A COMPREHENSIVE STUDY ON SEDIMENT MOVEMENT IN TENRYU RIVER WATERSHED AND ENSHU COAST

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A comprehensive study on surface sand quality in the Tenryu River watershed and the Enshu Coast was conducted with an aim at describing long-term sediment movement dynamics in a wide region. The study area exhibits a variety of sedimentary problems such as retention of sediments in reservoirs, riverbed degradation, dune erosion and coastal erosion. Sediment representation by magnetism and measurement of OSL (Optically Stimulated Luminescence) intensities was found to provide valuable information on the mechanisms of sand movement.

Key Words : *coastal erosion, regional sediment movement, reservoir sedimentation, OSL/TL measurements*

1. INTRODUCTION

Coastal erosion has been accelerating worldwide in the last century. The rate of decrease in land area in Japan, estimated by the comparison of old and new geographical maps, is reported to be 24 km^2 in recent 15 years (Tanaka, *et al.*, 1993). The erosion has been developed by various mechanisms, such as construction of ports and harbors, marine sand exploitation and decrease in sediment supply from the river. Since coastal erosion gradually develops in a wide area with a relatively long duration, the countermeasures should be considered for a large area with long time scales. Considering a fluvial system composed of a river watershed and a sediment cell of the adjacent coast, the estimation of sediment discharge from the river is essential for the regional sediment analysis. The sediment supply from the river is characterized by the watershed area and the climate but also influenced by various anthropogenic impacts such as construction of dams and weirs (Syvitski, *et al.*, 2005), river route change and sand dredging from the riverbed. Estimation of temporal and spatial distribution of sediment movement is of great importance for proposing an efficient countermeasure to coastal erosion.

The implementation of regional sediment management has been initiated by the Ministry of Land, Infrastructure and Transport, Japanese government. A frontier plan is compiled for the Tenryu River watershed, where riverine and coastal sediment management is coupled with discharge of sediments from reservoirs. In parallel to the practical implementation, a five year research project, entitled “Dynamic sediment management and coastal disaster prevention based on advanced technology”, has been started in 2006 aiming at collaborative monitoring of sediment movement based on advanced technologies. In the present paper, results of ongoing studies will be described for the Tenryu River watershed and the Enshu Coast, in which the regional movement and long-term evolution of the alluvial deposits in a relatively wide area, are investigated on the basis of the qualitative and quantitative analysis on surface sediments.

2. SEDIMENTARY PROBLEMS IN THE TARGET AREA

The target area of the present study is a fluvial system composed of the Tenryu River watershed and the Enshu Coast, which is located at the west of Shizuoka Prefecture, Japan (**Fig. 1**). The Tenryu River, which originates from Lake Suwa with a drainage area of 5090 km^2 and a route length of 213 km, flows to the south and feeds into the Pacific Ocean. The Enshu Coast is a long sandy beach and it has a double-arc concave shape separated in the middle where the Tenryu River delta is formed. In this paper, sediment movement characteristics will be described along the Tenryu River starting from the Yasuoka Dam to the river mouth with a total length about 130 km as well as on the coastal area stretching from the Ooi River mouth to the Atsumi Peninsula. Sediment movement characteristics elucidated in the existing studies are summarized as follows:

(a) The amount of sediment discharge from the Tenryu River is estimated at about 38×10^6 m^3/year (Ashida *et al.*, 1983), which is the largest in Japan. This is due to the sharp terrain and the fragile geology of the catchment area, where the Median Tectonic Line (hereafter referred to as MTL) passes though.

(b) The geology of the northwest part of the MTL, *i.e.*, the upstream region of the Tenryu watershed, is characterized by the igneous rock zone whereas the southeast of the MTL, *i.e.*, east of the downstream of the watershed, is composed of a sedimentary rock zone. Different geological rock zones are characterized by specific rocks and mineral components, *e.g.*, the granite rocks with quartz and feldspar being two typical mineral constituents are representative in the igneous rock zone.

(c) A series of dams have been constructed along the Tenryu River as well as its branches. In the main river route, five dams were constructed (**Fig. 1**) in which the Sakuma Dam, constructed about 70 km upstream of the river mouth in 1956, is one of the biggest dams in Japan and interrupts a huge amount of sediments inside the reservoir. The rate of the sediment retention at the Sakuma Reservoir amounts to two million cubic meters per year. Together with huge amount of sand exploitation from the riverbed during the rapid economic growth period in 1960's, it significantly reduced the sediment supply to the downstream zone and to the sea. The riverbed on the downstream of the dams has been degraded by 1-1.5 m.

Fig. 1 Tenryu River and Enshu Coast

(d) In the last several decades, serious coastal erosion has developed around the Tenryu River mouth and along the Enshu Coast. The terrace in front of the river mouth has been eroded. In order to mitigate this problem, various shore protection structures have been constructed, such as seawall, detached breakwaters and groins. The erosion is propagated to both sides of the river mouth, reaching the Nakatajima Sand Dune located 4 km west of the river mouth.

3. QUANTITATIVE DESCRIPTION OF SEDIMENT MOVEMENT

Figure 2 illustrates nearshore bathymetry of the Hamamatsu Coast, located on the west side of the Tenryu River mouth. The bathymetry survey has been conducted by the Ministry of Construction and the Shizuoka Prefecture since 1962. The comparison of bathymetries of 1971 and 2005 demonstrates significant coastal erosion and shore protection efforts by a series of detached breakwaters. **Figure 3** shows temporal variation of total sand volume in the nearshore area surrounded by the dashed line in **Fig. 2**. The arrow on the bottom of the figure indicates the occurrence of Tenryu River flood greater than 7000 m^3/s. In **Fig. 3**, sudden increase in the total sand volume between successive data is observed in the periods 1981-2, 1983-4, 1991-4 and 1999-2000, all of which correspond to the occurrence of large flood. By excluding these four periods, the sand volume in **Fig. 3** shows gradual steady decrease at a rate of 3×10^5 m^3/year. This amount is considered to be balanced by the westward longshore sand transport rate. **Figure 3**

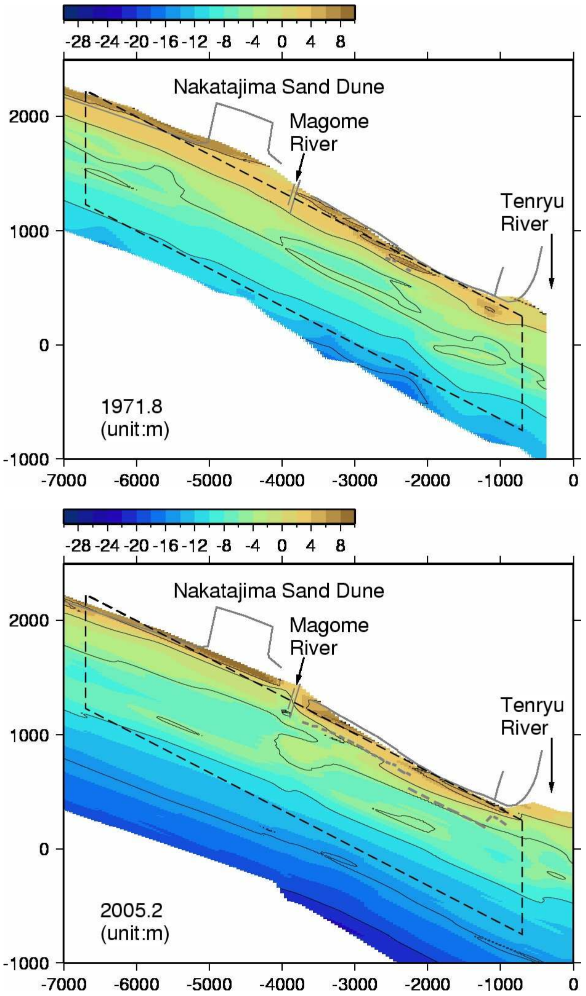


Fig. 2 Nearshore bathymetries of Hamamatsu Coast (1971 and 2005)

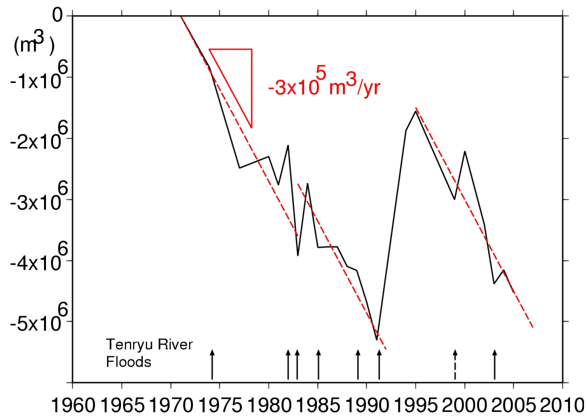


Fig. 3 Temporal variation of total sand volume on Hamamatsu Coast

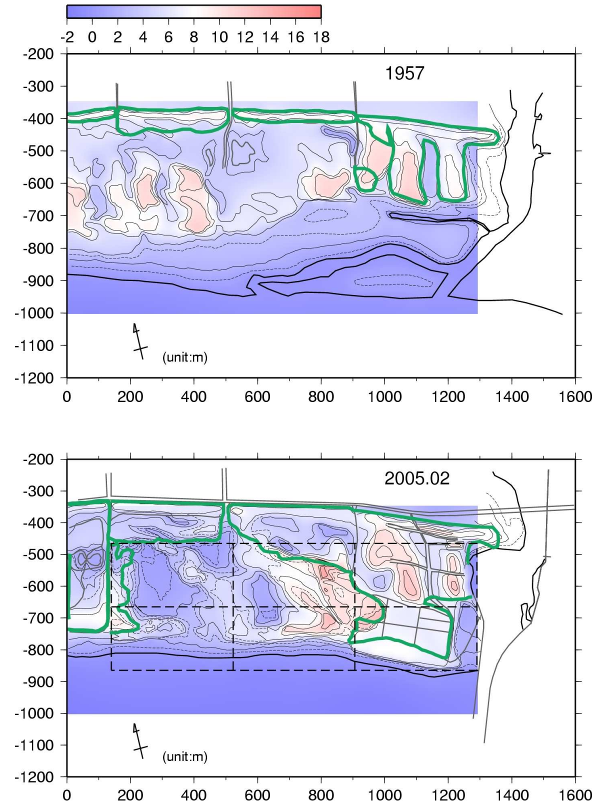


Fig. 4 Topographies of Nakatajima Sand Dune (1957 and 2005)

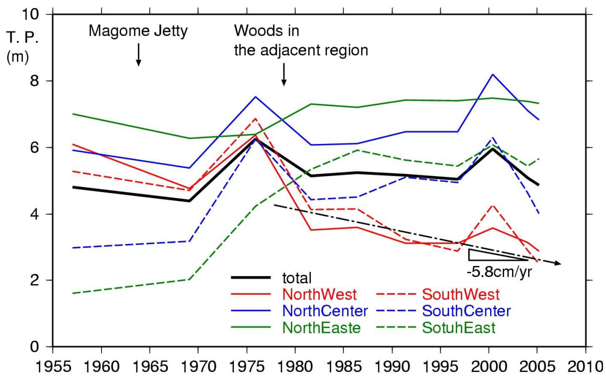


Fig. 5 Temporal variation of mean elevations on Nakatajima Sand Dune

also indicates that the sand supply from the Tenryu River is intermittent in the sense that it is dependent on the occurrence of large flood. However, when we assume that the formation of the river delta topography is dynamically in equilibrium, the average sand supply from the river should be balanced by the longshore sand transport rate. It is therefore concluded that the average sediment supply from the Tenryu River is estimated at 6×10^5 m^3/year, half of which can contribute to the sediment supply for the Hamamatsu Coast estimated at 3×10^5 m^3/year.

The decrease of the amount of sand is observed on coastal dunes as well. **Figure 4** illustrates topographies of the Nakatajima Sand Dune located 4km west of the Tenryu River mouth. The erosion of the dune is a major concern to the local government and residents since the dune is utilized for many purposes. The elevation of the dune has been lowered especially in the west part of the dune. **Figure 5** shows the mean ground elevation in the six sub-regions of the Nakatajima Sand Dune indicated by the dashed line in **Fig. 4**. The rate of decrease in the ground level in the west part of the dune is estimated at 5.8 cm/year, projecting the loss of the dune in less than 20 years.

4. INVESTIGATION ON SEDIMENT QUALITY

Sediment movement in the watershed scale will be influenced by many impacts in a wide area. Quantitative analysis on the influence of these impacts is difficult since most of them are exerted within the economic growth period and interact with each other along the temporal and spatial scales. Due to the superposition of various processes in a rather complex manner, a sediment budget analysis only based on the topography survey data sometimes fails to describe the complicated picture of sediment movement. Further investigation on the sediment quality will be useful for these situations. Such sediment quality is represented by certain physical and chemical properties, *e.g.*, sand size, specific density, grain color, shape, magnetism, radioactivity, the mineral components and the luminescence capability. In this study, investigation was conducted on the basis of sand mineral (magnetism) constituents and luminescence features, which are further specified in the following two subsections, respectively.

(1) Mineral (magnetism) analysis

In order to investigate the mineral (magnetism) characters of sediments, sediments were sampled at various locations in the watershed. Surface sand samples 10cm below the ground surface were collected. The collected sand samples were dried in the oven, which were then sieved to isolate grain size less than 2 mm. Then, sand particles were pasted on a white paper (3.0 cm by 1.5 cm) and designated using a scanner.

Qualitative analyses on the collected samples were conducted in terms of the sediment magnetism, which is directly related to the particle mineral constituents. Collected samples were sorted into three components, *i.e.*, particles with strong magnetism (mainly containing mineral constituents such as magnetite), particles with general magnetism (mainly containing mineral constituents such as biotite, amphibole and pyroxene) and particles without magnetism (mainly containing mineral constituents such as quartz and feldspar). By evaluating the weight ratio of every magnetic component and considering the geological features, quantitative discussion was carried out, through which we tried to achieve the sediment movement mechanism in the corresponding area. The sand component without magnetism is mainly white-colored; whereas the sediment component with magnetism, including both the strong and general magnetism, is mainly black-colored.

The scanned sand images are presented in **Fig. 6**. Images listed on the left column are from the main river route, whereas ones on the right column are from branches. At the same time, the weight ratio of three magnetic constituents for every sample is illustrated using pie chart.

Along the main river route, the sand color and the magnetism clearly reflect the local geology. The upstream region of the Tenryu River watershed, *e.g.*, the Wachino River area, is mainly composed of an igneous rock zone in which granite rocks are dominant. For other three main branches, Tooyama River, Misakubo River and Keta River, all of them pass though the sedimentary rock zone which are mainly composed of black-colored sediments. After merging with Tenryu River, the influence from branches can be observed. For Samples 2, 3 and 4 in the main riverbed, sand gradually changes color from white to black due to the sand supply from branches. Another important factor is that the presence of dams along the main river route also changes the sediment on the riverbed. The effect of the Sakuma Dam is the most significant. Considering the relevant geology, the entrapped sediments are mainly white-colored particles originated from igneous rocks. Hence, after the Sakuma Dam, the contribution of sediments from Keta River becomes dominant, which plays a significant role to black the Tenryu riverbed. This can be verified from Sample 4, which is collected just downstream of the Tenryu-Keta river conjunction. However, further looking at the sand samples in the downstream area, *i.e.*, Samples 5 and 6, both are located after the Funagira Dam, the sand color becomes somewhat bright comparing with the rather dark color of Sample 4. More discussions can be found in the trench study.

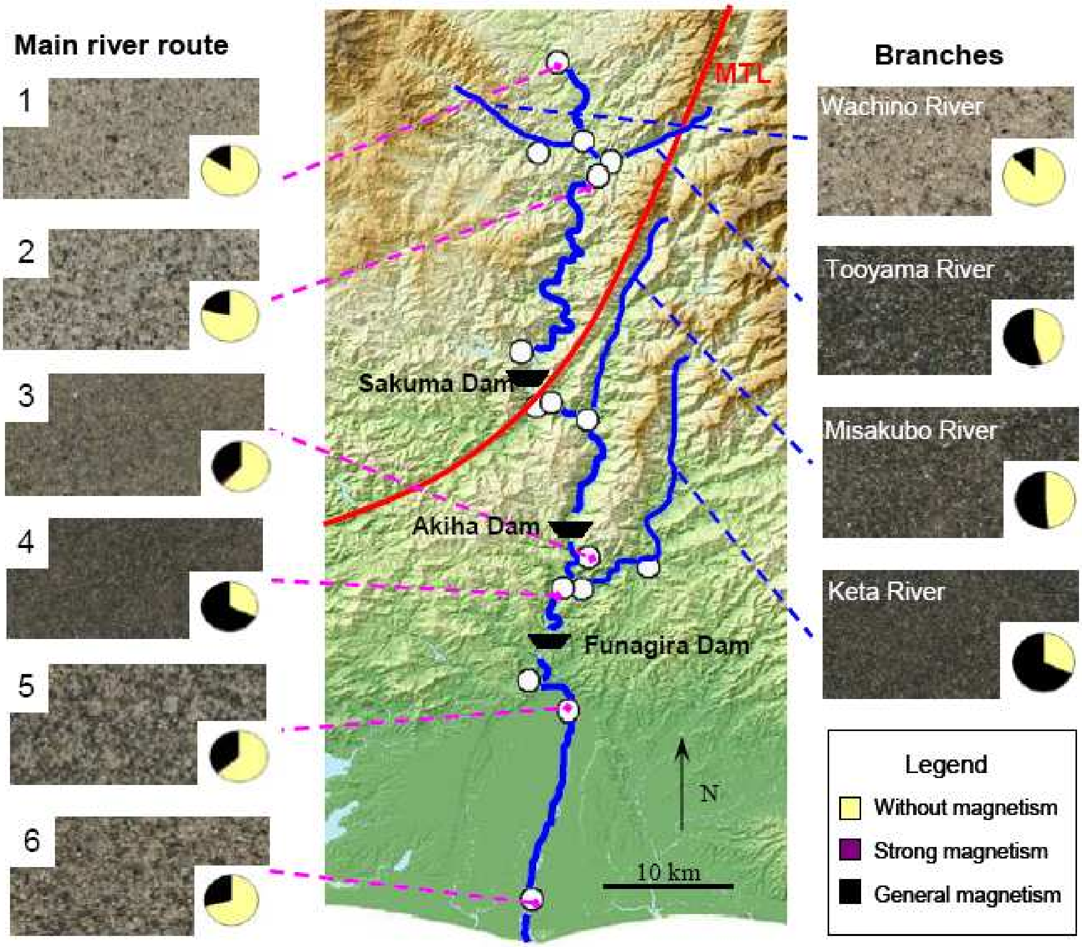


Fig. 6 Surface sand samples on the Tenryu watershed

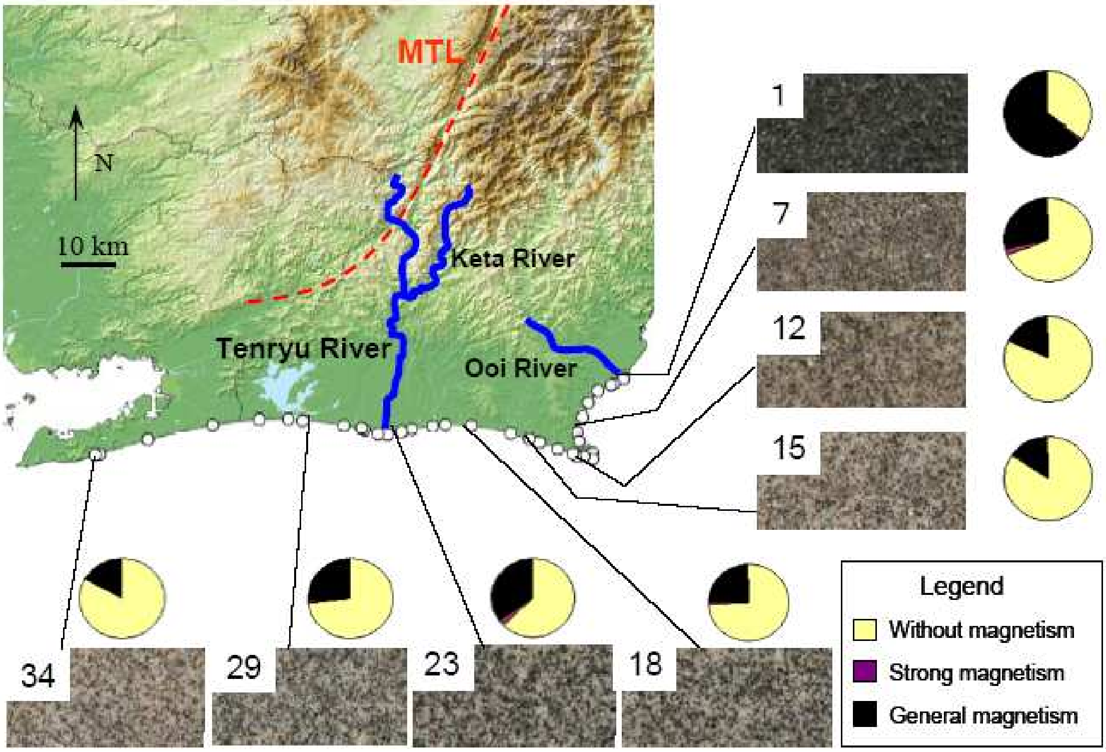


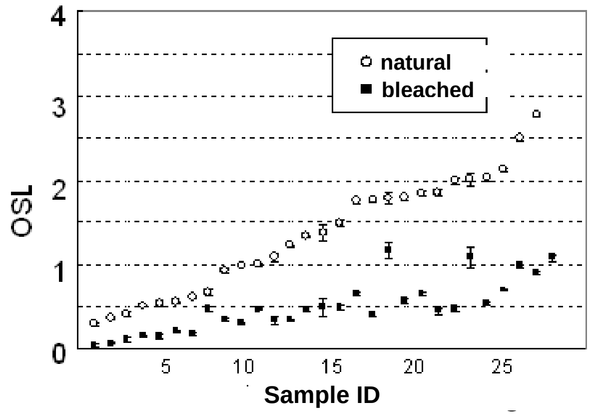
Fig. 7 Surface sand samples on the Enshu Coast

In order to understand sediment movement processes before the dam construction, a trench study was conducted at Iida Park (5 km from the river mouth), where the original river route before the construction of Sakuma Dam was located. Sediment samples in the trench were used to compare with the sand sample collected in the present riverbed at Kaketsuka (Sample 6 in **Fig. 6**). It was found that the magnetic constituents are almost the same for the Iida sample and the Kaketsuka sample, which demonstrates that the sediment contribution from the Keta River to the Tenryu riverbed sand constitution along the downstream river route is negligible. The deposit constituents from the present riverbed are nearly the same as ones from the old riverbed and there is no sediment accumulation in the present downstream riverbed. This considered to be ascribed to the scenario that the recent sediment supply from Keta River is washed away into the coastal area and cannot stay in the present riverbed. Along the River route, the effect from Keta River is limited just to the downstream of Tenryu-Keta river conjunction. To justify this scenario, OSL intensities for sand particles were measured.

Figure 7 illustrates surface sand samples collected along the Enshu Coast. The same magnetic sorting procedure was applied for sample investigation. It is found in **Fig. 7** that the sand sample is black at the Ooi River mouth, which is consistent with the geology of the Ooi River watershed. Going to the south, sand samples become white. The magnetism analysis also supports this observation. Grains without magnetism are about 30% in Sample 1 but about 70% in Sample 7. This may be ascribed to the significant sediment discharge from the Tenryu River, a certain part of the alluvial deposits from the Tenryu River can bypass the Omaezaki Cape and affect the coastal beach constitution over there. Considering that it may take a rather long time for the particles to move such long distance, it is assumed that these sands are old Tenryu discharge before the construction of the Sakuma Dam. Hence, they contain a large amount of white-colored components from the igneous rock zone, which bleach the coastal beach south of the Ooi River. After going around the Omaezaki Cape, Sample 12, to the Tenryu River mouth, Sample 23, the black sand component increases and the sand color turns to be dark. Passing though the river mouth and going further west, the black sand component decreases again as demonstrated from Samples 29 and 34. This is considered to be due to the change of the sediment delivery from Tenryu River. After the construction of Sakuma Dam, sediment discharge into the Enshu Coast is composed of a predominantly black-colored constituent owing to the contribution from Keta River in the sedimentary rock zone. After the Tenryu-carried sediments pour into ocean, these sands are gradually transported on both sides along the Enshu Coast owing to the longshore sediment transport.

(2) OSL/TL analysis

Quartz and feldspar grains exhibit laboratory-stimulated luminescence as a consequence of their natural radiation exposure while buried in a sediment environment (Aitken, 1998). Nuclear radiation is emitted when a nucleus undergoes radioactive decay. Such natural radiation induces the electron ionization in the grain crystal lattice. Luminescence is the emission of light from the particle crystal after being stimulated by certain external energy through the detrapping agency, such as heating or absorption of a photon of light. The



(a) Iida Trench

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naturally bleached particles

natural
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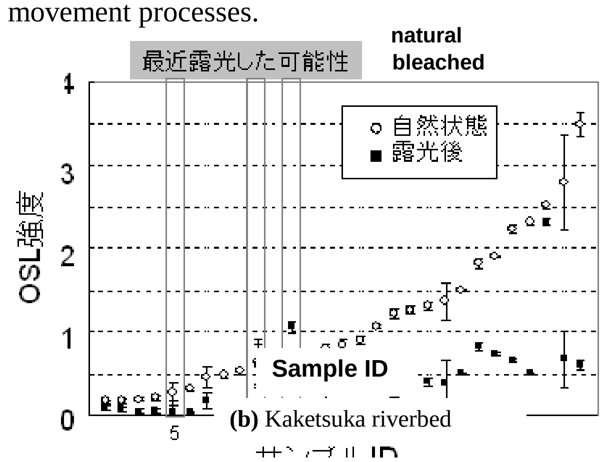

(b) Kaketsuka riverbed

Fig. 8 OSL intensities of sand samples collected at (a) Iida trench and (b) Kaketsuka riverbed

Figure 8 shows OSL intensities for sand samples at Iida trench (**Fig. 8(a)**) and Kaketsuka riverbed (**Fig. 8(b)**). Natural OSL intensities are compared with OSL intensities after complete sunlight bleaching. The sand particle is judged to be exposed to the sunlight in modern era if the two intensities are similar. No particles are judged to be exposed to the light for Iida trench samples. For Kaketsuka sample, very few sand particles are judged to be exposed to the light. This result shows that few sand particles are accumulated on the present riverbed, supporting the sediment movement scenario that most of sediment particles are directly flushed to the sea.

5. CONCLUDING REMARKS

A comprehensive investigation was conducted on the long-term evolution of sediments in a fluvial system composed of the Tenryu River watershed and the Enshu Coast. Investigation of sediment quality, combined with analysis of sediment quantity, was found to provide valuable information on the sediment movement mechanisms in a wide area.

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