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In search of marine terraces from Central Dobrogea (Casimcea Plateau, Western Black Sea). Preliminary inquiries on distribution, extension and vertical crustal movements

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ABSTRACT

Casimcea Plateau is an uplifted (exhumated) peneplain cut in Proterozoic green–schists and one of the oldest tectonic units around the Black Sea. Despite its overall monotonous physiognomy, the plateau is crossed by Casimcea Valley and presents a seaward façade to the east which preserves (sub)horizontal surfaces as testimonies of the paleoenvironmental changes (sea level and climate). This research aims to identify the marine and fluvio–marine terraces and to define their vertical distribution based on the morphometric analysis of two study sites (north – Ceamurlia; south – Tașaul Lake) using EU-DEM. 6 levels were identified as possible marine terraces within the 2–50 m altitude range and also some inferences were made concerning the age of the lower three levels. Also, the present work highlights a differential (stronger) uplift of the northern sector between Peceneaga – Camena and Ostrov – Sinoe faults reflected by both the elevation difference of 5–6 m between the terraces staircases identified at the two sites and by the elevation gaps analysed on an array of cross-fault transects carried on over Ostrov – Sinoe fault.

KEYWORDS Casimcea Plateau, morphometry, marine terraces, faults, uplift

1. Introduction

A marine terrace is any relatively flat, horizontal or gently inclined surface of marine origin, bounded by a steeper ascending slope on one side and by a steeper descending slope on the opposite side. In temperate regions marine terraces often result from marine erosion (abrasion or denudation) (marine-cut terraces or shore platforms) or consist of shallow–water to slightly emerged accumulations of materials removed by shore erosion (marine-built terraces) (Pirazzoli, 2005). Marine terraces are unique features which testify the long term geomorphological evolution in relation with paleoclimate and sea level oscillations.

The presence and spatial distribution of marine terraces across the Romanian coast of the Black Sea is a poorly–known issue despite the old debate concerning their existence and the frequency/number (Posea, 1980, 1983; Ielenicz, 1988). Most of these studies tried to identify the supposed marine terraces and to describe their physiognomy and spatial distribution but, at the same time uncertainty about their existence persists as long as no study proved this with clear evidence.

De Martonne (1921) identified three possible abrasion terraces in northern Dobrogea, whereas Brătescu (1943) concluded that marine terraces have been entirely submerged during the Holocene transgression. Latter, Roșu (1969) argued on the existence of marine terraces extending inland along the Danube and Danube Delta, identifying up to 7 abrasion levels (2–4 m; 8–10 m; 15–20 m; 30–45 m; 55–65 m; 75–85 m; 95–110 m). Ielenicz (1988) developed the previously proposed hypothesis (Posea, 1983) and concluded on the existence of four marine terraces levels (3–5 m, 6–8 m, 10–15 m, 20–30 m) along the present–day coastline.

The present study deals with the morphometric analysis of the lower reach of Casimcea Valley (Tașaul Lake basin) and the north–east façade of the Casimcea Plateau which fronts presently the Ceamurlia–Golovița–Zmeica–Sinoe lagoons.

The uplifting pattern associated with marine terraces is a subject of discussion in tectonically active basins. Within the Mediterranean basin, the association of marine terraces with the collision between Eurasian Plate and African Plate largely acknowledged, this factor being related to both seismic movements and coastal uplifting patterns (Cucci and Cinti, 1998; Zazo et al., 1999, 2003; Zecchin et al., 2004; Pirazzoli et al., 2004). On the other hand, although the relationship between the marine terraces extent, spatial distribution and vertical crustal movements along the Romanian Black Sea coastline is not well documented, this subject was extensively discussed within the southern Black Sea basin by Keskin et al. (2011), Yildirim et al. (2013), Mc Clain et al. (2016), Berndt et al. (2017), Spencer et al. (2017), Erturac et al. (2019; 2020) by analysing the terraces from northern Turkey, associated with the neo-tectonic and seismic movements related to the North Anatolian Fault.

The aim of this study is to identify and characterize those morphological features which could account for the existence of marine terraces in central Dobrogea. Additionally, we inspected the elevation differences between the identified terrace levels trying to assess the contribution of the vertical crustal movements, associated with some of the major tectonic faults based on the elevation differences between terrace levels.

2. Regional settings

Our study area overlays the Casimcea Plateau (Fig. 1), one of the most affected relief units around the Black Sea by the processes of marine transgression and regression during the geological–time due to its long lasting evolution (since Proterozoic; Săndulescu, 1984) and slightly uplifting. (Rădulescu et al., 1976 and Visarion et al., 1988). The Casimcea Plateau is placed between Babadag Plateau (N) and South Dobrogea Plateau. Peceneaga – Camena and Capidava – Ovidiu faults disrupt the plateau to the N and to the S rendering it a perched exhumated peneplain as it was affected by tectonic uplifting (Ciocârdel and Esca, 1966; Polonic et al., 1999).

Late Pleistocene loess deposits prevail, including silt or clayey silt and isolated Pleistocene calcareous pediments along the western banks of the Ceamurlia–Golovița–Zmeica–Sinoe Lagoon Complex. The geological features around Tașaul Lake are more heterogeneous: the Precambrian green–schists are predominant on the western bank and the Late Pleistocene loessoid deposits are predominant on the other side of the lake, interfering with Pleistocene calcareous layers.

As one of the oldest geological and geomorphological unit in western Black Sea, Casmicea Plateau displays a complex morphology with very steep vertical walls, terraces, canyons superimposed on a widely developed peneplaine with mild slopes resulted from long time subaerial evolution (Posea, 1980; Comănescu, 2004). This complex morphology is also imposed by the heterolytic composition with outcropping green schist, limestones or loess (Comănescu, 2004, Ielenicz et al., 2004) and their exposure to multiple shaping factors (i.e. tectonic, subaerial, coastal and marine) which acted at multiple time scales (Ielenicz, 1988). The genesis of marine terraces is generally associated with the highstands of sea level, which occurred during the odd Marine Isotope Stages (MIS) specific to warm (inter-glacial) periods from MIS 1, MIS 3, MIS 5a and MIS 5e to MIS 15 (Yildirim, 2013); during all these intervals the Black Sea basin was connected with the Mediterranean Sea, except MIS 3 (Badertscher et al., 2011).

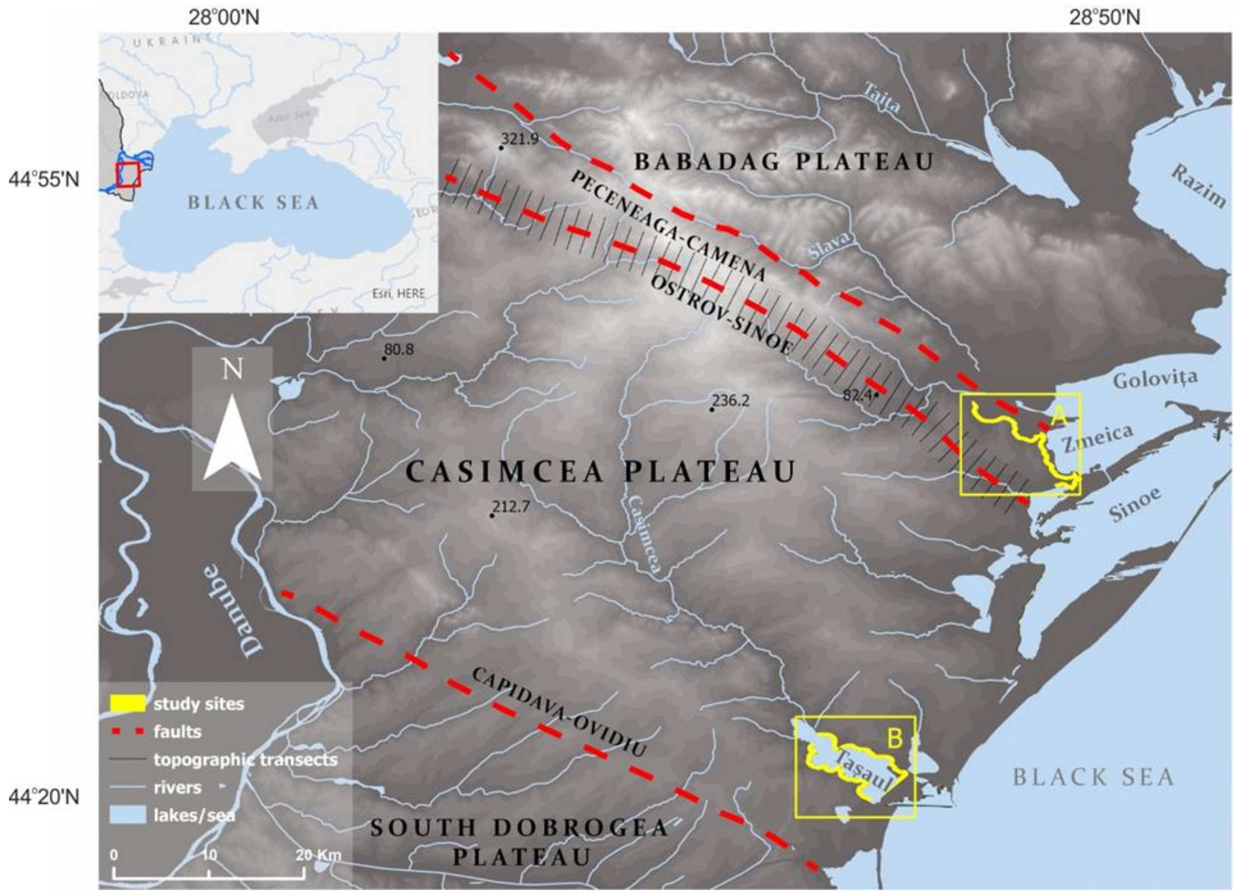

Figure 1 Location map showing the position of the study sites in the western Black Sea and in the Casimcea Plateau: Ceamurlia–Golovița–Zmeica–Sinoe Lagoon Complex (A) and Tașaul Lake (B) in the context of the major units of relief from Central Dobrogea

The Casimcea Plateau is mainly drained by Casimcea River, which is the most important river in region, excluding Danube, which crosses Central Dobrogea following an old syncline alignment from NW to SE parallel to the main faults. It sums up a drainage basin of 740 km^2, a length of 69 km and a multiannual average liquid flow of 0.65 m^3/s at Casian hydrometric station (Zaharia and Pișota, 2003). The present–day climate is dry–temperate, with mean annual temperature of ca. 11 °C and mean precipitation of ca. 400 mm/yr (Sandu et al., 2008). Most of this occurs during summer as heavy rainfalls within relatively short time intervals. This has a relatively high impact in sediment mobilization and subsequent morphological changes.

3. Methodology

For the hypsometry and slope analysis we used the Digital Elevation Model over Europe (EU-DEM) with a spatial resolution of 25 m and a vertical resolution of ±7 m (www.eea.europa.eu). Two polygons were created for the two study sites, both with a constant width of 400 m drawn upslope from the waterlines of the Tașaul Lake (but excluding the Casimcea river delta and the littoral barrier) and from the western waterlines of the Ceamurlia–Golovița–Zmeica–Sinoe lagoons. The slope values were distributed per altitude classes of 2 m elevation and reclassified to select and analyse the sub-horizontal (1–2°) and horizontal surfaces (≤1°); these values were associated with the hypsometric distribution by transforming the EU-DEM raster to points. All the resulted slope and elevation associated points were joined by using spatial analysis intersection tool in ArcGis Pro software; Arc Map 10.8, Global Mapper 15 and Google Earth Pro were used for identifying the areas with quasi-horizontal levels and for creating ranges of elevation profiles. The geological settings of our study sites and the position of the main faults (Pecenaga–Camena; Ostrov–Sinoe; Capidava–Ovidiu) were inspected on 1:50000 geological maps for this areas (153 d Jurilovca; L-35-118-D and 169 c Gura Dobrogei L-35-130-C).

The analysis concerning the vertical crustal movements of the areas situated north and south of the Ostrov – Sinoe fault comprised 53 transects (with the equidistance of 1-km) placed normal on the Ostrov – Sinoe fault. Each transect had a 4-km length with the mid-point right on the fault. Further, the cells (from the transects) placed at the same distance from the fault (e.g. 0–25 m, 25–50 m etc.) were averaged to get a cross-fault hypsometry pattern synthesized in the cross-fault averaged profile.

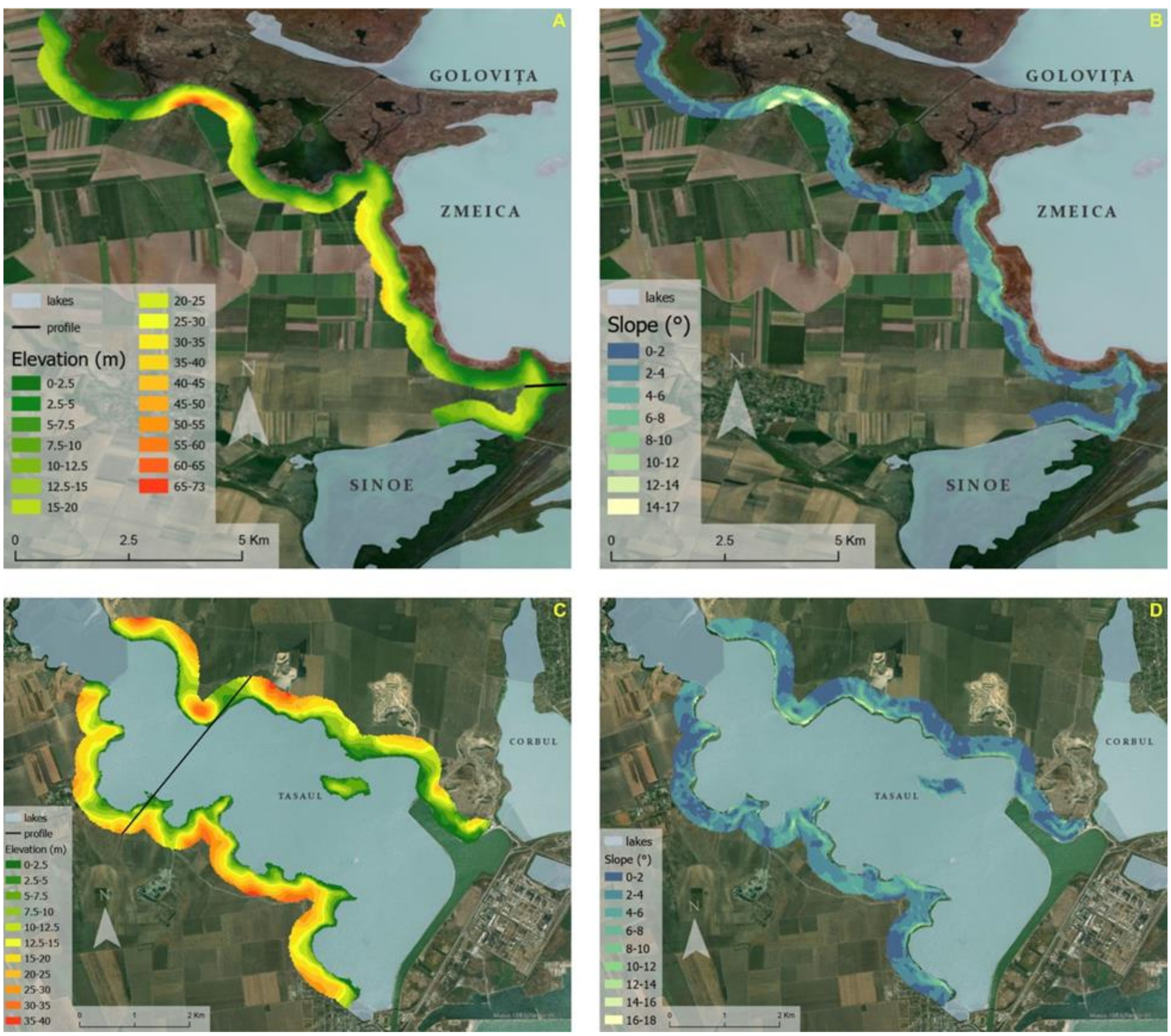

Figure 2 Elevation and slope maps of the two study sites from eastern Casimcea Plateau. A. Hypsometry Ceamurlia site); B. Slopes (Ceamurlia site); C. Hypsometry (Tașaul Lake); D. Slopes (Tașaul Lake)

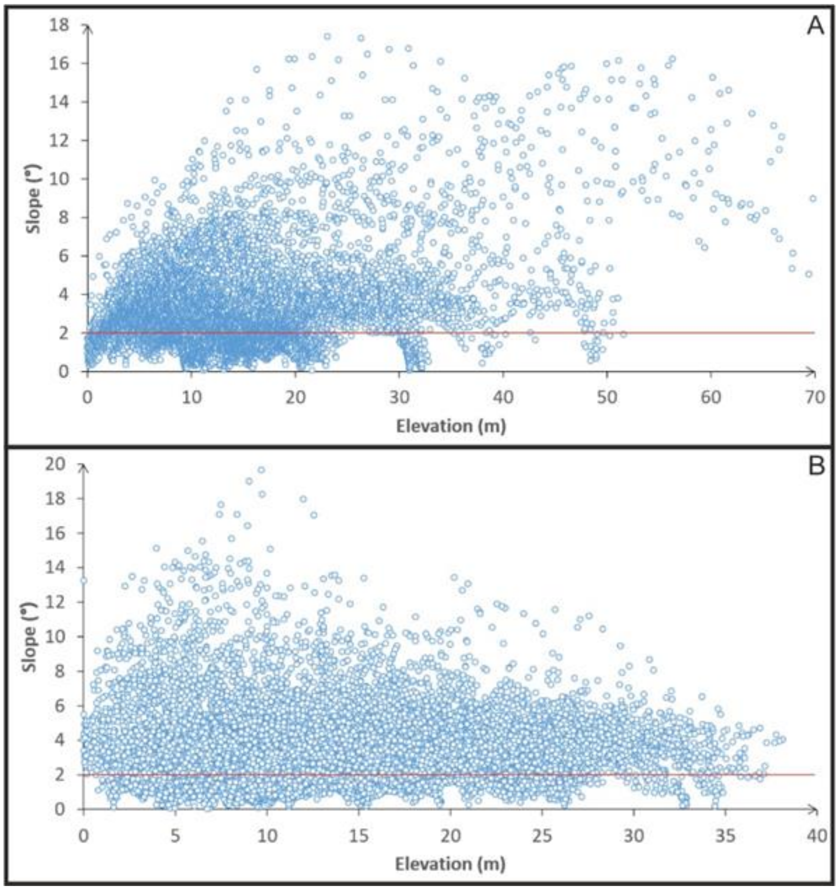

Figure 3 Co-distribution (scattered) of slopes and elevation in Ceamurlia (A) and Tașaul Lake (B)

4. Results

The spatial repartition of both elevation and slope is a suitable method that helped us to find the sub-horizontal levels which are susceptible to be marine terraces (Fig. 2). At our study sites which extend over a surface area of 312 km^2 (Tașaul) and 288 km^2 (Ceamurlia), the slope ranges between 0° and 19.6° for Tașaul and between 0° and 17.4° for Ceamurlia. In both areas, the steeper surfaces sit in the proximity of waterlines, followed by a transition to gentler slopes further inland. The sub-horizontal surfaces with slopes <2° and <1.5° represent 27.09%, respectively 15.22%, whilst the horizontal areas (with a slope <1°) total 6.15% for Tașaul. In the northern–exposed study site of Ceamurlia the frequency of the sub-horizontal surfaces is of 31.82% (with a slope <2°), respectively 18.14% (with a slope <1.5°). Regarding the horizontal areas with slopes <1°, they occupy 7.40%.

The elevation distribution in the two sites is roughly similar but with differences concerning the maximum altitudes. Thus, the area surrounding Tașaul Lake displays a range of heights between 0 m and 39.8 m, while the Ceamurlia hypsometry unfolds between 0 m to 73.1 m. Nevertheless, even if the elevation ranges are different in these two areas, it can be observed the same pattern of slopes distribution as shown by the joint analysis of elevation and slope (Fig. 3). The distribution of the sub-horizontal (1–2°) and horizontal (<1°) surfaces shows a very distinct pattern with a significant clustering within the following altitude intervals: 2–5 m, 7–11 m, 13–16 m, 22–27 m, 31–35 m for Tașaul and 0–2 m, 7–11 m, 13–16 m, 19–23 m, 28–33 m, 36–39 m and 46–49 m for Ceamurlia (Fig. 4). An array of cross-slope profiles which generally shows one to three steps on the same linear profile reveals the presence and the aspect of the quasi-horizontal levels. Figure 5 shows two topographic profiles that intercepted the levels of 2–5, 7–11, 13–16 m for Tașaul and the levels of 7–11 and 13–16 m for Ceamurlia.

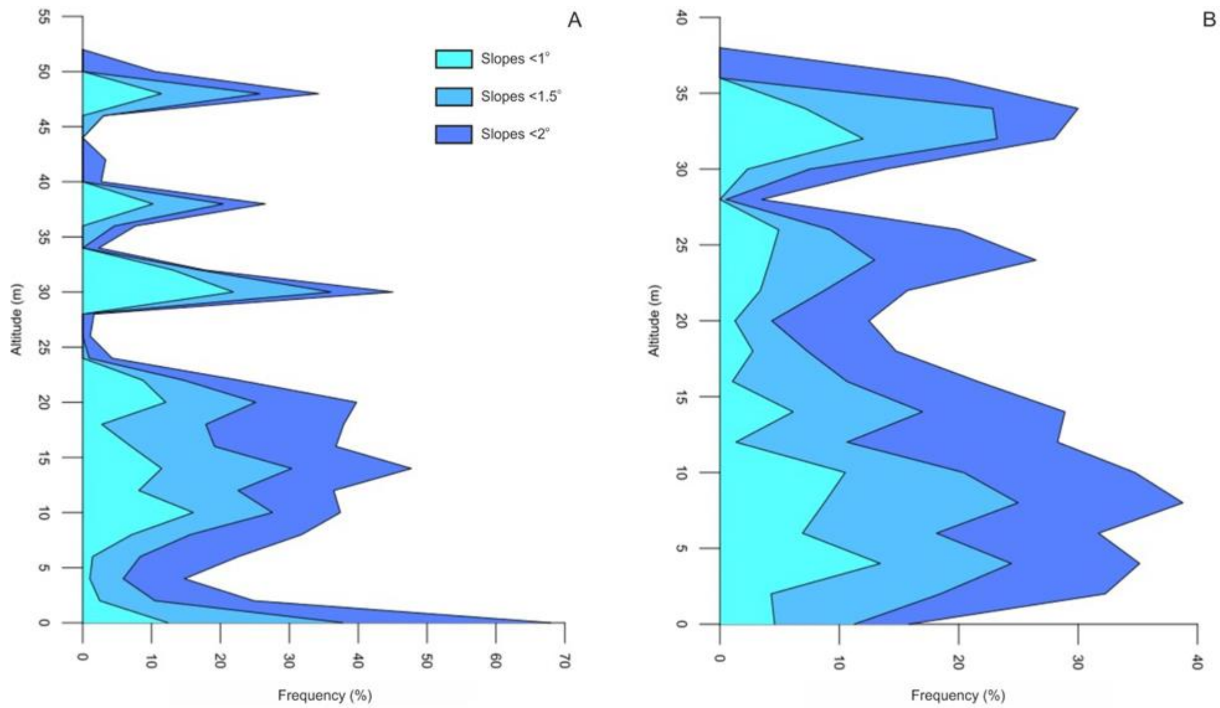

Figure 4 The distribution of elevation–slope within Ceamurlia (A) and Tașaul Lake (B) study sites

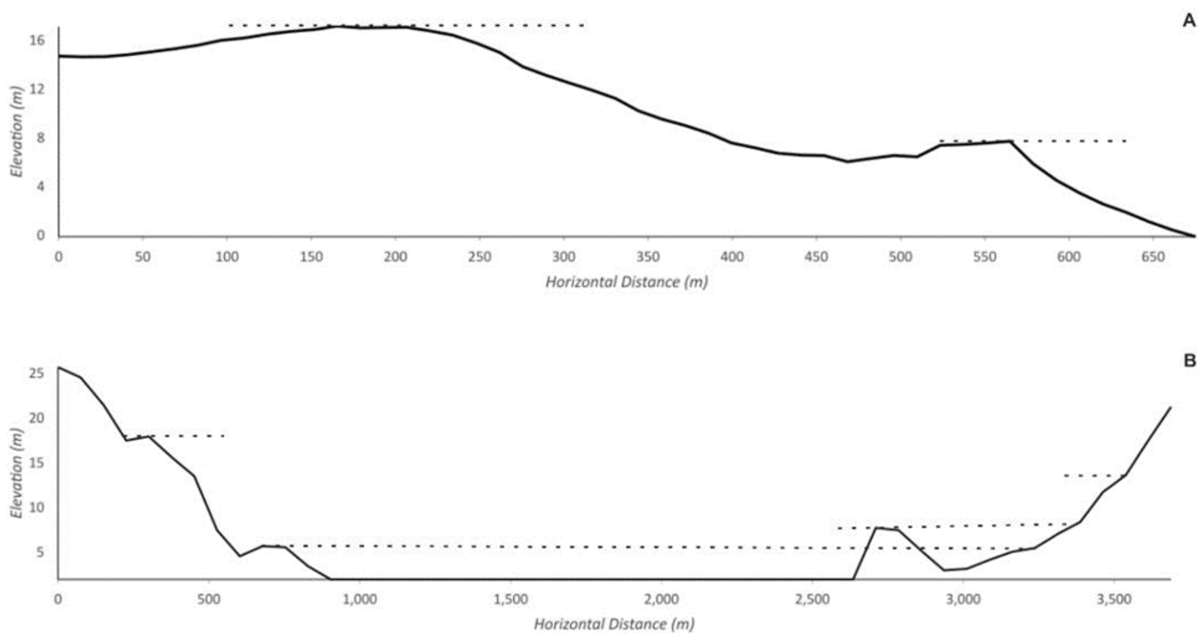

Figure 5 Selected topographic profiles showing the distribution of (quasi)horizontal surfaces from the two study sites. Two levels are indicated within the Ceamurlia site (A), while four were identified in the proximity of the Tașaul Lake (B)

5. Discussion

The two study sites have a common convex cross-slope profile which is specific to areas affected by lateral/horizontal erosion stronger than the overall vertical erosion; the latter one is derived from weathering, sheet–wash and rill–wash (including gullies and torrents). In these cases, the extra-erosion which acted horizontally and imposed both the upward slope convex profile but also the incision of (sub)horizontal steps at different altitudes seems to be mainly of marine origin (abrasion and hydraulic pressure) especially for the north–eastern façade of Casimcea

Plateau (Ceamurlia) and of combined origin – marine and fluvial – for the present Tașaul Lake slopes. Due to its frontal exposure to the north–eastern storm waves, Ceamurlia probably developed most of the (sub)horizontal steps during the intervals of Black Sea highstands when the marine waters could have occupied part of the territory which accommodates now the delta lagoons. On the present lower reach of Casimcea Valley, the reconnection to the Mediterranean Sea (ca 9400 BP, Ankindinova et al., 2020) and the subsequent early and mid-Holocene transgression drowned the floodplain and the base of the lateral slopes and transformed it firstly into a ria and later into a deep liman as suggested by the deep water of the present Tașaul Lake and by the thick Holocene sediments strata (>30 m, as indicated by drills) covering the former Casimcea floodplain within the present coastal barrier. The mouth of Casimcea River was closed by a sandy barrier by the time of the sea–level rise slowdown (ca. 5000 BP) as most of the coastal barriers from the western Black Sea (Caraivan et al., 2015; Vespremeanu–Stroe et al., 2016, 2017). The (sub)horizontal steps cut in the lateral slopes of the Tașaul Lake most probably are fluvial terraces which evolution was imposed by the high position recorded by the Black Sea which acted as a base level for the Casimcea River. It is reasonable to assume that some of these steps were also shaped by direct marine (ria) or liman water dynamics which shaped them as fluvio–marine terraces.

Our analysis highlights the presence of at least 6 (sub)horizontal steps cut into the slopes of the two study sites which probably are (all or most of them) marine or fluvio–marine terraces. Even though, the sites are located in different (north and south) sectors of the Casimcea Plateau at a relatively long distance (40 km) apart, the spatial (vertical) pattern of their distribution is near identical with the same vertical development of each terrace and the same vertical space in-between the terraces. This coherent pattern made us assuming that they have the same modelling agent of marine origin (e.g. waves). The only significant difference is the fact that terraces from the northern site are ca. 5–6 m higher than their correspondents from the southern site (Tașaul Lake) (Fig. 6). Noteworthy, the constant vertical difference for all terraces could be explained by the Ostrov – Sinoe fault line (re)activation after the development of the lower terrace and the vertical displacement of all the steps from Ceamurlia site (T1–T6) excepting the lowermost one (T0).

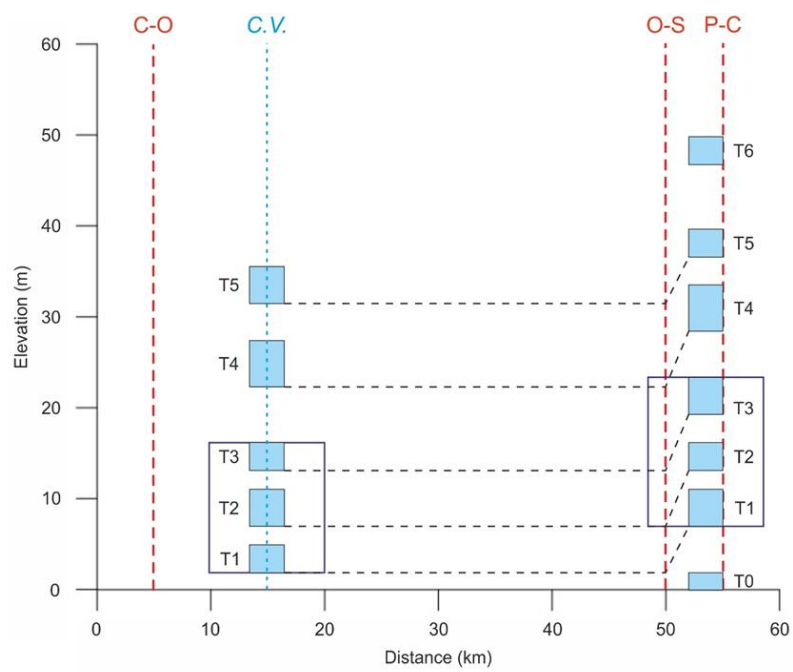

Figure 6 The altitudinal correlation between the possible marine terraces from the two study sites: C-O = Capidava-Ovidiu crustal fault; C.V. = Casimcea Valley; O-S = Ostrov-Sinoe fault; P-C = Peceneaga-Camena crustal fault

In the absence of field evidence (stratigraphy and chronology) is complicated to infer the age of these marine terraces. Still, most probably their formation is linked to the highest and the most long–lasting highstands of Black Sea from Middle and Late Pleistocene if we take into account the age (MIS15; ca. 600 ka) established for the oldest marine terraces from Black Sea (Keskin et al., 2011; Yildirim et al., 2013).

Faunal evidence for water intrusions from the Mediterranean Sea into the Black Sea during the last 600 ka (MIS 15 – present) shows a minimum of 6 intervals (Svitoch et al., 2000) and a maximum of 9 intervals (Zubakov, 1988) when the two seas were connected. But a more recent study reconstructing the reconnection history based on oxygen isotope (δ18O) signatures from a coastal cave (Sofular) provides evidence for at least twelve time intervals within the last 670 ka when water exchange between the Black Sea and Mediterranean Sea was established which should coincide with sea levels higher than the current Bosporus sill depth of –35 m b.s.l. (Badertscher et al., 2011). In our case, the 0–2 m terrace (T0) from the northern site should be middle and late Holocene as it corresponds with the current sea-level stabilization (5000 BP – present). The next three terraces levels, T1–T3, developed at small vertical distances (ca. 3 m) in-between them and the lowermost one (T1) seems to be formed either during MIS 3 (41–30 ka) when terrace formation was also reported for the Sakarya river (Erturac et al., 2019) or MIS 5a (84–72 ka) when the lowermost terrace was incised in Sinop region and Adapazari basin, Anatolia (Yildirim et al., 2013; Erturac et al., 2020). Next levels of terraces are even more difficult to assess in the absence of absolute dating, but with a possible correspondence of T2 or T3 (which are the best developed in Casimcea Plateau; highest frequencies) to MIS 5e (125–119 ka) when the last higher than present World Ocean level (0–10 m a.s.l.) was reported (Pirazzoli, 1991; 1996). The vertical crustal movements from Central Dobrogea were documented and mapped by several authors between 1966 and 1999 (Ciocârdel and Esca, 1966; Cornea et al., 1979; Polonic et al., 1999, cited in Dimitriu and Sava, 2007), which largely considered Dobrogea either quasi-stable or slightly uplifting.

Figure 7 Cross-fault averaged topographic profile (4 km long) intercepting Ostrov–Sinoe fault line showing the uplifting (N) and the lateral compartments

More recently, the emplacement of several GNSS stations (in 2013) enables permanent vertical movement monitoring which for this short time interval presents subsidence at rates between –10 mm/yr (Babadag) and –6 mm/yr (C. Midia) across the coastal strip of our study site (Dimitriu et al., 2017). Still, these values must be considered with caution due to the very short time of analysis (4 years) and the errors which could be associated with the station emplacement especially during first years when the terrain may compact and settle. Nevertheless, an uplifting tendency between Peceneaga – Camena and Capidava – Ovidiu crustal faults is firstly suggested by Rădulescu et al. (1976) and Visarion et al. (1988), cited in Biter et al. (1998), but also by Diaconescu et al. (2019) especially for the northern unit of Casimcea Plateau between the Peceneaga – Camena crustal fault and the Ostrov – Sinoe strike–slip fault. The south–north cross-fault averaged profile carried on in the present study for the Ostrov – Sinoe fault shows vertical differences up to 30 m depending on the cross-fault distances (it varies from 150.8 m in south to 179.5 m in the north; Fig. 7). The evolution patterns of faults and, generally, the crustal movements are subjects that need more complex analysis. Still, our results prove an uplifted activity north of Ostrov – Sinoe fault, for the compartment placed between the Ostrov – Sinoe and Peceneaga – Camena faults, which could be also responsible for the vertical gap between the altitudinal distribution of terraces from the two Tașaul Lake and Ceamurlia sites (Fig. 6).

6. Conclusions and future work

The present geomorphological analysis identified 7 (sub)horizontal surfaces, with the lowermost (0–2 m) corresponding to the late Holocene Black Sea level which suggests the probable presence of 6 marine terraces within the 2–50 m elevation range. The lower terraces (T1–T3) were most probably shaped during MIS 5 (MIS 5a, MIS 5e) but MIS 3 cannot be excluded as an alternative age for the lowermost one (T1). Our study also proves a differential (stronger) uplift of the northern sector between Peceneaga – Camena and Ostrov – Sinoe faults which is indicated both by the elevation difference of 5–6 m between the terraces staircases identified in the two sites and by the elevation gaps analysed on an array of cross-fault transects carried on over Ostrov – Sinoe fault.

Further work is needed to confirm and develop these preliminary results: it is necessary both an in-depth morphometric analysis carried on a higher accuracy DEM (with centimetre resolution) using drones and/or terrestrial laser scan and sedimentological and chrono-stratigraphical analyses to describe and date the deposits which overlay the marine terraces.

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