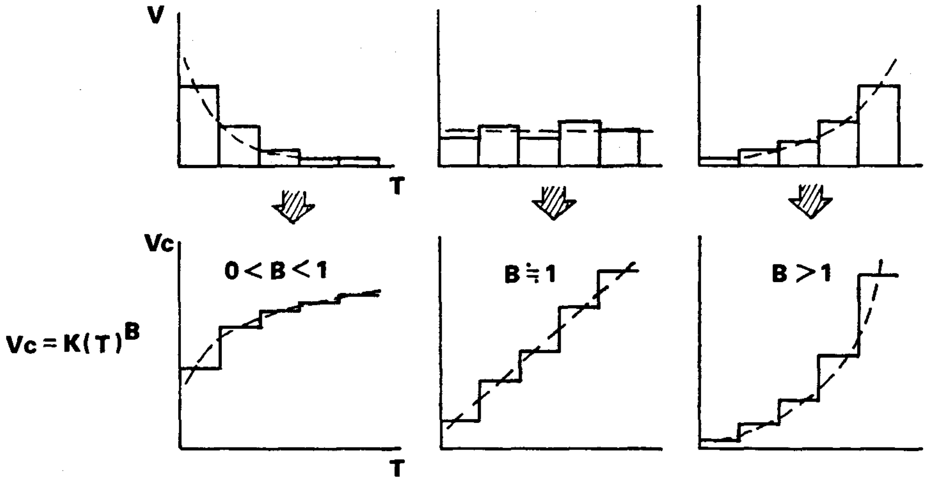

Fig. 18. Three kinds of distribution between volume (V), cumulative curve (V_c) and age (T).

図—18 年代別土石量の特徴的分布形(上)とその累計曲線(下)

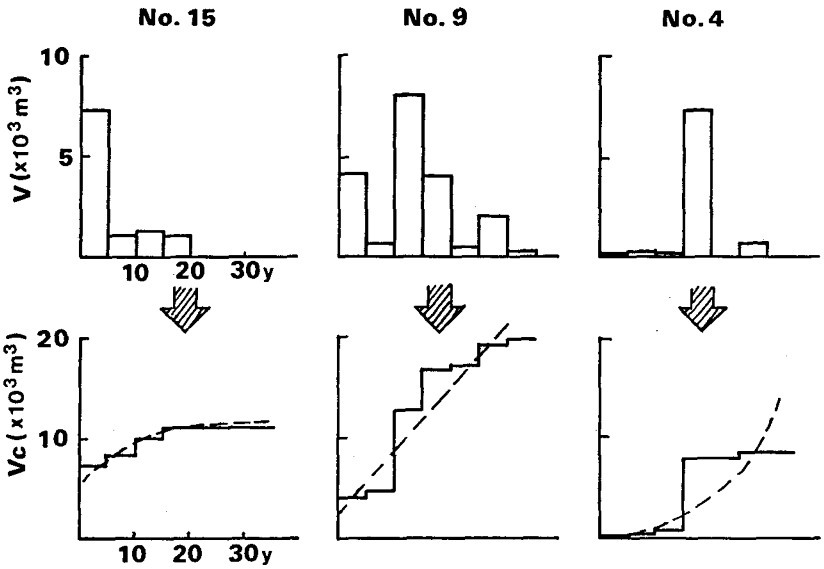

Fig. 19. Three kinds of age distribution of deposits formed in No. 4, No. 9 and No. 15 storages in Furano River.

図—19 富良野川拡幅部 No. 4, No. 9, No. 15 でみられた典型的な三種の年代別土石量分布形

The relation between the area and total volume is shown in Fig. 17 and is expressed as the power function,

$$V_s = aA^b$$

where V_s is the total volume of sediment, A is the area of the wide place, a is coefficient and b is exponent. The volume of sediment in this study were measured on the upper part above the lowest bed level of stream channel.

The total volume of sediment could be estimated by the area but the age distribution of deposits is difficult to be estimated only by the absolute criteria like width, area, slope etc. To analize the age distribution, the relation among storages should be taken into consideration[4]. The deposits made as an object of this study were from one to thirty-five years old and the volume of each every five years are shown in Table 1. Three kinds of distribution between volume (V) and age (T) of sediment are shown in upper part of Fig. 18. Left one shows a kind of distribution which most of the storages are occupied by young age deposits and the right one shows the old deposits are dominant. While in middle one young and old age deposits exist more or less equally. The cumulative volume (V_c) and the age of sediment are shown in lower part of Fig. 18. The cumulative curves are calculated by integrating upper curves. If the cumulative volume of each age can be expressed as the power function of age ($V_c = KT^B$), three kinds of distribution are determined by exponent B value and the sizes of storages are determined by coefficient K value. Left, middle and right distribution are determined by $0 < B < 1$, $B = 1$ and $B > 1$, respectively.

No. 15, 9 and 4 section in Table 1 are corresponding to above three kinds of distribution and are shown in Fig. 19. No. 15 is located at upper reaches where the "fixed" stream channel shown in Fig. 5 is formed. No. 9 is the section where the "divergent" stream channel shown in Fig. 7 is developing and a lot of even-aged forests are existed in the channel. No. 4 is the section where the "stable" stream channel shown in Fig. 9 is formed. SHIMIZU (1983) used this cumulative curve as "potential curve" to express the characteristics of basin[16]. From his analysis, three kinds of distribution were characterized as follows: Type No. 15 is formed after the large debris flow. The deposits in these channels are unstable so that debris movements have been frequently occurring. Type No. 9 is dominant form in torrent. Type No. 4 is formed at the channels approaching a stable condition. These estimation by SHIMIZU (1983) are almost same as the result analized by the shape of channel bed in this study.

To know the relationship among storages about the age distribution, B values of selected 15 storages were arranged from lower to upper reaches in Fig. 20. It can be roughly said that the age distribution have changed around 7 to 10 km where B value change from more than 1.0 to less than 1.0. B values less than 1.0 are also found in downstream No. 1 and 5 but, in this section, some of the stabilized steps are used for afforestation and the age of those steps could not be estimated. If those excluded deposits are taken into consideration, B values in lower reaches would become higher than shown in the figure. The age distribution of deposits in a storage is largely affected by the characteristics of near storages in upper reaches. At the location of 7.5 km, the check dam was constructed and No. 8 storage was formed. The divergent stream channel is developing in the No. 8 storage, but

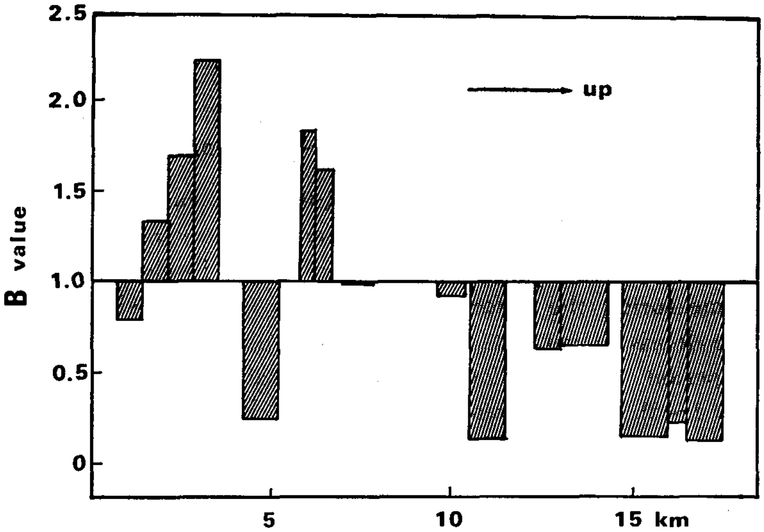

Fig. 20. B value of selected 15 storages which shows the shape of age distribution.

図—20 年代別土石量の分布形を示すB値の変化

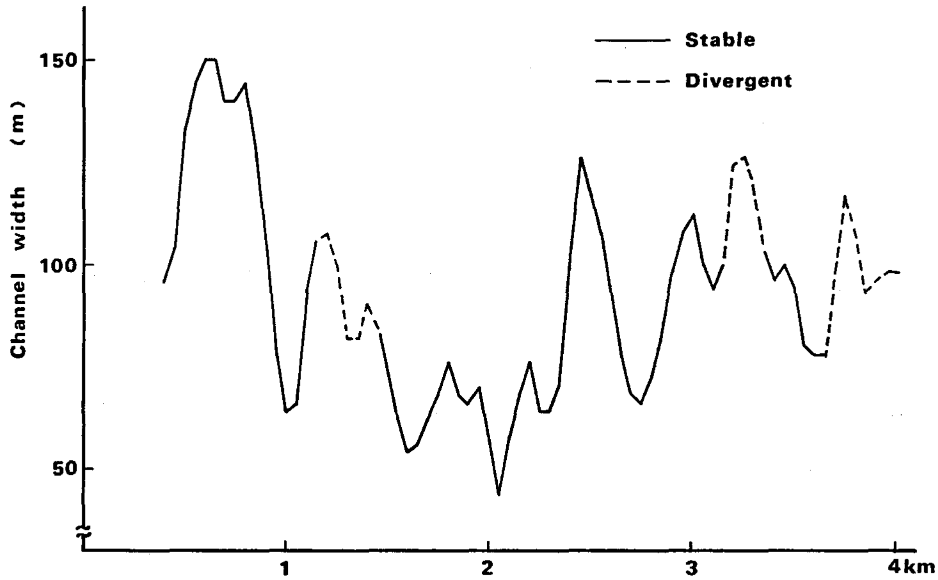

Fig. 21. The width and the shape of channel bed in downstream section of check dam which formed No. 8 storage.

図—21 富良野川2号ダム下流における河床幅の変化と河床形

downstream of check dam, the stable channels are formed regardless of the channel width. Fig. 21 shows the channel width and the shape of channel bed in downstream section of No. 8 storage. In contrast with Fig. 16 the stable stream channels are formed where channel width are relatively wide. Considering the fact that the stable stream channels are formed only downstream of this check dam, the influence of No. 8 storage was thought to be very large for the stability of downstream deposits.

VI. Estimation of debris movement in storage characterized by the shape of channel bed

The continuous surveying from 1972 to 1982 were carried out at Nukkakushi-furano River. The surveying section is located at upper reaches of No. 1 check dam and the average slope of that section is 9%. Twelve cross sectional lines were set for measuring the deformation of cross sectional shape of channel bed (Fig. 22). The debris movements were measured nine times in this section during the surveying period. This section could be divided into three parts that are wide area (Line No. 1～5), middle area (No. 6～8) and narrow area (No. 9～11). The representative measured lines are selected from respective parts and the deformation along these lines during ten years are shown in Fig. 23.

Line No. 1 selected from wide area showed very complex cross section and changes of configuration were observed over its width. Corresponding to the complex configuration of channel bed, divergent channel developed in this area

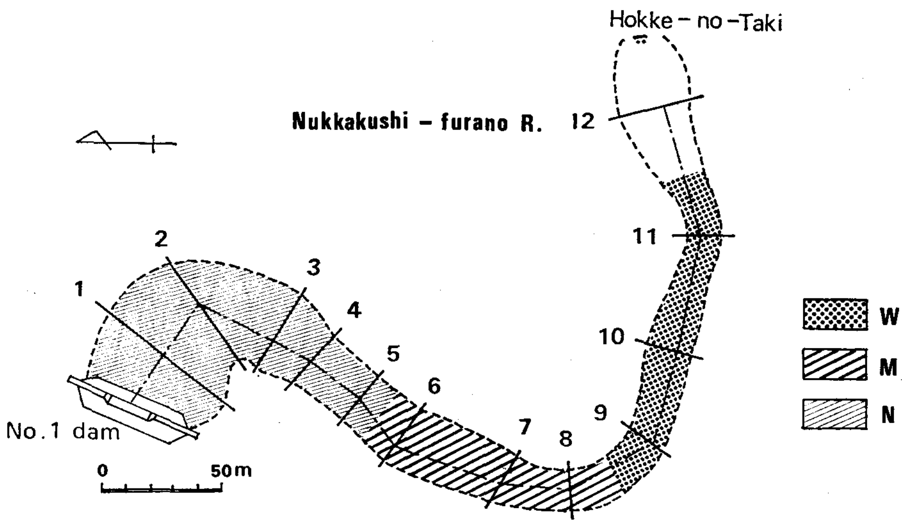

Fig. 22. Plain shape of investigated area at Nukkakushi-furano River and the location of measured lines.
(W: wide area, M: middle area, N: narrow area)

図—22 ヌッカクシフラノ川における河床変動調査区間の概要および調査測線の位置
(W: 拡幅部, M: 中間部, N: 狭さく部)

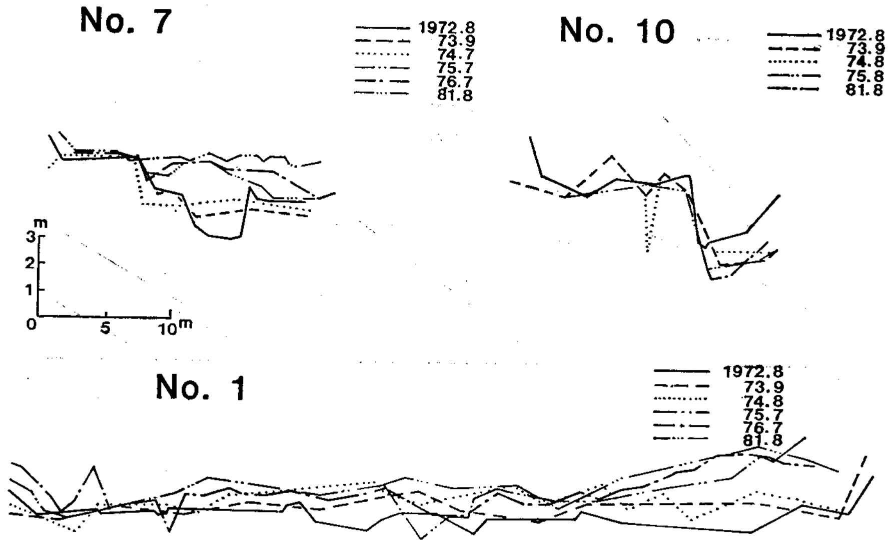

Fig. 23. The deformation on the representative measured lines (No. 1, 7, 10) from 1972 to 1982.

図—23 代表的三測線 (No. 1, 7, 10) における 1972 年から 1982 年までの河床変化

and the stream courses were frequently changed laterally. As a whole this line tended to rise in time, especially this tendency was prominant at the left bank. Line No. 7 selected from middle area showed the nearly stable channel in 1972. But the debris movements from 1973 to 1975 filled the stable stream course and, as a result, channel bed showed the nearly divergent channel. After that, the channel bed was deepened again until 1981 as figure shows. Line No. 10 selected from narrow area showed the stable channel in 1972 and have not changed so much during surveying period. The deposit on the right bank was stabilized well, therefore, the stream course was almost confined to the left bank.

The measured results can be arranged to show the relation between frequency and volume. The frequency of occurrence of the largest debris movement is thought to be once in ten years. The frequency of occurrence of the second large one is estimated two times in ten years because the movements larger than this one had occurred two times and can be re-expressed as once in five years[15]. With preceding calculations the relation between volume and frequency of occurrence of deposition and socuring were estimated in wide, middle and narrow areas. These relations were shown in Fig. 24. The number of absissa means frequency of occurrence, for instance, 10y shows once in ten years. In wide area the line of deposition located relatively higher than the line of scouring, in other words, the deposition was superior than scouring during ten years. In middle area, both lines were closely drawn and this means deposition and scouring had occurred in same degree. In narrow area the scouring is superior than deposition. To compare three figures, it was found that scouring in three areas had more or less same tendency but deposition, on the contrary, was different from the areas.

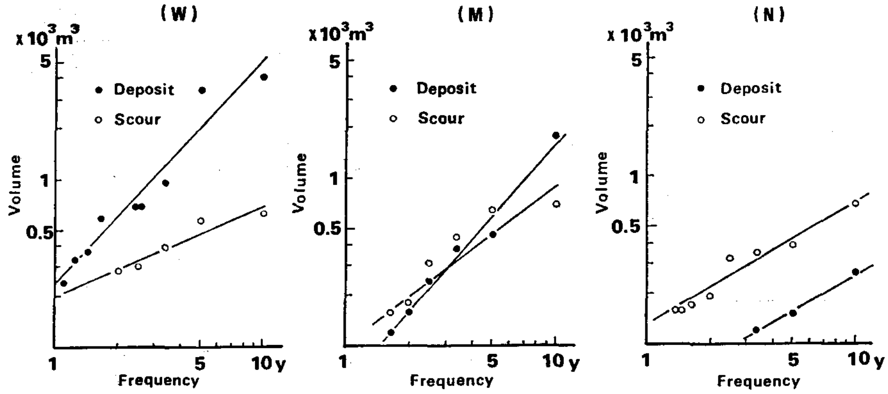

Fig. 24. The relation between volume and frequency of occurrence of deposition and scouring at each section (W, M, N).

図—24 各区間 (拡幅, 中間, 狭さく部) における発生頻度と変動土石量の関係

The debris movements in three areas characterised by the shape of channel bed are concluded as follows. In wide section the deposition was superior and deposits were formed over the whole area together with lateral movement of stream course. In middle section the deepening and filling process of stream course were repeated and, at the same time, the shape of channel bed was changed from stable to divergent. In narrow section the channel shape was almost fixed during ten years and deeping process was dominant. The field observation in Furano River and results of measurement in Nukkakushi-furano River showed that the depositional tendency would be continued for a long period in the area where the divergent stream channels develop. And in the stable channel section the bed is inclined to be scoured.

Conclusion

In the torrent the movement of water and debris are discrete in size and frequency. As a result the cross sectional shape of formed deposits are stepped and the age of vegetation on the deposit is even, in contrast with convex shape and sequential change of age in placid streams. Three types of channel shape as fixed, divergent and stable were observed in the torrent and the recent mevements in each section were clarified by the age distribution of deposits and field measurement. This discrete movement of debris makes alternate scouring and deposition like waves. Three kinds of wavy movements, which had different wave lengths, were found in Furano River but could not be explained in relation to the channel shapes. However, it could be said that the divergent channel developed in relatively wide places and the fixed channel were formed in narrow places, and these wide or narrow places make a unit of long wave movement. Moreover, as a result of several decades of movements, the stable channel developed in the area where the debris movements occurred at long time-intervals rather than the divergent channel. This occurrence pattern of debris movement in tim eseries was thought to be one of the chronological characteristics of the river and was expressed as "active" and "inactive" river by KAKI (1958)[8].

Consequently these configurations of torrential channel bed were found to be complex shapes which are formed by topographical and chronological caharacteristics of the river. The channel shape can be suddenly changed by large movement at any time in furture. Therefore, it should be understood as one phase in time series. However, it is possible to estimate the present condition and near future trends from the channel shape and the growing vegetation on the deposits.

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摘　　要

河床堆積地の特徴は，空間的にはその横断形に，時間的には成立する木本群落の樹齢構成に認めることができる。本研究では，まず急流河川と他の緩流河川に形成される河床地形，植物群落を比較し，急流河川における堆積地の形態的特徴を抽出した。つぎに急流河川における河床地形と土石の波状的移動を分類し，その経年的変化を河床変動調査結果と合せて考察した。

1) 急流河川において形成された河床内堆積地の横断形状は，切取られたようなステップ状の凹凸をなしているのが特徴である。またこうしたステップ(裸地)が形成されると同時に先駆性樹種が一斉に侵入し，天然生同齢林がステップ上に成立する。この同齢林の樹齢は，結果的にそのステップが形成されてから現在までの経過年数を示すことになる。これに対して，緩流河川において河床内に形成される砂レキ堆は，一洪水で形成されたものを除いて，丸味のある緩やかな凸形をなしているのが普通である。増水期(降雨・融雪)に水面下に沈む部分と近年形成された下流端は裸地となっており，上流端から中央にかけて植物群落が成立している。一般的に自然河川では，上流部にヤナギ等の木本類が生育し，下流にいくにしたがって草本類，裸地と続いている。これは砂レキ堆が下流に向って伸長するためで，植物群落の年齢は下流ほど若くなる傾向にある (図-2, 3)。

2) 急流河川でみられステップ状の堆積地形,成立する木本群落の樹齢の一様性に対して，緩流河川でみられる緩やかな凸形，砂レキ堆および成立する植物群落の年齢の連続的変化という対照は，両河川で起きている現象の違いを表していると考えられる。急流河川の多くは，平常流水は伏流して河床には見られず，洪水期に一気に増水するのが特徴であり，平常静止している河床内の土砂は，この増水時に急激な堆積・洗掘を繰りかえしながら移動する。こうした水と土砂の運動の不連続性は，結果的に流路変動にともなうステップ状堆積地を形成し，堆積域に形成された大規模裸地には一斉に木本が侵入する。これに対して緩流河川では，砂レキは連続的に掃流され砂レキ堆を徐々に伸長してゆくため，形成された小規模裸地には植生が順に侵入し，結果的には連続的な異齢林が成立するのである。

3) 火山性荒廃急流河川である空知川支流富良野川において3種の河床形が観察され，それぞれ定形流路・変動流路・安定流路と呼ぶことにした。定形流路は地形，地質的に狭さく部となっている区域にみられ,河床内堆積地も少なく,成立している木本群落の年齢も若い (図-5, 6)。変動流路は土砂移動の激しい拡幅部に発達しており，旧流路等の変動痕跡が多数みられ複数河道をもつ。また木本群落の樹齢も若いものから古いものまで多様に分布している (図-7, 8)。安定流路は，近年大規模な土砂移動が発生していない安定した区域にみられ，単一河道をもち，河岸の堆積地年代は古い (図-9, 10)。

4) 富良野川において波状的土砂移動が観測された。一つは交互砂レキ堆で河床形態のなかでは，最小単位を構成するものと考えられる (図-11)。これより大きな波状的土砂移動は，洗

掘と堆積の位置的・時間的交互性として認められ (図-12, 13), さらに大きな波状的移動は河道の拡幅，狭さくという地形変化によって形成されるものであると考えられる (図-14, 15)。本研究において，こうした波状的土砂移動と結果的に形成される河床形とを関連させて説明することはできなかったが，急流河川においては掃流力理論で説明することが難しい波状的移動が存在する。

5) 河床拡幅部に堆積している土砂の量は，その河床面積に比例していると考えられるが (図-17), その年代別堆積量の分布は，河床幅・面積・河床勾配等の絶対量であらわすことは難しく，各拡幅部間の相対的関係を考慮しなければならない。古い年代の堆積地が多く分布しているのが特徴である安定流路区間が，変動流路が発達している No. 8 拡幅部 (富良野川 2 号ダムによって形成される。) 下流においてのみ観察されることを考えると，No. 8 拡幅部の下流域に及ぼす影響が非常に大きいと解釈される (図-20, 21)。

6) 3 種の河床形区域における河床変動状況は，ヌッカクシフラノ川における10年間の継続観測により明かにされた。これによると，変動流路区間においては，流路は側方への変動をくり返しながら全体的には土砂を堆積させる傾向にあり，安定流路区間では河岸が安定し，河床を洗掘する傾向にある (図-22, 23, 24)。

7) 定形流路と変動流路・安定流路は地形的に決定される。つまり，地形的に制約を受ける場所では定形流路が形成されるが，地形的に開放された場所では変動もしくは安定流路が形成される。また，地形的に開放された場所で変動，安定流路が形成される理由としては，その区間で起っている近年の土砂移動状況が大きく影響していると考えられる。すなわち，相対的に土砂の流入・流出が激しい区間では，これにともなう流路変動が頻繁におこり，旧流路・現流路が網状に発達するが，流路変動を起すような土砂の流入がなく，現在の単一流路のみで流過させることができる区間では安定流路が発達する。結論的には，河床形は場の特徴と，現在生起している現象の複合形として位置づけることができる。

8) 現在の河床形は，時系列上の一形態であり，豪雨等に起因する大変動により瞬時に変化しうるものとして理解されなければならない。しかし，相対的に現在の河道状況をその形態および成立している植物群落から探ることは可能である。

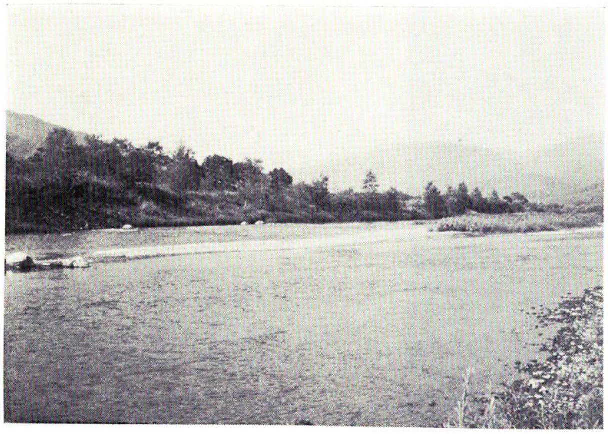

Photo. 1. A bar formed as island in placid river. The vegetation is established at upstream tip of the bar.

写真 1 緩流河川における中州状砂レキ堆。植生(ナガバヤナギおよび草本)は砂レキ堆上流部に成育している。

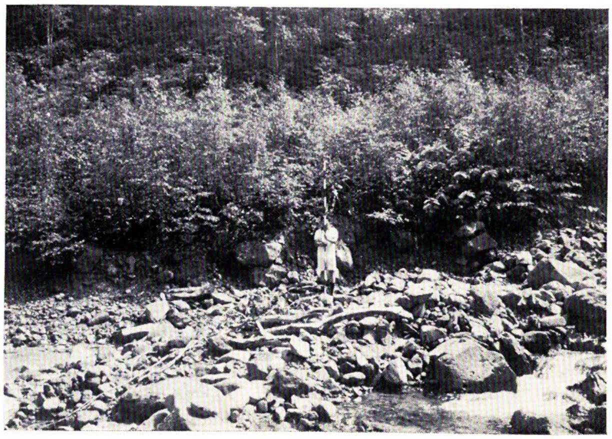

Photo. 2. A deposit formed in torrent. The trees on the deposit form even-aged forest.

写真 2 急流河川における階段状堆積地。堆積地上に天然生同齢林が成立している。

Photo. 3. A changed stream course located at higher place than former course.

写真 3 旧流路より高く位置している変動流路(現流路)

Photo. 4. Fixed stream channel. The deep V-shape gully is formed.

写真 4 定形流路区間。深いV字谷が形成され，堆積地はほとんどみられない。

Photo. 5. Divergent stream channel. Many stream courses are formed corresponding to many kinds of even-aged forest, but most of these courses are abandoned.

写真 5 変動流路区間。多くの堆積地が存在し，網状の流路痕跡が観察される。成立している同齢林の樹齢も多様である。

Photo. 6. Stable stream channel. The channel banks are stablized with old-aged forest and a single stream course is formed.

写真 6 安定流路区間。単一河道をもち，河岸の堆積地年代は古い。