MONITORING THE NOURISHED SAND LONGSHORE MOVEMENT BASED ON FELDSPAR LUMINESCENCE MEASUREMENT

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Abstract: In this study, monitoring the nourished sand longshore movement was conducted based on the feldspar luminescence measurement, including both Thermoluminescence (TL) and Optically Stimulated Luminescence (OSL). Nourished sand presents larger TL/OSL properties than the natural beach sand. Investigation on the spatiotemporal distribution of post-filling beach sand luminescence features at the Miyazaki coast and the Shounan coast, Japan, provides a new approach to evaluate the nourished sand movement characteristics. Comparing these two techniques, it is confirmed that the OSL is suitable for study on short-term sediment movement within a limited area; whereas, TL can be applied to the long-term and large-scale nearshore process assessment.

Introduction

In these years, beach nourishment has been increasingly applied as a countermeasure against coastal erosion problems. Different from coastal structures, *e.g.*, seawalls and breakwaters, periodical artificial beach replenishment, introduced as a soft coastal defence scheme, has been widely regarded as an environmentally acceptable approach to the beach and dune protection (Hanson *et al.*, 2002). However, up to now, the evaluation on the beach nourishment is mainly based on the bathymetry surveys, which are indirect, costly and normally carried out with an annual frequency. Considering the low temporal and spatial resolutions of the collected data, this method is not appropriate for examining the detailed coastal processes since the nearshore morphology is highly dynamic which, in general, is significantly modified by the episodic storm events. Other methods include applying fluorescent or dye-marked tracers in the target field. These approaches are laborious and time-consuming with respect to the tracer counting after filed samplings. At the same time, assessment on the nourished sand movement is difficult to achieve due to the mixing feature between the nourished and natural sands.

Recently, Rink (1999) and Liu *et al.* (2009a, b) suggested the use of natural residual thermoluminescence properties of quartz and feldspar grains as a possible transport indicator in the study of various coastal morphodynamic processes. In this approach, the nearshore sediment movement is directly investigated through the natural beach sands, as self-tracers, by focusing on their internal luminescence properties. This approach allows more reliability related to the field investigation on analyzing the corresponding coastal process. In this study, such technique was applied in monitoring and tracing programs following beach fills. Results show applicability of this approach for evaluating the temporal and spatial nourished sand distributions after beach nourishment implementation. In addition, nourished sands movement patterns were identified, especially after the extreme events.

Luminescence

In a sedimentary environment, quartz and feldspar particles undergo natural radioactive process. This induces the electron ionization in the grain crystal lattice due to the natural nuclear radiation effect, which builds up the latent luminescence signals in constituent mineral grains. The magnitude of luminescence signals in a grain is proportional to the accumulated energy obtained during the depositional burial. These accumulated internal luminescence signals can be stimulated by certain external energy, such as heating or exposure to the light. The signal released after the heating process is termed Thermoluminescence (TL); whereas, the light-stimulated luminescence signal is named as Optically Stimulated Luminescence (OSL). A detailed description can be referred to Aitken (1998). After sand particles are moved from their original sedimentary area, light exposure is accompanied with sand movement along the river and nearshore zone, which causes the reduction of particle luminescence signals.

In Japan, the predominant materials used for beach nourishment come from the depositional sediment stored on the riverbed or trapped inside the upstream dam reservoir of the nearby river. Liu *et al.* (2009a, b) applied the TL technique to investigate the nearshore sediment transport process in the Tenryu-Enshunanda fluvial system, and they found the riverine feldspar particles contain larger luminescence signals than coastal sands. Therefore, in case of a erosive coastal area that has virtually no input of sediment from other sources except the beach nourishment, investigation on the spatiotemporal distribution of beach sand luminescence signals in the vicinity of nourished spot could provide an opportunity for monitoring the nourished sand transport patterns. In this study, considering the nourished sand as a transport indicator, measurement on the luminescence signals of field-collected sand samples was implemented. Both TL and OSL techniques are adopted in this study for the inter-comparison and mutual confirmation on the experimental findings. When applying to investigate the nearshore sediment movement, field applicability of these two approaches is also specified using the sunbath test.

Research Area

Two typical coastal areas in Japan which are under regular beach fills are considered in this study, *i.e.*, the Miyazaki coast and the Shounan coast. During the field survey, surface samples (about 10 cm beneath the ground surface) were extracted in the intertidal zone along the target regions with a spatial interval of several hundred meters. In order to identify the nourished sand luminescence properties, sand samples were also collected from the residual bulk of artificially filled sands at the relevant locations during the field survey. Sample collection was carried out using opaque photographic film cases. Collected samples were immediately stored in the dark bag to avoid natural light exposure which may induce the underestimation of luminescence signals.

The Miyazaki coastal area (upper panel of Fig. 1), facing the Pacific Ocean, is an alluvial plain at the eastside of the Kyushuu Island, Japan, which formed after the depositional process of sediments carried from the mountain area through several dominant rivers in this region, such as the Hitotsuse River and the Ooyodo River. However, over the last several decades, with the completion of dams along the upstream river route, together with the overexploitation of riverine sediments for construction works, sediment discharge from rivers was reduced significantly. At the same time, harbors, airport runway and river mouth jetties were set up along the coastal area, which changed the nearshore sediment movement balance. All these anthropogenic impacts cause the coastal erosion problem along the Miyazaki coast, especially between the Hitotsuse River and the Ooyodo River. As a countermeasure against the erosion problem, beach nourishments were implemented at three locations along the target area since 2007, *i.e.*, Ishizakihama North (hereafter referred to as N-A), Ishizakihama South (hereafter referred to as N2007 since it was carried out in 2007) and Zoo Park (hereafter referred to as N-B) as illustrated in Fig. 1. Table 1 lists the general information about beach fills at each location, which includes the nourished materials' source, nourished sand size, beach fill period and amount. Field samplings were conducted twice in Jul and Oct, 2009. During the field survey, it was confirmed that most of N2007 nourished sands have been flushed out from their original location and mixed with natural beach sands. On the other hand, there exists a series of steep coastal scarps along the natural shoreline considering that the Miyazaki coast is highly erosive, especially after typhoon or storm events. Photo 1 shows the post-typhoon T0918 beach situation at the location 2.6 km south of the Hitotsuse River in 2009. Steep coastal scarp with a height around 6 m was formed, which indicates a large amount of scarp sands was eroded and mixed with the natural beach sands. Contribution from scarp sands should also be considered in case that beach sand luminescence signals are applied in this study. Taking this into account, TL/OSL samples were also picked up from the coastal scarps. From the recorded river water level data, it is confirmed that no significant river floods occurred in 2009 which demonstrates river sand supplies to the Miyazaki coast play a limited role to change the nearshore sand constitution during the study period.

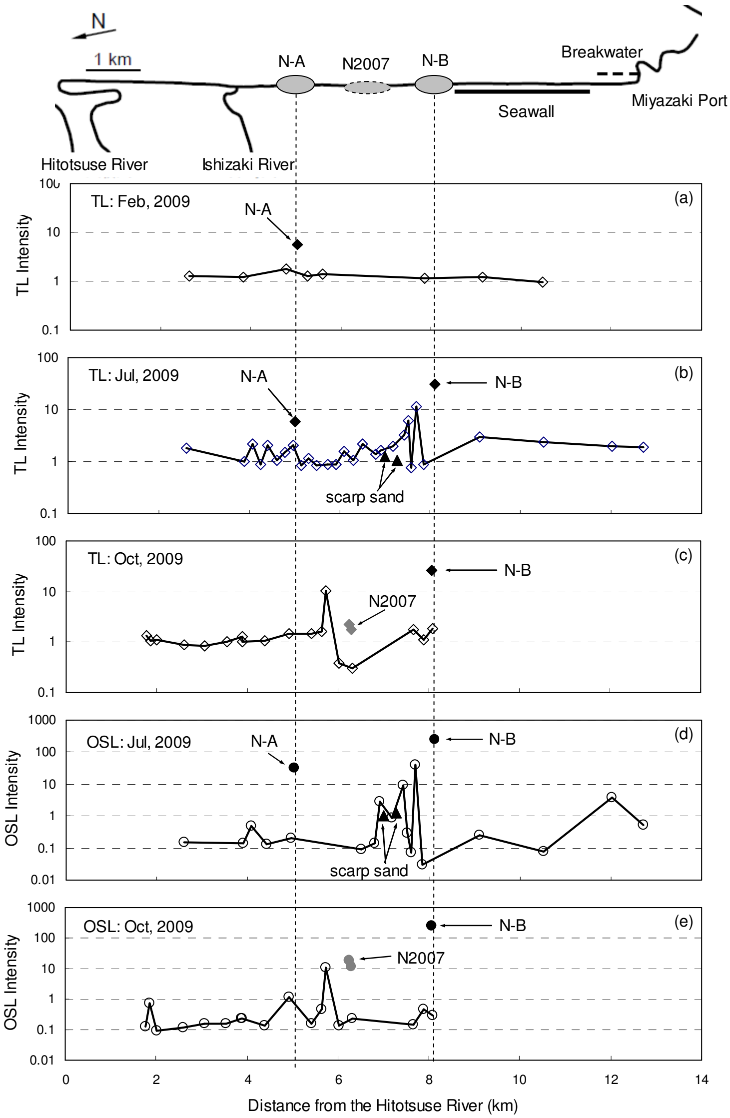

Fig. 1. TL and OSL intensity distribution along the Miyazaki Coast

Table 1. General information about beach nourishment along the Miyazaki Coast

Location	Nourishment materials	Injection period	Nourished sand size (D_{50}, mm)	Beach fill amount ($\times 10^4$ m^3)
Ishizakihama North (N-A)	Ooyodo/Sanzai riverine deposit	2007-2008	-	6.8
		2009	0.4	7.4
Ishizakihama South (N2007)	Ooyodo riverine deposit	2007	-	2.5
Zoo Park (N-B)	Omaru riverine deposit	2009	2.4	1.6

Photo. 1. Post-typhoon T0918 beach situation at the location 2.6 km south of the Hitotsuse River

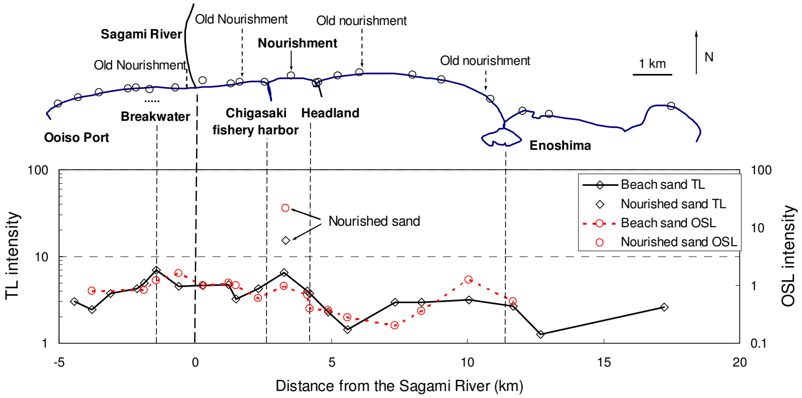

Fig. 2. TL and OSL intensity distribution along the Shounan Coast

As for the Shounan coast, similar to the Miyazaki coast, erosion problem occurs due to the construction of coastal structures, *e.g.*, harbor and headland, and dams along the Sagami River, which is the predominant sediment source for this region. Field sampling was conducted in Sep, 2009 with locations shown in the upper panel of Fig. 2. A series of beach nourishments was carried out along the Shounan coast to mitigate the erosion problem. During the field sampling, old nourishments specified in Fig. 2 had been washed away from their original locations. Only nourishment between the Chigasaki Harbor and the Headland was remained at the time of field sampling.

Laboratory Measurements

After field sampling, sample pre-treatment needs to be performed before the luminescence measurement to obtain pure feldspar grains. Such pre-treatment process is carried out in a dark room under the low intensity orange lighting condition (600 nm) under which little influence on the inherent particle luminescence signals is expected (Aitken, 1998). Initially, sand fraction with size of 180–300 μm is separated through wet-sieving. Subsequently, this fraction is treated with 15% H_2O_2 and 18% HCL to remove the organic material and carbonates, respectively. Then, a density separation in sodium-polytungstate at a density of 2.58 g/cm^3 is used to obtain the potassium-feldspar–rich fraction, which has a density between 2.53 and 2.58 g/cm^3. After drying the samples under the room temperature condition, a uniform layer of sands was mounted on 1 cm stainless-steel disc using silicone spray as an adhesive. A monolayer aliquot with each disc containing about several hundreds feldspar particles, was applied to avoid the heterogeneous effect from individual grains. At each location, four disks of sample aliquots were prepared and used for luminescence measurement. The averaged values are presented in the following discussions.

Luminescence measurements were performed on a Risø 48-sample automated TL/OSL Reader (model TL/OSL-DA-20) with an internal $^{90}Sr/^{90}Y$ β irradiation source. Sample TL signals were measured up to 500^{0}C with a heating ramp rate of 5^{0}C/s. Sample OSL signals were recorded using the infrared stimulation for 100 s at a temperature of 50^{0}C. A detection filter combination of a Schott BG39 and Corning 7-59 filters was used with a luminescence signal transmission window between 320 and 480 nm. This combination can effectively exclude luminescence signals from any quartz and from most plagioclase feldspar during measurements. These mineral components may remain in the feldspar fraction even after the density separation.

TL measurements were performed based on the TL test protocol proposed by Liu *et al.* (2009a). Normalization on the TL glow curve is achieved after dividing the natural TL signals by the averaged value of 10.8 Gy test dose induced TL signals over the temperature range of 200-400^{0}C, which, as mentioned in Liu *et al.* (2009a), represents the predominant part of test dose TL glow curve. In this study, the TL intensity is defined as the average value of the normalized natural TL signals between the temperature range of 260-380^{0}C, which, as mentioned in Liu *et al.* (2009b), covers the principal natural TL signals. As for OSL measurements, the test protocol is similar to the Single-Aliquot Regenerative-dose (SAR) protocol used for luminescence dating (Murray and Wintle, 2000). In which, the preheat and cut-heat conditions are determined from Ishibashi *et al.* (2009). Stimulation conditions used for OSL measurement is the same as Wallinga *et al.* (2000) for feldspar OSL tests. Duller and Augustinus (1997) argued that measurement of the initial OSL signal has the advantage of using only that part of the signal which is most sensitive to light, and of providing an enhanced signal-to-noise ratio. Taking this into account, the signal used in this study is the OSL signal detected in the initial 2 s of stimulation. Same as Wallinga *et al.* (2000), a background signal is subtracted from the initial OSL signal, based on the average OSL obtained in the last 10 s. This net signal is considered as the sample OSL response. The sensitivity-corrected normalized OSL intensity is estimated in terms of the OSL signal after a fixed test dose (0.9 Gy artificial irradiation). Comparison on such TL/OSL intensity among difference samples could be implemented regardless of the physical (*e.g.*, mass or shape) or intrinsic (*e.g.*, irradiation or stimulation responses) variations among different aliquots.

Results and Discussions

Miyazaki Coast

Fig. 1 demonstrates the TL/OSL intensity distribution along the Miyazaki coast for sands collected at different time periods. Sato *et al*. (2009) also measured the TL distribution along this area using field samples collected in Feb, 2009. Their data were reanalyzed and applied here for inter-comparison with results from the present study.

First, look at the nourished sand TL intensities at locations N-A and N-B (Figs. 1a, 1b and 1c), it is clear that TL intensity of the nourished sands is much larger than the nearby beach sands. This is ascribed to the fact that nourished sands come from the riverine deposits (Table 1), which contain large luminescence intensity. At the same time, TL intensity at N-B, riverine sediments from the Omaru River, is much larger than N-A, extracted from the Ooyodo River. This reveals the different geological sediment luminescence characteristics between these two rivers, which are in agreement with the finding in Sato *et al.* (2009)

who measured TL intensities of these two riverine samples. After the nourished sands are placed at the designed coastal beach filling spot, their luminescence properties, in general, keep unchanged if they are not moved by waves (no light exposure). This is also confirmed in Fig. 1. At location N-A (N-B), TL intensities are almost the same between Feb and Jul (Jul and Oct). Furthermore, considering the OSL properties of the nourished sands (Figs. 1d and 1e), same conclusions can be obtained, *i.e.*, nourished sand OSL intensity is larger than the nearby beach sand; N-B sands present a larger OSL signal than N-A sands; no significant change on N-B sand OSL intensity between Jul and Oct. Previous nourishment sand samples (N2007) were also collected in Oct field survey. As mentioned previously, almost all N2007 sands have been washed away from their original placement location. In Oct survey, only two samples of suspiciously untouched N2007 sands (with possible light exposure) were collected and analyzed. Results are shown in Figs. 1c and 1e. Taking into account that N2007 sands come from the Ooyodo River, the same as N-A, and comparing with N-A in Figs. 1b and 1d, both TL and OSL intensities are smaller for N2007 samples. This indicates that different from the N-A and N-B nourished sands which are still massive and heap together at the time of field sampling, these N2007 sands, generally in the form of small segments, may be exposured to sunlight after the placement in 2007. At the same time, considering the small residual amount of N2007 sands, their influence to the beach sand luminescence features can be neglected.

Subsequently, coastal scarp sands were sampled in Jul at locations about 7 km. In Fig. 1b, measurements show small TL intensities (about 1) for these scarp sands, which are almost the same as natural beach sands. From Miyazaki Coast documents 2009 (http://www.qsr.mlit.go.jp/miyazaki/html/kasen/sskondan), it is confirmed that such coastal scarp is generated after erosion of the old sand dune, which was formed with a time scale of thousand years by the wind-blown beach sands. Owing to the aeolian environments that such sand experienced, luminescence signals are almost bleached completely before deposition and burial in the sand dune, especially for OSL signals. In general, coastal dune sands present rather small luminescence intensities (Liu, *et al.*, 2009a). Considering the fairly weak natural radiation dose to the beach sand (0.5-1.0 Gy per thousand years, Rink, 1999), 1,000-year burial of such dune sand may only increase particle inherent luminescence signals by 1 Gy. Comparing to the test dose used for TL normalization in this study (10.8 Gy), 1 Gy of luminescence signal is insignificant in the measured TL intensity obviously. This explains the reason why scarp sands reveal a similar TL intensity as the natural beach sands. On the other hand, since test dose used for OSL normalization is only 0.9 Gy, 1 Gy increase in luminescence signals after sand dune burial do enhance the scarp sand OSL intensity by a value of 1. As shown in Fig. 1d, scarp sands presents an

OSL intensity about 1, which is larger than the beach sands whose OSL are only about 0.1. Comparing with the fairly large nourished sand OSL intensity (around 100) and considering the quick decaying feature of OSL signals as mentioned later, influence from scarp sands to the beach sand luminescence properties still plays a minor role.

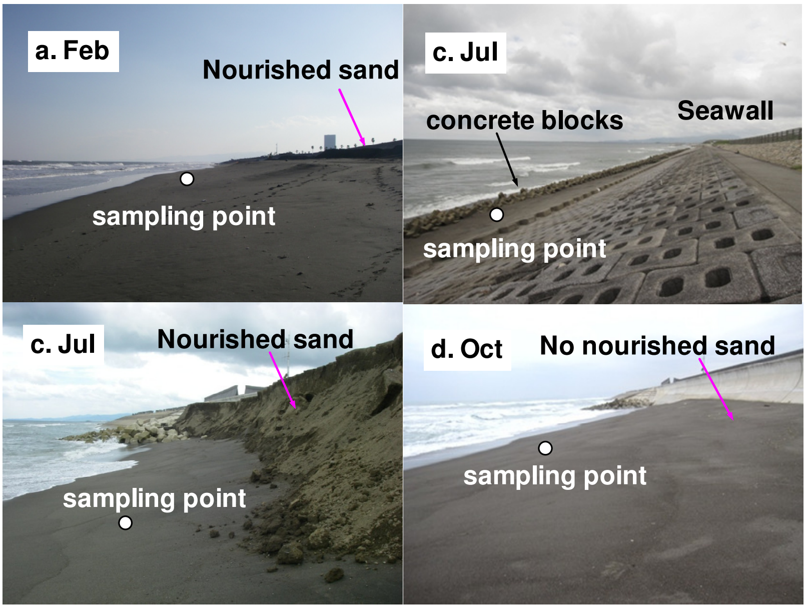

Photo. 2. Various field sampling situations

After checking both nourished and scarp sands luminescence properties as the two main possible sand sources for the Miyazaki coast, it is further confirmed that only nourished sands provide large luminescence intensity to the nearshore area, which can induce modification on the longshore beach sand luminescence signals. Hence, after looking at the spatial distribution of beach sand luminescence intensities, longshore movement of nourished sand can be detected. In Fig. 1a, beach sand TL intensity keeps a rather constant value (about 1) in the target region, which is smaller than the nourished sand TL intensity. Photo 2a presents beach sand sampling situation in front of N-B in Feb. It is clear that in Feb, nourished sands were remained at backshore, far away from the normal wave actions. Hence, nourished sands were not touched and mixed with natural beach sands. Accordingly, there is no clear modification on beach sand luminescence features in Feb. Significant transport of nourished sands, in general, occurs mainly during high wave conditions, such as storm and typhoon. Fig. 1b illustrates the TL distribution in Jul. Obvious longshore variation can be observed. Taking results at the south of N-B into account, they present TL intensities larger than the corresponding Feb samples in Fig. 1a. This is ascribed to the contribution from nourished sands at N-A and N-B which were transported southwardly by the May storm. Fig. 3 demonstrated the temporal distribution of wave height at the Miyazaki coast in 2009 and longshore transport rate estimated by the CERC formula. A severe storm with significant wave height more than 6 m attacked this area on May 28 as shown in Fig. 3a, which induced significant southward longshore sediment movement (Fig. 3b). Nourished sands at N-A and N-B were transported by the May storm and stored in between the seawall and shore-parallel concrete blocks. Photo 2b shows Jul beach sand sampling situation in front of the seawall. Different from the natural beach, *e.g.*, region between N-A and N-B, where sands were successively exposed to light by daily wave actions which reduce the nourished sand luminescence signals, sampling area in between the seawall and concrete blocks is sheltered and protected by these structures, which suppress the sand movement and avoid light exposure under normal waves. As a result, after nourished sands reach here, their large luminescence features can be preserved and detected in Fig. 1b. Large OSL intensity is also obtained at this region in Jul as shown in Fig. 1d. In Figs. 1b and 1d, large luminescence intensities are also confirmed at region between 7 and 8 km. Considering the values are even larger than N-A, it proves that such large TL/OSL values do not come from the contribution of nourished sands at N-A which, although, were moved here during May storm. Nourished sand at N-B is considered to be the only source to introduce such large luminescence signals. Photo 2c presents beach sand sampling situation in Jul. Comparing with Photo 2a, it is clear that beach erosion occurs during this period and in Jul, and that nourished sand at N-B was eroded and moved by the daily normal waves which mixed N-B sands with original beach sands and increased the luminescence signals. Fig. 3c illustrates the hourly longshore sand movement pattern around the time of Jul sampling. Northwardly longshore sand movement is confirmed then, which illuminates the reason of the large TL/OSL values at location between 7 and 8 km. These large TL/OSL values reduce further northward which indicates contributions from N-B gradually disappear. On Oct 7, a Typhoon T0918 with significant wave height of 7.8 m attacked this region which causes significant northwardly sand movement illustrated in Figs. 3a and 3b. After T0918, most nourished sands at N-B were moved away as shown in Photo 2d. Measured beach sand TL/OSL intensities around N-B present the natural beach sand values (Figs. 1c and 1e). One luminescence peak was confirmed at location 5.7 km, which is owing to the contribution from nourished sands at N-B that were transported here during T0918. At other locations, large TL/OSL values are not detected. This may be due to the specific local configuration at location 5.7 km. This location is the conjunction point between the vertical and mild-slope seawalls and there is a jetty made of concrete blocks penetrating into the sea which can trap northwardly moved sands to its south. Therefore, a certain amount of N-B nourished sands stored at this location where longshore sediment movement is blocked and sheltered by the structures. Light exposure at this location is therefore limited. Hence, large TL/OSL values are preserved here. On the other hand, the nourished N-B sands deposited at other locations after the T0918, lose their inherent large TL/OSL features since successive nearshore sand movement is undergoing before Oct sampling during which sand particles experiences continuous light exposure.

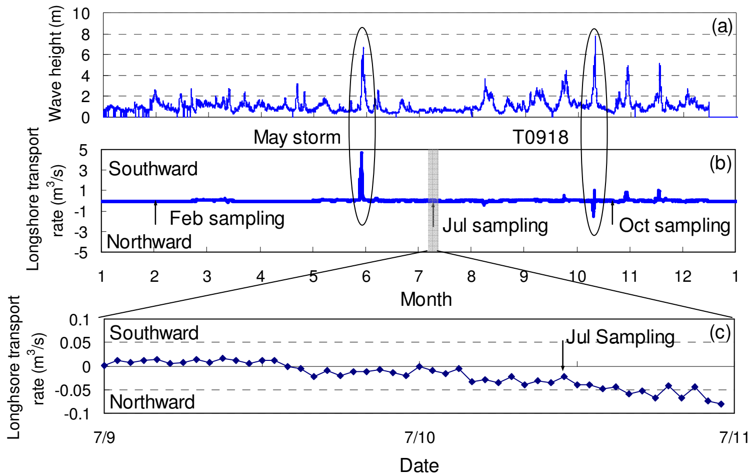

Fig. 3. Temporal variation of significant wave height and longshore sand transport rate estimated from the CERC formula along the Miyazaki Coast in 2009

Further look at the spatial variation of TL and OSL signals, *e.g.*, Figs. 1b and 1d, it is found that changing of OSL signal is much more significant than TL. For instance, between beach sand at location 7 km and nourished sand at N-B, decrease of TL intensity is in an order of 10; whereas, OSL intensity reduces by a factor of 1000. Considering that the travelling distance or light exposure experience is the same for these two tests, the above result indicates that sand OSL signal is more sensitive, and OSL signals reduces more rapidly to the light exposure (longshore sand movement) than TL. This is further confirmed from the sunbath test. Fig. 4 presents the sunbath test results for both TL and OSL which is conducted by exposing the treated natural feldspar samples to sunlight for different durations. Although different from the field conditions (sunbath test provides much efficient light exposure than the field situation), it is clear that within one day, OSL intensity reduced to only 9 percent of its original value. As for TL, it takes a much longer time, 13 percent of its original value remains even after two weeks sunbath. Taking this into account, it shows that OSL measurement is preferable for investigation on the short-term (event-induced) nearshore sediment movement within a limited area (local problem). On the other hand, TL measurement can be applied to a wide nearshore area to estimate a relative long-term sand transport pattern as demonstrated from studies in Liu *et al.* (2009b).

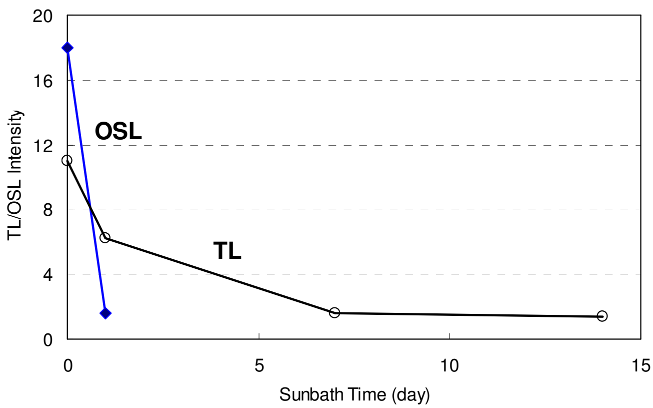

Fig. 4. Sunbath test for TL and OSL samples

Shounan Coast

Fig. 2 illustrates the luminescence signal distribution along the Shounan coast. Comparing with beach sand, nourished sand between the Chigasaki Fishery Harbor and the Headland reveals large luminescence intensities, which also increases the adjacent beach sand TL/OSL values. Nourished sands were mixing with original beach sands by daily waves during the field sampling. However, such influence is restricted within this local area due to the longshore movement limitation by the nearby coastal structures. In general, erosive spots present low TL/OSL intensities, *e.g.*, at locations 1.5 and 5.6 km. At these locations, beach sand movement is remarkable which results in more opportunities for sand particles to the light exposure and reduces their internal luminescence properties. At the same time, relative large TL/OSL values are observed at sand accretional areas, *e.g.*, behind the breakwater and at the west side of the Enoshima island. Taking into account the old beach nourishments implemented at Shounan coast as illustrated in the upper panel of Fig. 2, large TL/OSL values may represent the effect from these old nourished sands. These sands have large luminescence signals and after their deposition in the vicinity of structures, such signals are, in general, preserved owing to the limited sand movement owing to the shelter of corresponding coastal structures.

Conclusions

In this study, monitoring the nourished sand longshore movement at the Miyazaki coast and the Shounan coast was performed based on the feldspar luminescence measurements, including both TL and OSL techniques. The main conclusions are summarized as follows

1. Nourished sands from the riverine deposits present much larger TL/OSL properties than the native beach sands. Therefore, investigation on the spatiotemporal distribution of beach sand luminescence features provides an opportunity for assessment on the nourished sand transport patterns.

2. Along the Miyazaki coast, eroded scarp sands exhibit small luminescence signals which are almost the same as natural beach sands since these scarp sands consist of old wind-blown coastal dune sands.

3. Longshore sand movement at the Miyazaki coast after May storm/typhoon T0918 is revealed from beach sand luminescence measurements on Jul/Oct samples. Dominant southwardly longshore sand movement after May storm is confirmed with large TL/OSL values being detected in between the seawall and shore-parallel concrete blocks. The luminescence peak observed at location 5.7 km in Oct test corresponds to the northwardly longshore movement of N-B sands after the T0918. Large luminescence features at location 7 km in Jul test comes from N-B sands, which was transported there by daily normal waves at the time when conducting the Jul field sampling.

4. Comparing between TL and OSL results, as well as the sunbath test, it is confirmed that sand OSL signal is more sensitive to the light exposure or longshore sand movement than TL. Accordingly, OSL technique is preferable for investigation on the short-term (event-induced) nearshore sediment movement within a limited area (local problem). On the other hand, TL technique can be applied to a wide nearshore area to estimate a relative long-term sand transport pattern.

5. As for the Shounan coast, influence from the nourished sand was confirmed though the TL/OSL measurement. Erosive spots present low TL/OSL intensities; whereas, sand-accumulated areas show relatively large values, which is ascribed to the old nourishment.

Acknowledgements

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