Evidence from recent oceanographic surveys of a last rapid sea level rise of the Black Sea

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In 1997, Ryan and Pitman (Ryan *et al*., 1997) came forward with astonishing evidence suggesting that a catastrophic flood of the Black Sea 7,500 years ago could have played a primordial role in the spread of early farming into Europe and much of Asia. In 1999, in their book *"Noah's Flood, the new scientific discoveries about the event that changed history"* (Ryan and Pitman, 1999b) these two authors stated also that this flood could have cast such a long shadow over succeeding cultures that it inspired the deluge account in the Babylonian epic of Gilgamesh and, in turn, the story of Noah in the Book of Genesis.

This hypothesis arose from the results of a joint Russian-American expedition carried out in 1993 on the continental shelf south of the Kerch Strait and west of Crimea (Major, 1994; Ryan *et al*., 1997). These results were established from interpretation deduced from high-resolution seismic reflection profiles, cores precisely targeted on these profiles and on dating by carbon-14 Accelerator Mass Spectrometry of the informative layers. The survey revealed a buried erosion surface strewn with shelly gravel extending across the broad continental margin of the northern Black Sea to beyond its shelf break (Evsylekov and Shimkus, 1995; Major, 1994). The cores recovered evidence of sub-aerial mud-cracks at -99 m, algae remains at -110 m, and the roots of shrubs in place in desiccated mud at -123 m. Each site lay well below the -70-m level of the Bosphorus bedrock sill (Algan *et al*., 2001; Gökasan *et al*., 1997). This combination of evidence suggested to Ryan *et al*. that a drowning event in the Black Sea could be the consequence of a steady transgression on a vastly shrunken lake characterised by the deposition of a uniform drape of marine mud on the terrestrial surface equally thick in depressions as on crests of dunes with no sign of landward-directed onlap of the sedimentary layers in the drape (Ryan *et al*., 2003). The ^{14}C ages documented a simultaneous sub-aqueous colonisation of the terrestrial surface by marine molluscs at 7,100 y BP*. This age was assigned to the Holocene flooding event. However, flooding precludes the possibility of outflow to the Sea of Marmara during the prior shrunken lake

* y BP means years before present (1950) without neither correction for reservoir age nor calibration to calendar years. In Ryan et al. (1997) and Ryan, W. and Pitman, W., 1999a, ages were expressed in calendar years with 7,500 cal y BP equivalent to 7,100 y BP.

stage. Arguments for persistent Holocene outflow from the Black Sea to the eastern Mediterranean (Aksu *et al.*, 2002b) and for noncatastrophic variations in Black Sea sea level during the 10,000 y BP (Aksu *et al.*, 2002c) have been recently presented to contradict the flood hypothesis. In order to evaluate the validity of the catastrophic model or its replacement by a continuous outflow model, our review cites many papers published in the Soviet literature that contain pertinent observations and discussions not considered in arguments against catastrophic flooding.

More recently, in 1998 and 2002, two Ifremer oceanographic surveys completed the results from previous studies of seabed mapping and of subsurface sampling realised by Soviet scientists and various international expeditions. These recent surveys carried out on the north-western continental shelf of the Black Sea established that the Black Sea's lake level rised on the shelf to at least the isobath –40 to 30 m given by the landward limit of extend of the Dreissena layer characteristic of freshwater conditions. This rise in freshwater level would coincide with the functioning of the Black Sea as an important catchment basin of the melt water drained from the melting of the ice cap ensuing the Melt Water Pulse 1A , from the Bølling Allerød period (Bard *et al.*, 1990). It is possible that at that time the lake level filled by freshwater rose to the level of its outlet and spilled into the Mediterranean. However, in mid-Holocene at 7,500 y BP the onset of salt water conditions are clearly evidenced in the Black Sea. While this hypothesis has been discussed (Aksu *et al.*, 2002a; Aksu *et al.*, 2002b; Aksu *et al.*, 1999b; Aksu *et al.*, 2002c) the recent discoveries of the excellent preservation of drowned beaches, sand dunes and soils seem to bring credibility to the Ryan and Pitman assumption.

Geological background

The Black Sea is a 2.2 km deep basin with a broad northwest continental shelf (Fig. 1). Connection to the external Mediterranean Sea is over a sill in the Bosphorus Strait. The role that this strait has played in controlling the salinity and stratification of both seas to produce intervals of anoxia has been discussed widely (Abrajano *et al.*, 2002; Arkhangelskiy and Strakhov, 1938; Lane-Serff *et al.*, 1997; Muramoto *et al.*, 1991; Rohling, 1994; Scholten, 1974). The general view is that during periods of low global sea-level the Black Sea lost connection with the ocean, freshened from river discharge into a vast lake, became well ventilated and established a shoreline at the level of its outlet (Chepalyga, 1984; Hodder, 1990) in order to export excess water to the Mediterranean.

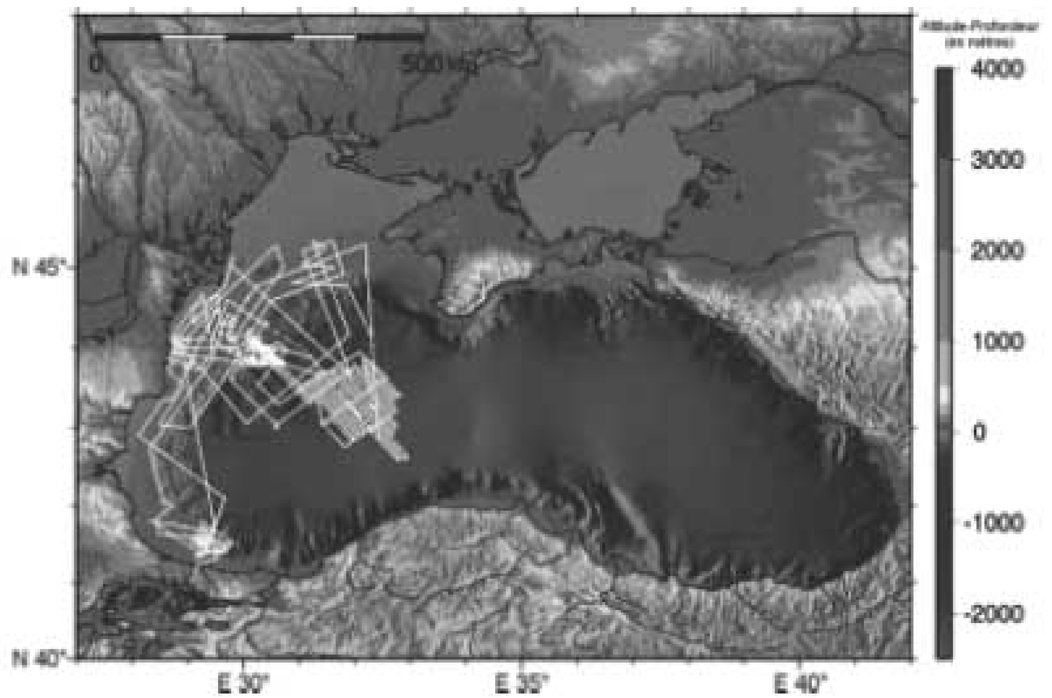

Fig. 1. Bathymetry of the Semi-enclosed Basin Black Sea and rooute location of the Ifremer surveys.

The North-western Black Sea receives the water and sediment discharges of the largest European rivers (Danube, Dniepr, Dniestr). For instance, the drainage basin of the river Danube is of 817,000 km^2. The Danube multiannual water discharge into the Black Sea is estimated at 6,047 $m^3.s^{-1}$ (almost 190 $km^3.yr^{-1}$), while its multiannual sediment discharge at the mouth zone was of about 51,7 million tons per year (t/yr) before the river damming (Bondar, 1998). After the damming in 1970 and 1983, one can estimate that the Danube total average sediment discharge could not be larger than 30-35 million t/yr, including only 4-6 million t/yr of sandy material (Panin, 1997). During the glacial lowstands and especially at the beginning of interglacials, the sediment discharges of these rivers were probably much higher.

It has long been recognised that the Black Sea was isolated from the Marmara Sea and the Mediterranean during glacial intervals when levels of the latter seas fell below the sill depth (at –35 m) of the Bosphorus. Similarly, it has been postulated that the water level of the Black Sea rose along with the Marmara and Mediterranean seas once their water levels rose above the Bosphorus sill depth (Degens and Ross, 1974). However, recent analyses of sediments deposited along the margins of the Black Sea suggest that water level fluctuations in the Black Sea were somewhat more complex, with high lake levels occurring during wet, late glacial intervals and low lake levels occurring during drier early interglacial times (Chepalyga, 1984).

Another widely-accepted hypothesis on the connection of the Black Sea with the external oceans postulates that this inland sea had always maintained a continuous outflow through the Bosphorus and Dardanelles Straits, even during the highly arid glacial intervals (Chepalyga, 1984; Kvasov and Blazhchishin, 1978). Essentially, it was assumed that the river input to and precipitation on the Black Sea have continuously exceeded any loss from local evaporation. Indeed, meltwater from former ice caps in Fennoscandia, northern Asia (Grosswald, 1980) and the central Alps has transformed the Black Sea into a giant freshwater lake a number of times in the past (Federov, 1971; Ross *et al*., 1970) and most recently during the Neoeuxinian stage of the Late Pleistocene (Arkhangelskiy and Strakhov, 1938; Federov, 1971; Nevesskaja, 1965; Nevesskaja and Nevesskiy, 1961; Ross *et al*., 1970) (Fig. 2).

Ryan *et al*. (1997) published evidence that during the last Quaternary glaciation, the Black Sea became a giant freshwater lake. This evidence includes new AMS ^{14}C dates, abrupt changes in

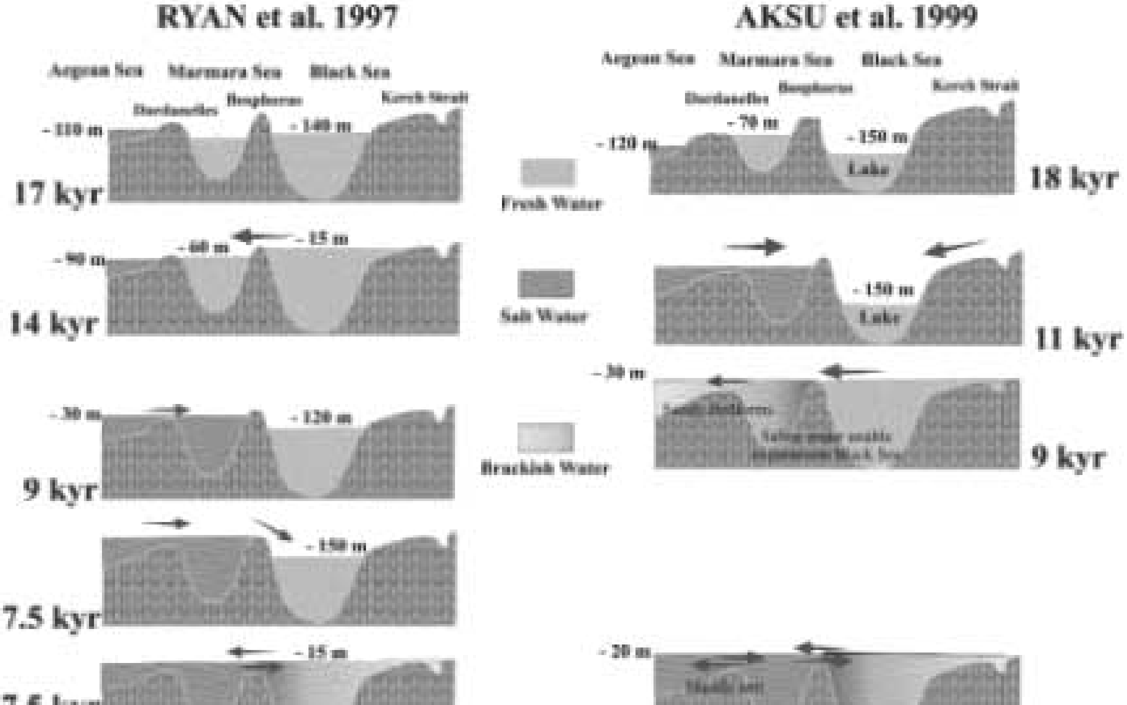

Fig. 2. Controversal schemes of the reconnection between the Black Sea and the Mediterranean.

the organic carbon content, water content and $D^{18}O$ of core material at about 7,150 y BP, as well as the occurrence of a widespread unconformity interpreted as an erosional surface subaerially exposed during the last glacial. From the depth distribution of the unconformity, the surface of this freshwater lake must have fallen to levels >100 m below its outlet. By about 7,150 y BP, the sill depth of the Bosphorus was breached and a catastrophic flooding of the continental shelf of the Black Sea was inferred (Fig. 2).

One piece of evidence that argues against catastrophic flooding is the different ages of sapropels in the eastern Mediterranean and the Black Sea. Sapropel S_1 in the Aegean is commonly taken to be deposited from about 9,600 to 6,400 calendar years BP (Aksu *et al.*, 1999a; Aksu *et al.*, 1999b; Fontugne *et al.*, 1994) but deposition could have lasted to 5,300 y BP (Rohling and de Rijk, 1999). During this time, nutrient-rich freshwater from the Black Sea reduced the surface salinity of the eastern Mediterranean, thus increasing the stability between the surface and deep waters and decreasing deep circulation (Aksu *et al.*, 1999a). High surface productivity and circulation stagnation are conditions favourable for sapropel formation. In the Black Sea, on the other hand, sapropel formation started about 550 years later than in the eastern Mediterranean (Rohling, 1994), when the denser Mediterranean waters displaced the nutrient-rich waters in the Black Sea towards the surface (Calvert, 1990; Calvert and Fontugne, 1987). This lag is probably too large to be accounted for by the catastrophic flooding hypothesis.

Archeological approach

The impact of climate on human evolution and development has long been discussed (e.g., (Stanley and Galili, 1996). Archaeological excavations in many areas of the eastern Mediterranean (Ammerman, 1989; Perlès, 2001) are uncovering evidence relating the emergence and spread of early farming communities, as related to environmental and social factors. It is assumed (Cita *et al.*, 1984) that the spreading of agriculture into the Western Mediterranean may have been initially induced by a cold event dated to 8,200 cal y BP (ca 7,500 uncorrected radiocarbon y BP), identified, for example, in the ice-core records of Greenland (Alley *et al.*, 1995) and marine records of the north Atlantic (Dahl-Jensen *et al.*, 1998; Strohle and Krom, 1997; von Grafenstein *et al.*, 1998).

However, the recent data analysed in the Black Sea cores relate to a very rapid change in the environmental and climatic conditions around the Black Sea lake. This could have induced an environmental stress for well-established and growing farming communities and resulted in forcing them to explore other areas outside Southwest Asia. This younger event is coincident with the introduction of euryhaline molluscs into the Black Sea to replace those of its Neoeuxine fresh to brackish lake (Lericolais, 2001; Ryan *et al.*, 2003; Ryan and Pitman, 1999b; Ryan *et al.*, 1997). However, evidence of a short-term cooling during Sapropel level S1 and dated at 7,500 cal y BP is surfacing in various areas of the Mediterranean (Ariztegui *et al.*, 2000; Emeis *et al.*, 2000; Lane-Serff *et al.*, 1997; Martinez-Ruiz *et al.*, 2000; Mercone *et al.*, 1999).

On the other hand, agricultural communities were established across Europe between 8,000 and 5,000 years ago. The best evidence currently available to archaeologists indicates that two different processes were involved: the colonisation of new habitats by populations of farmers and the adoption of agriculture by indigenous foragers (Bogucki, 1996). Despite efforts of archaeologists to clarify which of these processes was active in a particular region, there is still considerable regional debate between those who favour colonisation and those who argue for in situ development. The presence of domesticated wheat, barley, sheep, and goat unequivocally provides the vector for the Neolithic Diaspora in Europe. Since these species exist in their wild form only in the Near East, their dispersal was clearly from the south-eastern corner of Europe to the Northwest and to the west. Domestic livestock, of course, can move on their own, and the role of feral animals in expanding the range of domesticated species in Europe cannot be overlooked (Bogucki, 1996).

First colonisation of Near East Neolithic population is known to be around 8,200 cal y BP. These first population came through the Anatolian mountains with their domesticated wheat, barley, sheep, and goat and settled around the Aegean coastal zone. A second wave of colonisation appeared 100 years later, when these farmers decided to move into land generally following river courses (Lichardus and Lichardus-Itten, 1985). This gradual migration of farmers up the Danube Valley into central Europe represents one of the most striking events of the Neolithic period in Europe. These new settlers stayed fairly close to the banks of the river and its tributaries (Greg, 1988).

Around 7,500 cal y BP these Neolithic population gave birth to two population movements in Europe. One is the Danubian movement colonising all the North of Europe from Romania to the Paris basin through Hungary. They eventually occupied through the following millennium half of the North of Europe. The Neo-Balkanian painted pottery shows definite Asiatic similarities; there was painted pottery in Iraq in the earliest known cultures; Anatolia contains some varieties of it; the Iranian plateau is said to be full of it; there is painted pottery at Anau in Turkestan; and painted pottery penetrated early into Kansu in China.

The second population movement, usually called the Mediterranean movement (Fig. 3) had developed all along the Mediterranean coast (Malville *et al*., 1998) until the Catalonian littoral before moving northward along the Rhone river valley (Hodder, 1990). Despite these occurrences, Archeologists do not yet know by which route or routes it entered Europe from the east. It may have come across the Bosphorus, around the Black Sea, or from both quarters. Again, it may have travelled, farther east, either north or south of the Caspian.

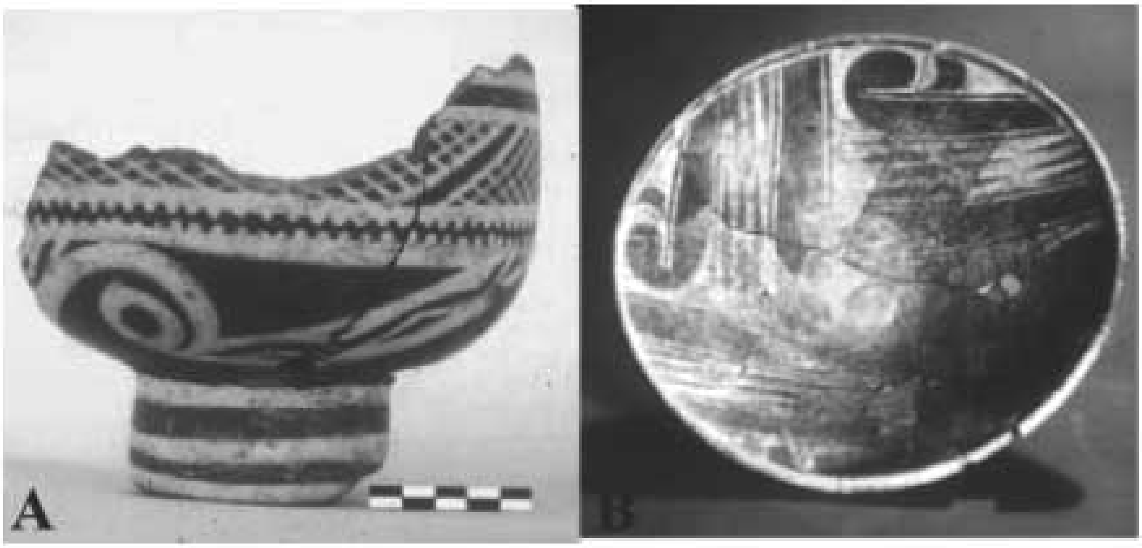

Fig. 3. **A.** Early-Neolithic from Kovacevo in Bulgaria (French-Bulgarian survey) (Photo by J.P. Demoule). **B.** Vase with golden ornaments from the Earlier Chalcolithic period of the Varna Necropolisin Bulgaria (from the Varna Archaeological Museum: http://www.varna-bg.com).

Observations

Topography

Bathymetry data were provided by multibeam echosounder (Fig. 4). Prominent in the northern half of the survey area are linear ridges four to five meters in relief and with an average spacing of 750 m. They strike almost uniformly at an azimuth of $75 \pm 10°$. The ridges are typically asymmetrical in cross-section with steeper sides facing to the Southeast. The ridges have a length to width ratio exceeding four. In addition, some tens depressions with diameters from 100 to 1800 meters and a negative relief of 3 to 9 meters populate the southern half of the corridor. Depths of individual depressions are greatest at the base of their Northeast walls and they shoal to the Southwest. In the centre of the surveyed corridor some depressions align in troughs between the linear ridges.

Subsurface structure

The ridges and depressions can be viewed in cross-section by very high resolution seismic reflection profileschirp system sweeping from 4 to 16 kHz. These tools (sub-bottom profiler and

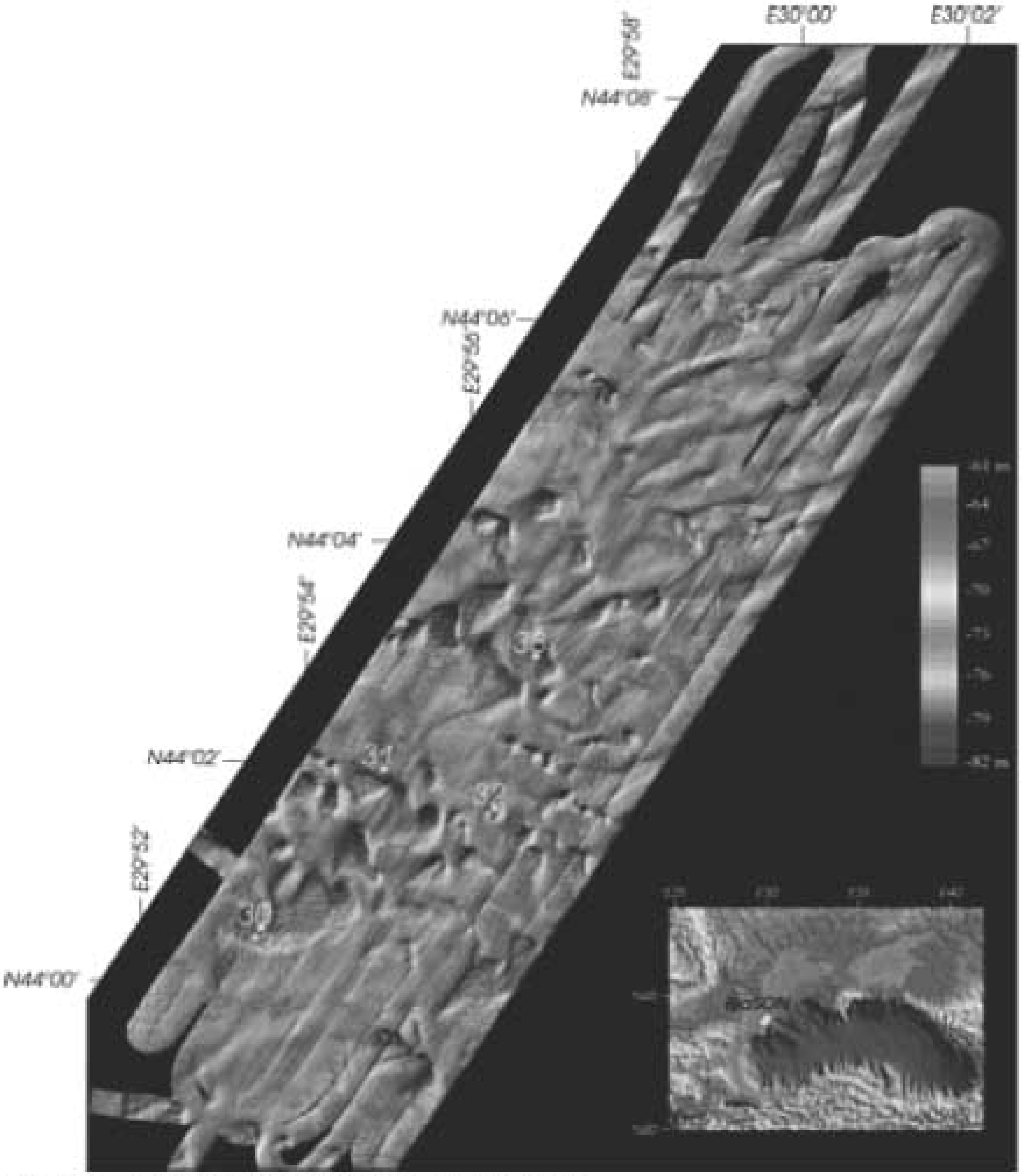

Fig. 4. The multibeam bathymetry covering a sand dune field.

Chirp sonar) provide a penetration to tens of meters and a definition of layering at the sub-meter scale. The profiles show that the ridges in the north are asymmetrical and with only one exception have their steeper side facing to the Southeast. These ridges are superimposed on a reverberant "bottomset" reflector that is sometimes conformable with subjacent strata but in many cases truncates them (Fig. 5). The high ground in the south has the appearance of a mound though it is also asymmetrical in cross-section with the crest and steeper slope predominantly on the south side. The interiors of the ridges and mounds contain steeply-dipping "foreset" clinoforms with the same asymmetry and orientation as the cross-section topographic profiles.

Everywhere across the mid and outer shelf the ridges, mounds and depressions are draped by a thin layer of sediment with a remarkably uniform thickness of no more than one meter (Fig. 5). The linear ridges surveyed in this study are aligned somewhat obliquely to the regional bathymetric contour and to the paleo-shoreline outlined by wave-cut terraces (Fig. 6).

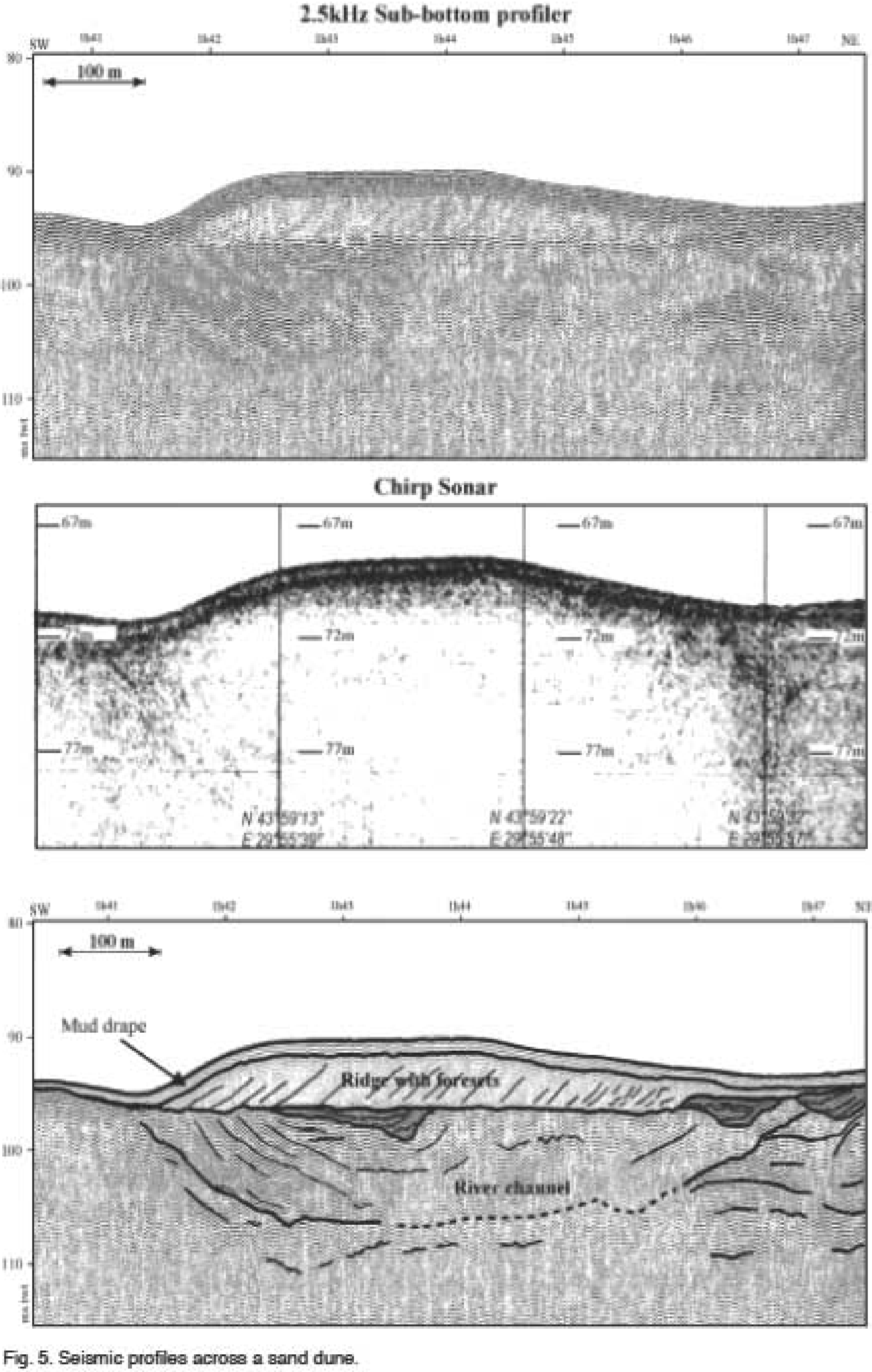

Fig. 5. Seismic profiles across a sand dune.

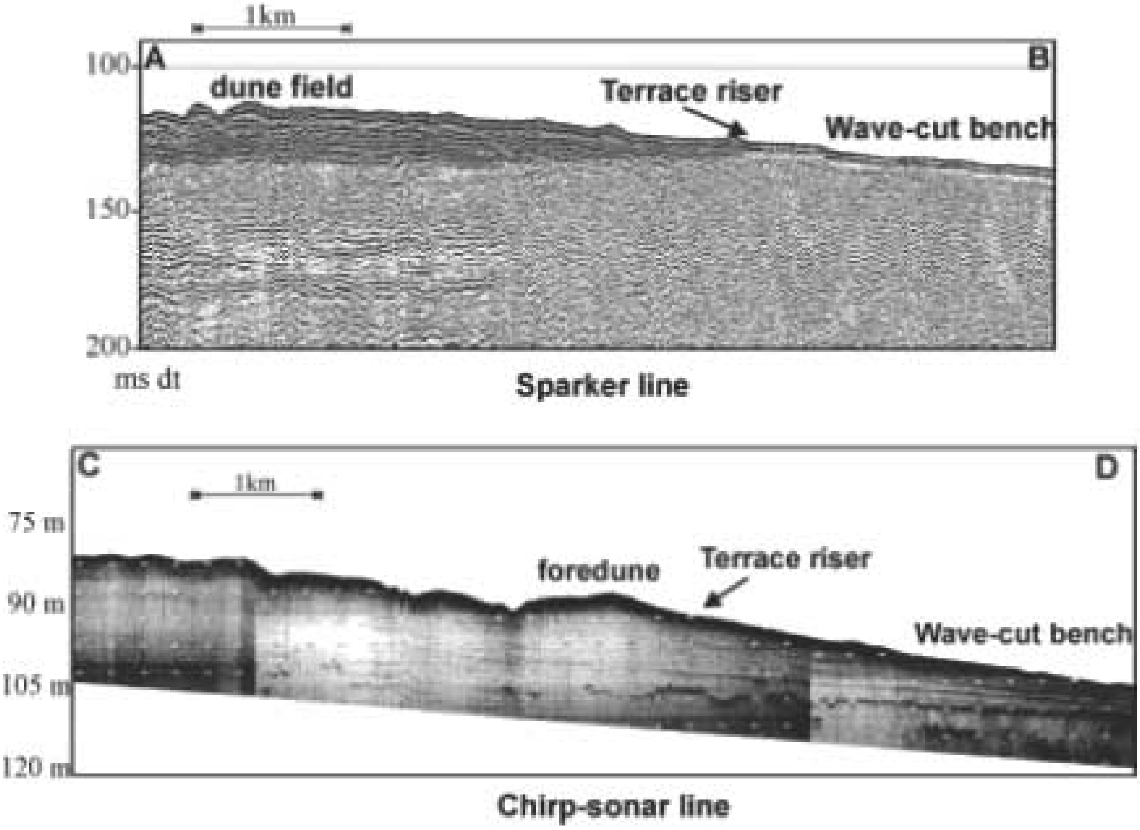

Fig. 6. Seismic profiles across the wave cut terrace.

Sediment cores

Sediments, obtained by coring methods, provide ground truth to the reflection profiles. Sampling into the interior of a ridge recovered dark sand rich in opaque heavy minerals and shell fragments (Fig. 7). The minerals include quartz, garnet and ilmenite. The shell fragments are those belonging the fresh-water mussels of the *Dreissena* species. Cores into the bedded sediments on which the dunes have formed consist of silty red and brownish clay with thin lenses containing fresh to slightly brackish water molluscs (*Dreissena* and *Monodacna* sp., respectively). These specimens return AMS radiocarbon dates spanning 8,585 to 10,160 ± 90 y BP (without reservoir and dendrochronologic calibration).

Molluscs within the uniform surface drape recoved in the BlaSON cores are exclusively salt-water species such as *Mytilus edulis* (also known as *Mytilaster*) and *Cerastoderma edule*. Those sampled near the base of the drape date in the range of 6,590 and 7,770 ± 80 y BP.

Within the cores that penetrate through the drape, basal contact is sharp with organic rich marine-mollusk bearing mud above, and a sand of variable thickness below rich with remains of *Dreissena* sp. Further, palynology analysis and studies of the dynokysts population realised by Speranta Popescu (Popescu, pers. comm.), detail a real onset of freshwater arrival during the Younger Dryas and abrupt replacement of Black Sea dynokyst by Mediterranean population at 7,150 y BP.

Discussion

The Sand dune fields and its wave cut terrace is interpreted as a coastal zone relict. This environment spanning the interval from 9,680 to 8,360 yr in a coastal setting with a wave-cut terrace at –100 m and dunes and pans between –80 and –65 m would have lain well below the level of the external ocean (Fairbanks, 1989). A lake below global sea level is only possible with a Bosphorus barrier shallower than the external ocean and the absence of outflow. The burial of the

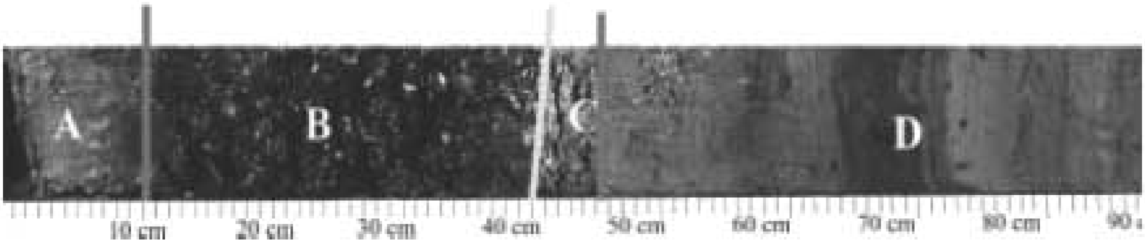

Fig. 7. Core recovered on the Dune field. **A.** Layer with Modulus dated from 3,000 yBP to present. **B.** Layer with *Mytilus Edulis* (6,900 to 3,000 yBP). **C.** Layer with *Dreissena*, the youngest is aged of 7,500 y BP.

dunes and pans by a drape of mud does not alone require a sudden filling of the depression once the Bosphorus barrier was breached. But taken with evidence of an abrupt passage from the shell hash to mud, a very condensed layer with brackish fauna only populating the shell hash substrate, and the impressive preservation of the dunes and pans with no preferential infilling of the depression, the evidence seems compelling for a rapid Black Sea terminal transgression. The Caspian sea which seems to have encountered a similar phenomena except for the last reconnection, presents all the coastal regions of Mazandaran and Gilan (Iran) sand dunes as high as 20 m made of sandy particles and fragments of shells and being parallel to the seashore. As for the relict Black Sea dunes, these dunes are occasionally cut across by wind blows.

As in the Caspian Sea (Kvasov, 1975; Svitoch *et al*., 2000), the Black Sea water level fluctuations appear to be directly linked to climate variability. These enclosed basin (when not connected to the Mediterranean for the Black Sea) has reacted almost by reaching highstand and outflow in cold periods and lowstand through evaporation in warm periods. When the Mediterranean penetrated through the Dardanelles Strait ca 12,000 y BP, the Marmara Sea was caught in a state below its outlet (Aksu *et al*., 2002a; Aksu *et al*., 1999).

Whether catastrophic flooding is hydraulically possible is an additional open question. Using a hydraulic model for the events following the connection of the Black Sea to the Mediterranean and assuming that the sill cross-section has remained more-or-less unchanged, Lane-Serff *et al*., (1997) showed that significant freshwater outflow from the Black Sea occurred only 500-1,000 years after the Mediterranean sea level reached the Bosphorus sill depth when a two-layer exchange between the two seas became established, because there is an upper limit to the water flux that could pass through the sill. This delay corresponds in order of magnitude to the lag between the onset of sapropel deposition in the Mediterranean and the Black Sea. Furthermore, Lane-Serff *et al*. (1997) demonstrated that it took 2,500-3,500 years for the bulk of the freshwater in the Black Sea to be replaced by salty Mediterranean waters and for euryhaline-marine conditions to be established. This period corresponds to the time of sapropel deposition in the eastern Mediterranean.

Whether or not this reconnection was catastrophic, the isue is about the consequences of a flood on the Neolithic population. The archaeological bases presented by Ryan and Pitman (1999) are predicated on a huge archaeological assumption, namely that after the beginnings of agriculture the ancient Near East suffered a drought forcing the first farmers to find refuge in a more friendly climate, on the pre-flood Black Sea coast. A more realistic picture of the Neolithic Diaspora in Europe may consider it to have been a mixture of various waves, currents, and eddies of people, animals, and plants. In some areas, an influx of migrating farmers swept with it any sparse local foraging populations as it deposited its own agricultural communities. Elsewhere, early farming communities appeared as isolated pioneer outposts in a multicultural landscape of foragers and farmers. The debate is still ongoing about the role of catastrophic events on population movement.