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Corresponding Author: Dipl.-Geogr. Daniel Kelterbaum,

Corresponding Author's Institution: University of Marburg

First Author: Daniel Kelterbaum

Order of Authors: Daniel Kelterbaum; Helmut Brückner, Prof. Dr.; Olha Marunchak; Alexey Porotov; Andreas Vött, Prof. Dr.

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 and 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 14C 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.

Cover Letter

Philipps Universität Marburg

Philipps-Universität - FB Geographie - 35032 Marburg

Fachbereich Geographie
Prof. Dr. Helmut Brückner
Tel.: 06421 28-24262
Fax: 06421 28-28950
E-Mail: h.brueckner@staff.uni-marburg.de
Sek.: Margot Rößler
Tel.: 06421 28-24259
E-Mail: roesslem@staff.uni-marburg.de
Deutschhausstraße 10
D-35032 Marburg
Web: www.uni-marburg.de/fb19
Az.: br/rö

Marburg, 15 February 2008

To
Prof. Dr. Valentina Yanko-Hombach
Guest Editor of Special Issue
Quaternary International

Submission of Paper for the Special Issue of Quaternary International

Dear Valentina,

hereby we want to submit our contribution to the above mentioned special issue. It is entitled:

The Holocene sea level story since 7500 BP – lessons from the Mediterranean,
the Black and the Azov Seas
(Brückner, H., Kelterbaum, D., Marunchak, O., Porotov, A. & A. Vött).

Any questions should be addressed to the corresponding authors:
daniel.kelterbaum@staff.uni-marburg.de and h.brueckner@staff.uni-marburg.de

We would be pleased if our paper was accepted for publication.

Best wishes,

Helmut Brückner

Contribution to the Special Issue of Quaternary International –
Guest Editor: Prof. Dr. Valentina Yanko-Hombach

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

Brückner, H.*, Kelterbaum, D.*, Marunchak, O.*, Porotov, A.# & A. Vött+

*Faculty of Geography, Philipps-Universität Marburg, Deutschhausstr. 10, D-35032 Marburg, Germany
#Faculty of Geography, Lomonosov Moscow State University, Moscow, Russia
+Department of Geography, University of Köln (Cologne), Albertus-Magnus-Platz, D-50923 Köln, Germany

Corresponding authors: daniel.kelterbaum@staff.uni-marburg.de; h.brueckner@staff.uni-marburg.de

1 Introduction

The turning point of the research about Holocene sea level changes of the Black Sea is the year 1998 when Pitman & Ryan published their book: “Noah’s flood. The new scientific discoveries about the event that changed history.” Before that date, sea level curves of the Black Sea differed in the steepness of the postglacial rise and the number and order of wiggles. The general trends were, however, comparable (Nevessky, 1961; Fedorov, 1977, 1978; Balabanov et al., 1981, 1988; Balabanov, 1984, 1987; Chepalyga, 1984; Voskoboinikov, 1982; see also the compilation by Pirazzoli, 1991). The Pitman & 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 at 7500 BP (Ryan et al., 1997), lately corrected to 8400 BP (Ryan, 2007: 63), divided the scientific community into three parties: those supporting the catastrophic scenario (Ryan et al., 1997; Pitman & 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, 2002b; Hiscott et al., 2002; Kaminski et al., 2002) or an oscillating one (Chepalyga, 2002, 2007; Balabanov, lately 2007; Glebov & Shel’ting, 2007; Konikov, 2007; Yanko-Hombach, 2007). It was this controversy that triggered the installation of IGCP Project 521. When looking at the so far achieved results (Yanko-Hombach et al., 2007), it is evident that the debate is vividly going on and a lot of research has still to be done.

Whatever the outcome, it is common opinion that at least since 7500 BP, the Mediterranean and the Black seas 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.

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 intends to document 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 differing tectonic settings, data bases (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 the normal wave action. Tidal differences are only noticeable in areas with a special coastal configuration, such as the northernmost Adriatic Sea, the Little Syrte or 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 left out. Firstly, one has to differentiate between rocky and sedimentary contexts. On a rocky coast, mechanical notches and abrasion platforms, created by pebbles due to wave action, are indicative, but not with a high precision concerning MSL (mean sea level).

The transgression peak of a marine terrace is marked by the foot of the cliff; this does, however, 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 metres deeper.

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. MSL can be calculated from that by analysing the modern-day analogue. This may then be transferred to the fossil record of a series of beach ridges or a flight of marine terraces according to the principle of uniformitarianism – given the fact that the environmental parameters have not changed meanwhile.

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 in-filled lagoon, (d) biological markers, and (e) a few 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. In the fossil record, (c) may be found when a lagoonal unit is covered by a terrestrial one.

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 – *Lithophyllum* or *Tenarea* being even more precise than vermetids. Coralline bioherms (algal ridges and trottoirs) are high precision indicators (±10 cm). Colonies of

Balanus sp. cluster in the eulittoral zone, but live in the splash zone as well. Of much lesser precision are rock pools, bioerosive forms found in the supralittoral zone, and holes of boring organisms (*Lithophaga*) in the sublittoral. The most famous example of the latter are 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 (as we know by now, bradysismic) effect by Charles Lyell (1830) initiated the research on sea level changes (see also 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 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). 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 ±10 cm (Scott & 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 no useful sea level indicator (see Section 3.2).

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 contribution 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), give 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).

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 Arc (Fig. 1). Another effect is the northward drift of the Arabian 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 uplifting 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, like the Russian and Scythian platform. 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 Kertch 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 are mud volcanoes (Saintot & 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 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.

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 when the peat covers a marine sediment or a marsh sediment if its base corresponds to MHW (mean high water, 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 be 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 changes in southern France

Laborel et al. (1994) and Morhange et al. (2001) used the coralline rhodophyte *Lithophyllum lichenoides* for reconstructing Holocene relative sea level changes at several coastal sites in southern France. In the Mediterranean, *Lithophyllum lichenoides* builds up narrow rims out of algal thalli in the lower midlittoral zone slightly above modern mean sea level. Such algal rims are found within a depth range of less than 50 cm which is the narrowest range found for Mediterranean littoral species (Laborel et al., 1994; Laborel, 2005; Laborel & Laborel-Deguen, 2005). Thus, *Lithophyllum lichenoides* represents an oustanding biological sea level indicator. While falling sea level leads to erosion of the rim by wave dynamics, a stable or slightly rising level allows new algal layers superposing dead thalli of the inner core and thus strengthening the rim. Gradually and constantly rising sea level, however, leads to the submergence of the older, cemented and partly *Corallina elongata*-encrusted rims, which are subsequently prone to bio-erosion in the lower mid- and the sublittoral zones.

Measuring the actual depth of submerged remains of *Lithophyllum lichenoides* rims and determining their ages by means of radiocarbon dating yields excellent palaeo-sea level data (Laborel et al., 1994; Morhange et al., 1996, 2001; Morhange, 2005). Fig. 2 illustrates the age-depth relations of 23 *Lithophyllum lichenoides* samples retrieved from the cliffy coast of La Ciotat, some 35 km to the west of Marseilles. The results show that, since 5000 cal BP, relative sea level has never been higher than today. From about 4500 to 1500 cal BP it rose by approximately 0.4 mm/a and later by 0.2 mm/a; only in the 20th century, the rate of sea level rise accelerated to 1.5 mm/a (Morhange et al., 2001: 325ff.).

Morhange (2005, see also Morhange et al., 2001) complemented the La Ciotat data by a set of geoarchaeological sea level markers from the ancient harbour of Marseilles. Based on former littoral deposits covered by younger sediments as well as on archaeological relics of quays and posts encrusted by *Balanus* cf. *amphitrite*, he was able to construct another curve for this region. This was possible as the upper limit of this *Balanus* population does not reach higher than MSL (mean sea level) and can therefore be used as sea level indicator.

The Marseilles data clearly corroborates the La Ciotat curve resulting in almost the same pattern and rates of sea level rise. Differences may be explained by slight anthropogenic compaction of archaeological structures and by the general difference between the two types of sea level indicators used for this study.

3.2 Relative sea level studies in the eastern Mediterranean

Many coastal areas in the eastern Mediterranean were already subject to 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 around 6000 and 3500 cal BP 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 & Andres (1991) for the Nile delta (Egypt). Some of these curves (Kelletat, 2005; Riedel, 1996) partly use beachrock as sea level indicator. Recent studies, however, show that beachrock is only a limited sea level marker (Knight, 2007; Kelletat, 2006, 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 & Andres, 1991; Müllenhoff, 2005).

In contrast, the type 2-curve (Fig. 3) shows a more or less continuous sea level rise during the past 6000 or so years. 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 & 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.

3.3 Akarnania and adjacent regions in northwestern Greece

Independent local relative sea level curves elaborated by Vött (2007) and Vött et al. (2006a, 2006b, 2007a, 2007b) for seven coastal plains 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 archaoelogical 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 toward the coast, sediment compactions as well as anthropogenic influences of the different study sites are well assessable (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). This can be explained by the overall tectonic pattern. Akarnania as a whole, separating 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 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 Cefalonia and Lefkada transform faults (e.g. Karakostas et al., 2004).

In general, the 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 that (iii) differences in relative sea level evolution predominantly reflect both local fault activity and (supra-) regional geodynamic patterns.

3.4 The contribution of archaeology – the example of Miletus, Turkey

The following example shows how the position of the former sea level can be deciphered in an archaeological context. Our 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 & Niemeier, 1997; Niemeier, 2005). 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, pers. comm. 2004).

Our vibracores from the southwest of the temple (Fig. 5) 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 Mil 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 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 vividly 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 assume that the postglacial sea level rise decelerated when reaching c. 10 m below its present position around 7000 BP (Fedorov, 1977; Konikov, 2007; Balabanov, 2007; Shuisky, 2007; Glebov & Shel’ting, 2007; Ivanov & Schmuratko, 1983). Thereafter, still major rises and falls, in some cases even to the order of up to 10 m [sic!] are postulated (see also: Selivanov, 2003; Shilik, 1997; Svitoch, 1999, Svitoch, et al. 2000). 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. [sic!] 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.

According to Balabanov (lastly 2007; see also Fig. 7, line A), 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: 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 evidence this curve suggests a sea level fall of at last 7-8 m.

Balabanov's sea level curve is a compilation 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. The data base shows that obviously only parts of these ages are closely related to former shorelines. In addition, the presented curve lacks, however, any consideration of the differential tectonics. Some samples are from the coastal areas of the Caucasus Mountains, a region with a general uplift trend; others are from the Crimea, also in an uplift setting (Smolyaninova et al., 1996), but with another speed; there are also dates from subsidence areas such as the Indolo-Kuban trough (see also the tectonic pattern of the Black and Azov Seas in Fig. 1). Already 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 we concluded in Section 2.1.

4.2 The Black Sea curves – seen from a Mediterranean perspective

A major discrepancy between sea level curves of the Mediterranean and the Black Sea are that the latter curve shows major and minor wiggles – re- and transgressive phases in relatively short times. Section 3 outlined the Mediterranean perspective. None of the Mediterranean curves shows the wiggles of the Black Sea curves (see Figs. 3, 6 and 7) although both seas have been connected at least since 7500 BP. It seems that the reason for the wiggles is the wish to create a single curve for the whole Black Sea. We have seen that due to differential local tectonics this is an impossible undertaking. The Mediterranean example clearly shows that there are only locally valid relative sea level curves.

As a possible solution we suggest 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 (see 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 (Fig. 7, line B) is an average curve plus envelope all over the Black Sea; local curves can only be developed if also sediment compaction and local tectonics are taken into account.

4.3 Archaeological arguments against the established curves of the Black Sea

Balabanov (2007) postulates more than five major wiggles covering more than 3 m (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 0BP sea level fell from about 0 m (MSL) to 7-8 m b.s.l. The following so-called Nymphaean Transgression caused a rapid rise which reached once more 0 m (MSL) 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 & Böttger, 2002) which led to the establishment of many harbour sites and trading posts all around the Crimea (Pantikapaion, Feodosia, Nymphaion, etc.), the Russian coast 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 tradition 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 Kertch Peninsula, Phanagoria on Taman Peninsula, Taganrog near the Don delta).

If a drop in sea level of seven or so meters had occurred during the time of the so-called Phanagorian Regression, all of these coastal settlements would have lost their harbours. The Greek 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. In the case of the Azov Sea, a vertical sea level drop of a few metres would have caused a horizontal shift in the shoreline of several kilometres since this marginal sea has a maximum depth of only 18 m. We have neither any historical nor any archaeological evidence for such a scenario. Therefore, something must be wrong with the sea level curves that show wiggles of several metres during the Holocene.

4.4 Towards more realistic sea level curves – the tectonic effect

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. We know from the Mediterranean example (Section 3) (a) that during Roman times sea level was around 1-2 m deeper 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.

The Gulf of Taman belongs to a geological syncline with a strong subsidence tendency (Saintot & 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 Hermonassa (Photo 1).

The map by Blagovolin & 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.

Recent studies by Fouache et al. (1998, 2000, 2004) demonstrate that – due to differential tectonics – the areas of Taman Peninsula have experienced different local sea level histories (Fig. 8). 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 Kertch Peninsula (Porotov, 2007).

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 are the sea level fluctuations of the past seven millennia. We cannot (yet) contribute to the Pitman & Ryan (1998) controversy.

5.1 Vibracore studies on Taman Peninsula

Our 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.). 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 the ^{14}C ages of dated peat layers, are summarized in Fig. 10. The detailed study of the fauna is still pending. The so far collected data lead to the following interpretation:

The profile reaches a depth of 9 m below surface (b.s.), 6.50 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 here. 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 semiterrestrial 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., sedimentation changed 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 indicate 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.

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 facies at 3.55-2.75 m b.s. is once again clayey silts. The reddish, 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, deposited 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.

Based on our studies at Semebratnee we found out that 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), sedimentation in the semi-enclosed basin decreased between 2300 and 300 BC.

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 Peninsula to the west and the Golubickaja Peninsula to the east (Fig. 11). Their ancient names are not bequeathed; Abramov & 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 our research to clarify the palaeogeographical situation in Hellenistic times and learn more about the evolution of sea level.

The first three cores are presented in a synopsis (Fig. 11). Each core reached the pre-Holocene stratum: a colluvial sediment of reworked loess with a palaeosol (The Taman Peninsula is covered by loessic sediments with a thickness of up to 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. At GOL 1, the marine sediments are rich in macrofossils and 3.75 m thick showing that the open marine condition 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. showing a coarser sediment structure and high contents of broken mollusc shells possibly deposited. by high energy events.

Rising sea level caused open marine conditions after having connected the Black and the Mediterranean Seas placing the Azov Sea directly at the foot of the ancient Golubickaja 2; The still visible dead cliffs at the Golubickaja 2 settlement site date from the time of the maximum transgression. Once the sand barrier had evolved, the marine cliff erosion stopped.

The erosion of loess by water and surf is very high and so it is explicable by recently observable erosional processes at the northern and southern coasts of Taman Peninsula how such a high cliff of more than 7 m can be developed at Golubickaja 24.

The easily erodable material (loess) of the headlands of the Taman Peninsula were relocated by the longshore current and 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* macro fossils. Again, these cores do not show interfingering palaeosols (except for the pre-Holocene one at the bottom) nor any erosional diconformities. This is a strong argument for the permanent rise in sea level.

5.2 Towards a new relative sea level curve for 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) 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 wheathering processes will start. Peat growth can stop abruptly by a marine ingression or by the rapid input of fossilizing alluvial deposits. Since in none of our corings there was any sign of peat erosion or wheathering we reject the idea of major regression phases for the Taman Peninsula.

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 and the overlying sediment was thick, compaction was estimated as being maximum 25 cm. In cases of a very thin peat layer, compaction is considered negligible.

The results of the data are given in Table 1. They are the base for the new relative sea level curve for the area around Semebratnee. This curve does not shows any sign of major or minor wiggles, but a strong sea level rise between 5200-2500 BC. Thereafter, the velocity of sea level rise decelerates. Under the probable assumption of co-seismic events, average sea level rise was not as high as estimated.

Our main conclusions for the eastern Taman Peninsula are:

(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 in core SEM 4 (Section 5.1) cannot be interpreted as indicators for sea level falls of the Black and Azov Seas.
(iii) The established curve *grosso modo* supports the one of Fouache et al. (2004), without any signs of major or minor wiggles; there are no relative sea level falls of several meters.
(iv) The Semebratnee core (Section 5.1) reflects a delta progradation by the Kuban River of more than 20 km.
(v) The Semebratnee core shows that till 300/200 BC a connection between the Azov and Black Seas was existing via an eastern Bosphorus, thus creating Golubickaja island.

6 Conclusion

The vivid debate on the sea level fluctuations of the Black Sea – stirred up by the Pitman & Ryan (1998) flood hypothesis – led to a closer look at the so far published sea level curves for the Black Sea. In this paper, we 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 a lot of the controversy is based on poor sea level indicators and the wrong use of ^{14}C datings (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). 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). However, there is neither archaeological evidence nor historic proof for such a scenario.

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, several layers of paralic peat were used. In none of the corings the peat shows 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 type 2-curve of the Mediterranean.

Our research on both sides of Golubickaja clearly shows that this area was once an island. We strongly assume that 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), it can be stated that 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. Therefore, the need for urgent research in archaeology, palaeogeography and geotectonic evolution is apparent.

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References

Abramov, A.P., Paromov, Ya.M., 1993. The early classic settlements of Taman peninsula. Bosporus collection. IA RAS n. 2, Moscow, pp.25-98 (In Russian).

Aksu, A.E., Hiscott, R.N., Yaşar, D., Mudie, P.J., 1999. Deglacial and post-glacial water levels and water exchange across the Black Sea-Marmara Sea-Aegean Sea shelves, eastern Mediterranean region. In: Saito, Y., Ikehara, K., Katayama, H. (Eds.), Land-Sea Link in Asia, Proceedings of an International workshop on Sediment Transport and Storage in coastal Sea-Ocean System. Tsukuba, pp. 463-468.

Aksu, A.E., Hiscott, R.N., Mudie, P.J., Rochon, A., Kaminski, M.A., Abrajano, T., Yaşar, D., 2002a. Persistent Holocene outflow from the Black Sea to the Eastern Mediterranean contradicts Noah's Flood hypotheses. GSA Today 12 (5), 4-10.

Aksu, A.E., Hiscott R.N., Kaminski M.A., Mudie P.J., Gillespie H., Abrajano T., Yaşar D., 2002b. Last glacial-Holocene paleoceanography of the Black Sea and Marmara Sea: stabile isotopic, foraminiferal and coccolith evidence. Marine Geology 190, 119-149.

Balabanov, I.P., Kvirkveliya, B.D., Ostrovsky, A.B., 1981. Recent History of the Development of Engineering-Geological Conditions and Long-Time Forecast for the Coastal Zone of the Pitsunda Peninsula. Ministry of Geology of the USSR, Second Hydrological Division, Metanierba, Tbilisi, 202 p (In Russian).

Balabanov, I.P., 1984. Change in the wave regime of the Black Sea in the Late Holocene. Izvestiia AN SSSR, seriia geograficheskaiia 5, pp. 70-81 (In Russian).

Balabanov, I.P., 1987. On the question of the location of the ancient Greek cities Pitiunt and Dioskoria. Izvestiia AN GSSR, seriia istorii, arkheologii, etnografii I istorii iskusstva 2, pp. 151-159 (In Russian).

Balabanov, I.P., Izmailov, Ya.A., 1988. Changes in level and hydrochemical regime of the Black Sea and the Sea of Azov during the last 20 ka. Water Resources 15, 539-546 (In Russian).

Balabanov, I.P., 2007. Holocene Sea-level changes of the Black Sea. In: Yanko-Hombach, V., Gilbert, A.S., Panin, N., Dolukhanov, P.M. (Eds.), The Black Sea flood question. Dordrecht, pp. 711-730.

Ballard, R.D., Coleman, D.F., Rosenberg, G.D., 2000. Further evidence of abrupt Holocene drowning of the Black Sea shelf. Marine Geology 170, 253-261.

Behre, K.-E., 2003. Eine neue Meeresspiegelkurve für die südliche Nordsee. Transgressionen und Regressionen in den letzten 10.000 Jahren. Probleme der Küstenforschung im südlichen Nordseegebiet 28, 9-63.

Blagovolin, N.S., Pobedonostsev, S.V., 1973. Recent vertical movements on the shores of the Black and Azov sea. Geomorphologia 3. pp. 46-55 (In Russian).

Brockmüller, S., Vött, A., Brückner, H., Handl, M., Schriever, A., 2005. Die holozäne Entwicklung der Küstenebene von Boukka am Ambrakischen Golf (Nordwestgriechenland). In: Beck, N. (Ed.), Neue Ergebnisse der Meeres- und Küstenforschung. Schriften des Arbeitskreises Landes- und Volkskunde Koblenz 4. Koblenz, pp. 34-50.

Brückner, H., 2003. Delta evolution and culture - aspects of geoarchaeological research in Miletos and Priene. In: Wagner, G.A., Pernicka, E., Uerpmann, H.P. (Eds.), Troia and the Troad. Scientific approaches. Springer Series: Natural Science in Archaeology. Berlin, Heidelberg, New York, pp. 121-144.

Brückner, H., Müllenhoff, M., Gehrels, R., Herda, A., Knipping, M., Vött, A., 2006. From archipelago to floodplain – geographical and ecological changes in Miletus and its environs during the past six millennia (Western Anatolia, Turkey). Zeitschrift f. Geomorphologie N.F., Supplement 142, 63-83.

Camuffo, D., Sturaro, G., Pagan, E., 2004. Sinking of Venice over the last three centuries: input from Canaletto's paintings and early photographs. In: CIESM (Commission Internationale pour l'Exploration Scientifique de la mer Méditerranée), Human records of recent geological evolution in the Mediterranean Basin - historical and archaeological evidence (Santorini, Greece, 22-25 October 2003). Monaco. CIESM Workshop Monographs, 24, pp. 57-62.

Chepalyga, A.L., 1984. Inland sea basins. In: Velichko, A.A., Wright, Jr. H.E., Barnowsky, C.W. (Eds. English edition), University of Minnesota Press. Minneapolis, pp. 229-247.

Chepalyga, A.L., 2002. The Black Sea. In: Velichko, A.A. (Ed.), Dynamics of Terrestrial Landscape Components and Inner Marine Basins of Northern Eurasia during the Last 130,000 years, GEOS, Moscow, pp. 170-182 (In Russian).

Chepalyga, A.L., 2007. The late glacial great flood in the Ponto-Caspian basin. In: Yanko-Hombach, V., Gilbert, A.S., Panin, N., Dolukhanov, P.M. (Eds.), The Black Sea flood question. Dordrecht, pp. 119-148.

Cocard, M., Kahle, H.-G., Peter, Y., Geiger, A., Veis, G., Felekis, S., Paradissis, D., Billiris, H., 1999. New constraints on the rapid crustal motion of the Aegean region: recent results inferred from GPS measurements (1993-1998) across the West Hellenic Arc, Greece. Earth and Planetary Science Letters 172, 39-47.

Dimitrov, L.I., 2002. Mud volcanoes – the most important pathway for degassing deeply buried sediments. Earth-Science Reviews 59, 49-76.

Dinu, C., Wong, H.K., Tambrea, D., Matenco, L., 2005. Stratigraphic and structural characteristics of the Romanian Black Sea shelf. Tectonophysics 410, 417-435.

Fedorov, P.V., 1977. Late Quaternary history of the Black Sea and evolution of the southern seas of Europe. In: Kaplin, P.A., Shcherbakov, F.A. (Ed.), Pleistocene Paleogeography and Sediments of the Southern Seas of the USSR. Nauka, Moscow, pp. 25-32 (In Russian).

Fedorov, P.V., 1978. The Ponto-Caspian Pleistocene. Moscow, Science (In Russian).

Filipova-Marinova, M., 2007. Archaeological and paleontological evidence of climate dynamics, sea-level change, and coastline migration in the Bulgarian sector of the Circum-Pontic region. In: Yanko-Hombach, V., Gilbert, A.S., Panin, N., Dolukhanov, P.M. (Eds.), The Black Sea flood question. Dordrecht, pp. 453-482.

Fornasier, J., Böttger, B. (Eds.), 2002. Das Bosporanische Reich: Der Nordosten des Schwarzen Meeres in der Antike. Zaberns Bildbände zur Archäologie. von Zabern, Mainz.

Fouache, E., Müller, C., Gorlov, Y., Gaibov, V., Porotov, A., 1998. Geoarcheological study of the Taman Peninsula and the Kouban Delta (Black Sea, Sea of Azov, Russia). In: Vermeulen, F., Papper, de M. (Eds.), Geoarchaeology of the landscapes of classical antiquity. International Colloquium Ghent, 23-24 October 1998. Leiden, pp. 97-104.

Fouache E., Müller C., Gorlov Y., Gaibov V., Porotov A., 2000. Geoarchaeological study of the Taman peninsula and the Kouban delta (Black Sea, Azov Sea, Russia). In: Vermeulen F., Papper, M. de (Eds.), Geoarchaeology of the landscapes of classical antiquity: colloque international Gand, 23-24 October 1998. Coll. Babesch. Leiden. Stichting Bulletin antike beschaving. Supplement 5, 97-104.

Fouache, E., Porotov, A., Muller, C., Gorlov, Y., 2004. The role of neo-tectonics in the variaton of the relative mean sea level throughout the last 6000 years on the Taman Peninsula (Black Sea, Azov Sea, Russia). Colloque Rapid Transgressions into semi-enclosed basins.

PICG 464. Gdansk, Polish Geological Institute, 8-9-10 Mai 2003. Polish Geological Institute, Special papers Vol. 11, 47-58.

Gehrels, R., 2005. Sea-level changes during the last millennium. In: Schwartz, M.L. (Ed.), Encyclopedia of coastal science. Dordrecht, pp. 830-833.

Geyh, M.A., 2005. Handbuch der physikalischen und chemischen Altersbestimmungen. Darmstadt.

Glebov, A.Y., Shel'ting, S.K., 2007. Sea-level changes and coastline migrations in the Russian sector of the Black Sea: Application to the Noah's Flood Hypothesis. In: Yanko-Hombach, V., Gilbert, A.S., Panin, N., Dolukhanov, P.M. (Eds.), The Black Sea flood question. Dordrecht, pp. 731-774.

Görür, N., 1988. Timing of the opening of the Black Sea basin. Tectonophysics 147, 247-262.

Govedarica, B., 2003. On the oscillations of the Black Sea level in the Holocene period from an archaeological viewpoint. In: Wagner, G.A., Pernicka, E., Uerpmann, H.P. (Eds.), Troia and the Troad. Scientific approaches. Springer Series: Natural Science in Archaeology. Berlin, Heidelberg, New York, pp. 95-104.

Hiscott, R.N., Aksu, A.E., Yaşar, D., Kaminski, M.A., Mudie, P.J., Kostylev, V.E., MacDonald, J.C., Işler, F.I., Lord, A.R., 2002. Deltas south of the Bosphorus Strait record persistent Black Sea outflow to the Marmara Sea since ~10 ka. Marine Geology 190, 95-118.

Hofrichter, R. (Ed.), (2003). Das Mittelmeer. Fauna, Flora, Ökologie. Heidelberg.

Ivanov, G.I., and V.I. Schmuratko, 1983. Characteristics of variation of the Black Sea level in Postglacial time. Water Resources 6, 314-321.

Izmailov, Y., 2007. Late Holocene coastlines of the Sea of Azov in the Kuban River delta. In: A. Chepalyga, Y. Izmailov, V. Zin'ko (Eds.), Field trip guide. IGCP 521-481 joint meeting and field trip, fig. 18 a, p. 36.

Kaminski, M.A., Aksu, A.E., Box, M., Hiscott, R.N., Filipescu, S., Al-Salameen, M., 2002. Late Glacial to Holocene benthic foraminifera in the Marmara Sea: implications for Black Sea-Mediterranean Sea connections following the last deglaciation. Marine Geology 190, 165-202.

Karakostas, V.G., Papadimitriou, E.E., Papazachos, C.B., 2004. Properties of the 2003 Lefkada, Ionian Islands, Greece, earthquake seismic sequence and seismicity triggering. Bulletin of the Seismological Society of America 94 (5), 1976-1981.

Kayan, I., 1997. Bronze Age Regression and Change of Sedimentation on the Aegean Coastal Plains of Anatolia (Turkey). In: Dalfes, H.N., Kukla, G., Weiss, H. (Eds.), Third Millennium BC Climate Change and Old World Collapse. Berlin/Heidelberg, pp. 431-450.

Kelletat, D., 2005. A Holocene sea level curve for the eastern Mediterranean from multiple indicators. Zeitschrift für Geomorphologie N.F., Supplement 137, 1-9.

Kelletat, D., 2006. Beachrock as sea-level indicator? Remarks from a geomorphological point of view. Journal of Coastal Research 22 (6), 1558-1564.

Kelletat, D., 2007. Reply to: Knight, J., 2007: Beachrock reconsidered. Discussion of: Kelletat, D., 2006. Beachrock as Sea-Level Indicator? Remarks from a Geomorphological Point of View, Journal of Coastal Research 22 (6), 1558–1564; Journal of Coastal Research, 23 (4), 1074–1078; Journal of Coastal Research, 23 (6), 1605-1606.

Knight, J., 2007. Beachrock reconsidered. Discussion of: Kelletat, D., 2006. Beachrock as sea-level indicator? Remarks from a geomorphological point of view. Journal of Coastal Research, 22 (6), 1558-1564. Journal of Coastal Research, 23 (4), 1074-1078.

Konikov, G.K., 2007. Sea-level fluctuations and coastline migration in the northwestern Black Sea area over the last 18 ky based on high-resolution lithological-genetic analysis of sediment architecture. In: Yanko-Hombach, V., Gilbert, A.S., Panin, N., Dolukhanov, P.M. (Eds.), The Black Sea flood question. Dordrecht, pp. 405-436.

Laborel, J., Morhange, C., Lafont, R., Le Campion, J., Laboel-Deguen, F., Sartoretto, S., 1994. Biological evidence of sea-level rise during the last 4500 years on the rocky coasts of continental southwestern France and Corsica. Marine Geology 120, 203-223.

Laborel, J., 2005. Algal rims. In: Schwartz, M.L. (Ed.), Encyclopedia of coastal science. Dordrecht, pp. 24-25.

Laborel, J., Laborel-Deguen, F., 2005. Sea-level indicators, biologic. In: Schwartz, M.L., (Ed.), Encyclopedia of coastal science. Dordrecht, pp. 833-834

Lambeck, K., 1996. Sea-level Change and Shoreline Evolution in Aegean Greece since the Upper Paleolithic. Antiquity 70, 588-611.

Lambeck, K., Antonioli, F., Purcell, A., Silenzi, S., 2004. Sea-level change along the Italian coast for the past 10,000 yr. Quaternary Science Reviews 23, 1567-1598.

Lambeck, K., Purcell, A., 2005. Sea-level change in the Mediterranean Sea since the LGM: model predictions for tectonically stable areas. Quaternary Science Reviews 24, 1969-1988.

Lericolais, G., Popescu, I., Guichard, F., Popescu, S.-M., Manolakakis, L., 2007. Water-level fluctuations in the Black Sea since the Last Glacial Maximum. In: Yanko-Hombach, V., Gilbert, A.S., Panin, N., Dolukhanov, P.M. (Eds.), The Black Sea flood question. Dordrecht, pp. 437-452.

Lyell, C. (1830): Principles of Geology. Vol. I., 511 pp. London.

Morhange, C., Laborel, J., Hesnard, A., Prone, A., 1996. Variation of relative mean sea level during the last 4000 years on the northern shores of the Lacydon, the ancient harbor of Marseilles. Journal of Coastal research 12 (4), 841-849.

Morhange, C., Laborel, J., Hesnard, A., 2001. Changes of relative sea level during the past 5000 years in the ancient harbor of Marseilles, Southern France. Palaeogeography Palaeoclimatology Palaeoecology 166, 319-329.

Morhange, C., 2005. Relative sea-level changes in Marseille's ancient harbors (France) during the Late Holocene. Zeitschrift für Geomorphologie, Supplement 137, 23-28.

Morhange, C., Marriner, N., Laborel, J., Todesco, M., Oberlin, C., 2006. Rapid sea-level movements and noneruptive crustal deformations in the Phlegrean Fields caldera, Italy. Geology 34 (2), 93-96.

Müllenhoff, M., 2005. Geoarchäologische, sedimentologische und morphodynamische Untersuchungen im Mündungsgebiet des Büyük Menderes (Mäander), Westtürkei. Marburger Geographische Schriften 141. Marburg/Lahn.

Nevessky, E.N., 1961. On the post-glacial transgression of the Black Sea. Doklady AN SSSR, 137 (3), 667-670 (In Russian).

Niemeier, B. & W.-D., Niemeier, 1997. Milet 1994-1995. Projekt 'Minoisch-Mykenisches bis Protogeometrisches Milet': Zielsetzung und Grabungen auf dem Stadionhügel und am Athenatempel. Archäologischer Anzeiger, 189-248.

Niemeier, W.-D., 2005. Milet von den Anfängen menschlicher Besiedlung bis zur Ionischen Wanderung. In: Cobet, J., Crawford, M., Weil, A., Saunders, B. (Eds.), Frühes Ionien. Eine Bestandsaufnahme. Milesische Forschungen 5 (in press).

Pavlopoulos, K., Theodorakopoulou, K., Bassiakos, Y., Hayden, B., Tsourou, T., Triantaphyllou, M., Kouli, K., Vandarakis, D., 2007. Palaeoenvironmental evolution of Istron (NE Crete) during the last 6000 years: depositional environment, climate and sea level changes. Geodinamica Acta 20 (4), 219-229.

Pirazzoli, P.A., (1991). World atlas of sea-level changes. Elsevier Oceanography Series, 58. Amsterdam, London.

Pirazzoli, P.A., 1996. Sea-level changes. The last 20,000 years. Chichester.

Pirazzoli, P.A., 2005. Sea-level indicators, geomorphic. In: Schwartz. M.L. (Ed.), Encyclopedia of coastal science. Dordrecht.

Pitman III, W.C., Ryan, W.B.F., 1998. Noah's flood. The new scientific discoveries about the event that changed history. New York.

Plassche, O. van de (Ed.), 1986. Sea-level research: A manual for the collection and evaluation of data. Norwich.

Porotov, A., 2007. Relative sea-level changes and submersion of archaeological sites along the northern shoreline of the Black Sea. Méditerranée 108, 29-36.

Reimer, P.J., Baillie, M.G.L., Bard, E., Bayliss, A., Beck, J.W., Bertrand, C., Blackwell, P.G., Buck, C.E., Burr, G., Cutler, K.B., Damon, P.E., Edwards, R.L., Fairbanks, R.G., Friedrich, M., Guilderson, R.P., Hughen, K.A., Kromer, B., McCormac, F.G., Manning, S., Ramsey, C.B., Reimer, R.W., Remmele, S., Southon, J.R., Stuiver, M., Talamo, S., Taylor, F.W., Plicht, J. van der, Weyhenmeyer, C.E., 2004. INTCAL04 terrestrial radiocarbon age calibration, 0-26 kyr BP. Radiocarbon 46 (3), 1029-1058.

Riedel, H., 1996. Die holozäne Entwicklung des Dalyan-Deltas (Südwest-Türkei) unter besonderer Berücksichtigung der historischen Zeit. Marburger Geographische Schriften 130. Marburg/Lahn.

Ryan, W.B.F., Pitman, W.C., Major, C.O., Shimkus, K., Moskalenko, V., Jones, G.A., Dimitrov, P., Görür, N., Sakınç, M., Seyir, H.I., Yüce, H., 1997. An abrupt drowning of the Black Sea shelf. Marine Geology 138, 119-126.

Ryan, W.B.F., 2007. Status of the Black Sea flood hypothesis. In: Yanko-Hombach, V., Gilbert, A.S., Panin, N., Dolukhanov, P.M. (Ed.), The Black Sea flood question. Dordrecht, pp. 63-88.

Saintot, A., Angelier J., 2000. Plio-Quaternary paleostress regimes and relation to structural development in the Kertch-Taman peninsulas (Ukraine and Russia), Journal of Structural Geology 22, 1049-1064.

Schwartz, M.L. (Ed.), 2005. Encyclopedia of coastal science. Dordrecht.

Scott, D.B., Medioli, F.S., 2005. Sea-level indicators – biological in depositional sequences. In: Schwartz. M.L. (Ed.), Encyclopedia of coastal science. Dordrecht, pp. 835-836.

Selivanov, A.O., 2003. Sea-level Changes in the North Black Sea and the Sea of Azov during the latest Pleistocene and Holocene. In:GI2S Coast, Research Publication, 4: Puglia 2003 – Final Conference IGCP Project N 437.

Serebrianny, L.R., 1982. The Change of the Black sea's level in the post-Glacial time with respect to the glacial history of the Caucasus mountains. Sea and oceanic level fluctuation for the last 15.000 years. Moscow, Nauka, pp. 161-167 (In Russian).

Shilik, K.K., 1997. Oscillations of the Black Sea and ancient landscape. Colloquia Pontica 3, pp. 115-129.

Shuisky, Y., 2007. Climate dynamics, sea-level change, and shoreline migration in the Ukrainian sector of the Circum-Pontic Region. In: Yanko-Hombach, V., Gilbert, A.S., Panin, N., Dolukhanov, P.M. (Eds.), The Black Sea flood question. Dordrecht, pp. 251-278.

Sivan, D., Lambeck, K., Toueg, R., Raban, A., Porath, Y., Shirman, B., 2004. Ancient coastal wells of Caesarea Maritima, Israel, an indicator for relative sea level changes during the last 2000 years. Earth and Planetary Science Letters 222, 315-330.

Smolyaninova, E.I., Mikhailov, V.O., Lyakhovsky, V.A., 1996. Numerical modelling of regional neotectonic movements in the northern Black Sea. Tectonophysics 266, 221-231.

Spadini, G., Robinson, A., Cloething, S., 1996. Western versus Eastern Black Sea tectonic evolution: pre-rift lithospheric controls on basin formation. Tectonophysics 266, 139-154.

Svitoch, A.A., 1999. Caspian Sea level in the Pleistocene: Hierarchy and position in the paleogeographic and chronological records. Oceanology 39, 94-101.

Svitoch, A.A., Selivanov, A.O., Yanina, T.A., 2000. Paleohydrology of the Black Sea Pleistocene basins. Water Resources 27, 594-603.

Voskoboinikov, V.M, Rotar, M.F., Konikov, E.G., 1982. Correlation of the rhythmic structure of Holocene liman sediments with sea level changes of the Black Sea. In: Kaplin, P.A. (Ed.), Sea Level Fluctuations. Moscow, pp. 264-274 (In Russian).

Vött, A., Brückner, H., 2006. Versunkene Häfen im Mittelmeerraum. Antike Küstenstädte als Archive für die Kultur- und Umweltforschung. Geographische Rundschau 58 (4), 12-21.

Vött, A., Brückner, H., Handl, M., Schriever, A., 2006a. Holocene palaeogeographies and the geoarchaeological setting of the Mytikas coastal plain (Akarnania, NW Greece). Zeitschrift für Geomorphologie N.F., Supplement 142, 85-108.

Vött, A., Brückner, H., Handl, M., Schriever, A., 2006b. Holocene palaeogeographies of the Astakos coastal plain (Akarnania, NW Greece). Palaeogeography Palaeoclimatology Palaeoecology 239, 126-146.

Vött, A., 2007. Relative sea level changes and regional tectonic evolution of seven coastal areas in NW Greece since the mid-Holocene. Quaternary Science Reviews 26, 894-919.

Vött, A., Brückner, H., Georg, C., Handl, M., Schriever, A., Wagner, H.-J., 2007a. Geoarchäologische Untersuchungen zum holozänen Landschaftswandel der Küstenebene von Palairos (Nordwestgriechenland). In: Lang, F., Freitag, K., Funke, P., Grüger, E., Jahns, S., Kolonas, L., Schwandner, E.-L., Vött, A. (Ed.), Interdisziplinäre Landschaftsforschung im westgriechischen Akarnanien. Archäologischer Anzeiger 2007 (1), 191-213.

Vött, A., Schriever, A., Handl, M., Brückner, H., 2007b. Holocene palaeogeographies of the central Acheloos River delta (NW Greece) in the vicinity of the ancient seaport Oiniadai. Geodinamica Acta 20 (4), 241-256.

Vouvalidis, K.G., Syrides, G.E., Albanis, K.S., 2005. Holocene morphology of the Thessaloniki Bay: Impact of sea level rise. Zeitschrift für Geomorphologie N.F., Supplement 137, 147-158.

Wagner, G.A., 1998. Age determinations of young rocks and artifacts. Berlin, Heidelberg.

Weickert, C., Hommel, P., Kleiner, G., Mallwitz, A. & Schiering, W., 1959/60. Die Ausgrabung beim Athena-Tempel in Milet 1957. Istanbul. Istanbuler Mitt. 9 (10), 1-96.

Wunderlich, J., Andres, W., 1991. Late Pleistocene and Holocene evolution of the western Nile delta and implications for its future development. In: Brückner, H., Radtke, U. (Eds.), Von der Nordsee bis zum Indischen Ozean. Erdkundliches Wissen 105, 105-120.

Yanko-Hombach, V., Gilbert, A.S., Panin, N., Dolukhanov, P.M. (Eds.), 2007. The Black Sea flood question: Changes in coastline, climate, and human settlement. Springer, Dordrecht, the Netherlands.

Yanko-Hombach, V.V., 2007. Controversy over Noah's Flood in the Black Sea: geological and foraminiferal evidence from the shelf. In: Yanko-Hombach, V., Gilbert, A.S., Panin, N., Dolukhanov, P.M. (Eds.), The Black Sea flood question. Dordrecht, pp. 149-204.

Captions of figures, photograph and table

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 = Kerci-Taman Depression, KaD = Karkinit Depression, NKD = North Kilia Depression, SSR = Suvorov-Snake Island Ridge, HD = Histria Depression.

Fig. 2: Relative sea level changes in southern France. Age – depth relations of 23 ^{14}C-dated samples of *Lithophyllum lichenoides*, supplemented by archaeological data. Source: modified from Morhange 2005 and Morhange et al. 2001.

Fig. 3: Compilation of Holocene sea-level curves from the eastern Mediterranean. Type 1-curves show a relative mid-Holocene sea level highstand between around 6000 and 3500 cal BP. In contrast, type 2-curves show a more or less continuous sea level rise during the past 6000 or so years. 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 & Brückner 2006, Fig. 4 (see Vött & Brückner, 2006, for further references).

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, 2007b.

Fig. 5: Determination of the Holocene transgression peak in the area of the Temple of Athena, Miletus (Turkey), based on archaeological and geological evidence. 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 (see this source for further information).

Fig. 6: Sea level curves for the Black Sea. Compilation by Pirazzoli (1991, Fig. 27), slightly changed. As for further details see there.

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. Exclusively using paralic peat samples as the best sea level indicator shows that the sea level evolution of the Black Sea generally follows the type 2-curve of the Mediterranean (see Fig. 3 and Section 3.2).

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.

Fig. 10: Core SEM 4 in the valley of Kuban close to the Scythian settlement Semebratnee. 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.

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. These results help 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.

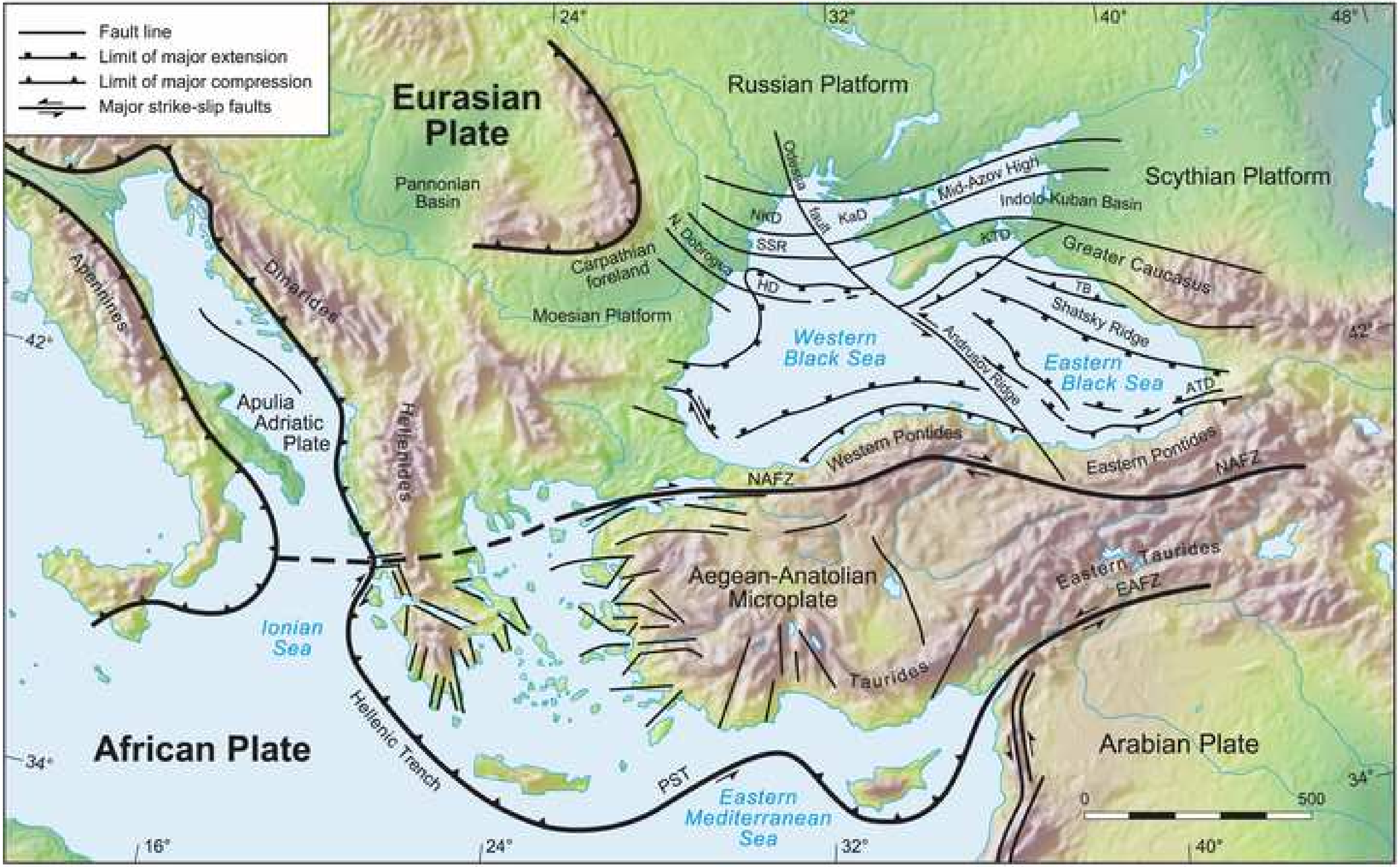
Fig. 12: Relative sea level curve of the Kuban River plain around the ancient settlement of Semebratnee, Taman Peninsula (SW Russia) since the mid-Holocene. See text for further explanations. Source: own research.

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 sea level rise, amplified in modern times. Photograph: H. Brückner 03/2006.

Tab. 1: Radiocarbon dated peat samples from vibracore SEM 4.

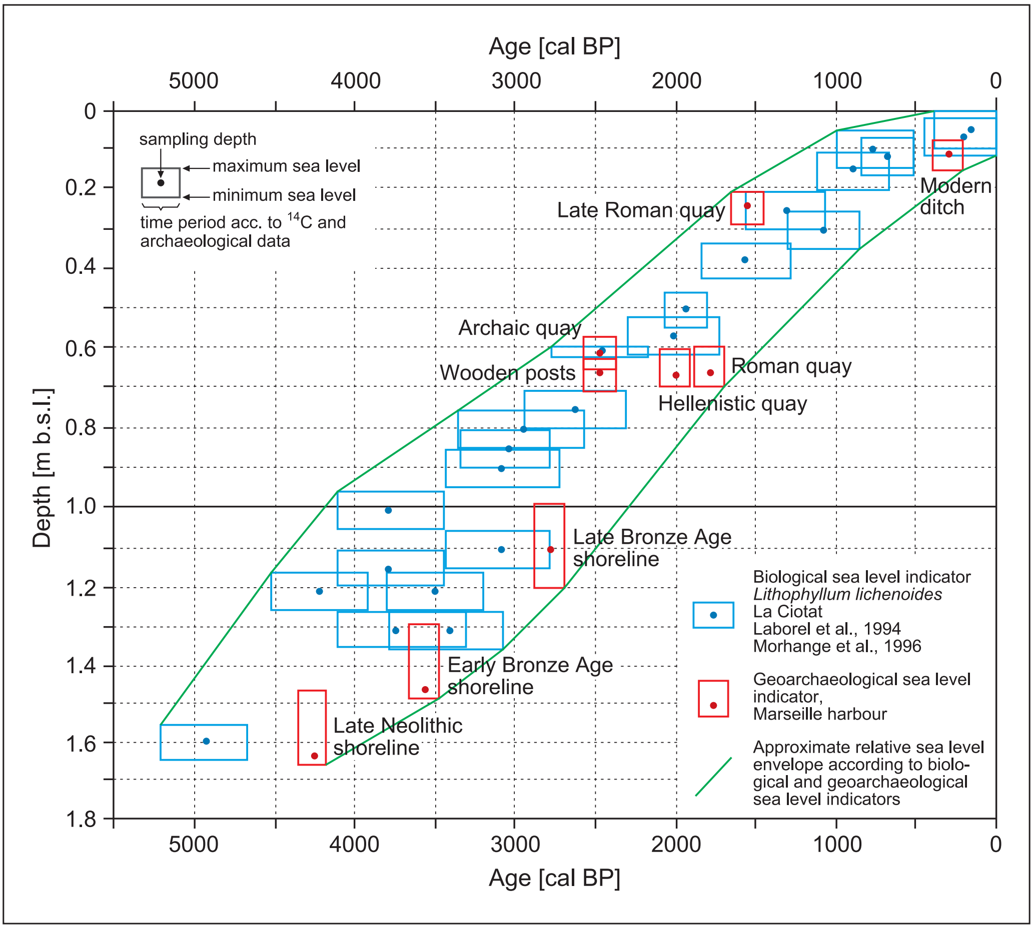
Coordinates of coring site SEM 04: 45° 08’ 36.7” N, 37° 30’ 30.2” E; b.s. = below surface; a.s.l. = above mean sea level; 1-sigma max; min (cal BC/BP) = calibrated ages, 1-sigma-range; “ ; ” = there are several possible age intervals because of multiple intersections with the calibration curve; Lab. 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).

Figure 1



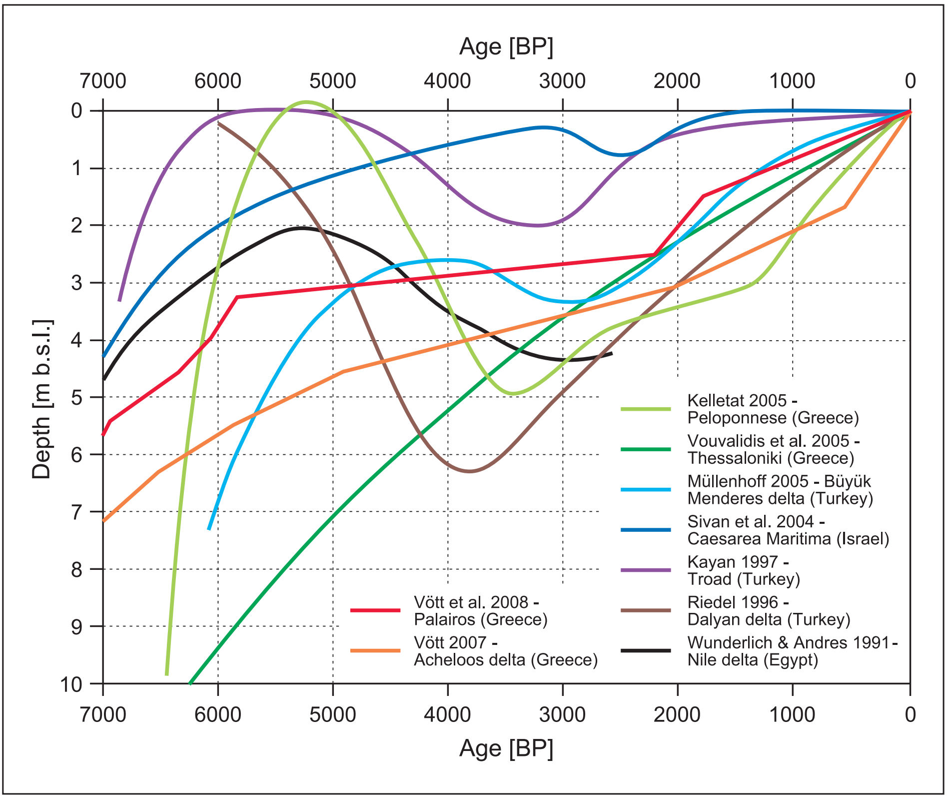
Topography: Mountain High Maps® Copyright © 1993 Digital Wisdom, Inc.

Figure 2



Age [cal BP]
5000
4000
3000
2000
1000
0
Depth [m b.s.l.]
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
sampling depth
maximum sea level
minimum sea level
time period acc. to ^{14}C and archaeological data
Late Roman quay
Modern ditch
Archaic quay
Wooden posts
Roman quay
Hellenistic quay
Late Bronze Age shoreline
Early Bronze Age shoreline
Late Neolithic shoreline
Biological sea level indicator
Lithophyllum lichenoides
La Ciotat
Laborel et al., 1994
Morhange et al., 1996
Geoarchaeological sea level indicator,
Marseille harbour
Approximate relative sea level envelope according to biological and geoarchaeological sea level indicators

Figure 3



Age [BP]
7000
6000
5000
4000
3000
2000
1000
0
Depth [m b.s.l.]
0
1
2
3
4
5
6
7
8
9
10
Vött et al. 2008 - Palairos (Greece)
Vött 2007 - Acheloos delta (Greece)
Kelletat 2005 - Peloponnese (Greece)
Vouvalidis et al. 2005 - Thessaloniki (Greece)
Müllenhoff 2005 - Büyük Menderes delta (Turkey)
Sivan et al. 2004 - Caesarea Maritima (Israel)
Kayan 1997 - Troad (Turkey)
Riedel 1996 - Dalyan delta (Turkey)
Wunderlich & Andres 1991 - Nile delta (Egypt)
Age [BP]

Figure 4

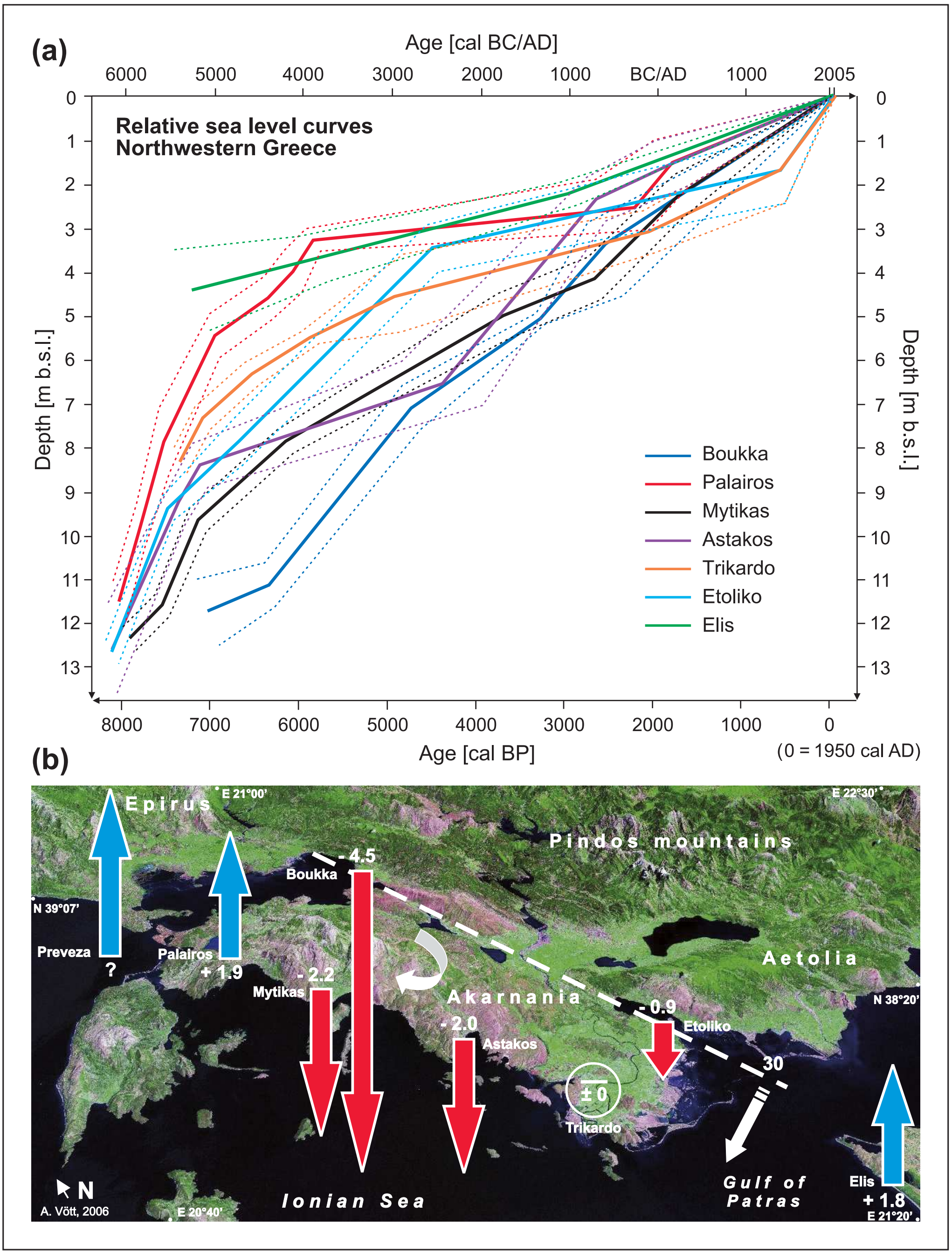
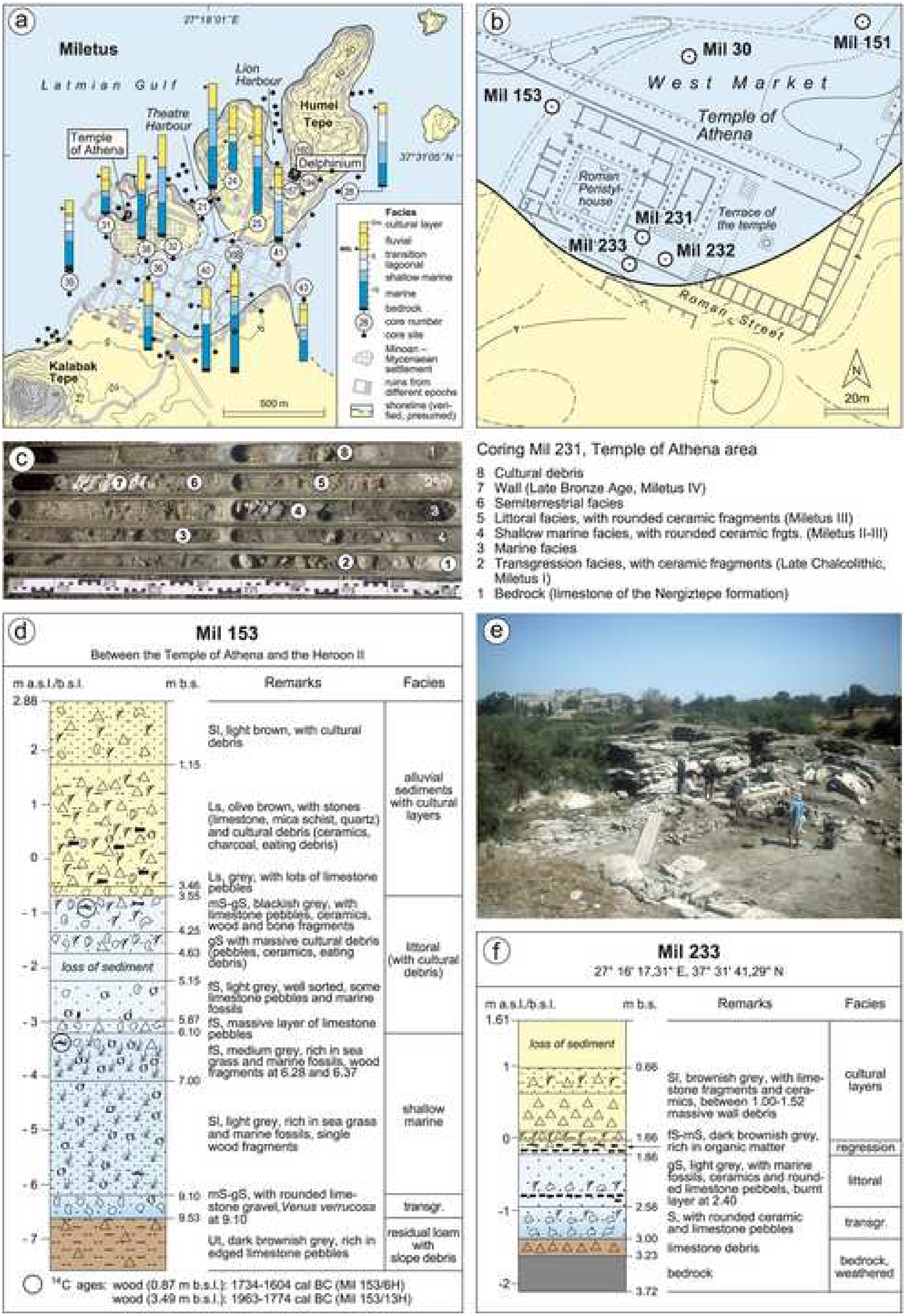

(a)
Age [cal BC/AD]
6000
5000
4000
3000
2000
1000
BC/AD
1000
2005
Relative sea level curves
Northwestern Greece
Depth [m b.s.l.]
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Boukka
Palairos
Mytikas
Astakos
Trikardo
Etoliko
Elis
8000
7000
6000
5000
4000
3000
2000
1000
0
Age [cal BP]
(0 = 1950 cal AD)
(b)
Epirus
E 21°00'
E 22°30'
Pindos mountains
Boukka
- 4.5
N 39°07'
Preveza
?
Palairos
+ 1.9
Mytikas
- 2.2
Akarnania
Aetolia
N 38°20'
- 0.9
Etoliko
- 2.0
Astakos
30
± 0
Trikardo
Gulf of Patras
Elis
+ 1.8
E 21°20'
Ionian Sea
N
A. Vött, 2006
E 20°40'

Figure 5

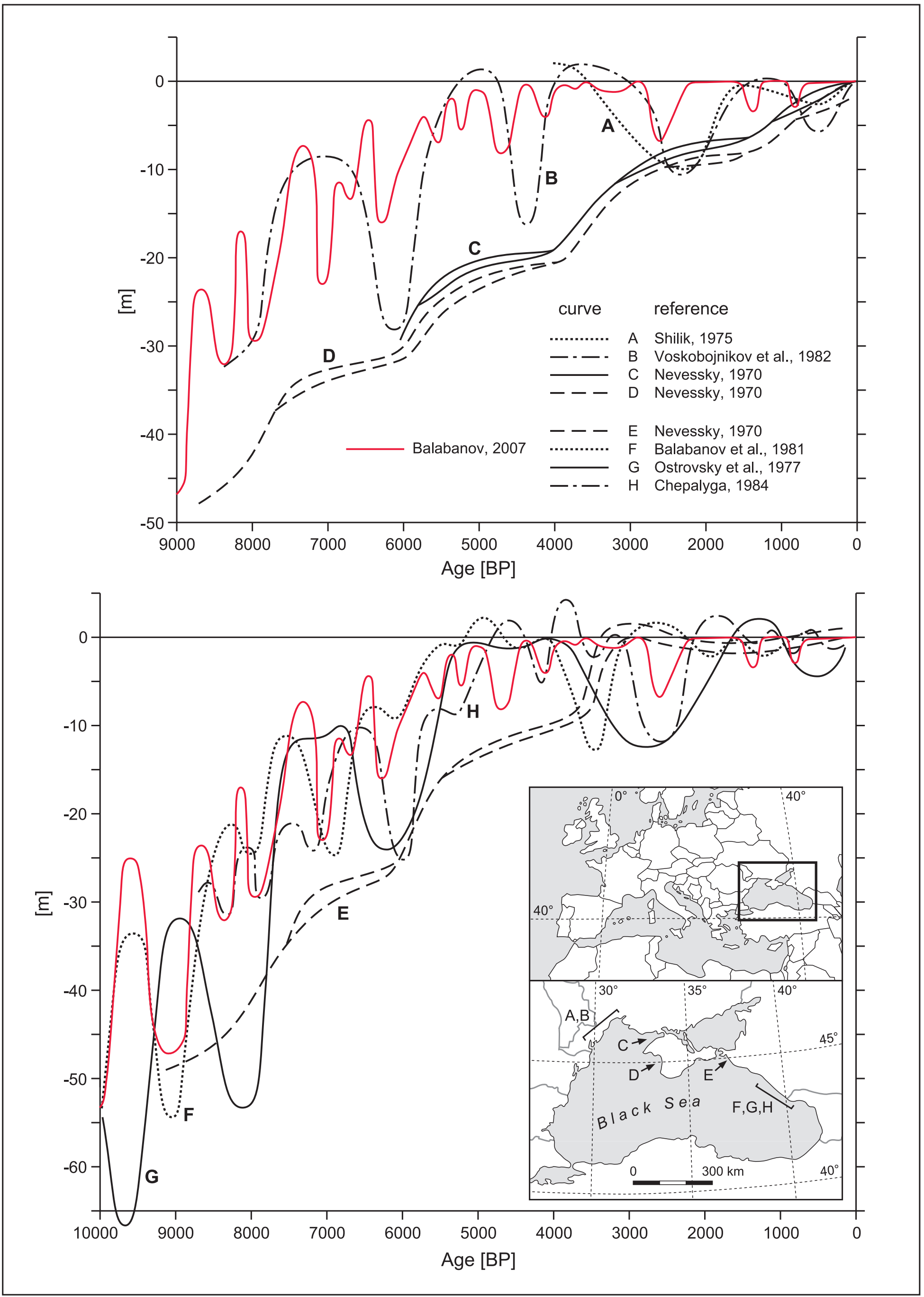
Click here to download high resolution image



Coring Mil 231, Temple of Athena area

8 Cultural debris
7 Wall (Late Bronze Age, Miletus IV)
6 Semiterrestrial facies
5 Littoral facies, with rounded ceramic fragments (Miletus III)
4 Shallow marine facies, with rounded ceramic frgts. (Miletus II-III)
3 Marine facies
2 Transgression facies, with ceramic fragments (Late Chalcolithic, Miletus I)
1 Bedrock (limestone of the Nergiztepe formation)

Figure 6



0
-10
-20
-30
-40
-50
[m]
A
B
C
D
curve
reference
A Shilik, 1975
B Voskobojnikov et al., 1982
C Nevessky, 1970
D Nevessky, 1970
E Nevessky, 1970
F Balabanov et al., 1981
G Ostrovsky et al., 1977
H Chepalyga, 1984
Balabanov, 2007
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Age [BP]
0
-10
-20
-30
-40
-50
-60
[m]
H
E
F
G
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Age [BP]
0°
40°
40°
30°
35°
40°
45°
A,B
C
D
E
F,G,H
Black Sea
0
300 km
40°

Figure 7

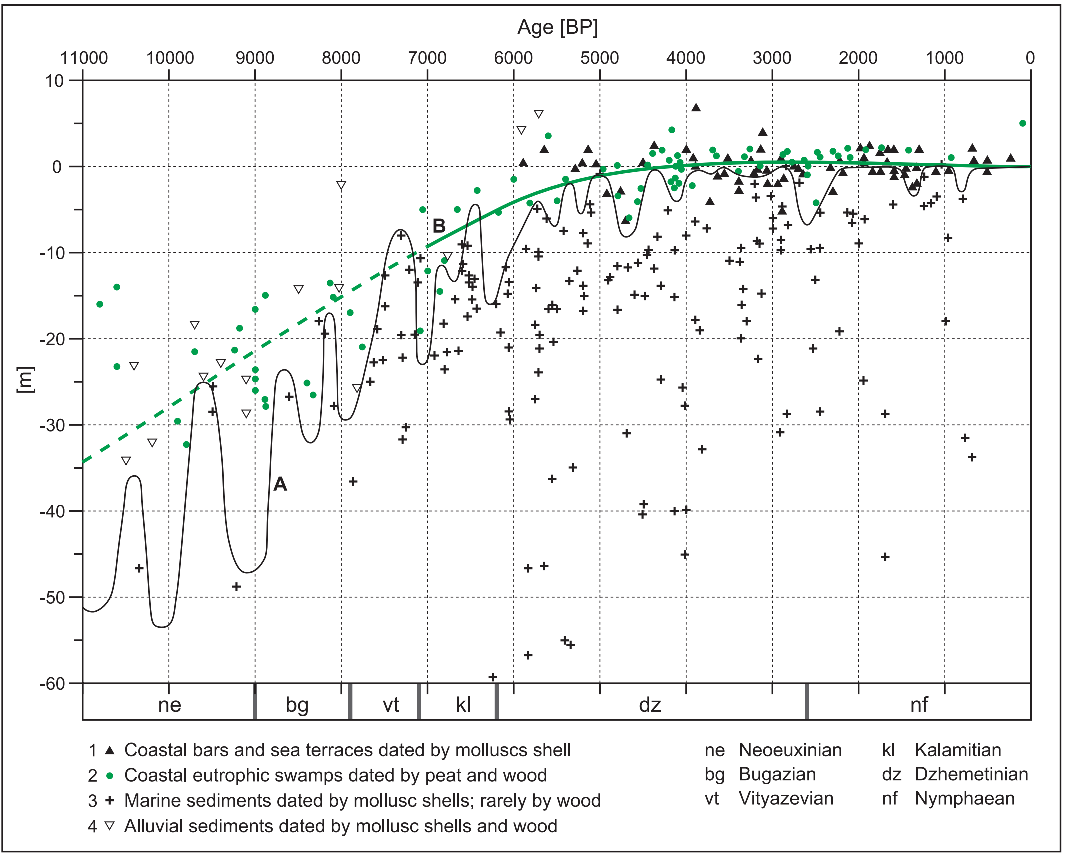
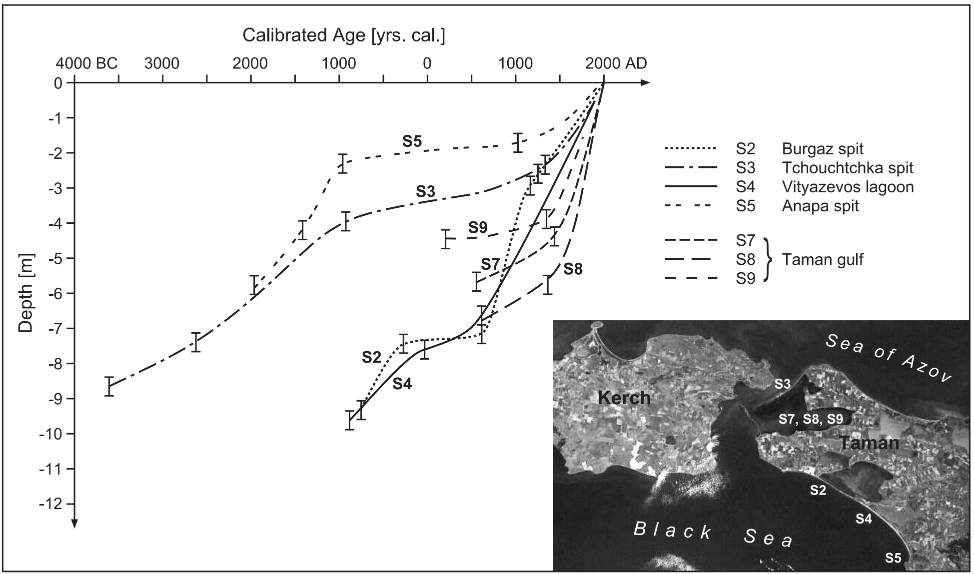
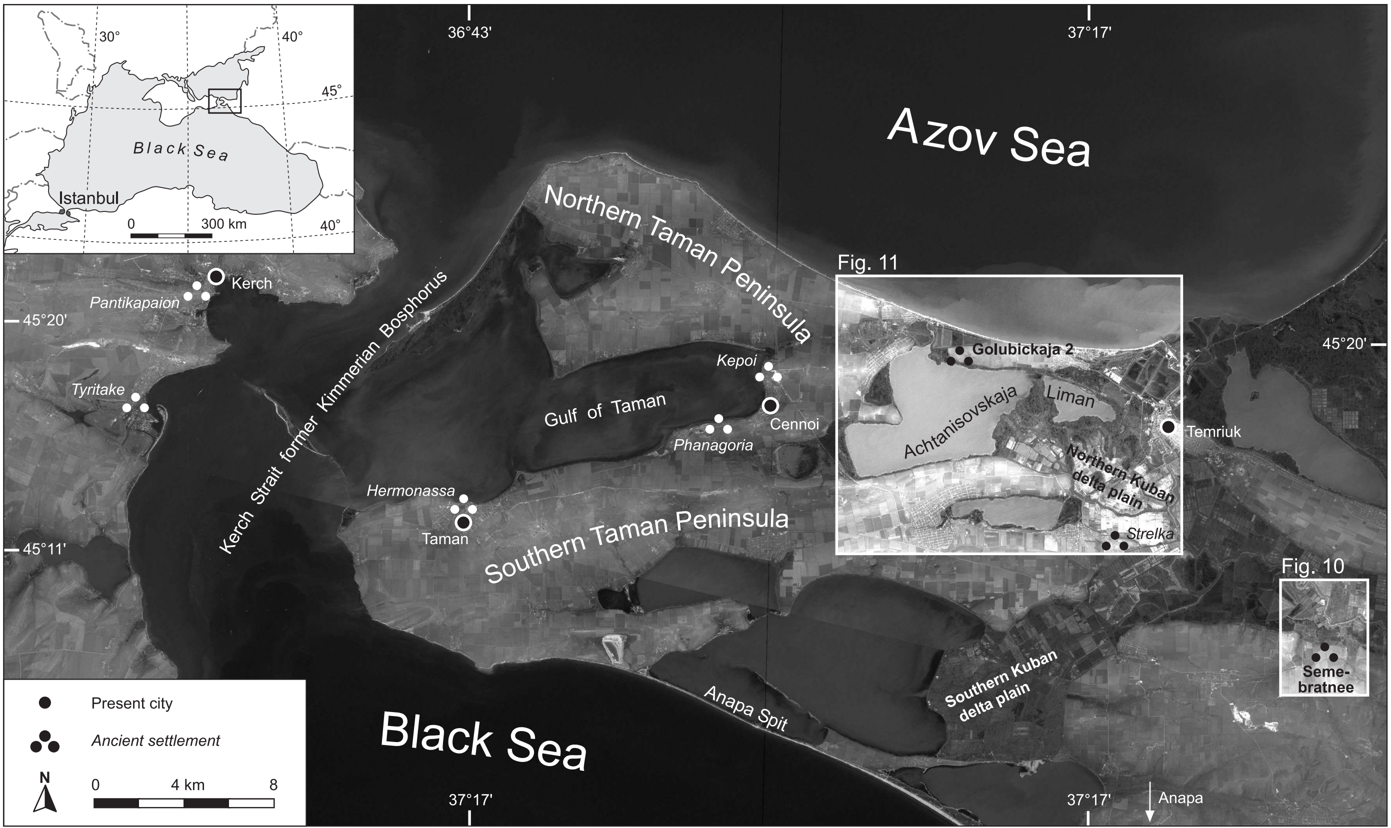

Age [BP]
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
10
0
-10
-20
-30
-40
-50
-60
[m]
A
B
ne
bg
vt
kl
dz
nf
1 ▲ Coastal bars and sea terraces dated by molluscs shell
2 ● Coastal eutrophic swamps dated by peat and wood
3 + Marine sediments dated by mollusc shells; rarely by wood
4 ▽ Alluvial sediments dated by mollusc shells and wood
ne Neoeuxinian
bg Bugazian
vt Vityazevian
kl Kalamitian
dz Dzhemetinian
nf Nymphaean

Figure 8



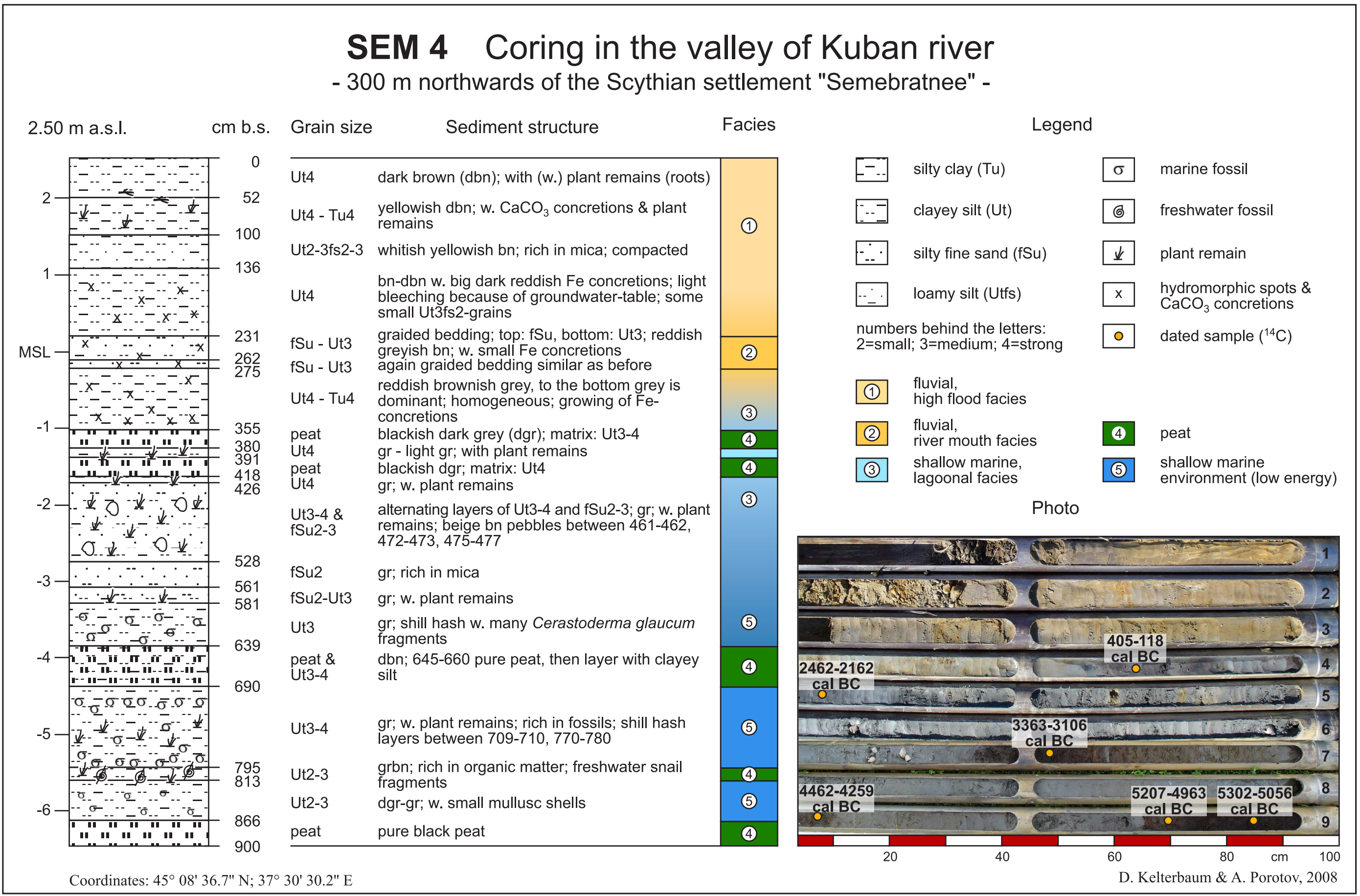
Calibrated Age [yrs. cal.]
4000 BC
3000
2000
1000
0
1000
2000 AD
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
Depth [m]
S5
S3
S9
S7
S8
S2
S4
S2 Burgaz spit
S3 Tchouchtchka spit
S4 Vityazevos lagoon
S5 Anapa spit
S7
S8
S9
Taman gulf
Sea of Azov
S3
Kerch
S7, S8, S9
Taman
S2
S4
S5
Black Sea

Figure 9



30°
40°
45°
Black Sea
Istanbul
0
300 km
40°
36°43'
37°17'
Azov Sea
Northern Taman Peninsula
Fig. 11
Kerch
Pantikapaion
45°20'
Kerch Strait former Kimmerian Bosphorus
Tyritake
Kepoi
Gulf of Taman
Cennoi
Phanagoria
Golubickaja 2
Achtanisovskaja
Liman
Temriuk
Northern Kuban delta plain
45°20'
Hermonassa
Taman
Southern Taman Peninsula
Strelka
45°11'
Fig. 10
Seme-bratnee
Southern Kuban delta plain
Anapa Spit
Black Sea
Present city
Ancient settlement
N
0
4 km
8
37°17'
37°17'
Anapa

Figure 10



SEM 4 Coring in the valley of Kuban river

- 300 m northwards of the Scythian settlement "Semebratnee" -

cm b.s.	Grain size	Sediment structure	Facies
0	Ut4	dark brown (dbn); with (w.) plant remains (roots)	①
52	Ut4 - Tu4	yellowish dbn; w. $CaCO_3$ concretions & plant remains	
100	Ut2-3fs2-3	whitish yellowish bn; rich in mica; compacted	
136	Ut4	bn-dbn w. big dark reddish Fe concretions; light bleeching because of groundwater-table; some small Ut3fs2-grains	
231	fSu - Ut3	graided bedding; top: fSu, bottom: Ut3; reddish greyish bn; w. small Fe concretions	②
262	fSu - Ut3	again graided bedding similar as before	
275	Ut4 - Tu4	reddish brownish grey, to the bottom grey is dominant; homogeneous; growing of Fe-concretions	③
355	peat	blackish dark grey (dgr); matrix: Ut3-4	④
380	Ut4	gr - light gr; with plant remains	
391	peat	blackish dgr; matrix: Ut4	④
418	Ut4	gr; w. plant remains	③
426	Ut3-4 & fSu2-3	alternating layers of Ut3-4 and fSu2-3; gr; w. plant remains; beige bn pebbles between 461-462, 472-473, 475-477	
528	fSu2	gr; rich in mica	
561	fSu2-Ut3	gr; w. plant remains	
581	Ut3	gr; shill hash w. many *Cerastoderma glaucum* fragments	⑤
639	peat & Ut3-4	dbn; 645-660 pure peat, then layer with clayey silt	④
690	Ut3-4	gr; w. plant remains; rich in fossils; shill hash layers between 709-710, 770-780	⑤
795	Ut2-3	grbn; rich in organic matter; freshwater snail fragments	④
813	Ut2-3	dgr-gr; w. small mullusc shells	⑤
866	peat	pure black peat	④
900			

Legend

- silty clay (Tu)
- clayey silt (Ut)
- silty fine sand (fSu)
- loamy silt (Utfs)
- numbers behind the letters: 2=small; 3=medium; 4=strong
- σ marine fossil
- freshwater fossil
- plant remain
- x hydromorphic spots & $CaCO_3$ concretions
- ● dated sample (^{14}C)
- ① fluvial, high flood facies
- ② fluvial, river mouth facies
- ③ shallow marine, lagoonal facies
- ④ peat
- ⑤ shallow marine environment (low energy)

Photo

Coordinates: 45° 08' 36.7" N; 37° 30' 30.2" E

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Figure 11

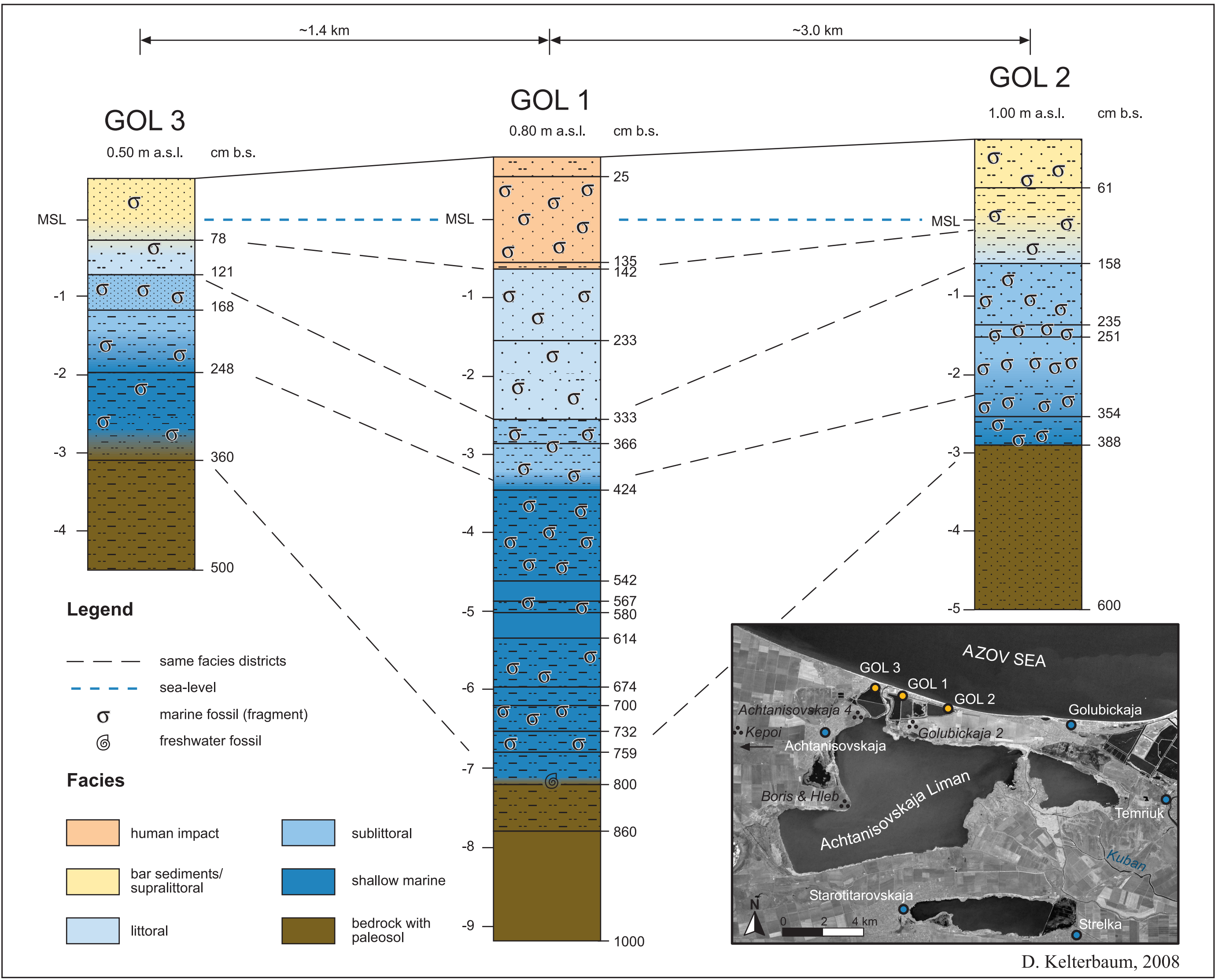
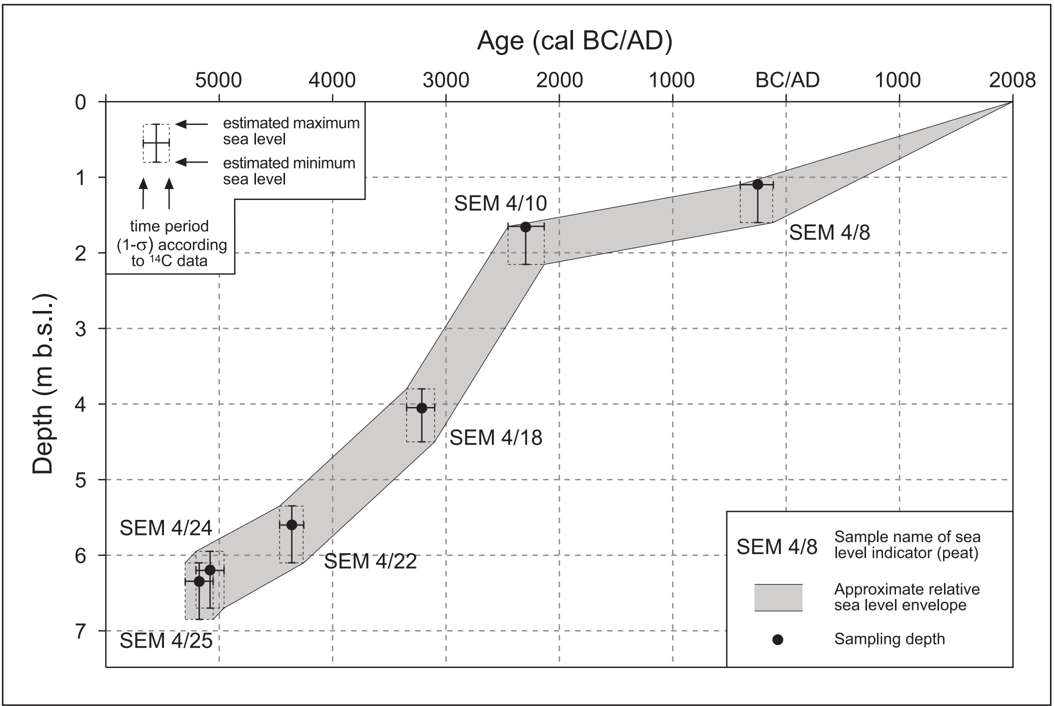

~1.4 km
~3.0 km
GOL 3
0.50 m a.s.l.
cm b.s.
MSL
78
121
168
248
360
500
-1
-2
-3
-4
GOL 1
0.80 m a.s.l.
cm b.s.
25
135
142
233
333
366
424
542
567
580
614
674
700
732
759
800
860
1000
-5
-6
-7
-8
-9
GOL 2
1.00 m a.s.l.
cm b.s.
61
158
235
251
354
388
600
Legend
same facies districts
sea-level
marine fossil (fragment)
freshwater fossil
Facies
human impact
bar sediments/ supralittoral
littoral
sublittoral
shallow marine
bedrock with paleosol
AZOV SEA
GOL 3
GOL 1
GOL 2
Golubickaja
Achtanisovskaja 4
Kepoi
Achtanisovskaja
Golubickaja 2
Boris & Hleb
Achtanisovskaja Liman
Temriuk
Kuban
Starotitarovskaja
Strelka
N
0
2
4 km
D. Kelterbaum, 2008

Figure 12



Age (cal BC/AD)
5000
4000
3000
2000
1000
BC/AD
1000
2008
0
1
2
3
4
5
6
7
Depth (m b.s.l.)
estimated maximum sea level
estimated minimum sea level
time period (1-σ) according to ¹⁴C data
SEM 4/10
SEM 4/8
SEM 4/18
SEM 4/24
SEM 4/22
SEM 4/25
SEM 4/8
Sample name of sea level indicator (peat)
Approximate relative sea level envelope
Sampling depth

Photo 1
Click here to download high resolution image

Table 1

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