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Ostracoda Assemblages in Core Sediments and Their Environmental Significance in a Small Lake in Northwest Tibet, China

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Abstract

A 107-cm-long lake core was drilled in South Hongshan Lake (35°10′N, 80°04′E, 5060 m a.s.l.) shows 150 yr of environmental change as inferred from ostracoda assemblages. Four species of ostracoda, which belong to four genera, have been identified. The ostracoda distribution in the core can be divided into six ostracoda assemblages as follows: OA1—*Ilyocypris biplicata–Limnocythere inopinata* assemblage; OA2—*Limnocythere inopinata–Leucocythere mirabilis* assemblage; OA3—*Leucocythere mirabilis–Limnocythere inopinata* assemblage, in which dominant species is *Limnocythere inopinata*; OA4—Nearly ostracoda free; OA5—*Eucypris inflata–Limnocythere inopinata* assemblage; and OA6—*Limnocythere inopinata* changes from dominant to sole species. These ostracoda assemblages, together with other proxies, imply the following environmental sequence for the past 150 yr in the study area. Shallow moving water appears in A.D. 1850–1884, followed by a warm-humid climate in 1884–1922. Lake level decreased and water temperature supported maximum ostracoda growth in 1922–1946, followed by cooling conditions in 1946–1960. From 1960 to 1980, declining lake level is closely linked with local precipitation. The period since 1982 is characterized by less precipitation and continuous aridity under warming climatic conditions.

Introduction

As part of the terrestrial hydrosphere, lakes are closely linked with atmosphere and biosphere. Because lake environments, especially their ecological conditions, are influenced by these linkages, lake biota may record changes in climate and environment within lake basins. Ostracoda are benthic shelled aquatic animals that are sensitive to environmental temperature, salinity, water depth, and nutrients. Shells of ostracoda are easily preserved in the sediments due to their calcium components. The features of ostracoda species and/or genera and their assemblages directly reflect lake sedimentary environments.

The Tibetan Plateau is widely known as an area sensitive to climatic changes (Flohn, 1968; Feng et al., 1998; Wu et al., 2005). Northwestern Tibet is in the so-called ''cold and dry core'' of the Eurasia continent (Zheng, 1996). Any slight fluctuation of climate may induce surface environmental changes and leave records in the lake sediments, especially in small lakes (Tang et al., 1999). We studied South Hongshan Lake (35°10′N, 80°04′E, 4900 m a.s.l.), located on the southern slope of the west Kunlun Mountains of the northwestern Tibet Plateau (Fig. 1). This area is in the coldest and the driest part of the Plateau with mean annual precipitation of 23.8 mm and mean annual temperature of $-7.7°C$ (Zhang and Li, 1999). The lake basin is closed, with a lake area of 3.35 km^2 and is mainly supplied by precipitation (rain in summer and snow in winter). The lake is shrinking in recent years and the present salinity is 9.4 g L^{-1} (Zhu et al., 2002). Soil is undeveloped in the drainage area, and vegetation is sparse. Due to the small lake surface area and simple hydrology, the sedimentary environment of the lake is sensitive to surface climatic changes.

Materials and Methodology

CORE COLLECTION AND SEDIMENTOLOGY

Past environmental changes in the South Hongshan Lake area are reconstructed based upon core SHC-2 obtained with a piston corer in 1998. The core site was 100 m from the lakeshore in 5 m water depth. The core length is 107 cm that did not penetrate through the lake sediments. Gray-greenish clayey silt appears from the top to a depth of 23 cm, with a 1-cm-thick interval of medium silt-fine sand at 17–18 cm depth. Gray-greenish silty clay appears from 23 to 68 cm depth; below 68 cm is gray-brownish clayey silt alternating with several bands of black fine sand. The core was sampled at 1-cm intervals.

For further understanding the modern ostracoda in the lake, we used a gravity corer to collect benthic sediments between water and sediments interface. Five samples were collected from the shoreline to the PISTON core site in 1 to 5 m water depth.

Besides the picking and identifying of ostracoda species in the 107 samples of the piston core, we also analyzed the particle size using MasterSizer 2000 made by Malvern Instruments Co. Ltd, UK. Total Organic Carbon (TOC) was analyzed by electric-heating-$K_2Cr_2O_7$ measurement with the analytic error of 0.05% (CAG-SSSC, 1983).

CORE AGE AND SEDIMENTATION RATE

Residual ^{210}Pb and ^{137}Cs were measured in the top 55 samples (55 cm) of the core to determine sediment age and deposition rate. After picking out grass debris, charcoal, and vegetation, we ground the samples to <0.1 mm and put them into 5-mL plastic boxes (net weight was 4–5 g each). These boxes were placed into
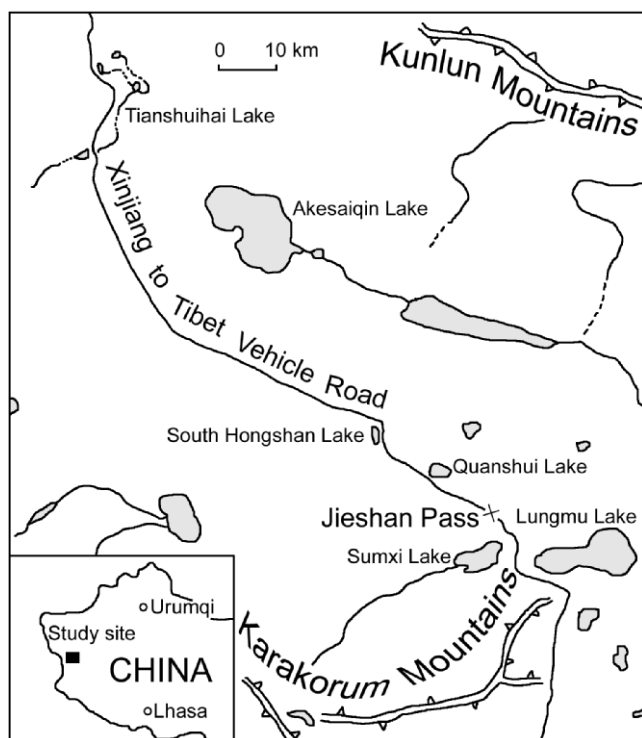
FIGURE 1. Sketch map of study area.

values of residual ^{137}Cs, the age of the core was determined (Pennington et al., 1973; Wan, 1999).

The peaks in the ^{137}Cs profile of this core clearly showed different larger scale nuclear explosion events. The appearance of another bomb product, [241]Am, at the same depth as that of the highest peak value of ^{137}Cs, confirms that the highest peak of ^{137}Cs was due to the peak in global nuclear testing in 1963. The average sedimentation rate over the 0- to 40-cm depth interval was inferred to be 7.2 mm a^{-1} from the profile of ^{210}Pb; this implies that 1986 and 1972 correspond to depths of 8 cm and 18 cm, respectively. These also coincide with two peaks in the ^{137}Cs attenuation curve. According to the sedimentation rate, 1963 and 1952 should correspond to depths of 24 cm and 32 cm. However, the peak values in ^{137}Cs are found at lower depths. This offset may be due to the downward migration of [137]Cs (Fig. 2).

According to the CIC (Constant Initial Concentration) model (Krishnaswamy et al., 1971), sedimentation rates vary with density for sediments that have not undergone diagenesis. Assuming mean diameters (Mz) of sediment particle size fully controls bulk density; we may estimate changing sedimentation rates in terms of particle sizes. Because there is little grain-size variation within the core and all of these sizes are in the same range (0–100 μm), we may apply the sedimentation rate of the top section to the full core. Thus, based upon the known drilling date (1998) and the sedimentation rates, we infer the time represented by the core is about 150 yr (1850–1997).

OSTRACODA EXTRACTION

We took 10 g from each of the 107 core samples and 5 modern benthic sediment samples and wet-sieved them in a 0.05-mm sieve. After removing the organic particles, these processed samples were put under the 8 × 10 microscope for picking ostracoda shells. In the modern benthic sediments, only *Limnocythere inopinata* and *Eucypris inflata* were found. Lower modern diversity of ostracoda possibly result from the obstruction that the surrounding high mountains present for exchange of water, air,

a "P"-shaped highly pure germanium well for measuring residual ^{210}Pb and [137]Cs. Supported Pb in each sample was assumed to be in equilibrium with the in situ Ra, and unsupported ^{210}Pb was calculated by subtracting Ra activity from total [210]Pb.

Although the amount of ^{137}Cs varies in different sediments due to its easy migration, the relative positions of the peak ^{137}Cs in vertical profile are generally difficult to alter (Wan et al., 1991). Therefore, according to the sedimentation rate determined by residual ^{210}Pb and absolute timing markers indicated by peak
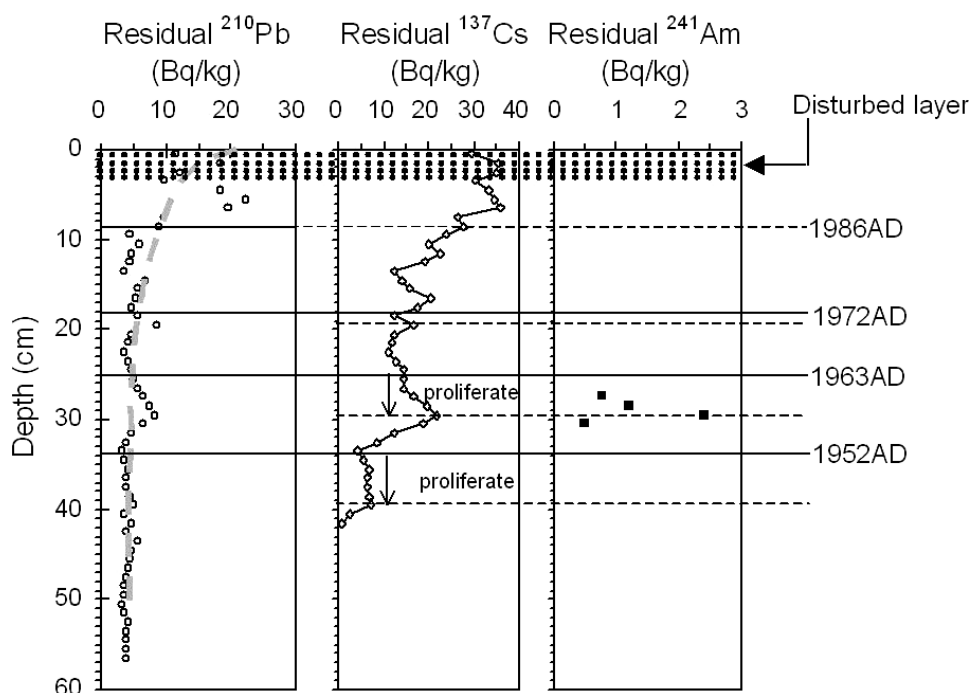

FIGURE 2. Residual ^{137}Cs and ^{210}Pb variations against depth.

and flora/fauna between the lake and surrounding regions. Ostracoda appeared in nearly all core samples, but less difference of their genera/species existed among different samples. Only 4 genera and 4 species were identified; these are *Limnocythere inopinata*, *Leucocythere mirabilis* Kaufmann, *Ilyocypris biplicata* (Baird), and *Eucypris inflata* (Sars).

Ecological Features of Ostracoda and Their Assemblages

ECOLOGICAL FEATURES OF OSTRACODA

To elucidate the environmental significance of ostracoda assemblages in the core sediment, it is necessary to understand their present ecological niches and climatic adaptation. The surface morphology of *Limnocythere* and *Leucocythere* differ only in accessory limbs in the male; both live in the same water condition with eurysalinity (hypo- to hypersaline) adaptation. However, there is a difference in water chemistry and water depth habitats of *Limnocythere inopinata* and *Leucocythere mirabilis*.

Limnocythere inopinata is a typical eurysalinity adaptation species. In the Austrian Alps, it is a key component of ostracoda in the shallow areas of Klopeiner Lake and in the coastal shallow zones of Mondsee lake (Danielopol et al., 1993). In the shallow Neusiedler Lake, it is the most abundant shelled benthic animal (Carbonel et al., 1988). This species is also found in Holz Maar and Schalkenmehrener Maar, which have moderately rich nutrient conditions. In the northern part of the Tibetan Plateau, this species is frequently found in the coastal zones of lakes, e.g., in Sipanguer Lake, Zhognai Lake, and Goulu Lake.

Leucocythere mirabilis mainly lives in oxygenated, nutrient-poor water while it is less common in the water with high organic matter. This species is widely reported in the lakes of Austria, Switzerland, and Scandinavia, but it is absent in some lakes in Germany due to high nutrients (Scharf, 1993). In Mondsee lake in Austria, this species appears in deep or subdeep water zones. Although this species is rarely found in benthic sediments of 3-m water depth, they move into much deeper water with increasing water temperature (Danielopol et al., 1993).

Ilyocypris biplicata is reported in ponds and streams of North America and Europe. In the Tibetan Plateau, it is found in pools, swamplands, and streams near Qinghai Lake (RAQOSD and NIGPCAS, 1988). Besides shallow water, these habitats are also characterized by moving water (Huang, 1985; Wang et al., 1990). In southern Tibet, some researchers consider *Ilyocypris biplicata* diagnostic of moving water (Peng, 1997).

Eucypris inflata lives in nonmoving water with salinities from 0.8 to 110.0 g L^{-1} (de Deckker, 1981); most of them may tolerate high salinity. They are found in the Caspian Sea, as well as Tianshuihai Lake and Xijinwulan Lake of the Tibetan Plateau (Zhang and Li, 1999).

Distribution and production of ostracoda are controlled by the parameters of their environment. Species that live in shallow water are strongly influenced by water/air temperatures. Given that ostracoda have their highest productivity within certain temperature ranges, their richness (genera or species) may imply temperature information (de Deckker and Forester, 1988). *Limnocythere inopinata* is the dominant species in the SHC-2 core; its abundance may reflect water/environmental temperature variations. However, since multiple environmental parameters impact productivity, ostracoda richness does not always coincide with variations in just one parameter. For example, most ostracoda live in environments with rich organic debris. This suggests that ostracoda abundance is not only controlled by temperatures, but also influenced by organic matter.

ASSEMBLAGES OF OSTRACODA

Although each species of ostracoda live in distinctive water conditions, an individual species cannot constrain environmental condition due to its adaptation to a range of temperature/salinity/water depth conditions. However, the occurrence of a group of ostracoda genera/species provides greater constraint on environmental conditions these ostracoda were living in. Therefore, identifying assemblages of different genera/species is necessary to understand past water/climatic conditions. We distinguish six ostracoda assemblages (OA) in the SHC-2 core (Fig. 3).

OA1: *Ilyocypris biplicata–Limnocythere inopinata*. This assemblage is dominated by *Limnocythere inopinata*, which accounts for 50 to 93% (average 73%) of individuals. The second most abundant species is *Leucocythere mirabilis* (average 23%). *Ilyocypris biplicata* accounts for 2 to 7% of the population, but is as high as 17% in some samples. Because *Ilyocypris biplicata* is diagnostic for flowing water, its presence even in small numbers is significant for environmental conditions. This assemblage appears below 82 cm in the core.

OA2: *Limnocythere inopinata–Leucocythere mirabilis*. This assemblage is composed of *Limnocythere inopinata*, *Leucocythere mirabilis*, and *Ilyocypris biplicata*. *Leucocythere mirabilis* accounts for more than 30% of the population on average. This assemblage appears between 82 and 56 cm depth in the core (*Leucocythere mirabilis* averages 35%) and 29 to 12 cm depth (*Leucocythere mirabilis* averages 31%). Higher percentages of *Leucocythere mirabilis* imply increasing water depth.

OA3: *Leucocythere mirabilis–Limnocythere inopinata*. Although the components of this assemblage are same as that of the OA2, the dominant species is reversed. *Limnocythere inopinata*, which indicates shallow water, reaches 50 to 97% of the population. This assemblage is found at 56 to 39 cm depth in the core (*Limnocythere inopinata* averages 76%) and 4 to 2 cm depth (*Limnocythere inopinata* averages 85%).

OA4: very few ostracoda appear in the core over the depth interval of 39–29 cm.

OA5: *Eucypris inflata–Limnocythere inopinata*. Three species, *Eucypris inflata*, *Limnocythere inopinata*, and *Leucocythere mirabilis*, appear in this assemblage, in which *Limnocythere inopinata* is dominant species. Although *Eucypris inflata* is less abundant, it is significant as a marker for higher salinity. This assemblage is found in two small intervals in the core at 20–19 cm and 2–1 cm depth.

OA6: *Limnocythere inopinata* changes from dominant species to sole species in this assemblage. Beside the simple composition, this assemblage shows the lowest total abundance in the core. This assemblage represents implies shallow water conditions that do not support ostracoda. This assemblage appears in the top 12–4 cm of the core.

Discussion of Paleoenvironment in the Lake Basin

We use the ostracoda assemblages (OA) and total ostracoda abundance, together with mean diameters (Mz) of grain size and Total Organic Carbon (TOC), to divide the SHC-2 core into a series of environmental stages (Fig. 3). The productivity of ostracoda depends on multiple environmental factors, including warm temperature, stable sediments structure, and plentiful clastic organic food (Carbonel et al., 1988). Generally, high terrestrial or aquatic organic matter boosts ostracoda productivity (Wang et al., 1990).

Stage I: 107–82 cm corresponds to the first stage (1850–1884), which is characterized by OA1. *Ilyocypris biplicata* (3% average)
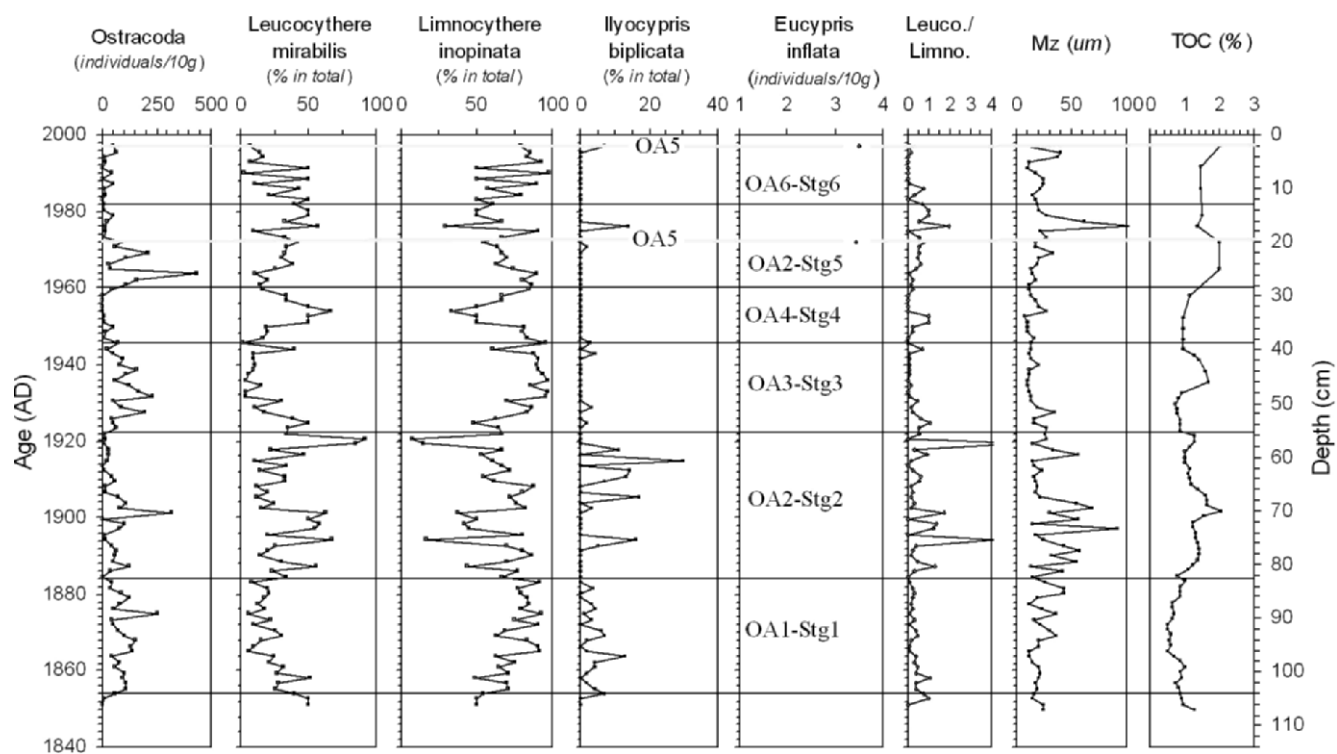
FIGURE 3. Variations of ostracoda species and their assemblages, together with grain size and TOC against depths and inferred ages.

appears in nearly every sample, which indicates running water flowing into a shallow lake. There are well-sorted black silty-fine sand bands at depths of 84–85 cm and 91–94 cm, which also implies that the core site is influenced by weak currents. The lower ratio of *Leucocythere mirabilis* to *Limnocythere inopinata* means that water depth is shallow. As a whole, this section reflects an environment of lakeshore zone with shallow water.

Stage II: 82–56 cm corresponds to the second stage (1884–1922). OA2 is the main ostracoda assemblage in this stage. Although *Ilyocypris biplicata* averages 4.2% in all samples in this stage, it only appears in few samples. The high percentages of *Leucocythere mirabilis* imply deep-water conditions, and the high ratios of *Leucocythere mirabilis* to *Limnocythere inopinata* suggest weak currents and comparatively deep water. In the end of this stage, *Ilyocypris biplicata* reaches as high as 20%, implying that the lake is rapidly supplied by moving water and therefore that the lake level is rising. The blooming of both *Leucocythere mirabilis* and *Limnocythere inopinata* means high water temperature. In this stage, the ratio of *Leucocythere mirabilis* to *Limnocythere inopinata* covaries with grain size and with TOC. On one hand, these observations suggest increasing water depth closely linked with surface running water in the lake basin. On the other hand, increasing TOC, mainly derived from terrestrial vegetation debris (Zhu et al., 2002), suggests that temperatures suitable for vegetation growth exist.

Stage III: 56–39 cm corresponds to the third stage (1922–1946). OA3, which is dominated by *Limnocythere inopinata*, appears in this section. The abundance of ostracoda is relatively high throughout this stage, indicating conditions favorable for ostracoda productivity. In this stage, sediments size is finer and shows less variation than in earlier phases, while TOC is at moderate levels. These environmental factors are favorable to ostracoda growth. Simultaneously, the abundance of *Limnocythere inopinata* indicates that lake water depth is shallow.

Stage IV: 39–29 cm corresponds to the fourth stage (1946–1960). OA4, with nearly no ostracoda, appears in this section. Due to low absolute abundances, the ratio of *Leucocythere mirabilis* to *Limnocythere inopinata* cannot be used to infer water depth changes. We infer that the lack of ostracoda in this stage indicates low water temperature and low organic matter content.

Stage V: 29–12 cm corresponds to the fifth stage (1960–1982). OA2 again is dominant in this section, but here with few *Ilyocypris biplicata*. The ratio of *Leucocythere mirabilis* to *Limnocythere inopinata* is high in one interval, corresponding to a coarsening of the sediment. This again suggests that increasing water depth is linked with an increase in surface water supply. The abundance of ostracoda gradually decreases through the stage, roughly paralleled by of the trend in TOC. This suggests that organic matter has strong effects on ostracoda productivity. A brief period of OA5 (grayish line) appears in this stage at a depth of 20–19 cm. Because *Eucypris inflata* possesses tolerance of high salinity, its appearance in this section suggests the variations in water inputs starts to affect lake chemistry.

Stage VI: 12–4 cm corresponds to the sixth stage (1980–1990). The assemblage in this stage is OA6, in which *Limnocythere inopinata* changes from dominant species to sole species. This reflects the lake shoaling and shrinking with reduced precipitation and increasing evaporation (Zhang and Li, 1999)

In the top section of 4–1 cm, ostracoda assemblages are not only dominated by OA6, but also influenced by OA5 (grayish line), which suggest that the lake level is decreasing and the salinity is increasing under enhanced evaporation.

Conclusions

Ostracoda bloom and decline depend on environmental conditions. Climate, through exchanges of heat and materials in water, has stronger influence on benthic conditions in small lakes;

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therefore, ostracoda genera/species and their assemblages can have environmental significance. In this study, information on lake level and water temperature variations is revealed by ostracoda assemblages. This information has further implication for climatic changes.

As a whole, the environment of South Hongshan Lake has been warm and dry over the past 150 yr. In 1850–1884, the core site was under shallow water, influenced by currents. This period is just after the Little Ice Age (LIA) (Shi et al., 1998; Wang et al., 1998), a time characterized by more humidity and surface water as ice retreated. Lake level rises, and water temperature increases during 1884–1922, which implies comparatively warm-humid climate. The highest lake level appears in this stage. This may be linked with continuous warming and greater precipitation from end of 19th century to beginning of 20th century (Li and Zhang, 1992). Lake level decreased and water temperature increased allowing high productivity of ostracoda in 1922–1946. This is coincident with climatic warming during the 1930s and 1940s (Su and Wang, 1995). Low temperatures and reduced organic matter contributed to the low ostracoda abundance in 1946–1960. Neighboring ice core records show lower temperatures during this period (Yao et al., 1996). Declining lake level from 1960 to 1980 is closely linked with local precipitation. Records of a weather station in northern Tibet show only 2 yr of heavy snow (1961–1962 and 1967–1968) (Lin and Chen, 1993) in this interval. Since 1980, decreasing lake level and lake area and increasing salinity impact the ostracoda assemblage in the lake. This is attributed to lower precipitation and continuous aridity under the warming climate since the 1980s.

Acknowledgments

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