

Rapid Erosional Development of Mountain Slopes and Valleys Caused by Large Landslides in Japan

Hiroshi MACHIDA

Introduction

There has been a considerable number of studies on the classification and the activity of erosional processes in mountainous districts, but little work has been done on the quantitative analysis of landform development caused by active processes, such as the study of the rate of erosion and the behavior of materials eroded from mountain slopes and valleys. These problems are fundamental for developing the study of dynamic geomorphology.

In the mountains of Japan, as introduced by Miyabe (1935), Ichikawa (1959), Iwatsuka (1959) and others, landslides and related phenomena occur somewhat frequently so that they are considered to be one of the major agents dissecting the mountain slopes. In addition, they usually supply so much debris to river beds that channels become unstable. This is due fundamentally to the topographical and geological conditions such as the presence of steep and long slopes composed of badly fractured rocks, and also frequent torrential rains and earthquakes must be mentioned as major initiating causes of landslides in Japan.

Of many types of landslides in the country, some of the largest slides or mudflows have a great influence upon river beds. The slides feed a large mass of debris into the rivers in some cases, and consequently the river beds are elevated and immediately severe deepening begins.

In the studies reported in this paper, the recent development of slopes and valleys owing to severe mass-movements and related erosion was clarified to make a contribution to the study of fluvial geomorphology.

First, the writer shows some case studies and then intends to discuss several characteristics of the slide and subsequent channel erosion.

The areas investigated are : _____

- 1) The Abe River area, Shizuoka prefecture

- 2) The Jôganji River area, Toyama prefecture
- 3) The Ura River area, a tributary of the River Hime, Nagano prefecture and several other mountainous areas.

The location of each area is shown in Fig. 1. Severity of erosion characterizes these areas. The upper part of each area is largely dissected because of the presence of less resistant bedrock and the prevalence of steep slopes, so that erosion control works are very important problems for the inhabitants.

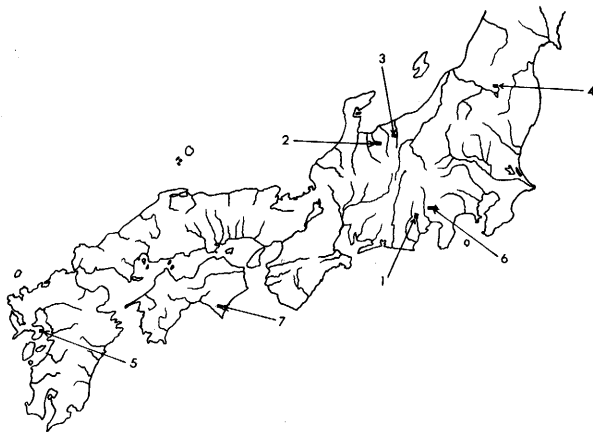


Fig. 1 Locations of studied areas.

- 1: Ohya slide, the Abe River
- 2: Tombi slide, the Jôganji R.
- 3: Hieda slide, the Ura River
- 4: Bandai Volcano
- 5: Mayuyama Volcano, Shimabara
- 6: Ohsawa Valley, Mt. Fuji
- 7: Kanagi slide, the Sakihama River

The methods used by the writer to analyse the recent erosional development in each area are summarized as follows:

First, the writer investigated the nature of the deposits and their topography in the upper part of the valley. Secondly, he confirmed that they were suitable as indicators to analyse the recent erosional development by consulting the documentary records of natural disasters of the past. Thirdly, he estimated the amount of erosion and deposition by measurements from large scale topographic maps (1/5,000 - 1/10,000).

Case Studies

The Abe River (Machida, H., 1959)

The upper area of the Abe River is composed of Mesozoic to Paleogene formations, chiefly alternations of sandstone and shale accompanying with thin layers of serpentine and various igneous rocks. Almost all beds are fractured in general, and especially shale is altered to easily eroded phyrritic rocks. The landform belongs to early maturity in general, so that the slopes are long and steep and small flat

or gentle erosional surfaces remain on mountain tops here and there.

Moreover, heavy rainfall characterizes this area. The average annual precipitation reaches 3,500 mm. at Umegashima-shinden, and the rainfall is very intensive; the maximum daily amount recorded during the past 15 years was 470 mm.

Landslide scars of a rapid movement type are very wide-spread in the drainage basin, and the largest is located in the uppermost part of the area, named "Ohya slide". Its area is calculated to be about 180 ha., and the relative height reaches about 700 metres.

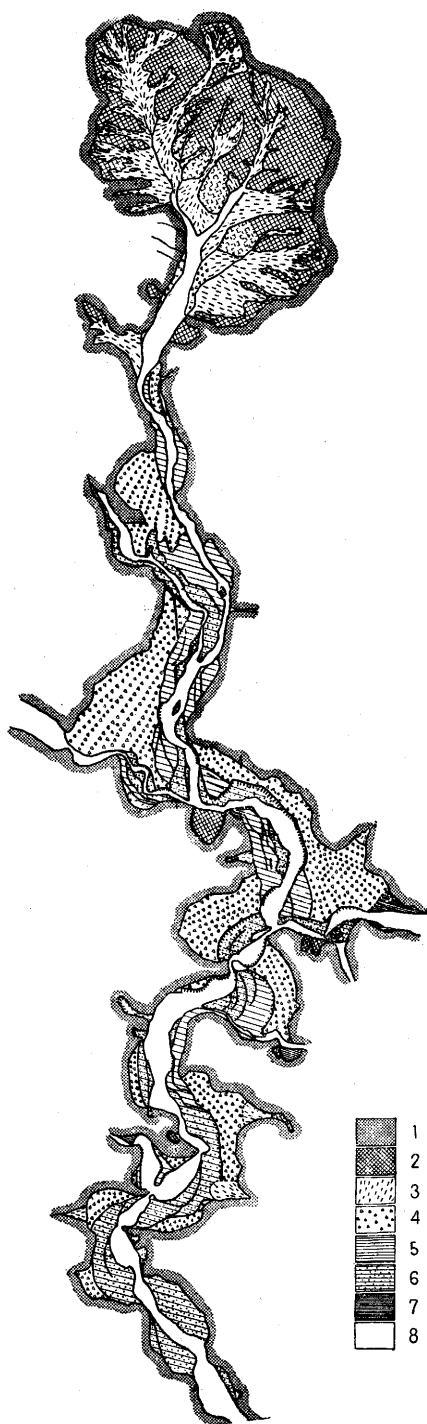
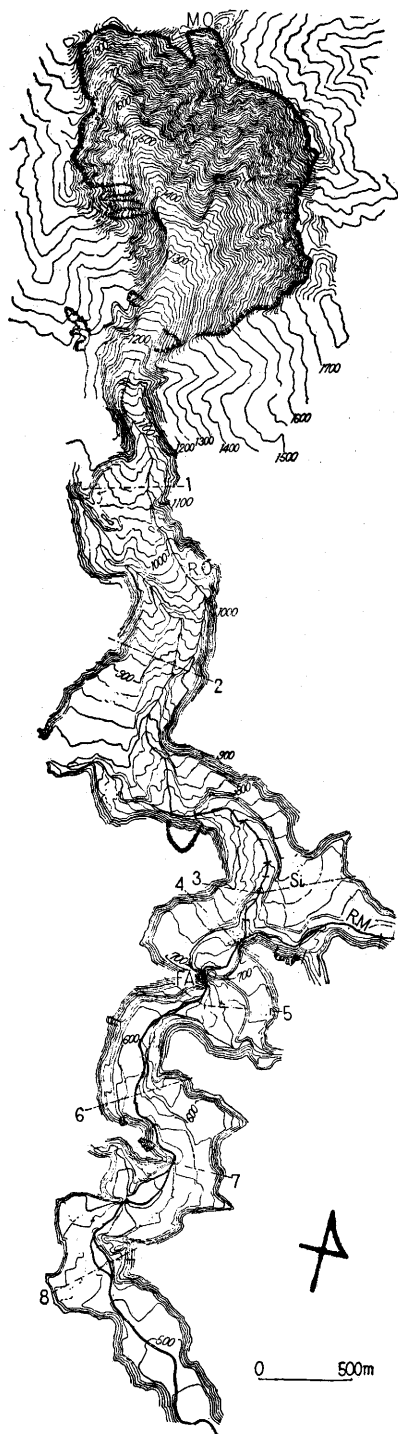
In the bottom of the valley characteristic river terraces develop extending about 7 - 8 Km. from the Ohya slide to the lower reaches (Fig. 2A, 2B). They are constructed chiefly of subangular gravels more than 70 metres thick, and a little stratified downstream. Cross sections of the terraces are shown in Fig. 3, and the longitudinal profile in Fig. 4. It is clear from their features that they were produced by the surges of erosion on the debris filled valley which had been formed by recurring mudflows derived from the Ohya slide.

The terraces are divided into two groups as shown in Fig. 2B, the higher terrace and the lower. The former, having a fan-shaped surface, is depositional in nature, while the latter is erosional, or a "non-cyclic terrace" in the sense of Cotton's classification (Cotton, 1940), which was formed by continued deepening accompanied by slight lateral erosion.

The volume of the mudflow deposit in the upper Abe River can not be calculated exactly because the lower limits have not been exposed everywhere. An approximate estimate, however, can be made from the topography, and it amounts roughly to $1.8 \times 10^8 \text{ m}^3$. From this large volume it is inferred that the depth of the Ohya slide should have reached several tens of metres, so that it must have been one of the largest rockslide types.

Some lacustrine deposits are to be found accompanying the mudflow deposits at the confluences of several tributaries and the River Abe, such as at the eastern part of Shinden village (Fig. 2B), suggesting apparently that the mudflows dammed almost all tributaries forming lakes and ponds. Consulting local records about old natural disasters, it was found that the most recent damming occurred in 1702 at the east of Shinden and that the lake remained until about 1867. The higher terrace surface, therefore, seems to have been formed at that time.

From the facies of the higher terrace deposit, the mudflow must have had a somewhat higher water content than in



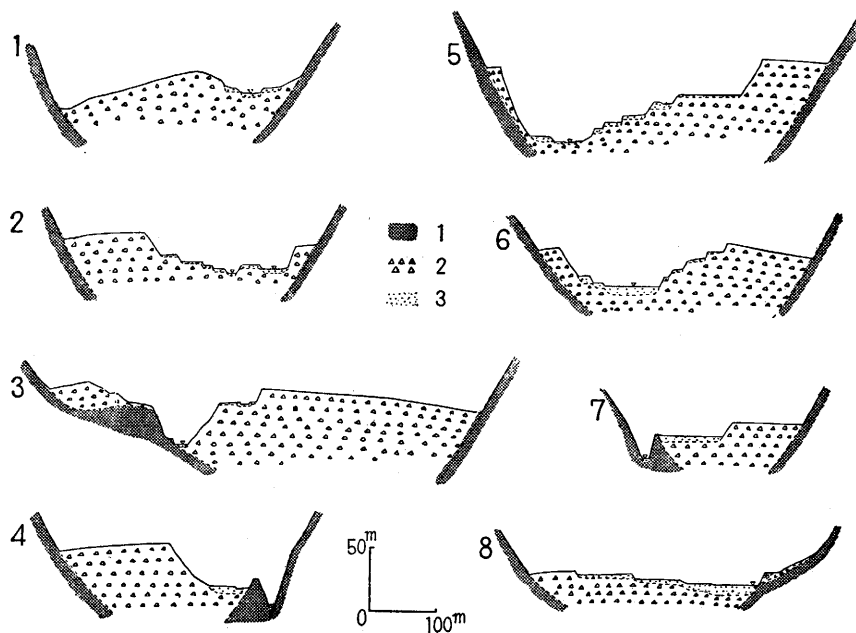


Fig. 3 Cross sections of the upper Abe River (Localities are shown in Fig. 2A) 1: bedrock 2: mudflow deposit 3: lower terrace gravels

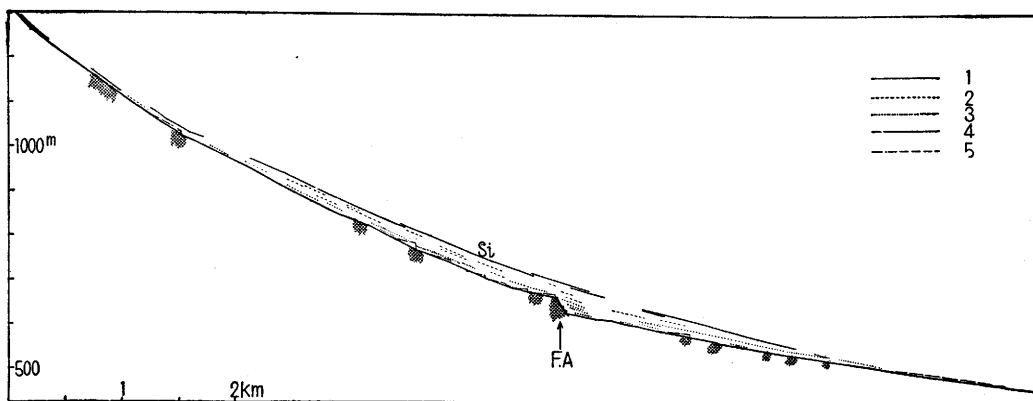


Fig. 4 Longitudinal profiles of the present river bed and terraces along the upper Abe River 1: higher terrace surface (formed in 1702) 2: lower terrace surface I (formed during the time from 18th c. to the end of 19th c.) 3: lower terrace surface II (formed since the end of 19th c.) 4: lowest present river bed (before the construction of erosion control dam) 5: ibid. (after the construction of dams) Hatched parts show the bedrock exposed by valley-slide superposition. abscissa: distance, ordinate: elevation above sea level

Fig. 2A Topographic map of the upper Abe River
RO: Ohya River RM: Mikohchi River Si: Shinden FA: Akamizu Fall

Fig. 2B Geomorphological map of the upper Abe River
1: valley-side slope 2: free face 3: scree 4: depositional surface of mudflow (higher terrace surface) 5: surface of lower terrace I 6: surface of lower terrace II 7: flat surface of lacustrine deposit 8: present river bed

the two cases described later. Besides, about ten records are to be found in manuscripts of 16th-17th centuries about occasional happenings such as landslides or floods in the surrounding area of Ohya slide and downstream. These suggest that the Ohya slide was repeatedly active and fed large volumes of debris to stream in those days.

Deepening in the waste filled valley floor of the upper reaches of the River Abe started immediately after deposition on those stretches where tractive power was at its maximum. Here, attention must be paid to the fact that deepening did not start from knick-points, which might not have been present on the original profile, but started along considerable lengths of the stream. The lowering and widening of the river bed has continued up to the present. As illustrated in Fig. 4, the relative height between the past valley floor represented as higher and lower terrace surfaces and the present one suggests the amount and the mode of deepening during these 260 years. The degradation of the river bed attains its maximum of 70m. along the middle stretches, and downstream the relative altitude of the higher terrace decreases and then the higher terrace plunges beneath the alluvial deposits.

It is easily pointed out that the longitudinal profile of the higher terrace surface is smoother than that of the present bed. Akamizu fall, the largest knick-point in the middle segment, strikingly characterizes the irregularity of the present river profile. In the course of rejuvenation, the stream cut into resistant ledges of sandstone, or buried valley-side slopes, and hence the fall was formed. The deepening attains the maximum relief of 70 metres below this knick-point.

The height of the fall is still increasing. Judging from the releveling work of channels, the height was increased about 12.7 metres between 1939 and 1965. So, the annual lowering of the bed at the bottom of the fall is 0.5 metres per year.

Further, it was estimated from the reports of several old residents that the fall began to grow at about the end of the 19th century, after the lower terrace-II (Fig.2B & 4) was formed. The lower terrace-II is distinguished from the lower terrace-I by a characteristic veneer which contains gravels such as serpentine transported from another drainage basin after the destruction of the dammed lakes.

The channel has gradually been lowered above the knick-point with the progress of time, while accelerated lowering has recently become outstanding in the course below the

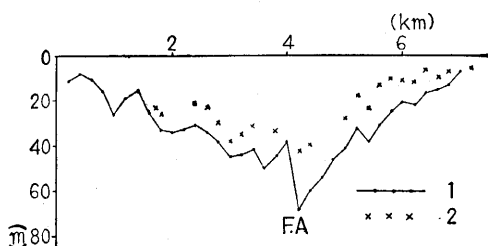


Fig. 5 Diagram showing the progress of degradation along the upper reaches of the Abe River
 abscissa: distance, ordinate: amount of lowering of the river bed
 1: amount of degradation from 1702 up to present 2: amount of degradation from 1702 to the end of 19th c.

knick-point. The progress of lowering of the channel is diagrammatically shown in Fig. 5.

The mass transported from the upper reaches to the lower during the past 260 years since 1702, is estimated to be $3.1 \times 10^7 \text{ m}^3$ on the assumption that it is equal to the volume of the rejuvenated valley. In consequence, the stream was transporting debris from the limited stretch at a rate of $1.2 \times 10^5 \text{ m}^3$ per year. This quantity obtained does not include the mass of debris from the Ohya slide scar itself neither the material from several tributaries. Besides, at present the Ohya slide scar does not produce so much debris as in the past and is considered to have become stable with the passage of time.

The rejuvenation after the mudflow deposition might have been caused by two factors: One is mentioned above, namely the decrease in load from the upper mountain slopes, the other may be the steepness of the valley floor constructed by the mudflow.

Under similar geological and topographical conditions, another case of rapid erosion was found in the upper area of the Sakihama River, in the southeastern part of Shikoku island, which will be shown later in Table 3.

The Jôganji River (Machida, H., 1962)

The Jôganji River is one of the typical torrential rivers in the Hokuriku district, central Japan. It rises from Tateyama volcano, a highly dissected volcano, at about 2,800 metres above sea level, and deeply undercuts the mountain composed of various basement complexes. In the lower part of the river have developed a large alluvial fan and a deltaic plain facing Toyama Bay. The entire length of the stream is only about 40 kilometres and the gradient is very steep.

The mountains in the upper drainage area of the river have been strongly eroded, possibly due to following topographic and geological conditions; the preservation of the long and steep slopes of the dissected caldera wall and the

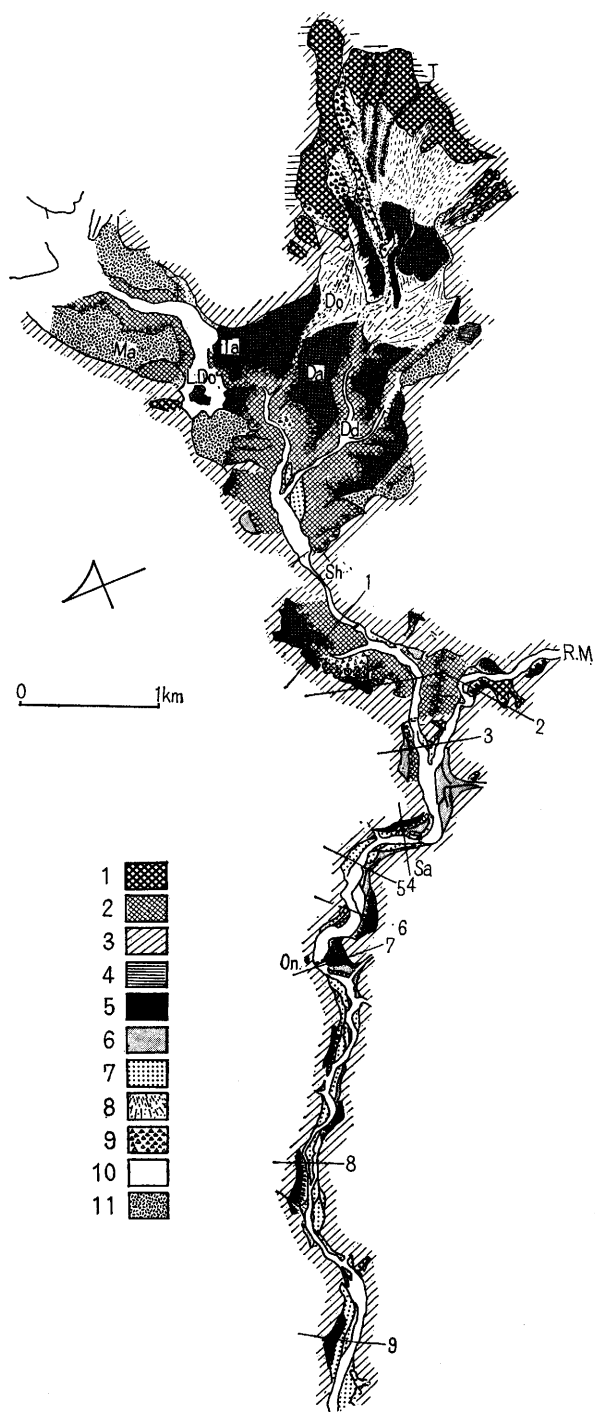


Fig. 6 Geomorphological map of the upper Jōganji River

1: free face in the landslide scar 2: escarpment of the higher terrace 3: valley side slope 4: gentle or flat surface on mountain top 5: higher terrace surface (formed from 1858 to 1885) 6: lower terrace surface I (formed during 1885 - 1930) 7: lower terrace surface II (formed during 1930 - 1960) 8: talus 9: recent slide debris 10: present river bed 11: depositional surface of older mudflows

T: Tombi slide, Da: Dashiwara-daira, Ma: Matsuo-daira, Ta: Tateyama hot spring, L.Do: Lake Dojō-ga-ike, Do: Dorō-dani River, Dd: Dashiwara-dani River, R.M.: Makawa River, Sh: Shiraiwa dam, Sa: Sabutani dam, On: Onigajō dam

presence below of less resistant pyroclastic materials, lavas, and granitic rocks, containing post-volcanic solfataric clay.

Enclosed within the caldera wall lies a huge volume of mudflow derived from the caldera wall, and badland topography extends over a vast area, and this is the most important source of bed load in the river.

In the bottom of the valley river terraces develop extending about 10 kilometres from the caldera wall to the lower reaches (Fig. 6). They are constructed chiefly of mudflow deposits, and on every higher terrace downstream from Shiraiwa dam site, fluvial terrace gravels overlie the mudflow conformably. Compared with the case of the Abe River, the mudflow deposit is less uniform in composition, so that it might have flowed down in a very turbulent condition. The depositional surface of mudflow, or higher terrace, at the stretches upstream from Shiraiwa dam site is more rugged with many flow mounds.

Cross sections of the terraces are shown in Fig. 7, and the longitudinal profile in Fig. 8. In this case also the higher terraces are distinguished from the lower, rejuvenated terraces.

The mudflow deposit can be traced upstream geologically and topographically. As a result, it was found that the mudflow originated from the gigantic slide scar on the caldera wall, named "Tombi slide", the largest of many slide scars in this area. Its area is 130 ha. and the relative height about 600 metres.

Judging from the records of natural disasters, the Tombi slide and related mudflow occurred on February 25, 1858, and was caused by an earthquake. Further mudflows followed twice; one on March 10, and the other on April 26 in the same year, both caused by torrential rain and snow-melting. The large mudflow dammed several tributaries at their confluences forming lakes. One of them can still be seen as Lake Dojô-ga-ike at present but others have already disappeared. It appears that the mudflow was deposited along the upper reaches of the River Jôganji, especially in the limited segment where the higher terraces are found, but a close examination of the distribution of the mudflow deposits indicates that the mudflows in 1858 flowed as far as the Jôganji alluvial fan and deltaic plain, about 40 - 50 Km. downstream from the source. On these plains one can find a peculiar deposit less than one metre deep under the sand layer and paddy soil. It consists of unsorted and practically unstratified materials containing large blocks and many

Fig. 7 Cross sections of the upper Jōganji River (Localities are shown in Fig. 6)

1: older terrace deposit including the river bed deposit before the mudflow accumulation 2: mudflow deposit of 1858 3: higher terrace gravels 4: lower terrace gra-

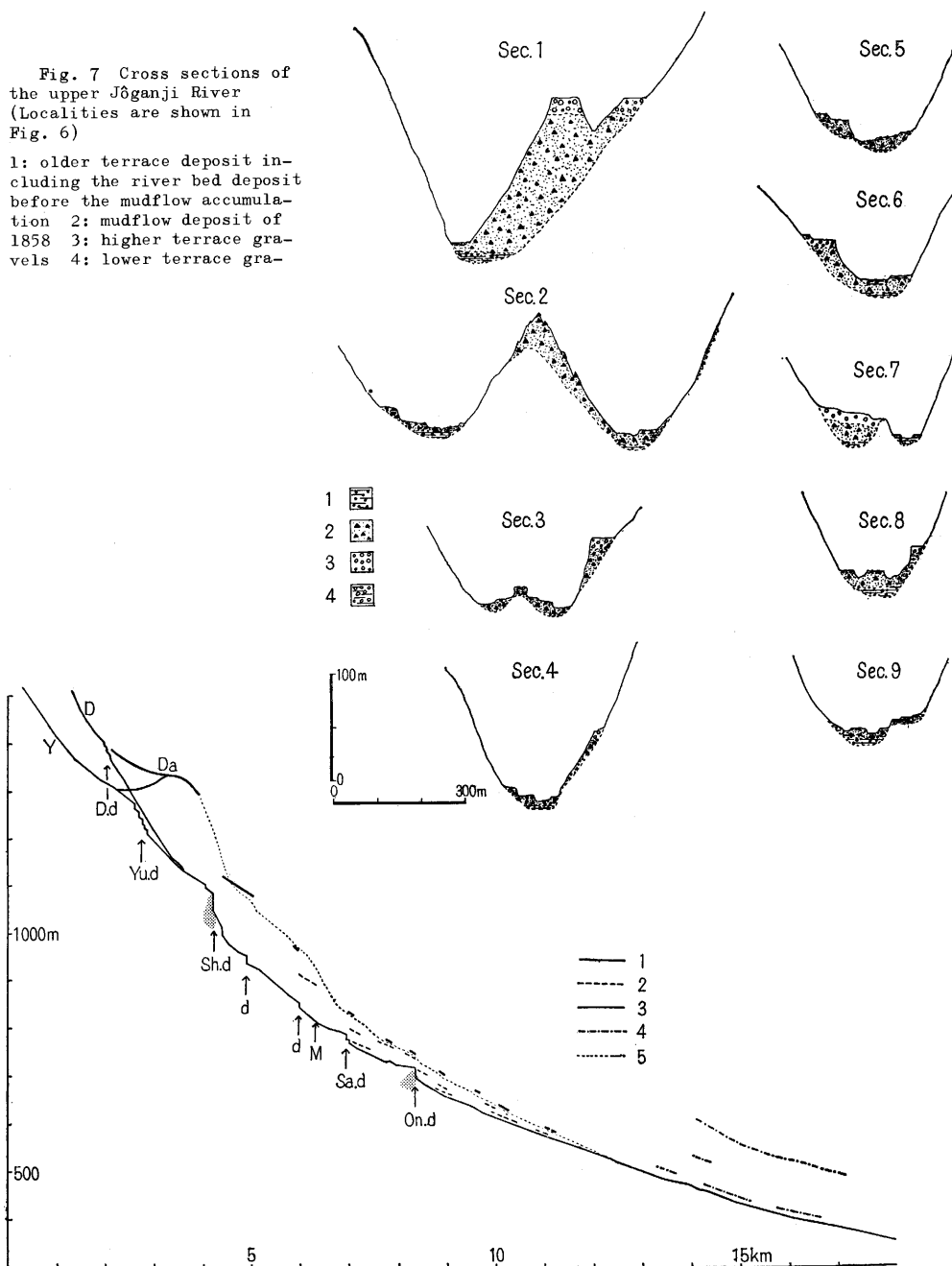


Fig. 8 Longitudinal profiles of present river bed and terraces along the upper Jōganji River abscissa: distance, ordinate: elevation above sea level 1: higher terrace surface 2: lower terrace surface 3: present river bed 4: Pleistocene terrace surface 5: original surface of 1858 mudflows (estimated), d: dam

pieces of wood. From these features it can be correlated with the mudflow deposit along the upper reaches. Its thickness is less than one metre, so the mudflow was deposited almost exclusively along the upper reaches, elevating the valley floor more than 150 metres at its maximum. The total amount of mudflow deposit is calculated roughly at $4.1 \times 10^8 \text{ m}^3$.

Channel scour on the waste filled valley floor began just after the deposition at the steepest part of the profile, which might have been near the present Shiraiwa dam site. Early rejuvenation might have occurred mainly as a retreat of the original knick-point. The debris eroded from upper reaches was transported and deposited on the mudflow deposit as the higher terrace gravels (Fig. 7). Then the head of the rejuvenated valley migrated some distance upstream, and the rejuvenation gradually extended downstream a distance of a few kilometres. The lowering of the channel attains a maximum of about 140 metres below the uppermost knick-point and gradually decreases downstream (Fig. 8).

The age of the formation of several lower terraces in the rejuvenated valley was roughly estimated from dendrochronology. And moreover, one can use the cross sections of the valley measured in 1922, from which the level of the past valley floor is clearly known at each section. From this data, one can illustrate the progress of the lowering of the channel as in Fig. 9. It is clearly shown that the degradation was faster in earlier stages especially along the upper reaches. In old manuscripts one can find some interesting records that in April 1858 some of the dammed

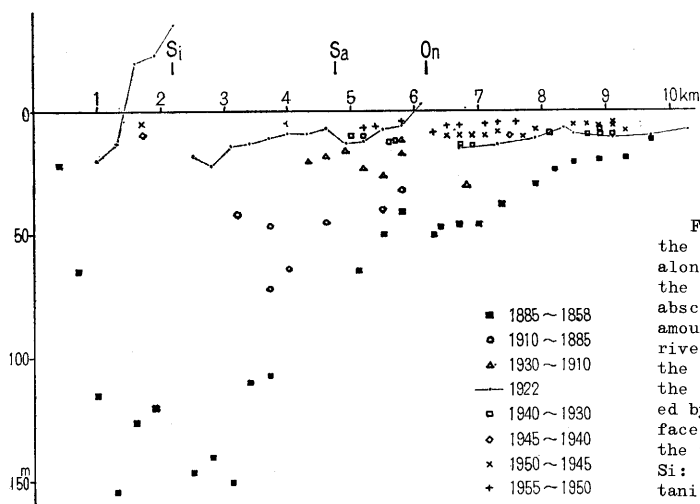


Fig. 9 Diagram showing the progress of degradation along the upper reaches of the River Jōganji
abscissa: distance, ordinate: amount of lowering of the river bed, estimated from the relative height between the past river bed, indicated by several terrace surfaces and measurement, and the present (1960)
Si: Shiraiwa dam, Sa: Sabutani dam, On: Onigajō dam

lakes were destroyed because of the heavy increase in discharge due to snow-melting, and that in 1922 an erosion control dam, the predecessor of the present Shiraiwa dam, was destroyed following heavy rain. On all such occasions, the scour might have been rapid, for example in the case of dam destruction in 1922, it was recorded that the scour attained at its maximum of several tens of metres. Recent decreases in the degradation along the upper reaches (Fig.9) may be due to decreasing gradients with a general reduction of the stream and to the effects of some erosion control dams which were constructed recently.

Compared with the tendency in the upper reaches, the deepening has been slower in general along the middle to lower reaches of the rejuvenated valley, but has been accelerated recently as shown in Fig. 9. This may suggest that the formation of the higher terrace was delayed in the lower course, that is to say, the surges of erosion extended from the upper to the lower reaches as in the case of the River Abe.

The severe erosion in the upper part of the rejuvenated valley might have been caused chiefly by the steepness and the roughness of the waste filled valley floor, and in the lower part, chiefly by the decrease in load.

The total amount of material eroded by the rejuvenation is calculated roughly at about $2.0 \times 10^8 \text{ m}^3$ during the past 100 years since 1858. Consequently about 50 % of mudflow deposit has been transported downstream.

These materials have been deposited covering a large part of the alluvial fan and delta on the occasion of floods the most severe being in 1891 and 1914. The changes of river bed on such plains are characterized by a conspicuous aggradation along the segment between 50 and 10 metres above sea level. This heavy deposition is due fundamentally to the decrease in gradient of the river at the boundary between fan and delta, and was promoted by repeated embankment. The relative height between the foreland and inland attains a maximum of 8 metres and averages about 3 - 5 metres. Judging from Mitsui's report (Mitsui, 1955) on the situation of the river profile on the fan region, the aggradation of the river bed had been faster in an earlier stages, 2 - 3 metres during early 50 years, and has been slower 1 - 2 metres during the last 50 years. It seems probable that the progress of deposition coincides with that of erosion in the upper rejuvenated valley.

In conclusion, then it was found that erosion in the Jôganji River during the past 100 years has progressed severely.

The Ura River, a tributary of the Hime River
(Machida, H., 1964)

The Hime River rises in the Shirouma range of high mountains, and flows through the conspicuous structural zone and empties into the Japan Sea. Throughout this structural zone, especially in the western areas of the middle Hime, several composite volcanoes are found such as Mt. Shirouma-Norikura, Mt. Hieda and Mt. Kazafuki from south to north. This mountain area gives rise to a very severely eroding stream, named the Ura River, joining the Hime in its middle reaches.

This drainage basin is one of the severest slide areas in the country. The slides occur rather frequently and are of such magnitude that single slides reach 100 to 200 ha. in area. So much debris was produced that the river bed itself was readily mobile and had a strong influence on the stability of the river bed of the Hime. The fragile volcanic rocks containing solfataric clay with abundant joints provide a favorable condition for these phenomena in the area. In addition, the annual precipitation of over 2,500 mm. 35 % of which falls in the form of snow, also provides a large amount of groundwater that may accelerate chemical weathering of the rocks and precipitate the mass-movements.

On August 8, 1911, there occurred a large landslide on the steep slopes of Mt. Hieda, on the southern divide of the Ura. In the following snow-melting season, two supplementary slides occurred on the scarp adjacent to the 1911 slide scar. Largest amount of debris poured down in the form of a typical mudflow and the River Hime was dammed at its confluence with the Ura.

This catastrophe was so striking that much attention was paid to it by geologists at the time. Details were described by Yokoyama (1912) immediately after the catastrophe. During the 60 odd years since 1911, erosion has progressed rapidly along the Ura River so that one can trace the topographic changes easily.

The Hieda slide occurred on the steep slopes of a highly dissected strato-volcano, and might have been related to the heavy rain which fell four days before the occurrence. The landslide debris originally swept about 6 kilometres down

the valley in the form of a mudflow and was deposited in the valley, raising the valley floor a maximum of about 100 metres and steepening the gradient. Fig. 10 is a geomorphological map of the middle to lower reaches of the River Ura. The surface of the mudflow deposit is comparatively rugged with many flow mounds. Just after the catastrophe, the superimposed river bed started incising itself due to the decrease in material provided from the slopes.

As mentioned previously, the mudflow dammed the Hime River at its confluence, forming a lake. When this dam itself was washed away during the floods in the following year, a knick-point was formed on the lower reaches of the Ura River, but this disappeared before it had time to migrate far upstream because of rapid deepening along the upper reaches and consequent deposition along the lower reaches. The changes in river profile are illustrated in Fig. 11. The profiles of 1911, 1912 and so forth were estimated by plotting from the terrace surfaces and topographic map surveys of 1912. From information such as photographs taken in 1912, 1936, and 1955 - 1965, it is also known that vertical erosion was rapid in the earlier stages but lateral erosion became more important during later stages.

The quantity of the mudflow deposit is roughly estimated at $1.5 \times 10^8 \text{ m}^3$. The area of the slide scar is about $1.8 \times 10^6 \text{ m}^2$, and the average depth of the landslide in 1911 - 1912 was calculated to be about 55 metres if the porosity was assumed to be 33 % in the mudflow deposit.

The mass eroded during the past 50 years, provided that it equals the mass eroded from rejuvenated stretches, is calculated to be $3.3 \times 10^7 \text{ m}^3$. In consequence the Ura introduced such heavy loads into the Hime that the river bed of the latter was elevated a maximum of 30 metres and caused an increase in the gradient below the point of confluence due to the bed load which may well persist for a long time (Fig. 11).

The same tendency in the profile changes as stated above has also been observed during a short period from 1964 to 1965. Because of the torrential rainfall on August 29, 1964, a large amount of debris started to slide rapidly on the very incompetent steep slopes of Mt. Kazafuki, about 3 kilometres upstream from Mt. Hieda. The debris flows which occurred repeatedly from summer to spring in the following year were smaller in magnitude than in the case of Hieda in 1911, but the bed of the Ura River was considerably altered. Fig. 12 shows an outline of the profile

Fig. 10 Geomorphological map of the middle to lower reaches of the Ura River

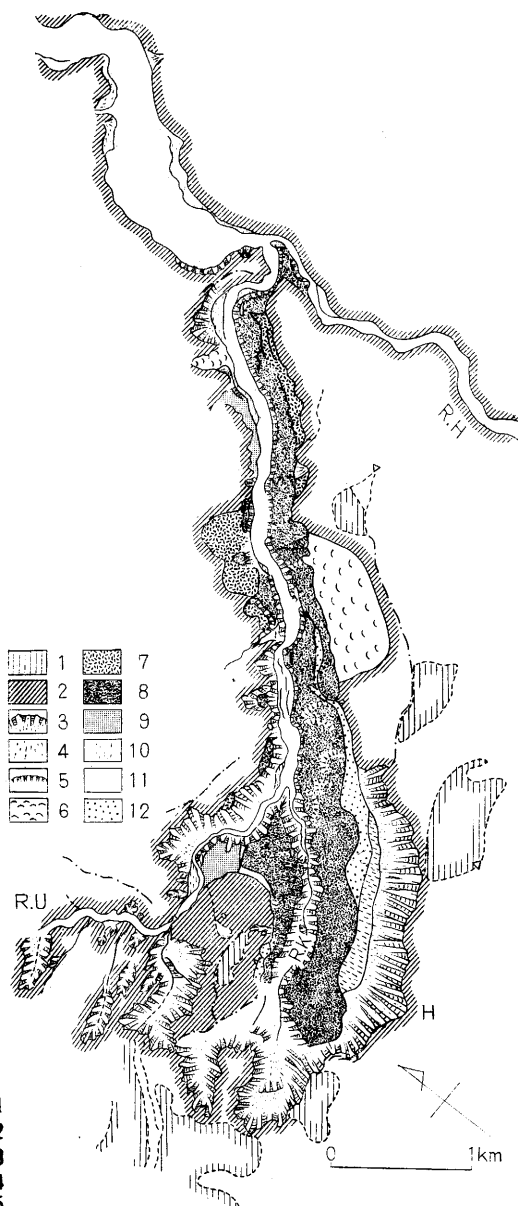
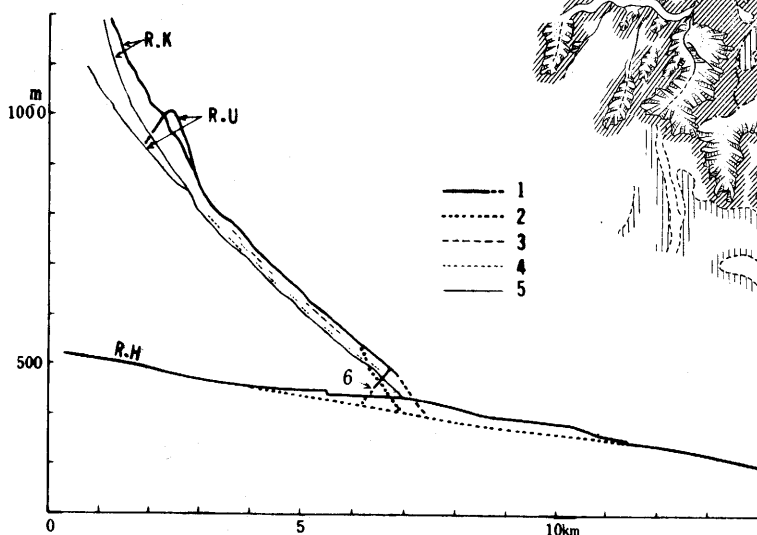
1: gentle or flat surface on mountain top 2: steep slope 3: escarpment of landslide scar 4: talus 5: escarpment of higher terrace 6: sliding block 7: depositional surface of older mudflow 8: depositional surface of the Hieda mudflow (higher terrace) 9: lower terrace surface I 10: lower terrace surface II 11: present river bed 12: river bed on the higher terrace

H: Mt. Hieda, RH: Hime River
RK: Kanayamazawa River, RU: Ura River

Fig. 11 Longitudinal profiles of the present river bed and the past along the River Ura and the Hime

abscissa: distance
ordinate: elevation

1: depositional surface of the 1911 mudflow, 2: river bed of 1912, 3: lower terrace surface I (formed approx. in 1922), 4: lower terrace surface II (formed approx. in 1936), 5: present river bed



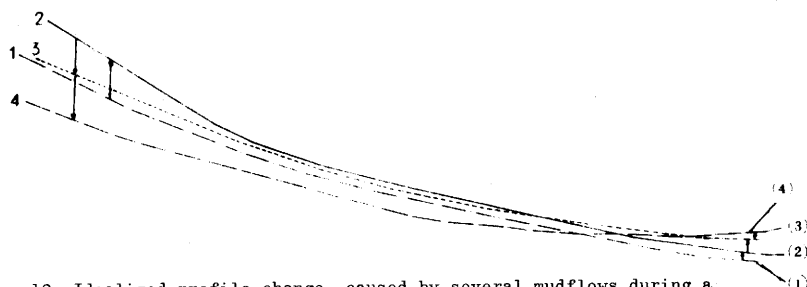


Fig. 12 Idealized profile change, caused by several mudflows during a short period from 1964 to 1965. 1: profile before Aug. 29, 1964, 2: profile on Aug. 29, 1964, when a steep slope of Mt. Kazafuki began to slide and a large mass of debris flowed downstream, 3 & 4: profiles after autumn, 1964

change. The scour has been continued along the upper reaches caused by several small mudflows which have a somewhat higher water content, reaching a maximum of 17 metres deep during a few months. Moreover, severe lateral erosion of the river bed has been observed everywhere, an estimated maximum of 20 metres from the cross sectional surveys. Deposition on the bed of the lower Ura and the Hime Rivers has also been clearly observed. Damming of the Hime River happened several times and aggradation of the bed at the confluence has reached maximum of 20 metres.

The influence of the Ura upon the lower course of the Hime, 25 - 30 kilometres downstream from the Ura area, has been increasing as follows. Considerable expansion of the fan at the mouth of the river, and widening and raising of the river bed on the fan have been observed, but their magnitude has not yet been so large as in the case of the River Jôganji. From the standpoint of the source of the bed load, it can be considered that the materials of the Hime below the confluence were derived from the three sources; (a) Mt. Hieda and its mudflow deposits, (b) Mt. Kazafuki ((a) and (b) were transported by the Ura), (c) the upper area of the Hime River. The proportions of debris supplied by each river were estimated by calculation from the lithologic analysis of gravels, the procedure of which is illustrated in Fig. 13. The results are as follows;

$$a_i x + b_i y = l_i \quad i = 1, 2, 3 \dots n$$

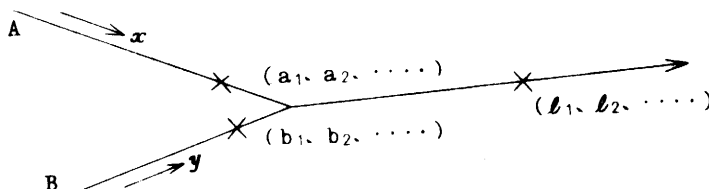


Fig. 13 Calculation of sediment transport rate by means of lithologic analysis of gravels. x, y : sediment transport rate from the tributaries A & B, respectively, i : number of rock types of gravels

(a) 41% (b) 26% (c) 33%. Area of the region (c) is twenty-one times as large as the combined area of the regions (a) and (b), which indicates the high rate of erosion in the latter. Consequently, it was found that more than half of the gravels of the Hime River came from the Ura River dissecting the mudflow deposits of 1911, although the Ura is only a small tributary of the Hime.

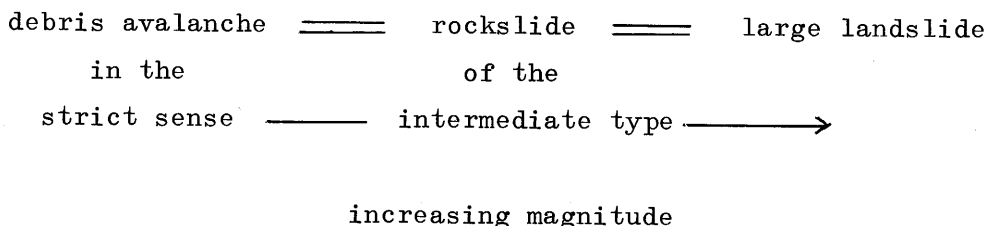
Discussion

Nature of large landslides and related mudflows

It is the gigantic landslide that caused the accidental change of the valley topography and precipitated the severe river erosion in each case studied. So, in order to evaluate these rapid denudation phenomena, one must elucidate the nature and the position of such large landslides in the whole series of mass-movements. The classifications of the various mass-movements proposed by Heim (1932), Sharpe (1937), Highway Research Board (1957) and many other authors, were based chiefly on the kind of material, and type and rate of movement. Each mudflow studied in this paper was an avalanche type of turbulent flow of fragmental materials originating from a large landslide, and from the viewpoint of its influence upon the development of valley, it is clear that the magnitude itself is the most important factor.

Thus, the author intends to propose a classification of mass-movements of rapid flowage type to stress the significance of the differences in magnitude. As will be seen in Table 1, three subdivisions are made namely, large landslides, rockslides of intermediate type, and debris avalanches. The volume of material involved gradually increases from left to right. This classification does not cover the whole range

Table 1 Classification of mass-movements
of rapid flowage type



of mass-movements but only the rapid flowage type in Sharpe's sense (1937), and the terms proposed are not used in the strictest sense of the word, because there have been no appropriate terms suggested as yet.

The previous classifications may seem to ignore the differences between large and small landslides or mudflows, and were concerned instead with the mode of mass-movement of debris avalanche type there defined. Moreover, it appears that the three subdivisions are closely related to differences in materials, type of movement, and basic conditions as well as active or initiating causes of occurrence. Table 2 shows a comparison of characteristics of these subdivisions.

Table 2 Comparison of characteristic features of mass-movements of rapid flowage type

	Large landslide & related mudflow	Rockslide of intermediate type	Debris avalanche
Order of volume eroded	$10^9 - 10^7 \text{ m}^3$	$10^6 - 10^4 \text{ m}^3$	$10^3 - 10^1 \text{ m}^3$
Kind of material	bedrock	bedrock & earth	earth
Shape of plan erosion scar section	usually wide at the base commonly indefinite form very deep	as well as at the top, deep	usually wide at the top & narrower downwards, controlled by original slope form superficial
Location & deformation of slope	not only at the valley head but also on spurs or ridges, developing a new valley slope & causing successive mass-movements such as debris avalanches, rockfalls & other small processes		usually on the valley head of the 1st order stream or lower wall, deformation is relatively small in extent on the occasion of single phenomena
Nature of debris flows	reaching to a maximum distance downstream, filling a valley to a large extent	reaching to a considerable distance, filling a valley	usually deposited at the foot of the erosion scar, forming a talus or scree
Geologic condition favoring the occurrence	in such limited conditions as fragile volcanic rocks & much fractured sedimentary rocks	several rocks with abundant joints, especially argillaceous rocks	various rock types, especially easily weathered rocks
Active or initiating causes	too complicated to be elucidated, possibly due to the water condition deep in the bed-rocks	unusual increase in groundwater	various causes such as heavy rainfall, earthquake and other natural as well as human agencies
Frequency	rare		frequent

Table 3 Large landslides which occurred in historical times

	Age of occurrence	Geologic & topographic condition	Initiating cause	Area of landslide	Amount of mudflow deposit	Average depth of landslide*	Amount of erosion after the mudflow deposition	Amount of deposition on fan	References
Bandai Volcano	1888	strato-volcano dissected to a considerable extent	phreatic explosion	3.8×10^6 m ²	1.2×10^9 m ³	2.0×10^2 m	m^3	m^3	Sekiya & Kikuchi (1890)
Tombi Slide, the J6ganji R.	1858	dissected volcano with a large erosion caldera	earthquake	1.3×10^6	4.1×10^8	2.0×10^2	$2.0 \times 10^8/100$ ys.	2.0×10^7	Machida (1962)
Hieda Slide, the Ura R.	1911	strato-volcano dissected to a large extent	possibly, heavy rainfall	1.8×10^6	1.5×10^8	5.5×10	$3.3 \times 10^7/50$ ys.		Machida (1964)
Ohya Slide, the Abe R.	16th c. - 1702	sheared clay-slate & sandstone of Paleogene or Mesozoic	possibly, heavy rainfall	1.8×10^6	1.2×10^8	4.5×10	$3.1 \times 10^7/260$ ys.		Machida (1959)
Mayuyama Volcano, Shimabara	1792	lava dome, highly brecciated lava	earthquake accompanied by the volcanic activity of Mt. Unzen	1.6×10^6	1.1×10^8	4.5×10			
Ohsawa Valley, Fuji Volcano	10th c. - present	young strato-volcano with very steep & long slope	1st large rockslide might have been caused by such a shock as earthquake	9.6×10^5	0.6×10^8	4.0×10		1.5×10^7	Ivatsuka & Machida (1962)
Kanagi Slide, the Sakihama R.	1746?	sheared clay-slate & sandstone of Paleogene	possibly, heavy rainfall	4.7×10^5	0.3×10^8	4.0×10			

* calculated on the assumption that the porosity was 33% in the mudflow deposit

Table 3 shows the large landslides and related mudflows recorded over several hundred years in Japan including the three previously mentioned cases. All of them caused decisive damage to inhabitants and caused accidental topographic changes in a similar way as in the cases reported. They differ particularly from the intermediate or small scale mass-movements in the following points (Table 2): a) The slide plane lies deeper in bedrock. Joints or faults in bedrock may probably provide the slide plane. b) The area of individual landslide scars is much more extensive. c) The occurrence is related more closely to the topography of high relief and especially to the limited geological factors, such as the prevalence of shattered rocks and solfataric clay, but their mechanism is too complicated to be analyzed conclusively.

It seems probable that the large landslides in the Alps and other high mountains described by many authors including Heim (1932), Sharpe (1937) and Kawada (1943) might come under the same category as those in Japan. So, it may be suggested that this type of landslide and mudflow characterizes denudation in mountains of high relief and are composed of badly fractured rocks, i.e., in the orogenic zones of the world.

The intermediate size rockslides take place more frequently than the large ones, but the planimetric area of individual slides is smaller, usually less than 10 ha. The slide plane, however, lies deep in bedrock, so that the sliding must be closely related to the lithologic or structural condition of bedrock. In Japan, it is well known that there has been a considerable number of such rockslides on steep mountain slopes of strong relief, especially on slopes composed of rather incompetent bedrock such as clay-slate, phyllite, serpentinite, milonite, several volcanic rocks and other decomposed igneous rocks.

As an example, on June 29, 1961, a large rockslide took place on the slopes of Mt. Ohnishi, Ina district, Nagano prefecture. It is evident that the occurrence was fundamentally caused by the condition of the rock, fractured milonite, and that it was initiated by the extraordinary heavy rain which fell two days before. It was closely related to an unusual increase in groundwater in the deep cleavage fractures. The area of the slide is about 15 ha. and the mass is estimated at about $3.2 \times 10^6 \text{ m}^3$. It is interesting to note that during the maximum rainfall many smaller debris avalanches occurred on all slopes, especially densely on slopes of granite (Murano, 1965).

Debris flows accompanied by intermediate rockslides also produce a considerable amount of debris and sometimes have a great influence on the river bed, but the scale is usually smaller than with the large landslides.

Although many causes of rockslide can be listed in general, the major cause may be unusual increases in hydrostatic pressure of groundwater in weak zones after heavy rain.

Mass-movements of the debris avalanche type have commonly occurred actually caused by heavy rainfall or earthquake, so that considerable attention has been paid to the mechanism of occurrence, classification according to moving types, control or prevention methods, etc. Such phenomena are superficial mass-movements on the slope and the slide plane does not reach deep into bedrock but lies in a weathered horizon. Thus material commonly pours down the slope when heavy rainfall saturates residual soils. In the mountainous districts of Japan, a large number of debris avalanche frequently occur in a limited area, such as in the Ina disaster in 1961, but individual slides produce relatively small amounts of debris and hence their influence is not on such a scale as large landslides or rockslides.

Again, it is pointed out that as landslides and related debris flows become smaller and smaller they are more and more widespread in distribution on almost all rock types if the slopes are sufficiently steep. On the other hand, large landslides and related phenomena are distributed under limited geological condition. In Japan, the historical cases as shown in Table 3 suggest that the condition of dissected volcanoes and of the badly fractured zone of sedimentary rocks are both favorable for their occurrence. As evidence in support of this, one can demonstrate several other cases which have occurred in pre-historic times closely related to these geological conditions. Consequently, such catastrophic progresses of erosion must have played an important role in dissecting volcanoes and other slopes composed of shattered rocks.

Significance of rapid topographical changes in the bottom of valleys

The series of recent topographic developments described in the previous chapter, are appropriate models for establishing some theses of river development.

The conditions of these erosional developments are

listed as follows:

1) The amount of debris accidentally produced from mountain slopes was deposited almost exclusively along the upper reaches, resulting in steepening of the gradient of the valley floor. 2) Further, the volume of debris entering the stream has gradually decreased from the slide scar. Under these conditions the river started to actively rejuvenate. The major characteristics are summarized as follows: a) The change of longitudinal profile caused by the rejuvenation progressed in the usual manner, i.e. the curvature of river profile increased with the passage of time as shown in Fig. 4 & 8. That is to say, downcutting started at the stretches where tractive power at its maximum, and gradually extended its range downstream as well as upstream. b) The materials produced from the rejuvenated stretches were transported downstream and deposited along the lower reaches of the river. c) The recent deposits after mudflow deposition on the lower course occupy a relatively small part of the mass transported from the upper reaches (less than 10 % in the cases of the Jôganji River and the Fuji-Osawa River, Table 3). d) There may be a tendency towards the reduction of topographic change with time. e) The rate of erosion seems to depend upon gradient of the bed and the discharge. For example, in the case of Mayuyama Volcano and the Kanagi slide (Table 3), the topographic change has been less than in the cases described in this paper, for the reason that the river gradients are not so steep with the exception of the uppermost part, and that discharge is not so high.

The conditions causing such erosional developments do not include all those of large scale, but the progress of such rejuvenation may be useful for the discussion of the development of river terraces in some cases, i.e., there may be a considerable degree of correspondence between the rapid terracing described here and the formation of climatic river terraces during the time from glacial to post-glacial ages, because it is commonly observed in Japan that some river terraces built in the Würm glacial age have a depositional character and a steep profile in the upper reaches while these Würm terraces have been entrenched by the post-glacial rivers. In consequence, the rapid changes in river profile may help to explain the mode of river terrace formation in the late Quaternary.

It is expected that further studies will be carried out on the correlation between a variety of geomorphological conditions and the modes of development.

Summary and Conclusion

It was demonstrated that the denudation in the torrential river basins has progressed rapidly enough to show the conspicuous changes of topography in the valleys as well as on the slopes.

In mountainous districts in Japan, rivers are usually torrential and the rapid progress of erosion such as in the cases reported must have played an important role in landform development, particularly in dissecting volcanoes and other mountains composed of highly shattered rocks.

It is also pointed out that the precise studies on the recent development of slopes and valleys is particularly significant for developing a synthesis of actual landform evolution, and hence this will be an important field for future geomorphological research.

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