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

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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 Bosporus, 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.

Keywords: Black Sea, Phanagorian regression, geoarchaeology, tectonics, Taman Peninsula

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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. Actually, 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 (Fedorov 1963) for the Black Sea region. It was based on archaeological and palaeogeographical research conducted around the ancient Greek colonies of the Cimmerian Bosporus, 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 ^{14}C-dated fossil coastal bars in the western and southern parts of Taman Peninsula show that contemporary coastal bar are related to differents sea levels. The dissymmetry can reach up to 6 m around 500 y 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. Also 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 ^{14}C BP for 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.

Keywords : Black Sea, Phanagorian regression, geoarchaeology, tectonics, Taman Peninsula

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 (excentricity) and 20 ky (precesion) periodicity. These sea level fluctuations endowed the restricted channels of the Bosporus and Dardanelles with the power to control the Black Sea's connection to the Mediterranean. When global sea level

dropped below the Bosporus 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 cycle studied presently. Among others the sea level history of the Black Sea for the last eight millennia has been discussed in many publications (Nevessky 1967; Fedorov 1977; Dzhanelidze 1980; Balabanov & Yzmailov 1988; Izmailov 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.

Two principal patterns define the regional distinction between the Black Sea and others seas, e.g. the Mediterranean, which have been substantiated by Balabanov & Izmailov (1988) and Balabanov (2007, 2009): the small magnitude of the tectonic deformation of the Holocene synchronous shorelines on the continental margin of the Black Sea, and 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 data base have been regarded recently by I. 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 under discussion till now. Among these small-scale fluctuations of sea level, most attention was focused on the so-called "Phanagorian regression", supposedly reflecting a major sea level change in the middle of the 1st millennium BC.

2. The Phanagorian Regression

The concept of the Phanagorian regression was established in 1963 when P. Fedorov published his thesis on the palaeogeographic evolution of the Black Sea region (Fedorov 1963). 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, same as 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 (Fedorov 1984). There are indeed other settlements on Taman Peninsula, some parts of which are nowadays submerged, e.g., Nymphaeum (Porotov 2006) 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 1975 a,b, 1997; Balabanov1982; Balabanov & Izmailov 1988; Izmailov et al. 1989; Shilik 1975a, b, 1997). 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 already pointed out by Porotov (2007). While 4-5 m below present sea-level is a medium value currently attributed to the Phanagorian regression, the values vary along the coasts of the Black Sea from 2 m via 3-4 m and 5-7 m up 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, all of them 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 ones. This is well summarized 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 ^{14}C-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 Abchazia. 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 ^{14}C-dated relict peat layers in different swamp areas with regard to their present position does, however, not permit to accept a possible relative fall in sea level of more than 2-3 m (Dzhanelidze 2007). This estimation 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 (Dzhanelidze 1980; Gorlov et al. 2004) despite of the existence of more extreme values of a sea-level fall during this period (Balabanov & Gey 1981; Balabanov & Gaprindashvili 1987, Balabanov & Izmailov 1988; Nikonov 1997; and others).

Traces of the disruption of the generally trangressive 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 & Trashchuk 1982; Inozemtsev et al. 1984; Molodykh et al. 1984; Gozhik & Novosel'sky 1989).

In contrast to this opinion several other studies on the topic that were recently published (e.g. Fouache et al. 2004; Giosan et al. 2006; Porotov 2007; Lericolais et al. 2007 and 2009; Brückner et al. 2010) question the concept of the Phanagorian regression.

3. Geological and geomorphological setting

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. 2). To the west the Strait of Kerch represents the border to Crimea (Ukraine). This small sea passage was called 'Cimmerian Bosporus' 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 had once debouched into the Black Sea, and the present-day northern branch which flows 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 occasionally 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 & 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 levelling processes (Blagovolin 1962; Blagovolin & Pobedonostsev 1973).

Intensive neotectonic deformation is described in the Eastern Black Sea and around the Taman Peninsula (Fig 3) (Meisner et al. 2009). Significant subsidence of the Eastern Black Sea during the Pliocene-Quaternary is recorded from seismic profiling as well as fast 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, Blagoweschenskaya 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

For this paper we compare our results from Taman Peninsula with data from other places in the Black Sea area. Over the last years we have carried out several corings in different geoarchives of the study area (fig. 2). Archival material collected at the end of the 1960s by

E.N. Nevesky (1967) for the Russian Shirshov Institute of Oceanology was used as well. This material was kindly given to us by Professor L.A. Nevesky

4.1 Corings

The corings (fig. 2) were done with the percussion coring device Cobra 248 of Atlas Copco Co. using augerheads with diameters of 6, 5 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 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 Nevesky (1967) was integrated.

Multi-proxy geochemical analyses were done in the laboratories of the Faculty of Geography at Philipps-Universität Marburg (Germany) to support the determination of facies changes (Vött et al. 2002, 2007). Combined with the grid of corings, 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 since 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 our case, we ^{14}C-dated mollusc shells, plant remains and peat. The ages determined on mollusc shells were corrected for an average marine reservoir effect of 408 years. 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, the Sea of Azov). AMS ^{14}C dating of ostracod and gastropod shells from the southwestern Black Sea cores combined with tephrochronology suggest variable reservoir ages for the late glacial Black Sea basin from 0 to 1450 yr (Kwiecen 2008, 2009). Fontugne et al. (2009) propose that chemoautotrophic productivity is contributing to the sedimentary organic matter explaining so the variation of reservoir ages evident during the Holocene in the anoxic Black Sea. Additionally, the discharge of river (Tab. 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 5.0.2; Reimer et al. (2004)]. The datings concerning the archival material of the Shirshov Institute of Oceanology collected in 1967 by Nevesky are integrated in the corings in the Gulf of Taman (see fig. 2, tabs. 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, we have been unable to find precise archaeological indicators, such as jetties and fishponds, on Taman Peninsula. It was also impossible to apply the methods proposed by Flemming (1979), Pirazzoli (1979), Morhange (2001) and by us 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, we focussed on (a) paralic peat layers and (b) the identification of shell assemblages, characteristic for thanatocoenosis fauna accumulated at a mean sea level and reflecting an average position of (palaeo-) sea level with an error margin of ±1 m (this is why we prefer to use envelopes in our sea level curves). Extracted shell material was palaeo-environmentally interpreted according to Kaplin et al. (2001) by T. Yanina at the 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, AMS-^{14}C dating at the Center for Applied Isotope Studies (CAIS), University of Georgia, Athens GA (USA) (Tabs 2 and 3).

5 . Results – sea level curves from Taman Peninsula

5.1 Coring results and interpretation

In this paper we compare our results obtained on Taman Peninsula with data of other places of the of Black Sea coast. We drilled several boreholes on the peninsula down to 12 meters b.s. (fig. 2). A first set consisted of six corings (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).

Coring S1 (fig. 2), located in the Kuban delta, contains peat at the base, then follow marine sediments of a semi-closed embayment topped by deltaic sediments (Fouache 2000a, b, 2004). Palynological analysis confirms that there was a marine environment during the Greek colonization (Bolikovskaya et al. 2004). The radiocarbon age of the basal peat (5940 ± 50 BP, uncalibrated Age) shows that the maximum landward inundation of the sea occurred during that time. The other cores S2 – S6 show an alternation between sandy biodetritic sediment, characteristic of beaches, and mainly clayey sediments rich in shells, characteristic of open marine condition (S2 and S3 in fig. 2; S4 in fig. 2, S5 and S6 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 is now submerged.

A second set of corings were carried out in the Kuban delta plain, the Golubitskaya sand spit system, the Soleni Liman and again on Anapa Spit. For detailed information concerning the palaeogeographical, geomorphological, sedimentological and environmental interpretation see, e.g., Brückner et al. (2010). As a typical example the coring profile DZHI 2 (see figs. 2 and 5) will be described in the following.

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 a 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 to 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; they were 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 meters. The fully marine facies end half a metre 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 grows. They contain

small pebbles of reddish silty clay, formed and transported by wave dynamics; features like that 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 a 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 nearby 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 three metres (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 Battacharya & 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. If one takes into account both factors, most of the ^{14}C 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 our 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. When taking a closer look at several areas of Taman Peninsula it becomes obvious that each one has its own relative sea level curve: there is one for the Kuban delta plain (DZHI), another one for the Golubitskaya sandbarrier (GOL) and a third one for Semebratnee (SEM) (fig. 6, left side). The same holds true for the curves, focussing on 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.

When we look at the right side of fig. 6, we can distinguish two clusters with rather similar curves: Burgaz Spit and western Anapa Spit (S2 and S4) on the one hand, Choushka 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. We can also identify a dissymmetry between contemporaneous sea levels. For example, in 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

When comparing the curves of fig. 6 it is interesting to note that 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 deltaplain (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. 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 Bosporus Strait make us question the whole concept of the so-called 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 our drillings carried out on Taman Peninsula (see chapter 5), 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 for 7 or so metres 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 etc. definitely exceeding evaporation. However, no major climatic fluctuation has been reported by ancient Greek or Roman authors that would substantiate such an assumption. Plus, 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

(see inserted box) – the three seas have acted as communicating water bodies. Therefore, a drop in sea level of 7 or so metres 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 Bosporus Strait.

EXTRA BOX

Since the publication of the book "Noah's flood" by Pitmann & Ryan (1998), the scientific community has been divided into three parties: (1) those supporting the catastrophic reunion of both seas around 7500 ^{14}C BP (Ryan et al. 1997, Pitman & Ryan 1998, Ballard et al. 2000, Govedarica 2003), later corrected in between 8400 to 9000 BP (Ryan 2007; Lericolais et al. 2007, 2009 and 2010; Marret 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 & Shel'ting 2007, Konikov 2007, Yanko-Hombach 2007). Siddal et al. (2004) calculated that the Black Sea should be filled up in 34 yrs using scenario (1). Sperling et al. (2003) demonstrated that Sapropel deposition in the Marmara Sea suggest absence of low salinity water from the Black Sea during S1. Even though the Sapropel deposition in the Black Sea is not sudden and started when the Black Sea anoxia was established (I.E. 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 in 7.6 ky BP together with arrival of Mediterranean Fauna. But in any case it is consensus that since 7500 BP (or 8400 cal 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, as we think, impossible – to explain that oscillations of several meters 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 major rivers Danube, Dniepr, Don etc.

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 (Canakkale Strait), the Sea of Marmara and the Bosporus with a relatively high speed would have evolved in order to equalize the differences in the water columns.

Such a northbound 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 westbound surface current in the Bosporus and the Canakkale 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 eastbound saline bottom counter-current, thus helping to drag the ship eastwards.

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 equalized 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 km^3 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, Southern Bug etc. Their average annual discharge at gauge stations close to their mouths is shown in tab. 1. The cumulated minimum annual discharge values sum up to ~194 km^3. Even for this worst case scenario, the water deficit would be balanced within 12.2 years (*de facto* it would be faster since then inflow from the Mediterranean speeded up the refilling process). With the best case scenario – maximum values sum up to ~512 km^3/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 km^3/a. 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 Bosporus were not taken into account. It is reasonable to assume that the contribution of these factors would equalize 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 colonization 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 the 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 or so meters, 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 for 5 or so metres would have caused a seaward shift in

the coastline for several kilometres. This can neither be substantiated by archaeological evidence nor by any historical accounts.

6.3 Arguments from geomorphological features

An argument against a major drop in sea level during the Late Holocene is that there is neither a sedimentological nor a palaeo-pedological evidence – e.g. a major erosional disconformity or any kind of palaeosol – in our corings. 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. Plus, this should definitely have created a prominent erosional disconformity.

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 & Chevelov (2010) calculated a cliff retreat of up to 20 m for the last century. Extrapolating this figure into the past, then several hundred meters have been eroded at some of the historic sites during the past 2 to 3 millennia. This may be one reason why in some cases archaeological remains are found offshore.

Others reasons why parts of some ancient coastal cities are submerged for a couple of metres is subsidence tectonics (Fouache et al. 2004; Brückner et al. 2010). This effect combined with the general sea level rise of 2 or so metres since the time of their foundation has led to the submergence of the Lower city of Phanagoreia and other cities around the Kimmerian Bosporus.

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. Our study presents for the first time relative sea level curves for different localities on Taman Peninsula for the last seven millennia. In particular we dealt with 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 & Izmailov 1988; Balabanov 2009; Chepalyga 2002; etc.). 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 collected 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 ^{14}C-dated the sieved mollusc shells. This method does, however, not give any good age estimates since the time resolution is bad (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 depositional 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 layers – which are amongst the most valuable sea level indicators – occur as transgressional paralic peat layers and in the

deltafront sediments of the Kuban River. Only the Semebratnee soite bears peat formations in the sediment column as intercalated layers (see Brückner et al. 2010). They can best be interpreted as marsh peats (Styan & Bustin 1983) that formed in cut-off oxbows during delta progradation; later they are flooded by the still 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 and 2004, North Sea; Sornoza et al. 1998, Ebro delta, Spain; Vött 2007, 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 aerial conditions. In none of the coring stratigraphy on Taman Peninsula did we find hints for erosional dicordances, 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 cannot be observed. Hence, only a minimal local regression of sea level has to be considered for the time of the peat formation (e.g. Sornoza et al. 1998) which can be easily initiated by the tectonic subsidence tendency 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 deltaïc sediments and subsidence. In fact, 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 Asov. Subsidence in major river areas is a wide-spread phenomenon around the world (e.g., Törnqvist et al. 2006, Vött 2007) and therefore can also assumed for the Kuban river valley.

8. Conclusion

We can summarize our arguments as follows:

(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) That the bottom of the excavated well in Phanagoria reaches down to 7-8 m below the present sea-level may also be the effect of strong local subsidence.

(3) Sediment compaction should be considered as well as the effect of compaction due to earthquakes.

(4) We have calculated that the hydrodynamic effect of communicating water bodies – here Black and Azov Sea having been connected with the Mediterranean at least since 7.5 kyr ^{14}C BP – would equalize major differences in water levels within a couple of years; it is impossible that a dissymmetry could persist for centuries. Since none of the Mediterranean sea level curves shows the Phanagorian regression/transgression wiggle, it is doubtful that it ever existed. We think it is a misinterpretation of the data. Bearing in mind the tectonic setting

(fig. 3), the trend of our 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 our corings 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 characteristic uplifting areas. The Gulf of Taman (S7, S8 and 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/year, the tectonic part of it being about 2-3 mm/yr. 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 we have three age estimates from our corings 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.

(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 one of them has ever been found in the sea level fluctuation models, e.g. Lambeck et al. (2005, 2007), Sivan et al. (2001).

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Legends of Figures and Tables :

Fig. 1: Sea level curves of the Black Sea as noted by various authors. 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 Nevessky (curve C). In the compiled curves the regression maximum varies from -5 m to -11 m. Source: own compilation based on various sources. _

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

Fig. 3: Major tectonic features of the Eastern Black Sea region with location of mud volcanoes and magnetic anomalies. Isobaths are in meters. 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. The Golubitskaya sand barrier is separating the Akthanizovskaya Liman from the Sea of Azov. Right photograph: Palaeo-cliff structure bordering the Soleni Liman in the centre of the Taman Peninsula.

Fig. 5: Example of a typical coring in the centre of the Kuban delta plain. Coring DZHI 2 at 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. As for the location of the coring site see fig. 2.

Fig. 6: Compilation of different sea level curves from Taman Peninsula based on results from corings.
Left side: Brückner et al. (2010) for SEM = Semebratnee, the ancient city of Labrys, Kelterbaum et al. (in review) for GOL = Golobitskaya, 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, S5 and S6 = Anapa Spit.

Fig. 7: Sea level curves for different parts of the Eastern Mediterranean. Source: Vött & Brückner (2006).

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

Table 2 : Radiocarbon Dates. All ages are calibrated with the calibration software Calib 5.0.2. For marine carbonates the reservoir age of 408 years (Hughen et al. 2004) is applied with delta R of 5 ± 35 years according to Jones & Gagnon (1994)

Table 3 : Radiocarbon Dates obtained on mollusc sample M (bs) = mollusc bulk sample ; M = mollusc (single valve) 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 5.0.2.   For marine carbonates the reservoir age of 408 years (Hughen et al. 2004) is applied with delta R of 5 ± 35 years according to Jones & Gagnon (1994)

Figure1
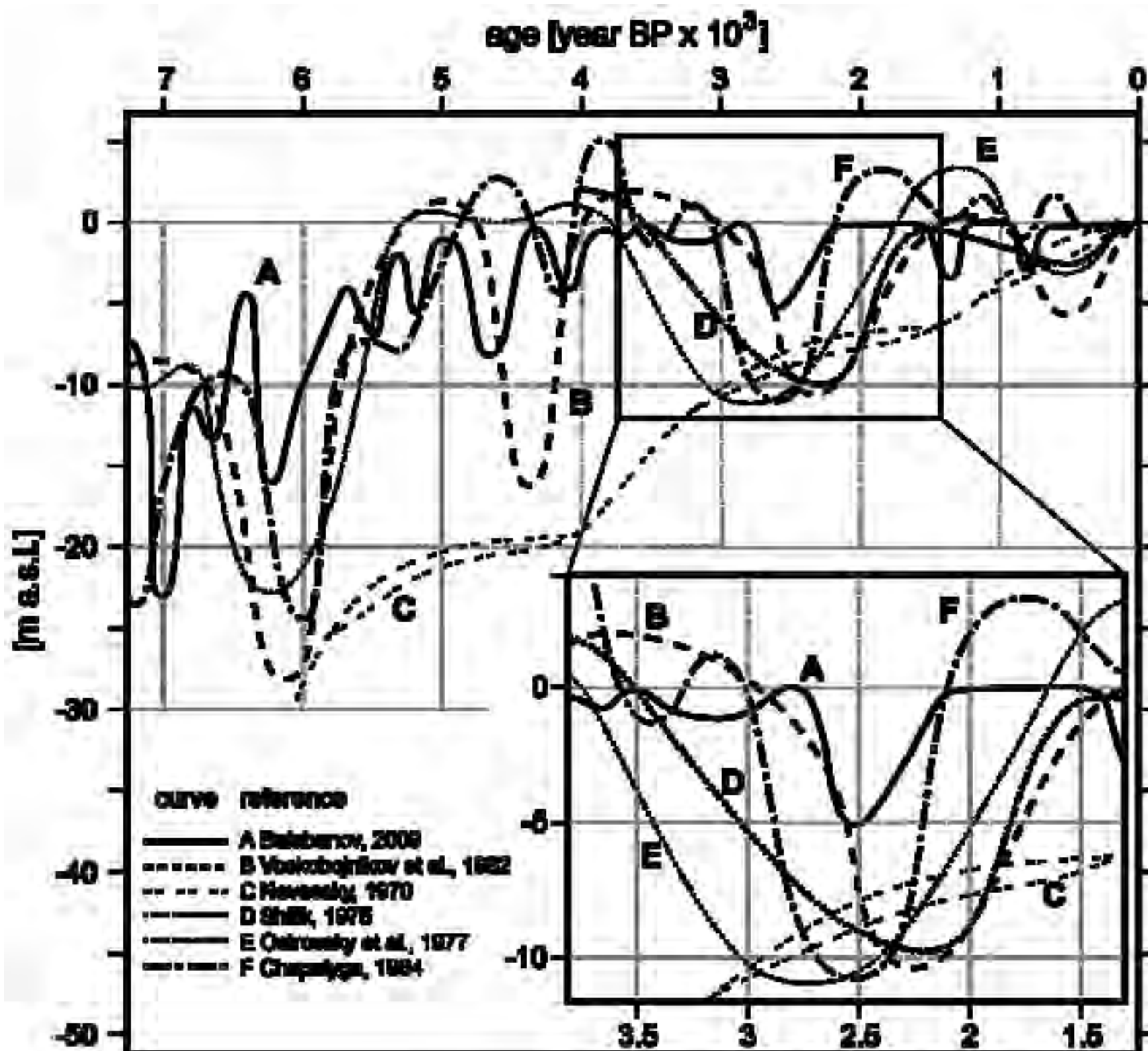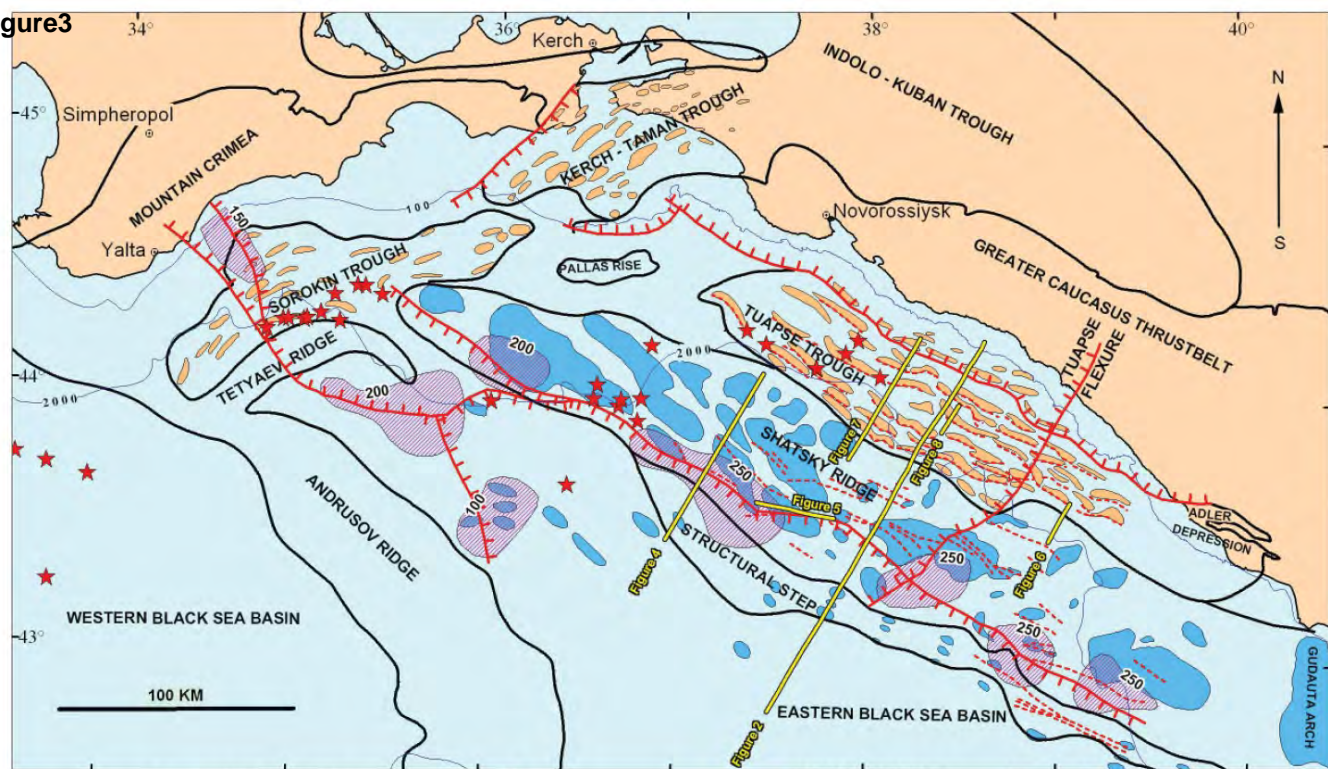**Click here to download high resolution image**

Figure1

Figure2

Figure3

Legend:

⌐ STRUCTURAL BOUNDARY	┴┴ FAULT	UPPER JURASSIC FOLD	MAGNETIC ANOMALY
★ MUD VOLCANO	--- SMALL FAULT	MIOCENE FOLD	—100— ISOBATH

Map labels: Simpheropol, Kerch, INDOLO - KUBAN TROUGH, MOUNTAIN CRIMEA, KERCH - TAMAN TROUGH, Novorossiysk, Yalta, SOROKIN TROUGH, PALLAS RISE, GREATER CAUCASUS THRUSTBELT, TETYAEV RIDGE, TUAPSE TROUGH, TUAPSE FLEXURE, SHATSKY RIDGE, ADLER DEPRESSION, ANDRUSOV RIDGE, STRUCTURAL STEP, WESTERN BLACK SEA BASIN, EASTERN BLACK SEA BASIN, GUDAUTA ARCH, 100 KM

Figure4
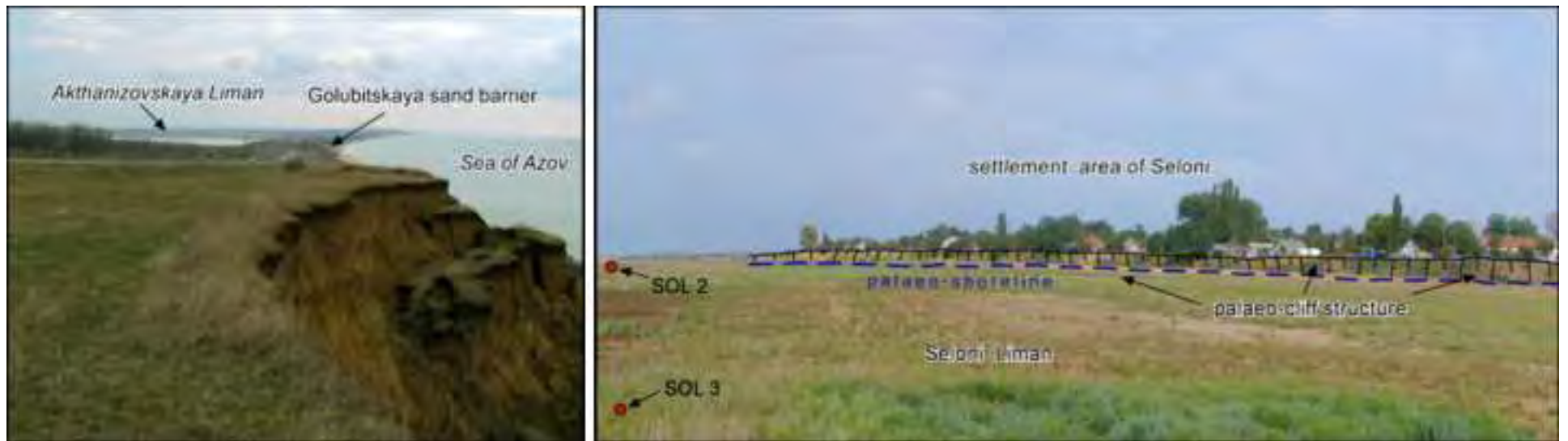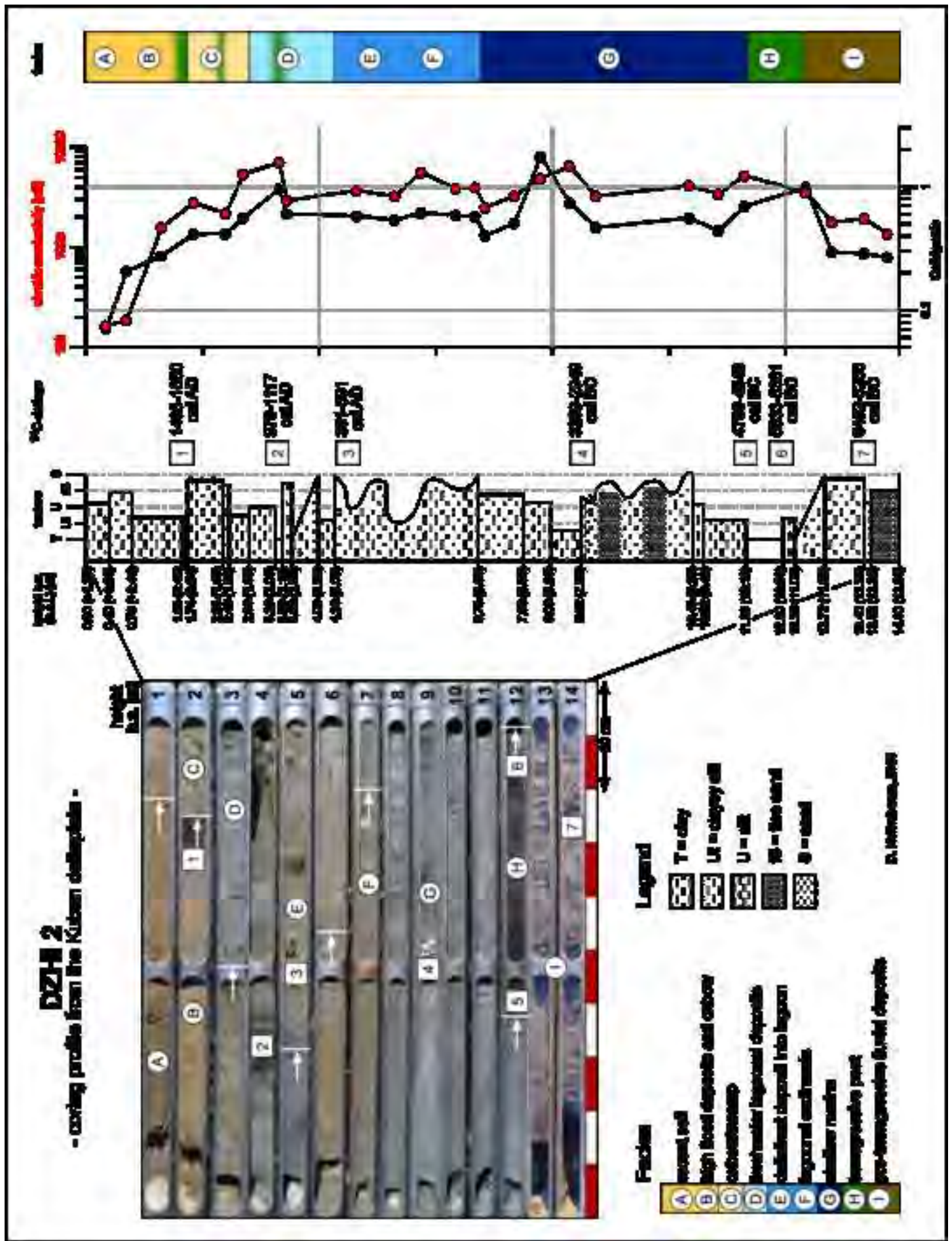**Click here to download high resolution image**

Figure5
Click here to download high resolution image

Figure6
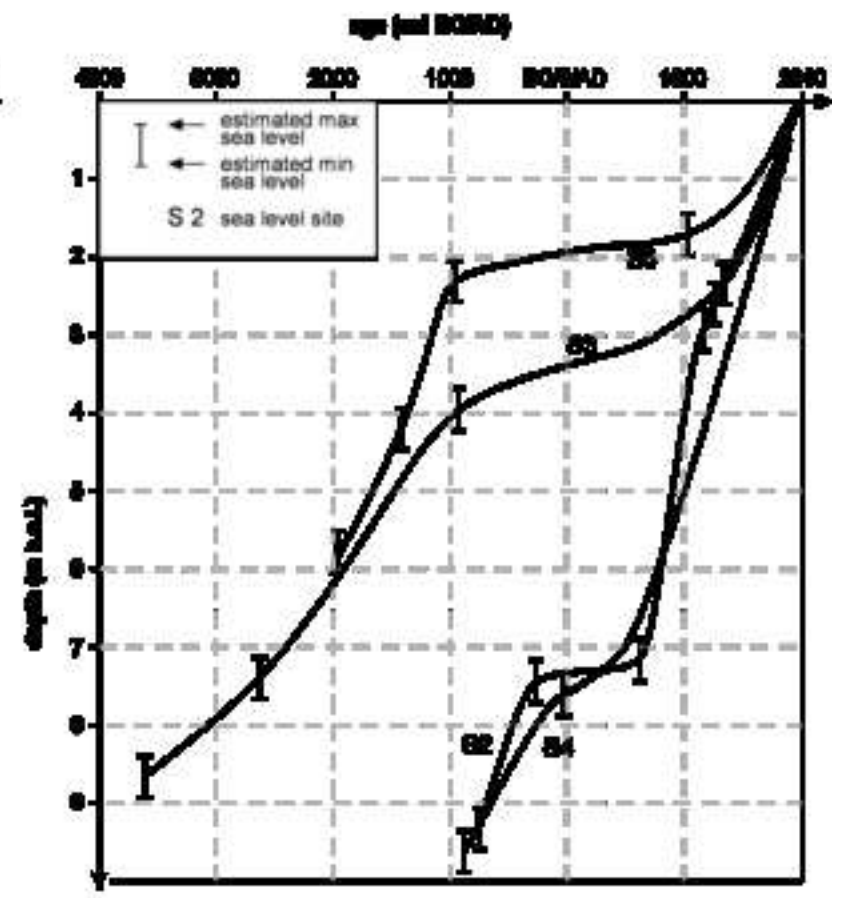**Click here to download high resolution image**
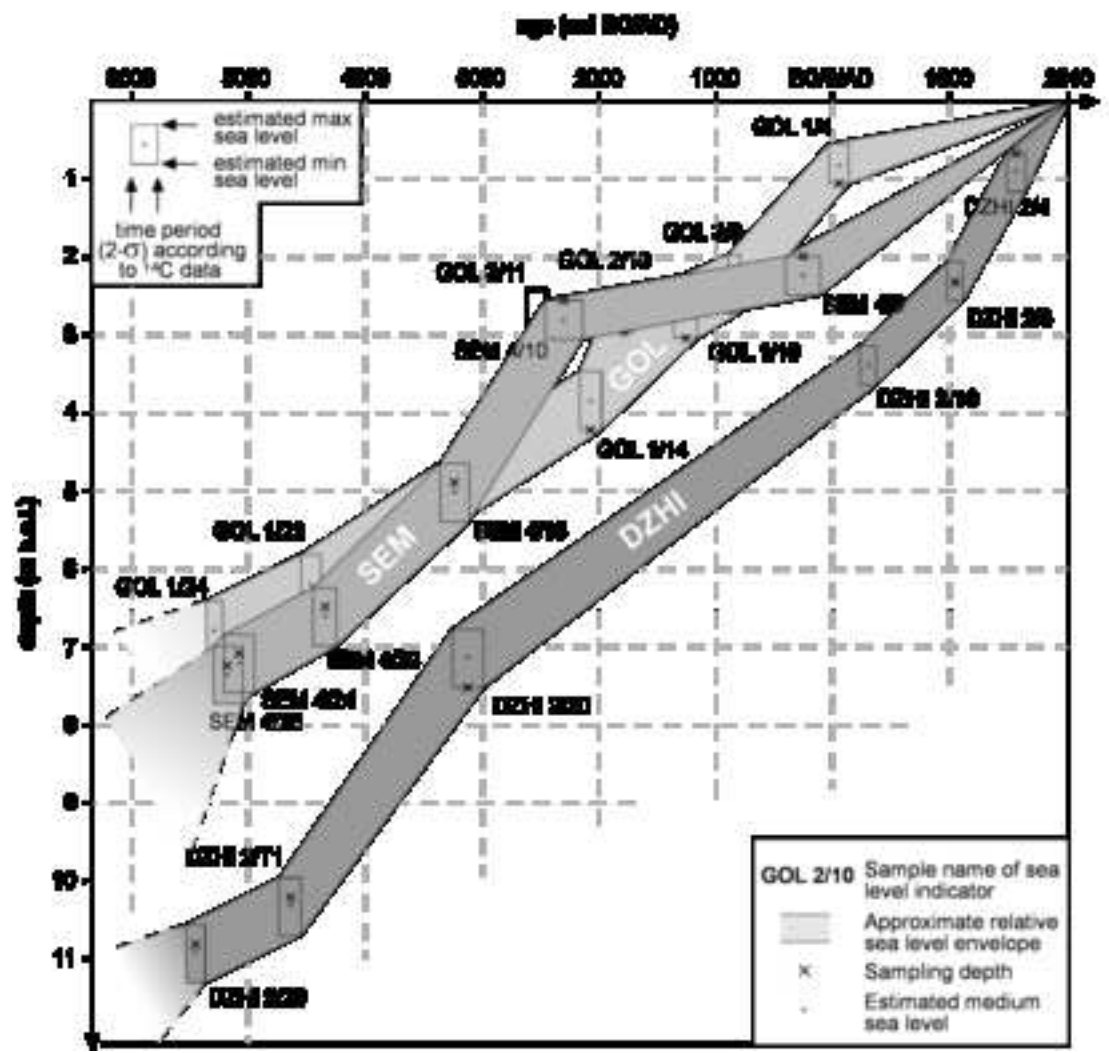
Table2
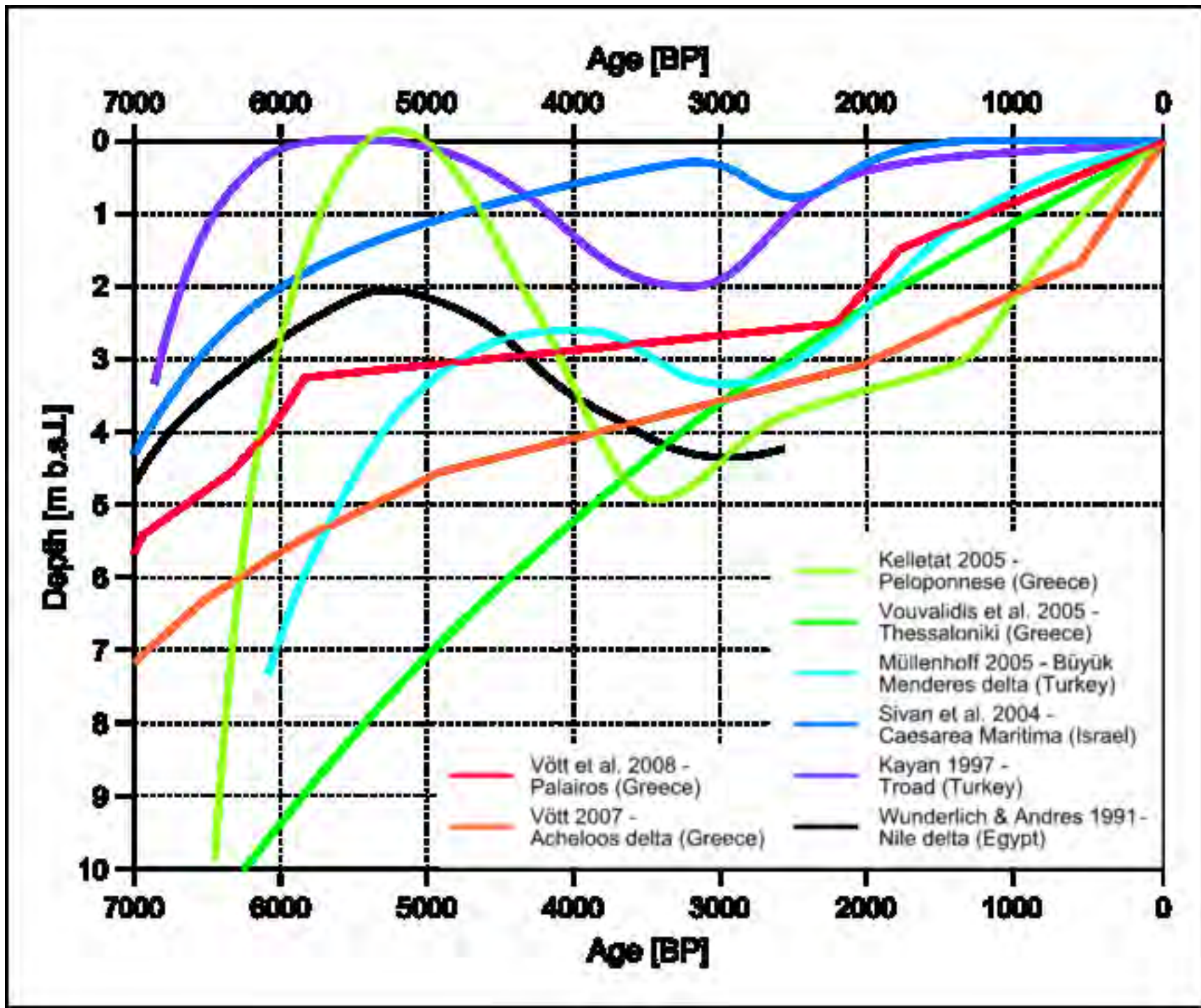
				14C Age			Calibrated ages	
							1 Sigma max; min	2 Sigma max; min
Sample ID	Lab. no.	d13C	material	(BP)	±	1 s	(cal BP)	(cal BC/AD)
DZHI 2/4	UGAMS 03178	-27,13	PR	301	±	24	305; 428	1495 AD ; 1650 AD
DZHI 2/8	UGAMS 03179	-26,21	PR	1015	±	24	925; 955	979 AD ; 1117 AD
DZHI 2/10	UGAMS 04142	0,27	M	1937	±	29	1410; 1529	351 AD ; 591 AD
DZHI 2/20	UGAMS 03180	-2,98	M	4790	±	25	4961; 5173	3289 BC ; 2949 BC
DZHI 2/29	UGAMS 03181	-28,30	PR	7521	±	30	8215; 8401	6452 BC ; 6266 BC
DZHI 2/T1	UGAMS 03182	-28,30	PR	5810	±	37	6563; 6666	4769 BC ; 4549 BC
DZHI 2/T8	UGAMS 03183	-27,55	PR	6511	±	27	7419; 7459	5533 BC ; 5381 BC
GOL 1/4	UGAMS 04137	-5,8	M	2201	±	35	1728; 1855	26 AD ; 285 AD
GOL 1/10	UGAMS 03184	-1,68	M	3347	±	24	3140; 3275	1378 BC ; 1120 BC
GOL 1/14	UGAMS 03185	-0,87	M	4013	±	24	3951; 4084	2198 BC ; 1932 BC
GOL 1/22	UGAMS 03186	-1,09	M	6015	±	26	6370; 6483	4588 BC ; 4355 BC
GOL 1/24	UGAMS 03187	-0,62	M	6722	±	25	7197; 7297	5400 BC ; 5204 BC
GOL 2/10	UGAMS 04140	2,06	M	3826	±	28	3699; 3830	1945 BC ; 1686 BC
GOL 3/9	UGAMS 03188	-29,24	PR	2673	±	26	2753; 2785	895 BC ; 799 BC
GOL 3/11	UGAMS 03189	-3,02	M	4356	±	26	4415; 4535	2685 BC ; 2421 BC
SEM 4/8	LU 5847	-27.0	PR	2240	±	110	2354; 2067	743 BC; 3 AD
SEM 4/10	LU 5846	-27.4	PR	3830	±	110	4411; 4091	2573 BC ; 1965 BC
SEM 4/18	LU 5831	-27.0	PR	4540	±	60	5312; 5055	3496 BC ; 3026 BC
SEM 4/22	LU 5848	-28.5	PR	5520	±	100	6411; 6208	4582 BC ; 4055 BC
SEM 4/24	LU 5845	-25.8	PR	6120	±	70	7156; 6912	5281 BC ; 4845 BC
SEM 4/25	LU 5849	-27.1	PR	6220	±	100	7251; 7005	5464 BC ; 4859 BC

Table 2 : All ages are calibrated with the calibration software Calib 5.0.2.   For marine carbonates the reservoir age of 408 years (Hughen et al. 2004) is applied with delta R of 5 ± 35 years according to Jones &   Gagnon (1994)

Table3

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

Table 3 : Radiocarbon Dates obtained on mollusc sample M (bs) = mollusc bulk sample ; M = mollusc (single valve) 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 5.0.2.   For marine carbonates the reservoir age of 408 years (Hughen et al. 2004) is applied with delta R of 5 ± 35 years according to Jones & Gagnon (1994)

Table1

River (gauge station)	Period of measurements	Discharge (av. annual) max (m³/s)	Discharge (av. annual) min (m³/s)	Discharge (av. annual) mean (m³/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 (m³/s)		*16,234.29*	*6,148.91*	*10,377.8*
Total amount (km³/year)		*511.96*	*193.91*	*327.3*

Tab. 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