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Natural and anthropogenic rapid changes in the Kara-Bogaz Gol over the last two centuries reconstructed from palynological analyses and a comparison to instrumental records

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Abstract

Palynological analyses (pollen and dinocysts) of a sediment core taken in the Kara-Bogaz Gol have been used to reconstruct rapid and catastrophic environmental changes over the last two centuries (chronology based on ^{210}Pb). A natural cyclicity (65 years) of water level changes in the Caspian Sea and in the Kara-Bogaz Gol and anthropogenic factors (building of a dam separating the CS and the KBG waters) combine to induce rapid changes in water levels of the KBG, in the salinity of its waters and in vegetation cover of its surroundings. The impact of low water levels on the dinocysts is marked by a lower diversity and the survival of two species that are typical of the KBG, the Caspian Sea species present in the KBG having disappeared. During periods of higher water levels (AD 1871 to 1878), the lake is surrounded by a steppe-like vegetation dominated by *Artemisia*; whereas during periods of low water levels (AD 1878 to 1913 and AD 1955-1998), the emerged shore are colonised by Chenopodiaceae. The period of AD 1913 to 1955 corresponding to decreasing water levels has an extremely low pollen concentration and a maximum of reworking of arboreal taxa. During the last low-level period, humans responded by abandoning the shores of the bay. What happened to the KBG can be used as an example of what may happen in the future for the Aral Sea.

A problem of reworking of Tertiary dinocysts into modern deposits has been detected owing to the knowledge of the modern dinoflagellate assemblages recently made available through a water survey. A comparison to modern surface pollen samples from Central Asia (Anzali, Caspian Sea south and central basins, Aral Sea, Lake Balkhash, Lake Issyk-Kul and the Chinese Tien-Shan range) allows us to establish the potential reworking of at least five arboreal pollen taxa possibly by run-off and dust storms.

Key words

Kara-Bogaz Gol, pollen, dinoflagellates, lake sediment, reworking, water level change

Introduction

The level of the Caspian Sea has fluctuated greatly in the last century with a drop of 3.25 m from AD 1900 to 1977 and a rise of > 2 m from AD 1977 to 1994 (Rodionov, 1994). The causes until now are still poorly understood but seem to have a cyclicity (Kroonenberg *et al*., 2000; Giralt *et al*., 2003). The Kara-Bogaz-Gol (KBG or sometimes referred to as the bay – zaliv, in Russian literature), literally the black throat lake, is connected by a narrow strait (proliv) to the east of the Caspian Sea (CS or the sea) (Fig. 1a). Its water level closely follows that of the CS; but, due to high evaporation rates, its level remains lower. In addition, the level of the KBG has artificially been changed by a dam built in 1980, which led to an unintentional catastrophic drying out. The KBG has therefore undergone several rapid level changes over the last two hundred years owing to both human and natural causes (see Frolov, 1999 and Giralt et al. 2003 for further details).

It is a challenge to reconstruct climatic changes as well as vegetation changes in semi-desertic and desertic areas owing to the usual lack of suitable sedimentary archives (continuous and anoxic). It is believed that the sedimentary infill of the last water body in the KBG is about 30 m thick, covering the last 10,000 years (Lepeshevkov et al., 1981). Hardly any palynological work is known from its infill, possibly none in non-Russian language. In addition the environmental variability of the desertic and semi-desertic region around the CS still remains extremely poorly known. Holocene palynological analyses from the region around the KBG in the desertic and semi-desertic environments are very scarce. One Holocene pollen diagram by Z. Aleshinskaya in the central basin of the Aral Sea (Tarasov et al., 1996) is available in the Global Pollen database. This study is the only one east of the CS and west of the high-altitudinal lake of Issyk-Kul (Giralt et al., 2002 and 2004), i. e. in a c. 2000 km W-E transect. A short report on a sediment core taken near the shore of the KBG in the late 1990s provides an idea of the hydrological changes during the Holocene reconstructed from the lithology, stable isotopes of C and O and geochemistry amongst others (Ferronskii et al., 2003). During a first phase dated from 9.2 to 8.5 ka, the KBG receives water from Rivers Karyn-Zaryk and Kaidak in the north; but the KBG did not outflow to the CS. During a second phase (8.5 to 2.2 ka), an intense river runoff into the KBG and a discharge in the central basin of the CS have been determined. From 2.2 ka to the present, the CS flows into the KBG.

In 1999, eight sediment cores (1 m long) were taken from the water surface in the N-W of the KBG (Giralt et al., 2003). Analysis of one the cores for its content in organic-walled palynomorphs (pollen, spores, dinoflagellate cysts and other microfossils) giving a history over the last two centuries (i. e. further back in time than the available instrumental record) is the central part of this paper. This investigation aims at providing information on changes of vegetation types, dinoflagellate cyst (or dinocyst) assemblages and in the physico-chemical conditions of the surface water mass. Instrumental data on water levels and precipitation have been compiled and compared to proxy data. Modern sample data (mosses, flood mud and core tops) from central Asia have been added in order to understand better the origin of pollen spectra of the KBG record, especially the arboreal pollen. They are from the west to the east: Lake Anzali, the south and central basins of the CS, the Aral Sea, Lake Balkhash, Lake Issyk-Kul and the Chinese Tien-Shan range. In order to understand the fossil record of dinocysts, a comparison has been made to dinoflagellate thecae obtained by recent algological surveys. Reworking of the sediment suggested by its Tertiary microfossil content is supported by new investigations on modern dinoflagellates.

General setting and instrumental data

The KBG is immediately surrounded by lowlands and low plateaux (Babaev, 1994). East of the KBG, the Ustyurt plateau ends with 300 to 320 m high cliffs (chink) that exhibit sediment outcrops of mainly Tertiary age (Babaev, 1994). The southern part of the Mangyshlak Plateau borders the KBG from the North as a cliff with outcropping of Tertiary sediments as well (Babaev, 1994). Its average altitude is 100-130 m. In the S-W, the plateau altitude lowers and it becomes a sand bank that separates the northern part of the KBG from the CS. The isolated low mountains of the Great and the Minor Balkhans (up to 1883 m) just c. 110 km south of the KBG are the most important relief nearby. The nearest mountain range, the Kopetdag (maximal altitude 2872 m), is c. 300 km S-E of the KBG.

The KBG is surrounded by sediment of marine origin for the oldest, and of marine or aeolian origin for the most recent (carte géologique internationale, 1988). The sediment age in the northern half of its perimeter is Miocene and Oligocene. In the north-east, the sediment becomes older: Oligocene, Eocene and Palaeocene. In the south-east, the sediment is then of upper Cretaceous age. In the south and west, there are Pleistocene and Holocene marine as well as some Holocene aeolian sediments. Isolated occurrences of Miocene are seen in the south-west. Deep drilling suggests that most of the bottom of the KBG is underlain by Oligocene sediment; in the east, the sediment becomes progressively older, to Palaeocene age (Geological map of the USSR, 1994).

The KBG is an overflow lake of the CS, east of its central basin. It lies between 50˚ 40’ and 52˚ 30’ E and 40˚ 35’ and 41˚ 50’ N at -28.4 m below global sea level (in 1995). It is linked to the CS by a narrow straight (110-300 m wide, 10-12 km long) where there is a strong inward flow and a water fall, since the surface of the bay can be up to 3 m below that of the CS. Two exceptions occurred at the beginning of the 20th century when strong winds caused the flow to change direction i. e. from the bay to the CS (Dzens-Litovsky and Charyyev, 1973). In general, the highest level in the CS, the strongest the flow is to the KBG. The evaporation at its surface is very high, about 16-20 km^3 of water per year (Buynevich *et al*., 1992), whereas the inflow of CS water is only of 22.2 km^3.yr in the 1940s (Karayeva, 1972). The KBG is fairly shallow with maximal depths not exceeding 10 m when full. A long instrumental record indicates that it has undergone considerable fluctuations over the last 160 years (Fig. 2). Recently the depth of the KBG has not exceeded 8.0 m. In brief, the KBG levels are the following: high until AD 1933, then there is a steep drop from AD 1933 to 1941, followed by a slower drop until AD 1980 (Fig. 2). Thereafter the level of the KBG has been artificially modified by a dam. An unintentional drying out of the water body took place as soon as AD 1983. At that moment the water levels reached the lowest point ever recorded (Fig. 2). Unfortunately, the long-planned closure of the channel started at a period of CS water level rise. Some opposed groups to the construction of the dam argued of a natural cyclicity of the CS levels already been observed since the Middle-Ages (Rich, 1992). In 1983, pipes were built through the dam to allow some water flow. In autumn 1992 the dam was destroyed; at this time the difference in water level between the sea and the bay was 7 m (Fig. 2). Streams of water rushed through the channel and washed away part of the coastal line of the strait, almost causing the doubling of the channel width (Frolov, 1999). Huge seawater volumes, up to 52.2 $km^3.yr^{-1}$, began flowing into the bay. Before the cutting off of the bay, the inflow of seawater was only < 5-10 $km^3.yr^{-1}$, i. e. 5-10 times less. During 1992-1995, its level had suddenly risen by 5 m. The dynamic of the filling of the bay after restoration of the flow is illustrated in figure 4. The CS levels have started to drop again in 1995. By 1998-1999 the flow to the bay was stabilized in the range of 18.0-18.5 $km^3.yr^{-1}$. It is probable that such volume of inflowing seawater in the bay is sufficient to provide a balance between inflowing seawater and evaporation with the surface of the bay (Frolov, 1999).

The water quality of the KBG primarily depends on the presence or absence of contact with the CS and on evaporation. The KBG is the largest sodium sulphate body of water of the world and has a predominance of Cl^+, Na^+ and Mg^+ with a high density (>1.2 $g.cm^{-3}$). The inflow of seawater determines the salinity of the bay. According to data for the period 1992-1999 (D. Lavrov, pers. comm.), volumes of flowing seawater in the bay in 1992 reached 11.3 $km^3.yr$. As a result of the expansion of the channel of the strait in 1994-1995, volumes of flowing seawater were of 40.8-52.2 $km^3.yr$ (Fig. 3), resulting in the dilution of the brine. The salinity has consequently lowered to 20 - 25. Further, there was the formation of a new brine caused by evaporation of the seawater from the surface and its interaction with salt sediments at the bottom of the bay, formed during the drying of the bay. By the end 1993, the salinity of the water already reached 50-60, and in August 1996, 200-210. Consequently, the KBG salinity is currently 10 to 20 times higher than that of the standard salinity of 12-13 of the CS (Kosarev and Yablonskaya, 1994). The salinity of waters in the bay is varied, from 40 till 100 (in the zone of water mixing), from 170 till 250 (the northwest and southwest part of the bay), and in shallow sites > 272, resulting in the precipitation of salts from the oversaturated solution. The very high salinity of the KBG has created conditions for the development of unique biotopes.

The temperature of the KBG water is variable depending on the season of the year, the depth and the total area of the bay. Intra-annual changes of temperature of the water for the whole bay are in the range of –3.5 to +33.0 ºC. In comparison with the CS whose salinity is much lower, cooling and heating of the KBG water occur on longer periods. In the winter even at temperatures of 0 - -3.5 ˚C, the water does not freeze nor does the bay become covered by ice. The lowest average-monthly temperature is observed at the end of December and the beginning of January. Water temperature reaches 25 ˚C in July.

The climate of Turkmenistan is an extreme continental type, or type Bwk of Köppen (Babaev, 1994; Orlovsky, 1994). The prevailing winds in northern Turkmenistan are from the N-E. Within Turkmenistan, the area around the KBG is considered as dry and mild with less temperature extremes owing to the influence of the CS and receiving winds from all directions. It is characterized by a small amount of precipitation (annual precipitation up to 95 mm). The data from Turkmenbashi (Krasnovodsk) station cover the period 1882-1990 (World Climate, 1999) (Fig. 2). Data for the period 1976-1997 were also obtained from Bulatov and Lavrov (unpublished) in the area of the KBG canal in Bekdash town. A 5 yr moving average reveals four periods of lower rainfall: 1881- 1892, 1899-1901, 1910-1917 and 1924-1950 separated by 3 periods of higher precipitation (Fig. 2). Around 1980, 1988 and 1992-94 slightly higher precipitations have been observed too. The average annual temperature is 12-15 ˚C with high summer temperature (from +26 up to +43 ˚C), and short cold winters (0 to -3 ˚C). Turkmenistan is part of the wind system of Central Asia (Orlovsky et al., 2005): cold unstable air from the NW and in the N in winter from the Siberian High and in the summer hot stable air from local thermal depressions. The direction of the wind however changes not only between years and according to the season of the year, but also within a day. It is necessary to note that windstorms in the bay occur year round owing to its geographic location (Karayeva, 1972). In the area of the KBG, prevailing wind directions are northern-easterly to south-easterly in autumn-winter and north-westerly and south-westerly in spring-summer. The wind speed in the bay according to our data (measurements of 1998-2002) amounts to 2.0 – 8.0 $m.s^{-1}$. The Karakum desert and the western regions of Turkmenistan are some of the most active sources of dust storms in Asia (Orlovsky et al., 2005). Dust storms occur under northern, north-eastern and south-eastern winds. When the KBG desiccated in 1980-1983, the dust storms turned into salt storms (Gill, 1996). In summary, the climate of the KBG area is highly continental, dry, with long hot summers and short, sometimes very cold, winters. Within a day the given parameters can change dramatically. In the Kopetdag, temperatures are lower on average but there is more rain: 300 mm. The dominant winds along the foothill plain of the Kopetdag are easterly. In the Atrek-Sumbar region (S-W of Turkmenistan), the climate is mild and subtropical.

The KBG area is surrounded by desert with *Salsola* and *Artemisia* species dominating its sparse vegetation (Rustamov, 1994). When the KBG was dry between 1980 and 1983, the emerged lakeshores, basically a sulfate-rich playa, were partly colonised by halophytes especially by *Halocnemum strobilaceum* (Chenopodiaceae) (Rustamov, 1994; Glushko, 1996; Gill, 1996). Some freshwater lakes are present in the NW border of the Karakum desert owing to water flow from the Ustyurt escarpment and the Great Balkhan Mountain. This allows the local growth of *Populus*, *Tamarix* and Cyperaceae (West, 1983). Winter and spring precipitation favours plant development (Orlovsky et al., 2005) with, in general, the best period for vegetation growth in March to May. The desert is replaced by a vegetation of East Mediterranean character in the Balkhan low mountains range (Great and Minor) and the Kopetdag. In favourable positions, shrubs and trees grow (such as ephedras, junipers and maples). In the SW of the Kopetdag, altitudinal belts have even been recognised (Fet, 1994; Popov, 1994). Some of the main associations are:

- Mediterranean short-tree woodland with *Ephedra, Acer, Vitis* and in the south of Turkmenistan with *Pistacia,*
- *Juniperus* woodland,
- Deciduous forest: *Ulmus, Juglans, Fraxinus,*
- Relic forest of *Platanus,*
- Desert riparian forest: *Populus, Salix, Elaeagnus, Tamarix.*

These ecological areas are much more extensive and diverse on the Iranian part of the Kopetdag (Djamali, 2004).

Alnus, Betula, *Corylus*, *Fagus*, *Quercus*, *Pinus, Pterocarya*, *Fagus* and *Taxus* are not mentioned in the flora of Turkmenistan (Fet and Atamuradov, 1994). The nearest localities for *A. subcordata*, *Q. castaneifolia* and *macranthera*, *T. baccata* are in the Iranian side of the Kopetdag (Browicz, 1982; Djamali, 2004) and for *Pinus* further away, in the Caucasus (Krüssman, 1995), as it is also absent from Northern Iran. In the east, it seems that *Pinus* is only present in the southern Pamir and Himalayas, but not in the Tien-Shan range. *Pinus, Pterocarya, Fagus*, *Betula* and *Corylus* are also absent from the Iranian side of the Kopetdag (Djamali, 2004).

Methods

The algological sampling of 22 stations (8 stations near the western coast and 14 in the NW quadrant of the lake) surveyed between 1998 and 2002 and sample treatment were performed according to standard algological methods (Clark, 1956; Wetzel and Ulano, 1990; Anonymous, 1989). Temperature and salinity at the sampling sites were recorded. The calculation of the amount of organisms was made with the use of a Palmer-Maloney Counting cell (17.9 mm in diameter, 0.4 mm depth), under a research microscope PZO (Poland) at magnifications 140-280x. The determination of the biomass was carried out by the method of Keller *et al.* (1980), calculating volumes of algal cell and equating them to forms of various geometrical figures. The determination of dinoflagellate species was performed using specialized literature (Kiselev, 1950; Proshkina-Lavrenko and Makarova, 1968).

Modern pollen spectra were obtained from twenty-three Central Asian samples from sediment core tops, flood mud or from moss pollsters (Table 1) extending from the SW coast of Iran (Lake Anzali, 590 km from the KBG) eastwards until the Chinese Tien-Shan range (2600 km), via the Aral Sea (700 km), Lake Balkhash (1750 km), Lake Issyk-Kul (2000 km) (Fig. 1a). Details on the treatment can be found in Kazancı et al. (2004) for Anzali; in Marret et al. (2004) for the CS and the Aral Sea; and finally in Giralt et al. (2004) for Lake Issyk-Kul. For the three Chinese Tien Shan range mosses: NaOH and sieving at 250 and 10 µm; and for the mud and the silt samples, heavy density liquid, were used as described in Dricot and Leroy (1989). For the Lake Balkhash, the treatment was the same as that for the Aral samples. The diagram is presented by histogram bars. The sequence of the samples is based on their increasing content of arboreal pollen (AP). The percentages of terrestrial taxa are calculated on a sum excluding the aquatics and the spores. Concentration, when available, is given in number of pollen and spores per ml of wet sediment.

Both sediment cores have been taken in the NW corner of the KBG, in the area that has been emerged during the period of low water levels after 1940 and recently covered by water again (Fig. 1b). The sediment was obtained in November 1999 using a piston corer (diameter of 6 cm) from a raft. The location of core KBG-08-01 is 53˚ 15’ E and 41˚ 51’ N. The core is 98 cm long and was taken under 80 cm of water. Core KBG-02-01 is located at 53º 05' E - 41º 40' N and it is 95 cm long. It was taken under approx. 2 m of water.

Cores KBG08-01 and KBG02-01 were longitudinally split and a detailed lithological description highlighting the main sedimentological features was carried out (Fig. 3). The mineralogical composition of core KBG-02-01 was determined every 1.5 cm by x-ray diffractions and the quantification of the different mineralogical species followed the standard procedure (see Giralt *et al*., 2003 for further details). The chronology is based on measurements of ^{210}Pb with the CIC model on core KBG 08-01, the same core as that of the palynological samples (Fig.3). The method has been given in Giralt *et al*. (2003).

Seventeen 3 - 4 ml of sediment (1 cm thick, or c. averaging of 2 years) were subsampled from core KBG 08-01 for palynological analysis *sensu lato*. The palynological extraction took place at Brunel University and at Queen’s University of Belfast for checking differences between methods and laboratories. The treatment consisted of a succession of $Na_4P_2O_7$, HCl, HF (several times), HCl washes and 250 and 10 µm sieving, with no acetolysis. Slides were made by mounting some of the residue in a glycerol medium. The concentration was calculated using the initial addition of *Lycopodium* tablets. The microfossils were counted with a light microscope at a magnification of 400x routinely and at 1000x for special identification. The preservation is highly variable and ranges from well-preserved pollen grains with visible cell content (including taxa absent from the British Isles) to obviously reworked pollen grains (loss of ornamentation, thickening and darkening of the exine). Most of the dinoflagellate cysts are extremely well preserved. The diagrams were plotted using the software psimpoll 4.10 (Bennett, 2003). The percentage pollen diagram is made on the sum of all terrestrial pollen grains (the ”sum” curve in the diagram). The sum is between 315 and 442 grains, except between 42.5 (AD 1922) and 17.5 cm (AD 1975) where it is lower (102-171 grains). Two samples (46.5 and 17.5 cm) were not included as their pollen sum was ≤ 53. The statistical analysis was done using psimpoll 4.10 (Bennett, 2003): zonation by CONISS after square-root transformation. The dinoflagellate cyst diagram (all 17 samples) is presented in percentages. The concentration diagram in number of pollen grains or dinocysts per ml of wet sediment shows only selected pollen curves and total concentrations of pollen and dinoflagellate cysts. The concentration value of the sample at 26.5 cm (AD 1956), for both pollen and microfossils, being out of the range of the other samples, has been divided by 10 in all diagrams and statistical analyses.

Reconstruction of dated changes in water levels

The sediments of both cores are mainly composed by centimetric to decimetric alternation of dark greyish silty-clay and light sandy layers, with some intercalations of whitish layers of salt and several levels rich in *Cerastoderma* sp. shells (Fig. 3). The uppermost 11 cm of core KBG-02-01 is sandy, mainly made up of homometric fine quartz grains. This sandy level was not observed in core KBG-08-01 and could be attributed to the coring location within the bay, i. e. core KBG-02-01 is closer to the shore than core KBG-08-01. A detailed description of the main microlithofacies can be found in Giralt et al. (2003).

The KBG sediments consist of sulphates (gypsum and glauberite), carbonates (calcite, aragonite, high-magnesian calcite and hydromagnesite) and terrigenous minerals (quartz, illite, chlorite and feldspars). The sediments are also composed of hydrated magnesium (epsomite) and sodium (mirabilite) sulphates. Owing to their high solubility these minerals were not quantified. Four mineralogical zones can be defined in core KBG-02-01 according to the cluster analyses on the mineralogical composition of the core (see Giralt et al., 2003, for further details). Zones 1 (from the top of the core to 33.5 cm of core depth) and 3 (from 54.5 cm to 69.5 cm of core depth) are mainly composed by gypsum; whereas zones 2 (from 33.5 cm to 54.5 cm) and 4 (from 69.5 cm to the bottom of the core) are mainly dominated by terrigenous minerals.

Core KBG-08-01 (used for pollen and dinocyst analyses) covers slightly less than two centuries from AD 1812 to 1998 (Table 2) (Giralt et al., 2003). The mean sedimentation rate is of 4.6 mm.yr^{-1}. Core KBG-02-01 (mineralogy and water level reconstruction) has not been dated, but has been correlated to core KBG-08-01 on the basis of common lithological features (Fig. 3). Two caveats have nevertheless to be kept in mind: the sedimentation rate can be very different according to the type of sediment within a core and according to the position of the core in the area emerged during low water levels (Fig. 4).

Reconstructed water level changes have been derived from the mineralogical composition of the sediment using a statistical approach (Fig. 3). This has allowed an extrapolation in the past: from AD 1900 (when the first water level measurements were taken) to 1812 (at the base of the core). The comparison between the reconstructed and the instrumental water level oscillations is high ($r^2 = 0.83$). The reconstruction shows a highly oscillating record with long and short trends in terms of high and low water level periods (Fig. 3). The reconstruction records 13 water level minima and 15 water level maxima. This reconstruction also records long-term oscillations. From AD 1812 to 1819 the KBG record indicates a high water level phase. This phase was followed by a period (AD 1820-1839) when the water level was generally low. Between AD 1840 and 1863 the water levels were high again, and between AD 1864 and 1896 the water levels were low, although there was a short high stand of 5 years (AD 1886-1890). From AD 1897 up to 1942 the lacustrine system records an important high stand and from AD 1943 up to the present day (1998) the reconstructed water level has been low. Broadly speaking, the high water level periods are lithologically represented by the decimetric to millimetric alternation of fine gypsarenites and muddy layers (core KBG-02-01) or by massive silty clays (core KBG-08-01), depending of the location of the cores (variable microtopography), whereas the low water periods are always represented by siliciclastic terrigenous levels (both cores). Wavelet analyses performed on the reconstructed water level record have pointed out the presence of two clear periodicities of 62.5 and 23.46 years.

The dinoflagellate thecae and cysts

Dinoflagellates are algae belonging to the Pyrrhophyta, a stem that has a complex lifecycle. Phytoplankton surveys mostly record them under their thecate form. About 20 % of the known species produce an organic-walled cyst that preserves well in sediments under anoxic conditions (Head, 1996). For the KBG, often the link theca-cyst is not well known (Table 3) owing to the difficulty of observation of complete life cycles. In the present state of knowledge, no cysts were found in the sediment for any of the thecae species (Table 3). The list of Dinophyceae taxa (Table 3) also provides the distribution in the KBG and in the CS.

KBG dinoflagellate thecae

Some of the results of a new detailed algological study on species assemblages, ecology and temporal changes are presented here.

At present, in the KBG, about 80 species and intra-species of algae have been listed (Bulatov, 2004). Dinoflagellates are represented only by seven taxa. The species variety of the dinoflagellates in the KBG after 1992 is stable and is almost monotonous across the whole bay. An exception should be made for the area of mixing of waters of the KBG and of the CS, since waters of low salinity (40 – 120, favourable to the existence of low salinity forms) flow into the bay. Most of the taxa are affiliated to marine forms, usually neritic phytoplankton of the CS. The occurrence of neritic species in the KGB is related to the shallowness of the bay. All the dinoflagellates identified from the plankton fraction from the KBG belong to Desmophyceae, except for two taxa, which are Peridinophyceae. In the first group, *Prorocentrum* is represented by five forms. Among representatives of this genus, the presence of four species has been observed (*P. cordatum, P. lima, P. scutellum and P. proximum*) accompanied with *Exuviaella caspica*. In the bay, the most widely distributed and the most productive are *P. cordatum* and *P. lima*; the others have a more limited distribution. Representatives of the coastal plankton from the class Peridinophyceae are two

Peridiniales genera: *Peridinium* and *Gonyaulax*. Each genus is limited to one taxon: *Peridinium* sp. and *Gonyaulax digitale*. The seasonal dynamics of the phytoplankton in the KBG has been the most fully studied in the period from summer 2000 until spring 2001. The study of seasonal dynamics in the bay indicated that the hydrological regime and abiotic factors (salinity and temperature) are the basic factors regulating the development of the phytoplankton. Most of the dinoflagellates are euryhaline and eurythermic. Their development falls in the summer and winter periods of the year. Their ranges of salinity and temperature are presented in table 4. The most frequent are *Prorocentrum cordatum* and *Peridinium* sp. The density and the biomass of dinoflagellates in the bay during 2000-2001 were variable depending on the season of the year, temperature, salinity, volume of CS inflow to the KBG and also concentration of nutrients. High values of biomass and density were noted in the summer at salinities of 60.0 – 264.0 and temperature up to 35 ˚C, mainly owing to the development of *P. cordatum* and *Peridinium* sp., and in the winter at salinities of 62.0 – 250.0 and temperature –2.5 - +8.0 ˚C, with *G. digitale, P. cordatum* and *P. lima*. The summer biomass is on average from 60.034 up to 203.417 mg.m^{-3} at density of 4,000 – 26,000 cells.l^{-1}; in the winter, it is 95.059 – 214.466 mg.m^{-3} and 6,500 – 17,600 cells.l^{-1} (Bulatov, 2004). The main role in the formation of the biomass is played by *P. cordatum* (biomass – 300,64 mg.m^{-3}). As the results show, dinoflagellates have a wide ecological and morphological variability that can be seen in changes of their form and an increase of the sizes of the thecae of *P. cordatum*. So *P. cordatum* thecae size in the bay increases up to 19.8-28.0 µm; whereas, at CS salinity, their size only is 16.0-20.0 µm (Proshkina-Lavrenko and Makarova, 1968). An interesting point is the discovery of *E. caspica* in the bay, which for the first time was described from hypersaline bays of the CS, in the Mertviy Kutluk and Kaidak bays (Kiselev, 1940). In the 1940s, after their drying out, and as a result of lowering of the level of the CS, *E. caspica* was considered to have died out and considered as a synonym to *P. lima*. In the bay, our data however confirm the presence of both *P. lima* and *E. caspica* thecae clearly separated by morphological differences. The high salinity of bay waters, in all probability, did not have a strong influence on the structure and the physiological condition of the Caspian forms of dinoflagellates, as can be seen by their migration to areas with a high degree of salinity (44-250). It confirms the results of the research of the morphological structure. The coastal waters of the bay are characterized by a high fluctuating salinity and temperature (Bulatov, new data). The presence of dinoflagellates in the brine of the bay once again allows confirming the assumption that marine forms of algae rapidly react to an increase in salinity (Anonymous, 1949). It is known that the chemical composition of brines of hypersaline reservoirs has an essential influence on the biodiversity of organisms. After 1992, the chemical composition of brines of the bay has profoundly changed. Chloride ions, that have a strong influence on the distribution of dinoflagellates in reservoirs (Kiselev, 1950), began to dominate. In the KBG, it is probable that the concentration of chlorides does not have a negative influence on the development of the dinoflagellates.

KBG dinoflagellate cysts

The taxonomy of new dinoflagellate cysts recovered from modern sediments from the CS and other central Asian lakes has recently been established (Marret et al., 2004). One new genus, *Caspidinium,* represented by *Caspidinium rugosum* and one new species, *Impagidinium caspienensis,* together with *Lingulodinium machaerophorum*, *Spiniferites belerius*, *Spiniferites cruciformis* (with a distinct variability in morphology), *Pyxidinopsis psilata*, *Pentapharsodinium dalei* and *Brigantedinium* sp. occurring in the CS have been observed in sediments from the KGB. Within these taxa, *L. machaerophorum* shows a strong variability in morphology, from the form with long bulbous processes to specimens with short and acuminate processes. We differentiate here three morphological types of *L. machaerophorum*, with *L. machaerophorum sensu stricto* (Deflandre et Cookson 1955) Wall 1967, *L. machaerophorum* var. A. and *L. machaerophorum* var. B.

1) *L. machaerophorum sensu stricto* is characterised by a spherical body with a microgranulate wall surface and long, large, flexible, hollow and distally closed processes (average 11.4 µm in length) with a large conical striated base. The tip of the processes is acuminate and bears granules. The archeopyle is formed by the loss of precingular paraplates (3P to 5P).

2) *L. machaerophorum* var. A has a spherical body, which diameter averages 50 µm, a strong granulate wall surface and has numerous, shorter (average 9 µm in length) and slender acuminate processes with a small striated conical base. When observed, the archeopyle consists of the loss of three precingular paraplates.

3) *L. machaerophorum* var. B has a spherical body (average 60 µm), a microgranulate wall surface and bears short (2-3 µm in length) bulbous and microgranulate processes with a large striated conical base.

A comparison of the list of cysts found in several cores from the south and the central basins of the CS, the Anzali Lake, the Aral Sea and the KBG show a common assemblage (Table 5). The KBG and the Aral Sea samples differ from the other sites by the typical presence of *L. machaerophorum* var. A and *S. belerius*. These 2 taxa are much more abundant in the KBG than in the Aral Sea; and, in comparison to the CS, they can be considered as typical local species.

Other dinocysts

The section “other” dinocysts contains reworked Tertiary cysts and rare indeterminable cysts. On the whole the preservation of all cysts is excellent, including some delicate ornamental features. The identification of the Tertiary forms of dinocysts has been confirmed by L. Londeix (pers. comm., Oct. 2004). *Deflandrea, Weltzelellia* (frequent), *Membranosphaeridium*, *Thalassiphora* and *Chiropteridium* amongst others. They are of Oligocene age.

Central Asian surface pollen sample

A brief description of the diagram is given based on four groups of samples (Fig. 5). 1) The five samples from Lake Anzali are very clearly dominated by high AP values, amongst which *Alnus* largely dominates and uniquely characterises them. 2) The four highest altitude samples in the Tien-Shan range and Lake Issyk-Kul can also easily be distinguished from all other samples by the abundance of *Picea*. 3) *Pinus* is only present in the remaining twelve samples, i. e. all the marine cores in the Caspian Sea, the Aral Sea and Lake Balkhash (at the exception of the “Tien-Shan 1300 m” sample). *Pinus* pollen grains have very low values (≤ 4 %) indicating long-distance transport. *Corylus, Quercus* and *Calligonum* have often a slightly better representation in these last samples. 4) The bottom three samples have less distinctive tree pollen values. They have however very high A-C values of > 50 %.

Tarasov et al. (1998) and Peterson (1983) provide additional surface samples from the area between the KBG and the Aral Sea and from the western Caucasus. They suggest that the arboreal pollen they found in Turkmenistan (*Alnus*, *Carpinus betulus* and *Ulmus*) is either from local depressions or wind transported from the Caucasus. Tarasov (pers. comm. 2005) suggests that the main pollen transport mechanism is strong westerly winds in spring and early summer when the easterly jet moves from their Mediterranean position to their middle-north European summer position. *Pinus* is present in the surface samples of eastern Georgia with values reaching frequently 20 % (Connor et al., 2004), Georgia being the nearest region to the KBG where *Pinus* trees grow.

Description and interpretation of the dinoflagellate sequence of the KBG sediments

Description

According to cluster analysis, the concentration diagram (Fig. 6) is best divided in two zones (cz). Below AD 1878.5 (cz 1), the concentration is very low. A percentage diagram (Fig. 7) can only be reliably constructed for the upper zone (cz 2). It is divided in 3 dinoflagellate zones (dz) with limits at 1964 and 1993. The samples show a low dispersion with a large dominance of *L. machaerophorum var. A* and *S. belerius*, both species typical of the KBG (Table 5). Other dinoflagellates cysts from the CS are present also, especially *L. machaerophorum* var. B and s. s..

Origin of the dinocysts

The source of the dinoflagellate cysts is complex.

1) Living in the CS: The CS dinocysts are well known from a series of Holocene core tops in the south and central basin (Marret *et al.*, 2004) and from Lake Anzali in Iran (Kazancı *et al.*, 2004). They are caught in the flow through the strait and most of them die as soon as they arrive in the hypersaline waters of the KBG. CS dinothecae are found in decreasing concentrations up to 6 to 8.5 km from the straight into the KBG. Some of them however have wide enough salinity tolerance to adapt to the modern high salinities of the KBG. Belonging to this group are: *L. machaerophorum var. B, L. machaerophorum s. s., P. dalei, I. caspienensis, S. cruciformis, P. psilata, Brigantedinium*.

2) Living in the KBG and not in the CS: Some taxa have been met neither in the CS core tops nor in lake Anzali, but they are present in the Aral Sea and in the KBG, two saline lakes (Table 5). Belonging to this group are: *L. machaerophorum* var. A. and *S. belerius*.

3) Known from the Tertiary at the latest: The Oligocene sediment outcrops around the KBG, including the shores near the coring locations.

Interpretation of the dinoflagellate diagram

The percentage diagram starts from a time with high water levels. The diagram is fairly stable (a long dz 1). It is disturbed however toward the top (dz 2 and dz 3). This is probably linked to the major environmental changes caused by the closure of the KBG and its drying out, as well as the previous decades of natural lowering. For a short while (dz 2 central part), CS taxa are less abundant reflecting directly the decrease and then interruption of the link to the CS. The impact of the dam is clearly recorded by a marked drop of the lake biodiversity. The CS species were not able to survive the extremely high salinities. Reworking of older sediment seems to reach a maximum in the same period (end of dz 2). The last sample at AD1997 (dz 3) contains a high amount of *S. cruciformis*, typical of the Aral Sea, the Caspian Sea and the Black Sea. It has been characterised as a legacy of the Paratethys Ocean (Marret et al., 2004). This is at the time when the KBG is connected again to the CS and when the CS reached its maximal levels (1995-96).

Description and interpretation of the pollen diagram

Description

Based on the statistical zonation, the diagram may be divided in four main pollen zones (pz) (Fig. 8). Some selected curves are also given in concentration (Fig. 6).

Pz 1 from AD 1817 to 1878: The four samples are largely dominated by *Artemisia* that reaches a clear maximum at 66 % and then decreases. Amaranthaceae-Chenopodiaceae (A-C) and Gramineae are the next most important curves. Reworked pollen grains are absent. The Arboreal Pollen (AP) values are in the range of 7–19 %.

Pz 2 from AD 1878 to 1913: The three samples indicate a peak in A-C (maximum at 47 %) whereas *Artemisia* remains around 32 %. Cereal pollen grains are present. Reworked pollen grains are frequent.

Pz 3 from AD 1913 to 1955**:** The three samples of this zone show a distinctive maximum of trees and shrubs pollen at 37 % (*Alnus* and *Quercus*, as well as *Pinus, Taxus, Betula, Carpinus betulus*-t., *Corylus* and *Ulmus-Zelkova*). Gramineae values peak at 9 %. Reworked pollen grains are frequent and form a continuous curve. This zone has a characteristic extremely low concentration: < 1000 grains per ml. The three features make this zone stand out from the three other zones.

Pz 4 from AD 1955 to 1998: The last three samples of the diagram show that A-C and *Artemisia* reach values similar to pz 2. AP % return to low values as earlier in zones 1 and 2. A low number of reworked grains was encountered. The first sample of this zone has a high concentration (10 times the plotted value) of 128,500 grains per ml, unequalled in this core.

Foraminifera linings have been found in the pollen slides and are presented at the right of the diagram (Fig. 8). Foraminifera shells belong to the genera *Ammonia, Cibicides* and *Elphidium* (H. Vonhof, pers. comm., 2004). The foraminifera lining percentages calculated on the pollen sum fluctuate between 0 and 4 %. At AD 1913 and 1975 (with low pollen concentrations, hence not plotted in Fig. 8), two maxima are reached with 11 and 70 %. In the latter sample, the increase is not an artefact as 30 linings have been counted.

Origin of the pollen grains

There seems to be multiple origins for the pollen grains, especially for the arboreal pollen. A thorough discussion is required especially as reworking of Tertiary dinocysts has taken place. Modern pollen spectra are used to help establish the origin of the KBG pollen (Fig. 5 and 1).

1) By wind transport

Because of the absence of local trees, it can reasonably be suggested that a majority of the AP is air-transported, originating from long-distance transport from the Kopetdag, the Alburz and maybe further afield from the Caucasus, the Pamir and the Tien-Shan range. Only pollen grains such as Cupressaceae (*Juniperus*), *Ephedra, Acer, Pistacia, Elaeagnus, Juglans, Platanus, Tamarix, Ulmus, Vitis, Fraxinus*, are possibly derived from the **regional pollen rain**. The pollen of trees from the Balkhans and from the Kopetdag can be easily detected over distances of several hundreds of km, as the local production of other taxa is low (Bottema and Barkoudah, 1979). The Pamir and the Tien-Shan Ranges, according to results from surface samples (Fig. 5), are not a likely source. Wind-transport of *Pinus* from the East and from the West is low as the presence of *Pinus* in very low percentages can be seen in pollen spectra from Aral Sea, Issyk-Kul and Anzali.

2) By water from the CS

Water transport from the CS **through the strait** could account maybe for some coastal vegetation formation represented by *Alnus* pollen grains. A comparison with sediment from the Anzali Lake shows the local over-representation of this pollen. But sediment from the south basin indicates that its importance is not maintained further off-shore (Fig. 5). Moreover two arguments are against significant water transport. Firstly the surveys of phytoplankton indicate that CS sub-littoral forms are mostly found within 8.5 km from the strait. Secondly, water transport has been demonstrated as a very poor way of transporting pollen grains horizontally as the vertical sinking movement is very rapid (10 days to one month) after the pollen grains enter the water from the atmosphere (Hooghiemstra et al., submitted; Neuer et al., 1997).

3) By reworking

A number of palynomorphs must have originated from **Tertiary sediment** that is around and below the KBG. Winds and especially wind storms are a very strong means of transporting both dust and sand (including palynomorphs) as seen also in NW Africa (Calleja et al., 1993). Run-off exists but remains minimal in the area and is limited to flash floods. Samples with the lowest concentrations correspond to a higher content in reworked grains and in AP, such as from AD 1922 to 1954 (pz 3). In the reworked pollen grains (Fig. 8), i. e. the grains that bear the characteristic features of reworking, one can find the clear dominance of Pinaceae. Most of the other reworked grains are taxa that may belong to a Late Quaternary pollen spectrum, such as *Picea*, *Alnus*, *Corylus*, and Tubuliflorae. Direct evidence from older sediment is scarce: one *Sequoia*, one *Carya* and possibly several small *Pinus* (≤ 50 µm) grains.

In summary, the transport of AP to the coring site by CS waters is minimal, if not absent. Air-transport from distant mountains (Kopetdag and Alburz) can explain the presence of some of the arboreal taxa. The surface samples have shown that long-distance aerial transport of pollen from the East and the West exists, but remains very low. Based on vegetation distribution and on pollen surface samples, our analysis leads to consider that ***Pinus, Betula, Corylus, Fagus*** and ***Pterocarya*** **are mainly reworked**. Other AP also have to be considered as reworked from the local Tertiary sediment; but this is impossible to estimate, as this reworking is not noticeable in the grain appearance and these plants may also grow regionally.

Environmental reconstruction

In Turkmenistan, the taxon Amaranthaceae-Chenopodiaceae (A-C) is largely dominated by chenopods, amongst which halophilous herbs, shrubs and short trees occur. *Halocnemum strobilaceum* is one of them. A-C could therefore be used as an indicator of both low rainfall and extensive dry shores. *Artemisia* lives in less saline areas and less extremely desertic conditions than A-C.

The large vegetation groups that are represented in the diagram are the following.

From the local vegetation and further a-field:

- Local halophilous vegetation: A-C, Plumbaginaceae;
- Desert vegetation: *Ephedra*, *Nitraria, Calligonum, Haplophyllum* and some other Chenopodiaceae*;*
- Semi-desert and steppe: *Artemisia* and Gramineae.

From the regional vegetation:

- Deciduous forest and juniper woodland
- Mediterranean short-tree woodland
- Riparian and wetland vegetation: *Salix, Elaeagnus, Tamarix* and *Typha-Sparganium.*

The interpretation pollen zone by pollen zone

A relative maximum of rainfall is suggested for zone 1, from AD 1817 to 1878 with the development of a steppe. Rainfall starts to decrease towards the end of this period. The vegetation indicates high aridity from 1878 to 1913 (Pz 2) and desert vegetation. Pz 3 from 1913-1955: The three spectra (and an additional sample that did not produce enough pollen for significant percentage) are unreliable for local and regional vegetation reconstruction for the following two reasons. Firstly, their pollen content is very low. Secondly, according to the existence of reworking in the dinocysts and the low probability of having such high percentages of AP, the arboreal assemblages seem to be dominated by elements originating from the erosion of Tertiary sediment. In Pz 4 (from 1955 to 1998), the vegetation reflects an arid environment similar to the period 1878 to 1913 (pz 2).

Discussion

Reworking

The establishment of reworking amongst the dinoflagellates and the pollen has been difficult because of the excellent preservation state of both. For the dinoflagellates, this has been facilitated by the presence of forms known until now only in the Tertiary. The absence of any “Tertiary” survival in an extreme environment has been confirmed by the surveys of modern dinoflagellates. For the pollen diagram, the use of surface samples spread over central Asia has allowed the pinpointing of a group of arboreal taxa that are certainly reworked. For most of the other arboreal taxa, uncertainty will always linger. If some taxa are eliminated from the AP % (Pinaceae, *Cedrus*, *Picea, Pinus, P.* haplostellate, *Betula, Corylus, Fagus* and *Pterocarya*) and added to the reworked curve, it is possible to see that: 1) the highest reworking % is in pz 3 (3 out of 4 samples ≥ 12 %); 2) the largest difference between the AP and the recalculated AP % is in pz 3 (≥ 6%); and 3) the recalculated AP % (*Alnus, Quercus* and *Taxus*) remains nevertheless the highest in pz 3 (3 out of 4 samples ≥ 19 %) especially between AD 1922 and 1939, which is a period of still high water levels and relatively high rainfall. The latter could justify some development of these three trees in Turkmenistan, although it is likely that a (large) portion of their pollen is reworked too.

The Tertiary forms are all reworked from the sediment underlying and surrounding the KBG. The mechanism in cause may have been run-off events/river flash floods (very rare), wave erosion of the cliffs (only during very high levels), but more likely during salt/dust bowl events which are a regular occurrence in the region. The latter is enhanced at lower water levels, with wider areas of exposed underlying sediment.

The causes for the extremely low pollen concentration of the four samples of pollen zone 3 (3 with pollen and one quasi sterile in pollen) are not clear. The only peculiarity of this zone is that it corresponds to a clear period of water level decrease.

Dinoflagellate cyst taxonomy, biogeography and ecology

Three forms of *L. machaerophorum* have been distinguished. One of them, L. *machaerophorum* var. A, is typical of the KBG. As observed in recent sediments from the Caspian Sea, dinocyst taxa show a high variability in morphology, for example *Spiniferites cruciformis* (Mudie et al., 2001; Marret et al., 2004). Regarding *L. machaerophorum*, changes in salinity conditions seem to affect the length and shape of the processes, with a trend for short processes in low saline environments (Lewis and Hallett, 1997).

The two dinocyst species typical of the KBG, L. *machaerophorum* var. A and *S. belerius*, are also found in the Aral Sea. Both lakes have a high and fluctuating salinity. From the biogeographical point of view the Amu-Darya (Darya means river) flowed into the CS just north of the Kopetdag through the Balkhan channel as recently as the 16th c. AD (Boomer et al., 2000). Further back in time, both lakes are part of the remnants of the Paratethys Sea (Marret et al., 2004). A comparative analysis of the KBG dinoflagellate survey list with that from the Aral Sea has shown three similar taxa - *P. cordatum, P. lima* and *P. scutellum* (Yel'muradov, 1981). The Caspian Sea and the Aral Sea have more species in common.

According to the standard scale of halobionts of Hustedt, the dinoflagellates of the KBG can be attributed to two ecological groups: mesohalobionts (6 species) and hyperhalobionts (1 species) (Table 4). It is necessary to take into account that most mesohalobionts are common inhabitants of the Caspian Sea but possess wide euryhalobiontic features. Their maximal development is connected with coastal zones of the bay, rich in biogenic elements.

In 1995 – 2000 in the Aral Sea, as a result of increased salinity up to 63.7, a sharp reduction of the taxonomic variety phytoplankton was noted (Mirabdullayev et al., 2001). Data on modern condition of dinoflagellates are generally poor and do specify the presence of *P. cordatum* in the salty Aral Sea, but do not provide information on modern conditions. However research on the survival rate of the Caspian populations of dinoflagellates under the KBG conditions can serve as a model for forecasting the survival rate of at least the three stated taxa in the conditions of increased salinity of the Aral.

The high salinity of the KBG waters is strongly reflected in the sizes and in the form of cells of some of the dinoflagellates from the Caspian Sea. This, apparently, is the reason for the formation of adaptive properties to extreme conditions of environment in highly-mineralised biotopes. Results of the measurements of sutures of *P. cordatum* from the KBG have shown significant deviations from known taxonomy. In the opinion of some researchers (Proshkina-Lavrenko and Makarova, 1968), *P. cordatum* is characterized by variability in the form and the sizes of cells, and also in the shell structure. According to Kiselev (1950), the cell sizes in Aral conditions reached 17.0 – 20.0 µm. In the Caspian Sea, on the contrary, at salinity of 1.2 – 7.0, there were cells in the size 5.0 – 16.5 µm; in increased salinity conditions up to 12.0 their sizes increased up to 16.0 – 20.0 µm. Under the conditions of the high KBG salinity, the sizes of *P. cordatum* cells reach 26.6 – 29.7 µm. Also two other taxa show variability: The sizes of cells *P. scutellum* under the KBG conditions reach up 28.4 – 46.2 µm, and in CS conditions: no more than 27.0 – 42.0 µm; accordingly for *G. digitale* these parameters are 26.0 – 42.0 µm and 27.2 – 36.4 µm. The salinity is clearly the forcing factor. In Karayeva's (1972) opinion, all cases of variability are connected to extreme environmental conditions.

Palaeoenvironments

A simple reconstruction of palaeoenvironments and palaeoclimate by palynology (pollen and dinoflagellate cysts) remains possible despite a series of problems: 1) the chronology is not very robust (no confirmation by ^{137}Cs and no smooth exponential curve of ^{210}Pb), but good enough for an estimation of sedimentation rates which provides reconstructed water levels fairly close to instrumental ones; and 2) an unknown amount of pollen and dinocysts are reworked although an attempt has been made to estimate it.

A period of maximum rainfall and probably water levels from AD 1817 to 1878 followed by a period of minima (AD 1878 to 1913), both corresponding well to reconstructed water levels from mineralogy (Giralt et al., 2003; Fig. 3).

After an unclear period influenced by reworking of sediment and palynomorphs, the environment from AD 1955 to 1998 resembles that from AD 1878 to 1913. Only the top two samples of the pollen diagram of core Aral 86 by Z. Aleshinskaya cover the same time period as core KBG-08-01. The Aral Sea pollen assemblages are very similar to those of the KBG. The AP % rises above 18 % only before 1900 yr ago.

The disturbance caused by the extremely low levels from the time of the dam construction is very well seen in the change of the relative abundances of the dinoflagellate species. The dinoflagellate assemblage shows disruption due to a catastrophic change caused by humans: after the building of the dam, the biodiversity dropped as the less tolerant CS species die out.

Impact on humans and foresight for the Aral Sea

The natural and anthropic rapid changes, highlighted in this investigation by palynology, have had catastrophic local and regional impacts on the small society around the KBG.

Before the 1920s, the area was only sporadically occupied by nomads who collected salt by hand. In the 1930s a progressive shift to large-scale production took place, and the towns of KBG (on the KBG shores) and later Bekdash (on the CS side) developed. As the water level dropped, the quality of the salt shifted from the precious sodium sulfate to sodium chlorure. In 1941 the town of KBG was totally abandoned and in 1999 the sulfate industry was officially dead (Gabell, 1963; USGS, 2001; Westerman, 2004). In 1995, the salinity being once again favourable to *Artemia*, a factory harvesting their cysts (used for dry fish food) open. It was the last industry surviving at the time of coring, but closed soon afterwards owing to a drop of shrimp population due to a salinity increase (in addition to a complex political situation). All the water to this factory and to the remnants of the town of Bekdash had to be brought in from a long distance by truck (E. Naessens, pers. comm. 2003; Westerman, 2004).

In general, the following negative effects have been listed by the Columbia Caspian project (no date) for the last period of low water levels. 1) White salt dust storms: 1000s of tons of salt, 100s of km away; 2) Infrastructure: dust settles on industrial installations, buildings and roads; 3) Agriculture: salt-laden dusts settled on major agricultural and pasture lands in the Caspian lowlands; 4) Water: salinisation of water sources; 5) Microclimate: accelerated desertification; 6) Health: respiratory problems; and 7) Population: ghost towns.

The history of the Kara-Bogaz Gol known from instrumental data complemented by core studies (mineralogical changes, steppe-desert alternation, drop of dinoflagellate diversity and human impact) has now been reconstructed for c. 2 water level cycles. If the cyclicity of 65 years for the Caspian Sea/Kara-Bogaz Gol system is confirmed (the CS levels have already started to decline since AD 1996), one can predict the effects on a few decades. The forecasted further drop of level of the Aral Sea (which has not reached yet the exceptional salinity of the KBG) will lead to similar effect to those of the KBG.

Conclusion

Combining pollen, dinoflagellate assemblages and sedimentology with instrumental and observational data has allowed us to reconstruct past water level and vegetation changes. Despite a potential fossil and sediment reworking by run-off events and dust storms, it is possible to reconstruct several water level changes. During periods of higher water levels (AD 1817 to 1878), the KBG is surrounded by a steppe-like vegetation dominated by *Artemisia*; whereas during periods of low water levels (AD 1878 to 1913 and AD 1955-1998), the emerged land areas are colonised by Chenopodiaceae. The period of AD 1913 to 1955 has an extremely low pollen concentration and a maximum of reworking of arboreal taxa; it corresponds to naturally decreasing water levels and intense evaporation.

These environmental changes are so rapid that they are a catastrophe for the local and regional environment and society. The artificial interruption of the flow of the Caspian Sea to the Kara-Bogaz-Gol has had a negative influence on the diversity of the dinoflagellates. Humans have suffered both directly (emigration, health, water resources) and indirectly (infrastructures, agriculture). Similar changes are predicted in the next decades. The Kara-Bogaz Gol environmental history could be used as a showcase for the future of the Aral Sea.

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Natural and anthropogenic rapid changes in the Kara-Bogaz Gol over the last two centuries by palynological analyses

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Tables

Table 1: Location of surface pollen samples in Central Asia. N/A means not applicable (no dinocysts in this location). Idem means the same as above.

Location	Nº on board Nº MHN	Sample #	Latitude N	Longitude E	Water depth (mbsl)	Corer type	Source: Sediment Pollen Dinocysts
North-central	SR9411 CP23 SR01 GS 9121CP	NcentralCP21	42º50'31"	49º51'17"	460	Pilot	Unpublished Unpublished SL Marret et al., 2004
Central Caspian	SR9409 CP20 SR01 GS 9418CP	centralCP18	41º32'53"	51º06'04"	480	Pilot	idem
Central Caspian	SR9409 GS20 SR01 GS 9418	centralGS18	41º32'53"	51º06'04"	480	Kullenberg	idem
South Caspian	SR9406 US14 SR01 US 9402	southUS02	39º16	51º29'	315	Box core	idem
South Caspian	SR9402 CP04 SR01 GS 9404CP	southCP04	38º43'34"	51º36'36"	405	Pilot	idem
South Caspian	SR9406 CP16 SR01 GS9414 CP	southCP14	39º16'18"	51º27'47"	315	Pilot	idem
South Caspian	SR9402 GS05 SR01 GS9405	southGS05	38º45'39"	51º32'16"	518	Kullenberg	idem
Enseli Lake	Enseli 1,6,8,12,15	Ens1, Ens6, Ens8, Ens12, Ens15	37º26’ 37º35’	49º15’ 49º27’	2.5	PVC tube	Kazanci et al., 2004 Idem idem
Balhkash Lake	BK4-1	BK2.5	46º11'51"	74º04'52"	2.5	Renberg corer	Unpublished Unpublished SL n/a
Balhkash Lake	BK4-1	BK26.5	46º11'51"	74º04'52"	26.5	Renberg corer	idem
N. small Aral Sea	AS17-5	AS0.5	46º31'04"	60º41'55"	0.5	Livingstone	Boomer et al., 2003 Unpublished SL Marret et al., 2004
N. small	AS17-5	AS6.5	46º31'04"	60º41'55"	6.5	Livingstone	idem

Aral Sea							
Issyk-Kul	IK-98-28	IKbc1	42º34.21	77º19.97	1	Box core	Giralt et al., 2004 SL in Giralt et al., 200 n/a
Issyk-Kul	IK-98-28	IKbc3	42º34.21	77º19.97	3	Box core	idem
Tien-Shan	Glacier no1	TSGMu	43º	87º	3800 m alt	Mud on ice	Unpublished SL Idem n/a
Tien-Shan	Glacier no1	TSGMo	43º	87º	3800 m alt	moss	idem
Tien-Shan	Tianshi lake shore	TS2000	43º40’	88º10’	2000 m alt	moss	idem
Tien-Shan	Payango	TS1500	43º45’	87º30’	1500 m alt	moss	idem
Tien-Shan	Gangou	TS1300	43º45’	87º30’	1300 m alt	Flood silt	idem

Table 2: Ages (in yr AD) of the fifteen palynological samples of core KBG99-08-01 by ^{210}Pb. The samples are 1 cm thick.

Depth in cm	**Age**
0.5	1997
17.5	1975
18.5	1973
26.5	1956
27.5	1954
34.5	1939
42.5	1922
46.5	1913
50.5	1904
57.5	1889
58.5	1887
66.5	1870
74.5	1853
82.5	1836
91.5	1817

Table 3: Link between modern thecae and fossil cysts of the Kara-Bogaz Gol dinoflagellates
CS: present in the Caspian; KBG: present in the Kara-Bogaz-Gol

Fossil cyst	Distribution	modern theca	Distribution
Lingulodinium machaerophorum var. B	CS/KBG	*Lingulodinium polyedrum*	
Lingulodinium machaerophorum s.s.	CS/KBG	*Lingulodinium polyedrum*	
Pentapharsodinium dalei	CS/KBG	*Pentapharsodinium dalei*	
Impagidinium caspienensis	CS/KBG	*? Gonyaulax sp.*	
Spiniferites cruciformis	CS/KBG	*? Gonyaulax sp.*	
Caspidinium rugosum	CS/KBG	*? Gonyaulax sp.*	
Pyxidinopsis psilata	CS/KBG	*? Gonyaulax sp*	
Brigantedinium sp.	CS/KBG	*Protoperidinium sp.*	
Lingulodinium machaerophorum. var. A	---/KBG	*Lingulodinium polyedrum*	
Spiniferites belerius	---/KBG	*Gonyaulax* sp	
Spiniferites bentori	---/---	*G. digitale*	CS/KBG
No cyst		*Prorocentrum cordatum*	CS/KBG

No cyst	*P. lima*	CS/KBG
No cyst	*P. scutellum*	CS/KBG
No cyst	*P. proximum*	CS/KBG
?	*Peridinium* sp.	CS/KBG
No cyst	*Exuviella caspica*	extinct?/KBG

Table 4: Range of salinity and temperature of dinoflagellata of the Kara-Bogaz-Gol bay derived from surveys in 2000-2001.

Name of taxon	Salinity	Temperature, ˚C
Exuviaella caspica	84.0	2.0 – 3.0
Prorocentrum cordatum	44.0 – 258.0	2.0 – 28.1
P. lima	70.0 – 244.0	-3.5 – +8.8
P. scutellum	84.0 – 256.0	2.0 – 20.0
P. proximum	240.0	25.0
Peridinium sp.	46.0 – 250.0	-2.5 - +21.0
Gonyaulax digitale	60.0 – 254.0	4.9 – 24.0

Table 5: Distribution of dinoflagellates in some central Asian lakes and seas. Most samples belong to the Holocene. The Last Glacial period might have been reached in cores CP14, GS18 and GS05. The √ symbol indicates presence.

	Caspian Sea							Iran	Aral S.	KBG
	CP04	CP14	CP18	GS18	CP21	US02	GS05	Anzali	AS17	KBG08
number of samples examined	2	28	36	17	37	1	5	5	9	15
Pyxidinopsis psilata	√	√	√	√	√	√	√	o	o	√
Spiniferites cruciformis	√	√	√	√	√	√	√	√	√	√
Caspidinium rugosum rugosum	√	√	o	√	√	o	√	√	√	o
C. rugosum	√	√	√	√	√	√	√	√	√	√
Impagidinium caspienense	√	√	√	√	√	√	√	√	√	√
Pentapharsodinium dalei	√	√	√	√	√	√	√	√	√	√
Lingulodinium machaerophorum var. B	√	√	√	√	√	√	√	√	√	√
L. machaerophorum s. s.	√	√	√	√	√	√	o	√	√	√
Brigantedinium sp.	√	√	√	√	√	√	√	√	√	√
L. machaerophorum var. A	o	o	o	o	o	o	o	o	√	√
S. belerius	o	o	o	o	o	o	o	o	√	√

Figure caption

Fig. 1a: Location map of the pollen surface samples. Abbreviations of names according to table 4. The frame around the KBG relates to figure 1b.

Fig. 1b: Map of the Kara-Bogaz Gol with core location showing the dynamics of the filling of the KBG after the restoration of the outflow of seawater from Caspian sea (adapted from Babaev, 1998).

Fig. 2: Instrumental data
CS level (L): Caspian Sea level from 1900 to 1976 from Lepeshevkov et al. 1981; CS level (V): Caspian Sea level from 1837 to 1996 from Voropayev 1997; KBG level (L): Kara-Bogaz Gol level from 1900 to 1976 from Lepeshevkov et al. 1981; KBG level (B-L): Kara-Bogaz Gol level from 1976 to1992 from Bulatov and Lavrov (unpublished data); KBG level (T): Kara-Bogaz Gol level from 1992 to 1999 from the Ministry of Nature Use and Environmental Protection of Turkmenistan; prec 5 yr average (K): Precipitation from the meteorological station of Turkmenbashi, 1882-1990 (Source: World Climate 1999) on a five year average; prec (B): Precipitation for the period 1976-1997 from Bulatov (unpublished) from Bekdash city. Downward black arrow shows sudden drop of KBG levels in 1980. pz = pollen zone; dz = dinocyst zone; cz = concentration zone.

Fig. 3: Log of the 2 cores with reconstructed levels to the left and ^{210}Pb content to right.

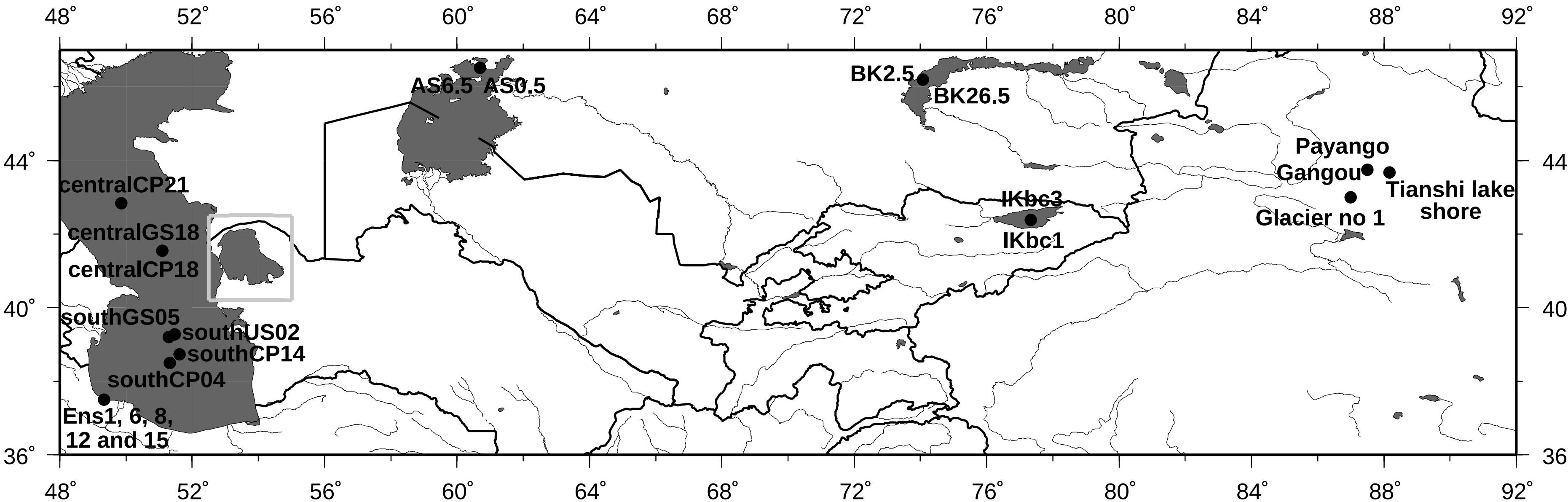
Fig. 4: Water inflow in km^3.yr^{-1} from the Caspian Sea into the Kara-Bogaz-Gol bay from 1977 to 1999 (Bulatov, unpublished).

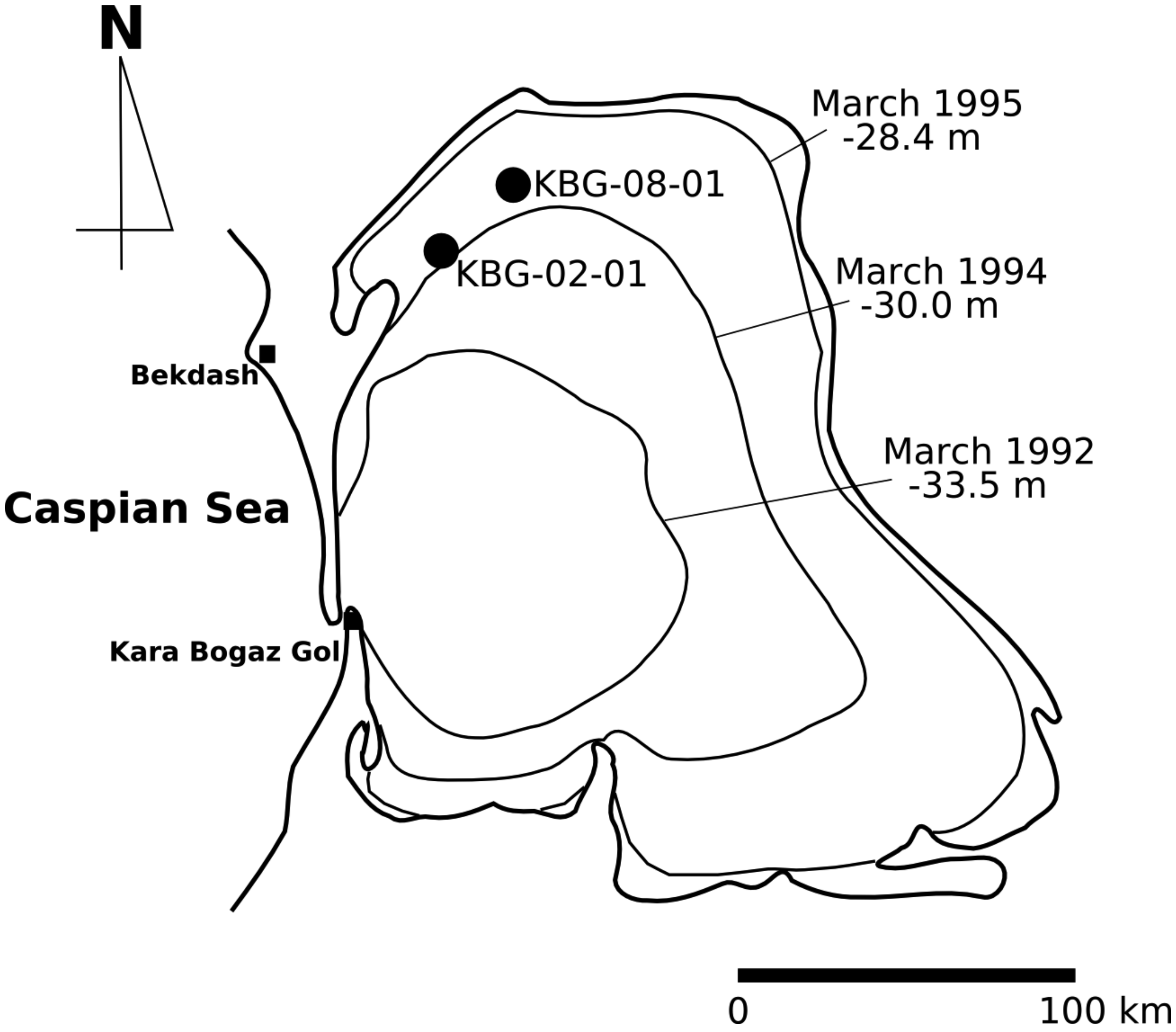
Fig. 5: Pollen from surface sediment from the Caspian Sea to the Tien-Shan. Black dots for values < 0.4 %.

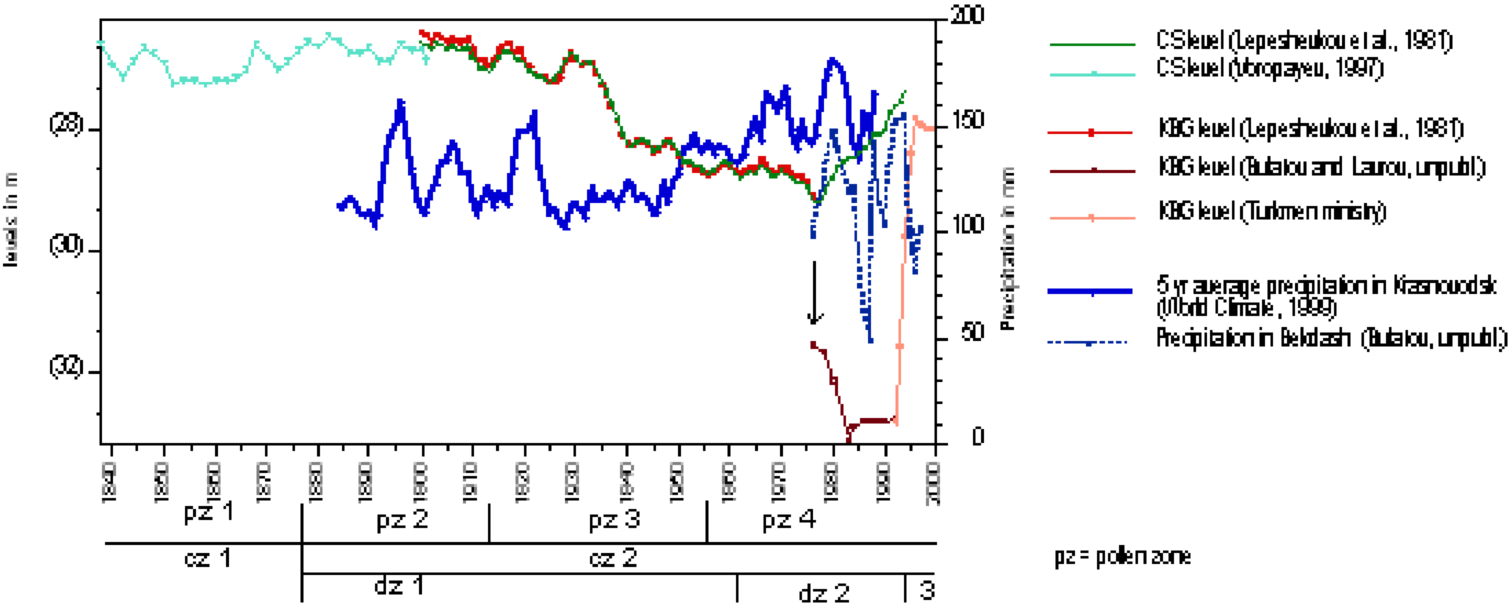
Fig. 6: Concentration diagram from core KBG99-08-01: selected pollen taxa, total dinoflagellates and other dinoflagellates. AP: arboreal pollen. The concentration values of the sample at AD 1956 have been divided by 10. CONISS zonation on 17 taxa, square-root transformation, black dots for < 50.

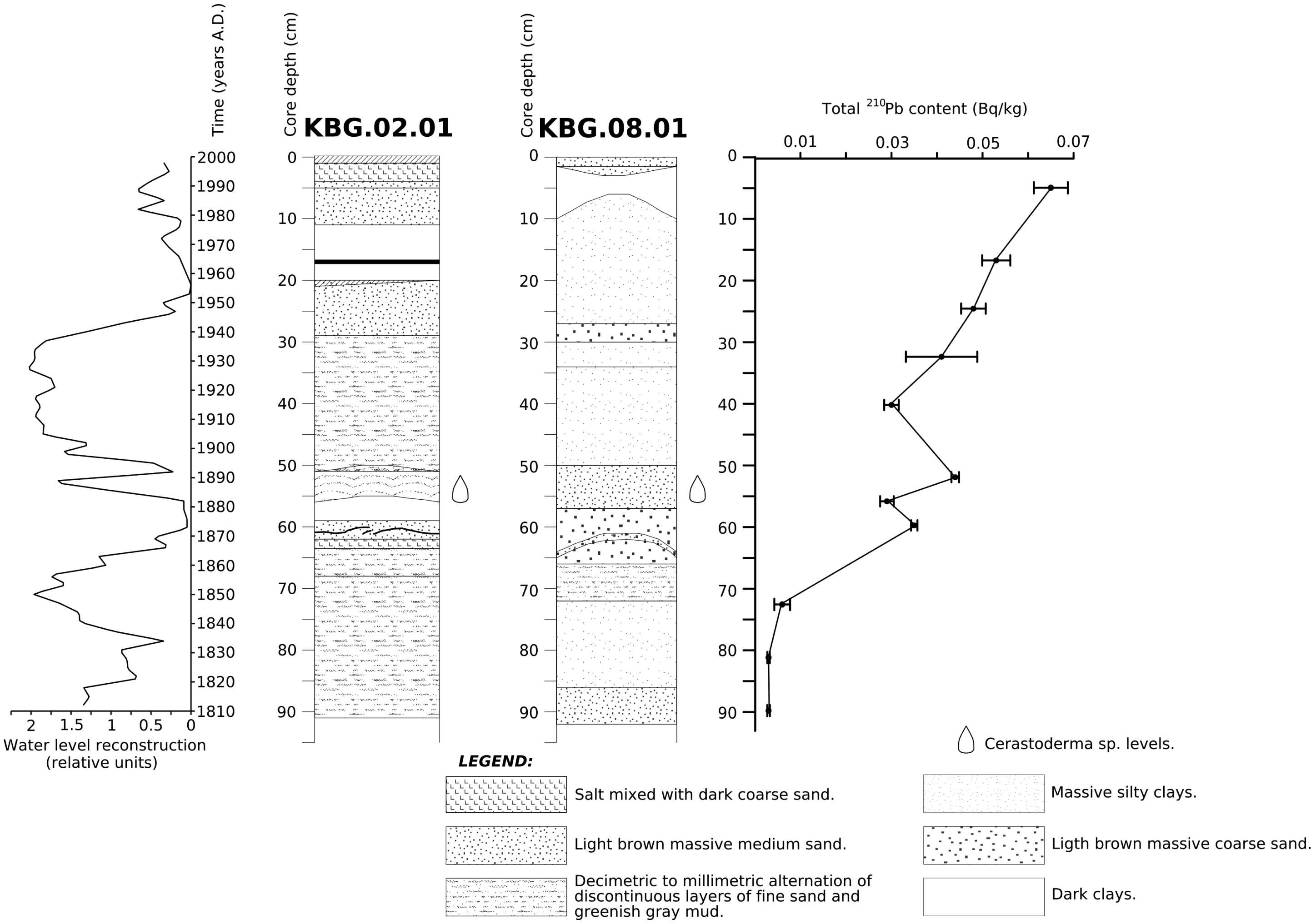
Fig. 7: Dinoflagellate cyst diagram in percentages from core KBG99-08-01 after 1880. To the left the KBG forms and to the right the Caspian forms. Other dinoflagellates (mainly Tertiary forms) at the extreme right. Zonation by CONISS, square root-transformation, black dot for values < 0.5, eight taxa selected.

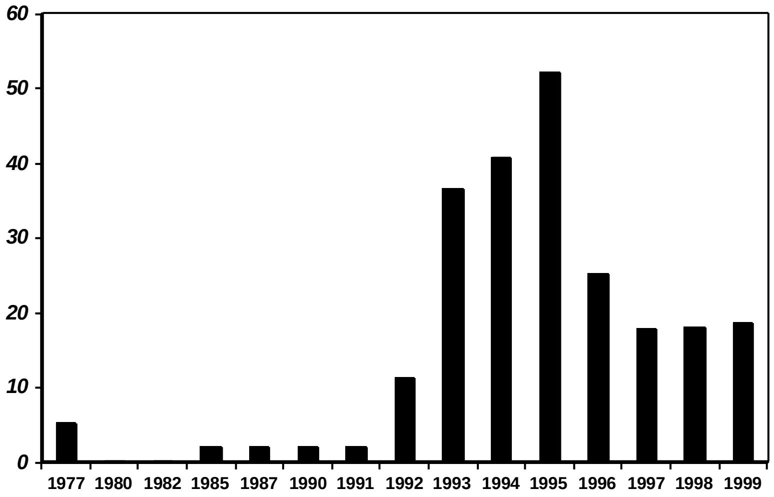
Fig. 8: Pollen diagrams in percentages from core KBG99-08-01.
AP: arboreal pollen. The curves of all Pinaceae and of *Betula*, *Corylus*, *Fagus* and *Pterocarya* are together to the left of the diagram because these pollen grains originate from plants that are not growing locally neither regionally. CONISS zonation on 11 taxa, black dots for < 0.5, square root transformation.


48°
52°
56°
60°
64°
68°
72°
76°
80°
84°
88°
92°
44°
40°
36°
AS6.5
AS0.5
BK2.5
BK26.5
centralCP21
centralGS18
centralCP18
southGS05
southUS02
southCP14
southCP04
Ens1, 6, 8,
12 and 15
IKbc3
IKbc1
Payango
Gangou
Tianshi lake
shore
Glacier no 1


N
March 1995
-28.4 m
KBG-08-01
KBG-02-01
March 1994
-30.0 m
Bekdash
March 1992
-33.5 m
Caspian Sea
Kara Bogaz Gol
0
100 km


levels in m
(28)
(30)
(32)
Precipitation in mm
200
150
100
50
0
1840
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
pz 1
pz 2
pz 3
pz 4
cz 1
cz 2
dz 1
dz 2
3
CS level (Lepeshevkov et al., 1981)
CS level (Voropayev, 1997)
KBG level (Lepeshevkov et al., 1981)
KBG level (Bulatov and Lavrov, unpubl.)
KBG level (Turkmen ministry)
5 yr average precipitation in Krasnovodsk (World Climate, 1999)
Precipitation in Bekdash (Bulatov, unpubl.)
pz = pollen zone


Time (years A.D.)
2000
1990
1980
1970
1960
1950
1940
1930
1920
1910
1900
1890
1880
1870
1860
1850
1840
1830
1820
1810
2
1.5
1
0.5
0
Water level reconstruction
(relative units)
Core depth (cm)
KBG.02.01
Core depth (cm)
KBG.08.01
0
10
20
30
40
50
60
70
80
90
Total ^{210}Pb content (Bq/kg)
0.01
0.03
0.05
0.07
Cerastoderma sp. levels.
LEGEND:
Salt mixed with dark coarse sand.
Light brown massive medium sand.
Decimetric to millimetric alternation of discontinuous layers of fine sand and greenish gray mud.
Massive silty clays.
Ligth brown massive coarse sand.
Dark clays.


60
50
40
30
20
10
0
1977
1980
1982
1985
1987
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999

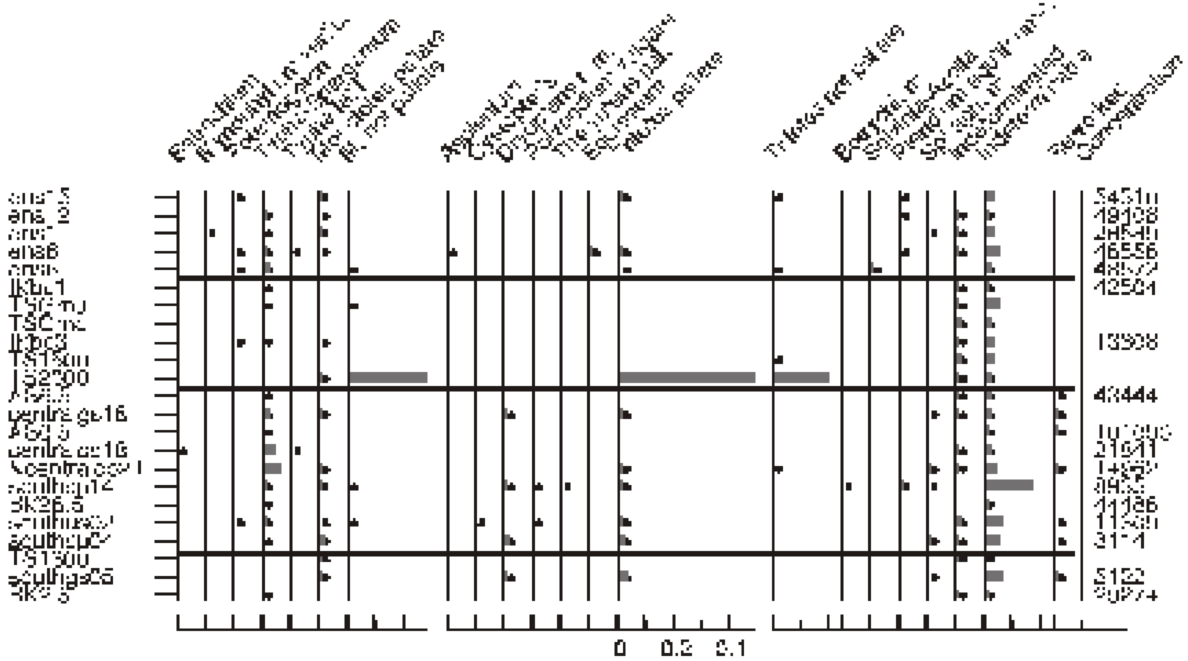


fig.5 leroy et al.

fig.5 leroy et al.

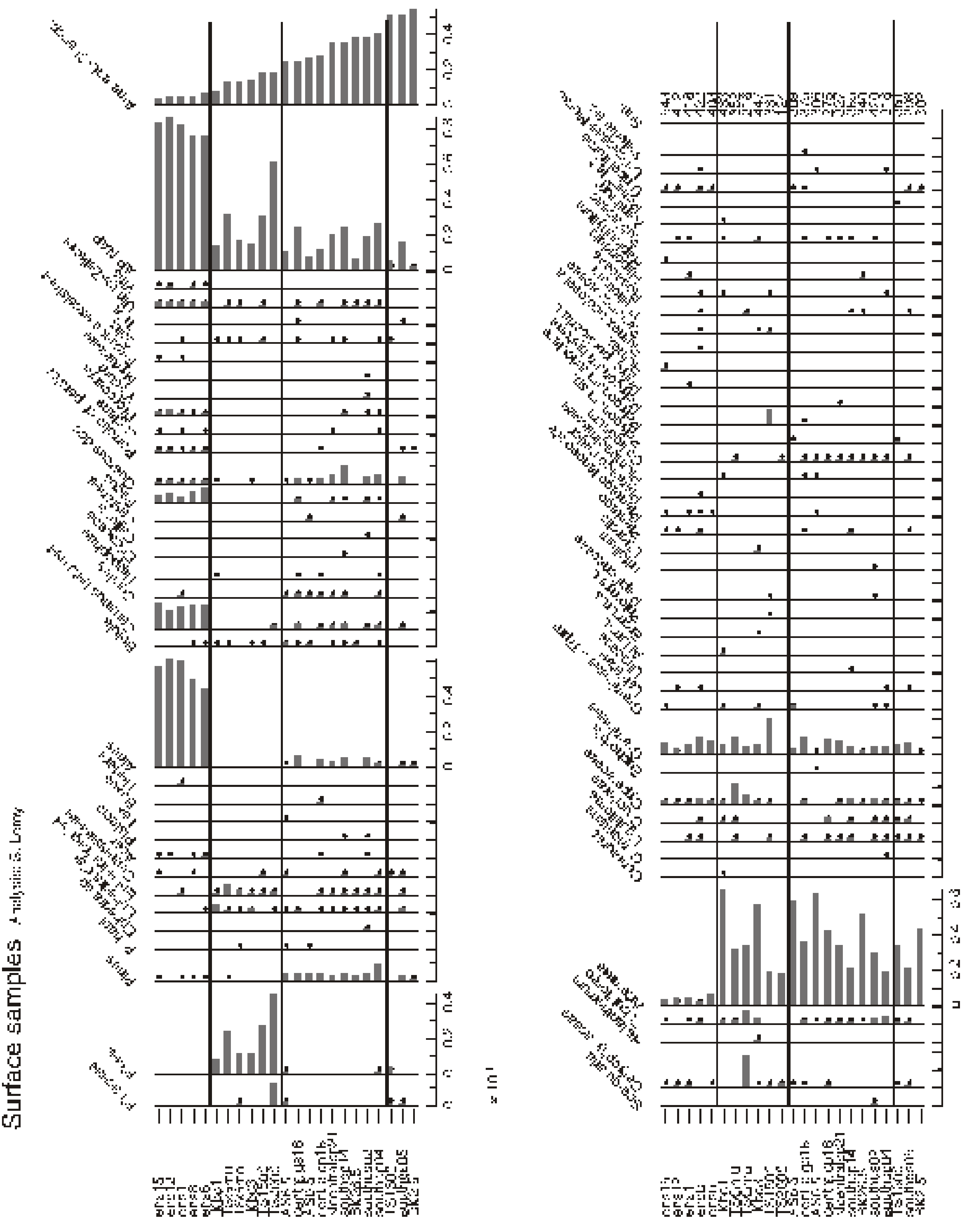


Fig. 6 Leroy et al.

Kara-Bogaz-Gol, pollen, dinoflagellates and microfossils in concentration Analysis: S. Leroy