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Palynological evidence for climatic change, anthropogenic activity and outflow of Black Sea water during the late Pleistocene and Holocene: Centennial- to decadal-scale records from the Black and Marmara Seas

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Abstract

Previous marine palynology studies of pollen and dinoflagellate cysts (dinocysts) in the Black Sea–Mediterranean corridor were made on short cores, allowing only millennial-century scale reconstruction of past climates. We now describe pollen accumulation rates for 5 cores with eleven ^{14}C ages over 30,000 years, and new decadal-scale data for a Holocene core with fourteen ^{14}C ages. Pollen influxes show *Pinus–Abies–Quercus* forest-steppe and deteriorating climate from 29.8–24 kyr BP, then colder, drier pre- and post-LGM conditions, with *Artemisia*, Cheno-Ams and *Ephedra* that lasted through the Bølling interstade. Deciduous oak returns by the Younger Dryas, and rapidly expands, followed by *Pistacia* by 9.3 kyr BP. Foraminiferal δ^{18}O shows 4 °C cooler than present late glacial summers and rapid Holocene warming. By 9 BP, influxes from *Quercus cerris, Tilia, Fagus, Castanea, Ulmus,* shade ferns, aquatics, swamp plants and δ^{18}O indicate warm winters (5 °C or more) and year-round precipitation (>600–1000 mm), not the dry conditions that would be required for Black Sea drawdown. There is mid-Holocene expansion of *Carpinus,* evergreen *Quercus* and *Pistacia.* Walnut, olive and cereal pollen suggest early cultivation attempts, but no sustained farming before 4.5 kyr BP.

Dinocyst assemblages show major changes traceable throughout the Corridor. Variability in process length marks low diversity ($N = 13$) Pleniglacial–early Holocene *Spiniferites cruciformis* assemblages, suggesting fluctuating salinity like the modern Caspian Sea, with brackish to saline conditions (~5–16‰). Distributions of euryhaline cysts *Spiniferites mirabilis* and *Spiniferites bentorii* show the Aegean and Marmara Seas were connected by ~11 kyr BP and linked to Black Sea by 9.3 kyr BP. There is no palynological evidence of either freshwater (salinity<3‰) for farming on the southwest shelf or of catastrophic marine flooding.

1. Introduction

The importance of marine pollen studies for land–sea correlation of regional climate change has been recognized since the earliest palaeoenvironmental studies of the Black Sea (Koreneva and Kartashova, 1975; Ross and Degens, 1974; Traverse, 1978). Organic-walled dinoflagellate cysts (dinocysts) are also important microfossils for understanding of the history of water exchange between the Mediterranean and Black Seas (Wall and Dale, 1973; Traverse, 1978) because calcareous microfossil records are discontinuous in the epi-continental seas of the Black Sea–Mediterranean corridor, and the preservation of thin-walled siliceous microfossils is poor in the deep (1–2.3 km) basins. Lack of quantitative core-top data linking modern microfossil assemblages with sea surface conditions in the uppermost (0–50 m) water layer has also prevented precise quantitative reconstruction of palaeosalinity from foraminiferal, coccolith and diatom data (Aksu et al., 2002; Ryan et al., 2003). The δ^{18}O values of planktonic foraminifera, however, have provided some quantitative proxy-data on the temperature and salinity of the subsurface water (Aksu et al., 2002), and were used to estimate the maximum salinity range of the early Holocene dinocyst assemblages that lack modern analogues (Mudie et al., 2001).

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In previous studies (Mudie et al., 2002a, b), we showed that organic-walled microfossils, including pollen, fern and moss spores, and dinocysts, are mostly well preserved and continuously present in deepwater Pleistocene to Holocene sediments of 1–2 m long gravity cores from the region. The organic content of these marine sediments is consistently high (~0.5–2% TOC; Abrajano et al., 2002), indicating that they have not been subject to subaerial or oxidizing bottom water conditions, and making it easy to distinguish the sporadic and rare (<2%) presence of oxidized (yellowish) reworked Tertiary pollen grains. Palynological studies were made of eight cores on transects along the Black Sea–Mediterranean Sea corridor (Fig. 1), where the surface salinity varies from a minimum of 16‰ in northwestern Black Sea to 39‰ in the Mediterranean Sea. The cores were dated by 20 radiocarbon ages covering the past ~33,000 years, giving a centennial–millennial scale resolution of palaeoclimatic and oceanographic events. The pollen assemblage zones revealed by relative abundance diagrams for these low resolution cores were correlated with major changes in pollen percentages of assemblages in selected lakes of northern Anatolia and southeastern Europe (Mudie et al., 2002a), for the time interval from the Allerød oscillation through the Sub-Atlantic period. Both the lake and marine pollen percentage diagrams indicate the early Holocene appearance of deciduous oak (*Quercus cerris*-type) and other hardwoods requiring a year-round supply of moisture amounting to more than 600 mm. We also showed that anthropogenic pollen markers, such as *Vitis* (grape), *Olea* (olive), Cerealia (cultivated grasses), and arable weed pollen species (mostly *Taraxacum*-type Liguliflorae, *Centaurea* and *Plantago*) are present in the low-resolution marine cores of the semi-enclosed marginal seas. The low resolution pollen diagrams also suggested that sustained agriculture or arboriculture began only after about 4000 BC, in contradiction to the hypothesis of Ryan and Pitman (1999) that early Neolithic farming began around the Black Sea before 7.1 kyr BP. The centennial–millennial scale resolution of the marine cores, however, prevented detailed sampling that might have revealed short-lived early agricultural or marine-inundation events as present in some cores from coastal lakes of Bulgaria, e.g., Lakes Durankulak and Varna (Bozilova et al., 1996) and the Veleka River estuary (Filipova-Marinova, 2003a, b).

Previously, we also showed that the dinocyst assemblages in cores from the Black Sea–Mediterranean corridor display moderate to high species diversity ($N = 33$), in contrast to only two species listed for surface samples in the western Black Sea (Atanassova, 1995). Principle component analysis of our core-top samples revealed two main assemblages along the Black Sea–Mediterranean Sea corridor (Mudie et al., 2004). Autotrophic gonyaulacoid cysts, including *Spiniferites delicatus*, *S. membranaceus*, *S. mirabilis*, *Bitectatodinium tepikiense*, and *Pentapharsodinium dalei* dominate the oligotrophic, hypersaline Aegean–Mediterranean water (35–38‰), and a predominance of heterotrophic protoperidinioids mark the modern low salinity Marmara Sea–Black Sea water (16–22‰). The full list of dinocyst species is given by Mudie et al. (2004), and is related to the modern dinoflagellate flora of the presently eutrophic Black Sea.

The distributions of these modern assemblages in the cores from the Marmara and Black Seas were used to estimate changes in surface water salinity for the past ~7.0 kyr BP. The problem of determining the salinity of

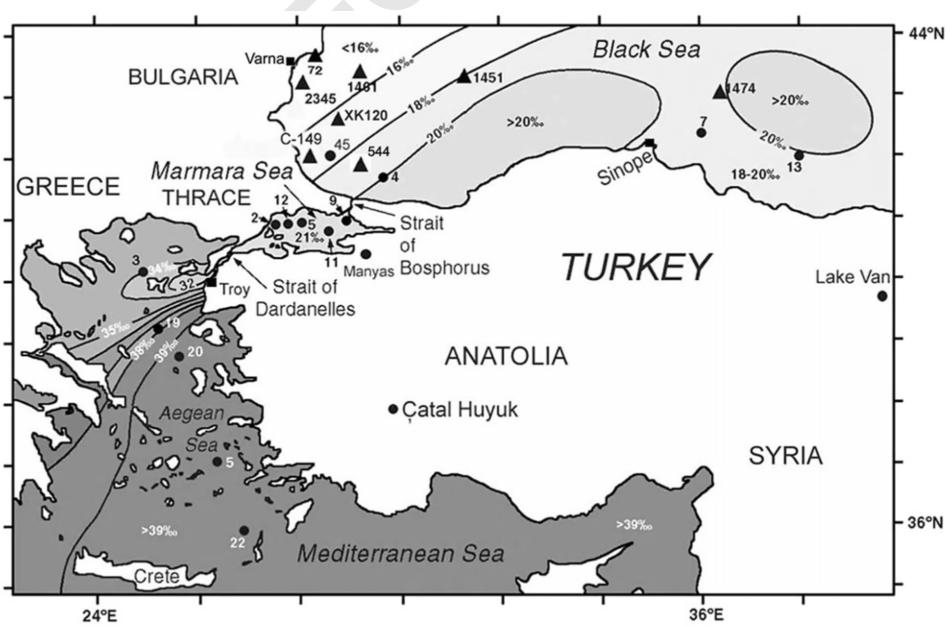

Fig. 1. Location map, showing Marmara Sea cores MAR97-02 (#2), MAR94-5 (#5), MAR97-11 (#11), MAR98-12 (#12) and Black Sea cores B-7 (#7) and MAR02-45 (#45) in relation to surface water salinity and other core sites mentioned in the text (triangles). Other large black dots mark positions of coretop samples and important lakes.

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older, early Holocene no-analogue dinocyst assemblages dominated by *Spiniferites cruciformis* was addressed by correlating the abundance of morphotypes of *S. cruciformis* against salinity estimates derived from planktonic foraminiferal $\delta^{18}O$ values (Mudie et al., 2001). It was concluded that the early Holocene *S. cruciformis* assemblages represent surface salinities ranging from <7 to 12‰, based on their co-occurrence with forams that live in the subsurface water column (hence in higher salinities than the surface 20 m where the dinoflagellates live), and based on other published estimates for surface-dwelling coccoliths.

In the present paper, we show how study of pollen accumulation rates (annual deposition per cm^2) in five of the low resolution cores, combined with the oxygen isotopic data and derived estimates of past sea surface temperature (SST), support our earlier interpretation of a relatively mild mid-Pleniglacial climate (~30–24 kyr BP), cold early late-Pleniglacial and flickering early post-Last Glacial Maximum (LGM) climate changes, followed by warm, humid early postglacial (Holocene) conditions. These marine pollen records can be closely related to the ~12.7 kyr BP varved pollen and isotopic record from Lake Van (Wick et al., 2003), and compared to earlier non-quantitative palaeo-humidity estimates (Van Zeist and Bottema, 1982) based on pollen data from Anatolian lakes (Van Zeist and Bottema, 1982) and other palaeoclimate records made from cores on the Bulgarian Shelf (e.g., Filipova et al., 2004; Atanassova, 2005). We will also discuss the salinity estimates derived from early Holocene dinocysts in light of new studies (Marret and Zonneveld, 2003; Marret et al., 2004; Leroy et al., 2006) who found similar dinocysts assemblages in recent sediments of the Kara Boğaz Göl, eastern Caspian Sea, where the salinities are 9–40‰, reaching 100‰. Finally, we report the initial results from new high resolution gravity (trigger weight) and piston cores from the southwestern Black Sea shelf that provide decadal-scale records of Holocene climate change and anthropogenic activity, and allow us to examine carefully the possibility that earlier low resolution cores missed the sampling of three events critical to the validation of the Ryan and Pitman "Noah's Flood" hypothesis: (1) a dry early Holocene period of Black Sea drawdown; (2) concomitant early Neolithic agriculture on extensive subaerial continental shelves surrounding a freshwater lake; and (3) a short period (less than 100 years duration) of catastrophic shelf flooding by Mediterranean sea water.

2. Materials and methods

2.1. Fieldwork and core description

Most of the cores in this study (Table 1) are gravity cores taken at sites selected from high resolution seismic surveys in the Aegean, Marmara and Black Seas, during many cruises between 1993 and 2002 (Aksu et al., 2002; Hiscott et al., 2002, 2006 for details). These cores range in length from ~90 to 230 cm, and twenty radiocarbon dates from mollusk shells or foraminiferal tests showed ages of 33,550 ± 330 to 1990 ± 50 yr BP uncalibrated radiocarbon years (Aksu et al., 2002). Note that throughout this paper, the ages for our cores ages are given in uncalibrated ^{14}C ages, but the calendar ages are corrected for a reservoir effect of 415 years. Sedimentation rates in these gravity cores range from a maximum of 46 cm/kyr in some cores from the Marmara Sea to minima of ~6–9 cm/kyr in the Aegean Sea. Box cores from the South Basin of the Black Sea (Duman, 1994) are also short (~1.0 m) with low sedimentation rates (~6–37 cm/kyr), except where turbidities were present. The age of the three distinctive units in the short Black Sea cores is estimated from the average values of three ^{14}C ages made on organic carbon, and confirmed by the well known ages of European pollen zone boundaries (Duman, 1994; Mudie et al., 2002a).

To increase the resolution of the palynological data from the condensed sequences in the deep basins of the Marmara and Black Seas, we have obtained a much longer (950 cm) core from a shallow basin at 69 m water depth, on the southwest Black Sea shelf (Hiscott et al., this volume). The seismic profiles show that the shelf basin occupies a transverse seabed depression that was connected to the deep western Black Sea basin throughout the Holocene. Fourteen radiocarbon ages show that the base of the core is ~9.3 kyr BP, with sedimentation rates ranging from 360 to 125 cm/kyr at the top and base, respectively, allowing for decadal-scale resolution of palaeoclimatic and palaeo-oceanographic events. The seismic profiles also show that there is an unconformity (Alpha 2) succeeded by onlapping deposits in the sediment record. This unconformity has an estimated age of 4.5–2.4 kyr BP.

2.2. Laboratory processing

Palynological samples, about 5–10 cm^3 volume (3–5 g dry weight), were taken n the average at 10 cm intervals in the refrigerated cores, as sub-samples of the sediment used to study foraminifera, coccoliths and various geochemical parameters, including carbon, sulphur and oxygen isotopes (Aksu et al., 2002). The pollen and dinocyst assemblages were extracted using standard methods for processing of Quaternary marine samples (e.g., Marret, 1993). This method for our samples uses Calgon detergent to disaggregate the sediment, then sieving with nylon screens of 125 and 10 μm mesh sizes to remove the sand fraction (>125 μm), and the finest silt and the clays (<10 μm). Cold hydrochloric acid (10%) is used to remove the carbonate minerals, and to dissolve the Lycopodium tablets that are added to provide a method of estimating pollen concentration. This is followed by a 12 h heating to 60 °C in 52% hydrofluoric acid to remove the silicates. If abundant amorphous organic matter is still present, thus obscuring the pollen grains, ultrasonification (30 s) and further sieving may be necessary, but at no time are either

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Table 1
Locations of cores, water depth, salinity (SST), radiocarbon ages and estimated sedimentation rates

Sample	Locality	Latitude N	Longitude E	Depth (m)	SSS summer	SSTsummer
MAR97-2	W. Marmara Sea	40.9	27.6	1080	24	26–28
MAR98-12	W. Marmara Sea	40.8	27.8	549	23	26–28
MAR97-5	Central Marmara Sea	40.9	28.1	1008	22	26–28
MAR97-11	SE Marmara Sea	40.7	28.4	111	22	26–28
MAR94-05	E. Maramara Sea	40.9	28.1	850	21–22	26–28
MAR02-45	SW Black Sea	41.7	28.3	69	17–18	22–23
B7	SE Black Sea	42.5	36.8	2120	22	22–24

Core	Isotope Lab No.	Depth (cm)	C-14 age (yr BP)	Cal. age	(Cal. BP)	Material	Sed. rate (cm/kyr BP)
MAR97-2	BE-118903	80	1990±50	1950±	110	Bivalve	40.2
	BE-118904	180	3810±50	3370±	120	Bivalve	48.46
MAR97-11	TO-7774	79	10,790±70	12,000±	633	*Turritella* spp.	7.3
	TO-7775	92	12,970±80	14,400±	500	White mussels	5.96
	TO-7776	174	14,940±90	17,400±	567	Small oyster	41.6
	TO-7777	204	15,590±90	18,150±	600	White mussels	46
MAR98-12	TO-8457	50	4200±100	4300±	300	Bivalve fragmt	11.9
	TO-8458	130	10,660±130	11,850±	667	*Nuculacea* spp.	12.4
MAR94-5	TO-5367	40	21,950±130	215,400±	310	Pteropods and	ND
	TO-5369	210	29,540±130	29,130±	1540	benthic forams	21.28
MAR02-45	TO-11006	158	2400±60	ND	ND	*Mytilus gallopr.*	120
Piston core	TO-11142	495	8380±70	ND	ND	*Truncatella sub.*	85
	TO-11007	810	9370±60	ND	ND	Bivalve	360
B-7	see Duman (1994)	20	3087	ND	ND	Organic carbon	6.48
		50	7077	ND	ND	Organic carbon	8.3
		120	8840	ND	ND	Palynozone	25.64

potassium hydroxide (KOH) or acetolysis treatment (acetic anhydride + sulphuric acid mixture) used because these oxidants damage fragile dinocysts, and can damage pollen grains, giving them the appearance of resuspended, subaerially oxidized grains. Acetolysis treatment also darkens cysts and makes them more difficult to distinguish from reworked, thermally altered Tertiary–Quaternary dinocysts (see discussion by Ravazzi, 2006). We also avoid use of Safranin stain that makes it difficult to recognize strongly altered palynomorphs which might have been reworked from older deposits in the drainage basin.

The processed palynology residues are mounted in glycerine gel and routinely counted at a magnification of ×2500, using a Zeiss Research interference light microscope, equipped with 35 mm camera and coloured glass filters. All slides are completely counted, yielding 150–500 grains. The slide collection and full data are archived at the Geological Survey Canada-Atlantic. Morphologically distinct pre-Quaternary pollen, spores and dinocysts were counted but not included in the totals used to estimate Pleistocene–Holocene pollen-spore and dinocyst abundances. Pollen-spore abundance per cm^3 sediment is estimated from the count of exotic Lycopodium spores, following the method given in Traverse (1988). Pollen deposition rates, commonly called pollen "influxes", are estimated by calculating the deposition times for 1 square centimeter of sediment and calculating the influx as also shown by Traverse (1988)

$$\text{Annual deposition} = \text{pollen/cm}^2 \text{ per yr} = \frac{\text{pollen/cm}^3}{\text{No. years for deposition of 1 cm sediment}}.$$

Annual accumulations of fern spores (Filicales) were calculated in the same way.

3. Results of low resolution palynology studies

3.1. Pleniglacial–LGM interval

The end of the middle Pleniglacial and the start of the late Pleniglacial intervals are recorded in Core MAR94-5 from the eastern Marmara Sea. This core consists of 170 cm of organic-rich, silty clay deposited between 29.5 and ~22.0 kyr BP, with an average sedimentation rate of 21.3 cm/kyr (Table 1). Pollen accumulation rates (Fig. 2) are high (1000–4000 grains per $cm^2 yr^{-1}$) from the base around 30.0 to 28.0 kyr BP, but they decline after about 24.0 kyr BP becoming almost an order of magnitude lower by the start of the LGM around 22.0 kyr BP. The oxygen isotope record shows correspondingly heavy values ($\delta^{18}O = +2.5$ to $+6‰$) until about 25.0 kyr BP, after which there is a steep decrease in $\delta^{18}O$, and a corresponding 4 °C increase in summer temperature. Tree pollen influx is dominated throughout by *Pinus* and deciduous *Quercus* species, with both declining towards the LGM, when *Pistacia* and evergreen *Quercus* increase, indicating the

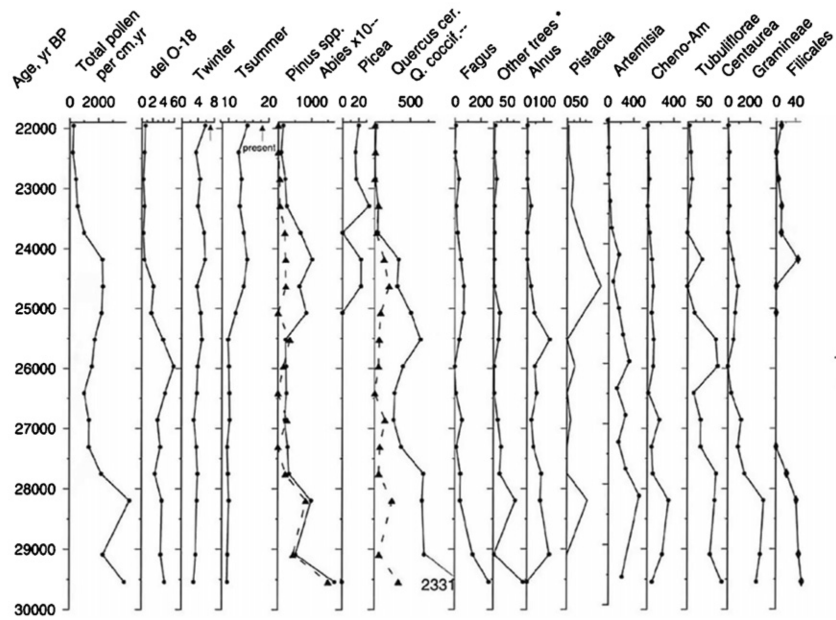

Fig. 2. Core MAR94-5: Annual pollen and spore accumulation rate (number of grains/cm^2/year), δ^{18}O and estimated seasonal temperatures (T°C), compared to modern values marked by arrows. * Trees include *Acer*, *Tilia, Ulmus.*

onset of drier conditions, particularly from ~25 to 24 kyr BP. The late Pleniglacial interval is also marked by the arrival of *Picea* pollen, when *Artemisia* pollen influx decreases and Tubiflorae grains dominate the herb pollen. Filicales spores and *Abies* pollen are common only during the mid-Pleniglacial interval when other deciduous forest tree pollen (mostly *Ulmus*, *Tilia*, *Acer)* are present with the *Quercus* spp. *Abies* pollen is notably present throughout most of this pre-LGM Pleniglacial section, and *Ephedra* is rare or absent.

Dinocysts in Assemblage Zone D2 of the pleniglacial interval in MAR94-5 were described and illustrated previously (Mudie et al., 2001, 2002b). This palynozone comprises a low diversity ($N = 13$ species) flora dominated ($>20\%$) by *Spiniferites cruciformis,* with only 3 other species (*Peridinium ponticum, Pyxidinopsis psilata* and *Lingulodinium machaerophorum)* being present in amounts more than 5%. A very wide range of spine length was also noted for *S. cruciformis,* and is shown here (Fig. 3) in relation to the salinity of the subsurface water as determined by a transfer function equation using the δ^{18}O measurements for the planktonic foraminifer, *Turborotalita quinqueloba* in the same samples (see Aksu et al., 2002, for details). There is a gradual increase in salinity from ~25 to 22 kyr BP during which time *L. machaerophorum* and other *Spiniferites* species (*S. bentorii*, *S. bulloideus*, *S. belerius*) begin to displace *S. cruciformis.* Although the salinity reaches modern subsurface salinity values of 21.5‰ around 22 kyr BP, the Pleniglacial dinocyst flora remains much less species-rich than presently found in the Marmara Sea and Black Seas where $N = 20$–33.

3.2. Late Glacial–Holocene interval

Low resolution pollen accumulation rates for the Late Glacial to early Holocene intervals in the Marmara Sea are represented by cores MAR97-11 and 98-12 (Figs. 4(a) and (b)). Core MAR97-11 (Fig. 4(b)) has four δ^{14}C ages ranging from 15.54 kyr BP at 204 cm to 10.79 kyr BP at 79 cm, and it contains an expanded record of pollen influx from ~16.5–13.0 kyr BP. Annual pollen deposition is low throughout (<150 grains/cm^2 yr), with maximal influxes just after the LGM and preceding the Bølling event (~13–12 kyr BP), but the resolution in this core does not include the cold Older Dryas (~12–11.8 kyr BP) or warm Allerød (~11.9–11 kyr BP) oscillations. *Pinus* and *Picea* are the only significant tree pollen present until after 13 kyr BP when deciduous *Quercus* and *Fagus* appear. *Ephedra* is persistently present from ~16 to 13 kyr BP, together with peak influxes of Cheno–Am (Chenopodiaceae–Amaranthaceae) and Asteraceae (Compositae, mostly *Centaurea*-type), and smaller amounts of *Artemisia* that reaches a peak during the Younger Dryas event (~11.0–10.5 kyr BP).

The dinocyst assemblage (D2) of Mudie et al. (2002b) in the pre-Holocene sediments of Core 79-11 is almost identical in composition to that in the late Pleniglacial section of MAR95-4 (Fig. 3), but also contains rare cysts of *Spiniferites ramosus* and *S. belerius* cysts, as found in the Kara Boğaz Göl section of the Caspian Sea (Leroy et al., 2006). The δ^{13}C values (Fig. 4) range from −25.2 to 26‰, indicating brackish, but not freshwater conditions (i.e., lighter than −27‰), according to the criteria of Lamb et al. (2006).

Core MAR98-12 (Fig. 4(a)) has only two ^{14}C ages (Table 1), but provides a relatively expanded time slice for the

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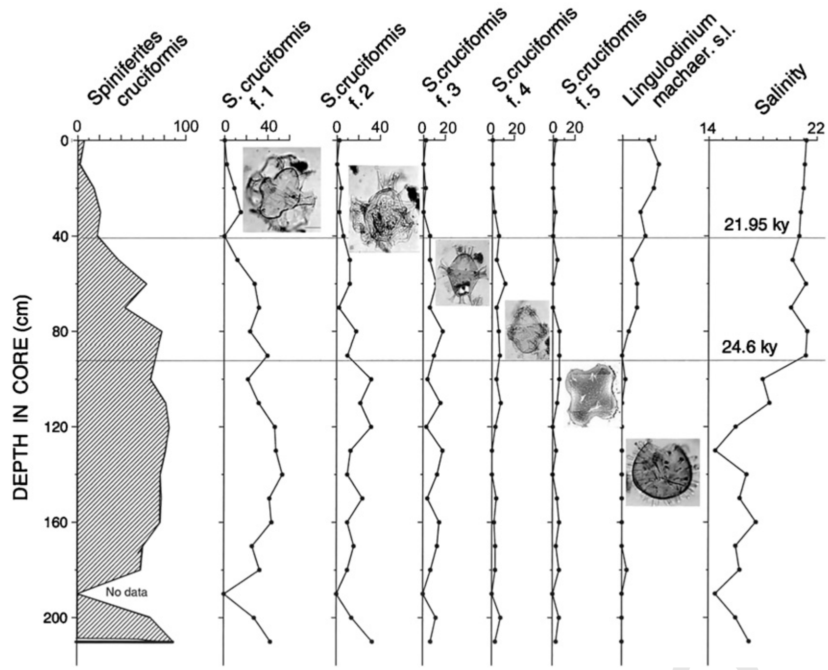

Fig. 3. Core MAR94-5: relative abundances of *Spiniferites cruciformis* s.l. and its five morphotypes, and *Lingulodinium machaerophorum* (*L. machaer*. s.l.) in relation to sub-surface salinity estimated from planktonic foraminifera in Pleniglacial to Late Glacial sediments with ages of 24.6 and 21.95 kyr BP. *Quercus cer*. = *Q. cerris*-type; *coccif*. = *coccifera*-type.

Older Dryas–Allerød–Younger Dryas intervals and for the early Holocene. Pollen influxes from 12.5 to 11 kyr BP are extremely low, and may represent mostly long-distance dispersal except for small peaks of Gramineae (Poaceae), Asteraceae and the persistent presence of *Picea* pollen. The Younger Dryas (11–10.5 kyr BP) is marked by a large influx of both tree species and the steppe pollen indicators, *Artemisia* and Cheno–Ams. Pollen of *Quercus* and *Fagus* also appear in significant amounts that are sustained through the early Holocene, where the Mediterranean scrub indicator *Pistacia* reappears, and where *Alnus* and Filicales (mostly *Dryopteris*/*Cystopteris*-type forest ferns) mark the presence of moist soils and establishment of forest vegetation. The Holocene section of Core 98-12 provides a low-resolution (~500 yr sample interval) picture of vegetation change in the Marmara Sea area. There is a 75% decline in pollen deposition during the late Neolithic period from ~7.5 to 4.0 kyr BP, mainly coinciding with the fluctuating abundance, then with decreases in deciduous *Quercus* and later, in *Fagus* forest trees and a decline in fern spore influx after 5.0 kyr BP. Other forest trees favoured for ship-building, like *Abies* and *Picea* (Doonan, 2004) also disappear or become very rare during the Neolithic.

Core B-7 (Fig. 5) from the deep southern basin of the Black Sea, northeast of Sinope, has the lowest sedimentation rates (Table 1) and therefore the percentage pollen diagram (Mudie et al., 2002a) cannot record the vegetation history of the region precisely enough to validate the apparent absence of catastrophic flooding at 8.4 or 7.1 kyr BP. The 10-cm sample intervals may also have failed to include a possible brief period of Neolithic agriculture before 7.1 kyr BP. However, the pollen influx data (Fig. 5) clearly show the presence of relatively high total influxes (~200 grains/cm^2 yr) for the early Holocene, and the same succession of reforestation indicators: *Quercus*, followed by *Pistacia*, and a strong presence of Filicales, as seen in MAR98-12. In the southern Black Sea core B-7, however, the post-Neolithic decline in total pollen begins about 1000 years later than in the Marmara Sea area (Fig. 6), although the Oleaceae appear simultaneously in the early Bronze Age, ~4.0 kyr BP, followed by a rise in Gramineae because of the presence of Cerealia pollen in addition to that of pasture and wild grasses. The south-eastern Black Sea core shows consistently higher influxes of *Artemisia* and Cheno–Am pollen than the Marmara Sea cores, as also seen in the modern surface assemblages (Mudie et al., 2002a).

3.3. Late Holocene/Anthropogene period

Core MAR97-2 (Fig. 6) from the north side of the central Marmara Sea has relatively high sedimentation rates (~38.5–40.2 cm/kyr) and provides snapshots of the vegetation changes during the Bronze Age Beyşehir Occupation Period from ~3.5 to 1.2 kyr BP and during the Ottoman Empire from ~1.2 kyr BP up to 1930 CE. The annual pollen influxes to MAR97-2 are less than 500 grains/m^2 yr, but nonetheless they clearly show a decline in total pollen and *Pinus*, and a corresponding increase in grasses and weedy herbs (Cheno–Am, particularly *Salsola*-type), Liguliflorae (mostly *Taraxacum*-type) and Tubuliflorae such as *Centaurea* and *Aster* that

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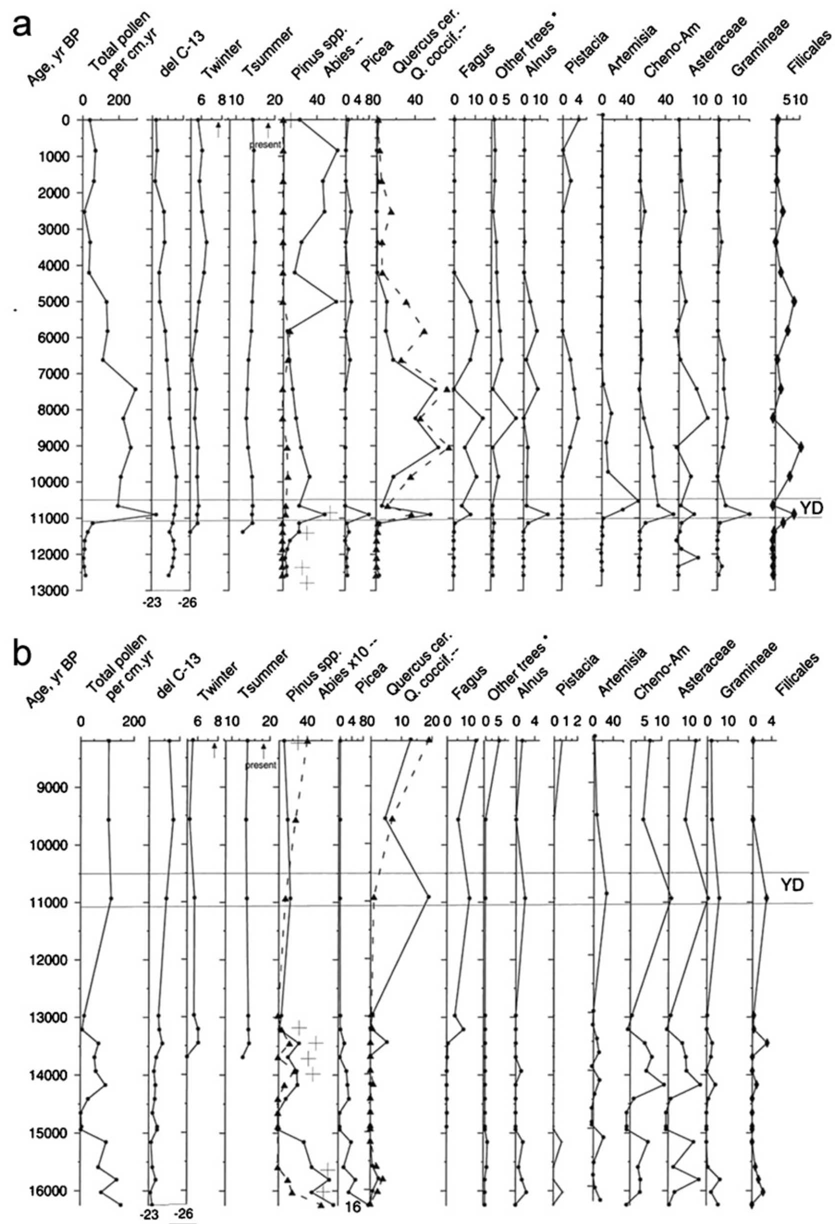

Fig. 4. Late Glacial–Holocene annual pollen and spore accumulation rates (number of grains/cm^2/year), δ^{13}C and estimated seasonal temperatures (T °C). Fig. 4(A). Core MAR98-12; * *Castanea, Tilia, Ulmus*. Fig. 4(B). Core MAR97-11; **Tilia, Ulmus*. + marks presence of *Ephedra* pollen.

distinguish the Beyşehir Occupation Period in Lake Manyas (Leroy et al., 2002).

4. Results of high resolution palynology studies

Core MAR02-45 consists of a long trigger weight (TWC) gravity core and a piston core (PC) that were obtained in 69 m water depth on the southwestern continental shelf of the Black Sea (Hiscott et al., this volume), about 50 km southeast of the submerged Eneolithic archaeological site at −5 m water depth in the Bay of Sozopol (Filopova-Marinova and Bozilova, 2002; Filipova-Marinova and Angelova, 2006). The seismic profiles and fourteen radiocarbon dates (Fig. 7) from the MAR02-45 cores (see Hiscott et al., this volume) indicate continuous sedimentation from ~9.3 to about 4.5 kyr BP, and high sedimentation rates ranging from 360 to 125 cm/kyr at the base and top allow decadal-scale resolution of major palaeovegetation events for much of the section. The initial results from 60 palynology samples from these cores are shown here, and represent sampling at intervals of 28–200 years around 7.1 and 8.4 kyr BP, i.e., times that have been postulated for catastrophic marine flooding of Neolithic farms and settlements (Ryan and Pitman, 1999; Ryan et al., 2003).

The pollen percentage diagrams for Cores MAR02-45 PC and TWC (Fig. 7) show no big peaks in total pollen concentration (number of grains per gram) that would mark a rapid flooding of vegetated extensive, low coastal plains. There is a slight increase in pollen concentration from about 7560 to 5900 yr BP, and a pollen minimum

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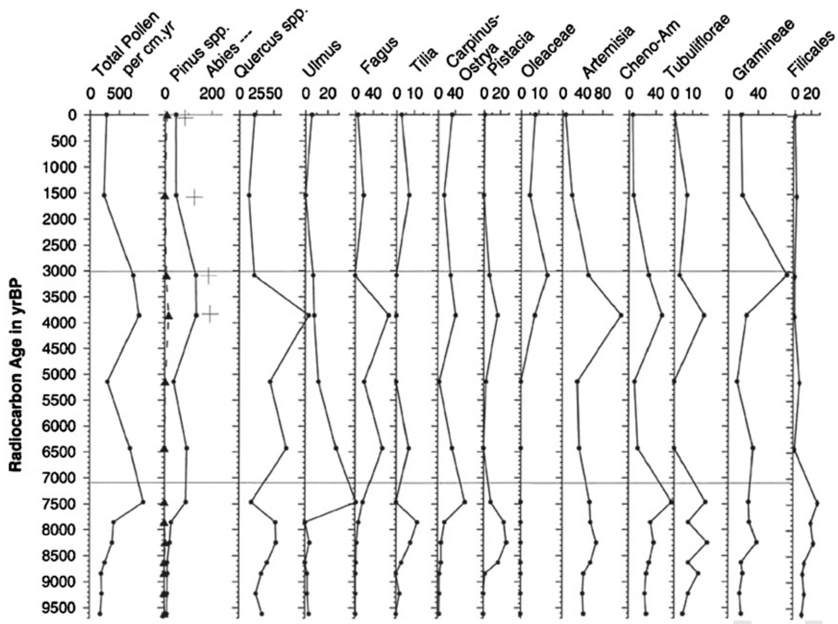

Fig. 5. Core B-7. Late glacial-Holocene annual pollen and spore accumulation rates (number of grains/cm^2/year). + indicates occurrence of *Ephedra* pollen.

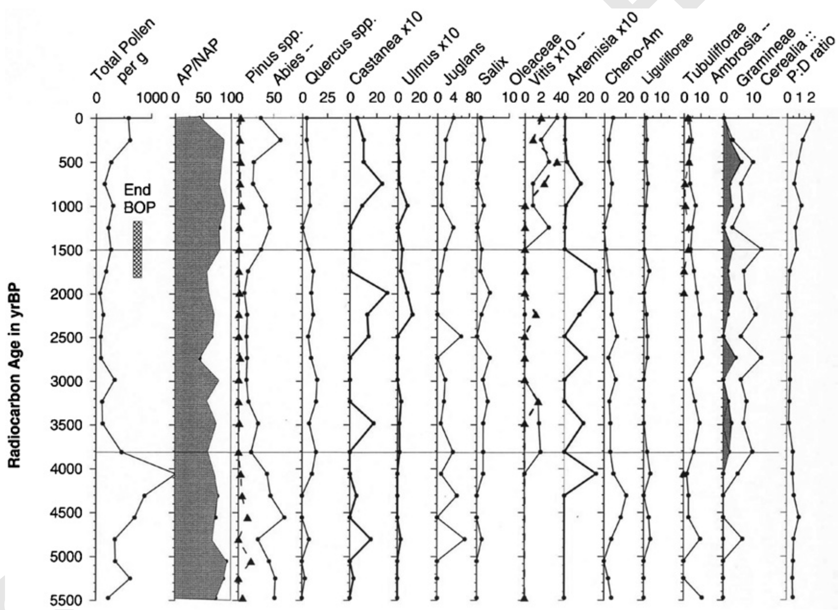

Fig. 6. Core MAR97-2. Late Glacial–Holocene annual pollen and spore accumulation rates (number of grains/m^2/year) and estimated seasonal temperatures (T°C). BOP = Beyşehir Occupation Period.

from about 2.4 to ~0.8 kyr BP. Tree pollen dominates throughout, with the softwoods (Conifers, mostly *Pinus* with minor *Abies* and *Picea*) declining at the expense of the hardwoods (including *Quercus*, *Carpinus*, *Ostrya, Acer, Fagus*, *Tilia*, *Ulmus*, *Fraxinus*, *Betula*, *Alnus* and *Salix*) after about 8.3 kyr BP. In the early Holocene, spores of drought-sensitive woodland ferns (*Thelypteris*, *Cystopteris*) contribute 10–20% of the total pollen-spore assemblages. Until ~8.4 kyr BP (500 cm in MAR02-45PC), the pollen of freshwater aquatics contributes 5–20% of the total pollen. The aquatics group includes pollen of the submergent or floating waterweeds *Callitriche, Hippuris, Hydrocharis, Myriophyllum,* the waterlilies *Nuphar* and *Nymphaea*, and the emergent cattails (*Typha*) and swamp reeds (*Cyperaceae)*. The pollen of *Artemisia* and Cheno–Ams make up about 50% of the other herbs until about 5.9 kyr BP, then they decline until reappearing strongly at the base of the TWC (~1.0 kyr BP). The other herbaceous pollen are dominated throughout by the Gramineae (Poaceae) and various Asteraceae, including at the top, the introduced North American weed, *Ambrosia*.

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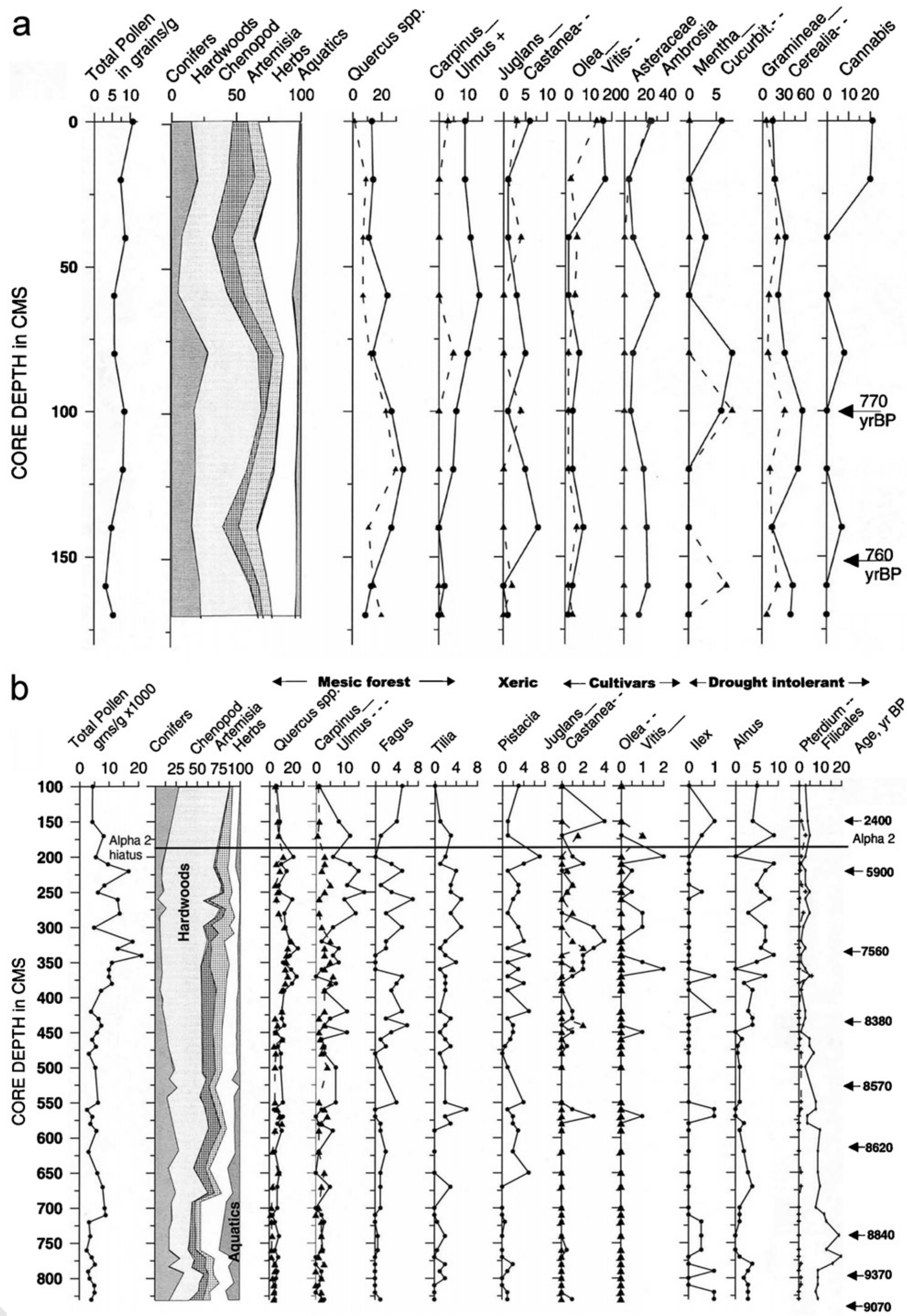

Fig. 7. Core MAR02-45: Pollen concentration and relative abundances of selected indicator species (calculated as % total pollen), and for total fern spores and Bracken Fern (*Pteridium aquilinum*), as % total pollen. Fig. 7(A). MAR02-45TWC (gravity core); Fig. 7B. MAR02- 45PC (piston core). ^{14}C ages are in yr BP.

Core MAR02-45TWC records events for the past ~1000 years and shows a further decline in Conifer pollen, which is almost all *Pinus*, with small amounts of *Abies* from the base to 80 cm. The hardwoods also decline, particularly the larger forest species like *Ulmus* and *Tilia*, but also, the smaller, more drought-resistant Eu-Mediterranean trees like *Carpinus* and *Ostrya.* After ~1.0 kyr BP, there are sustained pollen occurrences of Cerealia, Oleaceae (olive) *Vitis* (grape), and fruit-trees including *Juglans* (walnut), *Castanea* (chestnut), *Malus* (apple) and *Prunus* (plum, cherry). The herb record for the TWC includes the first appearances of *Cannabis* and Cucurbitaceae (squash), and *Mentha*-type pollen increases, reflecting either cultivation of mint or an increase in field weeds.

Fig. 8 shows the annual pollen deposition rate for selected pollen types in Core MAR02-45PC, and is plotted in the time domain for comparison with the low-resolution Core B-7 from the deep Black Sea basin (Fig. 6). Here we

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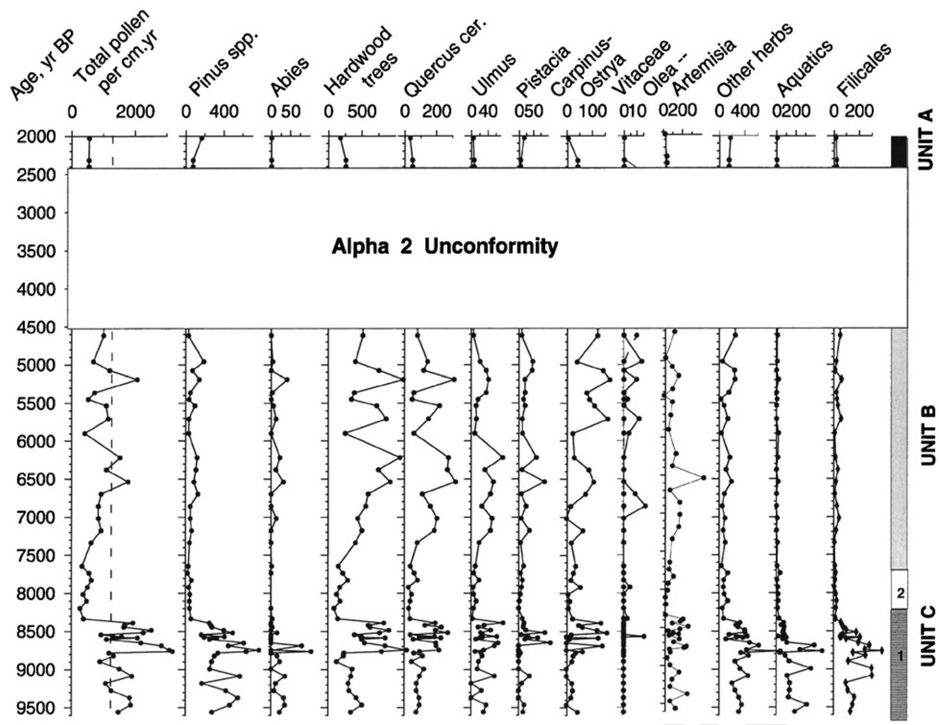

Fig. 8. Core MAR02-45PC. Late Glacial–Holocene annual pollen and spore accumulation rates (number of grains/cm^2.year). + indicates *Ephedra* pollen.

see that the average total pollen accumulation, 1273 grains/cm^2 yr, is higher than the southern basin average of ~500 grains/cm^2 yr, particularly in the early Holocene interval where the average sedimentation rate is 360 cm/kyr. In Core MAR02-45PC, there is a two-fold increase in accumulation from ~8.8 to 8.6 kyr BP and a doubling from ~8.6 to 8.4 kyr BP, separated by 50 yr of average pollen accumulation. A smaller peak also appears at about ~5.3 kyr BP. The early Holocene interval of high pollen influx is followed at 8.3 kyr BP by decline in all pollen influxes until about 7.0 kyr BP. This interval of low influx extends across both lithofacies and geochemical boundaries, and it corresponds to the decrease in sedimentation rate from 360 to 85 cm/kyr that probably marks a change in the pathways of riverine supply as former valleys to the southwest were gradually flooded (see Hiscott et al., this volume).

Pollen influx data for individual trees shows the same general pattern as in the southern basin core B-7. However, the high resolution shelf core shows frequent occurrences of *Ephedra* from 9.5 to 8.9 kyr BP, and a more persistent presence of *Abies* until the start of the Bronze Age, around 5.0 kyr BP. The high resolution record also shows the first appearance of Oleaceae pollen at 4.6 kyr BP, and that the sustained rise in *Pistacia* starts around 8.8 kyr BP, although its initial spread begins as early as 9.5 kyr BP.

Initial results of the dinocyst assemblages studied by Marret in MAR02-45PC show the presence of 33 taxa (Table 2) that can be grouped according to ecological affinity, as shown in Fig. 9. The detailed taxonomy and ecology of the dinocysts are reported by Marret et al., submitted). Here, however, we show that the *Spiniferites cruciformis–Pyxidinopsis psilata* assemblage dominated until 7.6 kyr BP, indicating salinities with a possible range of ~3–14‰ in the early Holocene (Mudie et al., 2004). The early Holocene assemblages also include up to 20% of *Pediastrum* and *Botryococcus* colonial algae (Fig. 9) that live in freshwater but are also common in low salinity marine sediments deposited off large deltas such as the Mackenzie and Lena Rivers (Matthiessen et al., 2001). Increased total sulphur from 8.4 and 8.2 kyr BP is evident in the palynology samples as a vast abundance of fine pyrite particles, and it coincides with the initial inflow of sulphate-rich Aegean water (Hiscott et al., this volume). This event is followed after ~700 years by displacement of the *S. cruciformis* assemblage by the euryhaline species *L. machaerophorum* that also dominates at the coastal Eneolithic site (Filopova-Marinova and Bozilova, 2002; Filipova-Marinova, 2003a), and by increased presence of Mediterranean indicators, including *Spiniferites belerius, S. mirabilis, S. ramosus, Operculodinium centrocarpum* and *Tectatodinium pellitum.*

5. Discussion

5.1. Vegetation and climate history

Previously, pollen assemblages were studied in 150 samples from 8 cores on the 300 km long geographical gradient from the Southern Black Sea (Core B-7) in the northeast (Fig. 1) to the Aegean Sea (Core A19) in the southwest, and the modern vegetation of the Black

Table 2
List of dinoflagellate cysts reported for cores from the southwestern Black Sea Shelf (A. in this study; B. from Filopova-Marinova et al., 2004; Atanossova, 2003), for the southeastern basin of the Black Sea (Mudie et al., 2002b), for the Caspian Sea and Kara Boğaz Göl (Marret et al., 2004), and for the Aral Sea (Sorrel et al., 2006).

Taxon	S.W. Shelf A	S.W. Shelf B	SE Basin Black S.	Caspian Sea and KGB	Aral Sea
Gonyaulacoid cysts					
Caspidinium rugosum Marret 2004	+			+	+
Gonyaulax apiculata (Pénard) Entz fil. 1891			+		
Impagidinium caspienensis Marret 2004	+			+	+
Lingulodinium machaerophorum sensu stricto	+	+	+	+	+
Ligulodinium machaerophorum var. A	+		+	+	+
Lingulodinium machaerophorum var. B	+		+	+	+
Operculodinium centrocarpum sensu Wall&Dale	+		+		
Pyxidinopsis psilata (Wall & Dale) Head 1999	+	+	+		
Polysphaeridium zoharyi(Rossignol) Bujak et al.	+				
Romanodinium areolatum Baltes					
Spiniferites belerius Reid 1974	+		+	+	
Spiniferites sp. cf. *S.belerius*	+				
Spiniferites bentorii (Rossignol) Wall & Dale 1970	+		+		
Spiniferites bulloideus(Deflandre et Cookson 1955) Sarjeant 1970			+		
Spiniferites sp. cf. *S. bentorii*	+				
Spiniferites cruciformis s.l. of Wall & Dale 1973	+	+	+	+	+
Spiniferites cruciformis forms1-5 (Mudie e.a.2001)	+		+		+
Spiniferites inaequalis Wall and Dale 1973	+		+		
Spiniferites membranaceus s.l.of Marret&Zonneveld	+				
*Spiniferites mirabilis*s.l.of Marret & Zonneveld 2003	+		+		
Spiniferites cf. *S.ramosus*	+	+	+		
Spiniferites sp.	+	+	+		
Tectatodinium pellitum Wall,1967 emend Head1994	+				
Protoperidinioid cysts					
Brigantedinium (protoperidiniacean) spp.	+			+	+
Brigantedinium simplex	+				
Dubridinium caperatum Reid 1974	+				
Echinodinium transparantum Zonneveld 1997	+				
Echinodinium spp.	+				
Pentapharsodinium dalei Indelicato et Loeblich III	+			+	+
Selenopemphix nephroides(Benedek) B & Sarjeant	+				
Votadinium calvum Reid, 1977	+				
Peridinium ponticum Wall and Dale 1973	+				
Xandarodinium xanthum Reid 1977	+				
Polykrikos schwartzii Chatton 1914	+				
Polykrikos kofoidii Bütschli 1873	+				
Gymnodinioid cysts					
Cyst of *Gymnodinium catenatum* Graham 1943	+				

Sea–Mediterranean corridor was mapped and briefly described (Mudie et al., 2002a). The results of these pollen studies were published as relative abundance (pollen percentage) diagrams (Aksu et al., 1995, 1999; Mudie et al., 2002a) in order to establish marine pollen zones for comparison with the lake records for the Black Sea–Mediterranean corridor. In the 2002 paper, we described the changes in modern pollen assemblages along a transect from the Aegean Sea to southeast Black Sea which show that although *Pinus* and *Artemisia* pollen are over-represented at the western and easternmost ends of the transect, respectively, there is generally a good correspondence between tree pollen assemblages and onshore vegetation. Mudie et al. (2002a) have also shown the close correlation between the tree and weed/agricultural pollen zone composition and ages of Marmara Sea pollen zones and those of lakes in the Pontic Mountains. The close agreement between marine and lake pollen diagrams in this region of lake-like inland seas is further illustrated and discussed by Cordova et al. (submitted). The general principles of marine palynology and onshore–offshore pollen transport are discussed in further detail in recent papers by Hooghiemstra et al. (2006) and Mudie and McCarthy (2006). It is clear that although bisaccate pollen (particularly *Pinus* and *Picea*) are likely to be over-represented in marine sediments, and many insect-pollinated herbs are under-represented in marine sediments, a statistical correlation of more than $R = 0.7$ can be expected between pollen zones for coastal inlets, shelf basins, and

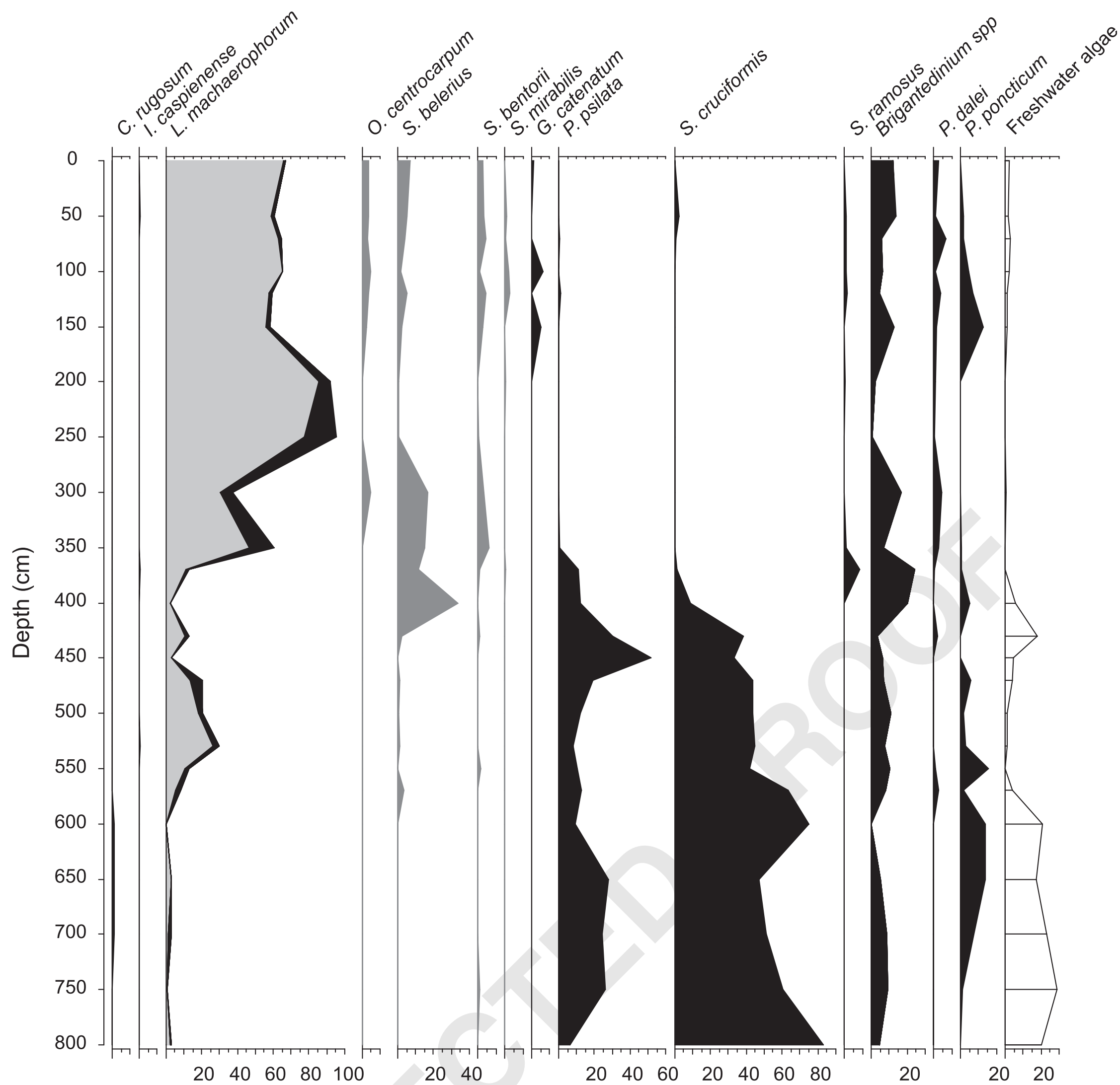

Fig. 9. Core MAR02-45PC: Relative abundances of selected indicator dinocyst species and freshwater algae (*Pediastrum* and *Botryoccocus*). All percent abundances are based on the total number of dinocysts counted; acritarchs are not included in any of the counts. Full names of taxa are shown in Table 2.

epicontinental seas and in large lakes like the Dead Sea and Caspian Sea.

In this paper we present the first studies of Black Sea–Mediterranean corridor cores to determine the changes in annual pollen influxes that record the migrations of forest trees and the changes in density of vegetation cover during the past 30,000 years. The new results in this paper include pollen influx (=annual accumulation at the seabed) records for the Pleniglacial time-slice from 29.5 to 21.9 kyr BP (Core MAR94-5), the early post-LGM to Holocene interval in Marmara Sea (Cores MAR98-12 and MAR98-11), the Holocene in the southeastern Black Sea basin Core B-7 and in the southwestern Turkish shelf core MAR02-45, and for a late Holocene Bronze Age core (MAR97-2) that spans the interval of Beyşehir Occupation Period in Anatolia from ~3.7 to 1.2 kyr BP. The only previous pollen influx studies for the Black Sea—Mediterranean Sea corridor were made on annual varves in Lake Van (Fig. 1), covering the past 12,500 years (Wick et al., 2003). Lake Van, at 1648 m a.s.l. in the easternmost Taurus Mountains of southeast Turkey, is the fourth largest terminal lake on Earth, and is located in a continental climate region in contrast to the humid sub-Mediterranean climates of the Black and Marmara Seas. Previous pollen diagrams have suggested that there was a remarkable delay in oak expansion during the early Holocene (Wick et al., 2003), perhaps giving rise to the idea that the early Holocene was cold and dry in the Black Sea region, like the LGM (18 kyr BP) interval north and east of the Black and Azov Seas (Cordova et al., submitted).

5.1.1. Pleniglacial–LGM interval

The relatively high pollen influxes during the end of the mid Pleniglacial and early late Pleniglacial (start of marine isotopic stage 2) in core MAR94-5 (Fig. 2) confirm the presence of *Pinus–Abies–Quercus* forest and relatively mild climatic conditions along the coast of the Marmara Sea from about 30 to 24 kyr BP. *Abies* pollen influx is notably

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consistent throughout most of this pre-LGM section, and *Ephedra* is rare or absent. The persistent presence of the montane Conifer species *Abies* suggests cooler temperatures , as also indicated by the oxygen isotope record: it was colder than now by 2–4 and 8 °C in winter and summer, respectively. Pollen of *Abies alba* and the predominance of *Cystopteris*-type fern spores also indicate areas of closed forest on cooler north-facing slopes, and a semi-humid climate (Bottema et al., 1995). Increased precipitation around ~27.0 kyr BP was also reported by Filipova-Marinova (2003a) for Core-2345 from −122 m water depth on the southern Bulgarian shelf, which is the only other published palynological report for this time interval on the western Black Sea shelf. The presence of deciduous oak (*Quercus cerris*-type pollen), *Fagus* and *Tilia* also mark this interval, indicating the year-round distribution of rainfall >600 mm. *Alnus* (alder) indicates some permanently swampy lowland areas within open steppe vegetation dominated by the light-demanding chamaephyte *Artemisia*, together with weedy Chenopodiaceae and Asteracaeae (mostly *Centaurea*) species. The near absence of the dry steppe/desert shrub *Ephedra* testifies to the relatively humid climate during the pre-LGM Pleniglacial interval.

From 24 to 22 kyr BP, there is a large decline in pollen influx for all species, including the drought resistant *Pinus* species and Gramineae, hence indicating a major reduction in total vegetation cover. It is notable, however, that there is an increased presence of *Picea orientalis,* and increased *Picea* is also reported for the Bulgarian Shelf (Filipova-Marinova, 2003a). *Picea orientalis* is a drought-tolerant spruce tree that grows with temperatures as low as −5.7 °C, suggesting the start of much colder, drier conditions in the two millennia prior to the LGM from ~22 to 18 kyr BP. The fern spores in this interval no longer indicate closed, moist forest: they are spores of *Pteridium*, the invasive, drought-tolerant bracken-ferns of woodland clearings. Surprisingly, the oxygen isotope record for MAR94-5 indicates a 4 °C rise in summer temperature for this interval just prior to the glacial maximum. If correct, this would have led to increased evapotranspiration and lower net precipitation just before the LGM.

5.1.2. LGM–Holocene interval

There are no pollen or $\delta^{18}O$ records for the full glacial interval (LGM) in the study region, and the record from MAR97-11 (Fig. 4(b)) is the only directly dated pollen sequence for the late Pleniglacial interval from ~16 to 15 kyr BP when a record from the outer Bulgarian Shelf (Core XK-120) begins with a basal age of 15,380 ± 540 yr BP (Atanassova, 2005). Caner and Algan (2002) report an inferred age of ~18–14 kyr BP for Pollen Zone D in core DM13 from the western Marmara Sea, but these ages are extrapolated from the ages of lithofacies in other dated cores.

The low resolution pollen stratigraphies for the Late Glacial to early Holocene intervals in the Marmara Sea cores MAR97-11 and 98-12 (Fig. 4) show a continuation of the low pollen influxes (<100 grains/cm^2 yr) until the Younger Dryas, suggesting relatively cold, dry conditions and a sparsely vegetated landscape until a slight (1 °C) warming just before the Allerød–Bølling interval (~13–11 kyr BP). This is consistent with the 18–16 kyr BP and 12–11 kyr BP palaeo-vegetation reconstructions of Van Zeist and Bottema (1982) for northern and western Anatolia, showing pine forest-steppe vegetation except along the south coast of the Black Sea, west and east of Sinope where there were closed forests. Filipova-Marinova et al. (2004) also report cold steppe conditions for the interval from 14.6 to 11.43 kyr BP on the Bulgarian Shelf, but note the presence of *Pinus* and some cold-tolerant, moisture requiring deciduous trees (*Quercus, Ulmus, Tilia*) during the late glacial interstades. At Lake Van, tree pollen influxes are less than 100 grains/cm^2 yr except during the YD interval where they increase up to ~500.

In MAR97-11, the early post-LGM interval is marked by notable fluctuations in total pollen influxes, and by the presence of *Pinus, Abies* and *Picea, Alnus* and ferns until the start of the Older Dryas cold event around 13 kyr BP. The steppe-desert shrub *Ephedra distachya* is also present throughout this interval, indicating areas of open, well-drained soils and annual rainfall less than 500 mm. The winter temperature and moisture limits for *Picea orientalis* are −5.7 and 400–700 mm/yr, and may provide an index of the climate in the coastal mountains, compared to modern values of 0–4 °C and 700–1000 mm.

The Younger Dryas (YD) event is marked by an increase in total pollen influx, as particularly evident in MAR98-12 where it is represented by three sample intervals, and there is a notable rise in *Quercus, Fagus, Alnus* and ferns, in addition to the light demanding steppe taxa *Artemisia*, Cheno–Am and Asteraceae, and the desert indicator, *Ephedra*. During the YD at Lake Van (Wick et al., 2003), stands of *Quercus, Pistacia* and *Salix* become established in the previously very arid desert-steppe, and the ostracode $\delta^{18}O$ values increase from 1‰ to a maximum of 5.5‰ between 12.5 and 10.5 kyr varve years ago. Filipova-Marinova et al. (2004) report that the driest, coldest interval was from about 11 to 10 kyr BP (13–11.5 cal kyr) in Core MC544 on the Bulgarian shelf rise (2500 m water depth). It is interesting, however, that there is no large decrease in either Twinter or Tsummer for the Marmara Sea region, and that the $\delta^{13}C$ values are relatively low (−25.2 to −26.2‰), indicating more humid conditions in the coastal region than at Lake Van or in the northwestern Black Sea.

5.1.3. Holocene interval

The low resolution influx data for both Marmara Sea cores (Fig. 4), and for the Black Sea core B-7 (Fig. 5) show that by 9 kyr BP, the drought-tolerant, light-demanding pine forest was replaced by deciduous oak (*Quercus cerris*-type pollen) and that *Fagus* was well established. These trees require year-round precipitation of >600 and

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>800 mm, respectively, and *Fagus* requires winter minimum temperatures of >3 °C. Other temperate climate forest trees include *Tilia*, *Ulmus* and *Castanea*, as also reported by Caner and Algan (2002) for other Marmara Sea cores. The presence of mesic forest trees clearly indicates warm, moist climate conditions during the early Holocene in the Marmara Sea area.

In the high resolution record for MAR02-45 (Fig. 8), the early Holocene interval of pine and deciduous tree pollen influx is followed at 8.3 kyr BP by large decline in all pollen influxes until about 7 kyr BP. The influx values (2000–3000 grains/cm^2 yr) for the peaks from 8.8–8.3 kyr BP are of the same order of magnitude as for the height of forest development at Lake Van (5000 grains/cm^2 yr), and therefore establish the local presence of forest trees along the coast of the southwest Black Sea. The subsequent interval of low influx extends across the lithofacies boundaries C2/C1 and C2/B (Fig. 8), and it starts about 100 years before the C2 event when total suphur increases, marking the first sustained inflow of Mediterranean water. Hence there are no major sediment grain-size or unfavourable taphonomic changes that can explain this early decline in pollen accumulation rates. The most likely explanation for this decrease is a reorganization of fluvial sediment supply because of transgressive flooding of the former early Holocene valley in this area (see Hiscott et al., this volume). The gradual valley drowning from around 9 to 7.5 kyr BP may have re-routed some major tributaries that formerly all flowed into the palaeovalley on the shelf, resulting in a decrease of sedimentation rates from 360 to 85 cm/kyr. It is also well known that *Pinus* pollen, the major contributor to the early Holocene pollen assemblages in Core MAR45PC, is over-represented in shelfal deltaic environments (see Traverse, 1988 for examples). A disruption of the drainage might therefore have contributed to the large, sustained decline in the pine pollen influx. At about 8355 yr BP, the sedimentation rate in Core C-149 from the Veleka estuary on the Bulgarian coast also dropped from about 2.2 to 0.43m/kyr (Filipova-Marinova, 2003b), suggesting a big change in the drainage patterns of the coastal Stranza mountains northwest of our study area. Filipova-Marinova (2003b) also reported a pine pollen percentage decline for around 8355 yr BP in Veleka estuary core C-149, but she attributed this event to the displacement of the light-demanding pine forest by expanding deciduous forests, rather than a change in the drainage system.

The new high resolution core MAR02-45 allows us to put some more precise ages on events that were reported earlier by Bozilova et al. (1996) for Lake Varna in northeast Bulgaria, such as the first arrival of *Quercus*, *Carpinus* and *Ulmus* at 8 kyr BP and the later arrival of *Fagus* at 6 kyr BP. The influx data for MAR02-45 (Fig. 8) clearly shows that these trees were present earlier in the southeast and began to expand around 8.5 kyr BP, not at 7 kyr. This reconstruction is in accord with the pollen diagram for Veleka Estuary that shows the presence of these pollen species before ~9.9 kyr BP (Filipova-Marinova, 2003b). Likewise, the expansion of *Carpinus betulus* appears to have taken place between ~6.6 kyr BP (Veleka Core C-149) and 6.5 kyr BP (MAR02-45), not at 7 kyr BP.

The low resolution cores show the appearance of the Mediterranean scrub species *Pistacia* at about 9 kyr BP, in accordance with the Mediterranean Sea records of Rossignol-Strick (1996), and the high resolution core further shows that it was already present by 9.5 kyr BP. The increases in the Mediterranean scrub oak, *Quercus coccifera*, together with *Pistacia*, in the mid Holocene of MAR98-12 (Fig. 4(a)), and the increase in *Carpinus-Ostrya* in B-7 (Fig. 8) suggested the onset of warmer, drier conditions after ~7 kyr BP. These observations can now be fine-tuned by the MAR02-45 time scale to about 6.5 kyr BP. *Pistacia* requires minimum winter temperatures of 10 °C, needs only ~400 mm of rainfall per year, and can survive summer drought.

The low resolution cores from Marmara Sea and the Black Sea (core B-7; Fig. 5) showed no evidence of sustained agriculture or arboriculture in the early Holocene, and display no unique peak of terrigenous organic matter at precisely 7.5 or 8.4 kyr BP as required by a model for abrupt, rapid (<100 years) flooding of a vegetated coastal plain. Similar results were reported by Filopova-Marinova and Bozilova (2002) and Atanassova (2005) for low resolution cores from Bulgarian shelf, although they interpreted the presence of more grass and chenopod pollen in those cores as indicating colder early Holocene climatic conditions. This discrepancy may reflect the greater proximity of the Bulgarian shelf to the Danube Delta and the continental climatic conditions north of the Black Sea.

5.1.4. *Anthropogene*

Cores from Lakes Varna and Durankulak, on the present north coast of Bulgaria, also show some evidence of cereal cultivation during two brief intervals, from 6.5 to 6 kyr in the Eneolith period, and during the early Bronze Age from ~5 to 4 kyr BP. In the north, sustained cereal cultivation, is only evident during the Iron Age, from about 2.8 kyr BP to the present. In contrast, at submerged archaeological sites (4–5 m b.s.l.) in Sozopol Harbour, SE Bulgaria, there is evidence of stockbreeding and wheat cultivation during the Late Eneolithic, from ~5.5 to 5.3 kyr BP (Filipova-Marinova and Bozilova, 2003; Filipova-Marinova and Angelova, 2006). It is not clear, however, that these farms were actually located at the Sozopol archaeological sites because the percentages (<5%) of freshwater algae are low, and brackish-saline water dinocysts are present, suggesting estuarine conditions more like that at the mouth of the present Danube River.

Our new high resolution data for the Black Sea Shelf show small fluctuating percentage peaks of walnut (*Juglans*), olive (*Olea*), grape (*Vitis*) and cereal pollen by 7.5 kyr BP, possibly suggesting some fruit harvesting and small-scale attempts at agriculture (Figs. 7 and 8). The

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pollen influx data for MAR02-45 (Fig. 8) and pollen percentages for Sozopol Harbour suggest that large scale deforestation, arboriculture and sustained cereal farming only begin after about 4.5 kyr BP, but unfortunately the Alpha 2 unconformity prevents detailed analysis for the start of this interval that is more clearly recorded in the Marmara Sea (MAR97-2, Fig. 6). The pollen record for the past 2000 years in MAR02-45TWC (Fig. 7(a)) shows an increase of cereal, olive and fruit-trees, and most recently, the cultivation of cannabis and mint.

The impact of anthropogenic influence is particularly well represented by the pollen influx record for the low resolution Core MAR97-2 (Fig. 6) from the north side of the central Marmara Sea that can be compared with the record from Lake Manyas (Fig. 1) on the south shore (Leroy et al., 2002, 2004; Cordova et al., submitted). It is notable that annual influx to this marine core is so low that they must be shown as grains per m^2, not per cm^2 as in the other cores rates. Deposition rates in Lake Manyas (see Cordova et al., submitted) are one or two orders of magnitude greater than in the Marmara Sea, yet the same vegetation changes are evident for the interval from 3.7 kyr BP to between 1.8 and 1.2 kyr BP, at the end of the Beyşehir Occupation Period (BOP). This period is a cultural interval seen in palynological records of sites in southern Turkey for the interval from about 4.5 to 1.2 kyr BP, and it is marked by rich arboriculture, including olives (*Olea*), manna ash (*Fraxinus ornus*) , sweet chestnut (*Castanea*), and vines (*Vitis*) in addition to cereals (Cerealia) and pasture herbs, including Tubuliflorae. The pollen accumulation rates for MAR97-2 clearly show the decrease in total pollen from 3.5 to 1.5 kyr BP that is also seen in Lake Manyas, reflecting near-elimination of *Pinus* and *Quercus* woodland, and the spread of the light-demanding shrub *Artemisia*, and weeds, such as *Taraxacum* (dandelion, Liguliflorae), *Chenopodium* and *Atriplex* spp. (Cheno–Ams).

It is also notable that pollen preservation in MAR97-02 is extremely poor during the Beyşehir Occupation Period, as indicated by the decline in the ratio of pollen:dinocysts (P:D; Fig. 6). The P:D ratio is an index of either a change in pollen influx or the preservation of thin-walled dinocysts (McCarthy and Mudie, 1998). In lakes and semi-enclosed seas, it is expected that pollen relative to dinocysts influx would be greater or equal to 1.0. In Core MAR97-02, thin walled protoperidiniod cysts are well preserved, showing that the bottom sediment are not highly oxidized (Hopkins and McCarthy, 2002), yet the pollen is very poorly preserved, hence the very low P:D ratios. Stellate hairs of *Quercus* and charcoal particles are also common throughout this interval of deforestation, providing further evidence for large scale clearance of oak woodland, forest burning, soil erosion and subsequent redeposition of oxidized pollen grains. These data provide strong supporting evidence for the argument (Leroy et al., 2002) that after 3.5 kyr BP, the Beyşehir Occupation Period extended into northern Anatolia from southwestern Turkey.

5.2. *Dinocyst assemblages and the catastrophic flooding hypothesis*

The ecological affinity of the dinocyst assemblages D1 and D2 of Mudie et al. (2002b) in the pre-Holocene sediments of the Marmara Sea and the early Holocene assemblages in the Black and Marmara Seas is crucially important for understanding the history of water exchange in the Black Sea–Mediterranean Sea corridor because no other microfossils are continuously present in the fossil record. Our previous interpretations of salinity ranges were based largely on a statistical analysis of 16 core-top assemblages from the samples shown in Fig. 1, and covered a salinity range from 16 to 39‰ in the modern seas (Mudie et al., 2004). As explained earlier in this paper, and shown in Fig. 3, for the no-analog *Spiniferites cruciformis* assemblage, we used the measured foraminiferal isotope record for MAR94-5 and its derived salinity estimates to look at the relationship between morphological variation in *S. cruciformis* and salinity change over the range of 16–22‰. We compensated for the higher values represented by the subsurface planktonic zooplankton (i.e., 16–22‰) by referring to earlier published estimates of salinity derived from coccolith data. The latter method was also used by Wall and Dale (1974), who originally described the early Holocene *Spiniferites cruciformis* assemblage from a location close to that of Core B-7 in the southern Black Sea basin.

It is important to note that Wall and Dale (1973) made no direct measurements of the early Holocene salinity, but their estimate of <7‰ has subsequently been quoted by other palynologists, particularly in the study of the Pleniglacial-recent Bulgarian Shelf cores examined by Filipova-Marinova (2003a, b) and Atanassova (2005). The ecological interpretations of the Bulgarian shelf dinocysts *Spiniferites cruciformis–Pyxidinopsis psilata* and *Lingulodinium–Spiniferites–Cymatiosphaera* assemblages as freshwater (stenohaline) or marine (euryhaline), respectively, were then cited by Ryan et al. (2003) in support of their catastrophic flood hypothesis. It is also important to note that the processing with acetolysis used for the Bulgarian Shelf cores significantly reduces the chance of recovering all the dinocysts, especially thin-walled protoperidinioid species (see Marret, 1993). A maximum of 13 species only is reported for the Bulgarian and Danube cores (see Table 2). Furthermore, the prevalence of the thick-walled prasinophyte *Cymatiosphaera* in the Bulgarian Shelf cores suggests selective recovery of the organic-walled palynomorphs. *Cymatiosphaera* is occasionally present in all our cores after ~7 kyr BP, but it has only been seen as a dominant species in southern basin samples that were treated with acetolysis (Mudie, unpublished data). This bias likewise poses a problem for the use of the Marine Influence Index of Traverse (1978, 1988) which is the ratio of dinoflagellates + acritarchs to total pollen, dinocysts and acritarchs.

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We are aware that *S. cruciformis* has also been found in the early Holocene sediments of a montane freshwater lake in Greece (Kouli et al., 2001), but as noted previously (Mudie et al., 2002b), the Black and Marmara Sea *Spiniferites cruciformis* complex has a wider range of morphological variation than found in this lake, and includes two morphotypes (forms 4 and 5) that were not reported for the freshwater lake. Most recently, Marret et al. (2004) described 3 morphotypes of *S. cruciformis* from surface sediments in the Caspian Sea area, where the salinity ranges from less than 5‰ to more than 14‰. For example, in the shallow Kara Boğaz Göl on the east side of the Caspian Sea, the salinity fluctuated from 46 to 264‰ from 2000 to 2001, during which time there were large blooms of *Gonyalax digitale* (the thecate dinoflagellate stage of *Spiniferites ramosus*-type cysts, *Nematosphaeropsis labyrinthus* and *B. tepikiense*) and a *Peridinium* species. The dinocysts in sediments of the saline inland sea (Table 2) include *Spiniferites cruciformis*, *Pyxidinopsis psilata*, *Lingulodinium machaerophorum* (3 morphotypes, including the short-spine form once thought to indicate lower salinity), *Brigantedinium* sp., *Pentapharsadinium dalei, S. belerius, S. bentorii*, and *Caspidinium rugosum* (Leroy et al., 2006). Assemblages from the Aral Sea (salinity ~10–15‰) recently reported by Sorrel et al. (2006) differ in lacking *Spiniferites* species and in the presence of *Romanodinium areolatum* (see Table 2).

It is therefore now clear that assemblages with *Spiniferites cruciformis* and *Pyxidinopsis* do not necessarily indicate freshwater or even brackish conditions—and the presence of *L. machaerophorum*, *P. dalei*, *S. belerius, S. bentori* and *Brigantedinium* do not mandate the influx of Mediterranean water. The same re-evaluation may well be true for other favourite mollusks, ostracodes and benthic foraminifera cited as freshwater, brackish water or marine indicators, and we are left to consider what can definitely be said about the ecological meaning of the pleniglacial and early Holocene *S. cruciformis* assemblages.

First, the association with inland seas, combined with the high variability in cyst morphology, indicates that they represent aquatic environments with highly fluctuating water levels and salinities. Such environments also contain large amounts of residual NaCl, and if used for cultivating clayey soils, would rapidly result in salt build-up, as documented for early Neolithic settlements in southern Turkey (Roberts, 1998) and for the past 4500 years in Oman (Jorgensen and al-Tikirti, 2002). Such fluctuating brackish water environments are unsuitable for long-term farming, although they might be settled fleetingly as temporary summer or winter fishcamps. Secondly, the studies of the inland Caspian and Aral Seas (Marret et al., 2004) have failed to record the presence of *Spiniferites mirabilis*, *T. pellitum, O centrocarpum* or *Selenopemphix nephroides,* all of which are well represented in the modern Aegean and Marmara Sea assemblages and which appear sporadically in the early Holocene of MAR02-45, suggesting occasional inflow of Mediterranean water. Thirdly, it is possible that *S. cruciformis* forms 4 and 5 of Mudie et al. (2001) are good indicators of Mediterranean water inflow, since they occur together with planktonic foraminifera but have not been found in freshwater lakes or the Caspian Sea. The stratigraphic distribution of these morphotypes in the early Holocene sediments of the Marmara Sea and in core B-7 from the southern Black Sea are described by Mudie et al. (2002a, b). It is also notable that *Spiniferites bulloideus, S. membranaceus and Nematosphaeropsis labyrinthea* have not been seen in the inland saline seas, but they occur sporadically in the middle Holocene sediments of Marmara Sea.

The new decadal-scale core MAR02-45 provides some important FADs (first appearance datums) for dinoflagellate arrivals in the Black Sea during the Holocene. Previously, the data from the Bulgarian shelf was interpreted as indicting a marine reconnection by 9 kyr BP, using the presence of *L. machaerophorum* as a marker (Filipova-Marinova et al., 2004; Atanassova, 2005). In light of the new data from the Caspian Sea, this may be an incorrect palaeoecological interpretation. Furthermore, most samples from the Bulgarian and Danube shelf cores were processed by the acetolysis method that destroys thin-walled dinocysts (see Marret, 1993; Hopkins and McCarthy, 2002).

In MAR02-45, *L. machaerophorum* is present by 9.3 kyr BP and it starts to increase around 8.6 kyr BP, after which time this species, which causes harmful algal blooms (HABs), increases rapidly. From 8.4 to 8.2 kyr BP, there is a notable increase in fine pyrite particles, less than 5 μm diameter, which corresponds to an initial pulse of sulphate-rich Aegean water that preceded the subsequent (~7.5 kyr BP) full reconnection between the Black Sea and the world ocean (Hiscott et al., this volume). The start of this first pulse was preceded by the decline of freshwater pond vegetation and is accompanied by the gradual, not abrupt, disappearance of the *S. cruciformis* assemblage. It is also notable that from 9.3 to ~7.6 kyr BP, the $\delta^{13}C$ values increase gradually from the post-glacial minimum of −27‰ to values between −24 and −25‰ that mark the present surface water, and there is a corresponding decline in terrigenous TOC. After 7.6 kyr BP, both $\delta^{13}C$ and terrigenous TOC are more variable and there appears to be an alternation between the dominance of the *L. machaerophorum* that causes HABs and Mediterranean dinocyst species, including *Spinferites bentorii, S. belerius, S. mirabilis* and *Pentapharsodinium dalei*. Two other HAB species, *Gymnodinium catenatum* and *Polysphaeridium zoharyi*, also appear in the sediments between ~5 and 2 kyr BP.

6. Conclusions

Palynological studies of the Black and Marmara Sea sediments provide important insight to three critical issues required to support Ryan and Pitman's catastrophic flood hypothesis and the idea of early settlement on the shores of the Black Sea.

(1) Both low and high resolution pollen influx data for the southwestern Black and Marmara Seas show the presence of mesic forest trees by at least 9.5 kyr BP, indicating that the early Holocene climate was relatively warm and humid, with year-round precipitation of >600–800 mm, and winter minimum temperatures of >3 °C. Freshwater marshes and alder swamps were also widespread. There is no evidence for a cold, dry conditions required to account for the 100 m drawdown of the Black Sea.
(2) The decadal-scale pollen influx record for the southwestern Black Sea shows that there may have been some fruit gathering and small-scale clearing during the Neolithic, but there was no sustained agriculture until ~4.5 kyr BP. Pine forest clearance is evident at all sites after ~4.3 kyr BP, and in northwestern Anatolia, there may have been extensive soil erosion.
(3) New dinocyst ecological data from the Caspian Sea confirm that the early Holocene Black Sea was not a freshwater lake but it contained brackish water that may have fluctuated between 5 and 15‰ or more. These relatively high salinities would have hindered early attempts at crop-growing on a shelf exposed during the time of lowered water level, and contradict the likelihood of Early Neolithic farming on the shelves.

It is thus clear that the marine palynological data from the Black and Marmara sediments and adjacent estuarine sites provide no evidence in support of the Flood Hypothesis of Ryan and Pitman.

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