Evidence of the Pan-Lake Stage in the Period of 40–28 ka B.P. on the Qinghai-Tibet Plateau

ZHENG Mianping, MENG Yifeng and Wei Lejun
Research & Development Center of Saline Lake and Epithermal Deposits, Chinese Academy of Geological Sciences, Beijing 100037

Abstract The Qinghai-Tibet plateau is one of major saline lake regions in China, where saline lakes are widespread and constitute an important object of researches on the palaeoclimatic change in the region. On the basis of comprehensive investigations of the evolution of the lake's surface and sediments on the plateau, the authors have further demonstrated the existence of a pan-lake stage (river and lake flooding stage) on the Qinghai-Tibet plateau during the period of about 40^{+}–28 ka B.P. and analyzed the palaeoclimatic characteristics of the pan-lake period and relationships between the ancient monsoons and the uplift of the plateau since the beginning of the Quaternary.

Key words: Qinghai-Tibet plateau, Late Pleistocene, pan-lake event, palaeoclimate

1 Palaeoclimatic Evolution of the Pan-Lake Stage in the Period of 40–28 ka B.P.

1.1 Changes of the lake surfaces on the Qinghai-Tibet plateau

During the period of 40–28 ka B.P., the expanse of the lakes of the Qinghai-Tibet was vast, being a few to a few dozens of times larger than that of the modern lakes. The lake water was fresh and tended to outflow, and the lakes and rivers were connected to form pan-lakes. The climate was mainly cold humid. About 30 ka B.P., the pan-lake system of the plateau began to be disintegrated from north to south. The ancient Qarhan Lake in the Qaidam basin in the northern part of the plateau became a saline lake at 30 ka B.P. and then became a self-precipitating evaporite lake at 25 ka B.P. Before 30 ka B.P., the ancient lake surface of the pan-lake stage was about 50–60 m above the modern one (Fig. 1) (Chen and Bowler, 1985; Wei et al., 1993; Zheng et al., 1996), and its area was at least up to 25000 km^2 (Fig. 2) (Zhu et al., 1990, 1994; Zheng et al., 1996), while the area of the modern lakes (including the playas) is 5850 km^2. The area ratio of the ancient lake to the modern lake is about 4.3 to 1, and their volume ratio is 50 to 1. The volume ratio (50: 1) of the ancient and modern Da Qaidam and Xiao Qaidam lakes north of Qarhan is close to it. In the south-western part of plateau, however, the pan-lake stage continued longer. For example, pan-lakes in the northern part of Tibet (an interior flow region) (Figs. 1 and 2) were widespread. The pan-lake areas of the Chagcam-Dong Co, Zabuye Zhari Nam Co and Bangkog-Siling Co covered about 4500, about 20000 and more than 10000 km^2, respectively; while the areas of their related 9, 41 and 20 modern lakes are only 270 (Zheng et al., 1983, 1989), 2742 and 3364 km^2, respectively (Fig. 2). The area ratios of the last two pan-lakes to their corresponding modern lakes are 3–11 to 1, whereas their volume ratios are about 20–42 to 1.

1.2 Recession and disintegration of pan-lakes and age dating

The lake surface remains in the northern part of Tibet plateau are well preserved. For example, the high lake surface (outflow surface) of the Zabuye-Zhari Nam pan-lake before 28 ka B.P. was 180–210 m higher than the modern lake surface. The ancient lake strandline and lake-eroded geomorphology are present all over the area. The sediments corresponding to the high lake surface are dominated by low-Mg calcite-bearing clay sediments of deep lake facies, yielding ostracods such as *limnocythere dubiosa* which is common in fresh water and weakly salt-tolerant and hypothermophilous *Leucocythere mirabilis*, as well as

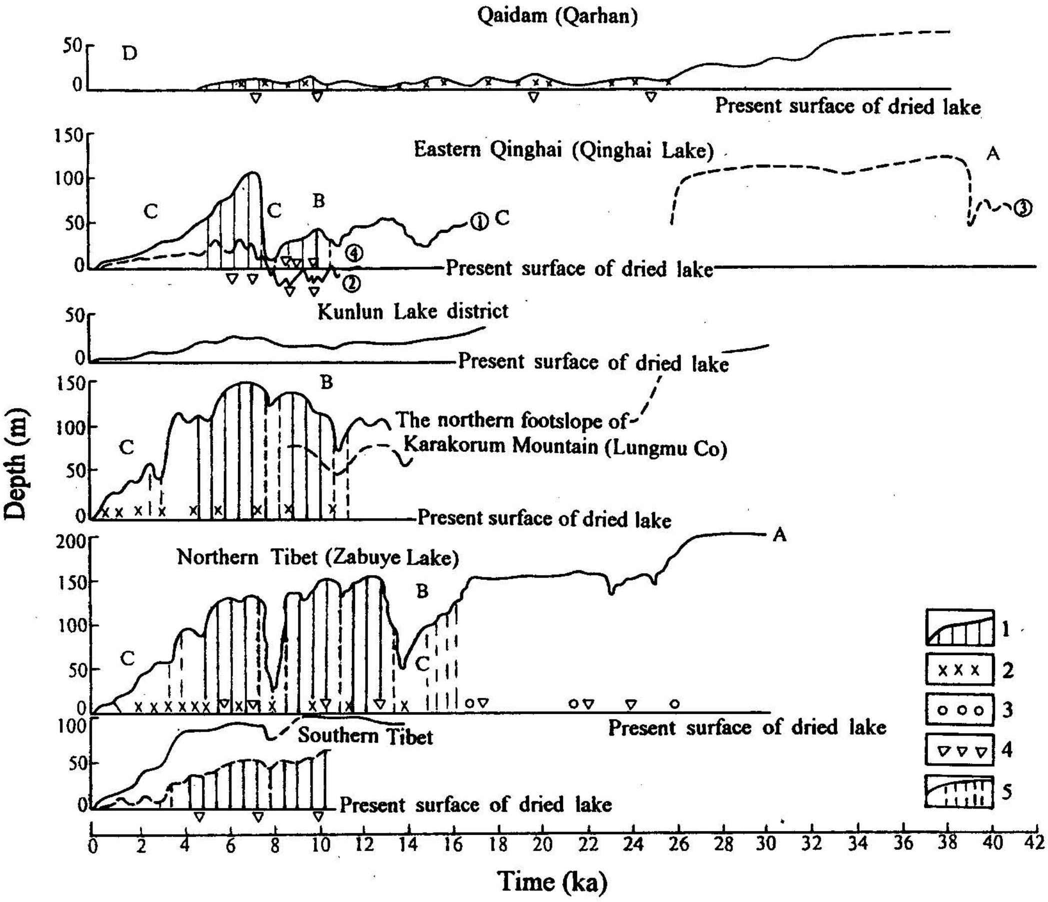

Fig. 1. Sketch map of the fluctuation of ancient lake surfaces on the Qinghai-Tibet plateau (after Zheng, 1997).
A. High lake surface (overflow surface); B. Medium lake surface; C. Low lake surface; D. Playa surface. 1. Warm slightly humid-warm humid; 2. salt-bearing segment; 3. *Ilyocypris* or *Pediastrum*; 4. high arbor sporopollen content segment; 5. cold slightly dry-cold dry.
① After Chen and Bowler, 1985; ② after Xu, 1992; ③ after Zhang et al., 1994; ④ after Shan et al., 1993.

fresh-water *Pediastrum simples* and *charophytes* that prefer clear and quiet water (Zheng et al., 1989).

The ancient lake strandline is the direct evidence of recession and disintegration of a pan-lake. Nine terraces of sand barriers are developed from the southern edge of Zabuye Lake to the Giaobuqu mountain pass within an area as long as 31 km in the Chaduixiong valley of the Zabuye area. We carried out a detailed survey of 3 geological sections of sand barriers. On the basis of ^{14}C isotope data and Quaternary studies, the ages of terraces 7, 6, 5, I-2 and I-1 are respectively ca. 23770, 12535, 8725, 5315 and 3530 a (Fig. 3). According to studies of China's loes sections and the sea level of the Yellow Sea (Shan et al., 1993; Rhodes et al.,1996), there was a humid warm climate stage (interglacial stage) about 36–25 ka ago and a dry cold climate stage (glacial stage) about 2.5 ka ago. According to the water level drop between barrier terraces 8 and 9 and the salinity increase indicated by studies of sedimentary minerals, we temporarily place the formation age of terrace 8 between 23.7 and 25 ka, and infer according to the recession intensity of terrace 8 in a vertical direction that the formation age of terrace 9 is 27.46 or 38 ka (corresponding to the late interglacial stage). According to instrumental measurements in July 1999, the top of terrace 9 was ca. 4628 m above sea level, i. e. its high lake surface is ca. 207 m higher than the modern lake surface.

1.3 Age of pan-lake disintegration

According to the authors' recent investigation, the water level of the Zabuye-Zhari Nam pan-lake gradu-

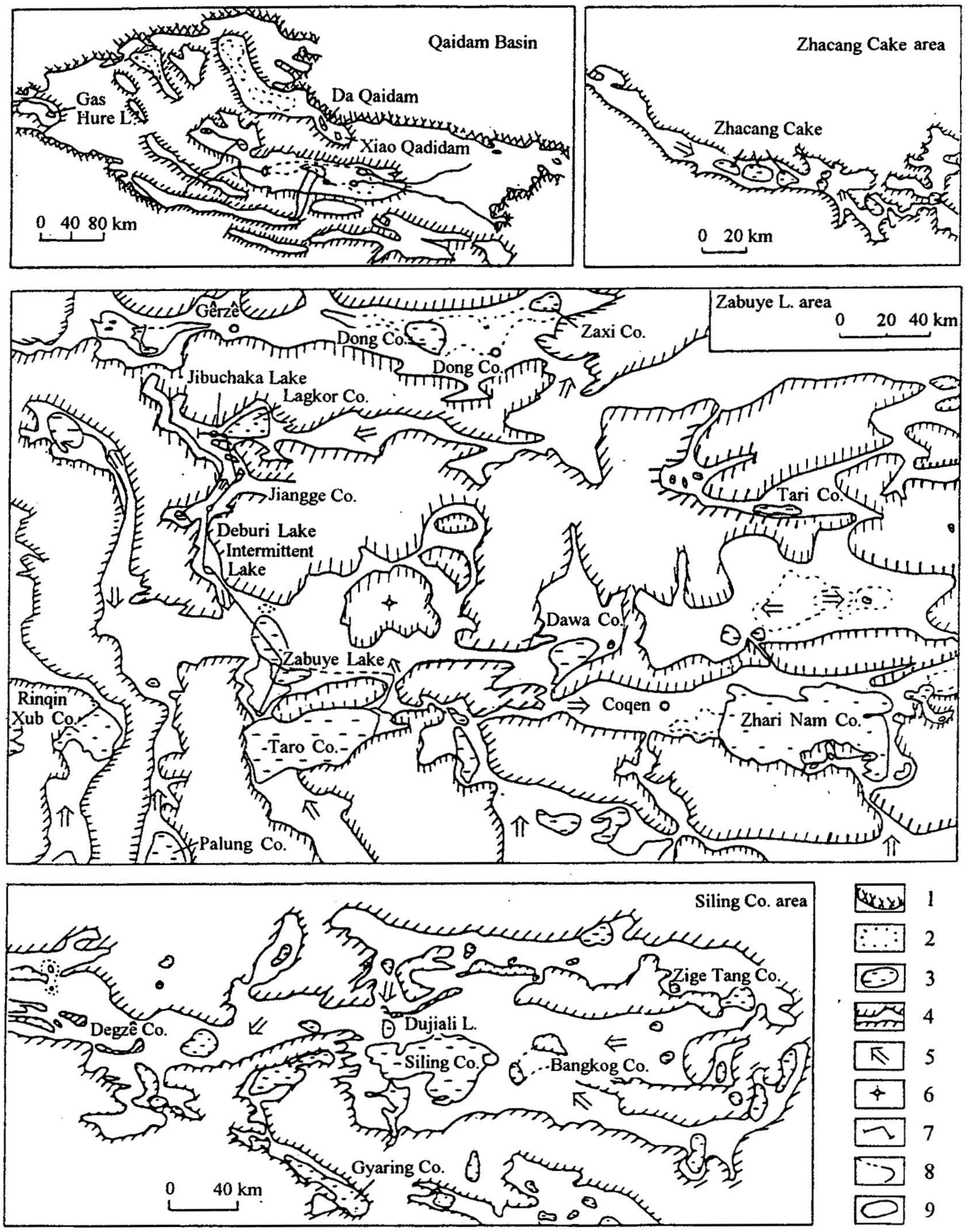

Fig. 2. Distribution of pan-lakes on the Qinghai-Tibet plateau during the late part of the late Pleistocene (40–28 ka B.P.).
1. Land area; 2. playa; 3. modern lake; 4. pan-lake; 5. direction of water mass migration; 6. ancient crater; 7. section location; 8. river or intermittent river; 9. dried clay lake.

ally dropped and the water area was reduced and disintegrated, as the plateau palaeoclimate became dry after 28 ka B.P. Take for example the Zabuye-Jibuchaka lake chain (Fig. 4), the lake-surface height of the mordern Zabuye and Jibuchaka lake surfaces are respectively 4421 and 4468 m. There is a water divide 4573 m above sea level between Zabuye and Jibuchaka. From the water divide northwards (from high to low), there are successively Derizhabu Lake, Jiangge Co., Xiza Co., Laguo Co., and Jibuchaka.

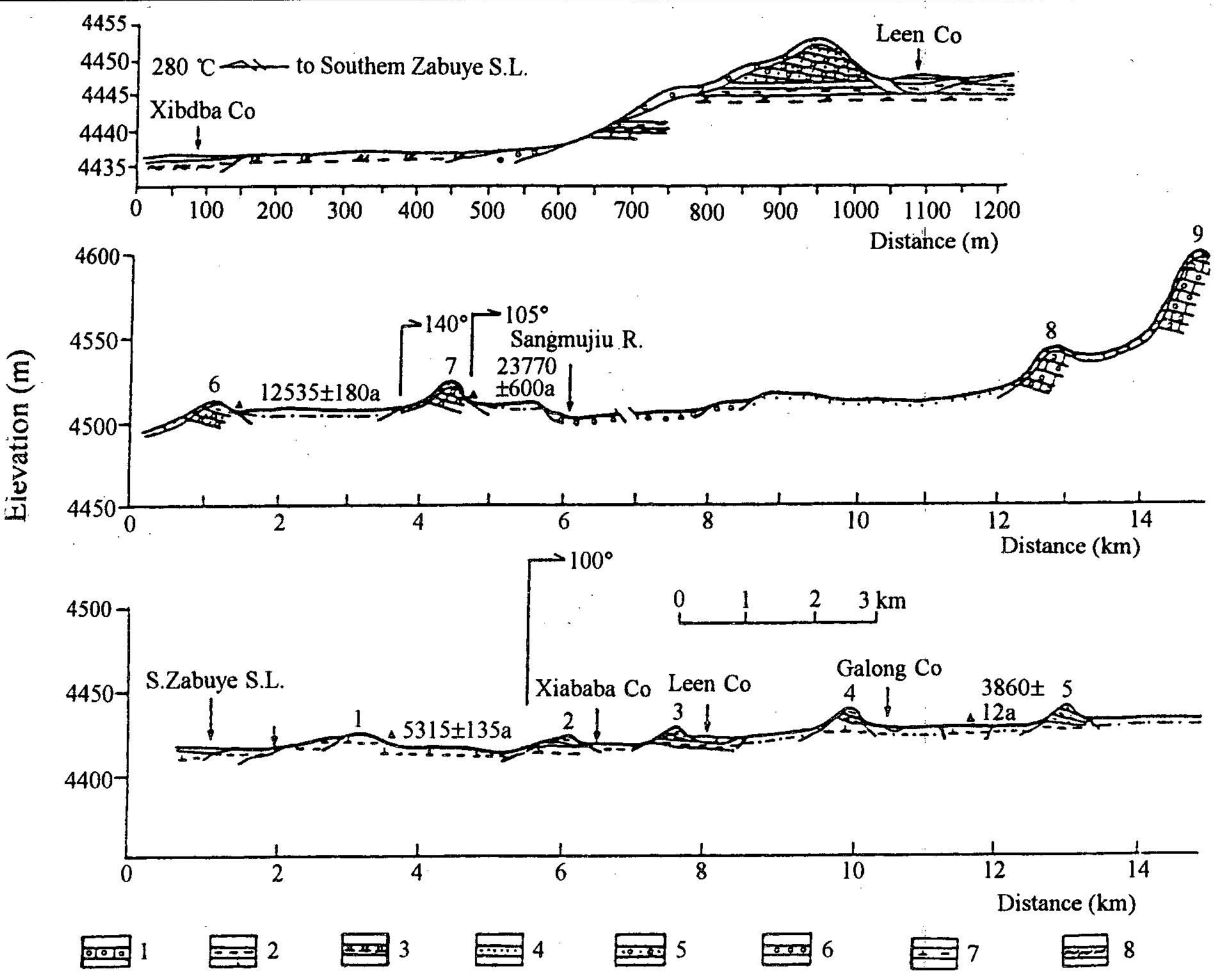

Fig. 3. Geological section of the Zhaduixiong sand barriers in the Zabuye lake area.

1. Greyish yellow calcareous sand and gravel; 2. greyish red to greyish brown clay; 3. greyish green carbonate-bearing clay; 4. greyish red, greyish yellow sand; 5. grey sandy gravel; 6. Grey loose sand and gravel; 7. greyish green clayey carbonate; 8. black mirabilite-bearing marl.

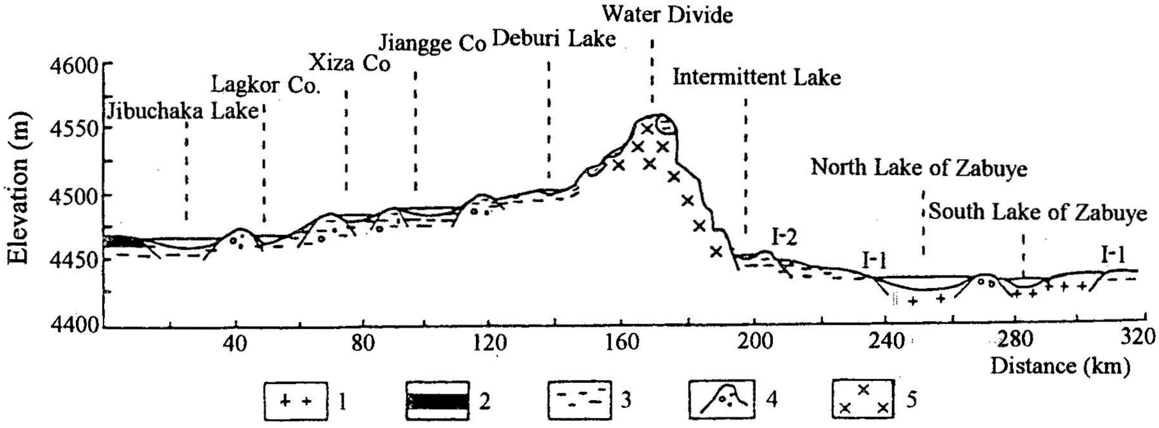

Fig. 4. Geological section of the Jibuchaka-Zabuye Lake sand barries in the Zabuye Lake area.

1. Salts; 2. Mg-borate; 3. carbonate; 4. sand barrier; 5. granite etc.

From the water divide southwards, there are intermittent lakes and Zabuye North Lake. The ^{14}C age of lacustrine greyish white carbonaceous clay at the top of the ancient water course on the east side of the

Table 1 Elevations and relative height differences of the Zabuye-Jibuchaka lake chain

Location	^{14}C age (a B.P.)	Elevation (m)	Relative height difference (m)								
			Water divide	Deburi Lake	Jiangge Co	Xiza Co	Lagkor Co	Jibuchaka Lake	Zabuye S. L. Terrace I-2	Zabuye S. L. Terrace I-1	Zabuye S. L. Modern S. L.
Water divide	9201±255	4573	0	67	84	88	103	105	133	148	154
Deburi Lake		4506		0	17	21	36	38	66	81	86
Jiangge Co	9094±148	4489			0	4	19	21	49	64	69
Xiza Co	8708±154	4485				0	5	17	45	60	65
Lagkor Co	7361±189	4470					0	2	30	45	50
Jibucha-ka Lake	8600±140	4468						0	28	43	48
Zabuye I-2	5315±135	4440							0	15	20
Zabuye I-1	3530±70	4425								0	5
Zabuye modern lake		4421									0

S.L.–Saline lake.

water dividecol is 5201±255 a. So we can infer that the latest time of separation of the two lakes was about 9100 a B.P. After that time, the water level of the ancient lake obviously lowered and underwent five stages of 9094±148, 8708±154, 8600±140 and 3530±70 a B.P. in proper order (Table 1), which reflects the stage-by-stage drying process of the palaeoclimate.

2 Palaeoclimatic Analysis

As stated above, there existed a young pan-lake stage on the plateau during about 40–28 ka B.P. The pan-lakes were widespread from north to south on the plateau, mostly freshwater ones. Rivers and lakes were connected and the water expanse was wide. According to the scale of the pan-lakes and micropalaeontological and geochemical data, the climate was mainly humid and cold and the precipitation was at least 1–2 times higher than the recent one, but the air temperature might be close to the recent one. Until the Holocene "climatic optimum", the area of its water expanse a nd its water depth and volume were respectively 0.7, 5 and 2 times larger than the recent ones.

According to an analysis of the growth conditions of *Picea purpurea* Mast, the mean annual air temperature at that time was over 3℃ higher than today's and the annual precipitation was over 100 mm more than today's (Xu, 1992). But the carbon and oxygen isotope analysis of ostracod shells indicate that the mean annual water temperature then was 1.8℃ higher than today's and that even in the Younger Dryas interval (from about 11 to 10.2 ka B.P.), the water temperature of the Qinghai Lake was also 0.3–0.5℃ higher than that of the modern one (Zhang et al., 1988, 1994).

Many researchers consider that the uplift of the lofty Himalayas and the plateau in the Quaternary was the main cause of climatic changes of the plateau. The large-amplitude uplift of the Qinghai-Tibet plateau since the early Pleistocene led to the uplift of the Himalayas and a series of nearly E-W trending mountains north of the Himalayas, which impeded the warm moist air-flow from the Indian Ocean, thus causing the climate of the plateau to become arid progressively. Some Quaternary sediments within the 10^4–10^5 a age range on the plateau can reflect such a change. In particular, in the late Pleistocene the elevation above sea level of the plateau had approximated the modern plateau's, so that the plateau became more arid. Sediments of ca. 10^4a age reflect the trend of nearly unidirectional change from humid cold (warm) climate to dry cold (warm) climate. The strong uplift of the plateau was very important to the climatic change of the plateau. But the palaeoclimatic history of the $n\times10^2$–$n\times10^3$a age range reflects that there were reverse changes of the plateau climate. The example is the discovery of plateau pan-lakes formed ca. 40 to 28 ka ago (Fig. 5). Although the Himalayas towered aloft on the southern edge of the plateau, it can not have

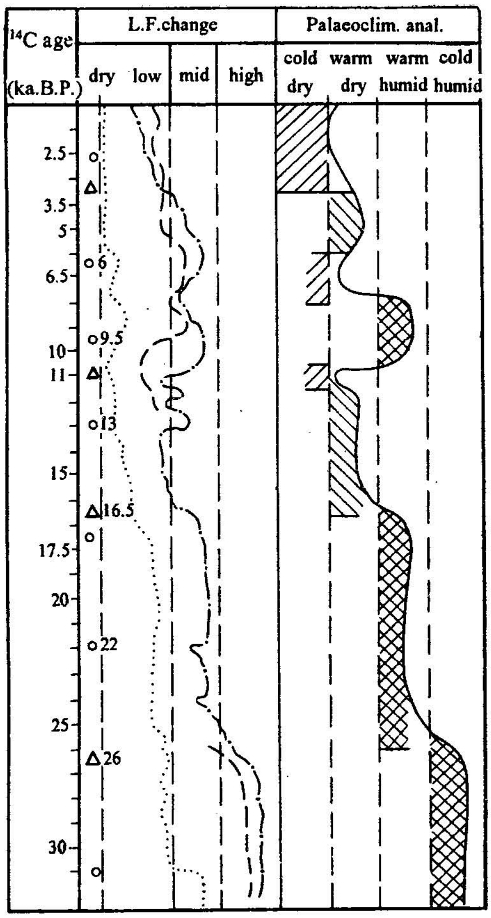

Fig. 5. Changes of the lake surfaces and palaeoclimate analysis on the Qinghai-Tibet plateau since 33 ka B.P.
1. Qarhan L.; 2. Zabuye L.; 3. Qinghai L.; 4. trend of palaeoclimatic change. Other symbols same as in Fig. 1.

completely stopped the warm humid South Asian airmasses from entering the lake areas of the plateau. It is especially in the global climatic change stage from the humid to warm (humid) climate, when voluminous warm humid air masses reached not only the south-central part of the plateau, but also the Qaidam basin in the north that was impeded by numerous mountains. Such a reverse change in the climatic history can hardly be explained by the view that the continuous uplift of the plateau can only have caused positive change (cold dry). For during the late Pleistocene the plateau had been uplifted, the mean height of the plateau had reached about 4000 m, and the short subsidence phase did not stop the plateau uplifting. The pan-lake stage of the plateau roughly corresponds with the cold stage (i. e. W1-W2 of the Würm glacial stage) (38–29 ka B.P.) of the global late Pleistocene first interglacial stage. The north-directed monsoon from the India Ocean was very strong then and influenced the whole Qinghai-Tibet plateau and even the Mu Us desert and Jungger north of the plateau (Rhodes et al., 1996).

Acknowledgments

This research was supported by the National Natural Science Foundation of China grants 49672116 and 49833010.

Manuscript received Jan. 2000
edited by Fei Zhenbi and Zhang Yuxu

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About the first author

Zheng Mianping Born in Fujian in 1934; graduated from the Department of Geology, Nanjing University, in 1956. He was studied the geology of saline deposits for more than 40 years and made systematic and pioneering studies on saline lakes of the Qinghai-Tibet plateau. Now he is chief of the Research & Development Center of Saline Lakes and Epithermal Deposits, Chinese Academy of Geological Sciences and an academician of the Chinese Academy of Engineering as well as a member of the Executive Committee of the International Society of Saline Lakes. E-mail: zmp@public.bta.net.cn