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Late Pleistocene Environmental Factors defining the Black Sea, and Submerged Landscapes on the Western Continental Shelf

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Abstract :

The Black Sea semi-enclosed basin is bounded by Europe, Asia Minor and the Caucasus and is ultimately connected to the Atlantic Ocean via the Mediterranean and Aegean seas and various straits. The Bosporus Strait connects it to the Sea of Marmara, and the Dardanelles Strait connects it to the Aegean Sea region of the Mediterranean. For about 15 years the sedimentary systems of the northwestern part of the Black Sea extending from the continental shelf and slope down to the deep-sea zone have been studied using geophysical and coring techniques. These results provide a robust record of water-level fluctuations in the Black Sea since the Last Glacial Maximum (LGM) and thereby shed new light on its disputed aspects. The deep-sea fan studies demonstrate that the last channel-levee system on the Danube fan developed during the LGM with a water level about 120 m lower than today

Keywords : Black Sea basin, Late Pleistocene environmental factors, marine sedimentology research, submerged landscapes, water-level fluctuation, western continental shelf

Introduction

The Black Sea semi-enclosed basin (Fig. 17.1) is bounded by Europe, Asia Minor and the Caucasus and is ultimately connected to the Atlantic Ocean via the Mediterranean and Aegean seas and various straits. The Bosporus Strait connects it to the Sea of Marmara, and the Dardanelles Strait connects it to the Aegean Sea region of the Mediterranean. These waters separate eastern Europe and western Asia. The Black Sea also connects to the Sea of Azov by the Kerch Strait (see Chapter 16, ~~pages [xxx]–[xxx]~~ for additional detail). The Black Sea water-level fluctuations are directly linked to changes in climate, river input and the balance between evaporation and precipitation, without any hysteresis effect compared to the Global Ocean (see discussion of sea level in Chapter 2, pages ~~[xxx]–[xxx]~~).

As a consequence of such fundamental climatic changes, there were modifications of landscapes and ecosystems extending into the Carpathian–Danubian–Pontian space, and corresponding adaptations by the human inhabitants. These changes were especially marked during the Epipaleolithic and Neolithic periods, associated with the final hunter-gatherer populations of the region and the spread of agriculture. Domestication of crops and animals is thought to have started in the

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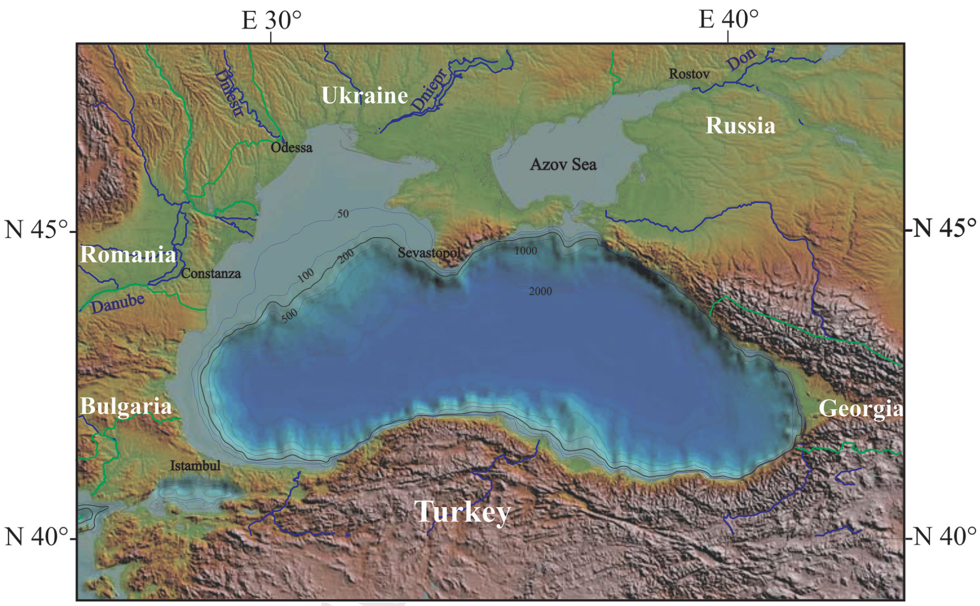

Fig. 17.1 Regional situation of the Black Sea showing simplified bathymetry, neighboring countries, and main river inputs.

Near East around 11,000 ~~BP~~ with a spread to Anatolia and the southern part of the Black Sea by about 10,000 ~~BP~~ (Ivanov & Avramova 2000).

The northwestern Black Sea shelf (Fig. 17.1) has been exposed as much as the European shelves were during sea-level lowstands, but with a regionally distinct timing due to the isolation of the basin. This now-submerged Black Sea shelf probably provided a crucial arena for the survival and dispersal of some of Europe's earliest inhabitants during the Stone Age, the early development of prehistoric societies, the initial spread of agriculture from the Near East, and the foundations for the earliest civilizations. The oldest hominin archaeological site outside Africa is located in Georgia, 200 km inland from the Black Sea coast at Dmanisi (see for example Lordkipanidze *et al.* (2013) for descriptions of skull remains about 1.89 million years old at this site). Much of the key evidence relating to these Pleistocene developments during multiple glaciations now lies buried on the sea floor. However, the water-level fluctuations of the Black Sea behaved independently from the global sea level during its period of disconnection from the Global Ocean in successive glaciations. In the aftermath of the last ice age, water levels in the Black Sea and the Aegean Sea rose independently until they were high enough to exchange water over the Bosporus sill. The exact timeline of this development has been subject to debate until recent dating of the re-connection obtained by Soulet *et al.* (2011b) based upon modeling experiments and micropaleontological reconstructions. For these authors, the Black Sea 'Lake' reconnection occurred in two steps, as follows: 1) Initial Marine Inflow (IMI) dated at 9000 cal BP followed by 2) a period of increasing basin salinity that led to the Disappearance of Lacustrine Species (DLS), a process lasting between 900 and 1000 years after the first reconnection, as also confirmed by Nicholas *et al.* (2011).

Regional Geology of the Black Sea Basin

The Black Sea is a land-locked basin, located between Europe and Asia Minor. It is generally considered to be the result of a back-arc extension associated with Mesozoic northward subduction of the Tethys Ocean beneath the Eurasian continent (Letouzey *et al.* 1978; Zonenshain & Pichon 1986; Finetti *et al.* 1988; Okay *et al.* 1994). At the end of the Eocene, the paleogeo-graphic reorganization stemming from the closure of the

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Tethys, and the associated collision of continental blocks, resulted in the individualization of two new sedimentary realms on both sides of the Alpine orogenic belts: the Mediterranean Sea to the south, and the Paratethys to the north. The wide intracontinental Paratethys Sea extended through central Europe from the western Alpine foredeeps, toward the Aral Sea in Asia (Steininger & Papp 1979). Its present remnants are the French Rhône and Swiss Molasse basins (western Paratethys), the Pannonian basin (central Paratethys), the Dacian, the Euxinic (i.e. Black Sea) ~~(Fig. 17.1)~~ and the Aralo-Caspian basins (eastern Paratethys). The Late Eocene to Middle Miocene paleoenvironmental and paleogeographical evolution of the Paratethys was characterized by a long-term trend of decreasing marine influence and a correlated reduction in size of the sedimentation domains, both resulting from the Alpine orogenic activity (Rögl 1999; Meulenkamp & Sissingh 2003). After the Middle Miocene, Paratethyan conditions evolved into drastically restricted marine environments (Fig. 17.2).

This paleogeographical reshaping culminated in overall uplift around Paratethys, leading to the progressive isolation, dislocation and, during the Pliocene, to the final infilling of most of the western Paratethyan basins (Meulenkamp & Sissingh 2003). This Neogene evolution was characterized by several successive closure episodes of the Paratethys marine connections towards the Mediterranean Sea and Indian Ocean (Rögl 1999; Meulenkamp & Sissingh 2003). On the one hand, severance of these connections resulted in the development of largely endemic faunas and floras which led to the establishment of specific Neogene stratigraphic scales for the Paratethyan sub-basins (Papp *et al.* 1974; Papaianopol & Marinescu 1995; Rögl 1998; Chumakov 2000). On the other hand, the episodic closures of the open seaways led to potential eustatic responses within the isolated basins. Depending on the hydraulic budget of the basin, its base level would evolve toward two main tendencies during isolation phases: either a positive hydraulic budget with a rapid rise in water, or a negative hydraulic budget with a

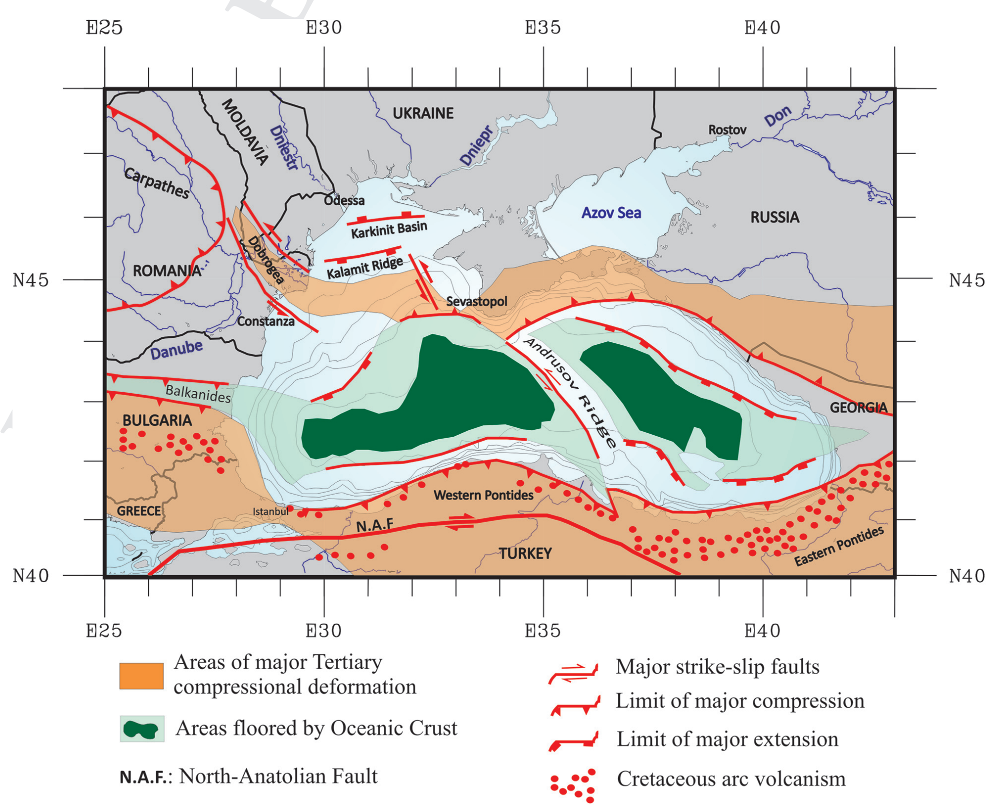

Fig. 17.2 Black Sea solid geology. After Dinu *et al.* (2002).

drastic fall in level. Because the basins have relatively small superficial areas, these eustatic responses could reach large amplitudes in a very short time. In the Late Miocene, just before the Messinian Salinity Crisis in the Mediterranean Sea (Hsü *et al.* 1973), the eastern Paratethys, including the Black Sea and Dacic basin, was connected to the Mediterranean realm by a shallow sill north of the Aegean Sea (Rögl 1999; Meulenkamp & Sissingh 2003). Presence of such a connection is supported by the influx of Mediterranean fauna (NN11) recorded in the Dacic basin (Mărunţeanu 1992; Clauzon *et al.* 2005). With regard to this paleogeographical situation, it has been proposed that the Mediterranean Messinian Salinity Crisis resulted in complete isolation of the eastern Paratethys.

Bathymetry and High Resolution Data

Global bathymetry of the Black Sea can be obtained through the International Bathymetric Chart of the Mediterranean (IBCM), which is an intergovernmental project created to produce regional-scale bathymetric maps and data sets, together with geological/geophysical overlays, of the Mediterranean region including the Black Sea ~~(Fig. 17.2)~~. Sponsorship of the IBCM project comes from the Intergovernmental Oceanographic Commission (IOC), a branch of UNESCO. As seafloor bathymetric data acquired with modern swath echo sounders provide coverage for only a small fraction of the global seabed, new global composite bathymetry has been built up. In 2009, a method for compilation of global seafloor bathymetry that preserves the inherent resolution of swath sonar raw data was published by Ryan *et al.* (2009). This Global Multi-Resolution Topography synthesis consists of a hierarchy of tiles with digital elevations and shaded relief imagery spanning nine magnification doublings from pole-to-pole (www.marine-geo.org/portals/gmrt). The compilation is updated and accessible as surveys are contributed, edited, and added to the tiles. Access to the bathymetry tiles is via web services and with WMS-enabled client applications such as GeoMapApp, Virtual Ocean, NASA World Wind, and Google Earth (Ryan *et al.* 2009). More recently the FES2012 project from the Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (LEGOS, Toulouse France) built a composite bathymetry based on ETOPO1 (Amante & Eakins 2009) and on a 1-km grid of a morpho-bathymetric map of the Mediterranean Sea derived from multibeam swath sonar surveys provided to the National Geophysical Data Center (NGDC) by Benoit Loubrieu (Institut Français de Recherche pour l'Exploitation de la Mer — IFREMER) and published and promoted by the Commission Internationale pour l'Exploration Scientifique de la mer Méditerranée (CIESM) (Loubrieu *et al.* 2008). Patches are then performed to update the original bathymetry with the most accurate local depths (or those believed to be so). Details on global and regional databases can be found on the LEGOS bathymetry database web page. All global databases have been updated before patching (www.legos.obs-mip.fr/recherches/equipes/ecola/projets/fes2012/bathymetry).

Here, part of the data used in the CIESM map was acquired in the Black Sea by the ASSEMBLAGE 5th European Project. Acquisition and reduction of multibeam bathymetry and imagery data sets were carried out to determine the sediment deposited since the last sea-level rise. Construction of Digital Terrain Models (DTM) of the bathymetry were generated to produce major maps of the western part of the Black Sea (Fig. 17.3).

Marine Sedimentology Research

For about 15 years the sedimentary systems of the northwestern part of the Black Sea extending from the continental shelf and slope down to the deep-sea zone have been studied using geophysical and coring techniques. These results (Popescu *et al.* 2001; 2004; Lericolais *et al.* 2007a,b; 2009; 2011; Popescu & Lericolais 2009; Soulet *et al.* 2010; 2011a,b; 2013) provide a robust record of water-level fluctuations in the Black Sea since the Last Glacial Maximum (LGM) and thereby shed new light on its disputed aspects. Recently, a wide range of work carried out in the Black Sea attempted to assess

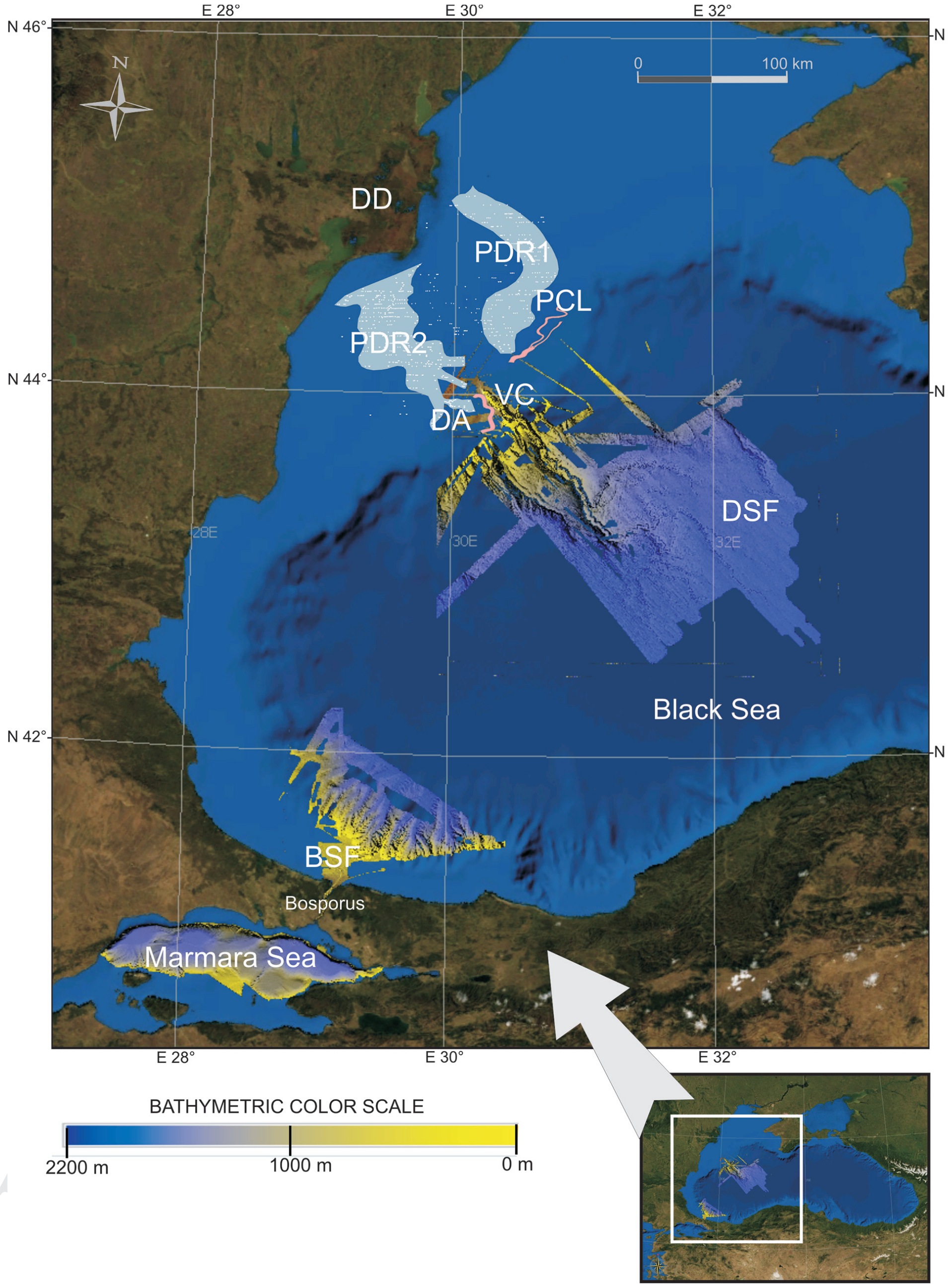

Fig. 17.3 Western Black Sea shelf presenting the location map of the geomorphological interpretation resulting from previous work. Popescu *et al.* (2001; 2004); Lericolais *et al.* (2007a). DD = Danube Delta; PCL = Paleocoastline; PDR1 = Paleo-Danube River 1; PDR2 = Paleo-Danube River 2; DA = Dunes area; VC = Viteaz canyon; DSF = Deep-sea fan; BSF = Bosporus-shelf fan.

the last cycle of sea-level rise, and provide scenarios to assist in quantifying the processes governing the transition from a low-salinity to a marine state while also addressing the variability expressed by this system (see also Chapter 16, pages ~~[xxx]–[xxx]~~). Six major critical factors were established prior to reconstructing the Black Sea water-level fluctuations since the LGM (Lericolais *et al.* 2011).

The existence of a LGM lowstand wedge at the shelf edge off the coasts of Romania, Bulgaria and Turkey (Lericolais *et al.* 2011). This observation includes evidence of a second small lowstand wedge dated between 12,000 cal BP and 9000 cal BP at water depths from 100 m to 120 m, identified during ASSEMBLAGE cruises on the outer shelf of Romania and Bulgaria (Lericolais *et al.* 2007a,b; 2009; 2011), and described on the Turkish shelf by Algan *et al.* (2002). This wedge is associated with the recovery of strata immediately below an observed unconformity consisting of dense mud with low water content, and containing desiccation cracks, plant roots, and sand lenses rich in freshwater mollusks (*Dreissena rostriformis*) with both valves still joined together.

Information on the building of the Danube Delta/pro-delta, showing that a former pro-delta built up at –40 m after the post-LGM meltwater pulses.

Mapping of meandering river channels capped by a regional unconformity, and extending seaward across the Romanian shelf to the vicinity of the –100 m isobath.

The presence of submerged shorelines with wave-cut terraces and coastal dunes, or delta mouth bars at depths between 80 m to 100 m below the Holocene Bosporus and Dardanelles Strait outlet sill to the Global Ocean.

Evidence on the western part of the Black Sea continental shelf of a shelf-wide ravinement surface, visible in high- to very-high-resolution seismic reflection profiles.

The presence of a uniform drape of sediment beginning at the same time above the unconformity, with practically the same thickness over nearby elevations and depressions and with no visible indication of coastal-directed onlap across the outer and middle shelf, except in the vicinity of the Danube Delta where this mud drape is overlapped by recent Danube sediments.

These critical factors enable quantification of the processes governing the transition from a semi-freshwater lake to a marine state and a better understanding of the last sea-level rise in the Black Sea. The scenario starts at the LGM about 21,000 years ago, when the Black Sea was probably a giant freshwater lake (Soulet *et al.* 2010).

Post-LGM Climate, Sea Level, and Paleoshorelines

Water-level fluctuation scenario

The deep-sea fan studies (Popescu *et al.* 2001; Lericolais *et al.* 2012; 2013) demonstrate that the last channel–levée system on the Danube fan developed during the LGM with a water level about 120 m lower than today. The proximity of the Scandinavian-Russian ice cap supplied glacial melt water into the Black Sea through the major drainage system of the larger European rivers (Danube, Dnieper, Dniester, and Bug), and this is registered as brownish layers identifiable in cores (Fig. 17.4) (Major *et al.* 2002a; Bahr *et al.* 2005; Soulet *et al.* 2013). The volume of water brought to the Black Sea after Meltwater Pulse 1A (MWP-1A) at approximately 14,500 cal BP (Soulet *et al.* 2011b) was sufficient to raise the water level from –40 m to –20 m. The –40 m limit has been

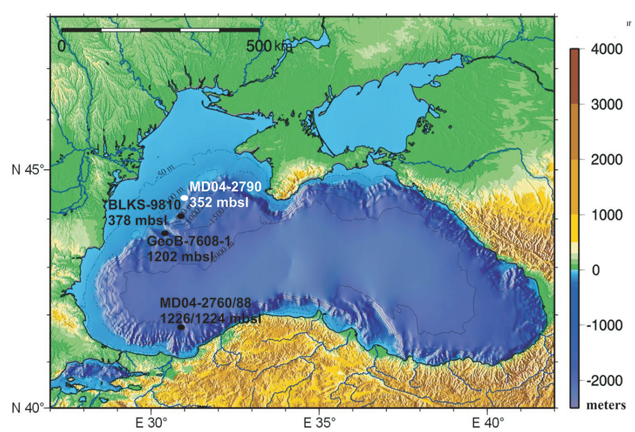

Fig. 17.4 Location of the cores used by Soulet *et al.* (2011a). The white dot indicates the location of the MD04 2790 coring site (44 12.8 N, 30 59.6 E) studied by Soulet *et al.* (2011a). Black dots represent the coring locations for previously published cores as follows: BLKS-9810 (Major *et al.* 2002b); GeoB 7608-1 (Bahr *et al.* 2005); and MD04-2760 and MD04-2788 (Kwiecien *et al.* 2008). The coring depths, in meters below sea level (MBSL), are indicated below the coring sites.

inferred from the Danube prodelta building (Lericolais *et al.* 2009), but this is not definitive and Yanko (1990) gives evidence for the –20 m limit. This last value for the transgression's upper limit would have brought the level of the Black Sea even higher in relation to the Bosporus sill, with a possible influx of marine species, such as Mediterranean dinoflagellates (Popescu 2004). Nevertheless, the rise in the water level of the Black Sea, which maintained fresh to brackish conditions, stopped deep-sea fan sedimentation.

Palynological studies conducted on BlaSON cores (Fig. 17.4) (Popescu 2004) show that, from the Bølling/Allerød to the Younger Dryas (i.e. from 14.7 ka to 12.7 ka), a cooler and drier climate prevailed. The flow from northeastern European rivers converged into the North Sea and the Baltic Ice Lake (Jensen *et al.* 1999), resulting in reduced river input to the Black Sea and a receding shoreline. These observations are consistent with an evaporative drawdown of the Black Sea and correlate with evidence of an authigenic aragonite layer present in all the cores studied (Strechie *et al.* 2002; Giunta *et al.* 2007). This drawdown is also confirmed by the forced regression-like reflectors recognized on the dune field mosaics (Lericolais *et al.* 2009). The presence of coastal sand dunes and wave-cut terraces confirms this lowstand. This had already been observed by several Russian authors, who considered a sea-level lowstand at about 90 m depth. Their observations were based on the location of offshore sand ridges described at the shelf edge south of Crimea. Around the Viteaz canyon (Danube canyon), the paleocoastline was forming a wide gulf in which two rivers (PDR1 and 2) were flowing (Fig. 17.3). Earlier studies had already proposed a depth of 105 m for this lowstand according to a regional erosional truncation recognized on the southern coast of the Black Sea (Demirbağ *et al.* 1999; Görür *et al.* 2001), but also based on the presence of a terrace on the northern shelf edge (Major *et al.* 2002b; Lericolais *et al.* 2007a).

On the Romanian shelf, preservation of sand dunes and small, buried incised valleys can be linked to a rapid transgression during which the ravinement processes related to water-level rise had insufficient time to erode the sea bottom to any substantial extent (Ahmed Benan & Kocurek 2000; Lericolais *et al.* 2004). Around 9000 cal BP, the surface waters of the Black Sea suddenly attained present-day conditions owing to an abrupt flooding of the Black Sea by Mediterranean waters, as shown by dinoflagellate cyst records (Popescu 2004) and recently demonstrated by Soulet *et al.* (2011b) and Nicholas *et al.* (2011). The inflow of marine water is confirmed by the abrupt replacement of fresh-to-brackish species by marine species. Furthermore, Soulet *et al.* (2011b) and Nicholas *et al.* (2011) demonstrate that the Black Sea 'Lake' reconnection occurred in two steps, with an Initial Marine Inflow (IMI) dated at 9000 cal BP, followed by a ca. 1000-year period of increasing basin salinity (as noted above in the Introduction, ~~pages [xxx]–[xxx]~~). This last event can also be related to the beginning of the sapropel deposit which is widespread and synchronous across the basin slope and floor. The Black Sea basin would have been flooded in ~1000 years, equalizing water levels in the Black Sea and Sea of Marmara. Such a sudden flood at a rate of about 10 m per century would have preserved lowstand coastal marks on the Black Sea's northwestern shelf.

From these syntheses, the water-level fluctuation diagram proposed (Fig. 17.5) is judged to be the one that best fits the recently published observations.

Discussion of sea-level curve and its archaeological implications

Many decades of work carried out by scientists from Russia and other eastern European countries (Andrusov 1893; Yaranov 1938; Nevesskiy 1961; Fedorov 1963; Kvasov 1968; Muratov *et al.* 1974; Ostrovskiy *et al.* 1977; Arslanov *et al.* 1978; Shimkus *et al.* 1980; Balabanov 1984) led to the publication of different hypotheses and curves for Holocene sea-level changes in the Black Sea. Using these different works a first synthesis effort was produced by Pirazzoli (1991). However, Ryan *et al.* (1997) published a hypothesis according to which a massive flood through the Bosporus occurred in ancient times. They claim that the Black Sea was a vast freshwater lake, but then about 7500 BP, later corrected to 8400 BP (Ryan *et al.* 2003; Ryan 2007), the Mediterranean spilled over a sill at the Bosporus, creating the current communication between the Black and Mediterranean seas. Subsequent work has

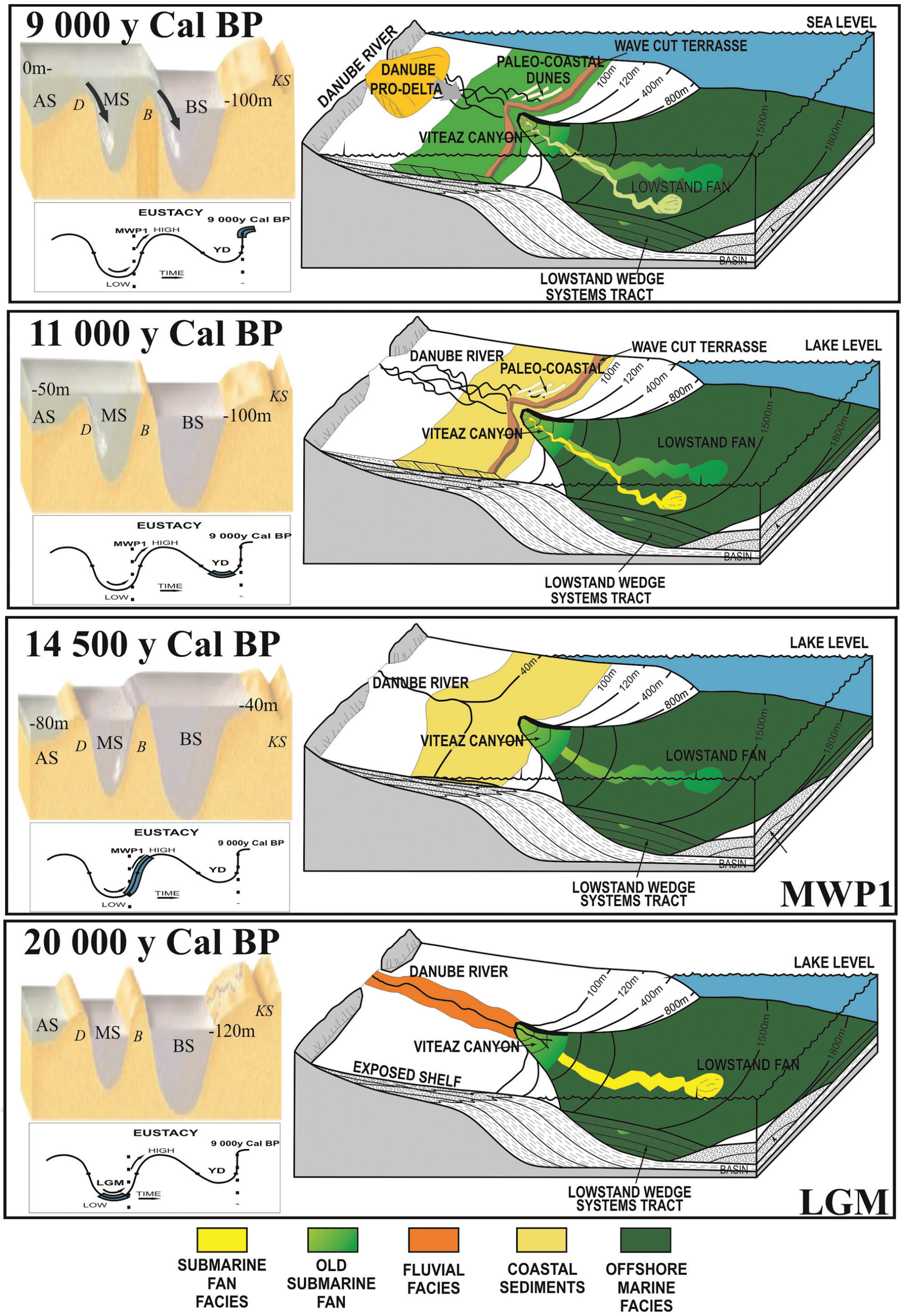

Fig. 17.5 Modified from Lericolais *et al.* (2009), where dates were calibrated using IntCAL09 with Soulet *et al.* (2011b) work and reservoir ages. The schematic scenario is inspired by Posamentier and Vail (1988) and shows water-level fluctuation in the Black Sea since the LGM, deduced from geomorphological results, supported by the Danube deep-sea fan functioning (Popescu *et al.* 2001), the results from palynology and dinoflagellates (Popescu *et al.* 2004) and the paleocoastline position.

both supported and discredited this hypothesis, and it is still a matter of active debate (Aksu *et al.* 1999; 2002; Ballard *et al.* 2000; Kerr 2000; Uchupi & Ross 2000; Görür *et al.* 2001; Major *et al.* 2002b; 2006; Ryan *et al.* 2003; Algan *et al.* 2007; Balabanov 2007; Hiscott *et al.* 2007; Giosan *et al.* 2009; Lericolais *et al.* 2009; 2010). Such a late reconnection would lead to a longer exposure of the Black Sea shelf allowing human settlements to become established near the coast. This has led some to associate the supposedly catastrophic flooding of the shelf with prehistoric flood myths, and this has become one of the most visible scientific debates of recent years, and one that has fascinated the public imagination.

This controversy was one of the triggers for the installation of IGCP (International Geoscience Programme) Project 521 ‘Black Sea-Mediterranean Corridor during the last 30 ky: sea level change and human adaptation’. The resulting book edited by Yanko-Hombach *et al.* (2007) is a good record of the state of research from geology to archaeology carried out in the Black Sea. However, many conclusions of studies presented in the volume should be considered cautiously as it is evident that a vigorous debate is ongoing and much research remains to be done (see also Chapter 16, ~~[pages [xxx]–[xxx]]~~).

Recent studies supported by the European Commission (described above) led to a synthesis on the assessment of the last sea-level rise in the Black Sea obtained from observations collected by a series of expeditions carried out between 1998 to 2005, in particular, the evidence of recent submerged landscapes, the erosion of which was due to wave action around 9000 cal BP (Soulet *et al.* 2011b). Based on these results, a sea-level curve was first published in 2009 by Lericolais *et al.* (2009). This curve (Fig. 17.6) is here adapted using recent calibration of radiocarbon dates (Soulet *et al.* 2011b). Before these important results, numerous Russian authors indicated a sea-level lowstand at about 90 m depth, based on the location of offshore sand ridges described at the shelf edge south of Crimea. The unique wave-cut terrace on the outer Romanian shelf presenting an upper surface varying between –95 m and –100 m is therefore consistent with a major lowstand level situated somewhere around 100 m depth and evidence that the Black Sea shelf had emerged at the beginning of the Holocene.

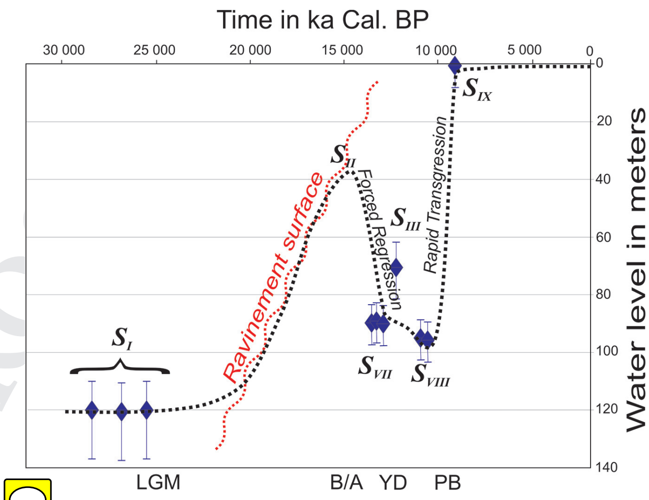

Fig. 17.6 Water-level fluctuation in the Black Sea since the Last Glacial Maximum. LGM = Last Glacial Maximum; B/A = Bølling/Allerød; YD = Younger Dryas; PB = Pre-Boreal. S_I to S_{IX} are the sequences interpreted and dated from the Romanian Black Sea shelf. ~~This figure is published in~~ Lericolais *et al.* (2009).

Modern Coastline and Coastal Processes: the Danube Delta

Before entering the Black Sea, the Danube forms a wide, branching delta, the second largest river delta in Europe. It is located between longitude E28°45′ and E29°46 and latitude N44°25′ and N 45°37′ covering a surface of almost 5800 km^2 (Fig. 17.3 ‘DD’), confined by the Bugeac Plateau to the north and by the Dobrogea region to the south (Panin 1996). The development of the delta starts at the point where the Danube River’s main channel divides into three main branches: the northern Chilia, the central Sulina and the southern St. George (Sfântu Gheorghe). A mosaic of shallow lakes and channels, fringed by reeds, lies between these branches. The Danube Delta is classified as a fluvial-dominated delta starting in a Black Sea embayment sheltered by a barrier (Panin 1983). After reaching the coast, the three main branches of the Danube Delta constitute four laterally offset lobes. Open-coast delta lobes are wave-dominated (Fig. 17.7), with the exception of Chilia III, the youngest lobe, which has a primarily fluvial-dominated morphology (Giosan *et al.* 2006). The wave-dominated lobes exhibit an

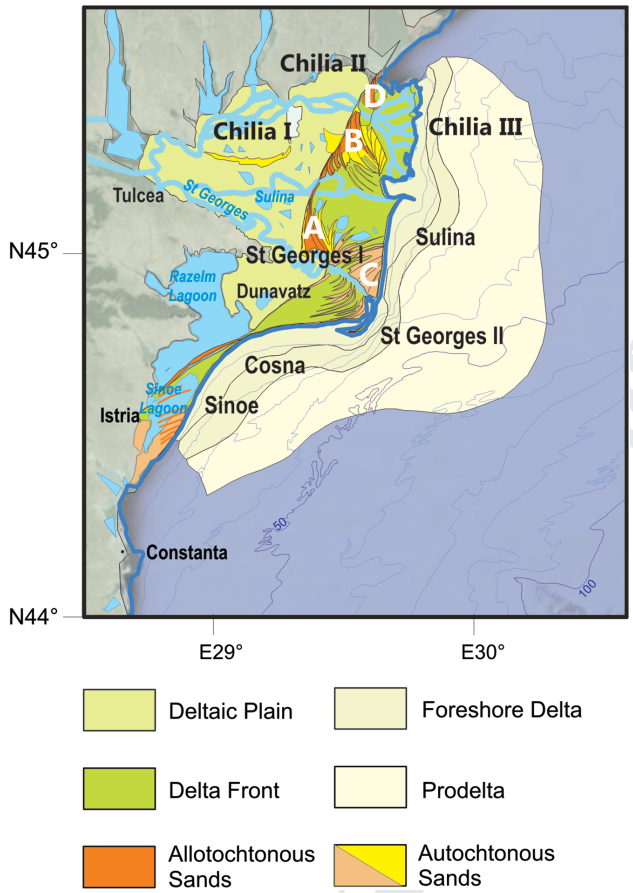

Fig. 17.7 Danube Delta morphology and lobe development sequence. After Panin *et al.* (1983); Giosan *et al.* (2006). Postulated locations for Cosna and Sinoe lobes are from Panin *et al.* (1983). Major beach ridge plains are (A) Caraorman; (B) Letea; (C) Saraturile; and (D) Jebrieni. Barrier systems of Zmeica, Lupilor, Istria, and Chituc-segment Razelm-Sinoe lagoons. Location of ancient city of Istria is indicated.

asymmetric morphology (Bhattacharya & Giosan 2003). Longshore drift obstruction at distributary mouths led to development of an extensive system of beach ridges and plains on the updrift side of these lobes, whereas on the downdrift side, barrier plains developed as a succession of sandy ridges separated by elongated marshes and/or lakes (Giosan *et al.* 2006). Early interpretations of the pattern of beach ridges established a relative chronology for the open-coast lobes (de Martonne 1931; Zenkovich 1956).

The St. George I was the first lobe formed at the open coast, followed by Sulina; subsequently, the St. George arm was reactivated, developing a second lobe (Fig. 17.7). Panin (1983) explained the rapid growth of the Sulina lobe as a forced regression during a postulated Black Sea Phanagorian regression around 3000 ~~BP~~ to 2000 ~~BP~~ (Chepalyga 1984). The subsequent reactivation of the St. George branch was attributed to a channel slope increase at the Phanagorian lowstand (Panin 1983). Within the remnant shallow basins of the Danube embayment, the northernmost distributary, the Chilia, developed two successive lacustrine deltas before building into the Black Sea (Fig. 17.7). The Danube Delta Plain extends southward into several generations of bay-mouth barriers (Zmeica, Lupilor, Chituc, Istria), delineating the Razelm-Sinoe lagoon system (Fig. 17.7).

Coastal and Shelf Geomorpho-Dynamics, Erosion, and Accumulation

The physiographic provinces represented in Figure 17.8 are divided into four main areas: the continental shelf, the continental slope, the glacis, and the bathyal plain.

The continental shelf is well developed in the north-western part of the basin. The shelf is well marked 140 km seaward off the Danube mouth, reaching 190 km westward off Crimea with its width decreasing southerly to almost 40 km in front of the Bulgarian coast. The continental shelf is nearly absent in the southern part of the Black Sea near the Sakarya canyon. The other parts of the continental shelf are very narrow and reach no more than 20 km in width, except for the area south of the Sea of Azov where the continental shelf can reach 40 km in width. The shelf break is located at around a depth of 100 m (Ross & Degens 1974); in front of the mouth of the Danube it reaches –120 m to –140 m south of the Viteaz canyon (or Danube canyon), but can be deeper than 170 m in the northern part of the canyon, probably because of recent tectonic activity.

The continental slope related to the narrow shelf of the south, east and north-east of the Black Sea basin and south of Crimea is relatively steep (2.5% according to Ross & Degens 1974). In contrast to the continental shelf

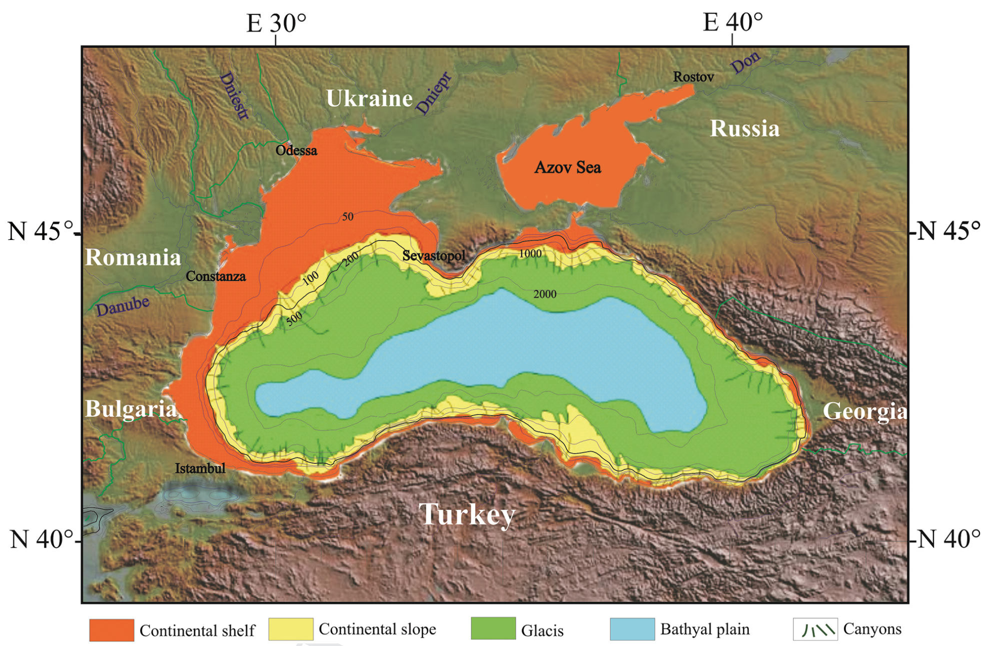

Fig. 17.8 Black Sea physiography. After Panin & Popescu (2007).

the slope is incised by numerous canyons. Slopes with a lower gradient are situated in the northwestern part of the Black Sea (Danube and Dnieper deep-sea fans) and to the south of the Sea of Azov (Don and Kuban deep-sea fans). This parameter is linked to the high rate of sedimentation due to fluvial sediment inflows. In these areas wide canyons are present. The Viteaz canyon and the Dnieper canyons have incised the continental slope, and also the continental shelf landward over a distance of 20 km.

The glacis forms the area along the margin where the terrestrial inflows are deposited. With slopes ranging from 0.1% to 2.5%, its width is a function of the volume of the inflows. The width reaches its maximum at the Danube and Dnieper fan location.

The bathyal plain is located in the center of the basin showing a slope less than 0.1% and a maximal depth of 2212 m.

The present-day Black Sea catchment area is dominated by the Danube River and by the rivers from the north of the Black Sea (Dnieper, Dniester, Southern Bug). At the easternmost part of the Black Sea catchment area, the River Don approaches the Volga River. The Kuban is the biggest river bringing water from the Caucasus into the Black Sea via the Sea of Azov. The annual discharge of these six biggest rivers (Danube, Dnieper, Dniester, Southern Bug, Don and Kuban) is 270.3 km^3/year (Fekete *et al.* 2000). The annual mean contribution of rivers from the Anatolian mountains is only 36 km^3/year and they are not included in the report of Fekete *et al.* (2000). Most of the river input running into the Caspian Sea is due to the Volga, Ural and Kura (Stolberg *et al.* 2006). The Aral Sea receives fresh water from the Syr Darya and Amu Darya; their discharge is 60.5 km^3/year (Fekete *et al.* 2000). The Ob and Yenisei (at present-day) discharge 965.1 km^3/year of water into the Arctic Ocean.

Conclusion

The Black Sea is surrounded by high-folded mountain chains, i.e. the Balkanides-Pontides belts to the south/south-west, the Great and Little Caucasus to the east and by the Crimea Mountains to the north, and the Danube Delta lowland is one of its main features. This sea is one of the largest almost-enclosed seas in the world, having roughly an oval shape. The Black Sea is locked in between the southernmost tip of the Crimea and Cape Kerempe on the Turkish coast, and is connected to the Mediterranean Sea through the Istanbul-Canakkale (Bosporus-Dardanelles) straits to the west and the Sea of Azov through the Taman–Kerch Strait to the north. Such a physiography is inherited from a peculiar pattern of previous specific sea-level fluctuations. The updated results obtained from oceanographic surveys carried out in the Black Sea have led to the proposal of a scenario for the transition of the Black Sea system from a lacustrine to a marine environment.

Aside from the controversy about the conditions of the last reconnection of the Black Sea, these recent syntheses have improved the chronology of the last reconnection, indicating that it occurred around 9000 years ago. This finding shows that the reconnection was not related to catastrophic drainage of the ice-dammed Lake Agassiz. Moreover, now it is possible to confirm that the replacement of lacustrine by marine biota needed almost 1000 years, the time required for the onset of the two-way flow circulation currently observed in the Sea of Marmara gateway. These results also suggest that the level of the isolated Black Sea was below the former Bosporus sill depth. The recent results obtained from pore water analyses (Soulet *et al.* 2010) suggest that the Black Sea was a freshwater lake prior to its reconnection with the Sea of Marmara and show that microfossils are often tolerant to a wide range of salinities. For example, the taxon that Marret *et al.* (2004) used as evidence of Black Sea salinity (*S. cruciformis*), has also been found in modern sediment from the brackish Caspian Sea. Moreover, this taxon shows extreme morphological variability (Wall & Dale 1974; Mudie *et al.* 2001). Such variability may be linked to fluctuations in salinity (Dale 1996). However, no clear relationship between the different morphotypes and surface salinity has been established (Kouli *et al.* 2001; Mudie *et al.* 2002).

The debate about the effect of possible salinity variations on the probability of human occupation of the Black Sea shelf during the Neolithic does not necessarily determine whether people lived there or not. Farmers have always valued good, flat, alluvial land, and modern artisanal agriculture in the Mediterranean region shows that crops will grow very close to salt water on sheltered coastlines. Thus the proposal that the fresh Black Sea 'Lake' (Ballard *et al.* 2000; Major *et al.* 2002b; Ryan *et al.* 2003) would have allowed coastal farming on exposed shelves is perfectly true, but a brackish or salty Black Sea (e.g. Mudie *et al.* 2001; Yanko-Hombach *et al.* 2007) would not have prevented settlement along the Black Sea coast. In either case people could have lived on the shelf, but, up till now, we do not have *in situ* evidence for such occupation.

If Neolithic farmers did live on the Black Sea shelf, a rapid flooding of the shelf would have accelerated their dispersal onto higher ground over a period of about 30 years. In spite of speculation that such a retreat from rising sea level would have influenced the rate of the spread of agriculture from the Middle East to northwest Europe, the genetic data which have been used to derive the spread of the so-called 'Neolithic Revolution' do not show a perturbation in the region of the Black Sea. The contours showing the 'frontier' or dates of Neolithization were first plotted by Ammerman and Cavalli-Sforza (1984), and have been refined and analyzed by numerous researchers more recently (e.g. Fort 2012), and there is no sign of a significant increase in rate or distortion in the process around the Black Sea. The spread of agriculture is now considered to have been caused proportionately 60% to 70% by demographic movement, and 30% to 40% by cultural transfer.

The specific sea-level fluctuations encountered in the Black Sea after the LGM allow us to think that early Neolithic populations could have lived near the Black Sea 'Lake' and experienced the rise of water level when this water body reconnected with the Global Ocean. If the level of the Black Sea drew down to a depth of 100 m below its present level between 14,000 ~~BP~~ and 10,000 ~~BP,~~ it is conceivable that one might find some buried Neolithic or earlier artifacts on the shelf of the Black Sea. Until archaeological remains are found *in situ on* the sea floor, the question remains unresolved.

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