SEDIMENT TRANSPORT STUDY ON THE TENRYU RIVER AND THE ENSHU COAST BASED ON ANALYSES OF SURFACE SEDIMENTS

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We investigated the present condition of regional sediment transport and its temporal change in Tenryu River and Enshu Coast in Japan. We focused on the distribution of geology in Tenryu River basin. By analyzing color and kinds of sediments, we tried to identify the origin of sediments and the impact of each tributary, dams and river vegetation on sediment transport. To obtain the sediment in old time (before dam construction) for comparison, we also performed trench study on the old track of the Tenryu River. We also investigated grain size distribution of sediments in the river vegetation. Through those studies above, we recognized that fine sediments do not accumulate on riverbed in lower Tenryu River except in the river vegetation but go straightly to the river mouth. It is why the effect of dams in midstream of the Tenryu River is not clear in riverbed in lower Tenryu River, but clear on coast around the river mouth.

1. INTRODUCTION AND RESEARCH AREA

Enshu coast, located in the central district of Japan, has been eroded significantly because of decrease in sediment supply from the Tenryu River, which has largest amount of sediment discharge in Japanese Rivers. It is mainly caused by the sediment retention in dam reservoirs in the midstream of the Tenryu River and sand mining for construction works. Among the dams, the largest one is the Sakuma Dam, which was completed in 1957 and has accumulated over 100 millions m3 of sediments up to now. Still now, the sediment transport is completely blocked by the Sakuma Dam. Therefore, comprehensive sediment management to the whole fluvial system is needed to solve this problem. First of all, to understand the present condition of sediment transport is important.

In terms of the attempt to investigate the sediment transport in the Enshu-Tenryu sediment system, Torii et al. (2004) performed numerical simulation of riverbed and shoreline change, which also predicted the change in grain size component. However, no studies of the regional sediment transport based on analyses of surface sediment itself have been carried out so far.

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In this study, we tried to understand the present condition of sediment transport process in the whole Enshu-Tenryu system by analyzing surface sediments. With regard to geology, Tenryu River has the Median Tectonic Line (MTL) in the middle of its basin. This tectonic line separates the geology extensively. On the north-western side of MTL, granite and its metamorphic rocks are dominant, therefore, whitish sand are dominant on the riverbed. On the other hand, on the south-eastern side, sedimentary rocks of Mesozoic or Paleozoic era, schist, and blackish sand are dominant. Because of such distribution of geology, every branch of Tenryu River has its characteristic in its sediments. And the largest dam, the Sakuma Dam is located nearly on MTL. Therefore, we tried to obtain the information of the geological component of the sediments at each place in Tenryu River and Enshu Coast, which tells us the origin of sediments and contribution of each branch and dams on sediment transport.

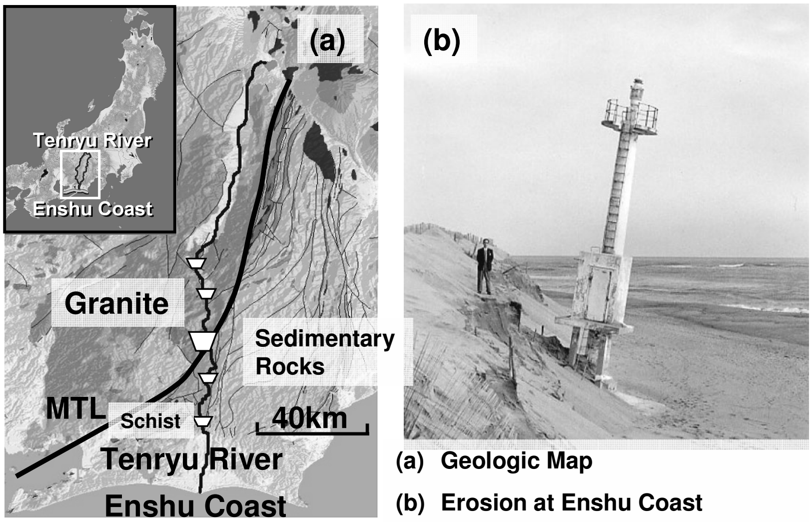

Figure 1: (a) Geologic Map of Tenryu River Basin (b) Lighthouse whose foot was scoured

Table 1: Dams in Tenryu River and Their Status (data from Okano, et al (2004))

Dam Name	Distance From the River Mouth	Capacity (1000m³)	Comp-letion	Status of Sedimentation	Sand/ Capacity
Yasuoka	130km	10761	1935	almost full	81.6%
Hiraoka	110km	42425	1952	almost full	84.5%
Sakuma	71km	326848	1956	not full/accumulating	34.6%
Akiha	47km	34703	1958	not full/decreasing	36.6%
Hunagira	30km	10900	1977	not full	8.3%

2. METHODOLOGY

2-1 Sampling of Surface Sediments and Analyses with Magnet

On May 12th and 13th in 2006, we collected surface sand in Enshu Coast at each place indicated in **Fig.2**. Sampling points were arranged to be nearly on the shoreline at high tide on that day. We collected samples which were located upper than the depth of 10cm from the surface.

Also, to obtain the sediments of riverbed in Tenryu River, on June 16th and 17th in 2006, we collected surface sand and gravels of riverbed at each place in **Fig.2**. We collected samples which located near the waterway, and upper than the depth of 10cm from the surface.

Fig.2 also shows the scanned image of sample sand which was pasted on two sided tape glued on white paper.

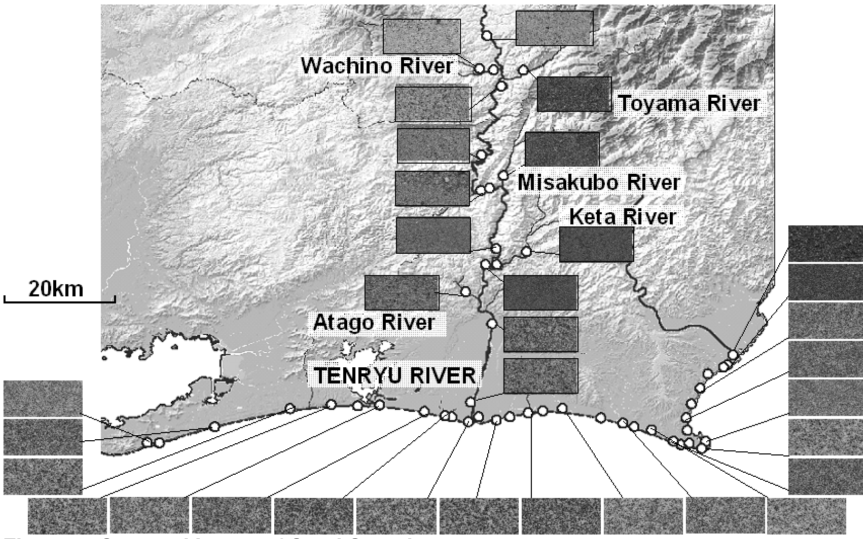

Figure 2: Scanned Image of Sand Samples

As we discussed in the above, sediments from the Tenryu River contain many kinds of minerals and rock fragments, and it indicates the origin of the sediments. Therefore, we classified the samples according to their geology.

To classify the sand samples effectively, we utilized its magnetism. By using magnets, we separated sand into magnet and non-magnet, which correspond to blackish sand and whitish sand. First, to remove an effect of grain size, we sieved the sand into same grain size class of 0.075-0.425mm. Next, we laid the sand in monolayer on a plate. As shown in **Fig.3**, we picked up sand grains which were attracted by Ferrite magnet (normal magnet) and Neodymium magnet (strong magnet) in this sequence. Sand which is attracted by Ferrite magnet is Ferro magnet. On the other hand, sand attracted only by Neodymium magnet is Parra magnet. By using magnet, we succeeded in quantifying the fraction of whitish sand and blackish sand.

We classified gravels according to their kinds of rocks (sedimentary rocks, granite, metamorphic rocks and others) by visual observation. Before the observation, we sieved the rocks into grain size 4-16mm.

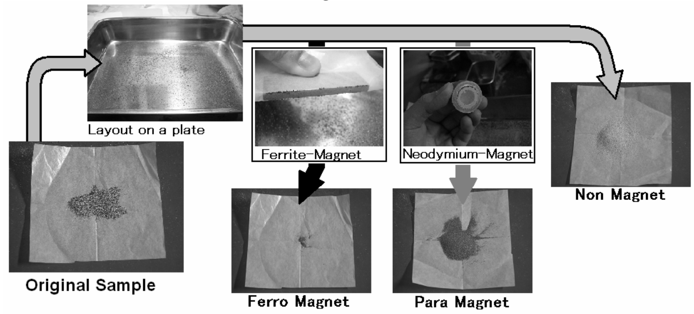

Figure 3: Procedure to Classification with Magnet

2-2 Trench Study and Optical Dating with OSL

Sediments on riverbed or coast are considered to be affected by dams or any other artificial structures or human activities. To compare the collected sediment with the sediments deposited before the dam construction, we performed trench survey on the old track of the Tenryu River shown in **Fig.4**, which was buried before the completion of the Sakuma Dam. Now, the place is utilized as a park. We selected investigation point in that park, which is indicated in **Fig.4**.

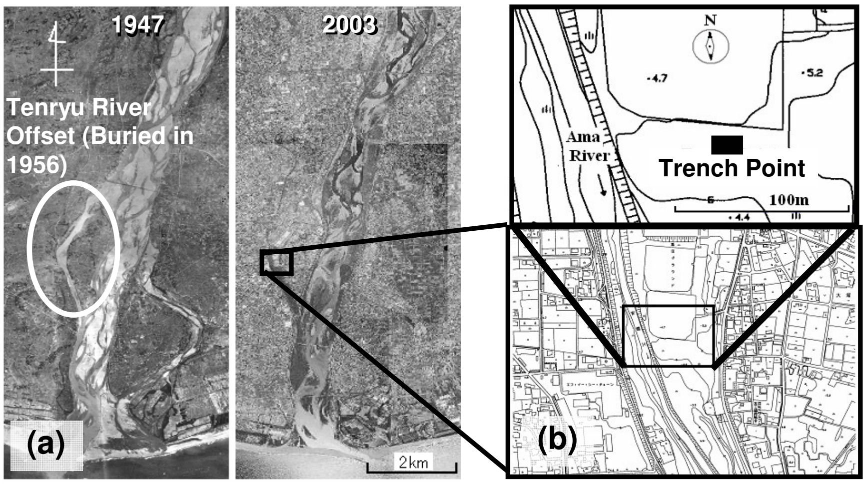

Figure 4: (a) Comparison of Aerial Photograph Around Tenryu River mouth (b) Location of the Trench

First, we performed a preliminary survey by digging the ground about 1m. At the bottom of that small trench, we found the “old” riverbed below the surface soil. Then, we dug the trench of 4m length, 1m width and 2m depth. **Fig.5** shows the sediment structures of the old riverbed observed at the trench wall. We collected sediment samples at every 10cm depth in the trench below the surface soil. We also investigated these sediments (sand and gravels) in the same methods with sediments sampled from coast and riverbed.

In addition, to confirm the difference of sediment from the trench and one from the present riverbed, we employed the dating technique using Optically Stimulated Luminescence (OSL). As introduced by Aitken (1998) and others, OSL is generated when quartz or feldspar is exposed to light. OSL intensity increases as the mineral grain absorbs dose, and the OSL signal is reset with enough exposure to sunlight. This resetting process is called “bleaching”. OSL is usually used to estimate the burial age of the sediments in the last hundred thousand years. Shirai, et al. (2006) showed that by investigating the ratio of bleached grains, which implies sunlight exposure condition of the grains in recent years, information on the sediment transport process was extracted. We compared sample’s OSL intensity between original condition (natural) and after sunlight bleaching to get the percentage of the bleached sediment grains.

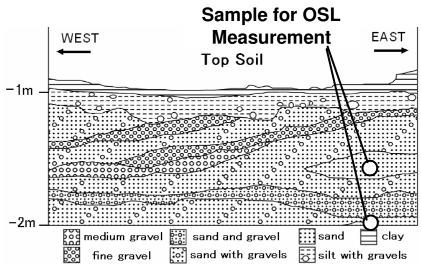

Figure5: Sketch of Trench Wall

To investigate the difference of condition of exposure to sunlight between sediments on old riverbed and present riverbed, we compared the bleaching percentage among the 2 samples from the trench and 1 sample from the present riverbed of the Tenryu River. Sampling points of the 2 samples of the trench are located at the depth of 160cm and 200cm from the ground respectively (see **Fig.5**). Sampling point of the riverbed is about 4km upstream from the Tenryu River mouth. Because the OSL intensity is easily canceled by the sunlight, we conducted sampling carefully to avoid the sample from being exposed to sunlight. We obtained samples by setting in opaque chlorinated polyvinyl chloride pipes capped with aluminum foil.

We followed Shirai, et al. (2008) in the process of the measurement except in the grain size of the specimens. We chose feldspar as specimen for OSL intensity investigation. All the processes were carried out in dark room with subdued orange light. Procedures of preparation of the specimen are as follows.

First, we sieved washed samples to collect particles whose grain size is 0.3-0.5mm. Next, we removed organic material and carbonate from specimens with peroxide (10%) and hydrochloric acid (10%), respectively. After heavy liquid separation using LST heavy liquid, we extracted feldspar by microscopic handpicking.

After this preparation, we laid the individual feldspar grain on the measurement disc with 1 cm diameter. Then, we start the measurement by an OSL-TL reader (Risø). The process of measurement is as follows.

After removing unstable OSL signals by pre-heating (250℃, 60s), we measured natural OSL intensity (OSL intensity of original condition of the particles) by irradiating infra-red (870nm). Next, we measured its sensitivity of the specimen to the artificial radiation for normalization. After irradiating β-ray (ca. 2 Gy), we performed cut-heating (250℃, 60s) to remove unstable signals and then measured OSL intensity again with infra-red.

With the procedures above, we estimated the normalized OSL intensity of every specimen. To obtain the OSL intensity of bleached samples, after exposing the measured samples to sunlight enough (over 7 hours), we measured OSL intensity again by the same procedure.

2-3 Investigation in River Vegetation

In recent years, river vegetation has developed significantly in the lower part of the Tenryu River. It is mainly caused by degradation of the low water channel compared to the high water channel because of the decrease in sediment supply from upstream and the reduction of floods by dam operations. We considered that the sedimentation process in such vegetation area is different from that in non-vegetated riverbed.

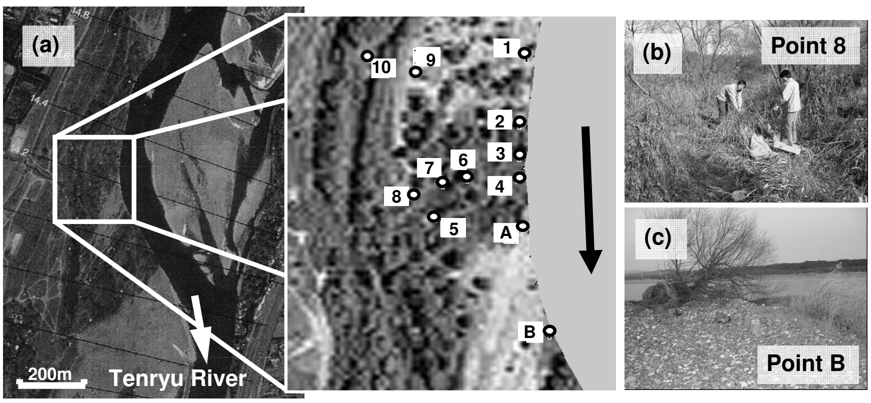

Figure 6: (a) Location of Investigation Point (b), (c) Condition of Point 8 and B

To investigate the sedimentation process in river vegetation, we performed grain size investigation on Jan. 14th and 15th in 2007. **Fig.6-(a)** shows the target area of this survey. It is located about 14km upstream from Tenryu river mouth. Points 1 to 10 were located inside the vegetation area (see **Fig.6-(b)**). To investigate the relationship between condition of vegetation and the grain size, we recorded the condition of vegetation (number of trees around the point, height and density of the grass) at every investigation point. Point A and B were selected as a point in non-vegetated riverbed for comparison. Point A was located at the middle of riverbed, without any shields against river flow. On the other hand, Point B was just downstream of drift wood whose height was about 3 to 4m (see **Fig.6-(c)**).

We investigated grain size distribution of the surface sediments at every investigation point. Because it is difficult to sieve wet samples, we sieved only sediments larger than 8mm on site, and the remainings were sieved after drying at laboratory.

To compare the magnetic component of sand in vegetation with that of other samples, we collected sand in river vegetation on Aug. 9th in 2007. In this time, because the river vegetation investigated above has been removed artificially, we chose another vegetation area near the river mouth (see **Fig.7**).

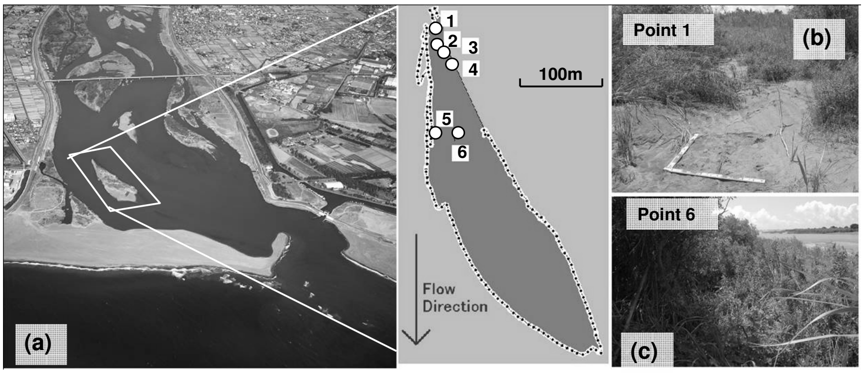

Figure 7: (a) Location of Investigation Points (b), (c) Condition of Point 1 and 6

3. RESULTS AND DISCUSSIONS

3-1 Results of Classification of Sediment Samples

Fig.8 shows the results of analyses on sand samples of coast with magnet. When we see the results from east to west, samples near the Ooi River mouth contains largest fraction of magnet, which means they are blackish. It is caused by the geology of the Ooi River basin, which is mainly composed of sedimentary rocks of the Mesozoic era and the Tertiary period. As it become far away from the Ooi River mouth, fraction of black sand in samples decreases because of the effect of the Tenryu River which has granite belt in upstream. However, at the points around Tenryu River mouth, fraction of black sand becomes larger to some extent. And as it becomes far from Tenryu River mouth westward, fraction of black sand decreases again. As a whole, except the area strongly affected by the Ooi River, only the points around Tenryu River mouth have blackish sand.

Recently, sediments from upstream of the Sakuma Dam do not reach downstream because the Sakuma Dam continues to trap sediments. Therefore, sediments discharged from the Tenryu River mouth should be affected such tributaries as the Misakubo River and the Keta River, whose sediments are blackish. Result of analyses on coastal sand suggests that because of the effect of the Sakuma Dam, sand discharged from Tenryu River mouth has become blackish in recent years, and its effect is now spreading to the coast around the Tenryu River mouth.

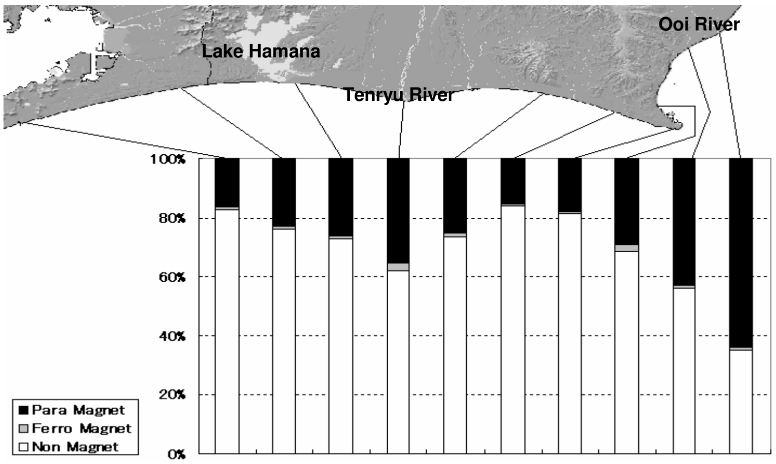

Figure 8: Result of Classification of Coastal Sand with Magnet

Fig.9 shows the results of analyses by magnet on samples from Tenryu riverbed, the trench (the depth of the sampling point was 190-200cm from the ground) and the river vegetation. When we see samples from riverbed, first, it appears that component of samples is strongly affected by geology of each tributary. The Wachino River is located in the granite belt, therefore, most part is white sand. The Tooyama River, the Misakubo River and the Keta River are located in the sedimentary rock area, therefore, it contains large amount of black sand. In the upstream of Tenryu mainstream, most part is white sand because of such rivers as the Wachino River, which comes from granite area. As it comes downstream, mainstream meets several tributaries from sedimentary rock area, such as the Tooyama River and the Keta River. Because of the effect of such tributaries, fraction of black sand becomes larger as it comes downstream. However, samples downstream of the Funagira Dam show smaller content of black sand (see the sample of **22km** and **4km**). The fraction of black sand in the sample from lowest part of the Tenryu River is smaller than that in the sample of coastal sand near the river mouth.

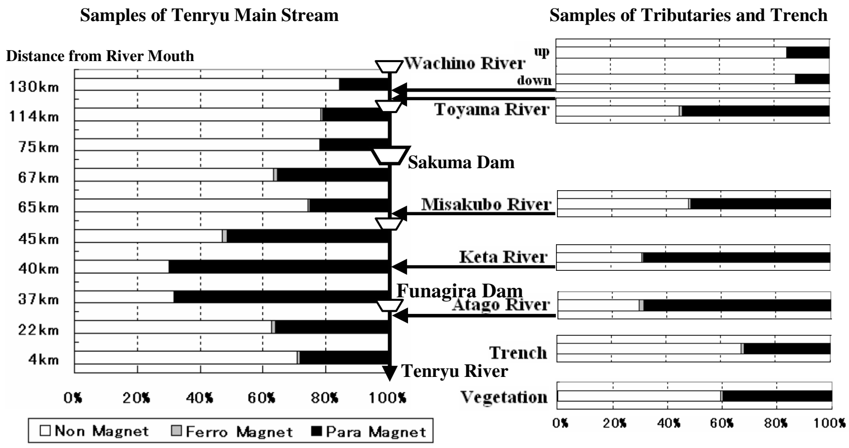

Figure 9: Result of Classification of Sand of Riverbed with Magnet (Grain Size: 0.075-0.425mm)

With respect to the effect of the Sakuma Dam, it is expected that in the downstream of the Sakuma Dam, sediments of the riverbed are strongly affected by such tributaries as the Misakubo River and the Keta River, whose main contents is black sand. Then, sand is expected to be blackish at every place lower than the Sakuma Dam. However, result of the analyses of sand was inconsistent with this prospect only in the downstream of the Funagira Dam.

As we explained in Section **2-3**, we also investigated the component of white and black sand of the samples in river vegetation. When we compare those results with those of non-vegetated riverbed (the sample of **4km** of mainstream), there are significant difference between them. Fraction of black sand in the sample from vegetation is larger than that of samples not only from riverbed but also from coast near the river mouth.

This result means not only that sand in the river vegetation are affected by such rivers as the Keta River and the Misakubo River which discharge black sand, but also that in the lower part of the Tenryu River, sand from upstream deposits only in vegetation, and on coast. The prominence of white sand in the sample of riverbed in lowest part of Tenryu River shows that riverbed is still being eroded and the no fresh sediments are deposited on the present riverbed. This is considered to be due to the Funagira Dam (see **Fig.9**) equipped with sediment discharge gates. Since the Funagira Dam flushes sediments in its reservoir only during heavy floods, fine sediments, originated from the Misakubo River and the Keta River, will be transported as washload and therefore will not be deposited on the riverbed except for vegetation zones. This scenario also accounts for the prominence of black sand on the coast around the river mouth. In addition, there were no significant differences in the ratio of black sand between sample from the trench and the present riverbed (**4km**). This result means sample from the present riverbed is 'old' and the riverbed is eroded now, which also supports our scenario.

Fig.10 shows the result of classification of gravels whose grain size is 4-16mm. In the most part, it shows the same tendency with the result of analyses of sand. Because of the difference of structural durability between granite and sedimentary rocks, the fraction of granite in these samples is smaller than that of white sand in sand samples. Although the effect of the Funagira Dam is not so clear in this result, it is consistent with the scenario explained in the above, because there is no significant difference between the components of riverbed sample (**4km**) and trench sample.

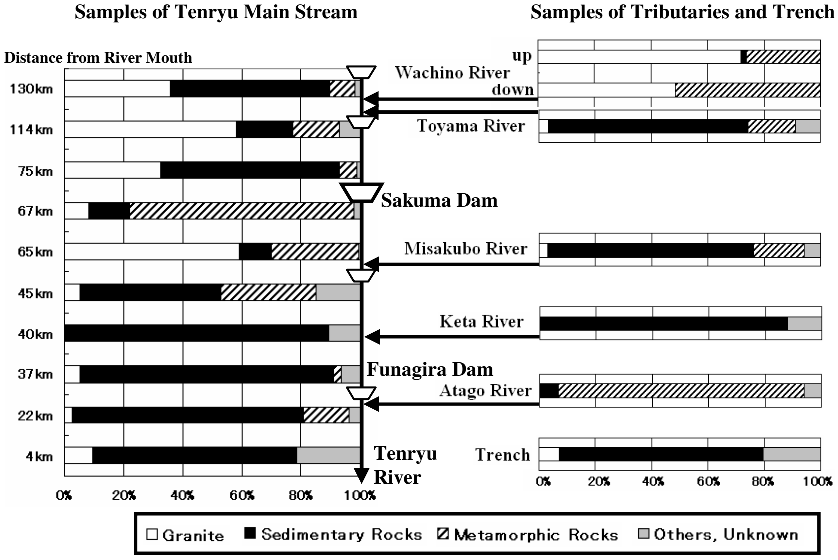

Figure 10: Result of Classification of Gravels from Riverbed by Visual Observation (Grain Size: 4-16mm)

3-2 Results of OSL Measurements

Fig.11-(a) shows the OSL intensity of samples from the trench, which was located at 160cm below the ground. Natural OSL intensity is higher than that of bleached sample in every specimen, which means no particle has been exposed to sunlight in recent years, which supported that we correctly found sediments of old riverbed. The result of sample from 200cm depth showed almost same result.

Fig 11-(b) shows the result of sample from present Tenryu riverbed which is located about 4km upstream from the river mouth. Most of the particles show no sign of exposure to sunlight in recent years. This result supports our scenario that the riverbed of lower Tenryu River is still being eroded and sediments on the riverbed is 'old', which are free from effect of Dams.

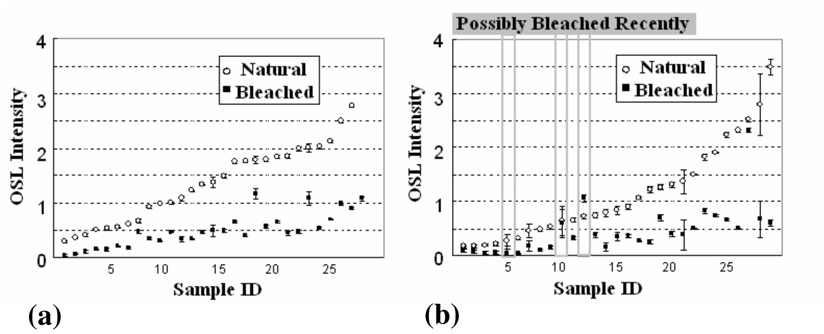

Figure 11: Comparison of OSL Intensity of Samples from Trench and Riverbed (a) Trench Sample (b) Riverbed Sample

3-3 Grain Size Distribution of Sediments in River Vegetation

Fig.12 shows the result of grain size investigation at the river vegetation 14km upstream from the river mouth. The pie chart indicates the weight ratio of each grain size range. Compared with the result of point A and B which were located on the non-vegetated riverbed, grain size of the sediments inside the vegetation area is significantly finer. As shown in **Fig.12-(b) and (c)**, as it becomes far from the water channel or it is surrounded by more trees, the sediments would also become finer. Especially, the points far from water channel such as point 7-10 contain considerable amount of silt (finer sediments than 0.075mm).

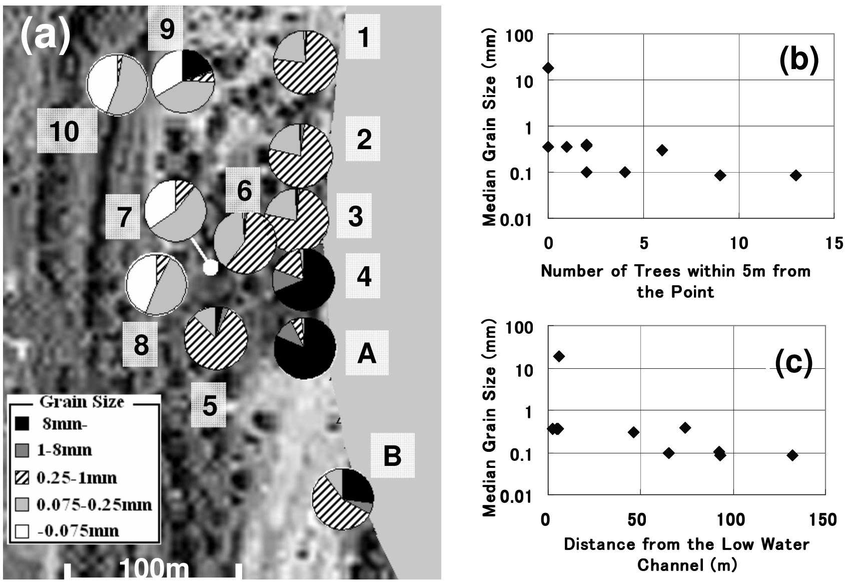

Figure 12: (a) Grain Size Distribution of Sediments in River Vegetation (b) Relation between Number of Trees around the Point and Grain Size (c) Relation between Distance from Water Channel and Grain Size

Fig.13 shows the spatial distribution of thickness of surface sediments layer and ratio of beach sand trapped by the vegetation more than non vegetated riverbed (point **A**). By counting the area of each category multiplied by the depth of surface layer, we calculated the amount of trapped beach sand in this vegetation area. It was estimated as 25,000m^3. Through the analyses of aerial photographs in time series, we estimated the period of deposit of fine sediments in this vegetation to be within 15years. Also, this kind of river vegetation has developed in whole area in the lower Tenryu River, which is defined as the section between the river mouth and 25km point. Taking those conditions into account, the amount of annual deposit of beach sand in the vegetation zone in the whole lower Tenryu River was estimated as 4.2x10^{4}m^3. Torii et al. (2004) estimated annual discharge of sediments whose grain size is between 0.106mm and 0.85mm is 10.8x10^{4}m^3. Compared to this amount, deposition of beach sand to the vegetation zone is significant.

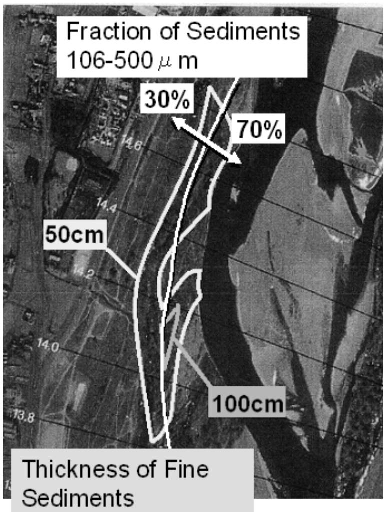

Figure 13: Estimation of Volume of Deposition of Fine Sediments in the River Vegetation

4. CONCLUSIONS

Analyses of surface sediments focused on their color and grain size were carried out to understand the present condition of sediment transport process of the Tenryu River-Enshu Coast system. We employed analyses technique using magnet to quantify the ratio of color of sample sand, and OSL intensity to confirm whether the sediment has been buried for a long time. We also investigated grain size distribution of sediments in river vegetation area to estimate its effect to entrap fine sediments. Main conclusion is as follows.

1. Effect of dams in the Tenryu River, which is observed as the prominence of blackish sand, is expanding on the coast around the Tenryu River mouth.
2. In the lower Tenryu River, fine sediments which compose beach sand will not deposit on the riverbed except in the river vegetation, but go straightly to the river mouth.
3. Measurements of OSL intensity support our scenario that the riverbed of the lower Tenryu River is still being eroded, and the present riverbed surface is covered with 'old' sediments.
4. The amount of deposition of beach sand in the river vegetation was estimated as 4.2x10^{4}m^3/year in the whole lower Tenryu River, which is

significant compared with the amount of sediment discharged from the Tenryu River mouth which amounts to $10.8x10^4m^3$/year.

ACKNOWLEDGMENTS

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