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LONGSHORE SEDIMENT MOVEMENT ALONG THE ENSHUNADA COAST INFERRED FROM FELDSPAR THERMOLUMINESCENCE

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Abstract

Investigation on the sediment movement characteristics was conducted in a broad research area with a 150-kilometer stretch along the Enshunada Coast and the Suruga Bay, Japan based on feldspar thermoluminescence (TL) properties. River sand grains (primary source) present a higher TL signal than beach sand. Along the nearshore area, local TL intensity peaks are observed at the river mouth and sample TL intensity gradually deceases with increasing distance from the river mouth, which indicates sediment longshore transport features. Far away from the river mouth, the decreasing trend on TL intensities terminates. Taking the spatial distribution of TL intensities into account, a quantitative estimation on the longshore sediment flux was carried out based on the total river sand discharge. A sunbath test was implemented to help to distinguish the beach sand constituents. Identification of coastal sand sources was achieved in terms of the profile and magnitude of the measured TL glow curves.

Key words: longshore sediment movement, thermoluminescence, feldspar grain, sediment source, Tenryu River, Enshunada Coast

1. Introduction

In the field, both qualitative and quantitative investigation of the nearshore sediment movement is of critical importance for various coastal applications, such as developing efficient countermeasures against the coastal erosion problems. In a case study of longshore sediment process within a specified coastal area, identification of sand source, transport route/amount and the corresponding influential region is necessary. Therefore, comprehensive studies by considering a rather broad research area with a macroscale stretch are expected for fully understanding the insight into the general sediment movement mechanism.

Traditionally, the use of fluorescent or dye-marked tracers to study the nearshore sediment transport was applied in field works (Voulgaris *et al.*, 1998; McComb and Black, 2005; Hiramatsu *et al*., 2008). However, such tracer studies suffer from many practical problems in terms of sand sampling and tracer concentration determination. Artificially injected tracers are different from natural coastal sands in physical and chemical properties, which may cause unreliable field measurements. Nevertheless, such tracer studies can only be applied in a rather narrow area within a relative short period, *e.g.*, at a spatial scale of several kilometers and a temporal scale of several months. On the other hand, in a case study, Yuhi (2008) evaluated the long-term and large-scale morphological changes due to various anthrophogenic impacts based on successive field survey records. However, such detailed and continuous survey data are usually scarce. At the same time, further looking at in-situ sediment qualities becomes a useful approach to explore the sediment movement process. From the sediment size distribution, Liu *et al.* (2000) estimated the source and the track path of sediments in a watershed and the nearshore zone. Sato *et al.* (2004) achieved the long-term changes in sand movement processes from the distribution of mineral composition. Recently, Rink (1999, 2003) and Liu *et al.* (2009) suggested the use of natural residual thermoluminescence (TL) properties of quartz or feldspar grains as a possible transport indicator in the study of various coastal depositional processes. Applying this approach, sediment particles constituting the investigated object (natural sands), themselves, are used as self-tracers to monitor the nearshore sand movement. This allows more reliability related to the field investigation on the nearshore processes. Pioneering studies have been carried out to verify the

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applicability of this new technique under several sediment movement circumstances. However, more detailed studies and field applications are needed to establish the feasibility of the particle TL properties as a useful tool for examining the nearshore sediment movement under more sophisticated and extended natural conditions.

In this study, we applied feldspar TL measurements to estimate the sediment movement in a broad research area with a 150-kilometer stretch along the Enshunada Coast and the Suruga Bay. Difference between river and coastal sample TL glow curves was observed. Influence from river sediment discharge to the nearshore sand constitution was discussed based on the spatial distribution of coastal samples' TL intensities. With respect to the measured TL signals, regional longshore sediment process was investigated from both qualitative and quantitative viewpoints. Identification of the coastal sand source was estimated in terms of the TL glow curve profile and magnitude. Intercomparison and discussion on the collected sample TL glow curve and intensity outline a general insight into the longshore sediment movement pattern within the target area.

2. Research Area and Methodology

In this section, the theoretical background of sand particle thermoluminescence, together with its applications in coastal engineering, is briefly introduced. Then, research area and field sampling locations for this study are specified. After that, laboratory preparation on collected samples and experimental methods are described.

2.1. *Thermoluminescence*

This study applied the use of thermoluminescence (TL) properties of feldspar particles as a tool for the investigation of sand transport in the nearshore zone. Constituent mineral grains, *e.g.*, quartz and feldspar, undergo natural radiation while buried in a sedimentary environment, which builds up the latent luminescence signal through the effect of exposure to the weak flux of ionizing radiation provided by thorium, uranium and potassium-40 and their daughter products in the sediment, as well as by cosmic rays and by rubidium-87 to a minor extent. Thermoluminescence is the laboratory-stimulated light emission from the particle crystal by heating the sample to a certain temperature. The light emission occurs during the recombination of electrons and holes between traps and luminescence centers in the defect structure of the quartz or feldspar crystal lattice. Further detailed descriptions can be found in Aitken (1998).

Figure 1 shows a schematic diagram to illustrate the grain TL signal accumulation/release process. The magnitude of luminescence signals in a grain is proportional to the accumulated energy that has been stored from the natural nuclear radiation during depositional burial, *i.e.*, Stage I in Figure 1. After sand particles are eroded from their depositional spots, sediment transportation along the river or nearshore zone is accompanied with the sunlight exposure, which reduces the particle luminescence signals by depopulating the trapped electrons, *i.e.*, Stage II in Figure 1. The more significant the light exposure, *i.e.*, the longer the particle travelling distance, the smaller the TL signals. Nevertheless, even with long-term subaerial solar exposure (at a time scale of several years), grains do not lose all their TL signals. This leads to a natural residual TL signal. Spooner (1987) found that TL signal generally decreases exponentially with solar exposure. After a long-time exposure, decrease of the natural residual TL becomes indistinct and tends to a small, but nonzero asymptote. Thereby, a correlation between sand TL signals and the corresponding moving distance is established. Consequently, the residual TL signals inherent in natural sand particles can be used as a transport indictor for describing the nearshore sediment movement process. In the downdrift direction, sand grain TL signals from a unique source will deplete as a function of travelling time, *i.e.*, duration of solar exposure during movement. If sands from other source are supplied into the littoral process, modification on the local TL signal is expected. By looking at the natural residual TL signal presenting in stage II, this study focuses on the characterization and identification of nearshore sediment movement features in the research area.

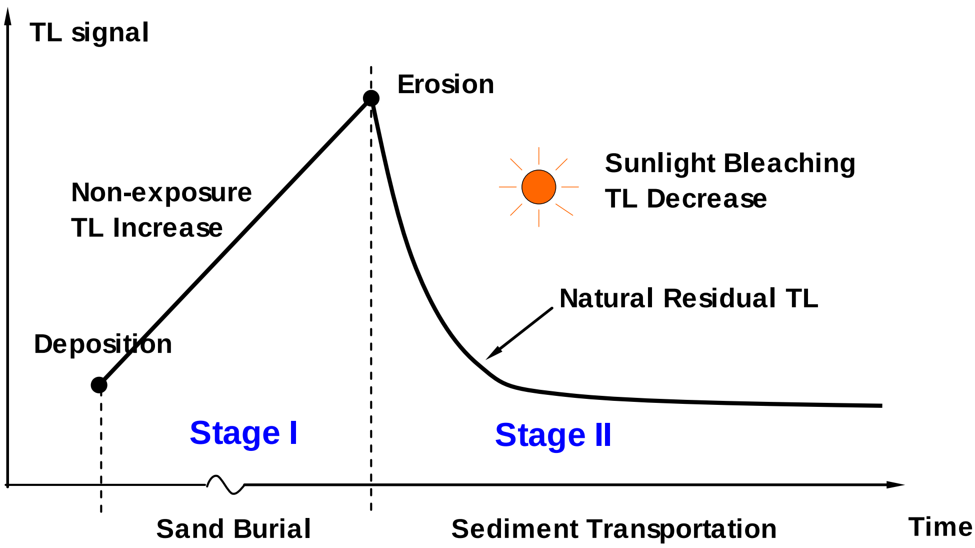

Figure 1 Schematic diagram on temporal variation of grain TL signal.

2.2. *Research area*

In this study, the target research area is the Enshunada Coast, which is located in the west of Shizuoka Prefecture, Japan, and has a double-arc shoreline profile with Tenryu River mouth extruding in the middle (Figure 2). Tenryu River, considering its large sediment discharge, is assumed to be the original and dominant sediment source for the littoral sands on the Enshunada Coast. This area has been suffered from coastal erosion induced by various natural and anthropogenic reasons. Detailed descriptions can be found in Liu *et al.* (2007). In order to distinguish the influential area from Tenryu sediment discharge, sample collection also went eastward to the nearshore region along the Suruga Bay where sand contribution from the Ooi River also plays an important role when considering longshore sediment movement.

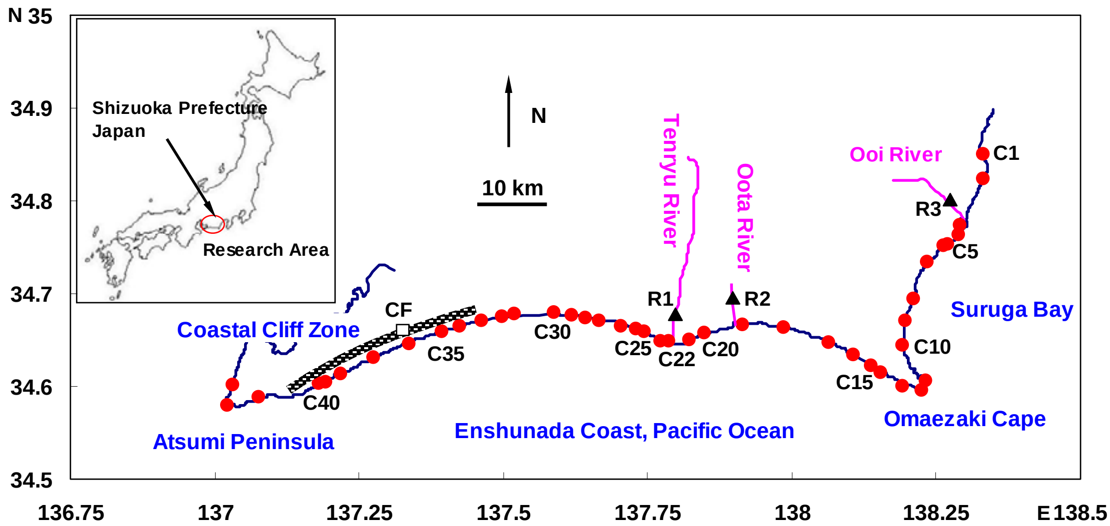

Figure 2. Research area and TL sampling locations for coastal samples ('●', C1 to C43),
river samples ('▲', R1 to R3) and coastal cliff sample ('□', CF).

In total, 43 surface samples (about 10 cm beneath the ground surface) were collected at the top of intertidal zone in the target coastal area, named as C1 to C43 starting from east to west as shown in Figure 1. Among those, samples C3 and C22 were collected at the Ooi and the Tenryu River mouth, respectively. Sample collections were carried out with a spatial interval of several kilometers. Detailed sampling was conducted in the vicinity of river mouth or coastal structures to reveal the local changes in TL properties. In order to identify the sand source, riverbed surface samples (about 5 km upstream of the river mouth) were also extracted along three major rivers within this research area, *i.e.*, the Tenryu River, the Oota River and the Ooi River with sample name R1, R2 and R3, respectively. Field samples, named as 'CF', were also collected from the coastal cliff located at the west side of the Enshunada Coast to recognize the nearby beach sand sources. During field sampling, dark film cases, together with black bags, were used to store the sand samples to prevent natural light exposure.

2.3. *Sample pre-treatment and TL measurement*

Laboratory preparation of the collected samples was conducted in semidarkness (under subdued orange light) to avoid the underestimation of luminescence signals. Sample pretreatment was conventional (Wallinga *et al.*, 2000). All samples were water washed and subsequently treated with 15% H_2O_2 and 18% HCL to remove the organic material and carbonates. Then, the K-feldspar rich fraction was obtained by a density separation in sodium-polytungstate at a density of 2.58 g/cm^3. The grain size fraction of 180-300 μm was used for further studies. Subsequently, a monolayer aliquot, with each disk retaining about several hundreds of feldspar grains, was applied in measurement to avoid the possible inhomogeneous features in luminescence signals from individual grains. Luminescence measurements were performed on a Risø 48-sample automated TL/OSL Reader with an internal ^{90}Sr/^{90}Y beta irradiation source. Sample TL signals were measured up to 500^{0}C using a heating ramp rate of 5^{0}C/s. A detection filter combination of a Schott BG39 and Corning 7-59 filter was used with a TL signal transmission window between 320 and 480 nm.

Measurements were performed based on the TL test protocol proposed in Liu *et al.* (2009), in which natural TL measurement was carried out after a preheat of 180^{0}C for 10 s to remove the unstable TL signals. To compare the samples collected at different locations, normalization of the natural TL signal is needed to compensate the inherent difference in samples, such as aliquot mass. Normalization was realized using an artificial test dose stimulation of 60 s (10.8 Gy dose). The normalized feldspar TL signal (after the average of four aliquots for every sample) was used in the following discussions.

3. Results and Discussions

3.1. *TL glow curves for river samples*

Sediment supply from the river discharge in a fluvial system is the dominant sand source for the adjacent coastal sediment cell. Therefore, consideration of river sand properties is necessary for investigation on the nearshore sediment movement. Figure 3 presents the normalized TL glow curves for three river samples (R1, R2 and R3) and one typical coastal sample (C22). It is found that all three river sample TL signals have much larger values, with a normalized TL peak value over ten, than that of coastal sample. Sand grains originating from the river upstream area have large TL signals since they undergo short travelling time and distance from their depositional burial stage under which TL signals are accumulating in particle crystal lattice. During the transport process, sand particles have the opportunity to exposure to sunlight and deplete their stored TL signals. Hence, large and small TL signals are expected for river and beach samples, respectively, as demonstrated in Figure 3. This is consistent with the result from Liu *et al.* (2009) in which they only investigated samples from the Tenryu River.

3.2. *TL glow curves for coastal samples*

Along the nearshore region and away from the river mouth (sand source), a decreasing trend in grain TL would be anticipated for a single sediment source condition because grain particles experience increasing light exposure during transport process. Figure 4 illustrates normalized feldspar TL glow curves from five coastal samples as shown in Figure 2, in which sample C22 was collected at the Tenryu River mouth and samples C19, C18, C17 and C16 were from the east side of the Enshunada Coast with an increasing distance from the Tenryu River mouth. It is found that the normalized natural residual TL signals gradually decrease with increasing distance from their primary source at the Tenryu River mouth. This is in agreement with the result from Rink (2003) who conducted TL measurements on nearshore samples along the coast of Israel. During the longshore sediment movement, sand particles undergo light exposure with respect to the moving time and distance, thus depopulate their stored TL signals in this process. Hence, a decreasing trend of TL signal is expected in the downdrift direction.

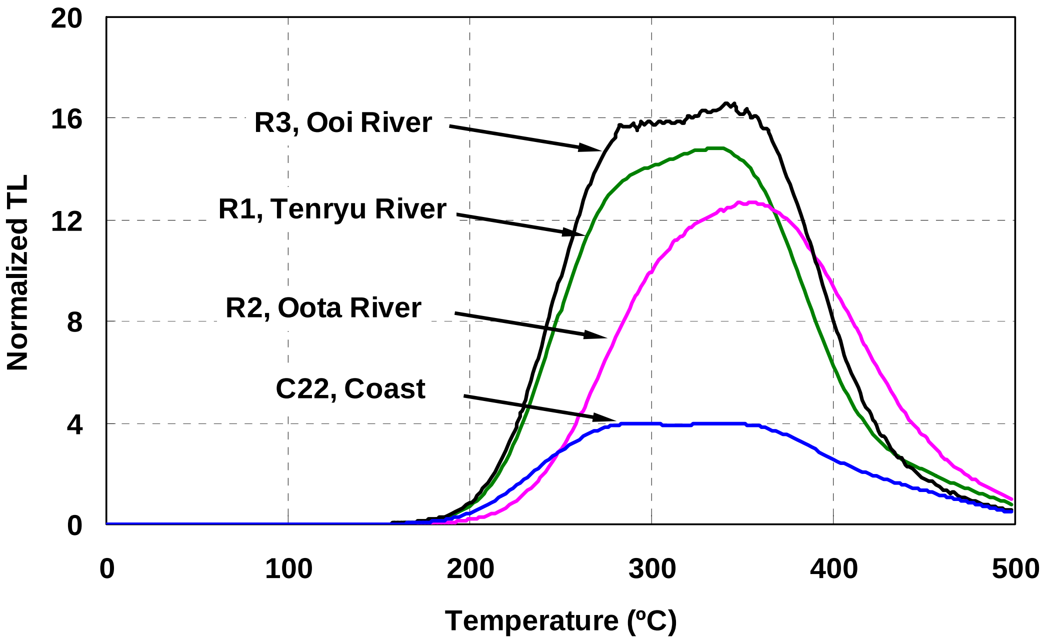

Figure 3. Normalized TL glow curves for three river samples (R1 at Tenryu River, R2 at Oota River and R3 at Ooi River) and one coastal sample (C22 at the Tenryu River mouth).

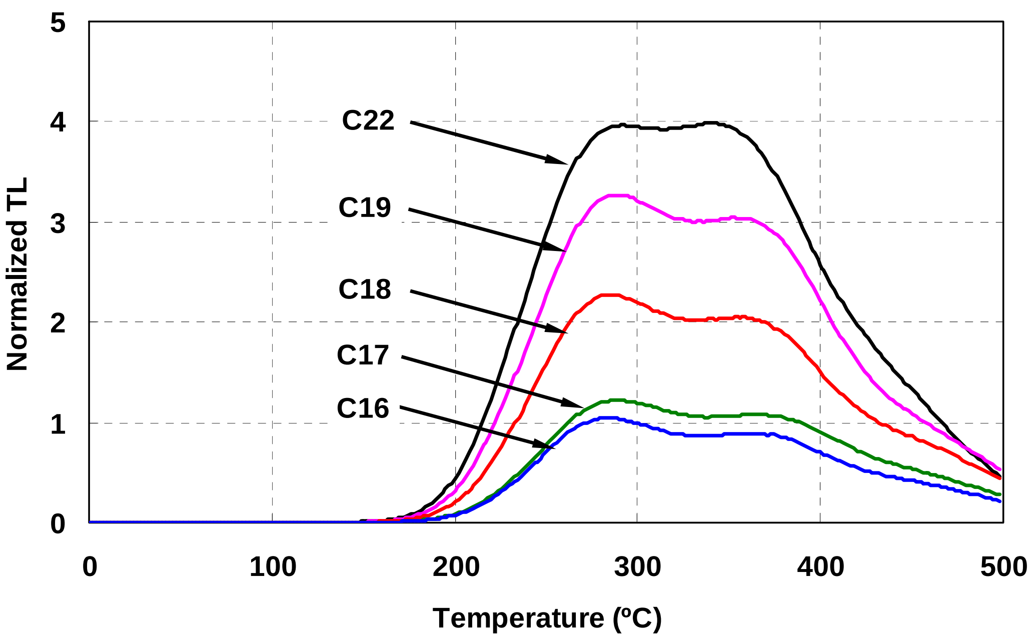

Figure 4. Normalized TL glow curves for coastal samples along the east side of the Enshunada Coast.

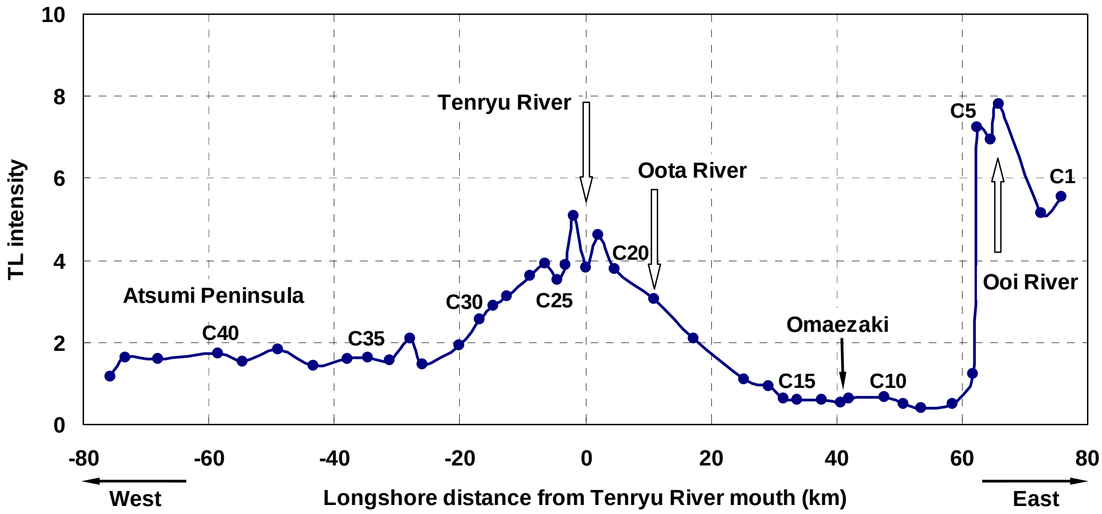

Figure 5. Spatial distribution of residual TL intensity in the research area.

3.3. *Spatial distribution of natural residual TL intensity*

Spatial distribution of the natural residual TL intensity in terms of the longshore distance away from the Tenryu River mouth is illustrated in Figure 5. Here, an eastward direction from the Tenryu River mouth is assumed to be positive. TL intensity is evaluated by considering average of the normalized TL glow curve over temperature range of 260-380^{0}C, which covers dominant TL signals as shown in Figure 4. It is found that TL intensity goes to a local peak value in the vicinity of the Tenryu River mouth. Influence from the river sand contribution can be observed which elevates the adjacent coastal TL intensity since river sands contain larger TL values as shown in Figure 3. Away from the Tenryu River mouth, TL intensity gradually decreases on both sides of the nearshore zone. This agrees with the scenario that during longshore sediment movement process, sand particles experience sunlight exposure which induces a decrease on grain TL signals as also seen from the TL glow curves shown in Figure 4. Spatial distribution of TL properties in this region reveals the TL signal decreasing process specified in stage II of Figure 1. In the nearshore downdrift direction, grain TL decreases as a result of continuous solar exposure during sediment transport process. Local TL intensity variation can also be observed around the Ooi River mouth. However, such phenomena can not be detected around the Oota River mouth. This is attributed to the small sediment discharge from the Oota River with a river length of 44 km and a catchment area of 488 km^2. Comparing with the Tenryu River with a length of 213 km and a catchment area of 5090 km^2 (10 km west of the Oota River), influence on the coastal sample TL intensity from Oota River originated sands, although they also present a large TL signal (Figure 3), can be neglected. Hence, considering the coastal sand constituents along the Enshunada coast, predominant contribution from Tenryu River is confirmed through the measured TL signal. This is regardless of the particle size, mineral components and sand color, which were used in the previous studies (Liu *et al.*, 2000; Sato *et al.*, 2004; Liu *et al.*, 2007).

Another interesting phenomenon is that around the river mouth, there exists certain fluctuation on the measured TL intensity, which is more obvious for Tenryu River mouth. Within a range of $\pm$5 km, clear variation on measured TL intensities is observed. Away from this area, modification on the coast sample TL intensity is rather smooth. This is owing to sediment inherent characteristics from the river sand supply. Liu *et al.* (2009) found that particle TL signal heterogeneity is rather significant for river samples since sediment movement caused by the unidirectional river flow, thereby, the TL signal bleaching by sunlight, is occasional and irregular (mainly during flood events) under river environment. Nevertheless, under coast environment, especially in the dynamic swash zone where field samples were collected, sand particles are frequently mobilized and exposure to sunlight by the continuous wave uprush and downwash motions. This induces a more uniform TL signal for coast samples. In the vicinity of river mouth, both mechanisms exist. Mixing process between river sands and original coast sands occurs. Hence, variation on TL signal induced by the non-uniform river sand appears around the river mouth. In case of a larger river sediment discharge, such spatial TL variation extends to a wide range. With respect to this point, it can be assumed that sand discharge from the Tenryu River is larger than that from the Ooi River. According to MLIT (2006), the total sediment discharge from the Tenryu River is around 9.7×10^5 m^3 per year (including slits with size less than 0.106 mm, sands with size between 0.106 and 0.85 mm and gravels with size larger than 0.85 mm), and the discharge from the Ooi River is about 1.45×10^5 m^3 per year. This argument can also be distinguished with respect to the nearshore extension where coastal sand TL signal is affected/enhanced by the relevant river supply. In case of the Tenryu River, it covers a range of about ± 30 km as shown in Figure 5. Within this range, increase in sample TL intensity is observed. TL intensity keeps a rather uniform, but small value beyond this area. As for the Ooi River, its effect is rather limited, *i.e.*, about 65 ± 5 km in Figure 5. This demonstrates sediment supply from the Tenryu River is greater than that from the Ooi River. Another scenario is that the longshore sediment movement is predominant around the Tenryu River; whereas, certain offshore sediment movement exists for the Ooi River discharge. From the measured nearshore bathymetry data, it is confirmed that the seabed has a steeper nearshore topography in the Suruga Bay (Ooi River) than that of Enshunada Coast (Tenryu River), which implicates the hypothesis that Ooi River-supplied sands may go directly into the offshore zone. Accordingly, longshore sand movement inferred from the measured TL intensity presents just in the limited area of the Ooi River mouth. As for the Tenryu River, longshore sand movement extends to a wide region indicated from the TL measurement.

Up to now, analyses on the longshore sediment movement based on coastal sample TL measurement are qualitative. At the same time, quantitative discussion on the longshore sediment flux around the river mouth can also be estimated from the spatial distribution of the measured TL intensity. Considering that coastal sands lose their inherent TL signals during longshore movement owing to the sunlight exposure, the longer distance away from the river mouth results in the smaller sand grain TL signal comparing to the sample TL collected at the river mouth. The decrease in particle TL intensity is proportional to the time duration of sunlight bleaching, that is, inversely proportional to the longshore sediment movement velocity in case of the same longshore travelling distance. After river-supplied sediments reach the nearshore zone, question on how and how much these sands will be distributed along the coastal area becomes important. Understanding on it can help us to develop efficient countermeasures against costal erosion problems. Traditionally, such nearshore sediment distribution is estimated from the measured bathymetry data. In this study, through the longshore distribution of sand sample TL intensities in the vicinity of river mouth, we can evaluate the proportional relationship of sand moving velocities between two sides of the river mouth, thus, estimation of the longshore sediment flux can be carried out based on the total river sediment discharge. According to the inclination of TL intensity profile presented in Figure 5, longshore sediment flux originating from the Tenryu and the Ooi River discharges was quantitatively estimated and listed in Table 1. As for TL intensity-based estimation, offshore sand loss was not included in the calculation. Inferred from TL intensity distribution, it is found that the Tenryu-contributed sands are almost equally distributed to both sides, which induced a nearly symmetric TL intensity profile around the Tenryu River mouth as illustrated in Figure 5. In case of the Ooi River, a rather asymmetric longshore sediment flux is estimated with most of sands (1.32×10^5 m^3/y, about 90% of the total river discharge) go to the left side of the river mouth. This is in agreement with the estimation from measured bathymetry data (1.37×10^5 m^3/y to the left side). Such asymmetric longshore flux distribution is caused by the nearshore wave direction in the target area. Predominant wave direction in this area is from south to north. Considering the Ooi River, shoreline along the Suruga Bay is in the northeast-to-southwest direction, hence, most of sands are transported to the north, *i.e.*, the left side of the river mouth, due to the wave-induced longshore currents. In case of the Tenryu River and taking into account that the Enshunada Coast is in the east-west direction, a symmetric distribution on Tenryu-contributed sands can be expected on two sides of the river mouth. Consequently, measured TL intensity distribution can be used as an indicator to quantitatively estimate the river-contributed sediment longshore distribution. Although the estimation is brief, this approach provides a rather simple and efficient way comparing with the traditional method based on the variation of measured seabed bathymetry data.

Table 1. Longshore sediment flux estimated from TL intensity distribution.

		TL spatial distribution from Figure 5 (TL/km)	Estimated longshore sediment flux ($\times 10^5$ m^3/y)	Total river discharge from MLIT (2006) ($\times 10^5$ m^3/y)
Tenryu River	Left	0.13	4.75	9.7
	Right	0.13	4.95	
Ooi River	Left	0.17	1.32	1.45
	Right	1.75	0.13	

3.4. ***Identification of sediment source***

Further look at Figure 5, it reveals that in the area far away from the Tenryu River mouth, *e.g.*, 30 km away, TL intensity decreasing trend terminates for both sides of the Enshunada Coast. Sand samples keep a rather constant TL intensity over there. However, a certain difference between the constant TL intensity values for two sides of the Enshunada Coast can be observed, *i.e.*, about 1.6 on the west side and 0.7 along the east side. It is proposed that the natural residual TL intensity from the same sand primary source will be depleted and achieve the same constant TL intensity value finally. This constant value implicates the hard-to-bleach TL component remained in feldspar grains, which cannot be thoroughly depleted under natural environment. This remaining TL signal represents the nonzero asymptotic value at the final state of the particle TL bleaching curve, *i.e.*, the late part of stage II shown in Figure 1. Under this stage, grain TL almost keeps a constant value even under long time solar exposure. Further longshore sand movement does not remove the remaining unbleachable TL signal. As a result, there has no significant change on the measured natural residual TL intensity after a certain distance from the river mouth. Nevertheless, sand samples on the west side keep a higher residual TL intensity than the east side one. Considering the above mechanism, it suggests that these sands may not reach the final unbleachable stage. Further decrease on TL signals can be expected to achieve a smaller natural residual TL intensity equal to the final value on the east side. At the same time, such high, but uniform TL distribution on the west side was detected, which should come from other external reasons except the sediment contribution from the Tenryu River.

In order to confirm these assumptions, sunbath test was performed using two coast samples, C13 on the east side and C36 on the west side. These two samples were selected considering that they are located in the TL-constant zone as shown in Figure 5. In order to provide a homogeneous laboratory lighting condition for data comparison, sunbath test was conducted using indoor fluorescent lamp to bleach the field samples with different time durations (10s, 1 min, 1 hour, 1 day and 1 week in this study). Afterward, TL intensity was measured and compared with the original natural residual TL intensity, *i.e.*, without any sunbath. Ratio between these two TL intensities is named as relative TL intensity. Figure 6 illustrates the sunbath test results with a logarithmic scale on sunbath time. For sample C13, even after long-time and successive light exposure, there is no clear change in the sample TL intensity. Measured results after various sunbath tests on sample C13 demonstrate a nearly constant TL value for sample C13, which is not depleted by further sunlight exposure. Hence, on the east side of the Enshunada Coast, after longshore transport from the Tenryu River mouth, sand particles lose their TL signal and in deed, reach a stable stage with a approximately constant TL feature. However, in case of sample C36, a decreasing trend is observed after one week light exposure. This means under continuous sunshine conditions, sand sample on the west side can be further bleached to a smaller TL intensity value (almost equal to that of C13) if there is no other sand supply to this area. Nevertheless, the fact that TL intensity keeps a higher constant value on the west side indicates other sand supplying source with a large TL intensity exists over there besides sediment contributed from the Tenryu River transported by the longshore sand movement.

On the west side of the Enshunada Coast, there exists a series of coastal cliffs. Figure 7(a) shows a photo of these coastal cliffs. It is understood that due to the short distance between cliff and shoreline (few tens of meters), these cliffs are suffering from erosion problems under episodic storm or typhoon conditions. Eroded cliff particles are transported to the nearby area and mixed with the coastal sands located at the Enshunada Coast. Consequently, coastal cliff serves as another sand source. From the geological viewpoint, these cliff sands were buried long time ago and excluded from sunlight exposure. Hence, they contain large TL signals. In order to verify this argument, sand samples were also collected from the coastal cliff, *i.e.*, sample CF (Figure 1) which is near to coastal sample C36. Figure 7(b) presents the normalized TL glow curve measured from the cliff sample, CF. Comparing to the corresponding coastal sample result, C36, it is clear that cliff sands hold a rather large TL intensity. After erosion and movement, cliff sands lose certain part of their inherent TL signals. However, due to the short travelling distance (short light exposure time), they still contain a relatively large TL features. With respect to the quantity of nearshore transported sands, eroded cliff sands only has a small amount due to the relatively occasional storm erosion events. Then, these sands mix with Tenryu-borne coastal sands of low TL intensities after an extensive longshore movement. As a result, sand samples along the west side of Enshunada Coast can keep a relatively high and constant natural residual TL signal. As shown in Figure 1, the coastal cliff zone extends to a wide range along the west side of Enshunada Coast. Taking results of Figure 5 into account, it is found that the stretch of coastal cliff zone just matches with the area where the TL intensity keeps a constant value. Hence, mixing process in this region from two different sediment sources, *i.e.*, Tenryu-contributed sands transported from far distance and cliff sands eroded from nearby area, was observed and confirmed after the TL measurement.

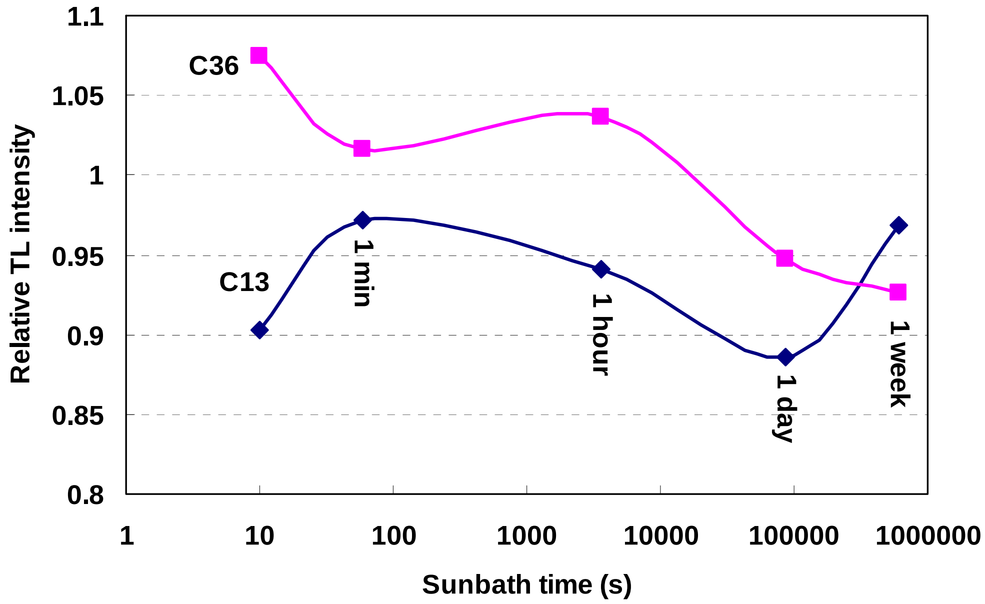

Figure 6. Sunbath test results for samples C13 and C36.

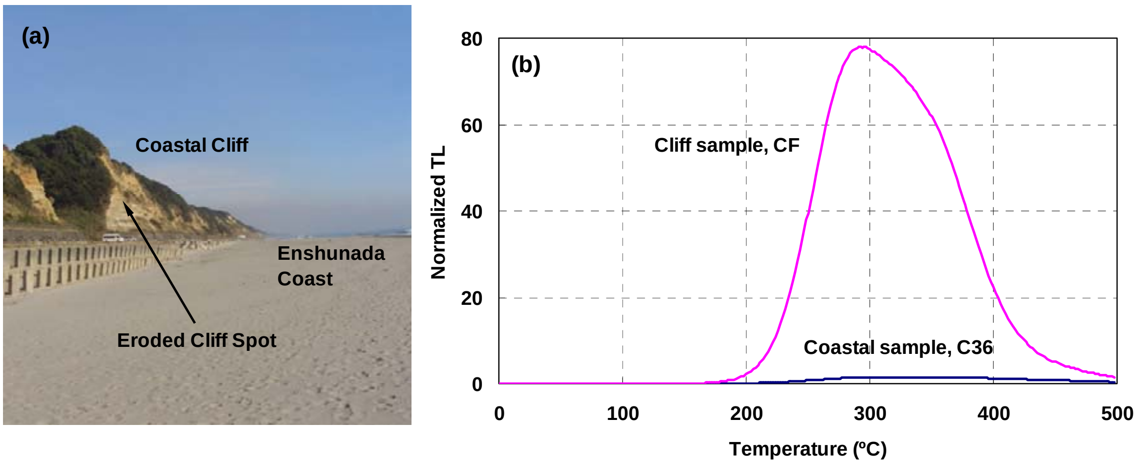

Figure 7. (a) Photo of coastal cliff along the west side of the Enshunada Coast.
(b) Normalized TL glow curves for coastal cliff sample, CF, and nearby coastal sample, C36.

Up to now, we focus on the magnitude of sample TL glow curves for discussions. Further considering the profile of TL glow curves can provide more information related to the sediment movement. Figure 8 demonstrates 3 normalized TL glow curves sampled in the vicinity of the Ooi River. Comparing with the TL glow curves around the Tenryu River as shown in Figure 4, there exists a clear difference in terms of glow curve profiles. In general, TL glow curve presents two local peaks within the temperature range. One is around temperature of 280^{0}C, and the other is around 360^{0}C. As for TL glow curves around the Tenryu River, the low temperature TL peak has a larger value than the high temperature TL peak; whereas, a different result, with the 280^{0}C TL peak being smaller than the 360^{0}C TL peak, is confirmed for TL glow curves around the Ooi River. This represents different sand natural TL characteristics from different sediment sources. During sediment movement, sand particles experience various bleaching process under different circumstances. This also induces local features on the grain TL signal. Hence, identification of sand source and judgment on a specified river-affected region can be implemented based on these properties of TL glow curves.

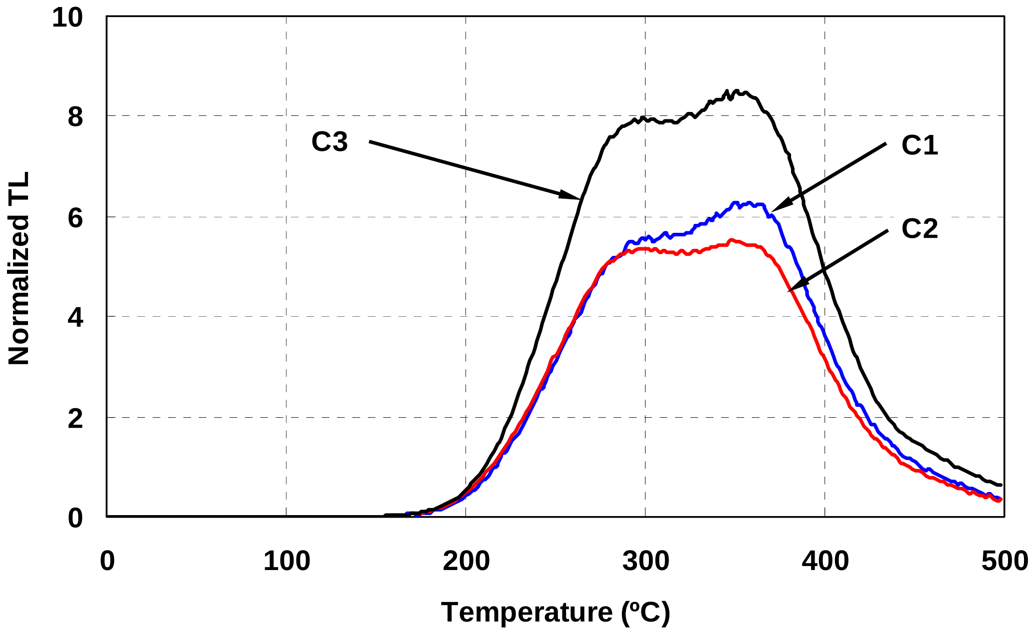

Figure 8. Normalized TL glow curves along east side the Ooi River.

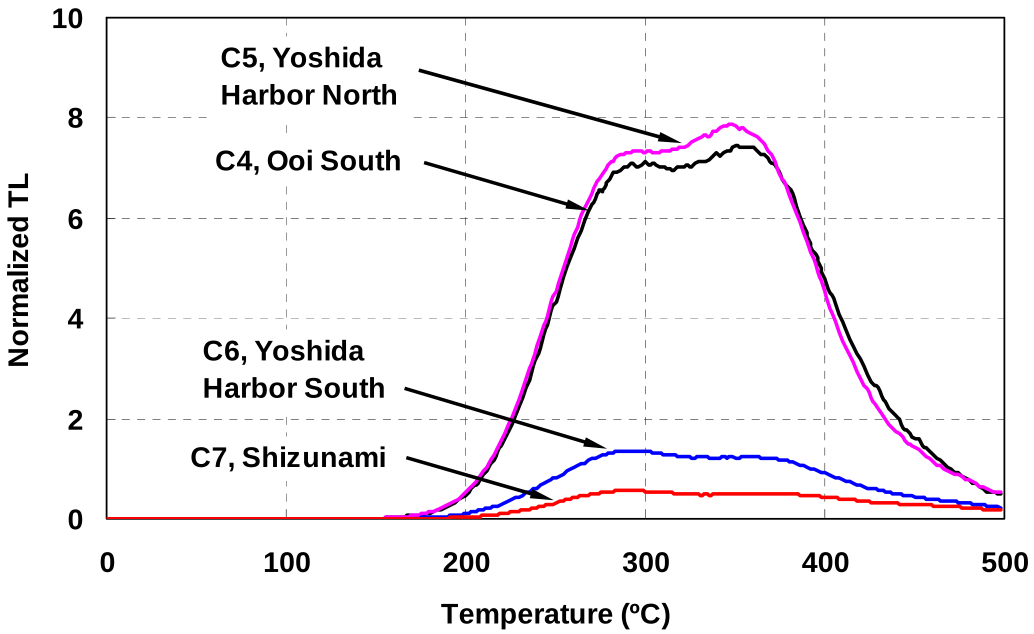

Figure 9. Normalized TL glow curves for samples C4, C5, C6 and C7 around the Yoishida Harbor.

Figure 9 illustrates the normalized TL glow curves for 4 samples collected at the right (south) side of the Ooi River mouth, along the shoreline of Suruga Bay. Samples C5 and C6 were collected on two sides of the Yoshida Harbor with a rather short distance in between, *i.e.*, about 1 km. However, there is a sudden drop on the measured TL signal between C5 and C6. Sudden decrease on the TL intensity between C5 and C6 can also be observed from Figure 5. Going further north by considering TL glow curve of sample C4 (about 2 km north of sample C5), which was collected at south of the Ooi River mouth, it presents a similar TL profile as that of C5; whereas, going further south and looking at sample C7 (Shizuname, about 3 km south of sample C6), its glow curve shows an analogous shape as that of C6. Taking TL signal magnitude into account, two groups can be classified, *i.e.*, C4/C5 with large TL intensity and C6/C7 with small one. Further looking at the TL glow curves between C4/C5 and C6/C7 and considering Figures 4 and 8, it is indicated that samples C4 and C5 are originated from the Ooi River with high temperature peak being larger than low temperature peak; whereas, samples C6 and C7 present curve profiles similar to that from the Tenryu River with high temperature peak being smaller than low temperature peak, which implicates that these sands are originated from Tenryu sediment discharge. It reveals the following scenario that due to the significant sediment supply from Tenryu River in the old days, a certain amount of sand particles from the Tenryu River goes eastward, bypasses the Omaezaki Cape and affects the nearshore beach constitution along the Suruga Bay. Such nearshore transport can extend as north as the location of the Yoshida Harbor, which is the physical boundary between Tenryu-originated sands and Ooi-originated sands. Therefore, identification on coastal sand sources is realized. Such Tenryu sand bypass movement pattern is also consistent with the finding from Liu *et al.* (2007), in which they tracked the sand movement based on the sand sample color and magnetic properties.

4. Conclusions

Longshore sediment movement along the Enshunada Coast and the Suruga Bay was investigated based on the feldspar thermoluminescence (TL) properties. Laboratory measurements on sand natural residual TL signals reveal the following conclusions:

1. As sediment primary source for the nearshore area, river sands present a higher TL signal than coastal sands. The latter experiences the TL signal depleting process during movement.
2. Owing to the river sand discharge with large TL features and gradual bleaching during longshore sediment movement, measured coastal sand TL signals present a local peak value around the river mouth and a decreasing trend with an increasing distance from the river mouth.
3. In the vicinity of river mouth, there exist certain fluctuations in terms of the coastal sand TL intensity, which is ascribed to the river sand supply with rather heterogeneous particle TL signals.
4. Comparing to the Tenryu River and the Ooi River, sediment discharge from the Oota River is fairly insignificant. Inferred from TL measurement, Tenryu-contributed sands are transported to a wider longshore region than that from the Ooi River.
5. Considering the spatial distribution of natural residual TL intensities, quantitative estimation on the longshore sediment flux based on the total river sand discharge was carried out. Eastward and westward sediment fluxes are almost equal in case of Tenryu River; whereas, predominantly northward sediment movement (about 90% of the total river discharge) is recognized for Ooi river supplied sands.
6. The decreasing trend on TL intensity terminates with uniform values being observed far away from the Tenryu River mouth. The constant residual TL intensity on west side is larger than east one. On east side of the Enshunada Coast, it is attributed to the unbleachable feldspar natural residual TL characteristics. Along the west side, mixing process between Tenryu-contributed sands transported from far distance and coastal cliff sands eroded at nearby area was undergoing and confirmed after the sunbath test and relevant TL measurements. This induces a relatively larger constant TL intensity value on the west side than the east side of the Enshunada Coast.
7. Further looking at the profile and magnitude of sample TL glow curves, identification on coastal sand sources was implemented. It is found that the Tenryu-originated sands can bypass the Omaezaki Cape and affect the beach constitution as far as the south of the Ooi River. Interface between these two sand contributions is detected around the Yoshida Harbor.

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References

Aitken, M.J., 1998. *An Introduction to Optical Dating: The Dating of Quaternary Sediment by the Use of Photon-Stimulated Luminescence.* London, Oxford Science Publications, 267p.

Hiramatsu, H., Tomita, S., Sato, S., Tajima, Y., Aoki, S. and Okabe, T., 2008. Sediment movement mechanism around the Magome River mouth based on color sand tracer experiments. *Proceedings of Coastal Engineering*, JSCE, 55(1), 696-700. (in Japanese)

Liu, H., Sato, S., Tajima, Y., Huang, G. and Fujiwara, H., 2007. Investigation on the historical evolution of alluvial deposits along the Tenryu River and the Enshu Coast. *Proceedings of the 4th Asian and Pacific Coastal Engineering Conference*, Nanjing, China, 1139-1150.

Liu, H., Kishimoto, S., Takagawa, T., Shirai, M. and Sato, S., 2009. Investigation of the sediment movement along the Tenryu-Enshunada Fluvial system based on feldspar thermoluminescence properties. *Journal of Coastal Research,* In press.

Liu, J.T., Huang, J.-S., Hsu, R.T. and Chyan, J.-M., 2000. The coastal depositional system of a small mountainous river: A perspective from grain-size distributions. *Marine Geology*, 165, 63-86.

McComb, P. and Black, K., 2005. Detailed observations of littoral transport using artificial sediment tracer, in a high-energy, rocky reef and iron sand environment. *Journal of Coastal Research*, 21(2), 358-373.

MLIT, 2006. *Documents on Sediment management, Basic Policy for River Maintenance, Tenryu River Fluvial System and Ooi River Fluvial System*, http://www.mlit.go.jp/river/basic_info/jigyo_keikaku/gaiyou/seibi/, Ministry of Land, Infrastructure, Transport and Tourism, Japan. (in Japanese)

Rink, W.J., 1999. Quartz luminescence as a light-sensitive indicator of sediment transport in coastal processes. *Journal of Coastal Research.* 15(1), 148-154.

Rink, W.J., 2003. Thermoluminescence of quartz and feldspar sand grains as a tracer of nearshore environmental processes in the southeastern Mediterranean Sea. *Journal of Coastal Research.* 19(3), 723-730.

Sato, S., Kajimura, T., Abe, M. and Isobe, M., 2004. Sand movement and long-term beach evolution in a fluvial system composed of the Samegawa River and the Nakoso Coast. *Coastal Engineering Journal*, 46(2), 219-241.

Spooner, N.A., 1987. *The Effect of Light on the Thermoluminescence of Quartz.* M.Sc. thesis, Dept. of Physics, University of Adelaide, Australia.

Voulgaris, G., Simmonds, D., Michel, D., Howa, H., Collins, M.B. and Huntley, D.A., 1998. Measuring and modeling sediment transport on a macrotidal ridge and runnel beach: an intercomparison. *Journal of Coastal Research*, 14(1), 315-330.

Wallinga, J., Murray, A. and Wintle, A., 2000. The single-aliquot regenerative-dose (SAR) protocol applied to coarse-grain feldspar. *Radiation Measurements*, 32, 529-533.

Yuhi, M., 2008. Impact of anthropogenic modifications of a river basin on neighboring coasts: case study. *Journal of Waterway, Port, Coastal, and Ocean Engineering*, 134(6), 336-344.