



Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

The Late Holocene evolution of the Black Sea – a critical view on the so-called Phanagorian regression

Eric Fouache^{a,*}, Daniel Kelterbaum^{b,*}, Helmut Brückner^b, Gilles Lericolais^c, Alexey Porotov^d, Vassily Dikarev^d

^a University of Paris-Ouest-Nanterre-La Défense, IUF, EA 375 GECKO and UMR 8591 Laboratoire de Géographie physique, 200 Avenue de la République, 92001 Nanterre CEDEX, France

^b Institute of Geography, Universität zu Köln, Albertus-Magnus-Platz, D-50923 Köln, Germany

^c IFREMER - Centre de Brest, Géosciences Marines - BP 70, F-29280 Plouzane cedex, France

^d Moscow State University, Geography Faculty, 119991, Moscow, GSP-1, 1 Leninskiye Gory, Russia

ARTICLE INFO

Article history:

Available online 21 April 2011

ABSTRACT

Throughout its geologic history, the Black Sea experienced major sea level changes accompanied by severe environmental modifications, including geomorphologic reshaping. The most spectacular changes were driven by the Quaternary glaciations and deglaciations that reflect responses to Milankovitch cycles of 100 and 20 ky periodicity. Major sea level changes were also considered for a shorter and more recent cyclicity. The concept of the Phanagorian re- and transgression cycle, supposedly with a minimum sea level stand of 5–6 m below its present position in the middle of the 1st millennium BC, was established in 1963 by Fedorov for the Black Sea region. It was based on archaeological and palaeogeographical research conducted around the ancient Greek colonies of the Cimmerian Bosphorus, in particular at the name giving site of Phanagoria, where underwater prospection had revealed the presence of a large number of submerged relics of the Classical Greek era.

Analyses of sediment cores as well as ¹⁴C-dated fossil coastal bars in the western and southern parts of Taman Peninsula show that contemporary coastal bars are related to different sea levels. The dissymmetry can reach up to 6 m around 500 BC. This and more evidence from drill cores confirms that on Taman Peninsula many of the apparent sea level changes are tectonically induced. The subsidence may have been initiated by the release of gas from mud volcanoes inherited along anticline axes. Other observations around the Black Sea confirm that submerged archaeological sites correspond to areas where subsidence has taken places, while the so-called Holocene highstand – said to have been located above the present-day sea level – is associated with uplift areas (triggered by the ongoing Caucasus orogeny). Recent oceanographic research carried out in the Black Sea area shows that since the Black Sea was reconnected with the Mediterranean Sea (i.e., 7500 ¹⁴C BP at the latest), both marine water bodies have been in equilibrium. This fact and arguments from archaeology, history, hydrodynamics etc. lead us to question the existence of the Phanagorian regression. It is important to note that none of the sea level curves established for the (eastern) Mediterranean shows a comparable regression/transgression cycle of several metres during the 1st millennium BC.

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1. Introduction and historical background

The Black Sea is one of the largest enclosed seas in the world experiencing major sea level changes accompanied by severe environmental modifications. The most spectacular changes were driven by the Quaternary glaciations and deglaciations that reflect responses to Milankovitch cycles of 100 ky (eccentricity) and 20 ky

* Corresponding authors. Fax: +33 2 35 65 41 00, +49 221 470 5124.

E-mail addresses: eric.g.fouache@wanadoo.fr (E. Fouache), kelterbd@uni-koeln.de (D. Kelterbaum), h.brueckner@uni-koeln.de (H. Brückner).

(precession) periodicity. These sea level fluctuations endowed the restricted channels of the Bosphorus and Dardanelles with the power to control the Black Sea's connection to the Mediterranean. When global sea level dropped below the Bosphorus sill, water level in the Black Sea varied according to regional conditions independent of those in the world ocean. Perhaps the most important consequence of these lowstands was the interruption of Mediterranean inflow into the Black Sea, which, lacking any saline contribution, gradually became a giant brackish to freshwater lake (Panin and Popescu, 2007; Soulet et al., 2010). The last 20 ky cycle of the Black Sea is probably one of the most puzzling cycles studied

presently. Among others, the sea level history of the Black Sea for the last eight millennia has been discussed in many publications (Nevesky, 1967; Ross et al., 1970; Degens and Ross, 1972; Fedorov, 1977; Ostrovsky et al., 1977; Dzhanlidze, 1980; Chepalyga, 1984; Balabanov and Izmailov, 1988; Izmailov et al., 1989; Artyukhin et al., 1989; Balabanov 2007, 2009; Panin and Popescu, 2007; etc.). The documented and/or postulated sea level changes reflect the general trends in the evolution of the basin and the regional peculiarities of the Holocene transgression.

Balabanov and Izmailov (1988) and Balabanov (2007, 2009) have described two principal patterns that according to their interpretation define the regional distinction between the Black Sea and other seas, e.g. the Mediterranean: (a) the small magnitude of the tectonic deformation of the Holocene synchronous shorelines on the continental margin of the Black Sea, and (b) short sea level fluctuations of several metres superimposed on the general transgression trend. The first one provided a basis for the sea level curve for the Black Sea region. Its principal pattern and database have been discussed recently by Balabanov (2007, 2009). The second one is related to the trace of rhythmic fluctuations of the sea level which are identifiable in the sedimentary record and coastal geomorphology of the Black Sea littoral.

Despite some evidence of such fluctuations for the past eight millennia, the number and amplitude of the intermediate regressions vary in different regions and are still under discussion. Among these sea level variations, much attention was focused on the so-called “Phanagorian regression”, supposedly reflecting a major sea level change in the middle of the 1st millennium BC. The aim of this study is to reconstruct a sea level curve of the Taman Peninsula, taking into account local tectonics which are widespread around the Black Sea (Giosan et al., 2006) – thereby clarifying the existence or non-existence of the so-called Phanagorian regression.

2. The Phanagorian regression

The concept of the Phanagorian regression was established in 1963 when Fedorov published his thesis on the palaeogeographic evolution of the Black Sea region (Fedorov, 1963; Nikonov, 1998). According to different sources, Fedorov proposed the most probable level of the Black Sea in the middle of the 1st millennium BC at a depth of 5–6 m below its present position (Fedorov, 1977). This assumption was based on submerged archaeological remains in the Gulf of Taman, first noticed at the drowned lower city of Phanagoria. Phanagoria is known from written sources to have been founded by Greeks from Miletus (now in Turkey) around the 7th century BC, as was Hermonassa, Kepoi and several other small settlements on Taman Peninsula (Paromov, 2006; Zhuravlev et al., 2010). Today, the so-called lower city of Phanagoria is located in the Gulf of Taman at a depth of 2 to 0 m below present sea level (b.s.l.) (Fouache et al., 2000a, b, 2004).

Additionally, the assumed fall in sea level was supported by the presence of cultural layers of Late Bronze/Early Iron Age on the surface of middle Holocene beach ridges that were traced at different places of the Black Sea margin. There are indeed other settlements on Taman Peninsula and Kerch Peninsula, some parts of which are nowadays submerged, e.g., Nymphaeum (Porotov, 2007) and at Cape Panagia (Kondrashov, 1995).

The problem was to interpret this phenomenon in the context of sea level evolution. In the scientific community of the former Soviet Union, only the concept of a lower sea level was taken into account for the time of the foundation of these ancient Greek settlements. Since, due to other findings, sea level was presumed to have been higher before that time, a major marine regression was presumed as being the most probable reason.

In the following decades the idea of a rapid sea level regression/transgression cycle during the 1st millennium, with the lowest position around 500 BC, was perpetuated (Shilik, 1975a, b, 1997; Balabanov and Izmailov, 1988; Izmailov et al., 1989). While the principal concept as such was accepted in some parts of the scientific community, the only discrepancies were the chronology boundaries and the amplitude, as pointed out by Porotov (2007). While 4–5 m below present sea level is a medial value currently attributed to the Phanagorian regression, the values vary along the coasts of the Black Sea from 2 m to 7–9 m b.s.l. and even more (e.g. Shilik, 1975a, b; Krustev et al., 1990; see Fig. 1).

The compilation in Fig. 1 gives a detailed overview of different sea level curves developed for the Black Sea. It is obvious that there are major discrepancies between the authors concerning the shape of the curves. Nevertheless, with the exception of Nevesky (1970), all show a major regression/transgression cycle in the 1st millennium BC, with a vertical sea level oscillation of up to 11 m.

The existing assessments of the low position of the relative sea level during the so-called Phanagorian regression belonged to three principal types of sea level indicators: geomorphological, lithological and archaeological. This is well summarised by Balabanov (2009).

The extensive study of the Holocene sedimentary complex along all continental margins of the Black Sea reveals the wide distribution of peat bog facies with ¹⁴C-age estimates of 2.0–3.0 ka BP at/or below the present sea level position; they lie upon coastal marine sands or liman (coastal lakes) silty clays. This swamp facies is often buried by a transgressive sedimentary sequence, reflecting the increase of accommodation space in deltaic/lagoonal environments and the formation and shifting of a new generation of beach ridges on open marine coasts.

Several examples of late Holocene sedimentary sequences for the eastern part of the Black Sea coastline were studied by Balabanov (2009) with special attention to Pitius Peninsula, Imeretinka's lowland (southern outskirts of present-day Sochi) and the coastal region of Abkhazia. There, the buried swamp/lagoon peat occurs at a depth of 2.5–4.5 m (up to 8 m) below present sea level.

More accurate data about a possible drop in sea level during the 1st millennium BC were recorded from the Colchis (Georgia). The review of ¹⁴C-dated relict peat layers in different swamp areas with regard to their present position does, however, not indicate a possible relative fall in sea level of more than 2–3 m (Dzhanlidze, 2007). This estimate is in good agreement with previous conclusions about the possible change in sea level during the late Holocene on the eastern coasts of the Black Sea (Dzhanlidze, 1980) despite the existence of more extreme values of a sea level fall during this period (Balabanov and Gey, 1981; Balabanov et al., 1981; Balabanov and Gaprindashvili, 1987; Balabanov and Izmailov, 1988; Nikonov et al., 1997; and others).

Traces of the disruption of the generally transgressive sequence by superimposed sea level fluctuations have been revealed in the sedimentary structure of different locations along the north-western part of the Black Sea (Balandin and Trashchuk, 1982; Inozemtsev et al., 1984; Molodykh et al., 1984; Gozhik and Novosel'sky, 1989). In contrast to this opinion, several other studies on the topic that were recently published (e.g. Fouache et al., 2004; Kaplin and Selivanov, 2004; Giosan et al., 2006, 2009; Porotov, 2007; Lericolais et al., 2007, 2009; Brückner et al., 2010) question the concept of the Phanagorian regression.

3. Geological and geomorphological setting of Taman Peninsula

The Taman Peninsula in south-western Russia is situated between the Black Sea in the south and the Sea of Azov in the north

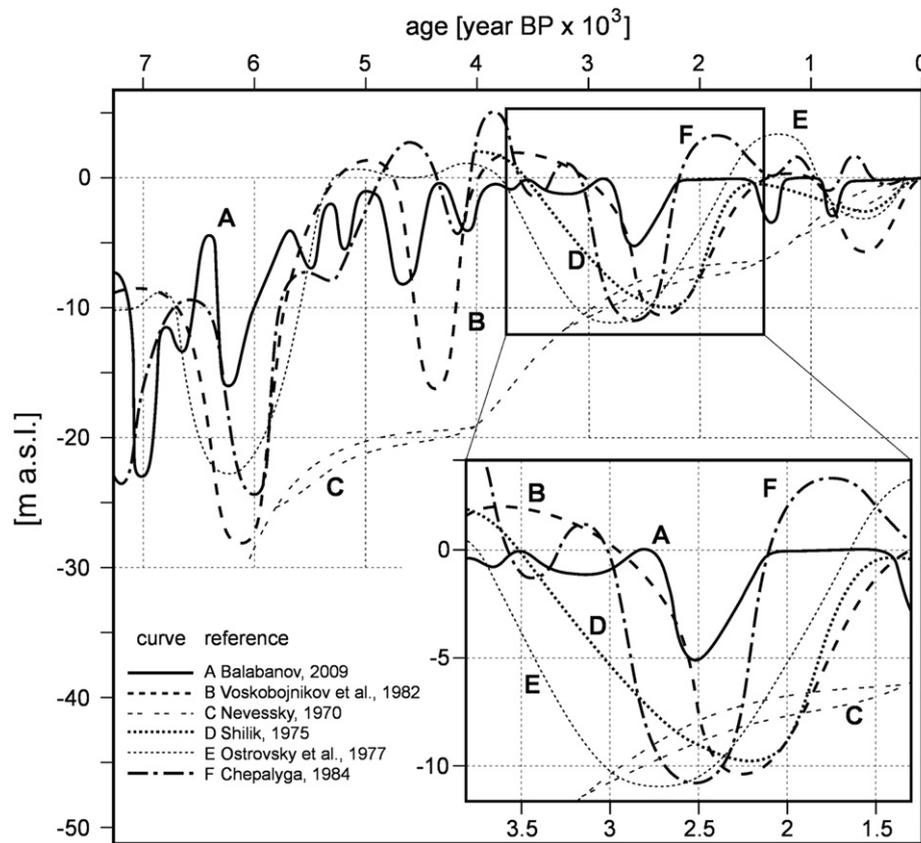


Fig. 1. Sea level curves of the Black Sea as noted by various authors (slightly changed after Pirazzoli, 1991). It is obvious that most of the curves have major transgression/regression cycles ("wiggles") which do, however, vary significantly. The inserted map focuses on the so-called Phanagorian regression featured by all of the authors except for Nevesky (curve C). In the compiled curves the regression maximum varies from -5 m to -11 m.

(Fig. 2). To the west the Strait of Kerch represents the border to Crimea (Ukraine). This small sea passage was called the 'Cimmerian Bosphorus' in Antiquity. Taman's topographic border to the east is formed by the recent delta plain of the Kuban (ancient name: Hypanis). Near Strelka the river is divided into an old southern branch which once debouched into the Black Sea, and the present-day northern branch which drains into the Sea of Azov.

Geologically, the Taman Peninsula is made up of Miocene and Pliocene rocks which are in many parts covered by Pleistocene loess deposits. The basement mostly consists of clay, sand and locally limestone. Compression tectonics, induced by the Alpine orogeny, provoked the emergence of these rocks and their folding along anticlines and synclines (Shnyukov et al., 1981; Saintot and Angelier, 2000). The whole peninsula is fractioned into tectonic blocks with slightly differing vertical and horizontal movements. The current relief is a result of the ongoing tectonics as well as erosional processes (Blagovolin, 1962; Blagovolin and Pobedonostsev, 1973).

Intensive neotectonic deformation is described in the Eastern Black Sea and around the Taman Peninsula (Fig. 3, after Meisner et al., 2009). Significant subsidence of the Eastern Black Sea during the Pliocene-Quaternary is recorded from seismic profiling as well as rapid growth of diapirs. Some of these diapirs, reflected in the seabed relief as swells, caused a significant reduction of the thickness of the Miocene strata. Such geomorphological features of mud volcano diapirism along the anticlinal axes (Shnyukov et al., 1981) produce up to 150 m high eruptive and sometimes destructive cones. As a whole, the landscape can be described as an undulating one, supplemented by several lagoons within the synclinal structures and mud volcanoes within the anticlinal structures.

The coastal geomorphology is dominated by wave action, showing typical features of a microtidal regime. In the only weakly consolidated bedrock, steep cliffs have formed due to strong abrasion, especially in the western part of the peninsula (Fig. 4). Sea level rise during the last decades intensified the abrasion processes. Sand barriers and spits have been built up by the longshore currents; thus, nearly all of the former open marine embayments were transformed into lagoons (e.g., Akthanizovskaya Liman, Blagoveschenskaya Liman; see Fig. 4), some of which are nowadays silted up due to sediment input by the prograding Kuban delta (Brückner et al., 2010).

4. Methodology

This paper compares results from Taman Peninsula with data from other places in the Black Sea area. Over the last years, several cores have been obtained from different geoarchives of the study area (Fig. 2). Archival material collected at the end of the 1960s by Nevesky (1967) for the Russian Shirshov Institute of Oceanology was used as well. This material was kindly provided by Professor Nevesky.

4.1. Cores

The cores (Fig. 2) were done with the percussion coring device Cobra 248 of Atlas Copco Co. using augerheads with diameters of 6 cm, 5 cm and 3.6 cm, respectively. A maximum depth of 12 m below present surface (b.s.) was reached. The coring strategy was based on transects through nearshore geoarchives, chosen by field survey and supported by satellite image interpretation. Position

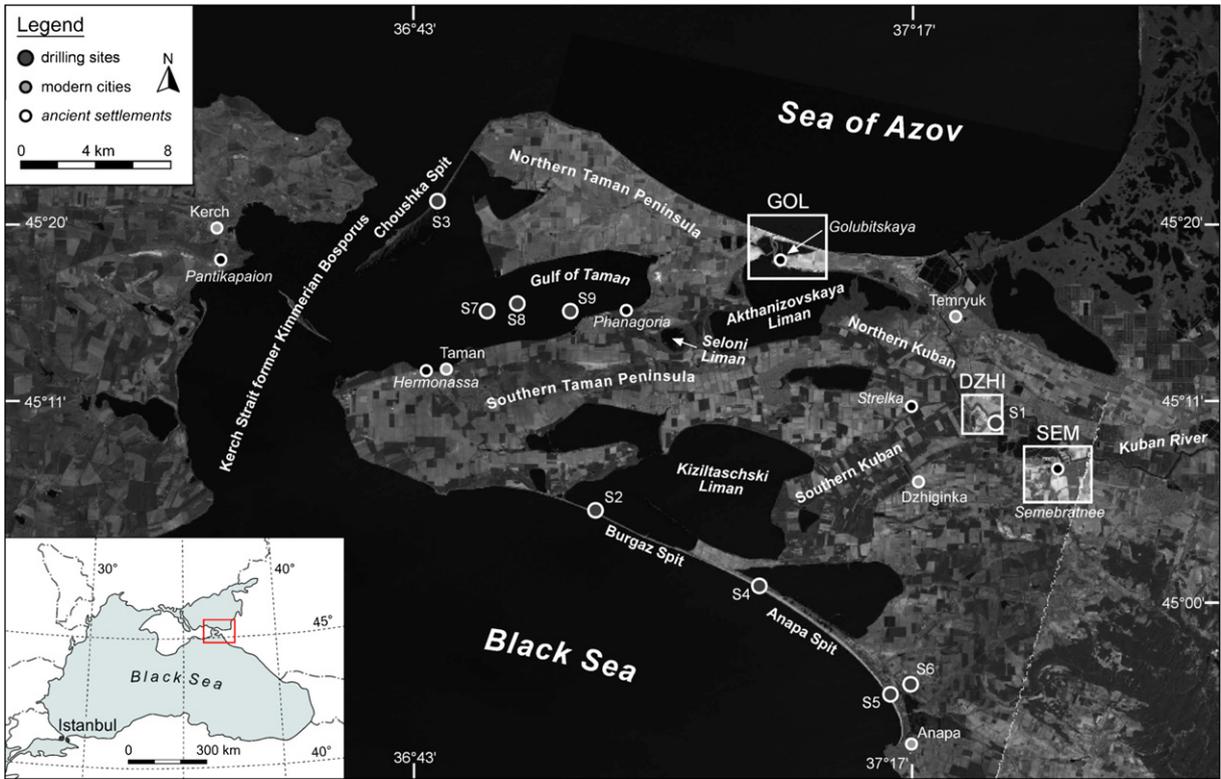


Fig. 2. Overview of the Taman Peninsula with the settlements and coring sites mentioned in the text. The areas of interest for this study are highlighted. Coring sites are indicated by a white dot. Compilation based on Landsat 7 and SRTM data.

and elevation of each coring site were measured by DGPS with a vertical resolution of less than 2 cm (Leica Geosystems Co.; Leica 530 SR). On site, the vibracores were studied for colour (Munsell Soil Color Charts), grain size, roundness and texture as well as for

macrofaunal and -floral remains. Former fieldwork carried out by Nevevsky (1967) was integrated.

Multi-proxy geochemical analyses were done in the laboratories of the Faculty of Geography at Philipps-Universität Marburg

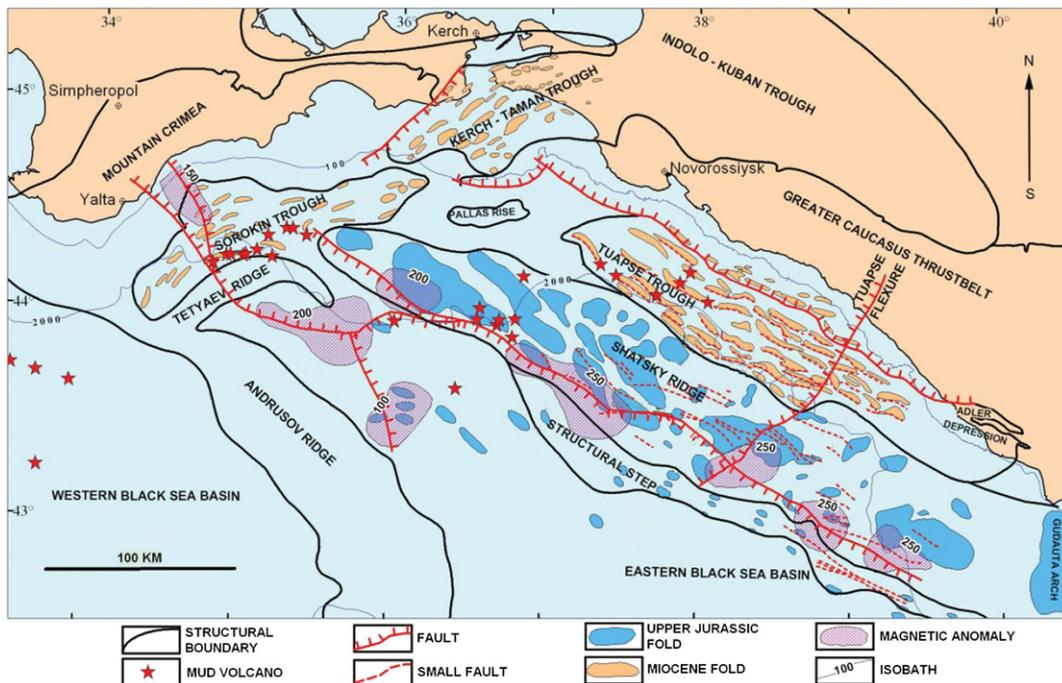


Fig. 3. Major tectonic features of the Eastern Black Sea region with location of mud volcanoes and magnetic anomalies. Isobaths are in metres. Modified from Meisner et al. (2009).



Fig. 4. Active cliffs and palaeo-cliffs of Taman Peninsula. Left photograph: Strong cliff erosion at the present shores of the Sea of Azov close to Peresip (height of cliff >40 m). In the background: The Golubitskaya sand barrier separates the Akthanizovskaya Liman from the Sea of Azov. Right photograph: Palaeo-cliff structure bordering the Soleni Liman in the centre of the Taman Peninsula.

(Germany) to support the determination of facies changes (Vött et al., 2002, 2007a, b), but they will not be discussed in this study. At first, samples were air-dried and hand-pestled. Calcium carbonate content was determined after the Scheibler method. The values of pH were determined in water and in a KCl solution. Combined with the grid of cores, the vertical and horizontal variations of the different milieus of deposition – marine, littoral, lagoonal, limnic, fluvial – are the basis for the reconstruction of the palaeogeographic evolution and palaeo-sea level stands in the area of research.

In a geoarchaeological context, the proper calibration and dendrochronological correction of the radiocarbon ages plays a major role, as at a given archaeological site, the ^{14}C -age estimates have to be compatible with the chronologies provided by the archaeological and the historical sciences. In this study, ^{14}C dating included mollusc shells, plant remains, and peat. The ages determined on mollusc shells were corrected for an average marine reservoir effect of 408 years (Stuiver and Braziunas, 1993). However, it has to be considered that the palaeo-reservoir effect is still unknown and may have varied widely in different marine environments, such as lagoons, coastal swamps or littoral zones, and as well in different seas (Mediterranean, Black Sea, Sea of Azov). AMS- ^{14}C dating of ostracod and gastropod shells from the south-western Black Sea cores suggest variable reservoir ages for the late glacial Black Sea basin from 0 to 1450 yr (Kwiecien et al., 2008, 2009). Fontugne et al. (2009) propose that chemoautotrophic productivity is contributing to the sedimentary organic matter, explaining the variation of reservoir ages evident during the Holocene in the anoxic Black Sea. Additionally, the discharge of rivers (Table 1) and their input of ^{12}C plays a role, especially in semi-enclosed basins such as the Black and Azov seas. The ^{14}C -age estimates presented in this

study were taken from those vibracores (see Fig. 2) that contained the most reliable sea level indicators. All dates are calibrated ages in cal BC/AD [calibration with Calib 6.0.1; CALIB v6.0.1 - <http://calib.qub.ac.uk/calib/download/calib601.zip>] (Reimer et al., 2009). The dates concerning the archival material of the Shirshov Institute of Oceanology collected in 1967 by Neveysky are integrated in the coring in the Gulf of Taman (see Fig. 2, Tables 2 and 3)

4.2. Sea level indicators

Archaeological remnants in the Gulf of Taman can be used for the determination of a widespread submersion of the area since Late Antiquity (Abramov, 1999; Blavatsky, 1985). So far, however, precise archaeological indicators, such as jetties and fishponds, have not been found on Taman Peninsula. It was also impossible to apply the methods proposed by Flemming (1979), Pirazzoli (1979), Morhange et al. (2001) and in Turkey (Fouache et al., 2000a) and Croatia (Fouache et al., 2000b) for the determination of the palaeo-sea level at a given time. Therefore, the focus was on (a) paralic peat layers, (b) molluscs *in situ* and (c) the identification of characteristic shell assemblages (thanatocoenosis fauna).

The relative position of sea level for paralic peat layers assumes a vertical difference of ± 0.5 m due to compaction and depositional factors (Pirazzoli, 1996; Behre, 2003). The relative position of *in situ* molluscs is estimated as +1 m and -0.5 m, respectively. Thanatocoenosis fauna is and was accumulated around mean sea level, reflecting an average position of (palaeo-) sea level with an error margin of ± 1 m (this is why envelopes are used in the sea level curves).

Extracted shell material was palaeo-environmentally interpreted according to Kaplin et al. (2001) by T. Yanina at the

Table 1
Average annual discharge of the most important rivers that flow into the Black Sea basin with maximum, minimum and mean values. Sources: Vorosmarty et al., 1998; Global River Discharge Database (updated 02/13/2010): <http://www.sage.wisc.edu/riverdata/index.php?qual=32>.

River (gauge station)	Period of measurements	Discharge (av. annual)		
		max (m ³ /s)	min (m ³ /s)	mean (m ³ /s)
Danube (Ceatal Izmail, ROM)	1921–1984	9417.17 (1941)	4023.58 (1921)	6499.0
Dnieper (Hydroelectr. Plant, UKR)	1952–1984	2656.33 (1970)	800.75 (1954)	1482.3
Don (Razdorskaya, RUS)	1891–1984	1657.42 (1942)	300.0 (1972)	790.4
Rioni (Sakochakidze, GEO)	1965–1984	523.83 (1978)	309.75 (1969)	408.6
Dniester (Bendery, UKR)	1965–1984	610.0 (1980)	234.08 (1984)	375.2
Kuban (Tikhovsky, RUS)	1965–1984	446.83 (1968)	186.42 (1969)	317.9
Kizilirmak (Inozu, TUR)	1976–1983	243.67 (1981)	171.75 (1979)	201.8
Sakarya (Botbasi, TUR)	1976–1983	481.0 (1981)	54.0 (1977)	192.3
Southern Bug (Aleksandrovka, UKR)	1965–1984	198.04 (1980)	68.58 (1975)	110.3
Total amount (m ³ /s)		16,234.29	6148.91	10,377.8
Total amount (km ³ /year)		511.96	193.91	327.3

Table 2

^{14}C dates. All ages are calibrated with the calibration software Calib 6.0.0 (Reimer et al., 2009). For marine carbonates the reservoir age of 408 years (Hughen et al., 2004) was applied with delta R of 5 ± 35 years according to Jones and Gagnon (1994). Abbreviations: PR = plant remains, M = marine mollusk shell *in situ*.

Sample ID (depth in m b.s.l.)	Lab. no.	$\delta^{13}\text{C}$	material	^{14}C -Age			Calibrated ages	
				(BP)	\pm	1 s	1 Sigma max; min (cal BP)	2 Sigma max; min (cal BC/AD)
DZHI 2/4 (-0.50)	UGAMS 03178	-27.13	PR	301	\pm	24	305; 428	1495 AD; 1650 AD
DZHI 2/8 (2.10)	UGAMS 03179	-26.21	PR	1015	\pm	24	925; 955	979 AD; 1117 AD
DZHI 2/10 (3.05)	UGAMS 04142	+0.27	M	1937	\pm	29	1410; 1529	351 AD; 591 AD
DZHI 2/20 (7.30)	UGAMS 03180	-2.98	M	4790	\pm	25	4961; 5173	3289 BC; 2949 BC
DZHI 2/29 (12.50)	UGAMS 03181	-28.30	PR	7521	\pm	30	8215; 8401	6452 BC; 6266 BC
DZHI 2/T1 (10.20)	UGAMS 03182	-28.30	PR	5810	\pm	37	6563; 6666	4769 BC; 4549 BC
DZHI 2/T8 (10.65)	UGAMS 03183	-27.55	PR	6511	\pm	27	7419; 7459	5533 BC; 5381 BC
GOL 1/4 (1.00)	UGAMS 04137	-5.8	M	2201	\pm	35	1728; 1855	26 AD; 285 AD
GOL 1/10 (2.97)	UGAMS 03184	-1.68	M	3347	\pm	24	3140; 3275	1378 BC; 1120 BC
GOL 1/14 (4.20)	UGAMS 03185	-0.87	M	4013	\pm	24	3951; 4084	2198 BC; 1932 BC
GOL 1/22 (6.55)	UGAMS 03186	-1.09	M	6015	\pm	26	6370; 6483	4588 BC; 4355 BC
GOL 1/24 (7.05)	UGAMS 03187	-0.62	M	6722	\pm	25	7197; 7297	5400 BC; 5204 BC
GOL 2/10 (2.89)	UGAMS 04140	+2.06	M	3826	\pm	28	3699; 3830	1945 BC; 1686 BC
GOL 3/9 (2.61)	UGAMS 03188	-29.24	PR	2673	\pm	26	2753; 2785	895 BC; 799 BC
GOL 3/11 (3.31)	UGAMS 03189	-3.02	M	4356	\pm	26	4415; 4535	2685 BC; 2421 BC
SEM 4/8 (2.00)	LU 5847	-27.0	PR	2240	\pm	110	2354; 2067	743 BC; 3 AD
SEM 4/10 (2.30)	LU 5846	-27.4	PR	3830	\pm	110	4411; 4091	2573 BC; 1965 BC
SEM 4/18 (4.83)	LU 5831	-27.0	PR	4540	\pm	60	5312; 5055	3496 BC; 3026 BC
SEM 4/22 (6.45)	LU 5848	-28.5	PR	5520	\pm	100	6411; 6208	4582 BC; 4055 BC
SEM 4/24 (6.97)	LU 5845	-25.8	PR	6120	\pm	70	7156; 6912	5281 BC; 4845 BC
SEM 4/25 (7.23)	LU 5849	-27.1	PR	6220	\pm	100	7251; 7005	5464 BC; 4859 BC

Geographical Faculty of Moscow State University. Conventional radiocarbon dating was performed at the Geological Institute of the Russian Academy of Sciences and at the Geographical Faculty of Moscow State University, and AMS- ^{14}C dating at the Centre for Applied Isotope Studies (CAIS), University of Georgia, Athens GA (USA) (Tables 2 and 3).

5. Results – sea level curves from Taman Peninsula

5.1. Coring results and interpretation

Several boreholes were drilled on the Taman Peninsula down to 12 m b.s. (Fig. 2). A first set consisted of six cores (S1–S6): one in the Kuban delta (S1), one each on Burgaz Spit (S2) and Choushka Spit (S3), and three on Anapa Spit (S4, S5 and S6).

Core S1 (Fig. 2), located in the Kuban delta, contains peat at the base, overlain by marine sediments of a semi-closed embayment topped by deltaic sediments (Fouache et al., 2000a, b, 2004). Palynological analysis confirms that there was a marine environment during the Greek colonisation (Bolikhovskaya et al., 2004). The radiocarbon age of the basal peat (5940 ± 50 BP, uncalibrated age) indicates that the maximum landward inundation of the sea occurred during that time. The other cores S2–S6 show an alternation between sandy biotrititic sediment, characteristic of beaches, and mainly clayey sediments rich in shells, characteristic of open marine conditions (S2–S6; all in Fig. 2). The biggest palaeogeographical change since Antiquity has taken place in the Gulf of Taman, where most parts of the former city of Phanagoria are now submerged.

A second set of cores was carried out in the Kuban delta plain, the Golubitskaya sand spit system, the Soleni Liman and on Anapa

Table 3

Radiocarbon dates obtained on mollusc sample M (bs) = mollusc bulk sample; M = mollusc (single valve), (CG = *Cerastoderma glaucum*, OE = *Ostrea edulis*, ChG = *Chione gallina*, ChLG = *Chlamys glabra*, SV = *Solen vagina*, LL = *Loripes lacteus*, AO = *Abra ovata*) at the Geological Institute of the Russian Academy of Sciences (GIN) and at the Geographical Faculty of Moscow State University (MGU). All ages are calibrated with the calibration software Calib 6.0.0 (Reimer et al., 2009). For marine carbonates the reservoir age of 408 years (Hughen et al., 2004) was applied with delta R of 5 ± 35 years according to Jones and Gagnon (1994).

Sample ID (depth b.s.l.)	Lab. no.	material	^{14}C -Age			Calibrated ages	
			(BP)	\pm	1 s	1 Sigma max; min (cal BP)	2 Sigma max; min (cal BC/AD)
S2 (3.2–3.5)	GIN-9934	M (bs), OE, CG, ChLG	1130	\pm	100	782; 568	1059 AD; 1431 AD
S2 (3.6–3.8)	GIN-9935	M (bs), OE, ChG, CG	1380	\pm	90	1031; 812	812 AD; 1235 AD
S2 (7.8–8.0)	GIN-9939	M, CG	2080	\pm	200	1870; 1409	191 BC; 716 AD
S2 (8.1–8.2)	GIN-9938	M, CG	2820	\pm	110	2702; 2417	867 BC; 339 BC
S2 (10–10.3)	GIN-9937	M, CG	3180	\pm	290	3373; 2670	1763 BC; 767 BC
S3 (2.8–3.0)	MGU-1504	M (bs), CG, ChG, SV	1260	\pm	60	877; 730	1024 AD; 1284 AD
S3 (4.2–4.5)	MGU-1520	M (bs), CG, ChG, LL	3390	\pm	150	3431; 3044	1657 BC; 895 BC
S3 (7.7–8.0)	MGU-1502	M (bs), CG, MG, ChG	4700	\pm	150	5208; 4787	3377 BC; 2561 BC
S3 (9.0–9.3)	MGU-1501	M (bs), CG, ChG	5430	\pm	120	5917; 5647	4165 BC; 3607 BC
S4 (6.7–7.0)	MGU-1575	M (bs), CG, LL, ChG	1930	\pm	60	1547; 1382	305 AD; 637 AD
S4 (7.8–8.1)	MGU-1565	M (bs), CG, AO	2660	\pm	60	2466; 2266	642 BC; 196 BC
S4 (10–10.3)	MGU-1574	M (bs), CG, AO	3370	\pm	45	3317; 3162	1418 BC; 1114 BC
S5 (2.5–3.0)	MGU-1517	M, CG	1595	\pm	50	1224; 1080	678 AD; 947 AD
S5 (3.0–3.5)	MGU-1529	M, CG	3390	\pm	120	3390; 3075	1599 BC; 963 BC
S5 (5.5–6.0)	MGU-1516	M, CG	3730	\pm	100	3804; 3528	1968 BC; 1437 BC
S5 (6.5–7.0)	MGU-1515	M, CG	4220	\pm	100	4437; 4144	2643 BC; 2035 BC

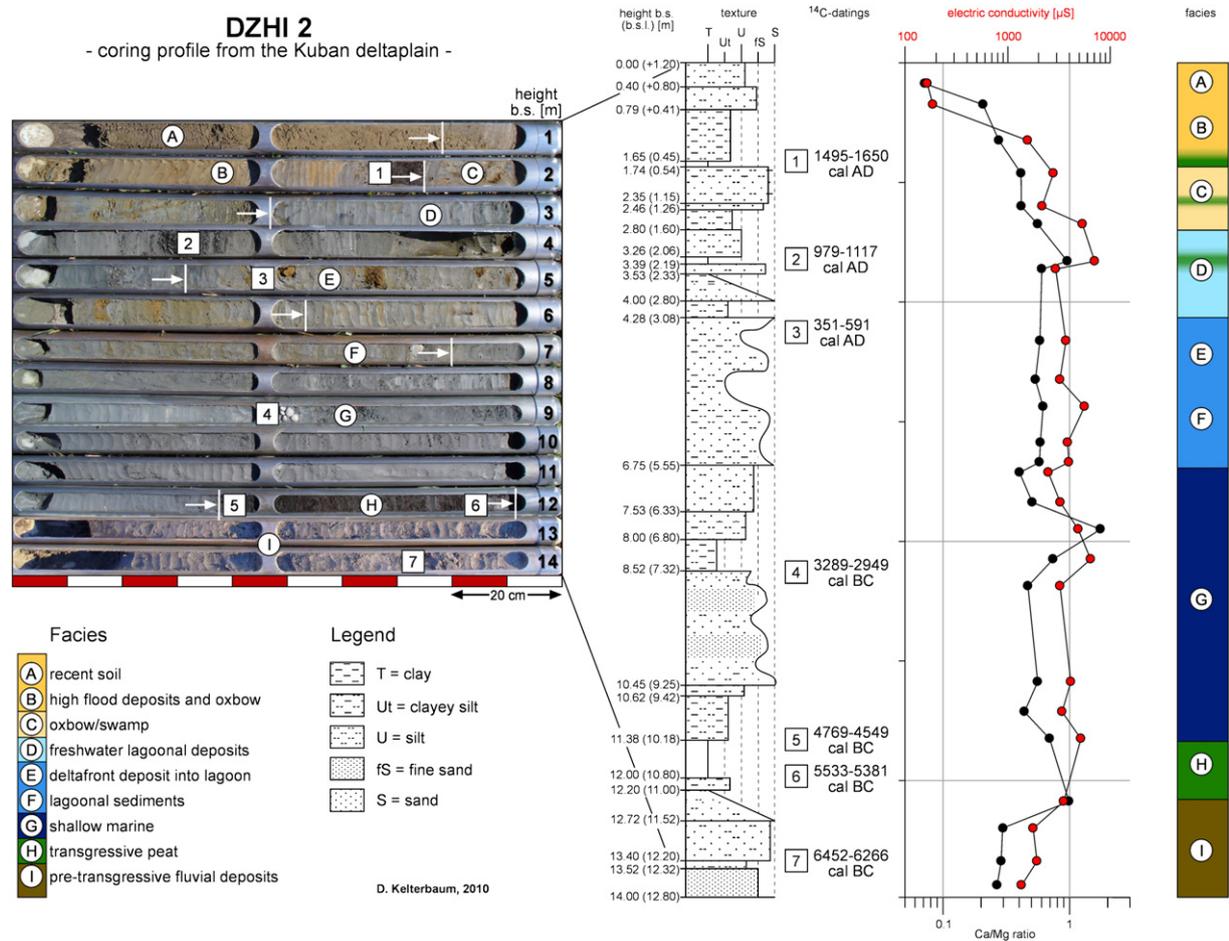


Fig. 5. Example of a typical core in the centre of the Kuban delta plain. Coring DZHI 2 (near Dschiginka) is shown with photographic documentation of the coring tubes [total coring depth: 14 m below surface (b.s.); diameter of augerheads: 6 cm (for 0–6 m b.s.), 5 cm (for 6–14 m b.s.), geological profile and ^{14}C -age estimates]. For the location of the coring site see Fig. 2.

Spit. For detailed information concerning the palaeogeographical, geomorphological, sedimentological and environmental interpretation see Brückner et al. (2010). As a typical example, the coring profile DZHI 2 (see Figs. 2 and 5) will be described.

DZHI 2 was carried out in the lower delta plain of the Kuban, located near the bifurcation of the Kuban river in its northern and southern distributary branches (coring depth: 14 m b.s.; surface elevation: 1.20 m a.s.l.; position of coring site: 45°11'20.8"N, 37°24'55.5"E). The lowermost section of the sediment column (12.80–11.10 m b.s.l.) consists of silty sand. Geochemical parameters as well as thin section analyses show a high content of organic matter and sulphide, and no marine macro- nor microfauna, which hints at a fluvial environment. Then follows a transgressive peat (11.10–10.17 m b.s.l.) which started to grow 5533–5381 cal BC and ended ~800 years later (4769–4549 cal BC). Such a paralic peat represents the former sea level; it is, therefore, an excellent sea level indicator. The peat is covered by bluish grey clayey silts, slightly enriched in calcium carbonate, deposited under open marine conditions. At a depth of 7.30 m b.s.l. a shell hash layer (among others *Cerastoderma glaucum*) was dated to 3289–2949 cal BC. Within the given sedimentary context, this age documents the continued marine environment and a water depth of several metres. The fully marine facies ends 0.5 m higher at 6.80 m b.s.l. with the first occurrence of laminae of fine sands. Up to 3.08 m b.s.l. their thickness increases. They contain small pebbles of reddish silty clay, formed and transported by wave dynamics; similar features can still be found on the shores of Taman Peninsula that are

bordered by active cliffs (see Fig. 4). This reflects an environmental change from a marine to a littoral or lagoonal milieu. Another hint for this definite change is the fact that the Anapa Spit was fully evolved at the beginning of the 2nd millennium BC, cutting off the study site from the open Black Sea (Fouache et al., 2004; Izmailov, 2007; Brückner et al., 2010). The same holds true for the Golubitskaya sand spit system in the north of Taman Peninsula, separating the former embayment from the Sea of Azov.

At a depth of 3.08 m b.s.l., the sedimentation changed dramatically to graded bedding of nearly 1 m thickness. In the lowermost part of this stratum at 3.00 m b.s.l., mollusc shells dating to the 4th–6th centuries AD (351–591 cal AD) represent another sea level indicator. It can be assumed that this material was deposited when the Kuban was near the site and debouched into the embayment, thus cutting off a small brackish lagoon with one of its distributaries. The lagoon is terminated by the formation of a paralic peat at 2.10 m b.s.l., dated to 979–1117 cal AD. The fact that this peat is 2.10 m b.s.l. can best be explained by later tectonic subsidence. It is known that earthquakes have occurred occasionally in this region (Nikonov, 1994).

The uppermost 3 m (2.10 m b.s.l.–1.20 m a.s.l.) are represented by brownish silt and sand layers reflecting flood events of the Kuban. A peat from an oxbow of the meandering river at 0.50 m b.s.l., dated to 1495–1650 cal AD, is another possible sea level indicator since it formed only slightly higher than the palaeo-sea level.

Overall, the upper sediment column represents the typical stratigraphy of a river-dominated delta front (after Bhattacharya

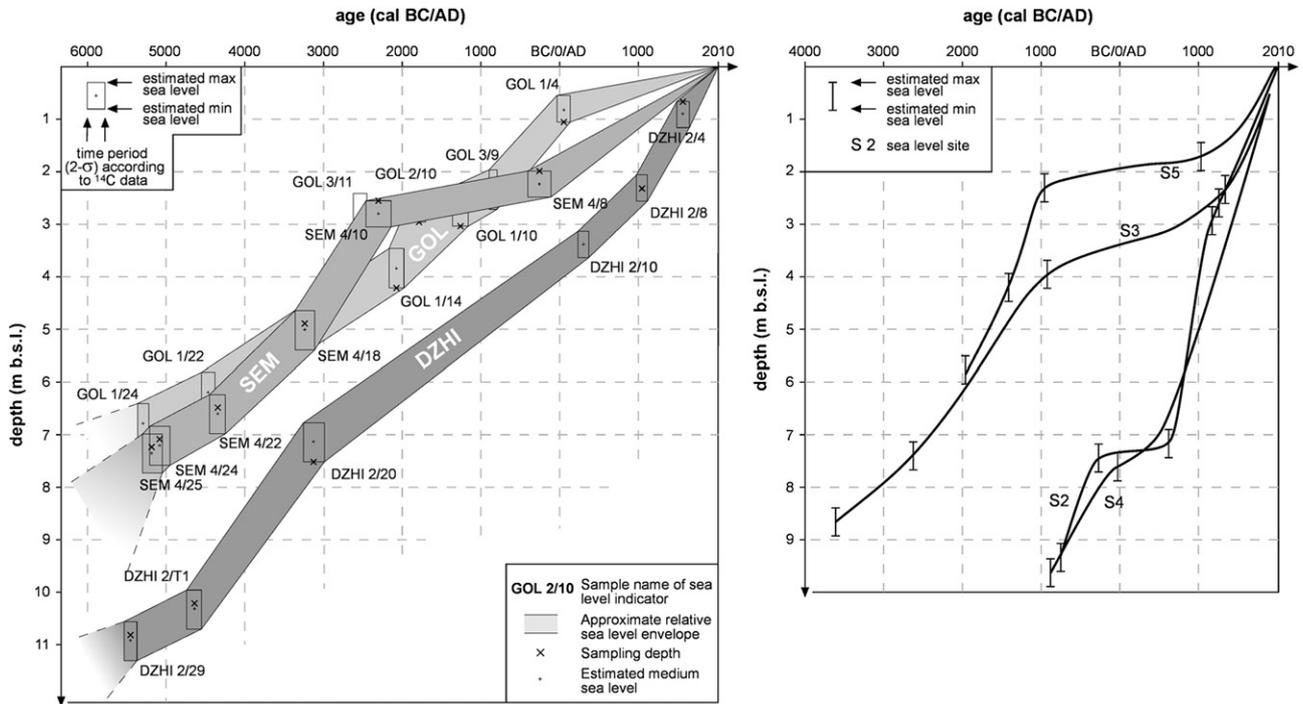


Fig. 6. Compilation of different sea level curves from Taman Peninsula based on results from sediment cores. Left side: Brückner et al. (2010) for SEM = Semebratnee, the ancient city of Labrys, Kelterbaum et al. (2011) for GOL = Golubitskaya, supplemented by research in the Kuban delta (DZHI = Dschiginka). The envelope bands give possible variation widths concerning the altitude of the sea level at a given time. Right side: Fouache et al. (2004). S2 = Burgaz Spit, S3 = Chouska Spit, S4 and S5 = Anapa Spit.

and Walker, 1992). It is vertically enlarged by the total subsidence of the area and the compaction of the deposited peat which results in a higher sedimentation. Taking into account both factors, most of the ¹⁴C-age estimates can be used for the reconstruction of the former sea level positions shown in Fig. 5.

5.2. Sea level curves

Following the coherence of the dating results – the deeper the shell or peat in the sedimentary column, the older the radiocarbon age – it is possible to reconstruct locally valid sea level curves. Considering several areas of the Taman Peninsula, each one has its own relative sea level curve: there is one for the Kuban delta plain (DZHI), another one for the Golubitskaya sand barrier (GOL) and a third one for Semebratnee (SEM) (Fig. 6, left side). The same holds true for the curves from sand spits (Anapa Spit and Burgaz Spit) and the Gulf of Taman (Fig. 6, right side). A synoptic view shows that the differences can best be interpreted by differential tectonics and compaction.

On the right side of Fig. 6, two clusters can be distinguished with rather similar curves: Burgaz Spit and western Anapa Spit (S2 and S4) on the one hand, Chouska Spit (S3) and the eastern part of Anapa Spit (S5) on the other. The Gulf of Taman is a transition zone between these two areas. There is dissymmetry between contemporaneous sea levels. For example, at 1000 BC sea level is located around –2 m below its present position in S5, around –4 m in S3 and around –9.5 m in S2 and S4.

5.3. Sea level curves and neotectonics

Comparing the curves of Fig. 6, the sites of Golubitskaya and Soleni from the central Taman area show a very similar sea level trend for the last seven millennia. On the other hand the estimated sea level band for the Kuban delta plain (DZHI curve) is different, showing a steeper gradient. This may be the effect of compaction of

the delta sediments. In addition there are good arguments that tectonics plays a definite role in the central part of the active Kuban graben structure, which was also observed by Kaplin and Selivanov (2004) and Selivanov (1995). In contrast, the central Taman Peninsula is tectonically relatively stable.

6. Points of criticism concerning major regressions of the Black and Azov seas during the last 7 millennia

Recent advances in Holocene sea level studies about the connection between the Black Sea and the Mediterranean via the Bosphorus Strait call into question the whole concept of the so-called

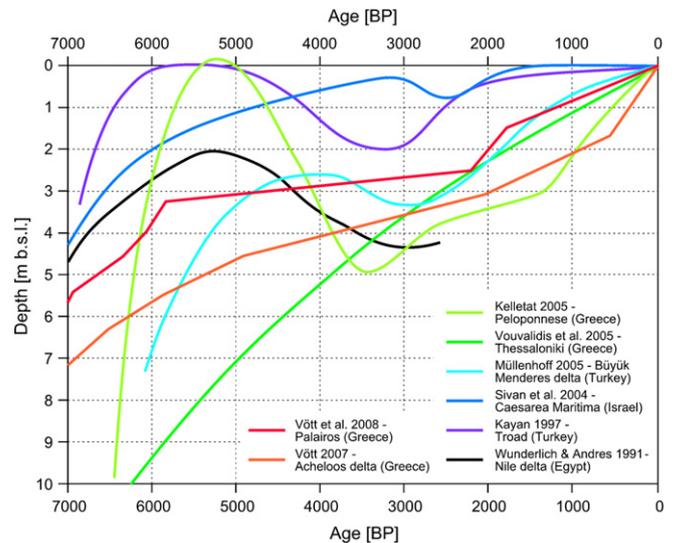


Fig. 7. Sea level curves for different parts of the Eastern Mediterranean. Source: Wunderlich and Andres, 1991; Kayan, 1997; Sivan et al., 2004; Kellelat et al., 2005; Müllenhoff, 2005; Vouvalidis et al., 2005; Vött and Brückner, 2006 (slightly modified).

Phanagorian regression. When comparing sea level curves from the Mediterranean (Fig. 7) with the Balabanov curve (included in Fig. 1) it is striking that none of the Mediterranean curves shows the Phanagorian wiggle, a fact already outlined by Brückner et al. (2010). Could it be that both seas react totally differently although they have been connected at least since 7.5 ka BP? Did all the researchers working in the (Eastern) Mediterranean, and especially in the Aegean Sea, miss the strong regression/transgression cycle during the 1st millennium BC? This seems very unlikely. Plus, there is no report from any of the Aegean coastal cities that they could not use their harbours anymore because of a major drop in sea level in the 1st half of the 1st millennium BC. The examples of Miletus (Brückner et al., 2006) and Ephesus (Kraft et al., 2007) are only two of many that could be listed here. In addition to the results from the drilling carried out on Taman Peninsula, none of which shows any evidence for the Phanagorian regression, there are several other facts and considerations why the idea of a major regression/transgression fluctuation of the Black Sea level during the 1st millennium BC did not happen.

6.1. Arguments from hydrodynamics

There is a principal problem of a fall and a subsequent rise in the level of the Black and Azov seas over ~7 m within 400 years. Which hydrodynamic or climatic factor would be a plausible mechanism for such a scenario? A major lowering of sea level might only happen if evaporation definitely exceeded the combination of areal precipitation, river discharge into the Black Sea basin and an inflow from the Mediterranean. The opposite should be the case during the following phase of the refilling of the basin, with precipitation definitely exceeding evaporation. However, no major climatic fluctuation has been reported by ancient Greek or Roman authors that would substantiate such an assumption. The climatic models do not support a major climatic change around 500 BC.

There is some evidence of solar insolation modifications during the time of the so-called Phanagorian regression which might be used for sea level lowering in a global sense (Mayewski et al., 2004). However, those insolation differences cannot be responsible for more than 0.5 m of water level modification and have a limited action in the Black Sea.

Moreover, since the Black and Azov seas have been connected with the Mediterranean and thus with the Atlantic Ocean – i.e. at least since 7.5 ka or, even more likely, since 8.4 ka BP – the three seas have acted as communicating water bodies. Therefore, a drop in sea level of ~7 m in the Black Sea could not have remained there for decades or centuries. It would have been filled by the tributary rivers and the inflow from the Mediterranean via the Bosphorus Strait.

Since the publication of the book “Noah’s flood” by Pitman and Ryan (1998), the scientific community has been divided into three parties: (1) those supporting the catastrophic reunion of both seas around 7500 ¹⁴C BP (Ryan et al., 1997; Pitman and Ryan, 1998; Ballard et al., 2000; Govedarica, 2003), later corrected to 9400–8400 BP (Ryan, 2007; Lericolais et al., 2007, 2009, 2010; Marret et al., 2009; Giosan et al., 2009); (2) those rejecting the lowstand of the Black Sea and favouring a rise in sea level, (2a) either a gradual one (Aksu et al., 1999, 2002a, b; Hiscott et al., 2002; Kaminski et al., 2002), or (2b) an oscillating one (Chepalyga, 2002, 2007; Balabanov 2007, 2009; Glebov and Shel’ting, 2007; Konikov, 2007; Yanko-Hombach, 2007). Siddall et al. (2004) calculated that the Black Sea should be filled up in 34 years using scenario (1). Sperling et al. (2003) demonstrated that sapropel deposition in the Marmara Sea suggests the absence of low salinity water from the Black Sea during the onset of the eastern Mediterranean Sapropel S1 (an organic-rich sediment layer that accumulated during the Early Holocene (Anastasakis and Stanley, 1986)). Even though the

sapropel deposition in the Black Sea is not sudden and started when the Black Sea anoxia was established (after 7500 BP), Thom (2010) tried to calibrate a hydrological model, but the model is unable to support the observed sudden onset of sapropel formation in the Black Sea 7.6 ka BP together with arrival of Mediterranean fauna. But in any case, there is consensus that since 7500 BP the Black Sea and the Mediterranean Sea have been connected. Therefore, the two marine water bodies should have been in equilibrium since then (Brückner et al., 2010). This being the case, it is difficult or impossible to explain that oscillations of several metres took place in one sea that lasted for a couple of centuries (such as the so-called Phanagorian regression), but did not affect the other sea. Seasonal and short time differences of a few decimetres can easily be explained by exceptional inflow from the Danube, Dniepr, and Don rivers.

Assuming that during the 1st millennium BC sea level of the Mediterranean was about 2 m below its present position, as several of the relevant sea level curves suggest (Fig. 7), there would still have been an altitudinal difference of 5 m. If so, a strong inflow from the Mediterranean through the Dardanelles (Çanakkale Strait), the Sea of Marmara and the Bosphorus with a relatively high speed would have evolved in order to equalise the differences in the water columns.

Such a northeastbound current has never been reported. On the contrary: since the connection of the seas, there has always been a surplus of water in the Black Sea basin as compared to the Aegean Sea, causing an outflow from the Black Sea into the Mediterranean – a fact which was very well known to the sailors in ancient times. When, for example, the Greeks from the mother town of Miletus (now in Western Turkey) wanted to visit their many colonies in the Black Sea region during Archaic times (7th–6th centuries BC), the major obstacle was the southwestbound surface current in the Bosphorus and the Çanakkale Strait (Hellespont). Since during that time it was not possible to sail against the wind, the obstacle could only be overcome by rowing, towing, sailing with westerly winds and/or using drift anchors: baskets filled with stones were sunken into the northeastbound saline bottom counter-current, thus helping to drag the ship into the Black Sea.

Another argument against the Phanagorian regression is the fact that a major difference in water levels between the Black Sea and the Aegean Sea (Mediterranean Sea) would have been equalised in only a couple of years; it would definitely not have remained for centuries.

Let us assume that during the peak of the Phanagorian regression ~500 BC the sea level difference was 5 m [–7 m in the Black Sea and –2 m in the Aegean Sea]. With the surface area of the Black Sea and the Sea of Azov being ~475,000 km² (Tolmazin, 1985), a water volume of 2375 km³ had to be filled.

The major rivers tributary to the Black Sea basin are (in order of importance): Danube, Dnieper, Don, Rioni, Dniester, Kuban, Kizilyirmak, Sakarya, and Southern Bug. Their average annual discharge at gauge stations close to their mouths is shown in Table 1. The cumulated minimum annual discharge values sum up to ~194 km³. Even for this worst case scenario, the water deficit would be balanced within 12.2 years (*de facto* it would be faster since inflow from the Mediterranean speeded up the refilling process). With the best case scenario – maximum values sum up to ~512 km³/yr – only 4.6 years were needed for the restoration of the equilibrium. After Tolmazin (1985), the average value of the total river runoff directed towards the Black Sea basin is ~350 km³/yr. In this case the deficit would be finished after 6.8 years.

For the calculations above precipitation and evaporation on the one hand, and a potential inflow of water from the Aegean Sea via the Bosphorus on the other were not taken into account. It is reasonable to assume that the contribution of these factors would equalise the difference in sea level even faster.

The essence of these reflections and calculations is the following: a major disequilibrium in the levels of the Black Sea and the Aegean Sea will be balanced in a couple of years; it will definitely not persist for centuries. Therefore, if the Mediterranean curves – tested at many sites by many different researchers – are correct, then the Phanagorian regression/transgression wiggle is impossible.

6.2. Arguments from archaeology and ancient historical accounts

The lack of evidence from written sources is another argument that no strong sea level fluctuations have occurred during the 1st millennium BC. Ancient writers would have noted such an event that would have affected all of the coasts and in particular the coastal settlements. However, the written sources remain silent. On the contrary: during the Greek colonisation in the Archaic times (7th and 6th centuries BC) all coastal settlements were founded close to the position of the present shoreline and not several kilometres off the present coast. That in some cases parts of the ancient settlements are nowadays submerged hints to a later subsidence and/or a general sea level rise since the time of their foundation, which is also known from the Mediterranean.

In addition, the archaeological findings contradict a regression of ~5 m, followed by a transgression of the same amount within a couple of centuries. Had this been the case, then the coastal settlers would have had to re-locate again and again their harbour installations – first seawards, then landwards. In areas with a shallow shelf, e.g. the whole Sea of Azov (maximum depth: 19 m) and the Odessa shelf (Ukraine), but also in many parts of Taman Peninsula, a vertical drop in sea level of 5 m would have caused a seaward shift in the coastline by several kilometres. This can neither be substantiated by archaeological evidence nor by any historical accounts.

6.3. Arguments from geomorphological features

Another argument against a major drop in sea level during the Late Holocene is that there is neither sedimentological nor palaeopedological evidence – e.g. a major erosional unconformity or any kind of palaeosol – in the cores. Had there been a major regression that was followed by a transgression 400 or so years later, then definitely a palaeosol would have formed on the surfaces that had been exposed to subaerial weathering. In addition, this should have created a prominent erosional unconformity.

Major geomorphological features on Taman Peninsula are recent and relict erosional cliffs (up to 50 m in height; see Fig. 3). They are formed in easily erodible unconsolidated Neogene bedrock. At Hermonassa, Sudarev and Chevelov (2010) calculated a cliff retreat of up to 20 m for the last century. Extrapolating this figure into the past, then several hundred metres have been eroded at some of the historic sites during the past 2–3 millennia. This may be one reason why in some cases archaeological remains are found offshore.

Another reason why parts of some ancient coastal cities are submerged by ~2 m is subsidence tectonics (Fouache et al., 2004; Brückner et al., 2010). This effect combined with the general sea level rise of ~2 m since the time of their foundation has led to the submergence of the Lower city of Phanagoria and other cities around the Cimmerian Bosphorus.

7. Discussion

Previous studies on the Holocene evolution of the Black Sea level underestimated or did not consider at all the role of tectonics, in this case mostly subsidence tectonics. This study presents for the first time relative sea level curves for different localities on Taman Peninsula for the last seven millennia. In particular it considered the problem of the

so-called Phanagorian regression, a presumed drop in sea level of 5–7 m or even more in the middle of the 1st millennium BC.

Several authors support the existence of this major regression/transgression cycle (e.g., Fedorov, 1963, 1977; Balabanov and Izmailov, 1988; Balabanov, 2009; Chepalyga, 2002). They back their theory on old data collected during Soviet times in coastal lowlands and deltas of the Caucasus foreland and the Crimea as well as on archaeological data collected, e.g., in Olbia or the Kerch-Taman region. Their radiocarbon ages lack exactly measured coordinates and, what is worse, the exact altitude above (present) sea level at the studied sites. Plus, most of these authors used bulk samples by sieving the whole sediment from 0.3 m up to 1 m thickness of the sedimentary column, and then conventionally ¹⁴C-dated the sieved mollusc shells. This method does, however, not give any good age estimates since the time resolution is poor (it may integrate over several centuries); in addition, it does not refer to specific sea level indicators. Often the sedimentary context is not well described and therefore it is not easy to reconstruct the exact position in relation to palaeo-sea level. This is discussed in detail by Brückner et al. (2010).

In the studied sediment columns it is interesting to note that peat – which is amongst the most valuable sea level indicators – occurs as transgressional paralic peat layers and in the delta front sediments of the Kuban River. Only the Semebratnee site bears peat formations in the sediment column as intercalated layers (see Brückner et al., 2010). They can best be interpreted as marsh peats (Styan and Bustin, 1983) that formed in cut-off oxbows during delta progradation; later they were flooded by the rising sea level and/or due to the changed direction of the estuary creeks. The evolution of these so-called “floating peats” is also explicable by the theory of small regression cycles which normally took place in subsiding areas (cf. Streif, 1990, 2004, North Sea; Sornoza et al., 1998, Ebro delta, Spain; Vött et al., 2007b, Acheloos delta, Greece; Coleman et al., 1998, Mississippi delta).

Another point of critique, concerning the existence of the Phanagorian regression, is the lack of erosional unconformities in the sediment column. They should be traceable if sea level had dropped by several metres, thus initiating erosion by water and weathering under subaerial conditions. In none of the drill cores on Taman Peninsula were hints for erosional discordances, staining of the sediment, incisions of former estuaries of the Kuban river, etc. In addition, if after the formation of a peat layer a major regression occurred, the peat would have decayed and weathered. Consequently, its colour and texture would definitely have changed. However, this was not observed. Hence, only a minimal local regression of sea level might be considered for the time of the peat formation (e.g. Sornoza et al., 1998) which may have been initiated by the tectonic subsidence in the Kuban graben structure.

Compared to the curves of Golubitskaya and Semebratnee, the one of the Kuban river delta plain shows a steeper gradient (Fig. 6). The reasons may be compaction of the deltaic sediments and subsidence. The tectonic factor (mostly subsidence) plays a major role for the proper interpretation of the sea level evolution based on data derived from the coastal areas of the north-western Black Sea and the Sea of Azov. Subsidence in major river areas is a widespread phenomenon around the world (e.g., Törnqvist et al., 2006; Vött et al., 2007a, b) and therefore can also be assumed for the Kuban river valley.

8. Conclusion

In summary:

- (1) Most of the studies which present major wiggles for the Black Sea level curve underestimate or do not even take into account at all the factor of local tectonics. It is one of our research results that this factor is a prominent one and varies both temporally and spatially.

- (2) The bottom of an excavated well in Phanagoria reaches down to 7–8 m below the present sea level, which may also be the effect of strong local subsidence. Additionally, a freshwater lens above the saline groundwater has to be taken into account.
- (3) Sediment compaction should be considered in all areas as well as the effect of compaction due to earthquakes.
- (4) The hydrodynamic effect of communicating water bodies – here the Black and Azov seas having been connected with the Mediterranean at least since 7.5 ka ¹⁴C BP – would equalise major differences in water levels within a couple of years; it is impossible that a dissymmetry could persist for centuries. As none of the Mediterranean sea level curves shows the Phanagorian regression/transgression wiggle, it is doubtful that it ever existed. Bearing in mind the tectonic setting (Fig. 3), the trend of the sea level curves (Fig. 6) fits well with similar curves for the Aegean Sea, showing a permanent post-glacial rise without being interrupted by major regressions/transgression wiggles.
- (5) None of the cores shows a major erosional disconformity or a buried palaeosol. Both features should have evolved during a major drop in sea level for a couple of metres and a later rise for the same amount at all of the sites that had been subaerially exposed.
- (6) There is a good correlation between different tectonic units of Taman Peninsula and the four different groups of relative sea level curves (Fig. 6). Burgaz Spit (S2) and Western Anapa Spit (S4) are located in two uplifting areas. The Gulf of Taman (S7–S9), Choushka Spit (S3) and the eastern part of Anapa Spit (S5 and S6) are located in a generally subsiding zone. Tectonic measurements (Nikonov, 1994; Nikonov et al., 1997) confirm the subsidence in the central zone of the Taman Peninsula. The present-day subsidence at Temryuk and the Kuban delta is estimated between 3.5 and 4 mm/yr, the tectonic part being about 2–3 mm/yr (Selivanov, 1995). For the Black Sea side, south of the peninsula, the average subsidence during the Upper Pleistocene is estimated at 2.5 mm/yr. These data confirm that the subsidence rates vary from one point to the other in the peninsula.
- (7) During the time of the so-called Phanagorian regression, there are three age estimates from the cores which show a sea level at 0.60–2.70 m b.s.l. during the first millennium BC. Taking into account a moderate average subsidence rate of 0.10 m/ka one has to subtract 0.25 m. Therefore, without the later subsidence, sea level was between 0.35 and 2.35 m b.s.l. by then.
- (8) Finally, the above listed arguments hold not only true for the so-called Phanagorian regression, but also for the many other major wiggles of the sea level curves for the Black Sea shown in Fig. 1. None of these regression/transgression cycles has been found in the Mediterranean (cf. Fig. 7), and none of them has ever been found in the sea level fluctuation models, e.g. (Lambeck and Purcell, 2005; Lambeck et al., 2007; Sivan et al., 2001; Sivan et al., 2001).

Acknowledgements

The authors D.K. and H.B. wish to express their gratitude to the Gerda Henkel Foundation (reference number: AZ 14/SR/07) and the Fritz Thyssen Foundation (reference number: AZ 20.08.0.010) for financially supporting their research on the peninsulas of Taman and Kerch, respectively.

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