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Formation of Holocene paleosols in a relict sand dune sequence at Kıyıköy, Türkiye

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Abstract: The paleoclimatic indicators from a relict dune and paleosol sequence observed south of Kıyıköy Port, NW Türkiye, provide insights into the variable paleoclimatic conditions in the western Black Sea coastal zone over the last 4700 yrs BP. The relict dune-paleosol sequence consists of reddish-brown coarse sands with abundant shells and overlying paleosol. Radiocarbon dating of *Donax trunculus* shells collected from the lowest part of the relict dune revealed the onset of sand deposition 4689 ± 123 yrs ago. The dark-colored paleosol layer, with an Rb/Sr ratio of 0.008, yielded an age of 287 ± 32 yrs cal BP. These findings indicate that the paleosol developed around the 1700s, during one of the coldest phases of the Little Ice Age. This layer is followed by a brown-colored buried soil, indicating a short-lived humid and rainy period, as evidenced by an Rb/Sr ratio of 0.42.

Key words: Relict dune, paleosol, Rb/Sr ratio, Little Ice Age, paleoclimate

1. Introduction

Paleosols, or fossil soils, formed under past climatic conditions, serve as archives with paleopedological importance, reflecting the climate and vegetation of the era in which they developed (Retallack, 1998, 2001). After their formation, these ancient soils are often buried by river sediments, flood debris, coastal dune sands, tsunami deposits, lava flows, and/or volcanic ashes. The paleoenvironmental significance of the micromorphological features of these sequences has been discussed, as they reflect key stages of pedosedimentary development (Kemp, 1999). In addition to reflecting the climate of their formation period, they also contribute to understanding geomorphic processes (Kraus, 1999), thus representing an underappreciated aspect of sequence stratigraphy that deserves more attention. Indeed, research has shown that paleosols have been addressed through a wide variety of quantitative proxies (Sheldon and Tabor, 2009; Tabor and Myers, 2015).

Studies on paleosols in Türkiye have primarily focused on the Pre-Quaternary period, mostly reported from the interior regions of the Anatolian peninsula (Pasquare, 1968; İnci, 1998; Küçükuysal and Kapur, 2014; Gürel and Özcan, 2016; Opluštil et al., 2018; Kadir et al., 2022). Late Quaternary paleosols have been identified among aeolianite layers that were used as an ancient shipyard on Dana Island (Erginal et al., 2021) and among fluvial deposits in NW Anatolia, where a Middle Paleolithic artifact was also discovered (Ocakoğlu et al., 2018). However, records of paleosols formed during the Holocene or just before are rather limited. Paleosols from the Hellenistic period or earlier have been identified on the southeastern Mediterranean coast of Türkiye (Beach and Luzzadder-Beach, 2008). A paleosol evidence reflecting the arid conditions of the Younger Dryas has also been reported from archaeological sites in southeastern Anatolia (Sedov et al., 2017).

Paleosols that developed on relict coastal dunes may be exposed at the surface due to deflation (Buynevich et al., 2007), although publications on the paleosol formation in Holocene relict dunes are notably limited. This study examines the paleoenvironmental records preserved in oxidized relict dune sands exposed in the Kıyıköy area along the Black Sea coast of Thrace, along with the paleosol layers developed on top of them.

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2. Methodology

2.1. Study area

The studied relict dune and paleosol sequences are located on the eastern coast of Kırklareli, near the Kıyıköy Port, along the Thracian Black Sea coast in northwestern Türkiye (Figures 1a and 1b). The Thracian coast of Türkiye extends from the mouth of the Rezve (Rezovo) River at the Bulgarian border down to the Bosphorus Strait. In the northwestern section of the Thracian coast, where the study area is located, the coastline is indented.

This coastal area forms a northeastward extension of the Istranca (Yıldız) Mountains, which consist of different lithological units such as gneiss, amphibolite, schist, limestone, sandstone, and igneous rocks. The coastal backshore features Middle to Late Eocene fossiliferous limestones with intercalations of sandstone and claystone outcropping. The sampling area is a 5-m-thick relict coastal dune sequence located near the Kazandere River's mouth, where it discharges into the Black Sea near Kıyıköy port. A beachrock sequence extends immediately in front of this dune deposit (Erginal et al., 2013). According to data from the Kumköy meteorology station, located 85 km southeast of the sampling site, the region receives an average annual precipitation of 831.4 mm. The average annual air temperature is 13.8 °C, while the average seawater temperature is 14.3 °C. The area experiences a humid-temperate Black Sea climate, and the tidal range is minimal, lesser than 10 cm (Medvedev, 2018).

2.2. Sampling and analyses

Samples were collected at 5 cm intervals from a 2-m-thick sequence predominantly composed of fine to medium-sized sand grains, and proxy element analyses of these samples were conducted using ICP-MS (Figures 1c and 1d). Total organic carbon was quantified employing the

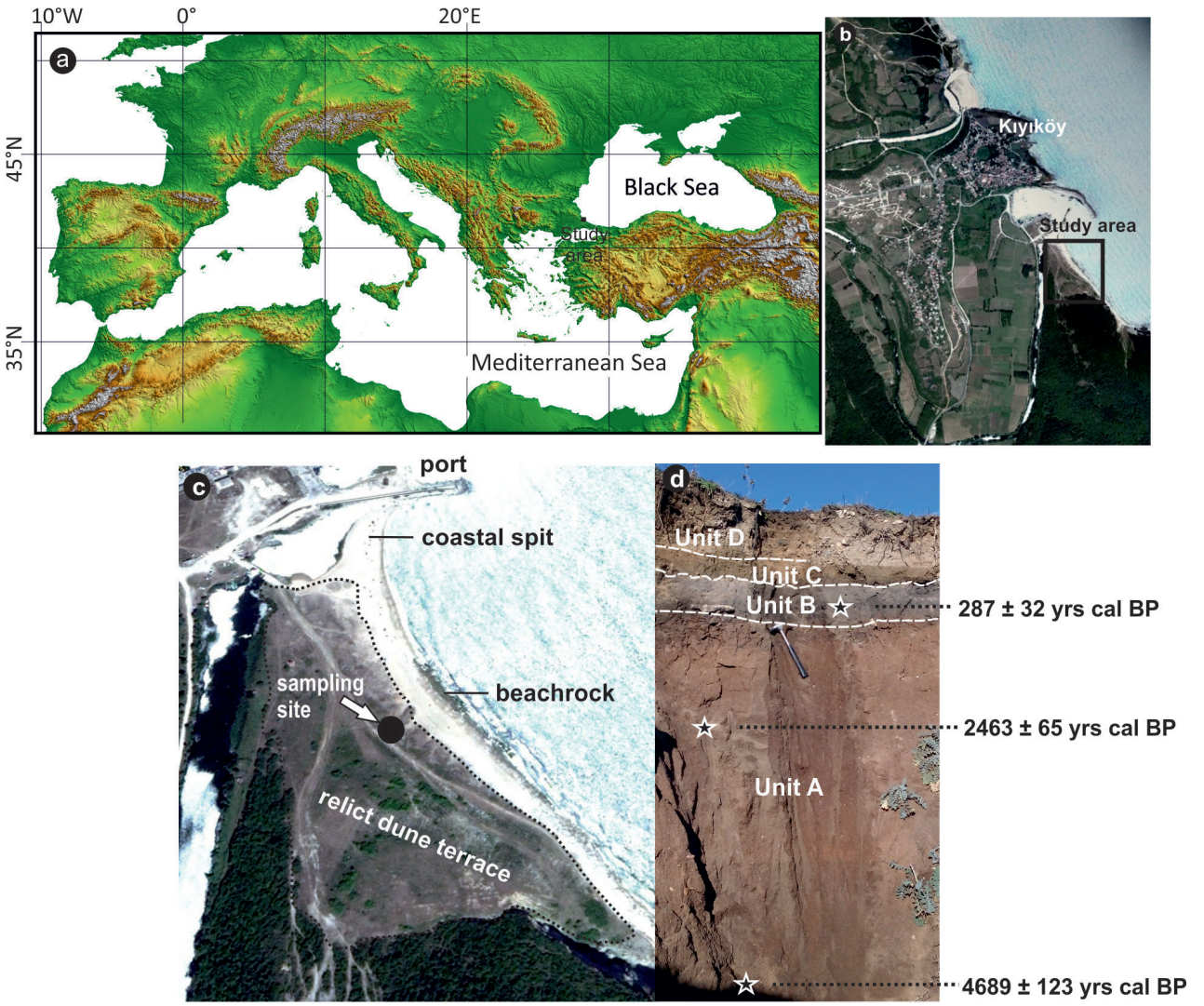


Figure 1. Location of the study area (a, b) and sampling sites (c, d).

Walkley-Black titration technique, which was outlined by Walkley and Black (1934). The $CaCO_3$ concentrations in each sample were measured using a Schibler Calcimeter, as detailed by Schlichting and Blume (1966). accelerator mass spectrometry (AMS) ^{14}C dating was performed in 2013 on two *Donax trunculus* shells buried in the lower (2 m) and middle (1 m) parts of the sequence. Additionally, AMS ^{14}C dating was conducted on the total organic carbon from the sand sequence at depths of 50 cm and 2 m to test the shell ages.

Trace element geochemistry has been used for a variety of applications (Sheldon and Tabor, 2009), including examining weathering intensity in paleosols (Kahmann et al., 2008), assessing leaching (Retallack, 1999; 2001; Sheldon, 2006), and provenance analysis (Sheldon, 2006; Hamer et al., 2007; Sheldon et al., 2009). The Rb/Sr ratio, calculated from data obtained through ICP-MS analysis, was used for this purpose here. Although shell fragments that could increase the Sr content in oxidized sand deposits were abundant, the Rb/Sr ratio was used for paleoclimatic evaluation due to the higher Sr concentration in the overlying shell-free paleosol layers. The mineral composition and textural properties were examined through thin sections. The quartz content of powdered samples was determined using XRD analyses.

2.3. Chronology and age-depth modeling

Accelerator Mass Spectrometry ^{14}C analyses of three samples (one bulk and two marine fossils) were carried out at TÜBİTAK-MAM radiocarbon laboratories (Table). The results of the marine fossils were calibrated using the Marine.20 calibration curve, while the bulk sample recovered from the paleosol was calibrated using IntCal (Heaton et al., 2020; Reimer et al., 2020). Subsequently, a reservoir correction of 410 ± 85 yrs was applied to the marine sample results (Siani et al., 2000). For age-depth modeling, a non-Bayesian "clam" script was executed in R Studio (Blaauw, 2010), providing a model within a 95% Gaussian confidence interval (Figure 2).

3. Results and discussion

3.1. Paleoclimatic implications of relict dune

The studied sequence begins with Unit A, a coastal deposit approximately 1.45 m thick at the bottom, composed of coarse-grained, poorly sorted, reddish-brownish sand containing angular grains and rock fragments. Petrographically, the studied relict dune sands are lithic arenite in composition (McBride, 1963; Folk, 1968). The thin section analyses of five samples taken from this unit indicate the presence of metamorphic rock-derived detrital grains alongside polycrystalline quartz grains. The metamorphic rock fragments primarily consist of quartz-epidote schist, quartz-mica schist, and marble. Additionally, individual plagioclase crystals are observed. Coarse and subhedral plagioclase crystals are enveloped by fibrous or flaky minerals. Plagioclase exhibits very distinct polysynthetic twinning. Plagioclase phenocrysts with opaque iron oxide rims and meniscus bridges are common (Figure 3).

The sands, loosely cemented with iron oxide, must have been deposited in a high-energy environment, as they exhibit low textural and mineralogical maturity. This unit contains a mix of lacustrine-terrestrial gastropods (*Helix pomatia*, *Bithynia* sp., *Cepaea* sp.) along with marine shells of *Donax trunculus* and *Venus gallina* (Figure 1d, Unit A). Additionally, although to a lesser extent, fragmented specimens of *Elphidium macellum*, *Elphidium* sp., *Ammonia parkinsoniana*, and *Ammonia* sp. have been identified, as previously noted in the beachrock samples located immediately in front of the sequence (Erginal et al., 2013).

The sedimentary characteristics of the quartz-rich (average 84%) sands forming this unit and the mixed fossil content suggest that these sands were likely transported from the beach face (the swash zone) to the backshore by strong storm waves or winds and deposited rapidly under terrestrial conditions.

Table. Radiocarbon ages and calibration of the dates. Note that a reservoir correction of 410 ± 85 years was applied to the Donax trunculus marine fossil samples (Siani et al., 2000).

Sample lab code	Material	Depth (cm)	Dated level	Measured age (yrs BP)	$^{13}C/^{12}C$ (o/oo)	Calibrated age (yrs BP)
439067	Bulk organic carbon	50	Paleosol	240 ± 30	–24.6	287 ± 32
338672	*Donax trunculus*	100	Iron-oxidized deposits	2850 ± 30	–0.6	2463 ± 65
338673	*Donax trunculus*	200	Iron-oxidized deposits	4560 ± 30	–0.6	4689 ± 123

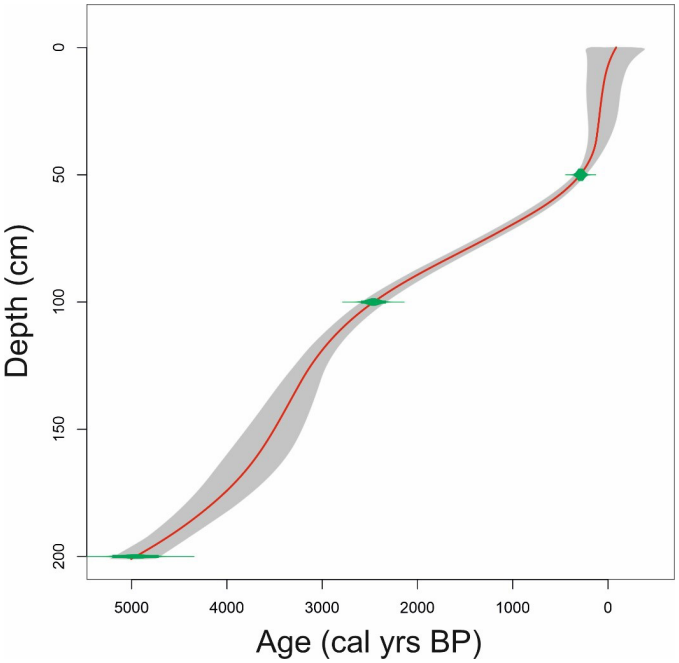


Figure 2. Age-depth model of the dune-paleosol sequence. The gray cloud indicates the iteration interval, while the red line represents the mean value of the calibrated ages. Green markers denote the radiocarbon samples.

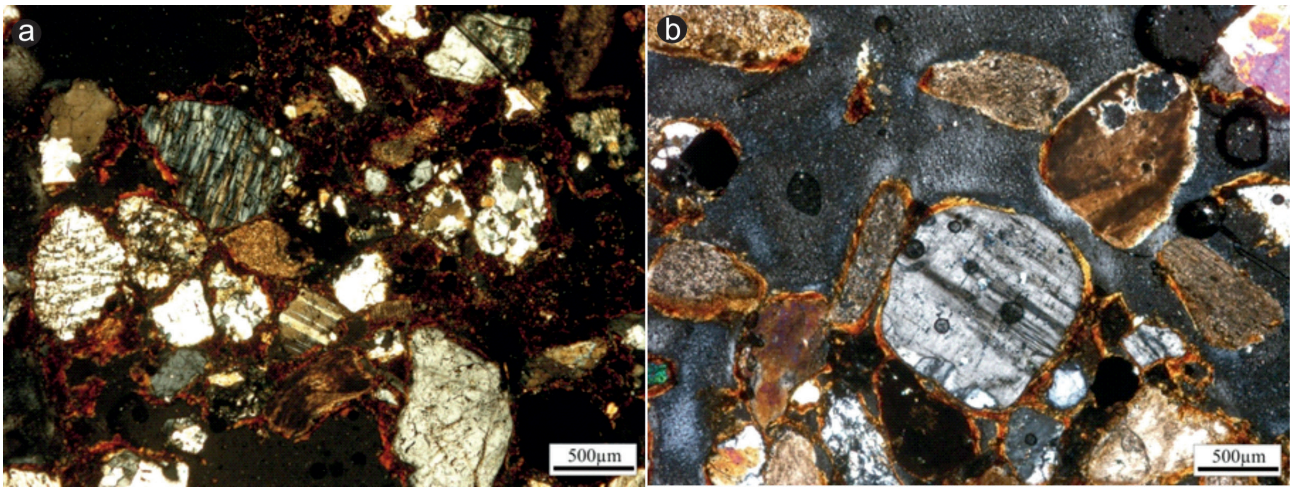


Figure 3. Thin-section photographs of samples taken from the relict dune sequence. (a) Iron oxide-cemented sandstone (lithic arenite) containing abundant, poorly rounded quartzite and quartz-micaschist fragments. The pore spaces between the grains are filled with meniscus cement; (b) iron oxide rims surrounding plagioclase and other metamorphic fragments.

The reddish color of the relict dune deposit is due to the abundance of iron oxide rims observed in thin sections. ICP-MS data also indicate an average iron content of 2%. The reddish-orange color of coastal sand dunes is typically characteristic of arid and semiarid conditions (Bullard and White, 2002), and the increase in redness has been associated with an increase in the stability and age of the dune (Hassani et al., 2019). As a result of rubification, a pedogenesis stage that reflects the release of Fe-bearing minerals by weathering (Roskin et al., 2012), leading to the formation of free iron oxides (Ben-Dor et al., 2006), these rims surround various minerals such as quartz, augite, and feldspar, as well as detrital grains, and they are dense enough to form meniscal bridges between grains. Thus, it

can be suggested that the rubification or early diagenesis started with the mobility of dissolved iron ions within the relict dune deposit, resulting from the weathering of metamorphic rock fragments and being transported by water.

The average zeolite content of 19 samples taken from this unit was determined to be 2.37%, based on XRD analyses. The zeolites within the aeolian sands are thought to have been transported from a considerable distance, specifically from the northeastern part of Thrace, originating from the zeolites found in the Eocene İslambeyli Formation (Ekinci-Şans et al., 2020) in the upper basin of Kazan Dere.

The sample taken from the bottom level of the sequence indicates that deposition began approximately 4689 ± 123 yrs ago (Table). During this period, Donax shells and broken foraminifera fragments mixed with terrestrial gastropods were incorporated into the coarse-grained basal deposit. Despite the abundance of shell fragments, the low levels of $CaCO_3$ indicate strong postdepositional weathering within the bottom of the sequence at depths between 2 m and 1.8 m.

The age obtained from the marine shells within the sands at the lowest level of the dune sequence corresponds to a period close to that of the beachrock previously studied in the same coastal zone, which yielded ages between 5460 yrs cal BP and 3500 yrs cal BP. The cementation texture of these beachrocks, extending right in front of the relict dune sequence, indicates that during the formation of the beachrock, the sea level was approximately 2 m lower than today, and arid conditions prevailed (Erginal et al., 2013). This lower sea level is comparable to findings from other studies. For instance, when considering curves that illustrate Holocene sea-level changes in the Black Sea, evidence suggests that around 5500 yrs ago, the sea level was 2 to 8 m lower than at present (Ostrovsky et al., 1977; Voskoboinikov et al., 1982; Tchepalyga, 1984; Balabanov, 2007; Filipova-Marinova, 2007). According to the sea-level curves by Filipova-Marinova (2007) and Balabanov (2007), it is understood that at 5400 yrs BP, the sea level was between 0 and −2 m, a finding consistent with sea-level changes in the Eastern Mediterranean (Fouache et al., 2012). Similarly, Giosan et al. (2006) reported that, based on optical and radiocarbon ages obtained from the beach ridge sands and shells in the offshore delta lobes of the Danube, the sea level fluctuated between +1.5 m and −2 m over the past 5000 yrs.

The presence of shells, carbonates, and microfossils in the relict beach sands suggests that these materials were transported from a subaerially exposed seafloor during low sea-level conditions and incorporated into the dune sequence, where they underwent iron oxidation under arid conditions, similar to the formation mechanism of carbonate eolianites (Brooke, 2001). The arid period during which the relict sands reddened is consistent with the warmest and driest phase, dated to approximately 4660–4400 yrs ago, as indicated by palynological data obtained from the Kuban delta region on the Taman Peninsula in the northern Black Sea region (Bolikhovskaya et al., 2018).

The middle section of the sequence is dated to 2463 ± 65 yrs ago. This unit has weak iron oxide cementation and contains quartz, plagioclase, epidote, and widespread opaque minerals. Opaqueness around the edges of plagioclase phenocrysts is typical. This period likely corresponds to a time of relatively warm and dry climate, with drought conditions still prevailing in the Black Sea region (Bolikhovskaya et al., 2018), although the aridity was less intense.

3.2. Paleoclimatic implications of paleosol

Above the Fe-oxidized relict dune deposit, Unit B marks the end of sand dune accumulation, indicates a transition to more arid conditions, and represents the initial stage of a paleosol formation. This unit consists of polycrystalline quartz, quartz-epidote schist, quartz-mica schist, and marble fragments, along with plagioclase crystals. The weathering of ferromagnesian minerals, leading to the formation of opaque minerals, is evident. At depths between 35 cm and 55 cm from the surface, this unit can be easily distinguished from the underlying sand dune unit due to its dark color.

The distribution of Rb/Sr was examined to understand the paleoclimatic records of this paleosol layer. As it is known, the weathering rate of plagioclase, which is rich in Ca and Sr, is higher than that of alkali feldspar, which is rich in K and Rb (Dasch, 1969; Chen et al., 1996). This leads to a differentiation between the distributions of Rb and Sr, resulting in an increase in the Rb/Sr ratio in the weathered detrital material (Liu et al., 2014; Minyuk et al., 2014). From this point, the changes in the Rb/Sr ratio in the paleosol were correlated with the weathering rate. Since the Unit B contains no shell fragments, it can be confidently concluded that the Sr is not shell-derived. According to the Rb/Sr calculation, the Rb/Sr ratio drops from 0.06 at the lowermost level to as low as 0.008 at the level representing the transition to Unit C.

The AMS ^{14}C age of the sample taken from the paleosol was determined to be 287 ± 32 yrs cal BP. This period corresponds to the Little Ice Age (LIA), dated between 1350 yrs CE and 1850 yrs CE (Mann et al., 2009). Although the records of the LIA along the Black Sea coasts are rather limited, the archives from Küçükçekmece Lake in Thrace provide comparable data on this subject (Akçer Ön et al., 2012). Multiproxy physical properties, geochemical, and stable O- and C-isotope data from lagoon sediments indicate dry conditions during the period of 750–220 yrs BP, while rainy conditions prevailed between 220 and 70 yrs BP (Akçer Ön et al., 2012). The Late Maunder Minimum,

occurring between 300 and 200 yrs BP, has previously been reported from Black Sea sediments (Çağatay et al., 2005; Güngör and Çağatay, 2006). Güngör and Çağatay (2006) identified an increase in carbonate content in core samples taken from the continental shelf of the western Black Sea during the coldest period of the LIA, approximately between AD 1750 and AD 1650, and associated increase in *E. huxleyi* production with this. The increase in the number of this coccolithophorid may also be related to the increased nutrient input during such cold periods (Hay et al., 1991). In this case, it can be said that the Unit B paleosol, containing an average of 1.58% organic carbon, 35.41% $CaCO_3$, and 69% quartz, and where the Rb/Sr ratio varies between 0.06 and 0.008 due to weak weathering, reflects the cold and dry conditions of the LIA period.

Following this extremely arid phase, Unit C developed under more humid conditions, as indicated by the higher Rb/Sr ratio (max. 0.42). This better-washed paleosol layer is found at depths of 25–35 cm from the surface and overlies Unit B with an erosional contact. It consists of reddish-brown, fine- to medium-grained sands. Its average quartz content is 52%. Compared to the Unit B paleosol, the overlying buried soil layer contains 16.57% $CaCO_3$ and an average Rb/Sr ratio of 0.25, indicating that dry conditions were briefly followed by wetter conditions. According to the age-depth model, this corresponds to a stage 110 yrs ago, marking the termination of the LIA.

This unit is covered by poorly sorted, angular to subrounded sandy gravels (Unit D), which form the uppermost part of the sequence, with a maximum thickness of 50 cm. The gravels are characteristic in size, ranging from 2 to 64 mm. At the topmost level of this unit, where layering characteristics are not observable, a gray-colored modern soil with low organic carbon content has developed.

4. Conclusion

Observations and multiproxy analyses, along with dating studies conducted on a relict dune ramp located about 1 m above sea level on the Black Sea coast of Thrace, reveal an ancient dune system formed during the Late Holocene and two buried paleosol levels developed on its upper part. The dune deposition, which began around 4600 yrs ago, and the subsequent rubification process reflect a dry period consistent with marine proxy data obtained from the Black Sea. The overlying paleosol developed towards the end of the Little Ice Age, during the Late Maunder Minimum, considering the margin of error in the age data, around the early or mid-18th century. The obtained results provide concrete data from the Turkish coast regarding coexistence of the Mid-Late Holocene relict dune rubification and paleosol records.

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References

Akçer Ön S, Çağatay N, Sakınç M (2012). Sedimentary records of Little Ice Age and Medieval Warm Period in Küçükçekmece Lagoon. İTÜDERGİSİ/d, 10(4) (in Turkish with an abstract in English).

Balabanov IP (2007). Holocene sea-level changes of the Black Sea. In: Yanko-Hombach V, Gilbert AS, Panin N, Dolukhanov P (editors). The Black Sea Flood Question: Changes in Coastline, Climate, and Human Settlement. Dordrecht, the Netherlands: Springer; pp. 711-730.

Beach TP, Luzzadder-Beach S (2008). Geoarchaeology and aggradation around Kinet Höyük, an archaeological mound in the Eastern Mediterranean, Turkey. Geomorphology 101: 416-428. https://doi.org/10.1016/j.geomorph.2007.04.025

Ben-Dor E, Levin N, Singer A, Karnieli A, Braun O et al. (2006). Quantitative mapping of the soil rubification process on sand dunes using an airborne hyperspectral sensor. Geoderma 131 (1-2): 1-21. https://doi.org/10.1016/j.geoderma.2005.02.011

Blaauw M (2010). Methods and code for 'classical'age-modelling of radiocarbon sequences. Quaternary Geochronology 5 (5): 512-518. https://doi.org/10.1016/j.quageo.2010.01.002

Bolikhovskaya NS, Porotov AV, Richards K, Kaitamba MD, Faustov SS et al. (2018). Detailed reconstructions of Holocene climate and environmental changes in the Taman Peninsula (Kuban River delta region) and their correlation with rapid sea-level fluctuations of the Black Sea. Quaternary International 465: 22-36. https://doi.org/10.1016/j.quaint.2017.08.013

Brooke B (2001). The distribution of carbonate aeolionite. Earth-Science Reviews 55: 135-164. https://doi.org/10.1016/S0012-8252(01)00054-X

Bullard JE, White K (2002). Quantifying iron oxide coatings on dune sands using spectrometric measurements: An example from the Simpson-Strzelecki Desert, Australia. Journal of Geophysical Research 107 (B6): 2125. https://doi.org/10.1029/2001jb000454

Buynevich IV, Bitinas A, Pupienis D (2007). Lithological anomalies in a relict coastal dune: Geophysical and paleoenvironmental markers. Geophysical Research Letters 34: L09707. https://doi.org/10.1029/2007GL029767

Chen J, Wang H, Lu H (1996). Behaviours of REE and other trace elements during weathering–evidence from chemical leaching of loess and paleosol from the Luochuan Section in Central China. Acta Geologica Sinica 9 (3): 290-302. https://doi.org/10.1111/j.1755-6724.1996.mp9003006.x

Çağatay MN, Güngör N, Yılmaz YZ, Sarı E (2005). Rapid changes in the ecological conditions of the Black Sea over the last 3kyr: evidence from sediment geochemistry. In: Özerler M, Sayın E (editors). The Role of Marine Studies in Ecosystems, ECOSYSTEM 2003, İzmir, Türkiye, pp. 85-96.

Dasch EJ (1969). Strontium isotopes in weathering profiles, deep-sea sediments, and sedimentary rocks. Geochimica Cosmochimica Acta 33 (12): 1521-1552. https://doi.org/10.1016/0016-7037(69)90153-7

Ekinci-Şans B, Esenli F, Kadir S (2020). Geology, mineralogy, and geochemistry of the smectite-bearing Eocene İslambeyli Formation in the Pınarhisar region, NW Thrace, Turkey. Arabian Journal of Geosciences 13: 378. https://doi.org/10.1007/s12517-020-05371-1

Erginal AE, Ekinci YL, Demirci A, Bozcu M, Öztürk MZ et al. (2013). First record of beachrock on Black Sea coast of Turkey: Implications for Late Holocene sea-level fluctuations. Sedimentary Geology 294: 294-302. https://doi.org/10.1016/j.sedgeo.2013.06.003

Erginal AE, Öniz H, Erenoğlu O, Sarıaltun S (2021). An under-recognised geoarchaeological heritage asset in Turkey: Dana Island, Mersin. Geoheritage 13: 89. https://doi.org/10.1007/s12371-021-00618-z

Filipova-Marinova M (2007). Archaeological and paleontological evidence of climate dynamics, sea-level change, and coastline migration in the Bulgarian sector of the circum-Pontic region. In: Yanko-Hombach V, Gilbert AS, Panin N, Dolukhanov P (editors). The Black Sea Flood Question: Changes in Coastline, Climate, and Human Settlement. Dordrecht, the Netherlands: Springer; pp. 453-481.

Folk RL (1968). Petrology of Sedimentary Rocks. Austin, TX, USA: Hemphill Publishing Co.

Fouache E, Kelterbaum D, Brückner H, Lericolais G, Porotov A et al. (2012). The Late Holocene evolution of the Black Sea - a critical view on the so-called Phanagorian regression. Quaternary International 266: 162-174. https://doi.org/10.1016/j.quaint.2011.04.008

Giosan L, Donnelly JP, Constantinescu S, Filip F, Ovejanu I et al. (2006). Young Danube delta documents stable Black Sea level since the middle Holocene: morphodynamic, paleogeographic, and archeological implications. Geology 34 (9): 757-760. https://doi.org/10.1130/G22587.1

Güngör E, Çağatay MN (2006). Rapid changes in the ecological conditions of the Black Sea over the last 3 kyr. İTÜ Journal Series D 5 (4): 23-33 (in Turkish with an abstract in English).

Gürel A, Özcan S (2016). Paleosol and dolocrete associated clay mineral occurrences in siliciclastic red sediments of the Late Miocene Kömişini Formation of the Tuzgölü basin in central Turkey. Catena 143: 102-113. https://doi.org/10.1016/j.catena.2016.04.003

Hamer JMM, Sheldon ND, Nichols GJ, Collinson ME (2007). Late Oligocene–Early Miocene palaeosols of distal fluvial systems, Ebro Basin, Spain. Palaeogeography, Palaeoclimatology, Palaeoecology 247: 220-235. https://doi.org/10.1016/j.palaeo.2006.10.016

Hassani M, Saadoud D, Chabou MC, Martín-Peinado FC, Sánchez-Marañón M (2019). Spectral signs of aeolian activity around a sand-dune belt in northern Algeria. Catena 182: 104175. https://doi.org/10.1016/j.catena.2019.104175

Hay BJ, Arthur MA, Dean WE, Neff ED, Honjo S (1991). Sediment deposition in the Late Holocene abyssal Black Sea with climatic and chorological implications. Deep Sea Research Part A. Oceanographic Research Papers 38 (suppl. 2): 1211-1235. https://doi.org/10.1016/S0198-0149(10)80031-7

Heaton TJ, Köhler P, Butzin M, Bard E, Reimer RW et al. (2020). Marine20—the marine radiocarbon age calibration curve (0–55,000 cal bp). Radiocarbon 62 (4): 779-820. https://doi.org/10.1017/RDC.2020.68

İnci U (1998). Lignite and carbonate deposition in Middle Lignite succession of the Soma Formation, Soma coalfield, western Turkey. International Journal of Coal Geology 37 (3-4): 287-313. https://doi.org/10.1016/S0166-5162(98)00010-X

Kadir S, Gürel A, Senem H, Külah T (2022). Geology of Late Miocene clayey sediments and distribution of palaeosol clay minerals in the north-eastern part of the Cappadocian Volcanic Province (Araplı-Erdemli), central Anatolia, Turkey. Turkish Journal of Earth Sciences 22 (3): 427-443. https://doi.org/10.3906/yer-1112-1

Kahmann JA, Seaman III J, Driese S (2008). Evaluating trace elements as paleoclimate indicators: multivariate statistical analysis of late Mississippian Pennington Formation Paleosols, Kentucky, USA. Journal of Geology 116 (3): 254-268. https://doi.org/10.1086/587883

Kemp RA (1999). Micromorphology of loess–paleosol sequences: a record of paleoenvironmental change. Catena 35 (2-4): 179-196. https://doi.org/10.1016/S0341-8162(98)00099-X

Kraus MJ (1999). Paleosols in clastic sedimentary rocks: their geologic applications. Earth-Science Reviews 47 (1-2): 41-70. https://doi.org/10.1016/S0012-8252(99)00026-4

Küçükuysal C, Kapur S (2014). Mineralogical, geochemical and micromorphological evaluation of the Plio-Quaternary paleosols and calcretes from Karahamzall, Ankara (Central Turkey). Geologica Carpathica 65 (3): 241-253. https://doi.org/10.2478/geoca-2014-0014

Liu J, Chen J, Selvaraj K, Xu Q, Wang Z et al. (2014). Chemical weathering over the last 1200 years recorded in the sediments of Gonghai Lake, Lvliang Mountains, North China: a high-resolution proxy of past climate. Boreas 43 (4): 914-923. https://doi.org/10.1111/bor.12072

Mann ME, Zhang Z, Rutherford S, Bradley RS, Hughes MK et al. (2009). Global signatures and dynamical origins of the LittleIce Age and medieval climate anomaly. Science 326: 1256-1260. https://doi.org/10.1126/science.1177303

McBride EF (1963). A classification of common sandstones. Journal of Sedimentary Research 33 (3): 664-669. https://doi.org/10.1306/74D70EE8-2B21-11D7-8648000102C1865D

Medvedev IP (2018). Tides in the Black Sea: observations and numerical modelling. Pure and Applied Geophysics 175: 1951-1969. https://doi.org/10.1007/s00024-018-1878-x

Minyuk PS, Borkhodoev VY, Wennrich V (2014). Inorganic geochemistry data from Lake El'gygytgyn sediments: marine isotope stages 6-11. Climate of the Past 10 (2): 467-485. https://doi.org/10.5194/cp-10-467-2014

Ocakoğlu F, Dinçer B, Akkiraz MS, Şahiner E, Brook GA (2018). Palaeolithic occupation of the Anatolian high plateau during a cold period: an MIS 6 aged artifact from the Avlamış Valley, Eskişehir, NW Turkey. Geoarchaeology 33 (5): 605-619. https://doi.org/10.1002/gea.21679

Opluštil S, Lojka R, Pšenička J, Yilmaz Ç, Yilmaz M (2018). Sedimentology and stratigraphy of the Amasra coalfield (Pennsylvanian), NW Turkey – New insight from a 1 km thick section. International Journal of Coal Geology, 195: 317-346. https://doi.org/10.1016/j.coal.2018.06.013

Ostrovsky AB, Izmaylov YA, Balabanov IP, Skiba SI, Skryabina NG et al. (1977). New data on the paleohydrological regime of the Black Sea in the Upper Pleistocene and Holocene. In: Kaplin PA, Shcherbakov FA (editors). *Paleogeography and Deposits of the Pleistocene of the Southern Sea of the USSR*. Moscow, Russia: Nauka; pp. 131-140 (in Russian).

Pasquare G (1968). Geology of the Cenozoic volcanic area of Central Anatolia. Atti della Accademia Nazionale dei Lincei 9: 53-204.

Reimer PJ, Austin WEN, Bard E, Bayliss A, Blackwell PG et al. (2020). The IntCal20 Northern Hemisphere radiocarbon age calibration curve (0–55 cal kBP). Radiocarbon 62 (4): 725-757. https://doi.org/10.1017/RDC.2020.41

Retallack GJ (1998). Core concepts of paleopedology. Quaternary International 51-52: 203-212. https://doi.org/10.1016/S1040-6182(97)00046-3

Retallack GJ (1999). Postapocalyptic greenhouse paleoclimate revealed by earliest Triassic paleosols in the Sydney Basin, Australia. Geological Society of America Bulletin 111: 52-70. https://doi.org/10.1130/0016-7606(1999)111<0052:PGPRBE>2.3.CO;2

Retallack GJ (2001). Soils of the Past: An Introduction to Paleopedology. Oxford, UK: Blackwell Science.

Schlichting E, Blume E (1966). Bodenkundliches Prakticum. Hamburg and Berlin, Germany: Verlag Paul Parey (in German).

Roskin J, Blumberg DG, Porat N, Tsoar H, Rozenstein O (2012). Do dune sands redden with age? The case of the northwestern Negev dunefield, Israel. Aeolian Research 5: 63-75. https://doi.org/10.1016/j.aeolia.2011.11.004

Sedov SN, Aleksandrovskii AL, Benz M, Balabina VI, Mishina TN et al. (2017). Anthropogenic sediments and soils of tells of the Balkans and Anatolia: composition, genesis, and relationships with the history of landscape and human occupation. Eurasian Soil Science 50: 373-386. https://doi.org/10.1134/S1064229317040093

Sheldon ND (2006). Abrupt chemical weathering increase across the Permian–Triassic boundary. Palaeogeography, Palaeoclimatology, Palaeoecology 231: 315-321.

Sheldon ND, Tabor NJ (2009). Quantitative paleoenvironmental and paleoclimatic reconstruction using paleosols. Earth Science Reviews 95 (1-2): 1-52. https://doi.org/10.1016/j.earscirev.2009.03.004

Sheldon ND, Mitchell RL, Collinson ME, Hooker JJ (2009). Eocene-Oligocene transition paleoclimate record from paleosols, Isle of Wight (UK). In: Koeberl C, Montanari A (editors). The Late Eocene Earth-Hothouse, Icehouse, and Impacts: Geological Society of America Special Paper 452: 241-248.

Siani G, Paterne M, Arnold M, Bard E, Métivier B et al. (2000). Radiocarbon reservoir ages in the Mediterranean Sea and Black Sea. Radiocarbon 42 (2): 271-280. https://doi.org/10.1017/S0033822200059075

Tabor NJ, Myers TS (2015). Paleosols as indicators of paleoenvironment and paleoclimate. Annual Review of Earth Planetary Sciences 43: 333-361. https://doi.org/10.1146/annurev-earth-060614-105355

Tchepalyga AL (1984). Inland sea basins. In: Velichko AA, Wright HEJ, Barnosky CW (editors). Late Quaternary Environments of the Soviet Union. Minneapolis, MN, USA: University of Minnesota Press; pp. 229-247.

Walkley A, Black I (1934). An examination of the Degthareff method for determining soil organic matter and proposed modification of the chromic acid titration method. Soil Science 27: 29-38. https://doi.org/10.1097/00010694-193401000-00003

Voskoboinikov VM, Rotar MF, Konikov EG (1982). Sviaz' ritmichnosti stroeniia tolshch golotsenovykh otlozhenii Prichernomorskikh limanov s kolebatel'nym rezhimom urovnia Chernogo moria Moscow, USSR: Moscow State University; pp. 264-274 (in Russian).