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Anthropogenic impact on vegetation and environment during the Bronze Age in the area of Lake Durankulak, NE Bulgaria: Pollen, microscopic charcoal, non-pollen palynomorphs and plant macrofossils

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Abstract

A new pollen core, called "Durankulak-3", comes from the lake of that name, situated at the Black Sea coast of northeastern Bulgaria. The location of the core close to archaeological sites permits the correlation of palynological data, including non-pollen palynomorphs (NPP) (spores of fungi, remains of algae etc., as defined by van Geel, B., 2001. Non-pollen palynomorphs. In: Smol, J.P., Birks, H.J.B., Last, W. M. (Eds.), Tracking environmental changes using lake sediments. Vol. 3: Terrestrial, algal and siliceous indicators. Kluwer Academic Press, Dordrecht, pp. 99–119.), microscopic charcoal, and plant macrofossils with the archaeological data. A detailed reconstruction of the past vegetation reveals the extent of anthropogenic influence in the area. Radiocarbon dates from the basal part of the core show that the palaeoecological record begins at about 4500 BP. This start corresponds to the end of Chalcolithic and transition to the Bronze Age in the area and is connected with a rise of the lake level around Great Island and the lake shore to the west.

Peaks of microscopic charcoal in the lowest part of the core coincide well with those of anthropogenic indicators in the pollen diagram and with the NPP, indicating fire and erosion. These signals can be attributed to the Early Bronze Age activities of nomadic tribes in the area, according to the archaeological record. A second peak of the anthropogenic indicators, well correlated with a peak in the NPP-dung indicators, is probably connected with the Late Bonze Age and Early Iron Age occupation of the area. This suggestion is supported by peaks of *Vitis*-pollen and the first appearance of *Juglans*-pollen. In the last zone the vegetation is more and more similar to that of the modern reduced forests and expanded steppe vegetation. In this part of the diagram more specialized crop weeds like *Agrostemma githago* and *Centaurea cyanus* appear, most probably originating from rye cultivated there during the Middle Ages. In parallel is the last peak of microscopic charcoal particles and NPP indicators for dung and erosion.

Keywords: non-pollen palynomorphs; microscopic charcoal; plant macrofossils; pollen analysis; anthropogenic impact; Northeast Bulgaria; Bronze Age

1. Introduction

Lake Durankulak is an exceptional case for Bulgaria because the shores of the lake were almost continuously

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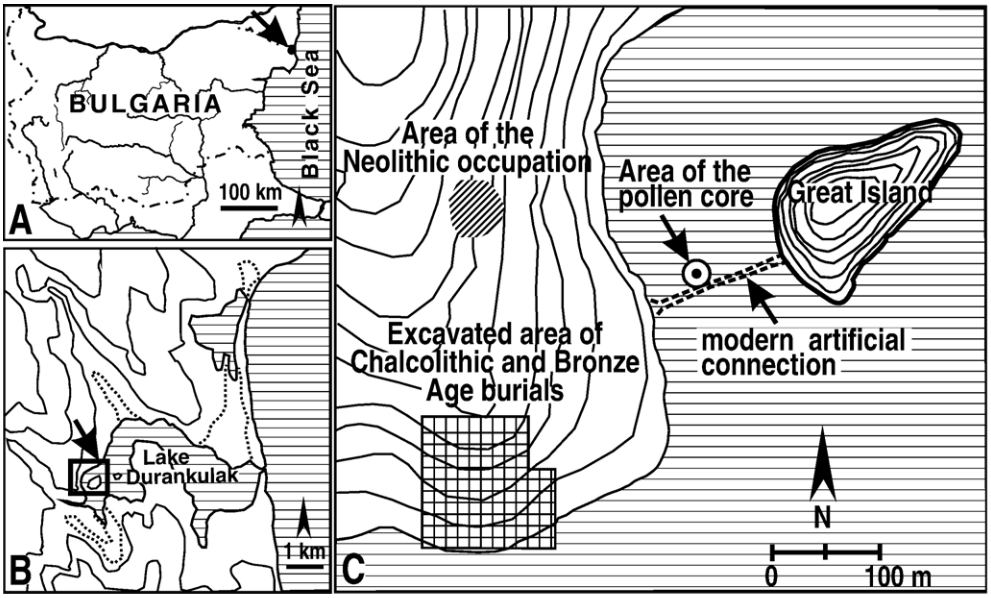

Fig. 1. Location of the site. Pointed with arrow: A — Lake Durankulak in Bulgaria; B and C — approximate position of the core in the lake Durankulak.

occupied from the Neolithic to the Middle Ages. This provides detailed information about past anthropogenic changes of the vegetation through pollen analysis of Lake Durankulak sediments.

Three pollen cores from Lake Durankulak (Durankulak-1:, Bozilova and Tonkov, 1985; Durankulak-2:, Bozilova and Tonkov, 1998; Durankulak-3:, Marinova, 2003) have already been studied. Other palynological and palaeoecological studies of coastal lakes and Black Sea sediments from the region of Durankulak on the Bulgarian Northern Black Sea coast have been carried out (Filipova, 1985; Shopov et al., 1992; Atanassova, 1995; Atanassova, 2005). They outline the main trends in the development of the Holocene vegetation in the region.

The subject of this work is the pollen-analytical study of core Durankulak-3, which is rich in microscopic charcoal and non-pollen palynomorphs (NPP — spores of fungi, remains of algae etc., as defined by van Geel, 2001). These two additional sources of information about human impact are useful in the Durankulak area, where many palynological anthropogenic indicators grow naturally and because of this are difficult to be used for reconstruction of human impact. Analysis of microscopic charcoal particles (particularly wood charcoal) is useful for studies of anthropogenic impact (Tolonen, 1986; Patterson et al., 1987; Clarke, 1990; Kangur, 2002). NPP are good indicators as well for local environmental conditions, as for stock breeding and local fires (Buurman et al., 1995; van Geel, 2001; van Geel et al., 2003). These sources of information are then compared with the results of plant macrofossil and pollen analysis in an attempt to get detailed information about human impact and environmental change in the area during the Bronze Age.

2. Study area

Lake Durankulak (43°15′4″N, 28°23′2″E) is situated on the Black Sea coast in north eastern Bulgaria (Fig. 1). Its area spans about 3 km^2, with maximum length of 5 km and width of 2 km. It is up to 4 m deep. The lake

Table 1
Chronology of the prehistoric and historic cultures in Dobrudzha, Western Black sea coast

Periods	Cultures	Age
Middle ages	**Proto-Bulgarians**	900–1000 AD
Roman period		45 BC–300 AD
Iron Age		700–600 BC–50 BC
	Thracians	1200 BC–800/700 BC
Bronze Age		
Late	**Coslogeni**	1400/1300–1050/1000 BC
Middle	Jamnaja	3150/3100–2600/2500 BC
Early	Černa voda III	3500/3400–2850/2650 BC
Transition	Černa voda I	3900/3800–3500/3400 BC
Chalcolithic		
Late	**Varna**	4550/4500–4100/4050 BC
Early	**Hamangia**	4750/4700–4550/4500 BC
Neolithic		
Late	**Hamangia**	5250/5200–4750/4700 BC

With bold are marked the cultures which occur on the Great Island of Durankulak (after Bojadzhiev, 1992; Görsdorf and Bojadzhiev, 1997).

Table 2
Sedimentological division of the core Durankulak-3

Depth [cm]	Sediment
0–17	Mud (grey-brown)
17–80	*Phragmites*-peat (black-brown)
80–137	Mud with thin sand layers (dark brown)
137–146	Calcareous mud
146–150	Shell-layer
150–203	Mud (dark grey-brown)
203–220	Clay-mud (black-grey)
220–222	Shell enrichment
222–272	Clay-mud to grey (black-grey)
272–288	Humic loess rich in organic matter
288	Loess with calc concretions
288–340	Loess

sediments fill two depressions in Miocene (Sarmatium) limestone. Some terrestrial karst depressions and fields situated in the immediate proximity show connection to Lake Durankulak. The water is slightly brackish (2‰ to 4‰) and meso- to eutrophic. The water surface of Lake Durankulak is about 40 cm asl. The lake is separated from the Black Sea by a sand dune 200–300 m wide. The separation of Lake Durankulak from the sea probably dates from the late Pleistocene–early Holocene (Popov and Mishev, 1974). According to some archaeological and geological observations, a small connection of its northern part with the Black Sea existed until about 3000 BC (Todorova, 2002).

The climate in the region is characterized by strong continental influence from the northeast and partly by the proximity of the Black Sea. The prevailing winds come from the northeast, the mean annual precipitation is 450–500 mm reaching a maximum in June and minimum in February. The proximity of the Black Sea moderates mean January temperatures to about 0 °C, and sea-breeze circulation plays a certain role for microclimatic conditions.

The modern vegetation surrounding Lake Durankulak is strongly anthropogenically influenced and intensively used for agriculture. Near Lake Durankulak one can find the following vegetation types: xerothermic oak forests and forest-steppe, psammophytic and halophytic plants on the sand dunes and sea shore, and river forests and hydrophyllous swamp vegetation. The potential natural vegetation consists of xerothermic oak forests with *Quercus pubescens*, *Q. cerris*, *Q. virgiliana*, *Tilia argentea*, *Fraxinus excelsior*, *Acer campestre*, and *Carpinus betulus*. In the depressions around the lake grow small stands of *Ulmus minor*, *Fraxinus excelsior*, *Crataegus monogyna*, *Corylus avellana*, *Pyrus pyraster*, and *Sambucus nigra*. On the edges of the lake grow populations of *Phragmites australis*. Sporadically there occur *Typha latifolia, T. angustifolia*, or *Schoenoplectus lacustris. S. tabernaemontani* is also present although less abundant. The swamp vegetation is represented by *Alisma plantago-aquatica*, *Glyceria maxima*, *G. fluitans*, *Butomus umbellatus*, *Caltha* sp., *Lythrum salicaria*, *Sparganium erectum*, and *Calystegia sepium*.

Psammophytes grow in the sand dunes near the lake, e.g. *Corispermum nitidum*, *Eryngium maritimum*, *Leymus racemosus*, *Elymus elongatus*, *Cakile maritima*, *Ammophila arenaria*, and *Secale sylvestre*.

Halophytes like *Puccinellia convoluta*, *Limonium gmelinii*, *Salicornia europaea*, *Aeluropus littoralis*, and *Elymus elongatus* can be found here and there on the lake shore.

3. Archaeological settings

Table 1 shows the history of human occupation and its archaeological classification in the region. On the southwestern shore (Fig. 1), close to Great Island some traces of Neolithic settlement are recorded (Dimov, 2003). In this area a prehistoric burial place was discovered. Some of the Late Chalcolithic and Early Bronze Age burials lie today under water between the lake shore and Great Island (Orachev, 1990).

Human occupation of Great Island in Lake Durankulak started during the late Neolithic to early Chalcolithic. No clear settlement activities are recorded on the island from the end of the Chalcolithic to the Late Bronze Age. Chalcolithic and Early Bronze Age burials along the shore of the lake (Todorova, 2002) date 5200–2200 BC (Table 1), and settlements of the Late Bronze Age (13th–12th cent. BC) and a Hellenistic sanctuary were found on the southern slope of the island. A Middle Age settlement on the

Table. 3
The ^{14}C data from the core Durankulak-3

Lab. nr.	Depth [cm]	Material dated	Sample weight [mg]	Carbon weight [mg]	Age BP	Age cal BC
KIA 12339	170	Partly carbonised wood fragments	6.82	5.0	3904±29	2469–2292
KIA 12340	172.5	Partly carbonised wood fragments	8.24	5.1	3908±31	2471–2292
KIA 12341	180	Partly carbonised wood fragments	6.71	4.0	4198±30	2815–2672
KIA 12342	182.5	Partly carbonised wood fragments	5.86	2.6	4153±35	2611–2596
KIA 12343	187.5	*Medicago*-fruits, wood fragments	7.15	3.4	4191±33	2819–2649

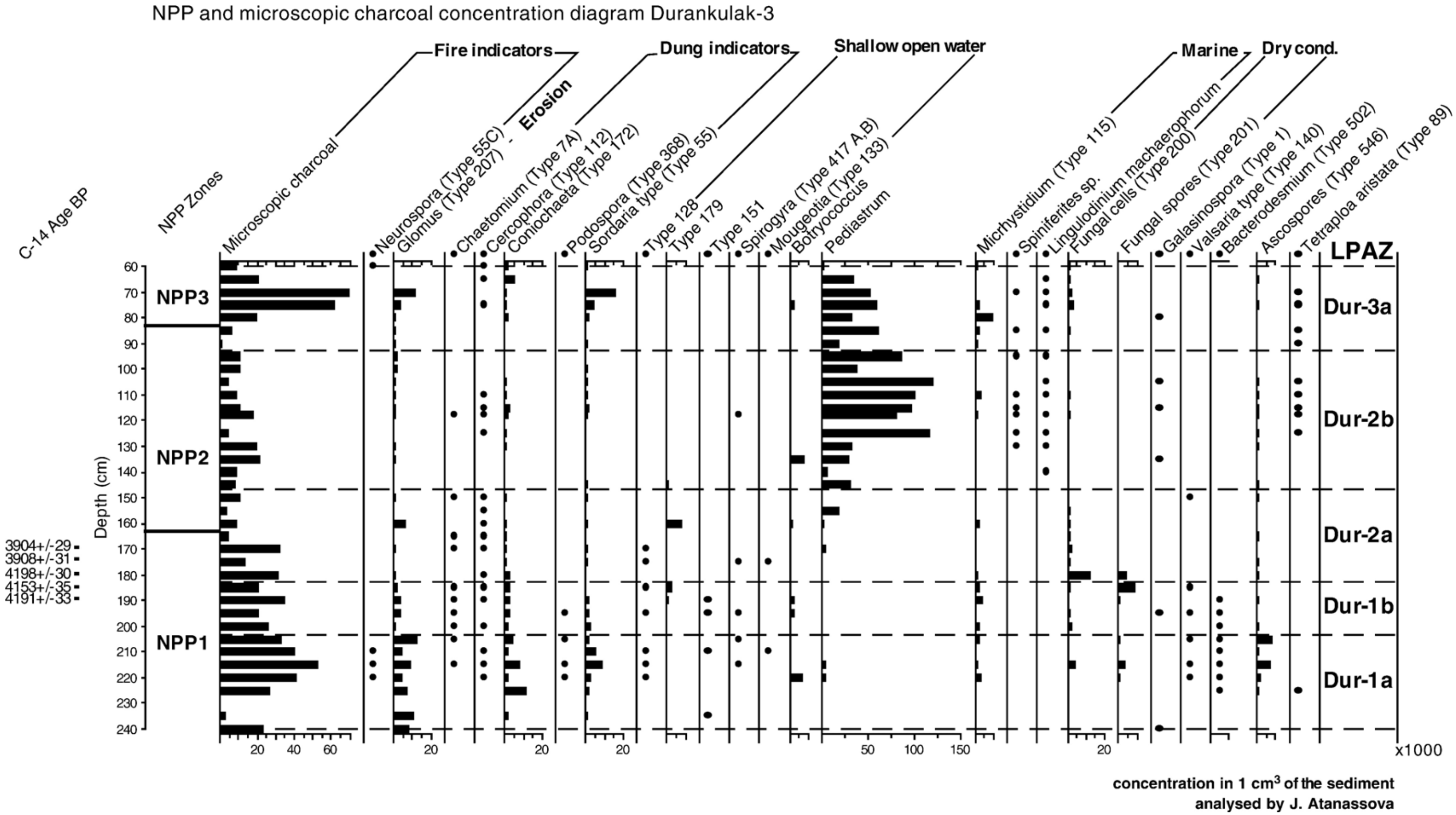

Fig. 2. Diagram of the microscopic charcoal and NPP.

Table 4
Summarised results of the study of microscopic charcoals and NPP — description of the NNP Zones including microscopic charcoal particles

NPP zones	Depth (cm)	Description
NPP 3	60–85	*Pediastrum* has high values Marine indicators occur sporadically (dinoflagellate cysts *Lingulodinium machaerophorum*, *Spiniferites* sp. and Acritarchs); the concentration of dung indicators (*Cercophora*-Type 112, *Coniochaeta* Type 172, *Sordaria Type* 55A) and of the indicator for erosion (*Glomus* Type 207) increases High concentration of microscopic charcoal particles occurs
NPP 2	85–160	Maximum of *Pediastrum* Marine indicators (dinoflagellate cysts *Lingulodinium machaerophorum*, *Spiniferites* sp. and Acritarchs) occur regularly but with low values Dung indicators (*Cercophora* -Type 112, *Coniochaeta* Type 172, *Sordaria Type* 55A) are present sporadically The concentration of the microscopic charcoal particles decreases sharply
NPP 1	160–240	Maximal values and variety of dung indicators (*Chaetomium* Type, *Cercophora* -Type 112, *Coniochaeta* Type 172, *Sordaria* Type 55A, *Podospora* Type) Maximal values of the indicator for erosion (*Glomus* Type 207) Regular occurrence of indicators for shallow open water (spores of *Spirogyra, Mougeotia*, Type 128, Type 151) High values of indicators for local dry conditions (fungal cells Type 200 and Type 201) Microscopic charcoal particles are present in high absolute concentration; occurrence of *Neurospora* Type 55C — indicator for fires

island is dated 900–1000 AD. The excavators (Todorova, 1985) attribute this settlement to the Proto-Bulgarians.

4. Methods and materials

4.1. Coring

The core Durankulak-3, which was taken in the summer of 1999, is 3.40 m long. It originates in a water depth of 80 cm from the narrowest area between the lake shore and Great Island about 40 m from the shore (Fig. 1).

The coring location is surrounded by the western lake shore and Great Island. Both areas are connected with anthropogenic activities (see Archaeological settings and Fig. 1). The distance between them is about 70 m, and hence the results of pollen analysis of this core probably reflect the local vegetation change in the closest zone of human activity around the Great Island of Lake Durankulak.

The core was taken with a piston corer (Wright, 1980). The advantage of this device is that it allows complete and continuous control over the coring process. The depth of the core can be easily determined and controlled (Aaby and Digerfeldt, 1985).

4.2. Stratigraphy and dating

The stratigraphic data are given in Table 2. From the lower part of the core five plant macrofossil samples were taken for AMS-dating (Table 3).

The dates were determined by the Leibnitz Laboratory of Age Determination and Isotope Studies, University Kiel (KIA 12339 to KIA 12343). The data cover the time span between ca. 4191 and ca. 3904 yr BP and correspond to the Bronze Age, according the ^{14}C data for the Bulgarian prehistory (Görsdorf and Bojadzhiev, 1997).

4.3. Pollen analysis

The core was kept refrigerated in the palynological laboratory of the Institute of Paleontology, University Bonn. Samples of 1 cm^3 for pollen analysis were taken at every 2.5 cm. For the palynological study the samples at 5 cm were processed by standard method (Faegri and Iversen, 1989). For calculation of the pollen concentration *Lycopodium*-spores were added during treatment of the samples by 10% HCl. The clay contamination was removed by ultrasonic sieving (5 μm). By this procedure some pollen grains (*Juniperus*) could be lost.

Up to 1000 pollen grains of terrestrial plants were counted. Only in the lowest interval (240 to 215 cm) about 700–800 pollen grains were counted because of the low pollen concentration and poor preservation, and in the lowest part (240–340 cm) the preservation was so bad that no pollen was recorded. The pollen sum consists of terrestrial arboreal (AP, trees and shrubs) and non arboreal pollen (NAP, herbs) of terrestrial pollen (trees, shrubs, herbs) and excludes aquatic and marsh plants, which are irrelevant for the reconstruction of human impact on the vegetation. They belong to the local vegetation

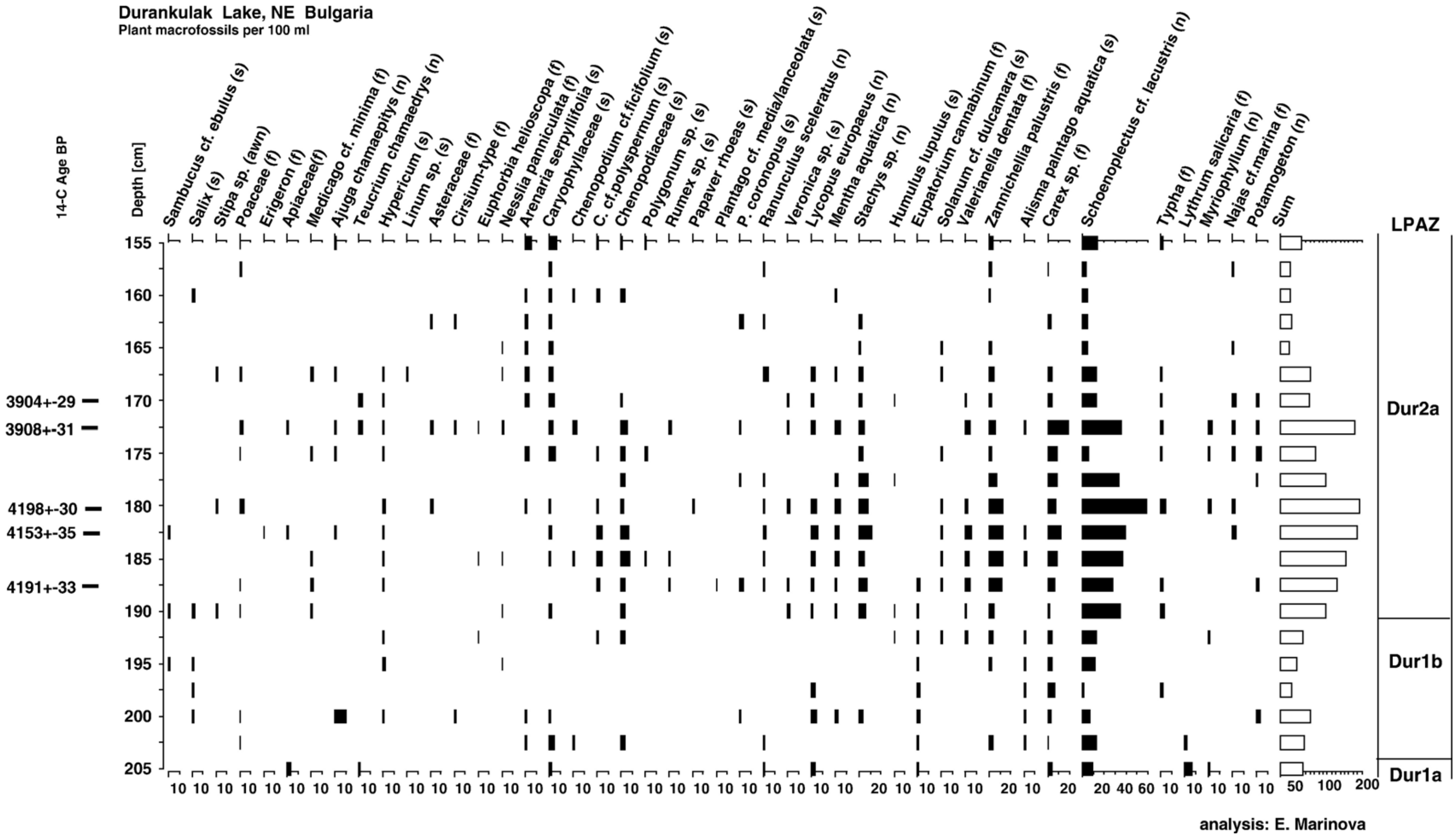

Fig. 3. Plant macrofossils diagram of the core Durankulak-3, Northeast Bulgaria; s — seed, f — fruit, n — nutlet.

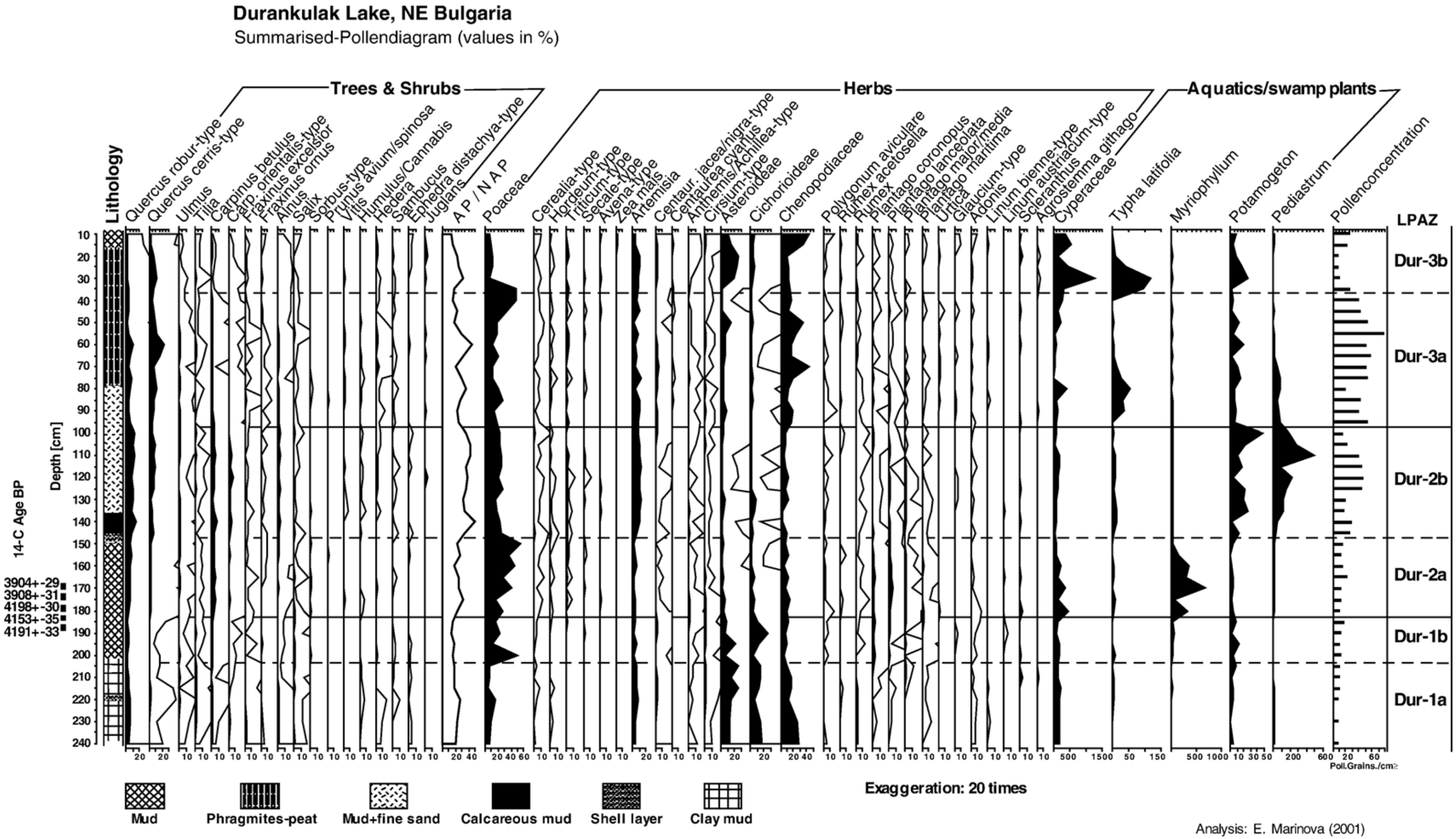

Fig. 4. Simplified percentage pollen diagram of the core Durankulak-3, Northeast Bulgaria (the local elements in absolute values).

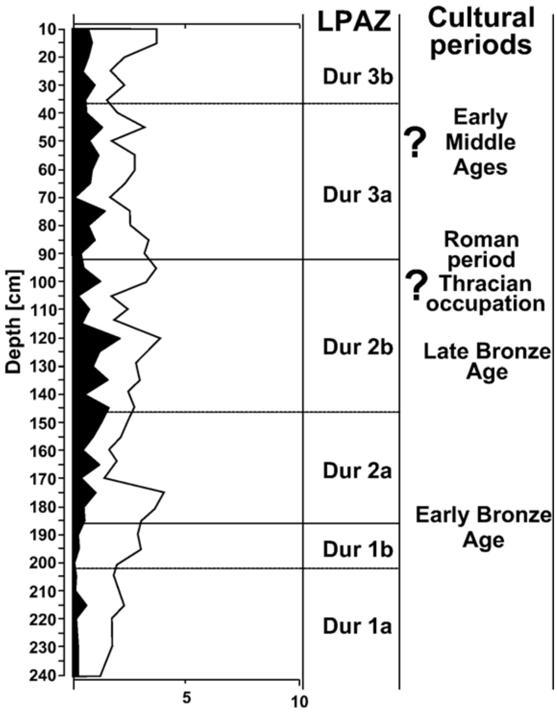

Fig. 5. Anthropogenic indicators (cumulative) found in the core Durankulak-3 (primary indicators in black, secondary indicators — white).

of the lake, are over represented, and would distort the intended picture of the surrounding vegetation.

The clearest palynological signal for anthropogenic impact is given by the introduced domesticated cereals (Cerealia-type, *Triticum*-type, and *Hordeum*-type; as primary indicators, Behre, 1990) and the increased abundance of weeds and ruderals growing on open disturbed ground (secondary indicators, Behre, 1990). In Bulgaria the latter include *Artemisia*, *Plantago lanceolata*, *Centaurea cyanus*, *C. jacea, Cirsium*, *Polygonum aviculare*, *Rumex*, *Urtica*, and Cichorioideae (Bozilova et al., 1996). Especially indicative for pastoralism is the increase of taxa such as *Juniperus*, *Scleranthus*, *Plantago lanceolata*, *Rumex*, *Cirsium*, *Centaurea*, and *Urtica* (Bozilova and Beug, 1994; Panovska et al., 1995). In the area of Durankulak the situation is more complicated because of the steppe influence (*Artemisia*, Asteroideae, Cichorioideae, *Cirsium*/*Carduus*-type, Apiaceae, and Chenopodiaceae) and psammophytic and halophytic taxa (Chenopodiaceae, *Elymus elongatus*, *Artemisia*, Brassicaceae). Thus it is possible that these pollen types increase in the pollen record by enlargement of the corresponding habitats without any anthropogenic influence. In this connection it should be mentioned that only in the uppermost zone (Dur 3a) of the pollen diagrams *Artemisia* and Cichorioideae increase parallel to the decrease of the AP-values during the occupation phases. Some of the wild grasses that are abundant in the area, like *Glyceria*, *Elymus*, *Agropyron*, and wild barleys, have pollen that is almost identical with *Hordeum*-type (Beug, 2004). There are many *Plantago* species in the area (*Plantago lanceolata*, *P. coronopus*, *P. maritima*, *P. major*), and poor pollen preservation in the lowest part of the core hampered precise identification. Therefore the estimation of the anthropogenic influence was made only with a reduced number of definite indicators (primary: *Triticum*-type, *Avena*-type, *Secale*-type, *Zea mays*, *Juglans*; secondary: *Agrostemma githago*-type, *Centaurea cyanus*, *Rumex acetosella*, *Polygonum aviculare*, *Scleranthus annuus*, *Chelidonium*, Dipsacaceae). Other potential anthropogenic indicators were included with caution.

4.4. Microscopic charcoal particles

Microscopic charcoal particles were counted on the pollen slides without additional preparation (Clark, 1982). Microscopic charcoal was identified as black, opaque, angular fragments over 10 μm in length. Results are expressed as concentration per cm^3 of sediment (using *Lycopodium* tablets — Stockmarr, 1971) (Fig. 2). Many authors recommend the size–class method (Waddington, 1969), which involves measuring the area of each charcoal particle, but Tinner and Hu (2003) point out that it is unnecessary to measure charcoal areas in standard pollen slides. In the present study the latter suggestion was followed.

4.5. Non-pollen palynomorphs

The NPP were counted in the samples prepared for routine pollen analysis. The "types" identified follow van Geel (2001) and van Geel et al. (2003). The same type numbers described by van Geel (1978, 1986, 2001) and van Geel et al. (1989, 1994, 1995) were used in the present work. As mentioned by van Geel (2001), among the NPP several types still have no taxonomic identification, but a large amount of information about their indicator value and stratigraphic distribution has been published, and they can also be used for palaeoecological reconstruction.

4.6. Plant macrofossils

Plant macrofossils were studied at 2.5 cm intervals in the lower part of the core (155 to 205 cm). After soaking for 5–10 min in 10% KOH the samples were processed with sieve meshes of 1 and 0.16 mm. The volumes of the samples ranged from 50 cm^3 to 80 cm^3, and the results were extrapolated to a sample volume of 100 cm^3. The

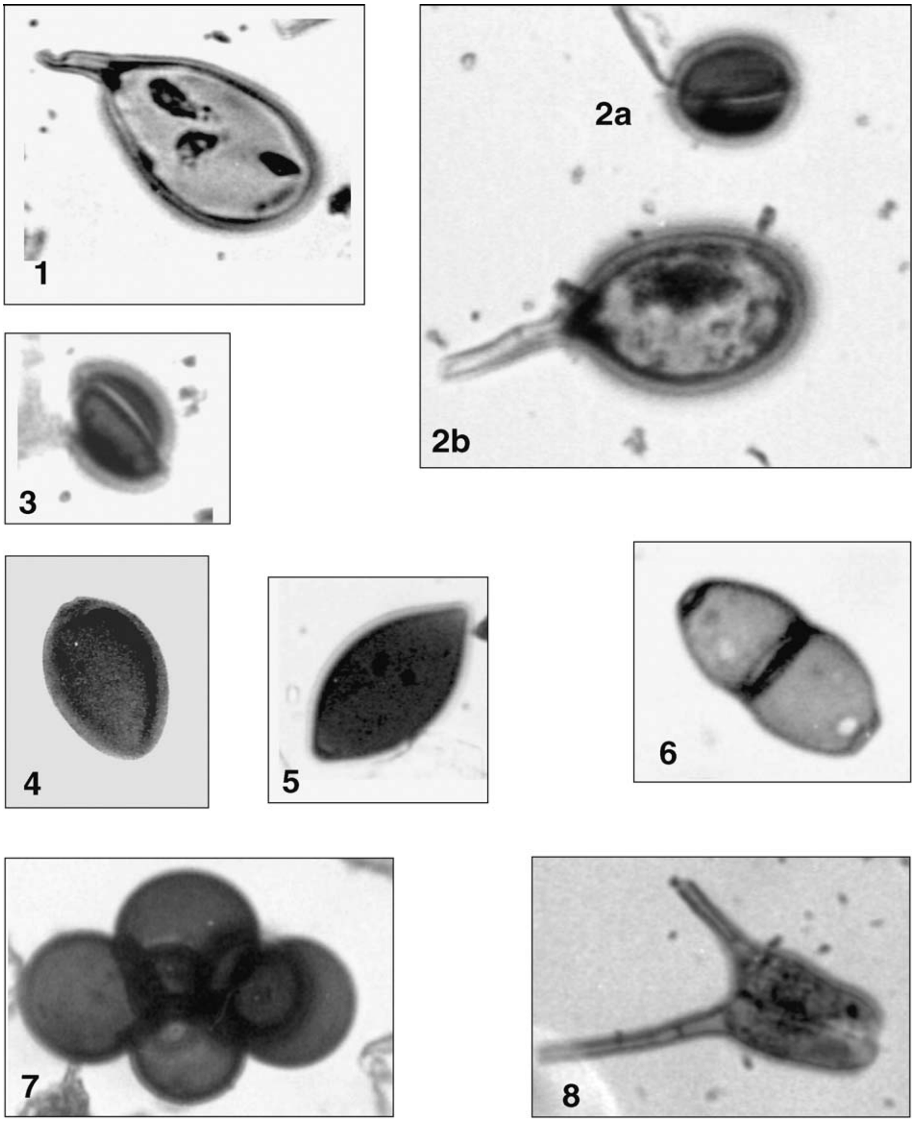

Fig. 6. Common non-pollen palynomorphs in the pollen core Durankulak-3. 1 and 2b: *Glomus* Type 207; 2a and 3: *Coniochaeta* Type 172; 4: *Sordaria* Type 55A; 5: *Sordaria* Type 55B; 6: Ascospores Type 546; 7: Fungal cells Type 200; 8: *Tetraploa aristata* Type 89.

plant macrofossils were identified at up to 40× magnification on a binocular microscope with reference books (Beijerinck, 1976; Katz et al., 1976) and reference collections of the Herbarium of the Sofia University and the Institute for Palaeontology, University of Bonn.

For calculations and drawing of the diagrams the programmes TILIA and TILIA GRAPH were used (Grimm, 1992a,b).

5. Results

The results of the study of charcoal particles and NPP are summarised in Table 4 and are shown in Fig. 2, presented as concentrations in cm^3 sediment. Two clear maxima of microscopic charcoal particles are apparent. The first could be dated to the first stages of the Bronze Age or the so called Proto-Bronze Age (Vajsov, 2002) (Table 2).

The plant macrofossils (Fig. 3) found in the pollen core show the wide ecological range of the habitats near the lake. A differentiation of local macrofossil assemblage zones was considered unnecessary for such a short part of the core. The macrofossil diagram (Fig. 3) corresponds to the LPAZ Dur 1b and LPAZ Dur 2a. In the lowest part of the core the concentration of plant macrofossils is relatively low, and it increases between 190 and 180 cm depth. The increase is connected mostly with the increasing number of fruits of *Zannichellia*, *Carex*, and *Schoenoplectus*. The other taxa almost do not change their concentration.

To facilitate the comparison of the palynological results with the analysis of microscopic wood charcoal, the NPP and plant macrofossils, the pollen diagram of the core Durankulak-3 (Fig. 4), and a cumulative diagram of the anthropogenic indicators (Fig. 5) are given. The most common NPP are shown in Fig. 6. On the right of the NPP- and macrofossil diagrams the corresponding LPAZ of the pollen diagram are plotted.

6. Discussion

Considering the ^{14}C data (Table 3) from the core Durankulak-3, the palaeoecological record starts probably with the transitional period between the Chalcolithic and the Bronze Age. This period was connected with decreasing occupation and invasions of steppe nomads (Todorova, 2002). The lake level apparently rose after the Chalcolithic, because the Chalcolithic burials lay partly under the modern water surface. The preserved pigments of *Spondilus*-shells found in these burials indicate that these graves were under the water until the modern period (Todorova, 2002), for such pigments can be conserved only in the anoxic conditions that water logging offers.

The first LPAZ **Dur 1** (240–183 cm) is dominated by herbaceous vegetation, mainly steppe elements like: Poaceae, *Artemisia*, Asteroideae, Cichorioideae, and Chenopodiaceae, as well as *Ephedra* (Fig. 4). According to the archaeozoological data on wild animals from the Late Neolithic and Chalcolithic burials of Durankulak the prevailing habitats were more or less open steppe (Spassov and Iliev, 2002). Considering the intense Chalcolithic occupation, which lasted more than 700 years (Bojadzhiev, 1992) during the Hamangia- and Varna-cultures, it could be guessed that the predominance of the steppe recorded in the core Durankulak-3 was not only connected with drier conditions in the Late Atlantic/Early Subboreal (Bozilova and Filipova, 1986) but was also enhanced by anthropogenic influence in the area. A study of sediments of Lake Schabla-Ezeretz, about 20 km south of Durankulak (Filipova, 1985), shows similar results during the Chalcolithic and the transition to the Bronze Age, when also a decrease of the forest vegetation was recorded. Information on the broader regional context shows that steppe vegetation and drier conditions predominated around 4000 BP in the areas close to the northern Black Sea, such as the Romanian plain (Tomescu, 2000) and the South Russian plain (Kremenetski et al., 1999). Studies of marine sediments from the northwestern part of the Black Sea (Shopov et al., 1992; Atanassova, 1995) show similar tendencies. During the period that corresponds to the end of the Chalcolithic and transition to the Bronze Age an increase of herbaceous vegetation with dominating *Artemisia* and Chenopodiaceae and some anthropogenic indicators (like Cerealia-type, *Triticum*-type, *Rumex*, *Plantago lanceolata*, *Polygonum aviculare*) were recorded.

In the first section of the LPAZ (**Dur 1a** 240–203 cm) (Fig. 4) all tree taxa are present with low proportions (AP < 20%). Considering the peaks of the curves of *Ulmus*, *Tilia*, *Fraxinus*, *Alnus*, *Humulus*, and *Hedera* in this zone, most likely the arboreal pollen originated from trees growing along the rivers flowing into the lake. In this part of the NPP-diagram (Fig. 2) occurs *Bactrodesmium* (Type 502, van Geel et al., 1986), which grows on *Fraxinus*, *Ulmus*, *Alnus*, and *Quercus* wood. The river forests near Lake Durankulak are represented in the macrofossil record by *Humulus lupulus*, *Sambucus* cf. *ebulus*, and *Solanum* cf. *dulcamara*. The last mentioned species grows also in the shrub area near the shores. From such areas *Salix* sp. (registered as pollen and macrofossils) could originate. At 220–215 cm a slight increase of the anthropogenic indicators (Cerealia-type, *Hordeum*-type, *Plantago lanceolata*, and *Rumex*) in the pollen diagram is recorded. This correlates well with one of the maxima of microscopic charcoal and a peak of the fire indicator *Neurospora* (Type 55C, van Geel, 1978). In the same LPAZ Dur 1, at depths between 225 and 195 cm, is a clearly visible peak of the erosion indicator *Glomus* (Type 207, van Geel et al., 1989), which is parallel to those of the microscopic charcoal and *Neurospora*, confirming also the anthropogenic disturbance in the area between the shore and the island. This could be interpreted as the result of human activities in the area. For the end of the Chalcolithic burned occupation horizons are also recorded (Todorova, personal communication).

In the second section of the zone (**Dur 1b**, 203–183 cm) (Fig. 4) the steppe vegetation is still dominant in the pollen diagram and in the plant-macrofossil record (Fig. 3) (*Stipa* sp., *Erigeron* sp., *Nesslia panniculata*). In this zone of increasing anthropogenic influence all curves of arboreal pollen decrease. Here starts also a rapid increase of the secondary anthropogenic indicators (Fig. 5) (*Plantago lanceolata* up to 4%, Fig. 4). In this section also seeds of *Plantago lanceolata*/*media* were found (Fig. 3). *Eupatorium cannabinum* in the macrofossil record is a species that spreads intensely after a destruction of riverine forests. Most likely because of the open landscapes in this period these forests were the main source for obtaining timber. Riverine forests could be also used because of many kinds for their valuable plant resources and also for transformation into pasture. The indicators of pasture appear in the pollen record as well as in the NPP and macrofossil record (Figs. 2 and 3). In the interval from 220 to 185 cm are maxima of many of the NPP indicators for dung, such as ascospores of *Chaetomium* (Type 7A), *Cercophora* (Type 112), *Coniochaeta* (Type 172), *Podospora*-type (Type 368), and *Sordaria*-type (Type 55A and 55B) (van Geel, 1978; van Geel et al., 1981, 2003). The macrofossils of *Medicago* cf. *minima* and *Euphorbia helioscopa* can be considered as indicators for pasture activities. Our results indicate intensive stock-breading and grazing in the area. High values of microscopic charcoal are characteristic for this sub-zone, and macro size charcoal particles are also found. Forest clearance in this area is not a plausible explanation, as the landscape was already open. Most probably some settlement activities caused the accumulation of the charcoal recorded.

Two ^{14}C dates are available (Table 3) that correspond to the Early Bronze Age, a period when some settlement activity was recorded on Great Island, and also burials and tumuli (Fig. 1) were found on the lake shore (Todorova, 2002). For building the tumuli also timber was needed. The archaeological data indicate that the human occupation in the area for this period was connected with North-Pontic nomadic tribes of the Protojamnaja and Jamnaja cultures (Todorova, 2002). It is difficult to say anything about the agricultural practices and stock-breeding of this culture, for so far only burials but no settlements are known. Artefacts from the graves have a ritual meaning and cannot be used as a reliable source of information for the Early Bronze Age economy in the area.

The zone LPAZ **Dur 2** (183–97 cm) (Fig. 4) is characterised by an increase of arboreal pollen, mainly connected with *Quercus robur*-type, *Q. cerris*-type, *Carpinus betulus*, and *C. orientalis*-type. In the whole zone the anthropogenic indicators are well represented.

The first subzone **Dur 2a** (183–147 cm) (Fig. 4) is still dominated by Poaceae and Chenopodiaceae, but the forests in the area started to increase.

Local elements like *Myriophyllum* and Cyperaceae increase during this period, probably connected with a lowering of the water level. The macrofossils of water plants (*Schoenoplectus lacustris*, *Myriophyllum spicatum*, *Zannichellia palustris*, and *Najas marina* Fig. 3) found in section Dur 1a–Dur 2a indicate more or less shallow water rich in nutrients, as well as a muddy substrate in the area from where the core was taken. *Ranunculus sceleratus*, which is typical for eutrophic conditions, occurred in the whole part of the core studied for plant macrofossils (Fig. 3). The NPP indicators of eutrophic conditions and shallow waters (*Spirogyra* spores, Type 132, Type 151, and Type 179, van der Wiel, 1983; van Geel et al., 1983, 1989) have also several maxima in this part of the core (Fig. 2). The alga *Mougeotia* (Type 313), which also indicates relatively high summer temperatures (van Geel et al., 1981) appears there. This corresponds to the modern conditions of the narrow area between Great Island and the lake shore from where the core originated. The drier climatic conditions during the transition from Atlantic to Subboreal could be a reason for considerable fluctuations in the water level, especially during the warmer summer months. But also sediment accumulation and expansion of shore plants could cause such changes. The peaks of fungal cells Type 200 and fungal spores Type 201 (van Geel et al., 1989; Kuhry, 1997), which proliferate on drying sediment and dead plant remains, also indicate exposure and low water depth during the growing season. In the macrofossil samples also some shore plants are recorded: *Alisma plantago-aquatica*, *Lythrum salicaria* and *Carex* sp. Some of these grow in the moist areas close to the lake, e.g. *Eupatorium cannabinum*, *Lycopus europaeus*, *Mentha aquatica*, and *Lythrum salicaria*. Some of the recorded plant macrofossils (*Hypericum* sp., *Ajuga chamaepitys*, *Teucrium* cf. *chamaedrys*) point to dry to semi-dry habitats, which could also be anthropogenically influenced. At 172.5 cm depth also *Papaver rhoeas* was identified. Today this plant belongs to the weed flora of the region (Kolev, 1963).

The sub-zone **Dur 2b** (147–93 cm) (Fig. 4) has the highest AP-pollen values in the whole profile (up to 60%). This is probably due to the expansion of forests and river-forests in the region. The peaks of the pollen of *Vitis*, *Prunus avium*/*spinosa*-type, and *Sorbus*-type might be connected with more humid conditions during this period, but human activity is a more likely explanation. In this context it is of interest that from the Late Bronze Age settlement numerous finds of *Prunus* cf. *avium* were established (Popova as cited in Bozilova and Tonkov, 1998). In the middle of this zone (at about 120 cm depth) a clear maximum of anthropogenic indicators parallels a *Pediastrum*-peak. *Pediastrum* species are usually ecologically classified as indicators of oligo- to mesosaprobic waters, but they have wide ecological tolerance (Komarek and Jankovska, 2001). There is a minor peak of microscopic charcoal, and dung indicators appear again. At this time *Juglans*-pollen appears for the first time (Fig. 4). An increase of the secondary anthropogenic indicators, like *Polygonum aviculare*, *Rumex*, and *Chelidonium* also occurs. This is probably connected with the LBA-Settlement (13–12th cent. BC) and the Hellenistic sanctuary (Todorova, 1985), located on the southern slope of the island.

The first presence of dinoflagellate cysts (*Lingulodinium* and *Spiniferites* sp.) is established at about 140 cm (subzone Dur 2b) (Fig. 2), followed by an increase of the acritarch *Micrhystridium* (Type 115). The regular presence of dinoflagellate cysts in subzones Dur 2b and Dur 3a indicate marine influence. Previous archaeological and palaeoecological considerations (Orachev, 1990; Todorova, 2002) suggest that the connection with the Black Sea was closed around 3000 BC. The first appearance of the acritarch *Micrhystridium* (Type 115) (Fig. 2) is rather earlier — around 220–222.5 cm depth (subzone Dur 1a). It is regularly present also in subzones Dur 1b and Dur 2a, together with such species as *Najas marina*, *Zannichellia palustris*, and *Myriophyllum*, probably *M. spicatum* (Fig. 3), which are tolerant of mild salinity, but dinoflagellate cysts are not established there. These facts show possible brackish conditions (subzone Dur 1a to Dur 2a) followed by increasing salinity caused by influence of marine water (subzone Dur 2b).

The third zone, **Dur 3** (93–10 cm) (Fig. 4), is characterised by a decrease in AP. Only *Q. cerris*-type remains as high as 20%. This probably reflects "islands" of oak forest, which were periodically reduced by man and replaced by steppe vegetation. In this zone new anthropogenic indicators appear that were not found previously in the pollen profiles. They correspond to the new, more-intense methods of land use and agriculture. The riverine forests decrease strongly, and the other forest types in the area are changed and degraded. Xerothermic species like *Q. cerris*, *Q. pubescens*, and partly *Carpinus orientalis* and Sub-Mediterranean shrubs with *Paliurus spina-cristi* start to prevail. The landscape became more and more similar to that of today. From this zone onward cereal crop weeds like *Agrostemma githago* and *Centaurea cyanus* occur in the pollen record. They are most probably connected with the rye cultivation during the Middle Ages. *Urtica* and *Chelidonium* reach their highest values here, indicating a progressive ruderalising of the habitats in the surroundings. The diagram of microscopic charcoal and NPP (Fig. 2) shows a well pronounced peak of charcoal particles and indicators for erosion and dung around 75–60 cm. They correlate very well with a peak of the anthropogenic indicators in the pollen diagram. The pollen find of *Zea mays* in the two uppermost samples points to the modern period, when this crop was introduced.

7. Conclusions

The study of sediments of the Lake Durankulak has given new information on the prehistoric human occupation of the region. The core of lake sediments in the proximity to archaeological sites has permitted the reconstruction of the environmental change and anthropogenic influence on the vegetation near Lake Durankulak. This reconstruction is based on four sources of palaeoecological information: analysis of pollen, microscopic charcoal, non-pollen palynomorphs, and plant macrofossils. In most cases a good correspondence between all four was observed, and the results complement each other. AMS-data obtained on plant macrofossils provided chronological control for the lower part of the core.

The reconstruction covers the period from the Early Bronze Age to modern time. The occupation in the area was almost continuous, and human activities in the area changed the landscape.

The study showed three periods of maximum human impact: 1. Early Bronze Age; 2. Late Bronze Age to Iron Age (including the occupation by the Thracians); 3. Early Middle Ages (Proto-Bulgarian occupation). The techniques used made it possible to extend the results of previous studies of this most interesting site.

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