A Study of the Movements of Bed-sediment along Azusa River, Japan

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I. INTRODUCTION

1. The Problem

Large movements of bed-sediment occur along mountain rivers in Japan and create a problem in the design, operation and maintenance of river control works, particularly dams as the effective storage volume of reservoirs behind dams becomes rapidly reduced due to accumulation of river sediment or debris.

2. Method of predicting the Debris Yield

Present methods in use for predicting Debris Yields, the volume of debris delivered to a particular point on the river system, may be grouped under four headings as follows:

i. comparison with existing data for similar catchment areas.
ii. installation of debris-load measuring stations.
iii. estimation of erosion rates and delivery ratios, based on experience.
iv. use of one of the theoretical or semi-empirical formulae.

The first and the third cases give only very approximate results. The second case refers to the measurement of suspended load in practice, for it is not an economical proposition to attempt to measure movements of bed-sediment directly. The fourth method can be used in some cases, the difficulties of calculation not withstanding, but if it is used on mountain rivers it almost always leads to gross over-estimation as the rivers do not in general carry their capacity load (section IV/1).

3. Measurements of Debris Yield in this study

Because of the many difficulties in using the above mentioned methods, a different line of approach was used in this study and measurements were restricted to the Debris Yield of the bed-load only, and direct measurements to within specified size ranges within the bed-load. Essentially, this method consists of analysing the movements of debris throughout the system from analyses of the geological composition of the bed material above and below major confluences, and correlating this data with existing yield data from measurements of accumulations behind debris control dams.

Step 1 : The first step in this process involves measuring the debris contributions from each tributary at all the major confluences, always working within the specified size ranges (section IV/1), expressed as a percentage of the material from both tributaries. This is done by accurately measuring the geological composition of the bed material in each tributary above and below the confluence. In a simple case, if the bed material of one tributary is 100% granite for example, and that of the other tributary is 100% sandstone, the percentages of granite and sandstone in the bed material below the confluence represent the contributions of debris from each tributary by percentage. In practice the compositions are almost always a mixture, in which case a simple calculation will give the proportions from each tributary (referred to here as "Debris Proportions" or simply "Proportions"). If there are three or more geological groups in the bed-sediment, three or more semi-independant calculations can be carried out for the Proportions, but more than three groups tends to lower the accuracy.

Step 2 : The next step is to connect the individual results for each confluence of step 1 into a continuous series starting at the downstream confluence. Two facts must be taken into account for the reaches of river between any pair of adjacent confluences:

i) there will be an additional Yield from the catchment area between the confluences, and

ii) the Debris-delivery Ratio must be taken into account as all the material passing the upper confluence may not reach the lower one or material may be transported from along the reach. If the Debris-delivery Ratio is estimated or assumed, the simplest way to do this is the measurement of the percentage reduction of a geological group which does not enter the river along the reach between the confluences. This will show the relative volume of debris added along the reach.

Step 3 : If the movements throughout the system are determined from step 2, the actual volume moving can be found in principal if the actual volume passing any one point on the system is ascertained from another source of data. However, this correlation is always approximate in practice due to the highly irregular nature of the debris movement and the virtual impossibility of ascertaining a true average for any of the results, for even if one obtains an average for two points on the system, these are not likely to be strictly compatible because the average condition at one point would be unlikely to occur at the same time as those at the other point. In practice, one has to compare the results obtained for step 2 with what Yield data exists for the catchment area, and derive possible values by a process of estimation and adjustment.

Aerial photographic interpretation was used extensively in this study, initially to examine the erosion processes qualitatively and to compile a map of erosion intensity, and later in the field, not only in geological mapping, but also to select Sampling Points and as a reference and qualitative check on the field results as they were obtained. Without large scale aerial photographs this part of the study would have been more difficult and time consuming; the level of interpretation required in the field is not high. The Azusa River is naturally divided into the Upper and Lower parts by a volcano which has dammed the river (Mt. Yakedake, Fig. 1).

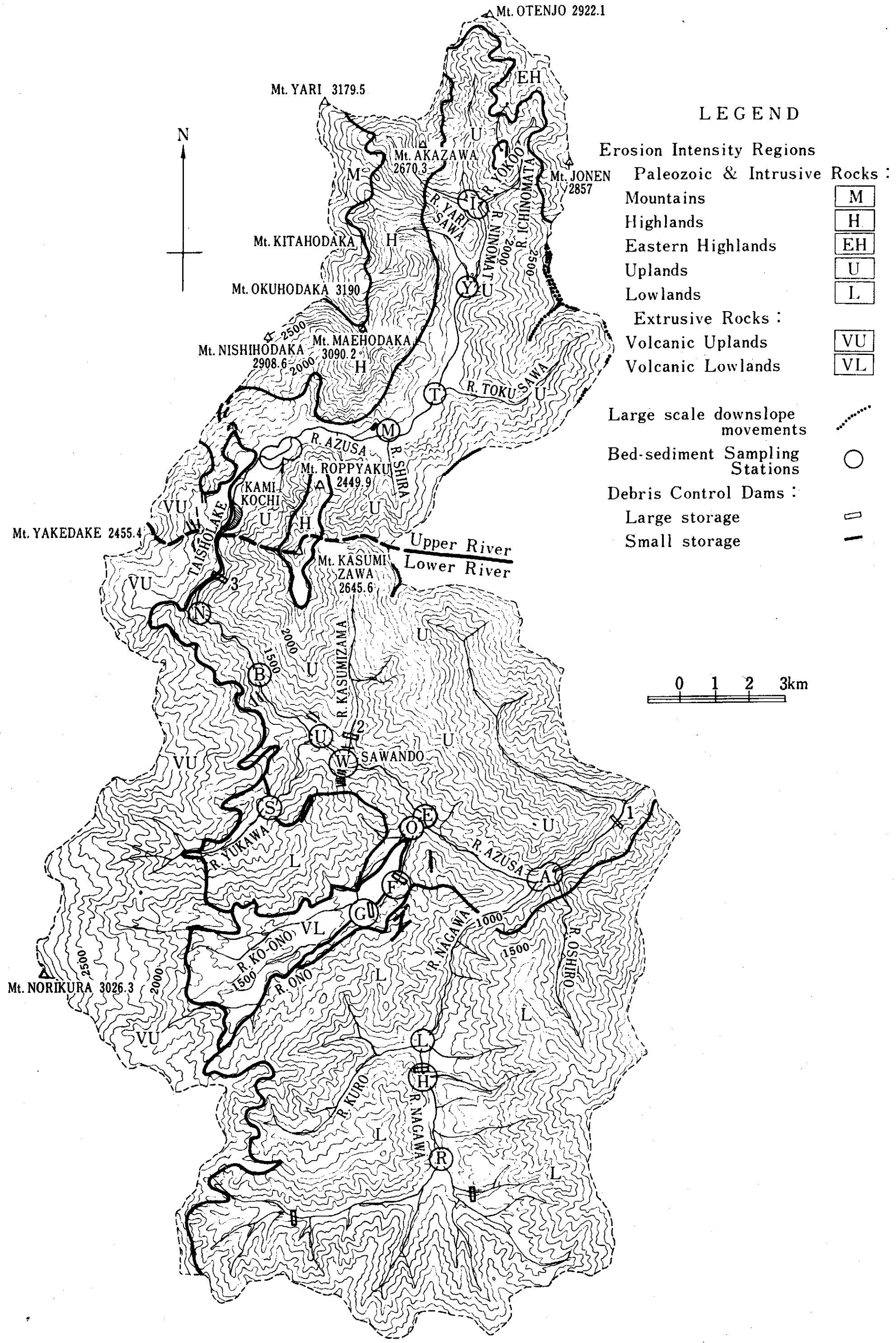

Fig. 1 Erosion insensity of the Azusa River

II. GEOLOGY

This region lies in the central part of the Hida Mountain Range in the southern region of the Japanese Alps. The upper part of the Azusa River Basin covered here lies in Paleozoic sediments which have been intruded in the north by Mesozoic porphyrite and granitic rocks, forming the main mountain mass of the region, and a smaller intrusion of granite is exposed in the south. The western flank of this region is ringed by Quaternary volcanic deposits. The geological map is shown on Fig. 2.

The Paleozoic sediments consists of a thick succession of interbeded sandstones, shales and cherts, and show a low degree of regional metamorphism, with folding maintaining a regional NE - SW strike. Zones of contact metamorphism around the intrusions show recrystallization to hornfels. There is, in general no sharp boundary between the sandstones, shales and cherts, making it difficult to separate these groups for bed-sediment identification. Beds of sandstone, shale or chert are usually found in groups of similar composition, probably in lenticular deposits. There are several small outcrops of Mesozoic conglomerate in the northern part of the region.

The intrusive bodies consist mainly of a black porphyrite forming the highest regions and granitic rocks of lower relief, with smaller bodies of quartz porphyry, micrographic granite and fine grained quartz diorite. The volcanic deposits are not differentiated on Fig. 2, and consist mainly of andesites and volcanic rubble from the two volcanoes on the western watershed, Mt. Yakedake and Mt. Norikura.

The wide flood plain of the Upper River is shown, and includes the present active flood plain as well as parts of the flood plain which are covered with vegetation and may be slightly elevated terraces. This flood plain is bounded by either alluvial fans (not shown on map) or by bedrock outcrops.

III. EROSION

Erosion is active throughout the region, but the most coarse materials forming the bed-sediment cannot be derived from areas of sheet erosion and are thought to be mainly derived from areas of channel erosion, i.e. from the "erosion scars" that are found throughout the region and described bellow. Evidence of large scale downslope movement is found, but they are not assumed to be an active mass removal agent at the present time.

1. Erosion Scars

A characteristic of this region is the large number of "erosion scars"

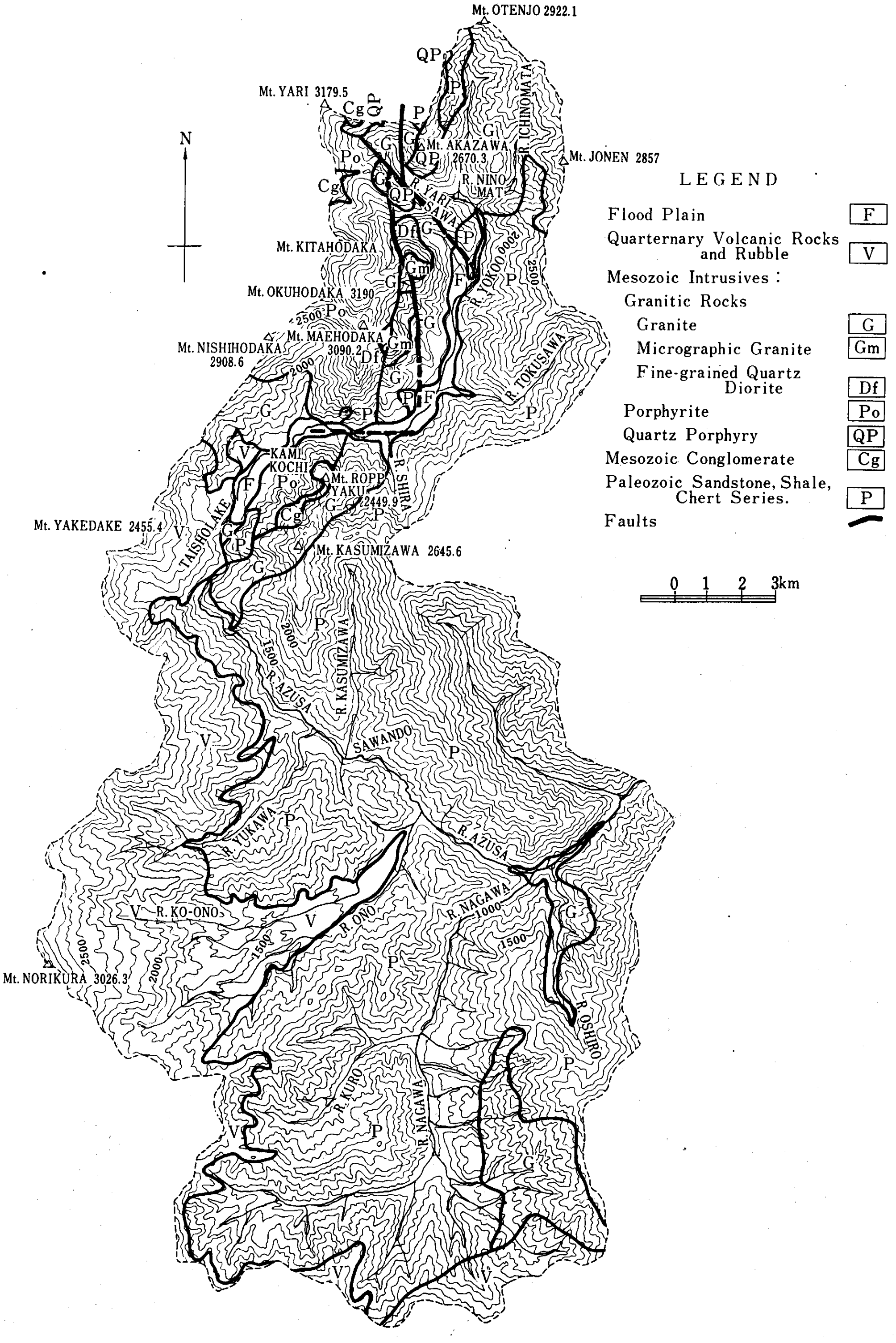

Fig. 2 Geological map of the Azusa River

or areas which the rapid removal of surface material has left bare, often exposing bed-rock unless they occur in recent deposits. These scars vary in size and shape, but observations show that most scars have formed according to one of two dominant patterns referred to as Types 1 and 2. Although these basic types are distinguished by pattern, they result from different mass removal processes.

Type 1 is formed due to instability of slopes. Failure takes place on the slope releasing a large volume of material which falls down to tne base ot the slope, forming its own channel down the slope if the failure does not reach the foot of the slope as is often the case. Growth occurs by sudden failure at or near the crest, and some erosion take place continuously on the exposed surface of the scar.
See Photograph No. 1 for illustration.

Type 2 is formed by toe failure due to undercutting by a river and occurs in loose material. Once began these scars grow vertically and laterally by further erosion along the toes and by mass removal from the exposed surfaces, which may proceed rapidly once the protective vegetation cover has been removed.
See Photograph No. 2.

Intermediate types of scars are found, and a different type of scar that is deep with "U" shaped valleys with vertical side walls is found in the two highest regions ("Mountains" and "Highlands", Fig. 1) which differs from the lower regions in that every valley tends to show erosion to some degree and the distinction between active and dormant scars is less clear.

2. Regional Classification of Erosion Intensity (Fig. 1)

"Erosion Intensity" here refers to mass removal from the land surface in general, and it is described thus because the classification was made based mainly on a study of the nature and density of erosional intensity in scars etc. Volcanic regions are classified separately from regions of Paleozoic sediments and intrusive rocks, because of their fundamentally different landforms and erosion patterns. The former are classified into two regions and the latter into four regions. This study was performed mainly by aerial photographic interpretation, and although afterwards checked in the field, was virtually finished in its final form before field work was started.

i. Mountains : This region is an old land surface of glacial morphology, with a horn, arêtes, cirques and scattered glacial deposits. Erosion within this region has produced much debris, but the debris has been caught in the cirques and on the glacial topography and little or none of it has found its way into the river system.
ii. Highlands : This region includes those parts of the main mountain mass which lies below the region described above, and where the newer, i. e. post-glacial, erosion cycle is causing severe erosion which is retreating into the higher region. It is a region of high relief,

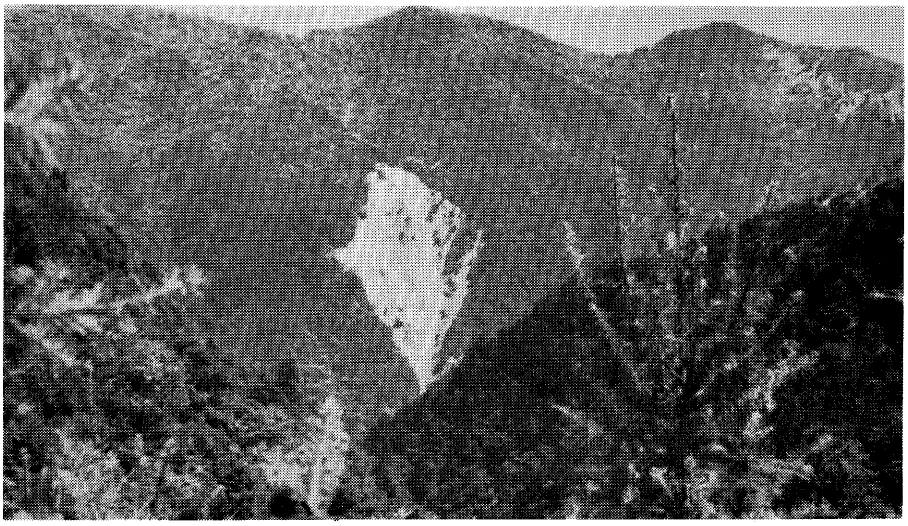

Photo. 1

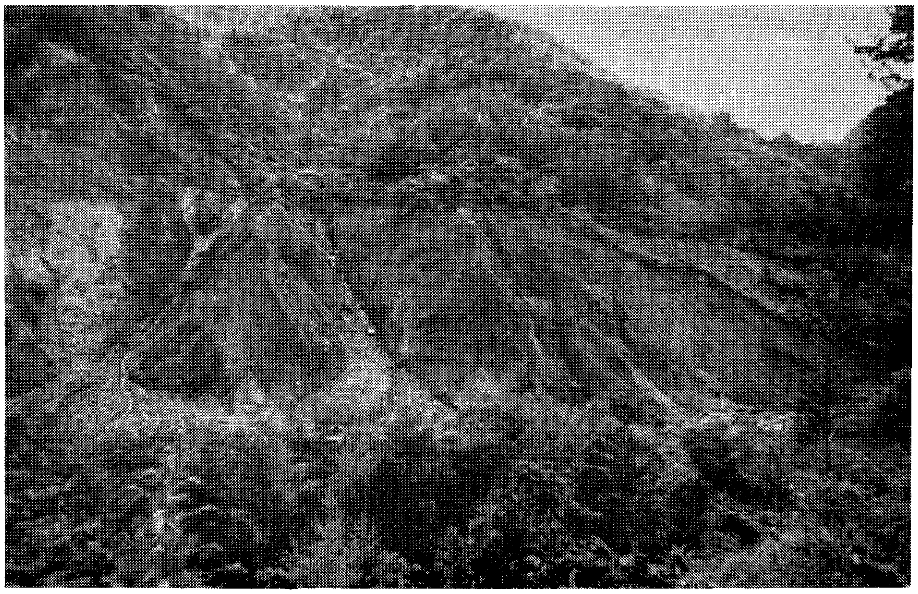

Photo. 2

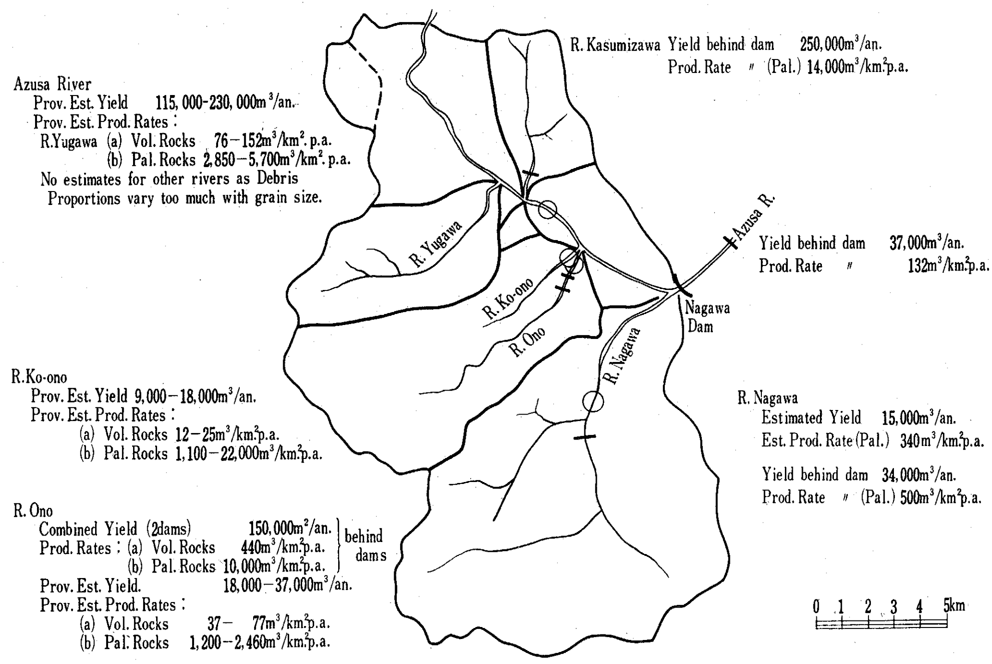

Fig. 3 Debris Yields of the Lower River

Provisionally estimated Debris Yields and Production Rates at the heads of the reservoir behind Nagawa Dam (circled) based on assumption that average geological compositon corresponds to average composition measured. Debris Yields and Production Rates behind debris control dams.

in the north, being re-eroded glacial valleys whose sides are partly burried under alluvial fans. Erosion scars are numerous, and every valley tends to be an active or dormant scar, vegetation being sparse and existing mainly on the ridges. Most of the scars here are in or close to rock, and bare rock is exposed in many places. In the higher parts of the region, the whole surface is incised bare rock with only sparse scrub or no vegetation.

The Eastern Highlands are formed on massive granite and in contrast to the above, have rounded smooth slopes with few scars. The distinctive feature of this region is that the crests of the ridges are bare of vegetation and actively weathered granite is exposed.

iii. Uplands : This is the most widespread region, and is of moderately high relief, with steep valley sides and it is heavily forested. At random locations throughout the region, failure has occured on the valley sides, and a scar of bare or weathered rock has been left where a mass of material has fallen away. Unless the scar is old, there is usually no vegetation present. The density of scars varies from place to place.

iv. Lowlands : This is a region of moderate relief, with a tendancy toward more rounded ridges and a more dendritic drainage pattern than the preceeding region. Scars are much fewer than in the previous region and smaller where they do exist.

v. Volcanic Uplands : This region covers most of the volcanic terrain, and is a region of moderate to high relief, the volcanic terrain being on the whole less dissected than others, particularly Mt. Norikura which in places near the top has a gently rolling topography, but where rivers have cut in, incusion has been deep, particularly in the rubble deposits.

vi. Volcanic Lowlands : This region covers the lower slopes of Mt. Norikura and the lava flows in the River Ono valley, both of which exhibit a gentle flow topography, internal drainage and almost no development of a surface drainage system except for the rivers crossing the region from above, and there is very little erosion.

IV. SUMMARY OF MAIN RESULTS

1. Field work was first carried out on the Upper River as the geological materials in the bed-sediment are more easily identified than in the Lower River. However, the Debris Proportions for the confluences in the middle section could not be found due to the width of the active flood plain there and the relatively small size of the tributaires which results in poor mixing of the debris below the confluence. The most important results here are the Sampling Accuracy Tests carried out at Kamikochi.

Samples were taken from along a 1 1/4 Km stretch of the river which is free from addition of debris for some kilometers upstream. Sampling was conducted on three size ranges, referred to as 10 mm. (9.52 - 15.8 mm), 5 mm. (4.6 - 9.52 mm.), and 2.5 mm. (2.5 - 4.6 mm.) size ranges respectively. At this Station a few samples were taken above and below these sizes, but above this size samples become too bulky to handle by a small field party, and below this size the individual particles become partly mineral rather than rock fragments and it is difficult or impossible to identify. It was established from these tests that a sample size of 2,250 particles gave the required accuracy, and was used as a standard throughout this project.

Using this sample size it was concluded that:

i. The geological composition can be measured from relatively small samples and that the composition is independant of the grain size distribution. The accuracy of measurement depends upon: (a) ease of identification and skill of operators, (b) random variations in the composition of the bed material which depend upon the river's characteristics (eg. wide flood plains show greater variations than rivers confined between narrow banks), and (c) sample size. However increasing the latter will not overcome errors due to (a) and (b), but too small a sample introduces unacceptably large variations.

ii. The grain size distribution varies widely, and a reliable average cannot be found even from large samples. The surface layer of the bed is almost always found to contain a large proportion of larger particles,which form an "insulating layer" against removal of material from below them. These pebbles are too large to be moved by the existing flow and so remain covering the bed, the smaller sizes have for the most part been moved away. This phenomena occurs during floods and prevents the river from carrying its capacity load.

iii. A practical difficulty is to allow a long enough stretch of river below confluences to allow for complete mixing of the bed-sediment, without having extra material added to the river below the confluence. Large scale aerial photographs are indispensable in this connection in the field.

At Kamikochi the standard deviation of the measured geological compositions of five samples was less than 2.2% in all cases (expressed as % of the whole sample) for the three main geological components, and of this it is estimated that less than 1% was due to errors in identification, the rest being due to random variations in the composition

Geological grain size distribution curves are shown on Fig. 4, where the heading inferred refers to sizes below 2.5 mm: larger sizes were measured directly. "Ss" corresponds to symbol "P" on Fig. 2; other symbols correspond directly."

One other result for the Upper River must be mentioned: Between Station "M" and Kamikochi, no Paleozoic Rocks enter the river, but the concentration of Paleozoic Rocks at Kamikochi is nearly 6% higher, which is greater than the known variations in measurement. This trend has been also found on the Lower River, and is thought to be due to non-uniform transport mechanism during floods owing to the differences in gradient and discharge between the main stream and the tributaries at different stages of the flood and hence their transporting capacities.

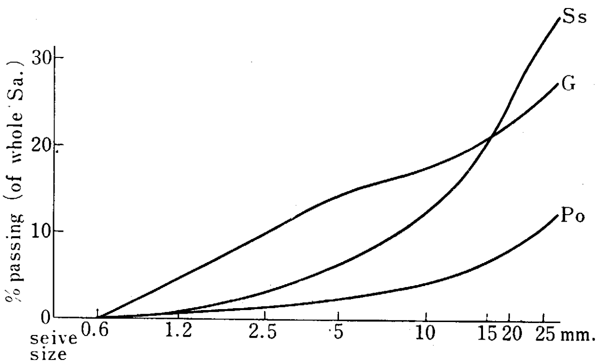

Fig. 4 Inferred average grain size distribution of geological materials for sizes between 25 mm and 0.6 mm.

2. In order to calculate the Debris Proportions for the Lower River, it was necessary to separate the sandstones, shales and cherts of the Paleozoic sediments; however, results were obtained for all the main confluences on the three size ranges (Step 1), and considerable differences exist between the movement on the different sizes. The accuracy with which this can be done depends upon the differences in geological composition of the bed-sediment between the tributaries in addition to the accuracy of sampling. If this difference is greater than 15%, the error in the results is less than 10%, and in practice better than this as several results can be averaged (for different geological materials). This accuracy is also affected by the relative volume of debris carried by the tributaries and their gradients, both of which should preferably be of the same order, but limits cannot be easily given.

3. The movement of debris along reaches of a river between confluences (Step 2) can be measured if:

i. The Debris-delivery Ratio is 100% (i.e. no aggradation or degradation).

ii.) and one of the geological groups in the bed-sediment does not enter the river along the reach, the percentage reduction of which indicates the volume of material entering the river along the reach.

The first requirement is almost never found in nature, in which case it is necessary to calculate or estimate the Debris-delivery Ratio independently (eg. from bed level surveys). Alternatively, one may assume a Debris delivery Ratio of 100%, and work out the results in terms of the downstream point on the system, in which case the results indicate the source of material arriving at that point.

In order to obtain the results in volume per annum, the results in percentage must be correlated with measured Debris Yields somewhere on the river, usually in the form of measured accumulations behind debris control dams. However, such data gives the yield behind the dam but gives no indication of the yield below the dam, and cannot be used directly unless the river was also sampled before the construction of the dam, except in the case of a dam situated at the downstream end of the river system under consideration. There is also the difficulty that the data may not be for the same period as the river analysis, and there are large fluctuations in the yield from year to year.

Practical results for the case of the reservoir to be formed behind Nagawa Dam are summarised in Fig. 3. The author has suggested a long-term study of a small catchment area chosen with suitable geological and other conditions in order to clarify some of the problems encountered during a study of this nature.

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No references directly to the methods used are known to the author; in addition to general references the following were consulted with reference to the Azusa River basin:

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