Optically Stimulated Luminescence to Date Coastal Dunes and a Possible Tsunami Layer on the Kavak Delta (Saros Gulf, NW Turkey)

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Abstract: Optically stimulated luminescence (OSL) dating was used to determine the timing of initial dune formation and reconstruct the evolution of coastal dunes that developed on the Kavak Delta, Saros Gulf, Turkey. Along a 500-m-long representative transect, dune sands were extracted from foredune, semistable (grey) dune, stable (dark) dune and dune-swamp boundary defined by a scarp 50–75 cm high. The data obtained showed that dune drift initiated 670 years ago. A pumice layer 15–20-cm-thick interbedded with marine clay and sand showed an OSL age of 340 years coinciding with underlying dune sand. XRF analysis showed that pumices were of similar composition to those erupted by plinian activity of Thera (Santorini) in 1628 BC. On the basis of OSL ages, these deposits, which are widely distributed on the western Anatolian coasts of Turkey, might have presumably transported landward along tide channels on the delta during a tsunami event that occurred in 1672 near Bozcaada and Kos islands according to tsunami history of the Aegean Sea.

Key Words: coastal dune, coastal geomorphology, dune boundary, OSL dating

Kavak Deltasında (Saros Körfezi, KB Türkiye) Kıyı Kumulları ve Olası Bir Tsunami Tabakasının Işık Uyarımlı Luminesan Yöntemiyle Yaşlandırılması

Özet: Kavak Deltası'nda (Saros Körfezi, Türkiye) kumul oluşumunun başlangıcı ve kumul evriminin rekonstrüksiyonu için Optik Lüminisans yaşlandırması uygulandı. 500 metrelik bir hat boyunca ön kumul, yarı hareketli (gri) kumul, hareketsiz (koyu) kumul ve 50–75 cm yükseklikte bir diklikle karakterize edilen kumul-bataklık sınırından kum örnekleri alındı. Elde edilen veriler kumul hareketinin 670 yıl önce başladığını göstermektedir. Denizel kum ve killerle aratabakalı olarak bulunan, 15–20 cm kalınlıktaki pomza tabakasının OSL yaşı 340 yıldır ve bu yaş örttüğü kumlarla tam bir uyum gösterir. Pomzaların XRF analizi, Thera'nın (Santorini) M.Ö. 1628 yılındaki plinien aktivitesi ile çıkan pomzalarla aynı bileşimi göstermiştir. OSL yaşlarına göre, Anadolu'nun batı kıyılarında geniş dağılım gösteren bu depolar Ege Denizi tsunami kayıtlarında 1672 Bozcaada-Kos Adaları tsunamisi olarak bilinen tsunami nedeniyle deltadaki gelgit kanalları boyunca iç kısımlara taşınmış olmalıdır.

Anahtar Sözcükler: kıyı kumulu, kıyı jeomorfolojisi, kumul sınırı, OSL yaşlandırma

Introduction

Coastal dunes are one of the most important components of coastal landforms and are of special significance for, in particular, understanding Holocene sea level oscillations, windblown sand transportation dynamics, regressive and progressive relocation of shoreline in coastal regions (Ritchie 1972; Goldsmith 1978; Bird 1984; Hesp 2000, 2002).

In most cases, dune relief is characterized by consecutively arranged dune forms of different age. They start with incipient dunes (or embryo dunes) near the beach and are followed leeward by foredune ridges, semistable (grey) dunes and stable (dark) dunes. Dating these different parts of dunes along a representative transect helps interpret the development of dunefields over time. In such attempts, dune ages based on Thermoluminescence has been previously provided by Singhvi *et al.* (1986) and Huntley & Prescott (2001). Recently, Optically Stimulated Luminescence (OSL) has been used as a reliable chronometric tool for dating Holocene relict foredunes (Murray-Wallace *et al.* 2002), stranded coastal barriers (Banerjee *et al.* 2003), parabolic dunes (Jungner *et al.* 2001) and dune accretion on archeological sites (Sommerville *et al.* 2001, 2003, 2007). The technique was widely used particularly because of its advantage in supplying age data in reconstructing the evolution of coastal environments on a time scale from thousands to decadal years (Ollerhead *et al.* 1994; Murray & Clemmensen 2001; Balarrini *et al.* 2003; Rink & Forrest 2005; Lopez & Rink 2008).

Despite the wide distribution of coastal dunes on Turkey's 8333-km-long coastline, determining the age of dunes has been ignored until now. In this paper, we test for the first time the application of OSL to date quartz-rich dune sands on the north coast of the Kavak delta. In addition, a possible tsunamigenic pumice layer deposited along the dune-swamp boundary is examined using OSL to initiate a discussion on tsunami impacts along the coastal lowland facing the Saros Gulf in northwest Turkey.

Study Area

The Kavak dunefield is located in the northern coast of the Kavak delta in the north Aegean Sea coastline of Turkey and lies between latitudes 40°39'24" N to 40°35'01" N and longitudes 26°47'57" E to 26°52'12" E (Figure 1a, b). The dunefield covers an area of 21.355 km^2 along a coastline of 12.3 km. The delta plain is crossed by the 64-km-long Kavak River draining an area of 845 km^2. It is bounded by Mount Korudağ (674 m) on the north and the Gelibolu plateau with average elevations ranging between 100–400 m in the south. Elevations on the delta plain vary between 0 and 10 m above the present sea level. The north and south parts of the area are predominantly formed by Eocene formations comprising fine- to medium-grained sandstone, yellowish-grey laminated claystone with intercalations of tuff, fine-grained turbiditic sandstone and mudstone (Sümengen & Terlemez 1991).

Methods

Sampling

Sampling for OSL dating was carried out along a transect crossing different parts of the dunefield. Sampling sites are shown in Figure 1c. In total, 11 samples were collected from five covered observation pits dug into sands of foredune, semistable dune, stable (old) dune and dune-salt swamp boundary (Figure 1c). Variations in horizon characteristics of dune sands with depth were considered in sampling (Soil Survey Staff 1993). Sampling depth was restricted to the sediments above ground water level. GPS (Garmin ETREX with 10 metres accuracy) was used to record the geographical coordinates of sampling sites.

OSL Dating

Sample Preparation and Instrumentation

Sediment samples were wet sieved under subdued red light and grains in the size range 90–180 μm were separated. Then quartz grains were extracted from sediment materials by usual chemical treatments comprising treatment by HCl (for the removal of carbonates) and then H_2O_2 for removal of the organics. The minerals were etched using HF, and this process dissolved feldspar grains yielding a residue of pure quartz. The samples were treated with HCl once more and then washed by distilled water several times. Clean quartz grains were dried in an oven at 50 °C. Several aliquots from each sample were prepared and spread over stainless-steel discs using silicon spray. All aliquots were tested for feldspar contamination using infrared stimulation before OSL measurements. A Risø TL/OSL reader was used for all OSL measurements using blue (470
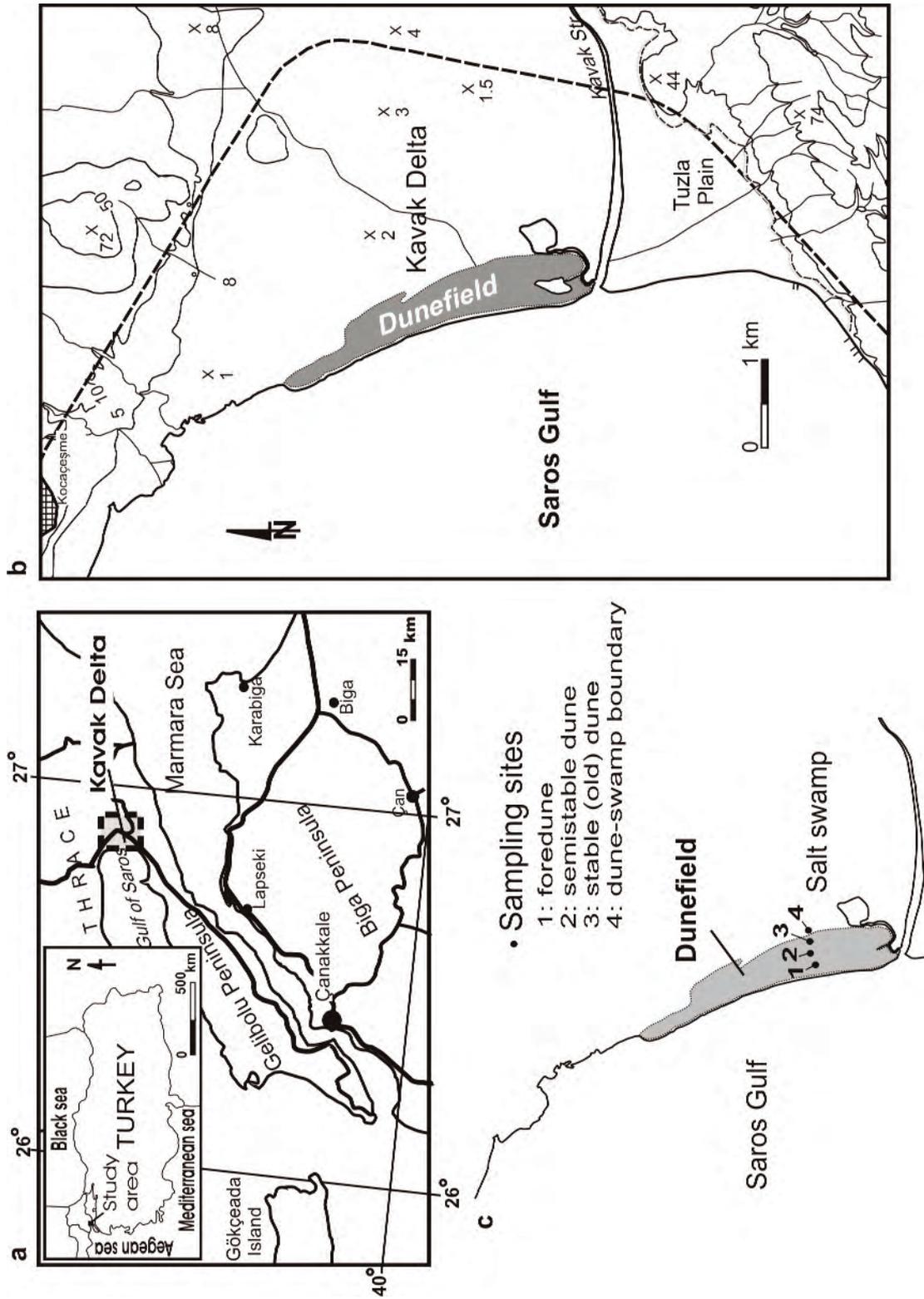
Figure 1. Location map of the study area in NW Turkey (**a**), topography of the area and spot heights (m asl) (**b**), and sampling sites (**c**).

nm) light stimulation through U-340 filters (Bøtter-Jensen & Murrat 1999). The reader was equipped with a beta irradiator employing a dose rate of 0.105 Gy/s to the samples. The dose rate required for age calculation was estimated using gamma spectral data and gamma dose rate measured at site.

Dose-response Curve and SAR Dose (D_e) Estimation

Figure 2 presents the dose response curve (growth) for the quartz from a representative sample PRF3-3. The regenerative doses were between 0 to 8 Gy. The growth curve using corrected OSL signal (L_i/T_i) via dose given in the laboratory can be defined by an exponential function. The mathematical function fitted by experimental data is one of the important criteria regarding dose estimate. The equivalent dose (D_e) can be obtained from the relevant corrected natural OSL signal (L_n/T_n) on the curve as presented in Figure 2.

The equivalent dose absorbed by the samples was obtained using single-aliquot regenerative (SAR) protocol based on a sequence of measurements with a number of cycles (Murray & Wintle 2000). In the first cycle the natural OSL signal (L_n) was measured first at 125 °C for 40 s and then a preheat treatment at 260 °C was applied to remove laboratory-induced signals from the OSL curve. The sensitivity change due to preheat temperature applied after natural OSL was monitored using 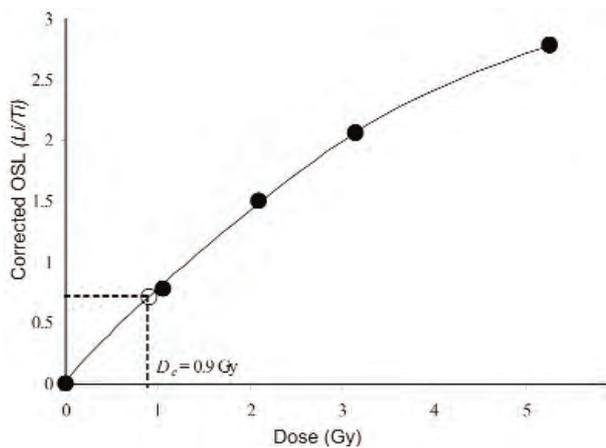a small test dose OSL signal of 0.5 Gy (T_n), and the ratio L_n/T_n was termed the corrected natural OSL signal. In the following cycles regenerative dose OSL signals (L_i) were measured at 125 °C for 40 s and corrected using the test dose OSL signal (T_i) recorded after the main OSL measurement. The first 0.8s of the initial OSL signal was used for the dose estimate after subtracting the background dose. Figure 3 indicates a typical OSL decay curve recorded for natural sample, bleached and irradiated to 1 Gy, 3 Gy and 5 Gy. The first regenerative dose was repeated in the last cycle to check for sensitivity correction, namely recycling ratio, as the ratio of these repeated doses and suggested recycling ratio of 0.90 to 1.10 (Murray & Wintle 2000). Using these criteria the recycling ratios were satisfactory for all samples investigated and close to unity.

Dose Recovery Test

In order to test the reliability of OSL measurements a dose recovery test was suggested by Murray & Wintle (2003). For the test the samples were subjected to a known dose and examined to determine how accurately they recovered the given dose. Therefore aliquots were bleached and then given a beta dose, close to the natural dose for each sample. Then the SAR procedure was employed using the same regenerative doses and the same test dose treatment as described before. For the sample PRF3-3, a 0.5 Gy test dose was applied and a laboratory dose of 1.05 Gy was recovered as 1.03 Gy, suggesting that the SAR method was suitable for the investigated samples.

Dose Rate and OSL Ages

The environmental dose rate used for dating was based on site measurements. Gamma dose rate was directly measured at site and total dose rate was derived from site measurements using the relative concentrations of major radioactive isotopes of the uranium and thorium series and of potassium with the assumption of secular equilibrium in the U decay series (Olley *et al.* 1996). Total dose rates vary between 1.41 and 1.49 Gy ka^{-1}. The contribution of cosmic rays to the dose rates was found to be between 0.18 and 0.26 Gy×ka^{-1} using altitude, latitute and depth of the sample location from the surface (Prescott & Hutton 1988, 1994).

Figure 2. Dose-response curve of quartz extracted from sample PRF3-3 can be described by an exponential function for a dose range from 0 to 5 Gy. The equivalent dose is found from corrected natural OSL signal (L_n/T_n).

All SAR data were consistent with stratigraphy. The samples were young, aeolian, and D_e values tend to form a simple Gauss distribution with no significant skewness in their descriptive statistics. Therefore, the mean value of the distribution of D_e values, in other words the Central-Age Model (CAM), was taken for the SAR dose estimate to be used for age calculation (Bailey & Arnold 2006). The number of aliquots evaluated for each sample are presented in Table 1. In principle, the OSL age is found from the ratio of SAR dose to the dose rate of the radiation environment. Errors on D_e values are calculated as uncertainty in OSL measurements. Overall errors in optical age estimates include systematic and random errors from calibration, dose-rate determination and optical measurements following the methods presented in Aitken (1998). The ages of the aliquots from each sample correlated well.

Results and Discussion

The Nature and Age of Dune Sands

OSL dating on 11 samples from foredunes, semistable dunes, stable dunes, and the dune-swamp boundary indicated that the time interval between the upper part of the foredune sands and the lower limit of stable dunes located 325 m apart was 490 years. The reason for sampling along such a transect was to determine the time of commencement of sand drift, which has previously given successful results in Murray & Clemmensen (2001). The results are presented in Table 1 and Figure 3a.

Foredunes

Foredunes start with a narrow incipient foredune zone comprising low ramps and ridges with scarce canopies of salt-tolerant pioneering plants. Incipient foredunes are not very extensive and are followed by

Table 1. The SAR ages of the samples taken from different coastal dune profiles.

| Sample Type Dune sand	OSL age (ka)	OSL dose (Gy)	n	Dose rate (Gy/ka)	Cosmic (Gy/ka)
Profile 1					
PRF1-1	0.18 ± 0.02	0.26 ± 0.03	5	1.44 ± 0.03	0.22
PRF1-2	0.24 ± 0.05	0.34 ± 0.07	11	1.42 ± 0.03	0.19
Profile 2					
PRF2-1	0.14 ± 0.06	0.21 ± 0.04	6	1.49 ± 0.03	0.26
PRF2-2	0.26 ± 0.11	0.37 ± 0.06	12	1.43 ± 0.04	0.21
PRF2-3	0.30 ± 0.02	0.43 ± 0.03	12	1.41 ± 0.00	0.18
Profile 3					
PRF3-1	0.33 ± 0.06	0.48 ± 0.08	11	1.45 ± 0.03	0.22
PRF3-2	0.53 ± 0.05	0.76 ± 0.07	12	1.43 ± 0.03	0.21
PRF3-3	0.67 ± 0.04	0.95 ± 0.05	12	1.41 ± 0.03	0.18
Dune-swamp boundary					
sand	0.22 ± 0.03	0.31 ± 0.05	10	1.45 ± 0.03	0.22
pumice	0.34 ± 0.04	0.51 ± 0.06	17	1.42 ± 0.03	0.25
sand	0.34 ± 0.03	0.50 ± 0.04	12	1.45 ± 0.03	0.22

*n: the number of aliquots.
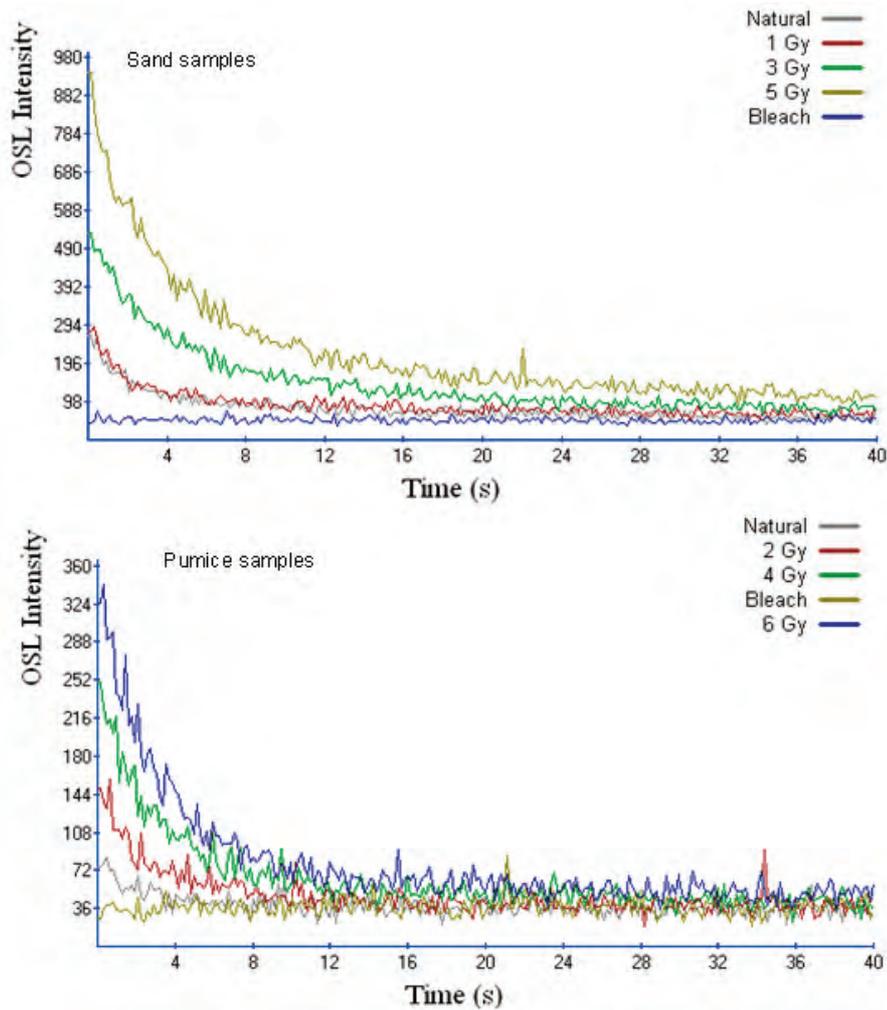
Figure 3. OSL decay curves of quartz from representative sandy and pumice samples. OSL signals were recorded from natural, bleached and irradiated aliquots; 1 Gy, 3 Gy and 5 Gy for sand samples and 2 Gy, 4 Gy and 6 Gy for pumice samples.

foredunes composed of different dune forms, such as transverse ridges and interfering circular to ellipsoidal low depressions (dune slacks), parabolic dunes and blowouts. Dune crests have altitudes ranging between 1 m and 3 m. On average, they comprise 95% sand, 70 % of which is formed by medium- to fine-grained sands (between 0.5–0.216 mm). Grain sizes below 0.216 mm average 23%. Clay and silt constitute only 2.1% and 2.6% of the analyzed samples, respectively. OSL ages of the upper (60–100 cm) and lower (100–140 cm) depths of foredunes were 0.18 ka and 0.24 ka, respectively.

Semistable (grey) Dunes

These dunes cover an extensive area between white foredunes and stable dunes. They are dominated by a slightly undulating topography consisting mainly of dune mounds with elevations varying between 1 m and 1.5 m, and circular or semi-circular wet dune slacks. Mostly, fine- to medium-grained sand forms the dominant component with an average proportion of 94%, similar to that of the foredunes. Grains ranging between 0.5 mm and 0.216 mm average 50.5% within the overall composition. The

470

fraction below 0.216 mm averages 47.9%. The rest, comprising clay and silt, totals 5.7%.

Semistable dune sands sampled from depths of 30–60 cm, 60–100 cm and 100–140 cm gave ages of 0.14 ka, 0.26ka, and 0.30 ka, respectively. These data reflect a regular trend of decreasing ages in depth with the exception of the youngest age (0.14 ka), which was possibly related to accumulation of sand by wind reworking on the top of these dunes.

Stable (Dark) Dunes

The third major dune type is the organic-rich stable dunes, located in the easternmost part of the dunefield. Morphologically, these dunes are characterized by low, undulating dune mounds separated by very shallow wet dune slacks. In vertical section, the dune sands are marked by clear variations in moisture, colour, and the contents of the clay and organic matter, etc. These stable dunes are composed of 91% sand-sized grains, with subordinate clay (6.1%) and silt (2.2%). On average, more than 99% of grain sizes are smaller than 0.5 mm, but the commonest grain size is the fraction below 0.216 mm, averaging 55.26%. The uppermost level of the dune material has a thin A horizon 0–5 cm thick, comprising slightly moist aggregated grains. Compared with other dune types here, the organic matter content was found to be highest, but rapidly decreases with depth. The enhanced organic matter content is caused by extensively developed diverse plant communities. Stable dune sands 425–500 m east of the shoreline were sampled at three depths (30–60 cm, 60–100 cm and 100–140 cm), yielding OSL ages of 330, 530, and 670 years, respectively. Thus, based on the oldest age of the deepest sample overlying the salt swamp deposits, it can be concluded that aeolian sand drift was initiated at least 670 years ago in the Kavak dunefield.

Pumice Layer as a Possible Indicator of 1672 Tsunamis?

In the easternmost part of the dunefield, coastal dunes terminate about 500 m east of the present shoreline. The dune-salt swamp contact is obviously defined by a slope-break of 50–75 cm; crossing this

entire zone from north to south (Figure 4b). At this contact, continuous pumice strata 15–20 cm thick were observed between dune sands (Figure 4c). The pumices were partly weathered, poorly rounded fragments with sizes smaller than 5 cm. They were embedded within marine clay and sand. On the basis of total-alkali-SiO_2 (TAS) (Le Maitre 2002), the pumices were dacite in composition. A comparative XRF analysis (Table 2) also showed they have the same composition as those erupted from Thera (Santorini) during its last paroxysmal plinian eruption in 1628 BC (Vespa *et al.* 2006).

Although the sedimentological traces of possible tsunamis were quite restricted, the absence of these volcanics within foredune, semistable and stable dunes may suggest its abnormal deposition along a very sharp boundary zone. Here, we speculate that abundant transportation of these deposits was probably associated with penetration of sea waves into inner parts of the dunefield following tidal channels in the delta. From this viewpoint, the OSL ages of pumices together with overlying and underlying sands were carried out. From the measurements, the pumices were found to have OSL age of 0.34 ka (Table 1). The same OSL procedure presented above for sand samples was also followed for the OSL evaluation of pumice samples. The quartz grains from the pumice samples were evaluated by the SAR protocol for equivalent dose estimate. The sensitivity change between the cycles of the SAR procedure was monitored using a fixed test dose OSL signal (0.5 Gy) and no significant sensitivity change was detected. The OSL decay curves from pumice samples recorded for natural, bleached and irradiated aliquots are presented in Figure 3, where the regenerative doses were 2 Gy, 4 Gy and 6 Gy. The growth curve established has a linear relationship from 0 Gy to 6 Gy. The overlying and underlying sands were also represented with ages of 0.22 ka and 0.34 ka, respectively, displaying coincidence with that of underlying sand. The absence of pumice within deeper sections of old dunes that yielded older ages between 530 and 670 may also explain the deposition of pumice on old dune sands 340 years ago.

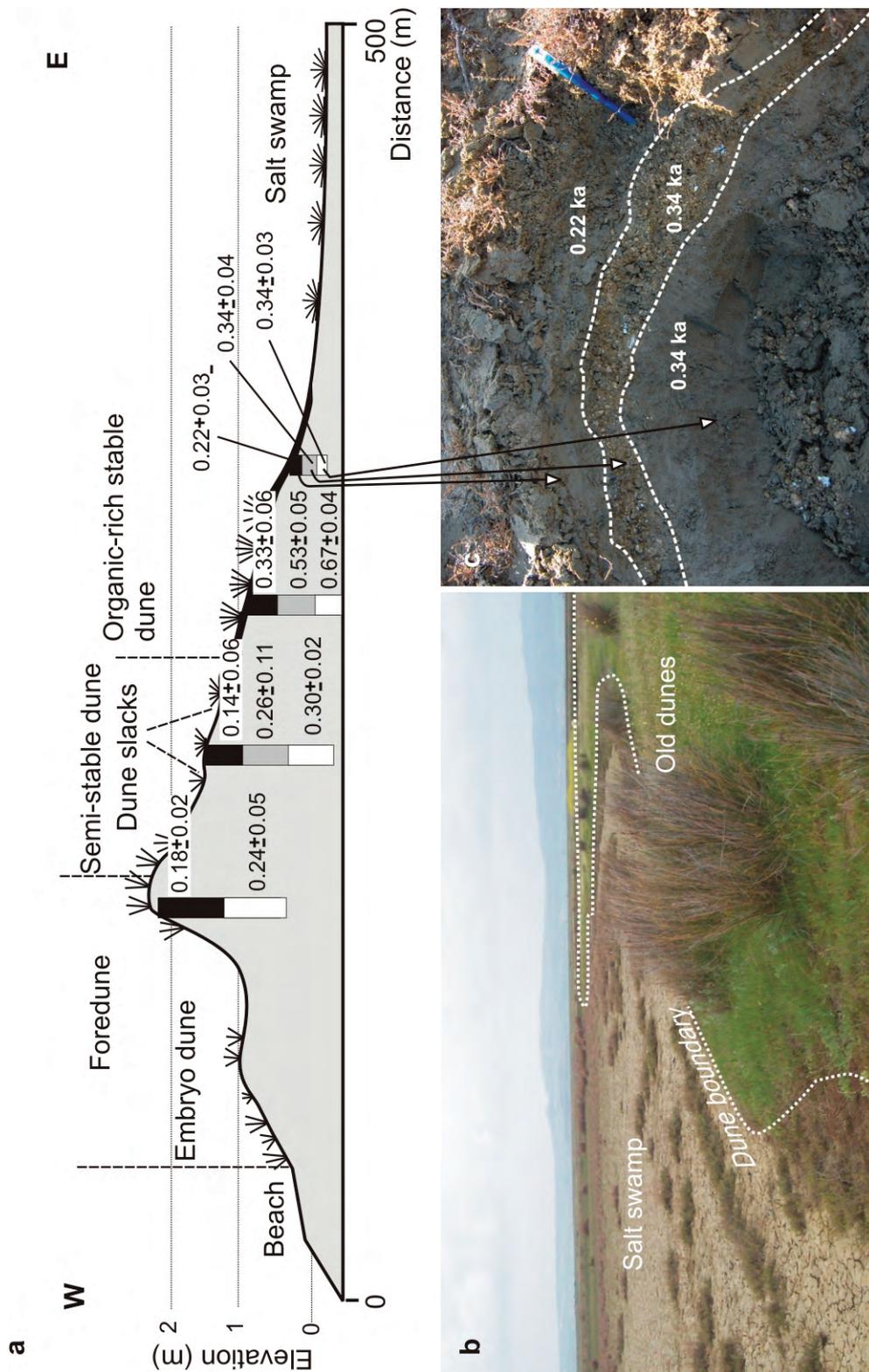On the basis of these findings, the most probable tsunami event on the Aegean Sea and near the

Figure 4. Simplified cross-section of the dunefield and age (years BP) data obtained from sampling pits (**a**), dune-salt swamp boundary (**b**) and pumice layer (between dashed lines) overlying old dune sands.

Table 2. XRF analyses of pumice found in the Kavak delta study area and Thera Island (Cape Riva Corner).

Pumice	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO
Kavak delta	71.83	13.69	0.18	1.43	1.81	0.49	3.91	2.74	0.07
CR/C	69.40	14.22	0.67	4.65	2.52	0.84	4.67	2.74	0.12

CR/C: Thera Island Cape Riva Corner (Vespa *et al.* 2006).

Turkish coast was the 1672 AD event which was generated from the Bozcaada and Kos islands (Shebalin *et al.* 1974; Papadopoulos & Chalkis 1984; Antonopoulos 1987; Ambraseys & Finkel 1995; Altınok & Ersoy 2000). In their list of tsunamis on the Aegean Sea coast of Turkey, Altınok & Ersoy (2000) demonstrated the presence of 90 tsunami records with differing degrees of reliability during the period between 1410 ± 100 B.C and 1999 A.D. The 1672 AD event was represented by low reliability (2 in scale of reliability according to Soloviev 1990) by Altınok & Ersoy (2000) and Papadopoulos *et al.* (2007) because of the lack of geological indicators on land. However, the destructive effects in the islands of Lesvos, Bozcaada (Tenedos) and Kos in the northeast and southwest coast of the Aegean Sea was ascribed by a questionable tsunami caused by a strong earthquake that occurred in 1672 (Sieberg 1932; Papadopoulos *et al.* 2007). Thus, we interpret the pumice deposits imbedded within marine clays and sands as tsunamigenic in origin, and this needs to be verified in detail by future investigations.

Conclusions

The OSL technique was successfully applied to quartz grains extracted from different parts of the dunefield. The ages obtained showed that dune sand drift initiated at least 670 years ago. The youngest age was 0.14 ka. The unusual presence of abundant pumice throughout the dune-swamp contact was interpreted an indicator of a possible tsunami event that occurred in 1672 AD near Bozcaada and Kos Islands.

Acknowledgements

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