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The Holocene sea level story since 7500 BP – Lessons from the Eastern Mediterranean, the Black and the Azov Seas

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ABSTRACT

This paper addresses the obvious controversy between the so far published sea level curves of the Black Sea and the Mediterranean. It starts with a discussion of the methods of reconstructing sea level curves, the evaluation of sea level indicators, and the application of the radiocarbon dating method. At least since 7500 BP, when the Black Sea and the Mediterranean were connected, both water bodies must have reacted synchronously on glacio-eustatic changes. It is documented that none of the Mediterranean sea level curves shows the major wiggles postulated for the Black Sea which are supposed to reflect trans- and regression cycles. The very shallow bathymetric condition of the Azov Sea and the northern Black Sea should have led to considerable and traceable shoreline displacements. There is neither archaeological nor historical evidence of mid- and late-Holocene regressions of several meters. The tectonic setting of the Black and Azov seas implicates that the tectonic signal often overrides the eustatic one. Therefore, only local sea level curves can be established. In this paper, based on vibracores, a locally valid sea level curve for the Taman Peninsula is demonstrated. Layers of paralic peat were used as sea level indicators and for ^{14}C dating. The shape of this curve follows the one known from the Mediterranean. This study also revealed that the present peninsula of Taman evolved out of a former archipelago.

1. Introduction

The book "Noah's flood. The new scientific discoveries about the event that changed history" by Pitman and Ryan (1998) has stimulated a vivid debate. It also led to a recognition of the work done by scientists from Russia and other eastern European countries (e.g. Ostrovsky, 1967; Balabanov et al., 1981; Arslanov et al., 1982; Badyukov, 1982; Balabanov, 1984, 1987; Nesmeyanov et al., 1987; Chapman and Dolukhanov, 1997; Shilik, 1997) concerning the Holocene sea level changes of the Black Sea. It became obvious that sea level curves of the Black Sea showed a general trend, although they differed in the steepness of the postglacial rise and the number and order of wiggles (Nevessky, 1961; Fedorov, 1977, 1978; Balabanov et al., 1981; Voskoboinikov et al., 1982; Balabanov, 1984, 1987; Chepalyga, 1984; Balabanov and Izmailov, 1988; see also the compilation by Pirazzoli, 1991). The Pitman and Ryan (1998) hypothesis of the separation between the Mediterranean and the Black Sea due to the glacio-eustatic lowstand of the Mediterranean and the drop of the level of the Black Sea beyond −140 m, plus the catastrophic reunion of both seas around 7500 BP (Ryan et al., 1997), later corrected to 8400 BP (Ryan, 2007: p. 63), divided the scientific community into three parties: those supporting the catastrophic scenario (Ryan et al., 1997; Pitman and Ryan, 1998; Ballard et al., 2000; Govedarica, 2003; Lericolais et al., 2007), and those rejecting the lowstand of the Black Sea and favouring a rise in sea level, either a gradual one (Aksu et al., 1999, 2002a,b; Hiscott et al., 2002; Kaminski et al., 2002) or an oscillating one (Chepalyga, 2002, 2007; Balabanov, 2007; Glebov and Shel'ting, 2007; Konikov, 2007; Yanko-Hombach, 2007). This controversy was one of the triggers for the installation of IGCP Project 521. "Black Sea-Mediterranean Corridor during the last 30 ky: sea level change and human adaptation". When looking at the achieved results to date (Yanko-Hombach et al., 2007), it is evident that the debate is vividly going on and a lot of research remains to be done.

Whatever the outcome, it is common opinion that at least since 7500 BP the Mediterranean and the Black Sea have been connected via the Bosphorus Strait (Yanko-Hombach et al., 2007). Since then, their water bodies must have reacted as a communicating system with the effect that the glacio-eustatic parts of their sea level curves should have been the same.

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How then did the sea levels of the Mediterranean, the Black and the Azov Seas fluctuate since 7500 BP? This question is an important one due to its consequences for the shifts in the shorelines which had major influence on the history of settling the coasts. This paper focuses on the last 7500 years. It presents the different positions, discusses probable reasons for discrepancies, and outlines a possible solution.

2. Methods of reconstructing sea level curves

Published sea level curves from the Mediterranean, the Black and Azov Seas show considerable differences due to varying tectonic settings, databases (OSL, ^{14}C, ceramics, archaeological evidence, etc.) and calibration of ^{14}C ages. Further reasons are the compilation of data from inhomogeneous areas, plus the lack of useful sea level indicators or difficulties concerning their interpretation.

2.1. Sea level indicators

Reasons for sea level fluctuations are manifold, the most important ones being eustasy and isostasy (both differentiated in glacial, hydrological and sedimentary causes), tectonics (subsidence, uplift, tilting), earth rheology, and sediment compaction.

A major problem when talking about past sea levels is identifying proper indicators and evaluating their precision. Fortunately, the Mediterranean, Black and Azov Seas have a microtidal regime, which makes the reconstruction easier. In general, their tidal ranges are only a few decimetres and therefore below normal wave action. Tidal differences are only noticeable in areas with a special coastal configuration, such as the northernmost Adriatic Sea, the Little Syrte, and some embayments of islands in the Aegean Sea.

The main question thus is to detect good sea level indicators under such conditions when tides can be discounted. Differentiation is required between rocky and sedimentary contexts. On a rocky coast, mechanical notches and abrasion platforms, created by pebbles due to wave action, are indicative of MSL (mean sea level), but cannot be determined with precision.

The transgression peak of a marine terrace is marked by the foot of the cliff. This does not represent MSL, but the farthest extent of the waves during major storms. Depending on the wave climate and the fetch, MSL may be decimetres and even meters lower.

A sandy or gravelly beach may be part of a beach ridge, a marine terrace, a delta or a shingle beach – lagoonal system. In such a sedimentary context, it is impossible to reconstruct MSL with high precision. The storm level forms the beach berm of a beach ridge/shingle beach and the transgression peak of a marine terrace (cf. Schellmann and Radtke, 2003) MSL can be calculated by analysing the modern-day analogue. This may then be transferred to the fossil record of a series of beach ridges/shingle beaches or a flight of marine terraces according to the principle of uniformitarianism, assuming that the environmental parameters have not changed.

The best sea level indicators are (a) the topset/foreset contact of a Gilbert type delta, (b) a river-mouth terrace, (c) the top of lagoonal sediments in a totally infilled lagoon, (d) biological markers, and (e) some archaeological criteria.

The case of (a) may be applied in areas of high uplift, such as southern Calabria and the northern Peloponnese where this boundary is exposed (see also Dumas et al., 1988, 2000; Brückner and Radtke, 1990). As for (b), see, e.g. Schellmann and Radtke (2003). In the fossil record (c) may be found when a lagoonal unit is covered by a terrestrial one (Vött, 2007). The use of geomorphological markers is discussed in Lambeck et al. (2004).

Biological markers (d) may be differentiated between those of rocky and those of sedimentary coasts. In the case of rocky coasts, bio-erosion and bio-construction features occur. Bio-erosive notches, created by gastropods such as *Littorina neritoides* which feed on endolithic cyanobacteria, as well as forms of bio-construction, such as algal rims, are excellent indicators, with *Lithophyllum* or *Tenarea* being even more precise than vermetids. Coralline bioherms (algal ridges and trottoirs) are high precision indicators ($\pm$10 cm) (see Laborel et al., 1994; Morhange et al., 2001; Laborel, 2005; Laborel and Laborel-Deguen, 2005; Morhange, 2005; see also Fig. 2). Colonies of *Balanus* sp. cluster in the eulittoral zone, but live in the splash zone as well. Of much lesser precision are rock pools, bio-erosive forms found in the supralittoral zone, and holes of boring organisms (*Lithophaga*) in the sublittoral. The most famous example of the latter is the borings of marine organisms up to 7 m a.s.l. in the marble columns of the Roman market hall (Marcellum, wrongly also attributed as Temple of Serapis) of Pozzuoli near Naples from the 2nd/3rd century AD. The discovery of this (bradysismic) effect by Lyell (1830) initiated research on sea level changes (cf. Morhange et al., 2006).

Biostratigraphy can offer a high resolution. Specific species of microfauna (especially foraminifera and ostracoda) have proven to be useful sea level indicators (e.g. Plassche, 1986). In the fossil record, paralic swamps (Pirazzoli, 1991) and salt marshes are excellent: "The most accurate way to calculate sea level changes from reconstructed palaeo-marsh surfaces is through the use of transfer functions based on modern foraminiferal distribution" (Gehrels, 2005: 831; see also Shennan et al., 1996; Marriner and Morhange, 2006; Marriner et al., 2006). Some assemblages of foraminifera are so sensitive to changes in elevation that they may help to relocate the former sea level with an accuracy of $\pm$10 cm (Scott and Medioli, 2005). The use of bio-films as indicators must still be tested for the fossil record.

Beachrock, one of the characteristic coastal features of the summer-dry subtropical zone, occurs in several coastal areas of the Mediterranean. Obviously, the seasonally high evaporation plays an important role in its formation. However, until the controversy of its genesis is solved (intertidal = eulittoral versus supratidal = supralittoral formation), beachrock is not a useful sea level indicator (see Section 3.1).

Other possibilities of the detection of sea level changes are historical descriptions, paintings in the naturalistic style, gauge data, and most recently satellite geodesy. A good example for the combination of these methods was published by Camuffo et al. (2004) for Venice.

The contributions from archaeology are harbour installations (with little precision) and Roman fish ponds (with high precision). Drowned architecture which had once been erected on land (e.g. houses, temples, graves), gives minimum values of the relative submergence. It is only in rare cases that from historical accounts former sea levels may be deduced with high accuracy. Not discussed here are sea level indicators from other than the Mediterranean–Black Sea region, such as isolated basins of deglaciation areas or ecological criteria from coral reefs. For more details about sea level indicators see also Plassche (1986), Pirazzoli (1991, 1996, 2005) and related articles in Schwartz (2005). Another approach is used by Lambeck et al. (2004) who reconstruct sea level history by feeding morphological, archaeological and geochronological data into a geophysical model.

2.2. Tectonic setting

The tectonic pattern of the Mediterranean and Black Sea region is dominated by the continent–continent collision between the African and the Eurasian plates. The major feature expressing the very active subduction of the former below the latter is the Hellenic Trench (Fig. 1). Another effect is the northward drift of the Arabian

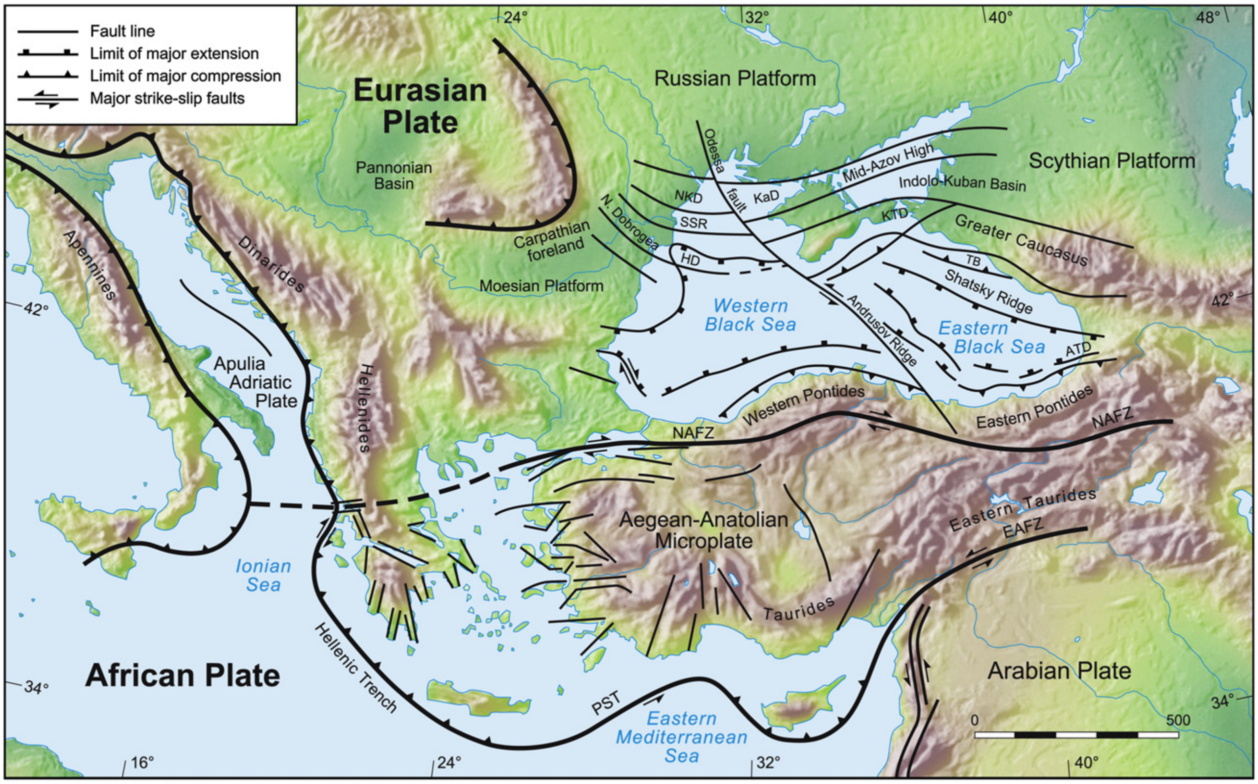


Fig. 1. Tectonic pattern of the eastern Mediterranean, the Black and Azov Seas. The map is focused on the tectonic structure of the western Aegean-Anatolian microplates and the Black Sea. Sources: Dinu et al. (2005), Hofrichter (2003), Aksu et al. (2002a,b), Spadini et al. (1996). Abbreviations: NAFZ = North Anatolian Fault Zone, EAFZ = Eastern Anatolian Fault Zone, PST = Pliny-Strabo Trenches, ATD = Adjaro-Trialet Depression, TB = Taupse Basin, KTD = Kerch-Taman Depression, KaD = Karkinit Depression, NKD = North Kilia Depression, SSR = Suvorov-Snake Island Ridge, HD = Histria Depression.

microplate which forces the Anatolian microplate to go west, thus creating the North Anatolian fault zone (NAFZ), one of the most active transform faults in the world. Due to the lateral extension of the Anatolian plate, several grabens evolved at its western edge.

This general pattern determines also the major tectonic features of the Black and Azov Seas outlined in Fig. 1. The Black Sea is bordered in the south by the tectonically active Pontides and in the northeast by the Caucasus. Caucasus, Pontides and the southern Crimean Mountains (Smolyaninova et al., 1996) are the major areas of uplift. The areas to the west and north of the latter are tectonically more or less stable regions of passive old shields, such as the Russian and Scythian platforms. There are also subsiding regions, such as the Indolo-Kuban basin to the north of the Caucasus and the Crimea. At the interface of these geoclinal structures are the Taman and Kerch Peninsulas. Therefore, both regions are tectonically stressed and intersected into numerous plate fragments of different tectonic behaviour.

The seismic activity of a region is expressed by the frequency and magnitude of earthquakes and volcanic eruptions. Both natural risks are well known from the eastern Mediterranean, but to a much lesser extent also from the northern Black Sea region. However, a specific geological and geomorphic feature of the latter is mud volcanoes (Saintot and Angelier, 2000; Dimitrov, 2002).

2.3. The problem of dating

Chances and pitfalls of different dating methods are well discussed in Wagner (1998) and Geyh (2005). Concerning the reconstruction of sea level curves, the ^{14}C-AMS method is often applied. The calculated ages should be given with a double standard deviation to include 95% of all cases. Moreover, a sea level curve that is based on ^{14}C ages should always be shown as an envelope curve. When radiocarbon dating marine mollusc shells, the problem of the reservoir effect arises. The average value used for the world ocean of 402 years (Reimer et al., 2004) may not be applicable for the Black and Azov Seas since their waters are brackish (salt concentrations much less than 25‰) and have specific thermohaline circulations. The problem of the determination of the shifts of the palaeo-reservoir-effects in space and time has not yet been settled. In addition, ^{14}C ages must be calibrated to sidereal years when being compared with archaeological or historical ages. Calibration programs are still being refined (Reimer et al., 2004).

For a reliable data point on a sea level curve, ^{14}C-dated peat from paralic swamps or marshes is applicable. The most favourable case is given when the peat covers a marine sediment (cf. Section 2.1.). As for bivalves, only those should be used that are still in living position (at least articulated) and that are sea level indicators, i.e. have only a narrow spatial tolerance concerning their ecological zoning. Single valves are normally rejected since they may have been reworked. Indicative ceramic fragments are appropriate, but may also have been reworked. The latter is obvious, if they are rolled. The luminescence dating method may be helpful, but its error range of around 10% is still high.

3. Lessons to be learned from the Mediterranean

3.1. Relative sea level studies in the eastern Mediterranean

Many coastal areas in the eastern Mediterranean were already subjects of sea level studies. In general, two different types of curves are described. The type 1-curve (Fig. 3) shows a relative mid-Holocene sea level highstand between 6000 and 3500 cal BP

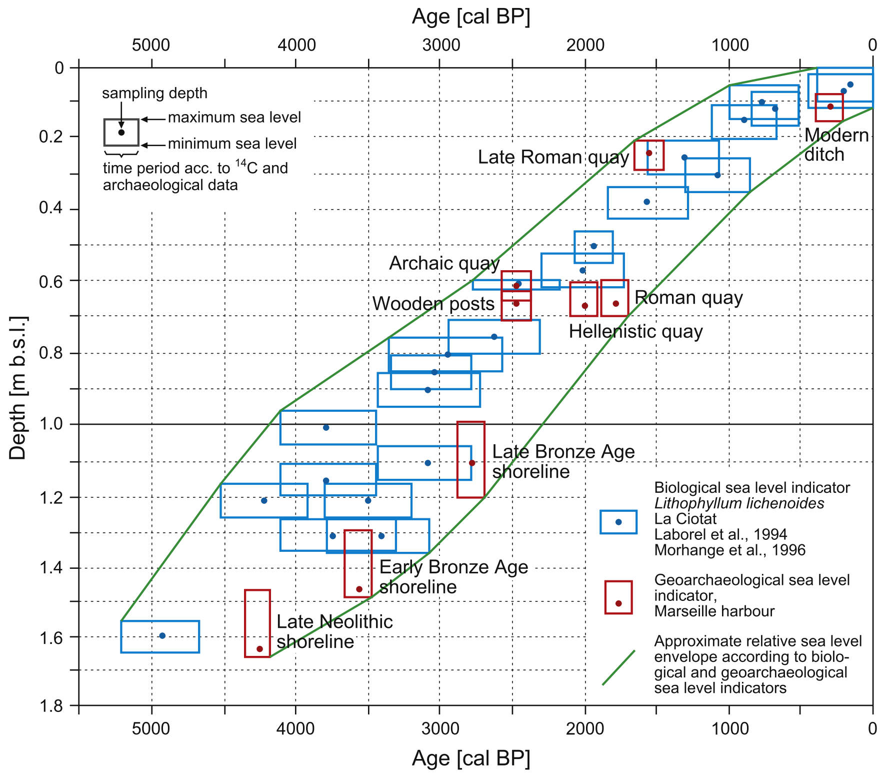


Fig. 2. Relative sea level changes in southern France near Marseilles. Age–depth relations of 23 ^{14}C-dated samples of *Lithophyllum lichenoides*, supplemented by archaeological data. The results show that, since 5000 cal BP, relative sea level has never been higher than today. Source: modified from Morhange (2005) and Morhange et al. (2001).

which partly reached or even slightly exceeded present MSL. Type 1-curves were found, for instance, by Kelletat (2005) for the Peloponnese and generalized for the entire eastern Mediterranean, by Müllenhoff (2005) for the Büyük Menderes graben (western Turkey), by Riedel (1996) for the Dalyan delta (southern Turkey) and by Wunderlich and Andres (1991) for the Nile delta (Egypt). Some of these curves (Riedel, 1996; Kelletat, 2005) partly use beachrock as sea level indicator. Recent studies, however, show that beachrock is only a limited sea level marker (Kelletat, 2006, 2007; Knight, 2007) which is mainly due to the fact that the genesis of beachrock is still not understood well enough. Other type 1-curves are based on weak geochronological evidence (Kayan, 1997) or do not take into account possible local differences in tectonic movements (Wunderlich and Andres, 1991; Müllenhoff, 2005).

In contrast, the type 2-curve (see Fig. 2 and some curves in Fig. 3) shows a more or less continuous sea level rise during the past 6000 years or so. Curves of this kind, based on sedimentological and geoarchaeological indicators, were described, for instance, by Vouvalidis et al. (2005) for the coastal plain of Thessaloniki, by Sivan et al. (2004) for the Israeli coast of Caesarea Maritima, by Pavlopoulos et al. (2007) for northeastern Crete and by Vött (2007) and Vött et al. (2007a) for several coastal sites in northwestern Greece, among which are the Palairos coastal plain and the Acheloos River delta (Fig. 3). Type 2-curves also resulted from glacio-hydro-isostatic modelling approaches such as those by Lambeck (1996), Lambeck et al. (2004) and Lambeck and Purcell (2005).

The synopsis depicted in Fig. 3 exemplarily shows that the search for a uniform sea level curve for the eastern Mediterranean is in vain. Sea level evolution is obviously influenced by strong local to regional factors. Besides local differences in sediment compaction, sediment supply from the hinterland, and coastal dynamics, differences in the local to regional neotectonic pattern are responsible for the differing sea level curves. Thus, to compare relative sea level curves predominantly means to compare relative differences in vertical tectonics of the earth's crust.

3.2. Akarnania and adjacent regions in northwestern Greece

Independent local relative sea level curves elaborated by Vött (2007) and Vött et al. (2006a,b, 2007a,b) for seven coastal plains

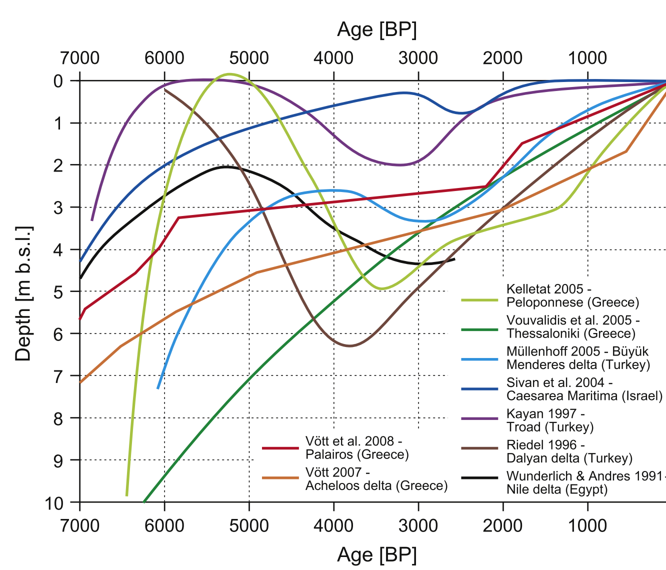


Fig. 3. Compilation of Holocene sea-level curves from the eastern Mediterranean. Type 1-curves show a relative mid-Holocene sea level highstand between 6000 and 3500 cal BP. In contrast, type 2-curves show a more or less continuous sea level rise during the past 6000 years or so. It is obvious that there is only one major wiggle for the type 1-curves, while the type 2-curves have none at all. Source: modified from Vött and Brückner (2006, Fig. 4).

and deltaic areas along a 150 km-long coastal strip in northwestern Greece are summarized in Fig. 4a. Sea level reconstruction was based on well-dated sedimentological and geoarchaeological sea level indicators such as peat from paralic swamps or submerged archaeological remains. The synopsis of curves shows that there are considerable differences in relative sea level evolution. By 6000 cal BC, for instance, the relative sea level in the Boukka coastal plain, southeastern Ambrakian Gulf, lies 7.30 m lower than around Elis in the northwestern Peloponnese (Brockmüller et al., 2005). As differences in climatic conditions, geological settings in the hinterland and sediment supply towards the coast, sediment compactions as well as anthropogenic influences of the different study sites can be readily assessed (see Vött, 2007), the differences in relative sea level evolution mostly reflect differences in the neotectonic evolution.

Deduced from local relative sea level data of the seven sites, Fig. 4b depicts in a synoptic view the vertical movement of each site relative to the Trikardo area in the central Acheloos River delta. Hence, the central part of the Akarnanian block (Mytikas, Boukka, Astakos) is characterized by strong tectonic subsidence. In contrast, its northern and southern flanks show minor relative subsidence (Etoliko), partly even relative uplift (Palairos, Elis). This can be explained by the overall tectonic pattern. Akarnania as a whole, drifting away from mainland central Greece by 5 mm/a (Cocard et al., 1999), is moving to the southwest and is, at the same time, subjected to strong subsidence. Bordered by the Ambrakian fault

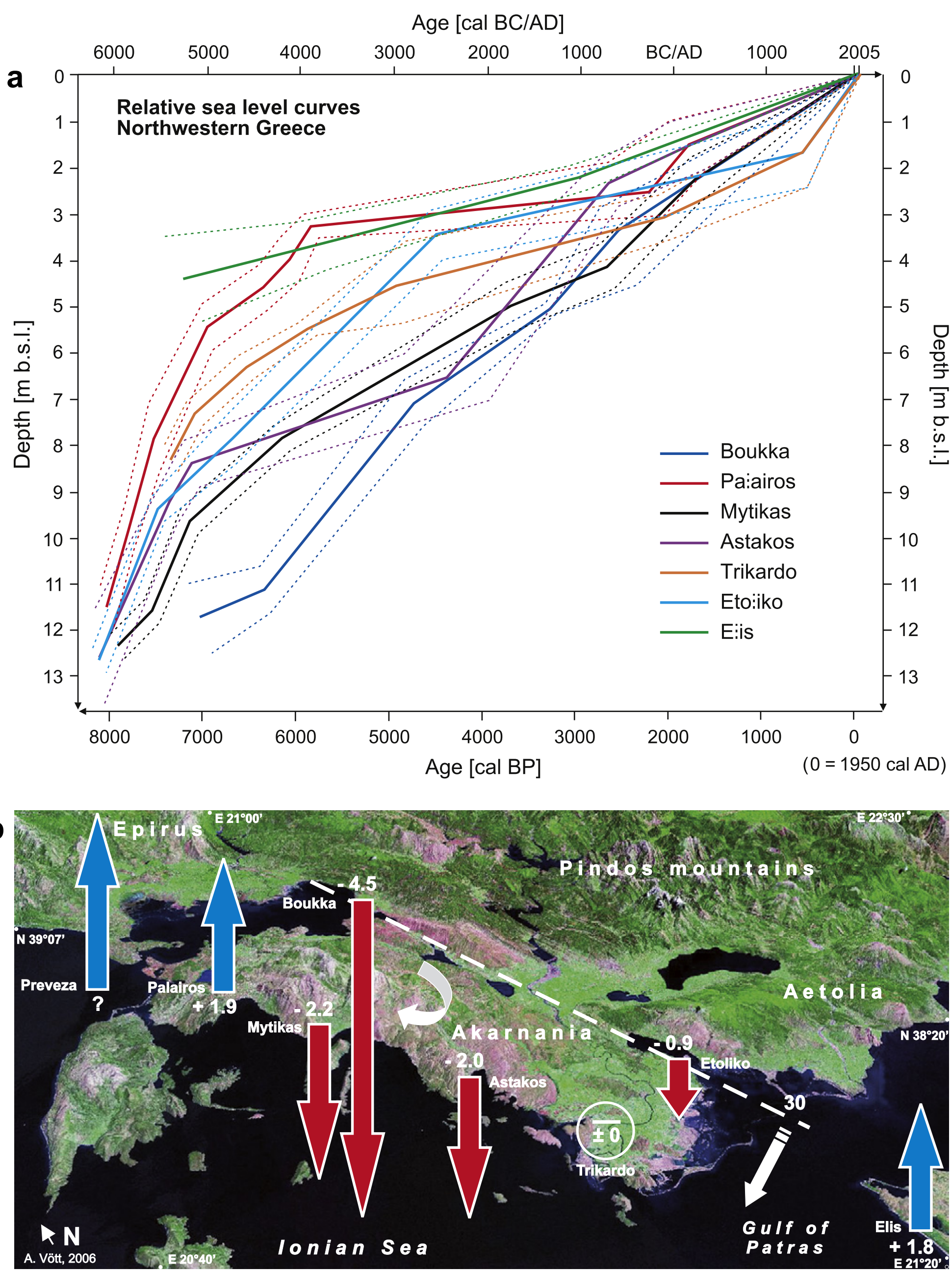


Fig. 4. (a) Relative sea level curves for seven areas along a 150 km-long coastal strip in Akarnania (NW Greece) and adjacent regions. (b) Vertical movement of each coastal site relative to the Trikardo area (marked with a white circle) as deduced from relative sea level data shown in Fig. 4a. The central part of the Akarnanian block (Mytikas, Boukka, Astakos) shows strong tectonic subsidence while the areas to the north (Palairos, Preveza) and to the south (Elis on the Peloponnese) are subject to relative uplift. Based on Vött (2007) and Vött et al. (2007a,b).

system to the north and the Corinthian graben system to the south, subsidence of Akarnania's flanks is thus decelerated or even reversed to an upward movement by the uplift dynamics of the adjacent Epirus and northwestern Peloponnese highlands. These dynamics seem to be related to the Hellenic Trench nearby, offshore the Ionian Islands, and the seismically highly active Cephalonia and Lefkada transform faults (e.g. Karakostas et al., 2004).

In general, studies in northwestern Greece revealed that (i) the relative sea level during the Holocene has never been higher than at present, (ii) there are no traces of a mid-Holocene highstand, and (iii) differences in relative sea level evolution predominantly reflect both local fault activity and (supra-) regional geodynamic patterns. The latter is exemplified for the central Mediterranean by Serpelloni et al. (2005) and Hollenstein et al. (2008).

3.3. The contribution of archaeology – the example of Miletus, Turkey

The following example demonstrates how the position of the former sea level can be deciphered in an archaeological context. Studies in Miletus have shown that the area around the (later) Temple of Athena had formerly been an island (Brückner, 2003; Brückner et al., 2006; see the reconstruction in Fig. 5a). This is an appropriate setting for the determination of the Holocene transgression peak. From the archaeological point of view, it is of special interest, since nearshore settlements are very much dependent on the position of sea level. Around the (later) Temple of Athena, the first settlement (Miletus I) dates from the Late Chalcolithic c. 3500–3000 BC (Niemeier and Niemeier, 1997; Niemeier, 2007). The oldest so far unearthed *in situ* finds from that time are directly lying on bedrock, 0.98 m b.s.l. (below present MSL; W.-D. Niemeier, personal communication, 2004).

Vibracores from the southwest of the temple (Fig. 5b,c) also revealed an anthropogenic setting on top of the bedrock (limestone) dating from Miletus I. It is covered by a layer of well sorted sand with marine organisms and well rounded limestone pebbles. The upper part of this littoral to shallow marine facies contains rolled ceramic fragments from the Middle Bronze Age (Miletus III), overlain by upper littoral and backbeach sediments (regression facies). They form the substratum for a wall from the settlement phase Miletus IVa (Late Minoan Ia, Late Bronze Age) which had been excavated by C. Weickert (Weickert et al., 1959/60). Its deepest point is presently at 0.21 m b.s.l.

The coring results can be interpreted as follows. During the time of the first settlement (Late Chalcolithic, Miletus I) coring sites Mil 232 and 233 were still dry land, while the sites Mil 231, 153, 151 and 30 had already been flooded by the sea (Fig. 5). During the Early Bronze Age at the latest, the area had changed into an island (Fig. 5a). Afterwards, local sea level reached its highest position (settlement phase of Miletus II, 3000–2000 BC). During Miletus II and III, coring sites Mil 232 and 233 were under littoral conditions, while the sites Mil 231 and 30 presented sublittoral to shallow marine environments. The shoreline of the maximum transgression was reconstructed only c. 4.50 m south of Mil 233. The Late Minoan Ia wall testifies to the fact that around 1700 BC it was once again possible to settle at this site (Fig. 5e).

What can be deduced from the archaeological findings for the local relative sea level history? During Miletus I, relative sea level must have been below its present level. In coring Mil 232, the deepest part of the Late Chalcolithic stone structure is at 2.52 m b.s.l., perhaps even at 2.83 m b.s.l. Sea level reached its highest position during the Early and Middle Bronze Age (Miletus II and III), presumably peaking during Miletus II around 2500 BC. The highest marine layers from those times are today located at 0.30 m b.s.l. Based on the moderate wave climate in the area, one can assume about 1 m of vertical difference between MSL and the top of these sediments. Therefore, the highest MSL during Miletus II can be reconstructed at c. 1.30 m b.s.l. The present position of these layers was most likely influenced by post-sedimentary tectonics since Miletus is situated at the southern flank of the Büyük Menderes graben. The Late Minoan Ia wall (Miletus IVa) shows that at least around 1700 BC local sea level had dropped and never returned to the area. We conclude that there was only one Holocene peak of sea level; several wiggles can be excluded (see also Müllenhoff, 2005).

4. The sea level story of the Black Sea

4.1. Sea level curves for the Black Sea

The fact that the Holocene sea level changes of the Black Sea are still actively being discussed is represented by the large number of recent publications about the fluctuations in sea level during the last 7.5 ka (see the excellent compilation in the volume edited by Yanko-Hombach et al., 2007).

Fig. 6 shows a compilation of sea level curves for the Black Sea. Several authors conclude that the postglacial sea level rise decelerated when reaching c. 10 m below its present position around 7000 BP (Fedorov, 1977; Ivanov and Schmuratko, 1983; Balabanov, 2007; Glebov and Shel'ting, 2007; Konikov, 2007; Shuisky, 2007). Thereafter, still major rises and falls, in some cases even to the order of up to 10 m [sic] are postulated (see also Shilik, 1997; Svitoch, 1999; Svitoch et al., 2000; Selivanov, 2003). While most of these curves show that Holocene sea level was never (much) higher than today, Filipova-Marinova (2007) presents another scenario: Based on 30 radiocarbon dates from the Bulgarian coast, she reconstructs a Holocene sea level curve with three peaks higher than present sea level: up to 5 m a.s.l. [!] at 5910 cal BP, up to 4 m a.s.l. at 3730 cal BP, and up to 1 m a.s.l. at 310 cal BP.

When discussing these different curves one has to bear in mind the time of their publication and that they were based on absolutely different data sets. Therefore, this discussion concentrates on the latest and most thorough compilation, i.e. the curve published by Balabanov (lastly 2007; see also Fig. 7, line A). Balabanov's sea level curve is a synthesis of more than 400 radiocarbon dates of different types of organic matter (marine and lagoonal shells, peat, wood, etc.) that have been produced during the last decades in different laboratories of the former USSR. According to this curve, the Holocene changes of the Black Sea include rhythmic fluctuations of several orders (from 10^3 to 10^2 years) which are superimposed on the general trend of sea level rise according to the transgression of the world ocean. The author subdivides Holocene stage 1 into four phases (see also Fig. 7): Neoeuxinian (ne), Bugazian (bg), Vityazevian (vt), and Kalamitian (kl). Holocene stage 2 covers the last 6000 years and contains two main transgressive phases, the Dzemetinian (dz) and Nymphaean (np) ones. Dz ended with the Phanagorean regression (~2.7–2.4 ka BP), the extent of which is still under discussion. Based on both geological and archaeological evidences this curve suggests a sea level fall of at least 7–8 m.

It is interesting to note that the idea of the transgressive–regressive pattern in the Black Sea was developed by geological surveys of the Black Sea coast and shelf of the Caucasus area conducted by the Ministry of Geology of the Soviet Union and the RSFSR. Geological surveys – begun at the end of the 1960s and continued up to 1990 – accomplished a large number of boreholes (depth up to 120 m on land and up to 40 m on the shelf). Many similar geological investigations were conducted both on estuaries and the coastal shelf of the Northwestern Black Sea.

It must, however, be noted that a few researchers published different curves for selected regions of the Black Sea. Studying the evolution of the Danube delta, Goisan et al. (2006,

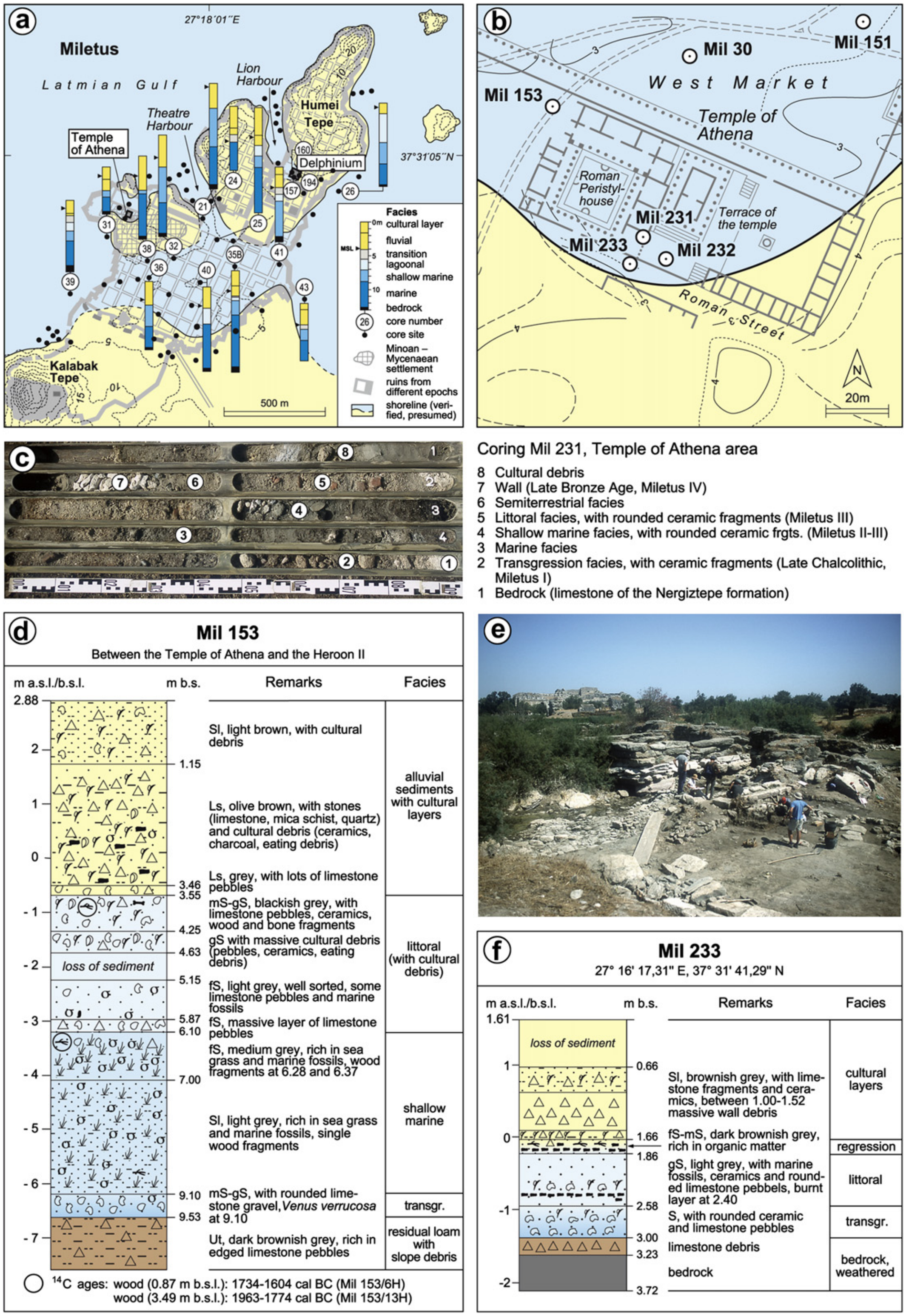


Fig. 5. Determination of the Holocene transgression peak in the area of the Temple of Athena, Miletus (Turkey), based on archaeological and geological evidence. There, sea level reached its highest position during the Early and Middle Bronze Age (settlement phases Miletus II and III), presumably peaking during Miletus II around 2500 BC. (a) Reconstruction of the Milesian archipelago during the maximum marine transgression around 2500 BC (only a few of the more than one hundred corings are indicated). (b) Section of Bendt's topographical map (1968) showing the position of the sanctuary within the city of Miletus, the coring sites mentioned in the text and the maximum marine transgression (shaded area). (c) Core Mil 231, with interpretation of strata (lower right corner: bottom of core at 5 m b.s., top of each core segment is to the left). (d) Details of core Mil 153, with geology, dating results, and facies interpretation. (e) The so-called temple terrace is the square building in the middle ground; the two persons standing in front of it are looking at the Late Minoan Ia and Ib walls (Miletus IV, 1700–1450 BC); in the foreground the area of corings Mil 231–233. (f) Details of core Mil 233, with geology, dating results, and facies interpretation. Source: Brückner et al. (2006), Fig. 3.

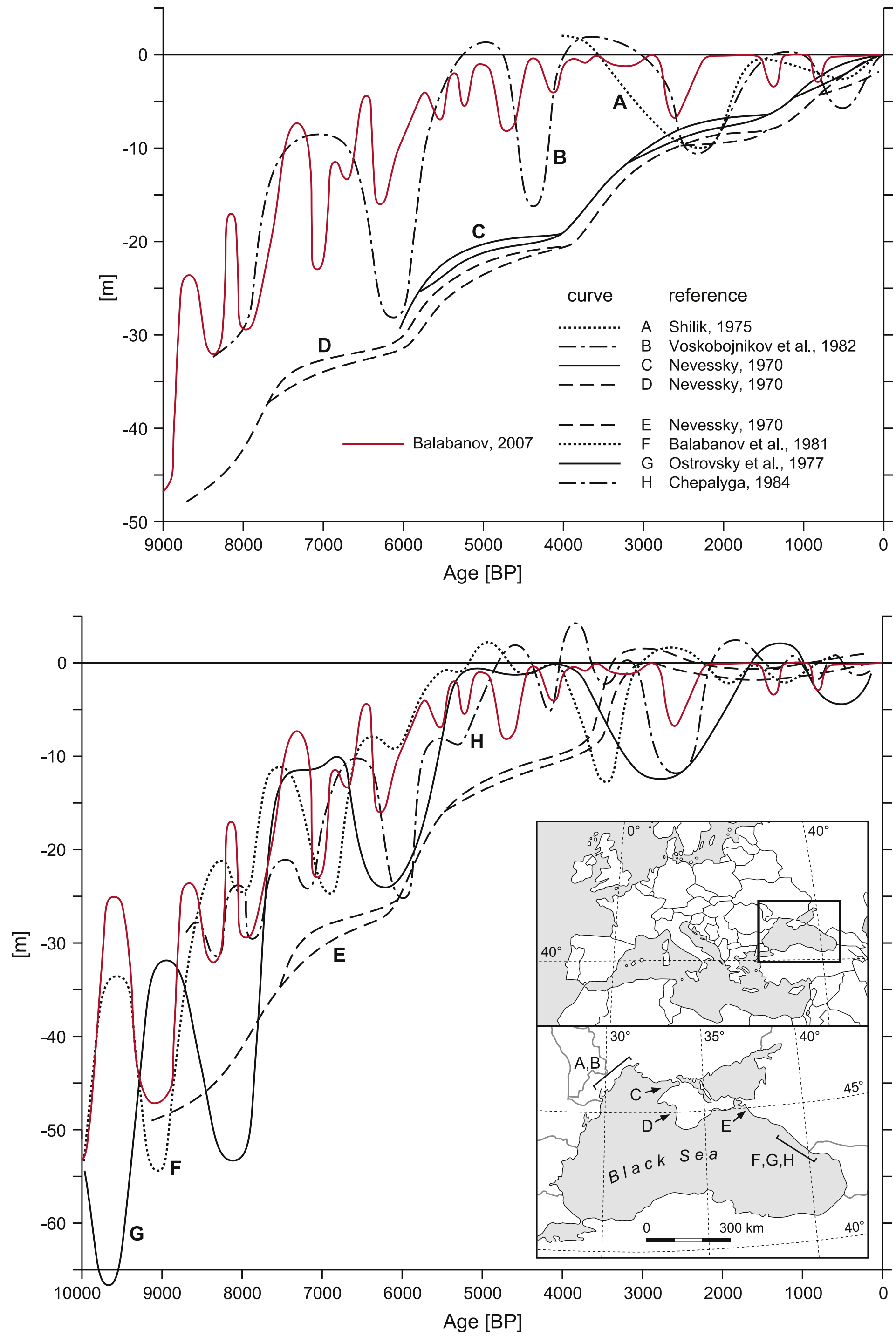


Fig. 6. Sea level curves for the Black Sea. Source: Pirazzoli (1991), Fig. 27, slightly modified.

2009) found neither major nor minor fluctuations in the Black Sea level evolution during the late Holocene.

4.2. The Black Sea – seen from a Mediterranean perspective

Traditional sea level curves from the Black Sea show numerous major and minor wiggles corresponding to regressive and transgressive phases within relatively short time periods. Section 3 outlined the Mediterranean perspective; the so-called type 2 of the Mediterranean curves is characterized by a more or less continuously rising sea level, even since the mid-Holocene. None of the Mediterranean curves shows (i) the large number and (ii) the extent of the wiggles of the Black Sea curves (cf. Figs. 3, 6 and 7), independent of the general nature of the used sea level indicators. This is in contrast to the fact that both seas have been connected at least since 7500 BP. This discrepancy obviously shows the demand for further research.

4.3. Discussion of relative sea level evolution

For the Black Sea, the traditional approach is linking sea-level changes to changes in the foraminiferal assemblages. Balabanov's

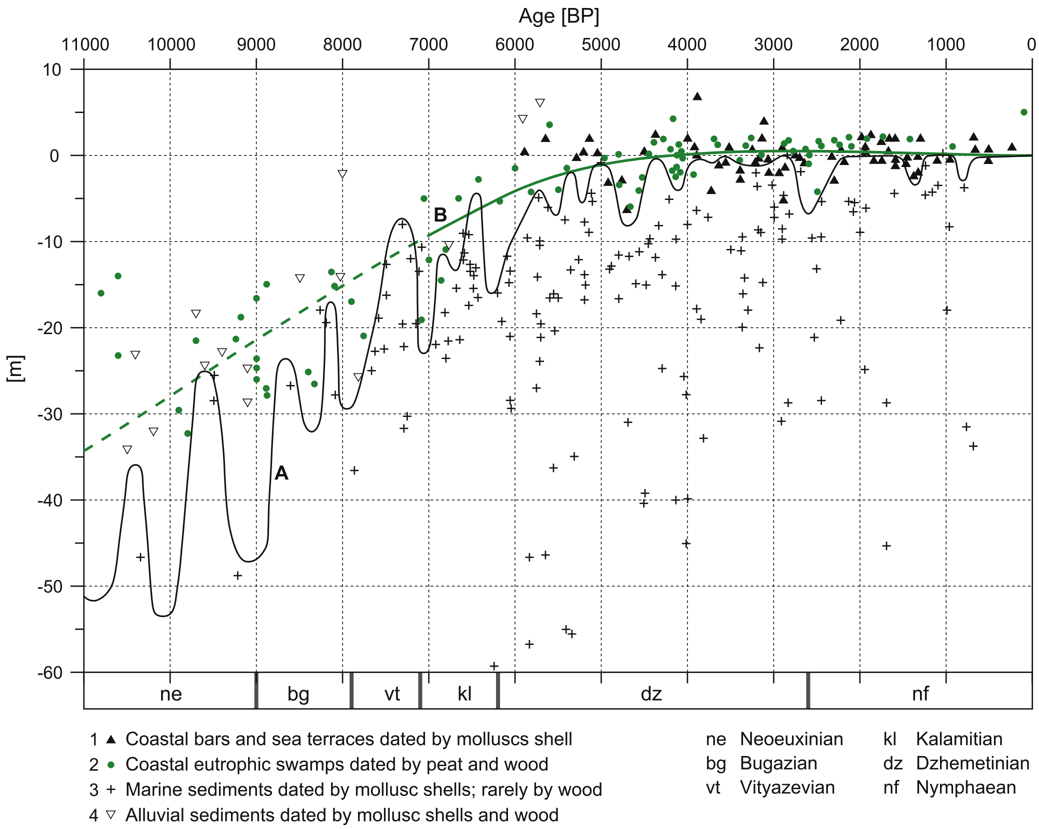


Fig. 7. Holocene sea level curve of the Black Sea according to Balabanov (2007). The curve is based on the interpretation of about 400 radiocarbon dates produced on mollusc shells, peat, and wood taken from various environmental settings. As for the trans- and regressive phases see Section 4.1. Line B shows the re-interpretation of the data set by the authors of this paper. Using exclusively paralic peat samples as the best sea level indicator shows that the sea level evolution of the Black Sea generally follows the trend of the type 2-curve of the Mediterranean (see Fig. 3 and Section 3.1). It has to be mentioned, however, that downward displacement due to compaction should be considered in all cases where the peat layer is thick or where it is underlain by compactible strata, such as clay and silt layers.

curve (2007) is also built upon a number of radiocarbon dated coastal peat units as well as on marine shells and wood fragments. It has to be taken into account that these indicators are of different quality regarding sea level reconstruction (Lambeck and Chappell, 2001; Milne et al., 2005). On the one hand, coastal swamp deposits may have been subjected to considerable sediment compaction and thus yield minimum lower values of a reconstructed sea level band (Long and Innes, 1993; Pirazzoli, 1996; Hanebuth et al., 2000; Behre, 2003). Shell and wood fragments retrieved from marine clastic sediments, on the other hand, may be much older than the time of sediment deposition due to reworking effects. In general, most reliable statements concerning relative sea level reconstructions are given by envelope curves showing a maximum and a minimum boundary for the palaeo-sea level evolution.

The database shows that obviously only parts of these ages are closely related to palaeo sea level stands. In addition, the presented curve (Fig. 7) lacks, however, any consideration of the differential tectonics. It has to be noted that many of the single points in the Balabanov (2007) curve are taken from the shores of the Caucasus Mountains. Due to the ongoing orogeny, this is, however, an uplift area where the littoral deposits have been displaced since the time of their deposition. The same holds true for former paralic peat bogs which may now be found above sea level but owe their origin to the coastal setting. The Crimea as well is in an uplift setting (Smolyaninova et al., 1996), but with another speed than the Caucasus Mountains. There are also dates from subsidence areas such as the Indolo-Kuban trough (see the tectonic pattern of the Black and Azov Seas in Fig. 1).

Decades ago, Serebrianny (1982) and other scholars had argued that, due to local tectonic movements, the synchronous shorelines in different Black Sea coastal regions vary considerably in elevation. This alone shows that it is impossible to produce *the* Holocene sea level curve for the entire Black Sea. In many areas, the local tectonic signal overrides the glacio-eustatic one – at least during the last 7500 years.

Moreover, the Balabanov curve does not offer a proper evaluation of the radiocarbon dates. Which ones are suitable sea level indicators? In Fig. 7, the author synthesizes ^{14}C dates produced on mollusc shells, wood and peat; the materials were taken from marine bars, spits and terraces as well as alluvial–lacustrine and lagoonal sediments. But only paralic peats are reliable sea level indicators, as concluded in Section 2.1.

The approach to find a single relative sea level curve for larger ocean basins has been pursued for several decades for different areas of the world. However, recent research has unequivocally proven that differences in local to regional tectonics make this goal unreachable (see the outcomes of IGCP Projects 61, 200, 367, 495). The Mediterranean example clearly shows that there are only locally valid relative sea level curves (cf. Section 3).

A possible solution is to take the Balabanov (2007) curve and filter out all data produced on coastal-lagoon peat, which is the best sea level indicator in a sedimentary context (cf. Section 2.1). Using only those ages, the wiggles are more or less neglectable and the general trend of the curve is comparable with the one known from the Mediterranean type 2-curve. This corrected curve, including its envelope (Fig. 7, curve B) is an average curve for the Black Sea. Local

Photo 1. Strong cliff erosion in the Gulf of Taman at Hermonassa (present Taman). Part of the ancient Greek settlement has already been destroyed. In the background, large landslides are slumping into the sea. The example shows the dramatic effect of local sea level rise, amplified in modern times. Photograph: H. Brückner 03/2006.

curves can only be developed if also sediment compaction and local tectonics are taken into account.

4.4. *Discussion of tectonic effects*

A strong indication that during antiquity sea level was lower than today is the fact that parts of the former harbour cities of Olbia, Pheodosia, Chersonessos, Phanagoria and others are nowadays submerged. It is known from Mediterranean examples (a) that during Roman times sea level was around 1–2 m lower than today due to the glacio-eustatic effect, and (b) that the influence of tectonics on the evolution of local sea level fluctuations is high (Section 3).

The Gulf of Taman belongs to a geological syncline with a strong subsidence tendency (Saintot and Angelier, 2000). The ancient settlement of Phanagoria was erected directly on its southern border with the effect that the lower city experienced subsidence while the position of the upper city is nearly stable. Subsidence was amplified by the post-Roman and especially the modern sea level rise which resulted in the drowning of the lower city and strong cliff retreat, eroding the upper city. The same is true for the ancient city of Hermonassa (Photo 1).

The map by Blagovolin and Pobedonostsev (1973) shows the crustal movements of the northern Black Sea region. Especially vulnerable are the tectonically fractured sedimentary coasts of Taman Peninsula and the estuaries in southern Ukraine. The Taman Peninsula shows areas with subsidence rates of 0.4–1.6 m/ka. Around the city of Phanagoria, 1–1.5 m for the last 2500 years was calculated (cf. Blagovolin and Pobedonostsev, 1973).

Recent studies by Fouache et al. (1998, 2000, 2004) demonstrate that, due to differential tectonics, different parts of the Taman Peninsula have experienced different local sea level histories (Fig. 8).

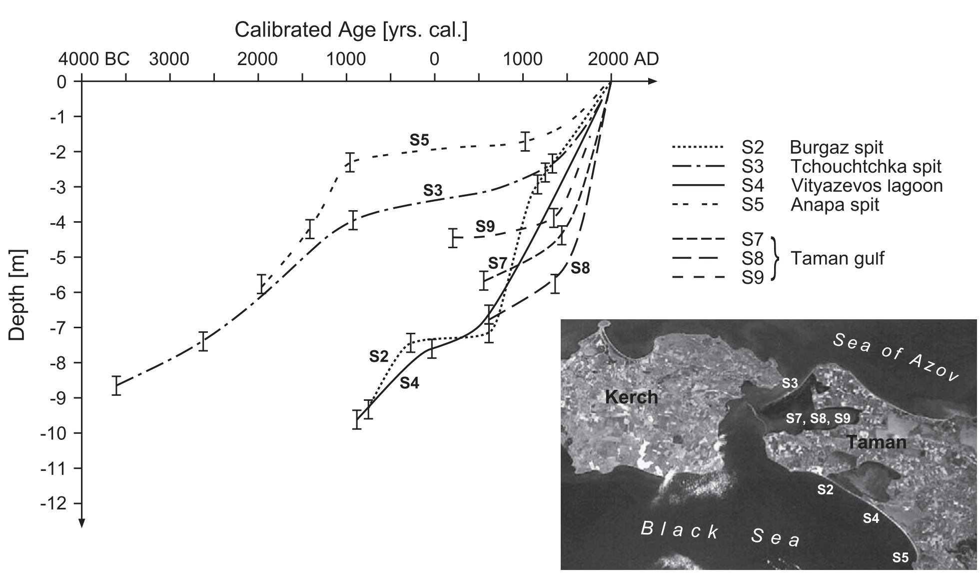


Fig. 8. Local sea level curves for Taman Peninsula (Russia). Source: Fouache et al. (2004); Fig. 4, slightly changed.

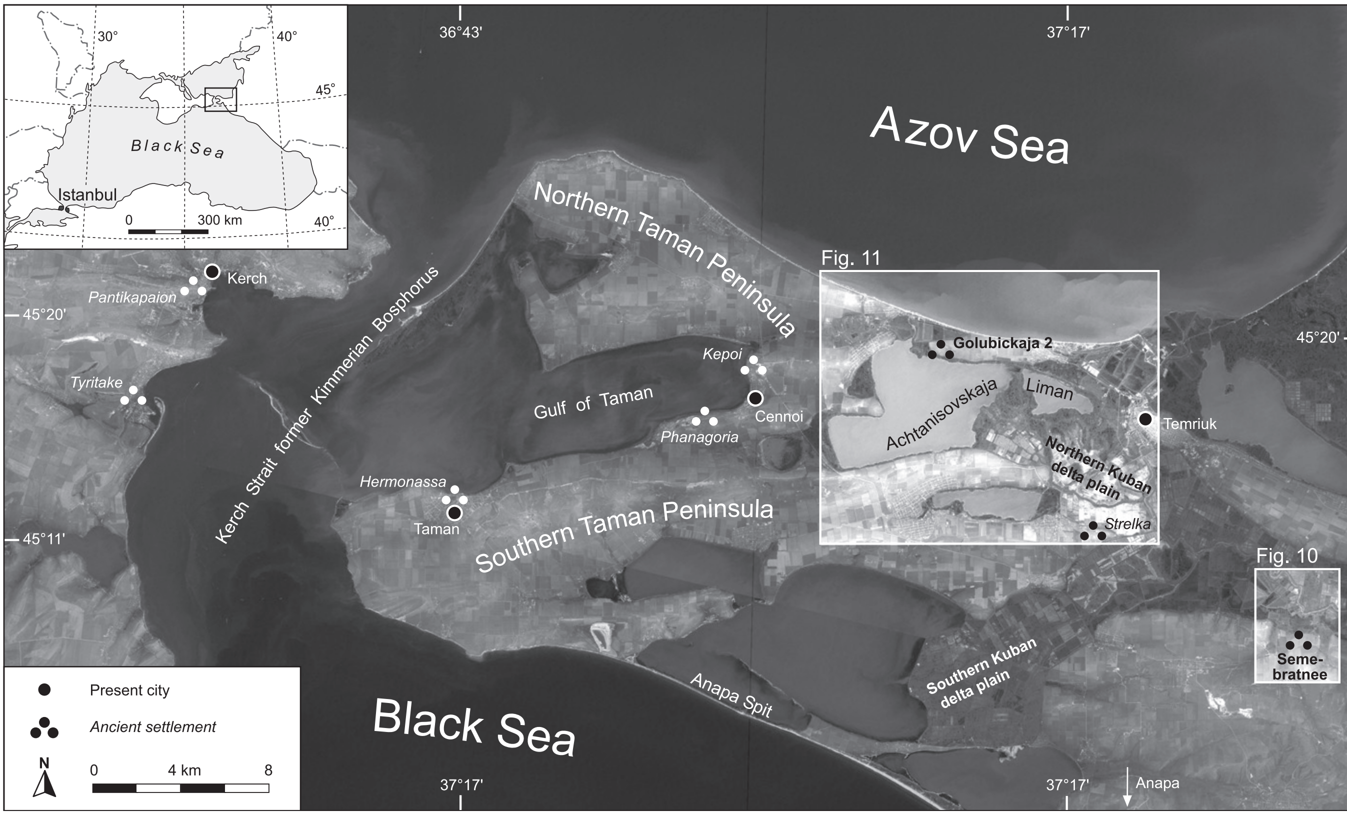


Fig. 9. Overview of Taman Peninsula with names and sites mentioned in the text. The background is a compilation of satellite images from Landsat Channel 2 (09/22/1999 and 05/09/2005) and SRTM.

Although sediment compaction and the suitability of the dated materials as sea level markers may be questioned, the published curves are similar to the Mediterranean ones, in that (i) they do not show major wiggles, and (ii) they vary from place to place. The synopsis of Fouache et al. (2004) presents three curves for the Gulf of Taman which have *grosso modo* similar shapes. They describe an accelerated sea level rise for the last 2000 years, most probably caused by increased subsidence of the Gulf of Taman (Fouache et al., 2004). The reason for the varying steepness may be due to differing rates of subsidence of this inlet-microplate. In other areas of the Taman Peninsula, the results of Fouache et al. (1998, 2000, 2004) from Anapa Spit can be confirmed by our observation. This is also the case for the adjacent Kerch Peninsula (Porotov, 2007).

4.5. Discussion of archaeological findings

Balabanov (2007) presents more than five major wiggles (Fig. 7). The terminology of the different high and lowstands follows name-giving sites. A very prominent regression is the so-called Phanagorian one when during 2700–2400 BP sea level fell from about 0 m to 7–8 m b.s.l. The following so-called Nymphaean Transgression caused a rapid rise which reached once more 0 m around 2200 BP.

This has to be discussed from an archaeological point of view. The Phanagorian Regression is very important since it covers the epoch during which the Greek colonisation of the northern Black Sea coast took place (Fornasier and Böttger, 2002) which led to the establishment of many harbour sites and trading posts all around the Crimea (Pantikapaion, Feodosia, Nymphaion, etc.), the Russian coasts of the Black and Azov Seas (Phanagoria, Gorgippia, Jeist, Taganrog, etc.), and in southern Ukraine (Olbia, Berezan, Tyras, etc.). The Kimmerian Bosphorus, presently the only connection between the two seas, was of special interest because it controlled the sea trade. During Archaic times, Miletus, the 'Ornament of Ionia' (Herodotus V, 28), founded more than 80 colonies in the area of the Black, the Azov and the Marmara Seas. We know from historic accounts that the Greeks established their coastal settlements near the waterline in strategic positions, like river mouths, coastal indentations, places suitable for fortification (e.g. Pantikapaion on Kerch Peninsula, Phanagoria on Taman Peninsula, Taganrog near the Don delta).

If a drop in sea level of c. 7 m had occurred during the time of the so-called Phanagorian Regression, all of these coastal settlements would have lost their harbours. The Greeks would have been forced to rebuild them in lower areas near the shoreline. The following Nymphaean transgression would then have drowned those installations in a short time and people would have had to re-settle on higher places. Even smaller drops in sea level are dramatic in areas with flat shelf profiles (see also the example of the Arabian Gulf, Teller et al., 2000). In the case of the Azov Sea, a vertical sea level drop of a few meters would have caused a horizontal shift in the shoreline of several kilometres since this marginal sea has a maximum depth of only 18 m according to bathymetric maps. There is neither any historical nor any archaeological evidence for such a scenario. Therefore, sea level curves that show wiggles of several meters during the Holocene have to be reconsidered under archaeological and historical aspects.

5. New data from Taman Peninsula

Based on vibracoring it was possible to get samples down to maximum depths of 15–20 m below surface. Therefore, the focus of this study is sea level fluctuations of the past seven millennia. The authors cannot (yet) contribute to the resolution of the Pitman and Ryan (1998) controversy.

5.1. Vibracore studies on Taman Peninsula

The research design follows the strategy published in Brückner (2003: Fig. 2). Since the low-lying geo-archives of the Taman Peninsula have a high groundwater table, field work had to focus on corings (with Cobra 248 vibracorer of Atlas Copco Co., 6 cm diameter). The stratigraphy was determined in the field, characteristic samples were taken for laboratory analyses, and peat layers sampled for radiocarbon dating. The important sites of Taman mentioned here are shown in Fig. 9.

Coring site SEM 4 is situated in the Kuban River plain, 15 km east of Temriuk. The site presently lies 20 km distant from the mouth of the Kuban River and 30 km distant from the Black Sea. At a distance of about 300 m to the south of SEM 4 is the Semebratnee (Seven Brothers) settlement which lies on the southern flank of the Kuban River delta plain. The results, including ^{14}C ages of dated peat layers, are summarized in Fig. 10. The peat layers are paralic ones indicated by the occurrence of the ostracod species *Cyprideis torosa*. However, a detailed study of the fauna is still pending. The collected data lead to the following interpretation.

The profile reaches a depth of 9 m below surface (b.s.), 6.50 m below sea level (b.s.l.), starting with a peat layer. The base of the peat dates to 5302–5056 cal BC, its top to 5207–4963 cal BC; thus representing about 150 years of peat growth. Then follow three strata of clayey silts with differing colours and contents of fossils and organic matter. The layer at 8.66–8.13 m b.s. is dark grey to grey and contains small fragments of mollusc shells (presumably *Cerastoderma glaucum*). It is covered by a thin layer (8.13–7.95 m b.s.), rich in organic matter including freshwater snails. Obviously, a former lagoonal environment had turned to freshwater conditions. According to radiocarbon dating, the freshwater swamp formed around 4462–4259 cal BC. It was fossilized by a layer of clayey silt, rich in fossils and plant remains (7.95–6.90 m b.s.), which was deposited in a lagoonal or shallow marine environment. At depths of 7.80–7.70 m b.s. and 7.10–7.09 m b.s., layers of shell debris occur. Then, the ecology turned more and more to semi-terrestrial conditions. The paralic peat at 6.90–6.39 m b.s. was dated to 3363–3106 cal BC. Peat growth ended abruptly when, once again, lagoonal sediments were deposited, including fragments of *Cerastoderma glaucum*.

At a depth of 5.81 m b.s., the sediment changes again to a generally coarser fraction, even with the occurrence of a few small pebbles. This layer is grey, rich in plant remains and mica; no macrofossils are visible. The coarsening of the average grain size and the pebbles indicates fluvial impact and estuarine deposition near the coring site.

This part of the profile ends with a 27 cm thick peat layer in a clayey matrix (4.18–3.91 m b.s.), radiocarbon dated to 2462–2162 cal BC. It thus seems that during about 1000 years roughly 2 m of sediment were deposited. This is the highest sedimentation rate documented in SEM 4, probably indicating fluvial impact into a lagoon or a semi-enclosed marine embayment. At 3.91–3.80 m b.s., a layer of clayey silt is sandwiched by two peat layers.

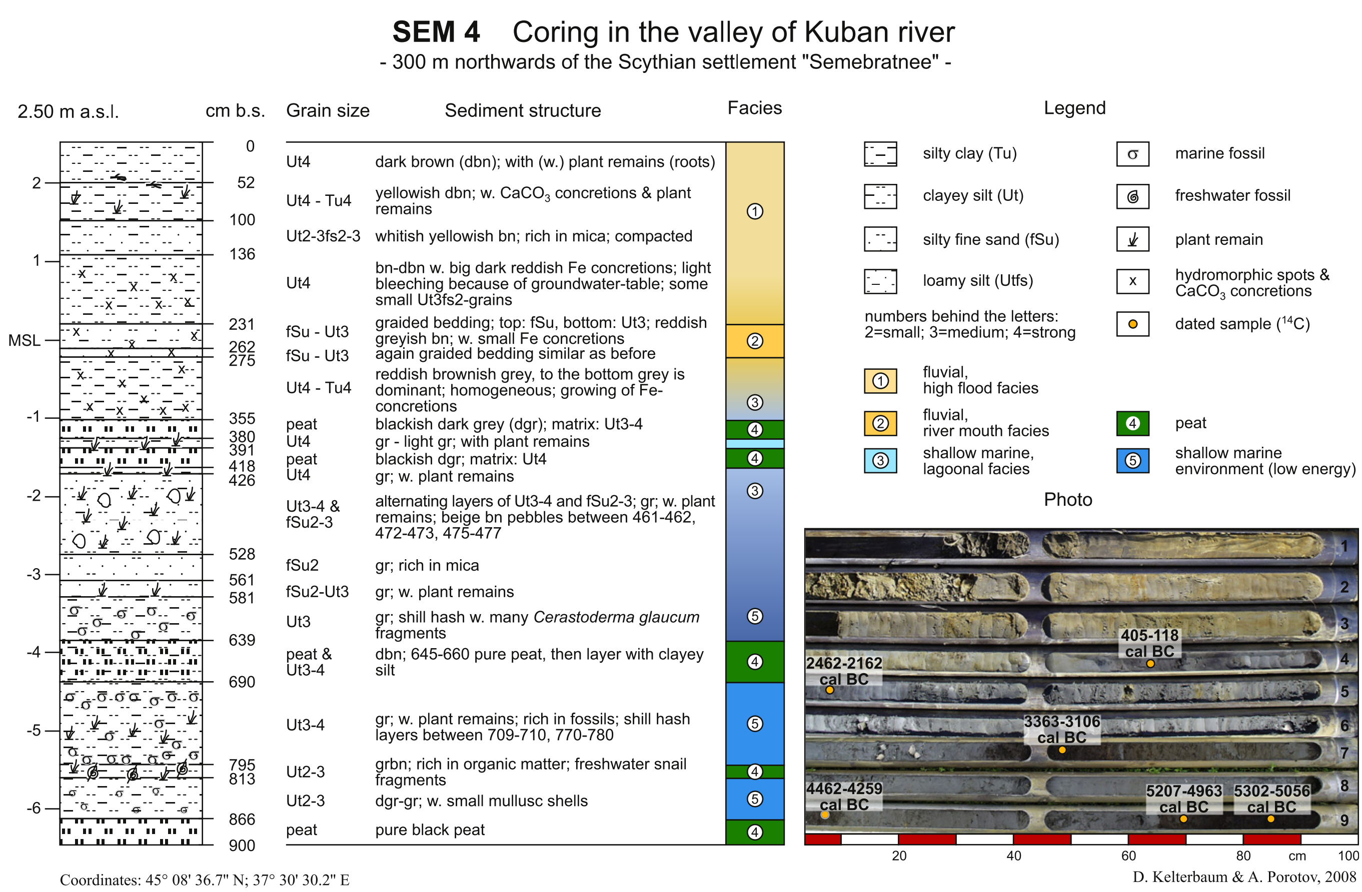


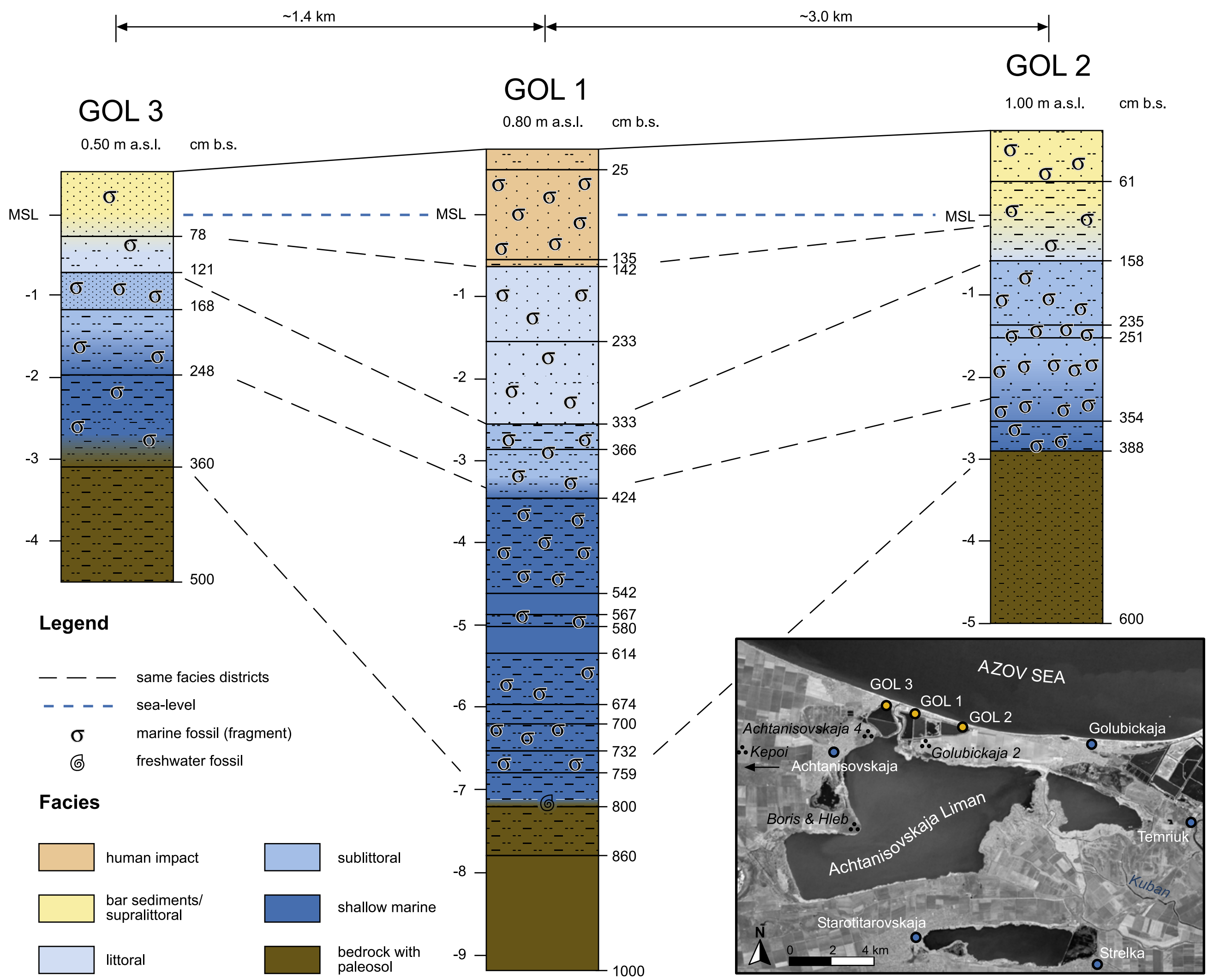
Fig. 10. Core SEM 4 in the valley of Kuban close to Semebratnee, a settlement founded by Scythians. Coring was carried out with vibracorer Cobra 248, diameter of augerheads: 6 and 5 cm. The strata show the general trend from marine via lagoonal to terrestrial/fluvial environments. Several interfingering peat layers were ^{14}C-dated and used as sea-level indicators in Fig. 12. Source: own research.

The subsequent layer at 3.80–3.55 m b.s. is rich in organic matter (mainly peat) and shows the last signal of the lagoonal system. The peat dates to 405–118 cal BC. The stratum at 3.55–2.75 m b.s. consists once again of clayey silts. The reddish to brownish grey colour indicates fluvial sedimentation leading to the siltation of the paralic swamp. From 2.75–1.00 m b.s., grain size coarsens upwards. This can be interpreted as a higher energy level during times of fluvial accumulation. The yellowish dark brown clayey silt encountered between 1.00 m b.s. and the present surface is typical of flood deposits of the Kuban River, accumulated during phases of high discharge in spring during times of snow melting in the Caucasus Mountains. It is important to note that the sediment is rich in mica, a typical mineralogical component of the Caucasus (Görür, 1988). This stratum is also rich in organic matter and carbonate concretions.

At Semebratnee, during the time of the Greek colonisation in the 7th-6th centuries BC, the area west of the Semebratnee settlement in the present Kuban River valley was a marine embayment. The sedimentary and chronostratigraphic records show that many environmental changes have occurred in the Kuban valley due to fluvial and coastal dynamics over the past seven millennia. The five peat layers encountered at SEM 4 do not indicate a regression in sea level as they are neither eroded nor weathered under subaerial conditions. In contrast, they were all, except for the uppermost, fossilized by shallow marine strata. Given the fact that since 3000 BP the connection to the Azov Sea was nearly closed by the evolving sand barrier system west- and eastwards of Golubickaja (Izmailov, 2007), shallow marine sedimentation in the semi-enclosed basin decreased between 2300 and 300 BC.

In the evolution of marine bar deposits, sea level fluctuations are one factor. Other, sometimes even overruling, factors may be sediment supply and coastal dynamics (e.g. intensity of the long-shore current).

There are several fortified ancient settlements at Achtanisovskaja Liman. Two of them are situated on opposite shores at the smallest part of the liman, between the mainland of the Taman



D. Kelterbaum, 2008

Fig. 11. Synopsis of corings on the sand barrier connecting Golubickaja and Peresip. It shows a marine transgression–regression cycle developed in a former loess gully. We interpret the gully as having formed during the late Pleistocene/early Holocene lowstand of the Sea of Azov, but ^{14}C datings are needed for a further interpretation and chronostratigraphic correlation. The cross-section helps to reconstruct the palaeogeographical setting with a former marine connection between the Sea of Azov and the Achtanisovskaja Liman. The satellite image shows the recent progradation of the Kuban River delta into the Achtanisovskaja Liman (see also Fig. 9). Source: own research. Note: After the completion of the manuscript, two more ^{14}C ages were processed: An *in situ* bivalve (*Cerastoderma glaucum*) which documents the first marine sedimentation in GOL 1 at a depth of 7.80 m b.s. dates from 5361–5219 cal BC. Sublittoral sedimentation ended in GOL 3 at a depth of 2.10 m b.s. around 895–795 cal BC. These results support our statement of a constant rise in sea level.

Peninsula to the west and the Golubickaja Peninsula to the east (Fig. 11). Their ancient names are not bequeathed; Abramov and Paromov (1993) referred to them as Achtanisovskaja 4 and Golubitskaja 2. Today the liman is separated from the open sea by the sand barrier of Peresip-Golubickaja. It was the aim of this research to clarify the palaeogeographical situation in Hellenic times and learn more about the evolution of sea level.

Three cores are presented in a synopsis (Fig. 11). Each one reached the pre-Holocene base: a colluvial sediment of reworked loess with a palaeosol (Taman Peninsula is covered by loessic sediments with a thickness of more than 20 m). During the transgression of the sea, clayey silts to silty clays with many mollusc shells were deposited.

In the middle of the sand barrier (core GOL 1), the boundary between weathered bedrock (palaeosol on loess) and the marine transgression is at 7.20 m b.s.l., in the adjacent cores GOL 2 and 3, at 2.88 and 3.10 m b.s.l., respectively. The palaeotopography may be interpreted as a loess gully, evolved during a lower seastand and flooded during the early mid-Holocene sea level rise. Freshwater fossils in a small band at the bottom of the incision feature reflect the last phase of the terrestrial environment. With the ongoing transgression, marine conditions were established. There is, however, not yet an age estimate for the timing of this incision.

At GOL 1, the marine sediments, 3.75 m thick and rich in macrofossils, show that open marine conditions prevailed for a long time. The environment changed to a sublittoral one, also reflected in GOL 2 and 3, when a sand barrier evolved due to the westbound longshore drift. The high cliffs of the Golubickaja coastal area were the source of these sediments. In core GOL 1, the formation of the sand barrier can be detected at 2.5 m b.s.l. Towards the top, fossils are rare and only in their juvenile stage due to increasing suspension as well as saline and thermal stress. The supralittoral facies starts at 0.80 m b.s.l. It has a coarser sediment structure and high contents of broken mollusc shells possibly deposited by high energy events.

The rise in sea level placed the Azov Sea directly at the foot of ancient Golubickaja 2. The still visible dead cliffs at this settlement site date from the time of the maximum transgression. Once the sand barrier had evolved, marine cliff erosion stopped.

The easily erodable material of the headlands of Taman Peninsula was relocated by longshore currents, thus creating sand spits and beach barriers. This was also the case at the sand barrier in front of Golubickaja 2, which is documented in the cores by the coarsening upward sequence and the lack of *in situ* macrofossils. Again, these cores do not show intercalated palaeosols nor any erosional unconformities. This is a strong argument for a permanent rise in sea level.

5.2. Towards a new relative sea level curve for the eastern Taman Peninsula

The relative sea level (RSL) curve based on the ^{14}C-dated peat layers of vibracore SEM 4 is shown in Fig. 12. Peat from paralic swamps is a very good sea level indicator (Section 2.1; see also Allen, 1990; Pirazzoli, 1991, 1996) and gives reliable ^{14}C ages. Coastal peat is formed in lagoonal or swampy areas disconnected from the open sea by beach ridges or river branches. Peat can grow up with a slowly rising sea level. If sea level falls, erosion or weathering processes will start. Peat growth can stop abruptly by a marine ingression or by the rapid input of alluvial deposits. In none of our corings was there any sign of peat erosion or weathering which should be the case if major regression phases had occurred after the peat formation.

In cases of peat samples from coastal swamps, palaeo-sea level is assumed to be within a band of 20–50 cm below sampling depth (Pirazzoli, 1996; Behre, 2003). For Fig. 12, we preferred the 50 cm upper limit. If the peat sample was taken from the upper part of a peat layer below thick strata of overlying sediments, compaction was estimated as being 25 cm at a maximum. In cases of a very thin peat layer, compaction was considered negligible.

The results of the data are given in Table 1. They are the base for the relative sea level curve for the area around Semebratnee. This curve does not show any sign of major or minor wiggles, but a strong sea level rise between 5200 and 2500 BC. Thereafter, the velocity of sea level rise decelerates. It has to be considered that the spacing of the ^{14}C dates – especially when using the 2-sigma-range – is so wide that only significant changes of sea level can be recognized. However, the general sea level trend shown in the curve of Fig. 12 corresponds well to that of the Mediterranean curves. As it stands, it is not yet sufficient evidence to reject the overall sea level rise in Balabanov's curve from ∼5500 to 2500 BP (disregarding the wiggles). Ongoing research will improve the suggested curve and establish its final shape.

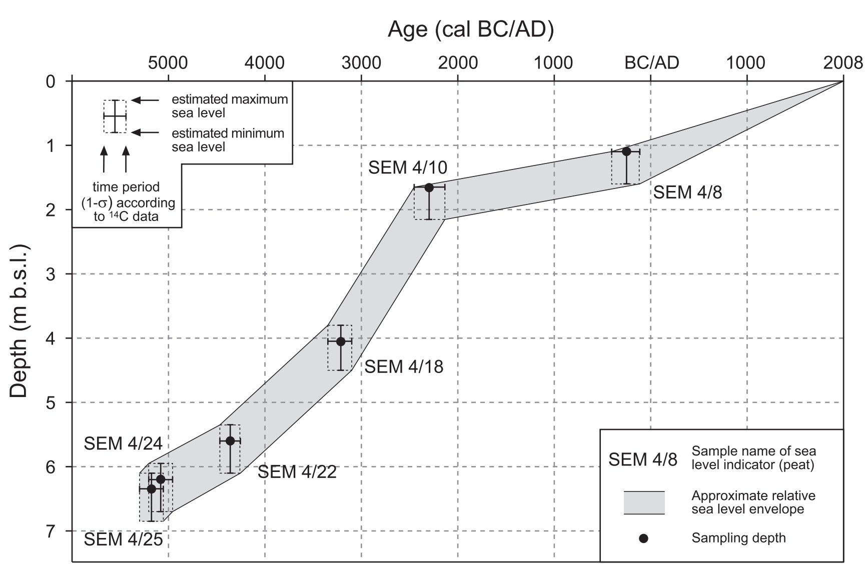


Fig. 12. Relative sea level curve of the Kuban River plain around the ancient settlement of Semebratnee, Taman Peninsula (SW Russia) since the mid-Holocene. Source: own research.

Table 1
Radiocarbon dated peat samples from vibracore SEM 4. Coordinates of coring site SEM 04: 45°08′36.7″N, 37°30′30.2″E; b.s. = below surface; a.s.l. = above mean sea level; 1-sigma max; min (cal BC/BP) = calibrated ages, 1-sigma-range; " ; " = there are several possible age intervals because of multiple intersections with the calibration curve; Lab. no. = laboratory number, Laboratory of Geochronology of St. Petersburg State University (LU). Calibrated ages according to the radiocarbon calibration program Calib5.0.2 (see Reimer et al., 2004).

Samples				Reconstruction of palaeo-sea level band		
Sample name	Sample description	Lab. No (LU).	Depth (m b.s.l.)	Upper limit (cm)	Lower limit (cm)	Palaeo mean sea level (m b.s.l.)
SEM 4/8	Peat	5847	1.10	±0	−50	1.35
SEM 4/10	Peat	5846	1.65	±0	−50	1.90
SEM 4/18	Peat	5831	4.05	±25	−50	4.18
SEM 4/22	Peat	5848	5.60	±25	−50	5.73
SEM 4/24	Peat	5845	6.20	±25	−50	6.33
SEM 4/25	Peat	5849	6.35	±25	−50	6.48

	Calibrated ages				
	Delta 13C (ppm)	14C Age (BP)	1-sigma max; min (cal BP)	1-sigma max; min (cal BC)	2-sigma max; min (cal BC/AD)
SEM 4/8	−27.0	2240 ± 110	2354; 2067	405; 118	743 BC; AD 3
SEM 4/10	−27.4	3830 ± 110	4411; 4091	2462; 2142	2573; 1965
SEM 4/18	−27.0	4540 ± 60	5312; 5055	3363; 3106	3496; 3026
SEM 4/22	−28.5	5520 ± 100	6411; 6208	4462; 4259	4582; 4055
SEM 4/24	−25.8	6120 ± 70	7156; 6912	5207; 4963	5281; 4845
SEM 4/25	−27.1	6220 ± 100	7251; 7005	5302; 5056	5464; 4859

It is interesting to note that a smooth sea level rise for the Holocene has long been inferred for the mid-Atlantic coast of the United States; this is a "best-fit" curve through ^{14}C dates which exhibit considerable scatter. Other workers using foraminiferal and pollen data have inferred smaller-scale climatic oscillations for this region (e.g., Fletcher et al., 1993; Leorri et al., 2006). The same is true for the postglacial sea level curve of the North Sea (see Behre, 2003). However, in both cases the wiggles are only of minor size; they do not show regressions of 7 m as in the case of the Phanagorian regression.

The main conclusions for the eastern Taman Peninsula are as follows.

(i) The relative sea level during the Holocene has never been higher than today (see Fig. 12); the Holocene trend is similar to the type 2-curves in the Mediterranean (Section 3.2. Fig. 3).
(ii) The dated peat layers in core SEM 4 (Section 5.1.) cannot be interpreted as indicators for sea level falls of the Black and Azov Seas.
(iii) The fact that the profile SEM 4 shows neither palaeosols nor a weathering of the peat layers indicates that the strata were never subdued to longer phases of subaerial conditions which would have occurred during major drops in sea level.
(iv) The established curve *grosso modo* supports the one of Fouache et al. (2004), without any signs of major or minor wiggles; there is no indication of relative sea level falls of several meters.
(v) The Semebratnee core (Section 5.1.) reflects a delta progradation by the Kuban River of more than 20 km during the last three millennia.
(vi) The Semebratnee core shows that until 300/200 BC a connection between the Azov and Black Seas existed via an eastern Bosphorus, thus creating Golubickaja island.

6. Discussion and conclusion

The debate on the sea level fluctuations of the Black Sea – stirred up by the Pitman and Ryan (1998) Genesis Flood hypothesis – led to a closer look at the so far published sea level curves for the Black Sea. This paper examined methods of reconstructing sea level curves and evaluated both sea level indicators and the application of the radiocarbon dating method. It is obvious that part of the ongoing controversy is based on poor sea level indicators and the questionable use of ^{14}C ages (Sections 2.1. and 2.3.). The tectonic setting of the Black and Azov Seas shows that the tectonic signal often overrides the eustatic one. This is the reason why only local sea level curves can be established. A single curve, covering all the coasts of the area under consideration, does not exist.

Since the connection of the Black Sea with the Mediterranean, i.e. at least since 7500 BP, both water bodies must have reacted in the same manner on climatic changes. None of the Mediterranean sea level curves shows several major wiggles reflecting trans- and regression cycles which are postulated for the Black Sea (Sections 3., 4.1. and 4.2.).

One may argue that the Black Sea is a virtually enclosed basin and may act independently of the Mediterranean. Martin et al. (2007) suggested that a number of fluctuations in the Balabanov curve correspond to well-documented ocean–atmosphere reorganizations that would have shifted evaporation–precipitation patterns over the region and influence runoff (cf. Konikov, 2007). However, the water exchange between the two water bodies via the Bosphorus and the Dardanelles is very strong (which was already well known by the sailors in ancient Greek times) and there is so far no argument, for instance from gauges or satellite geodesy measurements, supporting the independent water body hypothesis.

Another strong argument against mid- and late-Holocene regressions of several meters comes from the archaeological and historical sciences. Considering the shallow shelves of the Azov Sea and of major areas of the northern Black Sea coast, a vertical drop in sea level of a few meters would have caused a horizontal shift in the shoreline of several kilometres (!) in some areas (Section 4.3.). There is neither an archaeological evidence nor a historic account for such a scenario although there are many ancient settlements along the shores of the Asov and Black Seas.

In order to establish a more realistic, locally valid Holocene sea level curve we carried out several corings on Taman Peninsula. As for sea level indicators and material suitable for radiocarbon dating, layers of paralic peat were used. In none of the corings does the peat show signs of erosion or weathering which would be indicative of subaerial exposure due to a major regression. Instead, all peat layers, except for the uppermost, were fossilized by shallow marine strata. This resulted in the sea level curve shown in Fig. 12 which fits to the results of Fouache et al. (2004) for the Taman area of the Black Sea coast and that of Goisan et al. (2006, 2009) for the Danube delta, as well as the type 2-curve found for the Mediterranean. We concede that this curve definitely needs to be improved with more data.

The research on both sides of Golubickaja clearly shows that this area was once an island. Obviously, the mid-Holocene sea level rise created an archipelago. It was later turned into Taman Peninsula by (a) the evolution of secondary coasts due to longshore drift (beach barriers), (b) the progradation of the Kuban River delta, and (c) the sediment contribution of mud volcanoes. For the beach barrier system connecting Golubickaja and Temriuk, the evolution of which started around 3000 BP (Izmailov, 2007), the transition from archipelago to peninsula occurred soon after that date.

Today, coastal erosion with rapid cliff retreat effects many shores of the Azov and the northeastern Black Seas. Former coastal settlements, such as Kepoi, Hermonassa and Phanagoria, are being destroyed by marine abrasion. The urgent need for research in archaeology, palaeogeography and geotectonic evolution is apparent.

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Commentary

This paper has been reviewed by 5 reviewers, 3 Guest Editors, and by the Editor-in-Chief. The diversity of opinion expressed was substantial among reviewers. After consultation, I have decided as Editor-in-Chief to publish this work, with the inclusion of selected comments from reviewers and responses from the authors. The intent was to stimulate discussion of the sea-level history of the Black Sea, in the spirit of the deliberations held at Gelendzhik under the auspices of IGCP-521. As some reviewers requested anonymity, and some issues were raised by more than one reviewer, the summarized concerns are presented in an unattributed format.

1. Peats are not necessarily accurate indicators of the rates and magnitudes of sea-level change. This is especially true of non-basal peats but also of basal peats. At least some of the peats are non-basal and subject to stratigraphic displacement.

Response: Numerous researchers have used basal peats as sea-level indicators and found them most reliable among sedimentological indicators. We agree that non-basal peat layers are problematic due to the unknown effect of compaction; however, this is still the best we have and our sea-level reconstruction was corrected by estimated compaction. In our curve, this problem is buffered by an error bar for each sea-level indicator and enveloping curves. We estimated sediment compaction for non-basal peats used as sea-level indicators.

2. The accuracy of foraminifera and peats for sea-level determinations to ± 10 cm must be viewed skeptically. Marsh forams can live infaunally down to 0.5 m or so, including microtidal regimes like those of the Black Sea. The forams do not only live at the surface in all cases, and so are not necessarily accurate indicators of past sea levels. This may be especially true of microtidal regimes.

Response: The passage referred to was quoted from Gehrels (2005) and Scott and Medioli (2005). This is a powerful tool for sea-level reconstruction. In this study, we only used peat layers as sea-level indicators.

3. Peats would not necessarily be weathered during a regression if the peats have already been buried and have remained buried. Erosion does not occur everywhere during sea-level fall, e.g., in incised valleys.

In reconstructing the sea levels the writers suggest that peat layers indicated regressive positions. However, peat bogs should exceed sea level by 1.2–1.5 m. In this case the regressive sea level should be 1.2–1.5 m higher than that postulated by the writers. Only under these conditions could the relative altitude of waterlogged plain and the sea level have created the hydraulic gradient sufficient for both surface and underground runoff.

Response: In a normal case, coastal peat weathers when sea level is falling. Where coastal peat is buried, the age of the uppermost peat horizon represents sea level at the time of burial.

We quoted evidence from microfossil research by Dave Scott and Ronald Gehrels who both agree that coastal peats represent sea level with an accuracy of a few decimetres. If a peat grows 1.2–1.5 m above *groundwater table (which is close to sea level in a nearshore position) it changes its composition and turns from a coastal peat to a raised bog which has a totally different floral and faunal composition. We used coastal peats and not raised bogs for our reconstructions.*

4. While the Black Sea is connected to the Mediterranean, it is also subject to major runoff inputs that could easily and rapidly affect sea level within the Black Sea, given just the modern runoff rate and the volume of the surficial Black Sea down to sill depth. Silled basins, including those in the deep sea (e.g., Cariaco Basin of the Caribbean, Santa Barbara basin off California), behave differently from the ocean above.

Response: We are of the opinion that, during periods of high runoff, river water inflow into the Black Sea basin by large rivers such as Don, Dniestr, Donau, Dnepr, and Kuban Rivers, only results in short-term sea-level rise which does not leave any footprints in the sedimentological record. As the Black Sea system is an open one connected to the Mediterranean via the Bosphorus, the Marmara Sea (also a buffering system), and the Dardanelles, these short-term highstands will be equalized within a short time. There is no evidence of short-term water fluctuations at the Black Sea coast of Istanbul although this is the bottleneck of the system.

5. While the Black Sea may well reflect the behavior of the Mediterranean following reconnection, the Black Sea is a virtually enclosed basin and could therefore act virtually independently of the Mediterranean. These ocean–atmosphere reorganizations appear to correspond to the sea-level fluctuations inferred for Delaware (Leorri et al., 2006). Martin et al. (2007) further suggested that a number of fluctuations in the Balabanov curve correspond to well-documented ocean–atmosphere reorganizations that would have shifted evaporation–precipitation patterns over the region and influence runoff (see, e.g., Konikov's papers). Although at first glance, it would appear that Balabanov fitted sea-level regressions to the foraminiferal zone boundaries of Yanko-Hombach, a number of the inferred regressions correspond to a downward shift (in m bsl) of swamp peats, as would be expected. The fully marine sediments (crosses) of Balabanov's curve seem to provide a "lower bound" to the sea-level regressions.

Response: Since there is strong sedimentological and geochronological evidence of a real connection between the Black Sea and the Mediterranean since approximately 7500 BP, it is problematic to believe in a virtually enclosed basin hypothesis for the Black Sea. We agree that the deeper parts of the Black Sea basin sedimentologically and geochemically do behave quasi-independently from the Mediterranean. This issue, however, is not decisive for the question of sea-level fluctuations. The coupling between ocean and atmosphere at a given site may only cause sea-level fluctuations of less than 1 m. It is known from measurements at Marseille that the difference between highest and lowest air pressures results in an altitudinal change of sea level of maximum 70 cm (see Morhange et al.).

6. A problem is the writers' insistence in ascribing the low hypsometrical position of archaeological sites of Classical era (including Phanagorea) to recent tectonic submergence. This conclusion is in agreement with the general concepts which postulate that only local curves of sea-level changes could be constructed. This position in Russia had been held by L.S. Serebryanny. Yet this concept if not substantiated by evidence remains a pure abstraction. Balabanov and Izmailov (1988), based on numerous data related to the Pleistocene–Holocene deformations in the Black Sea – Eastern Azov Sea area, stated that 'the amplitude of possible Pleistocene–Holocene deformations in that area usually lay within the estimation accuracy of shore-line altitudes with the use of the totality of the litho-facies and geomorphic attributes'.

Response: Numerous sea-level studies from the Mediterranean unequivocally show that it is not possible to reconstruct a single curve for the whole basin; local and regional differences in the tectonic pattern result in considerable differences of the local and regional sea-level evolution (Vött, 2007; Marriner, 2007; Pirazzoli, 1991).

We agree that our coring data are not yet dense enough and that a series of cores would be better. However, this coring was a showcase to demonstrate our approach how to construct a sea-level curve. A similar approach was used by Fouache et al. (2003). Subsequently, we have obtained several cores from the Taman Peninsula which support our point of view.

7. The writers do not consider the evidence related to the elevated sea-level positions (close to the present-day one) in the time-span of 3–6 ka, particularly those based on the radiocarbon dates of mollusc shells from fossil sand barriers in the Taman Peninsula and eastern Azov Sea area (see Izmailov et al. (1989), Izmailov (2005)). If one takes into consideration that the present-day sand barrier in the Kuban Delta lies at the altitude of 1.5–2 m, the sea level at which the marine deposits between the peat layers were formed should have been by 3–4 m higher than that postulated by the writers.

Additionally, using several samples from different stratigraphical positions to produce one single radiocarbon age of a mixed carbonate powder does not correspond to the modern scientific standard. These ages have to be rejected as database for sea-level reconstruction. Re-interpretation of the radiocarbon database of Balabanov, considering only peat samples as the basis for a revised Black Sea curve indicates close similarities between the sea-level histories of the Black and the Mediterranean Seas after 7.5 ka BP.

Response: Taking into account the sampling strategy of Izmailov et al. (1989) and Izmailov (2005) for radiocarbon dating – bulk samples, produced by sieving out all marine shells from a whole meter of a given drill column, including (reworked?) single valves for dating, not regarding the palaeo-reservoir effect for marine carbonates – we are convinced (a) that the majority of these ^{14}C ages represent maximum ages only, and (b) that they cannot be used as sea-level indicators (a floating single valve of a shell in a given sedimentary column does not represent sea level).

We fully respect the scientific work of the reviewer and his colleagues and do not intend to discredit it. However, research in adjacent areas and progress in geo-scientific methods require a re-interpretation approach of existing data and new field studies for a better understanding of the complex Black Sea-level history.

It is not possible to use the present day sand barrier as a sea-level indicator. Concerning the northern Kuban deltaplain, the evolution of a sand barrier need not necessarily reflect sea-level fluctuations but rather can be an expression of changes in coastal dynamics and/or sediment supply.

8. The interpretation of SEM 4 core as a succession of transgressive–regressive stages does not contradict the general Black Sea curve (Balabanov, 2007), both in its main transgressive–regressive events and their subdivision. It possible to identify there seven of eight transgressive–regressive events (sea-level oscillations) which lay within the general Black Sea curve. The main controversy resides in the interpretation of this sequence.

Both SEM 4 and GOL 1 cores exposed a transgressive–regressive type of sequence, which the writers interpret only as a transgressive one, resulting from a slow, but, importantly, unidirectional rise of the sea level. The absence of traces of desiccation in the peat is seen as a lack of evidence of regressive sea-level falls. Hence the writers suggest that the sea-level drop should have followed peat formation. We consider this as the first error in the interpretation of the sequence. Peat is overlain by transgressive marine sediments. What kind of evidence of desiccation could be found?

Response: Had there been the sea-level drops of several metres as stated in the Balabanov curve, coastal peat would definitely have *desiccated, decayed and/or altered. There is no such sign in the peat layers unearthed by our coring. Had there been the postulated major sea-level drops there should be evidence by the formation of palaeosoils. None were found, either in our cores or in those by Eric Fouache et al. 2003. We agree that our coring data are not yet dense enough to exclude local sea-level fluctuations of a few decimetres (up to a meter or so). But we do not accept the fluctuations of several metres.*

The writers' conclusions remain based on extremely limited evidence: a few vibracores in the Kuban River Plain and the radiocarbon dates obtained for peat samples from these cores. This constitutes an obvious contrast with the methodology used by Russian and Soviet scholars, who base their conclusions on the complex studies of multiple in- and off-shore transects which include deep coring and sampling for all kind of mineralogical, grain-size, foraminiferal, pollen and diatom analyses supplemented by radiocarbon dating.

Response: We specifically address the problem of interpreting all of these data with respect to sea level. How does a deep core help for the reconstruction of the former sea level if it does not contain any specific sea-level indicators? A foram assemblage indicating a shallow marine environment does not indicate the definite position of sea level at the given time.

These data are usually correlated with the geomorphic analysis of coastal landforms, being part of high-resolution geological mapping of the coastal area. The use of limited source of evidence adopted by the writers results in obtaining a much simplified and smoothed curve of Black Sea level, which ignores numerous variations which became apparent only when an extended database is available. The difference in the database and the methodology of studies makes the writers' curve practically incomparable with those suggested by Russian and Ukrainian scholars.

Response: There is a conflict between the Russian and Ukrainian colleagues who produced sea-level curves for the Black Sea, and others working on the Mediterranean Sea-level fluctuations. Our argument is that the basic difference is not due to different databases but to different approaches in interpretation and evaluation of the quality of data. In principle, this focuses on the problem as to what can be used as a sea-level indicator and to what extent are the results reliable. Our manuscript offers a view on the history of the fluctuations of the Black Sea seen with Mediterranean eyes.