Paleoclimatic Records of Inner Mongolia, the Okinawa Trough and the South China Sea since the last Glacial Maximum

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Abstract

A sediment core was collected from a saline lake located near the northern limit of the East Asian Summer Monsoon in Inner Mongolia. It was found that coarse sediments had been deposited either during the shrinkage phase of the lake, or during the period when the sand dune had reactivated. These sediments had low organic carbon contents and high maturity indices, indicating that they had been deposited in an arid environment. On the other hand, fine sediments with high organic contents and low maturity indices had evidently been deposited during periods of high lake stand due to the peripheral migration of the sand-flat and the better preservation of the wind-carried dusts in the water body. Three humid phases, namely 13.4-8.0, 6.4-5.8 and 4.2-3.1 kyr B.P., were recovered, with the first the wettest, followed by the third phase, the next wettest.

The above dry and wet phases are consistent with those previously recovered from the same arid semi-arid transition zone. They are, however, not consistent with the humid Holocene Optimum revealed in east China, in Taiwan, in the Okinawa Trough and in the South China Sea. Further, the 4-2 kyr B.P. coldest period in the Holocene corresponds to a wet phase in Inner Mongolia (i.e. 4.2-3.1 kyr B.P.). These differences may be explained by enhanced evaporation over higher monsoon precipitation. This is the key factor in determining the effective humidity in the region near the northern boundary of the summer monsoon.

Introduction

Climate in East Asia is largely controlled by the East Asian monsoon system responding to the strength of high and low pressure cells which grow and decay seasonally over the Asian landmass. The monsoon draws winds and moisture mainly from the tropical Philippine and South China Seas during summer but exports cold, dry, strong winds from the Asian interior during winter. During the last glaciation, global cooling enhanced the Mongolia High Pressure. At this time the winter monsoon was greatly strengthened and the summer monsoon significantly weakened.

In an arid environment, plant productivity is mainly controlled by effective humidity and relatively minor changes in the quantity of rainfall can have a dramatic effect on the environment. The deserts of Inner Mongolia are near the northern boundary of the summer monsoon. Due to their dryness and the proximity to the Gobi desert — thought to be the major source of dust in the Greenland ice cores (Biscaye *et al.*, 1997) — the Inner Mongolia lakes provide an excellent setting to examine the paleoenvironmental changes, especially those involving long range transport of aeolisn dusts.

Geological setting

Lake Yanhaizi is one of many hypersaline alkaline lakes located 500 km west of Beijing on the Ordos Plateau, Inner Mongolia, on the border of the Gobi desert at an altitude of 1180 m (108°25'E -108°29'E, 40°06'E-40°10'E). It is 800 km from the nearest ocean, the Bohai Gulf, and about 1150 km from the East China Sea. Lake Yanhaizi covers a maximum area of 18 km^2, a maximum water depth of about 0.5 m, and has a drainage area of about 2000 km^2 in the deserts. The mean annual temperatures is 5.9℃, with the low mean monthly temperature of -12.2℃ in Jan. and the high mean monthly temperature of 21.6℃ in July. The mean annual precipitation is only 277 mm, concentrated between July and Sept. The mean annual evaporation is 2604 mm, concentrated between April and Aug. The lake's bedrock is mainly composed of Lower Cretaceous yellow-greenish sandstones belonging to the Dong Sheng and Yijinghuolou formations.

Lake coring shows that the upper 3.04 m of Quaternary sediment comprises predominantly mirabilite ($Na_2SO_4 \cdot 10H_2O$) crystals containing varying amounts of black quartz sand and silt. Between 3.04 m and 8.29 m is mainly black sand and silt with sand the most abundant between 5.70 and 7.30 m. The color turns to grey-green between 8.29 m and 11.70 m where silt and sand are the major components but between 9.70 m and 12.20 m sand is more abundant. The color turns to black again at 12.70 m and silt and clay are the major components between 12.10 m and 14.15 m. Grey-green silt and sand exist below 14.15 m until 16.22 m where sandstone is encountered.

Methods

A LECO CHN-932 elemental analyzer was used to determine total carbon (TC) and total nitrogen (TN) at 950℃. Total organic carbon (TOC) was determined after repeated rinsing of samples with 1N HCI to remove inorganic carbon. Precision was ± 0.01% for TC and ± 0.001 for TN. The TN values for the top 3.04 m are not reported because S in mirabilite interfered with the measurements. Minerals were determined with a SIMENS D 5000 X-ray powder diffractometer. Magnetic susceptibility was measured with a Bartington MS2B susceptibility meter. ^{13}C and ^{18}O analyses were performed on bulk samples using a SIRA 10 mass spectrometer calibrated with NBS 19. The precision was ±0.08 ‰. Grain size was determined with a Coulter LS-100 Laser particle size analyzer.

Samples of mostly humin and some organic matter were dated mainly by AMS at the Rafter Radiocarbon Laboratory, Institute of Geological and Nuclear Sciences, N. Z., and at the Leibniz Labor fur Altersbestimmung und Isotopenforschung, Christian-Albrechts-Universitat, Germany. Additional checks were done at the National Taiwan University by the conventional method. Near core-top sediments were measured for ^{210}Pb with a TENNELEC LB 5100-2800-II counting system.

Age Model

The ^{14}C ages are plotted on Fig. 2. Results from a nearby core YA-02 at the same depth and strata are also added. No systematic differences are found. The deposition rates are more or less constant except between 12.75 m and 14.50 m where the rate is much slower.

One major uncertainty with the measured dates is the reservoir effect which has been estimated to be about 1000-2000 yr for lakes in Inner Mongolia (Ren , 1998). Extrapolating the ^{14}C ages to the coretop gives an age of 879 yr , which is one indicator of the reservoir effect. Further, the ^{210}Pb age of the sample at 0.27 m is 241 yr whereas the ^{14}C age is 1110 ± 80 yr. The difference of 869 yr is another indicator of the reservoir effect . Finally, the ^{14}C age of the lake water is 887±21 yr which agrees with the above two values. As a result, we take 879 yr as the reservoir effect.

Results

The TOC values are generally low, between 0.09 and 1.08 %. There are three sections of relatively high TOC, between 3100-4200 B.P., 5800-6400 B.P. and 8000-13400 B.P. (Fig.3.). The higher values are taken to be representative of higher biomass productivity in the drainage (Pedersen and Calvert , 1990 ; Lou and Chen ,1997 ; Lou *et al.*, 1997). The productivity in an arid area is, in turn, controlled by effective precipitation (An *et al.*, 1993 ; Campbell *et al.*, 1994 ; Zhou *et al.*, 1994 ; Ayliffe et al., 1998) thus these three segments represent more humid environment. Desert sand samples nearby has a TOC content of 0.17 %, similar to the values found in the dry segments of the core. Further, desert sand samples are rounded, well sorted, and have a mode at about 300 mm. The sediment samples in the dry segments have similar features. On the other hand, sediment samples in the wet segments have a mode near 10 mm. These small particles are clearly aeolian.

Higher TOC/TN ratios have also been taken to represent higher productivity on land (Lou and

Chen, 1997 ; Meyers, 1997) but the signal is mixed (Fig. 3). Although the three humid segments indeed have slightly higher TOC/TN values than the dry segments between 4300-5900 B. P. and 6400-8000 B. P., the oldest dry segment before 13,400 B. P., however, has the highest TOC/TN. This may reflect preferential decomposition of organic nitrogen. The nearby desert sand samples have a TOC/TN ratio of about 9, similar to what is found in the dry segments in the middle of Holocene.

The Maturity Index is defined as the ratio of feldspar and the sum of feldspar and quartz. Higher values indicate drier environments (Hsu, 1989). Only 23 samples were analyzed but, indeed, the higher values generally occur in the dry segments.

The magnetic susceptibility has been reported to be two orders of magnitude higher at about 10 ka BP than during the Holocene in a nearby lake (Bernasconi *et al.*, 1997). Bernasconi *et al.*, also found higher concentrations of titanium, and suggested that the influx of titanomagnetite from the Gobi Desert had increased the magnetic material in that lake. Our magnetic susceptibility (Fig. 3) or titanium data (not shown), however, do not support this conclusion. In fact, our signal is wet for 10 ka BP when the magnetic susceptibility was actually slightly lower.

Bernasconi *et al.* (1997) also reported a ^{18}O minimum and low ^{13}C values associated with high susceptibility values. Fig.3 indicates that the wet phases generally have more positive ^{18}O and ^{13}C values and the dry phases have more negative values. Correlation with susceptibility is not apparent. On the other hand, more negative ^{18}O and ^{13}C values are clearly correlated to coarser sand, or dryer environment.

Discussion and Conclusions

Our data clearly indicate that the Holocene Optimum was a dry period in Inner Mongolia. This is clearly contrast to the humid phenomenum reported elsewhere in China. For instance, the high TOC content at Retreat Lake in Taiwan, taken as a wet signal (Chen *et al.*, in preparation) is almost a mirror image of the TOC signal at Lake Yanhaizi where low TOC reflects low humidity (Fig. 4). Also shown on Fig. 4 are the warmth index at the Three-Rivers Plain in Manchuria and the temperature differential (T-T av.) on the Loess Plateau. It is clear that the Holocene Optimum was warm (and generally wet). Data from both Retreat Lake and Lake Yanhaizi indicated that the Holocene Optimum started 8 kyr BP and started to cool at 4 kyr BP.

Fig.5 shows the monthly precipitation (P) and evaporation (E) at a weather station near Lake Yanhaizi between 1971 and 1980. Indeed, the higher the temperature the higher the precipitation is. But the rate of increase for evaporation is much higher, resulting in higher E-P at higher temperature. This may explain why the effective humidity was lower during the Holocene Optimum in Inner

Mongolia.

The mid-Holocene time period throughout the midlatitudes of the Northern Hemisphere was also marked by decreased atmospheric precipitation, increased summer insolation, and associated decreases in lake levels (COHMAP Members, 1988). Further studies such as Schweger and Hickman (1989) suggested that the early Holocene climate was very warm and arid in north-central Alberta between 10,000 and 3,000 BP. Sauchyn (1990) suggested that early Holocene climate was drier and warmer between 9120 and 4500 BP in southwestern Saskatchewan, with the warmest interval occurring from 7700 to 6800 BP. Allen (1994) documented abrupt limnological shift at the forest-prairie transition in South Dakota between 9.2 and 9.0 ^{14}C ka BP, resulting from a sudden decrease in catchment and the establishment of the closed-basin lake driven by global climatic warming. In deed, Valero Garces *et al.* (1995) and Smith *et al.* (1997) reported that the northern Great Plains of America was more arid in early and middle Holocene. There was a drought in Mid Holocene (8-4 kyr B.P.), followed by an abrupt transition to a relatively cooler and wetter late Holocene. Beierle and Smith (1998) also reported that at 10,000 BP, immediately following the Younger Dryas cold period, climate warmed dramatically, precipitation decreased and surface evaporation increased in southwestern Alberta. In fact, severe drought occurred until 6800 BP. In the Southern Hemisphere, lake levels were the highest between 12-8 kyrs B.P. in the Atacama Altiplano (22-24°S). This so called Tauca phase terminated between 8.8-8 kyr B.P., and was replaced by extremely dry Holocene (8-3.6 kyr B.P.) (Crosjean, 1998). These are all in broad agreement with our observations in Yanhaizi. Such agreements found in different continents may reflect a response to interhemispherical teleconnections.

Jian *et al.* (1996) and Li *et al.* (1997) studied the variations of *Pulleniatina obliquiloculata* in the Okinawa Trough (Core 255, 123°07'E, 25°12'N, w.d. 1575 m ; Core 170, 125°48'E, 26°38'N, w.d. 1470 m) and the SCS (Core 17940, 117°25'E, 20°07'N, w.d. 1727 m). *P. obliquiloculata* is a tropical planktonic foraminifer living primarily in a narrow belt between about 10°N and 10°S, and is very sensitive to winter temperature. This species was low in abundance around 10 kyr BP, abruptly increased in abundance about 7 kyr BP and then drastically decreased about 4 kyr BP. Wang (1999) termed this *Pulleniatina* minimum event, possibly suggesting winter SST changes (Fig. 6). Analysis of the coccolith (*Florisphaera profunda*) record confirmed the above (Cheng and Wang, 1998). The *Pulleniatina* minimum event around 4kyr B.P. and the low abundance around 10 kyr BP corresponded to the wet phases around 4 and 10 kyr BP found at Yanhaizi. On the other hand, the high abundance phase corresponded to the dry phase between 4.2 and 8 kyr BP at Yanhaizi.

In conclusion, preliminary evidence from a sediment core collected from Lake Yanhaizi in Inner Mongolia indicates that three humid phases, 13.4-8.0, 6.4-5.8 and 4.2-3.1 kyr B.P. existed since 14 kyr B.P. (^{14}C ages). But, in general, the Holocene Optimum was marked by relative dryness. This is in agreement with those found in the arid-semiarid zone elsewhere in the world but is contrary to the humid Hlolcene Optimum found elsewhere in China and Taiwan. The reason is that much enhanced evaporation over higher monsoon precipitation at Lake Yanhaizi reduced the effective humidity. The dry (warm) Holocene Optimum at Lake Yanhaizi also corresponds to the high temperature found in the Okinawa Trough and the South China Sea. Such correlations are indicative of the influence of the Asian monsoon which is associated with the global atmospheric circulation system.

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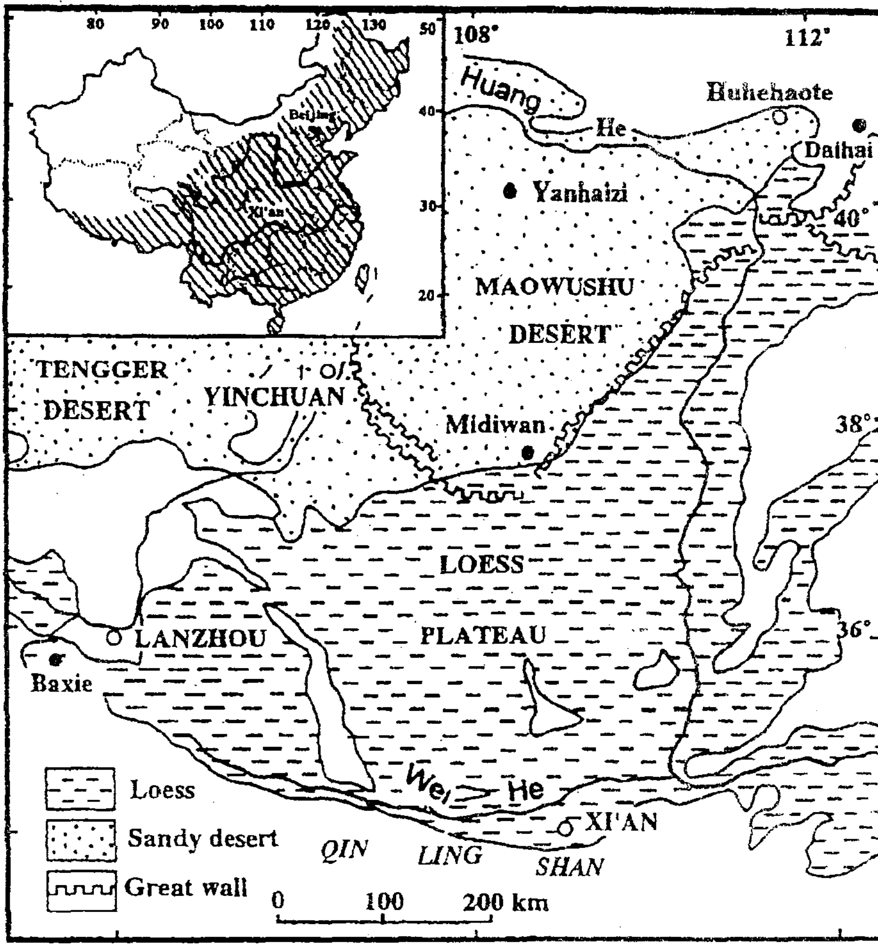
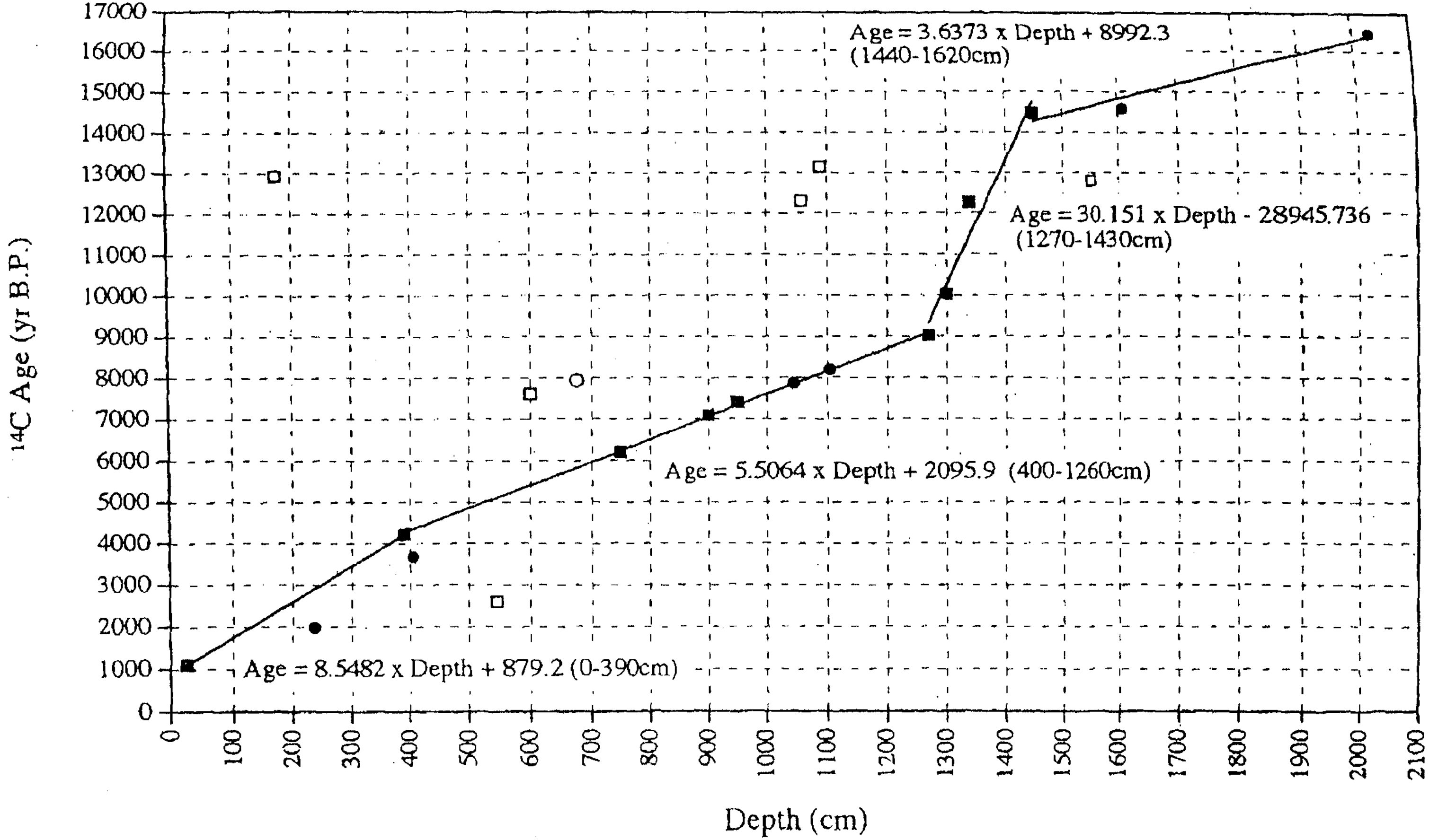


Fig. 1. Study Area



Ya01 年代模式。(■)代表 Ya01 定年點；(●)代表 Ya02 定年點；(□)代表去除之 Ya01 定年點；(○)則代表未使用之 Ya02 定年點。

Fig. 2. ^{14}C dates of Ya 01 (■) and Ya 02 (●). Lines represent age models.

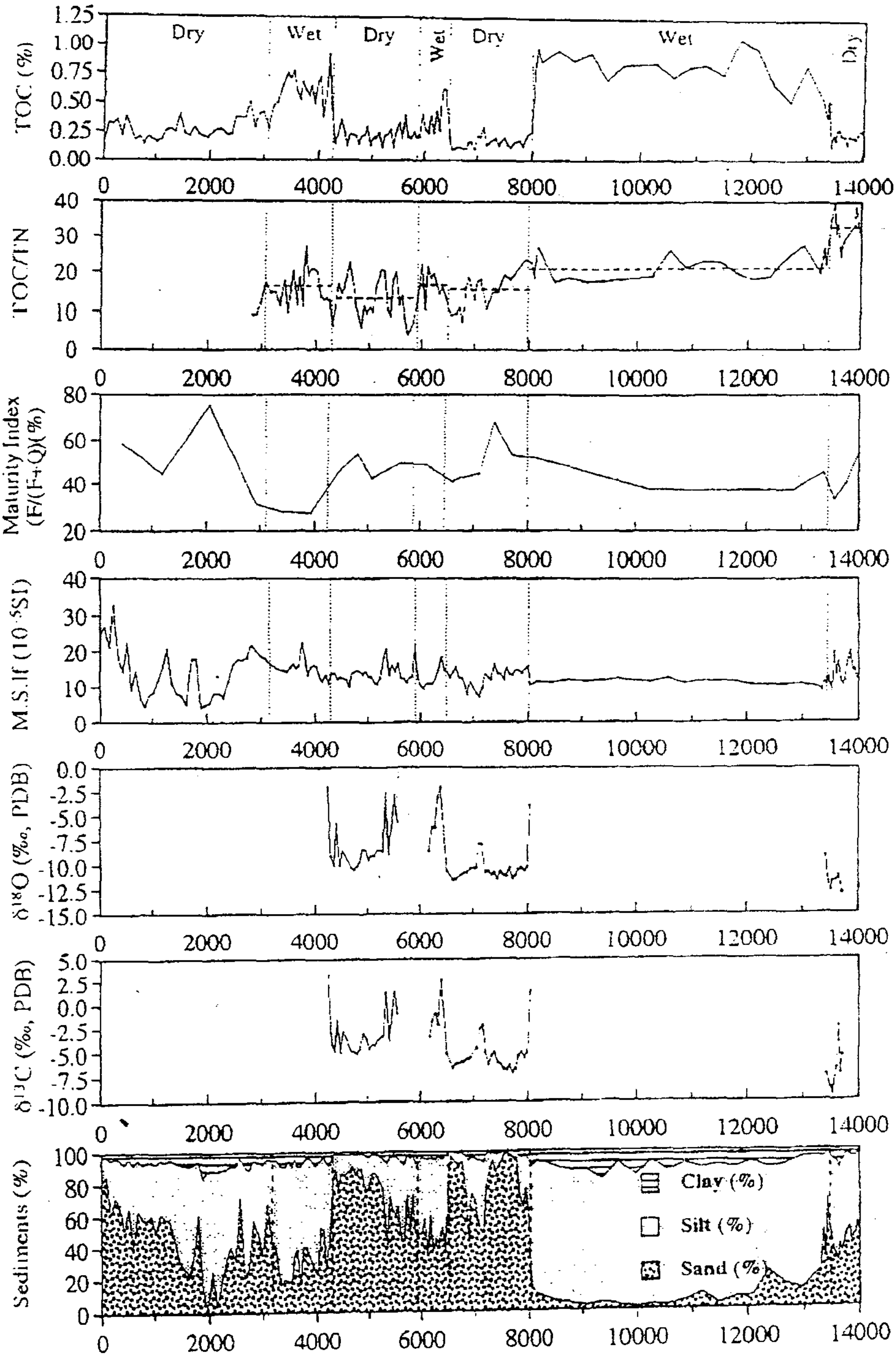


Fig. 3. Secular variations of TOC(%), TOC/TN ratio, maturity index, magnetic susceptibility $\delta^{18}O$ ($^0/_{00}$), $\delta^{13}O$ ($^0/_{00}$) and sediment composition for YA 01.

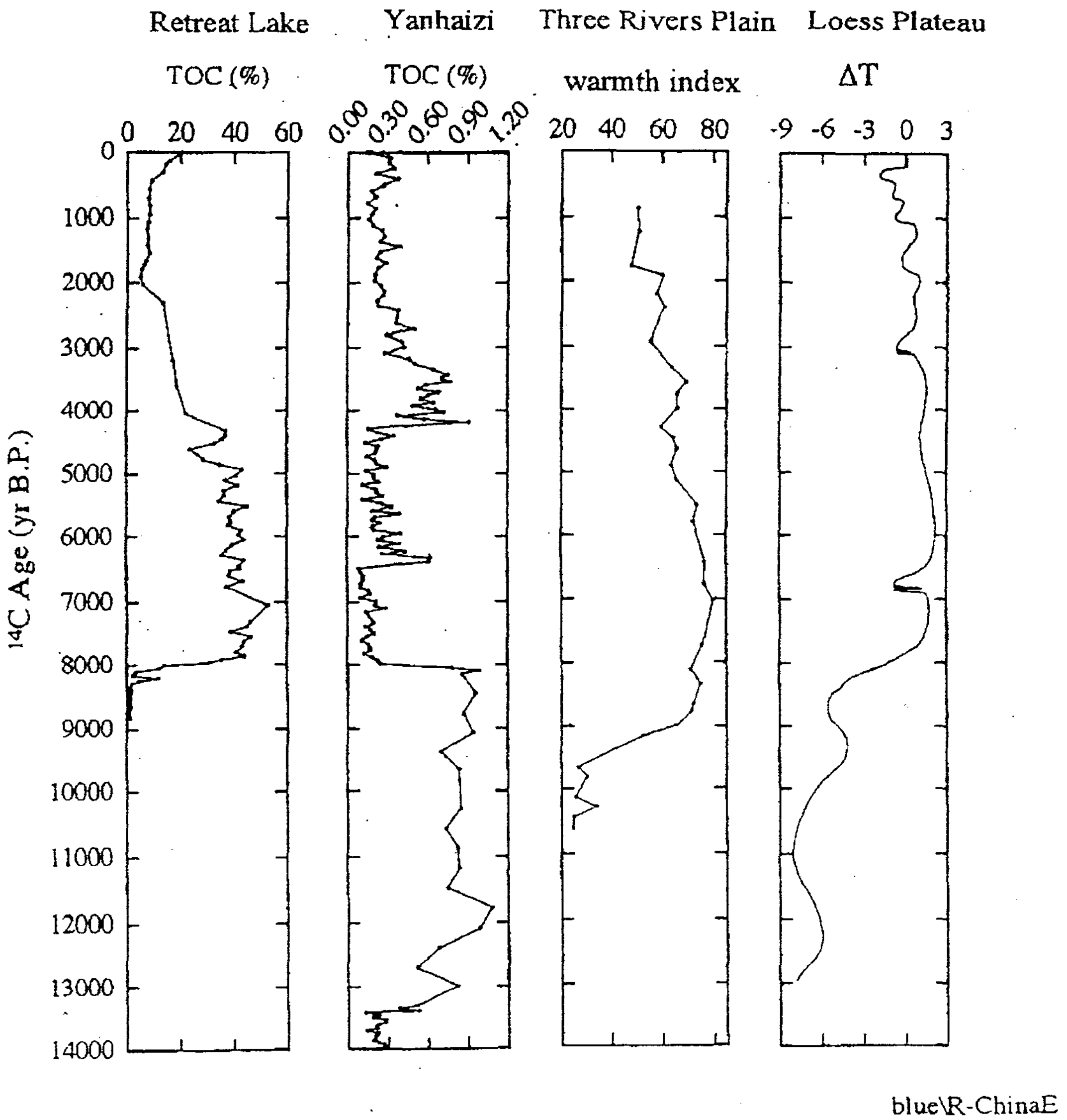


Fig. 4. Comparison of TOC in Retreat Lake and Lake Yanhaizi, the warm index at the Three Rivers Plain in Manchuria, and the ΔT (T-T average) on the Loess Plateau.

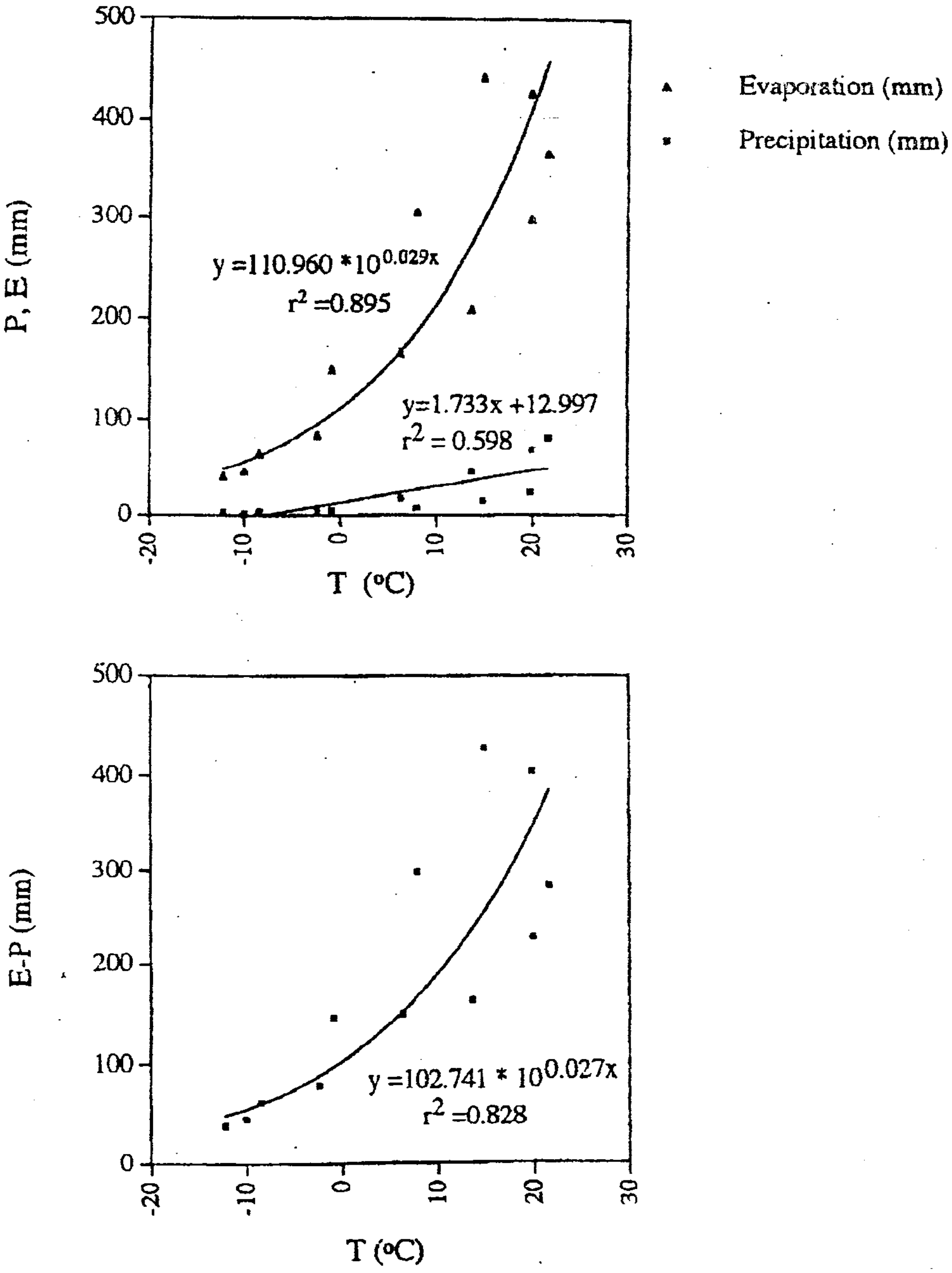


Fig. 5. Average monthly precipitation (P), evaporation (E) and E-P vs. temperature at a nearby weather station.

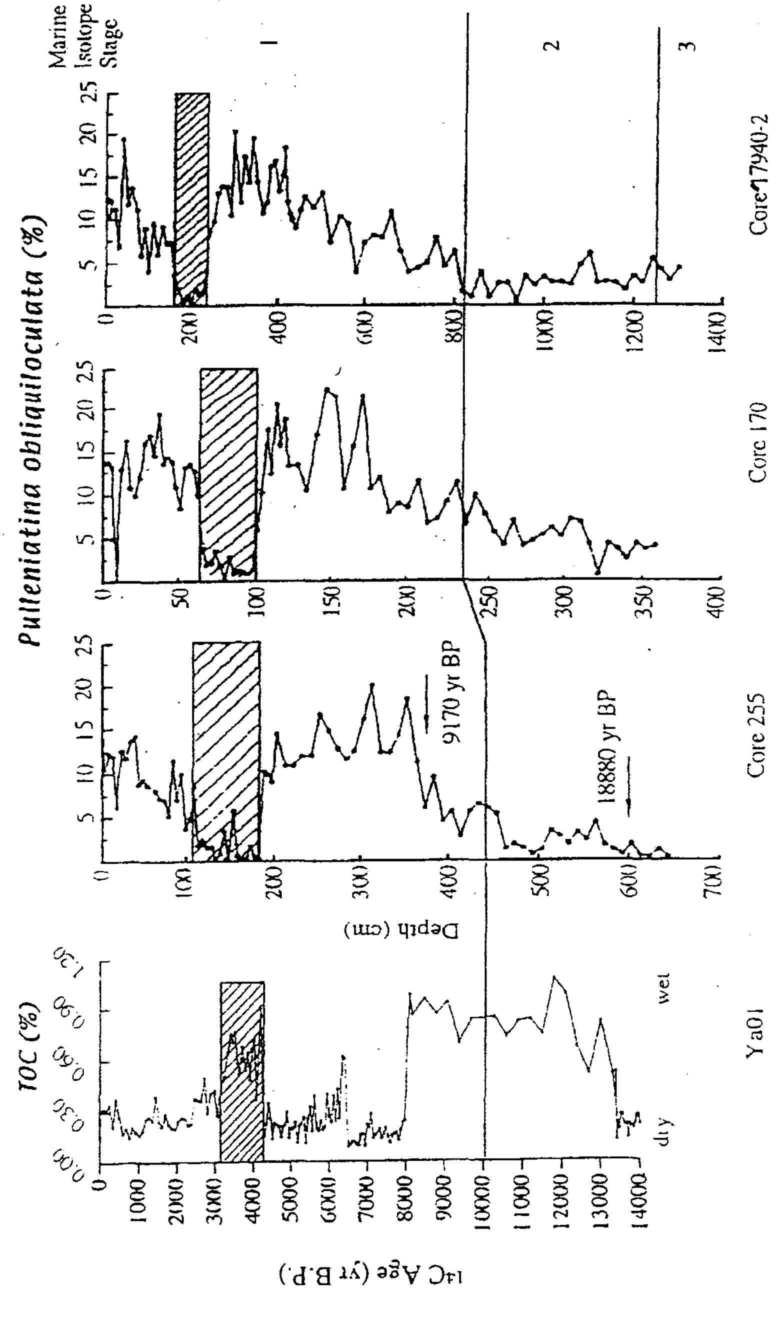


Fig. 6. Variations of a) TOC in Lake Yanhaizi and b) *Puleniatina obiquiloculata* (%) in planktonic foraminiferal fauna in cores from the Okinawa Trough (Cores 255 and 170) and c) the South China Sea (Core 17940). Shaded area denotes the humid event in Lake Yanhaizi and the cold event in the marine cores. The horizontal line connects the cores where the ^{14}C age is 10,000 yr B. P.